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Missouri River Main Stem Reservoirs

System Description and Operation

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MISSOURI RIVER MAIN STEM RESERVOIRS

System Description and Operation

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LIST OF ABBREVIATIONS

AOP	-	annual operating plan
ac.ft.	-	acre-feet
AF	-	acre-feet
B	-	Billion
cfs	-	cubic feet per second
COE	-	Corps of Engineers
CY	-	calendar year (January 1 to December 31)
elev	-	elevation
ESA		Endangered Species Act of 1978
ft	-	feet
FY	-	fiscal year (October 1 to September 30)
GIS	-	Geographic Information System
GWh	-	gigawatt hour
KAF	-	1,000 acre-feet
Kcfs	-	1,000 cubic feet per second
kW	-	kilowatt
kWh	-	kilowatt hour
M	-	million
MAF	-	million acre-feet
MRBA	-	Missouri River Basin Association
MRD	-	Missouri River Division
MRNRC	-	Missouri River Natural Resources Committee
msl	-	mean sea level
MW	-	megawatt
MWh	-	megawatt hour
plover	-	piping plover
pp	-	powerplant
RCC	-	Reservoir Control Center
RM	-	river mile
tern	-	interior least tern
tw	-	tailwater
USGS	-	United States Geological Survey
yr	-	year

DEFINITION OF TERMS

Acre-foot (AF, ac-ft) is the quantity of water required to cover 1 acre to a depth of 1 foot and is equivalent to 43,560 cubic feet or 325,850 gallons.

Cubic foot per second (cfs) is the rate of discharge representing a volume of 1 cubic foot passing a given point during 1 second and is equivalent to approximately 7.48 gallons per second or 448.8 gallons per minute. The volume of water represented by a flow of 1 cubic foot per second for 24 hours is equivalent to 86,400 cubic feet, approximately 1.983 acre-feet, or 646,272 gallons.

Discharge is the volume of water (or more broadly, volume of fluid plus suspended sediment) that passes a given point within a given period of time.

Drainage area of a stream at a specific location is that area, measured in a horizontal plane, enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into the river above the specified point. Figures of drainage area given herein include all closed basins, or noncontributing areas, within the area unless otherwise noted.

Drainage basin is a part of the surface of the earth that is occupied by drainage system, which consists of a surface stream or body of impounded surface water together with all tributary surface streams and bodies of impounded water.

Gaging station is a particular site on a stream, canal, lake, or reservoir where systematic observations of hydrologic data are obtained.

Runoff in inches shows the depth to which the drainage area would be covered if all the runoff for a given time period were uniformly distributed on it.

Streamflow is the discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than "runoff" as streamflow may be applied to discharge whether or not it is affected by diversion or regulation.

MISSOURI RIVER MAIN STEM RESERVOIRS

System Description and Operation

I. FOREWORD

This report presents a summary of pertinent data and a description of the Missouri River Main Stem Reservoir System (System), and discusses the operation of the System to serve Congressionally authorized purposes. Congress authorized the operation of the six main stem dams on the Missouri River for flood control, recreation, irrigation, water supply and water quality, navigation, hydropower generation, and fish and wildlife. The System is operated using guidelines published in the Missouri River Main Stem Reservoir System Master Manual, which describes the regulation of the six Missouri River main stem dams as a system. The Master Manual presents a highly technical description of the guidelines used in the operation of the System to serve the Congressionally authorized project purposes. The purpose of this document is to provide a less technical discussion of the operation of the System under the Master Manual guidelines.

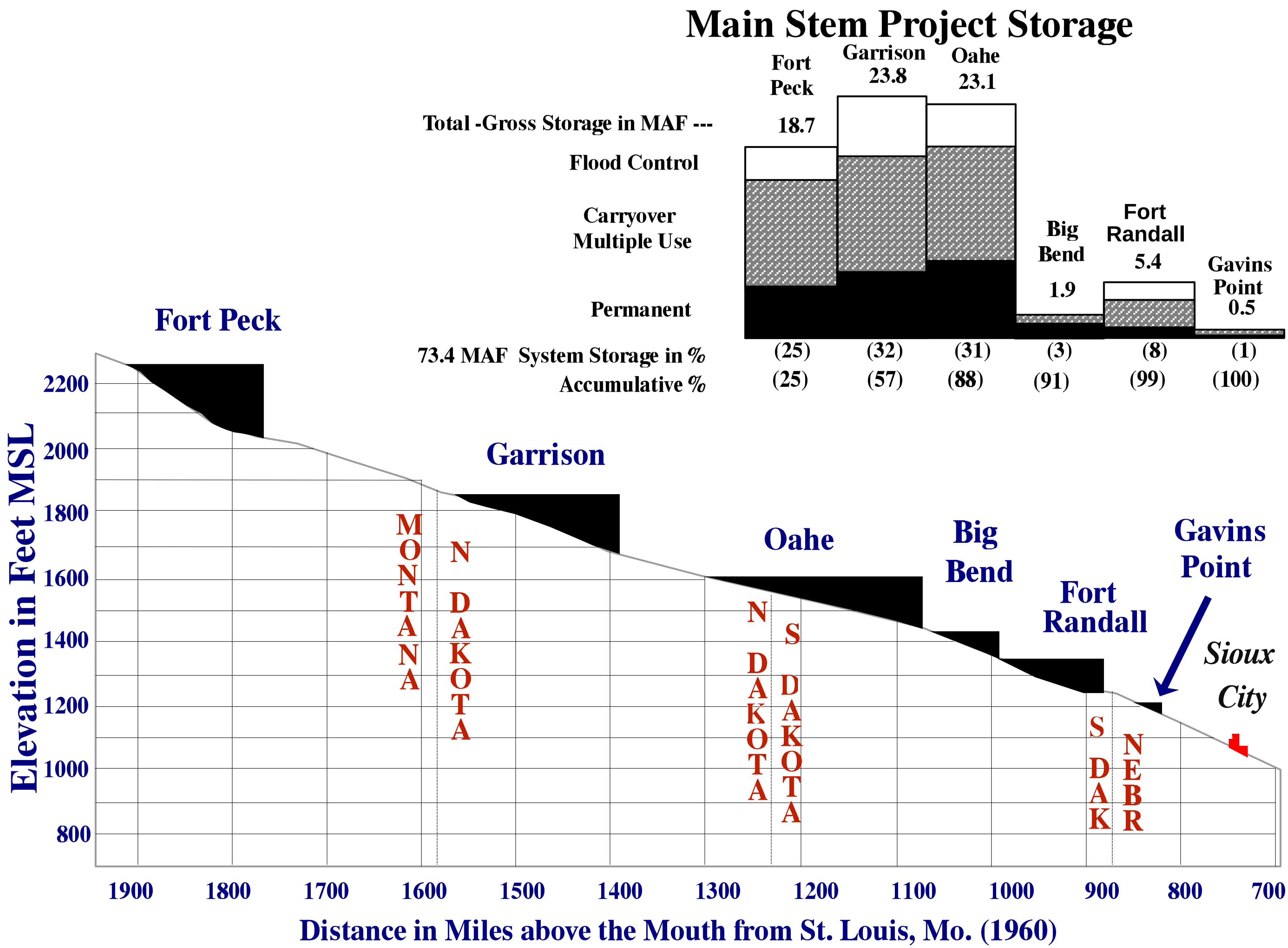
A review of the guidelines presented in the Master Manual is currently underway to determine if they best meet the contemporary needs of the basin. This review began in 1989 and includes the preparation of an Environmental Impact Statement (EIS). A draft EIS was published in September 1994 and was subjected to a full public review. In response to public comments, a Revised Draft EIS will be published in October 1999. The current schedule calls for completion of the review and implementation in the year 2002.

An Annual Operating Plan (AOP) is developed each year that presents a relatively detailed forecast of the upcoming year's System regulation to serve the authorized purposes. A draft AOP is published by October of each year. Public meetings on the Draft AOP are held in October and, after consideration of public comments, a Final AOP is published in early January.

II. DESCRIPTION OF MISSOURI RIVER BASIN AND MISSOURI RIVER

A. Basin Geography.

The Missouri River basin has an area of 529,000 square miles, including about 9,700 square miles located in Canada. The basin spans 10 states, including all of Nebraska; most of Montana, Wyoming, North Dakota, and South Dakota; about half of Kansas and Missouri; and smaller parts of Iowa, Colorado, and Minnesota. A map of the Missouri River basin identifying the major main stem and tributary Corps and certain Bureau of Reclamation civil works projects is presented as ***Plate 1***. A summary of engineering data for the six main stem reservoirs is shown on ***Plate 2***. ***Figure 1*** shows a profile of the main stem projects and displays the relative proportion of storage in the projects.



Profile of Missouri River Main Stem Reservoir System

Figure 1

Basin topography varies from the 56,000 square miles in the Rocky Mountain area in the West, where many peaks exceed 14,000 feet in elevation, to the approximately 370,000-square-mile Great Plains area in the heartland of the basin, to the 90,000-square-mile Central Lowlands in the lower basin, where the elevation is 450 feet above mean sea level (msl) near the mouth at St. Louis, Missouri. The Black Hills in South Dakota and the Ozarks in Missouri, consisting of 13,000 square miles, are isolated domelike uplifts that have been eroded into a hilly and mountainous topography. Stream slopes vary from about 200 feet per mile in the Rockies to an average of a foot per mile on the Missouri River as it flows through the Great Plains and Central Lowlands.

Several major Missouri River tributaries are shown on ***Plate 1***. They are the Yellowstone River, which drains an area of over 70,000 square miles, joining the Missouri River near the Montana-North Dakota boundary; the Platte River, with a 90,000-square-mile drainage area entering the Missouri River in eastern Nebraska; and the Kansas River, which empties into the Missouri River in eastern Kansas and drains an area of approximately 60,000 square miles. A prominent feature in the drainage pattern of the upper portion of the basin is that every major tributary, with the exception of the Milk River, is a right bank tributary flowing to the east or to the northeast. Only in the extreme lower basin, below the mouth of the Kansas River, is a fair balance reached between left and right bank major tributaries. The direction of flow of the major tributaries is of particular importance from the standpoint of potential concentration of flows from storms that typically move across the basin in an easterly direction. It is also important in another respect on the Yellowstone River, since early spring temperatures in the headwaters of the Yellowstone and its tributaries are normally from 8 to 12 degrees Fahrenheit higher than along the northern most reach of the Missouri near the Yellowstone confluence. This ordinarily results in ice breakup on the Yellowstone prior to the time the ice goes out of the Missouri River, thereby contributing to ice jam floods along the Missouri River downstream from the confluence to near Williston, North Dakota.

