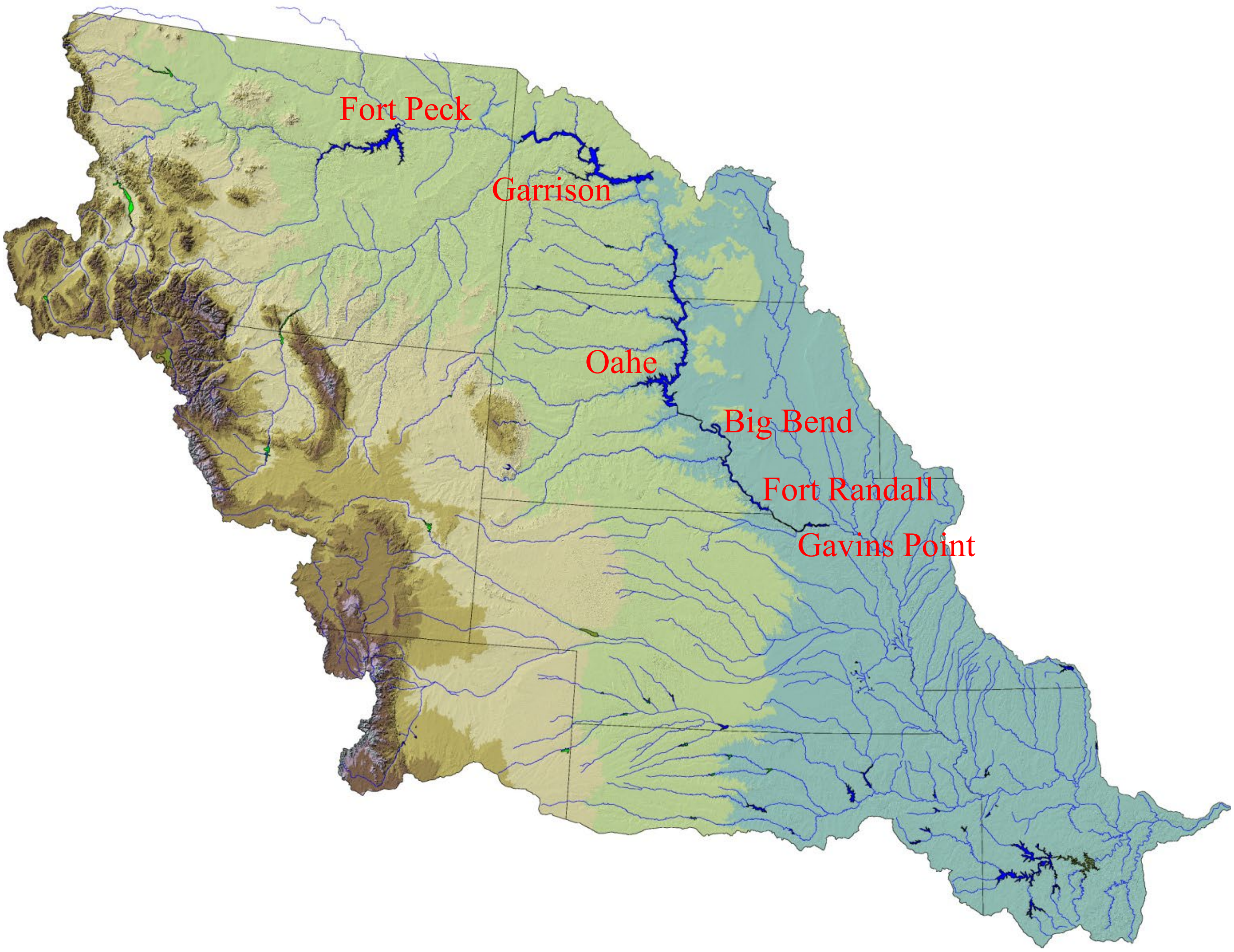
US Army Corps of Engineers ®
Northwestern Division

Hydrologic Statistics
Technical Report



Missouri River Basin Water Management Division
Omaha, Nebraska

May 2022

Missouri River Basin Water Management Division
Technical Report – Hydrologic Statistics, May 2022

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LIST OF ABBREVIATIONS AND ACRONYMS

Basin	Missouri River Basin
cfs	cubic feet per second
CWCP	Current Water Control Plan
DPR	detailed project reports
DRM	Daily Routing Model
ft	feet
HEC	Hydrologic Engineering Center
kAF	1000 acre-feet
LRS	Long Range Study
M	million
MAF	million acre-feet
Master Manual	Master Water Control Manual
MRBWM	Missouri River Basin Water Management Division
NWD	Corps' Northwestern Division
ResSim Model	Missouri River Reservoir System Planning Model
SWE	snow water equivalent
SSP	HEC Statistical Software Package
System	Missouri River Mainstem Reservoir System
T&E	Threatened and Endangered
USBR	U.S. Bureau of Reclamation

I. INTRODUCTION

A. Purpose

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 Mainstem Reservoir System (System). Results of this analysis include the development of hydrologic statistics consisting of pool- and release-duration relationships, pool-probability and release-probability relationships for each of the six System projects. The six projects comprising the 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 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.

B. Pool-Duration and Release-Duration Relationships

Duration relationships represent the cumulative distribution function of all data recorded at the site which can be based on annual or seasonal periods. For this study, two types of duration relationships, pool-duration and release-duration, were developed. 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. Seasonal duration relationships can be defined to represent particular months or seasons. For this study, annual pool-duration and release-duration relationships were developed as well as seasonal (May-August) pool-duration and release-duration relationships. The May-August period was selected because it is the period where regulation decisions most impact the threatened piping plover bird that nest in the reservoirs and river reaches of the Missouri River.

A duration relationship is not a probability relationship. It should not be interpreted on an 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 an annual duration relationship or the number of days during a particular month or season, if it is a seasonal duration relationship. Daily or monthly data can be used to develop a duration relationship. Daily data were used for this study. A shorter time step in the data used will typically result in a duration relationship with steeper slopes at the extremes. Duration relationships are developed by sorting the data from largest to smallest, ranking the values from 1 to n and using the generalized plotting position formula, $m/(n+1)$, where m is the rank of values with the largest value equal to 1 and n is the number of values in the data set.

C. Pool-Probability and Release-Probability Relationships

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 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. Also note that while a 100-year pool elevation occurs on average once every 100 years, a 100-year pool elevation can occur multiple times over a short period (e.g. 5-10 years). This is because the probability of a 100-year pool elevation is the same every year, and the occurrence of a 100-year pool elevation in recent years does not reduce or eliminate the probability of a 100-year pool elevation occurring in the next year.

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 can be inferred 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 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 System, maximum releases are dependent 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, hydropower requirements, recreation, fish and wildlife, irrigation, 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, such as 1997 and 2011, 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. Maximum releases depend heavily on the System storage at the start of a runoff event. A drought may reduce System storage to a level where a large runoff event requires minimal releases. However, if the System storage is at the top of the conservation pool, the same large runoff event will require large releases.

In order to address this, a Missouri River Basin Water Management (MRBWM) technical report has been scoped to determine release-storage probabilities at various System storage levels. This MRBWM technical report, tentatively entitled, *Hydrologic Statistics, Variable Storage Release Frequency Relationships* will include the use of Monte Carlo simulation to sample the probability distributions of runoff and starting System storage and individual pool elevations for the System, Fort Peck, Garrison, Oahe and Fort Randall in order to derive the probability distribution of the System releases and four individual project releases. The MRBWM office is currently developing risk analysis tools using the Hydrologic Engineering Center's (HEC) Watershed Analysis Tool (WAT).

II. BACKGROUND INFORMATION

As noted earlier, the six projects comprising the System are Fort Peck, Garrison, Oahe, Big Bend, Fort Randall, and Gavins Point. These reservoirs were constructed by the U.S. Army Corps of Engineers on the main stem of the Missouri River for flood control, navigation, irrigation, hydropower, water supply, water quality control, recreation, and fish and wildlife, including threatened and endangered (T&E) species. To achieve the multi-purpose benefits for which the mainstem reservoirs were authorized and constructed, they are operated as a hydraulically and electrically integrated system. Regulation of the projects began with Fort Peck (1940) as the sole mainstem project. Additional projects were added as Fort Randall (1953), Garrison (1955), Gavins Point (1955), Oahe (1962) and Big Bend (1964) were progressively brought into the System. The current System of six projects first filled and began operating as a six-project System in 1967. ***Plate 1*** shows the location of each of these reservoirs. Pertinent data for each project are listed in ***Table 1***.

A. Previous Reports

Prior to this study, the adopted pool-probability and release-probability relationships were based on studies completed in February 1999 and April 1976, with the dataset for both analyses starting in June 1967, when the System first filled. 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 Mainstem Reservoir System*. The 1999 study is referred to as, *Missouri River Mainstem Reservoir Hydrologic Statistics – RCC Technical Report F-99*. The 2013 study utilized an additional 14 years of historical data from the period 1967-2011 and is published as MRBWM Technical Report, *Hydrologic Statistics, September 2013*. The current updated study utilized an additional 9 years of historical data from the period 1967-2020. This updated study is published as MRBWM Technical Report *Hydrologic Statistics, May 2022*. Supporting data and reports referenced herein may be obtained from the MRBWM of the Northwestern Division, U.S. Army Corps of Engineers.

B. The Flood of 1881

The Flood of 1881 is sometimes referred to as the System flood control storage design flood. It is known from hydrologic records and gage heights along the Missouri River that the 1881 early spring flood was followed by one of the wettest summers of record. An estimated total volume of flood runoff at Sioux City, IA during the March-July 1881 period was more than 40 MAF, which at the time when the projects were designed, greatly exceeded the volume for any other year at this location for which records were kept. The severe flood sequence, as reconstructed from available stage records, served as the primary basis for the design of the flood control storage space in the System. The March-July 2011 runoff at this same location was 48.4 MAF.

Table 1
Pertinent Data for Missouri River Mainstem Projects

Description	**Fort Peck**	**Garrison**	**Oahe**	**Big Bend**	**Fort Randall**	**Gavins Point**
River Mile (1960 Mileage)	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
Incremental Drainage Area (sq. mi.)	57,500	123,900	62,090	5840	14,150	16,000
Gross Storage (kAF)	18,463	23,451	22,983	1,810	5,293	428
Flood Storage (kAF)	3,675	5,706	4,315	179	2,292	133
Top of Dam* (feet)	2280.5	1875.0	1660.0	1440.0	1395.0	1234.0
Maximum Surcharge Pool** (feet)	2253.3	1858.5	1644.4	1433.6	1379.3	1221.4
Top of Exclusive FC Pool*** (feet)	2250.0	1854.0	1620.0	1423.0	1375.0	1210.0
Top of Annual FC Pool (feet)	2246.0	1850.0	1617.0	1422.0	1365.0	1208.0
Base of Flood Control Pool (feet)	2234.0	1837.5	1607.5	1420.0	1350.0	1204.5
Spillway Capacity (cfs)	275,000	827,000	304,000	390,000	620,000	584,000
Outlet Capacity (cfs)	45,000	98,000	111,000	n/a	128,000	n/a
Powerplant Capacity (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

*All elevations in this report are referenced to the Local Project Datum.
**Maximum pool elevation with spillway gates opened.
***Maximum pool elevation with spillway gates closed.
n/a – not applicable

The flood control storage zones in the System reservoirs were designed in a series of Detailed Project Reports (DPR) in the mid-1940s to manage the 5-month runoff above Sioux City, IA of 40.0 MAF observed during March-July 1881, with maximum releases of about 100,000 cfs from Fort Randall and with all reservoirs reaching maximum pools at or near the top of their respective Exclusive Flood Control Zones. The 1881 flood inflows were based on estimates of what occurred, without reduction to allow for regulation effects of upstream tributary reservoirs or for consumptive use by upstream irrigation and other purposes. 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, the non-damaging channel capacity at that time, were assumed to be made from mid-April to mid-July from Fort Randall, with slightly lower releases from Garrison to Big Bend, without any requirement for reducing releases to desynchronize with downstream flood peaks. Thus, under today's conditions, the regulation effects due to upstream tributary storage and water-use developments might well be offset by release reductions necessary to recognize deteriorated downstream channel conditions and potential tributary flood inflows.

For this report, the analysis used the March-July runoff season volume of the 2011 flood at Sioux City, IA of 48.4 MAF, exceeding the 1881 design volume by 20 percent. The design reservoir releases from the 1881 event were not included in the 1976 or 1999 reports because of the roughness of the 1881 data and the inability to assign the runoff a reasonable percent chance of exceedance. The 1999 report indicated that the 1997 releases were considered the maximums of record. The addition of the much larger 2011 data point has shown that the assumed releases from the 1881 runoff event should be used in the release probability analysis as well as the 2011 releases. Use of the historical record back to the 1881 flood event, creates a longer period of record (140 years).

C. Vertical Datum.

The System projects were designed and constructed to a local project datum while recent hydrologic updates such as elevation-area and elevation-capacity curves and rating curve datums are in National Geodetic Vertical Datum of 1929 (NGVD29). Corps regulation, ER 1110-2-8160, dated March 1, 2009 and titled *Policies for Referencing Project Elevation Grades to Nationwide Vertical Datums*, specifies that a long-term effort should be programmed to transition from a legacy reference datum to the National Spatial Reference System, which is currently the National American Vertical Datum of 1988 (NAVD88). However, conversion from local datum/NGVD29 to NAVD88 has not been conducted on the System projects at this time and so the results from this study are given in local project datum. See Appendix A for adjustments for the three datums at each System project. These datum adjustments are provided for reference only and should not be used for construction or other purposes.

D. Missouri River Mainstem ResSim Model

Computer model simulation studies have been used by the MRBWM since the 1960's to simulate the operation of the System using a long-term hydrologic record. The Daily Routing Model (DRM) was developed during the 1990's as part of the Missouri River Master Manual Review and Update Study (Master Manual Review) to simulate and evaluate alternative System regulation for all of the authorized purposes under a widely varying long-term hydrologic record. For the Master Manual Review, a 100-year record of daily data, extending from 1898 through 1997, was used in evaluating alternatives for the USACE Final Environmental Impact Statement (FEIS). To develop the 100-year record, representative daily flow data were constructed from monthly observed records to cover the period from 1898 through 1929. Observed daily flow data were available for the period after 1929. For the 2013 hydrologic statistics analysis, the DRM was updated to include regulation criteria that was adjusted to reflect the new 2004 water control plan and input files were updated to include the actual regulation period through 2011.

The Missouri River Reservoir System Planning Study Model (ResSim Model) replaced the DRM and uses daily incremental reservoir reach inflows, streamflow depletions, evaporation data and reservoir operating rules based on the 2018 Master Manual to simulate operations of the System. The ResSim model was developed during the 2010s to conduct System planning studies.

The ResSim model only simulates the period-of-record (POR) from 1930 to present. Since the original development of the DRM model in 1997 there has been an additional 23 years of observed POR that include an extended drought period from 2000-2007 and historic flood years (2011 and 2019). Due to these additional years with varied runoff conditions and the nature of how flows were estimated prior to 1930, current and future System regulation studies will rely solely on data from 1930-present. Depletions for each reach throughout the Basin were estimated by the U.S. Bureau of Reclamation (USBR) from 1930-present at the 2017 level-of-depletion development and applied to the model to calculate all flow records.

E. Reservoir Regulation Studies and Data Analysis

The System has been operating as an integrated reservoir "System" since 1954 when Fort Peck and Fort Randall were both in operation. It was not until 1967 that initial fill of all six reservoirs comprising the present 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 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 the mid-1980s, special releases from Fort Randall and Gavins Point were required for T&E birds to accommodate nesting requirements during the summer months. The 2004 Master Manual revision increased water conservation during drought periods. The 2006 Master Manual incorporated the bi-modal spring pulse release from Gavins Point Dam for the benefit of the endangered pallid sturgeon; later removed in the 2018 Master Manual update.

When developing hydrologic data for a study of this type, it should be recognized that regulation criteria, available water supply or characteristics of the System will not remain static through the study period. Numerous criteria modifications have been made since System regulation first began and more can be expected in the future. Water resource development in the Missouri River Basin (Basin) is a dynamic process with the greatest effects upon regulation of the System being depletions to the available water supply as development progresses. It is anticipated that some continued development could occur in the future. While the System is now considered to be constructed, modifications in project structures are always possible. All of these conditions could affect the frequency estimates. Therefore, a considerable amount of engineering judgment, based on many studies and years of actual operation, was used in developing the frequency estimates in this report.

Use of long-term System regulation studies is one means of investigating a long-term period of hydrologic record and obtaining data that would be considered satisfactory for frequency estimates. A flow record extending from 1930 through 2020, representing 91 years of data is available. As previously discussed, MRBWM has developed and used computer models of the System and downstream Missouri River control points to simulate long-term reservoir regulation. The ResSim model was used in the analysis for this technical study. Criteria incorporated in these models reflect current regulation criteria to the extent possible. The ResSim model data set 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 2017 level of Basin water resource development.

3. The ResSim model utilizes a consistent set of reservoir regulation criteria throughout the period (1930-2020).

As referenced previously, refinements to criteria have been made during the period of actual System 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 occurred. 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.

3. The models are not capable of fully predicting runoff from plains 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.

The ResSim model uses scripted rule curves to model operations of the six Mainstem reservoirs. The criteria incorporated in the ResSim model reflect current regulation based on the 2018 Master Manual to the extent possible. There are limitations when comparing the results of the ResSim model with observed annual peak reservoir releases and pool data. The ResSim model rule curves cannot account for any changes or adjustments from typical operations that are made during actual regulation and those adjustments, in real-time, such as releases, may impact other reservoirs in the System. For example, releases at Gavins Point can directly affect the releases at Fort Randall, Big Bend and Oahe and hence their pool elevations. This can occur during flooding and non-flooding years.

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 regulation studies. As noted, the ResSim model utilized the rule curves established in the 2018 Master Manual against the continuous long-term record (1930-2020).

The large runoff events of 1975, 1997, 2011, and 2019 proved difficult for the ResSim model to exactly match actual pool elevations and releases while still effectively modeling more normal events at the projects. Actual operations during 1975, 1997, 2011, and 2019, did not follow the model rule curves exactly (e.g., surcharging reservoirs, maximum project releases). In order to reflect actual operation of the projects during significant high inflow events, data from 1975, 1997, 2011, and 2019 were replaced with observed data for all six projects from those same years.

Two data sets were used to determine the pool-probability relationships: 1) a graphical analysis of the 91 years (1930-2020) of simulated maximum daily pool elevations from the ResSim model (that includes observed data from 1975, 1997, 2011, and 2019) and 2) a graphical analysis of the 54 years (1967-2020) since the System first filled of observed maximum daily pool elevations based on the historical rank. In this report, the analysis based on the ResSim model is also referred to as "Simulated", while the analysis based on the 54 years of observed record is referred to as "Observed". Each graphical analysis was based on the Weibull plotting position formula. For the release-probability relationships, computed probability, expected probability and confidence limit relationships were created for both data sets using the HEC's Statistical Software Package (HEC-SSP 2.2). These relationships were then compared with the adopted pool-probability relationships from the 2013 study to obtain the adopted relationships for this study update.

For the 2013 study, in an effort to better approximate the percent chance of exceedance for the 2011 event, the post-2011 flood analysis, *Frequencies of the Upper Missouri Basin Runoff in 2011* was used. This analysis developed the runoff volume probabilities for both the annual, and the March through July period, for the Missouri River basin upstream of Sioux City, IA. The period of record used for the analysis was 1881 and 1898-2011. The runoff volume probability relationships were updated for the MRBWM Technical Report, *Missouri River Mainstem Reservoir System, Hydrologic Statistics on Inflows,* dated December 2020 and included runoff data from 1881 and 1898-2019. The 2019 runoff volume upstream of Sioux City, IA was 60.9 MAF, just 0.1 MAF less than the record 2011 volume. The result of the annual runoff volume analysis was an increase in the probability of the runoff volumes similar to the 2011 and 2019 volumes. The probability for the 2011 annual runoff volume changed from a range of 0.2 to 0.1 percent (500- to 1000-year recurrence interval) to 0.5 to 0.2 percent (200- to 500-year recurrence interval). The probability for the 2011 March to July runoff volume did not change in the update and still falls within the range of 0.2 to 0.1 percent. The updated runoff volume-probabilities are tabulated in Appendix E of the *Missouri River Mainstem Reservoir System, Hydrologic Statistics on Inflows* report and are included in this report as Appendix B for reference.

