US Army Corps of Engineers

Missouri River Region
Reservoir Control Center

Missouri River Region RCC Since 1953 Reservoir Control Center

October 1998

# Missouri River Main Stem Reservoirs

# Hydrologic Statistics

## RCC Technical Report O-98

*Missouri River Basin*

Table of Contents

# INTRODUCTION

The purpose of this report is to describe the methodology, assumptions, data used, and results of the statistical analyses of hydrologic data for the Missouri River Main Stem Missouri River Reservoir System. Results of this analysis include the development of hydrologic statistics consisting of pool and release duration relationships, pool-probability relationships, and release probability relationships for each of the six main stem reservoir projects. The six projects comprising the Missouri River Main Stem Reservoir system include Fort Peck, Garrison, Oahe, Big Bend, Fort Randall and Gavins Point. Pool duration and release duration relationships were based on observed data from historical reservoir operation records. Pool-probability and release-probability relationships were derived from historical records reflecting actual reservoir regulation and from the results of model simulation studies reflecting current regulation criteria over a long term hydrologic record. Results of these analyses were compared with the previously developed relationships to determine the recommended or adopted pool-probability and release probability relationships. This report contains a summary of the current reservoir regulation philosophy as well as a description of actual past regulation during some of the more significant high runoff years. It also contains a description of the assumptions used in the long term computer model simulation studies.

Pool duration relationships are used to define the percent of time that a given pool elevation is equaled or exceeded, while release duration relationships represent the percent of time that a given release from the reservoir is equaled or exceeded. Duration curves represent the cumulative distribution function of all data recorded at the site which can be based on annual or seasonal periods. Seasonal duration curves can be defined to represent particular months or seasons such as the navigation or non-navigation season. A duration curve is not a probability curve. It should not be interpreted on a annual event basis because it provides only the fraction of time that a given event was exceeded and not the annual probability of an event occurring. It can be used to determine the average number of days per year that a particular magnitude is equaled or exceeded if it is annual duration curve or the number of days during a particular month or season if it is a seasonal duration curve. Daily or monthly data can be used to develop a duration curve. A shorter time step in the data used will typically result in a duration curve with steeper slopes at the extremes. Duration curves are developed using class interval analysis. Class interval analysis involves subdividing the data into defined class intervals and computing the relative frequency of each class interval based on the number of data within each class.

Pool-probability relationships are used to define the annual probability of the reservoir pool level reaching or exceeding a certain elevation. Current standards are to express the probability in terms of annual “percent chance of exceedance.” For example, a given pool elevation that has an annual exceedance probability of 0.01 would have a 1 percent chance of being equaled or exceeded in any year. The percent chance of exceedance is equal to the exceedance probability multiplied by 100. Once the exceedance probability is estimated, the recurrence interval or return period can be computed as the reciprocal of the of the exceedance probability. For example, a given pool elevation with a 1 percent chance of exceedance would have a recurrence interval of 100 years. This means that over a long period of time, the given pool elevation would be equaled or exceeded on the average of once every 100 years.  This elevation would be commonly referred to as the 100-year pool elevation.

Release-probability relationships are used to define the annual probability of making a release from the reservoir equal to or greater than a certain discharge.  For an uncontrolled reservoir, the release probability relationship may be derived directly from the pool probability relationship and a fixed elevation-outflow relationship since the maximum outflow is a function of the maximum pool elevation.   For a regulated reservoir, such as those that comprise the Missouri River Main Stem reservoir system, the release-probability relationship must be determined independently of the pool-probability relationship since maximum releases do not necessarily correspond with maximum pool elevations.  For the Missouri River Main Stem Reservoir System, maximum releases are dependant on a variety of factors in addition to the pool elevation within the reservoir.  These factors include downstream flow targets for flood control, navigation, water supply, and environmental needs, hydropower requirements, recreation, and intra system balancing for all authorized purposes. Duration of the maximum releases can vary considerably from project to project and from year to year.  For example, evacuation of significant accumulated flood storage can require many months, of sustained high releases, while short term peaking hydropower releases can occur for durations less than one hour.   Therefore, if the duration or volume of the maximum releases is of concern, the release probability relationships defined in this report should not be used.  Additional release-volume-probability studies should be completed to determine the frequency of release volumes for various durations.

Prior to this study, the adopted pool probability and release probability relationships were based on a study completed in April 1976 with only nine years of actual historical data from the period of 1967 through 1975.  The April 1976 study is referred to as MRD-RCC Technical Report B-76 “100-year Maximum Releases and Pool Elevations -1975 Development Level -Missouri River Main Stem Reservoir System.”  This study has been updated utilizing 31 years actual historical data from the period of 1967 through 1997.  This updated study was completed by the Reservoir Control Center, Missouri River Region of the U.S. Army Corps of Engineers and is published as NWD-MRR-RCC Technical Report Number A-98.   Supporting data and reports referenced herein are on file in the Reservoir Control Center.

## BACKGROUND INFORMATION

Six projects comprise the Missouri River Main Stem System, including Fort Peck, Garrison, Oahe, Big Bend, Fort Randall, and Gavins Point Dams. These dams were constructed by the Corps of Engineers on the main stem of the Missouri River for flood control, navigation, irrigation, power, water supply, water quality control, recreation, and fish and wildlife. The main stem projects are operated as a hydraulically and electrically integrated system in order to achieve the multipurpose benefits for which they were authorized. Figure 1 shows the location of each of these reservoirs. Pertinent data for each project are listed in table 1.

**Table 1**
**Pertinent Data for Missouri River Main Stem Reservoirs**

| Description | Fort Peck | Garrison | Oahe | Big Bend | Fort Randall | Gavins Point | System Total |
|---|---|---|---|---|---|---|---|
| River Mile | 1771.5 | 1389.9 | 1072.3 | 987.4 | 880.0 | 811.1 | |
| Drainage Area (sq.mi) | 57,500 | 181,400 | 243,490 | 249,330 | 263,480 | 279,480 | |
| Gross Storage (kaf) | 18,688 | 23,821 | 23,137 | 1,859 | 5,418 | 470 | 73,393 |
| Flood Storage (kaf) | 3,692 | 5,711 | 4,303 | 177 | 2,294 | 149 | 16,326 |
| Carryover Storage | 10,785 | 13,130 | 13,461 | | 1,607 | | 38,983 |
| Top of Dam (ft-msl) | 2280.5 | 1875 | 1660 | 1440 | 1395 | 1234 | |
| Max Surcharge Pool (ft-msl) | 2256.1 | 1858.5 | 1644.4 | 1433.6 | 1379.3 | 1221.4 | |
| Max Operating Pool | 2250 | 1854 | 1620 | 1423 | 1375 | 1210 | |
| Max Normal Pool | 2246 | 1850 | 1617 | 1422 | 1365 | 1208 | |
| Base Flood Pool | 2234 | 1837.5 | 1607.5 | 1420 | 1350 | 1204.5 | |
| Base Carryover | 2160 | 1775 | 1540 | 1420 | 1320 | 1204.5 | |
| Spillway Cap (cfs) | 275,000 | 827,000 | 304,000 | 390,000 | 620,000 | 584,000 | |
| Outlet Cap (cfs) | 45,000 | 98,000 | 111,000 | 0 | 128,000 | 0 | |
| Power Plant Cap (cfs) | 16,000 | 41,000 | 54,000 | 103,000 | 44,500 | 36,000 | |
| Date of Closure | Jun 1937 | Apr 1953 | Aug 1958 | Jul 1963 | Jul 1952 | Jul 1955 | |

The flood control storage zones in the Missouri River main stem reservoirs were designed in a series of Detailed Project Reports in the mid-1940's to provide control of the severe 1881 flood, with maximum releases of about 100,000 cfs from all projects other than Fort Peck and with maximum pools at or near the top of the exclusive flood control storage space. The 1881 flood inflows were based on estimates of what actually occurred, without reduction to allow for operational effects of upstream tributary reservoirs or for consumptive use by upstream irrigation and other purposes. If the flood runoff were to recur today, its severity as far as the main stem reservoir designs are concerned would be significantly reduced by these factors. On the other hand, regulation criteria used in the 1881 reservoir design studies were based largely on hindsight, with little regard for downstream runoff conditions. Releases of approximately 100,000 cfs were assumed to be made from mid-April to mid-July from the five lowermost reservoirs, without any requirement for reducing releases to desynchronize with downstream flood peaks. Thus, under today's conditions, the impacts of reductions in upstream runoff due to the construction of tributary reservoir flood storage and increased water-use primarily for irrigation might well be offset by release reductions necessary due to deteriorated downstream channel conditions and potential tributary flood inflows.

The March through July flood season volume of the 1881 flood at Sioux City has been estimated in past studies to be about 42 million acre-feet (maf), compared to a March through July 1978 runoff of 31 maf and the 1997 runoff of 37 maf, the highest years since record keeping began in 1898. The 1978 flood season runoff approximates the 1 percent chance exceedance flood runoff and the 1997 runoff is between the 0.5 and 0.2 percent chance of exceedance. The 1881 flood sequence as it occurred is considerably more infrequent. However, the frequency of the 1881 flood runoff volume has not been determined, nor routed through the reservoir system using current regulation criteria. To do so would require a considerable amount of work and judgement since 1881 flows are not available at most key tributary reservoirs and downstream gaging locations, and the extrapolation of data would make the results of the analysis unreliable. The remainder of this report addresses the development of pool-probability and release-probability relationships for the main stem reservoirs, without consideration of the 1881 flood --except to recognize that it is much more severe than the 1 percent chance exceedance condition.

The main stem reservoirs have been operating as an integrated system since 1954 although it was not until 1967 that initial fill of the system was completed. During the period of initial fill, regulation of the projects was very atypical of what may be expected in the future. In addition, during the period that the reservoirs have been operating, regulation philosophy and criteria have been modified and past regulation does not entirely reflect current criteria. For example, beginning in 1986, special release consideration from Fort Randall and Gavins Point were required for least terns and piping plovers to accommodate nesting requirements during the May through August period. Modest changes have been made in flood control criteria as additional experience has been gained.

When developing hydrologic data for a study of this type, it should be recognized that neither regulation criteria, available water supply, or characteristics of the reservoir system will remain static through the years.  Numerous refinements to regulation criteria have been made since system operation first began and more can be expected in the future.  Water resource development, in the Missouri Basin, is a dynamic process and has the greatest effects with changes in streamflow depletions.  It is anticipated that some continued development could occur in the future. While the main stem system construction is complete, modifications in project structures are always possible. All of these conditions could affect the frequency estimates.  Therefore, a considerable amount of engineering judgement, based on many studies and experience gained from years of  actual operation, was used in developing the frequency estimates in this report.

One means of investigating a long-term period of hydrologic record and obtaining data that would be considered satisfactory for frequency estimates is by the means of long-term system regulation studies.  A flow record extending from 1898 to present time, representing 100 years of data is available.  There are two similar computer models of the Missouri main stem reservoirs and downstream Missouri River control points used to simulate long-term reservoir regulation.  One model uses a monthly time step called the Long Range Study (LRS) and the other uses a daily time step and is called the Daily Long Range Study (DLRS).  Daily data is not available before 1929 and as a result, the pre 1929 data used in the DLRS was estimated based on data available between 1898 to 1929.  The data derived in this time period is often referred to a "fabricated" data  Criteria incorporated in these models reflect current regulation criteria to the maximum extent possible.  In some respects the computer studies provide the most valid frequency estimates because:

1. The period of hydrologic records is far greater than the years of experience in system operation.
2. Hydrologic records used in the system operation studies have been adjusted to reflect a 1990 level of basin water resource development, and;
3. The daily model utilizes a consistent set of reservoir regulation criteria throughout the entire period.  As referenced previously,  refinements to criteria have been made during the period of actual reservoir operations.  These changes, although modest in nature, are not reflected in previously recorded releases and reservoir elevations.

While there are advantages to using a long-term study for development of frequency estimates, as described above, it should also be  recognized that the long-term studies do not entirely reflect regulation that may have been or actually was performed.  Reasons for this include:

1. System regulation is extremely complex and precludes writing a computer model that totally simulates system operation, particularly during extreme runoff events.
2. Simplification of regulation criteria is necessary for the long-term studies.  For example, long-term criteria cannot reflect the multi-year changing emphasis on operations for fish and wildlife enhancement that occurs in actual regulation.
3. Long term studies do not reflect limits on power generation that occurs during actual regulation due generally to power units being unavailable because of scheduled or unplanned maintenance outages.  Changes in value of marketed energy at a particular time also affects system generation.

4. The models are not capable of predicting runoff from spring and mountain snowpack conditions, as is done in real time regulation. The deviations between historic regulation and model results are the greatest during the extreme events.

Based on the discussion presented previously, it was reasoned that frequency estimates should be based on both the historical record of actual system regulation experience and on the long-term reservoir operation studies. The most recent long-term study reflecting current operation utilizing the Long Range Study (LRS) model is referred to as the Current Water Control Plan (CWCP). This study was completed as part of the Missouri River Master Water Control Manual Review and Update studies and is documented in Volume 2: Reservoir Regulation Studies-Long Range Study Model dated July 1994. That study has been updated and contains the experienced hydrologic record extending from 1898 through 1997 and reflects, to the degree possible in long-term studies of this type, regulation criteria at the current (1997) level, as well as Missouri Basin water resource development current to the last year of the study which is 1993. The results of the daily model (DLSR) were reviewed for this analysis as well. Significant short term differences have been noted between model results and actual operations for the recent flood years. Hydrologic data for the DLRS model was extended to include daily reach inflows through 1997.

Two methods were used to determine the pool-probability relationships, a graphical analysis of the 100 years (1898-1997) of simulated maximum daily pool elevations for the DLRS model simulation, and a graphical analysis of the 31 years (1967-1997) of observed maximum daily pool elevations based on the historical rank. Throughout this report, the analysis based on the DLRS model is referred to as “Simulated”, while the analysis based on the 31 years of historical record is referred to as “Observed”. Each graphical analysis was based on the Weibull plotting position formula. Eye fit curves for each of these methods were compared with the adopted curve from the 1976 study to obtain the adopted curve for this update study. Similar procedures were used to develop the release-probability relationships.

## MAIN STEM RESERVOIR SYSTEM REGULATION

Regulation of the main stem reservoir system follows a repetitive annual cycle. Winter snows and spring and summer rains produce most of the years's water supply which results in rising pools and increasing storage accumulation. After reaching a peak, usually during July, storage declines until early the following spring when the cycle begins anew. A similar pattern may be found in rates of releases from the system, with the higher levels of flows from mid-March to late November, followed by low rates of winter discharge from late November until mid-March, after which the cycle repeats. Two primary high risk flood seasons are the plains snowmelt season extending from late February through April and the mountain snowmelt period extending from May through July. Overlapping the two snowmelt flood seasons is the primary rainfall flood season which includes both upper and lower basin regulation considerations. 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 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 and Big Bend peaking power releases. The major maintenance period for the main stem power facilities extends from mid-February through May and from September to mid-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 turbins are normally required to provide navigation flow needs.

Normally, the navigation season extends from April 1 through December 1 during which time reservoir releases are increased to meet downstream target flows in combination with downstream tributary inflows. Much of the increased flow for navigation comes from the large carryover storage in Oahe Reservoir. Winter releases after the close of navigation season are much lower and vary depending on the need to conserve or evacuate main stem storage volumes, downstream ice conditions permitting. Minimum release restrictions and pool fluctuations for fish spawning management generally occur from April 1 through July. Endangered and threatened species nesting (interior least tern and piping plover) occurs from early May through August. During this period, special release patterns are made from Fort Peck, Garrison, Fort Randall, and Gavins Point to avoid flooding nesting sites on low-lying sandbar islands downstream from the projects.

The general regulation principles presented above provide the philosophy for main stem system regulation. Detailed operation plans are developed, and adjusted as conditions warrant due to changes in runoff and streamflow. Beginning in 1953, projected operation of the Missouri River main stem reservoir system for the year ahead was developed annually as a basis for advance coordination with the various interested Federal, State, and local agencies and private citizens. These regulation schedules are prepared by the Reservoir Control Center, Missouri River Region, Corps of Engineers. A discussion of the specific system regulation requirements for a few of the more significant runoff years is presented in the following paragraphs.

## REGULATION OF 1975 RUNOFF

Runoff during 1975 from the drainage area controlled by the Missouri River main stem reservoir system upstream from Sioux City, Iowa, totaled 35.5 million acre-feet (maf) which ranks as the seventh highest since the main stem first reached normal operating levels in 1967 and the eighth largest during the 1898-1997 period. Over 80 percent of the 1975 runoff originated upstream from Garrison. Upstream from Fort Peck and Garrison, the 1975 runoff was the highest on record, totaling 28.8 maf from those two reaches. In the process of regulating this unprecedented runoff, three of the projects (Fort Peck, Garrison, and Oahe) exceeded previous maximum reservoir elevations, while sustained releases from all projects were at higher rates than any previous release. All maximum release rates were well below the flow rates which occurred frequently prior to operation of the system and below those that would have occurred on numerous occasions since operation began.

In early 1975, it appeared that runoff above the reservoirs would be less than normal, due to a subnormal mountain snowpack. However, much above normal precipitation occurred over Montana and North Dakota through July. The most severe event was the extremely heavy rainstorm of 18-19 June centered to the east of the continental divide in Montana where average precipitation amounts exceeding 10 inches covered a 2,500 square mile area and an area of 10,000 square miles had an average rainfall exceeding 6 inches. Flood control provided by the reservoirs, prevented stages below the system from exceeding flood stage. Consequently, significant damages were prevented and credited to the system.

The regulation of runoff in 1975 resulted in the pool levels at Fort Peck and Garrison that were record highs. At Fort Peck, the pool reached elevation 2251.6, which is still the maximum level ever reached. This elevation is 1.6 feet above the top of the exclusive flood control pool and into the surcharge zone provided for the control of extraordinary floods. The Garrison pool level reached a maximum elevation of 1854.8, which is 0.8 foot into the surcharge zone and is still the highest level ever reached. Maintaining lower levels in the upstream reservoirs would have required substantial increases in the releases from these projects. When it became apparent that utilization of surcharge storage was probable, releases were increased up to the maximum rate believed practicable without causing substantial lowland flooding through the immediate downstream areas. Since encroachment into the surcharge zone of any reservoir project reduces the effectiveness of the project for control of subsequent flood inflows that may occur, consideration is given to the time of year and risk of subsequent floods. If the encroachment had occurred early in the flood season prior to mountain snowmelt, it would have been much more serious and greater project releases would have been made. However, actual encroachment occurred after it became evident that mountain snowmelt was essentially completed and the normal season of large runoff producing rains in upstream areas had passed. Maintaining relatively higher Fort Peck and Garrison reservoir levels than at downstream projects also served to maintain an increased overall flood control capability of the main stem system by providing additional flood control storage space in downstream projects.

Criticism of the 1975 system regulation by specific river interests was that higher than normal releases should have been initiated earlier in order that the maximum reservoir elevations and maximum release rates would have been at lower levels. However, prior to early May, runoff above the main stem reservoir system was forecasted to be in the sub-normal to normal range. The excess runoff resulted primarily from much above normal precipitation occurring in the April through early July period. Additionally, after it became evident that above normal inflows could be anticipated, tributary inflows to downstream reaches of the Missouri River were high enough to require restrictions to system releases during June in order to prevent significant flooding.

If a similar flood were to occur in future years, with current regulating criteria, it is doubtful that regulation would be the same as that experienced in 1975 for the following reasons:

1) Releases during the period extending from March through May were less than would normally be made with the amount of storage accumulated at Fort Peck. Reasons for this included low forecasts of subsequent runoff, the desire to make large releases during the later irrigation season because of temporary irrigation intake deficiencies, and power plant maintenance requirements. This combination, coinciding with such an unprecedented amount of runoff is considered to be remote.
2) Analysis of the release pattern in combination with pool levels indicates that during the 1975 flood there was a several-day delay in increasing releases to all levels, including particularly those that exceeded power plant capacity. Now that such a flood with a large volume has occured, and record releases were made without significant problems to at least the mouth of the Yellowstone, future releases could be expected to be higher during the early portions of a repetition of this event, resulting in lower maximum pool levels than those that occurred in 1975.

**REGULATION OF 1978 RUNOFF**

Runoff above Sioux City during 1978 totaled 40.6 maf, the second highest on record during the period of 1898 through 1997. System storage increased rapidly at the beginning of the 1978 navigation season. On March 22, system storage was 54 maf and increased at an average of more than 500,000 acre-feet per day during the remainder of the month. Storage gains continued at a high rate through April as plains snow melt runoff continued and mountain snowmelt began. As mountain snowmelt continued through the summer months, the system storage crested on July 23 at 69.3 maf.

Prior to the beginning of the navigation season, plans were made to provide less than full service navigation releases during the beginning months of the navigation season due to lower than normal storage levels that resulted from the basin-wide drought of 1977. The melting of the heavy snowpack over the plains area caused unprecedented daily system storage gains, and an upward adjustment of the forecasted annual runoff resulting in the decision to increase navigation support to full service. Gavins Point releases were gradually increased to the full power plant capacity of 35,000 cfs by the end of May as downstream tributary flows receded. Spills began the second week of June and continued into December to evacuate the flood waters stored. In October and November, maximum releases were maintained near 52,000 cfs. During a four day period in March, the Gavins Point pool rose from elevation 1205 to 1209.2, the highest pool elevation until 1995**.**

Releases from Fort Randall generally paralleled those from Gavins Point with the exception of the flood runoff period and a scheduled weekly cycle that permitted Fort Randall to share the Sunday release sags occasioned by the reduced power loads. Due to the large runoff that began about mid-March, releases were reduced to about 1,000 cfs for one week to limit the pool rise in Lewis and Clark Lake and permit Gavins Point releases to be held to a minimum. Lake Francis Case rose rapidly during the early part of the navigation season to a crest of 1362.5 in response to the reduced Fort Randall release and the high plains snowmelt runoff. Releases were increased to a maximum of 53,200 cfs in October to evacuate the flood storage, drawing the pool down to elevation 1339.3 by the end of November.

At Oahe, the pool level increased from elevation 1600 at the end of February to 1616.2 in July. Releases from both Oahe and Big Bend fluctuated quite widely from hour-to-hour and day-to-day to meet varying power loads and to back up system releases. Oahe outflows of at least 3,000 cfs were maintained during weekend daylight hours to enhance downstream fishing and recreational use during the recreation season. Oahe releases reached a maximum of 54,300 cfs in September. Lake Sharpe was maintained near elevation 1420 during the entire period.

At the beginning of the period, the Lake Sakakawea pool level was at elevation 1826, ten feet lower than one year earlier. Like the other projects, the level rose rapidly in response to the snowmelt runoff with an inflow of 150,000 cfs reported on March 27. It continued to rise before cresting at elevation 1849.5 on July 25. Releases from Garrison were reduced at the beginning of the navigation season to prevent flooding in the reach downstream of Bismarck as tributary streams crested at near record levels. Releases were gradually increased to full power plant capacity during June, reaching a maximum daily release of 39,300 cfs in September and October.

At Fort Peck, the pool level was near elevation 2230 in early March. It rose to elevation 2245 by the end of May and crested at elevation 2249.6 on July 20. Releases from the project were reduced from 8,000 cfs to only 3,000 cfs or less during the last two days of March and the first nine days of April to minimize flooding near the mouth of the Milk River as stages in that stream reached record levels. Release were gradually increased to full power plant capacity by late July, reaching a maximum of 14,800 cfs in August.

The regulation of the 1997 flood, which also involved a significant plains snowmelt component, would indicate that system releases would be initiated both earlier and at greater amounts than occurred in 1978 resulting in lower maximum pools and less system storage accumulation. The change is due to the recognition of the significant runoff volumes that occur with a heavy plains snowpack. These volumes were not available prior to 1997.

**REGULATION OF 1986 RUNOFF**

Runoff during 1986 above Sioux City was 36.2 maf, the fifth highest on record and the fourth highest during the period that the main stem reservoirs have been operating. System storage at the beginning of the 1986 navigation season was 58.4 maf. Heavy precipitation during April resulted in near record runoff volumes in many Missouri River tributaries. These large runoff volumes caused significant gains in storage in both Oahe and Fort Randall. Oahe set a new record high pool level in June 1986, a level not exceeded until 1995. Storage gains tapered off during early July, but heavy rains over portions of Montana and North Dakota caused additional storage accumulation resulting in a 1986 system storage crest of 65.2 maf on July 20.

Missouri River flows at Sioux City and all downstream locations exceeded navigation requirements by mid-March even though Gavins Point releases remained near the winter release level of 18,000 cfs. Missouri River flows continued well above normal during April with near record precipitation. As a result, Gavins Point releases during April averaged only 17,200 cfs, which, at that time, was the third lowest since the system became operational in 1967. Despite these low releases, rains caused the lower river to exceed flood stage at several locations downstream from the Platte River. Heavy May rains preceded by near record April rainfall caused unprecedented runoff in tributaries downstream from Garrison Dam. High inflows and low project releases combined to raise the Oahe pool into the exclusive flood zone, prompting a gradual increase in Gavins Point releases to 35,000 cfs by mid-May. Although it was desired to initiate spillway releases in late July, they were delayed to mid-August to facilitate the completion of nesting of least terns and piping plovers. In October, maximum daily releases from Gavins Point reached 45,000 cfs.

At Fort Randall, a minimum release of 20,000 cfs was targeted to enhance downstream fish spawning. However, because of high downstream tributary flows, this rate was not attained until mid-May. On one occasion during April, the daily flow was reduced to as low as 7,500 cfs because of flood control actions. The pool at Fort Randall fluctuated from a minimum of 1354.5 feet msl to a maximum of 1362.0.

Lake Sharpe was maintained between a minimum elevation of 1419.5 and a maximum of 1421.5 feet msl. At the beginning of the period, the Oahe pool was near elevation 1612.0 feet msl, 4.5 feet above the base of annual flood control. It reached a record elevation of 1618.5 feet msl on May 16, 0.2 foot higher than the previous record set in 1984. This remained the record pool elevation 1995.

Garrison releases began the period at 28,000 cfs and were gradually decreased to 14,000 cfs by the end of April. To keep the Oahe pool from filling higher, Garrison releases were reduced to 10,000 cfs by early May. Releases were maintained at this level until they were gradually increased in early June. The Garrison pool rose 4 feet in May, 6 feet in June and 2 feet in July, cresting at elevation 1848.7 feet msl.

At Fort Peck, the pool was near elevation 2229.1 feet msl at the beginning of the 1986 navigation season. This was 4.9 feet below the base of the annual flood control space and 6.9 feet lower than in 1985. The pool had been intentionally drawn down below normal levels to provide shoreline revegetation for improved fish spawning habitat. The pool refilled to the base of the annual flood control zone by the end of June and continued a gradual climb to elevation 2238.3 by the end of December.