B. Climatology.

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

Average annual precipitation ranges from as low as 8 inches just east of the Rocky Mountains to about 40 inches in the southeastern part of the basin and in parts of the Rocky Mountains at higher elevations. Prolonged droughts of several years' duration and frequent shorter periods of deficient moisture, interspersed with periods of abundant precipitation, are characteristic of the plains area. The normal seasonal maximum precipitation is observed throughout the basin during the spring and early summer months. Precipitation during the late summer and fall months is usually of the short-duration thunderstorm type with small centers of high intensity, although widespread general rains do occasionally occur, especially in the lower basin. Winter precipitation occurs in the form of snow in the northern and central portions of the basin and, in the lower basin states, it may occur as rain or snow or a mixture of both. Average annual snowfall ranges from 20 inches in the lower basin to 30 inches in the eastern Dakotas to near 50 inches in the high plains areas in the West. High elevation stations in the Black Hills and in the Rockies along the western edge of the basin receive in excess of 100 inches of snowfall. Following the winter season, snow depths up to 6 feet, with a water equivalent of 2 feet, are not uncommon at mountain locations. Snow does not usually progressively accumulate over the plains but is melted by intervening thaws. However, there have been exceptions over the northern plains when snow that accumulated on the ground throughout the winter had a water equivalent of 6 inches or more.

Due to its mid-continent location, the basin experiences temperatures noted for wide fluctuations and extremes. Winters are relatively long and cold over much of the basin, while summers vary from mild to hot. Spring is normally cool, humid, and windy; autumn is normally cool, dry, and fair. The basin experiences temperatures above 100 degrees Fahrenheit in summer and below -20 degrees Fahrenheit in winter.

C. <u>Water Supply</u>.

Records of monthly flows and their distribution above Sioux City, Iowa, are available for the period 1898 to date. During this period, there has been a substantial growth in the development of water-related resources in the Missouri River basin. This growth is expected to continue; therefore, for comparative purposes, it is necessary to adjust flows to a common development level. While selection of a particular level is rather arbitrary, computations are facilitated by selection of a base level that is relatively recent and also that is prior to major effects from this development that are readily quantifiable on resultant streamflow for an annual and monthly basis. The base level of 1949 meets these criteria because it represents a base prior to recent emphasis on water resource development and is prior to the time that the Main Stem Reservoir System and many major tributary projects were constructed. Required flow adjustments to reflect this base level are discussed later in this section.

1. <u>Runoff</u>. On average 23 percent of the annual water supply above Sioux City, Iowa, is received in the months of March and April as a result of plains snowmelt augmented by early spring rains. Roughly 48 percent of the annual runoff comes in the months of May, June, and July as a result of the melt of the mountain snowpack augmented by spring and summer rains. Runoff varies widely from year to year but averages 24.6 million acre-feet (MAF) annually above

Sioux City. Records dating back to 1898 indicate runoff has varied from a high of 49.0 MAF in 1997 to a low of 10.6 MAF in 1931. In this 100-year period the basin has experienced three periods of significant drought including the record 12-year drought of the 1930's and early 1940's; the 8-year drought of the 1950's, and the recent 6-year drought which began in 1987 and ended abruptly with the flood of 1993.

2. <u>Upstream Depletions</u>. Not all of the runoff from the drainage basin is available for storage in the reservoirs or release for downstream service. Some is lost by evaporation; some is intercepted and depleted for agricultural uses, including irrigation and municipal and industrial uses; and some runoff is regulated by upstream reservoirs.

a. <u>Evaporation Losses</u>. The System reservoir evaporation losses vary in magnitude and are the net losses that occur when precipitation on the reservoir surface is considered. Since there is a great variation in precipitation from year to year and the surface area of a particular project at its maximum operating level can be more than double the surface area at minimum pool levels, it is evident these losses may vary widely from day to day and year to year. In general, the sum of evaporation losses at the six projects has normally averaged near 2 MAF a year. In accounting for past operations, these losses are based on observed conditions at the projects and are dependent on the actual surface area of the reservoirs and prevailing weather conditions. In projecting future operations, they are based on average meteorological conditions and computed variations in surface area.

b. <u>Depletions</u>. As mentioned previously, the base level of development against which changes from the natural water supply are estimated is the year 1949. In comprehensive basin planning studies, the Bureau of Reclamation, in cooperation with other interested Federal and state agencies in the basin, has made detailed investigations of the various developments which affect the natural streamflows within the basin. Some of these developments deplete water, some accrete water, while others merely rearrange the natural supply. These developments include surface water irrigation, ground water irrigation and its effects on surface water supplies, municipal and industrial supplies, watershed treatment, rural domestic and livestock uses, tributary reservoirs, recreation lakes and stock ponds, evaporation from man-made ponds and reservoirs, and forestry practices. These studies indicate that the depletions above Sioux City, Iowa, resulting from all developments and water uses at the 1949 level, averaged about 3.8 MAF annually. Developments since 1949 have resulted in additional depletions currently averaging approximately 1.2 MAF annually, exclusive of main stem reservoir evaporation, for a total of 5 MAF.

c. <u>Upstream Reservoirs</u>. Regulation of the streamflow by the upstream tributary reservoirs affects the operation of the System. The most significant upstream projects are the Bureau of Reclamation's Clark Canyon, Canyon Ferry, and Tiber Reservoirs above Fort Peck, and Boysen and Yellowtail Reservoirs above Garrison. Their operation may increase or decrease inflows to the downstream main stem reservoirs over an extended period. The influence of these projects upon the System during the year ahead is estimated from forecasts provided by the Bureau; the extent of tributary reservoir impacts depends on current storage levels and the magnitude of the water supply.

D. Main Stem and Tributary Streamflow Characteristics.

Streams having their source in the Rocky Mountains are fed by snowmelt. They are clear flowing and have steep gradients with cobble-lined channels. Stream valleys often are narrow in the mountain areas and widen out as they emerge from the mountains onto the outwash plains. Flood flows in this area are generally associated with the snowmelt runoff period occurring in May and June. Occasionally, summer rainfall floods having high, sharp peaks occur in the lower mountainous areas, such as the Big Thompson River flood in July 1976 and the Rapid City flood in June 1972.

Streams flowing across the plains area of Montana, Wyoming, and Colorado have variable characteristics. The larger streams with tributaries originating in the mountain areas carry sustained spring and summer flows from mountain snowmelt, and they have moderately broad alluvial valleys. Streams originating locally often are wide, sandy-bottomed, and intermittent, and they are subject to high peak rainfall floods.

Streams in the plains region of North and South Dakota, Nebraska, and Kansas with the exception of the Nebraska Sandhills area, generally have flat gradients and broad valleys. Except for the Platte River, most of the streams originate in the plains area and are fed by snowmelt in the early spring and rainfall runoff throughout the warm season. Streamflow is erratic. Stream channels are small for the size of the drainage areas, and flood potentials are high. When major rainstorms occur in the tributary area, streams are forced out of their banks onto the broad flood plains.

Streams in the regions east of the Missouri River have variable characteristics. Those in the Dakotas, such as the Big Sioux and James Rivers, are meandering streams with extremely flat gradients and very small channel capacities in relation to their drainage areas. These areas are generally covered with glacial drift and contain many pothole lakes and marshes. Rainfall in the spring often combines with the plains snowmelt to produce floods that exceed channel capacities and spread onto the broad flood plains.

Streams in the Ozark Highlands of Missouri resemble mountain streams with their clear, dependable base flows. Much of the area is underlain by limestone, and there are cavernous underground springs. The hilly terrain produces high peak runoff, which contributes to frequent floods with large volumes due to this area's higher annual rainfall.

Regulation provided by the System reservoirs and by upstream tributary reservoirs has greatly reduced flood flows on the Missouri River from Fort Peck Dam downstream to the mouth of the Platte River below Omaha, Nebraska. Critical stages can be reached for a short time below the upper three main stem reservoirs during the winter freeze-up of the Missouri River. During this period, key locations are frequently monitored so that reservoirs can be regulated to prevent localized flooding. From Sioux City to the mouth of the Platte River, damaging floods are still possible, but their frequency of occurrence has been greatly reduced by the System. Below the Platte River to the mouth near St. Louis, the incremental drainage area is of sufficient size that above bankfull stages can be expected to occur frequently as a result of flood runoff from major storms over the tributary areas, although significant stage reductions due to System project regulation will usually occur.

<u>III. MAIN STEM RESERVOIR SYSTEM</u>

A. <u>System Description</u>.

The six dams spanning the Missouri River control runoff from approximately half of the basin. Those six dams, from the upper three giants of Fort Peck in eastern Montana, Garrison in central North Dakota and Oahe in central South Dakota, to the lower three smaller reservoirs including Big Bend and Fort Randall in South Dakota and Gavins Point along the Nebraska-South Dakota border, comprise the largest system of reservoirs in the United States. Four of the System reservoirs were named by the Congress: Lake Sakakawea (Garrison Dam); Lake Sharpe (Big Bend Dam); Lake Francis Case (Fort Randall Dam); and Lewis and Clark Lake (Gavins Point Dam). These names are used interchangeably in this report.

The combined storage capacity of all six reservoirs is 73.4 MAF, about three times the annual runoff. This high storage-to-runoff ratio lends an unusual degree of flexibility to the operation of the multipurpose reservoir system. In contrast, the ratio of reservoir storage to annual runoff in the Columbia and Ohio River basins is 1:5, approximately one acre-foot of storage for each five acre-feet of annual runoff.

The System storage is divided into four unique storage zones. The bottom 25 percent of the total storage comprises the permanent pool designed for sediment storage, minimum fisheries, and hydropower heads. The largest zone, comprising 53 percent of the total storage, is the carryover-multiple use zone designed to serve all project purposes, though at reduced levels, through a severe drought like that of the 1930's.

The annual flood control and multiple use zone, occupying 16 percent of the total storage, is the desired operating zone of the System. Ideally the System is at the base of this zone at the start of the spring runoff season. Spring and summer runoff is captured in this zone and then metered out throughout the remainder of the year to serve the other project purposes, returning the reservoirs to the base of this zone by the start of the next runoff season.

The top 6 percent of the system storage is the exclusive flood control zone. This zone is used only during periods of extreme floods and is evacuated as soon as downstream conditions permit.