III. MAINSTEM RESERVOIR SYSTEM REGULATION

Regulation of the System follows a repetitive annual cycle. Winter snowfall in the mountains and plains regions, accompanied with spring and summer rains, produce most of the year's water supply. Runoff from March through July usually results in rising pools and increasing storage accumulation through early July. Approximately 75 percent of the annual runoff into the System occurs during this 5-month (March-July) period. After reaching a peak, storage declines until late winter 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. The two primary high inflow 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 projects. During the fall, when power needs diminish, Fort Randall pool is drawn down to increase generation capacity during the winter period when the Fort Randall reservoir is refilled to base of flood control by Oahe and Big Bend peaking-power releases.

The major maintenance period for the mainstem power facilities extends from mid-February through May and from September to mid-November, coinciding with lower energy demand and off-peak energy periods. The exception is Gavins Point where maintenance is normally performed after the end of the navigation season since all three power facilities 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. Winter releases after the close of navigation season are much lower and vary depending on the need to conserve or evacuate System storage volumes, downstream ice conditions permitting. Minimum release restrictions and pool fluctuations for fish spawning management generally occur from April 1 to June 30. Nesting of the threatened piping plover (plover) occurs from early May through August. During this period, special release patterns are made from Garrison, Fort Randall and Gavins Point to avoid flooding nesting sites on low-lying sandbars and islands downstream from these projects. Flow operations for the interior least tern (tern), are similar to operations for the piping plover, but are not required anymore since the tern was delisted in February 2021.

Overall, the general regulation principles presented above provide the backbone philosophy for System regulation. Additional information and specific technical criteria can be found in the Master Manual. Detailed operation plans are developed, followed, and adjusted as conditions warrant as the System is monitored day-to-day. Beginning in 1953, projected operation of the 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 plans are prepared by MRBWM. A discussion of the specific System regulation requirements for a few of the more significant runoff years is presented in Chapter XI.

IV. FORT PECK

A. 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 System filled in June 1967 that the records reflected current System operations. During the period 1967-2020, the pool elevation has ranged from a low of 2196.2 feet in March 2007 to a maximum of 2252.3 feet in June 2011, a range of over 56 feet. The average annual pool elevation is 2230.5 feet, with a standard deviation of 12.7 feet. Daily releases from Fort Peck have ranged from a low of 0 cfs in April 1978 to a high of 65,900 cfs in June 2011. Average annual daily releases are 9,200 cfs since 1967, with a standard deviation of 2,800 cfs. ***Plate 2*** shows the Fort Peck daily pool elevations and releases for the period since the System has filled. Daily maximum, minimum and mean values of pool elevations and releases for each month are listed in ***Table 2***.

Table 2
Fort Peck Pool and Release Historical Records (1967-2020)

Month	Pool Elevation (feet)			Daily Release (cfs)		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean
Jan	2245.1	2197.5	2228.6	15,600	4,200	10,400
Feb	2244.4	2196.3	2227.7	15,500	4,100	10,600
Mar	2246.2	2196.2	2227.9	15,600	1,000	7,700
Apr	2247.3	2197.5	2229.1	25,100	0	7,300
May	2248.9	2198.4	2230.2	28,900	2,800	9,100
Jun	2252.3	2199.7	2232.6	65,900	3,000	10,500
Jul	2251.6	2202.3	2233.9	49,900	3,000	10,600
Aug	2250.1	2200.9	2233.0	35,200	3,800	10,200
Sep	2248.5	2,199.8	2231.9	25,200	2,700	9,000
Oct	2248.0	2199.7	2231.3	21,800	2,700	7,900
Nov	2246.3	2199.8	2230.7	22,300	2,700	8,200
Dec	2245.4	2198.9	2229.8	16,000	4,000	9,300
Annual	**2252.3**	**2196.2**	**2230.5**	**65,900**	**0**	**9,200**

B. Pool- and Release-Duration Relationships

Pool-duration and release-duration relationships were developed for both the historically observed (1967-2020) and the ResSim model (1930-2020) using HEC-SSP. Data for the ResSim model duration relationships were used for all years except 1975, 1997, 2011, and 2019 where observed elevations and releases were used to eliminate the influence of modeled outliers. ***Plate 3*** shows the pool-duration relationship for Fort Peck, while ***Plate 4*** shows the release-duration relationship. Both ***Plate 3*** and ***Plate 4*** show the simulated data along with the observed data. ***Table 3*** shows the observed pool elevations and releases for various percentages of time in which the values are equaled or exceeded for annual and seasonal (May-Aug) conditions. ***Plate 5*** and ***Plate 6*** show the seasonal May-August pool duration and release duration plots for Fort Peck. As mentioned in the Introduction, the May-August time period was selected because it is the period where regulation decisions most impact the threatened and endangered species that nest in the reservoirs and river reaches of the Missouri River.

Table 3
Fort Peck Pool- and Release-Duration Relationships
Daily Observed (1967-2020)

Percent of Time Equaled or Exceeded	Pool Elevation (feet)		Release (cfs)	
	Annual	May – Aug	Annual	May – Aug
Maximum	2252.3	2252.3	65,900	65,900
1	2248.8	2250.2	24,500	35,000
5	2245.8	2247.7	14,900	16,100
10	2243.6	2246.3	14,200	14,600
20	2240.4	2243.9	12,200	12,700
50	2235.6	2237.0	8,400	8,700
80	2218.9	2220.0	6,000	6,900
90	2209.5	2211.5	4,900	6,200
95	2202.1	2203.4	4,200	5,800
99	2198.5	2299.3	3,100	4,300
100	2196.2	2198.4	0	2,800

C. Pool-Probability Relationship

The maximum Fort Peck pool elevation of 2252.3 feet was recorded in June 2011. In this analysis, the 2011 pool elevation for the ResSim and observed data were plotted at approximately 0.7 percent chance of exceedance (140-year return period). The 0.7 percent chance of exceedance probability represents the historical record back to the 1881 flood event, creating a longer period of record. The 1975 pool elevation was plotted at the 1.4 percent chance exceedance probability as the second highest pool elevation in 140 years. Extrapolation of the eye-fit curve between the observed and simulated data indicates a reasonable pool-probability relationship. There was no change from the 2013 adopted Fort Peck pool-probability relationships. Results are shown in ***Table 4*** and on ***Plate*** *7*.

Table 4
Fort Peck Pool-Probability Relationship
Pool Elevations in feet

Percent Chance Exceedance	1999 Study	2013 Study	Observed (1967-2020)	Simulated (1930-2020*)	Adopted
50	2241.5	2240.0	2239.5	2238.0	**2240.0**
20	2246.5	2246.5	2246.5	2246.0	**2246.5**
10	2249.0	2249.0	2249.0	2247.7	**2249.0**
2	2251.0	2252.0	2251.3	2250.9	**2252.0**
1	2252.0	2252.5	2252.0	2252.1	**2252.5**
0.2	2253.0	2253.0	2253.0**	2253.0**	**2253.0**

* To eliminate the influence of modeled outliers, observed elevations were used in 1975, 1997, 2011, and 2019.
**Extrapolated: Maximum observed is 2252.3 feet

D. Release-Probability Relationship

The 5-month (March-July) inflow volume of the 2011 event at Fort Peck was approximately a 0.5 percent chance of exceedance event (200-year return period), based on Fort Peck inflow volume-duration probability relationships developed by MRBWM in the *Missouri River Mainstem Reservoir System, Hydrologic Statistics on Inflows,* technical report dated December 2020. For the Garrison reach, the 5-month runoff volume from March to July, 2011 for the upper basin was estimated to have a recurrence interval of greater than a 500 year event, so the Garrison peak release for 2011 was plotted as a 0.2 percent chance exceedance event. While the inflow volume to Fort Peck was only a 0.5 percent chance exceedance event, releases from the dam were affected by what was occurring downstream at Garrison and the other reservoirs. Fort Peck releases during the 2011 flood were adjusted to accommodate the larger downstream flood including utilizing all its available flood storage and surcharging the reservoir. The holding back of flood waters in Fort Peck reservoir likely increased the magnitude of the later evacuation releases. Therefore, the 2011 release of 65,900 cfs was plotted at the 0.2 percent chance of exceedance (500-year return period). Also, the maximum release for the 1881 design flood routing for Fort Peck was 25,000 cfs. The maximum release for the 1975 event was 35,400 cfs which was plotted as the second highest event in 140 years. This represents the historical record back to the 1881 flood event, creating a longer period of record.

Both the observed and simulated data indicated a relatively flat curve near the full powerplant discharge capacity of approximately 14,000 cfs between the 20 to 50 percent chance of exceedance. The Fort Peck release-probability relationship uses the powerplant capacity for the 50 percent chance of exceedance. From the 0.2 to 20 percent chance of exceedance, the curve closely matches the expected probability curve for the observed data. This relationship defines the adopted Fort Peck release-probability relationship. Results are shown in ***Table 5*** and on ***Plate 8***. ResSim model and observed data are shown on ***Plate 9*** and ***Plate 10***, respectively.

Table 5
Fort Peck Release-Probability Relationships
Discharges in cfs

Percent Chance Exceedance	1999 Study	2013 Study	Observed (1967-2020)	Simulated (1930-2020*)	Adopted
50	15,000	15,000	12,400	11,700	**14,000**
20	17,000	17,000	17,000	16,100	**17,000**
10	22,000	25,000	21,000	20,000	**21,000**
2	29,000	48,000	33,000	32,500	**34,000**
1	35,000	60,000	39,000	40,000	**42,000**
0.2	50,000	95,000**	59,000	62,500	**65,900**

* To eliminate the influence of modeled outliers, observed releases were used in 1975, 1997, 2011, and 2019.
** Extrapolated: Maximum observed is 65,900 cfs, June 2011.

V. GARRISON

A. 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 System filled in June 1967 that the records reflected current System operations. During the period 1967-2020, the pool elevation has ranged from a low of 1805.8 feet in May 2005 to a maximum of 1854.8 feet in July 1975, a range of almost 50 feet. The average annual pool elevation since 1967 is 1835.7 feet, with a standard deviation of 10.0 feet. Daily releases from Garrison have ranged from a low of 0 cfs in March 2009 to a high of 150,600 cfs in June 2011. Average annual daily releases are 22,200 cfs since 1967, with a standard deviation of 6,800 cfs. ***Plate 11*** shows the observed Garrison daily pool elevations and releases since the 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 and Release Historical Records (1967-2020)

Month	Pool Elevation (feet)			Daily Release (cfs)		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean
Jan	1845.3	1807.0	1833.4	34,200	12,500	22,200
Feb	1843.6	1806.6	1832.1	36,000	11,000	23,300
Mar	1847.9	1806.9	1832.2	37,800	0	19,000
Apr	1847.7	1806.6	1833.7	39,100	5,000	19,100
May	1853.3	1805.8	1834.4	85,500	9,100	22,200
Jun	1854.5	1809.1	1837.6	150,600	9,500	25,700
Jul	1854.8	1815.2	1840.5	141,700	9,500	27,000
Aug	1854.6	1811.9	1839.7	110,300	12,100	25,900
Sep	1851.3	1809.5	1838.0	61,600	6,000	21,600
Oct	1848.2	1809.3	1837.0	49,700	9,200	19,400
Nov	1847.4	1808.9	1836.2	50,100	9,300	20,000
Dec	1846.8	1807.8	1834.9	39,100	11,300	19,600
Annual	**1854.8**	**1805.8**	**1835.7**	**150,600**	**0**	**22,000**

B. Pool- and Release-Duration Relationships

Pool-duration and release-duration relationships were developed for both the historically observed (1967-2020) and the ResSim model (1930-2020) using HEC-SSP. Data for the ResSim model were used for all years except 1975, 1997, 2011, and 2019 where observed elevations and releases were used to eliminate the influence of modeled outliers. ***Plate 12*** shows the Garrison pool-duration relationship, while ***Plate 13*** shows the release-duration relationship. Both ***Plate 12*** and ***Plate 13*** show the simulated data and the observed data. ***Table 7*** shows the observed pool elevations and releases for various percentages of time in which the values are equaled or exceeded for annual and seasonal (May-Aug) conditions. ***Plate 14*** and ***Plate 15*** show the seasonal May-August pool duration and release duration plots, respectively.

Table 7
Garrison Pool & Release Duration Characteristics
Daily Observed (1967-2020)

Percent of Time Equaled or Exceeded	Pool Elevation (feet)		Release (cfs)	
	Annual	May-Aug	Annual	May-Aug
Maximum	1854.8	1854.8	150,600	150,600
1	1852.1	1853.9	58,100	104,600
5	1848.6	1850.9	37,500	46,300
10	1846.8	1849.1	31,800	37,900
20	1844.3	1847.3	27,300	30,000
50	1839.0	1841.2	20,100	21,000
80	1826.4	1828.3	15,000	16,200
90	1819.3	1820.6	12,800	14,900
95	1813.4	1815.7	11,000	13,600
99	1807.9	1809.1	9,900	10,300
100	1805.8	1805.8	0	9,100

C. Pool-Probability Relationship

The maximum Garrison pool elevation recorded was 1854.8 feet in July 1975. In July 2011, the second highest pool of record occurred at elevation 1854.6 feet. In this analysis, the 1975 pool elevation for the simulated and observed data were both plotted at approximately 0.7 percent chance of exceedance (140-year return period). The 0.7 percent chance of exceedance probability represents the historical record back to the 1881 flood event, creating a longer period of record. The 2011 pool elevation was plotted at the 1.4 percent chance exceedance probability as the second highest pool elevation in 140 years. The addition of 9 more years of observed data (2012-2020) did not appreciable change the Garrison pool-probability relationship from the 2013 Study and was adopted as the current relationship with the exception of the 50 percent chance exceedance value which was increased to match the observed data. Results of this analysis are shown in ***Table 8*** and ***Plate 16***.

Table 8
Garrison Pool-Probability Relationship
Pool Elevations in feet

Percent Chance Exceedance	1999 Study	2013 Study	Observed (1967-2020)	Simulated (1930-2020*)	Adopted
50	1848.0	1845.0	1845.3	1842.5	**1845.3**
20	1850.5	1850.5	1850.5	1848.5	**1850.5**
10	1852.0	1852.0	1852.0	1851.0	**1852.0**
2	1854.0	1854.0	1854.0	1853.8	**1854.0**
1	1854.5	1854.5	1854.5	1854.5	**1854.5**
0.2	1855.5	1855.5	1855.5**	1855.5**	**1855.5**

* To eliminate the influence of modeled outliers, observed elevations were used in 1975, 1997, 2011, and 2019.
** Extrapolated: Max observed is 1854.8 feet

D. Release-Probability Relationship

During June 2011 the maximum release from Garrison was 150,600 cfs. Since this release greatly exceeded the previous maximum release of 65,200 cfs in 1975, the plotting position was based on the estimate of the frequency of the 2011 March-July runoff volume. As noted earlier in the Fort Peck discussion and described in the December 2020 MRBWM technical report, *Missouri River Mainstem Reservoir System, Hydrologic Statistics on Inflows,* the 5-month runoff volume from March to July was estimated to have a recurrence interval of greater than a 500-year event. Therefore, a 0.2 percent chance of exceedance event was used as the plotting position for the 2011 maximum release from Garrison. Also, the maximum release for the 1881 design flood routing of 90,000 cfs was plotted as the second highest event in 140 years. Inclusion of these two extreme events creates a better estimation of expected releases between the 1 and 0.2 percent chance of exceedance.

Both observed and simulated data sets indicate a flat curve at a discharge of approximately 40,000 cfs (near the full powerplant capacity discharge) in the range of 10 to 20 percent chance of exceedance. The simulated data shows a distinct breakpoint occurring around the 10 percent chance exceedance range, then flattening again at approximately 50,000 cfs. The adopted Garrison release-probability relationship was based on the expected probability results from HEC-SSP analysis of the observed data between the 0.5 to 50 percent chance of exceedance, followed by a straight line fit to the 0.2 percent chance of exceedance. Results are shown in ***Table 9*** and ***Plate 17***. The ResSim model and observed data are shown on ***Plate 18*** and ***Plate 19***, respectively.

Since the release in 2011 from Garrison was the driving factor in the corresponding releases for the other four downstream reservoirs, the 0.2 percent chance exceedance was assigned to the 2011 event for the development of the remaining release probability relationships.

Table 9
Garrison Release-Probability Relationships
Discharge in cfs

Percent Chance Exceedance	1999 Study	2013 Study	Observed (1967-2020)	Simulated (1930-2020*)	Adopted
50	39,000	39,000	30,000	26,500	**30,000**
20	42,000	42,000	40,000	36,000	**40,000**
10	45,000	48,000	49,000	45,000	**49,000**
2	68,000	72,000	77,000	72,000	**77,000**
1	76,000	85,000	93,000	87,000	**93,000**
0.2	90,000	150,000	150,000	150,000	**150,000**

* To eliminate the influence of modeled outliers, observed releases were used in 1975, 1997, 2011, and 2019.

VI. OAHE

A. 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 System filled in June 1967 that the records reflected System operations. During the period of 1967-2020, the pool elevation has ranged from a low of 1570.2 feet in August 2006 to a maximum of 1619.7 feet in June 2011, a range of almost 50 feet. The average annual pool elevation since 1967 is 1602.7 feet, with a standard deviation of 10.8 feet. Daily releases from Oahe have ranged from a low of 0 cfs during many years to a high of 160,300 cfs in June 2011. Average annual daily releases are 24,600 cfs since 1967, with a standard deviation of 8,300 cfs. ***Plate 20*** shows the daily pool elevations and releases from Oahe for the period since the System filled. Daily maximum, minimum and mean values of pool elevation and releases for each month are listed in ***Table 10***.

Table 10
Oahe Pool and Release Historical Records (1967-2020)

Month	Pool Elevation (feet)			Daily Release (cfs)		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean
Jan	1610.0	1572.8	1599.4	54,000	800	21,100
Feb	1611.2	1571.9	1600.5	45,600	0	18,400
Mar	1617.9	1572.3	1602.5	57,400	0	18,300
Apr	1618.4	1573.5	1604.3	59,100	0	21,500
May	1618.8	1574.8	1605.2	86,300	0	22,500
Jun	1619.7	1575.8	1605.9	160,300	0	27,300
Jul	1619.6	1573.4	1605.9	150,500	0	31,600
Aug	1618.3	1570.2	1604.6	135,100	0	34,000
Sep	1617.5	1570.3	1602.8	80,500	200	30,300
Oct	1616.9	1571.4	1601.3	65,000	0	24,800
Nov	1615.9	1572.7	1600.3	65,500	0	23,700
Dec	1612.5	1572.8	1599.7	64,900	0	20,700
Annual	**1619.7**	**1570.2**	**1602.7**	**160,300**	**0**	**24,600**

B. Pool- and Release-Duration Relationships

Pool-duration and release-duration relationships were developed for both the historically observed (1967-2020) and the ResSim model (1930-2020) using HEC-SSP. Data for the ResSim model were used for all years except 1975, 1997, 2011, and 2019 where observed elevations and releases were used to eliminate the influence of modeled outliers. ***Plate 21*** shows the pool-duration relationship for Oahe, while ***Plate 22*** shows the release-duration relationship. Both ***Plate 21*** and ***Plate 22*** show the simulated data and the observed data. ***Table 11*** shows the observed pool elevations and releases for various percentages of time in which the values are equaled or exceeded for annual and seasonal (May-August) conditions. ***Plate 23*** and ***Plate 24*** show the seasonal May-August pool-duration and release-duration relationship plots, respectively.

