MISSOURI RIVER
MAIN STEM RESERVOIR SYSTEM
RESERVOIR REGULATION MANUAL

FORT RANDALL MANUAL

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
OMAHA, NEBRASKA
1978

MISSOURI RIVER

MAIN STEM RESERVOIR SYSTEM

RESERVOIR REGULATION MANUAL

In 7 Volumes | Volume 6

FORT RANDALL RESERVOIR (LAKE FRANCIS CASE)

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

1978

MISSOURI RIVER
MAIN STEM RESERVOIR SYSTEM
RESERVOIR REGULATION MANUAL

In 7 Volumes | Volume 6

FORT RANDALL RESERVOIR MANUAL

TABLE OF CONTENTS

TABLES

PLATES

PLATES

FORT RANDALL DAM AND RESERVOIR
MISSOURI RIVER
SOUTH DAKOTA

PERTINENT DATA

1. PURPOSE

Fort Randall Dam and Reservoir, in coordination with other projects in the Missouri River main stem system, is operated as a multiple-purpose reservoir for navigation, flood control, hydroelectric power, irrigation, water supply, recreation, fish and wildlife and other conservation purposes.

2. AUTHORIZATION

Authorized by the Flood Control Act approved 22 December 1944 (Public Law 534, 78th Congress, 2nd Session) as part of the general comprehensive plan for flood control and other purposes in the Missouri River Basin.

3. LOCATION OF DAM

State	South Dakota
Counties	Charles Mix and Gregory
River	Missouri River, 880.0 above the mouth (1960 mileage)
Town	Approximately 6 miles south of Lake Andes, South Dakota

4. DRAINAGE AREAS

Total Missouri River Basin, sq. mi.	529,350
Above Fort Randall Dam, sq. mi.	263,480
Oahe Dam to Fort Randall Dam, sq. mi.	19,990
Fort Randall Dam to Gavins Point Dam, sq. mi.	16,000
Fort Randall Dam to Sioux City, Iowa, sq. mi.	51,140

5. STREAM FLOW DATA

Natural Flow at Dam Site, c.f.s. (1898-1977)	
Maximum of Record (1952)	447,000
Minimum (1940)	2,300
Average	30,000

Actual Regulated Flow at Dam Site, c.f.s. (1953-1977)	
Maximum (1953)	103,000
Minimum (1960 & 1962)	0
Average	23,500

Average Annual Runoff at Dam Site, Acre-Feet (1898-1977)	21,700,000

6. RESERVOIR DATA

Approximate Length of Reservoir, miles (Pool Level at Maximum Normal Operating Level and 1960 River Conditions)	107
Shoreline, miles at Elev. 1350	540

Storage Capacity	Elevation M.S.L.	Gross Storage Acre-Feet	Gross Area Acres
Maximum Operating Pool	1375	5,600,000	102,000
Maximum Normal Operating Pool	1365	4,600,000	95,000
Base of Flood Control Pool	1350	3,300,000	78,000
Minimum Operating Pool	1320	1,600,000	42,000
Exclusive Flood Control	1365-1375	1,000,000	
Seasonal Flood Control	1350-1365	1,300,000	
Carryover Multiple Use	1320-1350	1,700,000	
Inactive Storage	~~1230~~-1320 1240	1,600,000	

7. DAM

Embankment Type - Rolled Earth Fill	
Abutment Formations - Niobrara Chalk	
Top of Embankment, Elev. Ft. m.s.l.	1,395
Total Crest Length, Feet (excluding spillway)	10,700
Maximum Height, Feet	165
Damming Height (Low Water to Max. Oper. Pool)	140
Top Width, Feet	60
Maximum Base Width, Feet	4,300
Fill Quantity, Cubic Yards	28,000,000

8. SPILLWAY

Location	Left Bank - Adjacent
Type - Chute, Concrete Lined with Gated Overflow Weir	
Crest Elevation, Feet m.s.l.	1,346
Crest Length, Gross, Feet	1,000
Crest Length, Net, Feet	840

Gates - Tainter - No. & Size, Feet	21 - 40 x 29
Design Discharge Capacity, c.f.s.	620,000
Discharge Capacity at Maximum Operating Pool, (Elev. 1375) c.f.s.	508,000

9. OUTLET WORKS

Location	Left Bank
Type - Concrete Lined Tunnels	
Tunnels, No. and Dia. in Feet (Tunnel No. 10 - Diameter Increased Downstream to 28 Feet for 22-Foot Steel Penstock)	4 - 22
Tunnels, Length, Feet, Approx.	1,013 (1)
Service Gates, Type	Vertical Lift Tractor
Service Gates, No. & Size in Feet	2 - 11 x 23 per tunnel
Regulating Gate, Type (2) (In Downstream End Tunnel No. 10 for Fine Regulation)	Vertical Lift Wheeled Gate
Emergency Gates, Type	Vertical Lift Tractor
Emergency Gates, No. & Size in Feet	4 - 11 x 23
Discharge Capacity per Tunnel, c.f.s. (Reservoir Water Surface at Elev. 1375)	32,000
Present Tailwater Elevation, Feet m.s.l.	1237-1240
Elevation, Intake Invert, Feet m.s.l.	1229
Elevation, Invert at Downstream Portal, Feet m.s.l.	1219

NOTES: (1) Length from upstream face of intake to downstream face of tunnel outlet portal.

(2) This gate unusable because of damage during high release period of 1975. Tunnel can be used without this gate.

10. POWER STRUCTURES

Location	Left Bank
Powerhouse, Type	Indoor, Reinforced Concrete
Tunnels - Concrete with Steel Penstocks	
Tunnels, No. & Dia. in Feet (Upstream) (Diameter Increased Downstream to 28 Feet for 22-Foot Steel Penstocks)	8 - 22
Tunnels, Length in Feet, Approx.	1,074 (3)
Service Gates, Type	Vertical Lift Tractor
Service Gates, No. & Size in Feet	2 - 11 x 23 per tunnel
Emergency Gates (See Outlet Works)	
Surge Tanks	59 Ft. Dia., 2 per Alternate Penstock

NOTE: (3) Length from upstream face of intake to scroll case.

11. POWER INSTALLATION

Average Gross Head Available, Feet	115
Number of Generating Units	8
Turbines, Type	Francis
Turbines, Speed, rpm	85.7
Discharge Capacity at Rated Head (112 feet) cfs	44,500
Generator Rating, KW	40,000

12. POWER AVAILABLE

Plant Capacity, KW	320,000
Dependable Capacity, KW (4)	285,000
Average Annual Energy, KWH (4)	1,715,000,000

NOTE: (4) Based on Operation Study 2-76-1975.

MISSOURI RIVER BASIN
MAIN STEM RESERVOIR SYSTEM
RESERVOIR REGULATION MANUAL
IN 7 VOLUMES - VOLUME NO. 6
FORT RANDALL DAM AND RESERVOIR

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. This manual is one of the 7 volumes being prepared for the main stem system of reservoirs as follows:

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

1-3. The system of reservoirs on the main stem of the Missouri River consists of six projects, Fort Peck (Fort Peck Lake), Garrison (Lake Sakakawea), Oahe (Lake Oahe), Big Bend (Lake Sharpe), Fort Randall (Lake Francis Case), and Gavins Point (Lewis and Clark Lake) constructed by the Corps of Engineers for the purpose of flood control and other multiple use purposes. In order to achieve the multipurpose benefits for which the main stem reservoirs are authorized and constructed, they must be regulated as a hydraulically and electrically integrated system. Therefore, the Master Manual presents the basic operational objectives and the plans for their optimum fulfillment, with supporting basic data. The Fort Randall Manual supplements the Master Manual by discussing the factors pertinent to the regulation of the Fort Randall Reservoir. The regulation of major tributary reservoirs located within the Missouri River Basin affecting the regulation of the Fort Randall project is detailed in separate manuals prepared for the individual tributary projects.

1-4. In an effort to reduce redundancy, frequent reference will be made in this, the Fort Randall project manual, to information contained in the Master Manual. This is particularly true with respect to details concerning organization, coordination with other projects and agencies, and other factors that are pertinent to operation of the system as a whole. This project manual should therefore be considered as a supplement to the Master Manual, presenting further information and expanding or emphasizing details that are of particular importance to the Fort Randall project.

SECTION II - DESCRIPTION OF MISSOURI RIVER AND DRAINAGE AREA

II-A Basin Geography

2-1. Areal Extent. The Missouri River Basin drainage area upstream from Fort Randall Dam includes all of Montana east of the continental divide, northern Wyoming, southwestern North Dakota, western South Dakota, a very small portion of northwestern Nebraska, and portions of the tributary Milk River drainage lying in southern Canada. The total area controlled by Fort Randall Dam is 263,480 square miles. This includes 57,500 square miles of drainage above Fort Peck Dam, 123,900 square miles between Fort Peck and Garrison Dams, 62,090 square miles between Garrison and Oahe Dams, and 5,840 square miles of incremental drainage area between Oahe and Big Bend Dams. Those portions of the Missouri River drainage area lying upstream from Big Bend Dam are described in the Fort Peck, Garrison, Oahe, and Big Bend Reservoir Regulation Manuals. The portion of the Missouri Basin described in this manual consists of the 14,150 square miles of incremental drainage area between Big Bend Dam and Fort Randall Dam, as well as the drainage area contributing to the Missouri River in the reach immediately below Fort Randall Dam. Further description of this downstream area is contained in the Gavins Point Reservoir Regulation Manual. Plate 1 is a general map of the Missouri River Basin while the incremental drainage area defined by the Big Bend and Fort Randall Dams and described in this manual is shown in more detail on Plate 2.

2-2. Topography. The Missouri River drainage area between Big Bend Dam and Fort Randall Dam forms a portion of the Great Plains province of the United States. The area to the north and east of the Missouri River is within the Glaciated Missouri Plateau consisting of gently rolling topography in which stream dissection and drainage are not well established except in areas immediately adjacent to the Missouri River. Drainage in upland areas is largely into pot holes, small intermittent lakes and a few larger permanent lakes. Most of the drainage in the Big Bend-Fort Randall incremental area lies within the Unglaciated Missouri Plateau which is to the south and west of the Missouri River. This region is characterized by numerous small hilly areas, buttes and hogbacks having elevations higher than the general level of the plains. While the region as a whole is rolling and rather thoroughly dissected by streams, there are small, nearly level areas on the stream divides. There are a few relatively larger areas of gently rolling relief scattered throughout the region.

2-3. The Unglaciated Plateau region, comprising most of the incremental drainage area, has a general west to east slope of about 10 feet to the mile. Elevations range from about 5,000 feet in the western part of the incremental drainage area to near 1,250 feet on bottom lands adjacent to the Missouri River. Badlands, characterized by extremely rough topography, are contained within the drainage area.

2-4. Land Use. Agriculture represents the primary use of the land in this portion of the Missouri Basin, estimated to extend over 95 percent of the total area. Cropland comprises about 18 percent of the total area. Woodlands, or forests, are generally restricted to bottom lands adjacent to streams or to woodlots and groves planted for protective or aesthetic purposes. Additionally, minor amounts of relatively sparse forests occur in extreme western portions of the incremental drainage area. Due to the general lack of an assured water supply, irrigation is practiced on only a minor amount of land in the incremental drainage area, with irrigated lands less than one percent of total cropland. Water areas in this incremental drainage make up about one percent of the total area, but the rivers, lakes, reservoirs, farm ponds and other bodies of water involved are extremely important to the region's economy.

2-5. Drainage Pattern. The drainage pattern of the Missouri River Basin is shown on Plate 1. Noteworthy in the drainage basin above Fort Randall Dam is the large area of the upper Missouri River Basin controlled by the Fort Peck, Garrison, Oahe, and Big Bend projects. These upstream main stem projects control about 95 percent of the total drainage contributing to the Fort Randall project, including all of the mountainous area contributing to the Missouri River above Fort Randall Dam.

2-6. The prominent feature of the incremental portion of the Missouri Basin between Big Bend and Fort Randall Dams is the single major tributary in this reach, the White River, a right bank tributary flowing in an easterly direction. This direction of flow is of particular importance from the standpoint of flow contribution from storms that typically move in an easterly direction. Additionally, it becomes important at the time of snow melt and ice breakup in the spring since normal temperatures at that time in the triubtary headwaters are significantly higher than at the tributary mouth, resulting in an aggravation to ice jamming near the mouth during the ice break-up period. The drainage pattern contributing from the area west of the Missouri in this reach is generally well defined. However, to the east of the river there are numerous potholes and depressions and portions of the region to the east will not contribute directly to streamflow unless substantial amounts of runoff were to occur, sufficient to fill and overflow the low depressions that normally restrict runoff.

2-7. The prominent White River tributary between Big Bend and Fort Randall Dams heads in northwest Nebraska, flows eastward through southwestern South Dakota and joins the Missouri River at River Mile 955 (1960 mileage) some 75 river miles above Fort Randall Dam and 32 river miles below Big Bend Dam. The White River drains 10,200 square miles of the 14,150 square miles drainage area between Big Bend and Fort Randall Dams. Minor tributaries entering Fort Randall Reservoir include Crow Creek and Platte Creek entering from the northeast and American Crow Creek, Bull Creek and Whetstone Creek, all right bank tributaries. The drainage area of each of these minor tributaries is less than 1,000 square miles.

2-8. Stream Slopes. The total fall of the Missouri River from Big Bend Dam to Fort Randall Dam is about 115 feet, averaging about one foot per river mile. Tributary stream slopes are significantly steeper, generally averaging between 5 and 8 feet per mile. Slopes at the tributary streams progressively tend to flatten toward their mouths.

II-B Climatology.

2-9. General. The incremental portion of the Missouri Basin discussed in this manual is located near the geographical center of the North American continent. The region lies near the center of the belt of westerly winds; however, the Rocky Mountains to the west form a barrier to a Pacific moisture source. Consequently, the climate of the region is generally classified as continental semi-arid. Through the region there is a marked seasonal variation in all weather phenomena.

2-10. Annual Precipitation. Annual precipitation over the Big Bend- Fort Randall drainage area generally increases from west to east, ranging from about 16 inches over portions of the tributary White River to about 23 inches at the Fort Randall Dam. The pattern of average annual precipitation throughout the Missouri Basin, including the incremental drainage area emphasized in this manual, is presented on an appropriate plate in the Master Manual. Wide variations from the average amounts may be experienced in any year, with severe, extended drought periods as well as successive years of well above normal amounts of precipitation occasionally occurring.

2-11. Seasonal Precipitation. Precipitation over the incremental drainage area between the Big Bend and Fort Randall Dams usually occurs as snow during the months of November through March and as rain during the remainder of the year. About three-fourths of the total yearly precipitation occurs during the rainfall season, with May, June and July normally being the wettest months. Most rainfall occurs in showers or thunderstorms; however, steady rains lasting for several hours or a day or two may occasionally occur. Excessive rainfall over a relatively large area is unusual; more common are intense thunderstorms resulting in large precipitation amounts in a short period of time over a very restricted area.

2-12. Precipitation occurring as snow usually is at a very slow rate. During the entire winter season about 20 inches of total snowfall can usually be expected through most of the incremental region. Snow does not usually progressively accumulate through the winter season, but is melted by intermittent thaws. However, there have been notable exceptions when plains area snow accumulations containing as much as 6 inches or more of water equivalent have blanketed large areas prior to a significant melt period. Snowfall is usually accompanied by high winds resulting in much drifting.

2-13. Temperatures. Resulting from its mid-continent location, this region experiences temperatures noted for fluctuations and extremes. Temperatures each year can usually range from a maximum of over 100 degrees Fahrenheit at some time during the summer months to a minimum of 30 degrees below zero or colder during the mid-winter period. Winters are long and cold; however, cold temperatures may be interrupted during periods of downslope or "chinook" winds when mild temperatures (for the season) prevail. Moderate temperatures usually prevail during the non-winter season, although periods of high temperature can be expected during every summer season, interrupted by outbreaks of cooler air from the north and west.

2-14. Evaporation. Annual evaporation from the surface of the Fort Randall Reservoir is normally slightly more than three feet. Studies made by the Reservoir Control Center conclude that the average net evaporation (evaporation adjusted for precipitation on the reservoir surface, runoff that would have occurred from land area now inundated by the reservoir and the channel surface area existing prior to development of the Fort Randall project) amounts to about 19 inches annually. Due to seasonal precipitation patterns, seasonal patterns of gross evaporation depths and to the lag in normal lake surface temperatures from corresponding air temperatures, essentially all of the annual net evaporation from Fort Randall Reservoir can be expected to occur during the six-month period, July through December.

2-15. Storm Potentialities. The source of moisture for all major storms in the plains region of the Missouri Basin is the Gulf of Mexico. Based on available moisture 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 at its highest. However, major storms result almost exclusively from conditions accompanying frontal systems, and since frontal passages are more numerous and more severe in May and June than later in the year, major storms occur more frequently in late spring and early summer than at the time of maximum moisture charges. Major storms alone do not provide a complete index to the probability of large amounts of runoff within the region. A sequence of minor storms may saturate the soil and subsequently contribute much larger volumes to streamflow than would be the case if dry conditions prevailed prior to the runoff producing events. During winter months continued minor storms are the rule, occasionally producing significant snow accumulations over the drainage area. Usually the highest annual flows experienced in the region result from melt of these snow accumulations. Severe flooding only occasionally will occur over portions of the basin due to an individual major storm event.

II-C Runoff.

2-16. Streamflow Records. With the exception of a few stations, records of runoff from the incremental area considered in this manual exist only from the early 1930's to date. As discussed in the Master Manual, planning of the main stem reservoir system made it desirable to extend Missouri River streamflow records to the extent practicable. In these studies it was not considered practicable to divide the upper Missouri Basin to the degree defined by all of the main stem reservoir projects. In view of the relatively small incremental area between Oahe and Big Bend projects (5,840 square miles) and the unavailability of stage data, the decision was made to eliminate the Big Bend site as a location for which Missouri River flows would be developed. Consequently, from the studies carried on at the time, based on main stem stages and the discharge records available, supplemented by analyses of stream data available in recent years, records of monthly incremental flows between the Oahe and Fort Randall dam sites were developed for an extended period and are now available from 1898 to date. Daily flows at tributary locations within the incremental area are avilable for varying periods of time since 1928. Inasmuch as water use for all purposes has expanded significantly since settlement of the region began, it is necessary to adjust main stem incremental inflow records to a common level of water resource development in order that flow data are directly comparable from year to year. The total flows originating in the Oahe to Fort Randall reach have been adjusted to the 1949 level of water resource development, with such adjustment being a continuing process as further data are accumulated. While any development level would have been satisfactory, the 1949 level, prior to recent accelerated resource development, was selected.

2-17. Sources of Runoff. The primary source of runoff from the Big Bend-Fort Randall incremental drainage area is melt of the snow accumulated during the winter months. However, on occasion rainfall during May and June has resulted in substantial runoff amounts from the total incremental area. Runoff is extremely variable from year to year. Throughout most of the drainage area annual runoff averages less than one inch. Generalized estimates of a mean annual runoff throughout the Missouri Basin are presented by a plate in the Master Manual, while normal contributions to annual runoff from drainage areas within or near to the incremental drainage area discussed in this manual are given in Table 1.

TABLE 1

NORMAL ANNUAL RUNOFF, MISSOURI RIVER BASIN
BETWEEN OAHE DAM AND FORT RANDALL DAM

Contributing Area	Drainage Area Square Miles	Average Annual Runoff(1) 1,000 AF	Inches
Bad River			
Ft. Pierre	3,107	108	0.65
White River			
Oacoma	10,200	377	0.69
Missouri River(2)			
Oahe Dam	243,490	20,906	1.61
Ft. Randall Dam	263,480	21,819	1.55
Oahe-Ft. Randall			
Incr. Drainage	19,990	913	0.86
Local Drainage(3)	6,683	428	1.20

(1)Based on available record at each location.
(2)Missouri River runoff at the 1949 level of water resource development.
(3)Incremental drainage area between Oahe and Ft. Randall Dams less Bad River of Ft. Pierre and White River at Oacoma.

2-18. Seasonal Runoff Pattern. Runoff from the Missouri River drainage basin between Big Bend and Fort Randall Dams usually follows a characteristic seasonal pattern as follows:

a. Winter is characterized by frozen streams and intermittent snowfall and thaws in the 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 during this period, which usually extends from late November into March, is very low.

b. Early spring is marked by a rapid melting of snow and ice upon frozen ground, usually in March or April, as temperatures rise rapidly, accompanied usually by very little rainfall. This causes a characteristic early spring ice breakup and rise. Ice jams are frequently experienced on tributary streams during this period. The rapid release of water from melting snow and ice jams results in a flashy "March" rise in flow. Annual maximum peak stages and flows frequently occur at this time along tributary streams.

c. Late spring consists of the months of May and June. At this time extensive general rains may occasionally occur, sometimes accompanied by severe local rainstorms. Runoff is usually quite low unless these rains occur.

d. Summer and autumn in this portion of the Missouri Basin are generally characterized by a lack of general rainfall and frequent, widely scattered thundershowers that contribute little to runoff. Total runoff to the Fort Randall incremental drainage area is usually very low from July through the remainder of the calendar year.

2-19. Total unregulated Missouri River runoff originating above the Fort Randall Dam usually follows a definite and characteristic annual pattern as illustrated on Plate 3. Normal monthly runoff from the total contributing area shows a general increase from January through June and then decreases through December. As illustrated on Plate 3, wide variations in total runoff have occurred during every month of the year. As would be expected, the variations are largest during the months comprising the March-July flood season, with total flood season volumes ranging from a maximum of 27.7 million acre-feet in March-July 1978, and 25.5 million acre-feet in March-July 1927 to a minimum of 5.5 million acre-feet in 1961. During 1975 the 1927 flood season runoff volume was almost equaled, while the four-month April-July period runoff during 1975 (23.8 million acre-feet) exceeded the 1927 volume during these months by 1.8 million acre-feet and the 1978 volume by 2.2 million acre-feet. The effects of project regulation upon these runoff patterns is discussed in Section X.

2-20. Plate 4 illustrates the average and maximum values of monthly runoff originating from the incremental drainage area between Oahe Dam and Fort Randall Dam. Average runoff from this incremental area is at a maximum through the March-June period, with the average monthly maximum occurring in March as a result of runoff from the melt of accumulated winter snow cover. As shown by this plate, greatest monthly runoff recorded from this reach occurred in May 1942 as a result of rainfall over the incremental drainage area. Very little runoff usually occurs, or has been recorded in any month, during the period extending from August through February. Monthly runoff from this incremental drainage area has frequently been calculated to be negative throughout the available record period, indicating that evaporation from the Missouri River channel (or other losses) often exceeds the flow of tributaries entering the Missouri River in this reach.

2-21. Floods. Regulation provided by Fort Randall and upstream main stem reservoir projects, augmented by upstream tributary reservoir storage space, has virtually eliminated flooding along the portion of the Missouri River in the vicinity of Fort Randall Dam. Many instances of above bank-full flows were experienced through this reach prior to construction of the main stem projects and would be continuing if the projects were not in operation. All floods recorded in this portion of the Missouri River prior to main stem reservoir operation occurred in the March-July flood season.

2-22. The Master Manual contains relatively detailed descriptions of several of the experienced Missouri River floods, including data that is pertinent to the incremental reach described in this Fort Randall Manual. Since there is little additional data beyond that given in the Master Manual for several of these floods, they will not be discussed further in this manual. Paragraphs that follow present descriptions of large flows that have originated in the Oahe to Fort Randall reach of the river. Plate 5 illustrates total Big Bend-Fort Randall incremental inflows experienced during selected runoff periods since regulation of Fort Randall began in 1958. Inflows shown on this plate are based on elevation changes of Fort Randall Reservoir, Fort Randall releases and the upstream Big Bend releases coincident with the changes in elevation.

2-23. 1942 Floods. As illustrated on Plate 5, monthly runoff during May 1942 from the Oahe-Fort Randall drainage area substantially exceeded that recorded in any other month during the 1898-1977 period of available record. June 1942 runoff from this reach was also well above normal and the 2-month, May-June incremental volume of over 2 million acre-feet in 1942 exceeded the next largest 2-month volume, that occurring in March-April 1952, by over 350,000 acre-feet. Extensive rainfall in several separate rainstorms occurred over the southern portions of South Dakota, beginning in late April 1942 and extending through most of June, with the heaviest amount in May. Although the crest flow of 35,300 cfs near the mouth of the White River has been exceeded on other occasions, there were five distinct crests on this stream during the May-June period, each exceeding 10,000 cfs. The Bad River, draining into the upstream Big Bend Reservoir also experienced large flows during this period. These 1942 flows were the first substantial runoff to occur from this portion of the Missouri River drainage since extreme drought conditions began in 1930. Studies conducted by the Reservoir Control Center indicate that, if the main stem reservoirs had been in operation at the time, there would have been no problems associated with the preventing downstream floods. However, following the severe drought period of the 1930's, much emphasis would be placed on filling vacant system storage space. Runoff originating only below Oahe Dam during May was considerably greater than necessary to sustain system release requirements and the combined May-June runoff from this drainage area would serve the requirement. Consequently careful scheduling of power releases from the upstream Oahe and Big Bend projects would have been necessary during this period in order to conserve water in the system while maintaining the Fort Randall exclusive flood control space vacant for the control of further inflows, should they have occurred.

2-24. <u>1952 Flood</u>. The second largest monthly runoff of record from the Oahe-Fort Randall incremental drainage area occurred in April 1952 as a result of melting of an extremely large snow accumulation. This was a portion of the large basin-wide flood discussed in the Master Manual. The crest flow of 51,900 cfs near the mouth of the White River is the largest crest that has been experienced at that location since records began in 1928. A crest of 28,100 cfs occurred on the upstream Bad River during this time. The main stem reservoir system was not in operation during 1952; however, as discussed in the Master Manual, studies conducted by the Reservoir Control Center indicate that the system would have controlled inflows to prevent downstream damages with a reserve of vacant exclusive flood control space remaining throughout the flood.

2-25. <u>1960 Flood</u>. The maximum mean daily incremental drainage area inflow into Fort Randall Reservoir since operation of the project began occurred in March 1960 when a crest daily flow of 60,000 cfs was computed. The runoff resulted from the melt of a substantial snow cover accumulated during the previous winter season. The crest flow near the mouth of the White River was 23,400 cfs while the upstream Bad River crested at 16,600 cfs at the same time. Considerable flow was added to the incremental drainage area crest from minor tributaries entering this reach of the Missouri River. This is confirmed by a recorded crest of 8,970 cfs from the 465 square mile drainage area of Medicine Creek at Kennebec, South Dakota.

2-26. <u>1962 Flood</u>. Frequent rainfall throughout May-July 1962 over the incremental drainage area resulted in three-month runoff at a level over 4 times the long term average. Runoff amounts from this incremental reach during June and July were the maximum of record for both of these months, as indicated on Plate 4. However, crest flows on tributary streams were not particularly high. Mean daily flows near the mouth of the White River crested at 20,000 cfs while the upstream Bad River crested at 10,500 cfs. Computed incremental flows from the total Big Bend-Fort Randall incremental drainage area crested at 28,000 cfs. Similar to the 1942 flood flows discussed earlier, the primary concern of regulation during a repeat of the 1962 rainfall flood, with the entire system in operation, would be conserving the available supply in an efficient manner rather than minimizing downstream flood damages.

2-27. Basinwide Floods. Essentially all major Missouri River floods of past record at the Fort Randall damsite have resulted from runoff originating in the upper Missouri Basin, an area controlled by Fort Peck, Garrison and Oahe Reservoirs. At times these floods have been augmented by flows originating from the Oahe-Fort Randall incremental drainage area. Floods of this type are described in the Master Manual.

2-28. Effects of the Fort Randall Project on Flood Inflows. Studies conducted by the Reservoir Control Center indicate that operation of the Fort Randall project in conjunction with other upstream reservoir projects would virtually eliminate significant flood damages in the reach extending downstream from Fort Randall to below Gavins Point Dam if any past floods of record were to recur. Further discussion of regulation effects on flood inflows is given in Section X of this manual, Examples of Regulation.

2-29. Water Travel Time to Fort Randall Reservoir. Since the level of Fort Randall Reservoir is normally at such a level to extend into the tailwaters of the upstream Big Bend project, releases from Big Bend appear in a few hours as Fort Randall inflows. The White River gaging station at Oacoma is also located very close to the reservoir with a travel time between the two locations a matter of a few hours at most. Runoff originating in the upper portion of the White River Basin would take about 5 days to travel to the reservoir; however, most of the incremental drainage area runoff, originating betwen Big Bend and Fort Randall Dams will appear as inflow to the reservoir within two days. A two-day travel time to Fort Randall Reservoir is also appropriate for White River flows observed at the Kadoka, South Dakota gaging station.

2-30. Water Quality. Tributary streams originating in the Big Bend-Fort Randall drainage area traverse areas with rocks and soils containing many soluble salts. Water quality is frequently poor since salts that are leached from the land cause the water in the streams to be highly mineralized. While dissolved solid concentrations on the order of 500 milligrams per liter prevail over most of the drainage area, there are portions where concentrations of up to 2,000 millgrams per liter occur. Since the incremental drainage area is mostly thinly populated, pollution problems caused by organic loading are not general, but confined to reaches below municipalities with inadequate waste water treatment. The quality of Missouri River water within and below Fort Randall Reservoir is considered to be good due to dilution of the incremental inflows by upstream reservoir releases and the stabilizing effect provided by the Fort Randall Reservoir and the other upstream main stem reservoirs.

2-31. Sediment. Average annual sediment flow of the White River is very high, amounting to 1,177 tons per square mile at Oacoma where the drainage is over 10,200 square miles. Much of this sediment originates in the Badlands areas of South Dakota and is the result of erosion during high flow periods. Since the upstream main stem reservoirs act as traps to sediment, there is no appreciable sediment inflow to Fort Randall Reservoir from Missouri River inflows. Average annual sediment inflow to Fort Randall Reservoir is estimated to be 16,600 acre-feet. Since the reservoir traps the inflowing sediment, releases are clear, but increasing sediment load is derived from the channel as they move downstream.

II-D. Missouri River Channel Below Fort Randall Dam.

2-32. Areal Extent. The Missouri River below Fort Randall Dam flows through a generally sparsely populated area down to the headwaters of Gavins Point Reservoir, a distance of about 40 river miles. Major tributaries entering this reach of the Missouri River are Ponca Creek, draining an area of 827 square miles, and the Niobrara River. This latter stream drains an area of 12,000 square miles and enters the Missouri immediately upstream from Gavins Point Reservoir in the vicinity of the municipality of Niobrara, Nebraska.

2-33. Channel Description. The Missouri River channel in this reach meanders through an alluvial flood plain and with normal Fort Randall releases required to sustain multiple-use requirements the water surface of the channel is usually 5 to 10 feet below the adjacent flood plain. However, in the reach extending about 10 miles upstream from the mouth of the Niobrara River, located 36 miles below Fort Randall Dam, this freeboard has been markedly reduced due to sediment deposited in the Missouri River by the Niobrara River. The relatively swift flows of the Niobrara River have always transported sediment into the Missouri River. Prior to construction of the main stem reservoir, periodic Missouri River flood flows would scour this sediment and transport it downstream on the Missouri River and a channel capacity in the 150,000 cfs range would be maintained through this reach. Since construction of the reservoir system, the periodic large flood flows have been eliminated and sediment continues to accumulate in this location. By the year 1975 the effects of the accumulated sediment had progressed to the extent that Fort Randall releases near the power plant capacity of 47,000 cfs resulted in some flooding and water logging of the adjacent low-lying flood plain. Use of portions of the flood plain for agricultural purposes has been restricted and remedial measures consisting of obtaining flowage easements have begun.

2-34. Throughout most of its length the Missouri River in this reach is a braided stream containing many small islands, sand bars and adjacent chutes. Channel widths at normal flows generally range upwards from near 1,000 feet in relatively restricted areas to a half-mile or more in some areas immediately above the mouth of the Niobrara River. Very little bank stabilization has been done in this reach of the river and the channel is characterized by eroding banks, although there are plans to construct stabilization structures at locations where erosion has been particularly severe. There are no communities developed on the adjacent flood plain upstream from the Town of Niobrara, Nebraska, located in the headwaters region of Gavins Point Reservoir. Due to the effects of the Niobrara River delta, the stage-discharge relation varies through the reach. Plate 6 is the relationship developed on the basis of recent Fort Randall releases at a location about 7 miles above the mouth of the Niobrara River. The stage-discharge relation in the Fort Randall tailwaters area is discussed in a later section of this manual. Plates 7 through 12 are recent photographs of the portion of the Missouri River channel extending from Fort Randall Dam to Niobrara, Nebraska.

2-35. River Ice. During every winter the Missouri River can be expected to have a complete ice cover extending from a point about 10 miles below Fort Randall Dam into the Gavins Point Reservoir. The upstream limits of this ice cover will vary, dependent upon the temperatures being experienced. In exceptionally cold periods the head of the ice cover can be expected to move upstream to such an extent that Fort Randall tailwater levels will be affected. The formation of an ice cover materially reduces the channel capacity; however, Fort Randall average releases during the winter season are always restricted to such an extent (to about the 20,000 cfs level) that problems associated with high river stages at this time of the year have not been reported since regulation of the project began. Since the river reach between Fort Randall Dam and Gavins Point Reservoir is relatively short and contains no major tributaries, the ice-cover is usually eroded by progressive melt during the spring season rather than the break-up and associated ice jams characteristic of the Missouri River prior to construction of the main stem reservoirs.