B. <u>System Operation</u>.

1. <u>Overview</u>. The System is operated to serve the Congressionally authorized purposes of flood control, recreation, irrigation, water supply and water quality, navigation, hydropower generation, and fish and wildlife. System operation is in many ways a repetitive annual cycle. Most of the year's water supply is produced by winter snows and spring and summer rains that increase the System storage. After reaching a peak, usually during July, storage declines until late in the winter when the cycle begins anew. A similar pattern may be found in rates of releases from the System, with the higher levels of flow from mid-March to late November, followed by low rates of winter discharge from late November until mid-March, after which the cycle repeats. The Water Control Calendar of Events shown on ***Figure 2*** displays the time sequence of many of these cyclic events which necessitates the varied regulation plans to accommodate the multipurpose objectives of the System. The two primary high risk flood seasons shown are the plains snowmelt and rainfall season extending from late February through April and the mountain snowmelt and rainfall period extending from May through July. Also the winter ice jam flood period extends from mid-December through February. The highest average power generation period extends from mid-April to mid-October with high peaking loads during the winter heating season (mid-December to mid-February) and the summer air conditioning season (mid-June to mid-August). The power needs during the winter are supplied primarily with Fort Peck and Garrison releases and the peaking capacity of Oahe and Big Bend. During the spring and summer period, releases are geared to navigation and flood control requirements and primary power loads are supplied using the four lower dams. During the fall when power needs diminish, Fort Randall pool is drawn down to permit generation during the winter period when the pool is refilled by Oahe-Bend peaking power releases. The major maintenance periods for the System hydropower facilities extend from March through mid-June and September through November, which normally are the lower demand and off-peak energy periods. The exception is Gavins Point where maintenance is performed after the end of the navigation season since all three power facilities are normally required to provide navigation flow needs. The normal 8-month navigation season extends from April 1 through December 1 during which time System releases are increased to meet downstream target flows in combination with downstream tributary inflows. Winter releases after the close of navigation season are much lower and vary depending on the need to conserve or evacuate System storage volumes, downstream ice conditions permitting. Minimum release restrictions and pool fluctuations for fish spawning management generally occur from April 1 through July. Endangered species nesting occurs from early May through mid-August.

Other factors may vary widely from year to year, such as the amount of water in storage and the magnitude and distribution of inflow received during the coming year. All of these factors will affect the timing and magnitude of project releases. The gain or loss in the water stored at each reservoir must also be considered in scheduling the amount of water transferred between reservoirs to achieve storage balance and to generate power. These items are continually reviewed as they occur and are appraised with respect to the expected range of operations.

Water Control Calendar of Events

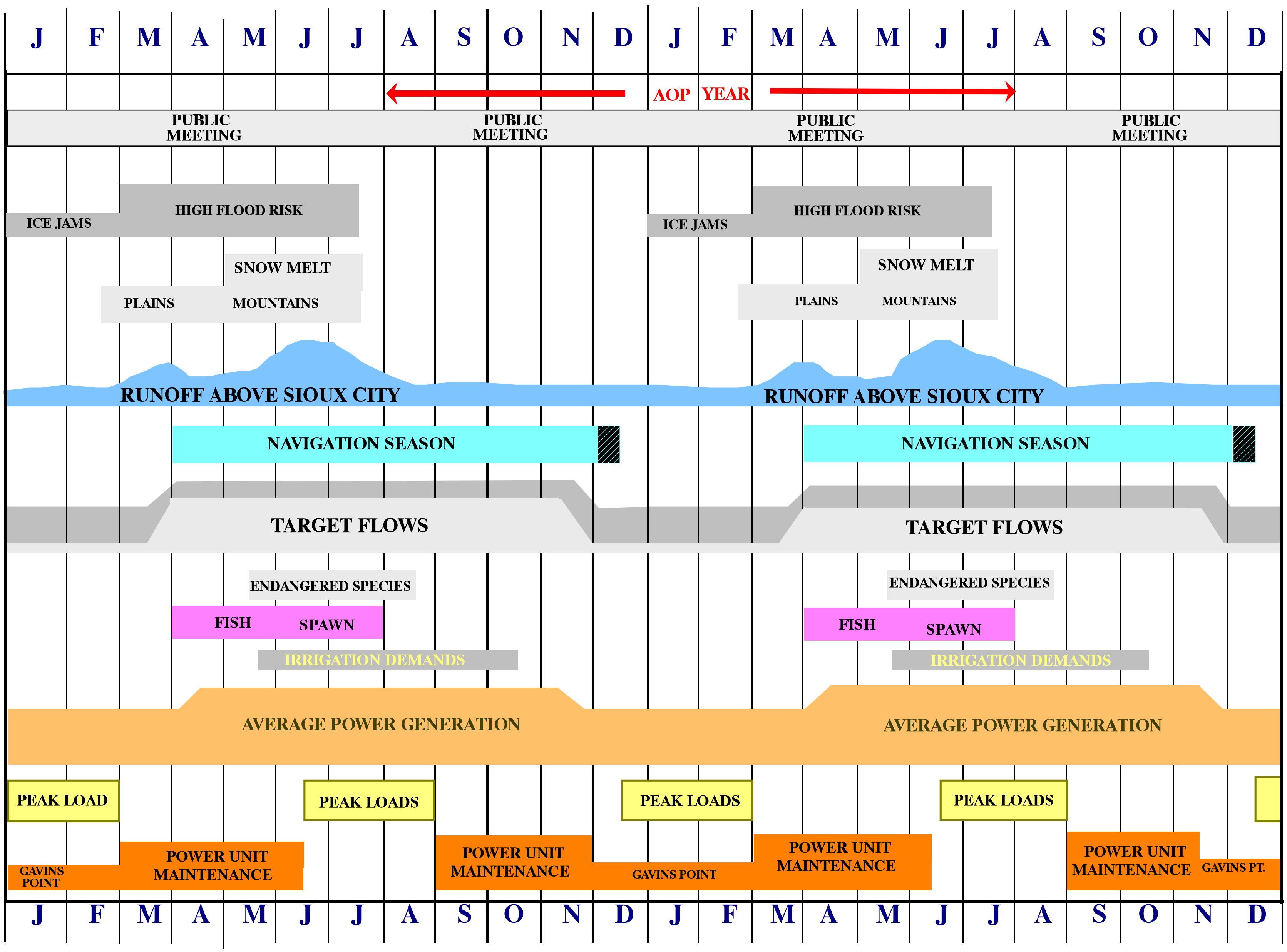


Figure 2

2. Project Regulation. Inflow to the System is subject to only very minor regulatory control by upstream tributary reservoirs. Because of this, and with System releases necessary to support downstream water requirements defined within a relatively narrow range, much of the flexibility of the System is derived from intrasystem regulation, or the transfer of water from one project to another.

Intrasystem regulation is an important tool in the operation of the System to meet the authorized purposes. It is used to regulate individual reservoir levels in the system to balance the water in storage at each project, maintain the seasonal capability of the hydropower system, and improve conditions for the reservoir fish spawn. It also can be used to regulate stages on the open river reaches between projects to desirable levels.

The presence of large reservoirs in the System increases intrasystem regulation flexibility. A small reservoir such as Lewis and Clark Lake (Gavins Point Dam) with storage of less than one-half MAF, can only tolerate a large difference between inflow and release for less than a day. Lake Sharpe (Big Bend Dam) is in this category as well; to a lesser extent so is Lake Francis Case (Fort Randall Dam), although its carryover multipurpose and annual flood control multiple-use storage of nearly 3 MAF make possible significant storage transfers and flow differentials extending usually a month or more. But it is the big upriver projects of Fort Peck, Garrison, and Oahe, with their combined 37.4 MAF of carryover multiple-use storage, plus an additional 10.1 MAF of annual flood control multiple-use storage, which provide the flexibility to adjust intrasystem regulation to better serve authorized purposes.

a. Summer Release Patterns. Intrasystem regulation to meet the needs of power generation follows a regular seasonal cycle. During the navigation season, when downstream flow requirements are high, large amounts of water are normally released from Gavins Point. This requires that large volumes of inflow to Gavins Point are supplied from generation at Fort Randall, and Fort Randall, in turn, requires similar support from Big Bend, and Big Bend from Oahe. Here the chain can be interrupted; usually Lake Oahe is large enough to support high releases for extended periods without high inflows. Generation at Fort Peck and Garrison are held to relatively lower levels during the summer to allow more winter hydropower production, unless the evacuation of flood control storage space, or the desire to balance storage between projects, becomes an overriding consideration.

b. Winter Release Patterns. With the onset of the nonnavigation season, conditions are reversed. Releases from Gavins Point drop to about one-third to slightly greater than half of summer levels and the chain reaction proceeds upstream curtailing daily average discharges from Fort Randall, Big Bend, and Oahe. At this time, Fort Peck and Garrison daily releases are usually maintained at relatively high levels (within the limits imposed by downstream ice cover) to partially compensate for the reduction in generation downstream.

c. Drawdown of Lake Francis Case. An additional means of partially compensating for the lesser amount of hydroelectric energy associated with the lower System winter release rate is the autumn drawdown of Lake Francis Case. In this operation, Oahe and Big Bend releases are reduced several weeks before the end of the navigation season. This leaves

Lake Francis Case with the task of supplying a portion of downstream flow requirements for the remainder of the season, a process which results in evacuation of a portion of its carryover storage space. This vacated carryover storage space is then refilled from Oahe and Big Bend releases during the nonnavigation season. The refill of the evacuated Fort Randall space allows winter releases from these upstream projects to substantially exceed those from Fort Randall.

Lake Francis Case is drawn down to 1337.5 feet msl except during severe drought periods. This provides a recapture space of about 900,000 acre-feet and increases the average winter energy generation about 150 million kWh.

d. <u>Recapture at Oahe</u>. While not as significant (in terms of pool level fluctuation) as recapture operations at Lake Francis Case, a similar operation of Lake Oahe coordinated with upstream Garrison and Fort Peck releases also significantly increases the amount of winter energy generation. During the 4-month winter period, Garrison releases normally can be expected to be at least 1 MAF more than Oahe releases. Recapture of these upstream releases generally results in a rise of about 5 feet or greater in Lake Oahe elevation during the winter months depending on the current storage level.

e. <u>Short-Term Adjustments</u>. The interaction among projects described above, repeated as it is year after year, might make intrasystem regulation appear to be a routine and rigid procedure. However, routine operations are often disrupted by the short-term extremes of nature. Heavy rains may raise river stages near the flood level, necessitating cutback at one project and a corresponding increase at others. Very hot or very cold weather may create sharp increases in the demand for power. Inflows for a week or for a season may concentrate disproportionately in one segment of the System, causing abrupt shifts in regulating objectives.

3. <u>Project Release Limits - Conservation Purposes</u>. Limitations imposed upon System regulation concern not only storage (which is varied in accordance with the flood control restrictions previously given and the requirements for active storage pools) but also releases.

a. <u>Maximum Rates - Summer</u>. During the summer, releases at all projects other than Gavins Point are normally within the powerplant discharge capacity, the river channel downstream usually being more than adequate to carry such releases. Discharges from all projects will usually be made through the power facilities. At times, support for the downstream navigation flows may require releases from Gavins Point in excess of powerplant capacity while, at all projects, special operational considerations may require releases bypassing the powerplants but usually for only relatively short periods of time. Unusually large inflows during any particular year may require significant releases beyond those through the power units at any or all projects in order to evacuate storage space and thereby maintain the flood control capability of the System.

b. <u>Maximum Rates - Winter</u>. Releases are more restricted during the winter period. An ice cover can be expected to form over major portions of the Missouri River every winter and its extension as far downstream as the river's mouth will occasionally occur. During and after formation, this ice cover reduces the discharge capacity of the river channel. In addition, during periods of ice formation and subsequent breakup, a substantial risk of ice jam formation and associated flooding exists. In the upper Missouri River, an ice cover once formed can be expected to remain through the winter; however, below Sioux City, ice formation or ice breakup can occur throughout this season. The maximum allowable winter releases are those that will not significantly increase the probability of flooding or intensify potential flooding during periods of ice cover. Below the System, such ice buildup can also jeopardize downstream navigation structures such as dikes and revetments. Since the travel time of any release from the System to areas of vulnerability is much longer than the time for which reliable forecasts of such events can be made, it is necessary to schedule winter System releases at a conservative level. With normal or below water supply conditions, a maximum permissible average release rate of 15,000 cubic feet per second (cfs) from Fort Randall has been established. This amount, plus the incremental inflow, is discharged from Gavins Point. The maximum daily winter release from Gavins Point usually ranges between 16,000 and 20,000 cfs. With an excess water supply, and evacuation of flood control storage space as a primary consideration, an average Gavins Point release rate of between 20,000 and 24,000 cfs is scheduled. The extent and location of river ice cover is important in determining the release rate. Experience accumulated during past winters indicates that at times it may be necessary to reduce System releases below these levels when bankfull to slightly above bankfull stages occur in the Nebraska City to St. Joseph reach of the Missouri River.