Table 11
Oahe Pool- and Release-Duration Relationships
Daily Observed (1967-2020)

Percent of Time Equaled or Exceeded	Pool Elevation (feet)		Release (cfs)	
	Annual	May-Aug	Annual	May-Aug
Maximum	1619.7	1619.7	160,300	160,300
1	1618.0	1618.5	59,800	130,100
5	1616.4	1617.6	47,300	52,300
10	1614.7	1616.8	40,900	45,200
20	1611.4	1615.3	33,700	37,300
50	1606.5	1609.5	23,100	27,300
80	1592.6	1594.2	13,700	17,500
90	1583.8	1587.4	9,200	11,200
95	1577.1	1577.9	5,600	7,000
99	1572.9	1574.0	1,300	1,000
100	1570.2	1570.2	0	0

C. Pool-Probability Relationship

The maximum Oahe pool elevation recorded was 1619.7 feet during June 2011. In this analysis, the 2011 pool elevation for the simulated and observed data were both plotted at approximately 0.7 percent chance of exceedance (140-year return period). The 0.7 percent chance of exceedance probability represents the historical record back to the 1881 flood event, creating a longer period of record. The adopted Oahe pool-probability relationship follows the 2013 study closely for both the observed and simulated data, with the exception of the 10.0 percent chance of exceedance, which was adjusted upward. Results of this analysis are shown in ***Table 12*** and on ***Plate 25***.

Table 12
Oahe Pool-Probability Relationship
Pool Elevations in feet

Percent Chance Exceedance	1999 Study	2013 Study	Observed (1967-2020)	Simulated (1930-2020*)	Adopted
50	1613.0	1613.0	1611.2	1611.0	**1613.0**
20	1617.0	1617.0	1617.4	1618.0	**1617.0**
10	1618.1	1618.1	1618.5	1619.3	**1618.5**
2	1619.5	1619.5	1619.5	1619.5	**1619.5**
1	1620.0	1620.0	1619.7	1619.7	**1620.0**
0.2	1621.0	1621.0	1621.0**	1620.5**	**1621.0**

* To eliminate the influence of modeled outliers, observed elevations were used in 1975, 1997, 2011, and 2019.
** Extrapolated: Maximum observed is 1619.7 feet.

D. Release-Probability Relationship

During June 2011, the maximum release from Oahe was 160,300 cfs. Since this release greatly exceeds any previous maximum release, the plotting position was based on the estimate of the frequency of the 2011 March-July runoff volume. As described in the December 2020 MRBWM technical report, *Missouri River Mainstem Reservoir System, Hydrologic Statistics on Inflows*, the 5-month runoff volume from March through July was estimated to have a recurrence interval of greater than 500 years. Therefore, a 0.2 percent chance of exceedance event was used as the plotting position for the 2011 maximum release from Oahe. Also, the maximum release for the 1881 design flood routing of 90,000 cfs was plotted as the second highest event in 140 years. Inclusion of these two extreme events creates a better estimation of expected releases between the 1 and 0.2 percent chance of exceedance.

Since Oahe is considered a "peaking" powerplant, daily releases are not necessarily representative of the maximum releases for the more frequent events. The listed powerplant capacity for Oahe is 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. The change in hourly discharge normally varies between 30,000 to 40,000 cfs but can be as high as 58,000 cfs through the powerhouse – well above the daily average release. It is not likely that releases greater than powerplant capacity would be made at Oahe unless required for flood evacuation of storage or to prevent overtopping of the spillway tainter gates. Once the average daily releases are in excess of the powerplant capacity, hourly peaking is no longer occurring.

For this study, records of maximum hourly releases were available for the period of 1976-2020. These records indicated that the lowest maximum hourly release of 42,500 cfs occurred in 2016 and the highest maximum hourly release of 160,500 cfs occurred in 2011. Also, for that 45-year period, 28 of the annual hourly peaks exceeded 56,000 cfs. A graphical analysis of annual maximum hourly releases was used to incorporate the hourly peak release-probability relationship with the release-probability relationship based on the annual maximum daily releases.

The adopted relationship follows the 2013 Oahe release-probability relationship with the exception of the 2 percent chance of exceedance which was increased slightly to better fit the observed data. The results of this analysis are shown in ***Table 13*** and ***Plate 26***. The ResSim model and observed data are shown on ***Plate 27*** and ***Plate 28***, respectively.

Table 13
Oahe Release-Probability Relationships
Discharge in cfs

Percent Chance Exceedance	1999 Study	2013 Study	Observed (1967-2020)	Simulated (1930-2020*)	Adopted
50	56,000	56,000	43,000	48,500	**56,000**
20	57,000	57,000	53,000	61,000	**57,000**
10	57,500	57,500	61,000	69,000	**57,500**
2	65,000	70,000	83,000	90,000	**72,000**
1	70,000	90,000	95,000	100,000	**90,000**
0.2	85,000	160,000	160,000	160,000	**160,000**

* To eliminate the influence of modeled outliers, observed releases were used in 1975, 1997, 2011, and 2019.

VII. BIG BEND

A. 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 System filled in June of 1967 that the records reflected System operations. During the period of 1967-2020, the pool elevation has ranged from a low of 1414.7 feet in September 1967 to a maximum of 1422.1 feet in June 1991, a range of about 7 feet. The average annual pool elevation since 1967 is 1420.4 feet, with a standard deviation of 0.2 foot. Daily releases from Big Bend have ranged from a low of 0 cfs during most years to a high of 166,300 cfs in June 2011. Average annual daily releases are 24,000 cfs since 1967 with a standard deviation of 8,400 cfs. ***Plate 29*** shows the observed daily pool elevations and releases from Big Bend for the period since the 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 and Release Historical Records (1967-2020)

Month	Pool Elevation (feet)			Daily Release (cfs)		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean
Jan	1421.7	1419.0	1420.5	56,500	0	20,600
Feb	1421.5	1419.4	1420.5	57,300	0	18,300
Mar	1421.6	1417.8	1420.4	69,200	0	18,900
Apr	1421.9	1417.7	1420.4	68,000	0	21,400
May	1421.8	1417.4	1420.4	83,900	0	22,500
Jun	1422.1	1417.9	1420.3	166,300	0	27,000
Jul	1421.2	1418.7	1420.3	155,000	0	30,200
Aug	1421.5	1417.8	1420.2	131,000	0	32,600
Sep	1421.8	1414.7	1420.3	74,500	0	29,200
Oct	1421.7	1414.9	1420.4	65,700	0	23,900
Nov	1421.5	1418.8	1420.4	65,800	0	23,100
Dec	1421.5	1418.1	1420.4	61,500	0	20,100
Annual	**1422.1**	**1414.7**	**1420.4**	**166,300**	**0**	**24,000**

B. Pool- and Release-Duration Relationships

Pool-duration and release-duration relationships were developed for both the historically observed (1967-2020) and the ResSim model (1930-2020) using HEC-SSP. ***Plate 30*** shows pool-duration relationships, while ***Plate 31*** shows the release-duration relationship. Both ***Plate 30*** and ***Plate 31*** show the simulated and the observed data. ***Table 15*** shows the observed pool elevations and releases for various percentages of time in which the values are equaled or exceeded for annual and seasonal (May-August) conditions. ***Plate 32*** and ***Plate 33*** show the seasonal May-August pool-duration and release-duration relationships, respectively.

Table 15
Big Bend Pool- and Release-Duration Relationship
Daily Observed (1967-2020)

Percent of Time Equaled or Exceeded	Pool Elevation (feet)		Release (cfs)	
	Annual	May-Aug	Annual	May-Aug
Maximum	1422.1	1422.1	166,300	166,300
1	1421.2	1421.2	60,900	125,600
5	1421.0	1421.0	49,000	52,300
10	1420.9	1420.9	42,600	46,800
20	1420.7	1420.7	34,900	39,300
50	1420.4	1420.3	23,300	27,600
80	1420.1	1420.0	10,600	13,100
90	1419.9	1419.8	4,500	6,900
95	1419.7	1419.5	1,000	2,500
99	1419.1	1419.0	0	0
100	1414.7	1417.4	0	0

C. Pool-Probability Relationship

Annual maximum pool elevations at Big Bend have fluctuated only 1.7 feet during the period of 1967-2020, with the maximum pool recorded of 1422.1 feet in 1991. The maximum pool occurred in June 1991 after a heavy rainfall event between Pierre and Big Bend. In this analysis, the 1991 pool elevation of 1422.1 feet was plotted at approximately 0.7 percent chance of exceedance (140-year return period). The 0.7 percent chance of exceedance probability represents the historical record back to the 1881 flood event, creating a longer period of record. In the 1976 study, it was assumed that the 1 percent chance exceedance pool elevation would be the maximum operating pool at elevation 1423.0 feet. The 1999 Big Bend pool-probability relationship was based on the observed relationship transitioning through an assumed 0.2 percent chance of exceedance pool near the maximum operating pool elevation. This relationship was retained as the adopted Big Bend pool-probability relationship. Results of this analysis are shown in ***Table 16*** and ***Plate 34***. It should be noted that Big Bend is considered a re-regulation project, is operated to follow power-peaking requirements, and generally the pool elevations are maintained in the range from 1420.0-1421.0 feet.

Table 16
Big Bend Pool-Probability Relationship
Pool Elevations in feet

Percent Chance Exceedance	1999 Study	2013 Study	Observed (1967-2020)	Simulated (1930-2020*)	Adopted
50	1421.3	1421.3	1421.3	1421.2	**1421.3**
20	1421.5	1421.5	1421.5	1421.3	**1421.5**
10	1421.8	1421.8	1421.7	1421.5	**1421.8**
2	1422.2	1422.2	1422.0	1421.9	**1422.2**
1	1422.4	1422.4	1422.1	1422.0	**1422.4**
0.2	1423.0	1423.0	1422.6**	1422.2**	**1423.0**

*To eliminate the influence of modeled outliers, observed releases were used in 1975, 1997, 2011, and 2019.
** Extrapolated: Maximum observed is 1422.1 feet.

D. Release-Probability Relationship

Since Big Bend is operated as a "peaking" powerplant, daily releases are not representative of the maximum releases. For this study, records of maximum hourly releases were obtained for the period of 1976-2020. These records indicated that the lowest maximum hourly release of 85,700 cfs occurred in 2009 and the highest maximum hourly release of 187,700 cfs occurred in 2011. Graphical analysis of maximum hourly releases was used to develop the adopted Big Bend hourly peak release-probability relationship.

During June 2011, the maximum average daily release from Big Bend was 166,300 cfs. Since this release greatly exceeded the previous maximum release, the plotting position was based on the estimate of the frequency of the 2011 March-July runoff volume. As described in the December 2020 MRBWM technical report, *Missouri River Mainstem Reservoir System, Hydrologic Statistics on Inflows*, the 5-month runoff volume from March to July was estimated to have a recurrence interval close to 500 years. Therefore, a 0.2 percent chance of exceedance event was used as the plotting position for the 2011 maximum release from Big Bend. Also, the maximum average daily release for the 1881 design flood routing of 100,000 cfs was plotted as the second highest event in 140 years. Inclusion of these two extreme events creates a better estimation of expected releases between the 1 and 0.2 percent chance of exceedance. The adopted Big Bend release-probability relationship was best fit to the observed and historical data. Results of this analysis are shown in ***Table 17*** and ***Plate 35***. The ResSim model and observed data are shown on ***Plate 36*** and ***Plate 37***, respectively.

Table 17
Big Bend Release-Probability Relationship
Discharge in cfs

Percent Chance Exceedance	1999 Study Average Daily	2013 Study Average Daily	2013 Study Peak Hourly	Observed (1967-2020)	Adopted Peak Hourly	Adopted Average Daily
50	55,000	55,000	103,000	51,000	**103,000**	**55,000**
20	61,000	61,000	105,000	64,000	**105,000**	**61,000**
10	65,000	65,000	107,000	73,000	**107,000**	**67,000**
2	72,000	80,000	109,000	94,000	**109,000**	**83,000**
1	75,000	90,000	120,000	104,000	**120,000**	**95,000**
0.2	80,000	160,000	190,000	160,000	**190,000**	**160,000**

VIII. FORT RANDALL

A. 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 System filled in June of 1967 that the records reflected System operations. During the period of 1967-2020, the pool elevation has ranged from a low of 1317.9 feet in December 1968 to a maximum of 1374.0 feet in July 2011, a range of over 56 feet. Since 1971, the pool has been drawn down to 1337.5 feet each fall to maximize winter-time hydropower generation, making the range approximately 36.5 feet. Prior to 1971, the annual fall drawdown was to 1320.0 feet. The average annual pool elevation since 1967 is 1351.1 feet, with a standard deviation of 2.2 feet. Daily releases from Fort Randall have ranged from a low of 0 cfs during May 1995 to a high of 160,000 cfs in July 2011. Average annual daily releases are 25,600 cfs since 1967, with a standard deviation of 9,200 cfs. ***Plate 38*** shows the observed daily pool elevations and releases from Fort Randall for the period since the System was first filled. Daily maximum, minimum and mean pool elevations and releases for each month are listed in ***Table 18***.

Table 18
Fort Randall Pool and Release Historical Records (1967-2020)

Month	Pool Elevation (feet)			Daily Release (cfs)		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean
Jan	1351.1	1324.7	1344.0	29,100	4,500	15,600
Feb	1356.4	1338.7	1349.4	34,400	900	13,800
Mar	1366.9	1345.1	1354.5	40,500	0	15,900
Apr	1370.8	1350.8	1356.9	53,000	1,400	22,000
May	1372.2	1349.0	1357.7	76,600	0	25,700
Jun	1373.9	1349.9	1357.7	155,300	500	29,300
Jul	1374.0	1351.9	1357.4	160,000	600	33,300
Aug	1369.3	1350.7	1356.2	149,500	3,100	35,500
Sep	1365.9	1342.3	1353.6	90,200	8,600	35,300
Oct	1358.9	1333.2	1347.4	76,400	3,200	33,200
Nov	1349.9	1318.0	1339.8	76,700	3,200	29,800
Dec	1348.3	1317.9	1339.1	65,800	900	17,600
Annual	**1374.0**	**1317.9**	**1351.2**	**160,000**	**0**	**25,600**

B. Pool- and Release-Duration Relationships

Pool-duration and release-duration relationships were developed for both the historically observed (1967-2020) and the ResSim Model (1930-2020) using HEC-SSP. ***Plate 39*** shows the Fort Randall pool-duration relationship and ***Plate 40*** shows the Fort Randall release-duration relationship. Both ***Plate 39*** and ***Plate 40*** show the simulated and observed data. ***Table 19*** shows the observed pool elevations and releases for various percentages of time in which the values are equaled or exceeded for annual and seasonal (May-August) conditions based on the observed data. ***Plate 41*** and ***Plate 42*** show the seasonal May-August pool-duration and release-duration relationship plots, respectively.

Table 19
Fort Randall Pool- and Release-Duration Relationships
Daily Observed (1967-2020)

Percent of Time Equaled or Exceeded	Pool Elevation (feet)		Release (cfs)	
	Annual	May-Aug	Annual	May-Aug
Maximum	**1374.0**	**1374.0**	**160,000**	**160,000**
1	1367.6	1370.4	68,800	139,100
5	1361.5	1364.3	51,000	55,500
10	1359.2	1362.0	43,300	46,700
20	1356.7	1359.8	33,600	36,800
50	1353.6	1356.1	24,200	28,100
80	1343.5	1354.7	14,000	22,000
90	1339.6	1354.0	10,300	17,600
95	1338.2	1353.4	7,700	12,600
99	1329.6	1351.7	3,000	2,900
100	1317.9	1349.0	0	0

C. Pool-Probability Relationship

During 2011, the Fort Randall pool reached elevation 1374.0 feet, the maximum of record. In this analysis, the 2011 pool elevation for the simulated and observed data were both plotted at approximately 0.7 percent chance of exceedance (140-year return period). The 0.7 percent chance of exceedance probability represents the historical record back to the 1881 flood event, creating a longer period of record. The 1997 pool elevation was plotted at the 1.4 percent chance exceedance probability as the second highest pool elevation in 140 years. Results of the ResSim model indicated low correlation between observed and simulated pools in some ranges. Some of this lack of correlation can be attributed to daily model constraints and parameters. The ResSim model does not utilize this project to maximize downstream flood control to the extent that is done in actual practice. In other words, the ResSim model attempts to remove the flood waters in Fort Randall more quickly than what has been done historically when flood stages downstream are low enough to allow for higher releases from Gavins Point. This affects both pool elevations and releases. Therefore, the adopted relationship was based primarily on an eye-fit of the observed data. There was no change to the pool probability relationship from the 2013 study. Results of this analysis are shown in ***Table 20*** and ***Plate 43***.

Table 20
Fort Randall Pool Probability Relationship
Pool Elevations in feet

Percent Chance Exceedance	1999 Study	2013 Study	Observed (1967-2020)	Simulated (1930-2020*)	Adopted
50	1360.0	1360.0	1360.0	1356.0	**1360.0**
20	1364.0	1364.0	1363.0	1360.0	**1364.0**
10	1366.0	1367.0	1367.0	1368.0	**1367.0**
2	1372.0	1372.0	1372.0	1372.5	**1372.0**
1	1375.0	1374.0	1373.5	1374.0	**1374.0**
0.2	1377.0	1377.0	1377.0**	1377.0**	**1377.0**

* To eliminate the influence of modeled outliers, observed releases were used in 1975, 1997, 2011, and 2019.
** Extrapolated: Maximum observed is 1374.0 feet.

D. Release-Probability Relationship

During 2011, the maximum release from Fort Randall was 160,000 cfs. Since this release greatly exceeded the previous maximum release of 67,500 cfs, made in 1997, the plotting position was based on the estimate of the frequency of the 2011 March-July runoff volume. As described in the December 2020 MRBWM technical report, *Missouri River Mainstem Reservoir System, Hydrologic Statistics on Inflows*, the 5-month runoff volume from March to July was estimated to have a recurrence interval of greater than 500 years. Therefore, a 0.2 percent chance of exceedance event was used for the plotting position for the 2011 maximum release from Fort Randall. Also, the maximum release for the 1881 design flood routing of 100,000 cfs was plotted as the second highest event in 140 years. Inclusion of these two extreme events creates a better estimation of expected releases between the 0.2 and 1 percent chance of exceedance.

The development of the final Fort Randall release probability-relationship was guided by the expected probability relationship produced from the observed data analysis as it best fit the historical data points. Results of this analysis are shown in ***Table 21*** and on ***Plate 44***. ResSim model and observed data are shown on ***Plate 45*** and ***Plate 46***, respectively.

Table 21
Fort Randall Release-Probability Relationship
Discharge in cfs

Percent Chance Exceedance	1999 Study	2013 Study	Observed (1967-2020)	Simulated (1930-2020*)	Adopted
50	41,000	45,000	37,000	46,000	**39,000**
20	50,000	50,000	48,000	59,000	**49,000**
10	55,000	56,000	58,000	68,000	**58,000**
2	69,000	84,000	84,000	91,000	**85,000**
1	85,000	100,000	98,000	102,000	**102,000**
0.2	88,000	160,000	160,000	160,000	**160,000**

* To eliminate the influence of modeled outliers, observed releases were used in 1975, 1997, 2011, and 2019.