SECTION III - WATER RESOURCE DEVELOPMENT

III-A General

3-1. History. Due to the lack of transportation facilities, development of water resources in the portion of the Missouri Basin extending through the vicinity of Fort Randall Reservoir began soon after settlement by the white man in the early 1800's. Initial development was concerned with navigation as a means of transportation in the region. The economy of the region is primarily agricultural. This, combined with the semi-arid climate, could have been expected to foster irrigation development. However, the lack of perennial streams in the region discouraged such development except in scattered areas in the White River headwater's region and in restricted areas immediately adjacent to the Missouri River. The most widespread development in relatively recent history has been construction of dams controlling small drainage areas to provide a water supply for the extensive livestock grazing practiced throughout this region. Control of floods became a major concern in the 1940's and in recent years municipal and industrial water supply, recreation, water quality enhancement, fish and wildlife and the environment have been of increasing importance.

3-2. Legislation. Federal legislation pertinent to water resource development throughout the Missouri Basin is summarized in the Master Manual. As indicated in that publication, the Flood Control Act of 1944 is of primary importance through this portion of the basin. This act authorized the construction of Fort Randall Dam, as well as the other multiple-purpose aspects of water resource development.

3-3. Reservoirs. One important means of water resource development in this section of the Missouri Basin is the construction of dams controlling sizeable drainage areas and development of the associated reservoirs. However, in the Big Bend-Fort Randall drainage area no sizeable reservoirs (other than Fort Randall) have been developed. The lack of an assured irrigation water supply and infrequent substantial runoff amounts as well as the sparsely settled area, resulting in only minimal flood damages, have precluded tributary reservoir development.

III-B. Functional Water Resource Development.

3-4. Flood Control. The Fort Randall Reservoir project is the only major flood control project constructed in this area of the Missouri River Basin. There are no local flood protection projects that affect, or are affected by, Fort Randall operation except those downstream from the main stem reservoir system, such as the protective works at Omaha and Kansas City.

3-5. Irrigation. Irrigation is practiced at scattered locations in the headwater's area of the White River and occasionally along the main streams. There are also plans to withdraw water from Fort Randall Reservoir to irrigate adjacent lands. There has been no Federally funded irrigation development in this portion of the Missouri Basin. In recent years there has been an increasing development of sprinkler irrigation where ground water supplies are available.

3-6. Navigation. Although navigation on the Missouri River through South Dakota opened up this region for initial Caucasion settlement, there is now no commercial navigation through this reach of the river. Storage has been provided in the Fort Randall Reservoir for multiple purposes, including Missouri River navigation; however, storage and releases from the project serve navigation only indirectly, after re-regulation by the downstream Gavins Point project. A description of the Missouri River navigation project is contained in the Master Manual.

3-7. Hydroelectric Power. The Fort Randall power plant, with an installed capacity of 320,000 Kw is the only hydroelectric power generating facility located in the incremental Missouri River drainage area discussed in this manual. All power generated by Federal facilities in the Missouri Basin is marketed by the Western Area Power Administration and Fort Randall power generation is integrated with the generation provided from other main stem projects, as well as that generated from other Federal and private facilities throughout the power marketing area. Further details concerning hydropower generation and the WAPA power marketing and transmission facilities are provided in the Master Manual.

3-8. Municipal and Industrial Water Supply. The municipality of Fort Andes, South Dakota has entered into agreements with the Corps of Engineers to withdraw water from Fort Randall Reservoir to serve its needs. There are also plans under consideration to use the reservoir as a source of water supply for communities in southeastern South Dakota including the City of Sioux Falls, the largest city in the state. Pickstown, South Dakota also uses the Missouri River in this vicinity as its source of water supply.

3-9. Land Treatment. In response to the program administered by the Department of Agriculture, land treatment measures designed to reduce erosion and local floods and to increase the local surface water supply are in operation throughout the incremental drainage area discussed in this manual. Associated with this program are many stock ponds or farm ponds that have been developed in recent years. While these ponds and other land treatment measures have a depleting effect on the overall water supply to the Missouri River and provide a degree of local flood protection, their effect on major Missouri River flood flows is minimal.

3-10. Fish, Wildlife and Recreation. The effects of water resource development upon fish and wildlife is a major concern through the drainage area in the planning and operational processes. Recreation opportunities have generally been increased as a result of water resource developments. To the degree practical, fish and wildlife interests are consulted prior to operation of projects and the potential effects upon these functions become an important constraint upon operations. Recreational use of the Fort Randall Reservoir continues to increase through the years and is a factor to be considered in actual regulation of the project.

3-11. Streambank Stabilization. Streambank erosion is a continuing process along the Missouri River and also along the tributaries in the region. Sediment inflow to the Fort Randall Reservoir results almost entirely from this erosion process along tributary streams contained within the incremental drainage area. Since Fort Randall Reservoir extends upstream to the tailwaters of the Big Bend project, bank stabilization measures are not required. Additionally, there is no appreciable sediment inflow to the project from this source.

III-C. Streamflow Depletions.

3-12. General. The major effect of the water resource developments in the incremental drainage between Big Bend and Fort Randall Dams on the regulation of the Fort Randall Reservoir is a depletion in the available water supply. As resource development continues, a growth in depletions can be expected. While increasing depletions probably benefit the flood control function, it is evident that they may have adverse effects on other functions that are dependent on the availability of a continuing water supply.

3-13. Depletion Growth. Prior to 1865 streamflow throughout the Missouri Basin was largely unused, except for transportation. Settlers and homesteaders in the late 1800's and soon after the turn of the century started substantial irrigation and mining ventures in several regions of the upper Missouri Basin. However, in the western Dakota drainage area contributing to the Missouri River reach discussed in this manual, the availabile water supply was very small and unreliable. Consequently, irrigation development occurred in only scattered areas, principally in the tributary headwater's region where a more dependable water supply was available. No large irrigation projects were developed. During the years 1910 to 1949 it is estimated that average annual depletions from the Big Bend-Fort Randall incremental drainage area increased by about 26,000 acre-feet. Increasing water resource development has occurred since 1949 with average annual depletions for this area increasing by 160,000 acre-feet during the 1949-1970 period.

3-14. A continuing increase in depletions is expected from this incremental drainage area. Estimates are that with a reasonable rate of water resource development, the increase in average annual streamflow depletion from the area extending from Big Bend to Fort Randall Dams will approximate 88,000 acre-feet during the next 50 years.

3-15. By 1970, the average annual depletions for the total drainage area above Oahe Dam, including the areas controlled by the upstream main stem reservoir projects had increased by about 3 million acre-feet above the 1949 "base level" selected for adjustment of streamflow records in the Missouri Basin. This amounts to about 14 percent of the total 1949 water supply available above Fort Randall Dam. Streamflow depletion projections made in connection with the Comprehensive Framework Study for the Missouri Basin indicate that by the year 2020 streamflow depletions for the total area above Fort Randall Dam may increase to almost 11 million acre-feet above the 1949 level. Subsequent depletion estimates have lowered this earlier estimate by 2-3 million acre-feet.

3-16. Depleting Functions. The water resource development functions resulting in most depletions from the tributary portions of this incremental drainage area are irrigation and land treatment measures. However, average annual evaporation from Fort Randall Reservoir is the major depleting influence within the total reach area, amounting to almost one-half of the average annual depletion increase that has occurred since 1910. Average annual evaporation losses from main stem reservoirs and major tributary reservoirs upstream from Fort Randall Dam total 1.8 million acre-feet or over 8 percent of the 1949 water supply above this location.

SECTION IV - HISTORY AND DESCRIPTION OF THE FORT RANDALL PROJECT

IV-A Project Development

4-1. General. The Fort Randall Reservoir project was planned and constructed by the Corps of Engineers' Omaha District under supervision of the Missouri River Division and the Chief of Engineers. The Definite Project Report prepared by the Omaha District was published in June 1946. Construction began in August 1946, with diversion of the Missouri River through the constructed outlet works accomplished in 1952. The first power unit started generating commercial energy in March 1954. By 1956 most major construction activities were completed.

4-2. Project Authorization. The need for flood control projects along the Missouri River and its tributaries was long recognized. Comprehensive development was proposed by the Corps of Engineers in House Document No. 238 (73rd Congress, 2d Session, 1934). While the Fort Randall project was not included in the document, the report did propose construction of reservoirs on both the main stem of the Missouri River and on tributary streams in the basin together with levees along the lower Missouri River as a flood control measure. The beneficial influence of the reservoirs upon Missouri and Mississippi River navigation was also recognized.

4-3. House Document 475 (78th Congress, 2d Session, 1944) presented the Corps of Engineers' plan for the overall development of the main stem of the Missouri River. This document proposed a dam at the Fort Randall site, together with other projects along the main stem of the Missouri River with such modifications as the Secretary of War and the Chief of Engineers might find advisable. Bureau of Recalamation plans for Missouri River development, as contained in Senate Document 191, 78th Congress, also proposed a series of dams along the main stem of the Missouri River, differing in some extent from those envisioned by the Corps. The difference between the plans were adjusted in an inter-departmental conference and the coordinated plan, including the Fort Randall project near its present site, was presented to Congress in Senate Document 247, otherwise known as the "Pick-Sloan Plan."

4-4. The Fort Randall project was then authorized by the Flood Control Act approved 22 December 1944 (Public Law 534, 78th Congress, 2d Session) as follows:

> "Sec. 9 (a) The general comprehensive plans set forth in House Document 475 and Senate Document 191, 78th Congress, 2d Session, as revised and coordinated by Senate Document 247, 78th Congress, 2d Session, are hereby approved and the initial

stages recommended are hereby authorized and shall be prosecuted by the War Department and the Department of the Interior as speedily as may be consistent with budgetary requirements."

4-5. Construction History. The initial construction contract for the Fort Randall project was awarded in August 1946 for relocation of U.S. Highways 18 and 281 to provide access to the damsite. Construction of Government housing and administration facilities soon followed. Initial earthwork began in September 1947 with diversion of the river through the completed outlet works and closure of the dam accomplished in July 1952. Storage space for deliberate regulation of inflow was available in 1953. The first power unit became operational in early 1954 with additional work placed on line in the following months and the final unit placed in operation in January 1956.

4-6. Relocations. Construction of the Fort Randall project involved the relocation of 31 miles of Federal highway, 33 miles of State highway and 9 miles of other roads. U.S. Highway 18 crossing the Missouri River was moved from a bridge 17 miles upstream from the Fort Randall Dam to the dam. U.S. Highway 281 was relocated in a similar manner. The crossing of U.S. Highway 16 at Chamberlain required some raising of the existing Missouri River bridge and modification of approach. Since Fort Randall began operation a crossing of Interstate Highway 90 near Chamberlain has been constructed as well as the Platte-Winner bridge over the reservoir some 41 miles above Fort Randall Dam. A new bridge to carry the Chicago, Milwaukee, St. Paul and Pacific Railroad across the Missouri River in the vicinity of Chamberlain was required as well as relocation of approaches to the bridge, and new depot and yard facilities in Chamberlain. It was necessary to relocate about 20 pole-miles of power, telephone and telegraph lines. Relocation or protection was required for portions of the developed area of Chamberlain, South Dakota, Oacoma, South Dakota and Indian Agency headquarters located adjacent to the reservoir area. It was also necessary to relocate six cemeteries containing approximately 400 graves.

4-7. Real Estate Acquisition. Approximately 114,163 acres in fee and 649 acres in easements were acquired for the Fort Randall Dam and Reservoir, including a total of 514 acres of flowage easements at 15 locations. In addition 173 acres were transferred from the Public Domain by Public Land Order. Of the total initially acquired, approximately 15,000 acres were later included as necessary real estate for the upstream Big Bend Dam and Reservoir. The basis for real estate acquisition over most of the reservoir area was a guide taking line of elevation 1375 feet m.s.l.

4-8. Operational History. Closure of Fort Randall Dam, together with the first impoundment of water, was in July 1952. This was the second of the main stem projects to be placed in operation and initially it was regulated in conjunction with the existing Fort Peck project for navigation and the maintenance of sufficient downstream flows for domestic and industrial uses and for water quality purposes. Fort Randall power generation began in 1954 with the completion of power unit No. 1 in March. Additional units were placed in operation during succeeding months with the eighth and final unit coming on line in January 1956. Inactive storage space (below elevation 1320 ft. m.s.l.) was filled in June 1954 and the multiple-use carry-over zone was first filled (to elevation 1350 ft. m.s.l.) in May 1957. Exclusive flood control storage space (above elevation 1365 ft. m.s.l.) has been utilized in only one year to date, that occurring in 1967. Further information concerning historical operation is contained in Section X of this manual. Detailed descriptions of each year's project operations are in the Annual Operating Plan reports published every August.

4-9. As discussed later in Section VIII of this manual, an annual fall drawdown of Fort Randall Reservoir is an important part of the regulation process designed to increase winter energy generation from the main stem system and also, during drought years, to permit utilization of the full winter peaking capability of the upstream Big Bend and Oahe power plants when system releases must be reduced to conserve storage. During years before 1971 this drawdown was to about elevation 1320 ft. m.s.l. prior to the start of the winter season. This annual drawdown resulted in considerable criticism from local interests. Cited were unsightly mudflats in the reservoir headwaters, blowing dust from exposed sandbars near Chamberlain, South Dakota, difficulty of access to the reservoir for stock watering, boat ramps out of the water, problems associated with fall irrigation, adverse effects on ice fishing, the discouraging effect on potential developments around the reservoir, and the general unfavorable impression created by the lowered reservoir level. In response to Section 226 of the Flood Control Act of 1970 a study of Fort Randall operations was made. As a result of this study, criteria for Fort Randall regulation were changed to limit the late fall drawdown to elevation 1337.5 ft. m.s.l., except during long-term drought and system refill periods when drawdown to as low as 1320 ft. m.s.l. would be allowed as necessary to maintain winter release values of 15,000 cfs from the upstream Oahe and Big Bend projects. Since 1970, the 1337.5 ft. m.s.l. drawdown limit has been effective. Further details concerning these operational changes are given in the Missouri River Division report of October 1972, entitled "Modification of Operation of Lake Francis Case, South Dakota."

IV-B. Description of the Fort Randall Project

4-10. Location. Fort Randall Dam is located at Missouri River Mile 880.0 (1960 mileage) in Charles Mix and Gregory Counties, South Dakota, approximately 6 miles south of the Town of Lake Andes. Fort Randall Reservoir extends 107 miles in a generally northwesterly direction to the Big Bend Dam located 21 river miles upstream from Chamberlain, South Dakota. Pickstown, South Dakota, a community developed for construction and operation of the Fort Randall project, is located on the bluffs adjacent to the dam.

4-11. Embankment. The dam consists of a concrete spillway section in the left bank abutment flanked by rolled earth fill embankments and outlet sections. U.S. Highways 18 and 281 cross the Missouri River on top of the dam. The dam has an over-all length of 10,700 feet at elevation 1395 feet m.s.l., the top of the dam. The embankment is of the rolled fill type, using materials obtained from the spillway and outlet works excavations. The total volume of fill in the embankment is approximately 50,000,000 cubic yards. The maximum base width is 4,500 feet and the top width is 60 feet. Rock fill riprap protection is provided for the upstream earth fill slopes above elevation 1310. The downstream slopes, including a chalk berm, have been topsoiled where necessary and seeded to vegetative cover. Plan and cross section of the embankment are shown on Plate 13.

4-12. Embankment freeboard was based on a Fort Randall Reservoir level of elevation 1379.3 feet m.s.l., the maximum level attained during routing of the spillway design flood. A set-up allowance of 2.5 feet and wave height plus ride-up allowance of 6.9 feet was developed in design studies. An additional safety factor of 6.3 feet resulted in a total freeboard allowance of 15.7 feet, establishing the embankment crest at elevation 1395 feet m.s.l.

4-13. Spillway. The Fort Randall spillway is a structure of the conventional chute type located near the left abutment of the dam. A large ravine upstream from the dam, supplemented by a relatively small amount of unlined excavation down to elevation 1325 ft. m.s.l., provided an excellent approach channel for the spillway. The approach channel is of such nature that water flowing from the reservoir will sweep through an arc of about 90 degrees before discharging over the spillway.

4-14. The spillway structure consists of an ogee crest weir with a crest elevation of 1346.0 feet m.s.l. surmounted by tainter gates, a roadway and service bridge and machinery platforms. The spillway has a gross length of 1,000 feet and is controlled by 21 tainter gates, each

40 feet long and 29 feet high, separated by piers 8 feet in length. The net length of the spillway crest is therefore 840 feet. The gates operate individually and may be opened or closed in 1-foot increments. A paved chute, 1,000 feet wide, connects the spillway weir with the stilling basin. From the downstream end of the weir the chute slopes downstream on a 4 percent grade a distance of 1,025 feet after which the slope steepens to a slope of 10 percent for a distance of 355 feet to a transition with the stilling basin floor. The chute is paved with concrete and has retaining walls 17 to 30 feet high.

4-15. A stilling basin 230 feet long is provided below the spillway chute. The floor of the stilling basin is at elevation 1198 ft. m.s.l. and has a bottom width of 971.5 feet. Sloping walls provide a top width (at elevation 1255 ft. m.s.l.) of 1,000 feet. The end sill is stepped at 5-foot increments from elevations 1198 to 1218 ft. m.s.l. The spillway discharge channel, with bottom elevation at 1218 is paved for a distance of 75 feet downstream from the back of the end sill of the stilling basin. The stilling basin walls continue 155 feet downstream from the back of the end sill. The discharge channel is contracted gradually to a minimum width of about 830 feet at the exit. The contracted channel represents a compromise between excessive excavation on the left bank and undesirable flow characteristics including excessive velocities with further contraction. It is expected that exit velocities will be high along the left bank for high discharges. Model tests indicate probable bottom velocities from 14 to 23 feet per second. Plan, profile and section of the spillway structure are shown on Plate 13, while spillway discharge rating curves are on Plate 14.

4-16. Outlet Works. The outlet works through Fort Randall Dam are located near the left bank of the river, approximately 800 feet riverward of the spillway structure. Tunnels providing for both powerplant releases and supplementary outflows are included. Plan and profile of the outlet works are shown on Plate 13. Discharge rating curves of the supplementary release tunnels are shown on Plate 15.

4-17. The approach channel from the river channel to the outlet works tunnel intake also serves the adjacent spillway and is approximately 6,400 feet long with a bottom width of 575 feet. The channel floor was constructed to elevation 1227 feet m.s.l. The prime function of the channel was to serve as an approach to the intake structure and conduits during the construction diversion period and until the reservoir pool reached the normal operating levels.

4-18. The reinforced concrete intake structure consists of twelve towers spaced 70 feet on centers and rising approximately 180 feet above their chalk foundation. Each tower is divided into a series of wells to accommodate two 11' by 23' service gates and two emergency gates which control the flow into the tunnels. A 49-foot transition connects the two 11' x 23' conduits in each tower with the 22-foot diameter tunnels. In order to increase the rigidity and stability of the structure, each pair of towers has a common base slab and are tied together at both the top and the bottom by a series of deep girders. The girders are so aligned as to furnish a continuous track for the gantry crane from tower to tower and provide support for the gantry-deck bridge. The continuous 53.5' x 827.0' gantry-deck is pierced by hatches located directly over the gate wells and in the downstream half of the deck slabs over the equipment and storage rooms of the tower unit. Access to the intake structure is effected by a service bridge connecting the gantry deck to the highway on the main embankment.

4-19. The flow through each conduit is controlled by gate installations in the intake structure located at the upstream end of the conduits. Each intake consists of two 11- x 23-foot rectangular gate passages which converge in a 49-foot length of transition section to a 22-foot diameter circular section. Each passageway is provided with twin gate slots, in tandem, for installation of the 11 x 23 foot emergency and service gates. The design of the water passages and air vents are nearly identical in both power and flood conduits, providing uniformity in construction.

4-20. Eight tunnels are used for power discharges and four are used to make supplementary releases. The No. 10 flood control tunnel is equipped with a special regulating gate to permit fine control of discharges from the reservoir. The lower portion of this gate broke off during the extended period of high releases in 1975 and has not yet been replaced. The twelve tunnels are in straight and parallel alignment with a uniform spacing of 70 feet on centers. Each tunnel is 870 feet long. The eight power tunnels (Nos. 1 to 8) and regulating tunnel No. 10 are constructued 22 feet in diameter for the first 215 feet downstream of the transition section connecting the intake structure with the tunnels. The remainder of each of these tunnels is 28 feet in diameter. The remaining flood control tunnels (Nos. 9, 11, and 12) are 22 feet in diameter throughout their entire length. Steel pipe penstocks 22 feet in diameter are installed in the downstream portion of the power tunnels and the No. 10 regulating tunnel. The invert elevation at the upper portal is 1,229 feet in all tunnels. The slope of all tunnels is slightly greater than 1%, but is not quite the same in all tunnels due to the details of construction.

4-21. A regulating gate was installed in the downstream end of tunnel No. 10 to provide fine regulation of outflow from the reservoir.

The gate was of the rectangular fixed-wheel type of welded construction. The wheels operate on tracks fixed to a gate frame supported by "C" shaped elements in tension, designed to carry the load upstream into a prestressed anchorage system embedded into the concrete anchor at the downstream end of the outlet pipe. The regulating gate hoist is of the dual-drive, chain-sprocket, type permitting operation at partial gate openings. The operating machinery is located in a control house directly above the regulating gate. As noted above, the gate failed in 1975 and has not been replaced.

4-22. The stilling basin extends downstream from the tunnel portal wall approximately 731 feet, and consists of a retaining wall on the landward side, a training wall separating the stilling basin and tailrace, and a series of baffle piers between these two walls to dissipate the energy resulting from the high velocity discharge from the flood control tunnels. The stilling basin is divided into an upstream primary basin and a downstream secondary basin by an ogee weir section located with the centerline of its crest 505 feet downstream of the portal wall of the tunnels. The ogee weir crest is at elevation 1244 or approximately 25 feet above the floor of the primary basin. The weir extends the full width of the stilling basin, a distance of 400 feet. In the primary basin, three training piers extend aproximately 198 feet downstream from the portal wall of the tunnels, to separate the flow from the four tunnels. The floor of the secondary basin is at elevation 1200. Two rows of baffle piers are placed across the width of the secondary basin, with the piers in each row staggered with respect to those in the other row. An end sill and cutoff wall are located at the downstream end of the basin's concrete floor slab. Appropriate drains and anchors are provided for the basin retaining walls and floor slabs as are necessary to assure stability of the structure.

4-23. Power Plant and Switchyard. The intake for the power tunnel as well as tunnel and penstock structures are as described in preceding paragraphs. Eight surge tanks are located upstream of the powerhouse and are connected in pairs to the penstocks serving each of units 1, 3, 5 and 7. The penstocks without surge tanks are connected to turbines with slow-acting governors, while the penstocks with surge tanks are connected to turbines with fast-acting governors. The surge tanks are constructed of rolled steel plates welded to form a tank 59 feet in diameter and 100 feet high.

4-24. The powerhouse structure is 561 feet long by 78 feet wide and consists of 8 generator bays, an erection bay, and a service bay. The longitudinal centerline of the units runs east and west, with Unit No. 1 being the west unit and No. 8 the east. Each of the generator bays is 70 feet wide, except No. 8 bay which is 73 feet. The erection and service bays, 70 and 76 feet in width respectively, extend westward from Unit No. 1. The generator room floor is at elevation 1273 feet m.s.l. and the turbine room floor at 1244 feet m.s.l. The powerhouse superstructure is reinforced concrete and structural steel. The powerhouse also contains office space, control room, public reception lobby and observation balcony, machine shop and all necessary water treatment, sewage treatment, heating and air conditioning facilities.

4-25. Eight hydraulic turbines of the vertical-shaft, single-runner, Francis type, with plate-steel spiral casings are installed in the powerhouse. The turbines are rated 57,500 hp at 112 feet net head and operate at 85.7 rpm. Governors of the isochronous, oil hydraulic-conventional type capable of full-opening or full closing time of 5 seconds are installed on units 1, 3, 5 and 7, with a governor time of 13 seconds used on units 2, 4, 6 and 8. Each governor on a main unit is arranged for load and frequency control.

4-26. The main generators are 40,000 kw, 3-phase, 60-cycle, 13.8 kv, wye-connected, 85.7 rpm units, with Class B insulation for normal temperature rise of 60 degrees C. The units are inclosed, forced-air cooled, with waste heat used to warm the generator room and the surge tank enclosures. Each generator has a direct-connected exciter permanently connected to the generator field, a pilot exciter, and a high speed voltage regulator. Main generator protective equipment includes a neutral reactor and circuit breaker, differential relays, ground detector, resistance temperature detectors and over-speed protection for each unit.

4-27. The tailrace is approximately 560 feet wide and extends 500 feet downstream from the powerhouse. The sidewall on the right bank is the switchyard retaining wall and the sidewall on the left is the boundary wall between the tailrace and stilling basin. The floor of the tailrace is paved for 146 feet downstream of the powerhouse. The top of the slab slopes upward from elevation 1192.75 at the end of the draft tubes to elevation 1209 at the downstream terminal, thus practically maintaining the slope of the draft tube floor. The chalk floor of the tailrace continues to slope uniformly upward to the approximate elevation of the river bed.

4-28. An outdoor switchyard containing the main transformers and switch gear is located immediately to the right and downstream from the powerhouse. The main high voltage busses, circuit breakers, transformers, disconnects, lightning arresters and instrument transformers are located outdoors. Main power transformers are single phase outdoor type units, connected delta on the low side and wye on the high side.

The switchyard is arranged for switching at 115 kv or 230 kv and further arranged so that any operating unit can serve any outgoing transmission line through either of the main high-voltage busses or through the 115/230 kv interconnecting transformer which will prevent shutdown of a generator due to bus failure.

4-29. A more detailed description of power facilities, as well as other structures developed at the dam site, is contained in the Fort Randall Operation and Maintenance Manual. Plan and section of the powerhouse is shown on Plate 13. Power plant tailwater rating curves and power plant characteristic curves are shown on Plates 16 and 17.

4-30. Fort Randall Reservoir. The reservoir formed by Fort Randall Dam lies in south central South Dakota, extending northward from the dam about 107 miles, past Chamberlain, South Dakota, to the tailwaters area of Big Bend Dam. In accordance with Public Law 88-97, approved 15 August 1963, the reservoir is also known as Lake Francis Case, in memory of the late senator from South Dakota. At normal operating levels the lake has a shoreline of 540 miles, a surface area of 79,000 acres and a maximum depth of 140 feet. Fort Randall Reservoir is long and narrow, largely confined to the Missouri River valley except where tributaries enter the reservoir. The largest of these tributaries, entering below Chamberlain, is the White River and forms the White River arm of the reservoir. A map of the reservoir area is given on Plate 18.

4-31. Allocation of storage space in Fort Randall Reservoir was based on main stem system requirements as described in Section V of the Master Manual. Types of storage space, with associated elevations and storage quantities for each type, are given in Table 2. In addition to this allocated space, the reservoir level during the spillway design flood crested at elevation 1379.3 feet m.s.l., representing a surcharge of about 0.45 million acre-feet of storage above the top of the exclusive flood control storage zone.

Area-capacity tables for Fort Randall Reservoir are on Plate 19.

TABLE 2
Fort Randall Reservoir Storage Space Allocations

Storage Designation	Elevation Feet m.s.l. From	Elevation Feet m.s.l. To	Storage Space Acre-Feet
Exclusive Flood Control	1365	1375	985,000
Flood Control & Multiple Use	1350	1365	1,317,000
Carry-over Multiple Use	1320	1350	1,731,000
Inactive	1240	1320	1,570,000
Total Storage			5,603,000

NOTE: Storage volumes are based on January 1978 capacity tables.

4-32. Boat Ramps and Recreation Facilities. Fluctuating levels have a significant effect on recreational use of the reservoir, particularly since the Fort Randall Reservoir level fluctuates from above elevation 1350 feet m.s.l. to elevation 1337.5 feet m.s.l. or below during every year. Fortunately, during the main recreation season (spring and summer months) levels are expected to be at elevation 1350 or above during every year. Numerous public use areas have been established around the shoreline of the project with a common development of most of these areas being a boat ramp providing access to the lake. Boat ramp elevations are given in Table 3. The Randall Creek Park project boat ramp was constructed for access to the Missouri River below the dam. This downstream ramp generally continues operable through the normal range of releases from the project. It is evident that many of these ramps become entirely inundated when reservoir levels exceed the base of the exclusive flood control storage zone.

TABLE 3

FORT RANDALL RESERVOIR BOAT RAMPS

Recreation Area	Ramp Type	Ramp Width	Elevation Feet m.s.l. Top	Elevation Feet m.s.l. Bottom
American Creek	Poured Concrete	60 ft.	1367.0	1337.0
Elm Creek (Ramp #1)	Concrete Plank	12 ft.	1365.0	1335.0
Elm Creek (Ramp #2)	Concrete Plank	12 ft.	1358.0	1348.0
Elm Creek (Ramp #3)	Concrete Plank	12 ft.	1351.0	1341.0
Joe Day Bay	Steel Landing Mat	10 ft		
North Point (North Bay)	Poured Concrete	20-60 ft.	1360.0	1333.6
North Point (St. Francis Bay)	Poured Concrete	30-60 ft.	1361.0	1326.0
Pease Creek (Ramp A)	Concrete Plank	24 ft.	1355.33	1340.33
Pease Creek (Ramp B)	Concrete Plank	12 ft.	1365.0	1352.99
Platte Creek	Poured Concrete	60 ft.	1365.0	1340.0
Randall Creek Park	Poured Concrete	40 ft.	1241.0	1229.0
Snake Creek East	Poured Concrete	60 ft.	1360.0	1334.8
Snake Creek West	Poured Concrete	20 ft.	1365.0	1345.0
South Scalp (Ramp #1)	Concrete Plank	12 ft.	1364.5	1355.5
South Scalp (Ramp #2)	Concrete Plank	12 ft.	1357.5	1349.5
South Scalp (Ramp #3)	Concrete Plank	12 ft.	1352.5	1342.5
South Wheeler	Poured Concrete	24-60 ft.	1358.0	1337.0
Whetstone Bay	Poured Concrete	60 ft.	1358.0	1337.0

4-33. Leasing of Project Lands. As indicated previously, essentially all land surrounding the Fort Randall Reservoir below elevation 1375 ft. m.s.l. has been acquired for project purposes. Unless unusual conditions should occur, inundation of lands lying between elevations 1365 and 1375 would not be expected. Consequently, on an annual basis, the Corps of Engineers makes tracts of land available for lease, generally for agricultural purposes, as a part of their land management program. The extent of leased lands is based on reservoir levels likely to occur, as well as other land management considerations. A major portion of the revenue from this leasing program is returned to the counties within which the leased land lies. During Fiscal Year 1977 the revenues returned to the local government (amounting to 75 percent of total revenues) from the Fort Randall Reservoir land leasing program amounted to over $119,000.00. All such leases provide for possible flooding of lands if needed for operational purposes and do not serve as an overriding constraint upon regulation of the project for authorized purposes.

4-34. Reservoir Aggradation and Backwater. The long term sediment depletion rate of Fort Randall Reservoir has been estimated at 16,600 acre-feet per year. Most of this deposition is contributed by the White River and is deposited in a delta which extends both upstream and downstream from the White River confluence. These deposits will be composed predominately of silt and clay with only 5 to 10 percent sand. Their average density is estimated to be 60 pounds per cubic foot, dry weight. However, new deposits contributed by the White River may be as light as 5 pounds per cubic foot, dry weight. A substantial redistribution of each year's accumulation of these semi-fluid deposits occurs during the annual late season drawdowns of the reservoir. These drawdowns move large quantities of material farther into the reservoir before the sediments have an opportunity to consolidate. This operational procedure lengthens the time it will take backwater effects from the delta to affect power releases from the upstream Big Bend project. With a Fort Randall Reservoir above about elevation 1842 feet m.s.l., the reservoir affects Big Bend tailwater; with the effects becoming increasingly large when the reservoir rises into the upper portions of the annual flood control and multiple-use zone or higher.

4-35. Tailwater Degradation. Since Fort Randall Dam entraps all inflowing sediments, the water released from the dam is sediment free. Thus, the suspended sediment load will gradually increase downstream from the dam as a result of bank erosion, scour from the river bed and sediment in flow from tributaries. As the finer sand particles in the streambed are gradually leached from between the larger sand or gravel particles and transported downstream, a gradual lowering or degradation of the channel below the dam occurs. As evidenced by the tailwater rating curves shown on Plate 16, a degradation of about 6 feet has occurred during the 1951-1975 period. This has a beneficial effect upon power production from the project. Although further degradation is expected, consideration has been given to speeding up the process by mechanical means.

SECTION V - ORGANIZATION FOR RESERVOIR REGULATION

5-1. Normal Regulation. The Fort Randall Reservoir is regulated as a component of the six project main stem reservoir system. As such, regulation must be fully coordinated with regulation of the other five projects. Therefore, regulation of all main stem reservoirs is as directed by the Missouri River Division Reservoir Control Center. Full details relating to organizational responsibilities, coordination, and communications pertinent to the system's regulation process are contained in Section VI of the Master Manual. Consequently, only a brief summarization is presented in this project manual and reference must be made to the Master Manual for a complete understanding of these factors.

5-2. Orders to project personnel specifying releases to be made from the Fort Randall project control the regulation process. These are issued by the Reservoir Control Center and are based on detailed analysis of current and expected hydrologic conditions throughout the Missouri Basin and functional needs of the Fort Randall project as well as the system as a whole. The coordination with other Corps of Engineer offices, outside agencies, and special interest groups is a responsibility of the Reservoir Control Center, as described in the Master Manual.