No daily release limitations exist at Big Bend where discharges are made almost directly into the downstream reservoir area. The maximum ice-covered channel capacity below Fort Peck and Garrison is estimated to be about 15,000 and 35,000 cfs, respectively, except during freeze-up. During freeze-up, releases are limited to lower levels until a stable ice cover is formed and the rough ice and streambed are smoothed sufficiently for the channel to accommodate increased releases.

c. Minimum Releases. There are no minimum daily flow requirements from the Oahe or Big Bend projects except that, at Oahe, weekend releases during the daytime hours of the recreation season are typically held above 3,000 cfs in the interest of downstream fishing and boating. Also, minimum daily releases from Fort Peck and Fort Randall are typically maintained during the fish spawning seasons. At Fort Peck, Garrison, Fort Randall, and Gavins Point, minimum daily releases are established as those necessary to supply water quality control and water intake requirements, which generally also furnish more than an adequate quantity of water for irrigation withdrawals below the reservoirs. However, municipal and industrial, powerplant, and irrigation intake problems have been experienced due to channel degradation, inadequate intake screens, sandbar formation, or to improper elevation of intakes. These problems may require a temporary increase above the open water minimum release rates until remedial action is taken. Since these are problems of access to water that is available, all intake owners are encouraged to develop intake facilities which will operate through the range of discharges required for other purposes.

d. Hourly Fluctuation of Release Rates. At all projects except Gavins Point, hourly release rates may vary widely as necessary to meet fluctuating power loads. Changes in release rates at the Gavins Point project are subject to limitations to restrict stage fluctuations downstream. Minimum hourly release restrictions are applicable at Fort Peck and Garrison due to downstream intakes, at Oahe to enhance recreational use in the downstream areas, and at Fort Randall during the fish spawning period. A uniform peaking release pattern has been established during the summer months at Garrison, Fort Peck, and Fort Randall for endangered birds nesting along the river below the projects.

C. Sediment Investigations.

Hydrographic resurveys of the main stem lakes, along with sediment sampling activities on the major tributary arms, and other special studies are planned and scheduled to meet the short term and long term needs related to sediment problems. A total of 667 sediment cross-section ranges for both aggradation and degradation have been established and maintained throughout the main stem reservoirs since completion of the System. Each lake is surveyed periodically (10- to 20-year intervals) to update reservoir capacities, to assess the progress of aggradation and degradation trends, to evaluate impacts of erosion sedimentation on project functions, and to seek early solutions to problems in light of changing field conditions and goals. The frequency of lake surveys was established based on historic data and reservoir size. Prior to 1986, the smaller lakes were surveyed at 5-year intervals and the larger lakes at 10-year intervals. Currently, Lake Sharpe, Lake Francis Case, and Lewis and Clark Lake are scheduled for 10-year intervals; Lake Oahe and Lake Sakakawea for 20-year intervals; and Fort Peck Lake for 25-year intervals. These regular lake surveys are supplemented with reconnaissance inspections of major problem areas about once every 5 years. Intervening and/or partial resurveys may be conducted if warranted by a special study, and/or if findings from reconnaissance investigations reveal the need. High flood events are the most likely causes for these additional surveys.

Five suspended sediment sampling stations are presently in operation on major sediment producing tributaries and headwater of the main stem lakes to measure incoming sediment load. These include stations on the Missouri River at Landusky, Montana; the White River at Oacoma, South Dakota; the Yellowstone River at Sidney, Montana; the Musselshell River at Mosby, Montana; and the Bad River at Fort Pierre, South Dakota.

Downstream of Gavins Point Dam, six more sediment sampling stations are maintained at Sioux City, Iowa; Omaha, Nebraska; Nebraska City, Nebraska; St. Joseph, Missouri; Kansas City, Missouri; and Hermann, Missouri. Data from these stations provide continuous observation of sediment load changes used to analyze impacts of main stem reservoirs and channelization below Sioux City on the downstream reach and to furnish vital information for the investigation of sediment related problems and formulation of remedial measures. All sampling is done by the U.S. Geological Survey (USGS) under a cooperative stream gaging program, including the computation of sediment load records.

Table I describes the sediment deposition in the System reservoirs according to the latest information available. This table indicates a loss of 4.4 percent in total storage to date with an annual sediment deposition rate of 89,000 acre-feet. Sediment and hydrographic survey data collected, combined with hydrologic and hydraulic data in the main stem reservoirs, have been used extensively to investigate specific issues and concerns. Issues recently investigated include Oahe headwater aggradation that has induced higher river stages and ground water tables in

Bismarck, North Dakota; deposition downstream of the Yellowstone River near Sidney, Montana, Williston, North Dakota, and Pierre and Fort Pierre, South Dakota; tributary flooding from delta development at White River, Niobrara River, and Bad River mouths; downstream degradation impacts on tailwater and the powerplant operation below the Garrison, Fort Randall, and Gavins Point Dams; and Missouri River aggradation and degradation trends below Gavins Point Dam.

TABLE I
MISSOURI RIVER RESERVOIR SYSTEM
PROJECT SEDIMENT DEPLETION TABLE
(Volumes in 1,000 Acre-Feet)

Project	Storage Capacity Original	Storage Capacity Current	Survey Date	Percent Loss	Total Storage Loss	Ac.Ft./Yr. Loss
Fort Peck	19,557	18,688	1986	4.4	869	18.1
Garrison	24,728	23,821	1988	3.7	907	25.9
Oahe	23,751	23,137	1989	2.6	614	19.8
Big Bend	1,980	1,859	1991	6.1	121	4.3
Fort Randall	6,208	5,418	1996	12.7	790	18.3
Gavins Point	575	470	1995	18.3	105	2.6
Total	76,799	73,393		4.4	3,406	89.0

The accumulation of sediment in reservoir headwaters and at the mouths of sediment laden tributaries has impacted project functions by reducing channel capacity and raising water surfaces, in some instances by several feet. Areas of particular concern include Williston, North Dakota (Lake Sakakawea headwaters); Bismarck, North Dakota (Lake Oahe headwaters); Pierre-Fort Pierre, South Dakota (Bad River delta and Lake Sharpe headwaters); the White River delta; Lake Francis Case headwaters; Verdel and Niobrara, Nebraska (Niobrara River delta); and Springfield, South Dakota (Lewis and Clark Lake headwaters.) These localized problems will continue to increase in severity if no remedial actions are taken. Additional information on each of these areas is included in the following paragraphs.

Lake Sakakawea headwaters extend upstream past the city of Williston, North Dakota. Corps-built levees protect Williston from the aggradation backwater effects. After construction of Garrison Dam, the Lewis and Clark and Buford-Trenton irrigation projects were operating in this backwater area. The Lewis and Clark project and a portion of the Buford-Trenton project were purchased by the Government for project lands. The remainder of the Buford-Trenton irrigation project continues to operate. Prior to 1979, there were numerous complaints and claims filed by landowners in this area alleging that high ground water levels resulted from the aggradation effects on the adjacent Missouri River near the Yellowstone confluence.

Ground water observation wells have been monitored in this area in cooperation with the State of North Dakota since the construction of Garrison Dam. Studies indicated that, to alleviate these problems, acquisition of additional lands would be a less expensive alternative than any permanent structural solution. Since this acquisition was opposed by the landowners, a temporary solution was constructed to improve drainage of two channels that drain a major portion of the affected area. These facilities include two earthen channel blocks with gated outlet conduits and electric pumps to discharge water during periods of high river stages. These improvements have been operating successfully since 1979.

Fort Peck releases are generally decreased prior to the beginning of the winter period to prevent ice-jam flooding during the winter freeze-in period on the reach of the Missouri River from the dam to the Williston, North Dakota, area. After a stable ice cover is in place, releases are gradually increased to 12,000 cfs for the remainder of the winter period to meet critical winter hydropower demands.

Continuing aggradation in the headwaters of Lake Oahe has contributed to high water problems in the Bismarck, North Dakota, area during the period of high Garrison summer releases and during the winter ice-in periods. There is a considerable amount of new housing being developed near the river in Bismarck. Releases from Garrison are reduced to 18,000 to 20,000 cfs during the winter ice-in period to prevent the stage from exceeding the critical ice-in stage of 14 feet. Flood stage at Bismarck is 16 feet. Once a stable ice cover is established, Garrison releases can be gradually increased.

Flooding in the Pierre-Fort Pierre area, especially at street intersections in the Stoeser Addition has been a recurring problem since 1979. High Oahe releases, coupled with the formation of river ice in the LaFramboise Island area, cause water to back up into a storm sewer outlet flooding street intersections. Release restrictions have been implemented in previous years to prevent flooding. Peak hourly releases as well as daily energy generation will be constrained to prevent urban flooding in the Pierre and Fort Pierre areas if severe ice problems develop downstream of Oahe Dam. This potential reduction has been coordinated with the Western Area Power Administration.

During the 1991 fall drawdown of Lake Francis Case, it was observed that the White River delta, which extends across Lake Francis Case, was having a damming effect that created two different lake elevations upstream and downstream of the delta. In recent times, the upper lake elevation has been as much as 6 feet higher than the lake downstream from the delta. The Corps has published a revised elevation capacity table for Lake Francis Case reflecting the effect of this phenomenon near elevation 1347 and below. On-going monitoring of this problem continues.