IX. GAVINS POINT

A. 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 System filled in June 1967 that the records reflected System operations. During the period of 1967-2020, the pool elevation has ranged from a low of 1199.8 feet in March 1969 to a maximum of 1212.3 feet in March 2019, a range of about 12.5 feet. The average annual pool elevation since 1967 is 1206.8 feet, with a standard deviation of 0.3 feet. Daily releases from Gavins Point have ranged from a low of 6,000 cfs during April 1969, June 1983, March 1992 and March, April and July 1993 to a high of 160,700 cfs in June 2011. Average annual daily releases are 28,300 cfs since 1967, with a standard deviation of 9,600 cfs. ***Plate 47*** shows the daily pool elevations and releases from Gavins Point for the period since the System was first filled. Daily maximum, minimum and mean values of pool elevations and releases for each month are listed in ***Table 22***.

Table 22
Gavins Point Pool & Release Historical Records (1967-2020)

Month	Pool Elevation (feet)			Daily Release (cfs)		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean
Jan	1208.9	1201.9	1207.3	31,000	7,800	17,700
Feb	1209.2	1203.2	1206.8	38,000	7,500	17,700
Mar	1212.0	1199.8	1205.8	90,500	6,000	20,200
Apr	1208.2	1201.5	1205.9	58,000	6,000	25,700
May	1209.5	1204.2	1205.9	77,000	8,000	29,200
Jun	1209.7	1204.3	1206.0	160,700	6,000	32,400
Jul	1208.9	1204.4	1206.4	160,300	6,000	35,100
Aug	1209.4	1204.7	1206.9	151,800	7,000	36,900
Sep	1208.8	1203.9	1207.4	90,100	14,000	37,000
Oct	1209.2	1206.1	1207.7	80,300	7,600	35,300
Nov	1209.0	1204.5	1207.6	80,100	7,500	32,200
Dec	1209.1	1203.9	1207.4	70,100	8,000	19,800
Annual	**1212.0**	**1199.8**	**1206.8**	**160,700**	**6,000**	**28,300**

B. Pool- and Release-Duration Relationships

Pool-duration and release-duration relationships were developed for both the historically observed (1967-2020) and the ResSim model (1930-2020) using HEC-SSP. ***Plate 48*** and ***Plate 49*** shows the pool-duration and release-duration relationships for Gavins Point, respectively. Both ***Plate 48*** and ***Plate 49*** show the simulated data along with the observed data. ***Table 23*** shows the observed pool elevations and releases for various percentages of time in which the values are equaled or exceeded for annual and seasonal (May-August) conditions. ***Plate 50*** and ***Plate 51*** show the seasonal May-August pool-duration and release-duration relationship plots.

Table 23
Gavins Point Pool- and Release-Duration Relationships
Daily Observed (1967-2020)

Percent of Time Equaled or Exceeded	Pool Elevation (feet)		Release (cfs)	
	Annual	May-Aug	Annual	May-Aug
Maximum	**1212.0**	**1209.7**	**160,700**	**160,700**
1	1208.5	1208.4	75,000	148,200
5	1208.2	1208.0	54,000	60,000
10	1208.1	1207.7	44,400	46,800
20	1207.8	1207.1	35,000	37,100
50	1206.9	1206.3	27,000	30,500
80	1205.8	1205.5	17,000	24,900
90	1205.3	1205.2	14,000	21,000
95	1205.0	1205.0	11,300	17,000
99	1204.5	1204.7	9,000	10,000
100	1199.8	1204.2	6,000	6,000

C. Pool-Probability Relationship

Historically, the observed annual maximum daily pool elevation at Gavins Point has varied 4.3 feet during the period of 1967-2020 with the maximum pool elevation of 1212.3 feet recorded in March 2019. The March 2019 event was a major flood that originated in the incremental drainage area of the Gavins Point reach. The rain on snow event caused the reservoir to fill quickly and the spillway gates were used in a surcharge operation that resulted in the pool rising 2.3 feet above the maximum operating pool of 1210.0 feet. Fort Randall releases were set to zero the day before the event and did not significantly add to the runoff coming into the reservoir. The runoff volume from the event exceeded the reservoir design flood for Gavins Point.

A pool-probability relationship was not derived for Gavins Point in the 1976 study. However, in the 1976 study it was assumed that the 1 percent chance exceedance pool elevation would be 1213.0 feet, based on incremental runoff occurring coincident with a starting Gavins Point pool exceeding elevation 1204.5 feet and Fort Randall releases exceeding 30,000 cfs. The 1999 Gavins Point pool-probability relationship was based on a straight-line connection of the 2 percent pool elevation of 1209.6 feet with the maximum pool elevation of 1211.0 feet assumed to be a 0.2 percent event. This resulted in a 1 percent pool elevation about three feet lower than that assumed in the 1976 study. The major factor influencing the change was the 30 years of operational history with major runoffs. The 1999 Gavins Point pool-probability was adopted for the 2013 study.

In March 2019, a large flood event occurred in the Gavins Point drainage area causing the pool to rise to an elevation of 1212.3 feet. An analysis of the incremental runoff event found in the MRBWM technical report, *Missouri River Mainstem Reservoir System, Hydrologic Statistics on Inflows,* dated December 2020, estimated the observed 1-day incremental inflow to Gavins Point of 120,500 cfs has a recurrence interval of just under 500 years. In this analysis, the maximum pool elevation of 1212.3 feet for the simulated and observed data were plotted at 0.2 percent chance of exceedance (500-year return period) to help better define the curve. As was explained in Section VIII-C for Fort Randall, the ResSim model does not utilize Gavins Point, in conjunction with Fort Randall, to maximize downstream flood control to the extent that is done in actual practice, affecting both the modeled pool elevations and releases. The 2020 Gavins Point pool-probability relationship is based on an eye-fit curve using observed data and has been adopted as the current relationship. Results of this analysis are shown in ***Table 24*** and ***Plate 52***.

Table 24
Gavins Point Pool-Probability Relationship
Pool Elevations in feet

Percent Chance Exceedance	1999 Study	2013 Study	Observed (1967-2020)	Simulated (1930-2020)	Adopted
50	1208.8	1208.8	1208.7	1207.7	**1208.8**
20	1209.0	1209.0	1209.0	1208.2	**1209.0**
10	1209.2	1209.2	1209.2	1209.2	**1209.2**
2	1209.6	1209.6	1209.8	1209.8	**1209.8**
1	1210.0	1210.0	1210.4	1210.4	**1210.4**
0.2	1211.0	1211.0	1212.3	1212.3	**1212.3**

* To eliminate the influence of modeled outliers, observed releases were used in 1975, 1997, 2011, and 2019.

D. Release-Probability Relationship

During June 2011 the maximum daily release from Gavins Point was 160,700 cfs. Since this release greatly exceeded the previous maximum release of 70,100 cfs in October 1997, the plotting position was based on the estimate of the frequency of the 2011 March-July runoff volume. As described in the December 2020 MRBWM technical report, *Missouri River Mainstem Reservoir System, Hydrologic Statistics on Inflows,* the 5-month runoff volume from March to July was estimated to have a recurrence interval of greater than 500 years. Therefore, a 0.2 percent chance of exceedance event was used for the plotting position for the 2011 maximum release from Gavins Point. Also, the maximum release for the 1881 design flood routing of roughly 100,000 cfs was plotted as the second highest event in 140 years. Inclusion of these two extreme events creates a better estimation of expected releases between the 1 and 0.2 percent chance of exceedance.

Table 25
Gavins Point Release-Probability Relationship
Discharge in cfs

Percent Chance Exceedance	1999 Study	2013 Study	Observed (1967-2020)	Simulated (1930-2020)	Adopted
50	38,000	38,000	36,000	43,000	**38,000**
20	47,000	47,000	48,000	55,000	**48,000**
10	54,000	57,000	58,000	64,000	**58,000**
2	72,000	84,000	88,000	86,000	**88,000**
1	80,000	100,000	105,000	97,000	**105,000**
0.2	100,000	160,000	155,000	126,000	**160,000**

* To eliminate the influence of modeled outliers, observed releases were used in 1975, 1997, 2011, and 2019.

X. SUMMARY

This report presented historical data, pool-duration, release-duration, pool-probability and release-probability relationships for pool elevations and releases from the System projects. Pool-probability and release-probability relationships were developed from historical records reflecting actual System regulation for a 54-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 and ***Table 27*** shows the adopted release-probability relationships.

Table 26
Missouri River Mainstem Reservoir System
Adopted Pool-Probability Relationships
Pool Elevations in feet

Project	Percent Chance of Exceedance					
	50	20	10	2	1	0.2
Fort Peck	2240.0	2246.5	2249.0	2252.0	2252.5	2253.0
Garrison	1845.3	1850.5	1852.0	1854.0	1854.5	1855.5
Oahe	1613.0	1617.0	1618.5	1619.5	1620.0	1621.0
Big Bend	1421.3	1421.5	1421.8	1422.2	1422.4	1423.0
Fort Randall	1360.0	1364.0	1367.0	1372.0	1374.0	1377.0
Gavins Point	1208.8	1209.0	1209.2	1209.8	1210.4	1212.3

Table 27
Missouri River Mainstem Reservoir System
Adopted Release-Probability Relationships
Discharge in cfs

Project	Percent Chance of Exceedance					
	50	20	10	2	1	0.2
Fort Peck	14,000	17,000	21,000	34,000	42,000	65,900
Garrison	30,000	40,000	49,000	77,000	93,000	150,000
Oahe	56,000	57,000	57,500	72,000	90,000	160,000
Big Bend	55,000	61,000	67,000	83,000	95,000	160,000
Fort Randall	39,000	49,000	58,000	85,000	102,000	160,000
Gavins Point	38,000	48,000	58,000	88,000	105,000	160,000

XI. SYSTEM REGULATION IN SIGNIFICANT RUNOFF YEARS

This chapter presents a general discussion of specific System regulation requirements for a few of the more significant runoff years. A more detailed discussion on the runoff events and System regulation can be found in the MRBWM's annual *Summary of Actual Regulation* reports or in Appendix A of the Master Manual for events prior to 2018.

A. Regulation of 1975 Runoff

Runoff above Sioux City, IA, during 1975, totaled 35.5 MAF, which ranks as the eleventh highest since mainstem regulation began and the twelfth highest during the period 1898-2020. Over 80 percent of the 1975 runoff originated upstream from Garrison. Upstream from Fort Peck, the 1975 runoff was the second highest on record, totaling 13.8 MAF, exceeded only in 2011 with 14.5 MAF. 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.

In early 1975, conditions indicated that runoff above the reservoirs would be less than normal, due to a below normal 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 June 18-19 centered to the east of the continental divide in Montana where average depths exceeding 10 inches covered a 2,500 square mile area and an area of 10,000 square miles had an average rainfall exceeding 6 inches. Control provided by the reservoirs prevented stages below the System from exceeding flood stage. Consequently, significant damages were prevented and credited to the System.

Gavins Point releases were gradually increased to the full powerplant capacity of 35,000 cfs by the end of May as downstream tributary flows receded. Spillway flows at Gavins Point began the second week of June rising to 60,000 cfs by late July and continuing into December to evacuate the flood waters stored. In October and November, maximum System releases were maintained near 61,000 cfs.

Fort Randall releases generally paralleled those from Gavins Point peaking at 60,500 cfs in September and October. The pool rose to above 1362.0 feet in mid-May and held near that elevation until mid-July before receding through the remainder of the summer and into fall. The maximum pool of 1362.8 feet occurred in July.

At Oahe, the pool steadily rose from mid-February to late August when it reached its maximum pool of 1617.9 feet. After reaching its peak, the pool steadily dropped through the end of November. Average daily releases topped 50,000 cfs starting in mid-July and steadily rose to above 57,000 cfs in August.

The Garrison maximum pool level reached elevation 1854.8 feet in July, which is 0.8 foot into the surcharge zone and remains the maximum level ever reached (1967-2020). The peak daily release was 65,200 cfs and is the second highest on record (1967-2020) for Garrison.

At Fort Peck, the pool reached elevation 2251.6 feet in July, the highest level reached prior to 2011. This elevation is 1.6 feet above the top of the Exclusive Flood Control Zone and into the surcharge zone provided for the control of extraordinary floods. The peak daily release was 35,400 cfs and is the second highest on record (1967-2020) for Fort Peck.

B. Regulation of 1978 Runoff

Above Sioux City, IA, runoff during 1978 totaled 40.6 MAF, the fifth highest on record (1898-2020). On March 22, System storage was 54.0 MAF. System storage increased rapidly at the beginning of the 1978 navigation season, gaining an average of more than 500,000 acre-feet (ac-ft) per day during the remainder of the month. Storage gains continued at a high rate through April as plains 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. As the melting of the heavy snowpack over the plains area caused unprecedented daily System storage gains, Gavins Point releases were gradually increased to the full powerplant capacity of 35,000 cfs by the end of May as downstream tributary flows receded. Spillway flows at Gavins Point began the second week of June and continued into December to evacuate the flood waters stored. In October and November, maximum System releases were maintained near 52,000 cfs. During a four-day period in March, the Gavins Point pool rose from elevation 1204.9 feet to 1209.2 feet, the fourth highest pool elevation on record (1967-2020).

Releases from Fort Randall generally paralleled those from Gavins Point. 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 the Gavins Point reservoir and permit Gavins Point releases to be held to a minimum. The Fort Randall reservoir rose rapidly during the early part of the navigation season to a crest of 1362.5 feet in response to the reduced Fort Randall releases and the high snowmelt runoff. Fort Randall releases were increased to a maximum of 53,200 cfs in October to evacuate the flood storage.

At Oahe, the pool level increased during the spring and summer to its highest peak of the year of 1616.2 feet in mid-July. Oahe releases reached a maximum of 54,300 cfs in September. The Big Bend reservoir was maintained near elevation 1420.0 feet during the entire period.

At the beginning of the period, the Garrison reservoir level was at elevation 1826.0 feet, ten feet lower than one year earlier. Like the other projects, the reservoir level rose rapidly in response to the snowmelt runoff, with an average daily inflow of 150,000 cfs reported on March 27. It continued to rise before cresting at elevation 1849.5 feet on July 25. Releases from Garrison were reduced at the beginning of the navigation season to prevent flooding in the reach downstream of Bismarck, ND as tributary streams crested at near record levels. Releases were gradually increased to full powerplant 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 2230.0 feet in early March. It rose to elevation 2245.0 feet by the end of May and crested at elevation 2249.6 feet on July 20. Fort Peck releases were gradually increased to full powerplant capacity by late July, reaching a maximum of 14,800 cfs in August.

C. Regulation of 1986 Runoff

Runoff during 1986 above Sioux City, IA was 36.2 MAF, the ninth highest on record (1898-2020) and the eighth highest from 1967-2020. 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 reservoirs. Storage gains tapered off during early July, but heavy rains over portions of Montana and North Dakota caused additional gains resulting in a 1986 System storage crest of 65.2 MAF on July 20.

Missouri River flows at Sioux City, IA and all downstream locations exceeded navigation requirements by mid-March and continued to be well above normal during April with near record precipitation. Record or near record April rainfall combined with heavy May rains caused unprecedented runoff in tributaries downstream from Garrison. The combination of high inflows into the reservoirs and low System releases resulted in the Oahe reservoir rising into its Exclusive Flood Control Zone, prompting a gradual increase in Gavins Point releases to 35,000 cfs by mid-May. 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. The Fort Randall reservoir peaked at 1362.0 feet in May. The peak daily release of 45,000 cfs occurred in October.

The Big Bend reservoir was maintained between a minimum elevation of 1419.5 feet and a maximum of 1421.5 feet. At the beginning of March, the Oahe reservoir level was near elevation 1604.0 feet, 3.5 feet below the base of Annual Flood Control and Multiple Use Zone. It reached an elevation of 1618.5 feet on May 16, a record at that time.

To keep the Oahe reservoir from filling higher, Garrison releases were reduced to 10,000 cfs by early May. Garrison releases were maintained at this level until they were gradually increased in early June. The Garrison reservoir rose 4 feet in May, 6 feet in June and 2 feet in July, cresting at elevation 1848.7 feet.

At Fort Peck, the pool was near elevation 2229.1 feet at the beginning of the 1986 navigation season. The pool had been intentionally drawn down below normal levels to provide shoreline re-vegetation for improved fish spawning habitat. The pool refilled to the base of the Annual Flood Control and Multiple Use Zone by the end of June and continued a gradual climb to elevation 2238.3 feet by the end of December.

D. Regulation of 1993 Runoff

During 1993, runoff above Sioux City, IA totaled 36.2 MAF, the tenth highest on record (1898-2020) and ninth highest since System regulation began in 1967. Downstream from Sioux City, IA to the mouth of the Missouri River, runoff during 1993 was an unprecedented 111.8 MAF, which was 255 percent of average. 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, more than 14.0 MAF below the base of the Annual Flood Control and Multiple Use Zone. System storage for the year peaked at 57.2 MAF on September 7. Low System releases to lessen downstream impacts had a significant impact on the accumulation of storage during July through September. The Great Flood of 1993, with its heavy downstream flooding and above-normal upstream inflows, not only ended the 6-year drought but nearly refilled the System to normal levels, a feat that with normal inflows and releases would have taken more than 6 years.

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. The average monthly release for July is still the lowest on record (1967-2020) for Fort Randall for any month. Daily average releases varied between 26,000 cfs in late May and 600 cfs in July. The Fort Randall pool elevation crested at 1361.0 feet at the end of July.

The Big Bend reservoir was maintained between elevations 1420.2 feet and 1421.2 feet. At Oahe, the pool was near elevation 1592.0 feet at the start of the year. It climbed to a crest of 1611.6 feet in September, rising nearly 20 feet and peaked 4.1 feet into the Annual Flood Control and Multiple Use Zone.

Garrison releases were low in 1993 despite the above normal runoff. The average annual daily release was 13,400 cfs. A record at the time that was surpassed during the drought of 2002-2007. The Garrison reservoir rose gradually from elevation 1819.5 feet at the beginning of the navigation season to a peak of 1837.8 feet in November.

The daily releases from Fort Peck averaged 5,700 cfs in 1993. A record at that time that was later surpassed during the drought of the 2000's. The Fort Peck pool elevation crested at 2228.4 feet in September.

E. Regulation of 1995 Runoff

Runoff above Sioux City, IA during 1995 totaled 37.2 MAF, the seventh highest year on record (1898-2020). System storage made its largest gains of the year in June due to the cold and wet spring that caused a month delay in the melt of the mountain snow. System storage peaked at 68.1 MAF on July 27. End-of-July storage was the highest since 1978.

In June releases from Gavins Point were increased to 35,000 cfs, which is full powerplant capacity. This was the first time since 1988 that full powerplant releases were 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. The maximum daily release of 56,100 cfs occurred in November. The Gavins Point reservoir recorded a then record high pool elevation of 1209.5 feet in May. This elevation was within 0.5 foot of overtopping the spillway gates (closed position). At the time, 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 nine days. Releases from Fort Randall were completely shut off on May 30. By June 1, the Fort Randall reservoir rose to a then record elevation of 1367.9 feet. The Fort Randall reservoir elevation gradually decreased, reaching 1338.3 feet 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. These low releases, in conjunction with high inflows, resulted in a then record high Oahe reservoir level of 1618.7 feet on June 25. Oahe releases were increased through the remainder of the summer and into the fall with a maximum daily release of 48,500 cfs in August. Big Bend pool levels were maintained between elevations 1419.4 feet and 1421.8 feet during this period.

During 1995 the Garrison reservoir level increased over 15 feet to elevation 1851.9 feet in August. Releases to evacuate Garrison flood control storage began in August. In September, the maximum daily release of 37,500 cfs was made and releases were maintained near powerplant capacity through the fall.

Fort Peck rose gradually to a peak elevation of 2244.2 feet in August, which is 10.2 feet into the Annual Flood Control and Multiple Use Zone and only 1.8 feet below the base of the Exclusive Flood Control Zone. Releases near powerplant capacity were made through the fall with a maximum daily release of 14,900 cfs in October.