5-3. Fort Randall project personnel are expected to continually furnish the Reservoir Control Center all information they may receive that is pertinent to the regulation process. This includes observations made by personnel was well as complaints or suggestions from those affected by project regulation. In addition, project personnel are responsible for informing the public in the local area of current and probable near-future regulation activities. It is the responsibility of the Reservoir Control Center to keep project personnel informed of such activities. Any requests for information that are complex, long-term in nature, or that involve policy are referred to the Reservoir Control Center.

5-4. The Omaha District is responsible for project maintenance, including maintenance of those facilities required to support the regulation process. District personnel also collect data pertinent to Fort Randall regulation and are responsible for analysis of runoff events, particularly over tributary drainage areas. The District is also responsible for flood fighting activities. Information available to the Omaha District considered pertinent to regulation of the Fort Randall Project or other main stem reservoirs is immediately furnished the Reservoir Control Center.

5-5. Emergency Regulation. If emergency conditions develop at the Fort Randall project, project personnel are expected to take appropriate action, depending on the nature of the emergency. When there is an immediate threat to serious injury or loss of life at the project, or the probability that serious damage may occur or has occurred to project facilities, prompt action is required and project personnel are expected to take the actions deemed necessary. Prompt notification of the Omaha District and Reservoir Control Center of the circumstances and actions initiated is then accomplished. Subsequent modification or continuance of regulation of project facilities would then be based on evaluation of conditions and affects by all offices concerned, and be directed by the Reservoir Control Center.

5-6. Loss of communication between the Reservoir Control Center and Fort Randall project personnel is an emergency of a different type for which plans can be made in advance. Exhibit A of this manual provides instructions for project personnel in case of such an event. These instructions are designed to continue operations for the functions for which the project was constructed through the period of communications failure. As indicated by Exhibit A, continuing efforts will be made by project personnel to re-establish communications with either the Reservoir Control Center or Omaha District Reservoir Regulation Section (or responsible personnel of those offices) in an effort to terminate the emergency.

SECTION VI - HYDROLOGIC DATA

6-1. General. Section VII of the Master Manual outlines the basic hydrologic data required for regulation of the Missouri River Main Stem Reservoir System, including the Fort Randall project, and gives agency responsibilities, communications methods and other details relevant to the data collection process. Reference is made to the Master Manual for this information. Succeeding paragraphs provide further details of particular interest to the regulation of Fort Randall Reservoir.

6-2. Fort Randall Project Data. Daily reports from the Fort Randall project to the Reservoir Control Center and to the Omaha District include hourly releases and pool elevations, periodic reports of tailwater elevations and wind conditions, and daily reports of maximum and minimum air temperatures, precipitation, pan evaporation and tailwater temperatures. Hourly data are obtained by power plant personnel from recorders located in the power house. A tailwater elevation recorder is also available at this location. Tailwater temperatures are obtained from a thermometer located in a power penstock. Air temperature, wind and evaporation data are obtained from a site located near the Fort Randall power plant in Pickstown, South Dakota. The Pickstown station also furnishes the National Weather Service current weather data that is distributed nationally at 6-hour intervals as a portion of the synoptic weather network.

6-3. Throughout the year project personnel investigate requests and complaints that occur as a result of Fort Randall regulation and report their recommendations and findings to the Reservoir Control Center. The effects of significant changes in release rates through the downstream reach are also investigated. The Reservoir Control Center keeps the project advised concerning anticipated changes in releases and reservoir levels. Based on this information, project personnel are responsible for informing downstream interests of any major change in the general level of release rates that may be scheduled, and also informing affected interests of unusual reservoir elevations that may be anticipated.

6-4. Precipitation and Temperatures. Whenever significant amounts of precipitation occur, reports from many more locations than shown in the basic network presented in the Master Manual are received by the Reservoir Control Center. The National Weather Service has established reporting criteria for these stations, with transmission to the Reservoir Control Center over the RAWARC teletype network. Plate 20 presents locations of precipitation reporting stations established by the National Weather Service in the drainage area discussed in this manual. These stations are also shown and listed in monthly summaries published and furnished the Reservoir Control Center by the National Weather Service. Temperature data obtained from first order National Weather Service Stations and available daily to the Reservoir Control Center are adequate for regulation purposes.

6-5. Snow. During the winter season reports of snowfall and accumulated snow depths are received from many of the National Weather Service stations shown on Plate 20. These reports are supplemented by weekly snow and water content reports from first order Weather Service stations and plains snow surveys conducted by Corps of Engineer personnel, as described in the Master Manual.

6-6. Stages and Discharges. Stage information reported to the Reservoir Control Center as indicated by the basic network in the Master Manual are supplemented by reports from many tributary locations, particularly during the March-July flood season or at other times of the year if unusual stages are occurring. Plate 21 indicates locations within the incremental drainage area where stage and discharges are available. Most stage reports are transmitted over the National Weather Service RAWARC Teletype. Most of the principal tributary locations have been rated by the Geological Survey and from available rating curves or tables an estimate of flows corresponding to reported stages is available along the principal streams at all times.

SECTION VII - ANALYSES PERTINENT TO REGULATION OF FORT RANDALL RESERVOIR

7-1. General. Regulation of the Fort Randall project as a component of the main stem reservoir system requires continuing analyses of available hydrologic information and, to the degree practicable, forecasts of future events. These are considered, in conjunction with the anticipated demands imposed, in serving the various project purposes. These considerations may be of a long-term nature or may be based on anticipated inflows and demands for a relatively short period in the future. Operational planning studies are discussed in the Master Manual. Also discussed in the Master Manual are analyses, forecasts, and studies which, while important for the regulation of the Fort Randall Reservoir, have essentially the same degree of importance for all of the other main stem projects. Analyses considered to be unique, or particularly important, to Fort Randall regulation are presented in the following paragraphs.

7-2. Precipitation and Temperature Forecasts. As discussed in the Master Manual, Weather Service forecasts of all meteorological elements are utilized by the Reservoir Control Center to the degree practicable in the regulation process. Weather Service forecasts are supplemented by forecasts developed by the Reservoir Control Center staff meteorologist. Particularly pertinent for the definition of inflows to Fort Randall Reservoir are forecasts prepared for southwestern and south central South Dakota. Since Fort Randall is the most downstream of the main stem projects containing a significant (in relation to the system as a whole) amount of storage space, forecasts that are pertinent to system release definition, as described in the Master Manual, are also very pertinent to definition of releases from Fort Randall. Factors relevant to runoff from the Fort Randall-Gavins Point incremental area are also important, particularly forecasts of metorologic conditions that indicate substantial flows on the Niobrara River tributary entering the Missouri River below the Fort Randall Dam.

7-3. Precipitation-Runoff Relationships. Infiltration of rainfall over the Missouri River basin between Big Bend and Fort Randall Dams ranges from 0.50 to 1.00 inch for the initial loss and from 0.10 to 0.25 inch per hour infiltration loss. These values are based on relatively few rainfall events because of the rarity of heavy rainfall centers in the area. Snowmelt infiltration ranges from zero for frozen ground, or ice under snow, to approximately the values shown for rainfall. Runoff during any particular rainfall or snowmelt event would amount to the estimated depth of rainfall or snowmelt less the infiltration losses. In actual practice, estimating the rainfall or snowmelt is very imprecise. This is due to the lack of a dense network of precipitation reporting stations, errors in estimating the snow cover available for melt, errors in estimating the snowmelt rate, as well as marked departures from the average infiltration or loss rates given above.

7-4. Unit Hydrograph Analyses. A conventional means of forecasting flows from a particular drainage area is by the use of unit hydrographs. However, unit hydrograph development and subsequent use of the developed hydrographs as a forecasting tool has been found to be impractical for the drainage area under consideration in this manual. Reasons for this include the large size of the drainage area, requiring the division of the area into may subareas, the lack of rainfall and subsequent runoff events for unit-hydrograph definition, the sparsity of rainfall reporting stations needed for both analysis and forecasting purposes, and the fact that by far the greatest amount of runoff that occurs from this drainage area does not result from particular rainfall events but results from progressive snowmelt, making runoff definition during a selected time period very imprecise. Further, with the large amount of storage space available in the Fort Randall Reservoir and the very nature of the regulation process, the effort necessary for a valid and complete analysis by means of unit-hydrograph procedures is not believed to be warranted. However, unit-hydrograph procedures will continue to receive consideration as a means of possibly improving the regulation process.

7-5. Plains Area Snowmelt Volume. In many years a major portion of the annual runoff from the plains contributing area above Fort Randall Dam is a result of melting the snow cover accumulated during the winter months. This melt usually occurs during late March or April and often results in the annual maximum peak flow from the Big Bend to Fort Randall drainage area. Basic data pertinent to plains area snowmelt volume analyses are precipitation during the late fall and winter months, winter season temperatures, water content of the accumulated snow cover prior to the melt period and soil conditions. However, even with these data, forecasts of the plains snowmelt runoff volume are usually quite imprecise.

7-6. Plains area snow surveys are made during any year that a substantial snow accumulation exists over the drainage area. One method of obtaining quantitative estimates of runoff volume is to compare water content of the current survey with surveys made in preceding years. This comparison will indicate which of the past years is most analogous to the current year for each portion of the total drainage basin between Big Bend and Fort Randall Dams. Forecasts are developed by assuming that the volume of snowmelt runoff from each portion of the basin should be similar to that observed in the most analogous year. These estimates are tempered by available ground condition data, which could either increase or decrease the losses at the time of runoff. If analogous data are not available for a particular portion of the basin, it is necessary to estimate the runoff volume by noting runoff depths during previous years from other areas where snow cover conditions appear similar to this year's snow cover over the areas in question.

7-7. Improvement in the techniques of forecasting the runoff resulting from plains snowmelt is being investigated as a technical study by personnel of the Reservoir Control Center and hopefully more precise and objective methods will be developed. In addition, the National Weather Service is investigating this matter and has initiated forecasts of plains snowmelt runoff volumes which are made just prior to the melt season. As experience is gained it appears probable that more valid estimates will be available than in the past.

7-8. Monthly Reach Inflow Forecasts. Soon after the first of each month throughout the year a forecast of incremental inflows originating between individual mainstem dams is prepared by the Reservoir Control Center, with the forecast period extending from the time the forecast is made through the succeeding March. Due to the relatively small drainage area between Oahe and Big Bend Dams, the normal lack of substantial runoff from this area and to the small amount of deliberate seasonal storage space in Big Bend Reservoir, the reach most pertinent to the Fort Randall project extends from Oahe to Fort Randall Dams and includes the Oahe to Big Bend incremental area. Since precipatation forecasts through such an extended period of time are not feasible, the forecasts are essentially based on three factors. These are monthly normal runoff, antecedent runoff, and accumulated snow over the incremental drainage area. In this reach snow contributions to runoff are important only during the early spring (March-April) period of plains snowmelt runoff. Consequently, long range forecasts for periods other than this early spring period consist primarly of subjectively modifying the long term normal runoff volume by experienced antecedent conditions. These forecasts are utilized to develop system regulation studies, as described in the Master Manual. Details and techniques currently applicable for forecast development are contained in the MRD RCC Technical Report MH-73, "Missouri River Main Stem Reservoirs, Long Range Inflow Forecasting Procedures."

7-9. Short Range Forecasts of Daily Inflow. Experience has indicated that a satisfactory method of anticipating Fort Randall inflows for periods of up to a week beyond the current date consists of combining anticipated daily releases from the upstream Big Bend project with anticipated inflows from the Big Bend-Fort Randall incremental drainage area. Most of the time the flows originating between these two projects can be considered in total and will be of the order of 1,000 cfs or less. However, at times substantial runoff originates from this incremental area. Forecasts of total incremental area inflows are then usually an extrapolation of past total runoff in which current hydrologic conditions pertinent to short-term runoff are given due consideration. Typical inflow hydrographs from the total incremental area are discussed in Section II. When substantial flows are occurring on the White River, gaged flows on this stream are used to provide a further index of subsequent incremental inflow to the project. With the relatively large amount of storage space available in Fort Randall, forecast emphasis is not toward exact definition of the incremental inflow hydrograph but rather toward a definition of incremental inflow volumes over a relatively long period of time (a week or more) in order that release adjustments from upstream projects, and on occasion from Fort Randall, can be scheduled in an optimum manner.

7-10. Stage-discharge relationships are maintained in the Reservoir Control Center for important tributary streamflow stations in the Oahe to Fort Randall incremental drainage area. These are kept current on the basis of discharge measurements made by the United States Geological Survey. Plate 22 indicates the present relationships at locations that are most important for developing short range inflow forecasts pertinent to Fort Randall regulation.

7-11. Flow Forecasts at Downstream Locations. Flows through the reach extending from Fort Randall Dam to the headwaters region of Gavins Point Reservoir generally consist almost entirely of Fort Randall releases, and any required flow forecasts consist of anticipated releases. Near the headwaters of Gavins Point Reservoir, Fort Randall releases are supplemented by flows from Ponca Creek and the Niobrara River. Forecasts of flows past Niobrara, Nebraska, below the confluence of these two tributaries with the Missouri River, consider this supplementation. Generally, forecasts of the flow supplementation consist of noting Niobrara River flows at Spencer, translating these flows by a travel time of one day to the Missouri River and developing the daily runoff from the remainder of the incremental drainage area. Extrapolation of future flows are based on hydrologic conditions occurring or anticipated in the incremental drainage area. Typical incremental drainage area hydrographs are presented in the Gavins Point regulation manual.

7-12. Downstream Stage Forecasts. There are no urban damage centers in the reach extending from Fort Randall Dam to the headwaters region of Gavins Point Reservoir. Stages adjacent to the town of Niobrara, Nebraska, in the Gavins Point headwater's region are influenced by the Niobrara River delta; however, the town has been relocated to higher ground and the relocated town is not affected by flows in the Missouri River. The agricultural region upstream from the Niobrara River delta formation in the Missouri River channel experiences some inundation and high groundwater problems with Fort Randall releases exceeding the power plant capacity of about 45,000 CFS. The changing effects of the Niobrara delta on Missouri River stages in this vicinity are illustrated by the rating curves given on Plate 6 for a location about 3 miles upstream of the mouth of the Niobrara. These rating curves show the upward shift of the rating curves during years of normal or lower releases from Fort Randall and the temporary lowering of the rating curve following years of high releases, such as 1975. Forecasts for this location are based on expected Fort Randall releases.

7-13. Routing Procedures. For purposes of anticipating inflows to Fort Randall Reservoir a simple translation of observed or anticipated upstream flows by the approximate travel time from the upstream location is an adequate routing procedure. The large storage capacity and associated regulation procedures do not require precise definition of anticipated inflows. Big Bend Reservoir is the only reservoir project of significant size contributing directly to the Fort Randall project. Since Big Bend releases normally enter directly into Fort Randall Reservoir, routing of these releases is not required for Fort Randall inflow estimates. A simple procedure for estimating Fort Randall inflows is to lag Big Bend mean daily releases by one day.

7-14. Fort Randall Reservoir Evaporation Estimates. Because of the large surface area, evaporation is an important component of the overall water budget of Fort Randall Reservoir. An estimate of the daily evaporation volume is required for developing daily inflow estimates as well as for more precisely estimating the effects of reservoir development upon the available water supply. While one means of estimating daily evaporation depths is application of the commonly used 0.7 factor to adjacent pan evaporation, this is not considered reliable for Fort Randall due to the marked difference between the lake surface temperature and pan temperature. MRD-RCC Technical Report JE-73 addresses this problem in detail and recommends the use of a variable pan-to-lake factor. This factor for Fort Randall varies from as little as 0.19 during periods when lake surface temperatures are less than air temperatures to as high as 1.62 when lake surface temperatures materially exceed air temperatures. During those portions of the year when pan data are not available, normal evaporation depths for the season of the year appears to offer the most practical means of developing evaporation estimates for day-to-day regulation activities. Reference is made to the cited Technical Report for further details pertinent to the development of evaporation estimates for this project.

7-15. In addition to evaporation, development of the effects of Fort Randall Reservoir upon streamflow must consider the offsetting effects of precipitation upon the reservoir surface and must also make allowances for the channel area in existence prior to the impoundment of water in the reservoir. Also, allowance must be made for that portion of the rainfall now falling on the reservoir surface which prior to the reservoir would have contributed to direct runoff from the area now inundated. Precise calculations of these factors are impractical. Therefore, in determining net evaporation, it is assumed that 75% of the precipitation that falls on the reservoir is effective in offsetting gross evaporation (this assumes that 10% would have fallen on original channel area and that 15% would have appeared as direct runoff from the former ground surface now inundated by the reservoir.)

7-16. Wind Effects on Water Surface Elevations. The general orientation of Fort Randall Reservoir is to the northwest of the damsite where the pool level recorder is located. Winds with a component from this direction result in set-up at the dam while a wind component from the opposite direction results in set-down. Plate 23 is a wind correction table for the pool level recorder at the dam. An anemometer is located near the dam; however, it should be recognized that only approximations of the wind effect on the reported pool level can be obtained with data from this instrument. The time required for set-up to be fully established, variations in wind velocity and direction over the reservoir surface and the unrepresentativeness of the observations at the dam will all result in deviations from calculated values. Synoptic surface weather maps may also be used for qualitative wind estimates or to determine the probable representativeness of the anemometer.

7-17. Daily Inflow Estimates. Estimates of inflow to the Fort Randall Reservoir are made each day for operational purposes. The steps involved consist of the following:

a. A plot of hourly pool elevations as given by the pool level recorder is maintained.

b. Utilizing reported winds, the set-up or set-down effects are estimated and average lake levels, adjusted for wind, throughout the past 24-hour period are determined.

c. Storage change equivalent to the estimated 24-hour elevation change is determined. Combining this with reported releases and estimated evaporation, an equivalent inflow is computed.

d. Big Bend releases and gaged White River flows are routed to the Fort Randall Reservoir. These are combined with estimates of ungaged flow and precipitation on the reservoir surface to obtain an additional estimate of reservoir inflow.

e. Differences in inflow estimates as determined by c and d are reconciled by judgement.

f. At times it will be necessary to adjust data for previous days on the basis of continuing trends in the lake level which were not evident during those days.

7-18. Unregulated Flows. Construction of Fort Randall Dam, together with the other main stem and tributary projects in the basin, has materially altered flows downstream from the dam. Flood peaks have been reduced and low flows augmented by reservoir regulation. A quantitative estimate of the effects of regulation upon flows at the damsite and important locations immediately downstream is frequently required. This represents a continuing effort by the Reservoir Control Center, involving such factors as reservoir evaporation, precipitation on the Fort Randall Reservoir, variations in travel time resulting from reservoir development, channel area inundated by the reservoir, runoff that could have been expected from previous overbank areas now inundated by the reservoir, inflows, outflows, and storage changes. Details of the required analyses are contained in the RCC Technical Study S-73, "Unregulated Flow Development," and, rather than repeating in this manual, reference is made to that publication.

7-19. In addition to unregulated flows, determination of flows at the 1949 level of basin development (prior to construction of Fort Randall Dam and other water resource development in the Missouri Basin) represents a continuing effort of the Reservoir Control Center. Fort Randall represents a location where such determinations are made. Reference is made to Section VIII of the Master Manual for further details of these analyses.

7-20. Evaluation of Regulation Effects. In evaluation of the effects of regulation upon downstream flows, and consequent flood damage reduction estimates, the Fort Randall project is considered to be a component of the main stem reservoir system. Damage reductions attributable to regulation of this individual project are not differentiated from those resulting from the 6-project system as a whole. Details of the evaluation process are given in Section VIII of the Master Manual and in other references cited in that publication.

SECTION VIII - MULTIPLE-PURPOSE REGULATION OF FORT RANDALL RESERVOIR

8-1. General. Aspects of multi-purpose regulation that are pertinent to the Missouri River mainstrem reservoir system as a whole, are discussed in Section IX of the Master Manual. Since continuing development of system operating plans requires coordination of plans for all main stem projects, this subject has been explored throughly in the Master Manual and will not be repeated in this, the Fort Randall project manual. Rather, the following paragraphs will be concerned with amplifying the operational objectives and requirements given in the Master Manual as they are pertinent to regulation of the Fort Randall project for the functions of irrigation, navigation, water supply, power, fish and wildlife, water quality and recreation. Regulation of the Fort Randall project for flood control is discussed in Section IX.

8-2 Basis for Service. As an introduction to regulation of the project, the need to conform to certain storage provisions and basic regulation criteria should be recognized. The bottom inactive storage zone of the Fort Randall Reservoir, or that zone lying below elevation 1320 feet m.s.l., is to remain permanently filled with water. This insures maintenance of a minimum power head, a minimum level for the design of irrigation diversion and other water supply facilities, and a minimum pool for recreation, fish and wildlife purposes. The top storage zones in the lake, extending above elevation 1365 feet m.s.l., are provided for handling the largest floods and to insure safety of the project structures. These upper storage zones are reserved exclusively for these purposes. Storage space intermediate to these zones, extending from 1320 to 1365 feet m.s.l., provides for the multiple-purpose enumerated in Paragraph 8-1 as well as for the control of moderate floods and, together with the upper zones, allows a degree of control of major floods including those approaching the maximum possible that can occur.

8-3. The following general approach is observed during regulation of the Fort Randall project:

a. Regulation of Fort Randall Reservoir as an individual project must be subordinate to regulation of the entire main stem system as a whole in most cases.

b. Flood control will be provided for by evacuating the storage space in the reservoir above elevation 1353 feet m.s.l., and limiting refill of the project during the winter months to this level, prior to March of each year. During those years that a significant snow cover accumulates during the winter months, the limit of fill prior to early March is at elevation 1350 feet m.s.l.

c. At all times releases will be such as to maintain the downstream Gavins Point Reservoir at the level appropriate for the season of the year as described in the Gavins Point regulation manual.

d. To the extent practicable, in view of the water supply originating upstream from Fort Randall Dam, the Fort Randall Reservoir will be maintained between elevations 1350 and 1365 feet m.s.l. during the months of March to early September by appropriate scheduling of releases from the upstream Oahe and Big Bend projects. During the late fall months of each year, prior to the end of the Missouri River navigation season, upstream reservoir release will be adjusted to lower the level of the Fort Randall Reservoir to elevation 1337.5 feet m.s.l. in each year, and to as low as elevation 1320.0 feet m.s.l. during severe and extended drought periods.

e. All irrigation and other upstream water requirements for beneficial consumptive purposes will be served.

f. By adjustment of Fort Randall Reservoir levels and releases, within the criteria designated above, the efficient generation of power to meet the area's needs as consistent with other uses and market conditions will be provided for.

g. Release from the downstream Gavins Point Reservoir to support Missouri River navigation will be backed up by releases from the Fort Randall project.

h. Insofar as possible without serious interference with the foregoing, the Fort Randall Reservoir will be regulated for maximum benefit to recreation, fish and wildlife.

8-4. Flood Control. Regulation of the Fort Randall project for flood control purposes is discussed in Section IX of this manual and therefore not presented in detail in this Section. However, it is evident that the storage of water during periods of high runoff and subsequent release during low water periods for multiple-use purposes is compatible with flood control. Similarily, water storage for flood control purposes is generally compatible with multiple-use regulation of the project.

8-5. Irrigation. Irrigation development on lands surrounding Fort Randall Reservoir has occurred to a small extent, and there are proposals by private interests to greatly expand the irrigated acreage by collective irrigation projects. There are no authorized or existing Federal irrigation projects from this reservoir. Since the reservoir level will be at elevation 1350 feet m.s.l. or above during the irrigation season, withdrawals of water for this purpose should present no great problems for the irrigators. Corps of Engineer regulation responsibilities in this connection will be limited to estimating withdrawals and utilizing the estimates in the development of reservoir inflows and in deriving estimates of the actual available water supply.

8-6. Currently there are no significant irrigation withdrawals from the Missouri River along the reach immediately below Fort Randall Dam which require maintenance of minimum flows. Even if such withdrawals should develop, releases necessary for other purposes throughout the irrigation season should be adequate for the necessary water supply. In common with other reaches of the Missouri River below mainstem reservoir projects, there may be some problems associated with access to the supply due to fluctuating release levels.

8-7. Water Supply and Quality Control. There are no present withdrawals from the Missouri River in the reach extending from below Fort Randall Dam to the headwaters of Gavins Point Reservoir for municipal and industrial purposes. The City of Springfield, South Dakota, withdraws water from the Gavins Point headwaters region; however, the intake is affected primarily by Gavins Point Reservoir levels rather than the magnitude of releases from Fort Randall. Municipal supplies are provided for the City of Lake Andes, South Dakota, from Fort Randall Reservoir, with the intake being operable through the entire range of reservoir elevations likely to occur extending upward from elevation 1320 feet m.s.l. Other intakes to serve water supply purposes from the reservoir are contemplated and their design should recognize planned variations in the reservoir level. The availability of good quality water in the reservoir and lack of significant pollution sources in the immediate downstream reach makes it unnecessary to schedule releases to serve only the water quality function.

8-8. Navigation. Although all Fort Randall releases are re-regulated by the downstream Gavins Point project, the primary burden of sustaining navigation flows on a continuing basis rests upon Fort Randall and the major upstream mainstem reservoir projects. Since Gavins Point Reservoir contains only a small amount of storage space and the pool level in this downstream project is held relatively constant from day to day, the daily release requirements for navigation must be translated upstream to Fort Randall. Ultimately the Fort Randall daily release for this purpose must be backed up by upstream projects, however, this back-up can be scheduled on a fairly long term basis, allowing variations in the Fort Randall storage level to meet daily and weekly variations in the navigation requirements.

8-9. Power Production. Hydroelectric power generated by the Fort Randall project is integrated with the power generated by the other main stem projects and many other public and private generation facilities in the Missouri Basin and surrounding areas. To the extent practical all releases are made through the power plant. Since the Fort Randall power plant units were completed in 1955, releases in excess of power plant capacity have been required only in years of an over-abundant water supply, primarily to serve the purpose of evacuating upstream storage space to provide control for the following year's flood inflow. The maximum sustained Fort Randall release since power plant operation began was in 1975 when flows of 60,000 cfs were released from mid-July through November. This represented releases bypassing the power plant ranging from 13,000 cfs in the early portions of the period, when reservoir levels were within the operating range above elevation 1350, to 18,000 cfs after the fall draw-down to elevation 1337.5 had been essentially completed. During the year 1975, total bypass release from Fort Randall represented only 16 percent of the total annual release volume. During the mid-July through November period of 1975, about 25 percent of the total releases bypassed the Fort Randall power plant. System regulation criteria, as described in the Master Manual, are designed to reduce bypass releases to a practicable minimum.

8-10. While hourly loadings of the Fort Randall Power Plant are scheduled by the Western Area Power Administration system power dispatcher in Watertown, South Dakota, these loadings must be within limits prescribed by the Reservoir Control Center of the Corps of Engineers. These limits are developed on the basis of daily as well as hourly releases required to serve functions other than power. Due to the changing power loads during the day, instantaneous releases will often fluctuate widely between zero and the full power plant capacity of about 48,000 cfs. Further discussion on power scheduling is presented in the Master Manual.

8-11. A seasonal variation in the general level of power releases from the Fort Randall Reservoir usually occurs, largely reflecting service being provided other functions. During the open-water season, relatively large releases are required from the lower-most reservoir of the main stem system (Gavins Point) for navigation. These releases are normally backed up by correspondingly large releases from the Fort Randall project, since relatively little inflow usually originates from the Fort Randall-Gavins Point portion of the basin during the navigation season. Additionally, during years of above normal water supply, the major portion of required system storage evacuation must be made during the open water season. These large releases generate substantial amounts of power.

8-12. During the winter months when navigation is not possible, releases from the reservoir system are usually restricted to less than one-half their navigation season level due to the reduced capacity of the ice-covered Missouri River channel below Gavins Point Dam. Corresponding reductions in releases and power production must also be made at Fort Randall. A means of partially compensating for the lesser amount of hydroelectric energy associated with lower winter release rates from Fort Randall and other main stem reservoirs is the pre-winter drawdown of Fort Randall Reservoir. In this operation, occurring several weeks prior to the end of the navigation season, Fort Randall inflows are maintained at less than outflow by reducing releases from upstream reservoirs. This leaves Fort Randall Reservoir with the task of supplying a portion of downstream navigation flow requirements from accumulated storage, resulting in lowering reservoir levels. This vacated storage space is refilled during the winter months by releases through upstream power plants in excess of those that would have been possible if drawdown of Fort Randall had not been made. The drawdown of Fort Randall will normally be limited to elevation 1337.5 feet m.s.l., except that during those years when system releases must be reduced due to a lack of available system storage a drawdown as low as elevation 1320 feet m.s.l. will be made as necessary to allow an average winter release rate of 15,000 cfs from the upstream Oahe project.

8-13. Fish and Wildlife. Regulation of Fort Randall Reservoir for fishery purposes largely involves pool level manipulations which will provide a suitable environment for the spawning and initial growth of game and forage fish. Stationary or rising reservoir elevations through the late March to early July period are desirable for this purpose. Additionally, some species such as the northern pike require the inundation of terrestial vegetation during the late March and April period for a suitable spawning habitat. Due to the relatively small amount of storage space (as compared to the large upstream main stem reservoirs) involved in providing significant elevation changes in Fort Randall Reservoir, as well as the normal seasonal operation of the project for other purposes, regulation of the project for northern pike spawning can often be accomplished with little disruption of the other functions the project was designed to serve. Maintaining a stationary or rising reservoir level through June is considerably more difficult, particularly if less than normal runoff originates above Fort Randall or if downstream navigation requirements are above the normal level. However, it can often be accommodated with relativ ease during years of above normal water supply.

8-14. Degradation of the Missouri River channel below Fort Randall Dam has resulted in formation of a coarse gravel bottom in some reaches downstream of the dam. This forms an ideal spawning bed for the sauger and walleyed pike species of fish. Additionally, paddlefish spawn in this reach of open water between Fort Randall Dam and the headwaters of Gavins Point Reservoir. Fluctuating stage levels resulting from power peaking operations can result in exposing eggs deposited during high water periods. As a consequence, an effort is made to reduce release fluctuations during the mid-March to mid-June period when spawning of these species takes place. This is accomplished by establishing a minimum instantaneous release level each spawning season that is dependent upon the anticipated general release level that will be necessary. In order to enhance spawning the minimum release level is established as high as practicable without serious interference with power production.

8-15. Recreation. Water based recreation upon the Fort Randall Reservoir is dependent on the constructed access facilities. Boat ramps constructed around the perimeter of the project have top elevations extending up to elevation 1365 feet m.s.l. and bottom elevations from 1326 to about 1340 feet m.s.l. as described in Section IV of this manual. Insofar as practical, consistent with the water supply, other functions, and conditions in the other main stem projects, Fort Randall Reservoir levels should be scheduled to provide continued access to the reservoir area for recreational use. The modification in Fort Randall operational procedures that was made in 1971, discussed in Section IV of this manual, was partly in response to demands for continuing access to the lake during the pre-winter drawdown of the reservoir. Even with this changed procedure, lowering of the pool level from the normal operating level of 1350 ft m.s.l. to the drawdown level (normally elevation 1337.5) should be delayed to the extent practicable. Boating and fishing on the Missouri River below Fort Randall Dam are also popular recreational activities during the summer months. Hourly Fort Randall release variations appear to have little adverse effect upon the use of tailwater areas since the higher power loads and consequent high releases desired by recreational interests usually occur during the daylight and evening hours when recreation use is highest. In addition, navigation release demands during the summer recreation season are usually quite high, limiting the power peaking that can be accomplished from Fort Randall.

8-16. Release Scheduling. As discussed in the Master Manual, long-term scheduling of releases from the Fort Randall project, as well as all other main stem reservoir projects, is normally based on continuing studies by the Reservoir Control Center in which all functional requirements, including flood control, are considered. These studies are made at maximum intervals of one month and incorporate current conditions with the most recent estimates of future runoff, as expressed in terms of forecast inflow to the individual reservoir projects. Service to all authorized functions receives consideration, including current projections of power demands and navigation requirements. The frequency of these studies is increased when previously unanticipated inflows occur that may have a substantial effect upon system regulation or upon regulation of individual reservoirs. An example of these studies is included in the Annual Operating Plan, published each year as described in the Master Manual.

8-17. On a short-term basis there are often modifications to the general long-term scheduling of Fort Randall releases, usually dictated by requirements of the downstream Gavins Point Reservoir or system release requirements. In the winter season long-term scheduling is usually followed much more closely than during the navigation season. Day-by-day variations in navigation release requirements must be reflected almost immediately by variations in the Fort Randall release level due to the lack of any substantial storage in the downstream Gavins Point Reservoir.

8-18. Reservoir regulation orders, furnished by the Reservoir Control Center to operating personnel at the Fort Randall project, are the basis for scheduling mean daily releases from this project. Since exact daily power demands cannot be anticipated, regulation orders usually allow a specified variation from this scheduled mean daily release rate. Allowable variations in Fort Randall release rates from those specified in the order are usually very low since this project effectively sustains system releases that are maintained within close tolerances. Hourly patterning of the Fort Randall mean daily release rate within limits prescribed by the Reservoir Control Center is accomplished by the Western Area Power Administration's scheduling of daily power production.

8-19. Scheduling of Fort Randall releases during periods when a failure in communications between the Reservoir Control Center and Fort Randall project personnel occurs is discussed in Section IX of this manual. Specific instructions designed to continue an acceptable level of services to multiple-purpose functions, consistent with circumstances then occurring, are given in Exhibit A.

SECTION IX - FLOOD CONTROL REGULATION OF FORT RANDALL RESERVOIR

9-1. Objectives of Flood Control Regulation. The flood control regulation objectives of the Fort Randall Reservoir are: (1) to coordinate regulation of Fort Randall with the regulation of the other main stem reservoirs on the Missouri River to prevent runoff from the drainage basin above Fort Randall Dam from contributing to damaging flows through the lower reaches of the Missouri River; (2) to utilize available storage space in the best possible manner to prevent or reduce flooding in the reach from Fort Randall Dam to the headwaters of Gavins Point Reservoir. The first objective given is the primary flood control objective for the main stem system as a whole. As a consequence, it is discussed in the Master Manual. The concerns of this manual are to amplify system regulation procedures as they apply particularily to the Fort Randall project to discuss regulation geared to reduce flooding along the Missouri River immediately below Fort Randall.