Sediment deposition in the vicinity of Springfield, South Dakota, has restricted access to Lewis and Clark Lake from the Springfield boat ramp during periods of low lake elevation. This deposition has also caused problems at the Springfield water intake structure. Farther upstream, a large delta continues to develop near the mouth of the Niobrara River. The sediment deposition from Niobrara down to Springfield increases the travel time of releases from Fort Randall to Lewis and Clark Lake. In 1994 the Omaha District conducted a study on sedimentation impacts in this area. A steady 35,000 cfs release from Fort Randall was made beginning on May 2, 1994, for 48 hours and the resulting water surface profile was surveyed. The water surface from upstream of Verdel, Nebraska, to below the mouth of the Niobrara River was higher than the water surface in the mid-1980's with a 44,000 cfs release which, in turn, was higher than a 60,000 cfs release in 1975. Some overbank flows occurred and rerouting of tributaries in this reach were noted during the test period. High releases coupled with degraded channel capacity caused lowland flooding in this reach during the period 1995 to 1997; however, the resulting swampy wetland conditions were very beneficial to migratory waterfowl and other wetland habitat users. In addition, the record high releases in 1997 caused a notable, although as of yet unquantified, increase in the channel capacity.

Downstream of Gavins Point a general lowering trend of the river level and the accumulation of sediment in marinas continue to be a concern for recreational boaters and marina operators. Sediment deposition resulting from high short duration flows forced marina owners to dredge in 1990, 1991, and in 1992. Flooding in 1993 deposited large amounts of sediment in many marinas making it the fourth consecutive year that sediment removal was necessary. From 1995 through 1997 most marina owners between Sioux City and Omaha did not have to deepen their entrances and dredge basins to provide access because of higher main stem flows. However, the return to normal service flows in 1998 along with the river channel degradation above Omaha caused significant problems for the marina operators. Channel capacity in the Sioux City area has increased 5,000 to 7,000 cfs at the full service navigation flow level resulting in a stage decrease about 2 feet. Early in the summer of 1998, higher tributary flows helped alleviate the situation, but as the summer progressed and tributary flows receded, the problem at marinas became more severe. There were times during 1998 when the marinas could not operate, especially during June when System releases were reduced for downstream flood control.

D. Reservoir Water Quality.

The Corps' Water Quality Management Program for the Missouri River System consists of analysis of the lakes and reservoir releases. The USGS monitors inflowing tributaries. Remote monitoring of releases for dissolved oxygen, pH, conductivity and temperature occurs at all projects. Monitoring is conducted to detect water quality problems and determine compliance with Federal water quality criteria as well as state and local water quality standards. An annual water quality report summarizes the ongoing and planned activities of the program and water quality conditions at each reservoir project. This report should be consulted for a detailed presentation of the water quality conditions at each project.

In general, water quality conditions at the Missouri River main stem dams are favorable although a few problems have been encountered. The problems that have been detected are: (1) those which arise as a result of the project or its operation; and (2) those which arise from non-project sources, such as agricultural activities, mining, and coal or oil production.

Potential concerns which may result from the projects or their operation include: (1) the potential for gas supersaturation if spillway releases are made from Fort Peck and Gavins Point Dams; (2) hypolimnetic oxygen depletion in Fort Peck, Lake Sakakawea, and Oahe;

(3) occasional fishkills below Oahe, Fort Randall, and Gavins Point Dams; and (4) increased rates of eutrophication due to accumulation and recycling of nutrients in the lakes.

The Missouri River projects have a significant moderating influence upon the Missouri River water temperatures and sediment concentrations. Most of the inflowing sediment load is retained within the impoundments. Winter releases from the dams cause a slight warming of the downstream waters ranging from 1 to 3 degrees centigrade. In the late spring, summer, and early fall, river temperatures downstream of the upper three lake projects are depressed on the order of 5 to 10 degrees centigrade.

Concerns which have resulted from land or water use policies outside the Federal project boundaries include: (1) pesticides detected in project waters, including diazinon at Fort Peck Lake, atrazine at Lake Sakakawea, atrazine and simazine at Lakes Oahe and Sharpe, atrazine and diazinon at Lake Francis Case, atrazine, alachlor, metolachlor, banvel, and metribuzin at Lewis and Clark Lake; (2) high selenium levels in the Missouri River and many of its tributaries; and (3) high metal concentrations, most of which originate from natural sources. To date, the problems have not affected the ability of the System to serve authorized purposes.

IV. RECURRING OPERATIONAL CONSIDERATIONS

A. Flood Control.

Flood control is the only authorized project function that requires the availability of empty storage space rather than impounded water. Actual flood events are generally unpredictable; therefore, detailed routing of specific major flood flows is accomplished when floods occur. There is a recurring pattern of high-risk flood periods during each year. There is a season when snowmelt, ice jams, and protracted heavy rains will almost surely occur with or without generating consequent floods; and there is a season when these situations are most unlikely and the flood threat is correspondingly low. The high risk flood season begins about March 1 and extends through the summer. As a consequence, regulation of the System throughout the fall and winter months is predicated on the achievement of a March 1 system storage level at or below the base of the annual flood control zone. Exceptions to this will occur due to the availability of replacement flood control space in major upstream tributary reservoirs. This type of space, available in the Bureau of Reclamation's Clark Canyon, Canyon Ferry, and Tiber Reservoirs, can effectively reduce the requirements for annual flood control space in the System. The available space for control of flood inflows in the combined System and tributary reservoirs has in the past been scheduled as discussed above and coordinated with the Bureau of Reclamation in Billings, Montana. Due to release limitations imposed by the formation of a downstream ice cover, a major portion of the required flood control space in the System must be evacuated prior to the winter season. Gavins Point winter releases exceeding 20,000 cfs are not normally scheduled. However, higher releases have been made on occasions when the downstream ice conditions permit or when required for evacuation of water during high runoff years. Since the results of ice jam flooding can be more severe when higher releases are made during the winter months, additional vigilance is required.

In general, individual System projects will also be scheduled to be near or below their respective base of annual flood control on March 1. Some departure is made possible due to the availability of upstream tributary flood control storage space and also in recognition of the relative ease by which the water in storage may be transferred downstream to other projects in the System even during the flood season.

During all but excessively dry years, water stored in the reservoirs will increase during the March-July season. The base of exclusive flood control defines the maximum level of storage that will be accumulated for purposes other than the flood control function.

The flood control levels for each reservoir are given in ***Table II.*** Other pertinent data for all projects are presented in the Summary of Engineering Data shown on ***Plate 2*** and on ***Figure 1.***

TABLE II
MAIN STEM
PROJECT STORAGE LEVELS

	Base of Annual Flood Control		Base of Exclusive Flood Control		Top of Exclusive Flood Control	
	Storage (MAF)	Elev. (ft)	Storage (MAF)	Elev. (ft)	Storage (MAF)	Elev. (ft)
Fort Peck	15.0	2234.0	17.7	2246.0	18.7	2250.0
Garrison	18.1	1837.5	22.3	1850.0	23.8	1854.0
Oahe	18.8	1607.5	22.0	1617.0	23.1	1620.0
Big Bend	1.7	1420.0	1.8	1422.0	1.9	1423.0
Randall	3.1	1350.0	4.4	1365.0	5.4	1375.0
Gavins Point	0.3	1204.5	0.4	1208.0	0.5	1210.0
Total	57.1		68.7		73.4	

Water stored in the annual flood control and multiple-use zones will normally be released through the powerplant of each of the individual projects except when evacuation of this zone prior to the winter season necessitates higher flow rates requiring flood control outlet or spillway releases. When the exclusive flood control zone in a particular reservoir is encroached upon, the control of subsequent flood inflows becomes the paramount factor. During such periods, releases may substantially exceed the powerplant release capacity, with the evacuation rate of any project dependent upon existing flood conditions, the potential for further inflows, and conditions of other reservoirs in the System. Maximum release rates at such times are limited by the flood control function of the System. Below Fort Peck, minor downstream flooding will occur when open water flows exceed 35,000 cfs. Open water channel capacity below each of the other reservoirs approximated 100,000 cfs or more at the time the reservoirs were constructed. Since that time, there is evidence that encroachment on the channel and channel deterioration below particular projects have occurred and flood problems would be experienced with releases of this magnitude. Reservoir releases, particularly those from Gavins Point, Garrison, and Fort Randall Dams, may need to be reduced to less than the immediate downstream channel capacity due to uncontrolled actual and potential tributary inflows below each project.

B. <u>Water Requirements - Downstream</u>.

Just as the water supply and upstream uses must be evaluated each year to determine the net supply into the System, so must System release rates be established. This is the only means of regulating the reservoir storage, since the weather and its resultant effects are not subject to control. Releases from the System fall into two classes. Open water releases in the range of 23,000 to 35,000 cfs are made from the lower most project, Gavins Point, in support of Missouri River navigation and other downstream uses. In years with above normal water supply or extended periods of downstream flooding, the navigation releases are increased to the extent necessary to evacuate the flood control storage space by the succeeding March, with due consideration of reduced channel capacities during the winter ice cover period. Daily releases of 12,000 to 24,000 cfs are generally made during the nonnavigation season for water quality and supply as well as power production and flood evacuation purposes.

1. <u>Navigation Requirements</u>. The Missouri River navigation channel extends for 734.8 miles from near Sioux City, Iowa (River Mile 732.3) to the mouth near St. Louis, Missouri (River Mile 0). Navigation on the Missouri River is limited to the normal ice-free season with a full length season normally extending from April 1 to December 1 at the mouth. To permit a viable navigation industry during the ice-free months, it is desirable to maintain navigable flows throughout this 8-month period. During past navigation seasons in years of adequate water supply, 10-day extensions either at the beginning or end of this normal season have been scheduled, downstream river ice conditions permitting. Experience with extensions and attempted extensions prior to the normal opening dates of the navigation season has generally not been satisfactory. In many years, the ice cover below the System is still in place at the time it is necessary to schedule increased releases from the System, prohibiting the early opening. Additionally, in those years when earlier-than-normal navigation releases are possible, experience has indicated that towboat groundings are much more frequent during this early period than during the remainder of the season. The increased incidence of groundings appears to be related to the cold water temperatures and their effect upon channel bed configuration. However, in spite of this experience, shippers have requested that when possible an earlier-than-normal opening be provided to aid in reducing the backlog of shipping accumulated during the winter months. Increased groundings are also experienced during the fall when stages lower despite constant releases. These problems are greatest in years when normal or lower reservoir releases are made. When water supplies are above normal, consideration is given to a 10-day extension of the season beyond the normal closing date.

Construction of the navigation works was declared complete in September 1981 although maintenance and corrective work will be required as the river itself continues to form its channel in response to changing flow conditions. System reservoir releases are scheduled to provide adequate flows for navigation according to established minimum and full-service flow targets at

Sioux City, Omaha, Nebraska City, and Kansas City. The target flows increase in a downstream direction because of the increased flow requirements needed to maintain similar flow depths with naturally increasing channel dimensions. The assignment of target flows is based upon available water supply that, when combined with winter releases needed to ensure water supply requirements and winter hydropower demand, obligates all of the available water supply during a normal year. These target flows may need to be evaluated and adjusted periodically to ensure compatibility between available water supply and current navigation channel conditions.