F. Regulation of 1996 Runoff

Runoff in the Missouri River Basin above Sioux City, IA in 1996 was 35.6 MAF, the eleventh highest on record (1898-2020) and very near the total runoff experienced in 1975. Although the runoff was less than in 1993 and 1995, peak stages on the river below the 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. An early and rapid melt of the heavy plains snowpack on frozen ground resulted in a record February runoff in the upper basin, 340 percent of normal. The mountain snowpack continued to accumulate into early May peaking nearly 20 percent above the normal peak accumulation.

System storage climbed to 60.2 MAF by March 1, nearly 3.0 MAF above the base of the Annual Flood Control and Multiple Use Zone. Record releases at the time were made from February to April in order to create adequate space to manage expected high inflows from the plains and mountain snowpack. Gavins Point releases gradually increased to full powerplant capacity by mid-March. Gavins Point spillway flows were initiated in early April, and by early May total Gavins Point releases had reached 45,000 cfs. Between storms in June, releases reached 50,000 cfs and by July 1, they reached 52,000 cfs and generally remained at that rate into the fall. Gavins Point releases increased to 55,000 cfs, the maximum of the year, in early November after tributary flows had declined. The peak System storage of 68.5 MAF occurred on July 7, 0.4 MAF higher than 1995's peak storage.

Releases from Fort Randall generally paralleled those from Gavins Point. Average daily releases during the year varied between 9,100 cfs in late May when System releases were cut back for downstream flood control, to 53,000 cfs in November for flood storage evacuation. The Fort Randall reservoir peaked at 1361.5 feet on June 28, 3.5 feet below the base of the Exclusive Flood Control Zone.

The Oahe pool steadily rose through the early part of the summer as the mountain snowmelt filled the upper reservoirs and System releases were restricted due to downstream flooding. The pool peaked at elevation 1618.7 feet on June 23, nearly identical to 1995's peak elevation, a record 1.7 feet into the Exclusive Flood Control Zone. Flood storage evacuation continued through the fall with releases reaching a maximum of 51,600 cfs in November before being cutback prior to the winter freeze-in.

High inflows during February caused the Garrison reservoir elevation to climb to 1839.6 feet by March 1, 2.1 feet into the Annual Flood Control and Multiple Use Zone. The largest storage gains of the year occurred during June as the snowmelt runoff entered the System. The Garrison reservoir peaked at elevation 1849.6 feet on July 23, 0.4 feet below the base of the Exclusive Flood Control Zone. Releases were higher-than-normal through the summer and fall, peaking at 36,800 cfs in July and August.

The Fort Peck pool peaked at 2247.3 ft, 1.3 feet into the Exclusive Flood Control Zone. 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.

G. 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 snowfall accumulated over the plains during the winter months. Snow accumulations began in October and the winter was extremely harsh throughout the upper basin, in relation to both 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 snowpack. Winter snows continued and by April 15, when the maximum mountain snowpack normally occurs, total accumulation was between 135 and 140 percent of normal in reaches upstream of Fort Peck and Garrison.

Runoff into the System resulting from the winter snow accumulation was unusually large. The January-February runoff exceeded the maximum set just one year earlier and the March-April total runoff is only exceeded by 1952 and 2019. The combined runoff for the five-month March-July period, which comprised the third highest runoff period, totaled 36.8 MAF. The total annual runoff was 49.0 MAF, third highest (1898-2020) only to the record runoff in 2011 and 2019.

Early in the year, MRBWM forecasted near record reservoir inflows. In response to the expected large inflows, System releases from Gavins Point 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. Despite the 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 to 70,000 cfs, at that time the highest on record, as downstream runoff and river stage forecasts permitted.

The Oahe and Fort Randall reservoir levels increased rapidly. Oahe entered its Exclusive Flood Control Zone on March 28. Fort Randall soon followed, reaching its Exclusive Flood Control Zone on April 5. The pool rises were in response to the unprecedented runoff from the record plains snowpack, whose melt was accelerated by warmer than normal temperatures. The Oahe reservoir rose to its peak of 1618.6 feet in early May. Fort Randall reservoir climbed to a maximum and record of 1372.2 feet on May 7, 7.2 feet into its 10-foot Exclusive Flood Control Zone. This elevation was 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. Fort Peck and Garrison reservoirs filled to the top of their Exclusive Flood Control Zones and infringed slightly into their surcharge zones while providing significant flood control benefits during the unprecedented runoff period. Garrison reservoir was peaking near elevation 1853 feet, one foot below the top of the Exclusive Flood Control Zone, when a 6-inch rainfall in the area occurred. The runoff from this rainfall event resulted in the pool reaching 1854.4 feet on July 4, slightly overtopping the closed spillway gates. This elevation was slightly less than the record 1854.8 feet experienced in 1975. Releases from Garrison peaked at 59,000 cfs in July. Fort Peck reached an elevation of 2250.3 feet on July 23, 2.0 feet less than the record peak of 2252.3 feet, which occurred in 2011. Fort Peck releases peaked in November at 22,300 cfs

H. Regulation of 2010 Runoff

The 2010 runoff year marked the third year in a row of above average runoff conditions following the drought of 2000-2007 in the Missouri River Basin. The 2010 runoff was 38.7 MAF, 156 percent of normal, the sixth highest on record (1898-2020).

At the end of 2009, the Missouri River Basin was almost entirely covered by plains snowpack as a result of October and early December snowfalls and continued to accumulate in the plains as above-average snowfall and colder-than-normal temperatures persisted into March. By the beginning of the plains snowmelt, many areas in the basin had accumulated four to six inches of snow water equivalent (SWE) from western North Dakota through much of South

Dakota to northwest Iowa, and three to four inches in surrounding regions of Montana, Nebraska, and southwest Iowa.

The mountain SWE in the reach between Fort Peck and Garrison peaked on May 13 at 88 percent of the average peak accumulation. In the reach above Fort Peck the mountain SWE peaked at 77 percent of average on April 15, which is the normal date for mountain snow accumulation to peak. In general, the precipitation during the 2010 calendar year was above average in the Missouri River Basin.

Flow support for the 2010 navigation season began on March 23 at Sioux City, IA, but increased releases were not necessary to meet downstream targets and System releases were not increased until late April. By June 15, releases had reached 33,000 cfs. A large storm centered over the Niobrara River Basin in mid-June increased Gavins Point local inflows dramatically. Fort Randall releases were reduced to 0 cfs for a period, but the high flows from the Niobrara River continued to increase the Gavins Point pool elevation. Gavins Point reservoir reached 1209.7 feet on June 14, at that time the highest pool elevation recorded since 1967, and 0.3 feet below the top of the closed spillway gates. Releases peaked at 49,100 cfs in early October and the System was regulated to bring the System storage to 56.8 MAF by the beginning of the 2011 runoff season.

Plains snowmelt runoff brought the Fort Randall pool elevation from 1349.0 feet to 1361.1 feet during March. Runoff from above-normal rainfall upstream and downstream of Fort Randall resulted in the pool elevation reaching a maximum of 1368.1 feet on June 22, 3.1 feet into the 10-foot Exclusive Flood Control Zone. Fort Randall releases reached a maximum of 48,300 cfs in late October.

Big Bend releases and elevations remained at normal levels throughout 2010. The Big Bend pool elevation peaked at 1421.4 feet in early February. The peak daily release was 56,700 cfs and the peak hourly release was 97,900 cfs.

The melting of the above-normal plains snowpack brought high inflows to Oahe and similar high flows downstream, which limited Oahe release rates. As a result, the Oahe pool elevation continued to climb steadily as above-normal rainfall across South Dakota and the lower Basin prolonged the period of high inflows and low releases. This became especially important as high local inflow into Fort Randall and Gavins Point brought both of those projects into their respective Exclusive Flood Control Zones. Oahe pool elevation peaked at 1617.9 feet, 0.9 feet into its 3-foot Exclusive Flood Control Zone. Releases from Oahe peaked at 49,100 cfs in September.

Although inflows were below normal, the Garrison pool rose steadily during March through May due to lower-than-normal releases. The month of June saw a significant pool rise due to a combination of above-normal inflows coupled with below-normal releases. Releases were cut to reduce high flows in the lower reaches of the Missouri River downstream of the System, and due to high reservoir levels at Oahe and Fort Randall. The mountain snowpack runoff resulted in the Garrison pool elevation peaking at 1851.4 feet, 1.4 feet into the Exclusive Flood Control Zone. Evacuation releases peaked at 31,200 cfs in November.

During March to June, a combination of normal to above-normal runoff into Fort Peck, and below-normal releases resulted in the pool rising over nine feet, from 2224.2 feet at the end of March to 2233.3 feet at the end of June, during the forage fish spawn. The reservoir peaked at 2235.8 feet, 1.8 foot into the Annual Flood Control and Multiple Use Zone. This marked Fort Peck's recovery from the 2000-2007 drought. The peak daily release of 8,800 cfs occurred in December.

I. Regulation of 2011 Runoff

The 2011 runoff year was the highest runoff year of record in the upper Missouri River Basin since 1898, resulting in a total annual runoff of 61.0 MAF (1898-2020), almost 2.5 times normal. It also marked the fourth consecutive year of above-normal runoff in the upper Missouri River Basin, immediately following the 2000-2007 drought. May (9.2 MAF), June (14.8 MAF) and July (10.2 MAF) had the highest inflows for their respective months in the 123-year period of record (1898-2020). The 34.3 MAF of runoff received during that 3-month period exceeded the total annual runoff in 109 of the 123 years of available record.

The winter of 2011 marked the third consecutive year of significant plains snowpack. The plains snowpack peaked about February 25 and was classified as "heavy" throughout most of the upper basin with SWE amounts varying between 4-6 inches with some areas exceeding 6 inches. As the System storage increased, as well as mountain snowpack and forecasted inflow, the service level was increased multiple times. On May 1 System storage was 65.5 MAF, occupying 8.7 MAF of the 16.3 MAF flood control storage space. While the mountain snowpack was very substantial, runoff from mountain snowpack normally extends over a 3-month period (May-July). System regulation studies indicated an average May System release of 57,500 cfs would be needed.

From May 20-22, generally between 5 and 8 inches of rain fell across the regions of eastern Montana, western South Dakota and northern Wyoming, covering an area of 50 million acres, which is the approximate size of the State of Iowa. In some isolated areas, 10-15 inches of rain fell over the 3-day period. Because this runoff came in the form of rainfall runoff rather than snowmelt runoff, the volume of runoff over this very large area quickly made its way to the Fort Peck and Garrison reservoirs and dictated a need to increase releases from all six reservoirs. Additional rain in late May and early June in the upper basin caused System releases to be scaled up from 80,000 cfs at the beginning of June to 150,000 cfs by June 15. This release rate was held until June 21 and then increased to 160,000 cfs over the next two days due to additional rain in South Dakota. System releases were maintained at 160,000 cfs until the end of July. System storage peaked at 72.8 MAF on July 1, occupying 98 percent of the allocated flood control storage space (16.0 MAF of 16.3 MAF).

Peak daily flows into Fort Peck set records in June 2011. The peak daily June inflow of 101,000 cfs occurred on June 6. The average annual daily release of 18,500 cfs was nearly two times normal and was the highest average annual release since the System first filled in 1967. The new record maximum daily average release from Fort Peck was established on June 15, 2011 at 65,900 cfs, exceeding the previous record maximum of 35,400 cfs set in July 1975. The highest record Fort Peck reservoir level of 2252.3 feet occurred on June 15, 2011, eclipsing the previous reservoir level of 2251.6 feet set in July 1975.

Peak daily flows into Garrison also set records in June 2011. A record daily inflow of 190,000 cfs occurred on June 13. The record maximum daily Garrison release of 150,600 cfs was established on June 25 and exceeded the previous maximum of 65,200 cfs (July 1975), The Garrison reservoir pool elevation peaked at 1854.6 feet on July 1, 0.6 foot above the top of its Exclusive Flood Control Zone and was the second highest recorded pool elevation on record. The record high pool elevation was 1854.8 feet set in July 1975.

Peak daily flows into Oahe also set records in 2011. The peak daily inflow of 210,000 cfs occurred on June 21. The record maximum daily release from Oahe occurred on June 20 at 160,300 cfs. Previously the record was 59,300 cfs, which was established in July 1997. The highest Oahe reservoir level during 2011 occurred on June 26 at 1619.7 feet, 0.3 foot below the top of the Exclusive Flood Control Zone. This reservoir elevation set a record for the highest pool since the System first became fully operational in 1967. The prior record was 1618.7 feet, which was set in 1995 and repeated in 1996.

Peak daily flows into Big Bend also set records in 2011. The peak daily inflow was 195,000 cfs, which occurred on June 21. The new record maximum Big Bend release was established at 166,300 cfs on June 26, 2011. The previous record of 74,300 cfs was set in July 1997. As a re-regulation project, Big Bend was operated within its normal regulating range during the 2011 event.

Maximum daily flows into Fort Randall also set a new record in 2011. The maximum daily inflow of 218,000 cfs occurred on June 21 and more than doubled the previous June maximum daily record of 95,000 cfs. The new record maximum Fort Randall daily release of 160,000 cfs was established on July 27. The previous record of 67,500 cfs was set in November 1997. The highest Fort Randall reservoir level during 2011 occurred on July 7 at 1374.0 feet, which exceeded the previous record high of 1372.2 feet, set in May 1997.

At Gavins Point, the maximum daily inflow of 168,000 cfs occurred on June 27. The new record maximum daily Gavins Point release was established at 160,700 cfs on June 27. The prior record was established in October and November 1997 at 70,100 cfs. The highest Gavins Point reservoir level in 2011 was 1208.6 feet, reached on February 11. As is the case with Big Bend, Gavins Point is considered a re-regulation project, and is used to smooth out releases from Fort Randall with a small amount of flood control storage available to manage local inflows.

J. Regulation of 2018 Runoff

Runoff during 2018 above Sioux City, IA was 42.1 MAF, 163 percent of average, the fourth highest on record (1898-2020). Runoff was above average in all six reaches in the upper Missouri River basin. Within the first six months of the runoff year (end of June) the upper Missouri River basin had already received 27.5 MAF, more than an average year's runoff.

Plains snowfall in the upper basin during the 2017-2018 winter varied from light to heavy. The deepest and most persistent plains snowpack occurred throughout much of Montana, and some of the heaviest plains snowpack persisted into April in northern Montana. Mountain snowpack peaked at 141 percent of average in the Fort Peck reach, and 137 percent of average in the reach from Fort Peck to Garrison.

Starting in March, the service level was increased to allow for increased flood storage evacuation. The service level was increased several more times during the spring and summer. System storage peaked on July 9 at 68.4 MAF, 0.7 MAF above the base of the Exclusive Flood Control Zone. Gavins Point daily releases ranged from 58,100 cfs to 45,900 cfs from August through November, with releases being reduced in response to downstream events. The Gavins Point reservoir peaked at 1208.9 feet in October.

Releases from Fort Randall generally paralleled those from Gavins Point while allowing for the incremental flow between the two projects. During April through November, Fort Randall releases ranged from 14,400 cfs to 58,200 cfs. The Fort Randall reservoir peaked at elevation 1362.4 feet, on July 5.

The highest 2018 Oahe midnight reservoir level of 1617.2 feet occurred on July 31, 0.2 foot above the base of the Exclusive Flood Control Zone. Big Bend's maximum midnight pool elevation of 1421.3 feet was recorded on December 12. Oahe's 2018 average annual inflow was 36,500 cfs, 144 percent of average. Oahe's average annual release was 34,900 cfs, 145 percent of average.

Due to the high runoff in the Garrison reach releases were increased throughout the spring and into June, peaking at 60,000 cfs. The pool peaked at 1853.2 feet on July 4, occupying 3.2 feet of the 4-foot Exclusive Flood Control Zone. Garrison releases remained above average late into the fall to evacuate water from the reservoir and ended the year with an average annual outflow of 33,900 cfs, 155 percent of average.

Releases from Fort Peck were elevated in 2018 to manage the high runoff, peaking at 20,500 cfs during June. The reservoir peaked at elevation 2247.9 feet, 1.9 feet into the 4-foot Exclusive Flood Control Zone. Releases remained above average into December to evacuate water from the reservoir. Fort Peck's average annual release was 12,900 cfs, 140 percent of average.

K. Regulation of 2019 Runoff

Runoff during 2019 above Sioux City, IA was 60.9 MAF, 236 percent of average, the second highest on record (1898-2020).

Gavins Point reservoir ended February at elevation 1205.8 feet, near its desired elevation for that time of year. Following the rain on snow event in March, inflows into Gavins Point increased rapidly, and the reservoir's available flood control storage quickly filled. Releases from Gavins Point reached 100,000 cfs for a short period and the reservoir was surcharged to elevation 1212.3 feet, 2.3 feet above the top of the Exclusive Flood Control Zone. Peak hourly inflows into the Gavins Point reservoir exceeded 180,000 cfs and the March 14 average daily inflow, with Fort Randall releases at 0 cfs, was 125,000 cfs, a daily volume of 250,000 acre-feet.

Once inflows into Gavins Point peaked, releases were reduced over several days as the inflow receded and the reservoir level gradually declined, falling below surcharge (elevation 1210.0 feet) on 17 March. March runoff into Gavins Point was 1.2 MAF, the highest on record and more than five times the average March runoff. The previous record was 0.7 MAF in 1952. Continued above normal runoff required Gavins Point releases to be well above average through the summer and fall. Daily releases ranged from 54,900 cfs to 80,300 cfs from May through November.

During the mid-March spring rain-on-snow event, Fort Randall releases were reduced to 0 cfs for several days. March runoff in the Oahe to Fort Randall reach was 1.6 MAF, the highest March runoff on record. The low Fort Randall releases combined with the high runoff from the plains snowmelt resulted in the Fort Randall reservoir rising 16.2 feet in March, ending the month at 1366.9 feet, 1.9 feet into its 10-foot Exclusive Flood Control Zone (1365.0 to 1375.0 feet. Due to above average precipitation in May, the reservoir peaked at elevation 1370.4 feet on June 1, 5.4 feet into its 10-foot Exclusive Flood Control Zone. Fort Randall releases ranged from 38,700 cfs to 76,700 cfs from May through December.

Due to the low Gavins Point releases during the spring flood event, Oahe releases averaged only 9,500 cfs in March. The lower-than-average Oahe releases, combined with melting plains snowpack throughout South Dakota, resulted in the reservoir rising 7.9 feet in March, ending the month at 1614.7 feet. March runoff into Oahe was more than four times the long-term average and the second highest March runoff on record. April runoff was more than three times average. The reservoir continued to rise into mid-April, reaching the base of the Exclusive Flood Control Zone, then started to fall before increasing again due to above average precipitation in May, and the resulting high runoff. The reservoir peaked on June 1 at elevation 1618.5 feet, 1.5 feet into its 3-foot Exclusive Flood Control Zone. Much above average July runoff in the Oahe reach (more than five times average) resulted in the Oahe reservoir rising back into the Exclusive Flood Control Zone in late July, reaching approximately elevation 1617.2 feet. Daily releases ranged from 39,100 cfs to 65,500 cfs from June to December.

Garrison runoff in March and April was 228 and 163 percent of normal, respectively. Garrison releases were stepped up in late April and mid-May to as high as 30,000 cfs. However, due to the rising reservoir levels in Oahe and Fort Randall in late May, Garrison releases were reduced to 15,000 cfs. As Oahe and Fort Randall reservoir levels began to decline in June, Garrison releases were stepped up to 46,000 cfs. The peak daily release was 49,400 cfs, which occurred in November. Total Garrison releases exceeded the powerhouse capacity and supplemental releases were made from the spillway. Garrison reservoir peaked at elevation 1852.3 feet in mid-July, 2.3 feet into its 4-foot Exclusive Flood Control Zone

Above normal spring runoff in the Fort Peck reach caused the reservoir to quickly rise. Fort Peck releases were increased to 9,000 cfs in mid-May and held near that rate into late June due to the comparatively high reservoir levels at downstream projects. Releases were increased to 15,000 cfs by mid-July and held at that rate into mid-December. Fort Peck reservoir peaked at elevation 2246.7 feet in mid-July, 0.7 feet into its Exclusive Flood Control Zone, and stayed in the Exclusive Flood Control Zone until July 31. The peak daily release was 15,800 cfs.

