MISSOURI RIVER
MAIN STEM RESERVOIR SYSTEM
RESERVOIR REGULATION MANUAL

OAHE MANUAL

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

MROED-HC

SUBJECT: Reservoir Regulation Manual, Oahe Dam - Lake Oahe, South Dakota

Murphy
gh/4610

Garvey

Slizeski

Burnett

Area Engineer, South Dakota Area

Inclosed for your information and retention are three copies of the above subject reservoir regulation manual.

FOR THE DISTRICT ENGINEER:

1 Incl (3 cys)
as

R. G. BURNETT
Chief, Engineering Division

DEPARTMENT OF THE ARMY
MISSOURI RIVER DIVISION, CORPS OF ENGINEERS
P. O. BOX 103, DOWNTOWN STATION
OMAHA, NEBRASKA 68101

MRDED-R

25 September 1978

SUBJECT: Reservoir Regulation Manual, Oahe Reservoir, South Dakota

District Engineer, Omaha
ATTN: MROED-HC

Seven copies of the subject manual are inclosed for your information and retention. It was agreed in conversation between Messrs. Franklin, MRD, and Garvey, OD, that three of these manuals would be made available to the South Dakota area office.

FOR THE DIVISION ENGINEER:

Lloyd A Duscha

1 Incl
as

LLOYD A. DUSCHA
Chief, Engineering Division

MISSOURI RIVER
MAIN STEM RESERVOIR SYSTEM
RESERVOIR REGULATION MANUAL

In 7 Volumes | Volume 4

OAHE RESERVOIR (LAKE OAHE)

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

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MAIN STEM RESERVOIR SYSTEM
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OAHE RESERVOIR MANUAL

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OAHE DAM AND RESERVOIR
MISSOURI RIVER
SOUTH DAKOTA

PERTINENT DATA

1. PURPOSE

Oahe Dam and Reservoir, in coordination with other projects in the Missouri River Main stem system, is regulated as a multiple-purpose reservoir for navigation, flood control, hydroelectric power, irrigation, water supply, water quality control, recreation, fish and wildlife and other allied 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	Stanley and Hughes
River	Missouri River, 1072.30 miles above the mouth (1960 mileage)
Town	Approximately 6 miles upstream from Pierre, South Dakota

4. DRAINAGE AREAS

Total Missouri River Basin, Sq. Mi.	529,350
Above Oahe Dam, Sq. Mi.	243,490
Garrison Dam to Oahe Dam, Sq. Mi.	62,090
Oahe Dam to Big Bend Dam, Sq. Mi.	5,840

5. STREAM FLOW DATA

Observed Flow at Dam Site, cfs (1898-1958)	
Maximum of Record (1952)	440,000
Minimum (1940)	2,300

Actual Regulated Flow at Dam Site, cfs (1958-1976)	
Maximum (1975)	57,500
Minimum (1963 and other years)	0
Average	23,200

Average Annual Runoff at Dam Site (1898-1975) Acre-Feet	20,900,000 (1)

(1) Adjusted to 1949 level of water resource development.

6. RESERVOIR DATA

Approximate Length of Reservoir, miles (Pool Level at Maximum Normal Operating Level and 1960 River Conditions)	231
Shoreline, miles at Elev. 1607.5	2,250

Storage Capacity	Elevation msl	Gross Storage Acre-Ft.	Gross Area Acres
Maximum Operating Pool	1620	23,500,000	371,000
Maximum Normal Operating Pool	1617	22,400,000	356,000
Base of Flood Control Pool	1607.5	19,200,000	313,000
Minimum Operating Pool	1540	5,500,000	118,000
Exclusive Flood Control	1617-1620	1,100,000	
Seasonal Flood Control	1607.5-1617	3,200,000	
Carryover Multiple Use	1540-1607.5	13,700,000	
Inactive Storage	1415-1540	5,500,000	

7. DAM

Embankment Type - Rolled Earth Fill	
Abutment Formations - Pierre Shale	
Top of Embankment, Elev. Ft. msl	1660
Total Crest Length, Feet (excluding spillway)	10,000
Maximum Height, Feet	245
Damming Height (Low Water to Max. Oper. Pool)	200
Top Width, Feet	60
Maximum Base Width, Feet	3,500
Fill Quantity, Cubic Yards	92,000,000

8. SPILLWAY

Location	Right Bank - Remote
Type - Gated Weir with Discharge Channel	
Crest Elevation, Feet msl	1596.5
Crest Width, Gross, Feet	456
Crest Width, Net, Feet	400
Gates - Taintor - No. & Size, Feet	8 - 50 x 23.5

Design Discharge Capacity, cfs	304,000
Discharge Capacity at Maximum Operating Pool, (elev. 1620) cfs	80,000

9. OUTLET WORKS

Location	Right Bank
Type - Concrete Lined Tunnels with Control Shafts	
Tunnels, No. and Dia. in Feet	6 - 19.75 Upstream & 18.25 Downstream
Tunnels, Length, Feet, Approx.	3496 to 3659 (2)
Service Gates, Type, No. & Size in Feet	1 - 13 x 22 per conduit, vertical lift; 4 cable suspension, tractor and 2 hydraulic suspension, wheeled type (fine regulation)
Emergency Gate, Type, Total No. and Size in Feet	1 - 13 x 22 Vertical Lift Tractor
Discharge Capacity Per Tunnel, cfs (Reservoir Water Surface at Elev. 1620)	18,500
Tailwater Elevation, msl (30,000 cfs)	1424-1425
Intake Invert Elevation, Feet, msl	1425-1455
Exit Portal Invert Elevation, Feet, msl	1420

Note (2) Length from upstream face of intake to downstream face of tunnel outlet portal.

10. POWER STRUCTURES

Location	Left Bank
Powerhouse, Type	Indoor, Reinforced Concrete
Penstocks - Concrete Lined with Steel	
Penstocks, No. & Dia. in Feet	7 - 24
Penstocks, Length in Feet, Approx.	3,280 to 4,005 (3)
Service Gates, No. & Size, Feet	1 - 10 x 32 Dia. for each penstock
Emergency Gates, Type & No.	1 complete set of bulkheads for one power intake
Surge Tanks, No. and Dia. in Feet	2 - 70 Ft. Dia. per penstock

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

11. POWER INSTALLATION

Average Gross Head Available, Feet	185
Number of Generating Units	7
Turbines, Type	Francis
Turbines, Speed, rpm	100
Discharge Capacity at Rated Head (185 ft) cfs	53,700
Generator Rating, KW	85,000

12. POWER AVAILABLE

Plant Capacity, KW	595,000
Dependable Capacity, KW (4)	470,000
Average Annual Energy, KWH (4)	2,604,000,000

Note (4) - Based on Operation Study 2-76-1975

MISSOURI RIVER BASIN
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IN 7 VOLUMES - VOLUME NO. 4
OAHE 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 multi-purpose 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 Oahe Manual supplements the Master Manual by discussing the factors pertinent to the regulation of the Oahe Reservoir. The regulation of major tributary reservoirs located within the Missouri River Basin affecting the regulation of the Oahe 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 Oahe 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 Oahe 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 Oahe Dam includes all of Montana east of the continental divide, northern Wyoming, southwestern North Dakota, northwestern 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 Oahe Dam is 243,490 square miles. This includes 57,500 square miles of drainage above Fort Peck Dam and 123,900 square miles of incremental drainage between Fort Peck and Garrison Dams. Those portions of the Missouri basin lying upstream from Garrison Dam are described in the Fort Peck and Garrison Reservoir Regulation Manuals. The portion of the Missouri Basin described in this manual consists of the 62,040 square miles of incremental drainage area between Garrison Dam and Oahe Dam, as well as the drainage area contributing to the Missouri River in the reach extending from Oahe Dam into the headwaters of Big Bend Reservoir (Lake Sharpe). Plate 1 is a general map of the Missouri River Basin while the incremental drainage area defined by the Garrison and Oahe Dams and described in this manual is shown in more detail on Plate 2.

2-2. Topography. The Missouri River drainage area between Garrison Dam and the headwaters of Big Bend Reservoir forms a portion of the Interior 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 Garrison-Oahe 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. Surrounded by the Unglaciated Plateau region is the Black Hills Section. This is an elliptical-shaped mountainous area about 65 miles wide and 125 miles long centered along the border separating Wyoming from South Dakota. Here the slopes are steep to precipitous, covered in places by bare, craggy rocks.

2-4. The Unglaciated Plateau region has a general west to east slope of about 10 feet to the mile, with elevations ranging from about 5,000 feet in the southwestern part of the incremental drainage area to near 1500 feet on bottom lands adjacent to the Missouri River. Within the Black Hills, mountain peaks extend to over 7,000 feet in elevation above sea level.

2-5. 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. The remainder is devoted to recreation, fish and wildlife, transportation and built-up areas. Pasture and range is the primary agricultural pursuit, utilizing about 75 percent of the total area. Cropland comprises about 18 percent of the total area while forest woodland extends over 5 percent of the incremental drainage area lands. Most of the forested lands are in the Black Hills region. About 13 percent of the incremental area is in Federal ownership, the remainder being owned by State, County, or private individuals. 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 area 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.

2-6. Drainage Pattern. The drainage pattern of the Missouri River Basin is shown on Plate 1. Noteworthy in the drainage basin above Oahe Dam is the large area of the upper Missouri River controlled by the Fort Peck and Garrison projects. These upstream main stem projects control three-fourths of the total drainage contributing to the Oahe project, including essentially all of the mountainous area contributing to the Missouri River above Oahe Dam.

2-7. The most prominent feature of the incremental Missouri Basin drainage between Garrison Dam to immediately below Oahe Dam is that every major tributary is a right bank tributary and flows 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 tributary headwaters are significantly higher than at the tributary mouths, resulting in an aggravation to ice jamming near their mouths 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. It is estimated that well over 1,000 square miles in this region to the east will not contribute directly to streamflow unless extreme runoff were to occur, sufficient to fill and overflow the low depressions that normally restrict runoff.

2-8. Major tributaries in the incremental reach extending from Garrison Dam to Lake Sharpe are the Knife, Heart and Cannonball Rivers draining North Dakota to the west of the Missouri River, and the Grand, Moreau, Cheyenne and Bad Rivers. The drainage of these latter tributaries is primarily in western South Dakota although a significant area in northeastern Wyoming and a small region of northwest Nebraska does contribute to the Cheyenne River. The major tributary in this reach is the Cheyenne River, draining an area almost five times as great as any other of the tributary streams. Table 1 lists tributary streams and their drainage areas, as well as locations of tributary mouths and other significant features along the Missouri River in this reach.

2-9. Stream Slopes. The total fall of the Missouri River from Garrison Dam to Oahe Dam is about 250 feet, averaging about 0.8 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. Slopes of Cheyenne River tributaries become much steeper than the average in the Black Hills region of South Dakota.

II-B Climatology.

2-10. 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. An exception is the Black Hills region of South Dakota where the high elevation, with associated orographic influences, create a relatively small area where the climate is classified as humid. Through the region there is a marked seasonal variation in all weather phenomena.

TABLE 1

MISSOURI RIVER DRAINAGE AREAS
GARRISON DAM TO BELOW OAHE DAM

Feature	Tributary Drainage Area Square Miles	Location, Missouri River Mile[1]
Garrison Dam	--	1389.86
Knife River	2,510	1375.72
Turtle Creek	813	1352.00
Painted Woods Creek	556	1348.88
Bismarck, N.D. gage	--	1314.50
Heart River	3,340	1311.00
Apple Creek	1,770	1300.68
Cannonball River	4,310	1269.62
Beaver Creek	717	1255.71
N.D. - S.D. State Line	--	1231.94
Spring Creek	1,530	1223.75
Grand River	5,700	1198.00
Mobridge, S.D. bridge	--	1197.78
Moreau River	5,400	1175.88
Cheyenne River	25,500	1110.21
Oahe Dam	--	1072.30
Pierre, S.D. gage	--	1066.50
Bad River	3,120	1065.19
Big Bend Dam	--	987.44

[1] Tributary location is at confluence with Missouri River. River Miles listed are based on 1960 conditions.

2-11. Annual Precipitation. Annual precipitation over most of the Garrison-Oahe drainage area increases from west to east, ranging from about 12 inches in the headwaters of the tributary Cheyenne River to almost 18 inches to the east of the Missouri River. The Black Hills region receives considerably more precipitation than surrounding areas, with average annual amounts ranging up to above 24 inches. 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 occasionally occurring.

2-12. Seasonal Precipitation. Precipitation over the incremental drainage area between the Garrison and Oahe dams usually occurs as snow during the months 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.

2-13. 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. However, in the Black Hills region, snowfall is much heavier. Over the plains area 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. Higher elevations in the Black Hills often progressively accumulate snow through the winter and early spring season up to a maximum accumulation in March or early April. Snowfall through the plains region is usually accompanied by high winds resulting in much drifting.

2-14. 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 frequently interrupted during periods of downslope or "chinook" winds when mild temperatures (for the season) prevail. Summers are normally relatively mild, particularly in the higher elevations of the Black Hills, but may be interrupted by short periods of extremely warm temperatures.

2-15. Evaporation. Annual evaporation from the surface of the Oahe Reservoir is normally slightly less 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 Oahe project) amounts to about 20 inches annually. Due to seasonal precipitation patterns and to the lag in normal lake surface temperatures from corresponding air temperatures, nearly all of the annual net evaporation from the Oahe Reservoir can be expected to occur during the five-month period, August through December.

2-16. 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

2-17. 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. From the studies carried on at the time, based on main stem stages and the discharge records available, records of monthly incremental flows between the Garrison and Oahe dam sites were developed for an extended period and are now available from 1898 to date. Daily flows at many locations within the incremental areas are available for varying periods of time since 1930. 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 Garrison to Oahe 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.

2-18. Sources of Runoff. The primary source of runoff from the Garrison-Oahe 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. The largest runoff producing region in this incremental drainage area is the Black Hills where average annual amounts over a restricted area exceeds four inches. Throughout most of the drainage area annual runoff averages less than one inch. Generalized estimates of mean annual runoff throughout the Missouri Basin are presented by a plate in the Master Manual, while normal contributions to annual runoff from tributary drainages through the incremental area are given in Table 2.

2-19. Seasonal Runoff Pattern. Runoff from the Missouri River drainage basin between Garrison Dam to below Oahe Dam usually follows a characteristic seasonal pattern as follows:

a. Winter is characterized by frozen streams, progressive accumulation of snow in the Black Hills of South Dakota and intermittent snowfall and thaws in the plains area where the season usually ends with a "spotty" snow cover of relatively low water content and a considerable amount of water in ice storage in the stream channels. Runoff 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. Due to the tendency of temperatures to rise above freezing first from the west, and the easterly course of the tributaries through this region, 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 usually occur at this time along tributary streams.

TABLE 2

NORMAL ANNUAL RUNOFF, MISSOURI RIVER BASIN BETWEEN GARRISON DAM AND BIG BEND RESERVOIR

Contributing Area	Drainage, sq. mi.	Average Annual Runoff[1] 1,000 AF	Average Annual Runoff[1] Inches
Knife River			
Hazen	2,240	131	1.10
Heart River			
Mandan	3,310	186	1.05
Cannonball River			
Breien	4,100	178	0.81
Grand River			
Little Eagle	5,370	171	0.60
Moreau River			
Whitehorse	4,880	133	0.51
Cheyenne River			
Edgemont	7,143	75	0.20
Wasta	12,800	266	0.39
Cherry Creek	23,900	626	0.49
Spearfish Creek (Cheyenne River Tributary)			
Spearfish	168	37	4.13
Bad River			
Ft Pierre	3,107	110	0.66
Missouri River[2]			
Garrison Dam	181,400	18,527	1.92
Oahe Dam	243,490	20,865	1.61
Garrison-Oahe,			
Incr. Drainage	62,090	2,338	0.71
Local Drainage[3]	18,290	913	0.92

(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 Garrison and Oahe Dams less Knife River at Hazen, Heart River at Mandan, Cannonball River at Breien, Grand River at Little Eagle, Moreau River at Whitehorse and Cheyenne River at Cherry Creek.

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 Oahe incremental drainage area is usually very low from July through the remainder of the calendar year.

2-20. Total unregulated Missouri River runoff originating above the Oahe damsite 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, ranging from a maximum of 24.7 million acre-feet in March-July 1975 to a minimum of 5.1 million acre-feet in 1961. The effects of project regulation upon these runoff patterns is discussed in Section X.

2-21. Plate 3 also illustrates the average and extreme values of monthly runoff originating from the incremental drainage area between Garrison Dam and Oahe Dam. Average runoff from this incremental area is at a maximum through the March-June period, with very little runoff occurring through the remainder of the year. The plot of maximum observed monthly flows illustrates that the largest amounts of incremental monthly runoff have occurred as a result of the melt of a large plains snow accumulation. Minimum runoff from the incremental area has been calculated to be negative in some years during nearly all months of the year, indicating that evaporation from the Missouri River channel (or other losses) often exceeds the flow of tributaries entering the Missouri River in this reach.

2-22. Floods. Regulation provided by Oahe and upstream main stem projects, augmented by upstream tributary reservoir storage, has virtually eliminated flooding along the portion of the Missouri River extending immediately below Oahe 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.

2-23. 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 Oahe 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 Garrison to Oahe reach of the river. Plates 4 and 5 illustrate total incremental inflows experienced during selected runoff periods since regulation of Oahe began in 1958. Inflows shown on these plates are based on elevation changes in Oahe Reservoir and releases from Oahe and the upstream Garrison project coincident with these changes in elevation.

2-24. Flood of 1950. Monthly runoff originating between Garrison and Oahe Dams during April 1950, amounting to 3.749 million acre-feet, was the second largest monthly runoff from this incremental area during the entire 1898-1976 period of available record. During the 30-day period beginning on March 25, incremental inflows contributing to flows at the Oahe dam site were the greatest of any similar length period during the period of available record, amounting to 4 million acre-feet. Snowfall had progressively accumulated over this incremental drainage area through the preceding winter season, which was characterized as being much colder than normal with well above normal precipitation. Runoff from tributary areas in South Dakota began during late March; however, maximum snowmelt occurred near mid-April. Crest inflow to the Missouri River from the total incremental area approximated 190,000 cfs. Crest flows near the mouths of tributary streams within the incremental areas were as follows:

Knife River	22,700 cfs, April 17
Heart River	30,500 cfs, April 19
Cannonball River	94,800 cfs, April 19
Grand River	82,800 cfs, April 18
Moreau River	20,900 cfs, April 19
Cheyenne River	14,500 cfs, April 18
Bad River	16,700 cfs, April 2

2-25. Flood of 1952. The maximum monthly runoff originating from the Garrison-Oahe reach of the Missouri River during the 1898-1976 record period occurred in April 1952 when a total of 3.953 million acre-feet was observed. This runoff resulted from a wet fall during 1951, well above normal precipitation, largely in the form of snow during the entire 1951-1952 winter season, formation of a significant ice layer over frozen ground during the early winter, and colder than normal temperatures throughout most of the winter season, resulting in a progressive accumulation of snow over a large portion of the incremental drainage area. Warm temperatures in late March and early April resulted in a rapid melting of the deep accumulated snow cover, contributing to extremely large tributary flows. Analysis indicates that total flows from the Garrison-Oahe incremental drainage area crested at 285,000 cfs; however, crest flows along the Missouri River were augmented by severe Missouri River ice jams and it does not appear probable that a repetition of the 1952 flood producing events, now that main stem projects are in operation, would result in as large a crest incremental flow, since ice jams along this reach of the Missouri River are now improbable. Crest flows experienced during 1952 near the mouths of tributary streams draining this incremental area were as follows:

Knife River	20,200 cfs, April 7
Heart River	30,000 cfs, April 4
Cannonball River	21,300 cfs, April 7
Grand River	17,900 cfs, April 2
Moreau River	36,900 cfs, April 5
Cheyenne River	38,500 cfs, April 3
Bad River	28,100 cfs, April 7

2-26. Early Spring Tributary Floods. Since regulation of the Oahe Reservoir began in 1958 there have been several instances when substantial amounts of runoff have occurred from the Garrison-Oahe incremental drainage area as a result of plains snowmelt. Inflows to the Oahe Reservoir from the incremental drainage area during this season in the year 1966, 1969, 1971 and 1972 are shown on Plate 4. Respective maximum monthly incremental area runoff amounts were 1.487, 1.087, 1.101 and 1.835 million acre-feet. The incremental area inflow hydrographs were developed on the basis of outflows from Garrison and Oahe as well as storage changes of Oahe Reservoir. Crest flows near the mouths of major tributaries contributing in this reach of the Missouri River during those floods as well as total incremental area crests are given in Table 3.

TABLE 3

EARLY SPRING FLOODS, MISSOURI RIVER TRIBUTARIES
BETWEEN GARRISON AND OAHE DAMS

	Crest Flows, cfs			
Tributary Area	1966	1969	1971	1972
Knife River	4,230	11,800	4,320	19,000
Heart River	7,720	18,800	4,100	9,500
Cannonball River	16,100	16,900	9,370	19,400
Grand River	10,000	9,760	7,370	15,000
Moreau River	14,400	7,370	10,300	21,000
Cheyenne River	17,700	2,650	13,400	4,500
Total Incremental Area	88,000	51,000	52,000	98,000

2-27. Late Spring Tributary Floods. While significant runoff from the Garrison-Oahe drainage area is more likely to occur during the early spring months as a result of plains' snowmelt, rainfall during the May-July period has also occasionally contributed to substantial runoff from this incremental area. Daily inflows to Oahe Reservoir, as developed from daily storage changes and releases from Garrison and Oahe for this season in the year 1962, 1967, 1970 and 1975, are shown on Plate 5. Respective maximum monthly incremental drainage area runoff amounts during these years were 1.077, 1.001, 0.972 and 1.169 million acre-feet. Crest flows from major tributaries contributing in this reach of the Missouri River and total incremental area crests during these flood events are given in Table 4.

TABLE 4

LATE SPRING FLOODS, MISSOURI RIVER TRIBUTARIES
BETWEEN GARRISON AND OAHE DAMS

	Crest Flows, cfs			
Tributary Area	1962	1967	1970	1975
Knife River	3,860	495	8,180	6,600
Heart River	2,480	208	15,030	8,300
Cannonball River	4,570	610	9,420	8,220
Grand River	11,000	2,900	8,280	7,290
Moreau River	17,500	14,500	7,260	10,900
Cheyenne River	36,300	43,800	7,280	12,600
Total Incremental Area	47,000	62,000	40,000	41,000

2-28. Bad River Floods. The Bad River, a tributary stream entering the Missouri River about 5 miles below Oahe Dam, is the only tributary from which high crest flows can have a direct effect upon Oahe release scheduling. Similar to the tributaries previously discussed, high flows on the Bad River are most likely to occur during the plains snowmelt period; although severe rainstorms have also at times caused significant crests. As may be noted from Table 2, average annual runoff from this tributary is only slightly greater than 100,000 acre-feet; however, on occasion this volume may be greatly exceeded during a single runoff event. The flood events discussed in preceding paragraphs as pertinent to the incremental drainage between Garrison and Oahe Dams are also representative of flood flows on the Bad River. Crest discharges during these years are given in Table 5 and are indicative of Bad River floods affecting Oahe regulation that may be experienced in the future.

TABLE 5

BAD RIVER FLOOD FLOWS AT FORT PIERRE, SOUTH DAKOTA

Year	Flood Type	Crest Flow (cfs)	Ten-Day Flood Volume, AF
1950	Plains snowmelt	16,700	176,970
1952	Plains snowmelt	28,100	376,670
1962	Rainfall	10,500	48,490
1966	Plains snowmelt	10,700	119,610
1967	Rainfall	43,800(1)	133,030
1969	Plains snowmelt	37,700	20,780
1970	Rainfall	3,800	49,110
1971	Plains snowmelt	3,510	33,560
1972	Plains snowmelt	2,100	29,950
1975	Rainfall	3,770	36,800

(1)Maximum flow of record (August 1928 to present).

2-29. Basinwide Floods. The runoff originating only from the incremental drainage area between Garrison and Oahe Dams will seldom be sufficient to tax the flood control capability of the Oahe project. Utilization of a major portion of the Oahe flood control storage space will usually be necessary only when large runoff amounts originate from the total Missouri Basin drainage area above Oahe Dam. Floods of this type are described in the Master Manual.

2-30. Effects of the Oahe Project on Flood Inflows. Studies conducted by the Reservoir Control Center indicate that operation of the Oahe project in conjunction with other upstream reservoir projects would virtually eliminate significant flood damages in the reach extending from Oahe Dam into Big Bend Reservoir 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.

2-31. Water Travel Time to Oahe Reservoir. The Master Manual contains plates from which estimates of water travel time throughout the Missouri Basin can be obtained. Table 6 presents the approximate time involved for changes in flow at upstream locations in the Garrison-Oahe drainage area to be reflected in Oahe inflows.

TABLE 6

WATER TRAVEL TIME TO OAHE RESERVOIR

Stream	Location	Approx. Travel Time in Days
Missouri River	Garrison Dam	2
Knife River	Hazen	2
Heart River	Heart Butte Dam	2
	Mandan	1
Cannonball River	Bentley	3
	Brien	1
Grand River	Shadehill Dam	3
	Little Eagle	1
Moreau River	Faith	3
	Whitehouse	1
Cheyenne River	Plainview	2
	Cherry Creek	1
Bad River(1)	Midland	1
	Fort Pierre	0

(1)Travel time is to Missouri River below Oahe Dam.

2-32. Water Quality. Most tributary streams originating in the Garrison-Oahe drainage area traverse areas with rocks and soils containing many soluble salts. Water quality is generally poor since salts that are leached from the land cause the water in the streams to be highly mineralized. An exception is the Black Hills area, where the natural chemical quality of the water is good but mining and smelter operations have seriously degraded the natural quality of some streams. Over much of this incremental drainage area, total dissolved solids in tributary streams range from 1,000 to 2,000 milligrams per liter although in portions of the Cheyenne River drainage the dissolved solids approach 4,000 milligrams per liter. 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 Oahe Reservoir is considered to be good due to dilution of the incremental inflows by upstream reservoir releases and the stabilizing effect provided by the Oahe Reservoir and the other upstream main stem reservoirs.

2-33. Sediment. Average annual sediment contributions to the Missouri River of major tributaries in the Garrison-Oahe incremental drainage area range from less than 100 tons per square mile for the Knife River to over 600 tons per square miles for the Moreau River. Most of the sediment transported by these tributary streams is the result of stream bank erosion during high flow periods. Since the upstream Garrison project acts as a trap to sediment originating above Garrison Dam, sediment inflow to the Oahe Reservoir due to Missouri River bank erosion is limited to a relatively short reach of the stream. Average annual sediment inflow to the Oahe Reservoir is estimated to be 32,300 acre-feet. Since the reservoir traps the inflowing sediment, Oahe releases are clear and have little opportunity to pick up any significant sediment contribution above the headwaters of the downstream Big Bend Reservoir.

II-D. Missouri River Channel Below Oahe Dam.

2-34. Areal Extent. The flat pool of the downstream Big Bend Reservoir extends upstream to the Oahe tailwater, consequently there is no portion of the original Missouri River channel below Oahe that is not influenced to some extent by the downstream lake. However, the backwater effects of Big Bend are generally not sufficient to result in extensive overbank storage through the first 10 miles of river length below Oahe Dam. The municipalities of Pierre and Fort Pierre are located respectively on the left and right banks of the Missouri River within this 10-mile reach. The only major tributary stream originating in the drainage area between Oahe and Big Bend Dams, the Bad River, enters the Missouri River about seven river miles below Oahe Dam. Plate 6 is a composite photograph through this reach of the Missouri River.

2-35. Channel Description. The Missouri River channel below Oahe Dam is contained within a relatively narrow alluvial flood plain. From Oahe Dam downstream about 5.8 miles to Pierre, the left bank of the channel is immediately adjacent to high steep bluffs. There is no flood plain along the left bank until the Missouri River flows past Pierre and most developed areas within that city are located on relatively high benches. The existing flood plain through this short reach of the river below Oahe Dam is along the right bank downstream to opposite Pierre, where Fort Pierre is located and where the Bad River enters the Missouri. Below the mouth of the Bad River LeFramboise Island divides the channel for a distance of about 3 miles, extending into the headwaters of Lake Sharpe.

2-36. Structures placed along the Missouri River between Oahe Dam and Pierre confine the channel to the left bank bluffs. These structures consist of training dikes and channel blocks which also serve the purpose of preventing erosion along the right bank of the stream. Additional bank protection in this reach to further reduce right bank erosion is contemplated. Extensive bank protection has been placed adjacent to both Pierre and Fort Pierre as an erosion control measure. Additionally, at the upstream end of LeFramboise Island a channel block has been placed across the left channel of the Missouri River around this island. Culverts in this block allow minor amounts of flow through this channel for water quality control purposes.

2-37. Channel Capacity and Stage-Discharge Relationship. Flood stage at the Pierre, South Dakota, gage is 15 feet. Prior to construction of the Big Bend project and the downstream channel block at LeFramboise Island, Missouri River flows of almost 200,000 cfs could be accomodated without exceeding the established flood stage. Since construction of the Oahe project several factors have influenced stages through this reach, including channel degradation, channel constriction resulting from channel blocks, and backwater effects resulting from both the level of the Big Bend Reservoir and from Bad River sediment deposition in the headwaters of this reservoir. Due to the great hourly variation in Oahe releases, definition of the current stage-discharge relationship at Pierre is rather indefinite; however, during 1975 Oahe releases in the 55,000 cfs range were maintained for an extended period. Measurements taken during this period indicated an upward shift of about 2.5 feet in the pre-project Pierre rating curve for this discharge. Based on this experience and the pre-project Pierre rating curve, the estimated current stage-discharge relationship is shown on Plate 7. This would indicate a 150,000 cfs channel capacity at the established Pierre flood stage of 15 feet. However, confirmation of the curve should be made if Oahe releases greater than 55,000 cfs are required in the future.

2-38. While significant damage probably will not occur with Pierre stages at 15 feet or below, overtopping of some areas of bank revetment or of channel blocks can be expected if Oahe outflows should significantly exceed the power plant capacity of about 55,000 cfs. Low lying areas of Fort Pierre adjacent to the Missouri River may also be adversely affected. High Bad River flows coinciding with large Oahe power plant releases can also adversely affect developed low-lying regions in Fort Pierre.

2-39. River Ice. Since the Oahe project first began operation in 1958 the formation of ice on the Missouri River in the Pierre and Fort Pierre area has not restricted operation of the project. However, it is possible that extended extremely cold temperatures could result in problems at some future time.

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 from Garrison Dam downstream to the headwaters of Big Bend 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 the Black Hills region of South Dakota and in restricted areas immediately adjacent to the Missouri River and other major tributaries. 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 Oahe Dam, as well as the other main stem projects and many tributary projects, and emphasized the 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. In addition to the Oahe project, a number of tributary reservoir projects have been constructed in the incremental drainage area between Garrison Dam and Oahe Dam. While initially some of these tributary projects may have been constructed for a single purpose, they all now serve several functions - although service to some functions may be incidental to a primary purpose. Most of the reservoir projects in this incremental drainage area of the Missouri Basin were developed by the Bureau of Reclamation for the primary purposes of irrigation and water supply. Flood control is also served by most of these projects. The Corps of Engineers has also constructed several reservoirs in this area, primarily for flood control. Recreation and fish and wildlife enhancement are served by all of these projects. Reservoirs in the incremental drainage basin having a usable storage capacity of 5,000 acre-feet or more are shown in Table 7 and on Plate 2.

3-4. The upstream tributary reservoirs stabilize flows and affect the regulation of the Oahe project by usually reducing the crest flows, providing significant runoff contributing to the crest flows orginates above these projects. In certain instances a reservoir may increase the size of the crest below the project over that which would be observed naturally either by the speed-up of travel time through the length of the reservoir or by delaying a portion of the runoff from a subarea to more nearly coincide with the crest on the main stream. However, with the storage space provided and the several reservoirs in this region that are tributary to the main stem, the possibility of the aggregate effect increasing Missouri River crest flows is very remote.

III-B. Functional Water Resource Development

3-5. Flood Control. In addition to the flood control storage provided in the Oahe project, reservoir storage space allocated to this purpose has been provided in several of the tributary reservoirs located within this region as shown on Table 7. Tributary reservoir flood control storage space in the region totals over 600,000 acre-feet and can be expected to store significant volumes of runoff during large plains snow melt events such as occurred in 1950 and 1952, as well as in other years. However, tributary flood storage accumulated during such an event is usually evacuated quite soon after it is stored. Additionally, there is no assurance that most tributary space in this region will be effective for control of runoff that may tax the space provided in main stem reservoir project. Consequently, the availability of tributary flood control storage space in this region has had little significant effect upon either storage requirements or upon operation procedures of the Oahe project or other main stem reservoirs. There are no local flood protection projects that affect, or are affected by, Oahe operation, except those downstream of the reservoir system, such as Omaha and Kansas City.

3-6. Irrigation. Irrigation is practiced at scattered locations through the incremental drainage area between Garrison and Oahe Dams. Along the Missouri River bottoms below Garrison Dam a number of individual irrigators draw water directly from the river. The major

TABLE 7

RESERVOIRS IN THE INCREMENTAL DRAINAGE BASIN BETWEEN GARRISON DAM AND OAHE DAM (Over 5,000 Acre-Feet Storage Capacity)

Reservoir	Stream	Basin	State	Total Storage (Acre-Feet)	Flood Control Storage (Acre-Feet)	Owner or Operator
Lake Edward Arthur Patterson (Dickinson Dam)	Heart R.	Heart R.	North Dakota	23,600	-	USBR
Lake Tschida (Heart Butte Dam)	Heart R.	Heart R.	North Dakota	219,500	150,500	USBR
Bowman Haley	Grand R.	Grand R.	North Dakota	115,400	59,300	CE
Shadehill	Grand R.	Grand R.	South Dakota	300,000	216,000	USBR
Angostura	Cheyenne R.	Cheyenne R.	South Dakota	90,200	-	USBR
Cold Brook	Cold Brook	Cheyenne R.	South Dakota	6,260	5,750	CE
Cottonwood Spgs.	Cottonwood Spgs.	Cheyenne R.	South Dakota	6,160	5,915	CE
Deerfield	Castle Crk. & Rapid Crk.	Cheyenne R.	South Dakota	15,100	-	USBR
Pactola	Rapid Crk.	Cheyenne R.	South Dakota	98,000	43,000	USBR
Keyhole	Belle Fourche	Belle Fourche R.	Wyoming	330,000	140,000	USBR
Belle Fourche	Owl Creek	Belle Fourche R.	South Dakota	178,400	-	USBR

federally funded irrigation projects existing in the incremental drainage area include the Fort Clark Unit along the Missouri River, the Dickinson and Heart Butte Units along the Heart River, the Belle Fourche project along the Belle Fourche River (tributary to the Cheyenne River), the Rapid Valley project along Rapid Creek (Cheyenne River tributary) and the Angostura unit on the Cheyenne River in southwestern South Dakota. There are also scattered private irrigation developments in the headwaters of the Cheyenne River in northeastern Wyoming. In total, about 130,000 acres are irrigated from surface water supplies in this incremental drainage area. Of this total, 86,000 acres are irrigated at Federally developed irrigation projects. In recent years there has been an increasing development of sprinkler irrigation where ground water supplies are available.