9-2. Method of Flood Control Regulation. In general, the developed method of regulation of the Fort Randall Reservoir 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 in the reservoir during each flood event, with regulation procedures based on the control of floods of approximate project design magnitude.

9-3. Storage Space Available for Flood Control Regulation. During any specific flood event all available space in the Fort Randall Reservoir will be utilized to the maximum extent practicable for flood control purposes. The control of floods will be combined with regulation for other beneficial water uses. Storage space allocated for flood control in the Fort Randall Reservoir totals 2.3 million acre-feet. Of this, 1.0 million acre-feet is exclusive flood control storage space, to be utilized only during unusually large flood season inflows. The remainder is annual flood control and multiple-use storage space that will be filled seasonally, to the extent required by the available water supply, and subsequently evacuated in the interest of flood control and other beneficial uses. Surcharge storage space has also been provided in the Fort Randall Reservoir to insure the safety of the project during extreme floods. However, utilization of this storage will usually provide some downstream flood reductions during the extreme flood events. Carryover multiple use storage space in Fort Randall, when evacuated, may also serve the flood control function although deliberate evacuation of this space to serve flood control will not be scheduled. Annual evacuation of a portion of the carryover storage space in Fort Randall is for the sole purpose of increasing winter power production from the upstream projects. Refill of the space will usually be made prior to the flood season; however, in years when the flood potential between Oahe and Fort Randall is particularly high, it may become desirable to delay complete refill until the flood runoff begins.

9-4. Flow Regulation Devices. Releases from the Fort Randall project may be made through the power plant, outlet works and the spillway. Normally discharge through the power plant will be used to the fullest extent possible in order to achieve the maximum economic returnfrom the project. The discharge capacity of the Fort Randall power plant ranges up to 48,000 cfs. When it is necessary to release at rates greater than the power plant is capable of maintaining, the outlet tunnels, capable of passing over 100,000 cfs will be used. If releases larger than the combined capacity of the power plant and outlet tunnels are required, they must be made over the spillway. The spillway is capable of discharging 500,000 cfs at the top of the exclusive flood control storage zone.

9-5. General Plan of Flood Regulation. Flood control regulation of the Fort Randall Reservoir to meet the stated objectives is based on consideration of the following factors:

a. Coordination of flood control regulation of Fort Randall with the regulation of the other main stem reservoirs and upstream tributary reservoirs as described in Section X of the Master Manual.

b. Channel capacity through the reach of the Missouri River immediately downstream from Fort Randall Dam.

c. Observed and anticipated inflows to Fort Randall Reservoir.

d. Space currently available within the Fort Randall Reservoir for storage of future inflows.

e. Anticipated inflows, releases and storage levels in the downstream Gavins Point Reservoir.

f. Release requirements from the Oahe project for purposes other than flood control.

9-6. The general plan of regulation applicable to most of the major main stem reservoirs is to have the flood control storage space evacuated prior to the beginning of the March-July flood season. Flood season inflows that are in excess of the current multiple-use requirements are deliberately impounded in the annual flood control and multiple-use storage space of the system, until such time there is reasonable assurance that adequate reserves are stored to satisfy multiple-use requirements to the beginning of the next flood season without drawdown into the carryover multiple use zone of storage. Deliberate fill of Fort Randall Reservoir is usually terminated at about elevation 1355 ft. m.s.l. since additional fill has an adverse effect upon overall system power peaking capability due to increasing tailwater levels at the upstream Big Bend project. However, if additional fill of the annual flood control and multiple-use space appears desirable for multiple-use purposes it will be made. This deliberate storage for present and future multiple use also serves the flood control function. Following the time that an adequate supply of multiple-use storage in the system is reasonable assured, releases in excess of current multiple-use requirements are made as a flood storage evacuation measure when these releases are not anticipated to contribute to significant downstream flooding.

9-7. Flood Control Constraints. The relatively short reach of the Missouri River extending from Fort Randall dam to the headwaters of Gavins Point Reservoir has no urban areas along the banks other than the relocated City of Niobrara, Nebraska, located in the extreme headwaters area of Gavins Point Reservoir at the confluence of the Niobrara and the Missouri. The city was relocated to higher ground because of high groundwater problems and potential future adverse effects due to aggradation and backwater from the downstream Gavins Point project. The existing groundwater problem is due to the higher Missouri River stages caused by the Niobrara River delta. With this relocation, urban flooding of Niobrara should be limited, unless it should be necessary to make extreme releases, much greater than would be expected with normal flood control regulation.

9-8. The delta formed in the Missouri River by accumulation of Niobrara sediment at the mouth of this tributary has severely restricted the channel capacity through the 10-mile reach extending above the mouth of the Niobrara River. Continuing flows at the maximum Fort Randall power plant capacity now result in some overbank flooding and waterlogging in this reach and flows in excess of this rate result in inundation of increasing amounts of agricultural areas. Summer homes built in this reach along the banks of the Missouri River experienced very little freeboard during 1975 when Fort Randall releases of 60,000 cfs were required for an extended period of time. Owners of the agricultural land affected have through court action been awarded damages, with the award contingent upon the plaintiffs delivering deeds conveying a perpetual easement to the flood lands required for operational purposes.

9-9. Within the Fort Randall Reservoir area, pool elevations approaching or exceeding the base of the exclusive flood control storage space have an adverse effect upon access to boat ramps in several of the recreation areas surrounding the reservoir. Camping facilities in some areas are also adversely affected. County roads, located in the reservoir area become inundated when reservoir levels are above elevation 1365 ft. m.s.l. While these are not serious constraints, they should be given consideration to the extent feasible in scheduling operations of the main stem reservoir system.

9-10. The major restraint affecting flood control regulation of Fort Randall is the status of the downstream Gavins Point project, including current and expected elevations, inflows, and outflows. With the lack of appreciable storage space in Gavins Point allowing only a minimum amount of re-regulation of Fort Randall releases, it becomes necessary to essentially consider all constraints to system flood control releases when scheduling releases from Fort Randall. The criteria applicable to system releases are given in detail in the Master Manual.

9-11. Coordinated System Flood Control Regulation. The main stem system of reservoirs, of which the Fort Randall Reservoir is an integral component, is regulated to reduce flooding to the maximum degree practical along the Missouri River below the system. Release scheduling from the Fort Randall project to accomplish this objective is based on studies performed by the Reservoir Control Center. The longer range studies of current operations extend from the current date through the succeeding months up to a 1 March date of the following year. All factors listed in paragraph 9-5 are considered to the extent possible in these studies. Such studies are made at a maximum interval of one month as new estimates of future inflows are developed and, if conditions change materially from those anticipated in previous monthly studies, additional within-month studies are made. The published Annual Operating Plan, discussed in the Master Manual, is based on one of these studies with deviations from the published plan based on the results of subsequent monthly (or more frequent) studies. Details of flood control regulation procedures applicable to the system of reservoirs are given in Section X of the Master Manual.

9-12. Exclusive Flood Control Regulation Techniques. The Fort Randall Reservoir will usually be operated at an elevation of 1365 ft m.s.l. or less. However, occasionally flood inflows will be of such magnitude that encroachment into the exclusive flood control zone above elevation 1365 will occur. Consequential actions will be dependent upon existing or anticipated conditions in the other reservoirs in the main stem system. If annual flood control and multiple use space remains vacant in the upstream Oahe Reservoir and is expected to remain available, an obvious action is to reduce Oahe releases to the minimum consistent with all functions being served. If exclusive flood control space is being utilized in all reservoirs, action will be on the basis of the studies described in the preceding paragraphs, with system releases and the balance of exclusive storage scheduled in each reservoir of the system in accordance with procedures discussed in the Master Manual. These procedures give evacuation of exclusive flood control storage in Fort Randall a higher priority than the evacuation of similar space in the major upstream reservoirs.

9-13. Fill of the exclusive flood control zone, and encroachment into the surcharge storage zone of the Fort Randall Reservoir, should be avoided by reducing Oahe releases and increasing Fort Randall releases to the extent possible without contributing to substantial downstream flood damages. If releases in excess of the power plant capacity appear necessary, they may be made through the outlet works tunnels or the spillway. If unusually large amounts of runoff should originate from above Fort Randall Dam, the emergency regulation curves given in Exhibit A will serve as a guide for regulation.

9-14. Surcharge Regulation Techniques. During exceptionally large flood inflows, all available flood control storage space may be utilized and the Fort Randall Reservoir may rise into the surcharge zone above elevation 1375 ft. m.s.l. Since the primary reason for providing surcharge space is to insure the safety of the Fort Randall Dam and also since real estate surrounding the lake has in general not been acquired above elevation 1375 ft. m.s.l., surcharge encroachment should be allowed only when necessary to prevent extensive downstream damage or if unprecedented flood inflows were to occur. When unprecedented flood inflows occur, the regulation curves given with the emergency instructions, Exhibit A, should be used as a guide for release scheduling. Portions of these regulation curves relate reservoir level and inflow to suggested release, with the suggested release based on typical recession curves, by the method outlined in EM 1110-2-3600. Use of these curves should prevent significant surcharge space encroachment except during the most extreme floods. If the reservoir should rise more than one-half foot into the surcharge space, release of inflows up to the full spillway capacity should be scheduled to prevent any further significant elevation increase.

9-15. Responsibility for Application of Flood Control Regulation Techniques. As described in Section VI of the Master Manual, the Missouri River Division Reservoir Control Center is responsible for and directs all regulation, including flood control regulation, of Fort Randall and the other main stem reservoirs. Instructions to assure continuation of Fort Randall regulation during periods of communication failure between the project and the Reservoir Control Center are given in succeeding paragraphs and in Exhibit A of this manual.

9-16. Emergency Regulation. Rapid communication is usually available between the Reservoir Control Center and operating personnel of the Fort Randall project. When communications are interrupted for any extended period of time, project personnel will be required to continue regulation, as discussed in Section V. Exhibit A of this manual outlines the emergency procedures to be followed. In general, these procedures are such that they will continue service to multiple-use functions through the period of communications failure at the approximate level prevailing prior to the communications outage, if Fort Randall inflows continue in the range of those previously anticipated. The emergency procedures also allow for increased inflows, up to those occurring during maximum possible floods, as developed for spillway design purposes.

9-17. Emergency regulation curves included with Exhibit A were developed by the method described in EM 1110-2-3600. A T_s value of 3.5 days was selected in curve development with this value based on experienced incremental inflow hydrographs as well as the Fort Randall Reservoir inflow hydrographs of maximum possible floods developed during spillway design studies. The developed emergency procedures recognize the relatively small amount of surcharge storage space provided in Fort Randall Reservoir, as well as the appropriate channel capacity existing below the reservoir extending downstream on the Missouri River to below Gavins Point Dam.

9-18. Fort Randall releases under emergency conditions are related to inflows, subject to the following:

a. Releases in excess of 100,000 cfs, the approximate Missouri River channel capacity below the main stem reservoir system, will not be scheduled until the level of Fort Randall Reservoir exceeds the base of the exclusive flood control storage space, elevation 1365 ft. m.s.l.

b. With a Fort Randall Reservoir level in the exclusive flood control zone (elevation 1365 to 1375 feet m.s.l.) minimum releases will be in the 50,000 to 100,000 cfs range, dependent upon the degree of encroachment, in order that this zone can be evacuated for control of subsequent runoff.

c. With a Fort Randall Reservoir level in the surcharge zone (above elevation 1375 feet m.s.l.) releases should be at the full spillway discharge capability.

d. In order to remain compatible with the spillway design of the downstream Gavins Point project, total Fort Randall releases should not exceed the full Fort Randall spillway capacity at the prevailing Fort Randall Reservoir elevation.

SECTION X - EXAMPLES OF FORT RANDALL REGULATION

X-A Historical Regulation.

10-1. Fort Randall Reservoir Elevations. Closure of Fort Randall Dam was made in July 1952, beginning the accumulation of storage in the reservoir. Initially the project was regulated for flood control and navigation and, in combination with the operational Fort Peck project, initiated the operation of the Missouri River main stem reservoir system. The minimum pool (elevation 1320 feet m.s.l.) was filled in mid-1954 in anticipation of the first power units coming on line. Prior to 1957 an interim base of flood control at elevation 1340 feet m.s.l. governed regulation of the project, recognizing continuing construction of the project and the incomplete nature of the system as a whole. Since 1957 Fort Randall has been regulated within the normal range of reservoir elevations. The base of the exclusive flood control zone, elevation 1365.0, has been approached during several years but exceeded only in 1967 when a maximum reservoir at elevation 1366.5 feet m.s.l. was recorded. At this maximum level, about 850,000 acre-feet of vacant storage space remained available to control additional flood inflows, should they have occurred. Plates 24 and 25 show the levels of the Fort Randall Reservoir since initial fill of the minimum pool occurred in 1954.

10-2. Plates 24 and 25 also illustrate the past annual variations in reservoir levels. Typically, the minimum level occurs in the early winter season at the end of the Missouri River navigation season. Recapture of winter power releases from upstream reservoirs raises the reservoir during the winter months to about elevation 1350 feet m.s.l. by early March. A continuing rise into the annual flood control and multiple-use zone is usually experienced into June, after which levels fall. The annual flood control and multiple use zone is slowly evacuated by early fall after which accelerated evacuation occurs in order that carryover space will be again available during the winter months for recapture of upstream power releases.

10-3. As illustrated on Plate 24, the fall drawdown of Fort Randall on a continuing basis began in 1962, after the upstream Oahe power units became available. During the years 1962 through 1970 the drawdown was to the 1320 feet m.s.l. level and in one year (1964) was drawn as low as elevation 1313.5 feet m.s.l. As discussed in Section IV of this manual, this annual drawdown generated many complaints, mostly of a recreational and environmental nature. Consequently, beginning in 1971, operational criteria were changed and since that time, drawdown has been limited to elevation 1337.5 feet m.s.l. The

1972-1977 reservoir levels shown on Plate 25 can be considered typical of reservoir levels that may be expected in the future unless the total Missouri River water supply to the entire system is much below normal. In event of a major extended drought, comparable to that experienced over the Missouri Basin during the 1930's, operational criteria are such that the 1962-1970 reservoir levels shown on Plate 24 would be typical until a recovery in the water supply occurred.

10-4. Fort Randall Releases. Experienced mean monthly releases from the Fort Randall project are also shown on Plates 24 and 25. A typical pattern of higher releases during the Missouri River navigation season than during the winter months is evident, as is a great variability in monthly releases, particularly during the 1969-1975 period when an above-normal water supply generally prevailed. Full service to navigation seldom requires Fort Randall releases in excess of 35,000 cfs; therefore, when releases exceed this amount, system storage evacuation for flood control purposes generally is occurring. It is of interest to note on Plates 24 and 25 that there is little relationship between the higher than usual releases and corresponding Fort Randall Reservoir elevations. Releases supplementary to those through the power plant (having a maximum discharge capacity of about 48,000 cfs) are occasionally necessary for storage evacuation purposes. On the other hand, mean daily releases have been reduced to zero at times to limit contributions to the downstream Gavins Point Reservoir. Hourly fluctuations of power releases between zero and full plant capacity frequently occur during any given day.

10-5. Regulation Effects. The historical effects of regulation provided by the Fort Randall Reservoir, combined with effects of regulation of upstream reservoir projects, upon mean monthly flows at the Fort Randall damsite are also illustrated on Plates 24 and 25 for the 1953-1977 period. Mean monthly unregulated flows shown on these plates are the computed estimates of flows at the damsite if none of the upstream projects, including Fort Randall, had been in operation. Mean daily maximum and minimum flows for each year of the 1954-1978 period for regulated (observed) and unregulated conditions are given in Table 4. From this table it is evident that regulation has resulted in substantial reductions to all annual crest flows that would have been experienced at the Fort Randall damsite. As a whole, it would appear that regulation has little effect upon the minimum mean daily flows that can be expected to occur annually. However, the time of the year that these minimum flows can be expected to occur has been modified. Unregulated flows usually experience an annual minimum during the late summer or early fall months, during the latter part of the growing season, while annual minimum regulated flows usually occur during the winter season when no crops are in production. The effects upon irrigation from the channel below Fort Randall Dam are obvious. The low regulated mean daily flows reflect the lack of a minimum mean daily release requirement during the winter season. Further discussion of the regulation provided at the Fort Randall damsite during particular years is contained in succeeding paragraphs and in the discussion of system regulation given in the Master Manual.

TABLE 4

ANNUAL EXTREME MEAN DAILY FLOWS
MISSOURI RIVER AT FORT RANDALL DAM

	Mean Daily Flow 1,000 cfs			
	Regulated		Unregulated	
Year	Maximum	Minimum	Maximum	Minimum
1954	32.3	5.7	73	4
1955	35.9	4.2	72	1
1956	50.4	3.3	110	5
1957	37.8	2.1	114	3
1958	36.5	2.4	74	2
1959	35.1	2.5	122	4
1960	40.3	0.0	201	3
1961	35.2	1.1	59	0
1962	30.8	0.0	126	1
1963	37.0	1.0	128	4
1964	34.8	0.4	214	3
1965	34.6	2.2	143	8
1966	35.8	3.0	128	4
1967	40.7	2.0	204	4
1968	39.7	4.7	121	4
1969	52.0	4.5	134	5
1970	43.8	4.9	131	2
1971	50.5	2.9	120	7
1972	48.2	11.5	231	8
1973	36.3	0.9	67	4
1974	42.1	4.5	142	3
1975	60.6	11.0	173	4
1976	41.4	9.7	109	3
1977	41.7	5.9	49	0
1978*	53.2	0.8	260	7

*Preliminary data

10.6. 1961 Regulation. Runoff originating from the total Missouri River drainage area above Fort Randall Dam during 1961 totaled about 9.8

million acre-feet, less than one-half of the long term average. Since runoff records first became available in 1898 there has been only one year with less runoff from this drainage area, that being 1931 when runoff totaled 9.4 million acre-feet. Additionally, during 1961 the initial fill of the main stem reservoir system had not been completed and the total storage within the main stem reservoir system was at extremely low levels. Therefore, the Fort Randall releases (regulated flows) shown on Plate 26 are illustrative of the release level from this project that is typical during periods of extremely deficient water supply. Comparison of regulated and unregulated flows on this plate indicates the supplementation of flows during the April-September growing season resulting from regulation of reservoirs primarily to support navigation on the Missouri River. From the Fort Randall pool elevation hydrograph shown on Plate 24, it is evident that the supplementation of flows is not at the expense of storage contained in Fort Randall Reservoir but rather from the larger upstream reservoirs. Development of water resources in the basin above Fort Randall Dam has continued since 1961 and, if 1961 hydrologic conditions should be repeated, the flow supplementation would be more marked. While similar regulated flows could be expected, the increased depletion occasioned by further water resource development would have the effect of resulting in an extended period of negative unregulated flows, indicating that during some years the current resource development is served only by withdrawal from storage. Weekly cycling of Fort Randall power releases from Fort Randall is very evident on Plate 25, reflecting low weekend power loads and the availability of re-regulating storage space in the downstream Gavins Point Reservoir. Since 1961 the upstream Oahe and Big Bend power plants have come into operation and have assumed more of the power cycling requirements, allowing Fort Randall power releases to be maintained at a more nearly uniform level, although some cycling continues to be practiced.

10-7. <u>1964 Regulation</u>. Unregulated mean daily flows at the Fort Randall damsite during 1964 crested at 214,000 cfs, among the largest unregulated crests that have occurred at this location since regulation by the Fort Randall Reservoir began in 1953. As illustrated on Plate 27, mean daily Fort Randall outflows during the flood period averaged about 25,000 cfs, although there was considerable variation from this rate, largely representing power peaking operations. Of interest is the period of a few days in mid-June when releases were extremely low. This represented regulation designed to reduce inflows into the downstream Gavins Point Reservoir occasioned by substantial runoff originating between Fort Randall Dam and Gavins Point Dam. Similar regulation has occurred several times since the projects became operational, with zero or near zero daily releases from Fort Randall. From Plate 24, it is evident that main stem system storage gains resulting from the 1964 runoff did not occur in Fort Randall Reservoir but in the upstream main stem reservoir projects. Actually, initial fill of upstream main stem reservoirs was in progress during 1964; however, if the 1964 runoff should be repeated with the system at normal operating levels, very little difference in Fort Randall regulation would be expected. A somewhat higher level of releases, particularly during the winter season, would probably occur.

10-8. 1967 Regulation. Total Missouri Basin runoff above Fort Randall Dam during the June-July period of 1967 was among the largest of record for this period of the year, almost 75 per cent greater than the long-term average. Combined with this runoff above Fort Randall Dam were severe flood flows originating below Fort Randall and in the Missouri River drainage areas below the main stem system of reservoirs. Damages prevented by the regulation of Fort Randall and the other main stem reservoirs during this flood period approached 250 million dollars. As illustrated on Plate 28, mean daily releases from the Fort Randall Reservoir during the flood period were generally less than 25,000 cfs although flows in the 175,000 cfs range would have occurred for a two-week period without upstream regulation. During June it was necessary to maintain releases at a very low level due to flooding along the lower Missouri River. Prior to 1967, initial fill of the main stem reservoir system had not been completed, and as a consequence, effort was being made to retain storage within the system while providing the downstream flood control. One result was a Fort Randall Reservoir crest at elevation 1366.5 feet m.s.l., 1.5 feet into the exclusive flood control space, as illustrated on Plate 25. If the system had been at normal operating levels prior to 1967, the general level of Fort Randall releases would have been higher and probably would have been quite comparable to those experienced in 1972 as described later. These higher releases would have also probably limited the maximum Fort Randall elevation to within the annual flood control and multiple-use storage space.

10-9. 1972 Regulation. Missouri Basin runoff above Fort Randall Dam during 1972 was more than 7 million acre-feet greater than the long-term average. March runoff was exceptionally large, as indicated by Plate 28, with an unregulated crest flow of 231,000 cfs, the largest unregulated crest at this location since regulation of the reservoir began in 1953. The mainstem reservoir system was at normal operating levels prior to 1972 and there was no significant change in system storage during the year. As a consequence, Fort Randall releases were maintained at well above normal rates through the year. The relative uniformity of releases during the April-November open-water season is illustrated on Plate 29 with releases being near the maximum power plant release capability through much of the season. Sharp temporary downward adjustments in the release rate represent reductions occasioned by downstream flood control considerations. From Plate 25 it is evident that, in spite of the large amount of upstream runoff, Fort Randall Reservoir elevations were maintained within the normal operating range.

10-10. 1975 Regulation. April through July runoff originating in the Missouri Basin above Fort Randall Dam during 1975 was the greatest experienced since runoff records began in 1898. While the crest unregulated flow of 173,000 cfs at the Fort Randall damsite was relatively small in relation to the flood season volume, the unusual aspect was the sustained large unregulated flows extending from late April through July, as illustrated on Plate 30. Also unusual was that most of the well above normal precipitation contributing to the record high runoff occurred after early April and extended through July. As a consequence, Fort Randall releases during the early portions of the year were continued at near normal levels. During May and June release increases were made; however, they were limited due to large inflows into the Missouri River below Gavins Point Dam and consequent flood control operations. Release restrictions continued through the first half of July, preventing probable inundation of cropland yet to be harvested in the Missouri River reach above the mouth of the Niobrara River. A release rate of 60,000 cfs began in mid-July, after harvest of low-lying crops, and continued at this level through the remainder of the 1975 open-water season. Although record high amounts of runoff originated above Fort Randall Dam, and releases were the largest necessary since operation of the project began, Fort Randall Reservoir levels were maintained in the normal range as indicated by Plate 25. Further information relating to this flood and regulation afforded by all reservoirs in the main stem system is given in the Master Manual and in the special Reservoir Control Center Technical Report describing the 1975 regulation.

10-11. Summary of Historical Regulation. Historical regulation of the Fort Randall project has proceeded for only a relatively short period of time; however, annual upstream runoff during this period has ranged from near the minimum to the maximum recorded since 1898. Therefore, regulation during these years is believed to be quite representative of conditions that are likely to prevail through the life of the project. Based on this experience, supplemented by analyses of the entire period of hydrologic record, it is believed that the regulation criteria developed for the Fort Randall project, and for the system as a whole (as presented in the Master Manual) as it affects Fort Randall regulation are reasonable and represent a near-optimum utilization and control of the water supply that may be available. Of course, studies will continue through the life of the project in an effort to improve criteria. In general, it may be stated that unless runoff originating upstream from the project is well above normal, Fort Randall releases will be maintained within the capacity of the Fort Randall power plant. Only in 1975 and 1978, the year that a record high amount of upstream runoff occurred, were significant supplementary releases made past the power plant. It is also evident that the amount of runoff originating upstream from the dam has little effect upon Fort Randall pool elevations. Only with extremely large amounts of runoff, greater than have been recorded to date, or when the total water supply is much below normal, such as during the drought of the 1930's, will the variations in seasonal reservoir levels depart significantly from the pattern prevailing during the 1972-1977 period shown on Plate 25. Daily variations from the general level of release rates illustrated on Plates 26 through 30 can be expected to continue, both as a response to downstream needs and to enhance power production from the project and the reservoir system as a whole.

X-B Long-Term Regulation Analyses.

10-12. Long-Term Studies. Simulated regulation of the Fort Randall Reservoir as a component of the main stem reservoir system, through the entire period of available hydrologic record, is a technique utilized by the Reservoir Control Center for the development and improvement of regulation criteria. Current regulation criteria are the result of many involved and detailed studies, augmented by actual regulation experience. Accomplishment of the long-term studies is described in Chapters V and IX of the Master Manual and in the detailed reports that have been published describing specific studies. From the long-term studies that incorporate current regulation criteria and water use, as well as studies that assume various potential future levels of water-resource development in the Missouri Basin, long-term examples of Fort Randall regulation are available. From the examples incorporating the present level of water resource development, conclusions relative to regulation of the Fort Randall project can be established, as described in succeeding paragraphs.

10-13. Fort Randall Elevations. Long-term analyses indicate that the level of Fort Randall Reservoir will vary from the base of the annual flood control and multiple-use space (elevation 1320 feet m.s.l.) up to the base of the exclusive flood control storage zone (elevation 1365 feet m.s.l.). This variation could occur in a single year, such as during a recurrence of 1942 flood conditions, or during or immediately following an extended drought period. However, with a normal water supply, variations between elevation 1337.5 and 1365 feet m.s.l. are the rule. Utilization of exclusive flood control storage space (elevations 1365 to 1375 feet m.s.l.) was not required in analyses of the entire 1898-1978 period of available record. However, in actual regulation, short-term criteria can be expected to differ somewhat from those used in the long-range studies; therefore, some short-term utilization of exclusive flood control storage space is quite probable in future years. A graph of approximate Fort Randall Reservoir levels that would be experienced with a repetition of the available hydrologic record is presented in the Master Manual.

10-14. On the basis of studies conducted for the 1975 level of Missouri Basin water resource development, the Fort Randall Reservoir elevation duration curve shown on Plate 31 was developed. This curve indicates that a lake level at or above elevation 1350 feet m.s.l., the base of the annual flood control and multiple use storage space, can be expected about 70 percent of the time. A frequency curve of annual maximum Fort Randall Reservoir elevations is shown on Plate 32. This curve was developed from the long-range study analysis, as tempered by actual regulation experience of the Fort Randall project. Experienced maximum reservoir levels tend to be about five feet higher than the simulated regulation study maximums in the 1350 to 1360 ft. m.s.l. range. Reasons for this include study criteria not reflecting actually experienced criteria and also the fact that study elevations are end-of-month elevations rather than crest reservoir levels. This curve indicates that a maximum annual reservoir level of 5 feet or more above the base of the annual flood control storage space, elevation 1350 feet m.s.l., can be expected in every year. An elevation of 1365 feet m.s.l., the base of exclusive flood control storage space, should be equaled or exceeded in about one year out of seven.

10-15. Average Fort Randall Reservoir levels and normal seasonal variations in these levels at the 1975 level of water resource development are shown on Plate 33. Comparison of values obtained from long-range studies to actually experienced data indicates that criteria are not entirely consistent, with actually experienced averages during the open water season about 3 feet higher than long-range study averages. An obvious conclusion is that consideration should be given to study criteria modification to more nearly reflect actual operating experience. Actually experienced averages show the characteristic increase in reservoir levels from the minimum at the end of the navigation season to a mid-March level of about elevation 1357.5 feet m.s.l. This increase can largely be attributed to recapture of upstream power releases. From mid-March through mid-July average levels remain relatively constant. Deliberate retention of storage at near this level provides a "cushion" to satisfy unexpected release demands for downstream navigation while continuing efficient power production from upstream projects. A gradual drawdown of storage through the later summer and early fall to elevation 1350, the base of the annual flood control zone, in early October is then the normal occurrence.

Accelerated drawdown in October and November to evacuate storage space for upstream winter power release recapture purposes then occurs. Reservoir levels during individual years will usually not vary significantly from the average levels. An exception would be in years of extremely deficient water supply when fall drawdown would be to elevation 1320 feet m.s.l. and, when necessary to reduce the length of the Missouri River navigation season, a drawdown occurring earlier in the year than indicated by the averages.

10-16. Fort Randall Releases. Long-term regulation studies indicate that a Fort Randall release in excess of the power plant capacity of about 48,000 cfs will be necessary at times during years experiencing an excess water supply, as confirmed by actual regulation of the project to date. Duration curves of mean monthly releases given on Plate 31 indicate that outflows in excess of the full power plant capacity will be necessary for about two percent of the time. A median mean monthly outflow of 32,000 cfs is indicated. The frequency curve of annual maximum releases shown on Plate 32 was developed from long-term regulation study results augmented by data experienced during actual regulation. This curve reflects instantaneous releases at full power plant capacity during all years to supply peak generation requirements. Further particulars regarding development of these frequency curves are given in MRD-RCC Technical Report B-76, "100-Year Maximum Releases and Pool Elevations.:

10-17. Average monthly releases based on long-term studies are shown on Plate 33. The seasonal release pattern illustrated by this plate reflects the restricted system releases during the winter months and higher releases needed to support Missouri River navigation or for flood storage evacuation purposes during the remainder of the year. Evacuation of Fort Randall storage space during the fall months for winter recapture of upstream power releases is not accomplished by increasing Fort Randall releases, but rather by reducing releases from upstream reservoirs while maintaining Fort Randall releases at rates required for navigation or system storage evacuation purposes.

X-C Emergency Regulation.

10-18. Maximum Possible (Spillway Design) Flood. The design flood for the Fort Randall spillway was a late spring or summer type of flood in which large Oahe and Big Bend releases resulting from large amounts of runoff in the drainage area above the Oahe project were augmented by runoff from a maximum possible rainstorm over the Oahe-Fort Randall drainage area. Crest inflows to the Fort Randall Reservoir were about 800,000 cfs. With similar assumptions of initial pool levels, regulation during the period of inflows exceeding spillway outflow of 620,000 cfs, equivalent to the full spillway discharge capacity at the crest reservoir level of elevation 1379.3 feet m.s.l., was computed. Due to the similarity to design studies, hydrographs are not included with this manual.

10-19. One-Half Maximum Possible Flood. To illustrate application of the emergency procedures given in Exhibit A, Fort Randall inflows approximating one-half of those used for spillway design purposes were assumed, together with an initial reservoir level of elevation 1355 feet m.s.l. Regulation by the emergency procedures alone resulted in reducing a crest inflow of about 400,000 cfs to a crest outflow of 140,000 cfs. The Fort Randall Reservoir crested at elevation 1375 feet m.s.l., the base of the surcharge storage space. Hydrographs during the flood period are shown on Plate 34.