APPENDIX A

Vertical Datums for the Six Mainstem Reservoirs

Table A-1
Mainstem Datums (in feet)

Local project datum	NGVD29	NAVD88
Fort Peck Reservoir		
0.0	-0.25	+1.82
(ex.) 2234.0	2233.75	2235.82
Garrison Reservoir		
0.0	-0.095	+1.215
(ex.) 1837.5	1837.405	1838.715
Oahe Reservoir		
0.0	-0.10	+1.14
(ex.) 1607.5	1607.4	1608.64
Big Bend Reservoir		
0.0	-1.130	-0.049
(ex.) 1420.0	1418.87	1419.951
Fort Randall Reservoir*		
0.0	-0.0126/-0.035	+0.937/+0.915
(ex.) 1355.0	1354.987/1354.965	1355.937/1355.915
Gavins Point Reservoir		
0.0	+0.8	+1.47
(ex.) 1208.0	1208.8	1209.47

* Fort Randall has two local datums

APPENDIX B

Upper Missouri River Basin
Annual Runoff Probabilities

Table B-1. Upper Missouri River Basin Annual Runoff Probability.
Above Sioux City, IA
Period of Record: 1898-2019 with 1880-1890 Historic Data

Exceedance Probability (percent)	Recurrence Interval (year)	Computed Curve (KAF)
0.1	1000	72,100
0.2	500	67,100
0.5	200	60,500
1.0	100	55,600
2.0	50	50,600
4.0	25	45,600
10.0	10	38,800
20.0	5	33,300
50.0	2	24,800
80.0		18,400
90.0		15,800
95.0		13,800
99.0		10,800

2011 Annual volume = 61,004 KAF

Table B-2. Upper Missouri River Basin March - July Runoff Probability.
Above Sioux City, IA
Period of Record: 1881, 1898-2019

Exceedance Probability (percent)	Recurrence Interval (year)	Computed Curve (KAF)
0.1	1000	50,400
0.2	500	47,000
0.5	200	42,400
1.0	100	39,000
2.0	50	35,400
4.0	25	31,800
10.0	10	26,800
20.0	5	22,700
50.0	2	16,300
80.0		11,500
90.0		9,500
95.0		8,100
99.0		5,900

2011 March - July volume = 48,380 KAF

**Table B-3. Annual Runoff Volume Rankings.
Missouri River above Sioux City, IA**

Rank	Year	Annual Runoff KAF	Rank	Year	Annual Runoff KAF	Rank	Year	Annual Runoff KAF
1	2011	61004	46	2017	29560	91	1926	22000
2	2019	60871	47	1913	29496	92	1987	21314
3	1888	58500	48	1979	29479	93	2007	21112
4	1887	51300	49	1950	29369	94	1902	20908
5	1881	50700	50	1889	29200	95	1938	20652
6	1997	49037	51	1920	29199	96	1946	20355
7	2018	42077	52	1951	28856	97	1963	20313
8	1885	41600	53	1906	28713	98	1960	20120
9	1978	40634	54	1882	28500	99	2005	20077
10	2010	38676	55	1948	28353	100	1959	20017
11	1995	37160	56	1947	28279	101	1905	19796
12	1927	36988	57	1898	28088	102	1966	19685
13	1884	36700	58	1914	27897	103	2012	19545
13	1886	36700	59	1976	27687	104	1932	19463
15	1986	36203	60	1970	27312	105	1956	19418
16	1993	36156	61	1924	27098	106	1981	19259
17	1996	35592	62	1983	26802	107	1954	19223
18	1975	35539	63	2008	26631	108	1985	18843
19	2014	35285	64	1925	26479	109	1980	18687
20	1883	35200	65	1998	26412	110	1930	18452
21	1909	34893	66	1918	26301	111	2006	18171
22	1907	34651	67	2015	25807	112	1933	18166
23	1952	34232	68	1904	25491	113	1989	17700
24	1982	33598	69	1953	25367	114	2003	17445
25	1912	33597	70	1942	25105	115	1939	17271
26	2009	33416	71	1974	25009	116	1958	16971
27	1917	33295	72	2013	24740	117	1941	16714
28	1971	33134	73	1929	24653	118	1990	16691
29	1916	32997	74	1901	24598	119	2000	16490
30	1972	32962	74	1903	24598	120	1992	16448
31	1915	32794	76	1922	24101	121	1955	16410
32	1908	32683	77	2016	24089	122	2004	16162
33	1965	32473	78	1994	23859	123	1977	16080
34	1899	32391	79	1968	23744	124	2002	15737
35	1880	32100	80	1964	23705	125	1936	14339
36	1890	31700	81	1900	23194	126	1935	14323
37	1943	31394	82	1910	23190	127	1937	14315
38	1923	31222	83	1949	23189	128	1919	13891
39	1999	31175	84	1973	23140	129	1961	12432
40	1967	31026	85	1921	22801	130	1988	12352
41	1984	30824	86	1945	22729	131	1940	12101
42	1962	30333	87	1911	22701	132	1934	11164
43	1928	30283	88	2001	22537	133	1931	10701
44	1969	30122	89	1991	22330			
45	1944	29726	90	1957	22079			

Table B-4. March – July Runoff Volume Rankings.
Missouri River above Sioux City, IA

Rank	Year	Annual Runoff KAF	Rank	Year	Annual Runoff KAF	Rank	Year	Annual Runoff KAF
1	2011	48380	46	2008	19633	91	2005	13697
2	2019	43139	47	1913	19415	92	1956	13504
3	1881	39660	48	1929	19365	93	2012	13293
4	1997	36565	49	1906	19318	94	1966	13198
5	1978	31430	50	1951	19288	95	1933	13093
6	2018	31089	51	2017	19254	96	2003	12928
7	1952	27694	52	1942	19111	97	1946	12720
8	2010	27649	53	1904	19056	98	1939	12695
9	1927	27358	54	1925	19036	99	1981	12530
10	1995	27063	55	1924	18933	100	1989	12283
11	1975	26862	56	1914	18814	101	1954	12278
12	1899	25728	57	1953	18773	102	1955	12264
13	1909	25688	58	1976	18460	103	1930	12135
14	1986	25162	59	1922	18316	104	2006	11985
15	1917	24964	60	1901	18094	105	1980	11879
16	1996	24629	61	1983	17981	106	1958	11866
17	1907	24401	62	1921	17776	107	1990	10970
18	2009	24393	63	1949	17618	108	2000	10954
19	1993	24337	64	1964	17499	109	1985	10791
20	1916	24124	65	1910	17209	110	1935	10595
21	1967	23813	66	1900	17082	111	1937	10563
22	1943	23790	67	1994	16986	112	2004	10404
23	2014	23731	68	2015	16811	114	2002	10331
24	1908	23681	69	2001	16665	114	1936	10262
25	1972	23523	70	1974	16542	115	1992	9449
26	1982	23144	71	1903	16337	116	1941	9420
27	1962	22940	72	1998	16229	117	1977	9391
28	1969	22913	73	1991	16102	118	1919	9275
29	1920	22754	74	1945	15915	119	1988	8355
30	1944	22686	75	2013	15905	120	1940	8028
31	1965	22657	76	1957	15796	121	1934	7301
32	1928	22531	77	1938	15641	122	1961	7058
33	1971	22496	78	2007	15227	123	1931	6353
34	1999	22024	79	1960	15146			
35	1948	21997	80	2016	15044			
36	1898	21954	81	1968	14970			
37	1950	21946	82	1932	14724			
38	1979	21764	83	1902	14552			
39	1912	21761	84	1911	14481			
40	1984	21608	85	1905	14360			
41	1947	21188	86	1987	14326			
42	1915	21000	87	1973	14196			
43	1970	20026	88	1926	14043			
44	1918	19821	89	1963	14005			
45	1923	19647	90	1959	13698			

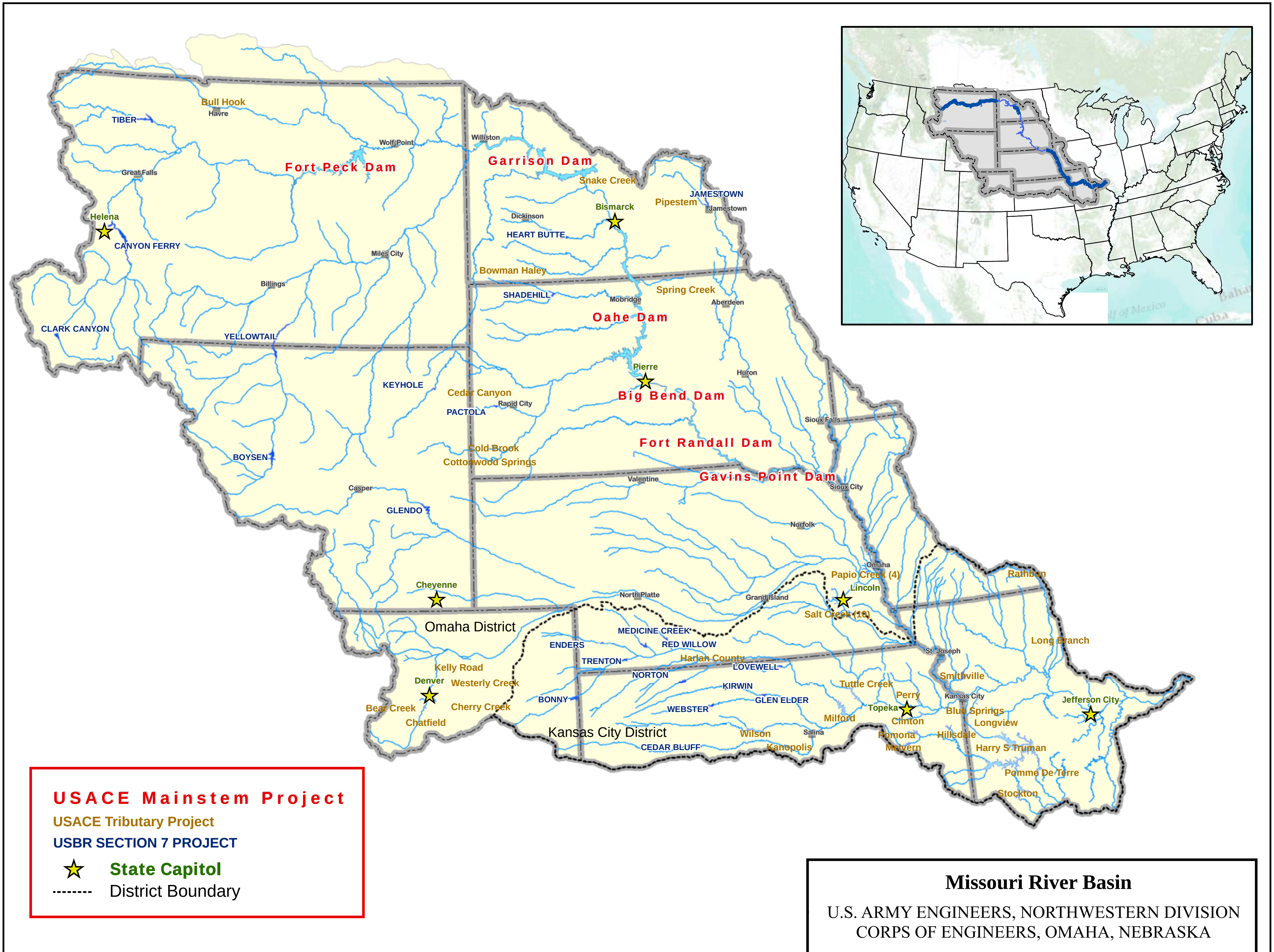

Plate 1. Missouri River Basin Map

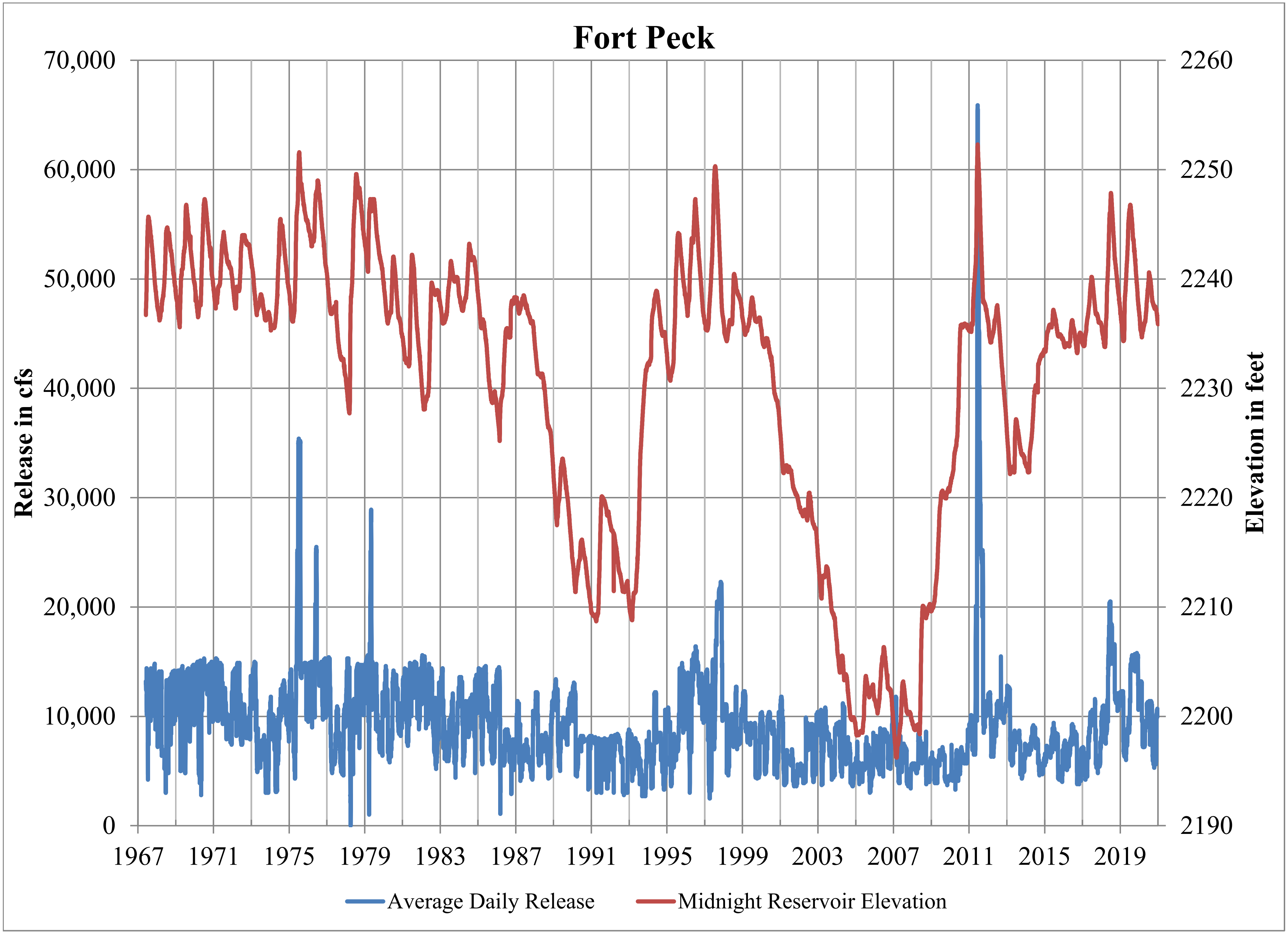

Plate 2. Fort Peck Daily Releases and Elevations.
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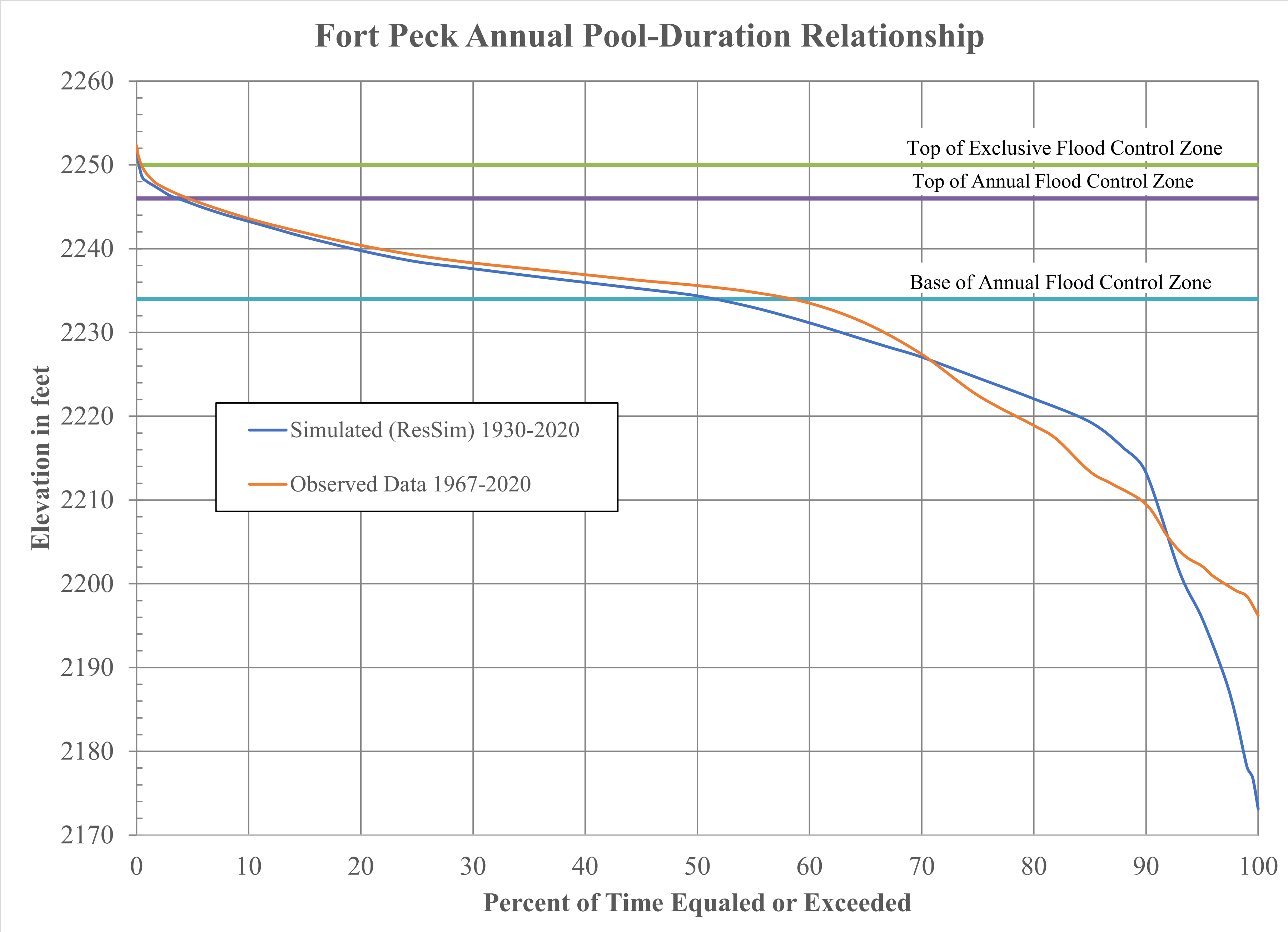

Plate 3. Fort Peck Annual Pool-Duration Relationship.
MRBWM Technical Report - Hydrologic Statistics, May 2022