3-7. Oahe Diversion Unit. The Oahe Diversion Unit is under construction by the Bureau of Reclamation. Plans are for irrigation of about 190,000 acres in the initial phase of development, provision of a municipal and industrial water supply in east-central South Dakota, development of fish and wildlife areas totaling about 40,000 acres, and the development of recreation facilities associated with the regulating reservoirs that form a portion of the diversion project. Water will be pumped from Lake Oahe into the 37 mile long Pierre Canal which flows into Blunt Reservoir, located on Medicine Knoll Creek, a minor left bank tributary entering the Missouri River a few miles downstream from Oahe Dam. From Blunt Reservoir water will be transported by gravity across the divide between the Missouri and James River valleys by means of the Highmore and Faulkton Canals to Cresbard Reservoir. From this reservoir canals will lead to irrigated land to the west of the James River. Another pumping plant will divert water from the James River at the James River Diversion Dam, located about 15 miles north of Huron, South Dakota, into Lake Byron for further distribution to irrigated lands to the east of the James River Valley.

3-8. The Oahe pumping plant, with a capacity of over 1,000 cfs is being constructed adjacent to the Oahe power house. The pumps will be connected to the surge tank riser of the seventh generating unit, with power to supply the pumps furnished by the main stem power plants. The diversion project requires 213 miles of major canals and 950 miles of smaller canals and laterals for the delivery of water to individual farmers. The three large reservoirs that will be formed by the project, Blunt, Cresbard and Byron, have respectable storage capacities of 185,000, 30,400 and 62,100 acre-feet. All are located outside of the Garrison-Oahe incremental drainage area.

3-9. 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. No tributary reservoir storage space has been allocated for this purpose. Storage has been provided in the Oahe Reservoir for multiple purposes, including Missouri River navigation; however, storage and releases from the project serve navigation only indirectly, after reregulation by downstream projects. A decription of the Missouri River navigation project is contained in the Master Manual.

3-10. Hydroelectric Power. The Oahe plant, with an installed capacity of 595,000 Kw, is the only hydroelectric power generating facility located in the incremental Missouri River drainage area discussed in this manual. At one time a hydroelectric power plant was operated in connection with the tributary Angostura reservoir project; however, this facility is now inactive. All power generated by Federal facilities in the Missouri Basin is marketed by the Bureau of Reclamation and Oahe 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 Bureau's power marketing and transmission facilities are provided in the Master Manual.

3-11. Municipal and Industrial Water Supply. The Missouri River between Garrison Dam and Oahe Dam is the source of water supply for the municipalities of Riverdale, Washburn, Bismarck and Mandan in North Dakota. Industrial water intakes in this reach of the river include the Standard Oil refinery near Mandan, the Basin Electric and United Power Association coal fired power plant near Stanton, Ottertail Power Company plant at Washburn and the Montana-Dakota Utilities power plant at Mandan. Adequate flows to sustain these facilities result from releases by the upstream Garrison project and in turn are reflected in the inflows to Lake Oahe. There are no major water intakes in the reach of the Missouri River extending from Oahe Dam to the headwaters of the Big Bend Reservoir. The municipalities of Pierre and Fort Pierre, located along this short reach, obtain their water supply by pumping from wells. The Oahe Diversion project, when operational, is expected to provide a municipal and industrial source to communities in east central South Dakota, particularly those located near to the James River in this region.

3-12. The supply of good quality water through western South Dakota is in general very inadequate. Plans are now under consideration to divert water from the Oahe Reservoir to provide a domestic supply for farms and communities in this region. Some plans include the diversion of this water as far as eastern Wyoming to provide a supply for development or slurry pipeline transport of large coal deposits located in the area.

3-13. 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 large portions of 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.

3-14. 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 tributary reservoirs in the basin and of the Oahe Reservoir continues to increase through the years and is a factor to be considered in actual regulation of these projects.

3-15. Streambank Stabilization. Streambank erosion is a continuing process along the Missouri River and also along the tributaries in the region. Sediment inflow to the Oahe Reservoir results almost entirely from this erosion process along streams contained within the incremental drainage area. The Missouri River below Oahe Dam to the headwaters of the Big Bend Reservoir has been fairly well stabilized by means of bank protection and the construction of channel blocks as described in Section II of this manual. Current proposals include further bank protective measures, encompassing nearly all of the readily erodible banks within this relatively short reach of the Missouri River.

III-C. Streamflow Depletions

3-16. General. The major effect of the tributary water resource developments in the incremental drainage between Garrison and Oahe Dams on the regulation of the Oahe 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.

3-17. 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 available water supply was very small and unreliable. Consequently, irrigation development occurred in only scattered areas, principally in the Black Hills Region where a more dependable water supply was available. The first major irrigation project to be developed was the Belle Fourche project that became operational after construction of the Belle Fourche Reservoir in the year 1908. Most other development occurred after 1949. During the years 1910 to 1949 it is estimated that average annual depletions from the Garrison-Oahe incremental drainage area increased by about 20,000 acre-feet. Reflecting the substantial development that occurred after 1949, average annual depletions within this incremental reach increased by 245,000 acre-feet between the years 1949-1970.

3-18. 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 Garrison to Oahe Dams will approximate 1 million acre-feet during the next 50 years. A major future depleting influence in this reach will be the Oahe Diversion Unit.

3-19. By 1970, the average annual depletions for the total drainage area above Oahe Dam, including the areas controlled by Fort Peck Dams, and Garrison had increased by about 2.7 million acre-feet above the 1949 "base level" selected for adjustment of streamflow records in the Missouri Basin. This amounts to about 13 percent of the total 1949 water supply available above Oahe Dam. Streamflow depletion projections made in connection with the Comprehensive Framework Study for the Missouri Basin indicate that by the year 2020 the total area above the Oahe Dam will increase to 10 million acre-feet above the 1949 level. Subsequent depletion estimates have lowered this earlier estimate by 2-3 million acre-feet.

3-20. Depleting Functions. The water resource development function resulting in most depletions in this region is irrigation. For example, the Missouri River Basin Framework Studies indicate that about 56 percent of the increase in average annual depletions in the western Dakota tributary drainage area between 1949 and 1970 can be attributed to water losses resulting directly from irrigation. Land treatment measures, including stock ponds, resulted in a depletion increase amounting to 31 percent of the total. Depletion increases resulting from rural domestic, livestock, mining and municipal and industrial uses together amounts to only 3 percent of the total increase. Of interest is that this expected 3 percent increase in depletions was almost entirely balanced by streamflow accretions due to modified forestry practices in the upper Cheyenne River Basin. An important depleting factor that cannot be assigned to any particular development function is evaporation from large multiple-purpose reservoirs. The 1949-1970 depletion increase in the western Dakota tributary drainage area resulting from large reservoir experation amounted to about 13 percent of the total increase. Average annual evaporation losses occurring from large tributary reservoirs constructed during the 1949-1970 period, together with main stem reservoirs, above Oahe Dam total 1.7 million acre-feet or over 8 percent of the 1949 water supply above this location.

SECTION IV

HISTORY AND DESCRIPTION OF THE OAHE PROJECT

IV-A. Project Development

4-1. General. The Oahe 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. Preparation of a Definite Project Report by the Omaha District was directed by the Chief of Engineers during January 1945, with the report published in February 1946. Construction began in August 1948, with diversion of the Missouri River through the constructed outlet works accomplished in 1958 and completion of the embankment occurring in 1961. Installation of power units followed and by 1966 most major construction was 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 Oahe project as it exists today 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 low dam near the present Oahe damsite, together with another low dam at the upstream Oak Creek site, with such modifications as the Secretary of War and the Chief of Engineers might find advisable. Bureau of Recalamtion plans for Missouri River development, as contained in Senate Document 191, 78th Congress, provided for a high dam near the present Oahe site. The differences between the plans were adjusted in an inter-departmental conference and the coordinated plan, including the Oahe project near its present site, was presented to Congress in Senate Document 247, otherwise known as the "Pick-Sloan Plan."

4-4. The Oahe 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 awarded for the Oahe Project was for the west access highway. Work started in August 1948. The first of the eight earthwork contracts for the construction of the dam embankment was let in May 1950. The final contract on the dam embankment was completed in 1961. The contract for the first of five stages for construction of the outlet works was awarded in 1953. The river was diverted through the outlet works tunnels on 3 August 1958. Earthwork on the spillway was completed in 1958 and the structure was completed in August 1963. Work on the power house and associated structures was started in 1958 and progressed well ahead of schedule. The first of the seven 85,000 KW generating units (Unit No. 1) begain delivery of power on 9 April 1962. The last generating unit (Unit No. 7) started production of power on 27 June 1963. Formal dedication ceremonies were held on 17 August 1962. Contracts consisting of Stage V, construction of roads, parking areas and seeding around powerhouse areas, crest roadway lighting and relocation of 38 miles of Northern Pacific Railroad tract in North Dakota were completed in 1966.

4-6. Relocations. The relocations required for the development of the Oahe Reservoir included portions of two Federal highways, a North Dakota state highway and numerous county and Indian Agency roads that would be inundated by the reservoir. Railroad relocations included the main east-west line and branch lines of the Chicago, Milwaukee, St. Paul and Pacific Railroad as well as branch lines of the Minneapolis, St. Paul and Sault Ste. Marie and the Northern Pacific Railroads. Relocation of many miles of telephone, telegraph and power lines, as well as several cemeteries, were required. Several towns and villages including the Cheyenne Indian Agency, Mobridge, Forest City, Whitlock Crossing, Kenel and Pollock in South Dakota, as well as Fort Yates and Cannonball in North Dakota, required varying degrees of relocation or protection. Several small communities were entirely abandoned. New highway bridges were constructed where US Highways 12 and 212 crossed the Missouri River valley. A new bridge was also constructed for the Missouri River crossing of the Chicago, Milwaukee, St. Paul and Pacific Railroad. Low steel on the bridges crossing Oahe Reservoir is at about elevation 1656 ft msl, providing 36 feet of clearance above the maximum operating pool at elevation 1620 ft msl.

4-7. Real Estate Acquisition. Over 400,000 acres of real estate in fee and 2,417 acres in easement were acquired by purchase and condemnation for the Oahe project in North and South Dakota. In addition, 13,381 acres were transferred by Public Land Order from the Public Domain. The basis for real estate acquisition over most of the reservoir area was a quite taking line of elevation 1620 ft msl, the maximum operating pool. An allowance from the taking line contour was made for possible bank erosion and the blocking out of perimeter ownerships to avoid excessive severances and expensive ground surveys. In the upstream end of the Oahe Reservoir, aggradation and backwater effects were recognized with real estate acquired up to near an elevation 1630 guide taking line. The guide taking line in this reach was based on the profile associated with an inflow of 65,000 cfs, a reservoir level of 1617, 25-year aggradation, and two feet of freeboard for wind effects. Consideration is now being given toward acquiring additional real estate in the Oahe Reservoir headwaters in recognition of reservoir aggradation that has occurred in this region.

4-8. Operational History. Closure of Oahe Dam and the first impoundment of water in the Oahe Reservoir began in July 1958. During the early years, Oahe Reservoir was regulated in conjunction with Fort Peck, Garrison, Fort Randall and Gavins Point Reservoirs to provide control of flood flows and to regulate available flows for production of additional power in the existing main stem hydroelectric plans, navigation and maintenance of sufficient flows for domestic and industrial uses and for water quality purposes. Oahe power generation began in 1962 with the completion of Unit No. 1 in April. Units Nos. 2, 3 and 4 went on the line in July, November and December 1962, respectively, followed by Units Nos. 5, 6 and 7 in 1963. Inactive storage (below elevation 1540 ft msl) was filled in 1962 and the multiple-use carry-over zone was first filled (to elevation 1607.5 ft msl) in 1968. Exclusive flood control storage space (above elevation 1617 ft msl) has been utilized in only one year to date, that occurring in 1975. 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.

IV-B. Description of the Oahe Project

4-9. Location. Oahe Dam is located at river mile 1072.30 (1960 mileage) on the Missouri River in Stanley and Hughes Counties, South Dakota approximately six miles upstream from Pierre, the capital city of South Dakota. Oahe Reservoir extends 231 miles in a northerly direction through central South Dakota and North Dakota. (Oahe Reservoir extends 231 miles in a northerly direction through central South Dakota and North Dakota, terminating near Bismarck, North Dakota.)

4-10. Embankment. The dam consists of rolled earthfill embankment with the outlet works tunnels in the right abutment and the power tunnels in the left abutment. State Highway 514 crosses the Missouri River on top of the dam. The embankment has a total length of 10,000 feet, maximum height of 245 feet and a top elevation of 1660 feet, msl. The total volume of fill in the embankment is approximately 92,000,000 cubic yards. The maximum base width is 3,500 feet and the top width is 60 feet. Plan and cross section of the embankment are shown on Plate 8.

4-11. Embankment freeboard was based on a Oahe Reservoir level of elevation 1644.4 feet msl, the maximum level attained during routing of the spillway design flood. A set-up allowance of 1.8 feet and wave height plus ride-up allowance of 7.3 feet was developed in design studies. An additional safety factor of 6.5 feet resulted in a total freeboard allowance of 15.6 feet, establishing the embankment crest at elevation 1660 feet msl.

4-12. Spillway. The Oahe spillway is a remote spillway located on the right bank of the Missouri River about a mile west of the right abutment of the dam. An unlined approach channel has been excavated in shale to elevation 1590 for a distance of approximately 1,300 feet upstream of the weir. The width of the channel in the weir area is about 472 feet. Upstream of the shale excavation the approach channel widens considerably due to the slope of the natural ground.

4-13. The spillway structure consists of a flat weir with a crest elevation of 1596.5 surmounted by tainter gates, a roadway and service bridge and machinery platforms. A depressed basin and paved apron is provided immediately downstream from the weir. The spillway is controlled by eight tainter gates, each 50 feet long by 23.5 feet high. The gross length of the spillway is 456 feet. The depressed basin extends 101 feet downstream from the weir. It has a bottom elevation of 1590 and steps back up to elevation 1596.5 at the end sill. The paved apron extends 209 feet downstream from the end sill of the basin and varies in width from 456 feet at the end sill to 395 feet at the downstream end. The apron has a constant elevation of 1596.5.

4-14. The provision of a conventional spillway chute and stilling basin has been deferred until the need for such structures has been determined by observation of the rate of erosion of the firm shale when water is being released through the spillway. An unlined discharge channel extends approximately two miles downstream of the spillway structure. The channel slopes from elevation 1596.5 downstream from the apron cutoff wall on a 0.00067 slope. Immediately downstream of the cutoff wall the channel bottom width is 395 feet and then converges to 334 feet wide at a point 341 feet downstream and then remains constant to the end of the channel. The side slopes have a transition from a 1 on 2-1/2 slope immediately downstream of the apron sidewalls to a 1 on 2 feet slope at a point 140 feet downstream. The side slopes in this transition are riprapped. The bottom of the channel has riprap protection for a distance of 240 feet downstream of the apron slab. Plan, profile and section of the spillway structure are shown on Plate 8, while spillway discharge rating curves are on Plate 9.

4-15. The design of the Oahe spillway and the lack of a stilling basin requires a definite spillway gate operating schedule in order that velocities through the unpaved discharge channel and consequent erosion may be reduced. The spillway operating criteria are as follows:

a. Each gate will be opened in turn with the sequence consisting of gates 3, 5, 4, 1, 2, 7, and 8.

b. Maximum changes of gate positions within each opening sequence are as follows:

Initial Position	Change in Position
All gates closed	Open in sequence to 2 feet
All gates 2' open	Open in sequence to 5 feet
All gates 5' open	Open in sequence to 6 feet
All gates 6' open	Open in sequence to 7 feet
All gates 7' open	Open in sequence to 8 feet
All gates 8' open	Open in sequence to 9 feet
All gates 9' open	Open in sequence to 10 feet
All gates 10' open	Open in sequence to 11 feet
All gates 11' open	Open in sequence to 12 feet
All gates 12' open	Open in sequence to wide open

c. Closing of gates will be in the amount and sequence which is the reverse of the opening schedule given in a and b.

4-16. Outlet Works. The outlet works are located on the right bank of the river and consist of an approach channel, six tunnels with intake structures and control shafts, a stilling basin and a discharge channel. Plan and profile of the outlet works are shown on Plate 8. Discharge rating curves of the tunnels are shown on Plate 10.

4-17. The approach channel from the river channel to the outlet works tunnel intake is excavated in the abutment of the dam and is approximately 2,000 feet long. The upstream portion of the channel is straight for a distance of about 1,300 feet and is on two levels. The lower level is at elevation 1425 with a bottom width of 100 feet and side slopes of 1 on 3 on the riverward side and 1 on 2 on the landward side. The upper level of the channel is formed by a berm 60 feet wide at elevation 1455. The remaining length of the approach channel curves toward the intake structure with transition zones on the bottom and side slopes to meet the grade and the 1 on 6 side slopes at the intakes.

4-18. The intakes are individual submerged type reinforced structures located at the upstream end of the tunnels. The structures, with a top elevation of 1530, will be submerged to a depth of 10 feet at the minimum operating pool elevation of 1540. Submergence increases to 90 feet when the reservoir surface rises to the maximum operating pool elevation of 1620. The intake structures are staggered in plan and elevation. The No. 1 structure is set furthermost upstream with the lowest invert elevation (1425). Each succeeding intake is located approximately 70 feet farther downstream with the invert elevation raised in increments of 6 feet. The channel apron extends for a distance of 100 feet immediately upstream of the intakes. The backfill slopes downstream and is covered with dumped riprap between the intake structures.

4-19. Six tunnels have been provided in the outlet works for flood control and regulation purposes. The tunnels are parallel to each other and are spaced 85 feet on centers. The tunnels are bored through the Pierre shale formation, and are concrete lined with finished inside diameters of 19.75 feet upstream of the control shafts and 18.25 feet downstream of the control shafts. The length of the tunnels from the upstream face of the intake to the downstream face of the tunnel outlet portal varies from 3496 feet to 3659 feet. The elevation of the intake invert varies from 1425 to 1455. The elevation of the invert at the portal exits is 1420 feet msl.

4-20. The control shafts for the outlet works tunnels are located near the axis of the dam and house the control and emergency gates and other appurtenant equipment necessary for control of flows in these tunnels. The structures are 85 feet on centers and fully underground except for the gantry deck at elevation 1661 and the downstream walls of the operating rooms exposed on the downstream slope of the embankment. The portion of the control structure below elevation 1620 are isolated units, each consisting of a concrete-lined vertical shaft with an outside diameter of 38 feet and water passage transitions from the circular section of the tunnels to the rectangular section for the gates. The control shafts are transformed from circular to octagonal and from octagonal to square to accommodate the control gate hoists and other operating equipment on the floor at elevation 1648. The isolated structures become continuous above elevation 1645. Inverts of the water passages at the shafts are elevation 1425 for tunnels 1 to 4, inclusive, and elevations 1449 and 1445 for tunnels 5 and 6, respectively. The six control gates include a 13 feet by 22 feet vertical lift cable suspended tractor type gate installed in each of tunnels 1 to 4 inclusive, and a 13 feet by 22 feet hydraulic lift, wheeled-type gate installed in tunnel 5 and in tunnel 6 for fine regulation. One 13 feet by 22 feet vertical lift tractor type emergency gate is provided for use in any of the six tunnels.

4-21. The stilling basin is located downstream of the tunnel portals and consists of training piers, drop sections, retaining walls, weir baffles and end sill. An ogee weir with a crest elevation of 1417.5 feet, msl, divides the stilling basin into a double stage type with a primary basin and a secondary basin. The basin floor slab is eight feet thick with the top of the slab at elevation 1395.5 for the primary basin and sloping from elevation 1393 to 1391 for the secondary basin. Two rows of concrete baffles, 6 feet high, are located in the secondary basin with the tops of the baffles at the same elevation as the end sill. The tops of the primary and secondary retaining walls are at elevation 1442 and 1430 respectively.

4-22. The overall length of the discharge channel is approximately 9,000 feet. The upper reach of the channel was excavated in shale to a bottom elevation of 1,390 feet, msl, and tapers from a width of 500 feet at the stilling basin to 400 feet about 3,000 feet downstream. In the middle reach a pilot channel, about 2,500 feet long was excavated to bottom width of 150 feet. Side slopes of the pilot channel were excavated on a 1 on 3 slope down to a berm about 70 feet wide at the water table at elevation 1430 feet, msl. Below the ground water level the pilot channel sides were excavated on a 1 on 1.5 slope. The remaining reach of the channel consisted largely of sandy material which was eroded by flows through the outlet works after closure of the dam.

4-23. Power Plant and Switchyard. The intake for the power tunnels is located near the left abutment of the dam, a short distance upstream from the toe of the embankment slope at elevation 1520. The seven intake towers, spaced 90 feet on centers, extend 145 feet above the level of the approach area at elevation 1520. A cylinder gate, 10 feet high by 30 feet in diameter provided in each of the intake towers, controls the water passing through eight openings into the 30-foot diameter shafts which connect with the tunnels at the bottom. The invert at the shaft and tunnel intersection is elevation 1390. Bulkhead platforms are provided on the outside of the tower at elevation 1620 for installing bulkheads. Three screw lift hoists and a hoist driving unit are supported on the floor at elevation 1645 (maximum flood pool). The seven intake towers are connected at the top by simple bridge spans to form a continuous gantry crane deck 50 feet wide by 583.5 feet long. This deck is at elevation 1665 or 5 feet above the top of the dam. The access bridge to the intake is an eleven span (simple span) bridge approximately 1,290 feet long and divided into three 70-foot, three 110-foot and five 150-foot spans. The bridge has a 24-foot-wide concrete deck with access to the intake structure at elevation 1664.91.

4-24. The seven power tunnels are located in the left abutment of the dam and extend from the downstream edge of the intake structure to the upstream face of the surge tank base structures. The tunnels are 24 feet inside diameter and curved in plan. The upstream portions of the power tunnels are concrete-lined and extend from the closure monolith at the intake structure to a point near the axis of the dam; varying in length from 945.5 feet for Tunnel No. 1, the riverward tunnel to 1257.5 feet for Tunnel No. 7, the landward tunnel. The downstream portions of the tunnels are steel-lined and extend from the terminus of the concrete-lined sections near the axis of the dam to the downstream edge of the tunnel entry structure, varying in length from 1976.4 feet for Tunnel No. 1 to 2389.8 feet for Tunnel No. 7. Downstream from the steel-lined section each power tunnel consists of a tunnel entry structure 80 feet long, a cut and cover section 96 feet long and the tunnel terminal structure 48 feet long. The cut and cover segment and terminal structure consist of reinforced concrete within which the penstocks are freestanding.

4-25. The seven penstocks have an inside diameter of 24 feet and extend from the end of the embedded steel liners through the cut and cover sections, the terminal structures and the surge tanks bases to connect with the spiral case extensions at the upstream wall of the power house. The total length of each penstock from the embedded liner to the spiral case extension is 294 feet. Two 70-foot diameter surge tanks, 145 feet in height, are provided for each penstock with the bottom of the tank at elevation 1515. Penstocks for Units Nos. 1 to 6, inclusive, each have a pair of 16 foot inside diameter risers connecting to its surge tanks. The two risers for Unit No. 7 were increased to 17 feet in diameter to permit tapping for the Oahe diversion project pumping plant. The surge tank base is 532 feet long and 165 feet wide supported by concrete sidewalls. A bubbler system is provided to prevent a solid ice cover from forming on the water surface in the surge tanks in freezing weather. The surge tanks are insulated by 4-inch-thick cellular glass blocks covered with aluminum siding.

4-26. The powerhouse structure encloses the seven generator bays, an assembly bay, and a control and service bay. Generator bay No. 7 is on the east end and the assembly bay, control bay and service bay on the west end. The powerhouse is located in the left abutment of the dam, oriented so that the flow through the powerhouse is approximately north to south. The overall size of the substructure area for each unit is 97 feet wide by 123 feet long. The assembly bay adjacent to generator bay No. 1 has an assembly area approximately 94 feet by 73 feet. The overall size of the service bay substructure is 40 feet wide by 101 feet long. The generator mezzanine floor is at elevation 1456, the turbine room floor at elevation 1438 and the low point in the draft tubes at elevation 1378. The powerhouse superstructure is of reinforced concrete and structural steel.

4-27. The seven hydraulic turbines are vertical-shaft, single runner Francis type, with welded steel scroll cases and elbow type draft tubes. Each turbine is rated at 128,500 hp at a net head of 185 feet when operating at 100 rpm. Governors are of the insochronous, oil hydraulic conventional type capable of full opening or full closing time of five seconds. The main generators installed in the power plant include seven 85,000 kw, 3 phase, 60 cycle, 13.8 kv, wye-connected, vertical shaft, water-wheel driven synchronous generators, with direct-connected main and field exciters and voltage regulators. The generators have a nameplate rating of 89,474 kva at a .95 power factor. The generators have been designed for 115% of the nameplate rating. Main generator protection includes neutral grounding, surge protective equipment, differential relays, ground detectors, resistance temperature detectors and overspeed protection for each unit.

4-28. The main power transformers consist of a three-phase transformer (No. 1) and three banks of three single-phase transformers (Nos. 2, 3 and 4) located in the transformer vaults on the draft tube deck at elevation 1456. The three-phase transformer has a voltage rating of 13.8-115 kv Grd. wye and a capacity of 103,000 kva. Main transformer banks No. 2, 3 and 4 each contain three single phase transformers and have a voltage rating of 13.8-230 Grd. wye/115 kv. Each of the single-hase transformers has a rated capacity of 68,677 kva.

4-29. The tailrace is 508 feet wide and 114 feet long ascending from elevation 1387 at the draft tube exit on a 1 on 6 slope to elevation 1404. The tailrace is paved with reinforced concrete anchored to the foundation. The east tailrace retaining wall is a semi-gravity type and varies in height from 68 feet at the upstream end to 3 feet at the downstream end. The west tailrace retaining wall is built to elevation 1456, retaining fill for the parking area and access to the powerhouse. It consists of two sections. The deep section adjacent to the powerhouse is a semi-gravity type and the remaining portion a cantilever type structure. The tailrace discharge channel has a width of 508 feet and extends for a distance of 1,200 feet downstream from the downstream end of the tailrace paving.

4-30. The Oahe switchyard is an outdoor type and is located on the right side of the tailrace at elevation 1456. The switchyard is divided into three sections; the autotransformer section, the 115 kv bays and the 230 kv bays. The autotransformer connects the 115 kv section of the switchyard to the 230 kv section through a 100,000 kva autotransformer. A 13.8 kv tertiary winding is provided in the autotransformer which is a source of power for the station service switchgear, for the 13.8 kv power line to the spillway and outlet works and to the power plant intake structure. The 115 kv section contains a generator bay, an autotransformer bay, two line bays and provisions for two future line bays. The 230 kv section contains three generator bays, an autotransformer bay, two sectionalizing bays, six line bays and provision for two future line bays.

4-31. A more detailed description of power facilities, as well as other structures developed at the dam site, is contained in the Oahe Operation and Maintenance Manual. Plan and section of the powerhouse is shown on Plate 8. Power plant tailwater rating curves and power plant characteristic curves are shown on Plates 11 and 12.

4-32. Oahe Reservoir. The reservoir formed by the Oahe Dam bisects southern North Dakota and northern South Dakota. At normal operating levels the lake has a length of 231 miles, a shoreline of 2,250 miles, a surface area of 356,000 acres and a maximum depth of 200 feet. Oahe Reservoir is long and narrow, largely confined to the Missouri River Valley; however, exceptions occur where major tributaries enter within the reservoir. These are known as arms and, proceeding upstream, respectively take their names from the Cheyenne, Moreau, Grand and Cannonball Rivers entering from the west. The reservoir area is shown on Plate 13.

4-33. Allocation of storage in Oahe 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 8. In addition to this allocated space, the reservoir level during the spillway design flood crested at elevation 1644.4, representing a surcharge of about 10.6 million acre-feet of storage above the top of the exclusive flood control storage zone.

TABLE 8

Oahe Reservoir Storage Space Allocations

Storage Designation	Elevation msl From	Elevation msl To	Storage Space Acre-Feet
Exclusive Flood Control	1617	1620	1,100,000
Flood Control & Multiple Use	1607.5	1617	3,200,000
Carry-Over Multiple Use	1540	1607.5	13,700,000
Inactive	1415	1540	5,500,000
Total Storage			23,500,000

NOTE: Storage volumes are based in January 1972 capacity tables. Area-capacity tables for Oahe Reservoir are on Plate 14.

4-34. Boat Ramps and Recreation Facilities. Fluctuating levels have a major effect on recreational use of the reservoir. Numerous public-use areas have been established around the shoreline. A common development of most of these areas is a boat ramp providing access to the lake. Boat ramp elevations are given in Table 9. Boat ramps have also been constructed for access to the Missouri River below the dam. These downstream ramps generally continue operable through the normal range of releases from the Oahe project. While most of these facilities are considered to be a portion of the Oahe project, others have been constructed by private interests or as a part of other Federal, State and private recreational developments.

4-35. Lake Pocasse. Spring Creek, a minor left bank tributary, enters Lake Oahe immediately to the south of the North Dakota-South Dakota boundary near the relcated community of Pollock, South Dakota. In the process of relocating a county highway near the mouth of this stream, a subimpoundment was formed and named Lake Pocasse. An embankment 3,200 feet long, with a maximum height of 40 feet and a crest at elevation 1625 ft,msl, separates Lake Pocasse from the Oahe Reservoir. The total drainage area above Lake Pocasse is 660 square miles, of which only about 300 square miles contributes to surface runoff, with the remainder contributing

TABLE 9

OAHE RESERVOIR BOAT RAMPS

Recreation Area	Ramp Type	Ramp Width	Elevation Top	Elevation Bottom	Date of Constr.
Beaver Creek (Ramp #1)	Concrete Plank	12 ft	1600.0	1585.0	1963
Beaver Creek (Ramp #2)	Poured Concrete	60 ft	1618.0	1598.0	1967
Cow Creek	Poured Concrete	60 ft	1617.33	1590.0	1967
Downstream	Poured Concrete	60 ft	1430.6	1415.0	1964
Forest City	Poured Concrete	60 ft	1617.0	1590.0	1967
Fort Rice	Concrete Plank	24 ft	1620.0	1595.6	1972
Fort Yates	Poured Concrete	30 ft	1618.44	1597.44	1968
Foster Creek	Poured Concrete	30 ft	1617.58	1598.08	1968
Hazelton	Concrete Plank	24 ft	1620.0	1593.0	1972
Indian Creek (Ramp #1)	Poured Concrete	68 ft	1615.0	1597.0	1964
Indian Creek (Ramp #2)	Concrete P ank	12 ft	1600.67	1573.67	1964
Indian Memorial (Stage I)	Poured Concrete	60 ft	1602.0	1575.0	1964
Indian Memorial (Stage II)	Poured Concrete		1617.0	1602.0	1967
Lake Pocasse	Poured Concrete	40 ft	1626.0	1613.0	1963
Little Bend	Concrete Plank	24 ft	1621.0	1597.17	1972
Suttons Bay (Ramp #1)	Poured Concrete	24 ft	1605.0	1579.0	1965
Suttons Bay (Ramp #2)	Poured Concrete	24 ft	1620.0	1600.0	1967
Swan Creek (Ramp #1)	Poured Concrete	24 ft	1598.33	1585.33	1965
Swan Creek (Ramp #2)	Poured Concrete	60 ft	1620.0	1595.0	1967
Tailrace Area Winter Ramp	Concrete Plank	24 ft	1435.5	1419.02	1972
Tailrace Public Use Area(StageI)	Poured Concrete	36 ft	1425.51	1418.0	1964
Tailrace Public Use Area(StageII)	Poured Concrete	40 ft	1430.31	1425.51	1964
West Pollock	Poured Concrete	30 ft	1622.0	1598.0	1968
West Shore PU Area (Stage I)	Concrete Plank	36 ft	1600.0	1570.0	1964
West Shore PU Area (Stage II)	Poured Concrete	41 ft	1617.0	1600.00	1967
Whittock's Bay, East	Concrete Plank	12 ft	1603.0	1573.00	1964
Whittock's Bay, East	Concrete Plank	24 ft	1620.0	1599.84	1972
Whittock's Bay, West	Poured Concrete	60 ft	1621.0	1585.0	1964

to potholes and depressions characteristic of the Missouri River drainage area in this region. A spillway, consisting of nine 6-foot by 8-foot box culverts, with a crest at elevation 1617 ft msl, has been provided through the embankment. Gated conduits with inverts at elevation 1602 and 1609 ft msl have also been provided for management of Lake Pocasse levels. The subimpoundment primarily serves waterfowl management purposes and, by agreement with the Corps of Engineers, is regulated by the Department of Interior's Fish and Wildlife Service. Further information relating to the embankment and subimpoundment is given in the Oahe Project Design Memorandum MO-113, "Campbell County, South Dakota, Road Relocation and Sub-Impoundment."

4-36. Fort Yates Protection. The village of Fort Yates, North Dakota, is located on the west bank of Lake Oahe about 10 miles to the north of the North Dakota - South Dakota boundary. Included within the village are the headquarters of the Standing Rock Indian Agency. As an alternative to relocation of this village, a levee was constructed to protect the village from high Oahe levels. This levee has a crest at elevation 1630 ft msl, 10 feet above the Oahe maximum operating pool, but almost 15 feet below the maximum level resulting from routing of the spillway design flood. If an extreme flood were to occur, this levee could be overtopped; however, the chances of such a flood occurring are very remote. Protected areas within Fort Yates lie as low as elevation 1619 ft msl and are drained by gravity into Oahe Reservoir. Ponding of interior runoff will occur in those rare occasions when the Oahe Reservoir is above this level.

4-37. Leasing of Project Lands. As indicated previously, essentially all land surrounding the Oahe Reservoir below elevation 1620 ft msl has been acquired (or protected) for project purposes. With the reservoir at normal operating levels, inundation of lands above elevation 1617 ft msl will usually not occur and, following years of subnormal water supply with decreasing Oahe levels, the probable maximum reservoir level during the following year will be correspondingly lowered. 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. All such leases are subject to 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.