**REGULATION OF 1993 RUNOFF**

During 1993, runoff above Sioux City totaled 36.2 maf, the sixth highest on record and fifth highest since main stem regulation began. Downstream from Sioux City to the mouth of the Missouri River, runoff during 1993 was an unprecedented 111.8 maf, which was 255 percent of average. Upstream from Sioux City, runoff was 147 percent of normal. Six consecutive years of below normal runoff in the upper Missouri River basin ended dramatically in 1993. System storage began 1993 at 42.7 maf, the second lowest January level since the system initially filled in 1967. System storage for the year crested at 57.2 maf on September 7 near the base of the annual flood control zone. Low releases from the main stem system because of the Great Flood of 1993 had a significant impact on the accumulation of storage during July through September. The Great Flood of 1993 with its widespread, severe downstream flooding, and above normal upstream inflows not only ended the 6-year drought but nearly refilled the main stem reservoir system to normal levels, a feat that under normal runoff conditions would have taken more than 6 years. Over 4.4 billion dollars in damages prevented resulted from the regulation of the main stem dams, the second highest to date.

Gavins Point releases averaged 11,200 cfs in April, 17,600 cfs in May, 17,000 cfs in June, and 8,000 cfs in July. April, May, and July monthly average releases were the lowest since the system reached normal operating levels in 1967. Daily average releases ranged from a minimum of 6,000 cfs in early July to a maximum of 24,300 cfs during late May and early June when cyclic peaking for endangered species was taking place.

Releases at Fort Randall averaged 7,600 cfs in April, 13,300 cfs in May, 13,900 cfs in June and 2,600 cfs in July. Releases during May and July were new record lows. Daily average releases varied between 26,000 cfs in late May and 600 cfs in July. At the beginning of the navigation season, the pool level was near elevation 1357.0 feet msl, climbing to a crest of 1361.0 by the end of July.

Lake Sharpe was maintained between elevations 1420.2 and 1421. 2 feet msl. At Oahe, the pool was near elevation 1592 at the start of the year. It climbed to a crest of 1611.6 feet msl in September, gaining nearly 20 feet and reaching 4.1 feet into the flood control pool.

Garrison releases averaged only 10,300 cfs during April, setting a new record low for the month. Beginning in mid-May the daily average release from Garrison was set at 16,000 cfs to establish a base flow condition for various authorized purposes and endangered birds nesting below the project. In mid-July, releases were reduced to the 12,000 to 15,000 cfs range to safeguard threatened and endangered birds and to help balance intra-system storage. The July monthly average release of 14,800 cfs was also a new record low. Lake Sakakawea rose gradually from elevation 1819.5 feet msl at the beginning of the navigation season to a crest of 1837.8 feet msl in November., 0.3 feet into the annual flood control pool.

Releases from Fort Peck averaged 6,000 cfs in April, increased to 7,000 cfs during May and June, then lowered in July to 4,000 cfs to safeguard threatened and endangered birds. Near the beginning of the navigation season, the Fort Peck pool was at elevation 2211.3 feet msl. It rose to a crest of 2228.4 feet msl in September, still 5.6 feet below the base of the annual flood control pool.

**REGULATION OF 1995 RUNOFF**

Runoff above Sioux City during 1995 totaled 37.6 maf, the third highest year on record (1898-1997). System storage was at the desired 57.2 maf, the top of the carryover multiple use zone on November 1, 1994. During the winter months, inflows to the system were below normal and the system storage fell slightly to 55.9 maf. System storage made its most impressive gains of the year in June from the cold and wet spring that caused a month delay in the melt of the mountain snow. The June storage gain of 4.4 maf was the highest June gain since the system filled in 1967. Peak system storage of 68.1 maf occurred on July 27. End of July storage was the highest since 1978. Record high pool elevations occurred at Gavins Point, Fort Randall and Oahe. Flood damages prevented exceeded 1.8 billion dollars.

Gavins Point releases were held near 17,000 cfs until mid-March, when flow support for the navigation season began as releases were gradually increased to 26,500 cfs. In April, Gavins Point releases were reduced to 12,000 cfs to reduce the threat of flooding downstream. By the end of May, releases were increased to 25,000 cfs as downstream flooding subsided. By the end of June releases from Gavins Point were increased to 35,000 cfs (power plant capacity). This was the first time since 1988 that full power plant release was made from Gavins Point. Spillway releases were added near the end of July and gradually increased to a total release of about 54,000 cfs in August. Releases were maintained near this level through the fall. In November, the maximum daily release of 56,100 cfs occurred. These high releases were made to evacuate the accumulated flood storage. Lewis and Clark Lake was targeted for elevation 1206 feet msl throughout the spring and summer of 1995. The pool elevation ranged from 1205.8 to a record high pool elevation of 1209.5 feet msl in May. This elevation was within 0.5 foot of overtopping the spillway gates as the May runoff in the reach from Fort Randall to Gavins Point was the highest of record.

Releases from Fort Randall generally paralleled those from Gavins Point. However, during the flood control operation from mid-April through early June, daily average releases were less than 10,000 cfs for all but 9 days. Releases from Fort Randall were completely shut off on May 30. By June 1, Lake Francis Case rose to an elevation of 1367.9 feet msl, the highest elevation since closure of the dam in 1952 (2.9 feet into the ten foot exclusive flood control zone). Lake Francis Case pool elevation gradually decreased reaching 1359.4 feet msl by the end of July and 1338.3 by the end of November as releases were increased to a maximum of 53,000 cfs by November.

At Oahe and Big Bend, daily average releases were well below normal during April through June to prevent flooding downstream. Oahe's releases averaged only 1,900 cfs in May, a record low. In June releases averaged 11,100 cfs. These low releases in conjunction with high inflows resulted in a record high pool level of 1618.7 feet msl on June 25. Releases were increased through the remainder of the summer and into the fall with a maximum daily release of 48,500 cfs in August. Evacuation of the flood storage gradually brought the pool elevation down to 1608.2 by the end of December. Big Bend pool levels were maintained between elevations 1419.4 and 1421.8 feet msl during this period.

Garrison releases averaged 12,300 cfs for the month of April, the fourth lowest on record. Releases were cycled from mid-May through early July to prevent endangered and threatened birds from nesting too low below Garrison. During May, the cycle was 1 day at 16,000 cfs followed by two days of 13,000 cfs. The cycling pattern was modified as Oahe's pool continued to climb. By June the cycle was 2 days at 10,000 cfs followed by 1 day at 13,000 cfs. During 1995 the pool at Lake Sakakawea climbed over 15 feet to elevation 1851.9 feet msl in August, the second highest pool elevation on record. Releases to evacuate flood control storage began in August. In September, the maximum daily release of 37,500 cfs was made and releases were maintained near power plant capacity through the fall.

Releases from Fort Peck averaged 5,800 cfs in April to support fish spawning below the dam. In May, releases were increased to near 7,000 cfs and remained at this level through the end of July. At the beginning of the navigation season, the elevation of the Fort Peck pool was 2231.5 feet msl. It rose gradually to a peak elevation of 2244.2 feet msl in August, which is 10 feet into the annual flood control and multiple use zone. Releases near power plant capacity were made through the fall with a maximum daily release of 14,900 cfs in October to gradually draw the pool down to elevation 2238.3 by the end of December.

**REGULATION OF 1996 RUNOFF**

Runoff in the Missouri River basin above Sioux City in 1996 was 35.6 MAF, very near the total runoff experienced in 1975 and 45 percent above normal. Although the runoff was less than in 1993 and 1995, peak stages on the river below the main stem system were higher in many cases than the 1993 and 1995 peaks. The high river stages were the result of both a very large snowmelt runoff and high flows on tributaries downstream of the system from rainfall events.

Evacuation of 1995's high runoff continued throughout the winter months of 1995-1996 and the system storage was on target to be at the base of the annual flood control pool by the first of March. However, an early, rapid melt of the heavy plains snowpack on frozen ground resulted in a record February runoff in the upper basin, 340 percent of normal. And while runoff was pouring into the main stem dams, snow was continuing to build in the mountains. The mountain snowpack continued to accumulate into early May peaking nearly 20 percent above the normal peak accumulation.

System storage declined to as low as 58.1 MAF in late January and early February, but was 60.2 MAF on March 1, nearly 3 MAF above the base of the annual flood control pool. Despite record releases from February to April, high inflows from the rapid melt of the mountain snowpack poured tremendous amounts of water into the system. The peak system storage occurred on July 7 at 68.5 MAF, 0.4 MAF higher than 1995's maximum.

Near the end of April, very heavy rain fell across southeastern Missouri, marking the end of a relatively dry period in the lower basin, and the beginning of a series of very heavy rainfall events below the main stem system. The heavy rains began in Missouri and gradually moved upstream as the summer progressed with much of the heaviest rain, including several events with as much as 6 to 12 inches, falling along the Missouri River in eastern Nebraska and western Iowa.

Gavins Point releases were held near 20,000 cfs until early February and then gradually increased to full power plant capacity by mid-March. Spillway flows were initiated in early April, and by early May releases had hit 45,000. Releases were reduced several times during May, June and July as significant downstream rainfall events occurred. Between storms in June, releases reached 50,000 cfs and by July 1, they reached 52,000 cfs where they remained until late fall. The releases reached their maximum of the year, 55,000 cfs, in early November after tributary flows had declined and cooler water temperatures made the additional increases possible without increasing stages downstream.

Releases from Fort Randall generally paralleled those from Gavins Point. Average daily releases during the year varied between 9,100 cfs in late May while system releases were cut back for downstream flood control, to 53,000 cfs in November for flood storage evacuation. Lake Francis Case peaked out for the year on June 28 at 1361.49 feet msl, 3.5 feet below the base of the exclusive flood control pool.

Lake Oahe was drawn down to within 0.4 feet of the base of the annual flood control pool prior to February's record runoff, then gained 3.5 feet, to 1611.1 feet msl by March 1. The pool continued on a steady rise through the early part of the summer as the mountain snow melt poured into the upper reservoirs and system releases were restricted due to downstream flooding. The pool crested at elevation 1618.67 feet msl on June 23, nearly identical to 1995's record crest and 1.7 feet into the exclusive flood control pool. Flood storage evacuation continued through the fall and before being cutback prior to the winter freeze-in. The pool ended the year at 1607.5 feet msl, the base of the annual flood control pool.

Lake Sakakawea reached the base of its annual flood control pool in early February, but high inflows during the month caused the lake elevation to climb to 1839.6 feet msl by March 1, 2.1 feet in to the annual flood control pool. The largest gains of the year, though occurred during June as the snowmelt runoff entered the system. Lake Sakakawea crested at elevation 1849.56 feet msl on July 23, just 0.4 feet from the exclusive flood control zone. High releases through the summer and fall lowered the pool to 1838.9 feet msl by the end of December, 1.4 feet into the annual flood control pool.

Fort Peck Lake was drawn down to within 2.6 feet of the base of the annual flood pool prior to February's high inflow, but rose to 2238.0, four feet into the annual flood control pool by March 1. The lake peaked out for the year at 2247.3 feet msl, 1.3 feet into the exclusive flood control pool. Releases varied between 3,000 cfs, due to flooding in the Williston, ND area during March, and 16,400 cfs for flood storage evacuation during July. Fort Peck Lake ended the year at 2236.0 feet msl, still 2 feet into the annual flood control pool.

**REGULATION OF 1997 RUNOFF**

Following three of four near record runoff years, 1997 was yet another year of record runoff, breaking all previous runoff records in the upper basin.

Unprecedented winter snows accumulated over the plains during the winter months. Snow accumulations began in October and the winter was extremely harsh throughout the upper basin both in relation to cold temperatures and snow accumulation. In the mountains, fall accumulations were also ahead of schedule, but the heavy January accumulation was the first indicator of a much above normal winter mountain snow pack. Winter snows continued and by April 15, when the maximum mountain snowpack normally occurs, total accumulation was between 35 and 40 percent above normal in the reaches upstream from Fort Peck and Garrison.

Runoff into the reservoir system resulting from the large winter snow accumulation was unusually large. Record and near record inflows occurred during each of the first 7 months of the year. The January-February runoff exceeded the maximum set just one year earlier and the March-April total runoff exceeded the 1952 historic maximum. May and June runoff were the fourth and third largest runoffs respectively in the 100 years for which runoff records have been developed and the May-June-July runoff was second only to the record 1975 runoff. Only two of the months, January and March, were by themselves maximum of records. The combined runoff for the March through July period, commonly the greatest runoff period, totaled 36.8 maf, 17 percent greater than the previous maximum set in 1978. The total annual runoff was 49.0 maf, 202 percent of average and 22 percent greater than the previous annual maximum which was experienced in 1978.

Water control personnel forecasted near record reservoir inflows. In response to the expected large inflows, system releases were increased to record levels early in the year and were maintained at rates significantly higher than previous levels. January releases were near historic highs and, beginning in February, record high releases began and continued throughout the remainder of the year. For the January-July period, system releases were 183 percent of average and 32 percent greater than the previous record for the period set just one year earlier. The Oahe and Fort Randall projects climbed into their exclusive flood control pools during March and April respectively, in response to the unprecedented runoff from the record plains snowpack whose melt was speeded by warmer than normal temperatures. Fort Peck and Garrison releases were minimized early in the runoff period, to the extent possible, to stem the rise in Oahe and Fort Randall pools.

The reservoirs formed by the Oahe and Fort Randall dams climbed rapidly, Oahe entering its exclusive flood control pool on March 28th. Fort Randall soon followed, reaching its exclusive pool on April 5th. Oahe climbed from a winter minimum level of 1607.5 to 1618.6 by early May, rising a total of 8 feet during the month of March alone. Fort Randall climbed from a late winter level of 1353 to a maximum of 1372.2 on May 7 (7.2 feet into its ten foot exclusive flood control zone), a level 4.3 feet higher than the previous maximum, set in 1995.

The melt of the mountain snowpack began in earnest during May, nearly a month later than normal, and occurred over a shorter than normal period due to relatively warm temperatures. Releases from both Fort Peck and Garrison Dams were increased significantly. Garrison's release was set at 59,000 cfs, the second highest rate of record. The historic maximum of 65,200 cfs occurred in 1975. Increases at Fort Peck were made later and were at a lower rate to help evacuate Garrison. Both were set at a rate that would result in the evacuation of the flood pool by the beginning of the upcoming flood season. Fort Peck releases were the fourth highest of record and the highest since 1979.

Fort Peck and Garrison reservoirs filled to the top of the their exclusive flood control zones and infringed slightly into their surcharge pools while performing significant flood control during the unprecedented runoff period. Garrison reservoir was peaking near elevation 1853 when a 6 inch rainfall in the reservoir area occurred which resulted in the pool reaching 1854.4 feet msl on July 4, 1997, slightly overtopping the spillway gates. This elevation was slightly less than 1854.8 feet msl experienced in 1975. Fort Peck reached an elevation of 2250.31 feet msl on July 23, 1997, 1.3 feet less than the 2251.6 feet msl record peak which occurred in July 1975. Some of the rise in Fort Peck was due to release reductions to stem the rise at Garrison. In addition, evacuation of flood storage in USBR Tributary reservoirs was also delayed to halt Garrison's pool rise.

System releases were maintained at record levels beginning in early February in order to maintain, to the extent possible, sufficient flood storage space to store the forecasted large runoffs. In spite of high downstream river stages, reservoir releases were continued at unprecedented rates throughout the period, reaching 58,000 cfs by late April. Flows were gradually increased, as downstream runoff and river stage forecasts permitted, to 70,000 cfs, the highest on record. The January through July system release was 83 percent greater than normal and was 32 percent higher than the record set just one year earlier. The record high releases are scheduled to continue throughout the open water period to evacuate the stored flood waters in preparation for the 1998 flood season.

The 1997 runoff was the greatest flood control test of the main stem system to date. Early releases precluded extensive basin damage but the high flows resulted in nearly 70,000 crop land acres not planted from Sioux City to St. Joseph along the Missouri River. Also, extensive erosion damage between and on the reservoirs occurred. Flood damages prevented were 5.2 billion, the largest to date.

## DAILY LONG RANGE STUDY (DLRS)

Computer model simulation studies have been used by the Reservoir Control Center since the 1960's to simulate the operation of the main stem reservoir system using a long-term hydrologic record. Prior to 1997, the Reservoir Control Center had used the Long Range Study Model (LRS) to simulate Missouri River Main stem reservoir operations. The LRS model was developed to evaluate regulation criteria for operation of the main stem reservoirs for all authorized purposes under widely varying hydrologic conditions. Although the model simulates the operating criteria for each of the main stem projects, it utilizes only historical monthly data and is not used for real-time day-to-day regulation. Development of a Daily Long Range Study Model (DLRS) or more often referred to as the Daily Routing Model was completed in 1997. The DLRS uses historical daily data and is being used for the Master Water Control Manual Update Study. Model results have been evaluated for this analysis and found to be of value with limitations due to its inability to integrate forecasted runoff. The DLRS was used in the analysis presented in this report.

Simulation in the DLRS model consists of 12 nodes, including the six main stem dams and six downstream gaging stations located at; Sioux City, Iowa; Omaha and Nebraska City, Nebraska; and Kansas City, Boonville, and Hermann, Missouri. Because Lake Sharpe and Lewis and Clark Lake have such a small reservoir storage volume in relation to the volume of water that normally passes through in the reservoirs on a daily basis, their storage volumes are fixed in the model and considered constant. Input data consist of historic reach inflows, stream flow depletions, evaporation data, downstream flow targets, reservoir characteristics including operational levels, routing factors, operational guide curves, power generation criteria, navigation guide criteria, and endangered species flow criteria.

Depletions for each reach upstream from Sioux City were estimated by the Bureau of Reclamation in 1987. These data were reviewed by the Reservoir Control Center and adjusted using data from the “Missouri River Basin Hydrology Study -Final Report” by the Missouri Basin States Association. Depletions upstream from Sioux City were estimated to average 4.8 million acre feet (MAF) per year, exclusive of main stem reservoir evaporation estimated at 1.7 maf per year. At the mouth, depletions were estimated to average 12 MAF per year without main stem reservoir evaporation.

Navigation guide criteria determines the flows and season length for navigation based on the system storage on March 15 and July 1. Four specific downstream navigation flow target locations are used: Sioux City, Omaha, Nebraska City, and Kansas City. Determination of whether navigation flows will be full service, minimum service, or an intermediate level is based on system storage values on March 15. For the current water control plan, if the system storage is above 54.5 MAF on March 15, full service navigation are provided. If the system storage value is below 54.4 MAF on March 15, minimum service navigation flows are provided. If the system storage value is between 57.5 and 54.5 MAF on March 15, a linear interpolation between the system storage value and the navigation service level is used to determine the navigation flow targets. On July 1, both the navigation service level and navigation season length are determined. For the current water control plan, if the system storage value is at or above the 52 MAF on July 1, the navigation season length is set at 8 months. When the system storage on July 1 is below 41 MAF, a 6 month navigation season is determined. Between these two levels, the navigation season length is determined by linear interpolation.

Based on the discussion presented previously, it was reasoned that frequency estimates should be based on both the historical record of actual system regulation experience and on the long-term reservoir operation studies. The most recent long-term study reflecting current operation utilizing the DLRS model is referred to as study CWCP. This study was completed as part of the Missouri River Master Water Control Manual Review and Update studies and is documented in Volume 2: Reservoir Regulation Studies-Long Range Study Model dated July 1994, revised in the spring of 1998. That study contains the experienced hydrologic record extending from 1898 through 1993 and reflects, to the degree possible in long-term studies of this type, regulation criteria at the current (1997) level, as well as Missouri Basin water resource development current to the last year of the study which is 1993. The results of the daily model (DLSR) were reviewed for this analysis as well. Significant short term differences have been noted between model results and actual operations for the recent flood years. Hydrologic data for the DLRS model was extended to include daily reach inflows through 1997.

## FORT PECK

## HISTORICAL RECORDS

Historical records for Fort Peck pool elevations and releases date back to 1937, when the dam was first closed. It was not until the main stem system filled in June of 1967 that the records reflected normal system operation. During the period of 1967 through 1997, the pool elevation has ranged from a low of 2208.7 ft msl in April of 1991 to a maximum of 2251.6 ft msl in July of 1975, a range of almost 43 feet. The average annual pool elevation since 1967 is 2235.1 ft msl with a standard deviation of the annual means being 9.8 feet. Daily releases from Fort Peck have ranged from a low of zero cfs for one day in April of 1978 to a high of 35,400 cfs in July of 1975. Daily release has averaged 10,100 cfs since 1967 with a standard deviation in the annual mean discharge of 3,900 cfs. Figure 2 shows the daily pool elevations and releases from Fort Peck for the period since the main stem system was first filled. Daily maximum, minimum and mean values of pool elevation and releases for each month are listed in Table 2.

**Table 2**
**Fort Peck Pool & Release Historical Records (06/1967-11/1997)**

| Month | Pool Elevation (ft msl) | | | Daily Release (cfs) | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Mean | Maximum | Minimum | Mean |
| Jan | 2245.1 | 2209.3 | 2232.9 | 15,600 | 6,500 | 11,600 |
| Feb | 2244.4 | 2208.8 | 2231.9 | 15,500 | 4,800 | 12,200 |
| Mar | 2246.2 | 2208.8 | 2232.0 | 15,600 | 1,000 | 9,000 |
| Apr | 2247.3 | 2208.7 | 2233.2 | 25,100 | 0 | 8,100 |
| May | 2247.7 | 2209.3 | 2234.5 | 28,900 | 2,800 | 9,600 |
| Jun | 2250.1 | 2212.5 | 2236.9 | 35,100 | 3,000 | 10,600 |
| Jul | 2251.6 | 2212.5 | 2238.6 | 35,400 | 3,000 | 10,900 |
| Aug | 2250.0 | 2211.4 | 2237.8 | 35,200 | 3,800 | 10,800 |
| Sep | 2248.5 | 2211.4 | 2236.8 | 20,500 | 2,700 | 9,800 |
| Oct | 2248.0 | 2211.4 | 2236.0 | 21,800 | 2,700 | 9,300 |
| Nov | 2246.3 | 2210.9 | 2235.3 | 22,300 | 2,700 | 9,600 |
| Dec | 2245.4 | 2209.6 | 2234.1 | 14,700 | 4,500 | 10,200 |
| Annual | 2251.6 | 2208.7 | 2235.1 | 35,400 | 0 | 10,100 |

## POOL & RELEASE DURATION

Pool duration and release duration relationships were developed using the DLRS which used data from 1898 to 1997. Figure 3 shows the pool duration relationship for Fort Peck, while Figure 4 shows the release duration relationship. Both Figure 3 and Figure 4 show the DLRS data along with the observed data. Table 3 shows the pool elevation and release for various percentages of time in which the values are equaled or exceeded.

**Table 3**
**Fort Peck Pool & Release Duration Characteristics**

| Percent of Time Equaled or Exceeded | Pool Elevation (ft msl) DLRS | Release (cfs) DLRS |
|---|---|---|
| Maximum | 2251.0 | 31,000 |
| 1 | 2246.9 | 21,000 |
| 5 | 2245.0 | 15,500 |
| 10 | 2243.1 | 14,300 |
| 20 | 2241.0 | 13,000 |
| 50 | 2235.1 | 9,500 |
| 80 | 2219.0 | 3,800 |
| 90 | 2203.0 | 3,400 |
| 95 | 2173.0 | 3.200 |
| 99 | 2163.0 | 3,000 |
| 100 | 2158.0 | 1,600 |

## POOL PROBABILITY

In 1975, the maximum pool elevation of 2251.6 feet msl was recorded at Fort Peck. Results of the DLRS indicate that the peak daily pool for 1975 would be 2248.3 feet msl which would rank as the sixth highest out of the 100 years of simulated record. DLRS results also indicate that the maximum daily pool elevation of 2250.7 feet msl during the simulation period would occur during 1997. Graphical analysis of the observed peak pool elevations indicates a good fit for all events less frequent than 80 percent chance exceedance. Extrapolation of the eye-fit curve between the observed and simulated data based on the shape of the curve from the observed data indicates a reasonable pool-probability relationship. Therefore, this curve was adopted for the Fort Peck Pool Probability relationship. Results are shown in Table 4 and on Figure 5.

**Table 4**
**Fort Peck Pool Probability Relationship**
**Pool Elevations in Feet MSL**

| Percent Chance Exceedance | 1976 Study | Observed (1967-1997) | Simulated (1898-1997) | Adopted |
|---|---|---|---|---|
| 50 | 2240.0 | 2242.0 | 2242.0 | 2241.5 |
| 20 | 2246.5 | 2246.5 | 2246.0 | 2246.5 |
| 10 | 2249.0 | 2249.0 | 2248.0 | 2249.0 |
| 2 | 2251.0 | 2252.7* | 2249.5 | 2251.0 |
| 1 | 2252.0 | 2254.0* | 2250.0 | 2252.0 |
| 0.2 | 2253.0 | 2256.5* | 2251.0* | 2253.0 |

* extrapolated

**RELEASE PROBABILITY**

The maximum observed release from Fort Peck was 35,400 cfs in 1975. Results of the DLRS indicate that the maximum daily outflow of 35,000 cfs would be reached during eleven years, 1898, 1908, 1909, 1913, 1916, 1917, 1927, 1948, 1953, 1975, and 1997. Both the observed and simulated curves indicated a relatively flat curve with a discharge near 15,000 cfs (near power plant capacity ) from the 70 percent chance exceedance to the 20 percent chance exceedance range. The observed remained flat until the 20 percent chance exceedance while the simulated moved to the 30,000 cfs range in a somewhat linear fashion. For events less frequent, both curves showed an abrupt breakpoint at 10 percent value. Values of 35,000 cfs occurred near the 3 percent chance of exceedance for the observed, and 10 percent for the simulated data. A straight line was assumed from the 20 percent to the 0.2 percent and slope steepened between the 2 and 0.2. This curve was used to define the adopted release-probability relationship. Results are shown in Table 5 and on Figure 6.