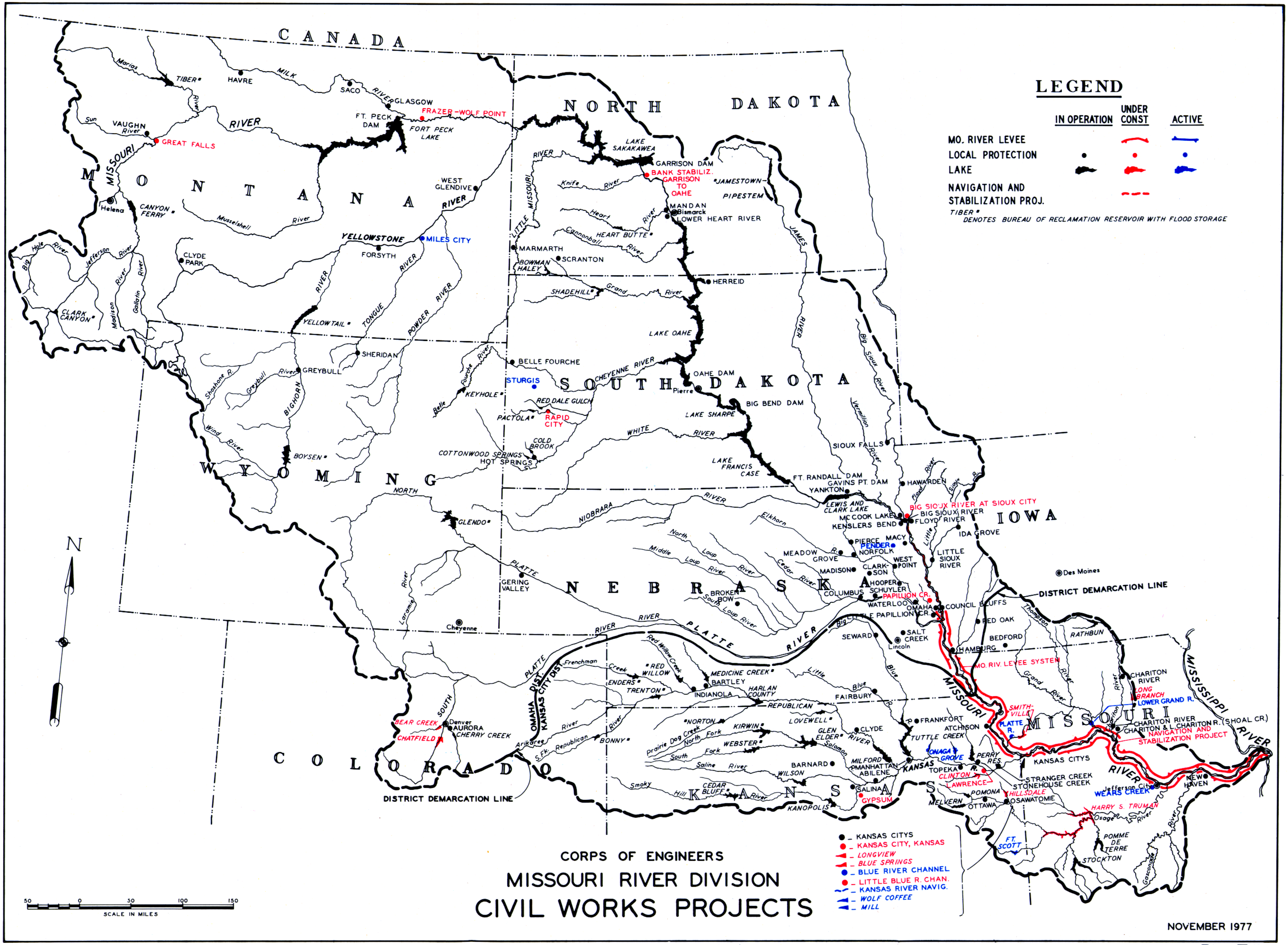
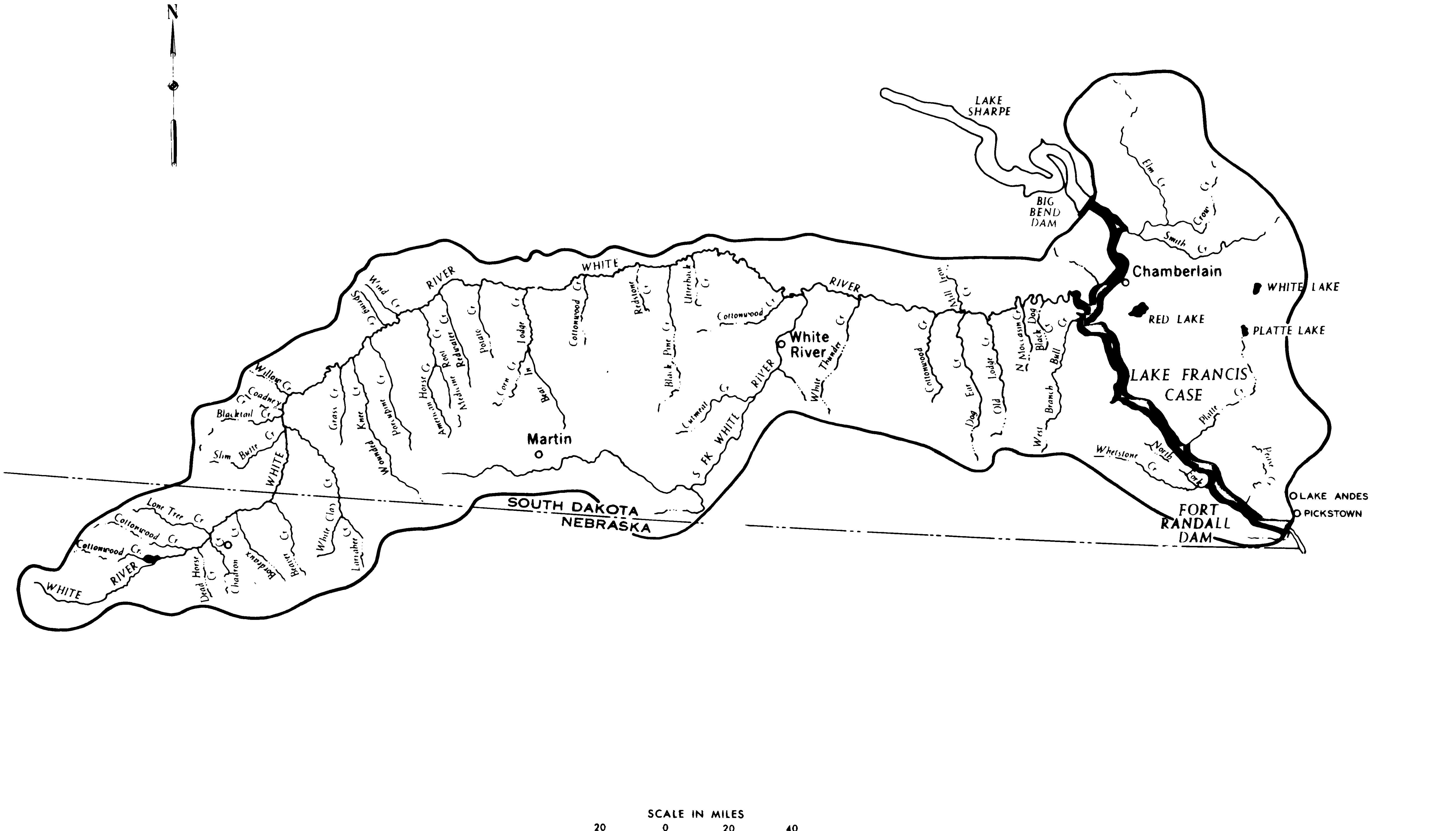

CANADA
NORTH DAKOTA
SOUTH DAKOTA
MONTANA
WYOMING
NEBRASKA
IOWA
MISSOURI
KANSAS
COLORADO
LEGEND
IN OPERATION
UNDER CONST
ACTIVE
MO. RIVER LEVEE
LOCAL PROTECTION
LAKE
NAVIGATION AND STABILIZATION PROJ.
TIBER • DENOTES BUREAU OF RECLAMATION RESERVOIR WITH FLOOD STORAGE
TIBER
HAVRE
SACO
GLASGOW
FRAZER-WOLF POINT
FT. PECK DAM
FORT PECK LAKE
VAUGHN
GREAT FALLS
Helena
CANYON FERRY
WEST GLENDIVE
YELLOWSTONE
MILES CITY
FORSYTH
CLYDE PARK
CLARK CANYON
YELLOWTAIL
SHERIDAN
GREYBULL
BOYSEN
GLENDO
Cheyenne
GERING VALLEY
LAKE SAKAKAWEA
GARRISON DAM
BANK STABILIZ. GARRISON TO OAHE
JAMESTOWN
PIPESTEM
MANDAN
Bismarck
LOWER HEART RIVER
HEART BUTTE
MARMARTH
BOWMAN HALEY
SCRANTON
HERREID
SHADEHILL
LAKE OAHE
BELLE FOURCHE
STURGIS
KEYHOLE
RED DALE GULCH
PACTOLA
RAPID CITY
COLD BROOK
COTTONWOOD SPRINGS
HOT SPRINGS
OAHE DAM
Pierre
BIG BEND DAM
LAKE SHARPE
LAKE FRANCIS CASE
FT. RANDALL DAM
GAVINS PT. DAM
YANKTON
LEWIS AND CLARK LAKE
SIOUX FALLS
HAWARDEN
BIG SIOUX RIVER AT SIOUX CITY
BIG SIOUX RIVER
FLOYD RIVER
MC COOK LAKE
KENSLERS BEND
IDA GROVE
PIERCE
MACY
PENDER
NORFOLK
LITTLE SIOUX RIVER
MEADOW GROVE
MADISON
CLARKSON
WEST POINT
Des Moines
HOOPER
COLUMBUS
SCHUYLER
PAPILLION CR.
WATERLOO
OMAHA
COUNCIL BLUFFS
LITTLE PAPILLION CR.
BROKEN BOW
RED OAK
SEWARD
SALT CREEK
Lincoln
BEDFORD
HAMBURG
RATHBUN
MO. RIV. LEVEE SYSTEM
CHARITON RIVER
LONG BRANCH
LOWER GRAND R.
DISTRICT DEMARCATION LINE
SMITHVILLE
PLATTE R.
CHARITON RIVER
CHARITON & L. CHARITON R. (SHOAL CR)
NAVIGATION AND STABILIZATION PROJECT
MEDICINE CREEK
BARTLEY
RED WILLOW
ENDERS
TRENTON
INDIANOLA
HARLAN COUNTY
FAIRBURY
LOVEWELL
NORTON
KIRWIN
WEBSTER
GLEN ELDER
CLYDE
FRANKFORT
ATCHISON
TUTTLE CREEK
PERRY RES.
ONAGA GROVE
KANSAS CITYS
MILFORD
MANHATTAN
ABILENE
TOPEKA
CLINTON
LAWRENCE
STRANGER CREEK
STONEHOUSE CREEK
BARNARD
WILSON
CEDAR BLUFF
SALINA
GYPSUM
KANOPOLIS
POMONA
OTTAWA
MELVERN
HILLSDALE
OSAWATOMIE
HARRY S. TRUMAN
Jefferson City
WEARS CREEK
NEW HAVEN
POMME DE TERRE
STOCKTON
FT. SCOTT
OMAHA DIST.
KANSAS CITY DIST.
BEAR CREEK
CHATFIELD
Denver
AURORA
CHERRY CREEK
BONNY
DISTRICT DEMARCATION LINE
MISSISSIPPI RIVER
MISSOURI RIVER
PLATTE RIVER
KANSAS CITYS
KANSAS CITY, KANSAS
LONGVIEW
BLUE SPRINGS
BLUE RIVER CHANNEL
LITTLE BLUE R. CHAN.
KANSAS RIVER NAVIG.
WOLF COFFEE
MILL
N
SCALE IN MILES
50 0 50 100 150
CORPS OF ENGINEERS
MISSOURI RIVER DIVISION
CIVIL WORKS PROJECTS
NOVEMBER 1977

PLATE I

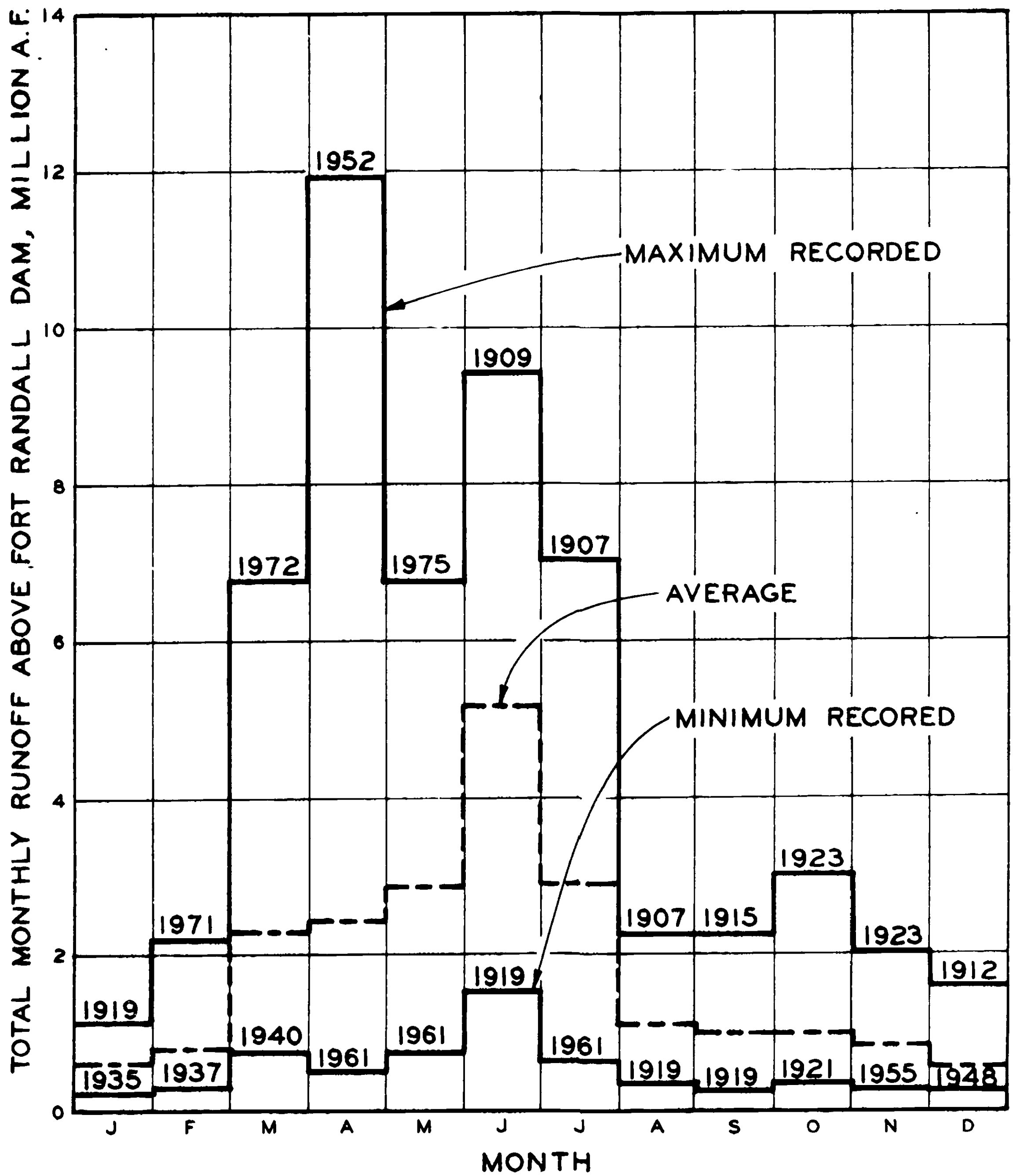


INCREMENTAL DRAINAGE AREA BETWEEN BIG BEND DAM AND FORT RANDALL DAM

PLATE 2

NOTE:

RECORD PERIOD, 1898 - 1977

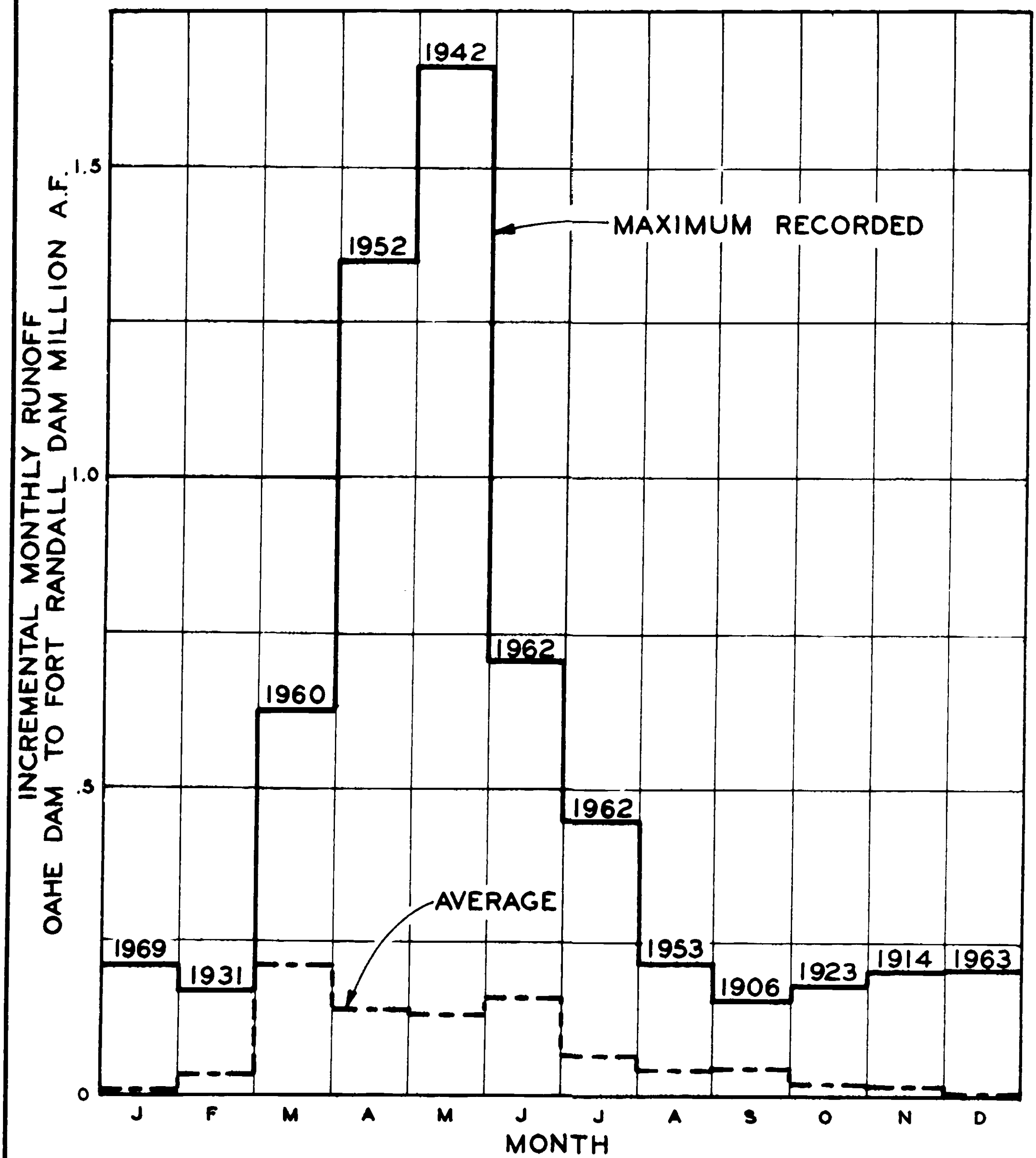


UNREGULATED
MONTHLY RUNOFF DISTRIBUTION
MISSOURI RIVER
ABOVE FORT RANDALL DAM

PLATE 3

☆ U.S. GOVERNMENT PRINTING OFFICE 1972 700 040

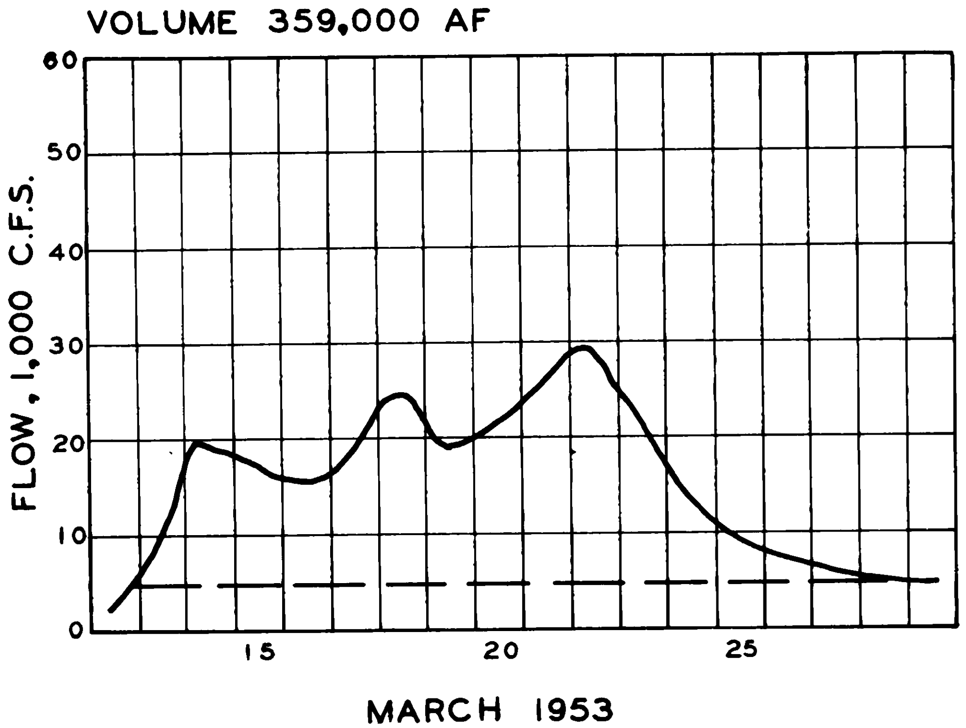
NOTE:
RECORD PERIOD, 1898-1977

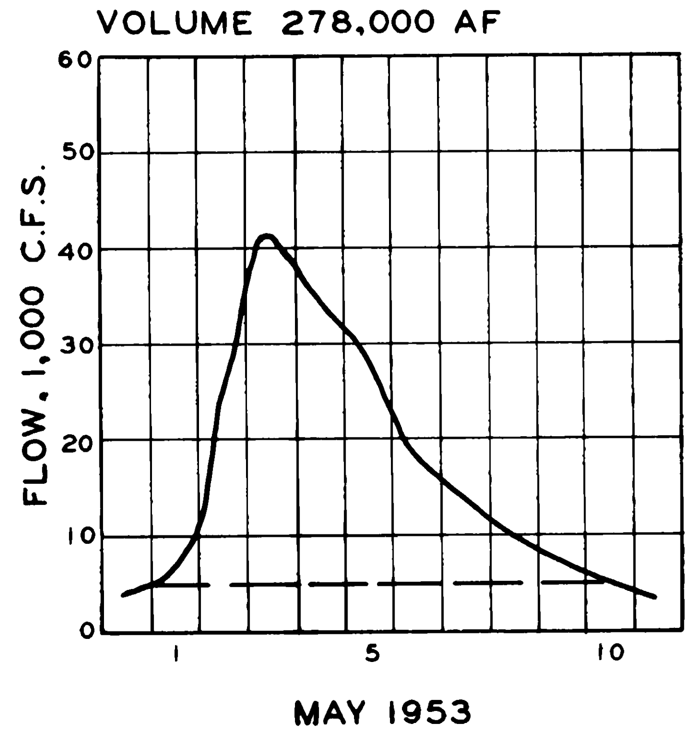


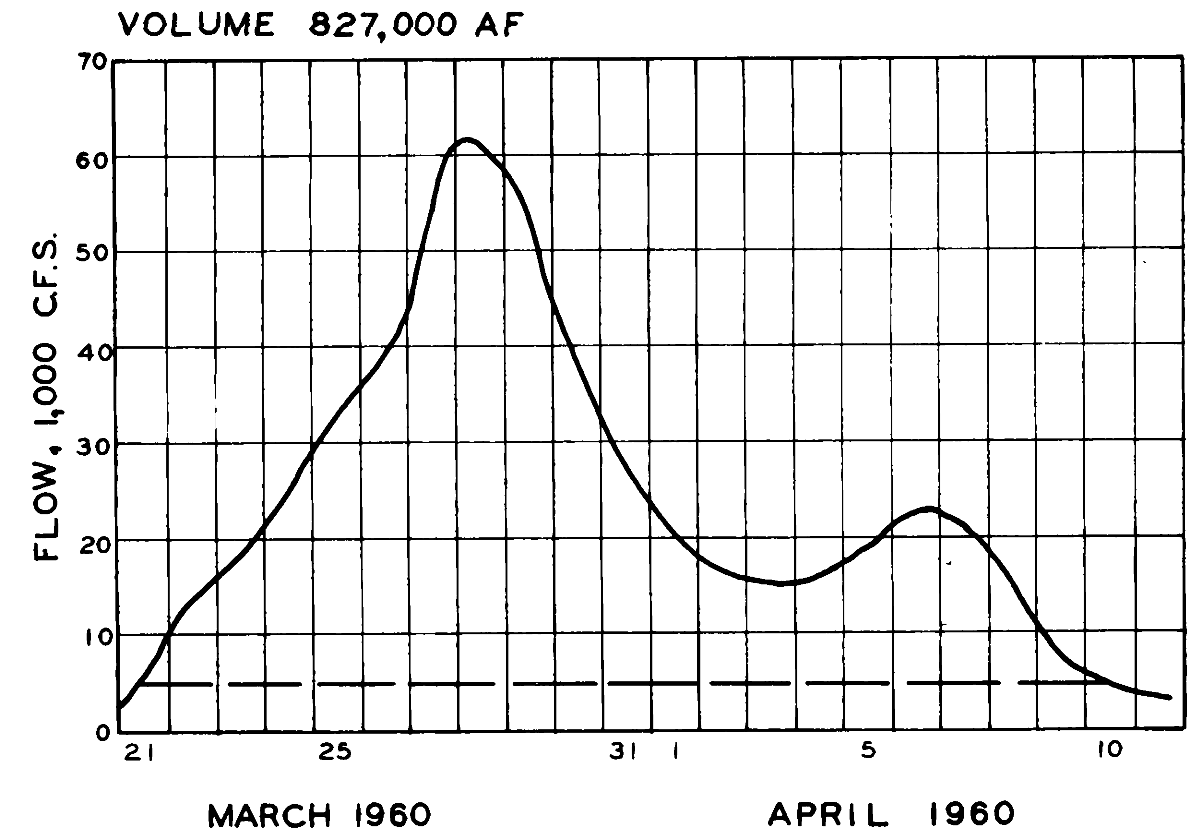
MONTHLY RUNOFF DISTRIBUTION
MISSOURI RIVER
BETWEEN OAHE DAM AND FORT RANDALL DAM

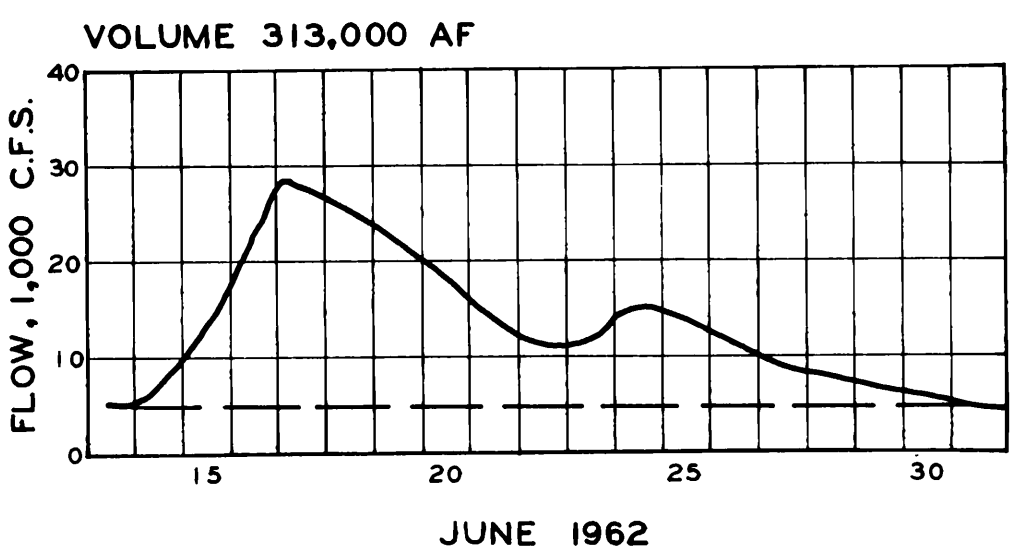
PLATE 4

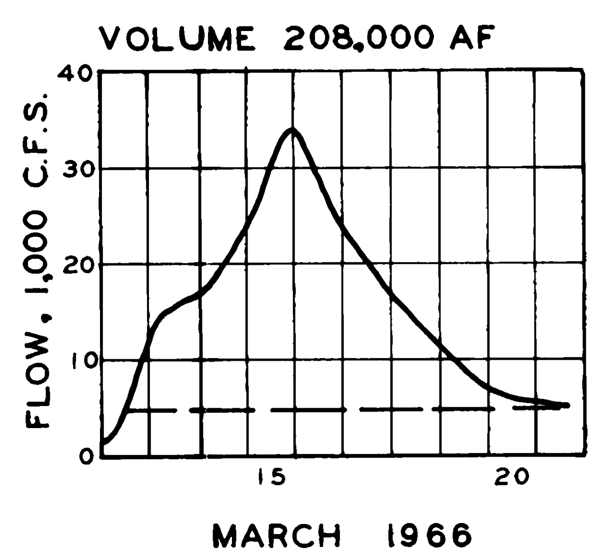
☆ U.S. GOVERNMENT PRINTING OFFICE 1972 768-646







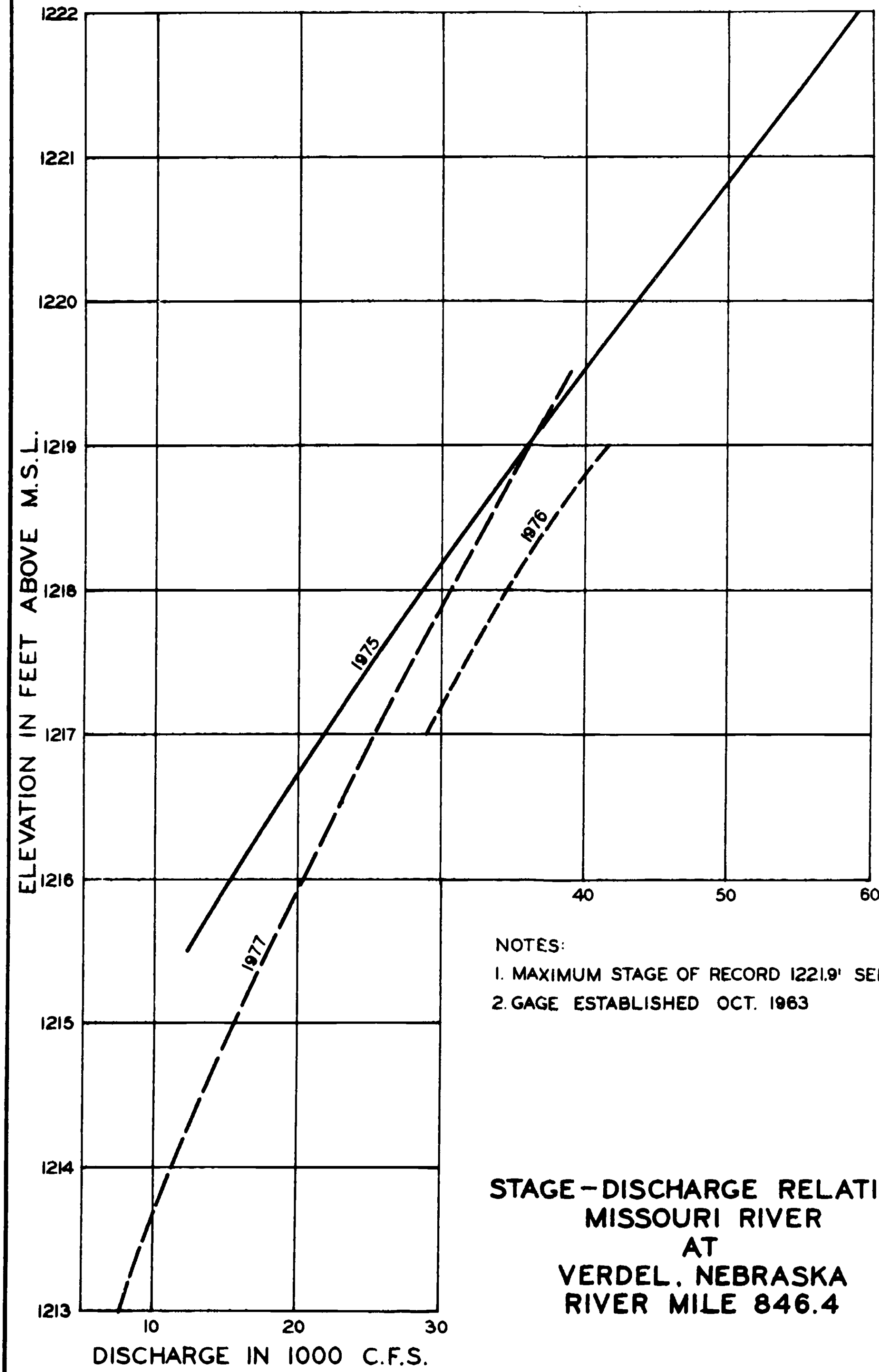




NOTES:

1. Hydrographs based on computed mean daily incremental inflows to Fort Randall Reservoir.
2. Indicated volumes are above a base flow rate of 5,000 C.F.S.

INCREMENTAL INFLOWS
BIG BEND DAM TO FORT RANDALL DAM



NOTES:

1. MAXIMUM STAGE OF RECORD 1221.9' SEP. 14, 1975
2. GAGE ESTABLISHED OCT. 1963

**STAGE–DISCHARGE RELATION
MISSOURI RIVER
AT
VERDEL, NEBRASKA
RIVER MILE 846.4**

PLATE 6

☆ U.S. GOVERNMENT PRINTING OFFICE 1972 760-847

NOTES:

Aerial photos taken October 1974.
River mileage established in 1960.

AERIAL PHOTO
MISSOURI RIVER VALLEY
RIVER MILE 875 TO 880

SCALE: 1 INCH = 2000 FEET

PLATE 7

NOTES:

Aerial photos taken October 1974.
River mileage established in 1960.

SCALE: 1 INCH = 2000 FEET

AERIAL PHOTO
MISSOURI RIVER VALLEY
RIVER MILE 868 TO 874

PLATE 8

NOTES:
Aerial photos taken October 1974.
River mileage established in 1960.

N

SCALE: 1 INCH = 2000 FEET

AERIAL PHOTO
MISSOURI RIVER VALLEY
RIVER MILE 862 TO 867

PLATE 9

NOTES:

Aerial photos taken October 1974.
River mileage established in 1960.