4-38. Reservoir Aggradation and Backwater. Major sediment deposition has occurred and will continue to occur in deltas at the head of the Oahe Reservoir and in the tributary arms of the Cannonball, Grand, Moreau, and Cheyenne Rivers. Smaller deltas can also be expected to develop where other streams enter the reservoir. The location and growth of individual delta formations will be dependent upon the sediment inflow of each contributing stream and corresponding pool elevations. Redistribution and consolidation of the delta deposits will occur whenever the reservoir is drawn down for significant periods of time. The long term sediment depletion rate for the Oahe Reservoir has been estimated at 32,300 acre-feet per year. Proportionately, the Cheyenne River drainage is expected to contribute about 40 percent of this total; the Moreau, Grand and Cannonball River drainages about 20 percent; the main stem drainage above Lake Oahe, including the Heart River, another 20 percent; and all other tributary drainages the remaining 20 percent. As previously discussed, the effects of aggradation and backwater at the head of Lake Oahe are expected to require acquisition of additional real estate in the vicinity of Bismarck, North Dakota.

4-39. Tailwater Degradation. Due to construction of dikes and channel blocks in the Missouri River channel below Oahe Dam, and to the downstream Big Bend project, there has been no significant change in the tailwater rating curve below the Oahe power plant. This is evidenced by the curves shown on Plate 11.

SECTION V

ORGANIZATION FOR RESERVOIR REGULATION

5-1. Normal Regulation. The Oahe 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 for release from the Oahe 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 Oahe 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. Oahe 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 as 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. They also collect data pertinent to Oahe regulation and are responsible for analysis of runoff events, particularly over tributary drainage areas. The District is responsible for flood fighting activities, for regulation of Corps of Engineer tributary reservoirs located in the incremental drainage area, and for flood control regulation of the USBR reservoir projects located in the incremental drainage area. Information available to the Omaha District considered pertinent to regulation of the Oahe Project or other main stem reservoirs is immediately furnished the Reservoir Control Center.

5-5. Emergency Regulation. If emergency conditions develop at the Oahe 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 effects by all offices concerned, and be directed by the Reservoir Control Center.

5-6. Loss of communication between the Reservoir Control Center and Oahe 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 Oahe 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 Oahe Reservoir.

6-2. Oahe Project Data. Daily reports from the Oahe project to the Reservoir Control Center and to the Omaha District include hourly releases and pool elevations, as well as 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 records 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 Oahe power plant.

6-3. Throughout the year project personnel investigate requests and complaints that occur as a result of Oahe 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. Project personnel are also responsible for informing downstream interests of any major change in the general level of release rates that may be scheduled.

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 15 presents locations of key 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 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 15. 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 16 indicates key 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. During those periods when significant inflows are occurring to tributary reservoirs or when flood storage is accumulated or being evacuated from these projects, daily reports of elevation and releases are furnished the Reservoir Control Center from the tributary reservoirs located in the Garrison-Oahe incremental drainage area and listed in Table 7.

SECTION VII

ANALYSES PERTINENT TO REGULATION OF OAHE RESERVOIR

7-1. General. Regulation of the Oahe 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 are analyses, forecasts, and studies which, while important for the regulation of the Oahe 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 Oahe 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 to regulation of the Oahe project are forecasts prepared for southwestern North Dakota and western portions of South Dakota. Of particular importance in scheduling Oahe releases are forecasts of meteorologic conditions that precede or indicate substantial flows on the Bad River tributary entering the Missouri River immediately below the Oahe Dam.

7-3. Precipitation-Runoff Relationships. Infiltration of rainfall over the Missouri River basin between Garrison Dam and Pierre, South Dakota, ranges from 0.50 to 1.00 inch for the intial 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 runoff is not very exact. 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 many 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 Oahe 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 Oahe 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 Garrison to Oahe 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 Garrison and Oahe 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 Garrison and Oahe Dams is prepared by the Reservoir Control Center, with the forecast period extending from the time the forecast is made through the succeeding March. Since precipitation forecasts through such an extended period 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 primarily 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 Oahe inflows for periods of up to a week beyond the current date consists of combining anticipated daily releases from the upstream Garrison project with anticipated daily flows from each of the major tributaries contributing to this reach of the Missouri River together with an allowance for local runoff. During significant flood events each tributary stream should be individually considered; however, most of the time the runoff originating between Garrison Dam and Oahe Dam can be considered in total, with forecasts largely 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.

7-10. Stage-discharge relationships are maintained in the Reservoir Control Center for all important streamflow stations in the Garrison-Oahe incremental drainage area. These are kept current on the basis of discharge measurements made by the United States Geological Survey. Plate 17 indicates the present relationships at locations that are most important for developing short range inflow forecasts pertinent to Oahe regulation.

7-11. Flow Forecasts at Downstream Locations. Flows through the reach from Oahe Dam to the headwaters of Big Bend Reservoir usually consist only of Oahe releases. An exception is when significant runoff occurs from the Bad River drainage area. Since the Bad River enters the Missouri immediately below the Oahe Dam, forecasts of flows at the mouth of the Bad River consist of totaling forecast flows of this stream at the Fort Pierre gaging station and anticipating Oahe releases. Bad River flow forecasts are made by noting flows at the Fort Pierre and Midland gaging stations, together with incremental flows originating between these locations, translating Midland flows to Fort Pierre by a travel time of one day and the extrapolation of future Midland and incremental drainage area flows. Extrapolation should be based on hydrologic conditions occurring or anticipated in the Bad River Basin.

7-12. Downstream Stage Forecasts. The only time when forecasts of stages in the open water reach of the Missouri River below Oahe Dam at Pierre, South Dakota, will be required for regulation purposes is when releases in excess of the Oahe power plant may be required. Such releases have not been made in operations to date. Pierre stage forecasts should be made on the basis of anticipated Oahe releases and the Pierre rating curve shown on Plate 7. Since the rating curve has not been confirmed by releases in excess of power plant capacity, appropriate adjustments to the curve, based on experienced stages will be required for valid forecasts.

7-13. Routing Procedures. For purposes of anticipating inflows to Oahe 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 seorage capacity of Oahe Reservoir and associated regulation procedures do not require precise definition of anticipated inflows. The lack of streamflow information from a considerable portion of the incremental Garrison-Oahe drainage area also precludes such precision.

7-14. Routing procedures are also utilized to translate the effects of upstream reservoirs to the Oahe damsite in order that the total reservoir effects at this location may be determined. These procedures are based on travel time to the Oahe damsite which would be appropriate prior to the development of either tributary or main stem reservoirs. A simple lag-average routing method is used with coefficients as given in Table 10 below.

TABLE 10

Lag-Average Routing Coefficients,
Upstream Reservoir to Oahe Dam

Reservoir	Average Days	Lag Days
Garrison	3	4
Heart Butte	3	5
Shadehill	3	4
Keyhole	3	5
Pactola	2	4
Angostura	2	4
Oahe Inflow	1	4

Notes: 1. Data averaged is at the mean daily rate.
2. Lag given is the number of days from the last day of mean daily values averaged.

7-15. Oahe Reservoir Evaporation Estimates. Due to the large surface area, evaporation is an important component of the overall water budget of Oahe. 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 common 0.7 factor to adjacent pan evaporation, this is not considered reliable for Oahe, 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 Lake Oahe varies from as little as 0.13 during periods when lake surface temperatures are less than air temperatures to as high as 3.42 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. This report also recommends procedures for the adjustment of observed Oahe pan evaporation to representative pan evaporation and adjustment of initial estimates at the time of detailed analyses of the effects of the project upon streamflow.

7-16. In addition to evaporation, development of the effects of Oahe upon streamflow must consider 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 entirely impractical. 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 10% would have appeared as direct runoff from the former ground surface now inundated by the reservoir).

7-17. Wind Effects on Water Surface Elevations. The general orientation of the Oahe Reservoir is to the north 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 18 is a wind correction table for the pool level recorder at the dam. An annemometer is located adjacent to 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 annemometer.

7-18. Daily Inflow Estimates. Estimates of inflow to the Oahe 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. Garrison releases and gaged tributary flows are routed to the Oahe 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.

7-19. Unregulated Flows. Construction of Oahe 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 Oahe 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 diversions to the Garrison Diversion Irrigation Project and Oahe Storage changes. Details of the required analyses are contained in the RCC Technical Study S-73 and, rather than repeating in this manual, reference is made to that publication.

7-20. In addition to unregulated flows, development of flows at the 1949 level of basin development (prior to construction of Oahe Dam and other water resource development in the Missouri Basin) represents a continuing effort of the Reservoir Control Center. Oahe Dam represents a location where an analysis of such development is made. Reference is made to Section VIII of the Master Manual for further details of these analyses.

7-21. Evaluation of Regulation Effects. In the evaluation of the effects of regulation upon downstream flows, and consequent flood damage reduction estimates, the Oahe 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 six-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 OAHE RESERVOIR

8-1. General. Aspects of multi-purpose regulation that are pertinent to the Missouri River main stem 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 thoroughly in the Master Manual and will not be repeated in this, the Oahe 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 Oahe project for the functions of irrigation, navigation, water supply, power, fish and wildlife, water quality and recreation. Regulation of the Oahe 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 Oahe Reservoir, or that zone lying below elevation 1540 ft msl, is to remain permanently filled with water. This insures maintenance of a minimum power head, a minimum level for the future design of irrigation diverson and water supply facilities, and a minimum pool for recreation, fish and wildlife purposes. The top storage zones in the lake, extending above elevation 1617 ft msl, are provided only for the handling of the largest floods and to insure safety of the project structures. These upper storage zones are reserved exclusively for this purpose. Storage space intermediate to these zones, extending from 1540 to 1617 ft msl, provides for the multiple-purposes 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 Oahe project:

a. Regulation of Oahe as an individual project must be subordinate to regulation of the entire main stem system as a whole.

b. Flood control will be provided for by evacuating the storage space in the reservoir above elevation 1607.5 ft msl to the degree practicable prior to March of each year.

c. At all times when an adequate reserve of vacant flood control storage space is available, releases will be such as not to contribute to significant flooding along the Missouri River below Oahe Dam in the vicinity of Pierre and Fort Pierre, South Dakota.

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

e. By adjustment of 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.

f. Releases from the reservoir system to support Missouri River navigation will be backed up by releases from the Oahe project as appropriate to maintain storage reserves in downstream reservoirs at normal seasonal levels.

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

8-4. Flood Control. Regulation of the Oahe 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. Similarly, water storage for flood control purposes is generally compatible with multiple-use regulation of the project.

8-5. Irrigation. When the Oahe Diversion Project becomes operable, large quantities of water will be pumped from the Oahe project by the Oahe pumping plant for irrigation and other uses in the James River Valley in east-central South Dakota, as described in Section III of this manual. These withdrawals will be controlled entirely by the Bureau of Reclamation. Corps of Engineer regulation responsibilities in this connection will be limited to noting daily withdrawals and utilizing these in the development of reservoir inflows and in deriving estimates of the actual available water supply. If other irrigation withdrawals directly from the Oahe Reservoir should develop, similar regulation responsibilities are anticipated.

8-6. Currently there are no significant irrigation withdrawals from the Missouri River along the reach immediately below Oahe Dam which require maintenance of minimum flows. Even if such withdrawals should develop, outflows to supply them should not be required, provided the downstream Big Bend Reservoir is at normal operating levels. When these normal levels occur, the upstream limits of the Big Bend project extend to the Oahe tailwater vicinity.

8-7. Water Supply and Quality Control. Extension of the upstream limits of Big Bend Reservoir into the Oahe tailwater area precludes the necessity of making Oahe releases for water supply purposes. However, an extended period of limited releases from Oahe can result in water quality problems in the headwaters region of Big Bend due to inadequate sewage treatment in the populated Pierre and Fort Pierre area. Oahe outflows will dilute this poor quality water and move it downstream into Lake Sharpe. Fort Pierre sewer outfalls are into the Bad River and fluctuating Oahe releases often have the effect of creating reverse flows near the mouth of this tributary stream. This can lead to water quality and corresponding odor problems with inadequately treated sewage from the community.

8-8. It appears that in future years Oahe Reservoir will become a source of domestic water supply for large regions of western South Dakota and consideration is also being given to the transport of Oahe water as far as eastern Wyoming for coal development in that region. In order to obtain an assured water supply withdrawal facilities must be designed to be operable with Oahe levels through the entire range of variations that may occur with elevation 1540, the minimum level, a basis for design. As a consequence, it would not now appear that this coal development will affect regulation beyond consideration of its minor depleting effect upon the available water supply.

8-9. Navigation. All Oahe releases are reregulated by downstream main stem reservoirs prior to serving the system's navigation function. Consequently, the regulation of Oahe Reservoir for this function consists primarily of backing up the downstream projects' navigation releases. This is not necessarily a day-by-day regulation consideration, due to storage normally available for this purpose in the downstream projects. Rather, it is usually a matter of scheduling Oahe releases to maintain downstream reservoirs in a range of desired seasonal levels, while recognizing that downstream project releases are required to sustain the navigation function of the reservoir system.

8-10. Power Production. Hydroelectric power generated by the Oahe 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 from the Oahe project are made through the power plant. Since the Oahe power plant came on the line in 1962, there have been no significant Oahe releases other than through the power plant. A supplementary release is occasionally required for test and maintenance purposes during normal operation; however, such outflows represent only a very minute fraction of total releases. During the large runoff year of 1975, when flood season runoff above Oahe Dam was the greatest in the available record period extending back to 1898, Oahe releases at or very near to the power plant capacity were made for a four and one-half month period. Any power unit failure during this period would have required supplemental releases, as would have additional inflows to Oahe. These additional inflows could have resulted either from modifications in upstream project regulation or from basin runoff in excess of that actually occurring.

8-11. While hourly loadings of the Oahe power plant are scheduled by the Bureau of Reclamation's 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 at times when demand is light up to the full power plant capacity, exceeding 50,000 cfs, during the heavy load hours. Further discussion on power scheduling is presented in the Master Manual.

8-12. A seasonal variation in the general level of power releases from the Oahe Reservoir usually occurs, 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 are normally backed up by correspondingly large releases from the Fort Randall, Big Bend and Oahe projects since relatively little inflow usually originates from the Oahe-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.

8-13. 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. With the limited system storage capacity downstream from the Oahe project, reductions in system releases also will usually require a reduction in the average level of Oahe releases. However, Oahe winter power releases are increased above essentially the run-of-the-river flows by a pre-winter drawdown in the level of the downstream Fort Randall Reservoir. During the winter season Oahe power releases are then maintained at a higher level by the process of transferring about one-million acre-feet of storage from Oahe into Fort Randall Reservoir. During those years, system storage reserves have been seriously depleted as a result of extended sub-normal water supplies. a greater amount of storage transfer is contemplated by the process of increased pre-winter drawdown of the downstream Fort Randall Reservoir. Similar regulation of Oahe, coordinated with upstream Garrison and Fort Peck releases, also significantly increases the amount of winter energy generation. During the four-month winter period, Garrison releases normally can be expected to be at least one million acre-feet more than Oahe releases. Recapture of these upstream releases results in a rise of up to five feet or more in the Oahe elevation during the winter months.

8-14. Fish and Wildlife. Regulation of Oahe 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. The provision of such conditions at Oahe is not possible on a continuing annual basis; however, in some years runoff events are such that fish spawning can be enhanced for some species with little adverse effect upon other project functions. Since prolonged inundation destroys terrestial vegetation, it can only be reestablished by lowering and maintaining the level of Lake Oahe below the vegetative zone for an extended length of time during the growing season. The growing season coincides with and extends beyond the March-July flood season; therefore, maintenance of lowered Oahe levels to establish vegetation becomes practical when flood season runoff originating above Garrison Dam is also less than normal.

8-15. Inundation of vegetation established around the edge of Oahe Reservoir during the March-April spawning period is more feasible than on the shores of the upstream main stem reservoir projects. The normal recapture of Garrison power releases during the winter months will often raise the level of Oahe up to the vegetated shore line while substantial amounts of runoff from the Garrison-Oahe incremental drainage area during the plains area snow melt period can assure inundation of an established vegetative cover. While the opportunities to enhance reproduction of the March-April spawning species can often occur, the chances of continuing an increase in the level of the Oahe Reservoir into June and July, thereby enhancing reproduction of late-spawning species, are more remote. However, the possibility of this type of regulation during future years when runoff conditions are appropriate, should be recognized.

8-16. Recreation. Water based recreation upon the Oahe Reservoir is dependent on the constructed access facilities. Boat ramps constructed around the perimeter of the project have top elevations extending from 1615 to 1621 ft msl and bottom elevations from 1570 to 1598 ft msl, 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, Oahe levels should be scheduled to provide continued access to the reservoir area for recreational use. Boating and fishing on the Missouri River below Oahe Dam is also a popular recreational activity during the summer months. Hourly Oahe 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 at the highest. However, reduced daily power demands usually are experienced during weekends, particularly on Sundays, and as a consequence it may be necessary to schedule minimum Oahe releases during weekend daylight hours to satisfy the weekend recreation and fishing demand in the tailwater area. Since access to the tailwaters is not a problem in that the normal flat pool of the Big Bend Reservoir extends into the area, the minimum releases are primarily a fish attraction measure.

8-17. Release Scheduling. As discussed in the Master Manual, scheduling of releases from the Oahe 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, perhaps resulting in modifications of the current and projected Oahe release level, is increased when previously unanticipated inflows occur that may have a substantial effect upon system regulation. An example of these studies is included in the Annual Operating Plan, published each year as described in the Master Manual.

8-18. Reservoir regulation orders, furnished by the Reservoir Control Center to operating personnel at the Oahe 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 Oahe release rates from those specified in the order are frequently quite high since Oahe and the downstream Big Bend power plants are often designated as the "swing" plants, designated to meet the fluctuations in actual system load from that anticipated when release schedules are established. Due to the limited fluctuations allowed in the level of the downstream Big Bend Reservoir, releases scheduled from both the Oahe and Big Bend projects, as well as "swings" or variations in actual releases from scheduled releases are normally very similar. Hourly patterning of the Oahe mean daily release rate within limits prescribed by the Reservoir Control Center is accomplished by the Bureau of Reclamation scheduling of daily power production.

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

SECTION IX

FLOOD CONTROL REGULATION OF OAHE RESERVOIR

9-1. Objectives of Flood Control Regulation. The flood control regulation objectives of the Oahe Reservoir are: (1) to coordinate regulation of Oahe with the regulation of the other main stem reservoirs on the Missouri River to prevent runoff from the drainage basin above Oahe 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 Oahe Dam to Big Bend. 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 Oahe project and to discuss regulation geared to reduce flooding along the Missouri River immediately below Oahe Dam.

9-2. Method of Flood Control Regulation. In general, the developed method of regulation of the Oahe 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 appropriate project design magnitude.

9-3. Storage Space Available for Flood Control Regulation. During any specific flood event all available space in the Oahe 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 Oahe Reservoir totals 4.3 million acre-feet. Of this, 1.1 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 allowed 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 Oahe Reservoir to insure the safety of the Oahe project during extreme floods. Utilization of this storage however, will usually provide some downstream flood reductions during these extreme flood events. Carryover multiple use storage space in Oahe, when evacuated, will also serve the flood control function although deliberate evacuation of this space to serve flood control will not be scheduled.

9-4. As discussed in the Master Manual, replacement flood control storage space has been provided in certain upstream tributary reservoirs. There is reasonably firm assurance that in years of large runoff from the total drainage area above Oahe Dam (including the drainage area above Fort Peck and Garrison Dams) that the replacement storage in these tributary reservoirs will be utilized for the control of main stem floods. Due to the relative ease of transferring storage between the main stem projects, including Fort Peck-to-Garrison-to-Oahe, or vice versa, the availability of existing tributary replacement storage space allows regulation of the Oahe Reservoir and other upstream main stem reservoirs at higher levels than would be possible with a strict adherence to specified flood control storage allocations. Essentially, tributary replacement storage space is utilized to replace a corresponding amount of the annual flood control and multiple-use space in the main stem system, including such space in Oahe Reservoir. In practice, this means that annual flood control and multiple use storage space within the system equivalent to the upstream replacement storage space need not be evacuated prior to the March-July flood season. Usually the allowable excess main stem storage will be within either the Fort Peck or Garrison projects, although on occasion, particularly with an abnormal distribution of winter inflows, water equivalent to at least a portion of the tributary replacement space may be stored in the annual flood control and multiple-use space assigned to the Oahe project.

9-5. As discussed in the Master Manual and in manuals for main stem projects upstream from Oahe, storage space in tributary reservoirs that do not have assigned replacement space can also be utilized to reduce the evacuation of main stem annual flood control and multiple use space, provided there is reasonable assurance that flood season fill of this tributary space will occur at the time main stem storage reserves may be taxed. Due to runoff characteristics of the drainage area between Garrison and Oahe Dams, there can be no assurance that a significant amount of flood season runoff will be stored in tributary reservoirs within this incremental area. Therefore, conditions in the Garrison-Oahe tributary projects are seldom a factor in annual scheduling of main stem reservoir releases for flood control purposes.

9-6. Flow Regulation Devices. Releases from the Oahe 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 return from the project. The discharge capacity of the Oahe power plant ranges up to 57,500 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. Due to the probable erosion in the unlined spillway discharge channel resulting from spillway discharges, releases from the Oahe spillway should be scheduled only when considered absolutely necessary for regulation purposes. In addition, operation of spillway gates, if required, must be in accordance with schedules designed to reduce discharge channel erosion. The spillway gate operating schedule is given in Section IV of this manual.

9-7. General Plan of Flood Regulation. Flood control regulation of the Oahe Reservoir to meet the stated objectives is based on consideration of the following factors:

a. Coordination of flood control regulation of Oahe 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 Oahe Dam.

c. Observed and anticipated flows of the tributary Bad River enering the Missouri River immediately downstream from Oahe Dam.

d. Observed and anticipated inflows to Oahe.

e. Space currently available within the Oahe Reservoir for storage of future inflows.

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

9-8. The general plan of regulation applicable to most of the main stem reservoirs, including Oahe Reservoir, 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 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. This deliberate storage for future multiple use also serves the flood control function. Following the time that an adequate supply of multiple-use storage is reasonably assured, releases in excess of current multiple-use requirements are made as a storage evacuation measure when they are not anticipated to contribute to significant downstream flooding.

9-9. Local Flood Control Constraints. The short reach of the Missouri River between Oahe Dam and Big Bend Reservoir contains the municipalities of Pierre and Fort Pierre, South Dakota. The Bad River is the only significant tributary entering in this reach and high water problems in Fort Pierre are usually adjacent to the Bad River channel and associated with large flows on this stream. Analysis has indicated that Oahe releases within the Oahe power plant capacity have little effect upon Bad River stages in the lower reaches of the tributary. Problems resulting from ice formation in the short reach of the Missouri River extending from Oahe Dam past Pierre and Fort

Pierre have never been experienced. Open water Missouri River stages at Pierre with releases at full power plant capacity are well below the damage level. Additionally, Pierre flows equivalent to full Oahe power plant releases plus the maximum Bad River flow of record (about 100,000 cfs) can be exceeded to result in Pierre stages well below the established flood stage. Consequently, there appear to be no flood control constraints in the area immediately downstream from Oahe Dam that would inhibit Oahe releases up to the full power plant capacity, provided the downstream Big Bend Reservoir was at or below its normal operating level of elevation 1420 ft msl. Backwater effects from a high level of Big Bend Reservoir, combined with large flood flows from the Bad River could require some restriction in Oahe power plant releases; however, resultant actual increased damages resulting from full power plant releases to the Missouri River water front areas of Pierre and Fort Pierre even under these conditions would be minimal. The major purpose of Oahe power plant release reductions during periods of large Bad River flows would be to minimize unfounded criticism toward regulation of the project or to assist Big Bend and other downstream projects in achieving optimum flood control regulation.

9-10. Oahe releases in excess of power plant capacity could be expected to result in damages along the Pierre and Fort Pierre water fronts, dependent upon the level of releases sustained. However, such releases will seldom occur and, if necessary, will practically always represent releases made in response to overall reservoir system regulation requirements to which local constraints must be subordinated.

9-11. Coordinated System Flood Control Regulation. The main stem system of reservoirs, of which Oahe 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 Oahe project to accomplish this objective is based on studies performed by the Reservoir Control Center. The longer range studies extend from the current date through the succeeding months up to a 1 March date when the start of the following flood season occurs. All factors listed in paragraph 9-7 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 oen 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 Oahe Reservoir will usually be operated at an elevation of 1617 ft msl or less. However, occasionally flood inflows will be of such magnitude that encroachment into the exclusive flood control zone above elevation 1617 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 Garrison Reservoir and is expected to remain available, an obvious action is to reduce Garrison 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.

9-13. At times encroachment into the Oahe exclusive flood control space will occur or will be anticipated when ample annual flood control storage space remains vacant in the downstream Fort Randall project. When this occurs Oahe releases will normally be maintained at full power plant capacity in an effort to transfer the excess storage downstream, while at the same time developing the maximum practical revenue for the government. Flood control storage space within the main stem reservoir system downstream from Oahe is relatively limited; therefore, Oahe releases at the maximum power plant rate for an extended time must also be accompanied by above normal release rates from the reservoir system. Unless unprecedented inflows occur from the drainage area between the Garrison and Oahe Dams, Oahe releases in excess ov the power plant capacity of 57,500 cfs will not be scheduled, except during a deliberate coordinated process of storage evacuation from the main stem reservoir system as a whole.

9-14. Encroachment into the surcharge storage zone of the Oahe Reservoir and use of the Oahe spillway should be avoided by increasing releases to the extent possible without contributing to substantial downstream flood damages. If releases in excess of the power plant capacity appears necessary, they should be made through the outlet works tunnels, with spillway releases a last resort in order to prevent extensive erosion through the unlined spillway discharge channels. If unusually large amounts of runoff should originate from the Garrison-Oahe drainage area, the mergency regulation curves given in Exhibit A will serve as a guide for Oahe regulation, with discharges limited to the combined capacity of the outlet works and power units as long as the level of the reservoir is at elevation 1621 or below.

9-15. Surcharge Regulation Techniques. During exceptionally large flood inflows, all available flood control storage space may be utilized and the Oahe Reservoir may rise into the surcharge zone above elevation 1620 ft msl. Since the primary reason for providing surcharge space is to insure the safety of Oahe Dam and also since real estate surrounding the lake has in general not been acquired above elevation 1620 ft msl, significant 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 and reservoir levels exceed elevation 1620, 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. A T_s value of 5 days was used in curve development.

9-16. 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 Oahe and the other main stem reservoirs. Instructions to assure continuation of Oahe 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.

9-17. Emergency Regulation. Rapid communication is usually available between the Reservoir Control Center and operating personnel of the Oahe 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 Oahe 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.

9-18. Emergency regulation curves included with Exhibit A were developed by the method described in EM 1110-2-3600. A T_s value of five days was selected in curve development with this value based on experienced incremental inflow hydrographs as well as the Oahe inflow hydrographs of maximum possible floods developed during spillway design studies. The developed emergency procedures recognize the large discharge capacity of the Oahe power plant, the large amount of discharge channel erosion that would probably result from spillway releases, the great amount of surcharge storage space that has been provided in the reservoir and the channel capacity along the Missouri River below Oahe Dam and below the main stem system.

9-10. Oahe releases under emergency conditions are related to inflows, subject to the following:

a. Releases in excess of full power plant capacity will not be scheduled until the level of the Oahe Reservoir exceeds the base of exclusive flood control storage space, elevation 1617 ft msl.

b. With the level of the reservoir in the exclusive flood control range, elevations 1617 to 1620 ft msl, releases will be restricted to the capacity of power plant plus outlet works, with no releases over the spillway.

c. With the level of the reservoir between elevations 1620 and 1621 ft msl, the spillway gates will not be opened for release purposes and releases in the range between full power plant capacity and full power plant plus outlet capacity will be made through these latter structures to prevent or minimize any further rise in the lake level, irrespective of inflows that are occurring. Releases in excess of power plant capacity will also be made through the outlet tunnel as necessary to lower Oahe Reservoir to elevation 1620 in a reasonable period of time. With the spillway gates closed through this range of elevations, small flows over the top of the gates will occur; however, this should result only in minor erosion along the spillway discharge channel.

d. The discharge capacity of the outlet works plus power plant is about 170,000 cfs. With Oahe releases of this magnitude, resultant flood damages can be expected downstream, particularly along the Missouri River below the main stem reservoir system. Therefore, with an Oahe elevation between 1621 and 1625 releases at the 170,000 cfs rate are planned. Some balance between damages experienced in the reservoir area and those occurring downstream should result. In this range spillway gates should be opened only to the extent necessary to prevent over-topping, with the remainder of the flow through the power plant and outlet works.

e. As the Oahe level exceeds elevation 1625, it will be necessary to open wpillway gates and increase outflows to insure safety of the structure and also to prevent, insofar as practicable, overtopping of protective works constructed in the reservoir area. Developed procedures specify the full opening of spillway gates together with full power plant releases. However, outlet gates may be closed to minimize downstream damages.

SECTION X

EXAMPLES OF OAHE REGULATION

X-A. Historical Regulation

10-1. Oahe Reservoir Storage Accumulation. Closure of Oahe Dam was made in August 1958, beginning the accumulation of storage in the reservoir. Initially the project was regulated for flood control and for recapture of winter power releases from the upstream Garrison project while maintaining outflows that, with re-regulation provided by downstream main stem projects, would serve navigation on the lower Missouri River. It was not until 1962 that sufficient water was stored to fill the minimum pool and allow generation from the first power unit coming on line at that time. Less than normal runoff originating above Oahe Dam during 1963 and 1964, together with the requirements for filling upstream reservoir storage space, resulted in no further progress toward initial fill in those years. Well above normal runoff in 1965 and 1967 accelerated the initial fill of the Oahe Reservoir and in January 1968 the carryover multiple-use zone provided in the project was first filled. Since that time, through 1976, near normal to well above normal annual runoff has been experienced from the total drainage area above Oahe, resulting in reservoir levels generally in the normal operating range. Exclusive flood control storage space provided in Oahe has been used only during the maximum-of-record flood season runoff occurring from the upstream contributing area in 1975. At the time the reservoir level rose less than one foot into the exclusive flood control storage zone, leaving over two feet of space for the control of additional inflow, should it have occurred. Plates 19 and 20 show the levels of the Oahe Reservoir since initial fill of the minimum pool (elevation 1540 ft msl) occurred in 1962.

10-2. Plates 19 and 20 also illustrate the past annual variation in reservoir levels. A minimum level usually occurs in late fall at the close of the Missouri River navigation season. Throughout the winter months the recapture of power releases from upstream main stem projects result in a generally rising reservoir level to near the base of the annual flood control storage zone by early March in those years when system storage reserves are filled. Additional increases in Oahe levels after late March are largely dependent upon the magnitude and timing of flood season runoff from the contributing drainage area. The annual maximum reservoir level usually occurs prior to June, after which time levels gradually decline throughout the remainder of the Missouri River navigation season.

10-3. Oahe Releases. Experienced mean monthly releases from the Oahe project are also shown on Plates 19 and 20. A typical pattern of higher releases during the Missouri River naivgation season than during the winter months is evident, as is a great variability in monthly releases, particularly during the 1969-1976 period when an above- normal water supply generally prevailed. Releases in excess of 57,500 cfs, the approximate power plant capacity, have not been necessary even during 1975 when the flood season runoff above the Oahe Dam was the largest experienced since records began in 1898. Mean daily releases ranging from zero to near the full power plant capacity occur at times. Hourly fluctuations in release between those extremes are very common.

10-4. Regulation Effects. The historical effects of regulation provided by the Oahe Reservoir combined with regulation of upstream reservoir projects upon mean monthly flows at the Oahe damsite are also illustrated on Plates 19 and 20. Mean monthly unregulated flows shown on these plates are the computed estimates of flows at the damsite if none of the upstream projects, including Oahe, had been in operation. Mean daily maximum and minimum flows for each year of the 1956-1976 period for regulated (observed) and unregulated conditions are given in Table 11. 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 Oahe damsite. Minimum regulated flows are usually less also than would have been experienced without upstream regulation; however, this results because the Big Bend Reservoir headwater extends to the Oahe tailwater region and reflects the corresponding lack of a minimum Oahe mean daily release requirement. Further discussion of the regulation provided at the Oahe damsite during particular years is contained in succeeding paragraphs and in the discussion of system regulation given in the Master Manual.

10-5. 1961 Regulation. Runoff originating from the total Missouri River drainage area above Oahe Dam during 1961 totaled about 9.3 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 9.1 million acre-feet. Additionally, during 1961 the total storage within the main stem reservoir system was at extremely low levels. Therefore, the Oahe releases (regulated flows) shown on Plate 21 are illustrative of the general release level from this project that would occur during periods of extremely deficient water supply. However, since the Oahe power plant was not functioning in 1961, the daily fluctuations in release rate that would now occur are not apparent on the plate. Comparison of regulated and unregulated flows on this plate indicates the supplementation of flows during low water periods resulting from operation of upstream reservoirs. Development of water resources in the basin above Oahe has continued since 1961 and, if 1961 hydrologic conditions should be repeated, the supplementation

TABLE 11

Annual Extreme Mean Daily Flows

Missouri River at Oahe Dam, South Dakota

Year	Mean Daily Flow, 1,000 cfs			
	Regulated		Unregulated	
Year	Maximum	Minimum	Maximum	Minimum
1959	33.0	5.6	127	3
1960	28.9	1.3	187	3
1961	30.0	2.8	56	0
1962	28.2	1.1	116	5
1963	36.6	0.0	120	2
1964	42.6	0.0	214	2
1965	39.7	3.0	143	6
1966	41.4	3.7	122	2
1967	50.3	2.6	187	4
1968	44.4	0.1	120	4
1969	54.9	3.4	125	5
1970	54.1	0.6	130	0
1971	54.3	4.6	119	6
1972	54.9	0.3	232	6
1973	49.5	0.0	66	3
1974	53.1	0.3	142	1
1975	57.5	0.0	172	3
1976	55.2	3.3	112	2
1977	51.4	0.0	42	0
1978*	52.9	0.0	254	5.8

*preliminary

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 the current resource development is served only by withdrawal from storage.

10-6. 1964 Regulation. Unregulated mean daily flows at the Oahe damsite during 1964 crested at 214,000 cfs, among the largest unregulated crests that have occurred at this location since regulation by the Oahe Reservoir began in 1958. As illustrated on Plate 22, mean daily Oahe outflows during the flood period averaged about 25,000 cfs and it is apparent that storage of the large inflows within Oahe and other upstream reservoirs had no effect upon the normal Oahe release pattern maintained through the flood period. Actually, during 1964 initial fill of Oahe and other upstream mean stem reservoirs was in progress. From Plate 20 it is evident that main stem system storage gains resulting from the 1964 runoff did not occur in Oahe but in the upstream Fort Peck and Garrison projects.