**Table 5**
**Fort Peck Release Probability Relationship**
**Discharges in CFS**

| Percent Chance Exceedance | 1976 Study | Observed (1967-1997) | Simulated (1898-1997) | Adopted |
|---|---|---|---|---|
| 50 | 15,000 | 14,700 | 18,000 | 15,000 |
| 20 | 15,000 | 15,400 | 25,000 | 17,000 |
| 10 | 15,000 | 24,000 | 28,000 | 21,000 |
| 2 | 28,000 | 40,000* | 33,000 | 29,000 |
| 1 | 35,000 | 50,000* | 34,000 | 35,000 |
| 0.2 | 50,000 | 70,000* | 35,000 | 50,000 |

* extrapolated

## GARRISON

## HISTORICAL RECORDS

Historical records for Garrison pool elevations and releases date back to 1953, when the dam was first closed. It was not until the main stem system filled in June of 1967 that the records reflected the system operation. During the period of 1967 through 1997, the pool elevation has ranged from a low of 1815.0 ft msl in May of 1991 to a maximum of 1854.8 ft msl in July of 1975, a range of almost 40 feet. The average annual pool elevation since 1967 is 1838.4 ft msl with a standard deviation of the annual means being 8.6 feet. Daily releases from Garrison have ranged from a low of 4,100 cfs in March of 1997 to a high of 65,200 cfs in July of 1975. Daily release has averaged 22,900 cfs since 1967 with a standard deviation in the annual mean discharge of 8,400 cfs. Figure 7 shows the daily pool elevations and releases from Garrison for the period since the main stem system was first filled. Daily maximum, minimum and mean values of pool elevation and releases for each month are listed in Table 6.

**Table 6**
**Garrison Pool & Release Historical Records (06/1967-11/1997)**

| Month | Pool Elevation (ft msl) | | | Daily Release (cfs) | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Mean | Maximum | Minimum | Mean |
| Jan | 1845.3 | 1816.9 | 1835.8 | 34,200 | 12,700 | 24,500 |
| Feb | 1843.6 | 1815.7 | 1834.3 | 36,000 | 11,000 | 25,800 |
| Mar | 1847.9 | 1815.5 | 1834.4 | 37,800 | 4,100 | 20,800 |
| Apr | 1847.7 | 1815.2 | 1836.0 | 39,100 | 8,700 | 20,100 |
| May | 1848.0 | 1815.0 | 1836.7 | 41,200 | 9,100 | 22,500 |
| Jun | 1853.7 | 1817.9 | 1839.7 | 50,100 | 9,500 | 24,000 |
| Jul | 1854.8 | 1822.0 | 1842.9 | 65,200 | 9,500 | 26,000 |
| Aug | 1854.6 | 1821.1 | 1842.4 | 65,100 | 12,100 | 25,700 |
| Sep | 1851.3 | 1820.9 | 1840.9 | 50,100 | 6,000 | 22,000 |
| Oct | 1848.2 | 1820.9 | 1839.9 | 49,700 | 9,200 | 20,900 |
| Nov | 1847.4 | 1821.2 | 1839.1 | 50,100 | 9,300 | 21,600 |
| Dec | 1846.8 | 1818.8 | 1837.4 | 39,100 | 12,500 | 21,500 |
| Annual | 1854.8 | 1815.0 | 1838.4 | 65,200 | 4,100 | 22,900 |

## POOL & RELEASE DURATION

Pool duration and release duration relationships were developed using the DLRS which used data from 1898 to 1997. Both Figure 8 and Figure 9 show the DLRS data along with the observed data. Figure 8 shows the pool duration relationship for Garrison, while Figure 9 shows the release duration relationship. Table 7 shows the pool elevation and release for various percentages of time in which the values are equaled or exceeded.

**Table 7**
**Garrison Pool & Release Duration Characteristics**

| Percent of Time Equaled or Exceeded | Pool Elevation (ft msl) DLRS | Release (cfs) DLRS |
|---|---|---|
| Maximum | 1855.0 | 66,000 |
| 1 | 1851.0 | 48,500 |
| 5 | 1848.5 | 38,000 |
| 10 | 1846.1 | 34,000 |
| 20 | 1844.3 | 28,700 |
| 50 | 1838.0 | 22,300 |
| 80 | 1825.0 | 16,200 |
| 90 | 1813.0 | 12,400 |
| 95 | 1788.0 | 10,700 |
| 99 | 1778.0 | 10.100 |
| 100 | 1773.3 | 6,000 |

## POOL-PROBABILITY

The maximum pool elevation recorded for Lake Sakakawea was 1854.8 ft msl during 1975. In 1997, the second highest pool of record occurred with an elevation of 1854.4 ft msl. Results of the DLRS simulation indicated that the 1975 event would rank seventh out of 100 years of record with a maximum daily pool elevation of 1852.9 ft msl. The DLRS also indicated that the maximum daily pool elevation would be 1854.7 ft msl based on the 1997 event. Pool probability curves were eye-fit through the observed, and simulated data. The curves had similar shapes which compared favorably with the results of the 1976 study. Results of this analysis are shown in Table 8 and on Figure 10.

**Table 8**
**Garrison Pool-Probability Relationship**
**Pool Elevations in Feet MSL**

| Percent Chance Exceedance | 1976 Study | Observed (1967-1997) | Simulated (1898-1997) | Adopted |
|---|---|---|---|---|
| 50 | 1845.0 | 1847.0 | 1848.0 | 1848.0 |
| 20 | 1850.0 | 1850.5 | 1851.0 | 1850.5 |
| 10 | 1852.0 | 1852.0 | 1852.0 | 1852.0 |
| 2 | 1853.5 | 1854.3 | 1853.5 | 1854.0 |
| 1 | 1854.0 | 1855.0* | 1854.0 | 1854.5 |
| 0.2 | 1855.0 | 1856.0* | 1855.0* | 1855.5 |

*extrapolated

**RELEASE-PROBABILITY**

The maximum release from Garrison was 65,200 cfs during 1975. In 1997, a release of 59,100 cfs was made. Results of the DLRS indicated that the 1975 event would tie fourteen other events for the highest release of 65,000 cfs. Both the eye fit curves for the observed and simulated events showed a negatively skewed curve becoming asymptotic to the full power plant capacity discharge of about 40,000 cfs in the range of about 50 to 20 percent chance exceedance. The simulated values show a distinct breakpoint occurring between the 20 and 10 percent chance exceedance range with a negative skew becoming asymptotic to the maximum release assumed in the model of 65,000 cfs for events less frequent than a 1 percent chance of exceedance. The 65,000 cfs limit imposed on the model is the channel capacity downstream from Garrison Dam. The adopted release probability curve was based on a straight line eye-fit favoring the observed over the simulated data for events less frequent than 20 percent, transitioning to the full power plant capacity at the 50 percent event. Results are shown in Table 9 and on Figure 11.

**Table 9**
**Garrison Release Probability**
**Discharge in CFS**

| Percent Chance Exceedance | 1976 Study | Observed (1967-1997) | Simulated (1898-1997) | Adopted |
|---|---|---|---|---|
| 50 | 38,000 | 32,000 | 42,000 | 39,000 |
| 20 | 39,000 | 39,000 | 42,000 | 42,000 |
| 10 | 43,000 | 45,000 | 64,000 | 45,000 |
| 2 | 61,000 | 55,000 | 65,000 | 68,000 |
| 1 | 70,000 | 60,000 | 66,000* | 76,000 |
| 0.2 | 90,000 | 70,000* | 70,000* | 90,000 |

* extrapolated

## OAHE

## HISTORICAL RECORDS

Historical records for Oahe pool elevations and releases date back to 1958, when the dam was first closed. It was not until the main stem system filled in June of 1967 that the records reflected the system operation. During the period of 1967 through 1997, the pool elevation has ranged from a low of 1580.7 ft msl in November of 1989 to a maximum of 1618.7 ft msl in June of 1995, a range of almost 38 feet. The average annual pool elevation since 1967 is 1604.7 ft msl with a standard deviation of the annual means being 8.7 feet. Daily releases from Oahe have ranged from a low of zero cfs during many years to a high of 59,300 cfs in July of 1997. Daily release has averaged 25,300 cfs since 1967 with a standard deviation in the annual mean discharge of 12,600 cfs. Figure 12 shows the daily pool elevations and releases from Oahe for the period since the main stem system was first filled. Daily maximum, minimum and mean values of pool elevation and releases for each month are listed in Table 10.

**Table 10**
**Oahe Pool & Release Historical Records (06/1967-11/1997)**

| Month | Pool Elevation (ft msl) | | | Daily Release (cfs) | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Mean | Maximum | Minimum | Mean |
| Jan | 1609.5 | 1582.0 | 1601.1 | 54,000 | 800 | 21,800 |
| Feb | 1611.2 | 1583.4 | 1602.7 | 45,600 | 0 | 19,000 |
| Mar | 1617.9 | 1585.9 | 1605.1 | 57,400 | 0 | 18,800 |
| Apr | 1618.4 | 1586.6 | 1607.1 | 59,100 | 0 | 22,800 |
| May | 1618.6 | 1587.1 | 1607.8 | 52,500 | 0 | 24,000 |
| Jun | 1618.7 | 1588.1 | 1608.1 | 54,300 | 0 | 26,300 |
| Jul | 1618.6 | 1587.5 | 1607.8 | 59,300 | 0 | 31,400 |
| Aug | 1618.3 | 1584.5 | 1606.4 | 58,900 | 0 | 34,600 |
| Sep | 1617.5 | 1583.2 | 1604.4 | 54,500 | 200 | 31,100 |
| Oct | 1616.9 | 1580.9 | 1602.4 | 57,500 | 0 | 25,500 |
| Nov | 1615.9 | 1580.7 | 1601.8 | 57,700 | 0 | 24,500 |
| Dec | 1610.2 | 1582.1 | 1601.0 | 51,400 | 0 | 22,100 |
| Annual | 1618.7 | 1580.7 | 1604.7 | 59,300 | 0 | 25,300 |

## POOL & RELEASE DURATION

Pool duration and release duration relationships were developed using the DLRS which used data from 1898 to 1997. Both Figure 13 and Figure 14 show the DLRS data along with the observed data. Figure 13 shows the pool duration relationship for Oahe, while Figure 14 shows the release duration relationship. Table 11 shows the pool elevation and release for various percentages of time in which the values are equaled or exceeded.

**Table 11**
**Oahe Pool & Release Duration Characteristics**

| Percent of Time Equaled or Exceeded | Pool Elevation (ft msl) DLRS | Release (cfs) DLRS |
|---|---|---|
| Maximum of record | 1620.0 | 61,000 |
| 1 | 1618.3 | 55,000 |
| 5 | 1615.0 | 45,000 |
| 10 | 1612.3 | 36,000 |
| 20 | 1609.0 | 31,300 |
| 50 | 1604.3 | 24,400 |
| 80 | 1594.6 | 16,900 |
| 90 | 1580.8 | 13,100 |
| 95 | 1558.9 | 9,000 |
| 99 | 1543.5 | 3,600 |
| 100 | 1538.4 | 3,000 |

## POOL-PROBABILITY

During 1995 and 1996, the maximum pool of record, elevation 1618.7 ft msl, occurred at Oahe. The third highest observed pool of 1618.6 ft msl occurred in 1997. Fourth and fifth highest observed pools of 1618.5 ft msl and 1618.3 ft msl occurred in 1986 and 1984, respectively. Based on the DLRS, six events equaled or exceeded an elevation 1619.0 ft msl during the 100 year simulation, 1915, 1927, 1984, 1986, 1995, and 1997. Eye fit curves were quite similar for the observed and simulated pool elevations and compared quite favorably to the results of the 1976 study at higher pool levels. Results of this analysis are shown in Table 12 and on Figure 15.

**Table 12**
**Oahe Pool-Probability Relationship**
**Pool Elevations in Feet MSL**

| Percent Chance Exceedance | 1976 Study | Observed (1967-1997) | Simulated (1898-1997) | Adopted |
|---|---|---|---|---|
| 50 | 1610.0 | 1613.0 | 1610.0 | 1613.0 |
| 20 | 1615.0 | 1617.0 | 1617.0 | 1617.0 |
| 10 | 1617.0 | 1618.0 | 1618.5 | 1618.1 |
| 2 | 1619.0 | 1619.1* | 1619.4 | 1619.5 |
| 1 | 1620.0 | 1619.5* | 1619.5 | 1620.0 |
| 0.2 | 1621.0 | 1620.0* | 1619.6* | 1621.0 |

***** extrapolated

## RELEASE-PROBABILITY

The maximum daily release from Oahe was 59,300 cfs in 1997. The second highest daily release of 57,500 cfs occurred in 1975. Results of the DLRS indicate that the 1975 event would tie with twenty one other events for the maximum daily release of 60,000 cfs. In some years, maximum daily and maximum hourly releases can vary significantly, since Oahe is operated to meet peak power demands. It is not likely that releases greater than power plant capacity would be made at Oahe unless required for emergency evacuation of storage, or to prevent overtopping of the spillway tainter gates. Since the pool-probability relationship indicated that the 1 percent chance exceedance pool would equal the top of the spillway tainter gates, it is not likely that the spillway gates or outlet works would be open under this condition. If all the gates were opened one foot, the spillway discharge would be about 12,000 cfs. Adding this discharge to the full power plant capacity would yield a total discharge near 70,000 cfs for the 1 percent chance exceedance event, which is consistent with the 1976 study assumptions. Therefore, 70,000 cfs was adopted for the 1 percent chance exceedance event and the adopted curve transitioned through the curve developed from maximum hourly releases. Although the annual event results in a discharge higher than the listed power plant capacity of 54,000 cfs, releases in excess of the rated capacity can occur during periods of higher than normal pool elevations or for short durations of high releases not sufficient to fill downstream channel storage and increase the tailwater significantly. Results of this analysis are shown in Table 13 and on Figure 16. For the last nine years, the maximum hourly flow, peak flow, has been collected. Oahe is a big power generating facility and as a result, the hourly discharge can very significantly to meet peak power demands. This change in hourly discharge is normally around 30,000 to 40,000 cfs but can be as high as 58,000 cfs above the average daily release.

**Table 13**
**Oahe Release Probability Relationship**
**Discharge in CFS**

| Percent Chance Exceedance | 1976 Study | Observed (1967-1997) | Simulated (1898-1997) | Adopted |
|---|---|---|---|---|
| 50 | 57,500 | 50,000 | 52,000 | 56,000 |
| 20 | 57,500 | 54,000 | 58,000 | 57,000 |
| 10 | 57,500 | 55,000 | 59,000 | 57,500 |
| 2 | 65,000 | 60,000* | 60,000 | 65,000 |
| 1 | 70,000 | 62,000* | 61,000* | 70,000 |
| 0.2 | 85,000 | 67,000* | 62,000* | 85,000 |

* extrapolated

## BIG BEND

## HISTORICAL RECORDS

Historical records for Big Bend pool elevations and releases date back to 1963, when the dam was first closed. It was not until the main stem system filled in June of 1967 that the records reflected the system operation. During the period of 1967 through 1997, the pool elevation has ranged from a low of 1414.7 ft msl in September of 1967 to a maximum of 1422.1 ft msl in June of 1991, a range of about 7 feet. The average annual pool elevation since 1967 is 1420.3 ft msl with a standard deviation of the annual means being 0.5 feet. Daily releases from Big Bend have ranged from a low of zero cfs during most years to a high of 74,300 cfs in July of 1997. Daily release has averaged 25,300 cfs since 1967 with a standard deviation in the annual mean discharge of 14,500 cfs. Figure 17 shows the daily pool elevations and releases from Big Bend for the period since the main stem system was first filled. Daily maximum, minimum and mean values of pool elevation and releases for each month are listed in Table 14.

**Table 14**
**Big Bend Pool & Release Historical Records (06/1967-11/1997)**

| Month | Pool Elevation (ft msl) | | | Daily Release (cfs) | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Mean | Maximum | Minimum | Mean |
| Jan | 1421.7 | 1419.0 | 1420.4 | 56,500 | 0 | 21,800 |
| Feb | 1421.4 | 1419.4 | 1420.4 | 57,300 | 0 | 19,300 |
| Mar | 1421.6 | 1417.8 | 1420.3 | 69,200 | 0 | 19,900 |
| Apr | 1421.9 | 1417.7 | 1420.4 | 68,000 | 0 | 23,100 |
| May | 1421.8 | 1418.9 | 1420.4 | 55,700 | 0 | 24,400 |
| Jun | 1422.1 | 1418.2 | 1420.3 | 71,000 | 0 | 26,700 |
| Jul | 1421.2 | 1418.7 | 1420.2 | 74,300 | 0 | 30,600 |
| Aug | 1421.2 | 1417.8 | 1420.2 | 67,100 | 0 | 34,000 |
| Sep | 1421.8 | 1414.7 | 1420.2 | 66,100 | 0 | 30,600 |
| Oct | 1421.7 | 1414.8 | 1420.2 | 65,700 | 0 | 25,900 |
| Nov | 1421.5 | 1418.8 | 1420.3 | 63,700 | 0 | 24,500 |
| Dec | 1421.4 | 1418.7 | 1420.4 | 58,600 | 0 | 21,900 |
| Annual | 1422.1 | 1414.7 | 1420.3 | 74,300 | 0 | 25,300 |

## POOL & RELEASE DURATION

Pool duration was developed using the DLRS which used data from 1898 to 1997. Figure 18 shows the DLRS data along with the observed data. Pool duration and release duration relationships were developed using historical daily records for the period of June 1967 through November 1997. Figure 19 shows the release relationship based upon observed data. Table 15 shows the pool elevation and release for various percentages of time in which the values are equaled or exceeded.

**Table 15**
**Big Bend Pool & Release Duration Characteristics**

| Percent of Time Equaled or Exceeded | Pool Elevation (ft msl) DLRS | Release (cfs) Based on Historical |
|---|---|---|
| Maximum of record | 1421.2 | 74,300 |
| 1 | 1421.1 | 57,700 |
| 5 | 1421.0 | 49,400 |
| 10 | 1420.9 | 44,600 |
| 20 | 1420.7 | 37,500 |
| 50 | 1420.4 | 25,400 |
| 80 | 1420.2 | 11,600 |
| 90 | 1420.0 | 4,700 |
| 95 | 1419.9 | 0 |
| 99 | 1419.8 | 0 |
| 100 | 1418.1 | 0 |

## POOL-PROBABILITY

Annual maximum pool elevations at Big Bend have fluctuated only 1.7 feet during the period of 1967 through 1997, with the maximum pool recorded of 1422.1 ft msl in 1991. The maximum pool based upon simulation would have occured in 1996 at an elevation 1421.7. A pool probability relationship was not developed for Big Bend as part of the 1976 study. However, the 1976 study assumed the 1 percent chance exceedance pool elevation would be the maximum operating pool at elevation 1423 ft msl. Therefore, the adopted pool probability curve was based on the observed curve transitioning through an assumed 0.2 percent exceedance pool near the maximum operating pool elevation. Results of this analysis are shown in Table 16 and on Figure 20.

**Table 16**
**Big Bend Pool-Probability Relationship**
**Pool Elevations in Feet MSL**

| Percent Chance Exceedance | 1976 Study | Observed (1967-1997) | Adopted |
|---|---|---|---|
| 50 | -- | 1421.4 | 1421.3 |
| 20 | -- | 1421.5 | 1421.5 |
| 10 | -- | 1421.8 | 1421.8 |
| 2 | -- | 1422.2* | 1422.2 |
| 1 | 1423.0 | 1422.4* | 1422.4 |
| 0.2 | -- | 1422.7* | 1423.0 |

* extrapolated

**RELEASE-PROBABILITY**

The observed maximum daily release from Big Bend was 74,300 cfs in 1997. Since Big Bend is operated as a peaking hydropower plant, daily releases are not representative of the maximum releases. In the 1976 study it was assumed that outflows in excess of the power plant capacity would be very rare while the full release capability of the power units would be frequently utilized for short durations or portions of the day. Therefore, it was assumed that the 1 percent chance exceedance event would be equal to the power plant capacity of 103,000 cfs. For this study, a maximum release of 110,000 cfs was adopted for the 0.2 percent event. Results of this analysis are shown in Table 17 and on Figure 21. The Peak on the curve represents the peak hourly discharge from Big Bend.

**Table 17**
**Big Bend Release-Probability Relationship**
**Discharge in CFS**

| Percent Chance Exceedance | 1976 Study | Observed Average Daily (1967-1997) | Adopted Average Daily | Adopted Peak Hourly |
|---|---|---|---|---|
| 50 | 110,000 | 55,000 | 55,000 | 103,000 |
| 20 | 110,000 | 61,000 | 61,000 | 105,000 |
| 10 | 110,000 | 65,000 | 65,000 | 107,000 |
| 2 | 110,000 | 72,000* | 72,000* | 109,000 |
| 1 | 110,000 | 75,000* | 75,000* | 110,000 |
| 0.2 | 110,000 | 80,000* | 80,000* | 110,000 |

* extrapolated

## FORT RANDALL

### HISTORICAL RECORDS

Historical records for Fort Randall pool elevations and releases date back to 1952, when the dam was first closed. It was not until the main stem system filled in June of 1967 that the records reflected the system operation. During the period of 1967 through 1997, the pool elevation has ranged from a low of 1317.9 ft msl in December of 1968 to a maximum of 1372.1 ft msl in May of 1997, a range of over 50 feet. Since 1971, the pool has drawn down to 1337 ft msl each fall making the range approximately 33 feet. Prior to 1971, the annual fall drawdown was to 1320 feet msl. The average annual pool elevation since 1967 is 1351.4 ft msl with a standard deviation of the annual means being 8.1 feet. Daily releases from Fort Randall have ranged from a low of zero cfs during May of 1995 to a high of 67,500 cfs in November of 1997. Daily release has averaged 26,400 cfs since 1967 with a standard deviation in the annual mean discharge of 12,900 cfs. Figure 22 shows the daily pool elevations and releases from Fort Randall for the period since the main stem system was first filled. Daily maximum, minimum and mean values of pool elevation and releases for each month are listed in Table 18.

**Table 18**
**Fort Randall Pool & Release Historical Records (06/1967-11/1997)**

| Month | Pool Elevation (ft msl) | | | Daily Release (cfs) | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Mean | Maximum | Minimum | Mean |
| Jan | 1350.5 | 1324.7 | 1344.5 | 27,600 | 4,500 | 15,500 |
| Feb | 1356.4 | 1338.7 | 1349.9 | 25,400 | 900 | 13,800 |
| Mar | 1362.4 | 1345.1 | 1355.3 | 40,500 | 600 | 16.500 |
| Apr | 1370.8 | 1352.0 | 1357.3 | 53,000 | 1,400 | 23,500 |
| May | 1372.2 | 1352.5 | 1358.1 | 55,500 | 0 | 26,900 |
| Jun | 1371.4 | 1352.3 | 1357.9 | 56,000 | 500 | 28,900 |
| Jul | 1368.8 | 1351.9 | 1357.4 | 60,100 | 600 | 32,900 |
| Aug | 1369.3 | 1350.7 | 1356.2 | 62,000 | 3,100 | 35,900 |
| Sep | 1365.9 | 1343.2 | 1353.8 | 64,300 | 8,600 | 35,900 |
| Oct | 1357.0 | 1333.2 | 1347.5 | 67,000 | 6,100 | 35,300 |
| Nov | 1349.9 | 1318.0 | 1339.3 | 67,500 | 3,200 | 31,700 |
| Dec | 1348.3 | 1317.9 | 1338.6 | 59,600 | 900 | 17,800 |
| Annual | 1372.2 | 1317.9 | 1351.4 | 67,500 | 0 | 26,400 |

## POOL & RELEASE DURATION

Pool duration and release duration relationships were developed using the DLRS which used data from 1898 to 1997. Both Figure 23 and Figure 24 show the DLRS data along with the observed data. Figure 23 shows the pool duration relationship for Fort Randall, while Figure 24 shows the release duration relationship. Table 19 shows the pool elevation and release for various percentages of time in which the values are equaled or exceeded based on the observed data.

**Table 19**
**Fort Randall Pool & Release Duration Characteristics**

| Percent of Time Equaled or Exceeded | Pool Elevation (ft msl) DLRS | Release (cfs) DLRS |
|---|---|---|
| Maximum of record | 1373.0 | 61,000 |
| 1 | 1361.8 | 59,800 |
| 5 | 1355.8 | 49,600 |
| 10 | 1355.3 | 39,300 |
| 20 | 1354.8 | 33,100 |
| 50 | 1353.1 | 25,900 |
| 80 | 1343.2 | 15,000 |
| 90 | 1341.0 | 11,000 |
| 95 | 1337.8 | 9,500 |
| 99 | 1337.3 | 6,000 |
| 100 | 1337.0 | 1,000 |

## POOL-PROBABILITY

During 1997, the Fort Randall pool reached elevation 1372.2, the maximum of record. Results of the DLRS indicated little correlation between observed and simulated pools. Some of this lack of correlation can be attributed to daily model constraints and parameters. The model does not utilize this project to maximize downstream flood control as is done in actual practices. The model currently lacks the ability to forecast plains snowmelt runoff also. Therefore, the adopted curve was based primarily on an eye-fit of the observed data. The 100 year pool has increased from 1370 feet msl in the previous study to 1372 which is the adopted primarily because the 30 year operational history now includes an actual elevation of 1372.17 due to melt of a heavy plains snow pack. The magnitude of the event also occured in 1952 and would have had similar results if this project had been in operation. Also, a comparison of maximum daily and maximum monthly pool elevations indicated an average difference of 1.8 feet with a maximum difference of 4.9 feet due to the fall drawdown. Results of this analysis are shown in Table 20 and on Figure 25.

**Table 20**
**Fort Randall Pool Probability Relationship**
**Pool Elevations in Feet MSL**

| Percent Chance Exceedance | 1976 Study | Observed (1967-1997) | Simulated (1898-1997) | Adopted |
|---|---|---|---|---|
| 50 | 1361.5 | 1360.0 | 1355.5 | 1360.0 |
| 20 | 1364.5 | 1363.0 | 1358.0 | 1364.0 |
| 10 | 1366.0 | 1365.0 | 1362.0 | 1366.0 |
| 2 | 1369.0 | 1369.0 | 1366.0 | 1370.0 |
| 1 | 1370.0 | 1370.8 | 1368.0 | 1372.0 |
| 0.2 | 1372.0 | 1374.0* | 1372.0* | 1375.0 |

* extrapolated

## RELEASE-PROBABILITY

The maximum observed release from Fort Randall of 67,500 cfs was experienced in 1997. Based on the DLRS, there are 30 releases that tie for the highest release out of 100 years with a maximum daily release of 60,000 cfs. The adopted curve was based on the simulated curve transitioning to the power plant capacity at the annual event. Results of this analysis are shown in Table 21 and on Figure 26.