AERIAL PHOTO
MISSOURI RIVER VALLEY
RIVER MILE 856 TO 861

SCALE: 1 INCH = 2000 FEET

NOTES:

Aerial photos taken October 1974.
River mileage established in 1960.

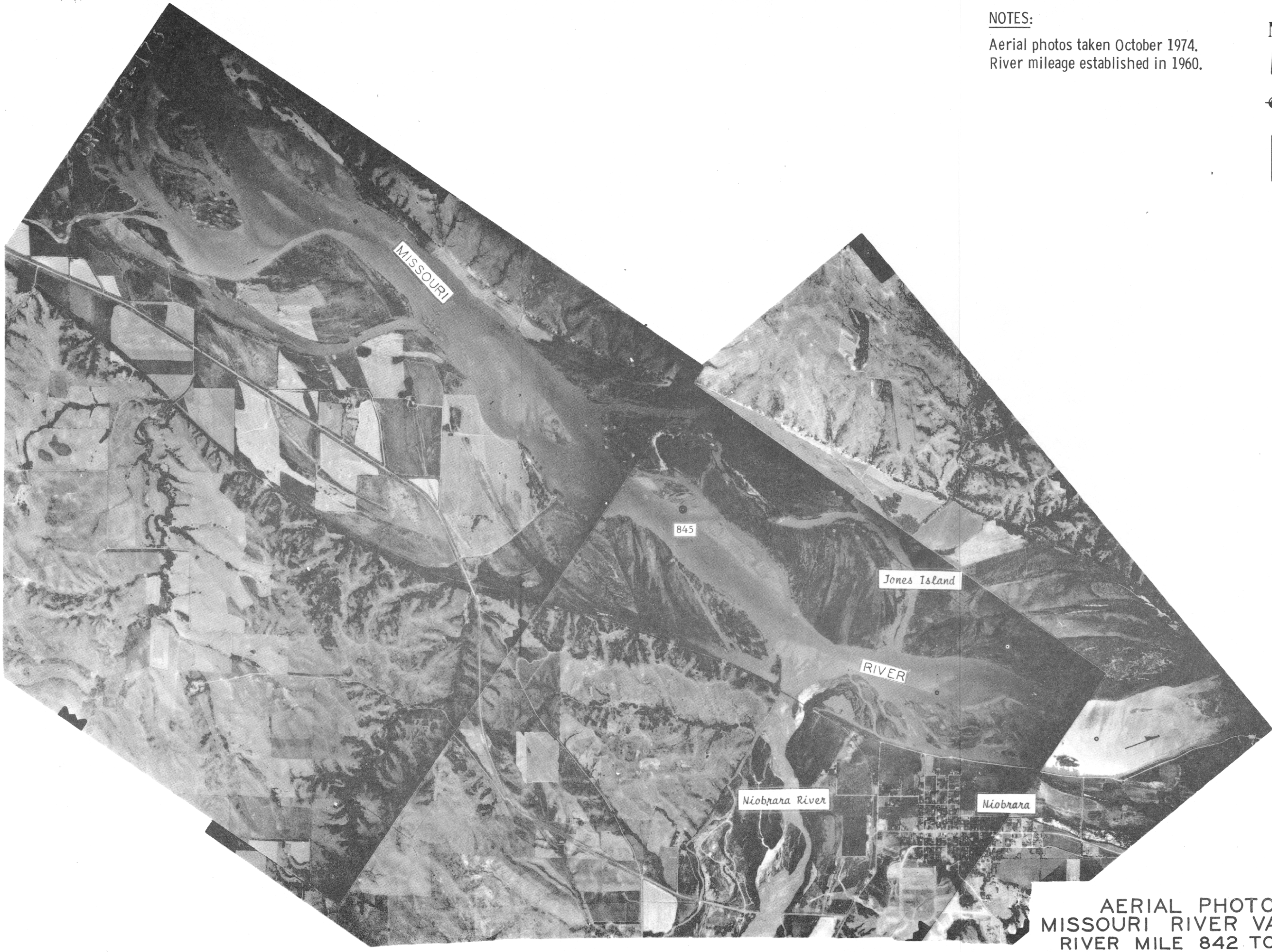
SCALE: 1 INCH = 2000 FEET

AERIAL PHOTO
MISSOURI RIVER VALLEY
RIVER MILE 849 TO 855

PLATE 11

NOTES:

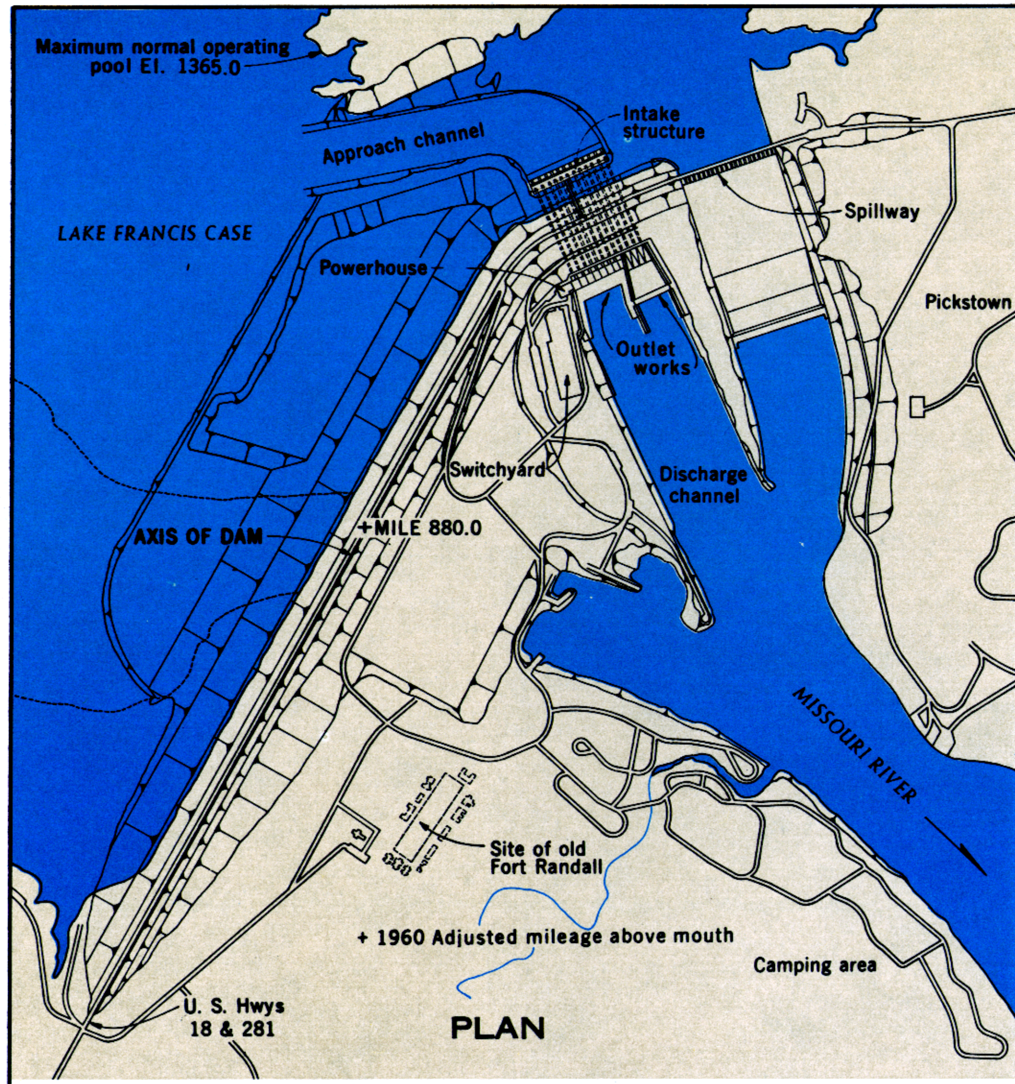
Aerial photos taken October 1974.
River mileage established in 1960.



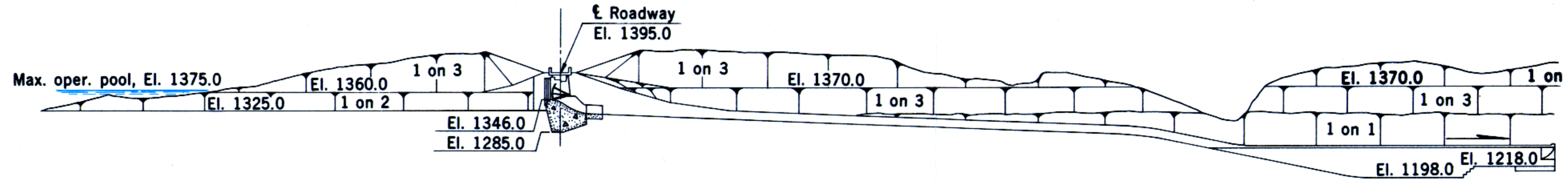
SCALE: 1 INCH = 2000 FEET

AERIAL PHOTO
MISSOURI RIVER VALLEY
RIVER MILE 842 TO 848

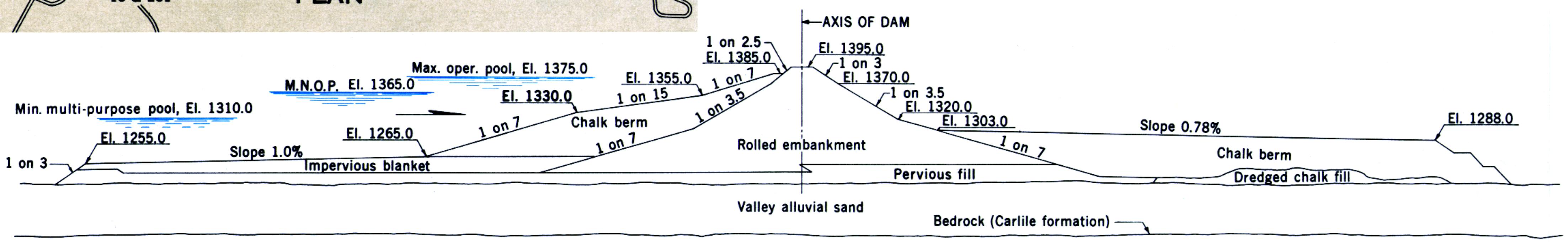
PLATE 12



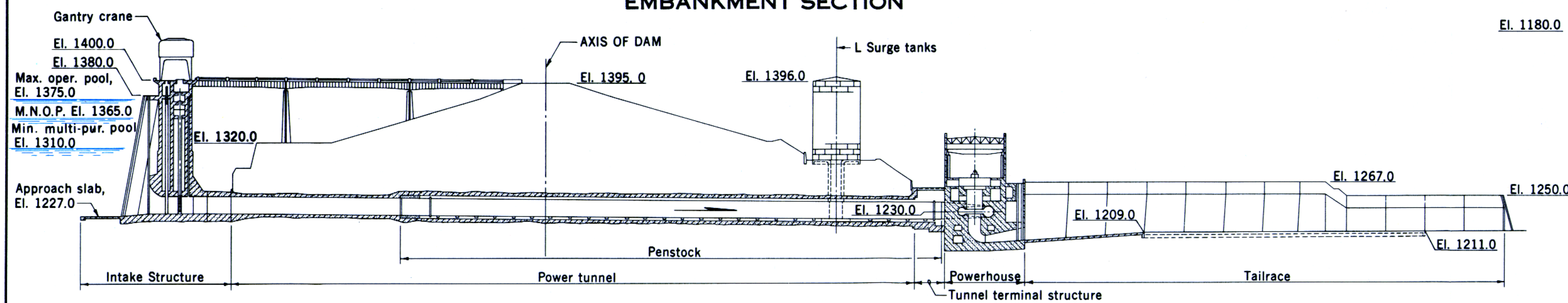
PLAN



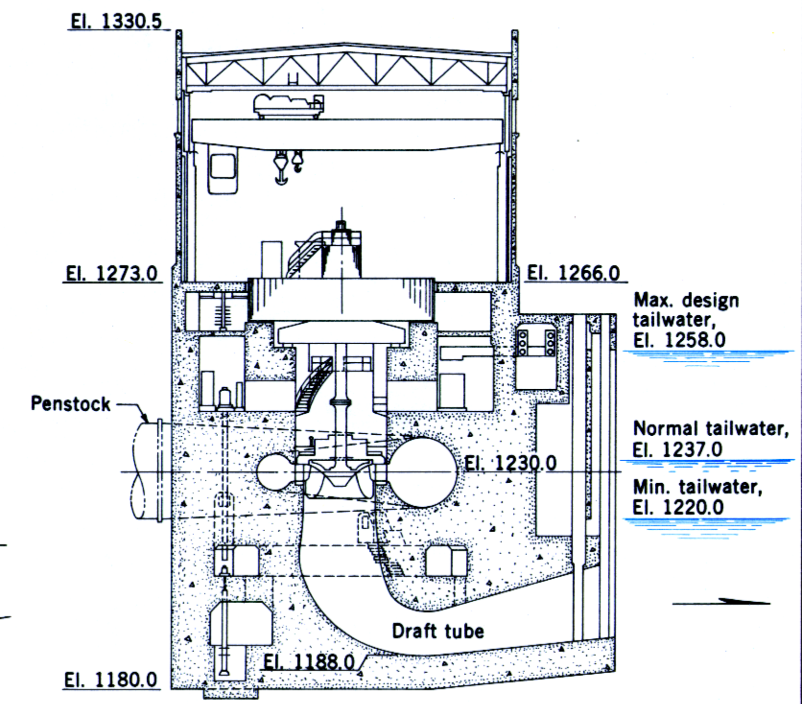
SPILLWAY PROFILE



EMBANKMENT SECTION



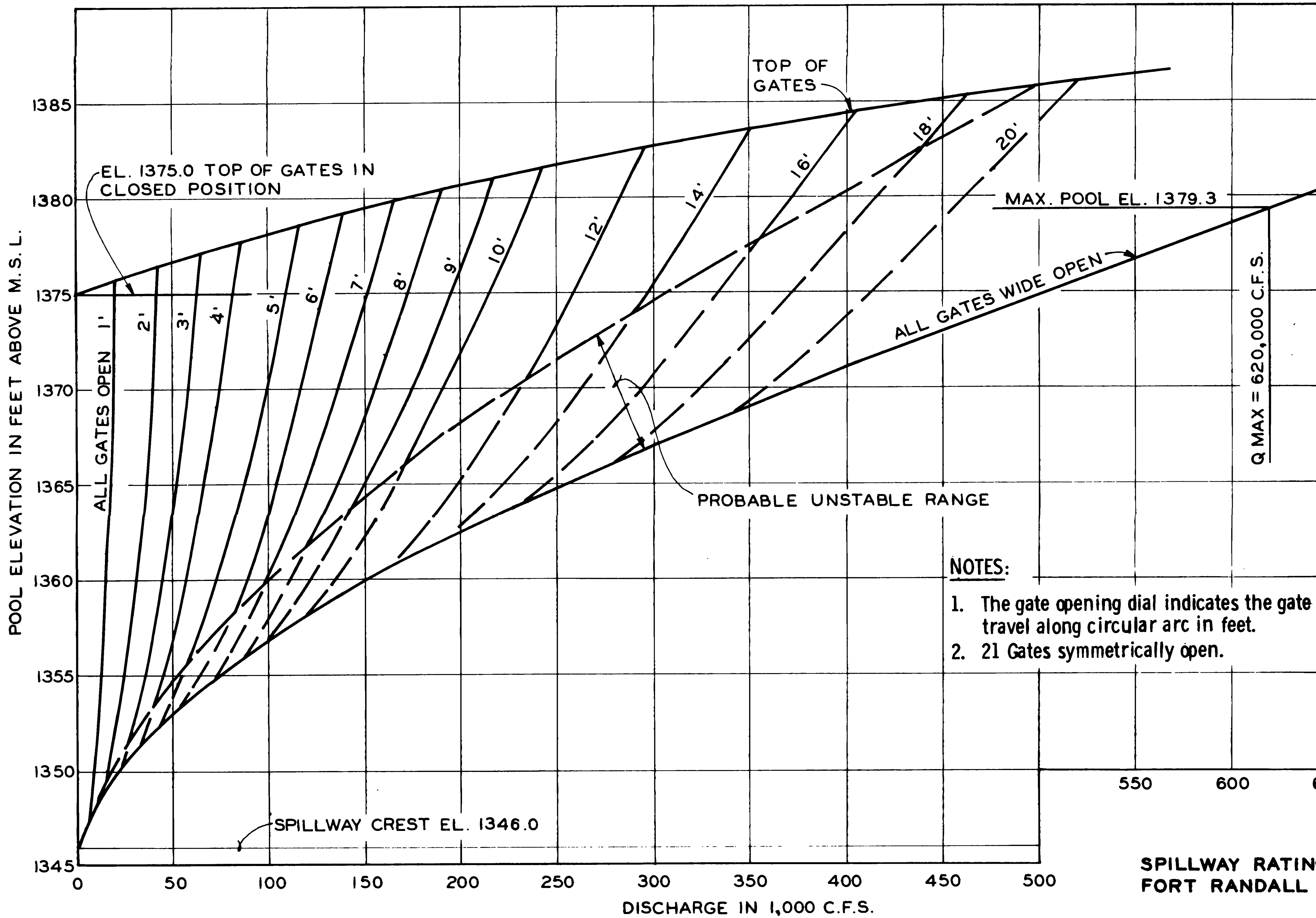
OUTLET WORKS PROFILE



POWERHOUSE SECTION

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

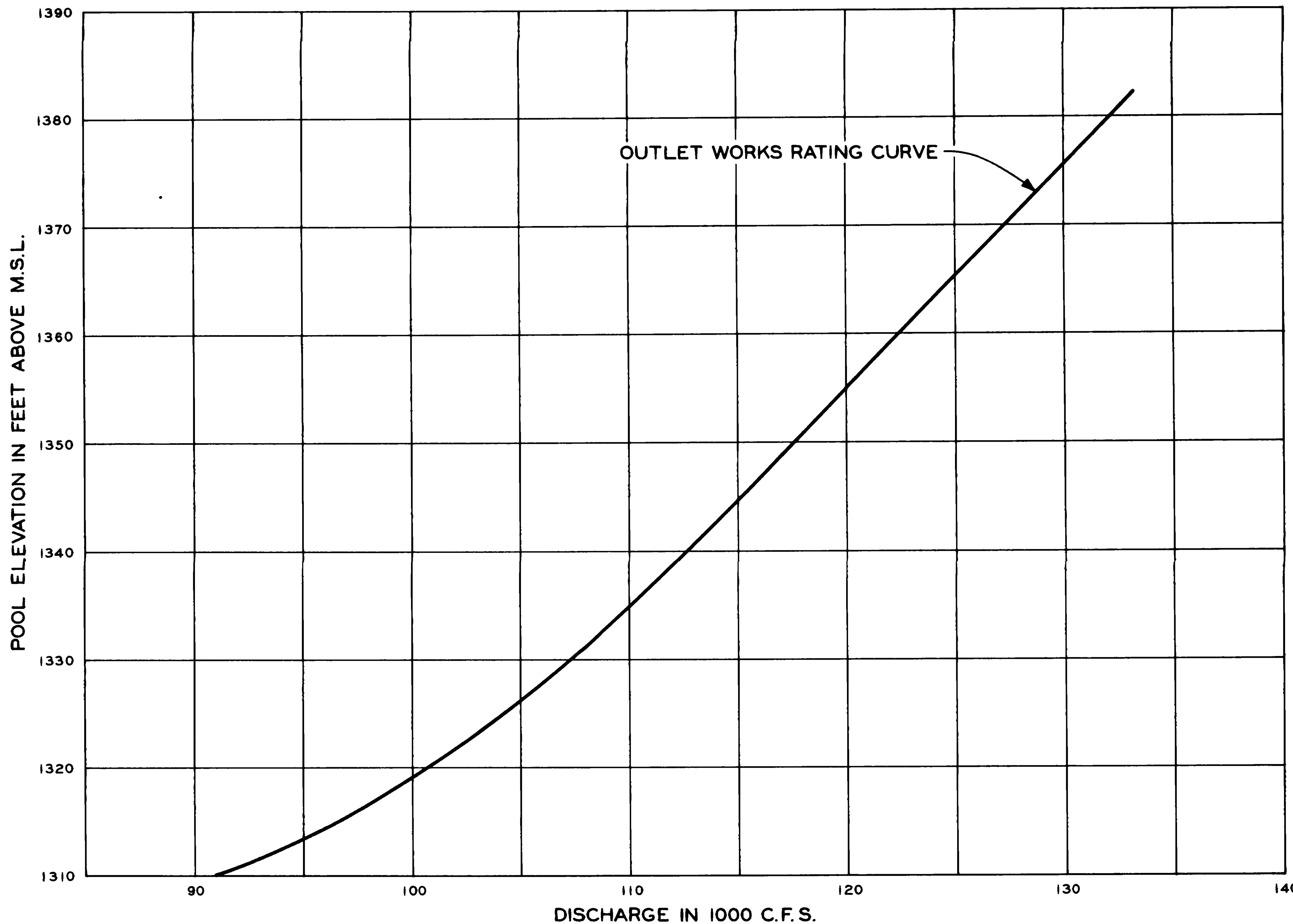


NOTES:

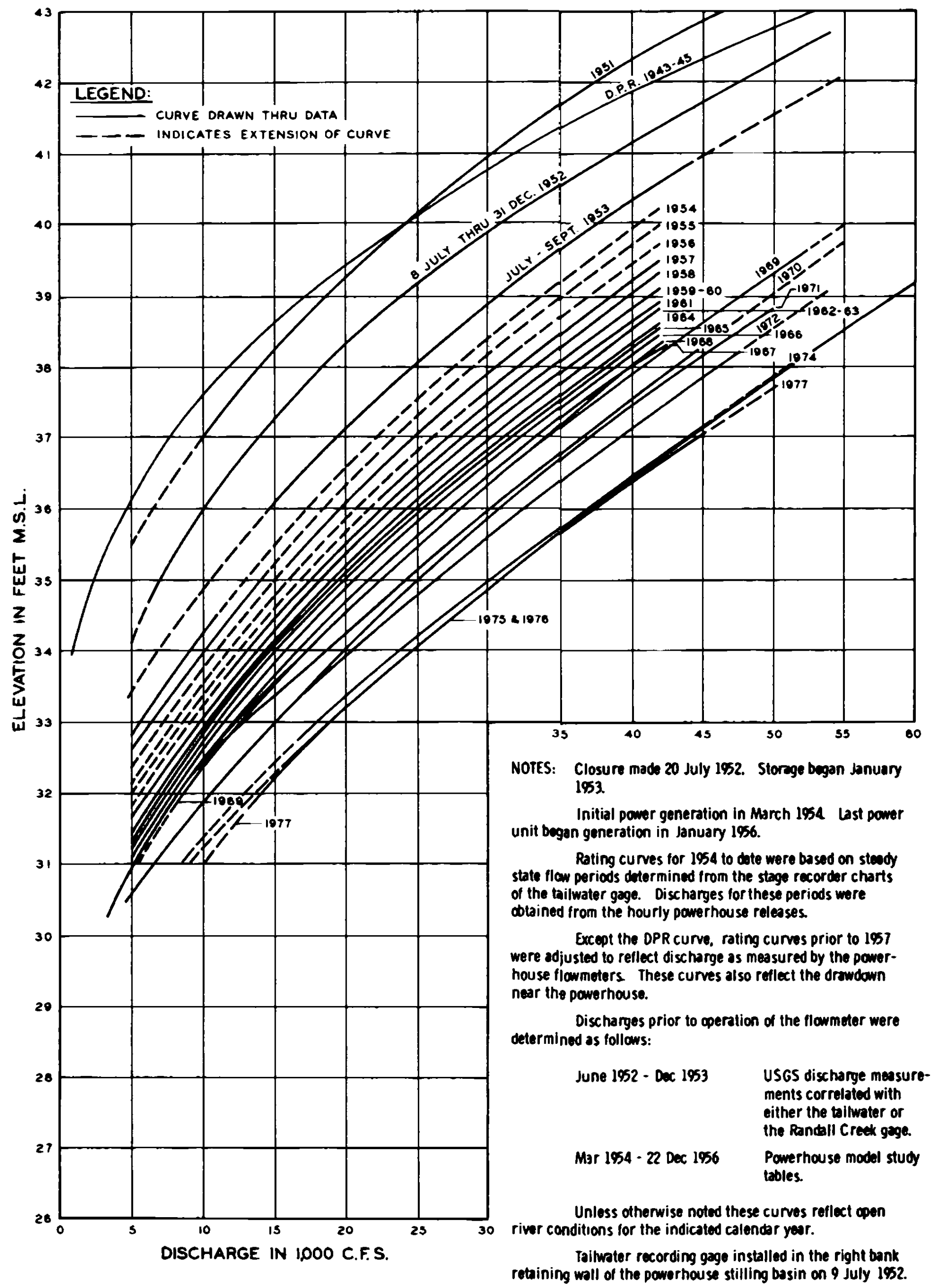
1. The gate opening dial indicates the gate travel along circular arc in feet.
2. 21 Gates symmetrically open.

SPILLWAY RATING CURVES
FORT RANDALL PROJECT

☆ U.S. GOVERNMENT PRINTING OFFICE: 1972-700-1



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:

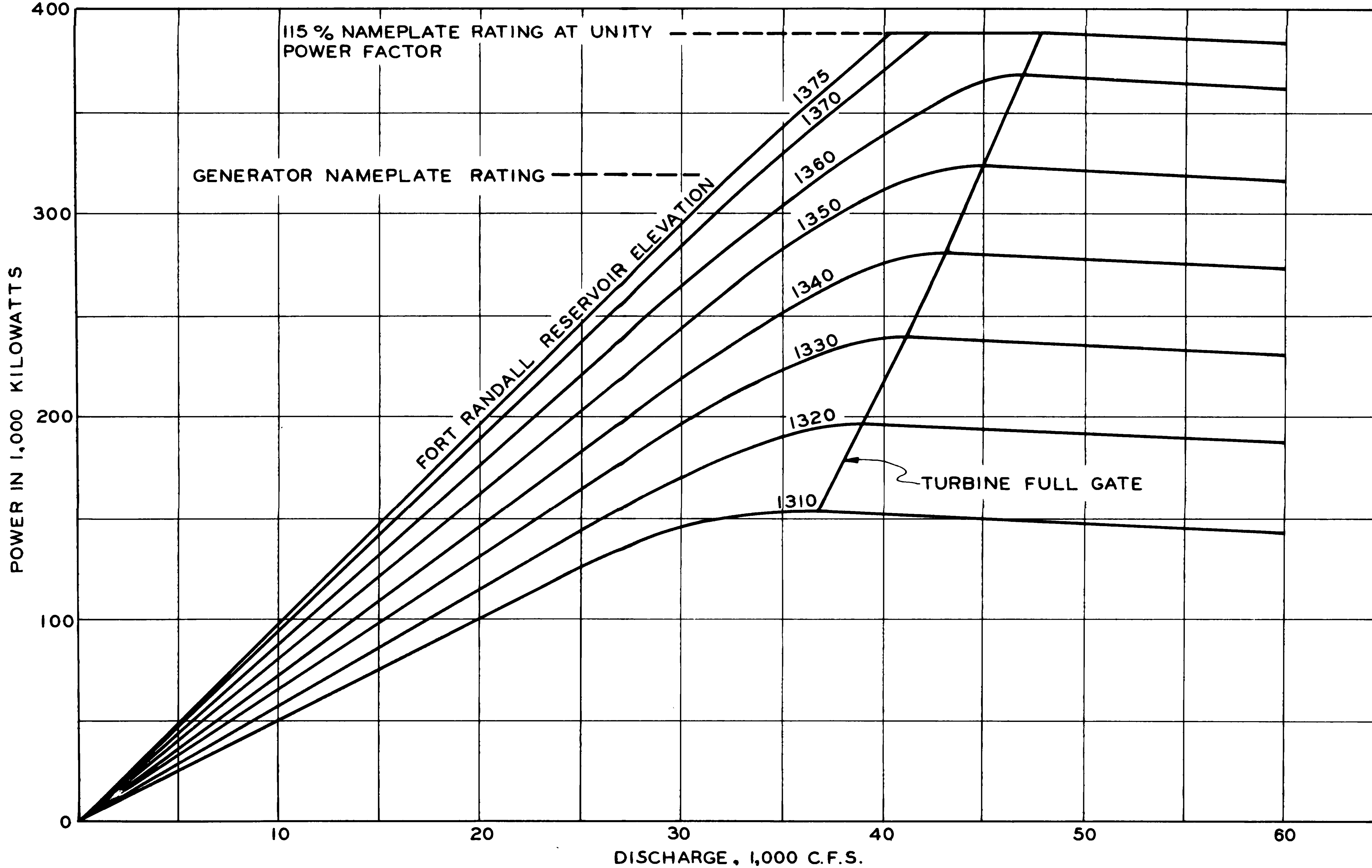
June 1952 - Dec 1953	USGS discharge measurements correlated with either the tailwater or the Randall Creek gage.
Mar 1954 - 22 Dec 1956	Powerhouse model study tables.

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.