10-7. 1967 Regulation. Total Missouri Basin runoff above Oahe Dam during the June-July period of 1967 was among the largest of record for this period of the year, almost 70 percent greater than the long-term average. Combined with this runoff above Oahe Dam were severe flood flows originating below Oahe and in the Missouri River drainage areas below the main stem system of reservoirs. Damages prevented by the regulation of Oahe and the other main stem reservoirs during this flood period approached 250 million dollars. As illustrated on Plate 23, mean daily releases from the Oahe 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. The initial fill of the Oahe Reservoir was accomplished during 1967 with an elevation gain of about 20 feet, as illustrated on Plate 20.

10-8. 1972 Regulation. Missouri Basin runoff above Oahe Dam during 1972 was more than 6 million acre-feet greater than the long-term average. March runoff was exceptionally large, as indicated by Plate 24, with an unregulated crest flow of 232,000 cfs, the largest unregulated crest at this location since regulation of the reservoir began in 1958. Oahe releases through the year were well within the power plant capacity. Prior to 1972 the entire main stem reservoir system, including the Oahe Reservoir, was filled to normal operating levels. As illustrated on Plate 21, the level of Oahe throughout the year remained within the normal operating range. Somewhat greater than normal drawdown prior to and following 1972 was scheduled to investigate the relationship between the maximum level of the Oahe Reservoir and the minor embankment movement that had been observed.

10-9. <u>1975 Regulation</u>. Flood season (March-July) runoff originating in the Missouri Basin above Oahe Dam during 1975 was the greatest experienced since runoff records began in 1898. While the crest unregulated flow of 172,000 cfs at the Oahe 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 25. 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, Oahe releases during the early portions of the year were continued at near normal levels. Downstream constraints prohibited significant release increases during May and June and it was not until July that outflows were increased to the full capacity of the Oahe power plant. With full power plant releases, stages on the Missouri River below the main stem reservoir system were maintained very close to flood stage, leaving very little room to accommodate downstream incremental flood inflows, should they have occurred. As illustrated on Plate 21, a generally continuing rising Oahe Reservoir level occurred from mid-January through most of August, with a maximum elevation of 1617.9. This is the only time that exclusive flood control storage space has been used in the Oahe project and use of this space was necessary to re-regulate Garrison releases that were about 10,000 cfs greater than those from Oahe during the July-August period. 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 1975 regulation.

10-10. <u>Summary of Historical Regulation</u>. Historical regulation of the Oahe project has proceeded for only a relatively short period of time, and a substantial portion of this historic period was consumed in the initial fill of Oahe and other main stem reservoirs. However, annual upstream runoff during this period has ranged from near 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 Oahe project, and for the system as a whole (as presented in the Master Manual) as it affects Oahe 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 very unusual conditions occur, Oahe releases will be maintained within the capacity of the Oahe power plant. Greater releases are very apt to contribute to downstream floods and it would appear that such would be necessary only if an Oahe level higher than elevation 1620 appeared probable. With the large amount of storage space provided in the Oahe Reservoir and in other main stem reservoirs, chances are quite remote that such a high level will occur, as evidenced by regulation of the maximum flood season runoff of record during 1975.

10-11. When the level of Oahe releases is less than full power plant capacity, great variations in release have occurred, from hour-to-hour, and day-to-day. Plates 21 to 25 illustrate the daily variations and the weekly cycle in release rates occasioned by lower power demands during weekends. During any one day releases have frequently ranged from zero to the full power plant capacity and, in order to efficiently produce power, these patterns are expected to continue.

X-B Long-Term Regulation Analyses

10-12. Long-Term Studies. Simulated regulation of the Oahe 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 of regulation criteria and the subsequent analyses of those criteria, as well as criteria modification, with respect to service provided to authorized project functions. 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 Cahpters 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 incroporate current regulation criteria, as well as any desired level of water-resource development in the Missouri Basin, long-term examples of Oahe regulation are available. From the examples incorporating the present level of water resources development, conclusions relative to regulation of the Oahe project can be established as described in succeeding paragraphs.

10-13. Oahe Reservoir Elevations. Long-term analyses indicate that the levels of the Oahe Reservoir will fluctuate from the minimum pool (elevation 1540 ft msl) upward to somewhat above the maximum normal operating pool (elevation 1617 ft msl). Utilization of all the available exclusive flood control storage space in the reservoir (up to elevation 1620 ft msl) was not required in an analysis of the entire 1898-1976 period of available record. Average levels of Oahe for the 1898-1976 period vary seasonally from a low at elevation 1591 in December to a high near elevation 1600 in April, with an overall average near elevation 1595. Extreme drawdown (below elevation 1580) will occur only in the event of a severe drought extending over several years, such as experienced in the Missouri Basin during the 1930's. A graph of probable Oahe 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 Oahe Reservoir elevation duration curve shown on Plate 26 was developed. This curve indicates that a lake level at or above elevation 1607.5, the base of the annual flood control and multiple use storage space, can be expected about 23 percent of the time and an elevation of 1602 equaled or exceeded one-half of the time. A frequency curve of annual maximum Oahe elevations is shown on Plate 27. This curve was developed from the long-range study analysis, as tempered by actual regulation experience of the Oahe project. From this curve it is evident that a maximum annual lake level at or above the base of the annual flood control storage space, elevation 1607.5, can be expected in six years out of every 10. An elevation of 1617, the base of exclusive flood control storage space, should be equaled in one year out of ten. Average Oahe Reservoir levels and normal seasonal variations in these levels at the 1975 level of water resource development are shown on Plate 28. The characteristic rise of over eight feet during the first three months of the year is due to re-regulation of high winter power releases from upstream main stem projects, combined with the usual period of highest seasonal runoff from the incremental drainage area between Garrison and Oahe Dam. After navigation releases from the system begin in late March, there is normally little further increase of the Oahe Reservoir level and decreasing levels are the rule during the May-December period.

10-15. Oahe Releases. Long-term regulation studies indicate that an Oahe release in excess of the power plant capacity of about 57,500 cfs will be rare, as confirmed by actual regulation of the project to date. Duration curves of mean monthly releases given on Plate 26 indicate that outflows in excess of the full power plant capacity will be necessary for less than one percent of the time. A median mean monthly outflow of 23,000 cfs is indicated. The frequency curve of annual maximum releases shown on Plate 27 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. Average monthly releases based on long-term studies are shown on Plate 28. 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 during much of the remainder of the year. Reduced outflows during October and November allow the evacuation of space in the downstream Fort Randall Reservoir for recapturing power releases from the upstream reservoirs in the forthcoming winter period. The increased December releases permit the Oahe project to serve a higher than usual proportion of the system's winter power generation while freeze-up of the Missouri River channel is occurring below Fort Peck and Garrison Dams and restricting releases from those projects.

X-C. Emergency Regulation.

10-16. Maximum Possible Early Spring Flood. As discussed in Section IX, regulation curves have been developed for emergency conditions and are included with Exhibit A of this manual. One example of using this set of curves as the only criteria for regulation of the Oahe Reservoir is shown on Plate 29. The flood examined is the maximum possible early spring plains snowmelt flood, which was developed for spillway design purposes, having a crest inflow of almost one million cfs. An initial level of the Oahe Reservoir at elevation 1610 was considered to be reasonable for this season of the year. Respective crest reservoir level and release are elevation 1640.3 ft msl and 308,000 cfs. Of this crest outflow about 260,000 cfs was through the spillway with the remainder through the power plant, which was assumed to be operable through the flood period. These crest values are relatively close to those developed in the Definite Project Reports at the time Oahe was designed in the mid-1940's. At that time the computed peak reservoir elevation was 1644.4 and the peak release was 304,000 cfs. These DPR studies did not assume the power plant would be available for making releases during the SDF.

10-17. Maximum Possible Late Spring Floods. Use of the emergency regulation procedures given in Exhibit A during the maximum possible late spring flood, as developed for spillway design purposes, is illustrated on Plate 30. An initial Oahe level at elevation 1614 ft msl was considered reasonable. The crest inflow of about 1,250,000 cfs was controlled to a crest outflow of 335,000 cfs of which about 285,000 cfs was over the spillway and the remainder through the power plant, which was assumed to be operable through the flood period. A crest Oahe level at elevation 1643 was coincident with the crest outflow.

EXHIBIT A

EMERGENCY REGULATION PROCEDURES

FOR THE

OAHE RESERVOIR

DEPARTMENT OF THE ARMY
MISSOURI RIVER DIVISION, CORPS OF ENGINEERS
P. O. BOX 103, DOWNTOWN STATION
OMAHA, NEBRASKA 68101

MRDED-R

SUBJECT: Reservoir Regulation Order, Emergency Regulation Procedure for Oahe Reservoir

TO: Power Plant Superintendent
Oahe Power Plant

FROM: Missouri River Division
Reservoir Control Center

1. Procedures applicable to the regulation of the Oahe 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 Oahe 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 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 Oahe pool level remains below elevation 1608 ft msl.

c. If the Oahe pool level is above elevation 1608, 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 24 hours will be estimated by computing the storage change during the 24-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 24-hour period. The approximate mean inflow in cfs is equivalent to the mean outflow in cfs plus one-half the storage change in acre-feet during the 24-hour period. Twenty-four hour inflow may also be approximated by the equation:

Inflow - Outflow + (187,000 X 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), make release specified by the rule curve. However, releases will not be increased to a rate which is greater than twice the average rate for the preceding 24 hours.

(5) With an Oahe pool at or below elevation 1617, releases will be limited to the capacity of the available power units.

(6) With an Oahe pool between elevations 1617 and 1620, releases will be limited to the combined capacity of all available power units and the total discharge capacity of the outlet works tunnels.

(7) With an Oahe pool between elevations 1620 and 1622, the combined capacity of all available power units and the discharge capacity of outlet works tunnels will be used to prevent further rise in the level of the reservoir or to lower the level of Oahe to elevation 1620 at a rate of 0.1 to 0.2 feet per day. Spillway gates will not be opened with the pool in this elevation range.

(8) With an Oahe pool between elevations 1622 and 1625 a total release of 170,000 cfs will be maintained. Spillway gate openings will be required, but only as necessary to prevent spill over the top of gates. Reductions in outlet releases will be made to compensate for spillway gate openings to maintain total releases specified.

(9) With Oahe at elevation 1625 or above, spillway gates will be fully opened and outlet gates closed. Total release will consist of the combined capacity of all available power units and the spillway.

(10) The following criteria will govern operation of Oahe spillway gates:

(a) The maximum allowable reservoir level differential above the top of the spillway gates is one foot or an Oahe level as high as elevation 1621 is allowable prior to opening the spillway gates.

(b) All gates will be operated at a uniform gate setting.

(c) Gates will be opened in the following sequence:
3, 5, 4, 6, 1, 2, 7 and 8.

(d) With a five foot opening or less, the maximum increment of opening is two feet. From a five foot to a 12 foot gate opening, the opening increment is limited to one foot. Beyond an opening of 12 feet, the spillway gates will be operated in one increment to the full opening of 45.5 feet.

(e) Closing of gates will be in a reverse sequence to that given in paragraph (c) with incremental closings similar to the openings specified in (d).

(11) With an Oahe pool below elevation 1617, any release adjustments made necessary by these instructions should be made once daily. With an Oahe pool above elevation 1617, the analysis and necessary adjustments should be at intervals of 12 hours or less.

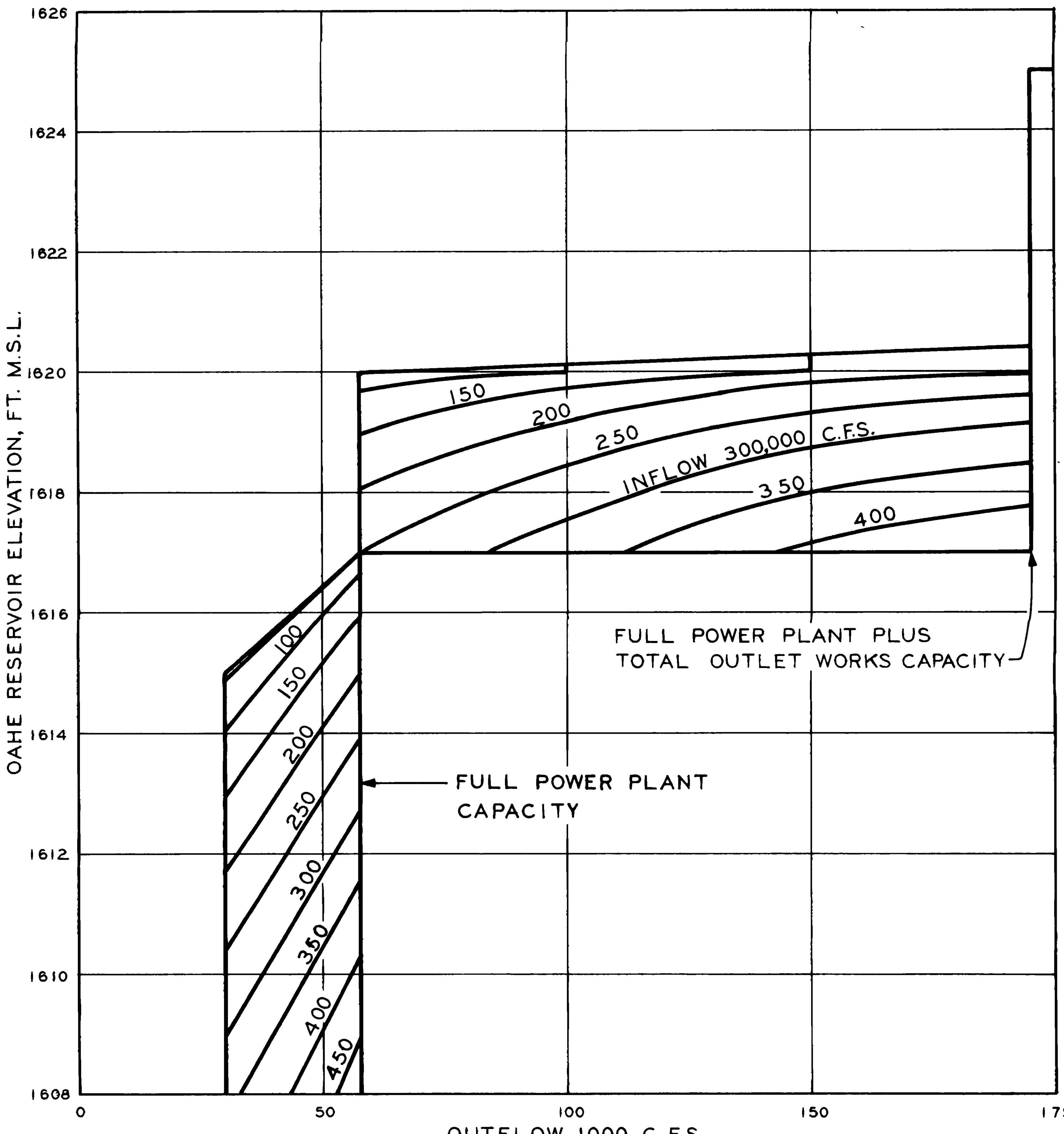
(12) If release is less than full power plant capability, power plant loading will be patterned similar to recent experience or as prescribed by the WAPA if communication with their Systems Operations Office is possible.

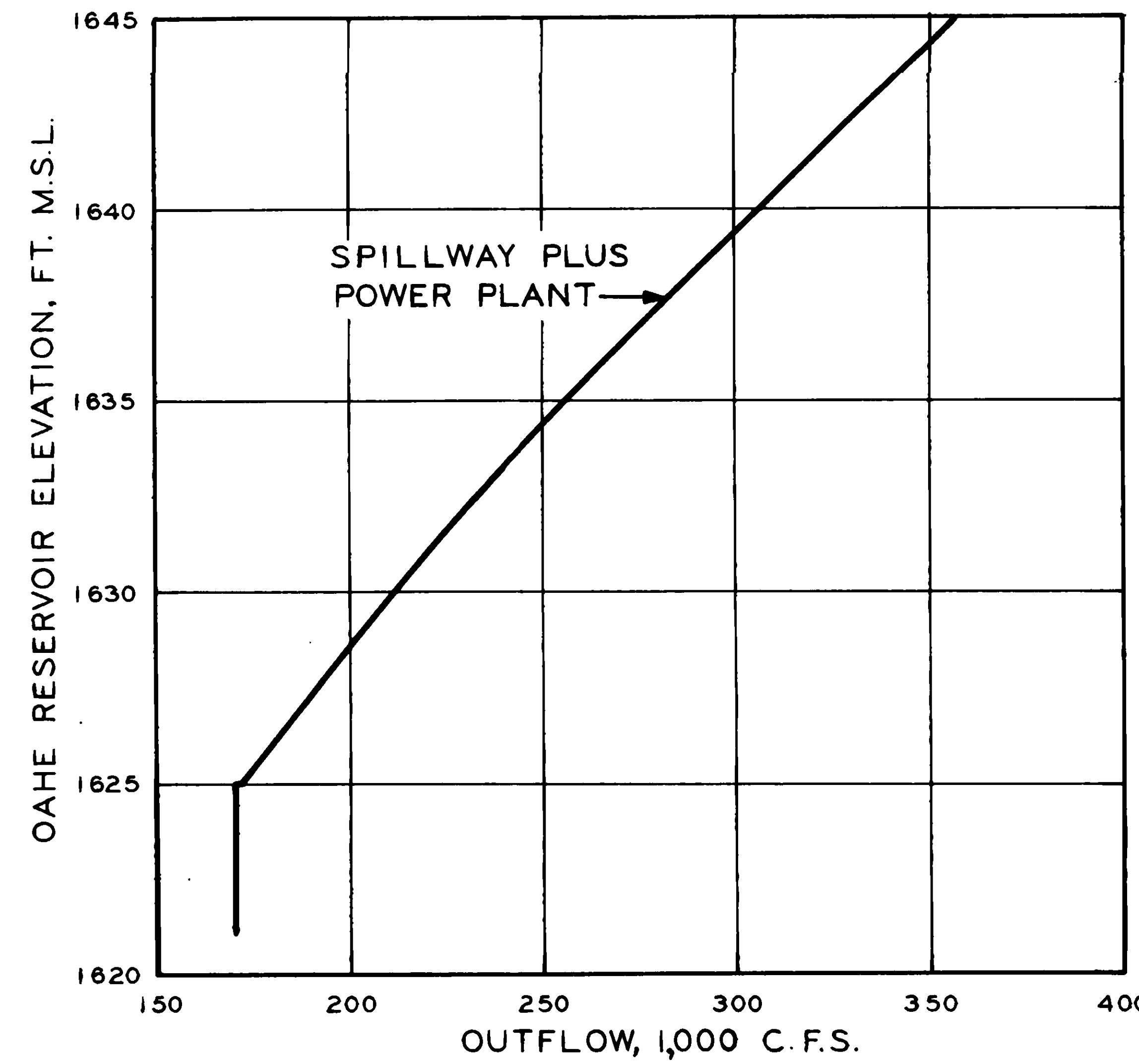
4. In the event of downstream flooding, as reported to or anticipated by the Power Plant Superintendent, releases will be reduced as deemed necessary to alleviate these conditions. However, with Oahe above elevation 1617, releases will not be reduced below those levels defined by the emergency curve, Inclosure 1.

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

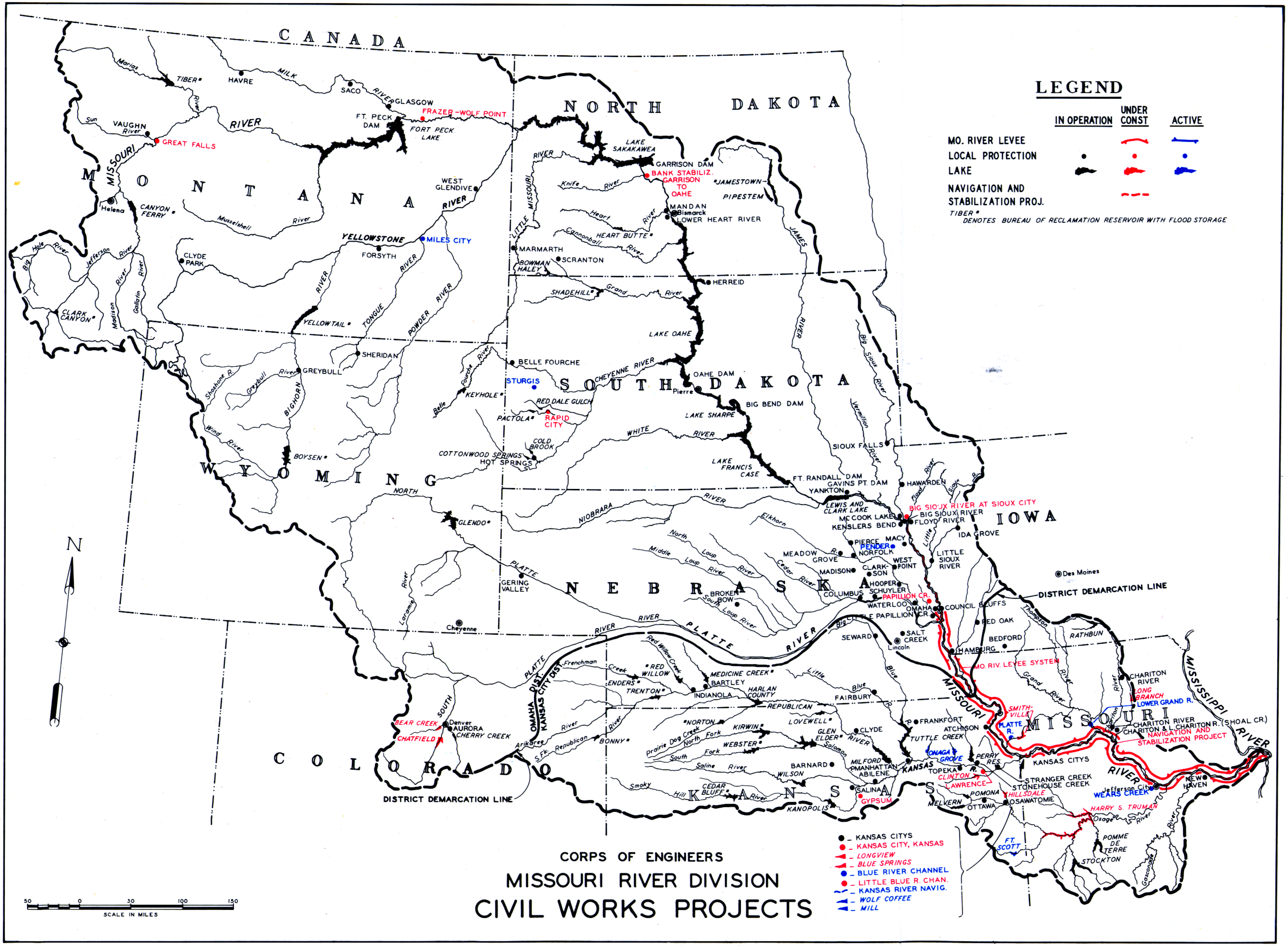




NOTES:

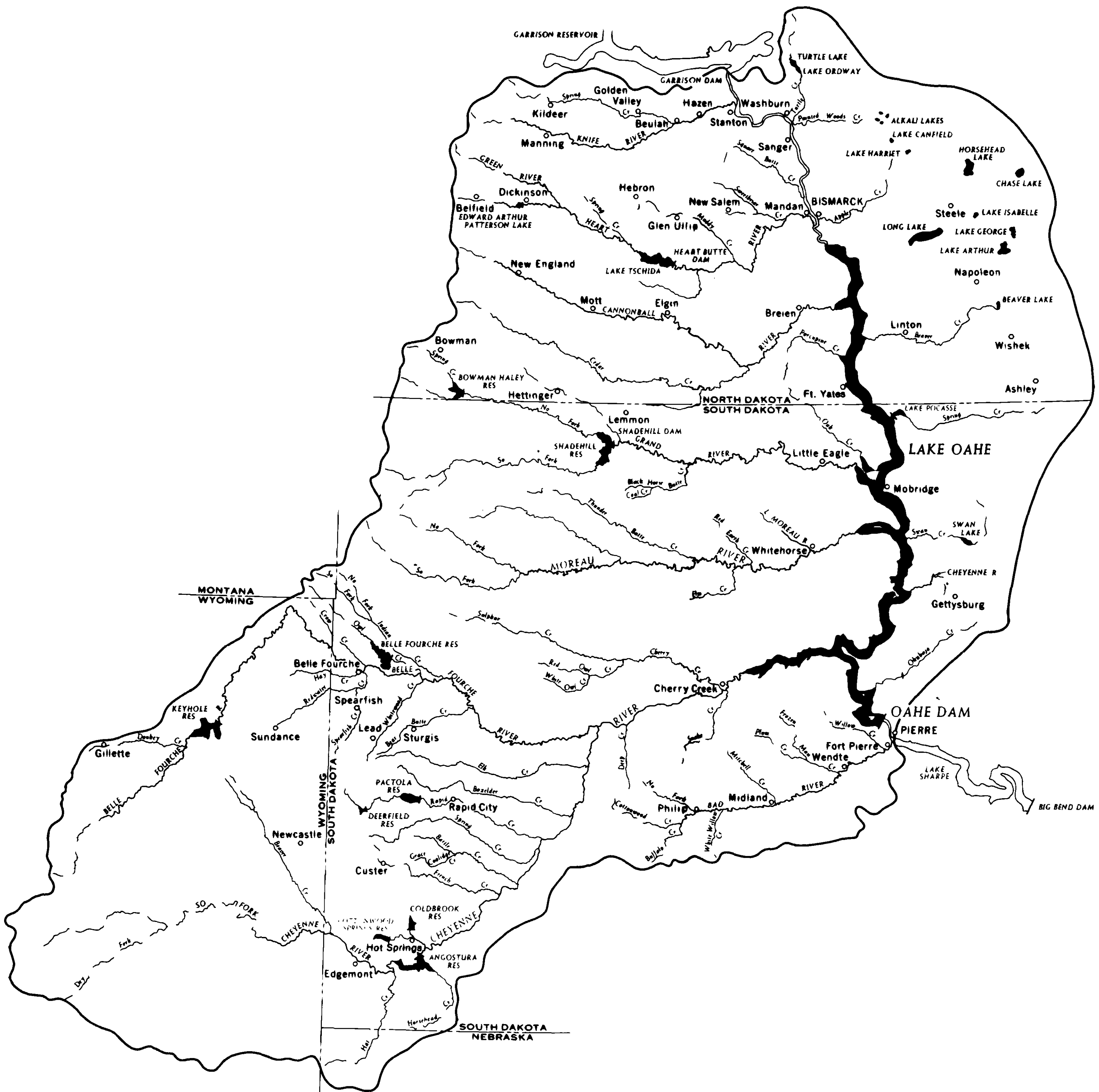
1. NUMBERED CURVES REPRESENT INFLOW IN THOUSAND C.F.S.
2. EMERGENCY PROCEDURE WILL CONSIST OF:
   A. ENTER CURVES WITH CURRENT POOL ELEVATION.
   B. PROCEED TO CURVE WHICH EQUALS INFLOW AS DETERMINED FOR PRECEDING 24-HOURS.
   C. MAINTAIN RELEASE AS INDICATED BY POINT OF INTERSECTION.
   D. NO RELEASE SHALL EXCEED A RATE GREATER THAN TWICE THE AVERAGE RELEASE RATE FOR THE PRECEDING 24-HOURS.