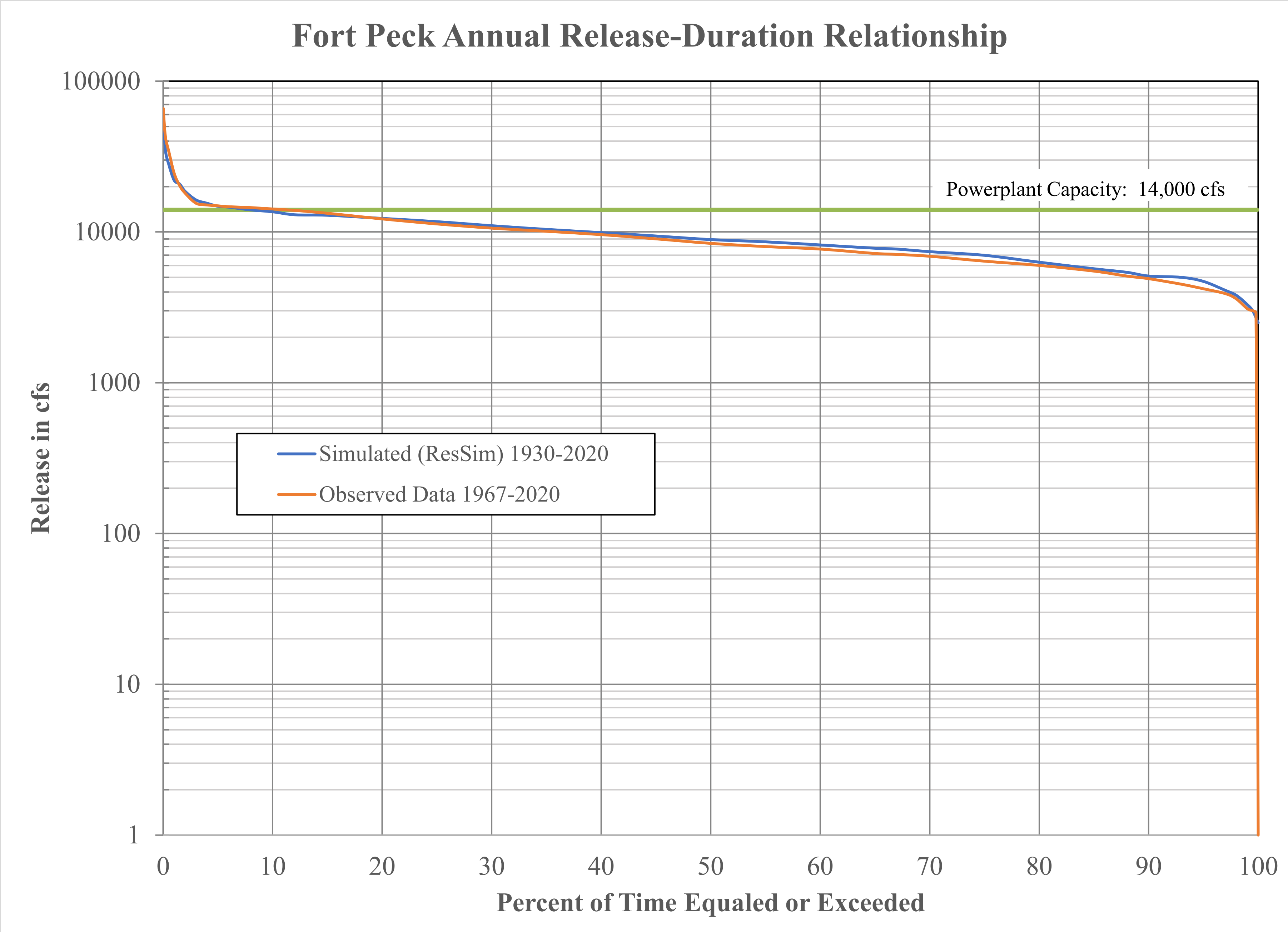

Plate 4. Fort Peck Annual Release-Duration Relationship.
MRBWM Technical Report - Hydrologic Statistics, May 2022

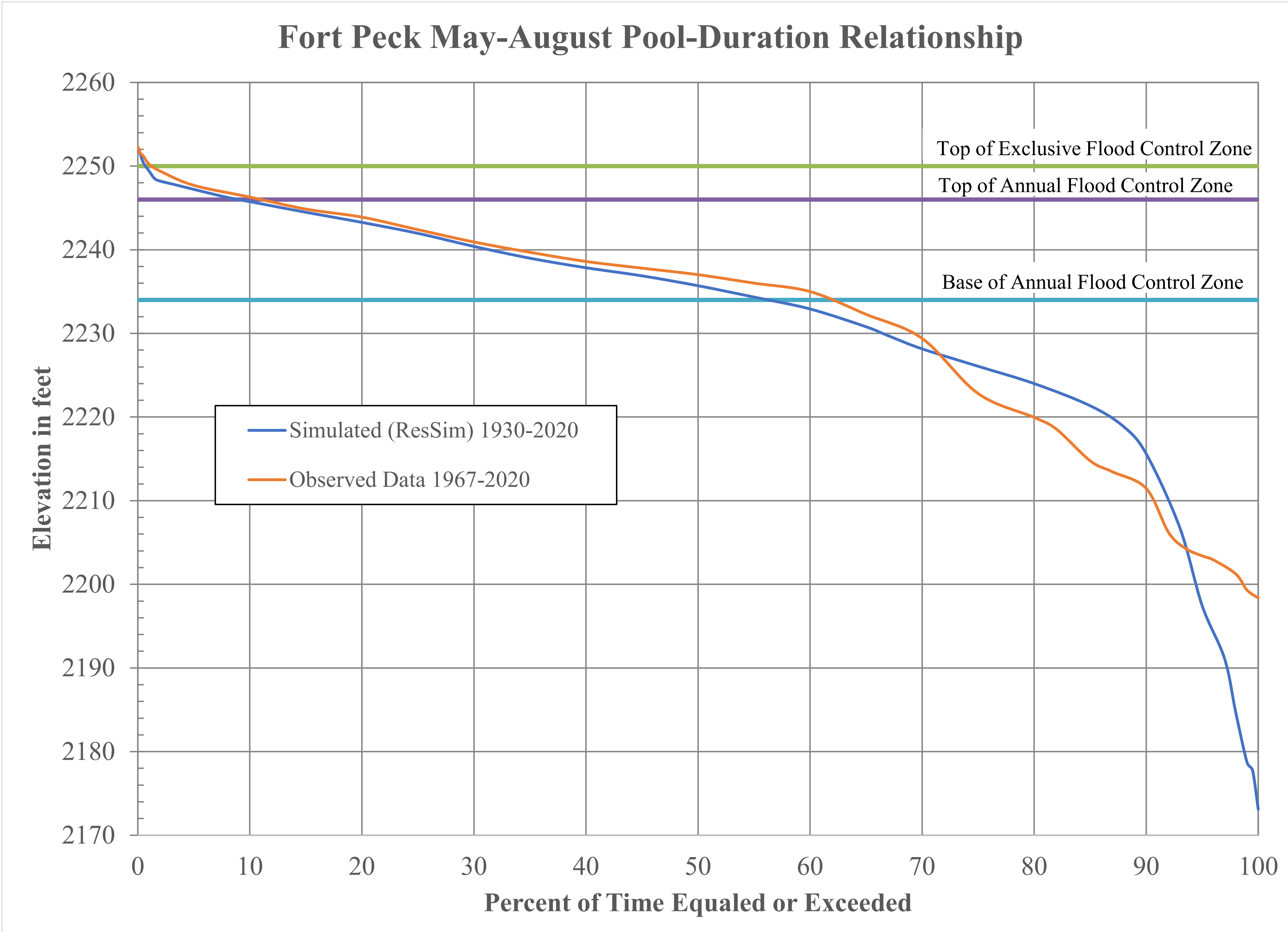

Plate 5. Fort Peck Pool-Duration Relationship (May-August).
MRBWM Technical Report - Hydrologic Statistics, May 2022

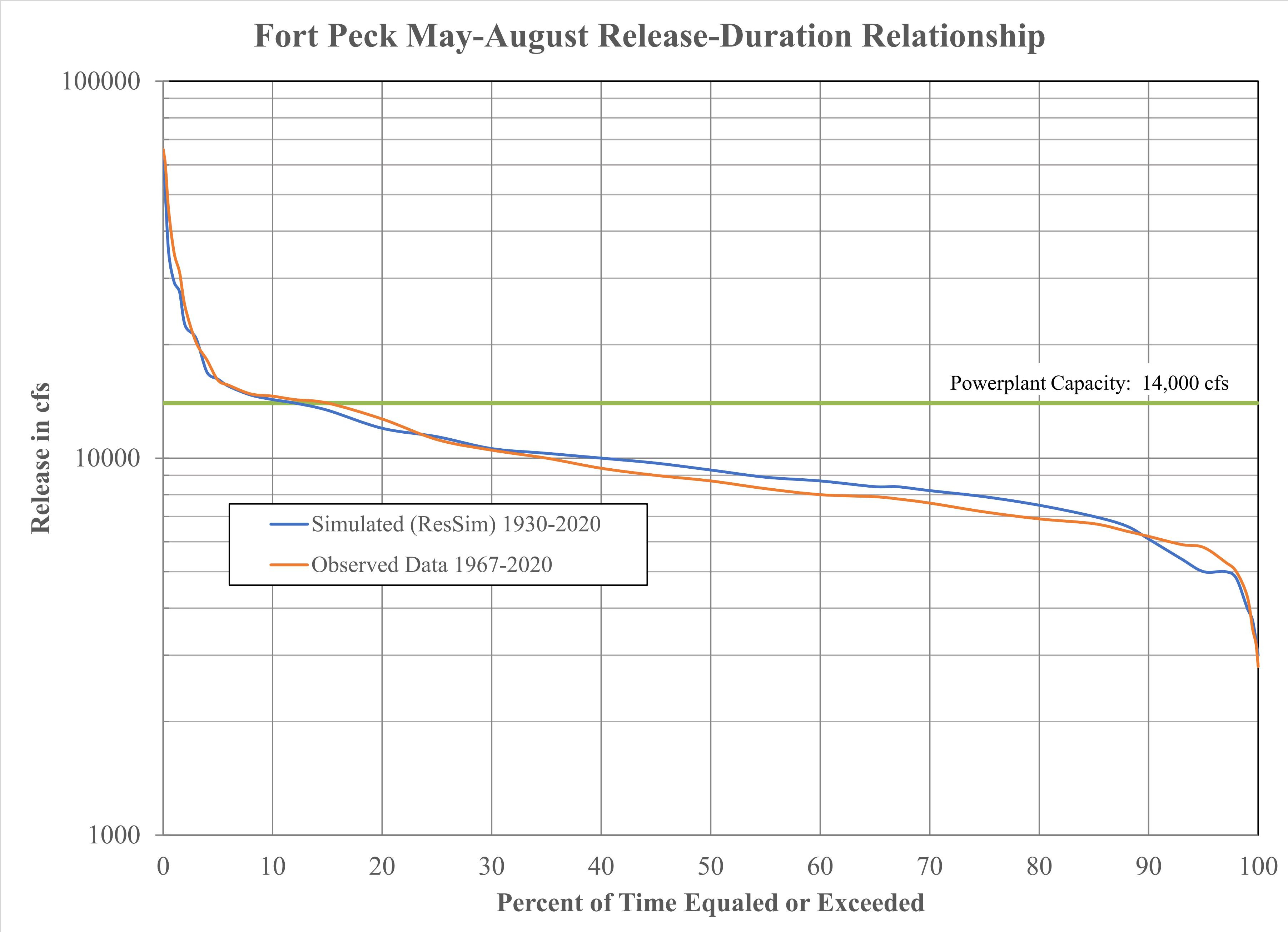

Plate 6. Fort Peck Release-Duration Relationship (May-August).
MRBWM Technical Report - Hydrologic Statistics, May 2022

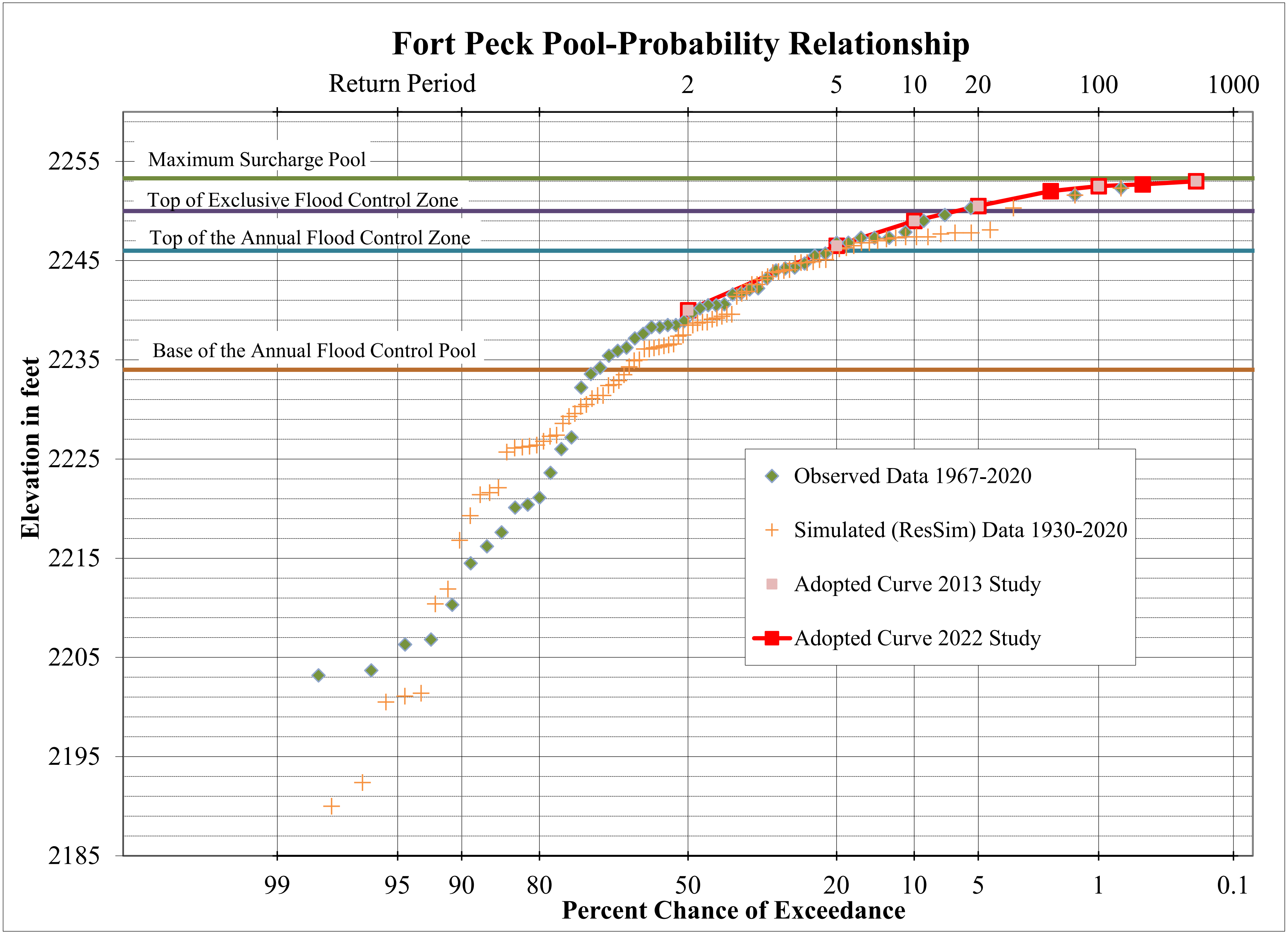

Plate 7. Fort Peck Pool-Probability Relationship.

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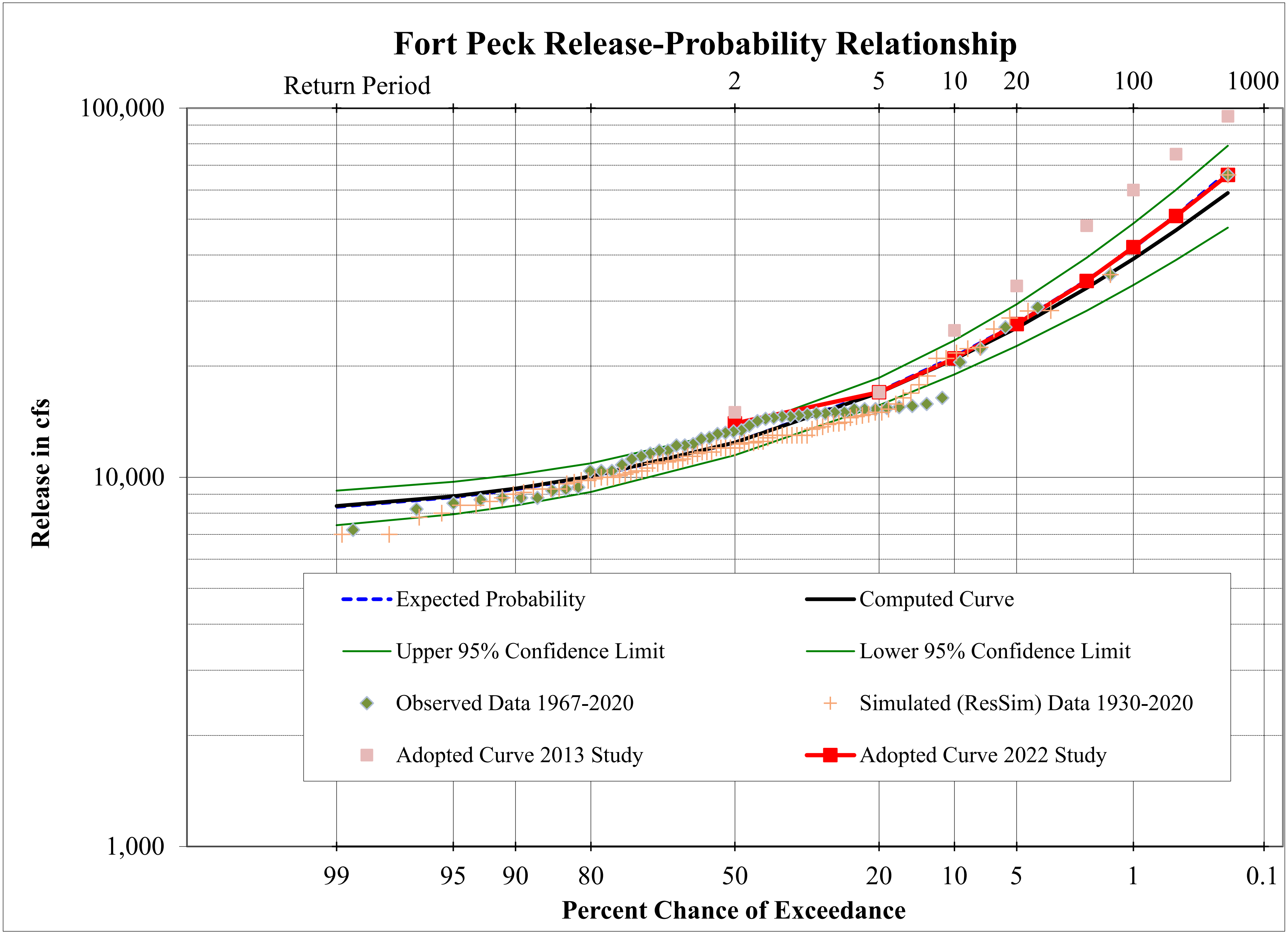

Plate 8. Fort Peck Release-Probability Relationship.