**Table 21**
**Fort Randall Release Probability Relationship**
**Discharge in CFS**

| Percent Chance Exceedance | 1976 Study | Observed (1967-1997) | Simulated (1898-1997) | Adopted |
|---|---|---|---|---|
| 50 | 48,000 | 40,000 | 50,000 | 41,000 |
| 20 | 49,000 | 47,000 | 59,000 | 50,000 |
| 10 | 55,000 | 52,000 | 60,000 | 55,000 |
| 2 | 69,000 | 61,000 | 61,000* | 69,000 |
| 1 | 75,000 | 65,000 | 62,000* | 75,000 |
| 0.2 | 88,000 | 74,000* | 65,000* | 88,000 |

* extrapolated

## GAVINS POINT

## HISTORICAL RECORDS

Historical records for Gavins Point pool elevations and releases date back to 1955, when the dam was first closed. It was not until the main stem system filled in June of 1967 that the records reflected the system operation. During the period of 1967 through 1997, the pool elevation has ranged from a low of 1199.8 ft msl in March of 1969 to a maximum of 1209.5 ft msl in May of 1995, a range of about 10 feet. The average annual pool elevation since 1967 is 1206.8 ft msl with a standard deviation of the annual means being 1.2 feet. Daily releases from Gavins Point have ranged from a low of 6,000 cfs during April of 1969, June 1983, March 1992 and March, April and July of 1993 to a high of 70,000 cfs in October and November of 1997. Daily release has averaged 29,000 cfs since 1967 with a standard deviation in the annual mean discharge of 12,100 cfs. Figure 27 shows the daily pool elevations and releases from Gavins Point for the period since the main stem system was first filled. Daily maximum, minimum and mean values of pool elevation and releases for each month are listed in Table 22.

**Table 22**
**Gavins Point Pool & Release Historical Records (06/1967-11/1997)**

| Month | Pool Elevation (ft msl) | | | Daily Release (cfs) | | |
|---|---|---|---|---|---|---|
| | **Maximum** | **Minimum** | **Mean** | **Maximum** | **Minimum** | **Mean** |
| **Jan** | **1208.9** | **1205.2** | **1207.6** | **31,000** | **7,800** | **17,600** |
| **Feb** | **1208.4** | **1203.2** | **1206.9** | **34,700** | **7,500** | **18,000** |
| **Mar** | **1209.2** | **1199.8** | **1205.3** | **42,000** | **6,000** | **20,700** |
| **Apr** | **1208.2** | **1201.5** | **1205.5** | **58,000** | **6,000** | **27,300** |
| **May** | **1209.5** | **1204.2** | **1205.6** | **60,000** | **10,000** | **30,600** |
| **Jun** | **1208.8** | **1204.3** | **1205.8** | **60,100** | **6,000** | **31,800** |
| **Jul** | **1208.9** | **1204.4** | **1206.6** | **60,000** | **6,000** | **34,800** |
| **Aug** | **1209.4** | **1204.7** | **1207.3** | **65,100** | **7,000** | **37,200** |
| **Sep** | **1208.8** | **1203.9** | **1207.4** | **68,000** | **14,000** | **37,700** |
| **Oct** | **1209.2** | **1206.4** | **1207.8** | **70,100** | **7,600** | **37,400** |
| **Nov** | **1209.0** | **1204.5** | **1207.7** | **70,100** | **7,500** | **34,100** |
| **Dec** | **1209.1** | **1203.8** | **1207.4** | **57,000** | **8,000** | **19,900** |
| **Annual** | **1209.5** | **1199.8** | **1206.8** | **70,100** | **6,000** | **29,000** |

## POOL & RELEASE DURATION

Pool duration and release duration relationships were developed using the DLRS which used data from 1898 to 1997. Both Figure 28 and Figure 29 show the DLRS data along with the observed data. Figure 28 shows the pool duration relationship for Gavins Point, while Figure 29 shows the release duration relationship. Table 23 shows the pool elevation and release for various percentages of time in which the values are equaled or exceeded based on the observed data.

**Table 23**
**Gavins Point Pool & Release Duration Characteristics**

| Percent of Time Equaled or Exceeded | Pool Elevation (ft msl) DLRS | Release (cfs) DLRS |
|---|---|---|
| Maximum of record | 1208.7 | 74,000 |
| 1 | 1207.8 | 60,400 |
| 5 | 1207.4 | 51,300 |
| 10 | 1207.2 | 40,800 |
| 20 | 1207.1 | 34,600 |
| 50 | 1206.4 | 28,300 |
| 80 | 1205.9 | 17,300 |
| 90 | 1205.8 | 12,900 |
| 95 | 1205.6 | 12,500 |
| 99 | 1205.1 | 8,300 |
| 100 | 1204.1 | 7,400 |

## POOL-PROBABILITY

Historically, the observed maximum daily pool elevations at Gavins Point have varied only 1.4 feet during the period of 1967 through 1997 with the maximum pool elevation of 1209.5 being reached in 1995. A pool-probability relationship was not derived for Gavins Point in the 1976 study. However, it was assumed that the 1 percent chance exceedance pool elevation would be 1213 ft msl. This elevation derived in 1976, was based on the possibility of the 1 percent chance exceedance incremental runoff occurring coincident with a starting Gavins Point pool exceeding elevation 1204.5 and Fort Randall releases exceeding 30,000 cfs. Results of the DLRS model indicate that the Gavins

Point pool elevations would have exceeded 1209 feet msl five time during the 100 year simulation. The simulated 1995 event ranked 15 out of the 100 year of simulation with a pool elevation of 1208.7. The adopted curve was based on a straight line connection of the 2 percent pool elevation of 1209.6 ft msl with the maximum pool elevation of 1211 ft msl assumed to be a 0.02 percent event. This results in a one percent pool elevation about three feet lower than that assumed in the 1976 study. The major factor influencing the change is the 30 years of operational history with major runoffs. Results of this analysis are shown in Table 24 and on Figure 30.

**Table 24**
**Gavins Point Pool Probability Relationship**
**Pool Elevations in Feet MSL**

| Percent Chance Exceedance | 1976 Study | Observed (1967-1996) | Adopted |
|---|---|---|---|
| 50 | -- | 1208.8 | 1208.8 |
| 20 | -- | 1209.0 | 1209.0 |
| 10 | -- | 1209.2 | 1209.2 |
| 2 | -- | 1209.6* | 1209.6 |
| 1 | 1213.0 | 1209.7* | 1210.0 |
| 0.2 | -- | 1210.0* | 1211.0 |

* extrapolated

**RELEASE-PROBABILITY**

The maximum daily release from Gavins Point during the 1967 through 1997 period was 70,100 cfs in 1997. Simulation of the 1997 year produced a discharge of 65,000 cfs. Some reasoning for the difference in the discharge can be attributed to the fact the DLRS cannot forecast precipitation such as snow melt. Since the 1997 year was not modeled it cannot be used for comparison; however, based on the DLRS, the maximum daily release of 72,900 cfs would have occurred in 1952. Emergency releases in the reservoir regulation manual call for minimum releases of 100,000 cfs when the pool is above elevation 1212 ft msl. Therefore, the adopted curve was based on the simulated curve transitioning through a release of 80,000 cfs for the one percent event to a discharge of 100,000 cfs for the 0.2 percent event. Results of this analysis are shown in Table 25 and on Figure 31.

**Table 25**
**Gavins Point Release-Probability Relationship**
**Discharge in CFS**

| Percent Chance Exceedance | 1976 Study | Observed (1967-1997) | Simulated (1898-1996) | Adopted |
|---|---|---|---|---|
| 50 | 37,000 | 38,000 | 42,000 | 38,000 |
| 20 | 47,000 | 46,000 | 58,000 | 47,000 |
| 10 | 54,000 | 53,000 | 62,000 | 54,000 |
| 2 | 72,000 | 69,000 | 67,000 | 72,000 |
| 1 | 80,000 | 80,000* | 73,000* | 80,000 |
| 0.2 | 100,000 | 100,000* | 95,000* | 100,000 |

* extrapolated

## SUMMARY

This report presented historical data, duration curves, and probability curves for pool elevations and releases from the Missouri River Main Stem Reservoirs. Pool probability and release probability relationships were developed from historical records reflecting actual regulation experience for a 29 year period and from long term model simulation studies reflecting current system regulation criteria. Table 26 shows the adopted pool probability relationships for each of the projects, while Table 27 shows the adopted release probability relationships.

**Table 26**
**Missouri River Main Stem Reservoir System**
**Adopted Pool-Probability Relationships**
**Pool Elevations in Feet MSL**

| Project | 50% | 20% | 10% | 2% | 1% | 0.2% |
|---|---|---|---|---|---|---|
| Fort Peck | 2241.5 | 2246.5 | 2249.0 | 2251.0 | 2252.0 | 2253.0 |
| Garrison | 1848.0 | 1850.5 | 1852.0 | 1854.0 | 1854.5 | 1855.5 |
| Oahe | 1613.0 | 1617.0 | 1618.1 | 1619.5 | 1620.0 | 1621.0 |
| Big Bend | 1421.3 | 1421.5 | 1421.8 | 1422.2 | 1422.4 | 1423.0 |
| Ft Randall | 1360.0 | 1364.0 | 1366.0 | 1370.0 | 1372.0 | 1375.0 |
| Gavins Pt | 1208.8 | 1209.0 | 1209.2 | 1209.6 | 1210.0 | 1211.0 |

**Table 27**
**Missouri River Main Stem Reservoir System**
**Adopted Release-Probability Relationships**
**Discharge in CFS**

| **Project** | **50%** | **20%** | **10%** | **2%** | **1%** | **0.2%** |
|---|---|---|---|---|---|---|
| Fort Peck | 15,000 | 17,000 | 21,000 | 29,000 | 35,000 | 50,000 |
| Garrison | 39,000 | 42,000 | 45,000 | 68,000 | 76,000 | 90,000 |
| Oahe | 56,000 | 57,000 | 57,500 | 65,000 | 70,000 | 85,000 |
| Big Bend | 103,000 | 105,000 | 107,000 | 109,000 | 110,000 | 110,000 |
| Ft Randall | 41,000 | 50,000 | 55,000 | 69,000 | 75,000 | 88,000 |
| Gavins Pt | 38,000 | 47,000 | 54,000 | 72,000 | 80,000 | 100,000 |


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

Figure 1

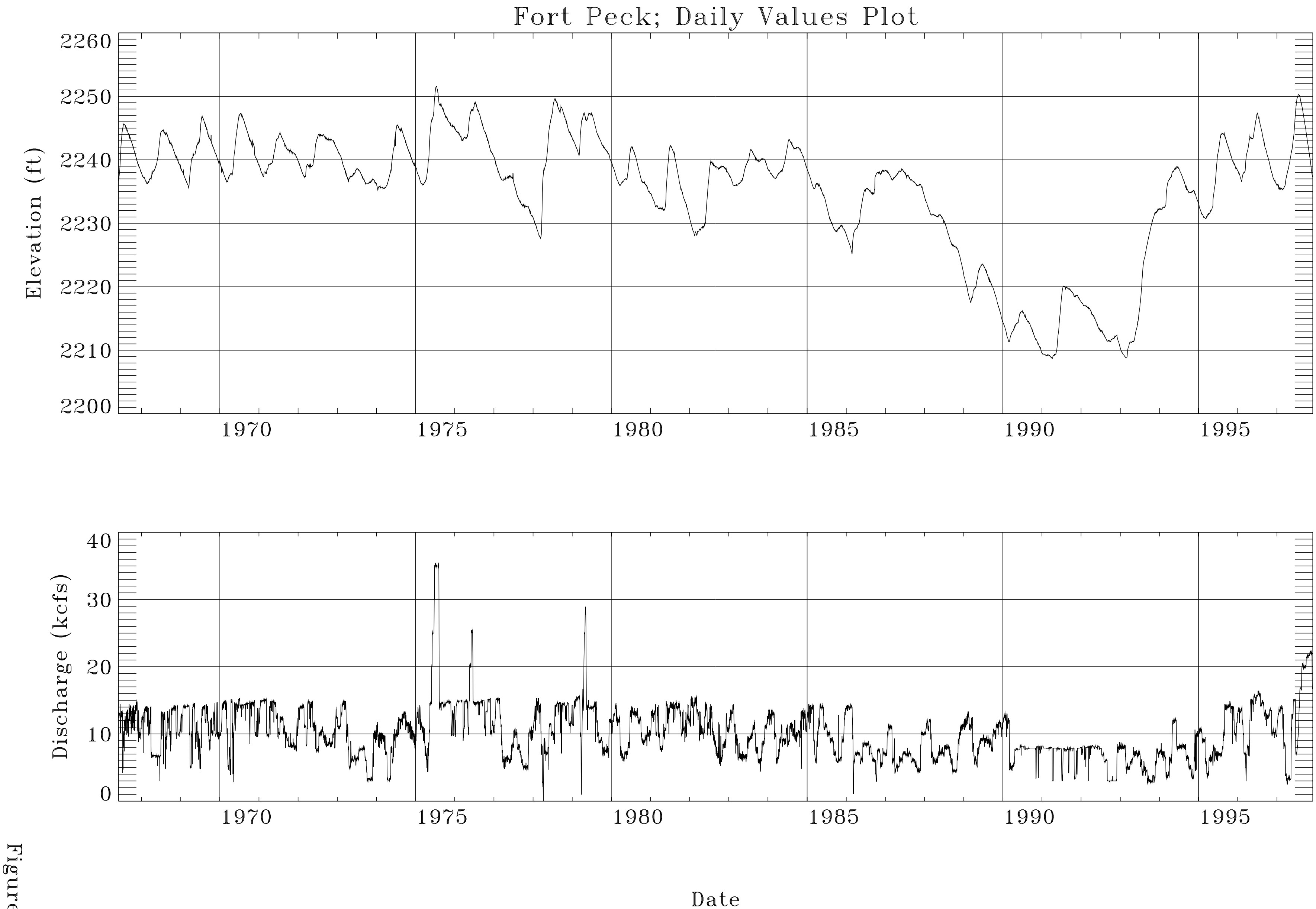
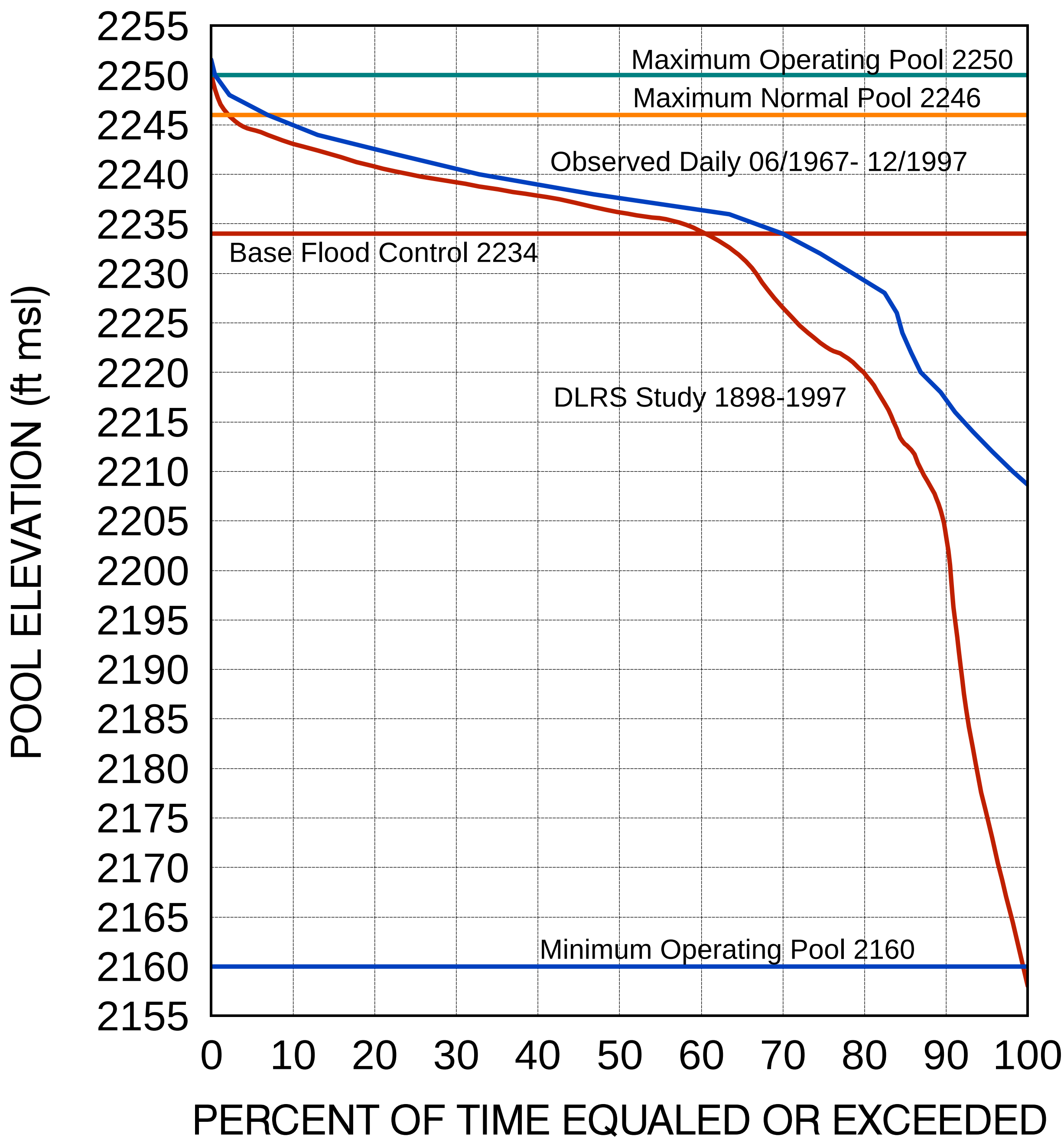

Fort Peck; Daily Values Plot
Elevation (ft)
2260
2250
2240
2230
2220
2210
2200
1970
1975
1980
1985
1990
1995
Discharge (kcfs)
40
30
20
10
0
1970
1975
1980
1985
1990
1995
Date

Figure 2

# FORT PECK LAKE

## POOL DURATION RELATIONSHIP

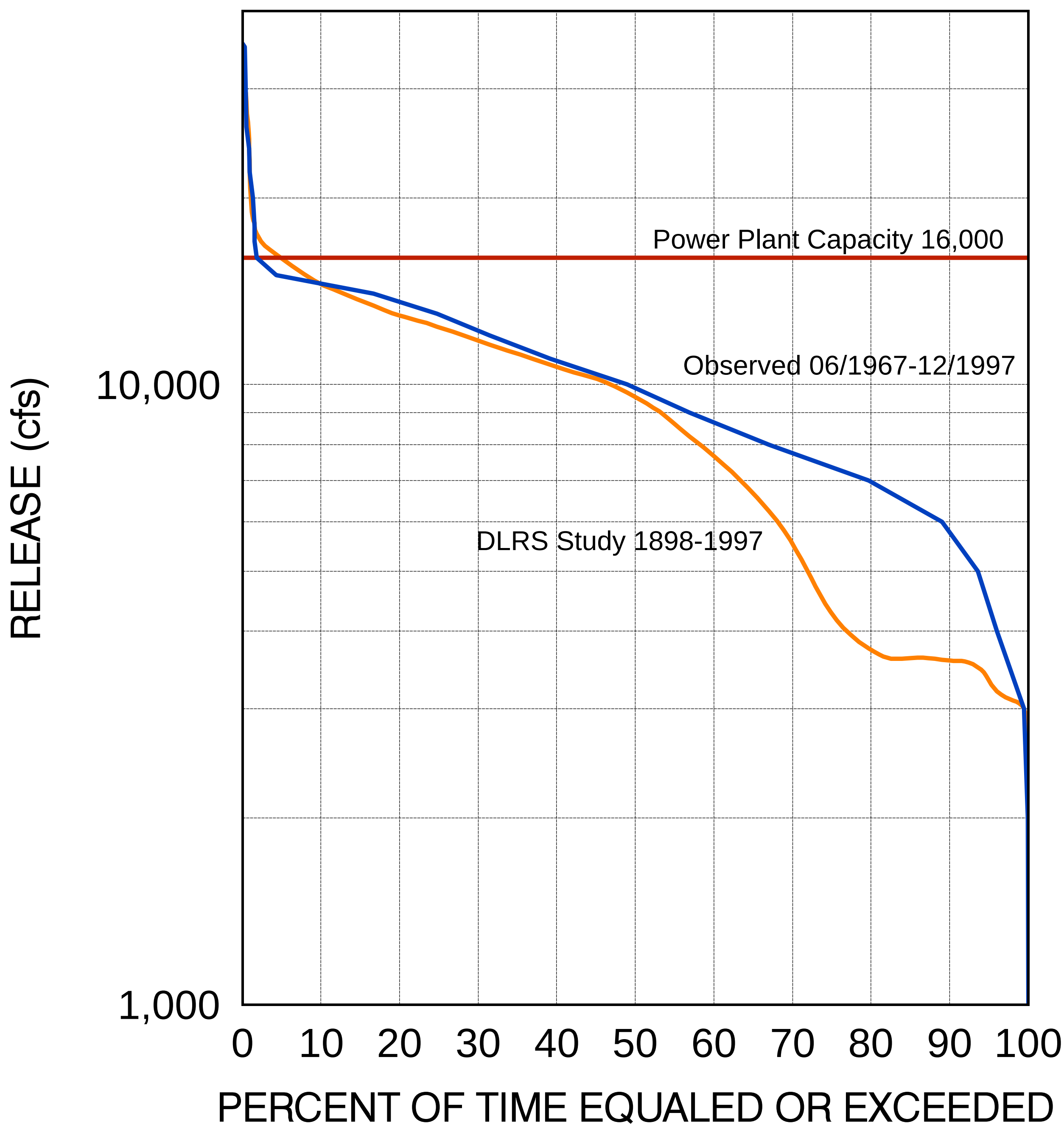



Observed Daily 06/67-11/97

FIGURE 3

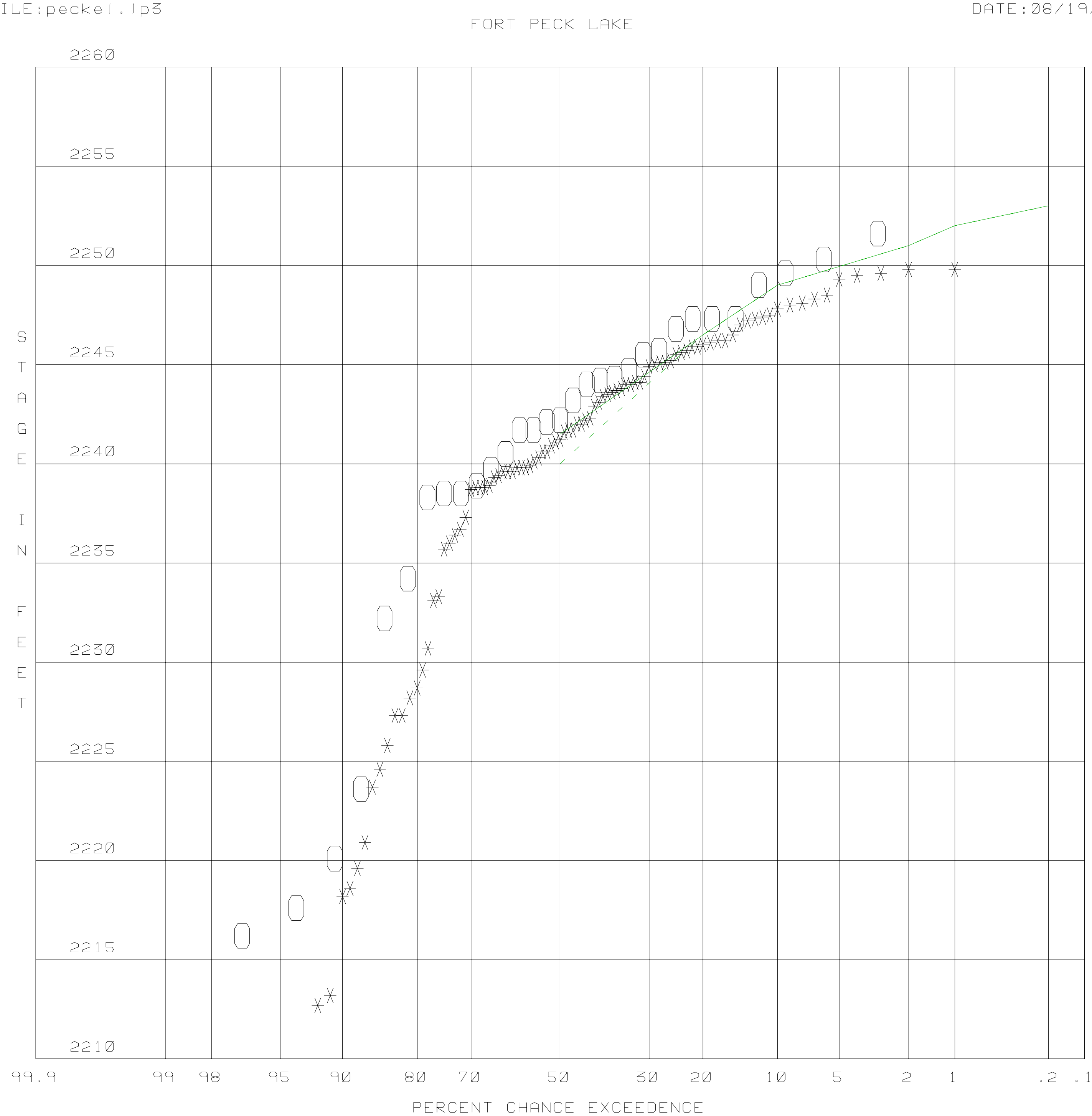
# FORT PECK LAKE

## RELEASE DURATION RELATIONSHIP




Observed Daily 06/67-11/97

FIGURE 4




LEGEND:

OBSERVED

SIMULATED

ADOPTED

1976 STUDY

MAX POOL ELEVATION = 2256.1

MAX OP. POOL ELEV = 2250.0

MAX NORMAL POOL ELEV = 2246.0

BASE FLOOD CONTROL = 2234.0

MISSOURI RIVER MAIN STEM RESERVOIRS

POOL-PROBABILITY RELATIONSHIP

FORT PECK

RESERVOIR CONTROL CENTER

MISSOURI RIVER REGION

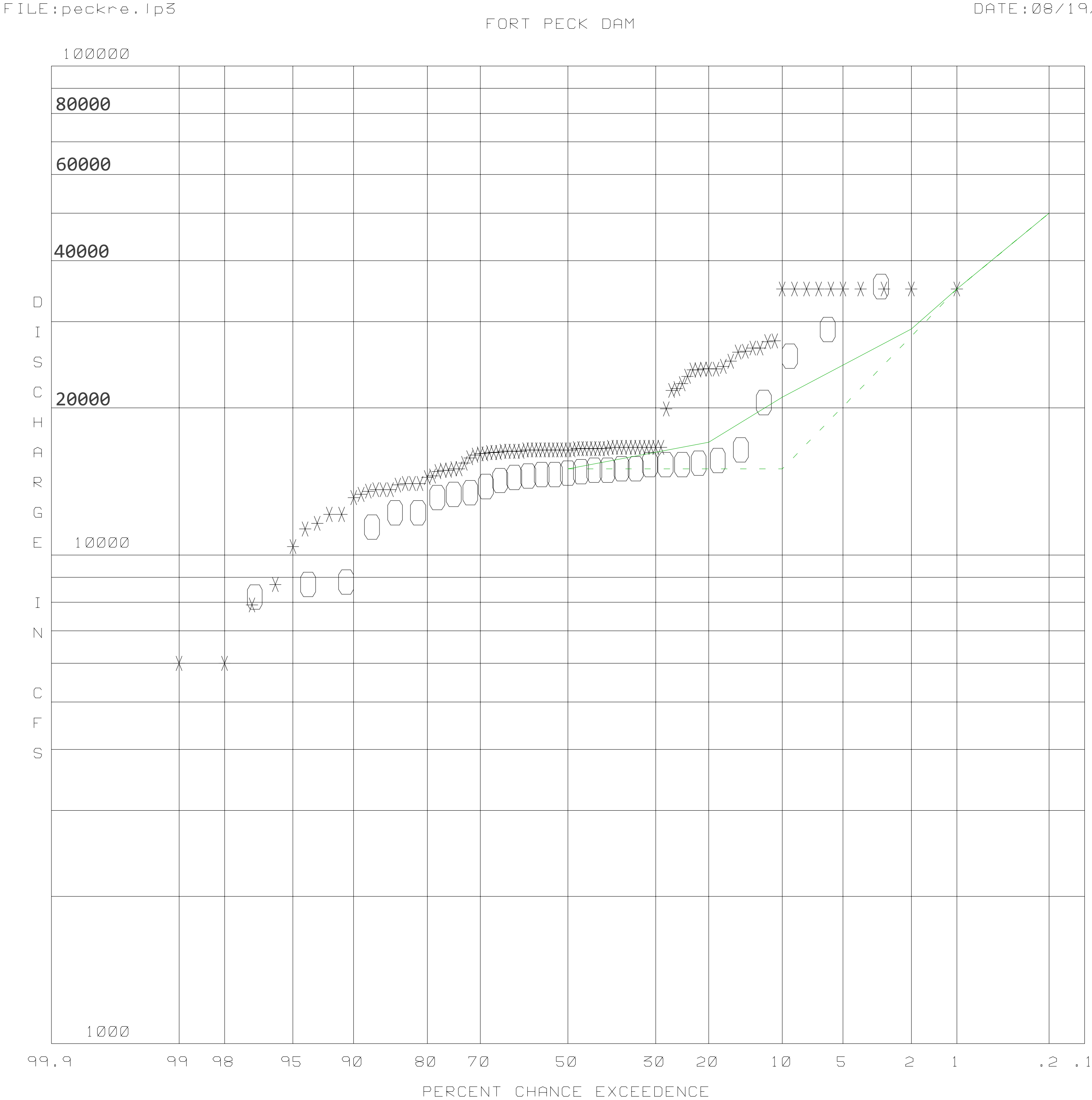
U.S. ARMY CORPS OF ENGINEERS

AUGUST 1998

FIGURE 5

FILE:peckre.lp3

DATE:08/19/98




LEGEND:

OBSERVED

SIMULATED

ADOPTED

1976 STUDY

POWER PLANT CAPACITY = 16,000

OUTLET CAPACITY = 45,000

SPILLWAY CAPACITY = 275,000

MISSOURI RIVER MAIN STEM RESERVOIRS

RELEASE-PROBABILITY RELATIONSHIP

# FORT PECK

RESERVOIR CONTROL CENTER

MISSOURI RIVER REGION

U.S. ARMY CORPS OF ENGINEERS

AUGUST 1998

FIGURE 6

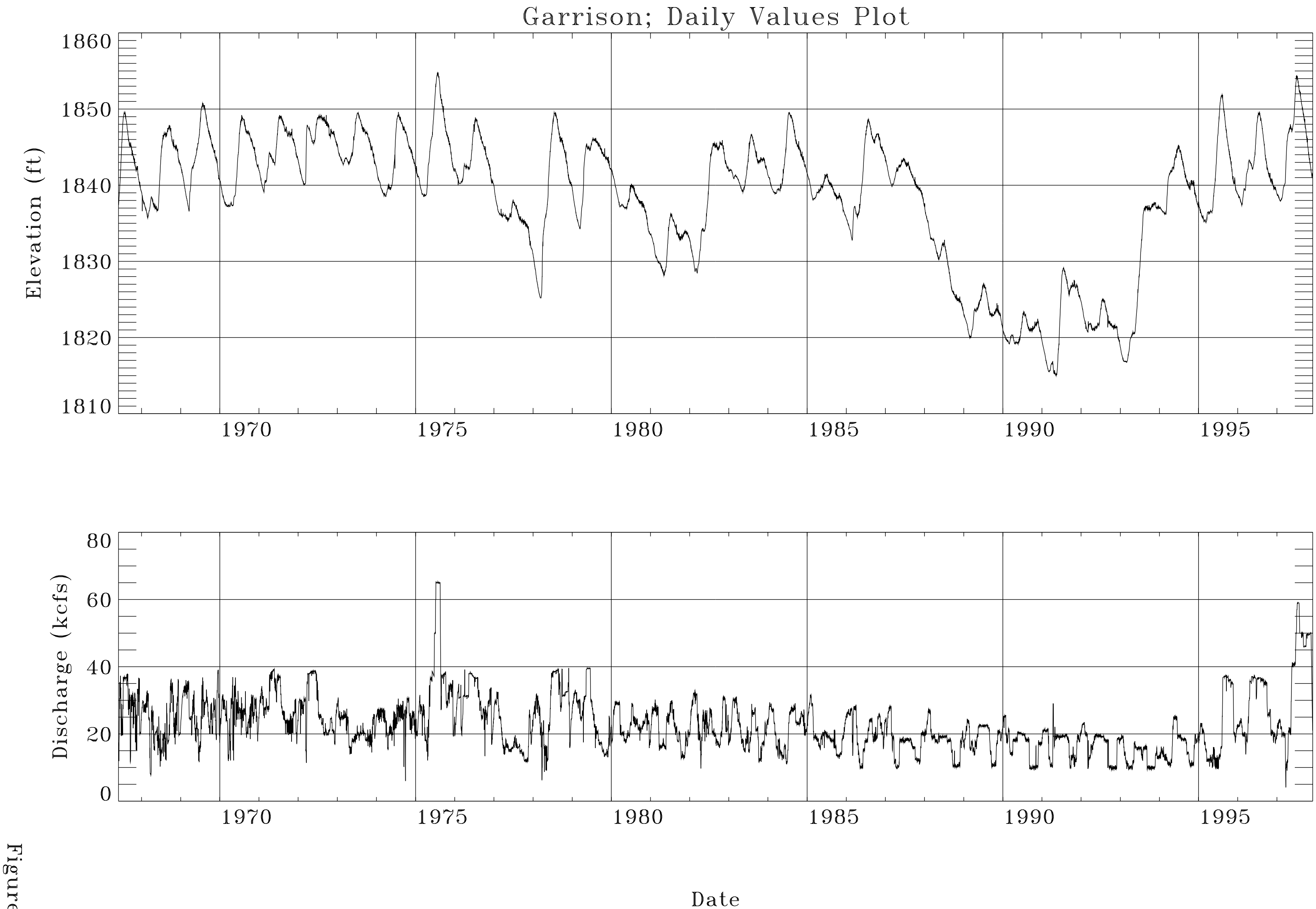
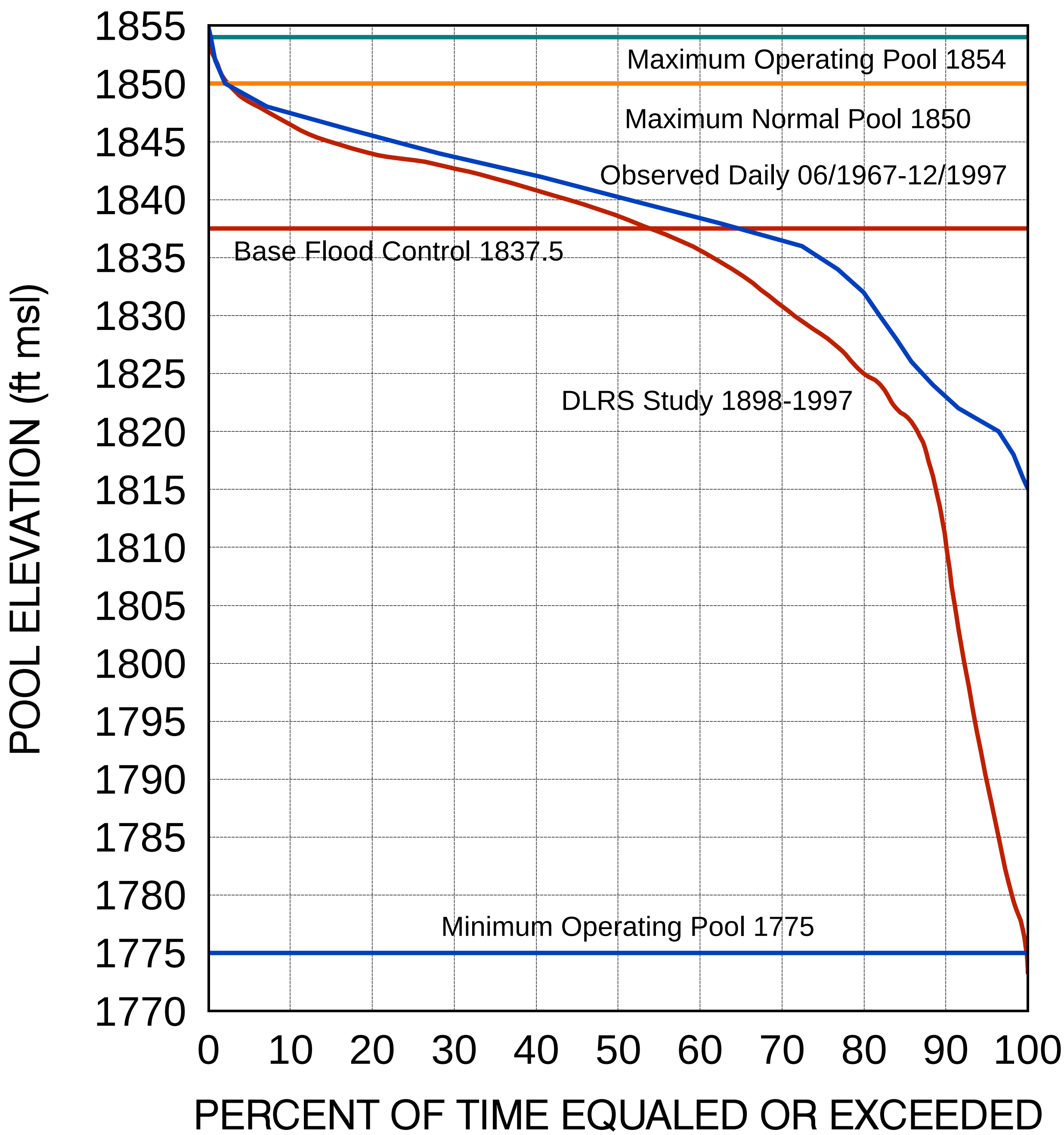

Garrison; Daily Values Plot
Elevation (ft)
1860
1850
1840
1830
1820
1810
1970
1975
1980
1985
1990
1995
Discharge (kcfs)
80
60
40
20
0
1970
1975
1980
1985
1990
1995
Date

Figure 7

# LAKE SAKAKAWEA

## POOL DURATION RELATIONSHIP

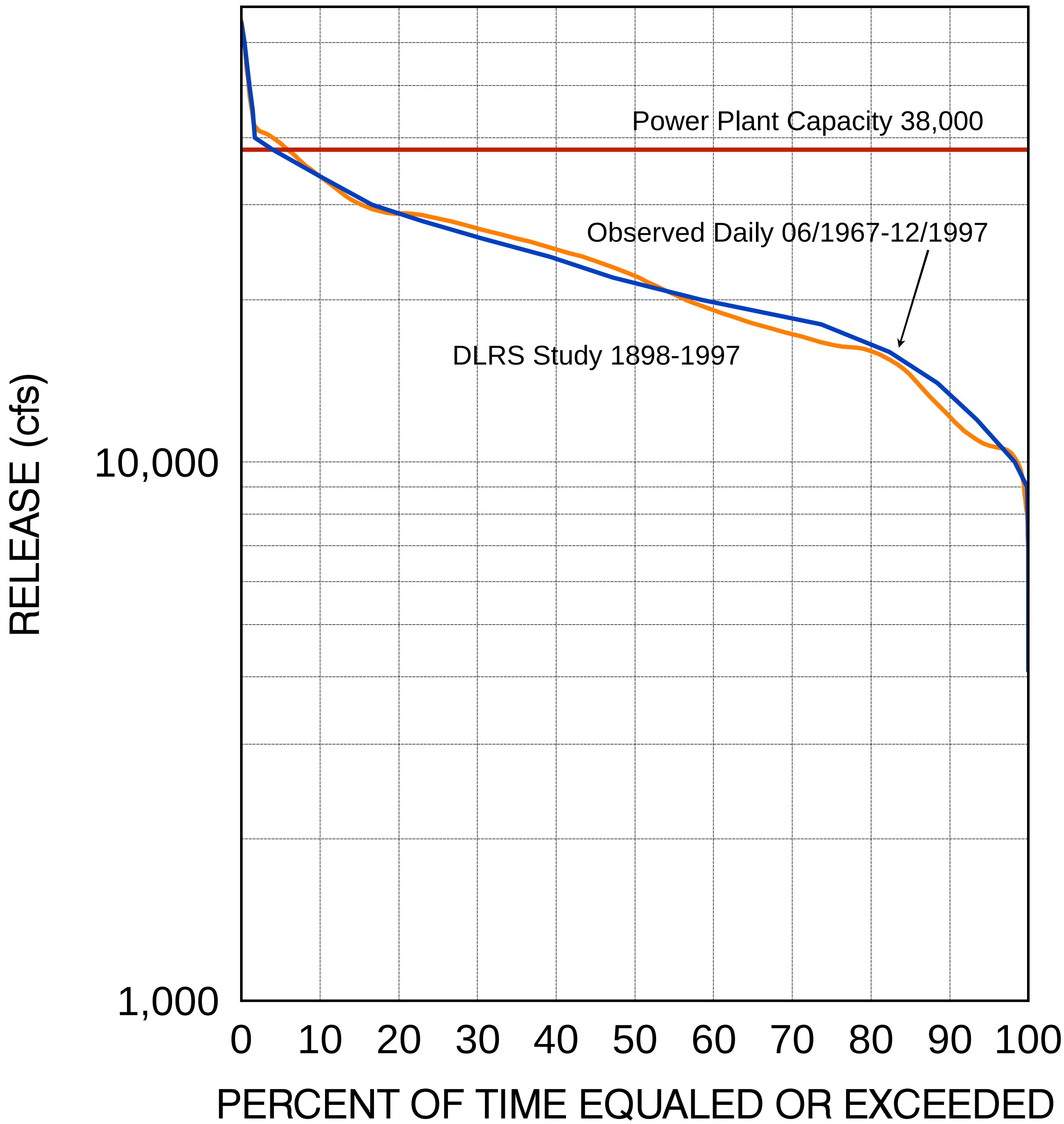



Observed Daily 06/67-11/97

FIGURE 8

# LAKE SAKAKAWEA

## RELEASE DURATION RELATIONSHIP



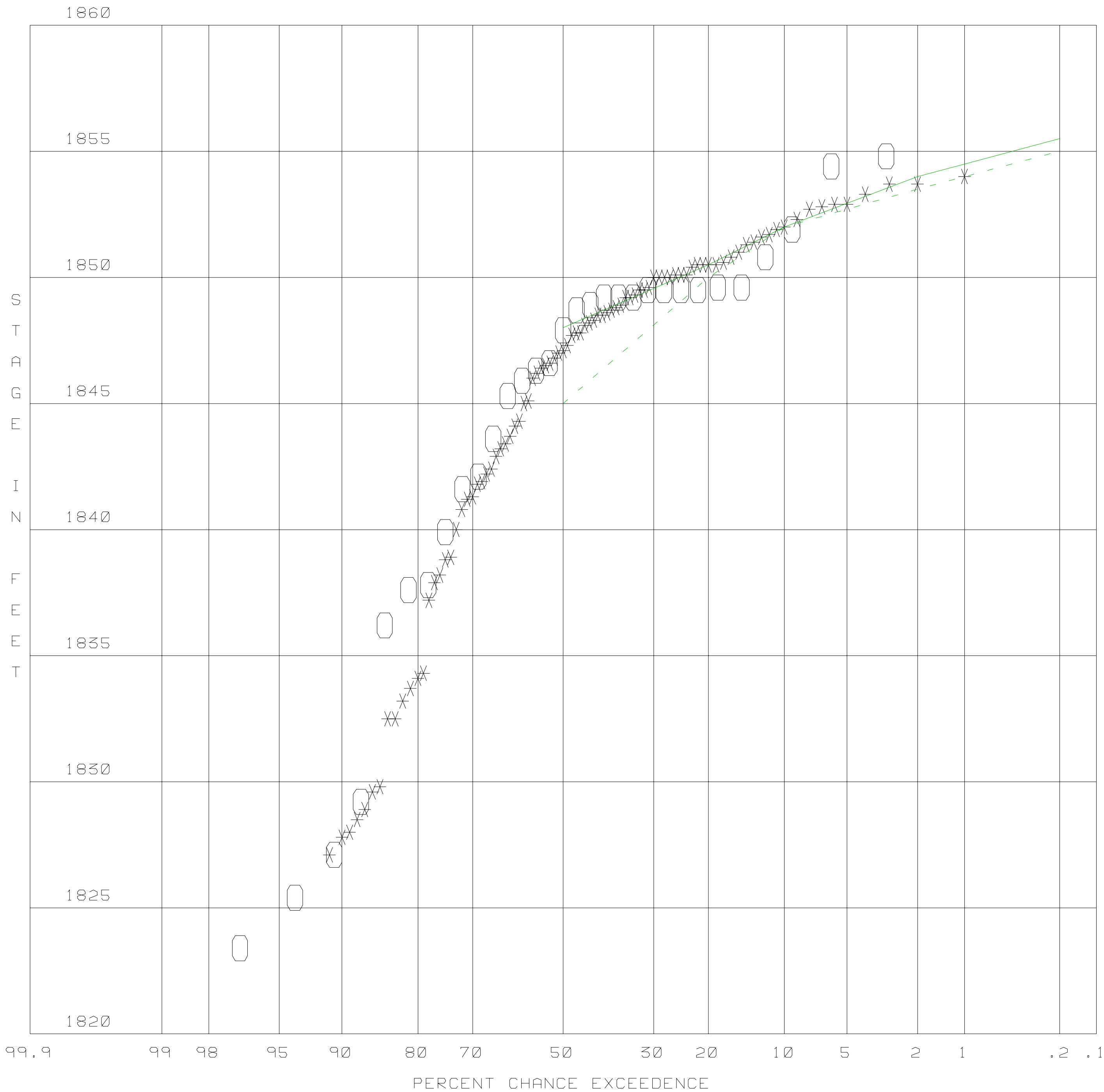

Observed Daily 06/67-11/97

FIGURE 9

FILE:garrel.lp3

DATE:08/19/98

LAKE SAKAKAWEA




LEGEND:

OBSERVED

SIMULATED

ADOPTED

1976 STUDY

MAX POOL ELEVATION = 1858.5

MAX OP. POOL ELEV = 1854.0

MAX NORMAL POOL ELEV = 1850.0

BASE FLOOD CONTROL = 1837.5

MISSOURI RIVER MAIN STEM RESERVOIRS

POOL-PROBABILITY RELATIONSHIP

GARRISON

RESERVOIR CONTROL CENTER

MISSOURI RIVER REGION

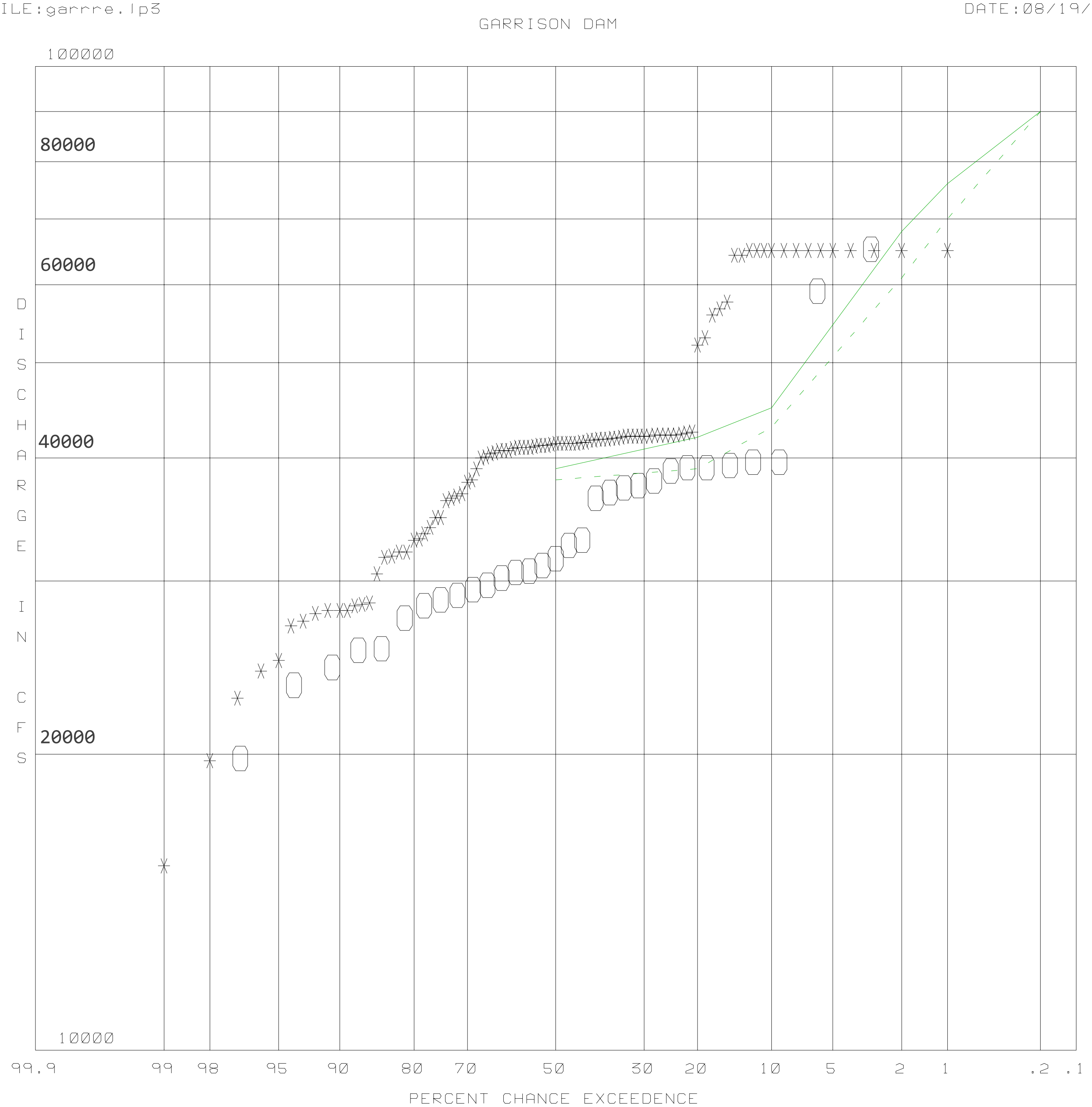
U.S. ARMY CORPS OF ENGINEERS

AUGUST 1998

FIGURE 10

FILE:garrre.lp3

DATE:08/19/98




LEGEND:

OBSERVED

SIMULATED

ADOPTED

1976 STUDY

POWER PLANT CAPACITY = 38,000

OUTLET CAPACITY = 98,000

SPILLWAY CAPACITY = 827,000

MISSOURI RIVER MAIN STEM RESERVOIRS

RELEASE-PROBABILITY RELATIONSHIP

GARRISON

RESERVOIR CONTROL CENTER

MISSOURI RIVER REGION

U.S. ARMY CORPS OF ENGINEERS

AUGUST 1998

FIGURE 11

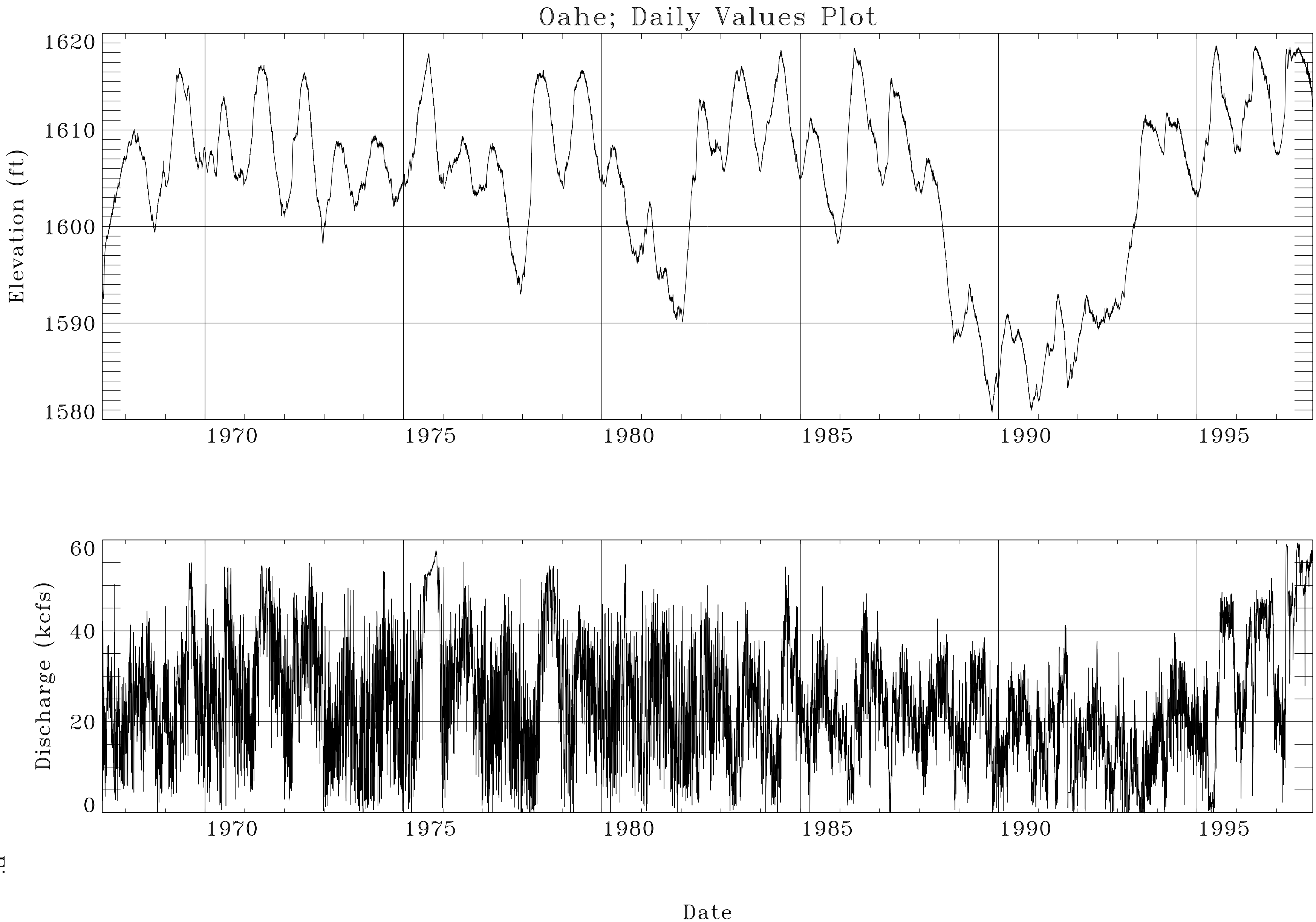
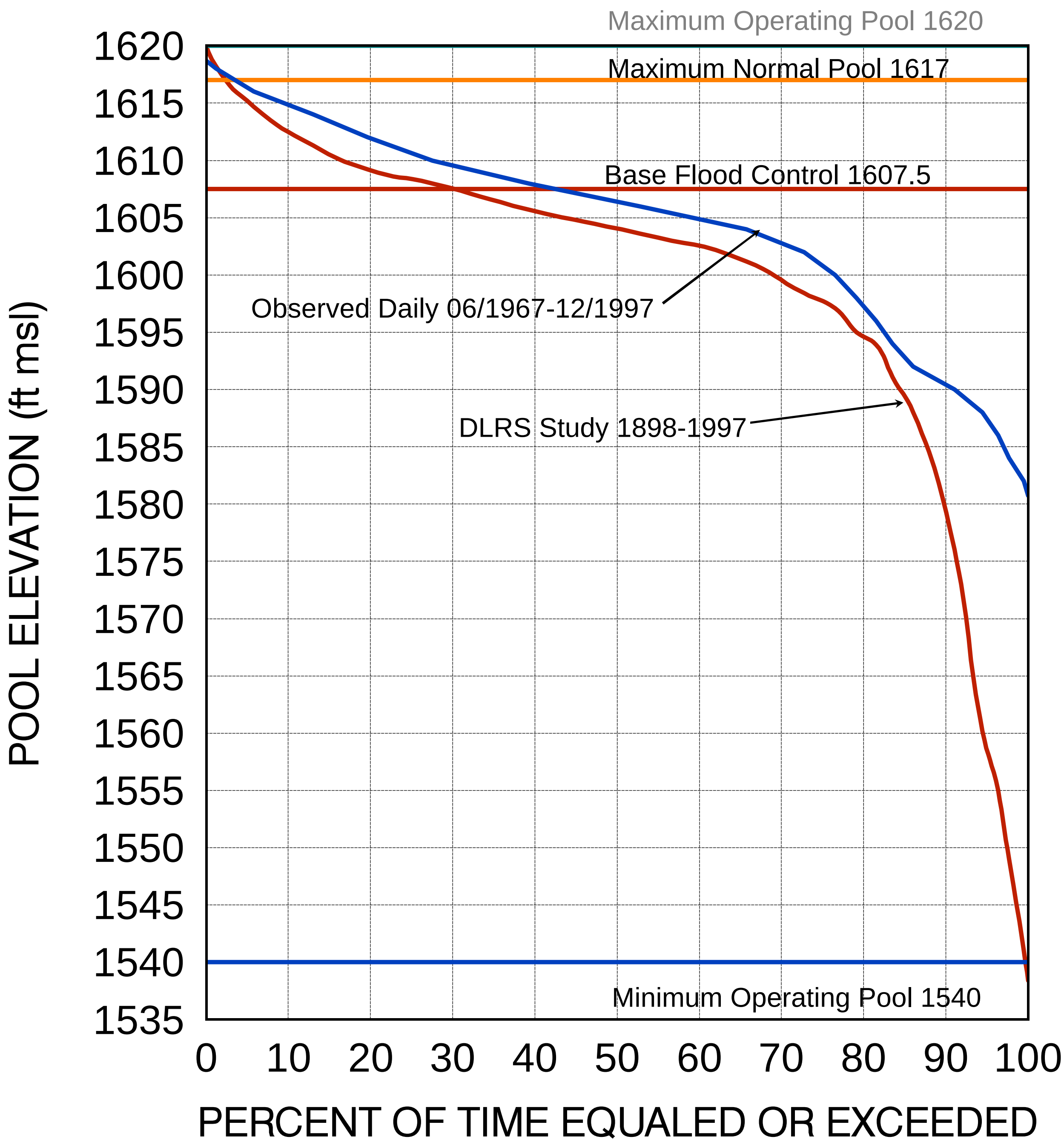

Oahe; Daily Values Plot
Elevation (ft)
1620
1610
1600
1590
1580
1970
1975
1980
1985
1990
1995
Discharge (kcfs)
60
40
20
0
1970
1975
1980
1985
1990
1995
Date

Figure 12

# LAKE OAHE

## POOL DURATION RELATIONSHIP

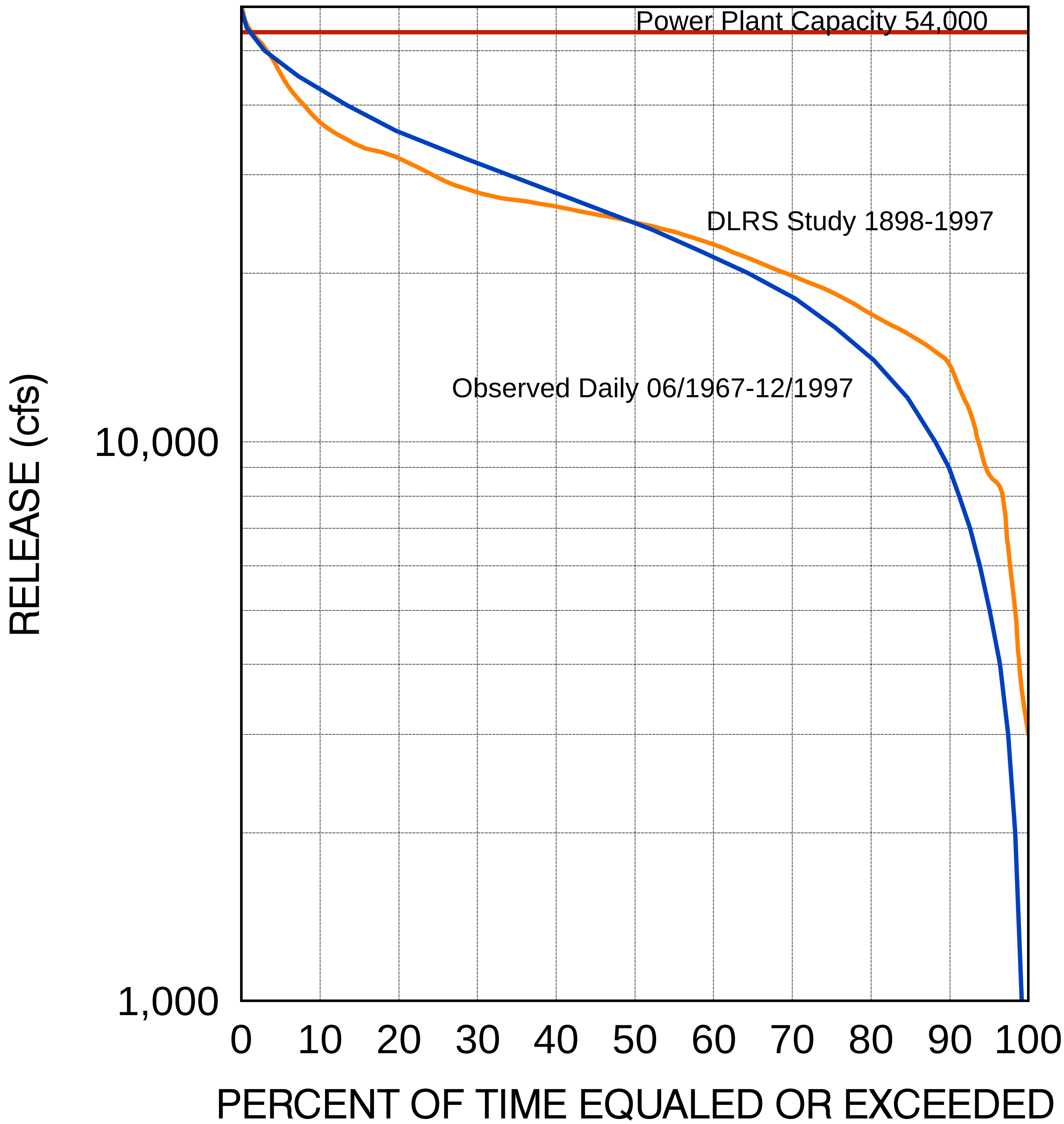



Observed Daily 06/67-11/97

FIGURE 13

# LAKE OAHE

## RELEASE DURATION RELATIONSHIP

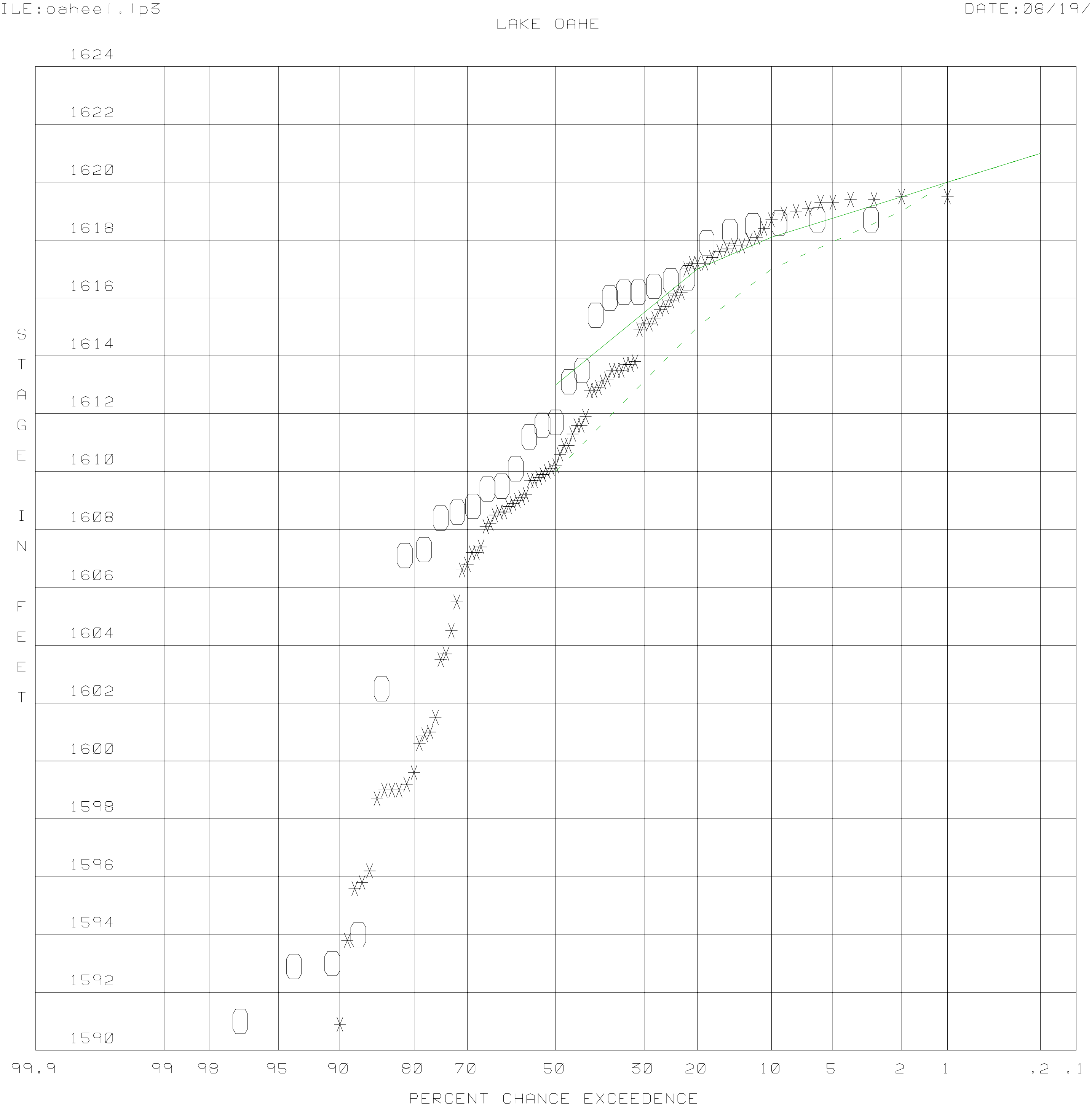



Observed Daily 06/67-11/97

FIGURE 14

FILE:oaheel.lp3

DATE:08/19/98




LEGEND:

OBSERVED

SIMULATED

ADOPTED

1976 STUDY

MAX POOL ELEVATION = 1644.4

MAX OP. POOL ELEV = 1620.0

MAX NORMAL POOL ELEV = 1617.0

BASE FLOOD CONTROL = 1607.5

MISSOURI RIVER MAIN STEM RESERVOIRS

POOL-PROBABILITY RELATIONSHIP

OAHE

RESERVOIR CONTROL CENTER

MISSOURI RIVER REGION

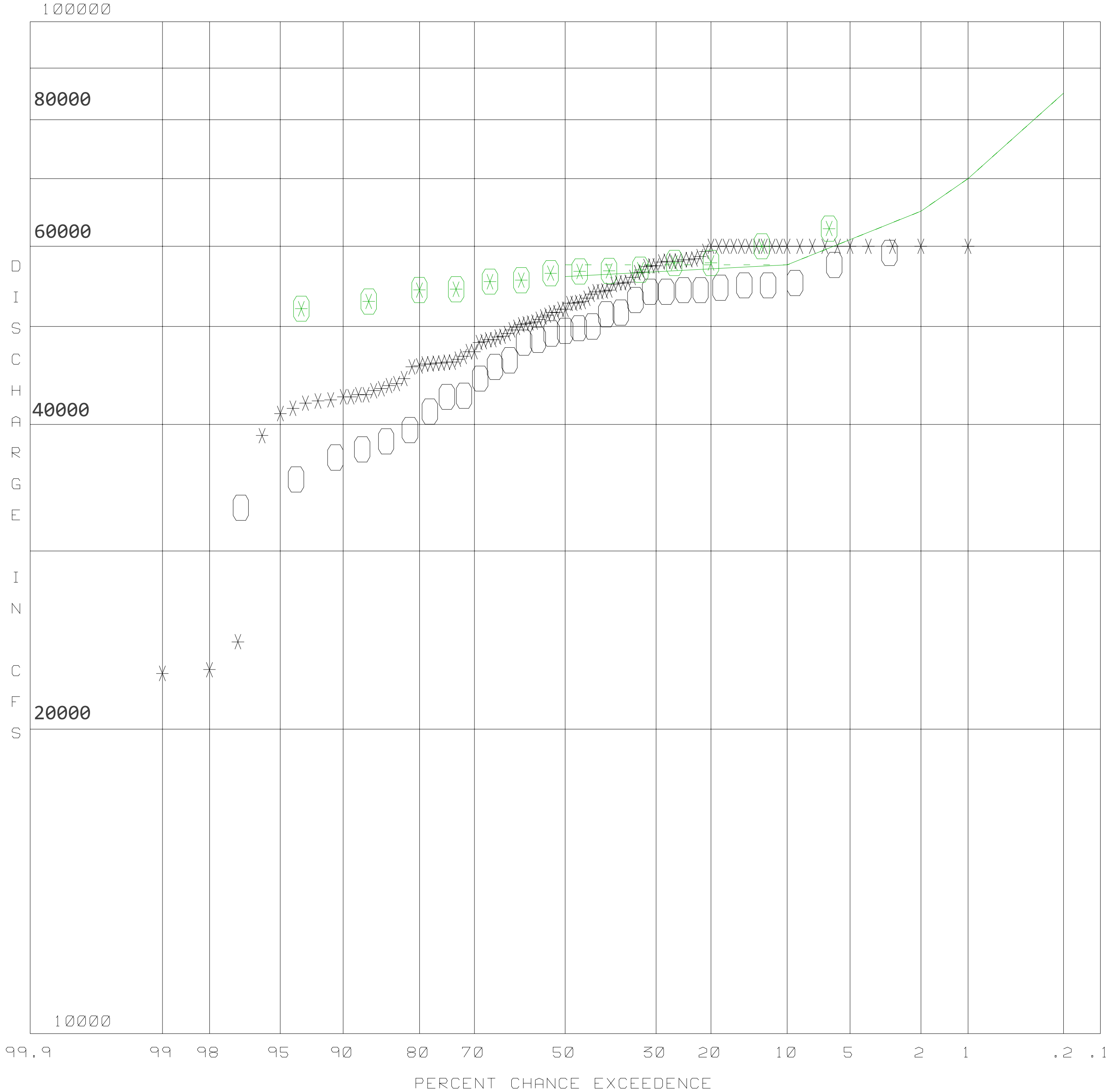
U.S. ARMY CORPS OF ENGINEERS

AUGUST 1998

FIGURE 15

FILE:oahere.lp3 DATE:08/19/98

OAHE DAM




LEGEND:

OBSERVED

SIMULATED

MAX HOURLY

ADOPTED

1976 STUDY

POWER PLANT CAPACITY = 54,000

OUTLET CAPACITY = 111,000

SPILLWAY CAPACITY = 304,000

MISSOURI RIVER MAIN STEM RESERVOIRS

RELEASE-PROBABILITY RELATIONSHIP

OAHE

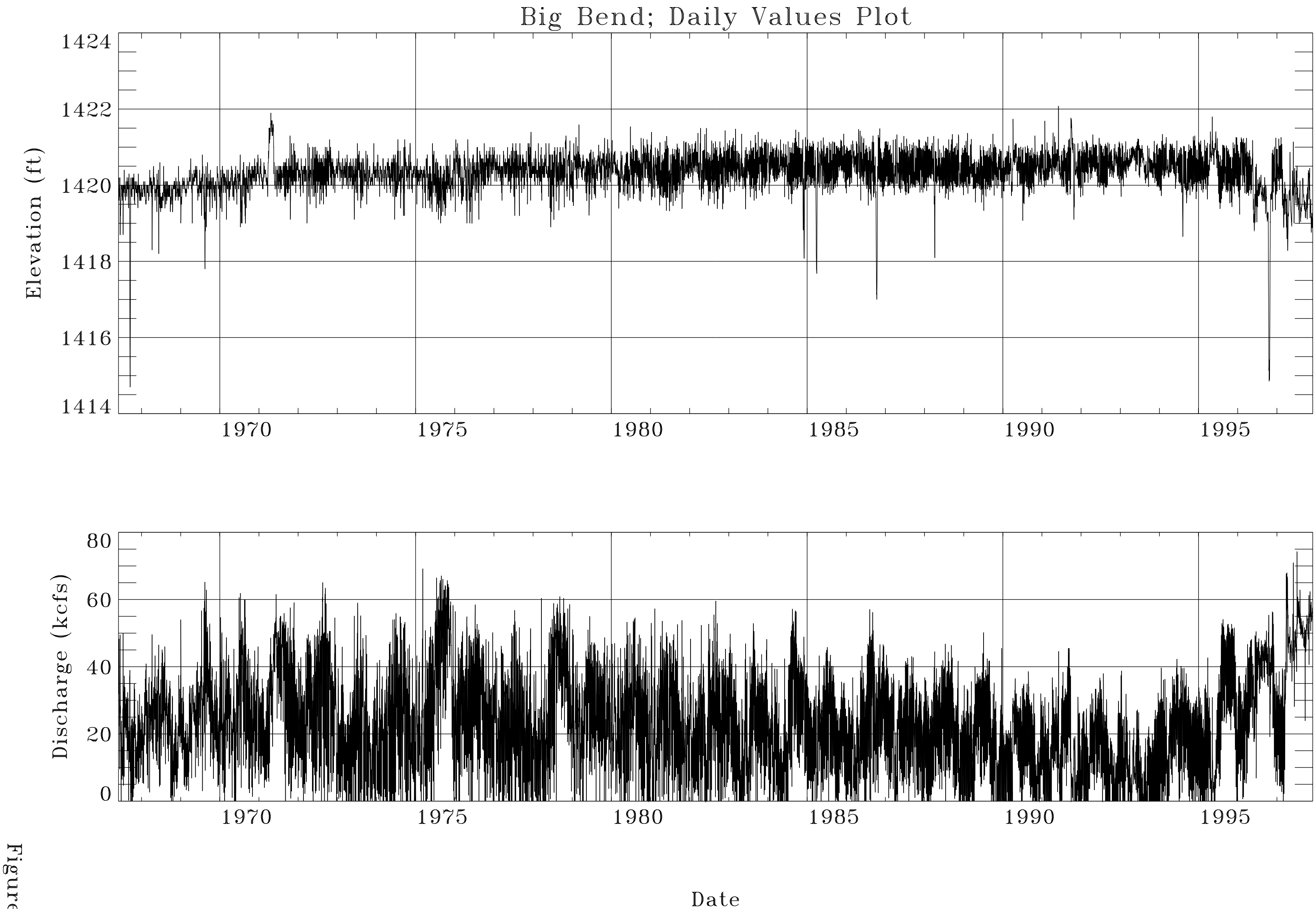
RESERVOIR CONTROL CENTER

MISSOURI RIVER REGION

U.S. ARMY CORPS OF ENGINEERS

AUGUST 1998

FIGURE 16

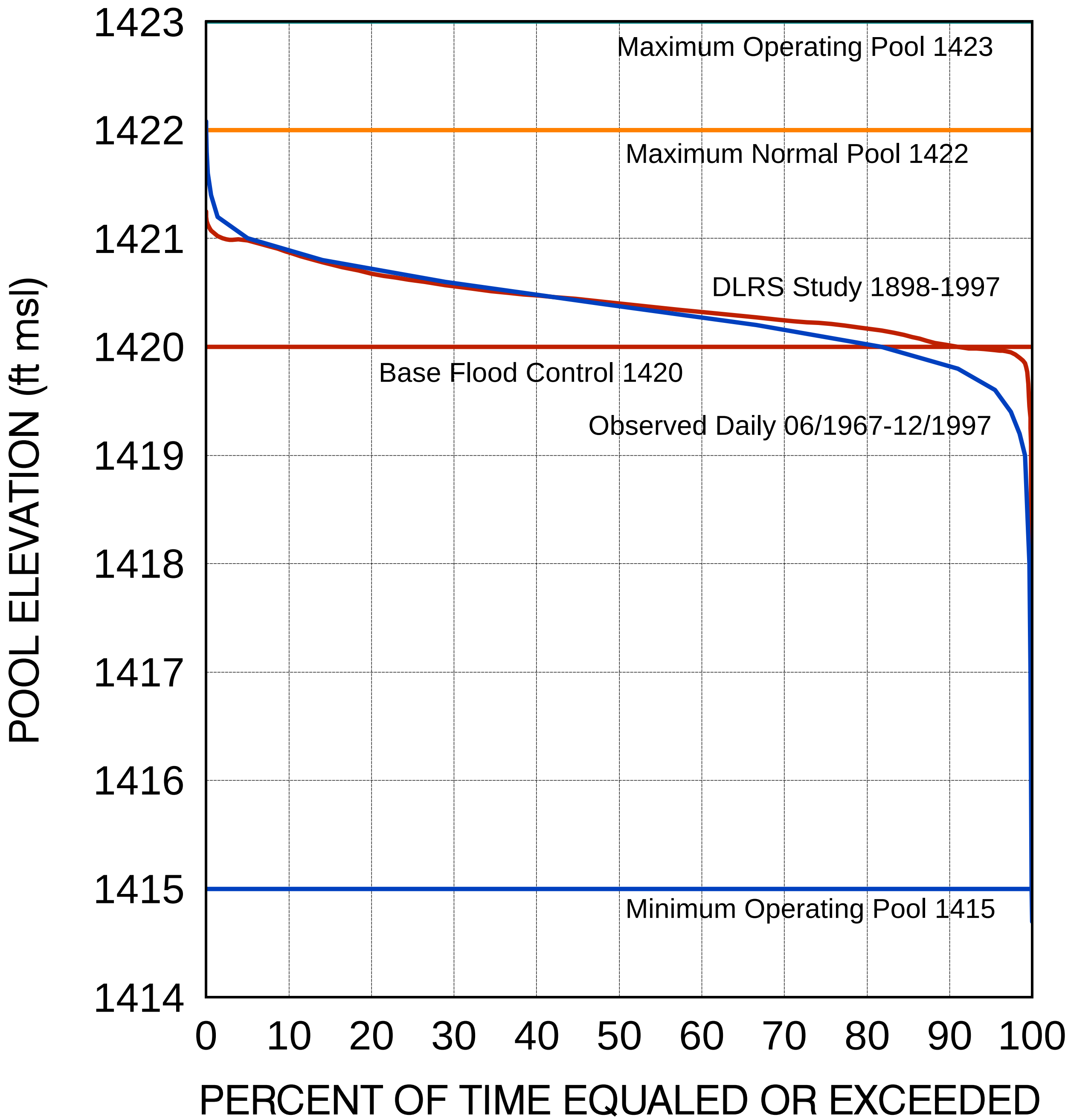


Big Bend; Daily Values Plot
1424
1422
1420
1418
1416
1414
Elevation (ft)
1970
1975
1980
1985
1990
1995
80
60
40
20
0
Discharge (kcfs)
1970
1975
1980
1985
1990
1995
Date