EMERGENCY REGULATION CURVES
OAHE RESERVOIR



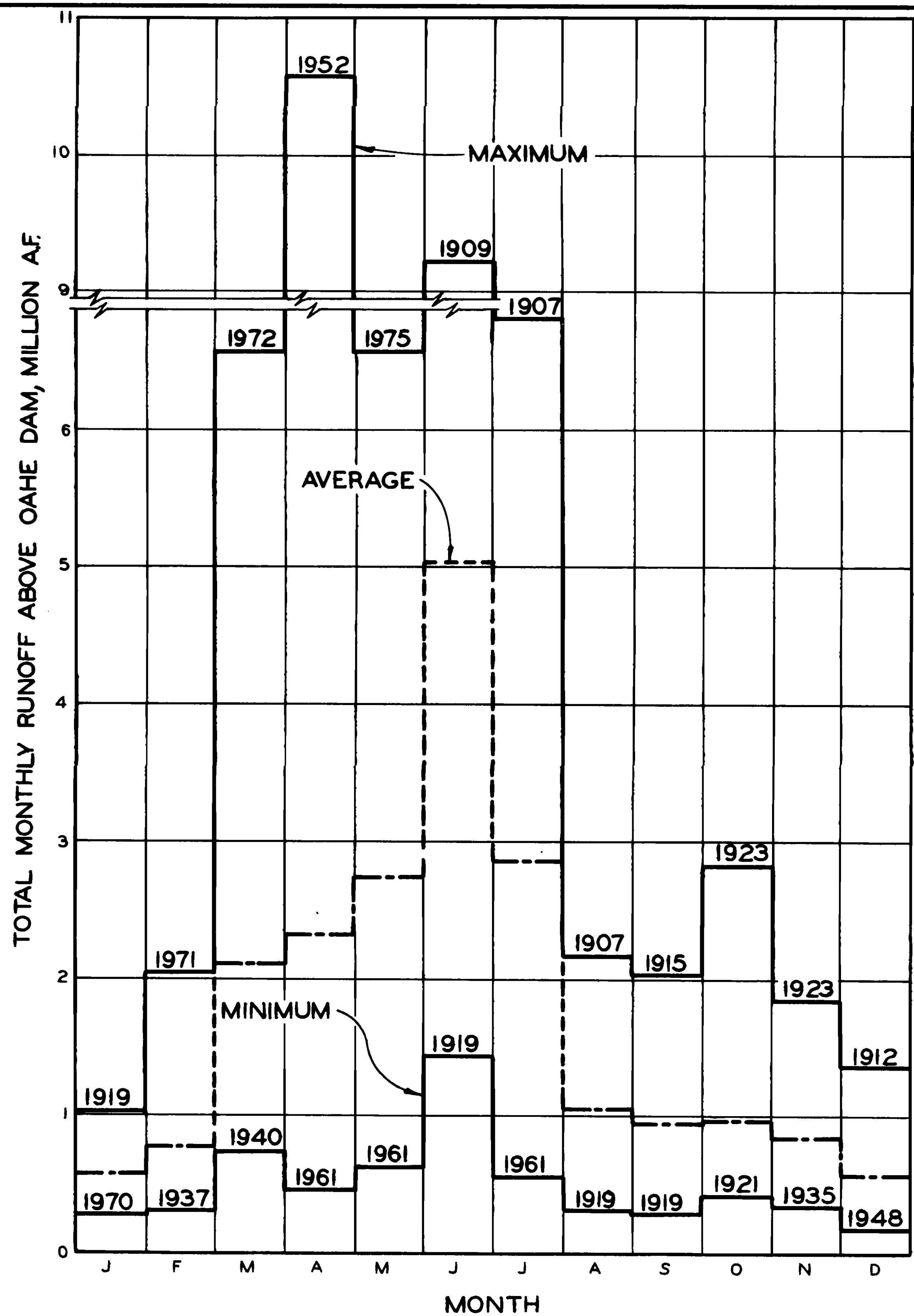
CORPS OF ENGINEERS
MISSOURI RIVER DIVISION
CIVIL WORKS PROJECTS

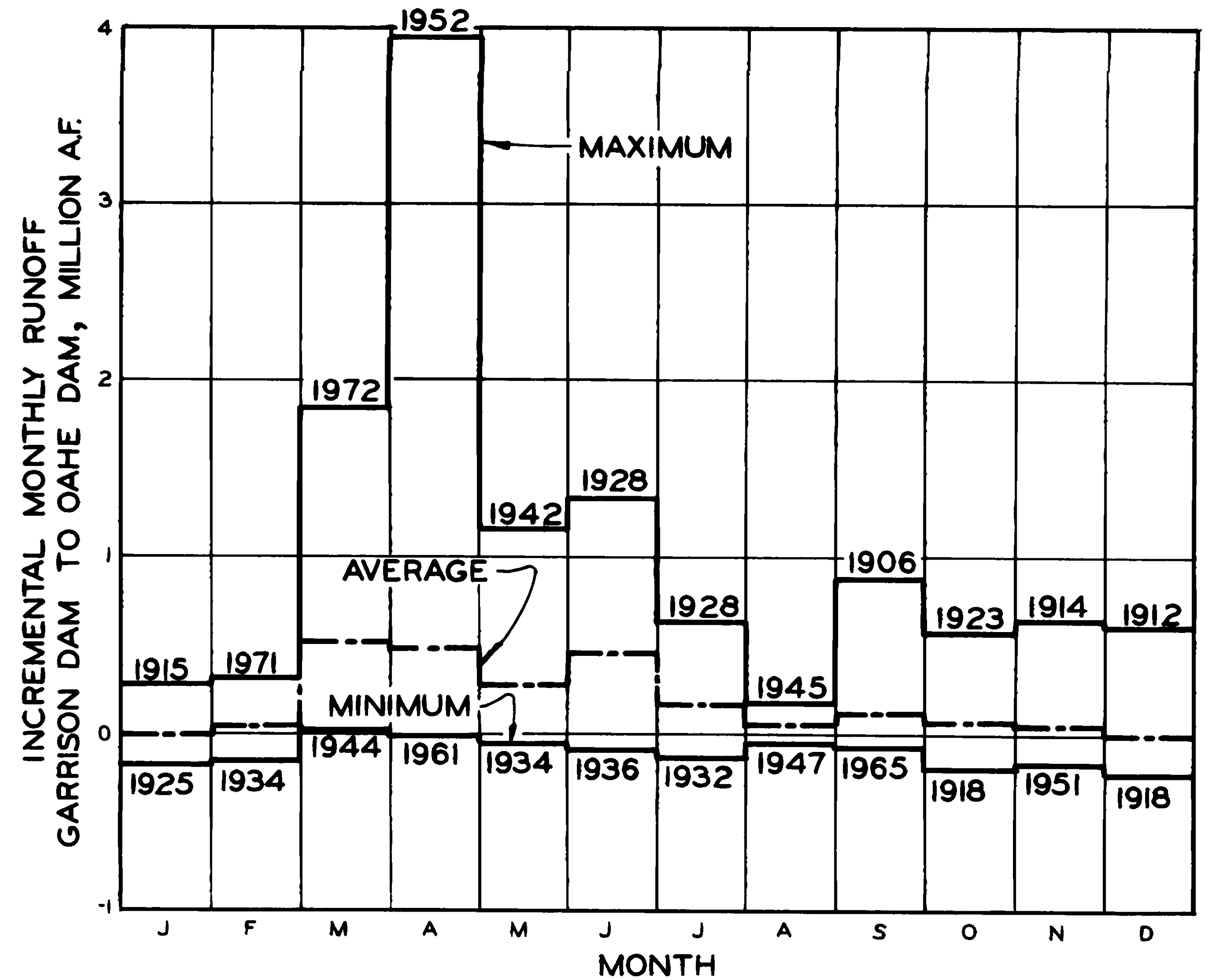
PLATE I



OAHE RESERVOIR
INCREMENTAL DRAINAGE AREA BETWEEN
GARRISON DAM AND BELOW MOUTH OF BAD RIVER
GENERAL MAP

★ U.S. GOVERNMENT PRINTING OFFICE: 1972-760-4

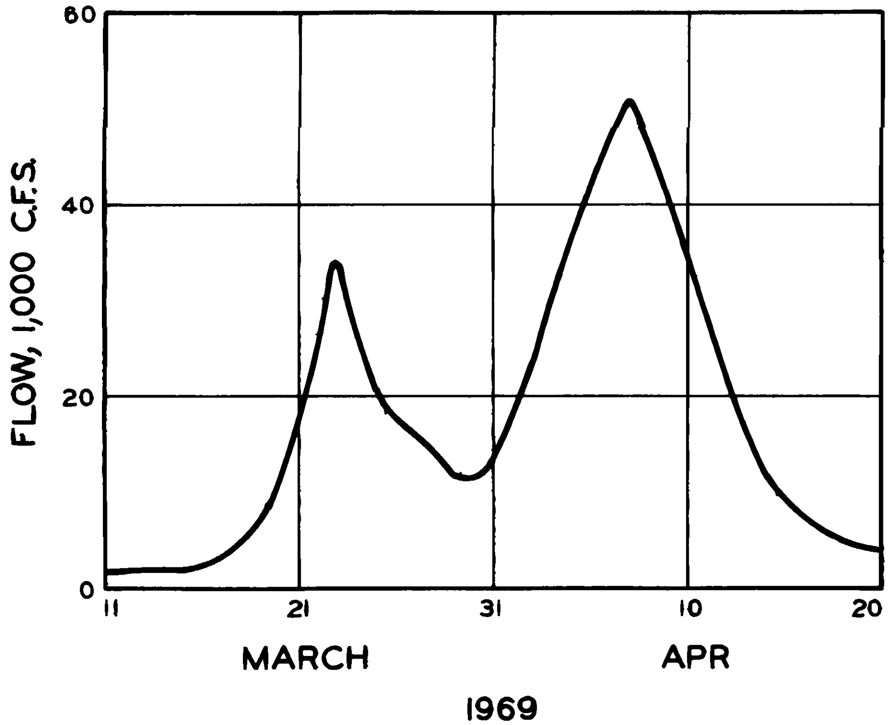


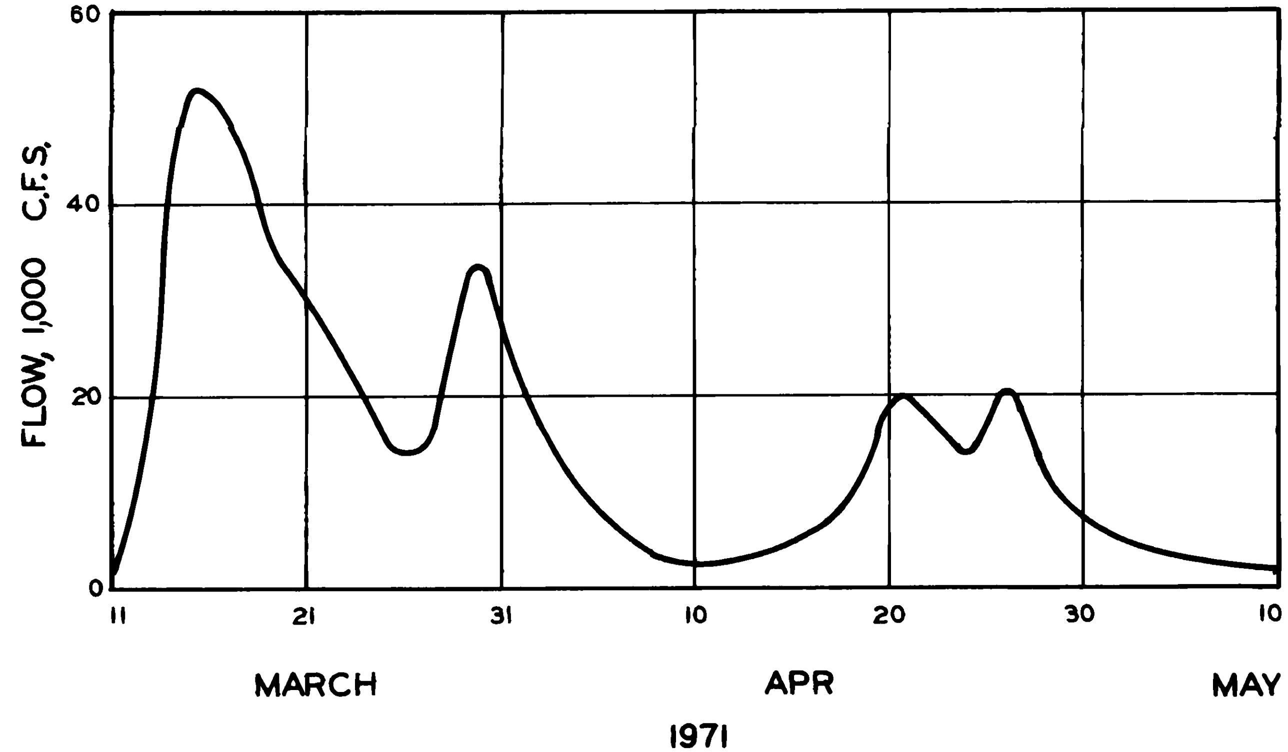


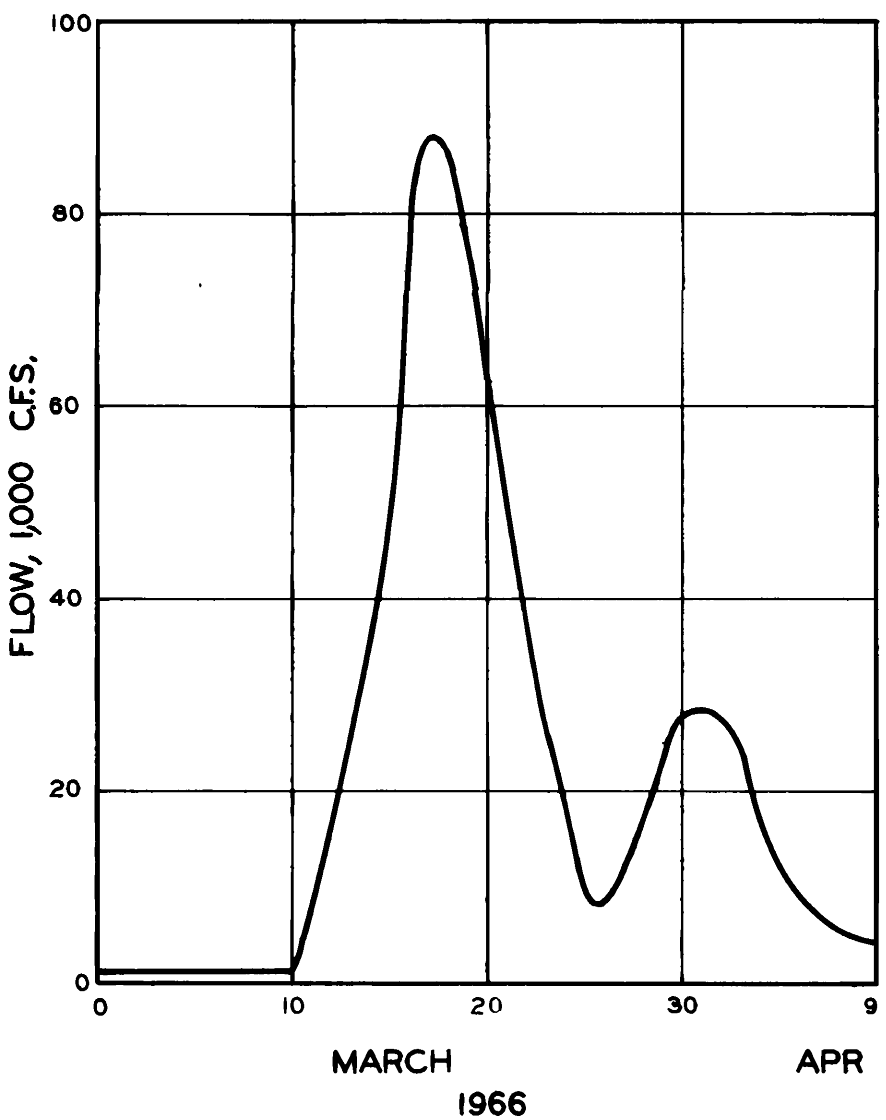
NOTES:

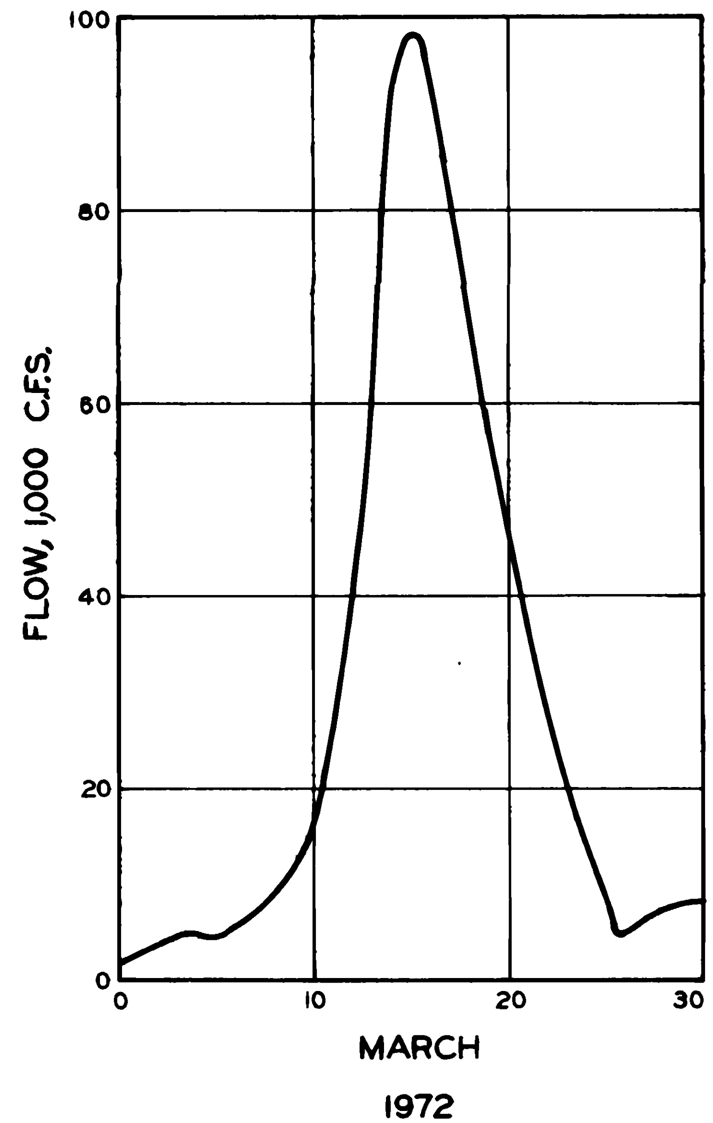
1. RECORD PERIOD EXTENDS FROM 1898 TO 1976.
2. RUNOFF ADJUSTED TO THE 1949 LEVEL OF WATER RESOURCE DEVELOPMENT. (WITHOUT UPSTREAM RESERVOIRS IN OPERATION.)