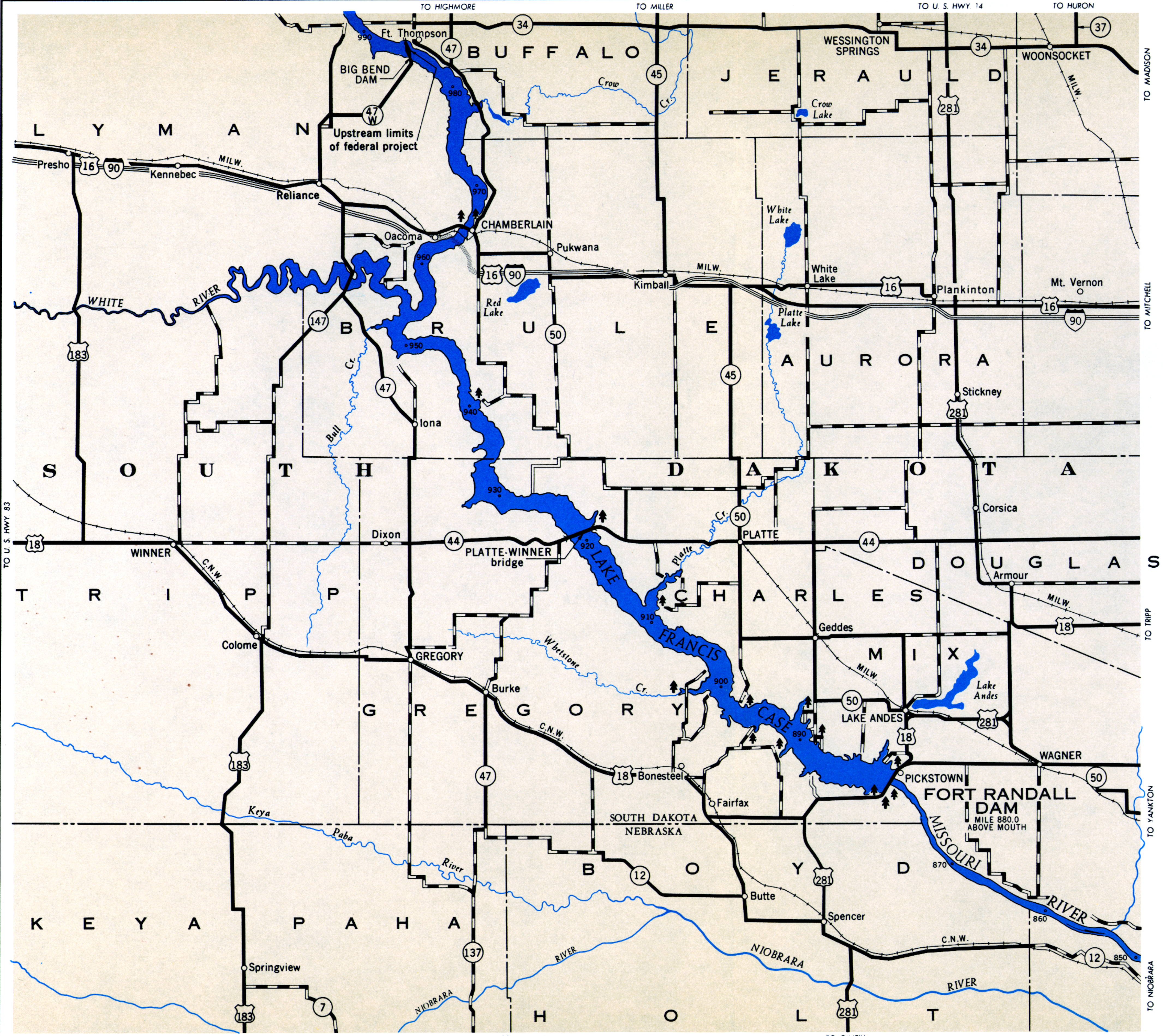
TAILWATER RATING CURVES
FORT RANDALL PROJECT

☆ U.S. GOVERNMENT PRINTING OFFICE: 1977-768-047



POWER PLANT CHARACTERISTICS
FORT RANDALL PROJECT

PLATE 17



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 18

FORT RANDALL
AREA AND CAPACITY DATA

Effective 1 Jan 1978

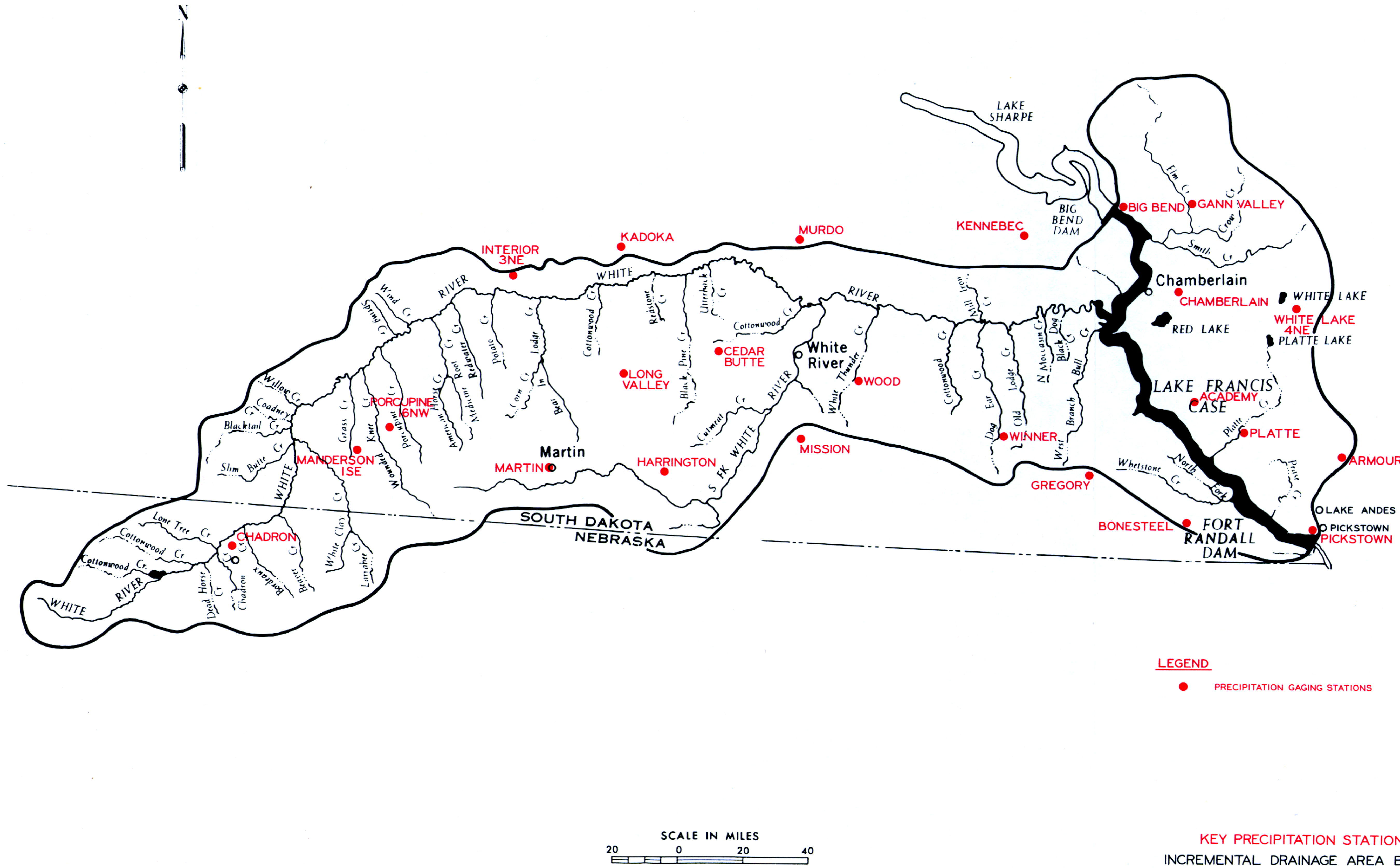
FORT RANDALL PROJECT
AREA IN ACRES
(1972 SURVEY)

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

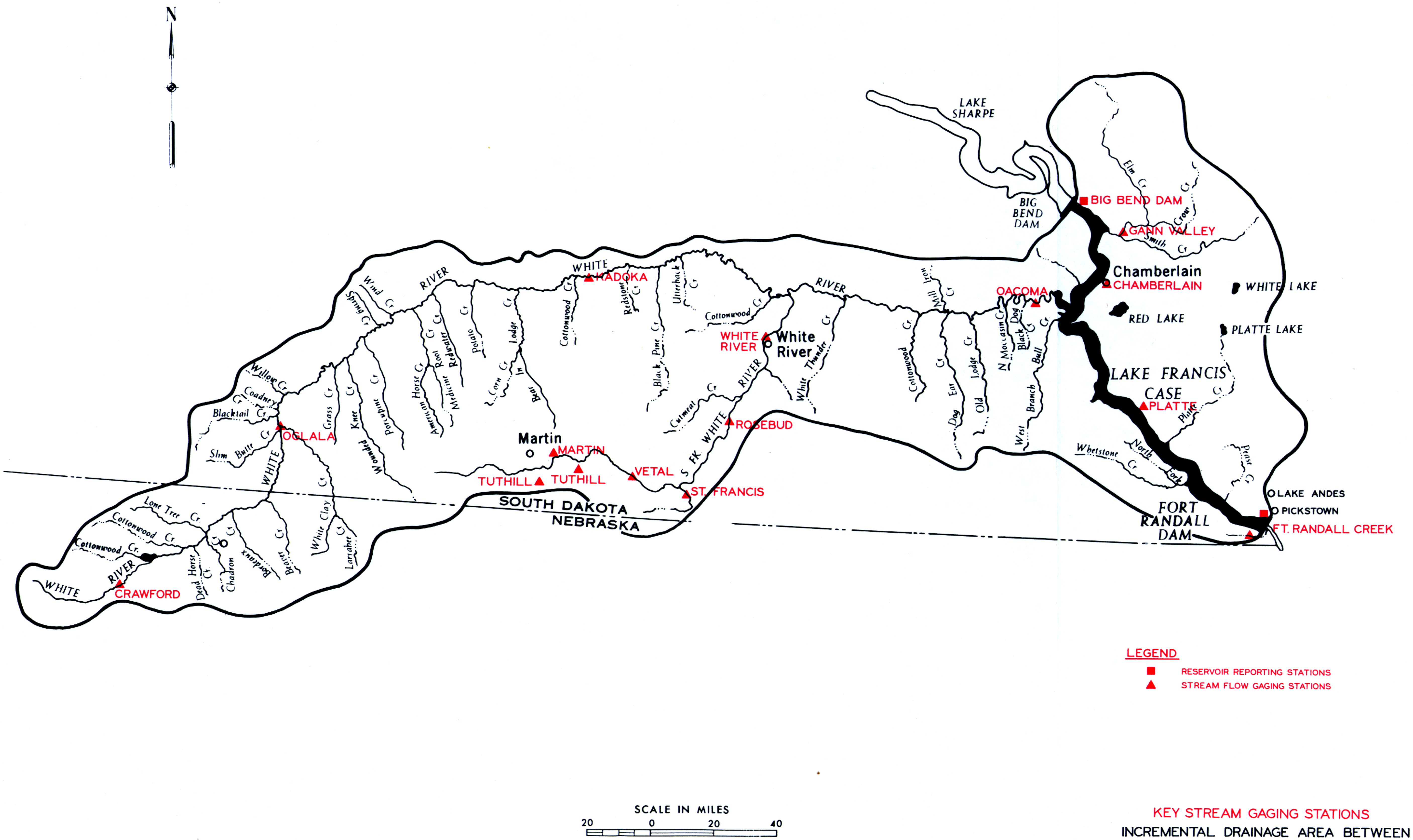
FORT RANDALL PROJECT
CAPACITY IN ACRE-FEET
(1972 SURVEY)

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									



KEY PRECIPITATION STATIONS

INCREMENTAL DRAINAGE AREA BETWEEN BIG BEND DAM AND FORT RANDALL DAM



KEY STREAM GAGING STATIONS

INCREMENTAL DRAINAGE AREA BETWEEN BIG BEND DAM AND FORT RANDALL DAM

PLATE 21

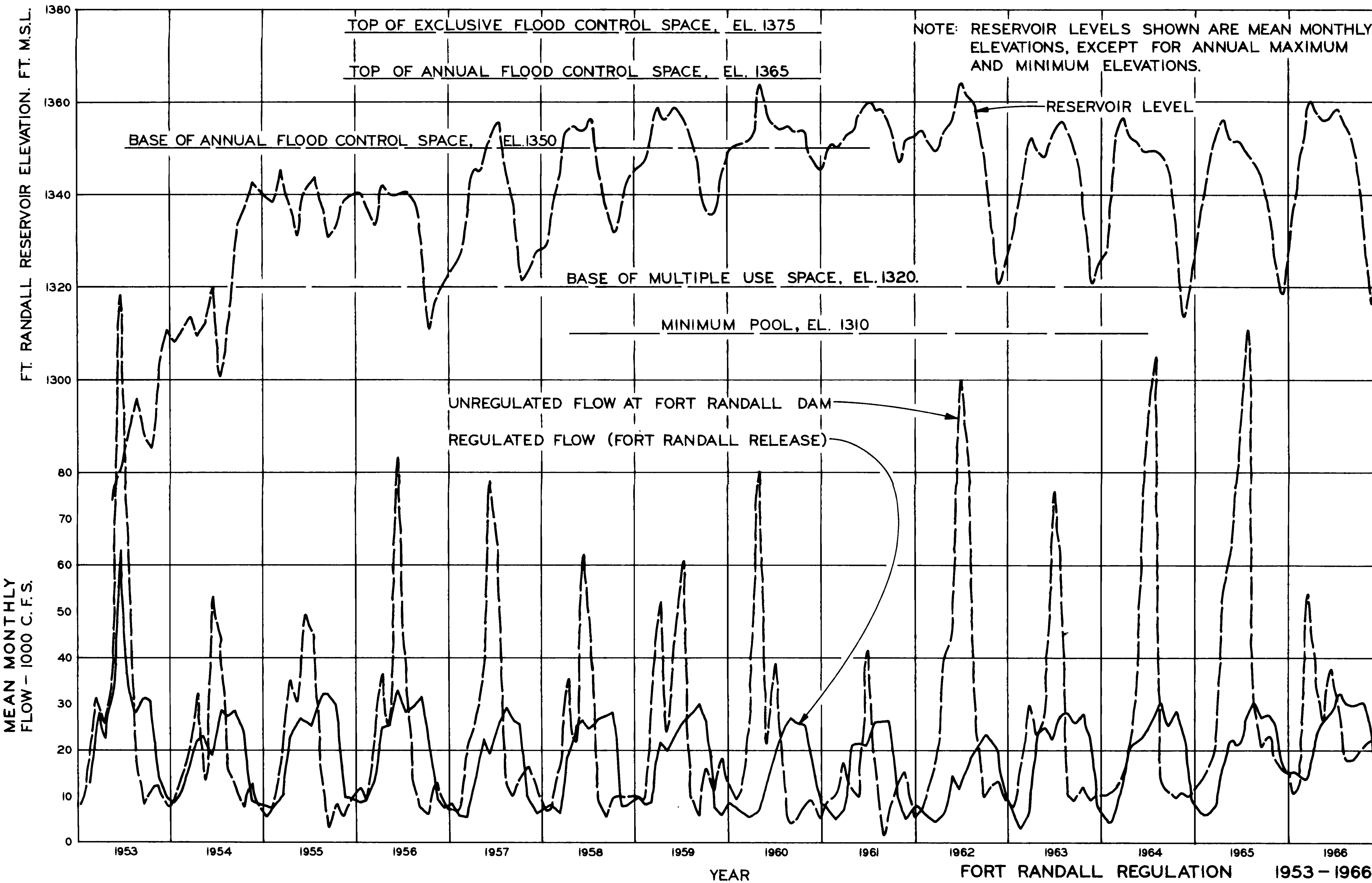
STAGE DISCHARGE TABLE FOR
SELECTED KEY GAGING STATIONS BETWEEN
BIG BEND DAM AND FORT RANDALL DAM

Gage Height feet	White River Near Kadoka, SD Gage Datum 2122.18 msl (cfs)	Little White River Below White River, SD Gage Datum 1912.78 msl (cfs)	White River Near Oacoma, SD Gage Datum 1377.29 msl (cfs)	Crow Creek Near Gann Valley, SD Gage Datum 1434.73 msl (cfs)
0	0	0	0	0
1	0	0	0	0
2	0	0	0	0
3	0	80	100	7
4	60	530	500	75
5	390	1,270	1,420	197
6	1,050	2,220	2,680	344
7	2,150	3,170	4,500	510
8	3,550	4,200	6,700	710
9	5,050	5,380	9,400	910
10	6,850	6,550	13,100	1,130
11	8,850	7,750	17,600	1,400
12	10,900	9,000	23,200	1,690
13	13,150	10,200	30,000	2,000
14	15,550	11,500	37,000	
15	18,050	12,800	45,500	
16			54,000	

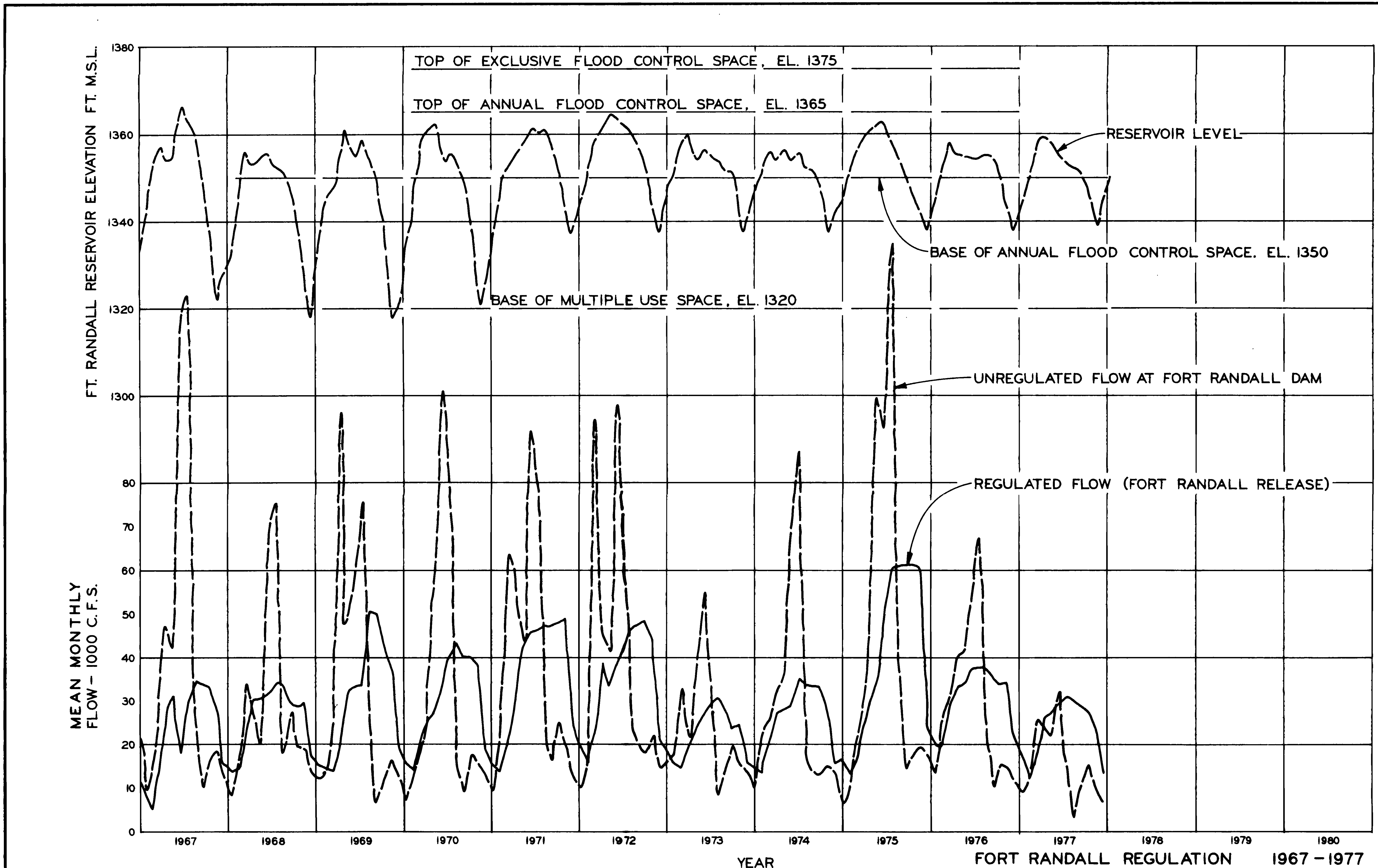
RESERVOIR ELEVATION CORRECTIONS AT THE FORT RANDALL DAM
TO ALLOW FOR WIND TIDE EFFECTS

ELEVATION 1350 M.S.L.
(TRUE ELEVATION = REPORTED POOL ELEVATION + CORRECTION)
WIND SPEED - MILES PER HOUR

WIND DIR.	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70
360	-0.0	-0.0	-0.0	-0.0	-0.1	-0.2	-0.3	-0.4	-0.6	-0.8	-1.2	-1.6	-2.1	-2.5	-3.0
10	-0.0	-0.0	-0.0	-0.0	-0.1	-0.1	-0.2	-0.3	-0.4	-0.6	-0.9	-1.2	-1.6	-2.0	-2.4
20	-0.0	-0.0	-0.0	-0.0	-0.0	-0.1	-0.2	-0.2	-0.3	-0.4	-0.6	-0.8	-1.1	-1.4	-1.7
30	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.1	-0.1	-0.2	-0.3	-0.3	-0.4	-0.6	-0.7	-1.0
40	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.1	-0.1	-0.1	-0.2	-0.2	-0.3	-0.3
50	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0
60	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.1	+0.2	+0.2	+0.3	+0.4	+0.5	+0.6	+0.7	+0.8
70	+0.0	+0.0	+0.0	+0,0	+0.1	+0.2	+0.3	+0.4	+0.5	+0.7	+0.8	+1.1	+1.3	+1.5	+1.7
80	+0.0	+0.0	+0.0	+0.1	+0.2	+0.3	+0.4	+0.6	+0.8	+1.0	+1.3	+1.5	+1.8	+2.2	+2.5
90	+0.0	+0.0	+0.0	+0.1	+0.2	+0.4	+0.6	+0.8	+1.0	+1.3	+1.6	+2.0	+2.4	+2.7	+3.1
100	+0.0	+0.0	+0.0	+0.1	+0.3	+0.5	+0.7	+0.9	+1.2	+1.6	+2.0	+2.4	+2.8	+3.2	+3.7
110	+0.0	+0.0	+0.0	+0.1	+0.3	+0.5	+0.8	+1.1	+1.4	+1.8	+2.2	+2.7	+3.1	+3.6	+4.1
120	+0.0	+0.0	+0.0	+0.2	+0.4	+0.6	+0.8	+1.2	+1.5	+2.0	+2.4	+2.9	+3.3	+3.9	+4.4
130	+0.0	+0.0	+0.0	+0.2	+0.4	+0.6	+0.9	+1.2	+1.6	+2.1	+2.5	+2.9	+3.5	+4.0	+4.6
140	+0.0	+0.0	+0.0	+0.2	+0.4	+0.7	+0.9	+1.3	+1.7	+2.2	+2.6	+3.1	+3.6	+4.2	+4.8
150	+0.0	+0.0	+0.0	+0.2	+0.4	+0.6	+0.9	+1.2	+1.6	+2.1	+2.5	+2.9	+3.5	+4.0	+4.6
160	+0.0	+0.0	+0.0	+0.2	+0.4	+0.6	+0.8	+1.2	+1.5	+2.0	+2.4	+2.9	+3.3	+3.9	+4.4
170	+0.0	+0.0	+0.0	+0.1	+0.3	+0.5	+0.8	+1.1	+1.4	+1.8	+2.2	+2.7	+3.1	+3.6	+4.1
180	+0.0	+0.0	+0.0	+0.1	+0.3	+0.5	+0.7	+0.9	+1.2	+1.6	+2.0	+2.4	+2.8	+3.2	+3.7
190	+0.0	+0.0	+0.0	+0.1	+0.2	+0.4	+0.6	+0.8	+1.0	+1.3	+1.6	+2.0	+2.4	+2.7	+3.1
200	+0.0	+0.0	+0.0	+0.1	+0.2	+0.3	+0.4	+0.6	+0.8	+1.0	+1.3	+1.5	+1.8	+2.2	+2.5
210	+0.0	+0.0	+0.0	+0.0	+0.1	+0.2	+0.3	+0.4	+0.5	+0.7	+0.8	+1.1	+1.3	+1.5	+1.7
220	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.1	+0.2	+0.2	+0.3	+0.4	+0.5	+0.6	+0.7	+0.8
230	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0
240	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.1	-0.1	-0.1	-0.2	-0.2	-0.3	-0.3
250	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.1	-0.1	-0.2	-0.3	-0.3	-0.4	-0.6	-0.7	-1.0
260	-0.0	-0.0	-0.0	-0.0	-0.0	-0.1	-0.2	-0.2	-0.3	-0.4	-0.6	-0.8	-1.1	-1.4	-1.7
270	-0.0	-0.0	-0.0	-0.0	-0.1	-0.1	-0.2	-0.3	-0.4	-0.6	-0.9	-1.2	-1.6	-2.0	-2.4
280	-0.0	-0.0	-0.0	-0.0	-0.1	-0.2	-0.3	-0.4	-0.6	-0.8	-1.2	-1.6	-2.1	-2.5	-3.0
290	-0.0	-0.0	-0.0	-0.0	-0.1	-0.2	-0.3	-0.4	-0.7	-1.0	-1.5	-1.9	-2.4	-2.9	-3.6
300	-0.0	-0.0	-0.0	-0.0	-0.1	-0.2	-0.3	-0.5	-0.8	-1.2	-1.6	-2.1	-2.7	-3.3	-3.9
310	-0.0	-0.0	-0.0	-0.1	-0.1	-0.2	-0.4	-0.5	-0.9	-1.3	-1.7	-2.2	-2.9	-3.5	-4.1
320	-0.0	-0.0	-0.0	-0.1	-0.1	-0.2	-0.4	-0.6	-1.0	-1.4	-1.9	-2.4	-3.0	-3.7	-4.3
330	-0.0	-0.0	-0.0	-0.1	-0.1	-0.2	-0.4	-0.5	-0.9	-1.3	-1.7	-2.2	-2.9	-3.5	-4.1
340	-0.0	-0.0	-0.0	-0.0	-0.1	-0.2	-0.3	-0.5	-0.8	-1.2	-1.6	-2.1	-2.7	-3.3	-3.9
350	-0.0	-0.0	-0.0	-0.0	-0.1	-0.2	-0.3	-0.4	-0.7	-1.0	-1.5	-1.9	-2.4	-2.9	-3.6

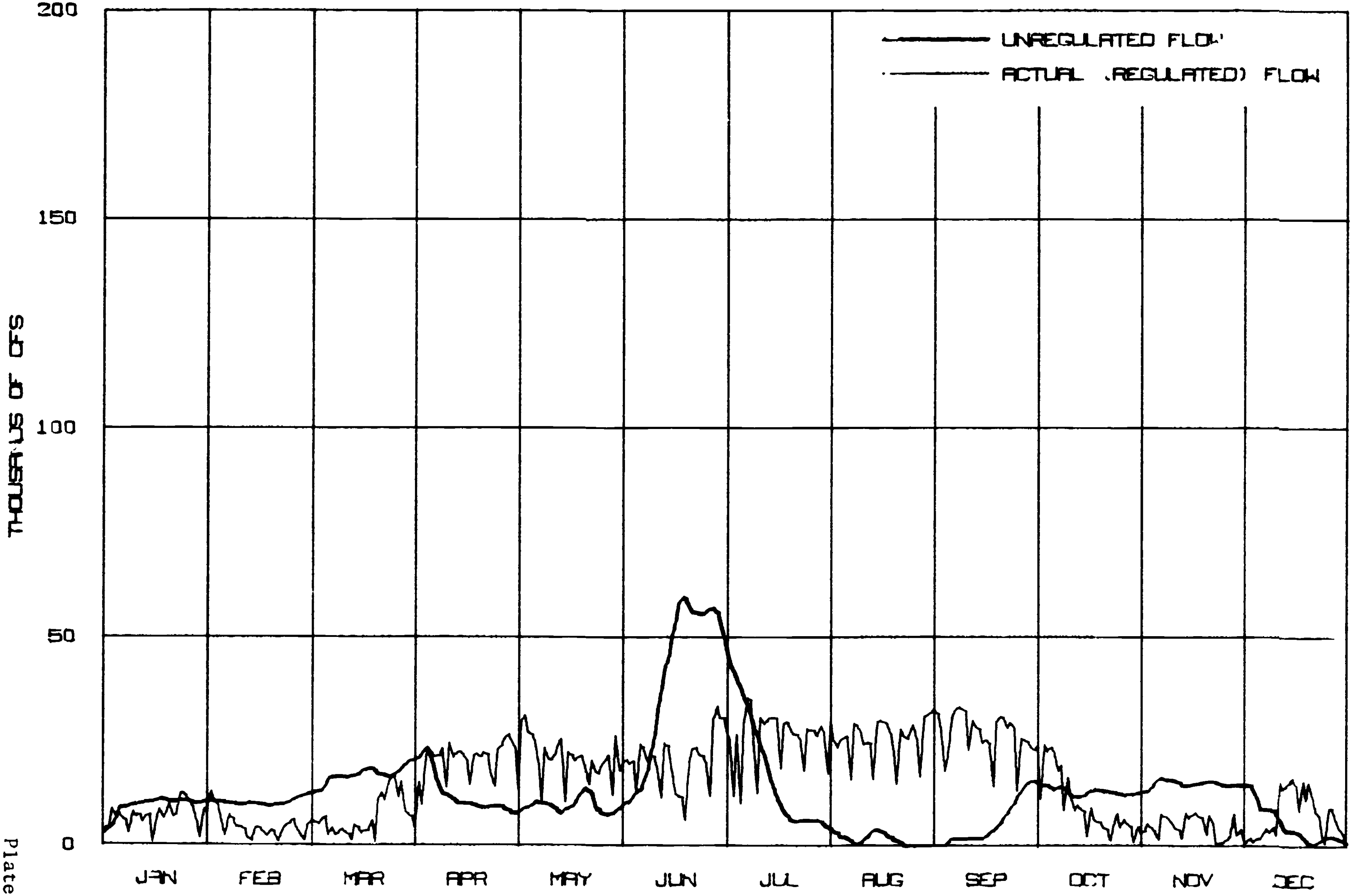


FORT RANDALL REGULATION 1953 – 1966



FORT RANDALL REGULATION 1967 - 1977

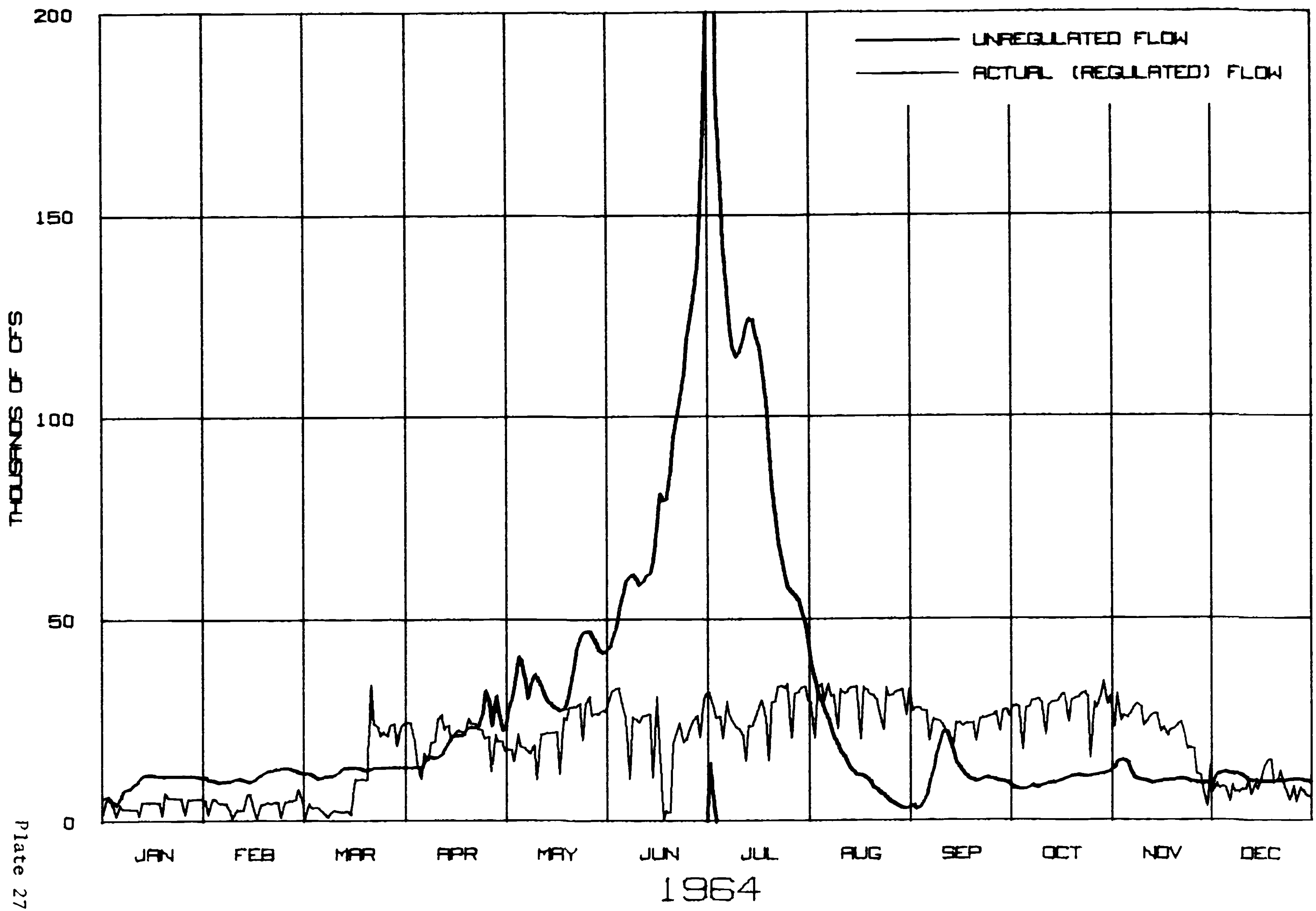
U.S. GOVERNMENT PRINTING OFFICE: 1977-788