Figure 17

# LAKE SHARPE

## POOL DURATION RELATIONSHIP

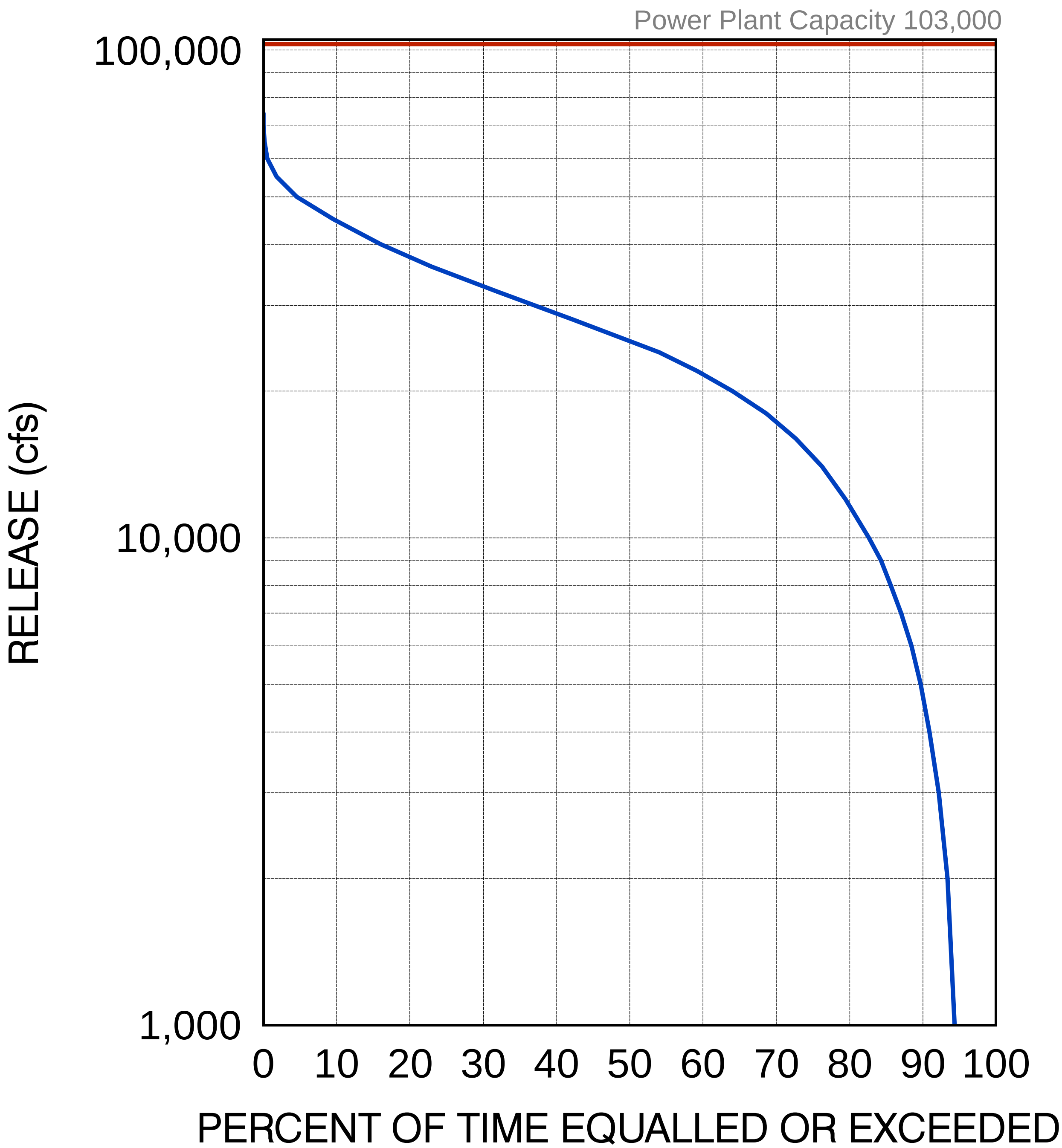



Observed Daily 06/67-11/97

FIGURE 18

# LAKE SHARPE

## RELEASE DURATION RELATIONSHIP

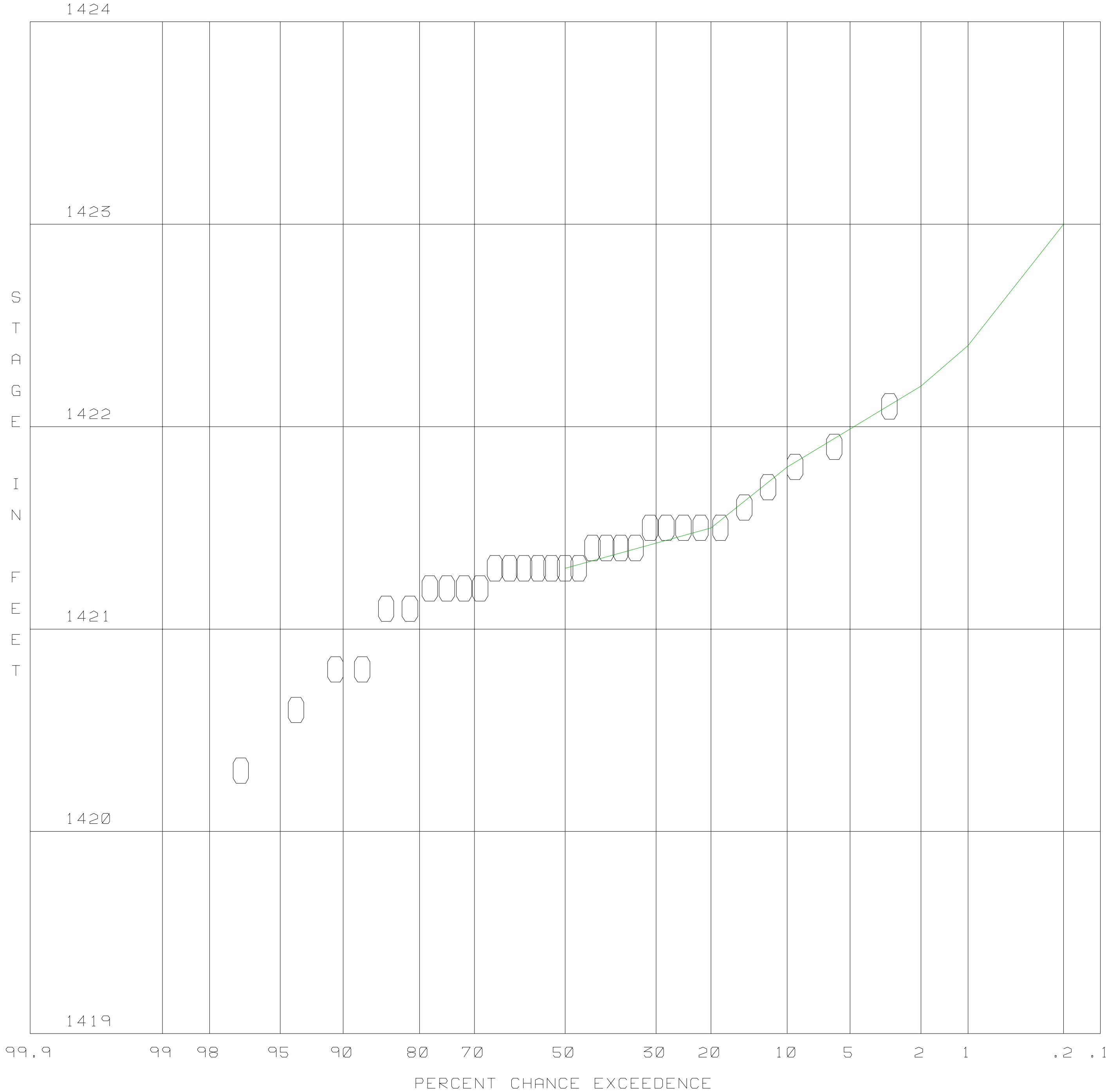



Observed Daily 06/67-11/97

FIGURE 19

FILE:bendel.lp3 DATE:08/19/98

LAKE SHARPE




LEGEND:

OBSERVED

ADOPTED

MAX POOL ELEVATION = 1433.6

MAX OP. POOL ELEV = 1423.0

MAX NORMAL POOL ELEV = 1422.0

BASE FLOOD CONTROL = 1420.0

MISSOURI RIVER MAIN STEM RESERVOIRS

POOL-PROBABILITY RELATIONSHIP

BIG BEND

RESERVOIR CONTROL CENTER

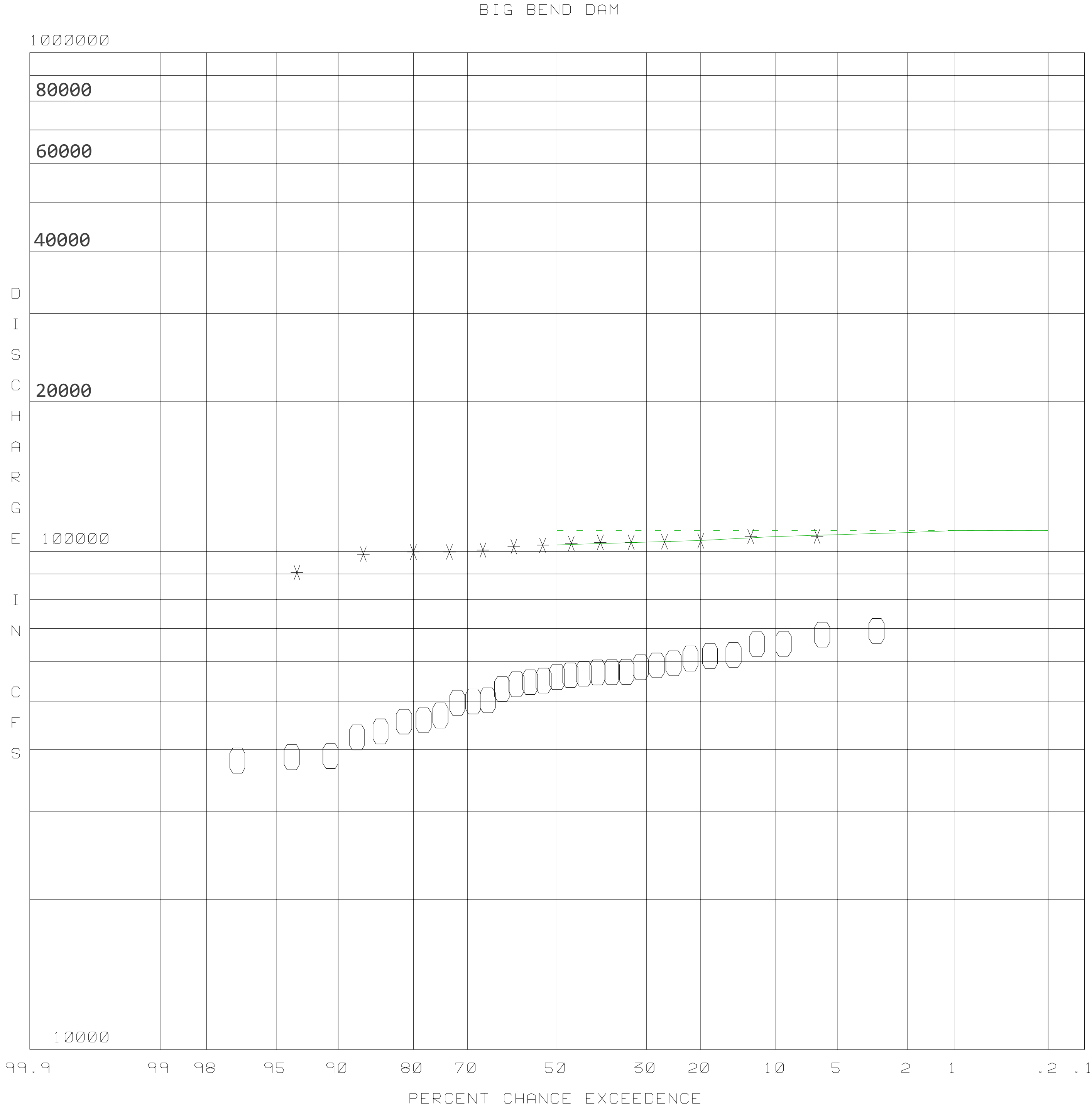
MISSOURI RIVER REGION

U.S. ARMY CORPS OF ENGINEERS

AUGUST 1998

FIGURE 20

FILE:BENDRE.LP3 DATE:09/02/98




LEGEND:

OBSERVED

MAX HOURLY

ADOPTED

1976 STUDY

POWER PLANT CAPACITY = 103,000

OUTLET CAPACITY = 0

SPILLWAY CAPACITY = 390,000

MISSOURI RIVER MAIN STEM RESERVOIRS

RELEASE-PROBABILITY RELATIONSHIP

BIG BEND

RESERVOIR CONTROL CENTER

MISSOURI RIVER REGION

U.S. ARMY CORPS OF ENGINEERS

AUGUST 1998

FIGURE 21

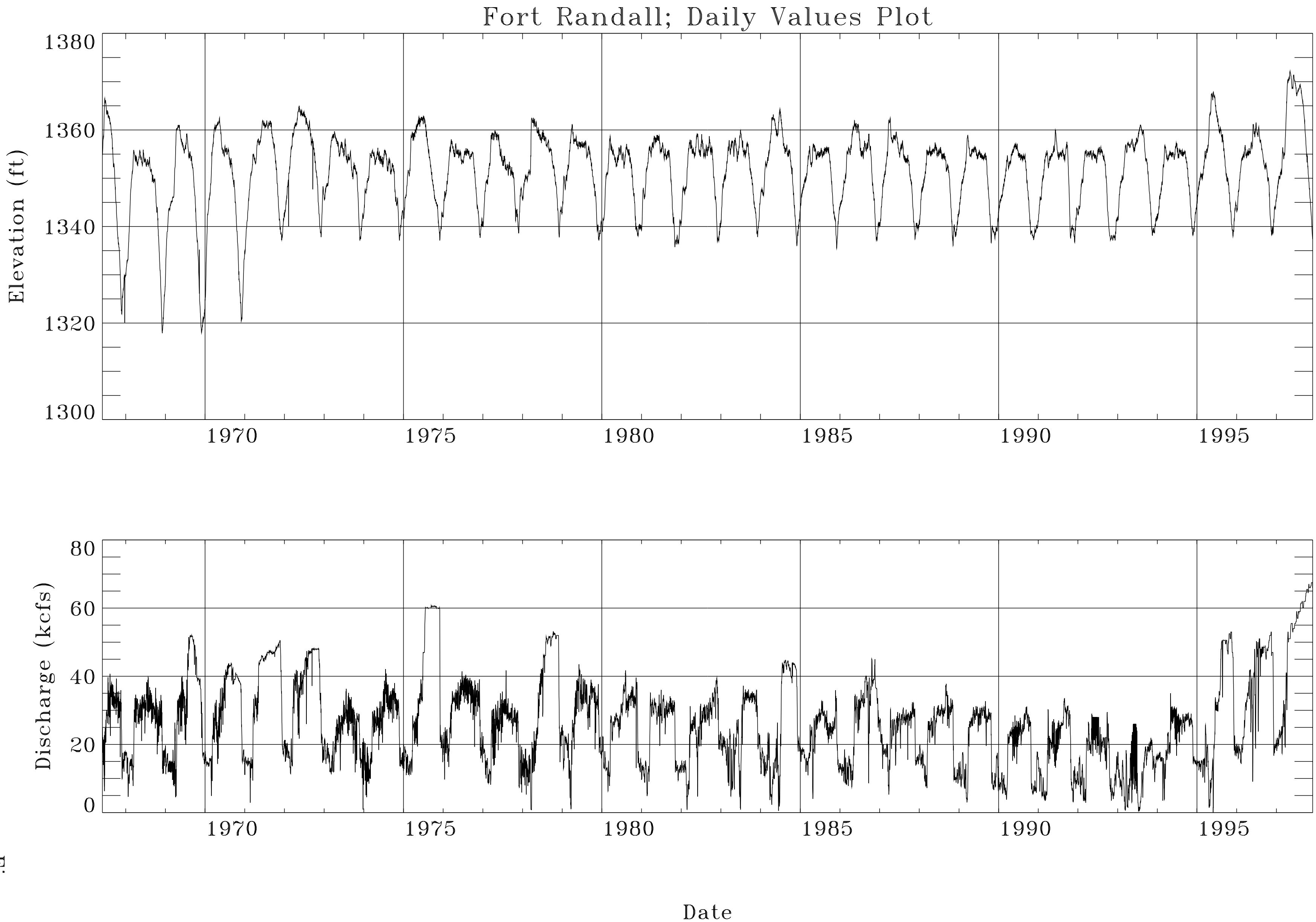
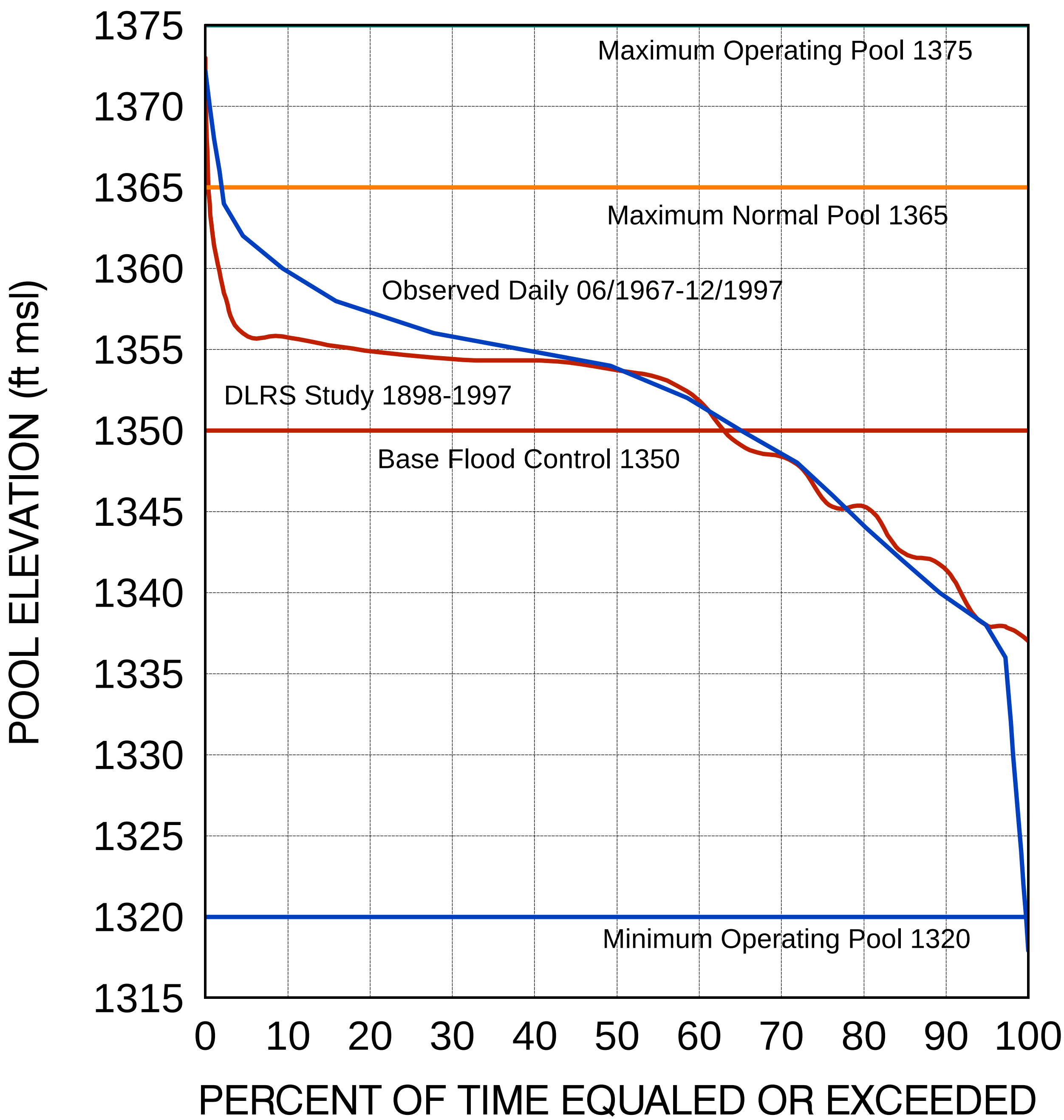

Fort Randall; Daily Values Plot
Elevation (ft)
1380
1360
1340
1320
1300
1970
1975
1980
1985
1990
1995
Discharge (kcfs)
80
60
40
20
0
1970
1975
1980
1985
1990
1995
Date

Figure 22

# LAKE FRANCIS CASE

## POOL DURATION RELATIONSHIP

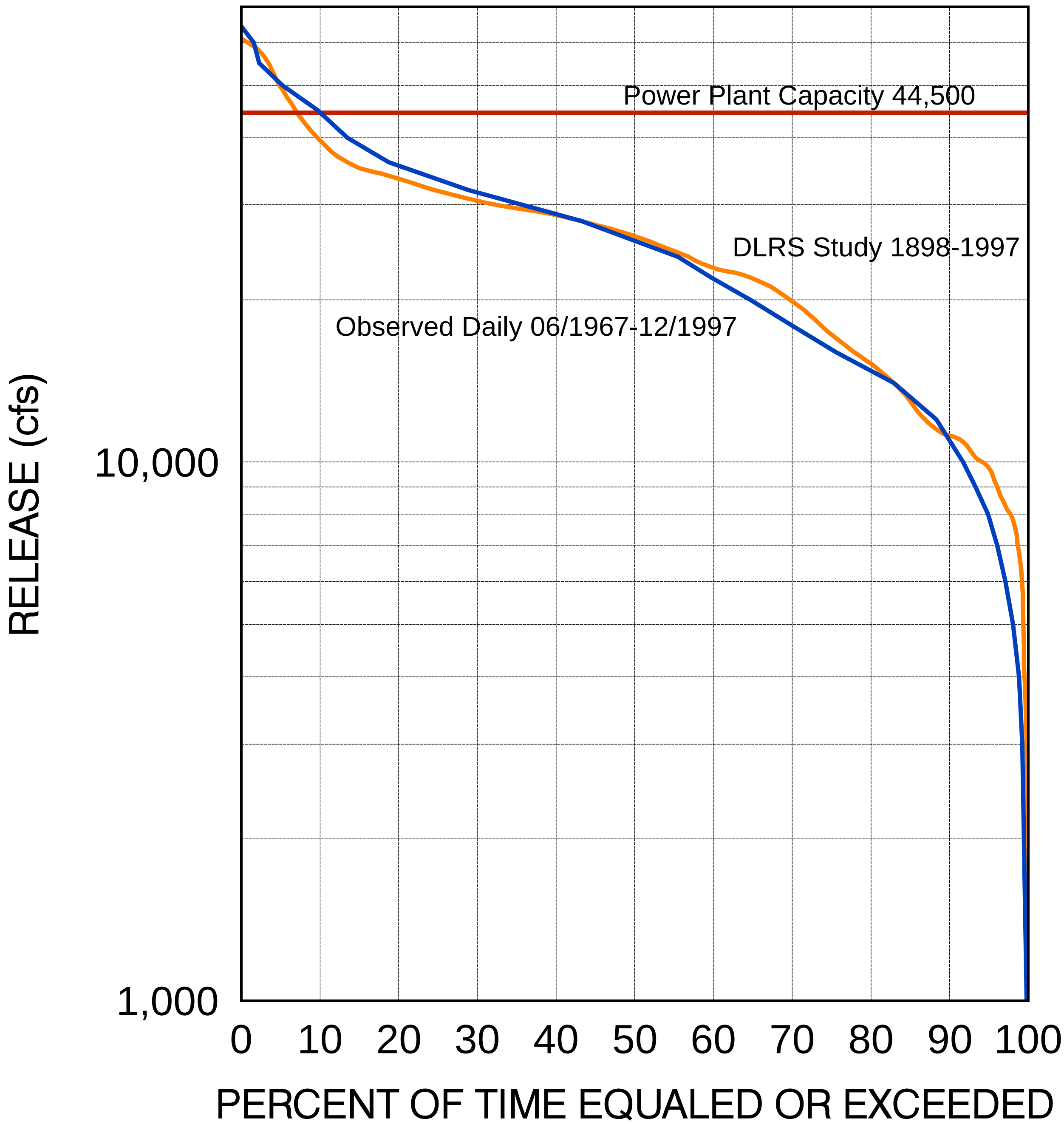



Observed Daily 06/67-11/97

FIGURE 23

# LAKE FRANCIS CASE

## RELEASE DURATION RELATIONSHIP

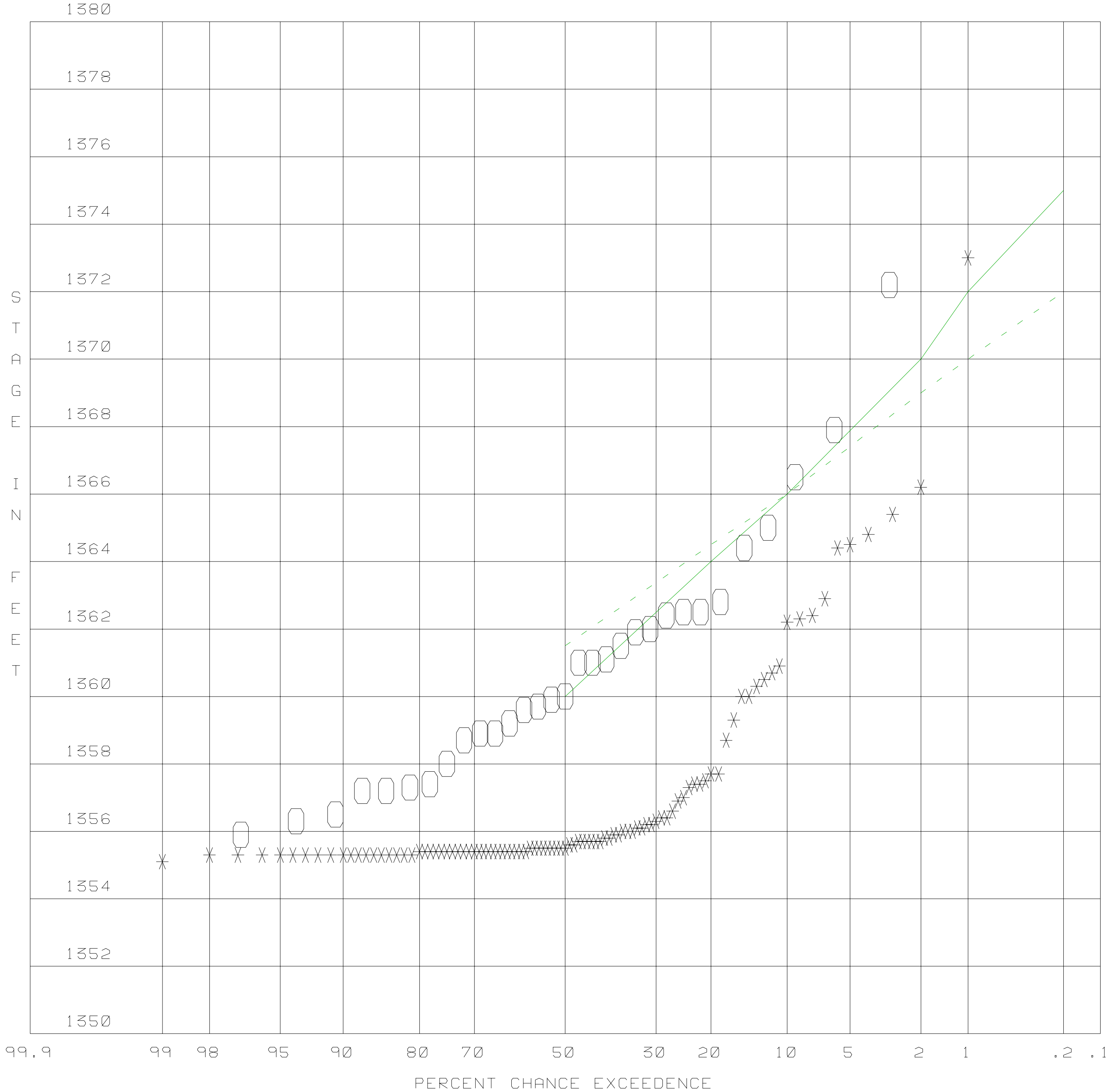



Observed Daily 06/67-11/97

FIGURE 24

FILE:randel.lp3 DATE:08/19/98

LAKE FRANCIS CASE




LEGEND:

OBSERVED

SIMULATED

ADOPTED

1976 STUDY

MAX POOL ELEVATION = 1379.3

MAX OP. POOL ELEV = 1375.0

MAX NORMAL POOL ELEV = 1365.0

BASE FLOOD CONTROL = 1350.0

MISSOURI RIVER MAIN STEM RESERVOIRS

POOL-PROBABILITY RELATIONSHIP

# FORT RANDALL

RESERVOIR CONTROL CENTER

MISSOURI RIVER REGION

U.S. ARMY CORPS OF ENGINEERS

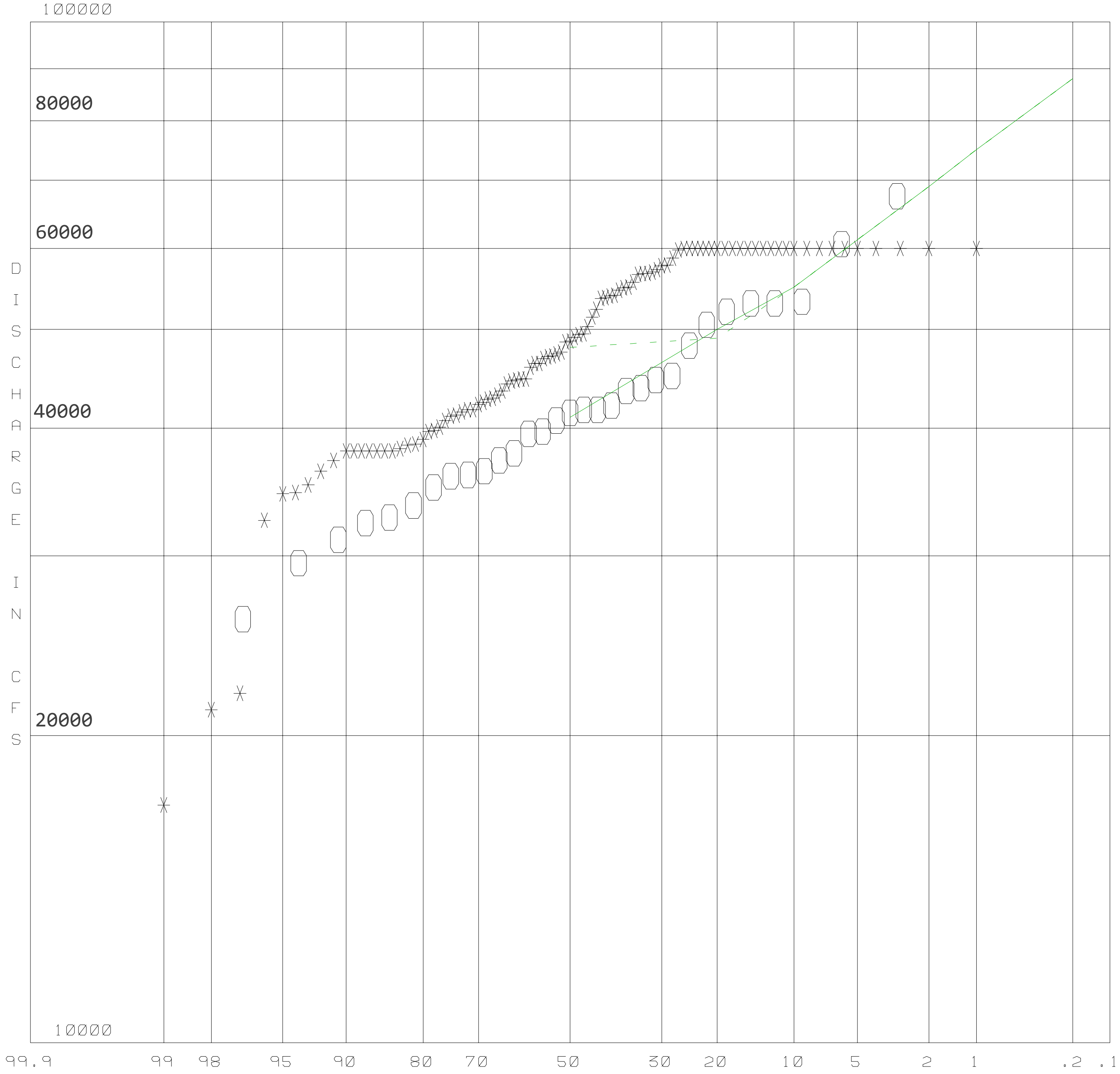
AUGUST 1998

FIGURE 25

FILE:randre.lp3

DATE:09/02/98

FORT RANDALL DAM




LEGEND:

OBSERVED

SIMULATED

ADOPTED

1976 STUDY

POWER PLANT CAPACITY = 44,500

OUTLET CAPACITY = 128,000

SPILLWAY CAPACITY = 620,000

MISSOURI RIVER MAIN STEM RESERVOIRS

RELEASE-PROBABILITY RELATIONSHIP

FORT RANDALL

RESERVOIR CONTROL CENTER

MISSOURI RIVER REGION

U.S. ARMY CORPS OF ENGINEERS

AUGUST 1998

FIGURE 26

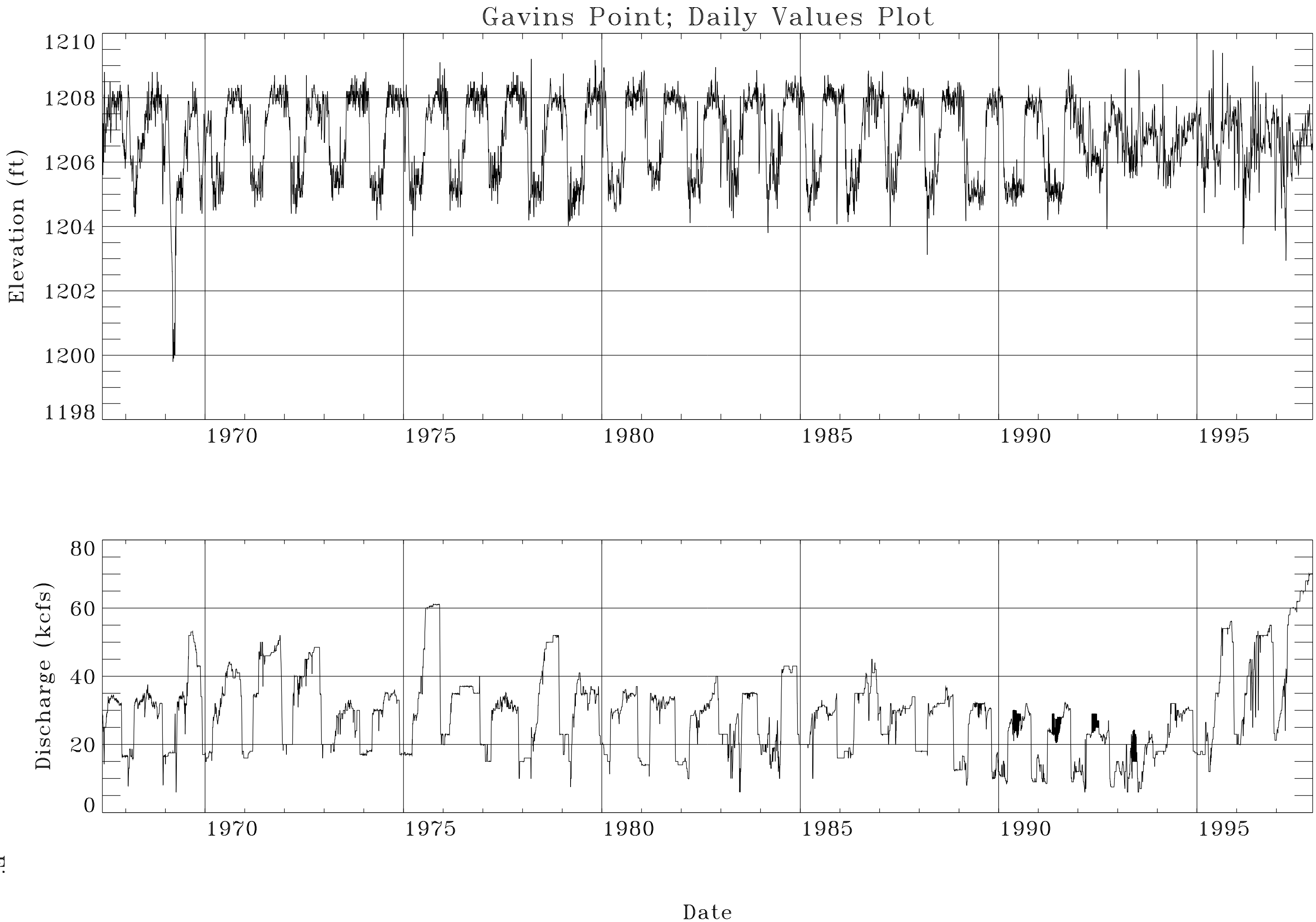
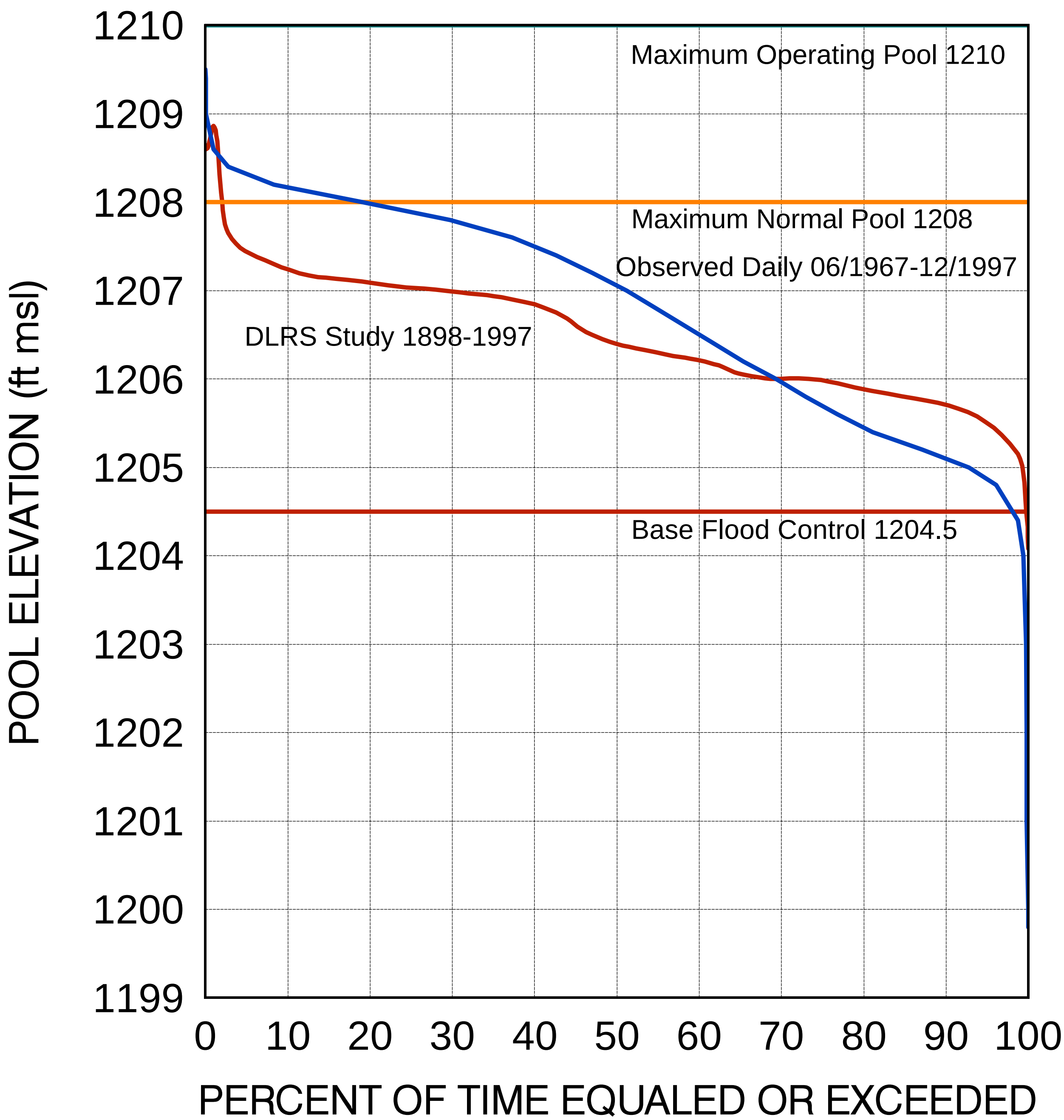

Gavins Point; Daily Values Plot
Elevation (ft)
1210
1208
1206
1204
1202
1200
1198
1970
1975
1980
1985
1990
1995
Discharge (kcfs)
80
60
40
20
0
1970
1975
1980
1985
1990
1995
Date

Figure 27

# LEWIS & CLARK LAKE

## POOL DURATION RELATIONSHIP

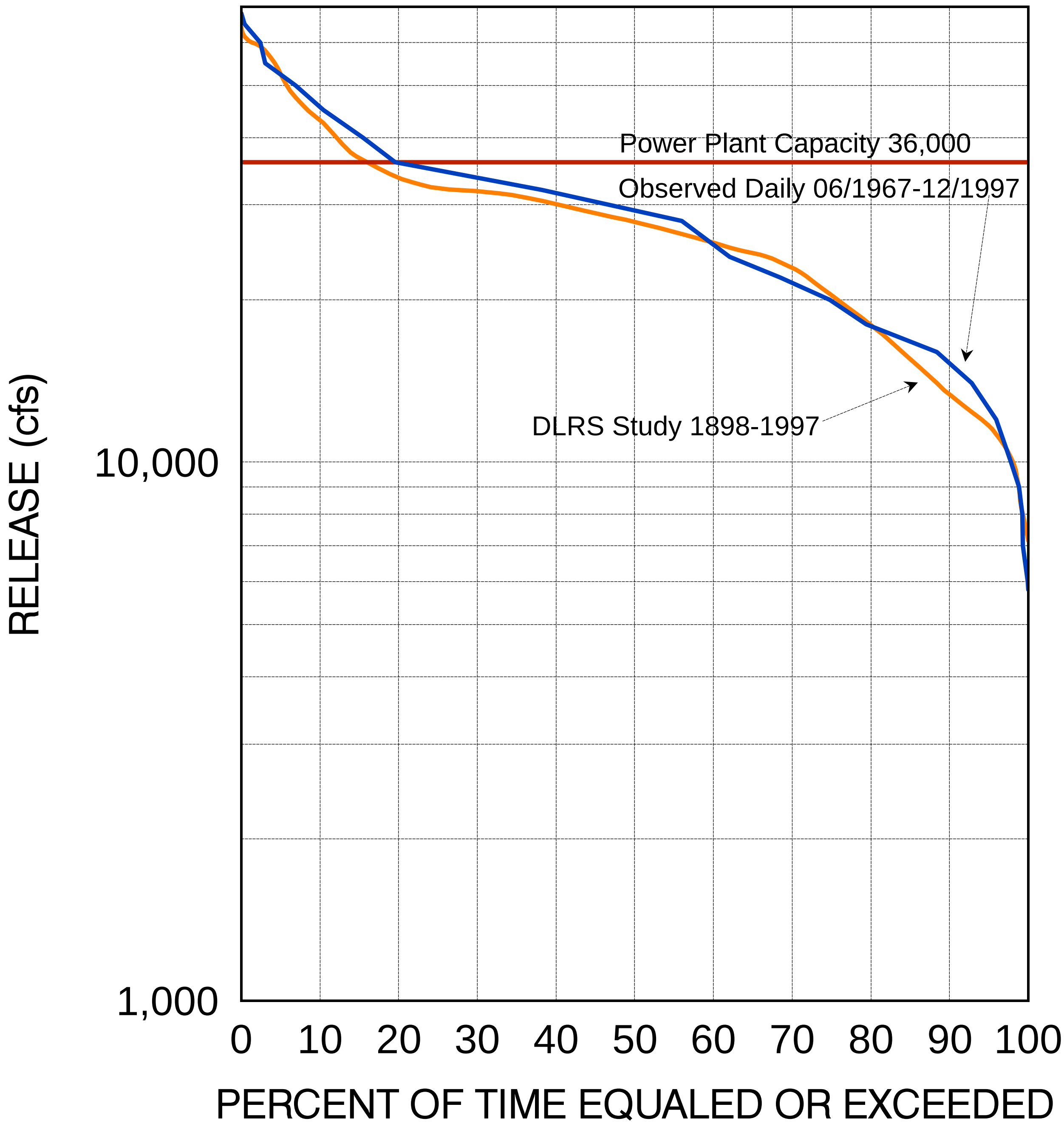



Observed Daily 06/67-11/97

FIGURE 28

# LEWIS & CLARK LAKE

## RELEASE DURATION RELATIONSHIP

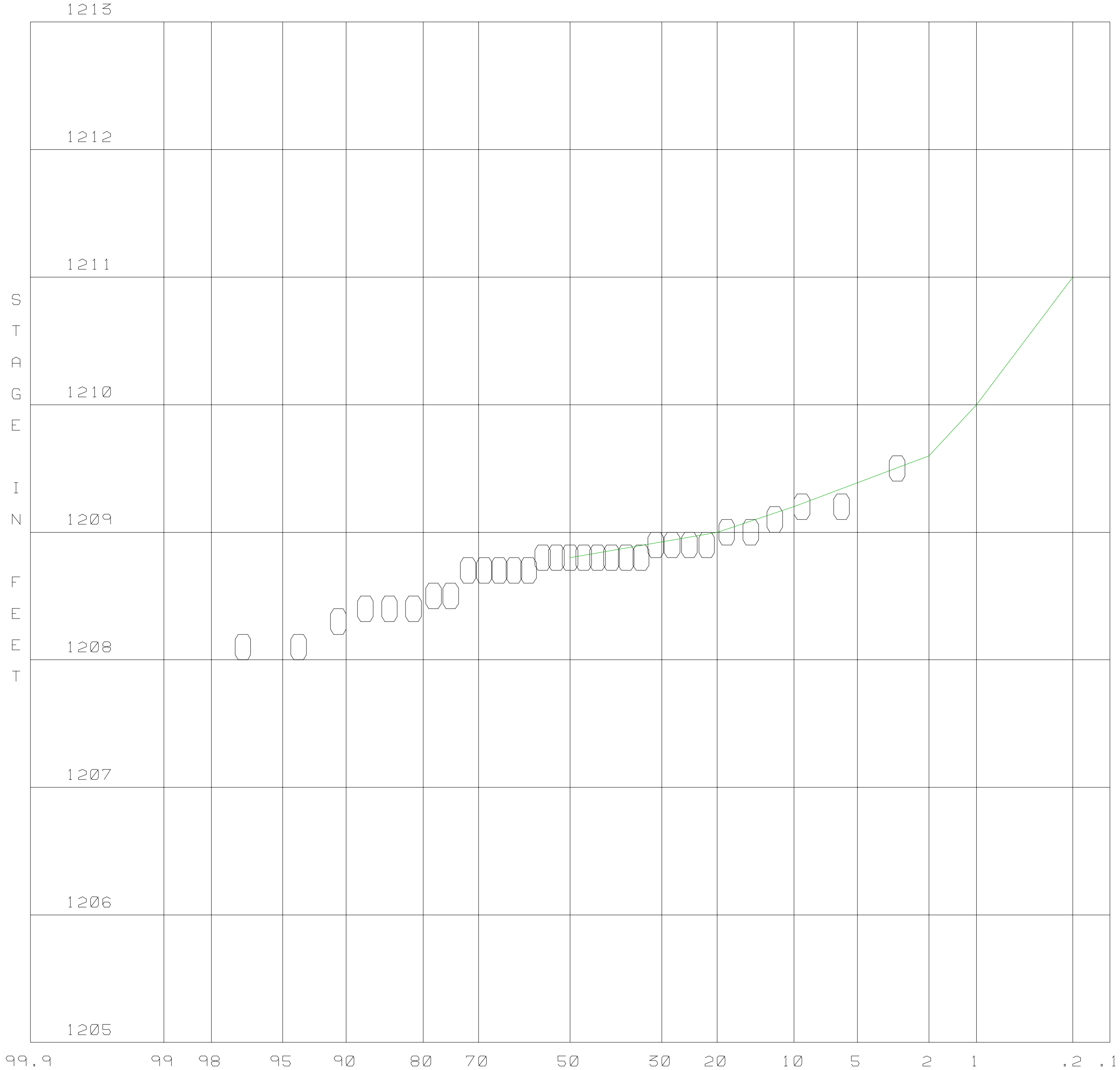



Observed Daily 06/67-11/97

FIGURE 29

FILE:gavnel.lp3 DATE:08/19/98

LEWIS & CLARK LAKE




LEGEND:

OBSERVED

ADOPTED

MAX POOL ELEVATION = 1221.4

MAX OP. POOL ELEV = 1210.0

MAX NORMAL POOL ELEV = 1208.0

BASE FLOOD CONTROL = 1204.5

MISSOURI RIVER MAIN STEM RESERVOIRS

POOL-PROBABILITY RELATIONSHIP

GAVINS POINT

RESERVOIR CONTROL CENTER

MISSOURI RIVER REGION

U.S. ARMY CORPS OF ENGINEERS

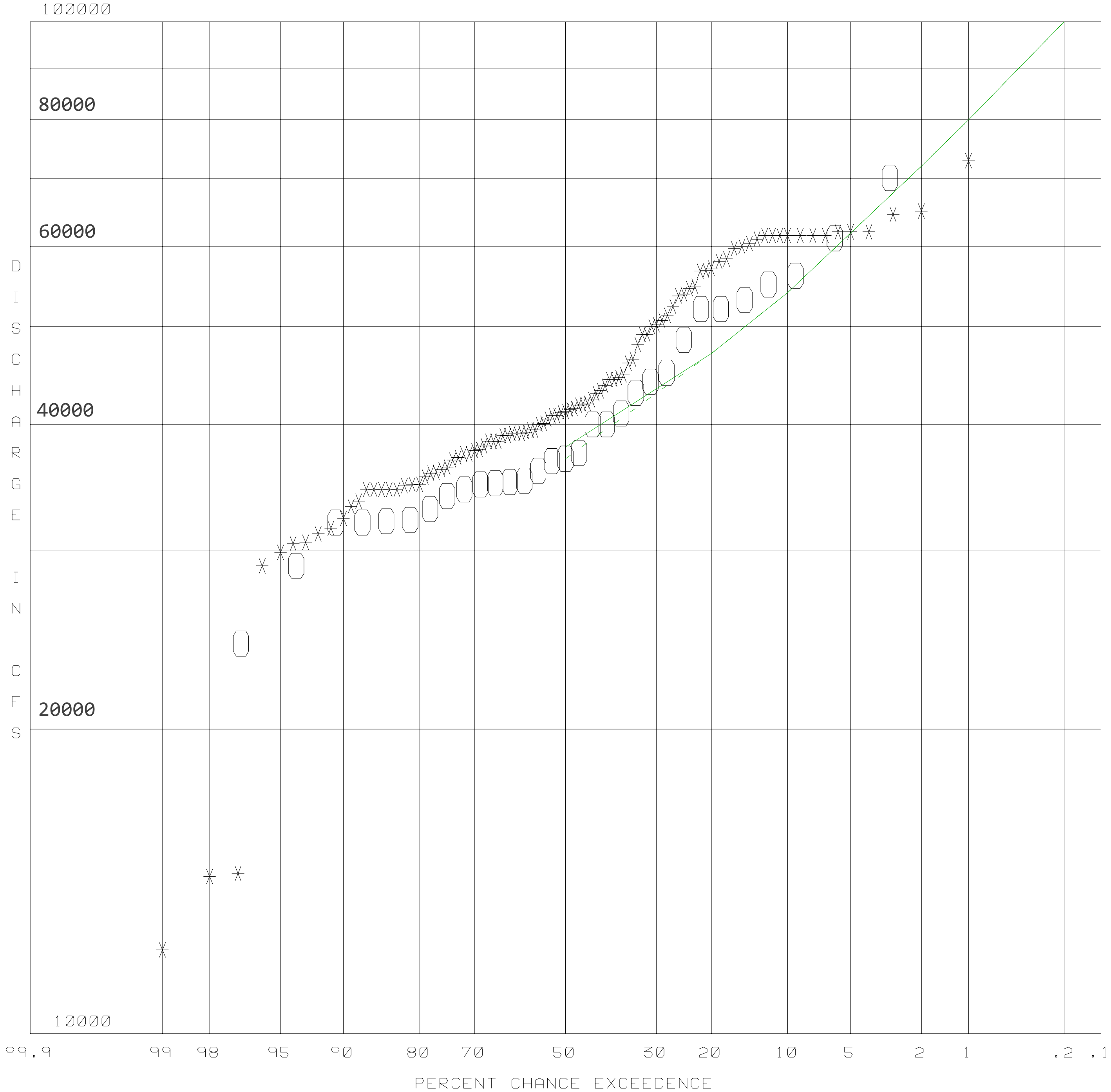
AUGUST 1998

FIGURE 30

FILE:gavnre.lp3

DATE:08/19/98

GAVINS POINT DAM




LEGEND:

OBSERVED

SIMULATED

ADOPTED

1976 STUDY

POWER PLANT CAPACITY = 36,000

OUTLET CAPACITY = 0

SPILLWAY CAPACITY = 584,000

MISSOURI RIVER MAIN STEM RESERVOIRS

RELEASE-PROBABILITY RELATIONSHIP

GAVINS POINT

RESERVOIR CONTROL CENTER

MISSOURI RIVER REGION

U.S. ARMY CORPS OF ENGINEERS

AUGUST 1998

FIGURE 31