UNREGULATED
MONTHLY RUNOFF DISTRIBUTION
ABOVE OAHE DAM



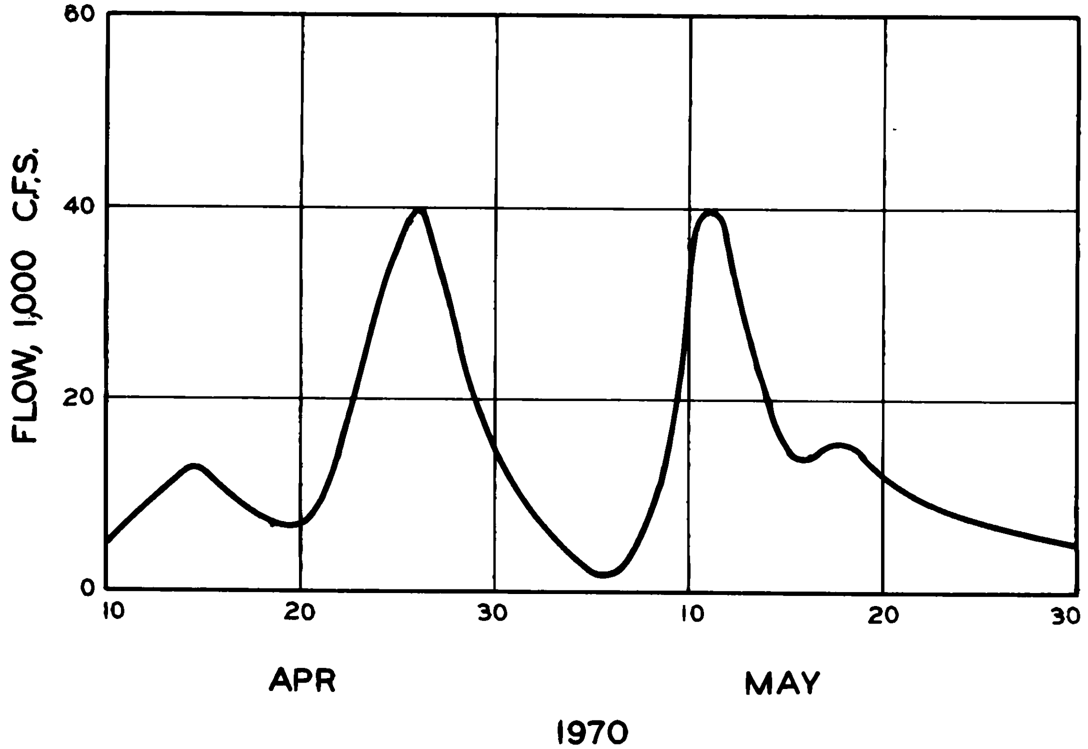


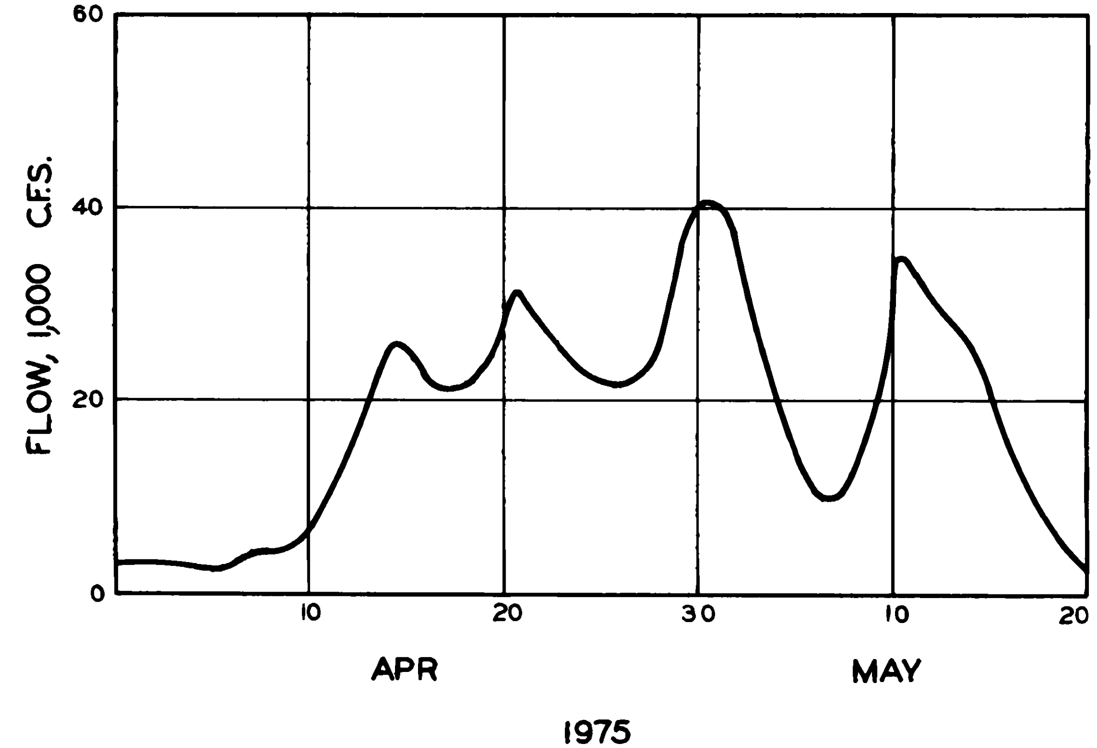


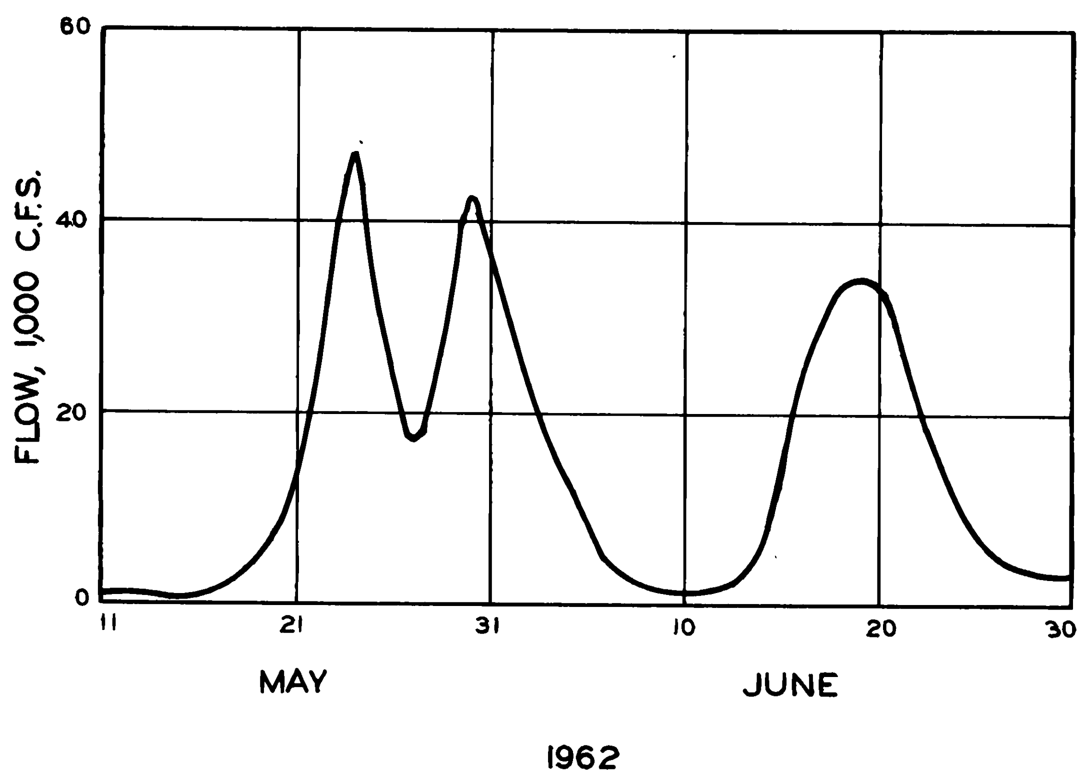


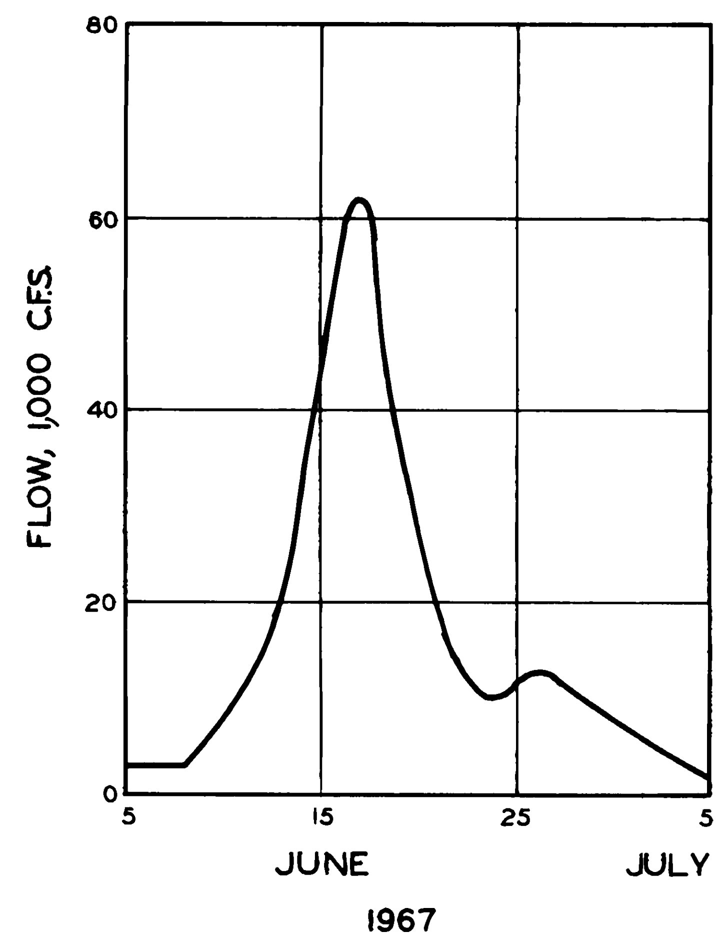
TOTAL INCREMENTAL INFLOWS
EARLY SPRING FLOOD SEASON
GARRISON DAM TO OAHE DAM

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



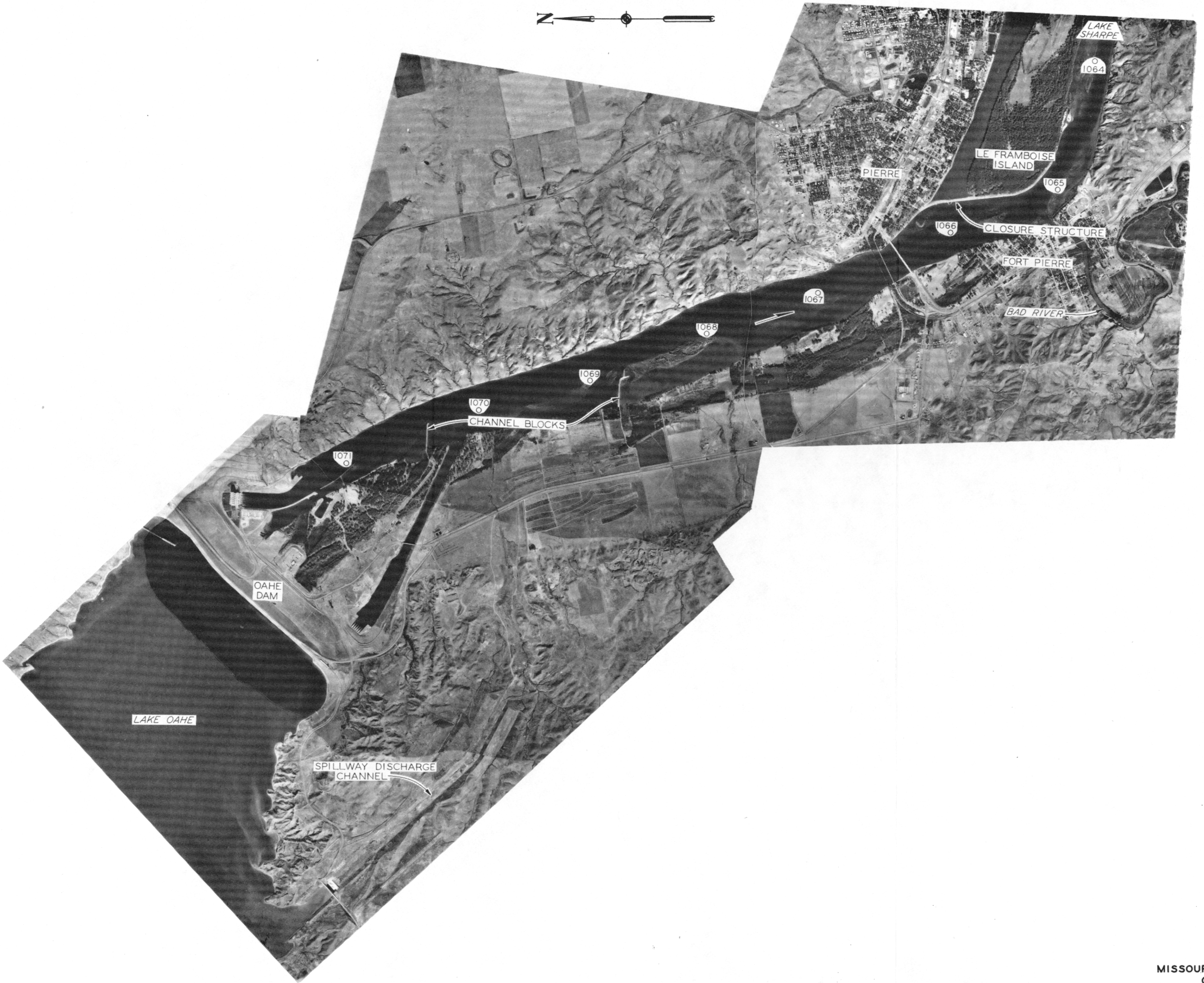




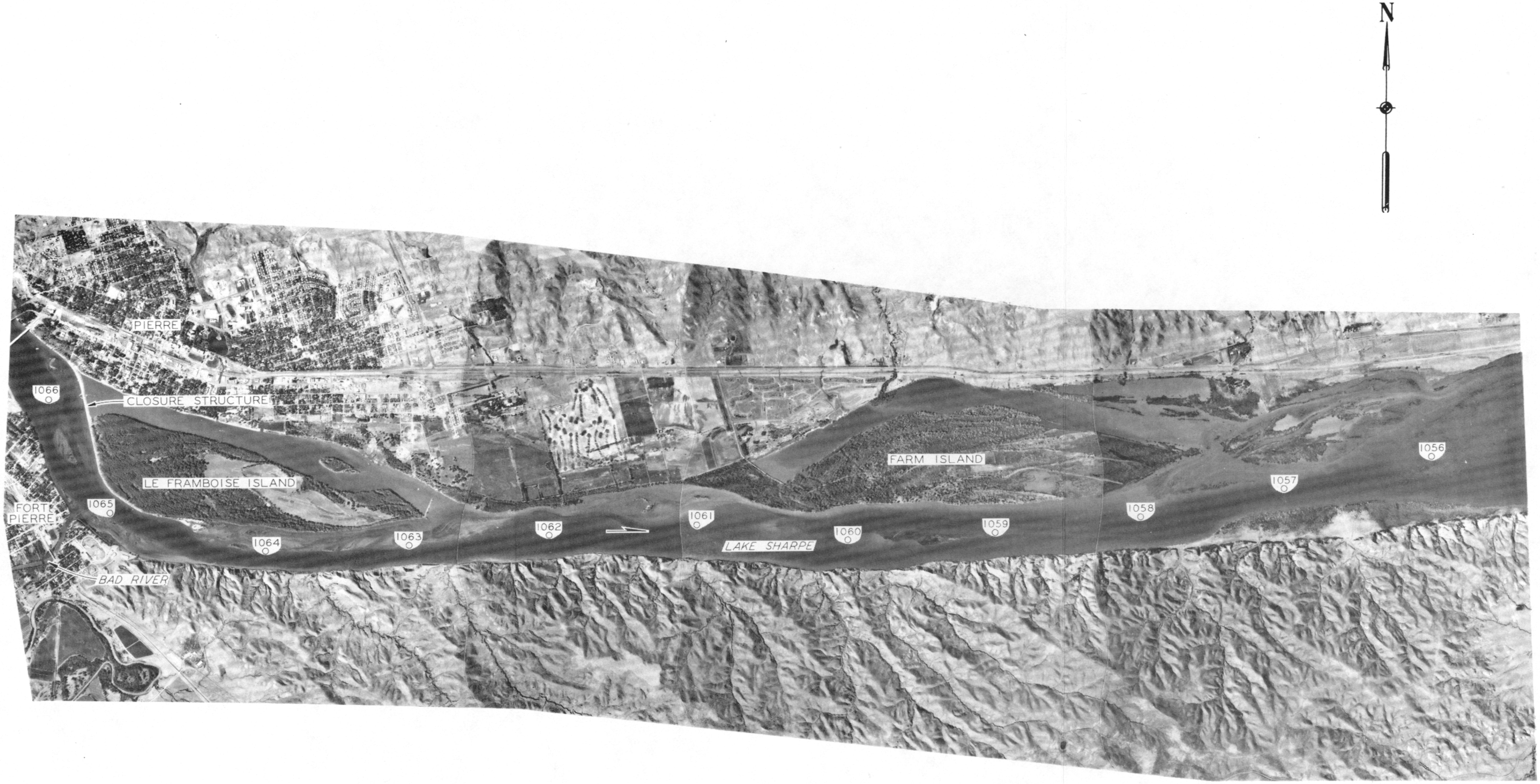


TOTAL INCREMENTAL INFLOWS
LATE SPRING FLOOD SEASON
GARRISON DAM TO OAHE DAM

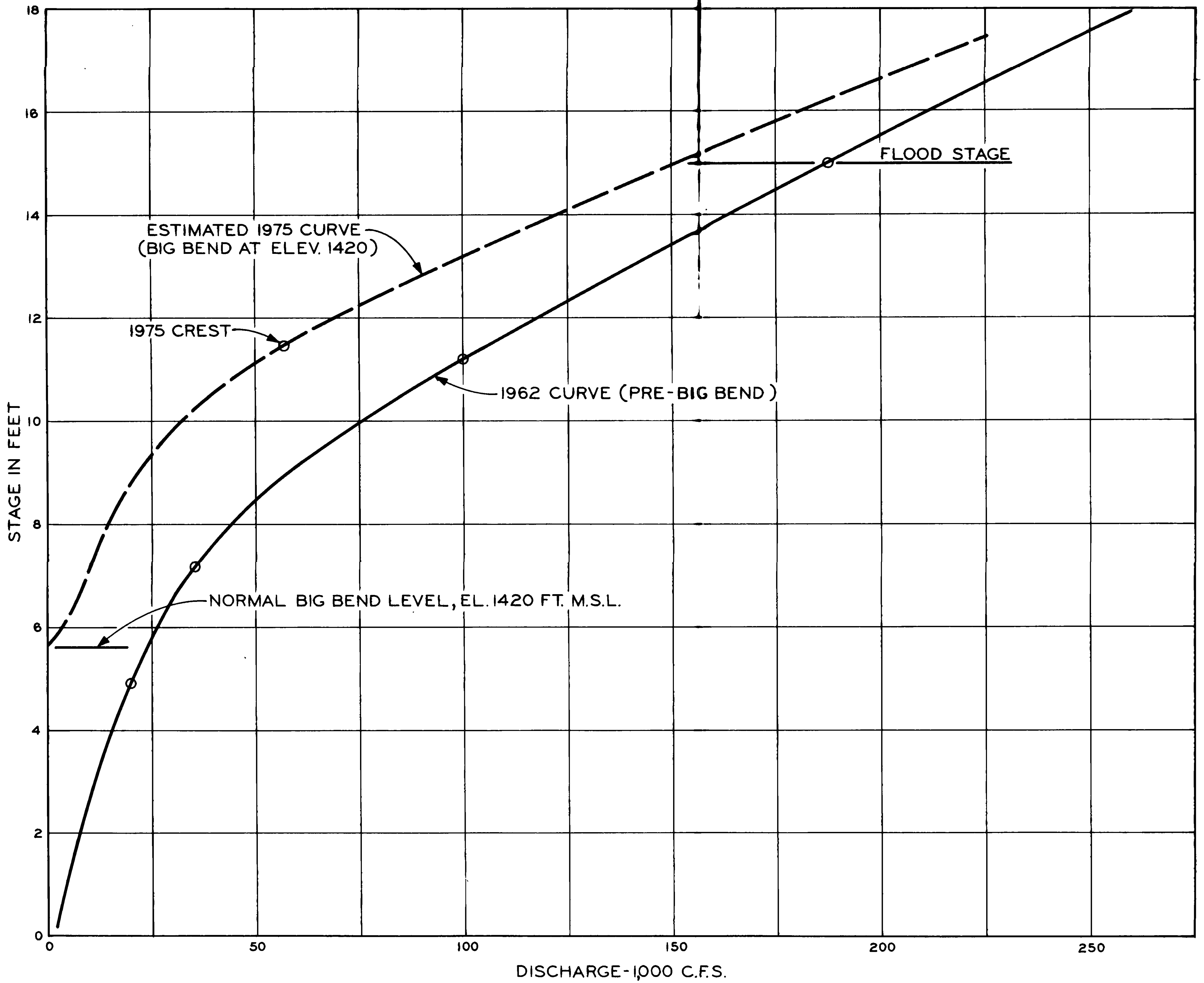
PLATE 5



MISSOURI RIVER – BELOW OAHE DAM

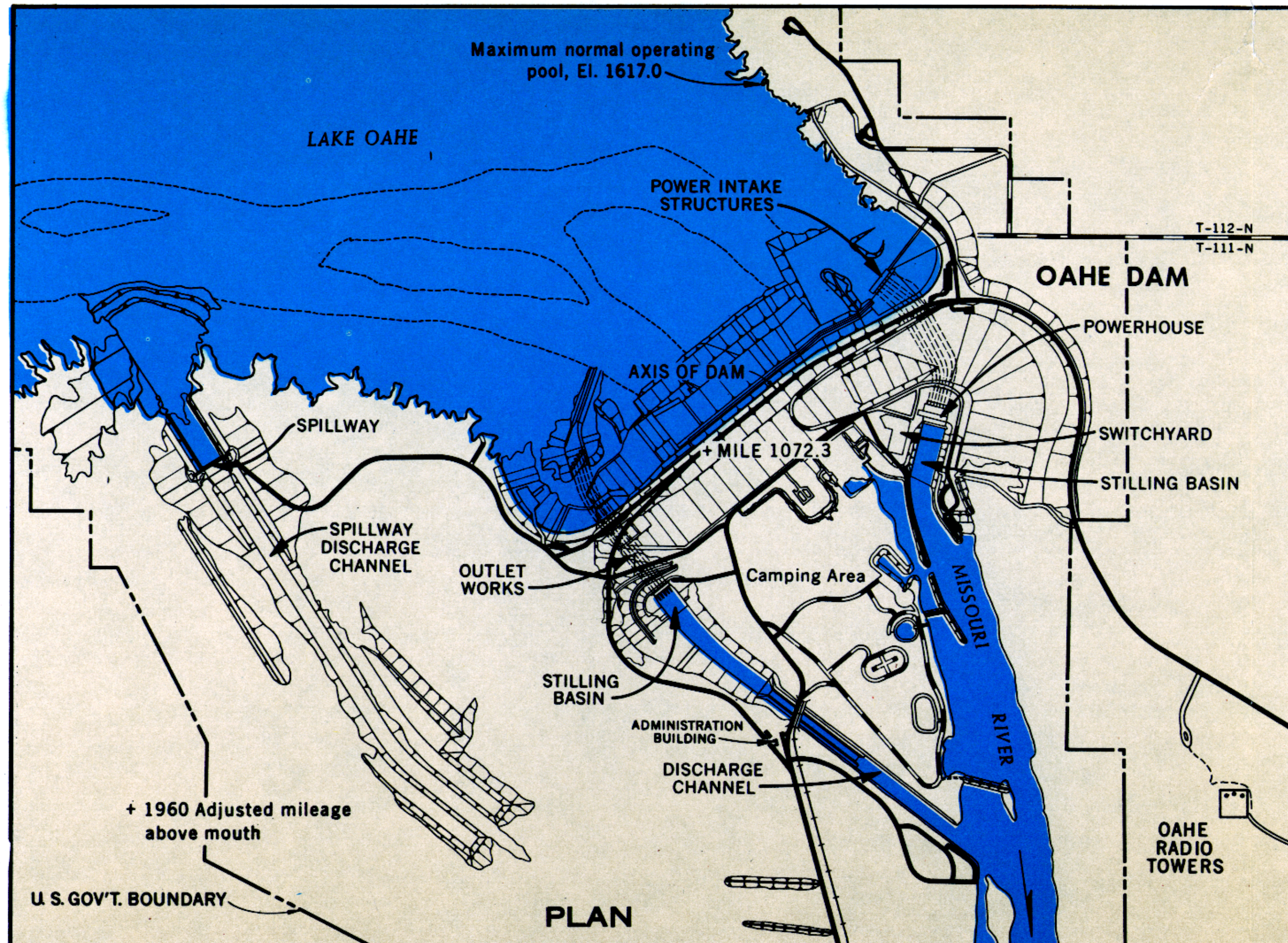


MISSOURI RIVER-BELOW
OAHE DAM

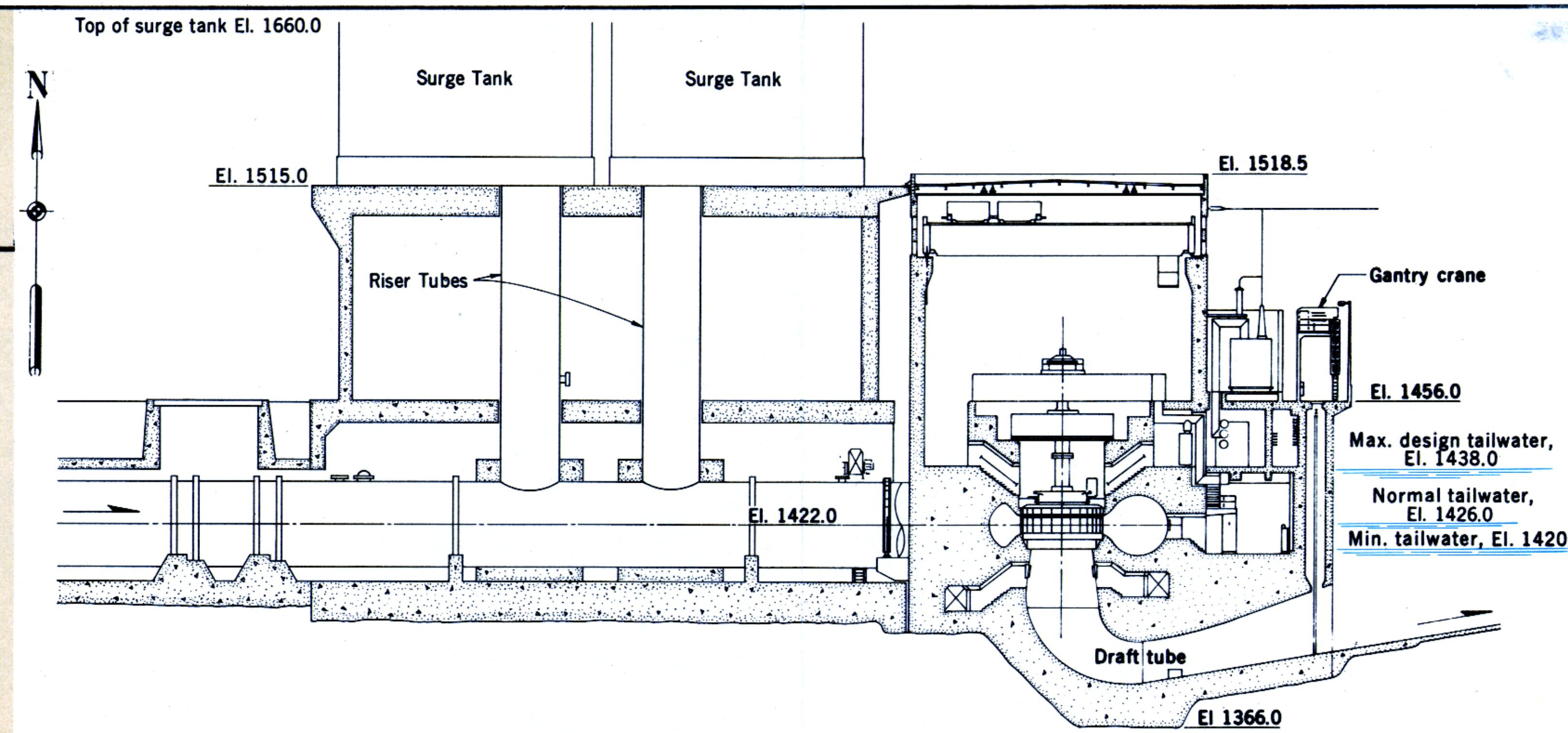


NOTE:
MAX. STAGE OF RECORD-
25.4', APRIL, 1952

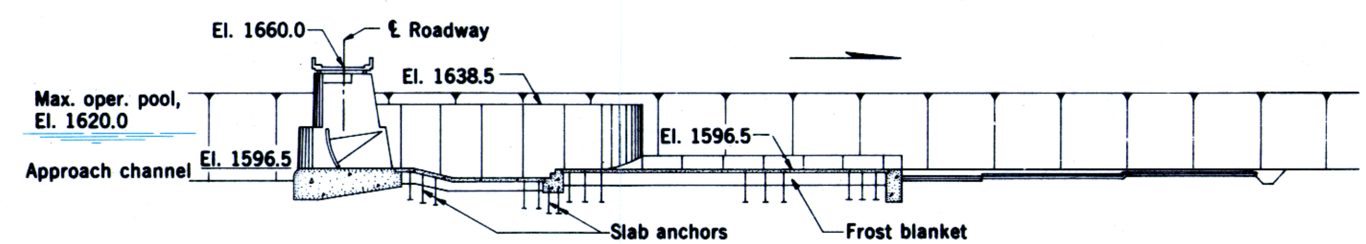
STAGE-DISCHARGE RELATIONSHIPS
MISSOURI RIVER AT PIERRE,
SOUTH DAKOTA



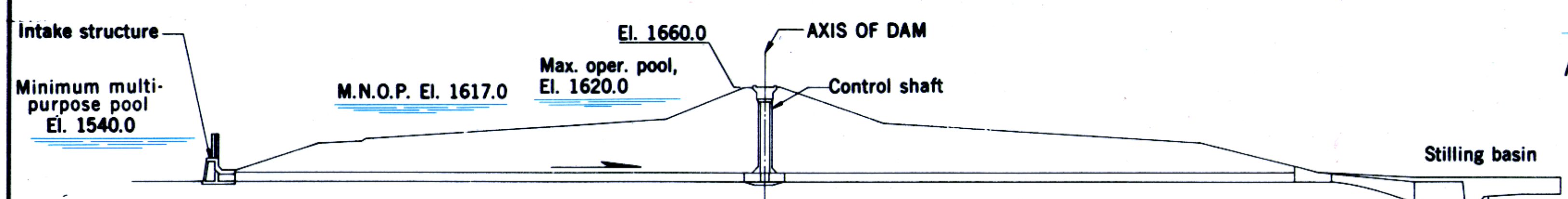
PLAN



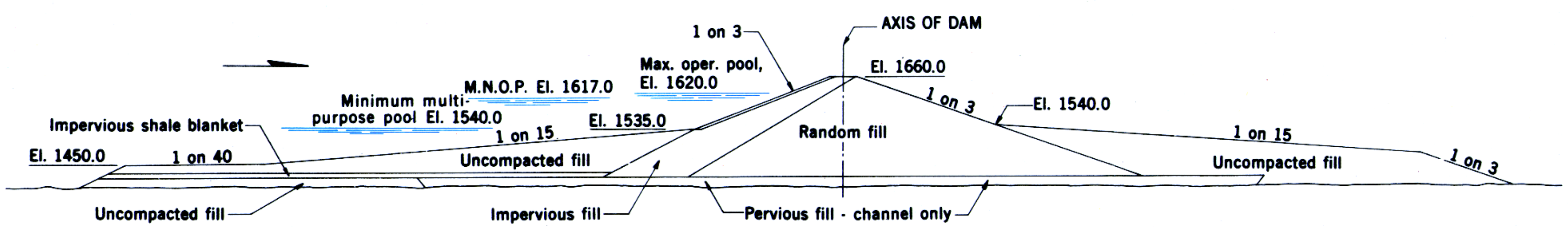
POWERHOUSE SECTION



SPILLWAY PROFILE

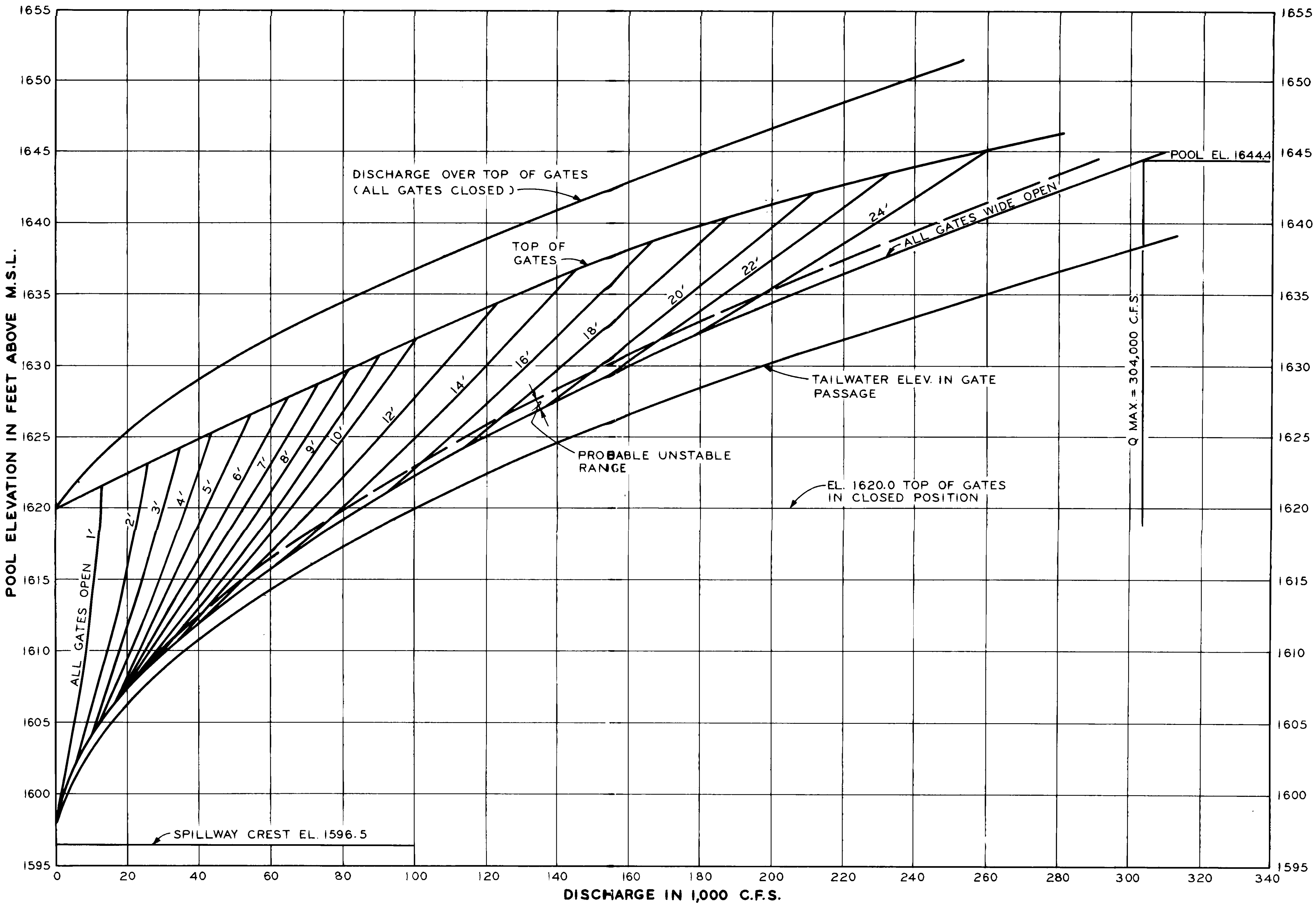


OUTLET WORKS PROFILE
FLOOD CONTROL TUNNELS

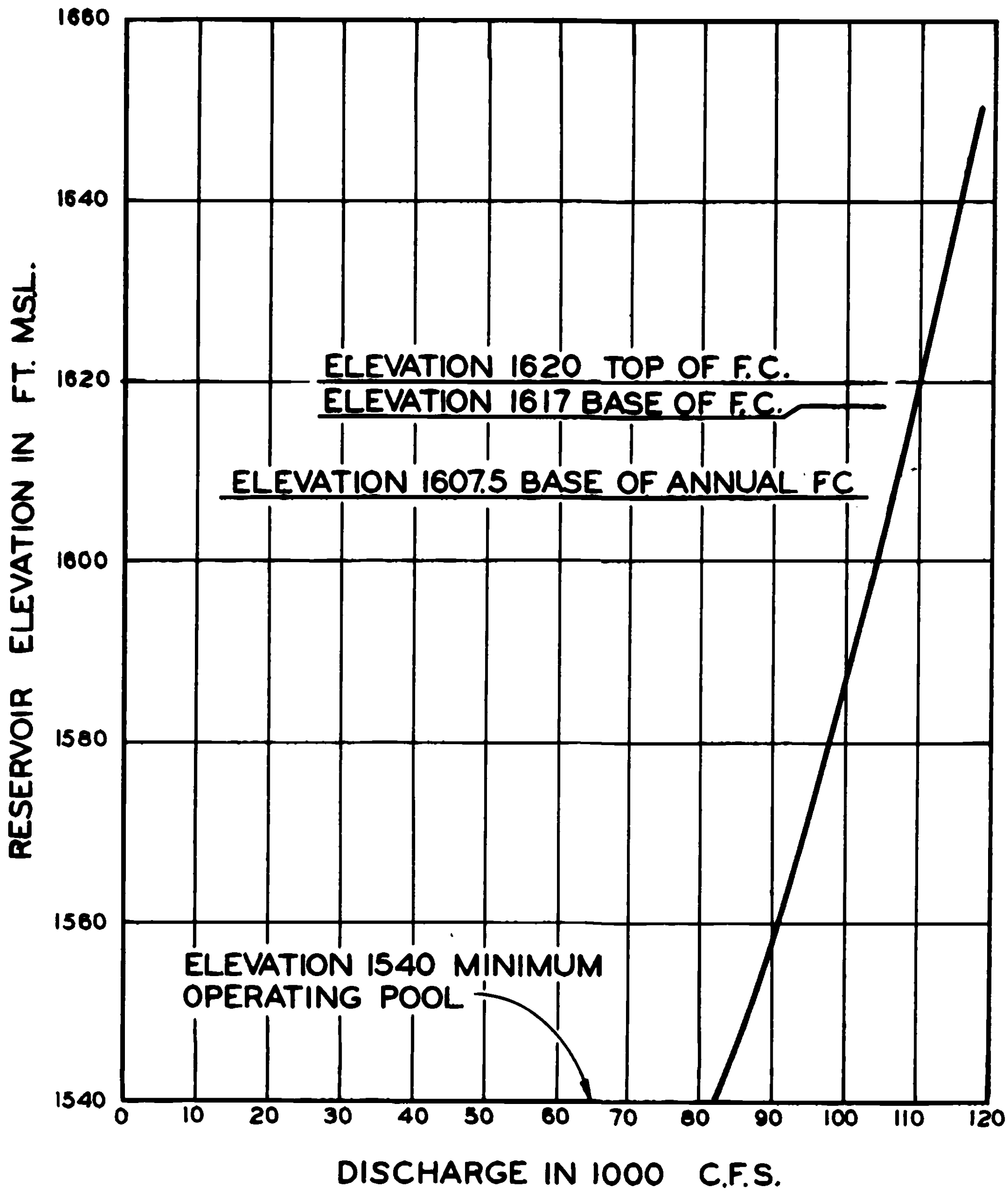


EMBANKMENT SECTION

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

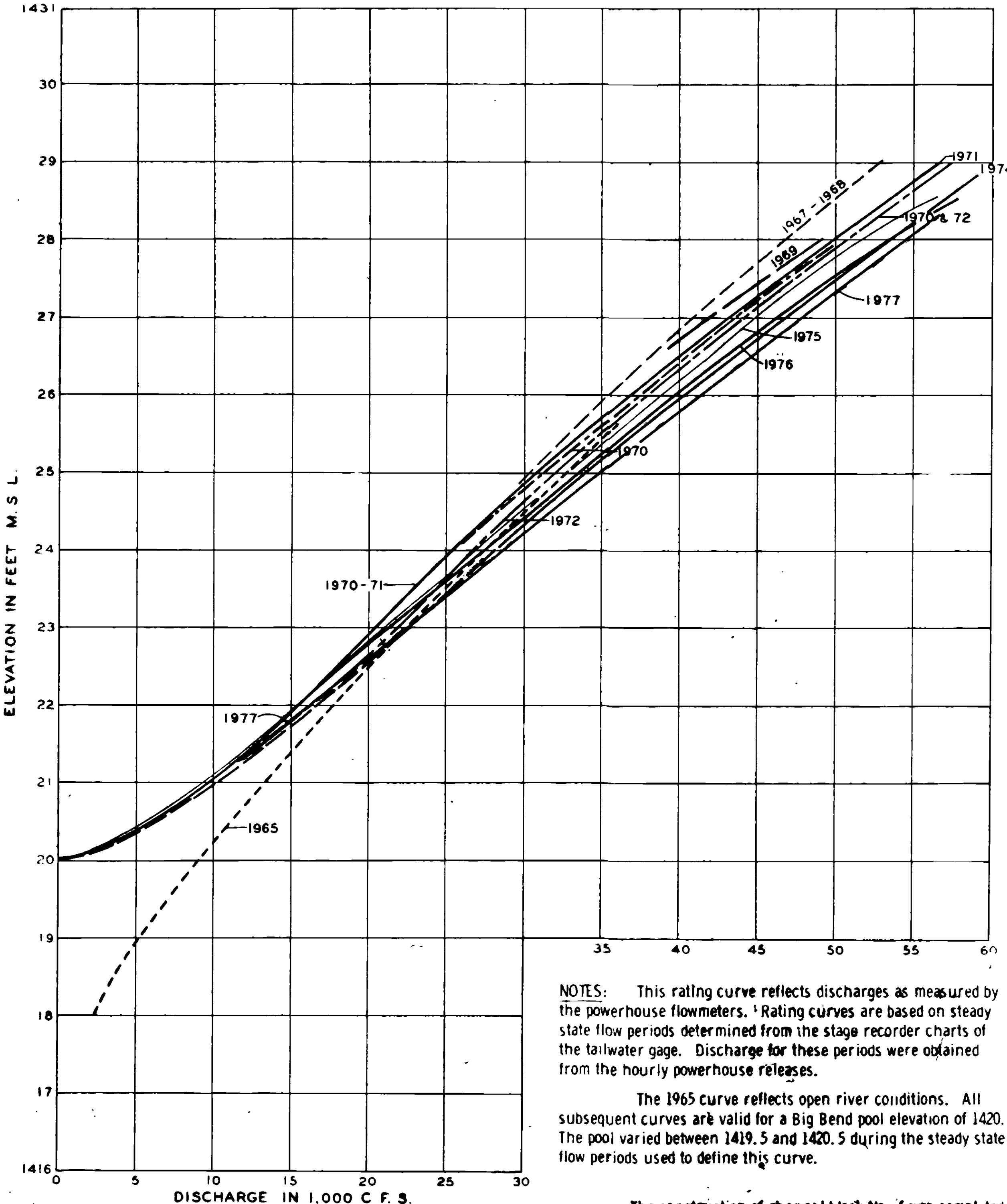


SPILLWAY RATING CURVES
OAHE PROJECT



NOTE:
CURVE REPRESENTS TOTAL DISCHARGE CAPABILITY OF 6 TUNNELS.

OUTLET WORKS RATING CURVE
OAHE DAM & RESERVOIR

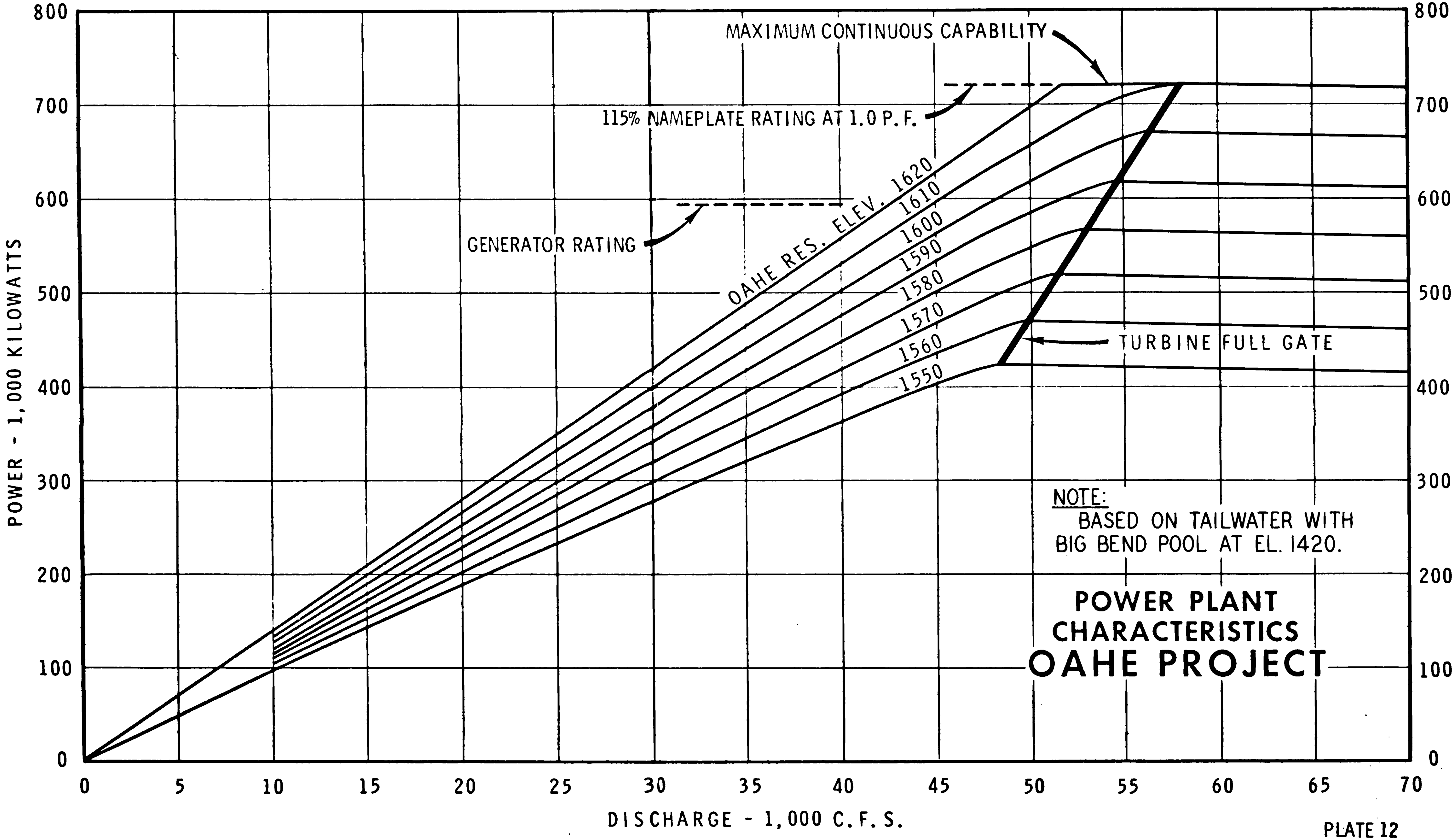


NOTES: This rating curve reflects discharges as measured by the powerhouse flowmeters. Rating curves are based on steady state flow periods determined from the stage recorder charts of the tailwater gage. Discharge for these periods were obtained from the hourly powerhouse releases.

The 1965 curve reflects open river conditions. All subsequent curves are valid for a Big Bend pool elevation of 1420. The pool varied between 1419.5 and 1420.5 during the steady state flow periods used to define this curve.

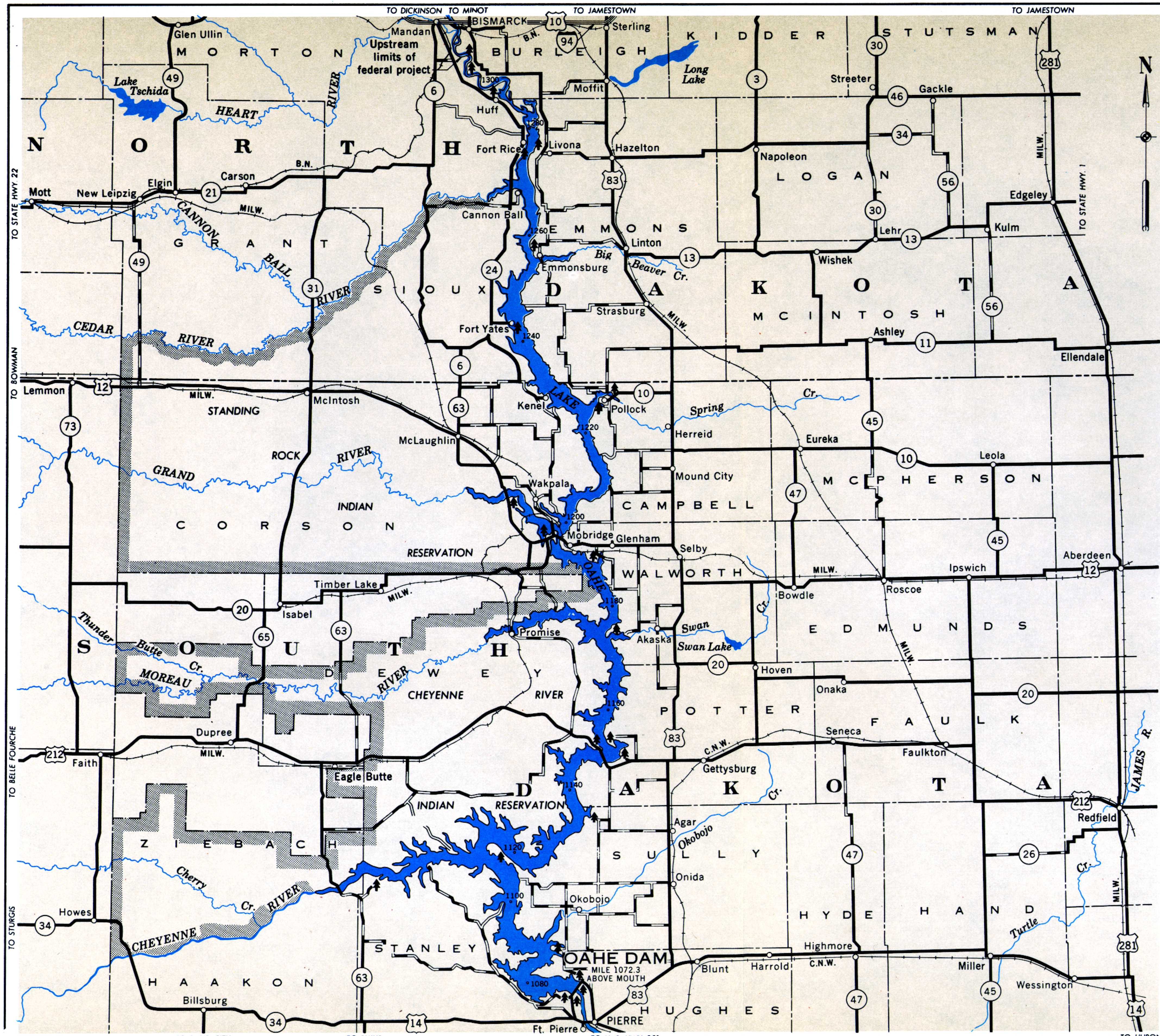
The construction of channel block No. 6 was completed 15 June 1967. An extension of channel block No. 6 to River Island was completed 12 July 1970.

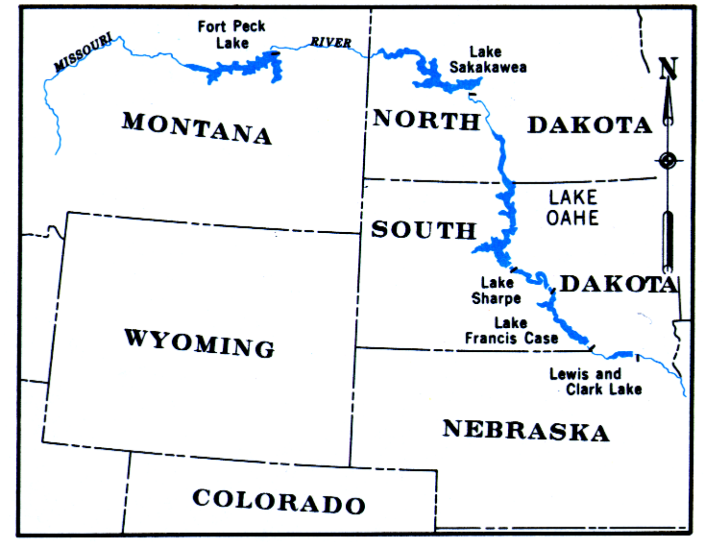
OAHE PROJECT
POWERHOUSE
TAILWATER RATING CURVES
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA



POWER PLANT CHARACTERISTICS

OAHE PROJECT





LOCATION MAP

↑ Recreation area

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

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

SCALE IN MILES
10 0 10 20

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

OAHE PROJECT

EFFECTIVE 1 JAN 1981

AREA IN ACRES

(1976 SURVEY)

ELEV	0	1	2	3	4	5	6	7	8	9
1410	0	0	0	0	0	0	0	18	27	34
1420	94	157	219	379	637	922	1152	1382	1680	2044
1430	2425	2768	3114	3508	3951	4404	4826	5254	5726	6243
1440	6754	7223	7719	8296	8955	9624	10234	10864	11586	12400
1450	13257	14079	14876	15685	16506	17323	18126	18941	19788	20661
1460	21539	22394	23258	24160	25098	26035	26938	27860	28844	29888
1470	30977	32059	33101	34101	35058	36013	37000	37974	38895	39742
1480	40571	41366	42226	43182	44235	45304	46311	47332	48448	49653
1490	50921	52171	53370	54525	55637	56737	57861	58985	60081	61150
1500	62188	63220	64285	65398	66557	67727	68869	70034	71198	72421
1510	73665	74897	76114	77328	78539	79768	81019	82241	83400	84497
1520	85492	86436	87508	88795	90296	91833	93226	94656	96303	98167
1530	100162	102108	103947	105718	107420	109099	110809	112527	114218	115879
1540	117493	119084	120734	122483	124329	126223	128084	129913	131747	133584
1550	135339	137007	138801	140850	143154	145505	147691	149912	152374	155075
1560	157881	160591	163245	165946	168695	171441	174143	176871	179681	182574
1570	185464	188282	191139	194131	197257	200364	203339	206399	209722	213306
1580	217121	220949	224540	227832	230825	233806	237025	240137	242835	245120
1590	246996	248807	251059	253918	257383	261018	264320	267617	271312	275405
1600	279626	283643	287634	291837	296253	300644	304832	309147	313856	318959
1610	324309	329577	334639	339553	344320	349018	353772	358566	363341	368097
1620	372842	377591	382350	387115	391886	396660	401432	406202	410971	415741
1630	420512									

OAHE PROJECT

EFFECTIVE 1 JAN 1981

CAPACITY IN ACRE-FEET

(1976 SURVEY)

ELEV	0	1	2	3	4	5	6	7	8	9
1410	0	0	0	0	0	0	0	13	36	67
1420	104	255	418	693	1177	1968	3021	4272	5786	7632
1430	9875	12483	15412	18711	22428	26613	31237	36266	41745	47719
1440	54231	61227	68678	76665	85270	94575	104518	115044	126246	138216
1450	151047	164731	179205	194483	210576	227496	245223	263749	283105	303321
1460	324427	346399	369216	392916	417536	443113	469606	496990	525327	554678
1470	585104	616633	649223	682835	717425	752952	789452	826953	865401	904743
1480	944926	985886	1027658	1070338	1114023	1158808	1204632	1251431	1299297	1348324
1490	1398604	1450166	1502947	1556906	1611998	1668181	1725473	1783904	1843444	1904067
1500	1965744	2028444	2092185	2157015	2222981	2290130	2358436	2427868	2498464	2570264
1510	2643307	2717595	2793102	2869824	2947759	3026902	3107295	3188941	3271778	3355742
1520	3440773	3526727	3613645	3701743	3791235	3882336	3974902	4068789	4164214	4261395
1530	4360548	4461719	4564764	4669614	4776200	4884455	4994398	5106073	5219453	5334509
1540	5451212	5569494	5689381	5810965	5934347	6059624	6186794	6315792	6446621	6579286
1550	6713790	6849964	6987804	7127566	7269504	7413874	7560515	7709257	7860340	8014805
1560	8170491	8329767	8491673	8656257	8823566	8993648	9166448	9341934	9520190	9701297
1570	9885339	10072226	10261903	10454505	10650165	10849020	11050894	11255698	11463693	11675142
1580	11890306	12109385	12332205	12558466	12787869	13020116	13255482	13494167	13735757	13979838
1590	14225997	14473830	14723612	14975949	15231449	15490716	15753486	16019356	16288721	16561981
1600	16839532	17121233	17406818	17696501	17990493	18289007	18591781	18898672	19210075	19526384
1610	19847994	20175003	20507149	20844282	21186256	21532922	21884292	22240466	22601424	22967148
1620	23337619	23712833	24092802	24477533	24867032	25261305	25660352	26064169	26472756	26886112
1630	27304239									