Operating experience during the 1960's and the drought of 1987 to 1992 demonstrated that flows of 25,000 cfs at Sioux City and Omaha, 31,000 cfs at Nebraska City, and 35,000 cfs at Kansas City were the minimum flows that permitted navigation. When minimum-service flow levels are supported, experience has indicated that it is necessary to reduce drafts by 1 foot and restrict tow sizes to reduce the number of lost time events and groundings and to minimize dredging. With the present level of streamflow depletions, inflows to the System are sufficient to support the minimum flow levels or higher for the full 8-month navigation season in 89 years of the 100-year record period. When System storage reserves are adequate, it is desirable to maintain navigation flows above the minimum levels. This minimizes the need for emergency dredging and allows barge loadings to greater depths than would be possible with minimum flows. In addition, the increased releases which provide the improved service to navigation will reduce the probability of having to release at rates which provide little or no benefit to navigation or to hydropower generation during flood storage evacuation. Based upon numerous operation studies and consideration of the effects the flow levels will have on navigation, target flow levels 6,000 cfs greater than the minimum flows specified above have been selected as the "full service" level for navigation under present day depletion conditions. With the present level of streamflow depletions, inflows to the System are sufficient to support full service flows for the 8-month navigation season in 41 years of the 100-year streamflow record period.

Operating experience has shown that flow rates of 31,000 cfs at Sioux City and Omaha, 37,000 cfs at Nebraska City, and 41,000 cfs at Kansas City will be adequate to maintain the designed 9-by-300-foot channel with a minimum of groundings and little or no emergency dredging. Slightly greater flows are required at the mouth (approximately 45,000 cfs) but tributary flows below Kansas City are usually adequate to provide the needed incremental flows. Although a 9-foot channel is not provided 100 percent of the time, the problem areas are generally transient and short term in nature. Increased flows would provide some relief, but experience has shown that, regardless of the support provided, some groundings do occur.

The average monthly Gavins Point release rates needed to provide minimum and full-service flows at all target locations, based on operating experience with tributary inflow, 1954 to 1979, are given in ***Table III***.

TABLE III
GAVINS POINT RELEASES NEEDED TO MEET
NAVIGATION REQUIREMENTS
1954 - 1979
(Discharges in 1,000 cfs)

Service Level	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Average
	Month									
Minimum	22.8	22.8	24.8	24.0	26.7	28.2	28.5	27.5	27.5	25.9
Full	28.8	28.8	30.8	30.0	32.7	34.2	34.5	33.5	33.5	31.9

The average seasonal Gavins Point releases which would be required to sustain full service navigation flows have varied from 28,100 cfs to as high as 39,700 cfs, while average monthly requirements have ranged from 13,000 cfs less than to 8,000 cfs greater than the values tabulated in ***Table III***. With normal inflows below the System, Sioux City flows will average about 35,000 cfs over the entire 8-month navigation season during periods when these full-service navigation targets are utilized for System regulation.

The amount of increase in navigation flow above minimum levels is a matter of operating judgment to be arrived at each year and will require a corresponding adjustment in the average Gavins Point release rates. These values serve as a guide in evaluating future operations; actual releases, of course, stem from day-to-day adjustment to take advantage of downstream tributary runoff. The values presented in ***Table III*** are the results of an analysis that included historic data up to 1979. A study that is currently underway includes historic data for the time period from 1979 to the present. The results of that study will most likely result in a change to the values presented in ***Table III***.

2. Nonnavigation Requirements. When releases are not being made to support navigation, other factors become applicable in fixing release rates, as follows:

a. Water Quality Control. Downstream water requirements for water quality, given in ***Table IV***, were established by the Federal Water Pollution Control Administration in 1969 and reaffirmed by the Environmental Protection Agency in 1974, after consideration of (1) the current status of PL 92-500 programs for managing both point and nonpoint waste sources discharging into the river, and (2) the satisfactory adherence to the 5.0 ppm dissolved oxygen requirement of Federally approved water quality standards.

TABLE IV
MINIMUM DAILY FLOW REQUIREMENTS
FOR ADEQUATE DISSOLVED OXYGEN
(cubic feet per second)

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

b. Water Supply Requirements. Numerous water intakes are located along the Missouri River both within and below the System. These intakes are primarily for the purposes of municipal water supplies, nuclear and thermal electric powerplant cooling, and for irrigation supplies withdrawn directly from the Missouri River. Over the past years, water access problems have been associated with several of these intakes; however, in most cases the problems have been a matter of sandbars or sediment deposition at the intake restricting access to the river rather than insufficient water supply. Other water supply problems can occur during the winter months due to ice jamming on the river. Floating or frazil ice can block the water intake facilities directly which can reduce flow to unacceptable rates.

Operation guidelines indicate that a minimum daily average release of 3,000 cfs from Fort Peck is satisfactory for municipal water supply. This is also an ample rate to meet most irrigation demands below the project. However, the formation of sandbars has at times restricted flows to the intake of the Bureau of Indian Affairs irrigation pumping plant near Frazer, Montana, temporarily requiring Fort Peck releases above this minimum level.

At Garrison, it is desirable to maintain minimum average daily releases of at least 10,000 cfs during the open-water season and the ice-cover season to provide sufficient river depths for satisfactory operation of municipal and irrigation water intakes in North Dakota. In this reach of the river, as well as that below Fort Peck, fluctuations in release levels at times require the resetting of irrigation pumping facilities to achieve access to available water or to prevent inundation of pumps.

In the reach immediately downstream from Fort Randall, the city of Pickstown experiences problems with its municipal water intake when the tailwater recedes below elevation 1228.6 feet msl. During past flood control operations requiring sustained low discharges, peaking operations of Fort Randall releases have been coordinated with the city to allow a 3- to 4-hour duration release of 10,000 cfs. This operation raises the tailwater elevation and provides the city with an opportunity to refill its water storage tank.

The minimum daily flow requirements established for water quality control are designed to prevent operational problems at municipal and electric/nuclear powerplant intakes at numerous locations along the Missouri River below the System. Similar to problems that have been experienced within the System at other locations, this is a matter of intake elevations or river access rather than inadequate water supply. Evaluations are continuing by appropriate state agencies in coordination with water plant operators to determine the minimum stage and flow requirement at each intake location for satisfactory hydraulic operation. In the meantime, when storage reserves are at high levels, releases for navigation and for power production purposes during the nonnavigation season will be at levels which operating experience has shown are adequate for all downstream needs. However, if it becomes necessary to reduce System releases below the 12,000 cfs level, continuing surveillance of these downstream intakes will be required and, if necessary, additional releases will be made in order to assure adequate water supplies for uninterrupted intake operation.

3. Integration of Downstream Requirements. In years of excess water supply, summer and fall releases above full-service, an extension of the navigation season, and increased winter releases are utilized to evacuate flood control storage. Releases above full service to evacuate excess water in storage increases the risk of downstream flooding should unexpected rainfall occur. Because of this, the first tool used to evacuate excess water in storage is up to a 10-day extension of the navigation season. This procedure increases the service provided to navigation, by providing a longer season, and to hydropower, by increasing the amount of winter energy generation. Next, winter releases are increased, relative to a normal year, to evacuate water. And lastly, summer and fall service level increases are instituted. Increasing winter releases slightly increases the risk of minor ice-induced flooding, but reduces the risk of summer and fall open water flooding. The open water flooding poses the highest flood damage potential, because of the existence of agricultural crops on the floodplain at that time of year. Releases to evacuate flood storage at rates above full-service requirements during the open water season also usually have a beneficial effect upon the navigation and power functions. Prior to July 1, releases greater than full service are reduced by 5,000 cfs since there is a greater risk of downstream flooding inflows in the spring and early summer.

With normal or less-than-normal water supply, navigation and power releases during the open water season will be based on existing and anticipated System storage and may provide less than full-service navigation requirements when storage reserves have been reduced. Under such conditions, winter power releases are also reduced. Fort Randall releases are scheduled at a maximum rate of 20,000 cfs less than the average navigation service level at Sioux City. Full-service winter power releases of 15,000 cfs from Fort Randall correspond with full-service navigation service that, in normal runoff years, provides an average navigation season flow of about 35,000 cfs at Sioux City. If, due to a severe drought depleting System storage reserves, it becomes necessary to reduce navigation season lengths to less than 8 months, winter power releases from Fort Randall will also be reduced to the minimum flows necessary for water intake requirements.

C. **Power Production**.

Western Area Power Administration (Western) markets hydroelectric energy and capacity from the System. Firm energy is marketed on both an annual and a seasonal basis, recognizing the seasonal pattern of releases made for navigation and required for flood control. During the navigation season, releases from the four uppermost reservoirs are varied in an effort to generate the greatest amount of energy at the times the power loads are the greatest. During the winter period, the most critical with respect to maintaining load requirements, releases from Fort Peck and Garrison are scheduled at relatively high rates to compensate for reduced power production at the downstream powerplants. The fall drawdown at Fort Randall makes available space for recapture of winter power releases from upstream reservoirs. In years of low energy generation due to downstream ice problems or low water availability, energy from other sources is obtained in the winter to help serve firm loads. Generally, the navigation season energy generation is adequate to meet firm load requirements, although during periods of reduced System releases for downstream flood control or during extended drought periods, Western must also purchase large amounts of energy.

Western Area Power Administration operates the Integrated Transmission System within the Mid-Continent Area Power Pool (MAPP). MAPP has a procedure called "Line Loading Relief" which requires the pool members to curtail schedules to keep from overloading transmission facilities. These curtailments at times require Western to reduce generation on the Corps' Missouri River main stem hydropower system to preserve transmission reliability. This "Line Loading Relief" may be called on short notice at any time of the day and is performed by reducing the load at one or more of the powerplants for an unforeseen duration, usually a few hours. Line loading relief reductions are usually accomplished by reducing Oahe generation but can also occur at Fort Randall and Garrison. Reductions in plant generation could be anywhere from a few megawatts to a few hundred megawatts. Depending on system release requirements, the reduction in powerplant releases could result in adjustments for more supplemental releases.

The Federal power system consists of the facilities listed in ***Table V***. The hydroelectric powerplants, substations, and other power facilities are interconnected with the extensive Integrated Transmission System in Western's Eastern Division, Pick-Sloan Missouri Basin Program, power marketing area which includes Montana east of the Continental Divide, North and South Dakota, eastern Nebraska, western Minnesota, and western Iowa. The transmission network is interconnected with numerous REA-financed cooperatives, municipal power systems, and investor-owned utilities. The Eastern Division transmission network is interconnected with the Southwestern Power Administration at Maryville, Missouri, and with the Western Division transmission network. The Western Division is interconnected with the Colorado River Storage Project.