1961

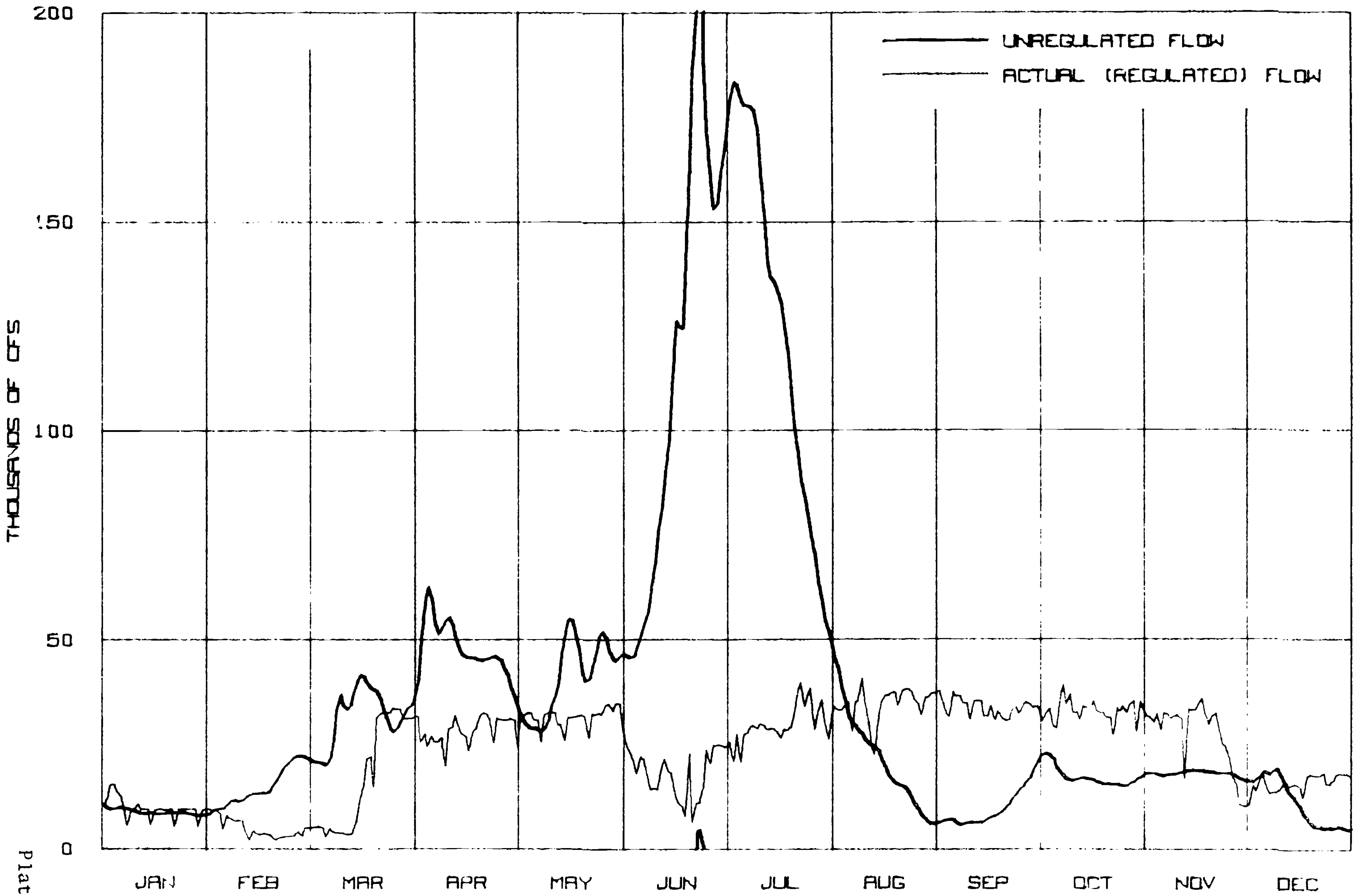
ACTUAL AND UNREGULATED FLOWS

MISSOURI RIVER AT FORT RANDALL DAM



ACTUAL AND UNREGULATED FLOWS

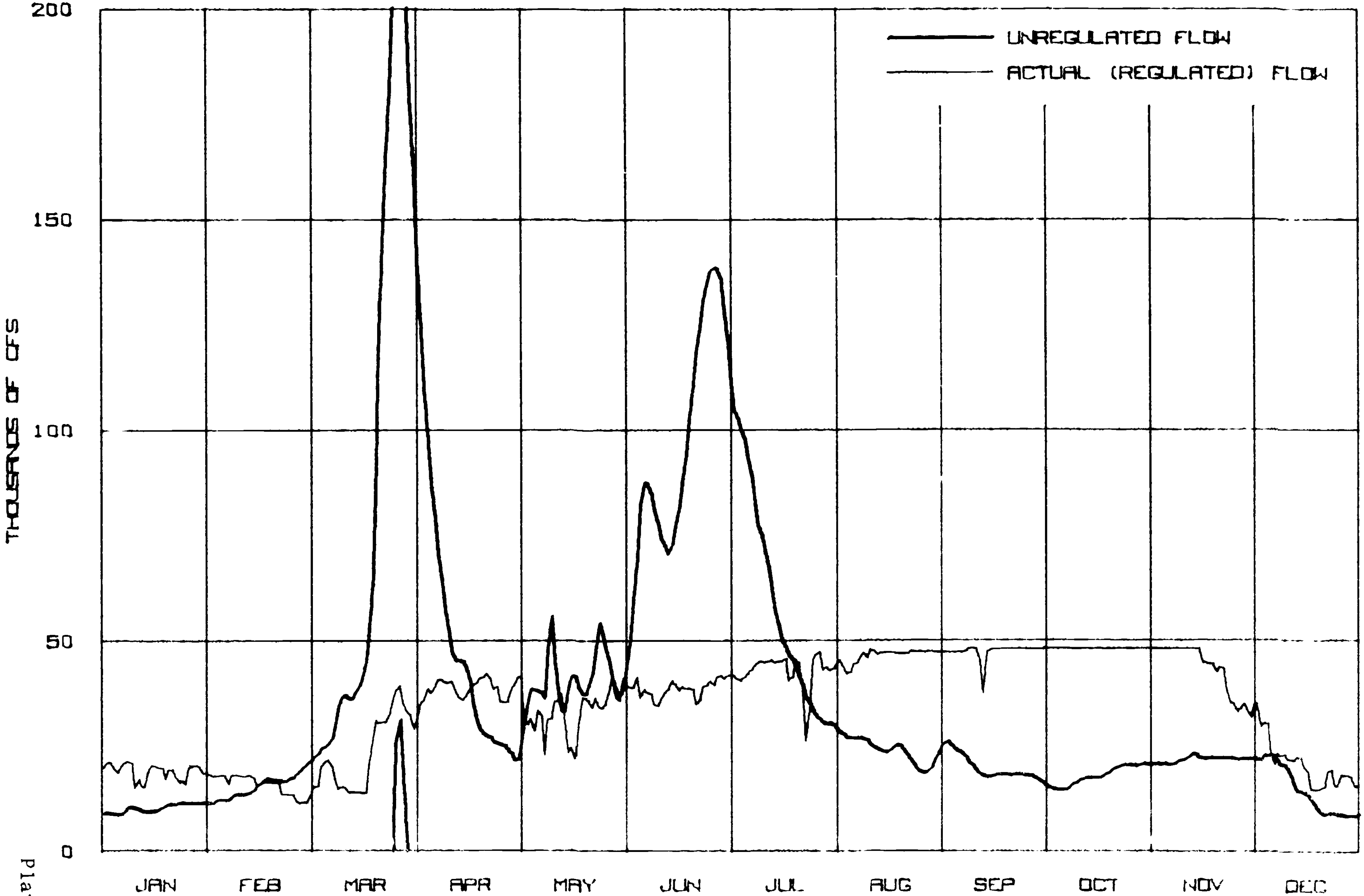
MISSOURI RIVER AT FORT RANDALL DAM



1967

ACTUAL AND UNREGULATED FLOWS

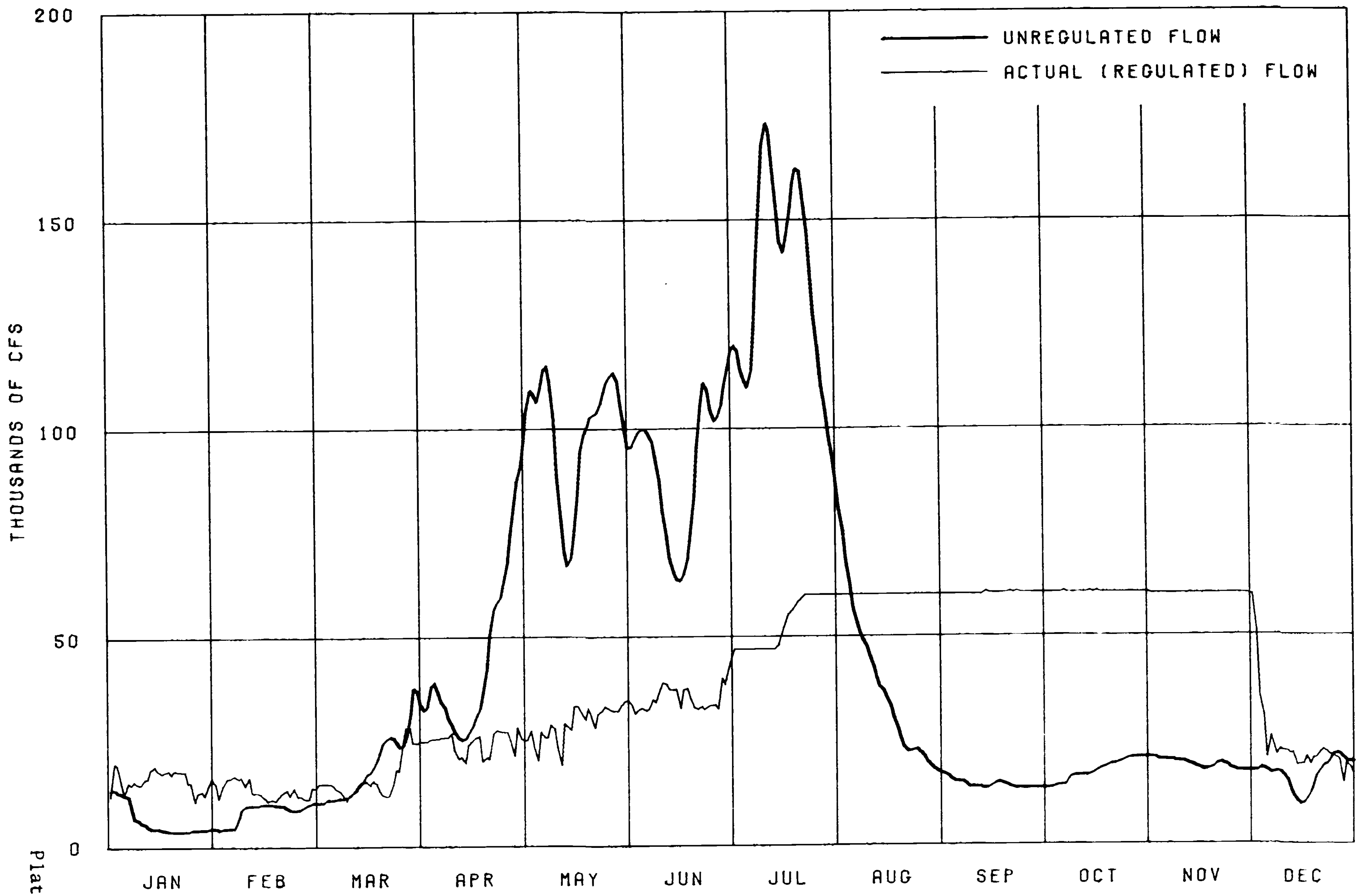
MISSOURI RIVER AT FORT RANDALL DAM



1972

ACTUAL AND UNREGULATED FLOWS

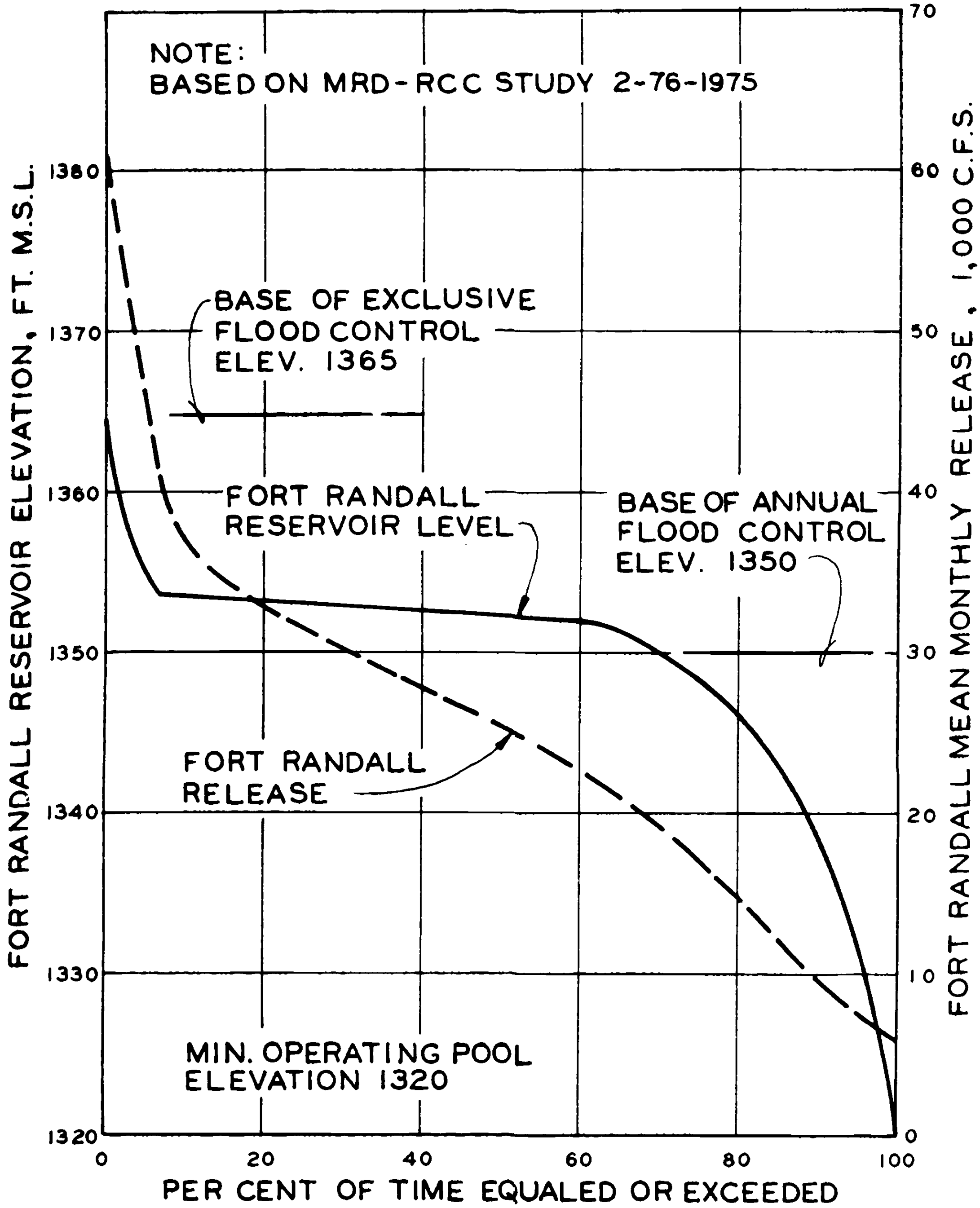
MISSOURI RIVER AT FORT RANDALL DAM



1975

ACTUAL AND UNREGULATED FLOWS

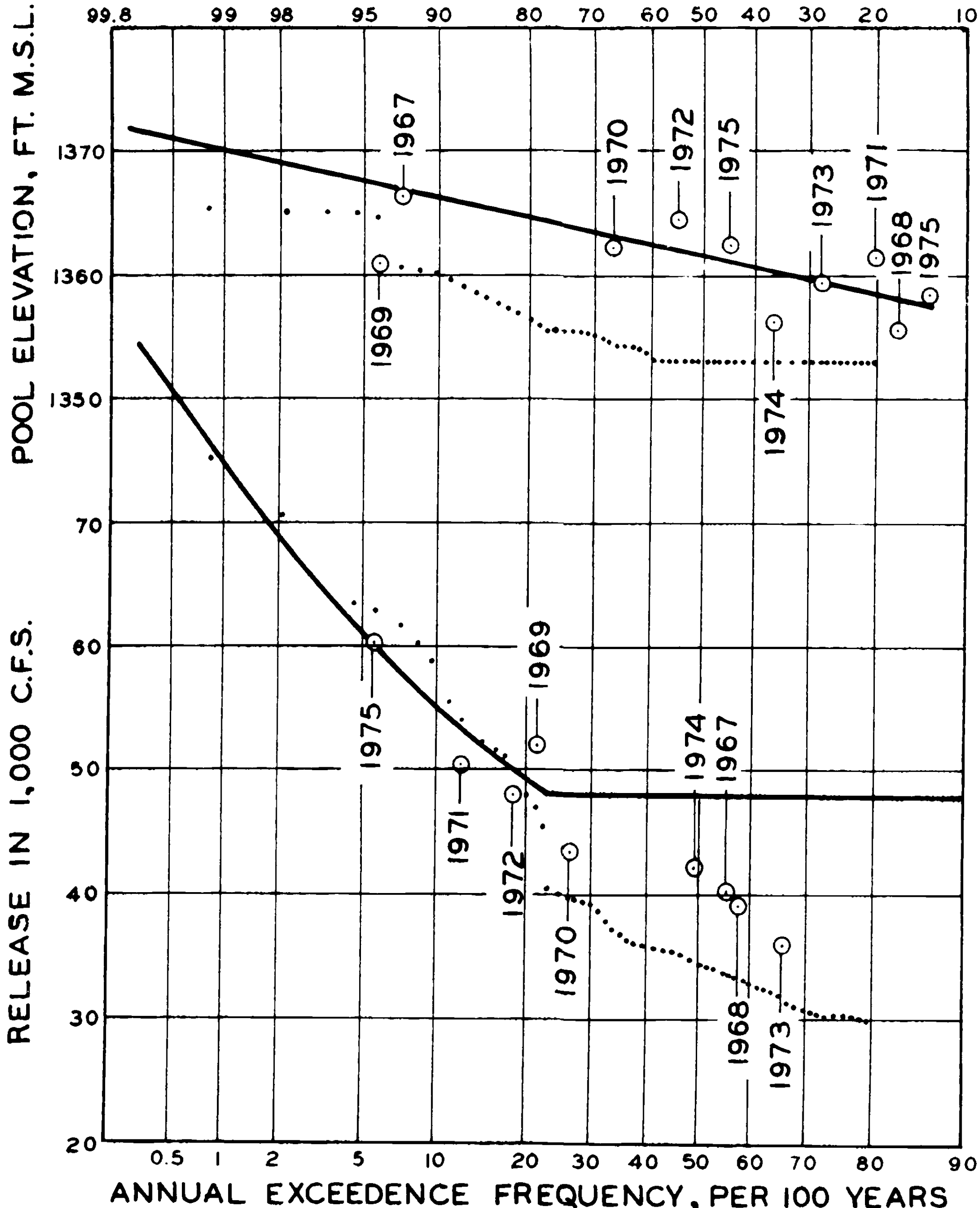
MISSOURI RIVER AT FORT RANDALL DAM



DURATION CURVES FOR
POOL LEVELS AND RELEASES
FORT RANDALL PROJECT

PLATE 31

☆ U S GOVERNMENT PRINTING OFFICE 1972 780 847

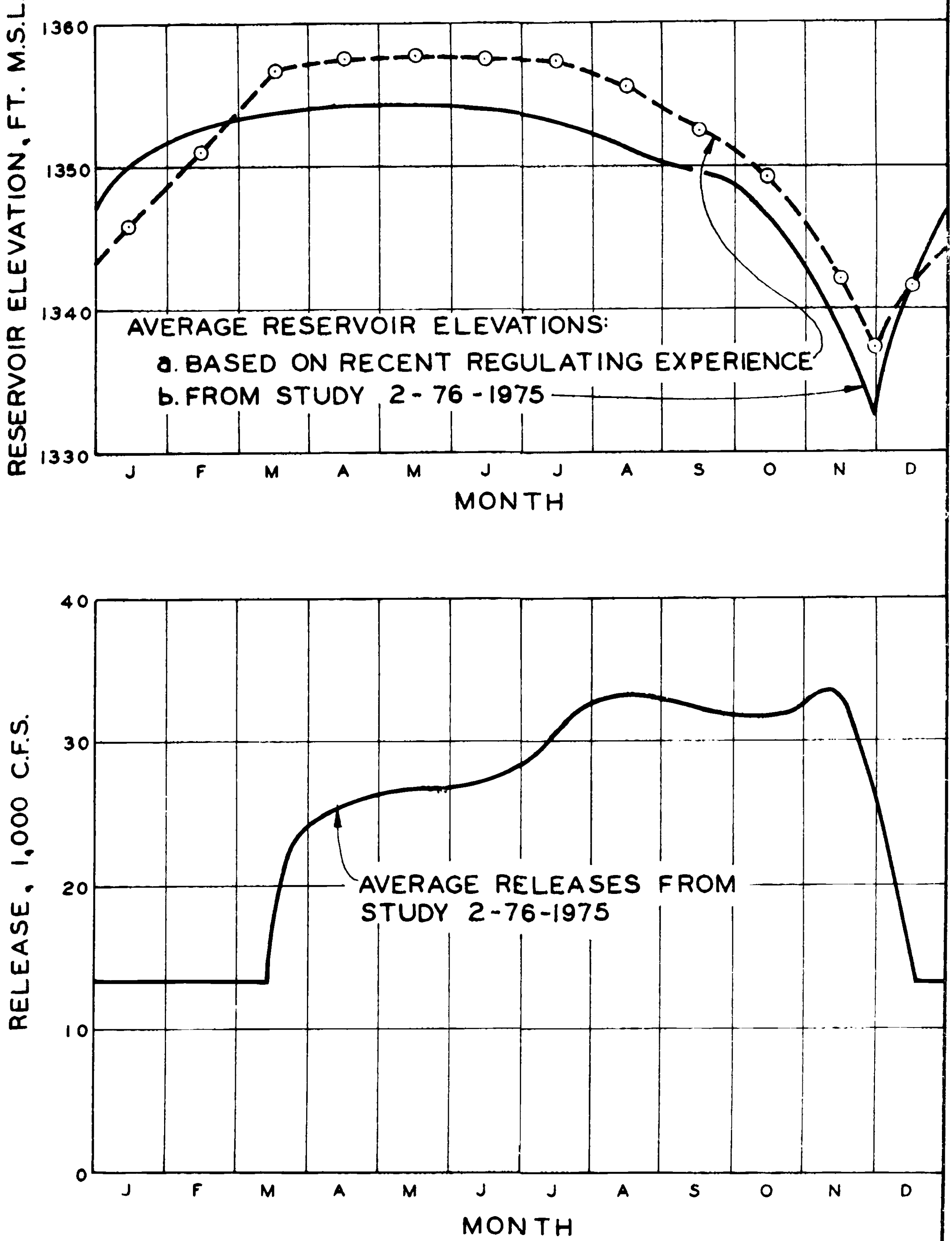


NOTES:

1. SMALL POINTS ARE BASED ON RESERVOIR REGULATION STUDY 2-76-1975, USING MEAN MONTHLY RELEASES AND END OF MONTH ELEVATIONS.
2. LARGE CIRCLES ARE BASED ON ACTUAL DAILY DATA FOR LISTED YEAR.

ANNUAL EXCEEDENCE FREQUENCY CURVES FOR MAXIMUM POOL LEVELS AND RELEASES FORT RANDALL PROJECT

☆ U.S. GOVERNMENT PRINTING OFFICE 1972 780 646

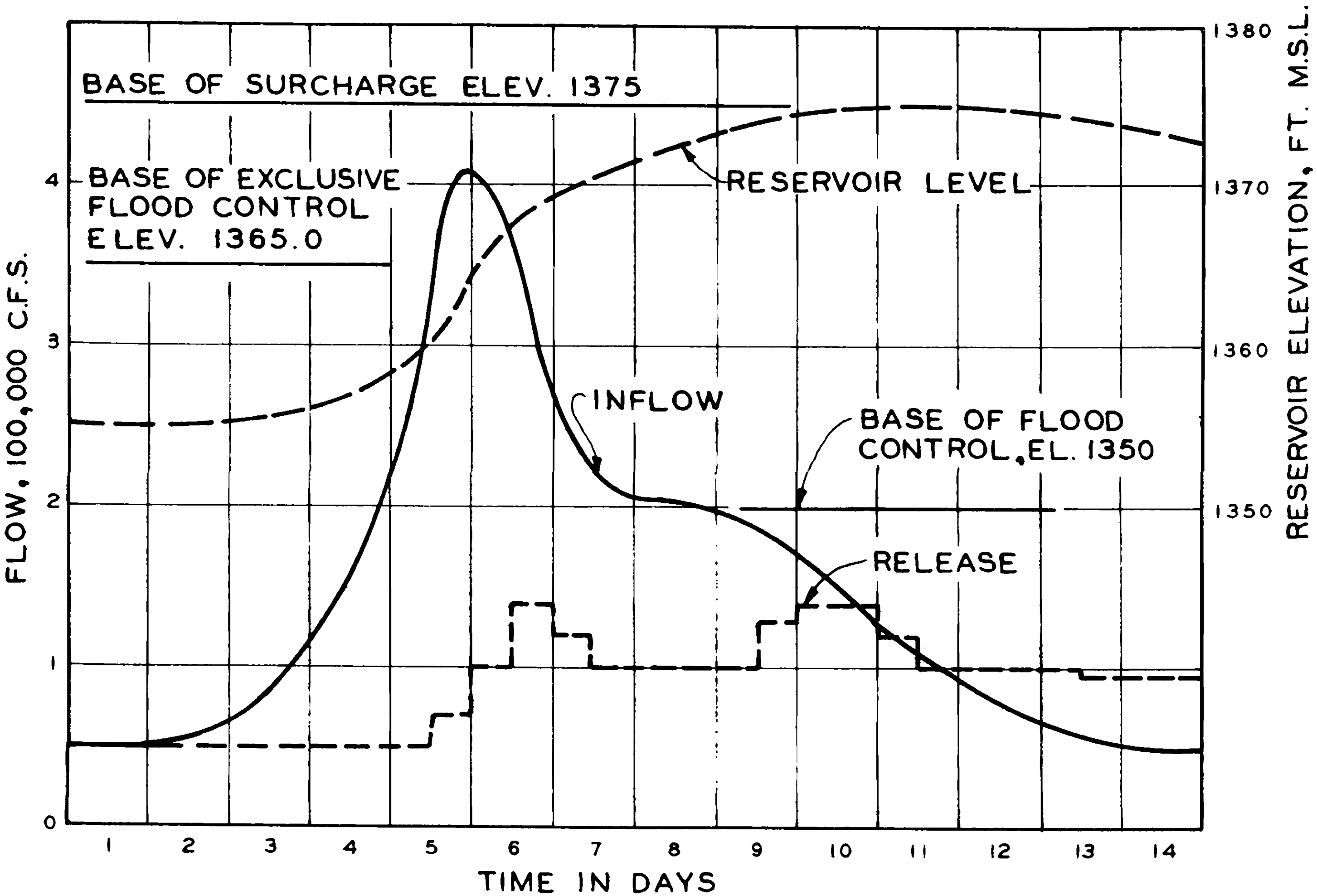


AVERAGE REGULATION
FORT RANDALL RROJECT

PLATE 33

☆ U.S. GOVERNMENT PRINTING OFFICE 1972 760 646

EXAMPLE OF EMERGENCY REGULATION
OF FORT RANDALL FOR ONE-HALF
OF SPILLWAY DESIGN FLOOD



NOTE: ASSUMES RESERVOIR REGULATION IN EFFECT CALLS FOR RELEASE OF 50,000 C.F.S.

PLATE 34

U.S. GOVERNMENT PRINTING OFFICE 1972 780 046

EXHIBIT A

EMERGENCY REGULATION PROCEDURES

FOR

FORT RANDALL RESERVOIR

DEPARTMENT OF THE ARMY
OMAHA DISTRICT. CORPS OF ENGINEERS
6014 U.S. POST OFFICE AND COURTHOUSE
OMAHA, NEBRASKA 68102

MRDED-R

SUBJECT: Reservoir Regulation Order, Emergency Regulation Procedure for Fort Randall Reservoir

TO: Power Plant Superintendent
Fort Randall Power Plant

FROM: Missouri River Division
Reservoir Control Center

1. Procedures applicable to the regulation of the Fort Randall Reservoir during any period that communication with the Missouri River Division Reservoir Control Center or the Omaha District Reservoir Regulation Section is not possible are outlined in the following paragraphs. These instructions supersede all previously furnished emergency reservoir regulation criteria.

2. Normally, reservoir regulation orders specifying project releases and power production will be furnished your office by the Reservoir Control Center and your office will report daily to the Reservoir Control Center and the Omaha District pertinent data relating to regulation of the Fort Randall Reservoir. These data will include reservoir elevations, releases, power generation and related hydrologic data. The MRD teletype network will normally be used for transmission of orders and reports. However, if this network is inoperative, alternate means of communication are to be utilized. These include direct telephone, the MRD radio network, relay of data by other main stem project offices and utilization of Western Area Power Administration (WAPA) communication facilities.

3. When daily communication, as outlined in paragraph 2 above, cannot be established, the following will apply:

a. Every reasonable effort will be made by the Power Plant Superintendent to re-establish communications with the Reservoir Control Center or the Omaha District Reservoir Regulation Section, including use of any Federal, commercial or private means of communication.

b. Following a communication failure, the provision of the latest regulation order will be extended. Hourly power plant loading will follow the WAPA loading schedule, if available. If the hourly schedule has not been received from the WAPA, power plant releases will be made to provide the daily energy schedule specified in the latest order and will be patterned similar to recent experience. If requested by the WAPA Power Systems Operations Office and if power emergency conditions have been declared, energy generation may be increased to the maximum allowable limit shown on the latest regulation order. These procedures will continue to be utilized until communications are re-established as long as the Fort Randall pool level remains below elevation 1355 feet m.s.l.

c. If the Fort Randall pool level is above elevation 1355, procedures given in paragraph b will be applicable during the first day of communication failure, after which conditions will be reviewed to determine if the release level should be changed. Procedures are as follows:

(1) Minimum release will be the release specified in the most recent available regulation order.

(2) The mean inflow for the preceding 12 hours will be estimated by computing the storage change during the 12-hour period on the basis of pool elevations observed at the damsite. Normally, the pool elevation will follow a relatively smooth curve. Therefore, any sudden fluctuations in the pool level recorder trace from a smooth curve (probably due to wind effects on the reservoir gage) should be disregarded and the storage change based on an extrapolation of the smoothed pool level curve through the 12-hour period. The approximate mean inflow in cfs is equivalent to the mean outflow in cfs plus the storage change in acre-feet during the 12-hour period. Twelve-hour inflow may also be approximated by the equation:

Inflow = Outflow + (95,000 X 12-hour elevation change in feet)

(3) Utilizing the inflow as developed above and the current pool elevation (as indicated by the smoothed pool level curve), determine the rule curve release by use of the emergency curves shown on the attached Inclosure 1.

(4) If the rule curve release developed by (3) is greater than the release given by (1), and the reservoir level is between 1355 and 1375, make release specified by the rule curve.

(5) With Fort Randall pool at or below elevation 1365, releases will be limited to a maximum of 100,000 cfs.

(6) While releases may be made by any combination of powerplant, outlet tunnels or spillway releases, total releases should not exceed those that would be possible through the spillway alone, subject to considerations in (5) above.

(7) With a Fort Randall pool above elevation 1375, release inflows up to the full spillway release capacity in order to prevent further increases in the reservoir elevation. After inflows peak, maintain releases at the maximum release rate reached until the reservoir level drops below elevation 1375.

(8) With Fort Randall pool below elevation 1355, any release adjustments made necessary by these instructions should be made once daily. With Fort Randall pool above elevation 1355, the analysis and necessary adjustments should be at intervals of 12 hours or less.

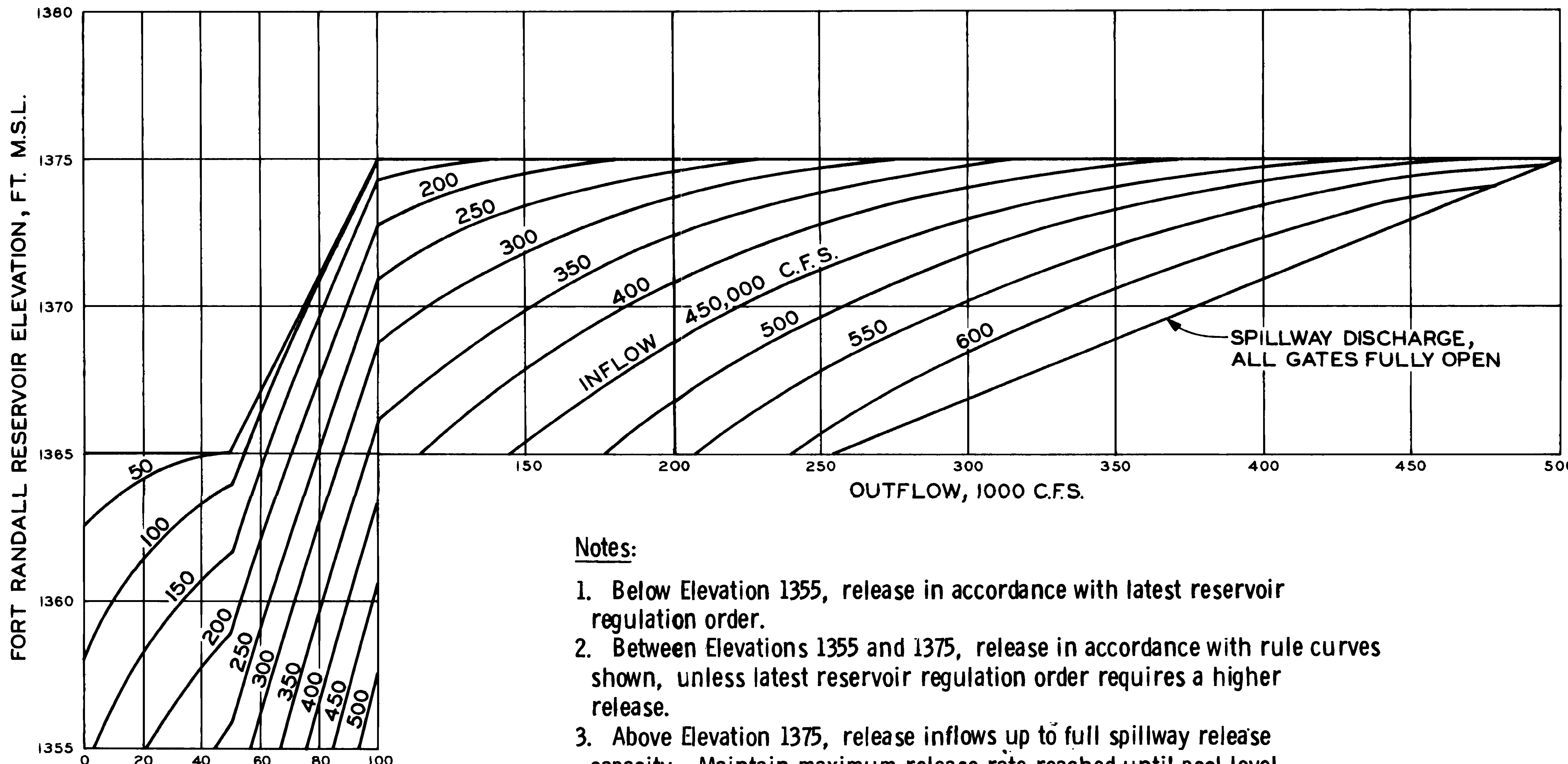
(9) If release is less than full power plant capability, power plant loading will be patterned similar to recent experience or as prescribed by the WAPA if communication with their Systems Operations Office is possible.

4. In the event of downstream flooding, as reported to or anticipated by the Power Plant Superintendent, during such time the Fort Randall elevation is below elevation 1355, releases will be reduced as deemed necessary to alleviate these conditions. However, with the Fort Randall Reservoir above elevation 1355, releases will not be reduced below those levels defined by the preceding emergency instructions.

5. The foregoing procedures are not intended to relieve the Power Plant Superintendent of taking such additional measures believed necessary to assure the safety of the project.

1 Incl
Rule Curve

ELMO W. McCLENDON
Chief, Reservoir Control Center



Notes:

1. Below Elevation 1355, release in accordance with latest reservoir regulation order.
2. Between Elevations 1355 and 1375, release in accordance with rule curves shown, unless latest reservoir regulation order requires a higher release.
3. Above Elevation 1375, release inflows up to full spillway release capacity. Maintain maximum release rate reached until pool level drops below 1375.

EMERGENCY REGULATION CURVES
FORT RANDALL RESERVOIR

EXHIBIT A - INCLOSURE 1