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

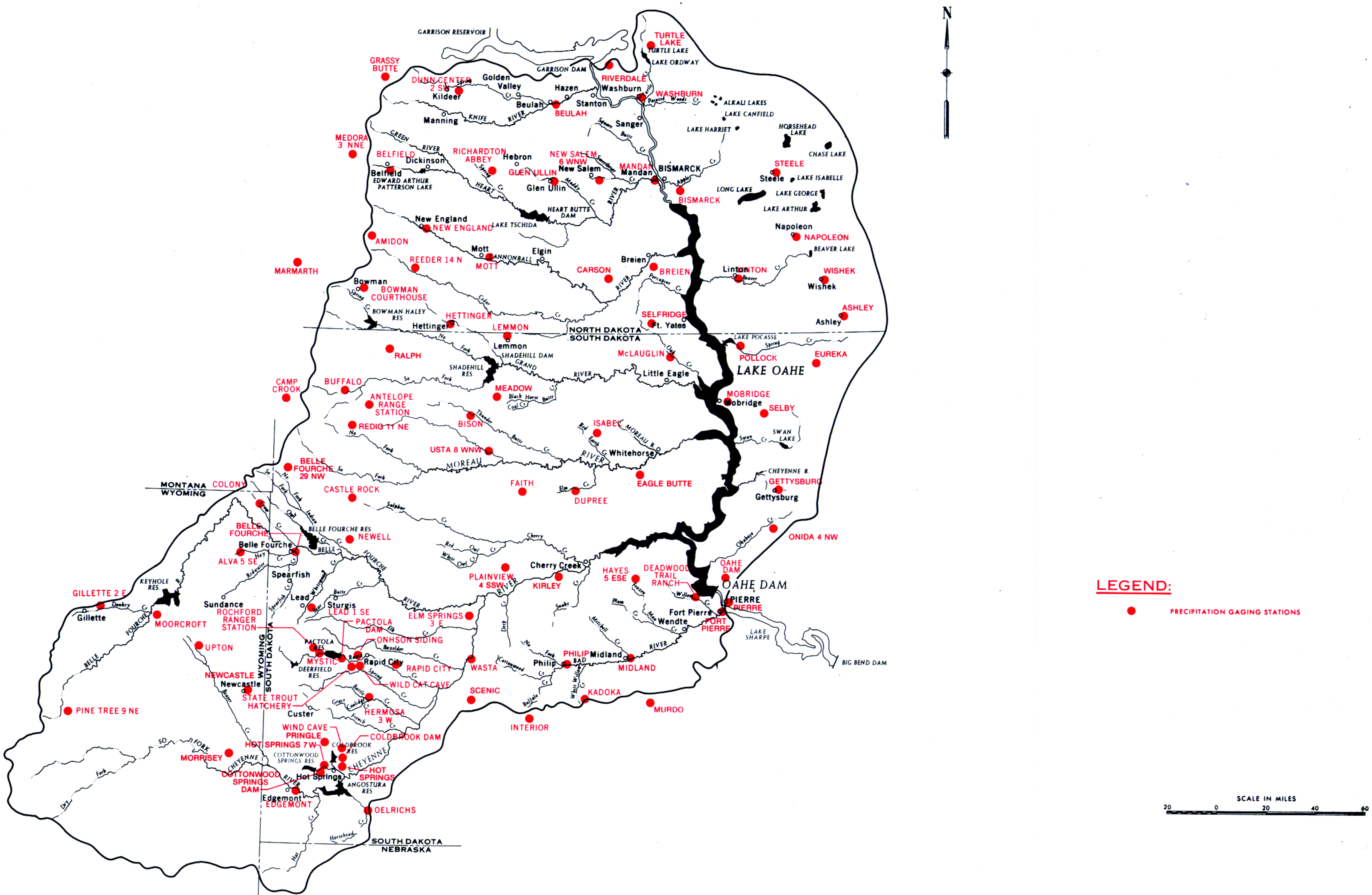
EFFECTIVE 1 JAN 1972

ELEV	0	1	2	3	4	5	6	7	8	9
1410	0	0	0	0	0	0	0	12	24	36
1420	213	405	477	607	796	1044	1350	1715	2140	2622
1430	3073	3399	3685	4019	4403	4834	5314	5444	6422	7048
1440	7626	8065	8473	8951	9500	10120	10810	11570	12402	13303
1450	14197	14989	15730	16487	17262	18055	18865	19692	20536	21398
1460	22222	22964	23697	24483	25322	26213	27158	28155	29205	30309
1470	31424	32491	33517	34533	35537	36530	37513	38484	39445	40395
1480	41312	42194	43087	44023	44999	46017	47077	48179	49323	50508
1490	51702	52856	53978	55094	56201	57301	58394	59480	60558	61629
1500	62671	63678	64694	65747	66838	67966	69132	70335	71577	72855
1510	74123	75326	76502	77696	78910	80141	81390	82658	83945	85250
1520	86466	87520	88570	89741	91032	92444	93977	95630	97404	99298
1530	101200	102959	104626	106297	107971	109648	111327	113010	114695	116383
1540	118002	119511	121026	122632	124330	126120	128002	129975	132041	134199
1550	136236	137961	139643	141490	143508	145695	148054	150584	153283	156153
1560	158922	161312	163587	166016	168600	171337	174229	177275	180475	183830
1570	187156	190240	193213	196239	199320	202455	205644	208888	212185	215538
1580	218940	222349	225713	229017	232259	235441	238562	241622	244623	247563
1590	250343	252957	255634	258515	261599	264888	268380	272077	275978	280083
1600	284052	287545	290901	294463	298227	302195	306368	310745	315325	320110
1610	324827	329176	333380	337698	342128	346668	351321	356086	360963	365952
1620	370950	375818	380602	385385	390169	394953	399736	404520	409304	414087
1630	418870	421198	423873	429350	435347	441802	447591	453341	460229	468255
1640	477063	485705	493648	500952	507616	513960	520518	527289	534059	540830
1650	547600									

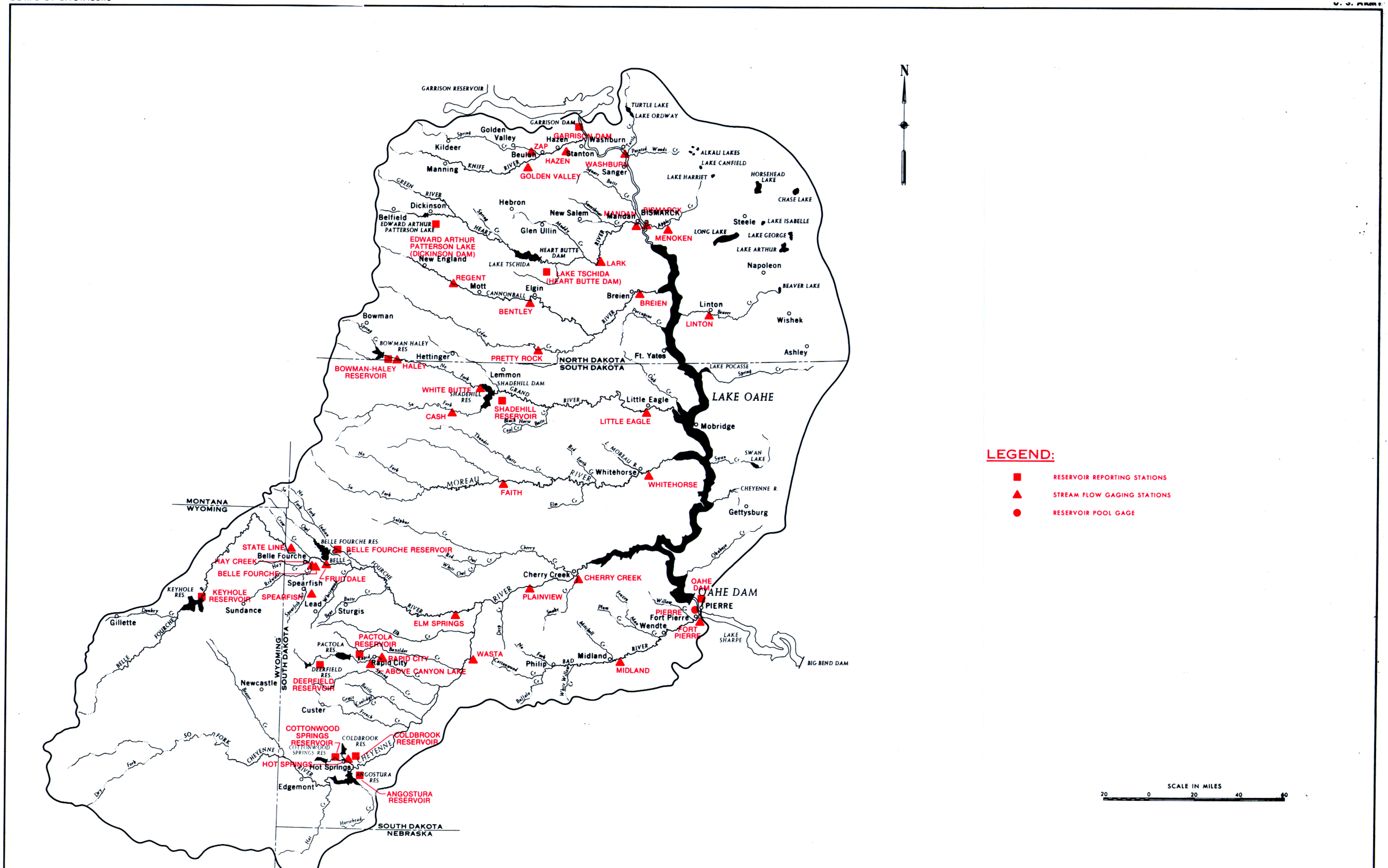
OAHE PROJECT
CAPACITY IN ACRE-FEET
(1968 SURVEY)

EFFECTIVE 1 JAN 1972

ELEV	0	1	2	3	4	5	6	7	8	9
1410	0	0	0	0	0	0	0	6	24	55
1420	97	481	908	1435	2122	3027	4210	5728	7641	10008
1430	12886	16154	19684	23524	27723	32330	37392	42959	49080	55803
1440	63177	71055	79307	88001	97210	107002	117450	128622	140591	153426
1450	167197	181820	197176	213280	230151	247805	266261	285535	305645	326608
1460	348442	371053	394370	418447	443336	469091	495763	523407	552074	581818
1470	612692	644667	677674	711702	746740	782776	819801	857802	896770	936693
1480	977560	1019318	1061948	1105493	114994	1195492	1242029	1289647	1338388	1388294
1490	1439405	1491699	1545118	1599656	1655306	1712059	1769909	1828848	1888869	1949965
1500	2012128	2075308	2139485	2204696	2270980	2338372	2406912	2476636	2547583	2619790
1510	2693294	2768037	2843947	2921041	2999340	3078861	3159622	3241642	3324939	3409533
1520	3495440	3582465	3670481	3759606	3849963	3941671	4034851	4129625	4226112	4324433
1530	4424708	4526834	4630626	4736087	4843221	4952030	5062517	5174685	5288537	5404075
1540	5521303	5640080	5760326	5882132	6005590	6130792	6257831	6386797	6517782	6650879
1550	6786180	6923352	7062114	7202638	7345095	7489654	7636486	7785763	7937654	8092330
1560	8249961	8410175	8572586	8737349	8904619	9074549	9247293	9423007	9601844	9783958
1570	9969504	10158271	10349985	10544697	10742463	10943337	11147373	11354626	11565150	11778997
1580	11996226	12216878	12440925	12668305	12898959	13132824	13369841	13609948	13853086	14099195
1590	14348212	14599882	14854127	15111151	15371157	15634350	15900933	16171111	16445088	16723067
1600	17005254	17291172	17580344	17872975	18169270	18469430	18773661	19082167	19395151	19712818
1610	20035371	20362473	20693723	21029234	21369120	21713490	22062456	22416132	22774629	23138059
1620	23506534	23879960	24258171	24641164	25028941	25421503	25818848	26220976	26627888	27039984
1630	27456063	27877324	28298460	28725070	29157160	29595764	30040765	30490946	30947447	31411405
1640	31883958	32365532	32855369	33352829	33857274	34368062	34885195	35409098	35939773	36477217
1650	37021433									



OAHE RESERVOIR
INCREMENTAL DRAINAGE AREA BETWEEN
GARRISON DAM AND BELOW MOUTH OF BAD RIVER
KEY PRECIPITATION STATIONS



OAHE RESERVOIR

INCREMENTAL DRAINAGE AREA BETWEEN GARRISON DAM AND BELOW MOUTH OF BAD RIVER

KEY STREAM GAGING STATIONS

STAGE-DISCHARGE TABLE FOR
KEY GAGING STATIONS BETWEEN
GARRISON DAM AND BIG BEND DAM

Gage Height	Knife R. at Hazen N.D.	Missouri River at Bismarck N.D.	Heart River Near Mandan N.D.	Cedar Creek at Pretty Rock N.D.	Cannonball River at Bentley N.D.	Cannonball River at Breien N.D.	Grand River at Little Eagle S.D.	Moreau River at Faith S.D.	Moreau River Near Whitehorse S.D.	Cheyenne River Near Wasta S.D.	Belle Fourche River Near Elm Springs S.D.	Cheyenne River at Cherry Creek S.D.	Bad River at Fort Pierre S.D.	Bad River at Midland S.D.
	Gage Datum	Gage Datum	Gage Datum	Gage Datum	Gage Datum	Gage Datum	Gage Datum	Gage Datum	Gage Datum	Gage Datum	Gage Datum	Gage Datum	Gage Datum	Gage Datum
	1712.4 MSL	1618.4 MSL	1638.7 MSL	2155.2 MSL	2252.1 MSL	1676.5 MSL	1625.7 MSL	2238.7 MSL	1661.5 MSL	2262.8 MSL	2171.6 MSL	1699.3 MSL	1427.8 MSL	1333.4 MSL
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	135	5,600	0	0	20	300	0	7	70	370	480	244	0	0
4	400	10,200	40	195	260	1,600	202	298	618	2,060	2,240	1,730	414	34
6	790	18,200	400	850	670	3,100	1,140	980	1,580	4,820	5,450	4,800	700	381
8	1,300	26,800	1,500	1,550	1,340	4,800	2,860	2,210	2,580	8,900	10,260	9,640	1,440	920
10	1,900	36,500	4,000	2,300	2,200	6,800	5,900	3,810	3,760	14,380	16,800	16,400	2,450	1,580
12	2,500	49,000	5,500	3,200	3,200	9,800	8,840	6,045	5,020		24,700		3,650	2,360
14	3,400	66,500	8,000	4,300	4,300	14,800		8,620	6,430		35,000			3,260
16	4,300	80,500	10,000		5,500	24,000			8,190					
18	5,300	100,500	13,500		6,830	41,000			10,880					
20		140,000	17,000		9,100	66,000			14,400					
22		180,000	22,000			92,000								
24		240,000	32,000											
26														
28														
30														
	1977 MRO Flood Study	1977 MRO Flood Study	1977 MRO Flood Study	1977 USGS Rating Table	1977 USGS Rating Table	1977 MRO Flood Study	1976 USGS Rating Table	1971 USGS Rating Table	1975 USGS Rating Table	1975 USGS Rating Table	1975 USGS Rating Table	1975 USGS Rating Table	1975 USGS Rating Table	1975 USGS Rating Table

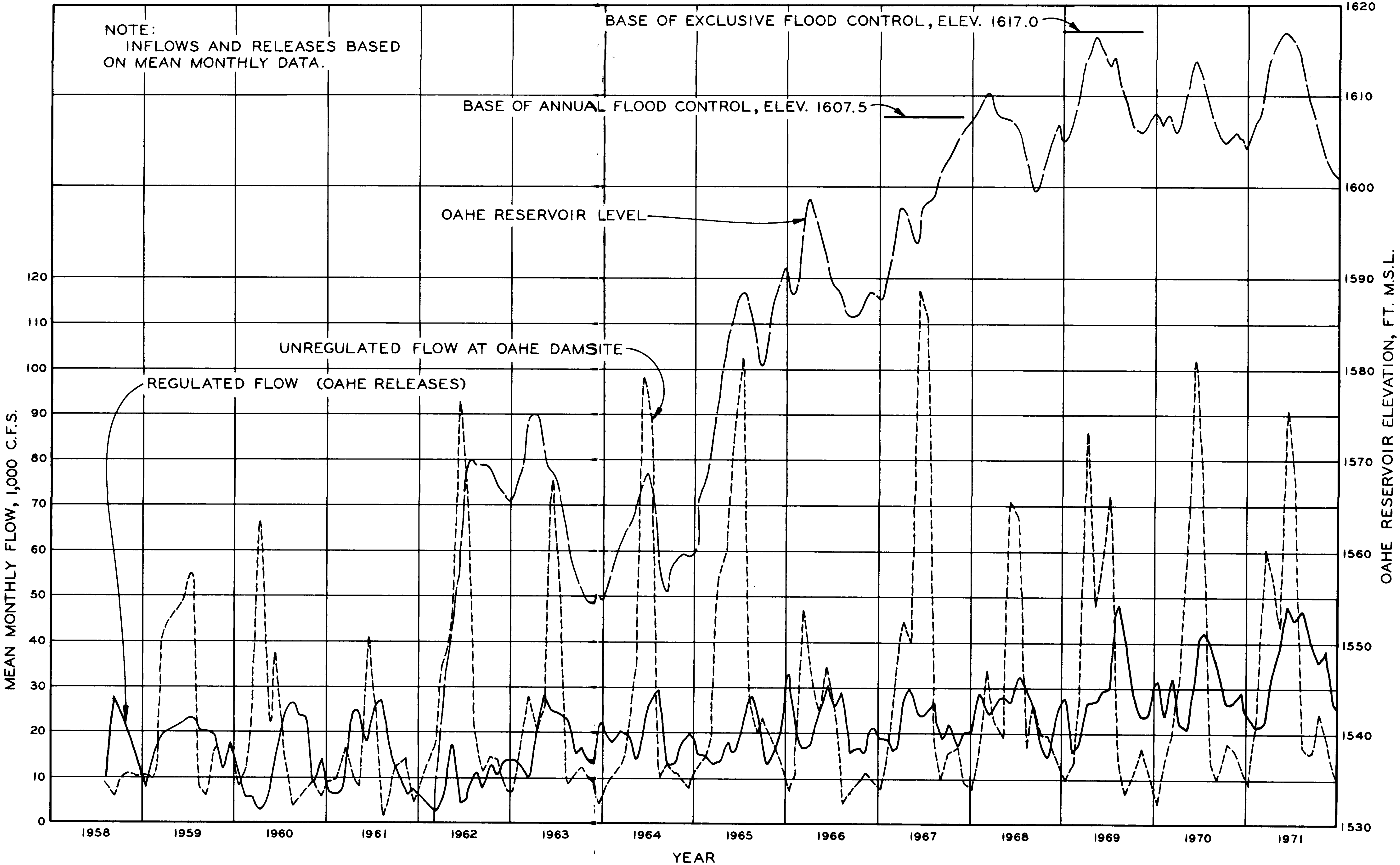
RESERVOIR ELEVATION CORRECTIONS AT THE OAHE DAM
TO ALLOW FOR WIND TIDE EFFECTS

ELEVATION 1620 M. S. L.

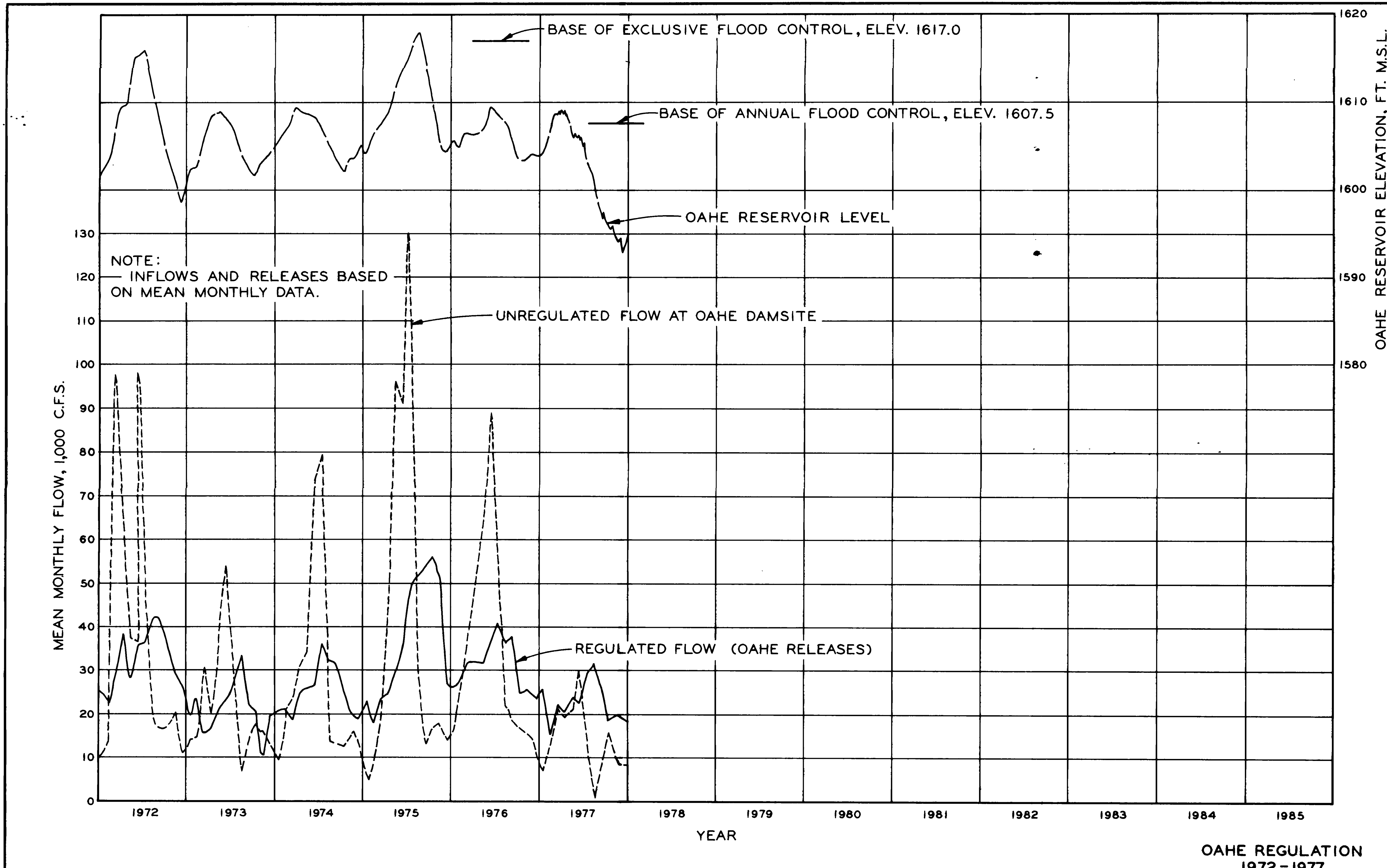
(TRUE ELEVATION = REPORTED POOL ELEVATION + CORRECTION)

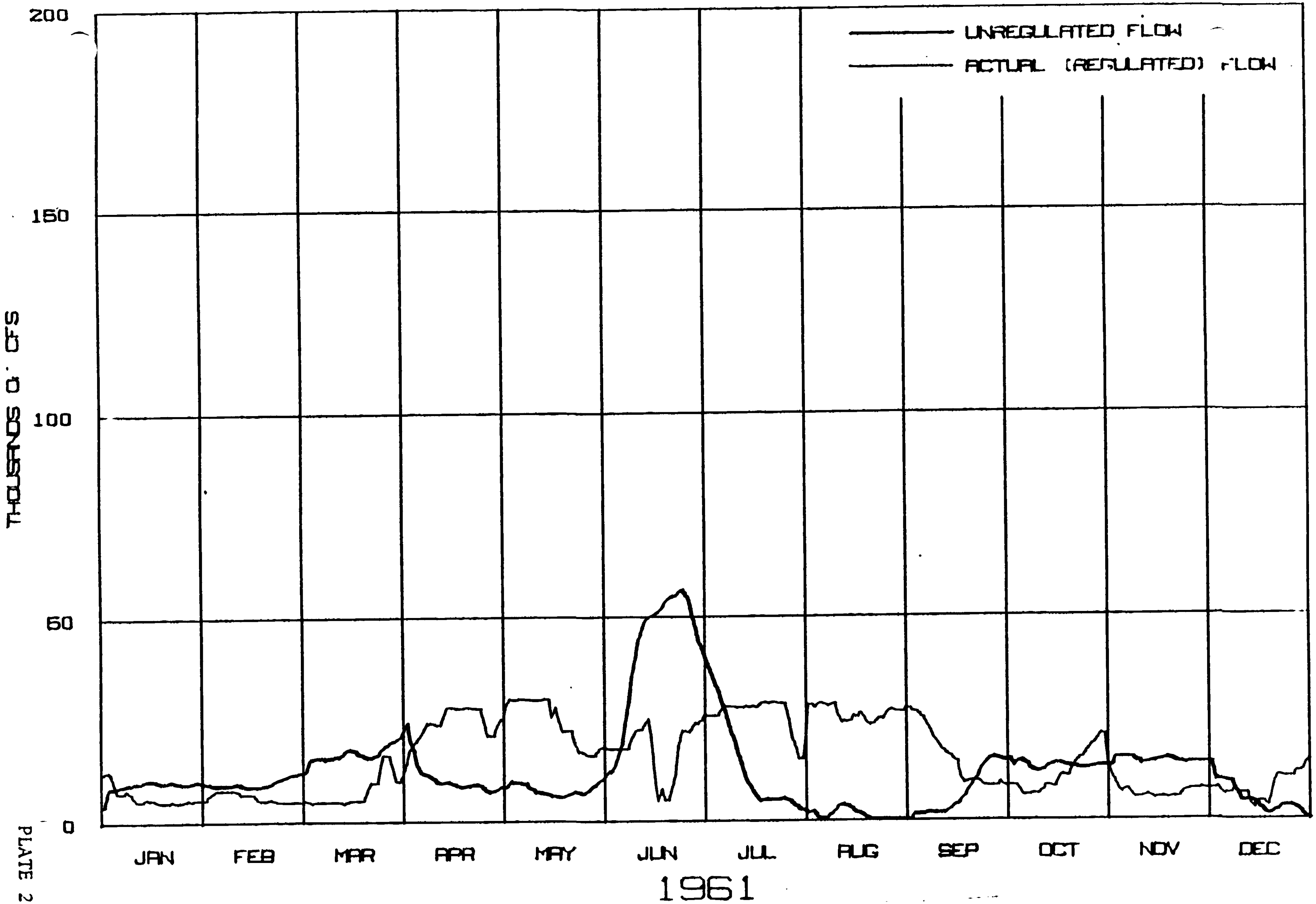
WIND SPEED - MILES HOUR

ND DIR.	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70
360	-0.0	-0.0	-0.1	-0.1	-0.3	-0.4	-0.6	-0.9	-1.4	-2.0	-2.8	-3.5	-4.4	-5.3	-6.2
10	-0.0	-0.0	-0.0	-0.1	-0.2	-0.4	-0.5	-0.9	-1.4	-2.0	-2.7	-3.5	-4.3	-5.2	-6.0
20	-0.0	-0.0	-0.0	-0.1	-0.2	-0.3	-0.5	-0.8	-1.3	-1.8	-2.5	-3.3	-4.1	-5.0	-5.8
30	-0.0	-0.0	-0.0	-0.1	-0.2	-0.3	-0.4	-0.7	-1.1	-1.6	-2.2	-2.9	-3.7	-4.5	-5.3
40	-0.0	-0.0	-0.0	-0.1	-0.2	-0.3	-0.4	-0.6	-0.9	-1.3	-1.9	-2.5	-3.2	-3.8	-4.7
50	-0.0	-0.0	-0.0	-0.1	-0.1	-0.3	-0.3	-0.4	-0.6	-1.0	-1.4	-1.9	-2.5	-3.1	-3.7
60	-0.0	-0.0	-0.0	-0.1	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.9	-1.3	-1.7	-2.1	-2.7
70	-0.0	-0.0	-0.0	-0.0	-0.1	-0.1	-0.2	-0.3	-0.3	-0.4	-0.5	-0.6	-0.9	-1.2	-1.5
80	-0.0	-0.0	-0.0	-0.0	-0.0	-0.1	-0.1	-0.1	-0.1	-0.2	-0.3	-0.3	-0.4	-0.4	-0.5
90	-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
100	+0.0	+0.0	+0.0	+0.0	+0.1	+0.1	+0.2	+0.3	+0.4	+0.5	+0.6	+0.8	+0.9	+1.1	+1.3
110	+0.0	+0.0	+0.0	+0.1	+0.1	+0.3	+0.4	+0.6	+0.8	+1.0	+1.3	+1.5	+1.8	+2.2	+2.5
120	+0.0	+0.0	+0.0	+0.1	+0.3	+0.4	+0.6	+0.9	+1.2	+1.5	+1.9	+2.3	+2.8	+3.2	+3.7
130	+0.0	+0.0	+0.1	+0.2	+0.3	+0.6	+0.9	+1.2	+1.5	+2.0	+2.5	+3.0	+3.5	+4.0	+4.6
140	+0.0	+0.0	+0.1	+0.2	+0.4	+0.7	+1.0	+1.4	+1.8	+2.3	+3.0	+3.5	+4.1	+4.7	+5.4
150	+0.0	+0.0	+0.1	+0.3	+0.5	+0.8	+1.2	+1.6	+2.1	+2.6	+3.3	+3.9	+4.5	+5.3	+6.0
160	+0.0	+0.0	+0.1	+0.3	+0.5	+0.9	+1.3	+1.7	+2.3	+2.9	+3.5	+4.2	+4.9	+5.7	+6.6
170	+0.0	+0.0	+0.1	+0.3	+0.6	+0.9	+1.3	+1.8	+2.4	+3.0	+3.7	+4.3	+5.1	+5.9	+6.8
180	+0.0	+0.0	+0.1	+0.3	+0.6	+0.9	+1.4	+1.8	+2.5	+3.1	+3.7	+4.4	+5.2	+6.0	+6.9
190	+0.0	+0.0	+0.1	+0.3	+0.6	+0.9	+1.3	+1.8	+2.4	+3.0	+3.7	+4.3	+5.1	+5.9	+6.8
200	+0.0	+0.0	+0.1	+0.3	+0.5	+0.9	+1.3	+1.7	+2.3	+2.9	+3.5	+4.2	+4.9	+5.7	+6.6
210	+0.0	+0.0	+0.1	+0.3	+0.5	+0.8	+1.2	+1.6	+2.1	+2.6	+3.3	+3.9	+4.5	+5.3	+6.0
220	+0.0	+0.0	+0.1	+0.2	+0.4	+0.7	+1.0	+1.4	+1.8	+2.3	+3.0	+3.5	+4.1	+4.7	+5.4
230	+0.0	+0.0	+0.1	+0.2	+0.3	+0.6	+0.9	+1.2	+1.5	+2.0	+2.5	+3.0	+3.5	+4.0	+4.6
240	+0.0	+0.0	+0.0	+0.1	+0.3	+0.4	+0.6	+0.9	+1.2	+1.5	+1.9	+2.3	+2.8	+3.2	+3.7
250	+0.0	+0.0	+0.0	+0.1	+0.1	+0.3	+0.4	+0.6	+0.8	+1.0	+1.3	+1.5	+1.8	+2.2	+2.5
260	+0.0	+1.0	+0.0	+0.0	+0.1	+0.1	+0.2	+0.3	+0.4	+0.5	+0.6	+0.8	+0.9	+1.1	+1.3
270	-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
280	-0.0	-0.0	-0.0	-0.0	-0.0	-0.1	-0.1	-0.1	-0.1	-0.2	-0.3	-0.3	-0.4	-0.4	-0.5
290	-0.0	-0.0	-0.0	-0.0	-0.1	-0.1	-0.2	-0.3	-0.3	-0.4	-0.5	-0.6	-0.9	-1.2	-1.5
300	-0.0	-0.0	-0.0	-0.1	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.9	-1.3	-1.7	-2.1	-2.7
310	-0.0	-0.0	-0.0	-0.1	-0.1	-0.3	-0.3	-0.4	-0.6	-1.0	-1.4	-1.9	-2.5	-3.1	-3.7
320	-0.0	-0.0	-0.0	-0.1	-0.2	-0.3	-0.4	-0.6	-0.9	-1.3	-1.9	-2.5	-3.2	-3.8	-4.7
330	-0.0	-0.0	-0.0	-0.1	-0.2	-0.3	-0.4	-0.7	-1.1	-1.6	-2.2	-2.9	-3.7	-4.5	-5.3
340	-0.0	-0.0	-0.0	-0.1	-0.2	-0.3	-0.5	-0.8	-1.3	-1.8	-2.5	-3.3	-4.1	-5.0	-5.8
[illegible]	-0.0	-0.0	-0.0	-0.1	-0.2	-0.4	-0.5	-0.9	-1.4	-2.0	-2.7	-3.5	-4.3	-5.2	-6.0