TABLE V
FEDERAL HYDROELECTRIC POWERPLANTS
Eastern Division, P-S MBP

Corps of Engineers	**Nameplate Capacity - kW**	**Number of Units**
Fort Peck	185,250	5
Garrison	517,750	5
Oahe	786,030	7
Big Bend	494,320	8
Fort Randall	320,000	8
Gavins Point	132,300	3
Subtotal	2,435,650	36
U.S. Bureau of Reclamation		
Canyon Ferry	50,000	3
Yellowtail(1)	125,000	4
Subtotal	175,000	7
TOTAL	2,610,650	43

Federal Transmission System

Circuit Miles	**Voltage**
7,745	34,500-345,000 Volts
Substations	**Capacity**
99	8,006,639 kVA

(1) Only 50 percent of 250,000 kW total capacity to Eastern Division

D. Fish and Wildlife.

Construction of the System has been one of the most important contributions to sport fishing in the Missouri basin in this century. The large, popular lakes attract fishermen from many states to fish for trophy size northern pike, walleye, sauger, lake trout, and the chinook salmon. Because of extensive management, the big reservoirs are producing more sport fish than the Missouri River did before impoundment. The construction and operation of the System has altered the natural streamflow of the Missouri River. An early spring rise and a late spring-summer rise characterized the natural hydrograph. High flows resulted from the plains snowmelt, from March and April rains, and from the mountain snowmelt and rains in May, June, and July. Low flows typically occurred in late summer and fall. Regulation of flows by the System has reduced spring flows and has increased fall and winter flows, thus altering the habitat of native riverine fish species. Specific flow and habitat requirements for the native species in decline are mostly unknown; however, it is Federally accepted that an operation scenario that more closely mimics the pre-dam hydrograph would provide more value to native riverine species. Currently the following five species of fish and wildlife are listed or are candidates for listing as Federal threatened or endangered species: interior least tern (endangered); piping plover (threatened); pallid sturgeon (endangered); sturgeon chub and sicklefin chub (candidates). Introduced game species such as small mouth bass are increasing in abundance in some river reaches. Sport fishing for salmonoid species has become increasingly popular in river reaches below the three most upstream reservoirs. For instance, in North Dakota, state records for five species of trout/salmon have come from the free flowing river.

Fish production and development in the System is related to water levels and releases during the spawning period. The Federal and state fish and wildlife agencies recognize that water supply is not always adequate, making it impossible to operate each reservoir each year for optimum fish management. They have indicated that a good spawn of a fish species is not necessary each year to maintain the fishery resource in a specific reservoir. Therefore, one or more reservoirs may be selected each year for emphasis in the improvement of fish management and, to the extent that inflows and requirements for other purposes allow, the selected projects are regulated to improve fishery resources.

Fish and wildlife interests seek to provide conditions most suitable for fish spawning in all System reservoirs at appropriate times. This involves raising lake levels to where shoreline vegetation or rock spawning habitat is present and regulating reservoir or river levels at or above these levels during the spring spawning season. Downstream of Lake Sharpe, Lake Francis Case, and Lewis and Clark Lake, this can normally be accomplished. Provision of desirable levels at Lake Oahe for spawning usually requires accumulation of a plains snowcover during the winter months and moderate early spring runoff from the melting of this snowcover. The normal distribution of inflows into Fort Peck Lake and Lake Sakakawea, together with regulation for other purposes, in particular power generation, results in pool level variations which are not at all favorable for northern pike spawning. An attempt is being made to overcome this by alternately holding one of the reservoirs at a lower elevation through one or more years and subsequently raising the lake level to flood terrestrial vegetation for spawning habitat. Reservoir level manipulations can be accomplished by varying project releases; however, due at times to effects on hydropower production and more frequently because of natural inflow timing problems, the operation of the two uppermost projects for pike spawning has not been possible in most years.

Fisheries managers are equally concerned for propagation of forage fish to feed game fish. Since forage fish spawn later in the season than most predators, a stationary or rising pool level extending through June is considered desirable. Fortunately, such an operation is usually compatible with normal operations at Fort Peck and Garrison and can be accommodated with relative ease during years of high water supply to Oahe and Fort Randall. During years of deficient supply or abnormal distribution of the supply, such an operation may not be possible at one or more of the main stem projects. Successful fish spawn in the river reaches between projects requires that water levels not drop during or after spawning takes place. When operational flexibility exists, water releases are not reduced during the May spawn period.

Waterfowl management on the System centers on the Charles M. Russell, Audubon, and Pocasse National Wildlife Refuges established on Fort Peck Lake, Lake Sakakawea, and Lake Oahe. Under intensive management, wildlife production on the refuges has been substantial. Large numbers of migrating waterfowl use the reservoirs in the fall until time of freeze-up. Many then winter on the open water below dams, in nearby refuge areas, or on the open river reaches between Yankton and Sioux City.

1. Threatened and Endangered Species. The Endangered Species Act of 1973 (ESA), as amended, provides for the protection of Federally listed threatened and endangered species. The Act requires Federal agencies to ensure that their actions do not jeopardize the continued existence of a threatened or endangered species.

In 1985 the interior least tern and the piping plover were Federally listed as endangered and threatened species, respectively. These small shore birds nest on barren, low-lying sandbars and islands downstream from Fort Peck, Garrison, Fort Randall, and Gavins Point Dams from early May through mid-August. When available, they also use beaches and islands on the reservoirs for nesting. The Corps and the U.S. Fish and Wildlife Service (Service) completed formal Section 7 ESA consultation for terns and plovers on the operation of the System in 1990. The pallid sturgeon was Federally listed as an endangered species in October 1990. The Corps and the Service are currently in formal Section 7 ESA consultation regarding the operation of the System for all Federally listed species, including the pallid sturgeon.

Prior to their Federal listings, interior least tern and piping plover nests were periodically inundated as a result of project releases for flood control, navigation, and hydroelectric power generation. Since the time they were listed, the Corps has participated in habitat and population studies relative to the interior least tern and the piping plover in the Missouri River reach from Fort Peck, Montana, to Ponca State Park, Nebraska. In the past, the Corps has provided additional habitat by removing vegetation from higher elevation islands, pushing sand to higher elevations at historic nesting sites, and installing artificial islands. Nesting use is monitored at these sites. The Corps is striving to avoid adverse impacts on these species and will continue to adjust System operations to benefit Federally listed threatened and endangered species while continuing to serve all authorized project purposes. Ten stream gages were automated with satellite data collection platforms during the 1986-1988 period in the river downstream from Garrison, Fort Randall, and Gavins Point Dams to provide the information needed to correlate nesting habitat with reservoir releases. The river reaches have been modeled using dynamic modeling so that stages can be estimated for various release patterns prior to making the releases. The model cannot predict stage increases and nest flooding due to rainfall runoff events. A Geographic Information System (GIS) of the nesting site areas by river reach is being developed to provide spatial analysis of nesting sites and better represent historic nesting information.

Releases from the main stem dams are closely monitored during the nesting season. A uniform peaking release pattern has been established during the summer months at Garrison, Fort Peck, and Fort Randall for endangered birds nesting along the river below the projects.

Additionally, releases from Gavins Point are increased in early May when the birds arrive to provide the System flexibility to meet navigation target flows later in the nesting season when downstream tributary flows begin their normal decline in July and August.

2. Environment. Development of the System has transformed a major portion of the Missouri River valley extending from eastern Montana through the Dakotas from an area typical of alluvial streams into a chain of long, relatively deep lakes. This development, in an area where such lakes did not exist naturally and which is characterized as being relatively dry, has had a great effect upon the environment of the area. Acquisition and subsequent management of lands associated with the individual projects by the Corps of Engineers has changed use patterns of areas adjacent to the lakes from those experienced prior to project development. Regulation of the reservoirs also has significantly affected the flow regime of the Missouri River through those reaches below the System and in those reaches between System reservoirs where the river is still more or less in its natural state. Through observations and discussions with interested individuals and agencies, suggestions for environmental management have been received and are being implemented where practical.

A major environmental consideration has been the effect of various operational practices upon fish and wildlife, including threatened and endangered species. Improvement of fish spawning activities by appropriate habitat management and subsequent spawning is an important consideration in reservoir operations. Suggestions have been made and adopted to the degree practical for improving migratory waterfowl habitat and hunter access along the river below the projects. However, some suggestions, such as reducing flows during the migration to provide more sandbars, are difficult to implement without seriously impacting other authorized project purposes. Nevertheless, as suggestions are received, they are considered and evaluated with Federal and state fish and wildlife agencies and, where feasible, implemented to the degree practical. Another area of environmental concern is the management of project lands. At the present time, the major development emphasis on these lands is for water-oriented recreation. However, large areas of project lands are now being managed almost exclusively for wildlife. Fluctuating water levels in the reservoirs are also a concern to many project users. However, it must be recognized that some fluctuation in reservoir levels is unavoidable if the reservoirs are to serve authorized project purposes. A continuing objective in regulation of the System is to minimize departures in pool elevations from normal, full multipurpose levels to the maximum practical extent consistent with operation for other authorized project purposes.

The maintenance of relatively uniform release rates is also an environmental objective of many interested parties. While the construction and operation of the System has had a great effect on reducing high flows and supplementing low flows relative to the pre-dam flow regime, some fluctuations in release rates continue to be unavoidable if authorized project purposes are to be served. As a consequence, access to the river may be more difficult at times, fishing success may be affected, the sediment load in the river may be increased, and users of fixed boat docks may be inconvenienced. Release fluctuations are being minimized to the maximum practical extent considering release requirements for other authorized purposes. Improvement of the downstream water quality is another environmental consideration receiving emphasis at this time. As discussed elsewhere, relatively good quality water is stored and released from the reservoirs.