OAHE REGULATION
1958-1971

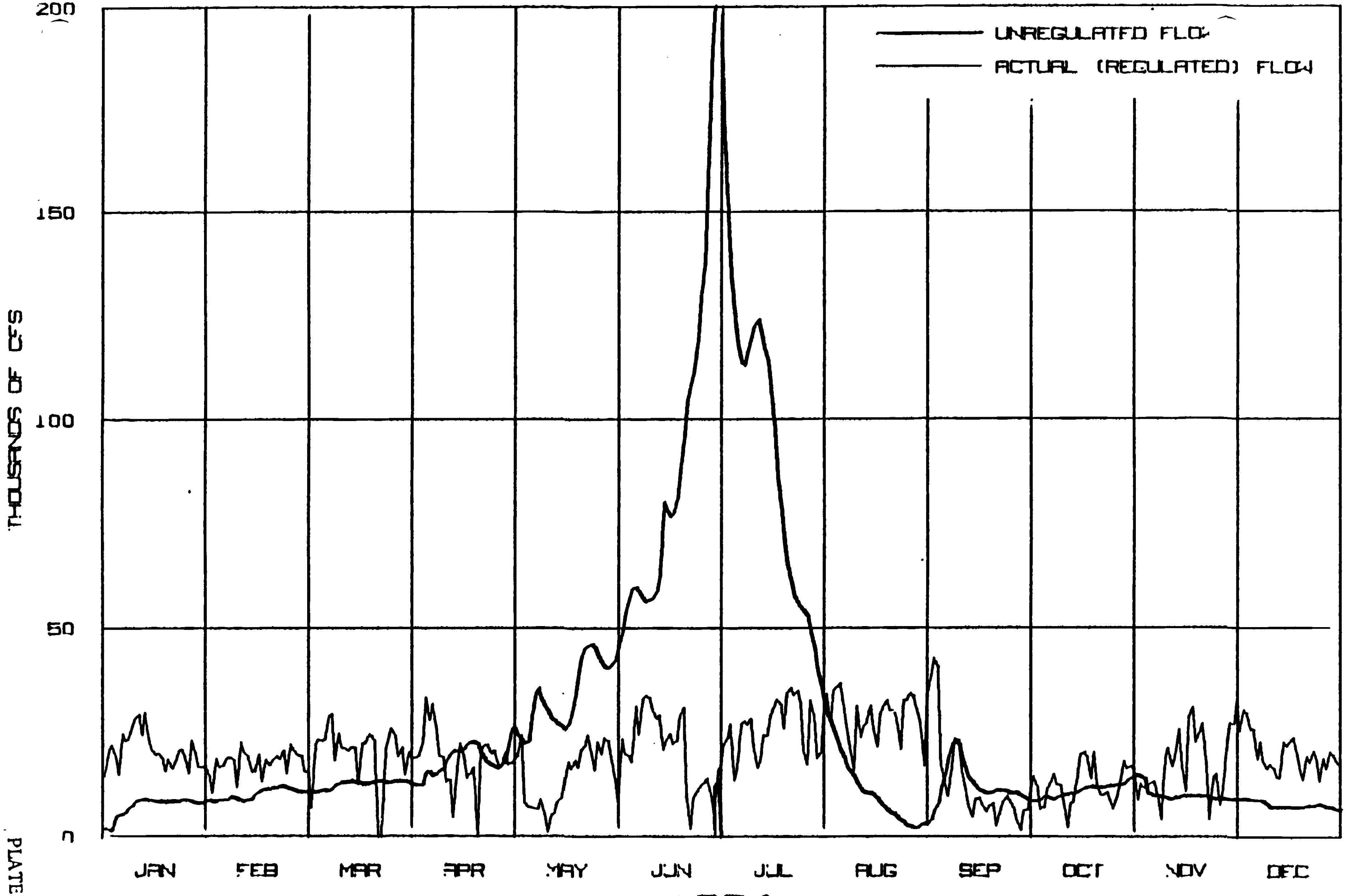

BASE OF EXCLUSIVE FLOOD CONTROL, ELEV. 1617.0
BASE OF ANNUAL FLOOD CONTROL, ELEV. 1607.5
OAHE RESERVOIR LEVEL
NOTE:
INFLOWS AND RELEASES BASED ON MEAN MONTHLY DATA.
UNREGULATED FLOW AT OAHE DAMSITE
REGULATED FLOW (OAHE RELEASES)
MEAN MONTHLY FLOW, 1,000 C.F.S.
OAHE RESERVOIR ELEVATION, FT. M.S.L.
0
10
20
30
40
50
60
70
80
90
100
110
120
130
1580
1590
1600
1610
1620
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
YEAR
OAHE REGULATION
1972 - 1977



ACTUAL AND UNREGULATED FLOWS

MISSOURI RIVER AT OAHE DAM

PLATE 21

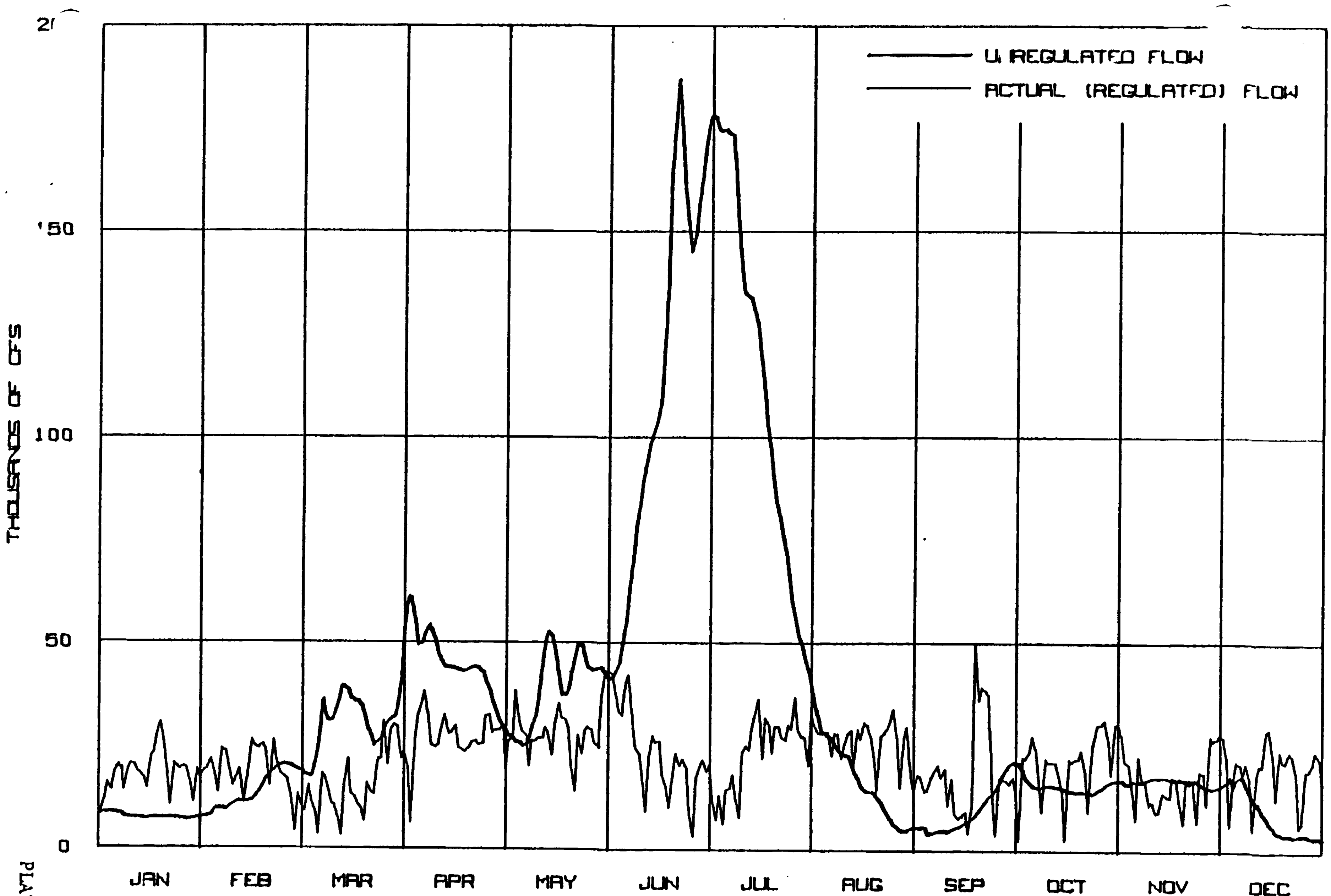


1964

ACTUAL AND UNREGULATED FLOWS

MISSOURI RIVER AT OAHE DAM

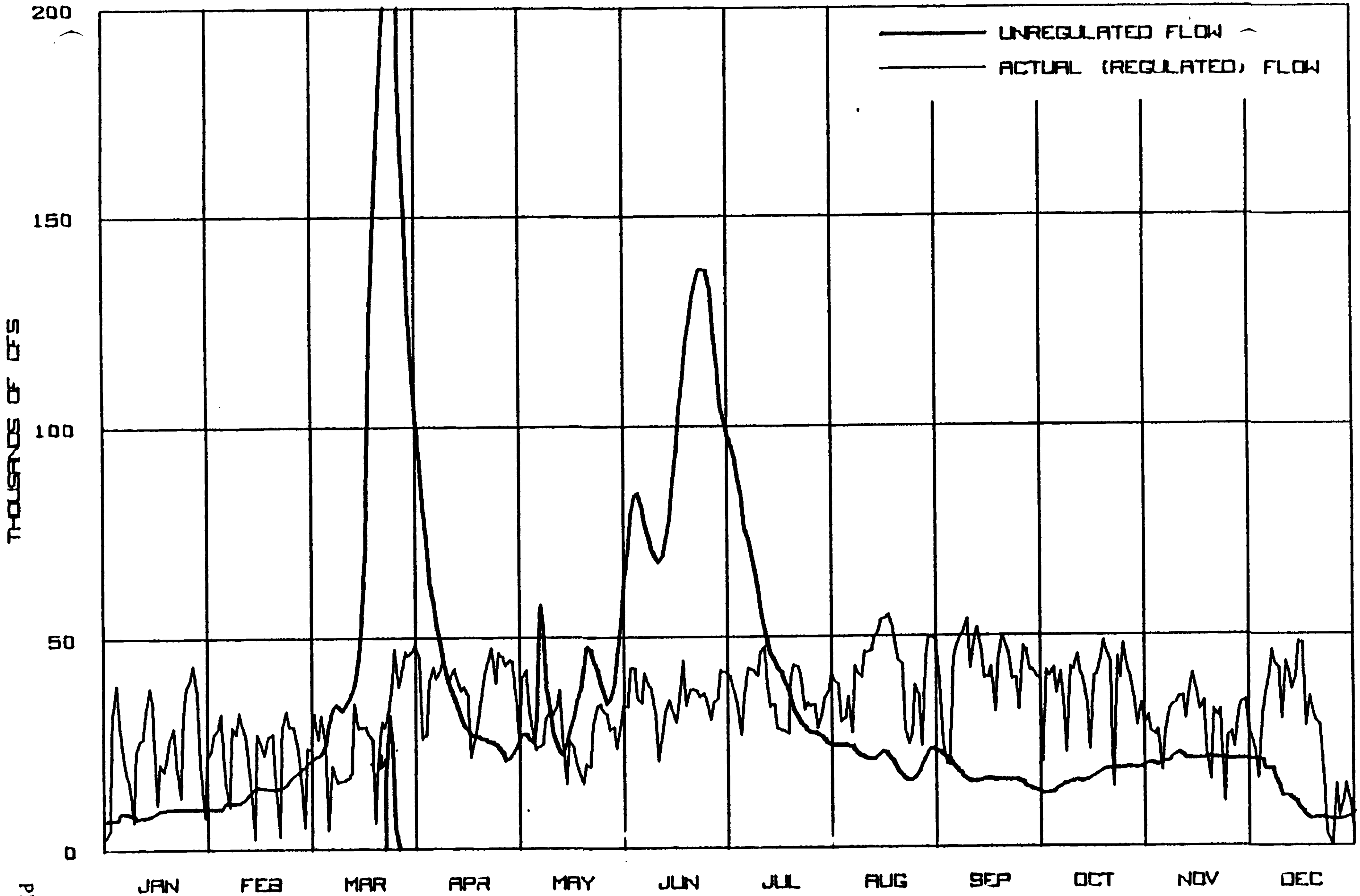
PLATE 22



ACTUAL AND UNREGULATED FLOWS

MISSOURI RIVER AT OAHE DAM

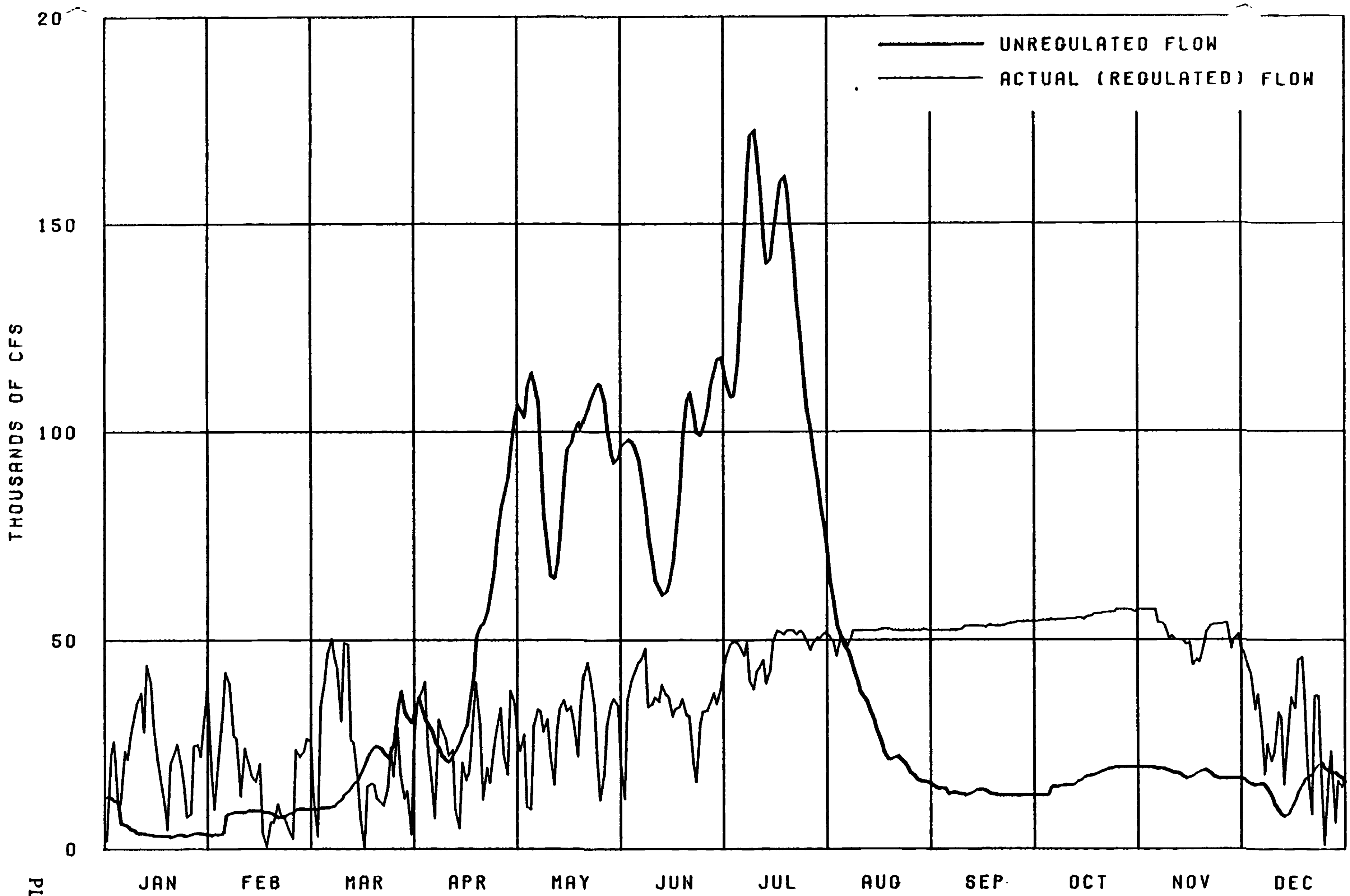
PLATE 23



1972

ACTUAL AND UNREGULATED FLOWS

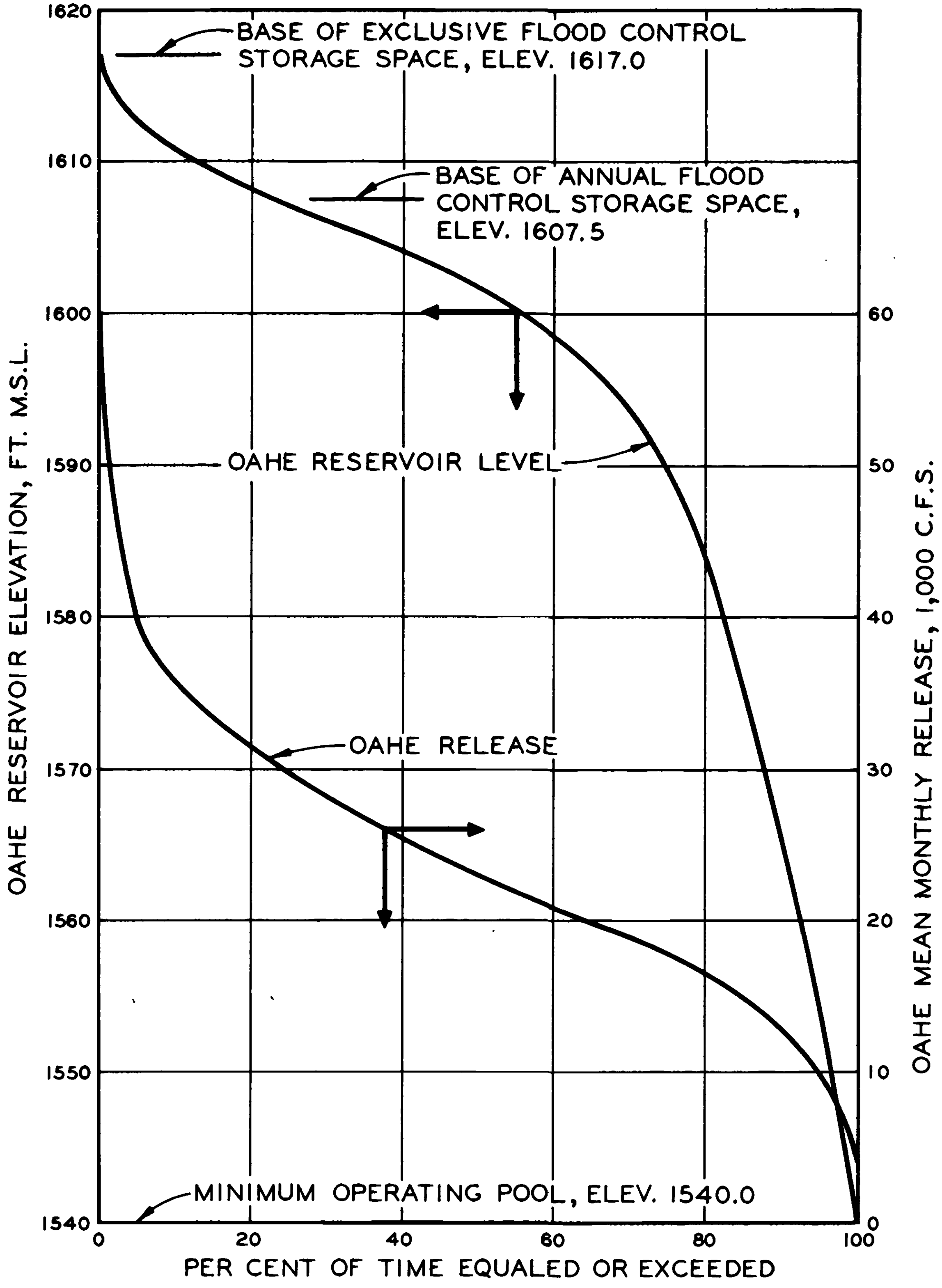
MISSOURI RIVER AT OAHE DAM



1975

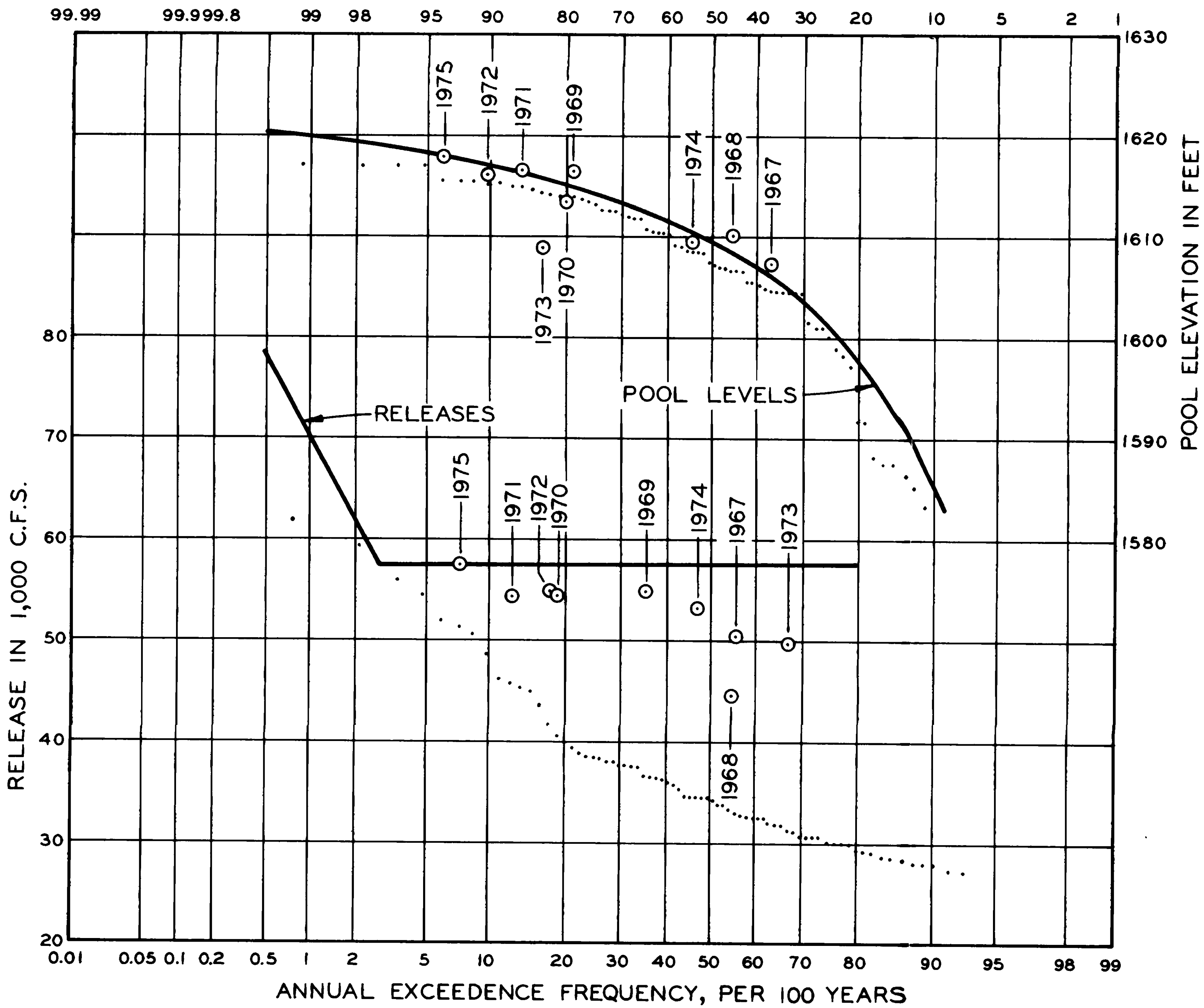
ACTUAL AND UNREGULATED FLOWS

MISSOURI RIVER AT OAHE DAM



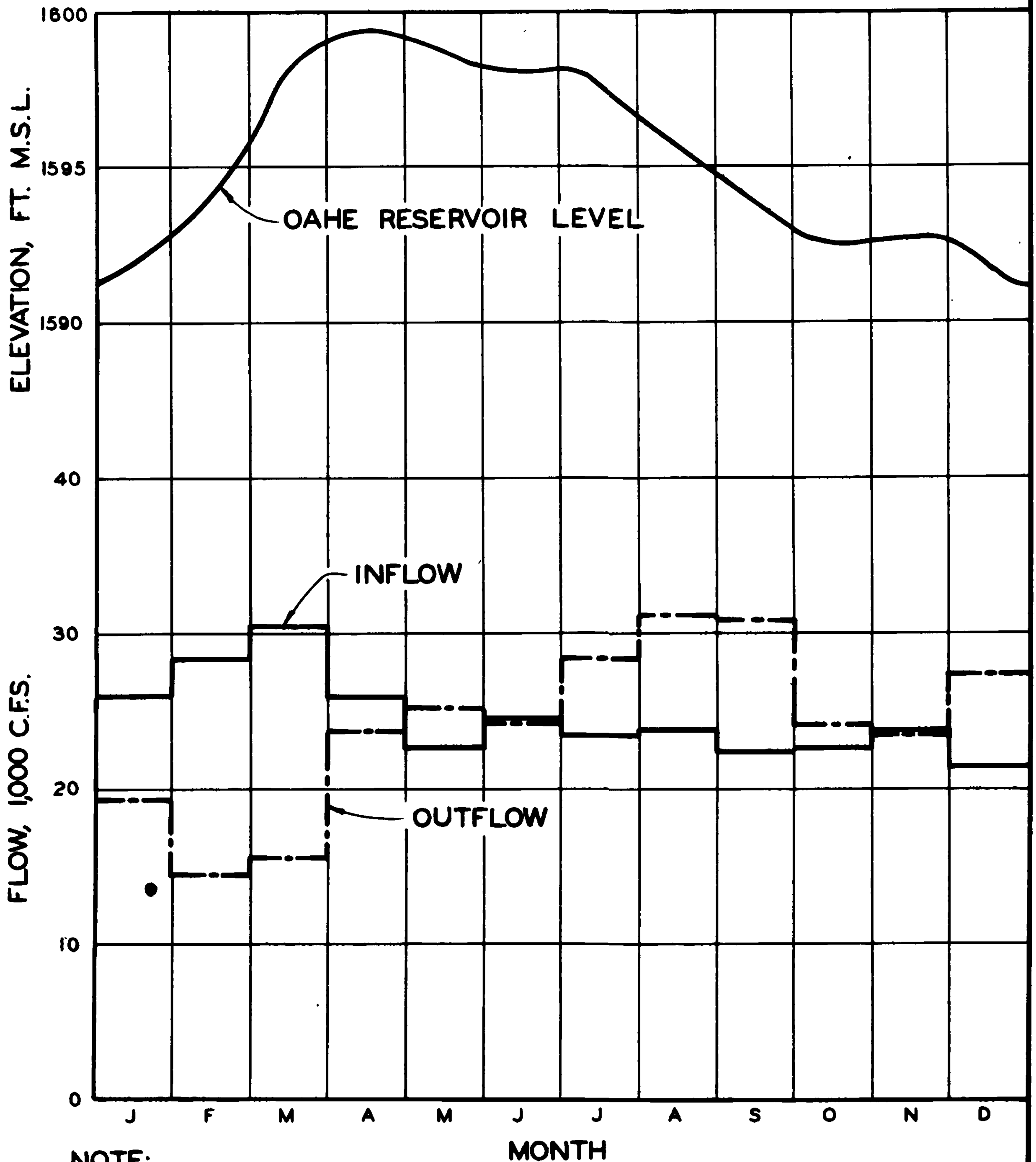
NOTE:
BASED ON 1975 LEVEL OF WATER RESOURCE DEVELOPMENT AS ANALYZED IN MRD-RCC STUDY, 2-76-1975

DURATION CURVES FOR
POOL LEVELS AND RELEASES
OAHE PROJECT



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.

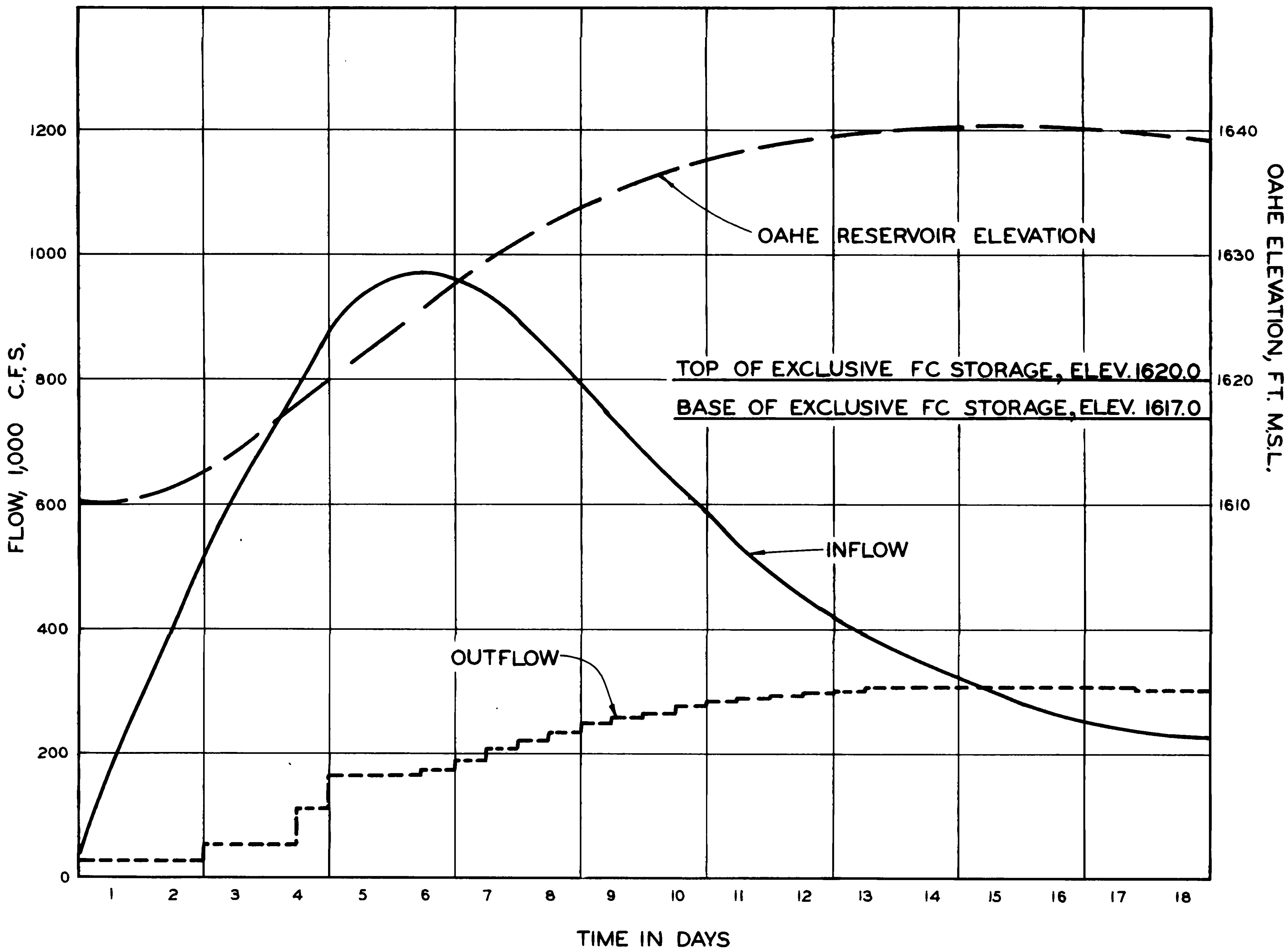
ANNUAL EXCEEDENCE FREQUENCY CURVES
FOR
MAXIMUM POOL LEVELS AND RELEASES
OAHE PROJECT



NOTE:
DATA FROM MRD-RCC
REGULATION STUDY, 2-26-1975.

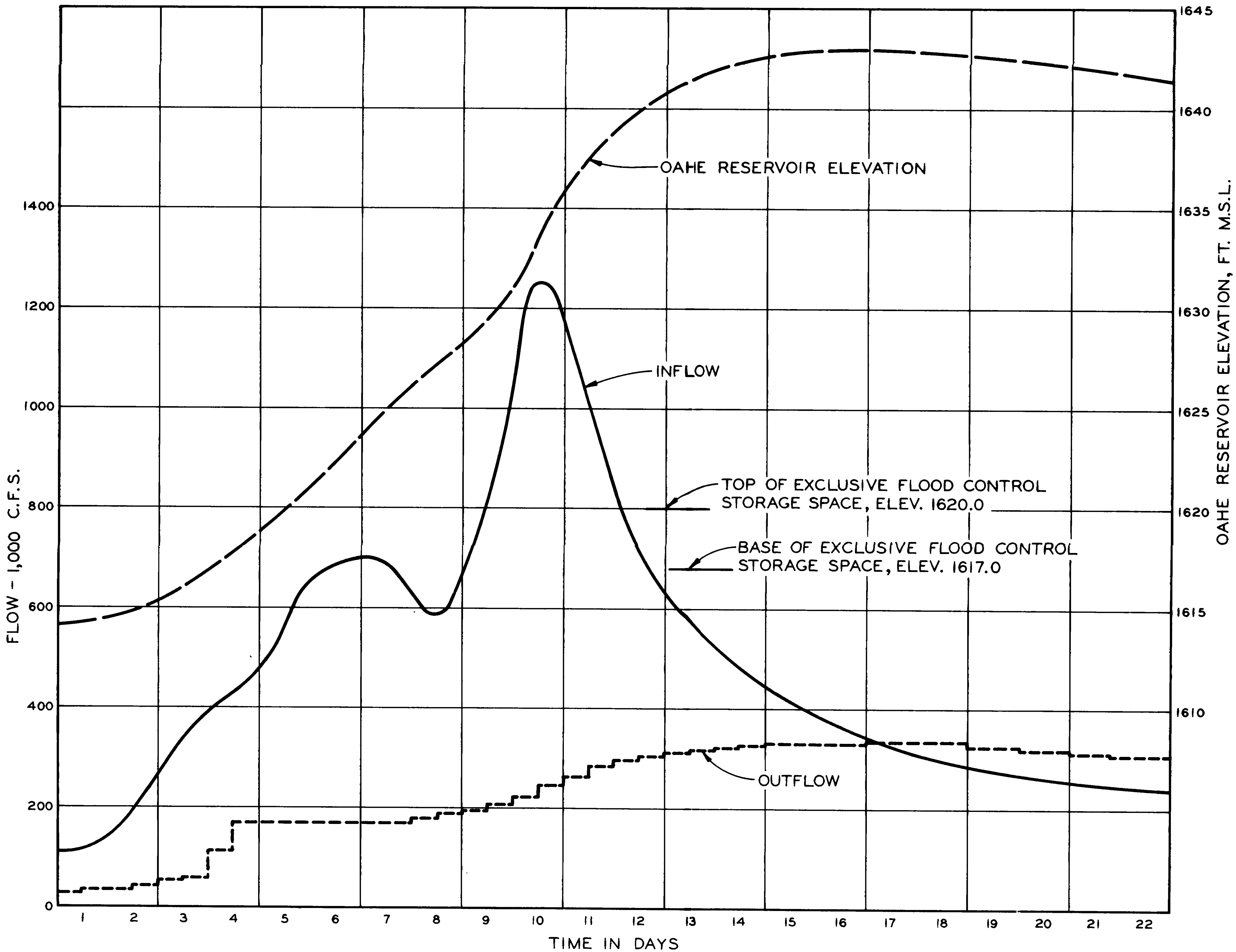
MONTHLY AVERAGE INFLOWS
OUTFLOWS AND RESERVOIR LEVELS
OAHE PROJECT

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



OAHE EMERGENCY REGULATION
MAXIMUM POSSIBLE
EARLY SPRING FLOOD

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



OAHE EMERGENCY REGULATION OF THE MAXIMUM POSSIBLE LATE SPRING FLOOD

PLATE 30