Missouri River Basin

Plate 1

Summary of Engineering Data -- Missouri River Main Stem Reservoirs

Item No.	Subject	Fort Peck Lake	Garrison Dam - Lake Sakakawea	Oahe Dam - Lake Oahe
1	Location of Dam	Near Glasgow, Montana	Near Garrison, ND	Near Pierre, SD
2	River Mile - 1960 Mileage	Mile 1771.5	Mile 1389.9	Mile 1072.3
3	Total & incremental drainage areas in square miles	57,500	181,400 (2) 123,900	243,490 (1) 62,090
4	Approximate length of full reservoir (in valley miles)	134, ending near Zortman, MT	178, ending near Trenton, ND	231, ending near Bismarck, ND
5	Shoreline in miles (3)	1520 (elevation 2234)	1340 (elevation 1837.5)	2250 (elevation 1607.5)
6	Average total & incremental inflow in cfs	10,200	25,600 15,400	28,900 3,300
7	Max. discharge of record near damsite in cfs	137,000 (June 1953)	348,000 (April 1952)	440,000 (April 1952)
8	Construction started - calendar yr.	1933	1946	1948
9	In operation (4) calendar yr.	1940	1955	1962
	Dam and Embankment			
10	Top of dam, elevation in feet msl	2280.5	1875	1660
11	Length of dam in feet	21,026 (excluding spillway)	11,300 (including spillway)	9,300 (excluding spillway)
12	Damming height in feet (5)	220	180	200
13	Maximum height in feet (5)	250.5	210	245
14	Max. base width, total & w/o berms in feet	3500, 2700	3400, 2050	3500, 1500
15	Abutment formations (under dam & embankment)	Bearpaw shale and glacial fill	Fort Union clay shale	Pierre shale
16	Type of fill	Hydraulic & rolled earth fill	Rolled earth filled	Rolled earth fill & shale berms
17	Fill quantity, cubic yards	125,628,000	66,500,000	55,000,000 & 37,000,000
18	Volume of concrete, cubic yards	1,200,000	1,500,000	1,045,000
19	Date of closure	24 June 1937	15 April 1953	3 August 1958
	Spillway Data			
20	Location	Right bank - remote	Left bank - adjacent	Right bank - remote
21	Crest elevation in feet msl	2225	1825	1596.5
22	Width (including piers) in feet	820 gated	1336 gated	456 gated
23	No., size and type of gates	16 - 40' x 25' vertical lift gates	28 - 40' x 29' Tainter	8 - 50' x 23.5' Tainter
24	Design discharge capacity, cfs	275,000 at elev 2253.3	827,000 at elev 1858.5	304,000 at elev 1644.4
25	Discharge capacity at maximum operating pool in cfs	230,000	660,000	80,000
	Reservoir Data (6)			
26	Max. operating pool elev. & area	2250 msl 246,000 acres	1854 msl 380,000 acres	1620 msl 374,000 acres
27	Max. normal op. pool elev. & area	2246 msl 240,000 acres	1850 msl 364,000 acres	1617 msl 360,000 acres
28	Base flood control elev & area	2234 msl 212,000 acres	1837.5 msl 307,000 acres	1607.5 msl 312,000 acres
29	Min. operating pool elev. & area	2160 msl 90,000 acres	1775 msl 128,000 acres	1540 msl 117,000 acres
	Storage allocation & capacity			
30	Exclusive flood control	2250-2246 975,000 a.f.	1854-1850 1,489,000 a.f.	1620-1617 1,102,000 a.f.
31	Flood control & multiple use	2246-2234 2,717,000 a.f.	1850-1837.5 4,222,000 a.f.	1617-1607.5 3,201,000 a.f.
32	Carryover multiple use	2234-2160 10,785,000 a.f.	1837.5-1775 13,130,000 a.f.	1607.5-1540 13,461,000 a.f.
33	Permanent	2160-2030 4,211,000 a.f.	1775-1673 4,980,000 a.f.	1540-1415 5,373,000 a.f.
34	Gross	2250-2030 18,688,000 a.f.	1854-1673 23,821,000 a.f.	1620-1415 23,137,000 a.f.
35	Reservoir filling initiated	November 1937	December 1953	August 1958
36	Initially reached min. operating pool	27 May 1942	7 August 1955	3 April 1962
37	Estimated annual sediment inflow	18,100 a.f. 1030 yrs.	25,900 a.f. 920 yrs.	19,800 a.f. 1170 yrs.
	Outlet Works Data			
38	Location	Right bank	Right Bank	Right Bank
39	Number and size of conduits	2 - 24' 8" diameter (nos. 3 & 4)	1 - 26' dia. and 2 - 22' dia.	6 - 19.75' dia. upstream, 18.25' dia. downstream
40	Length of conduits in feet (8)	No. 3 - 6,615, No. 4 - 7,240	1529	3496 to 3659
41	No., size, and type of service gates	1 - 28' dia. cylindrical gate 6 ports, 7.6' x 8.5' high (net opening) in each control shaft	1 - 18' x 24.5' Tainter gate per conduit for fine regulation	1 - 13' x 22' per conduit, vertical lift, 4 cable suspension and 2 hydraulic suspension (fine regulation)
42	Entrance invert elevation (msl)	2095	1672	1425
43	Avg. discharge capacity per conduit & total	Elev. 2250 22,500 cfs - 45,000 cfs	Elev. 1854 30,400 cfs - 98,000 cfs	Elev. 1620 18,500 cfs - 111,000 cfs
44	Present tailwater elevation (ft msl)	2032-2036 5,000 - 35,000 cfs	1670-1680 15,000- 60,000 cfs	1423-1428 20,000-55,000 cfs
	Power Facilities and Data			
45	Avg. gross head available in feet (15)	194	161	174
46	Number and size of conduits	No. 1-24'8" dia., No. 2-22'4" dia.	5 - 29' dia., 25' penstocks	7 - 24' dia., imbedded penstocks
47	Length of conduits in feet (8)	No. 1 - 5,653, No. 2 - 6,355	1829	From 3,280 to 4,005
48	Surge tanks	PH#1: 3-40' dia., PH#2: 2-65' dia.	65' dia. - 2 per penstock	70' dia., 2 per penstock
49	No., type and speed of turbines	5 Francis, PH#1-2: 128.5 rpm, 1-164 rpm , PH#2-2: 128.6 rpm	5 Francis, 90 rpm	7 Francis, 100 rpm
50	Discharge cap. at rated head in cfs	PH#1, units 1&3 170', 2-140' 8,800 cfs, PH#2-4&5 170'-7,200 cfs	150' 38,000 cfs	185' 54,000 cfs
51	Generator nameplate rating in kW	1&3: 43,500; 2: 18,250; 4&5: 40,000	3 - 109,250, 2 - 95,000	112,290
52	Plant capacity in kW	185,250	517,750	786,030
53	Dependable capacity in kW (9)	181,000	388,000	534,000
54	Avg. annual energy, million kWh (13)	1,170	2,472	2,898
55	Initial generation, first and last unit	July 1943 - June 1961	January 1956 - October 1960	April 1962 - June 1963
56	Estimated cost September 1996 completed project (14)	$158,428,000	$299,938,000	$346,521,000

Summary of Engineering Data -- Missouri River Main Stem Reservoirs

Big Bend Dam - Lake Sharpe	Fort Randall Dam - Lake Francis Case	Gavins Point Dam - Lewis & Clark Lake	Total	Item No.
21 miles upstream Chamberlain, SD	Near Lake Andes, SD	Near Yankton, SD		1
Mile 987.4	Mile 880.0	Mile 811.1		2
249,330 (1) 5,840	263,480 (1) 14,150	279,480 (1) 16,000		3
80, ending near Pierre, SD	107, ending at Big Bend Dam	25, ending near Niobrara, NE	755 miles	4
200 (elevation 1420)	540 (elevation 1350)	90 (elevation 1204.5)	5,940 miles	5
28,900	30,000 1,100	32,000 2,000		6
440,000 (April 1952)	447,000 (April 1952)	480,000 (April 1952)		7
1959	1946	1952		8
1964	1953	1955		9
1440	1395	1234		10
10,570 (including spillway)	10,700 (including spillway)	8,700 (including spillway)	71,596	11
78	140	45	863 feet	12
95	165	74		13
1200, 700	4300, 1250	850, 450		14
Pierre shale & Niobrara chalk	Niobrara chalk	Niobrara chalk & Carlile shale		15
Rolled earth, shale, chalk fill	Rolled earth fill & chalk berms	Rolled earth & chalk fill		16
17,000,000	28,000,000 & 22,000,000	7,000,000	358,128,000 cu. yds	17
540,000	961,000	308,000	5,554,000 cu. yds.	18
24 July 1963	20 July 1952	31 July 1955		19
Left bank - adjacent	Left bank - adjacent	Right bank - adjacent		20
1385	1346	1180		21
376 gated	1000 gated	664 gated		22
8 - 40' x 38' Tainter	21 - 40' x 29' Tainter	14 - 40' x 30' Tainter		23
390,000 at elev 1433.6	620,000 at elev 1379.3	584,000 at elev 1221.4		24
270,000	508,000	345,000		25
1423 msl 61,000 acres	1375 msl 102,000 acres	1210 msl 31,000 acres	1,194,000 acres	26
1422 msl 60,000 acres	1365 msl 95,000 acres	1208 msl 28,000 acres	1,147,000 acres	27
1420 msl 57,000 acres	1350 msl 77,000 acres	1204.5 msl 24,000 acres	989,000 acres	28
1415 msl 51,000 acres	1320 msl 38,000 acres	1204.5 msl 24,000 acres	450,000 acres	29
1423-1422 60,000 a.f.	1375-1365 985,000 a.f.	1210-1208 59,000 a.f.	4,670,000 a.f.	30
1422-1420 117,000 a.f.	1365-1350 1,309,000 a.f.	1208-1204.5 90,000 a.f.	11,656,000 a.f.	31
	1350-1320 1,607,000 a.f.		38,983,000 a.f.	32
1420-1345 1,682,000 a.f.	1320-1240 1,517,000 a.f.	1204.5-1160 321,000 a.f.	18,084,000 a.f.	33
1423-1345 1,859,000 a.f.	1375-1240 5,418,000 a.f.	1210-1160 470,000 a.f.	73,393,000 a.f.	34
November 1963	January 1953	August 1955		35
25 March 1964	24 November 1953	22 December 1955		36
4,300 a.f. 430 yrs.	18,300 a.f. 250 yrs.	2,600 a.f. 180 yrs.	92,500 a.f.	37
	Left Bank			38
None (7)	4 - 22' diameter	None (7)		39
	1013			40
	2 - 11' x 23' per conduit, vertical lift, cable suspension			41
1385 (12)	1229	1180 (12)		42
	Elev 1375 32,000 cfs - 128,000 cfs			43
1351-1355(11) 25,000-100,000 cfs	1228-1239 5,000-60,000 cfs	1155-1163 15,000-60,000 cfs		44
70	117	48	764 feet	45
None: direct intake	8 - 28' dia., 22' penstocks	None: direct intake		46
	1,074		55,083	47
None	59' dia, 2 per alternate penstock	None		48
8 Fixed blade, 81.8 rpm	8 Francis, 85.7 rpm	3 Kaplan, 75 rpm	36 units	49
67' 103,000 cfs	112' 44,500 cfs	48' 36,000 cfs		50
3 - 67,276, 5 - 58,500	40,000	44,100		51
494,320	320,000	132,300	2,435,650 kw	52
497,000	293,000	74,000	1,967,000 kw	53
1,052	1,846	749	10,187 million kWh	54
October 1964 - July 1966	March 1954 - January 1956	September 1956 - January 1957	July 1943 - July 1966	55
$107,498,000	$199,066,000	$49,617,000	$1,161,068,000	56

Remarks

(1) Includes 4,280 square miles of non-contributing areas.
(2) Includes 1,350 square miles of non-contributing areas.
(3) With pool at base of flood control.
(4) Storage first available for regulation of flows.
(5) Damming height is height from low water to maximum operating pool. Maximum height is from average streambed to top of dam.
(6) Based on latest available storage data.
(7) River regulation is attained by flows over low-crested spillway and through turbines.
(8) Length from upstream face of outlet or to spiral case.
(9) Based on 8th year (1961) of drought drawdown (From study 8-83-1985).
(10) Storage volumes are exclusive of Snake Creek arm.
(11) Affected by level of Lake Francis case. Applicable to pool at elevation 1350.
(12) Spillway crest.
(13) 1967-1997 Average
(14) Source: Annual Report on Civil Works Activities of the Corps of Engineers. Extract Report Fiscal Year 1996.
(15) Based on Study 8-83-1985

Corps of Engineers, U.S. Army
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