Fort Peck Simulated (ResSim Model) Peak Elevations and Releases

Year	Elevation	Release	Year	Elevation	Release	Year	Elevation	Release
1930	2236.1	9,900	1962	2229.3	11,000	1994	2242.6	11,700
1931	2228.6	8,600	1963	2236.4	9,600	1995	2244.8	15,300
1932	2219.3	9,300	1964	2243.9	15,000	1996	2247.7	21,000
1933	2221.6	8,400	1965	2247.3	25,200	1997	2250.3	22,300
1934	2216.8	11,400	1966	2241.4	13,700	1998	2243.4	13,000
1935	2200.5	10,900	1967	2246.5	14,100	1999	2239.6	13,000
1936	2192.4	9,300	1968	2245.1	13,900	2000	2236.3	10,000
1937	2180.0	7,000	1969	2246.8	14,800	2001	2230.5	10,000
1938	2201.4	7,000	1970	2247.4	22,500	2002	2230.3	9,300
1939	2210.4	9,800	1971	2244.9	14,600	2003	2226.8	11,100
1940	2201.1	11,000	1972	2243.1	13,600	2004	2221.4	10,600
1941	2190.0	9,800	1973	2238.5	12,000	2005	2222.1	8,000
1942	2211.9	7,800	1974	2244.1	12,000	2006	2226.3	8,800
1943	2235.0	10,100	1975	2251.6	35,400	2007	2226.1	11,200
1944	2236.5	12,300	1976	2247.4	17,800	2008	2232.5	8,400
1945	2237.4	9,000	1977	2237.5	13,000	2009	2239.6	9,100
1946	2234.9	10,000	1978	2248.1	27,000	2010	2246.0	13,500
1947	2242.6	12,000	1979	2247.4	21,700	2011	2252.3	65,900
1948	2247.8	28,200	1980	2243.8	14,700	2012	2239.2	13,000
1949	2239.1	11,600	1981	2246.2	18,800	2013	2231.4	12,400
1950	2241.9	10,400	1982	2247.0	21,000	2014	2236.2	12,000
1951	2244.7	12,500	1983	2244.0	14,000	2015	2238.7	10,400
1952	2246.3	16,900	1984	2245.1	16,400	2016	2236.6	9,300
1953	2247.2	15,000	1985	2238.5	13,000	2017	2238.8	10,300
1954	2234.3	11,100	1986	2244.8	14,500	2018	2247.8	28,300
1955	2231.4	12,400	1987	2239.4	13,000	2019	2246.8	15,800
1956	2226.4	11,700	1988	2236.1	10,200	2020	2241.7	13,000
1957	2225.7	11,400	1989	2231.1	12,500			
1958	2229.6	10,900	1990	2227.4	12,800			
1959	2233.5	14,000	1991	2232.9	11,700			
1960	2232.4	13,000	1992	2227.3	12,400			
1961	2226.2	12,000	1993	2238.8	9,700			

Plate 9. Fort Peck Simulated (ResSim Model) Data 1930-2020.
Peak elevations in feet, peak releases in cfs.

Fort Peck Observed Peak Elevations and Releases

Year	Elevation	Release	Year	Elevation	Release
1967	2245.7	14,800	1994	2238.9	12,200
1968	2244.7	14,200	1995	2244.2	14,900
1969	2246.8	14,700	1996	2247.3	16,400
1970	2247.3	15,300	1997	2250.3	22,300
1971	2244.3	15,300	1998	2240.5	12,700
1972	2244.0	14,900	1999	2238.3	12,300
1973	2241.7	15,000	2000	2235.4	10,400
1974	2245.5	13,300	2001	2226.0	11,800
1975	2251.6	35,400	2002	2220.4	10,400
1976	2249.0	25,500	2003	2214.5	10,800
1977	2240.5	15,400	2004	2206.8	11,200
1978	2249.6	15,300	2005	2203.7	8,500
1979	2247.3	28,900	2006	2206.3	10,400
1980	2242.1	14,600	2007	2203.2	11,800
1981	2242.2	15,000	2008	2210.3	8,800
1982	2239.7	15,600	2009	2221.1	7,200
1983	2241.6	14,400	2010	2235.9	8,800
1984	2243.2	13,800	2011	2252.3	65,900
1985	2238.5	14,600	2012	2237.61	15,500
1986	2238.3	14,500	2013	2227.2	12,800
1987	2238.5	11,400	2014	2233.6	9,200
1988	2234.2	12,200	2015	2237.2	9,400
1989	2223.6	13,400	2016	2236.2	9,300
1990	2216.2	13,100	2017	2240.2	11,600
1991	2220.1	8,200	2018	2247.9	20,500
1992	2217.6	8,800	2019	2246.8	15,800
1993	2232.2	8,700	2020	2240.6	13,200

Plate 10. Fort Peck Observed Data 1967-2020.
Peak elevations in feet, peak releases in cfs.

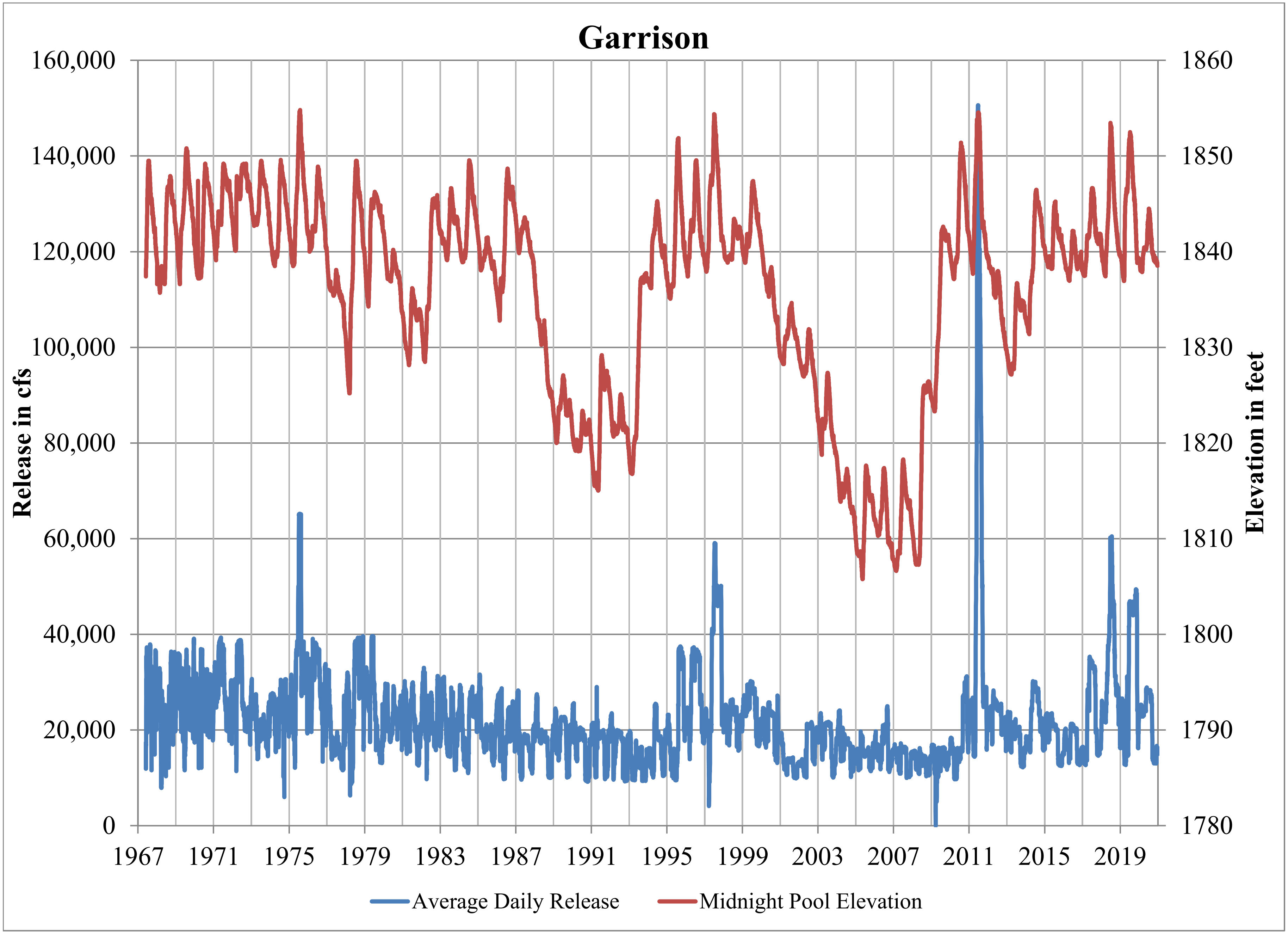

Plate 11. Garrison Daily Releases and Elevations.

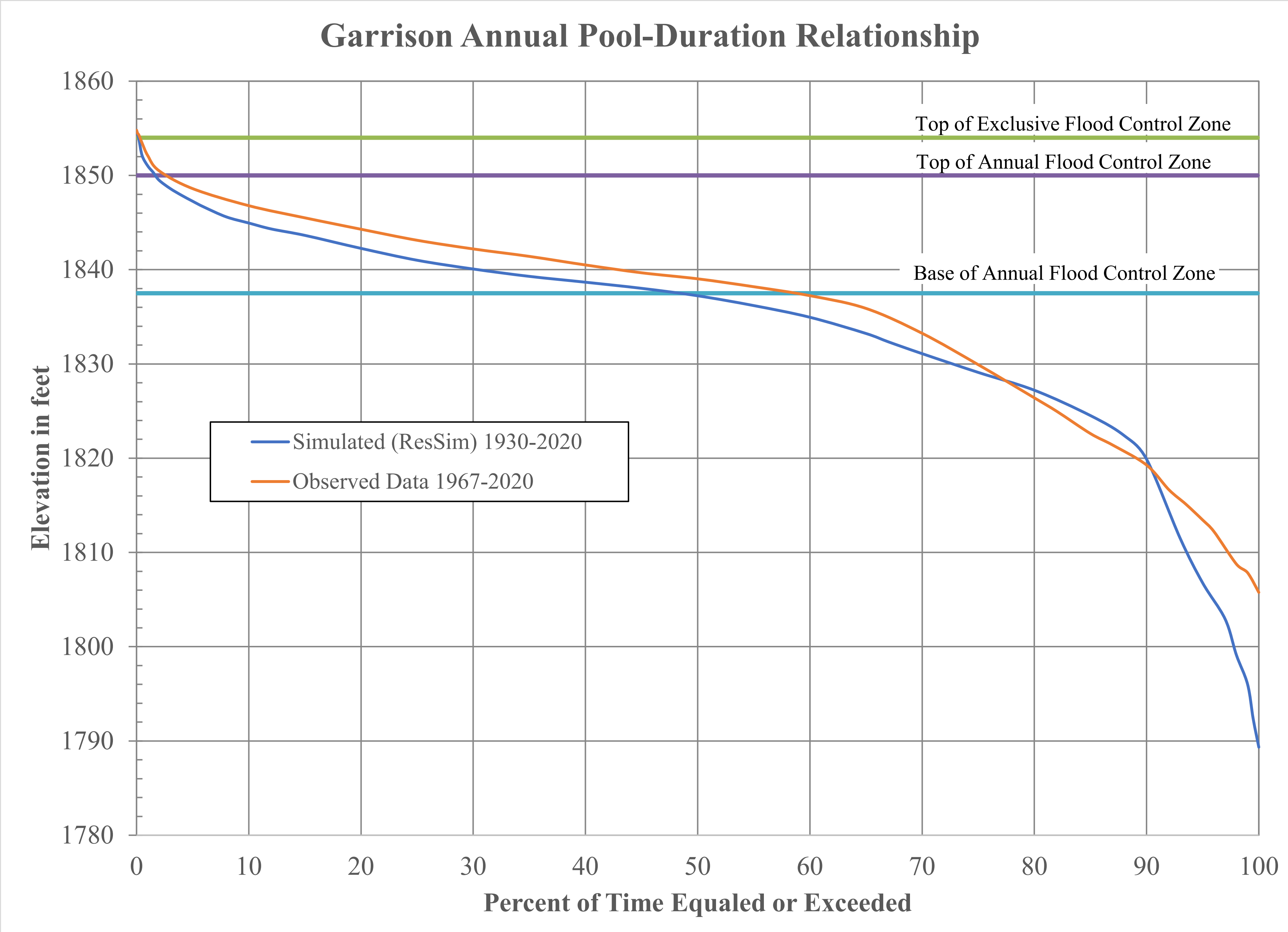

Plate 12. Garrison Annual Pool-Duration Relationship.
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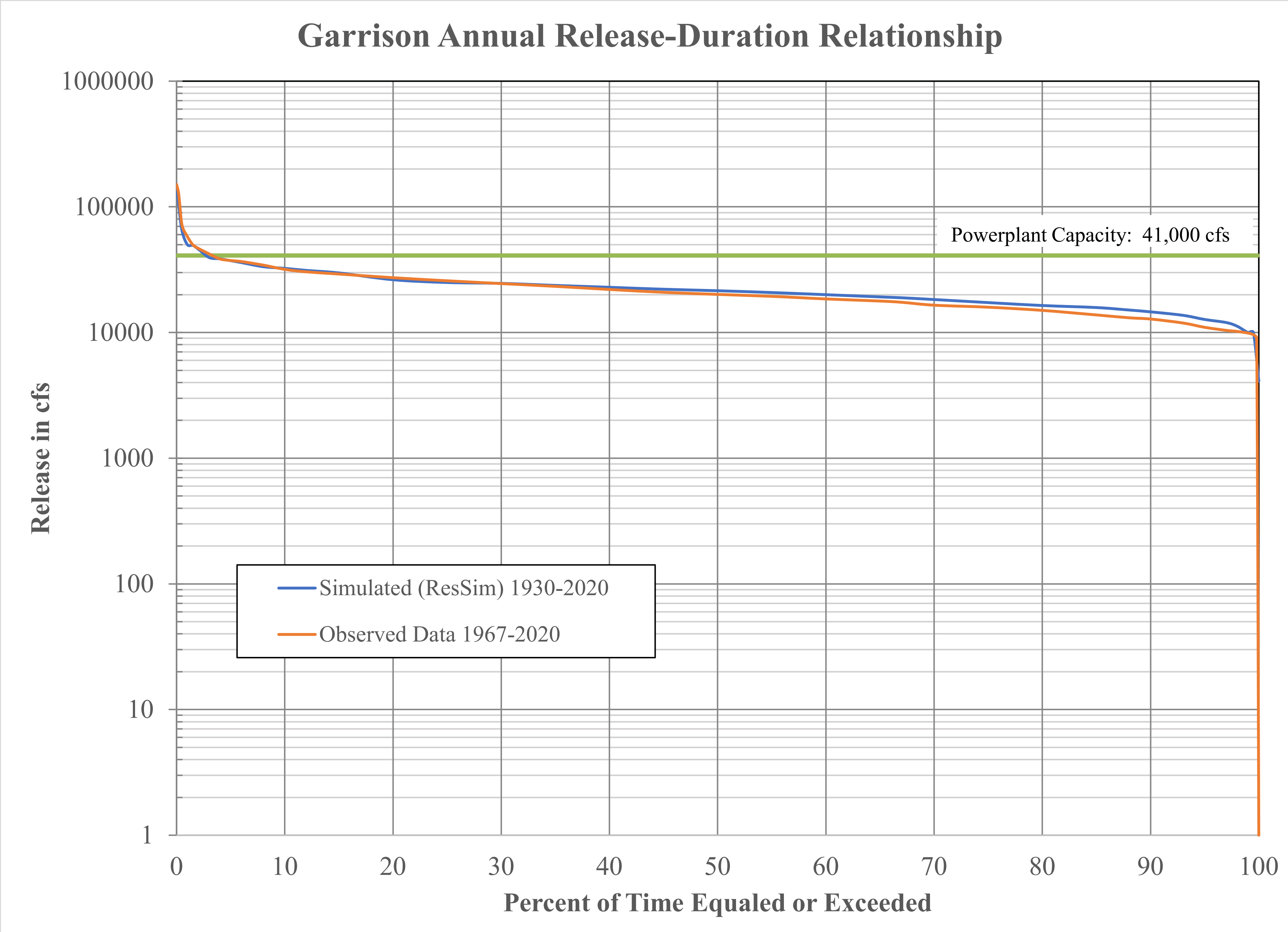

Plate 13. Garrison Annual Release-Duration Relationship.
MRBWM Technical Report - Hydrologic Statistics, May 2022

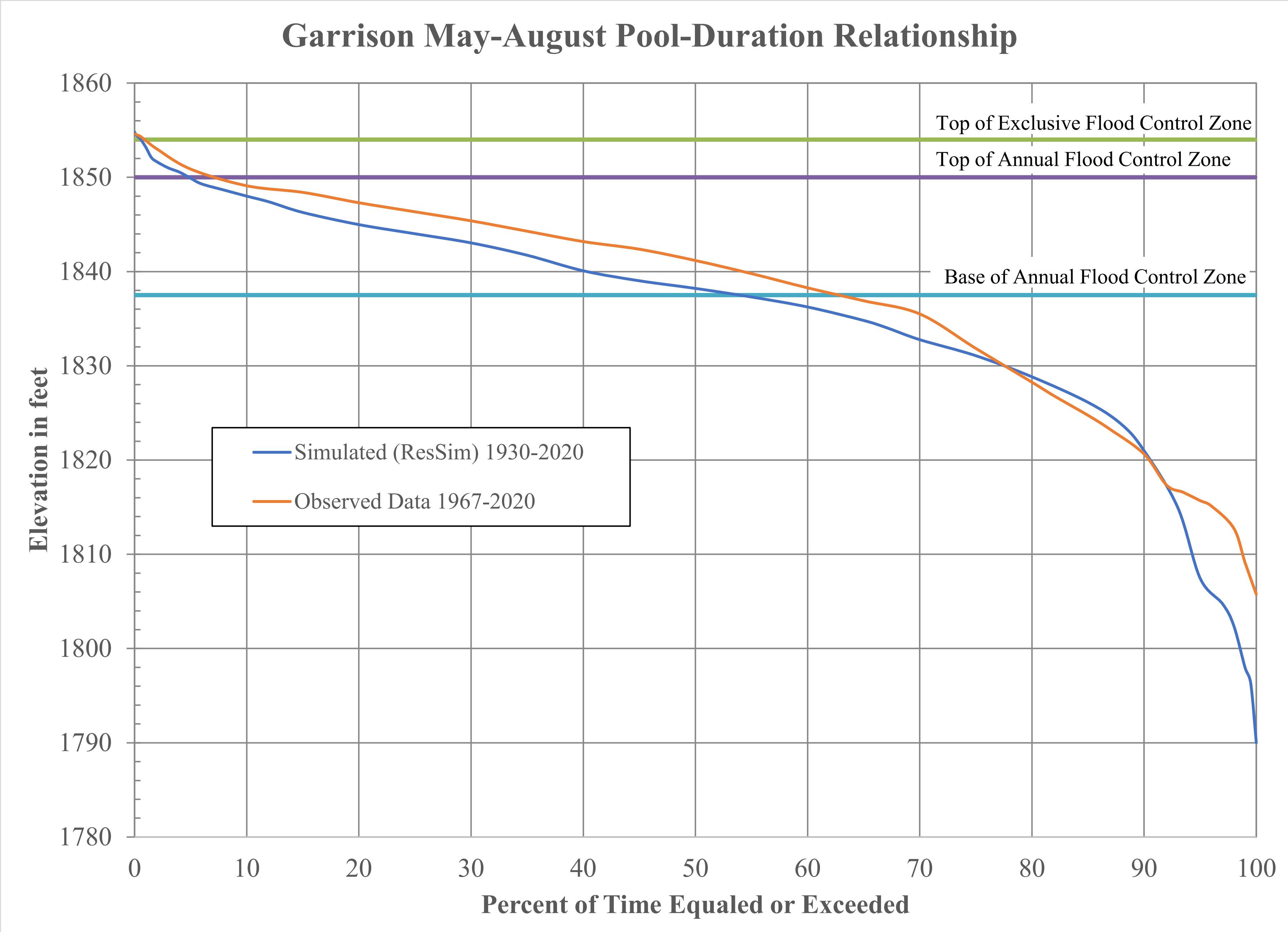

Plate 14. Garrison Pool-Duration Relationship (May-August).
MRBWM Technical Report - Hydrologic Statistics, May 2022

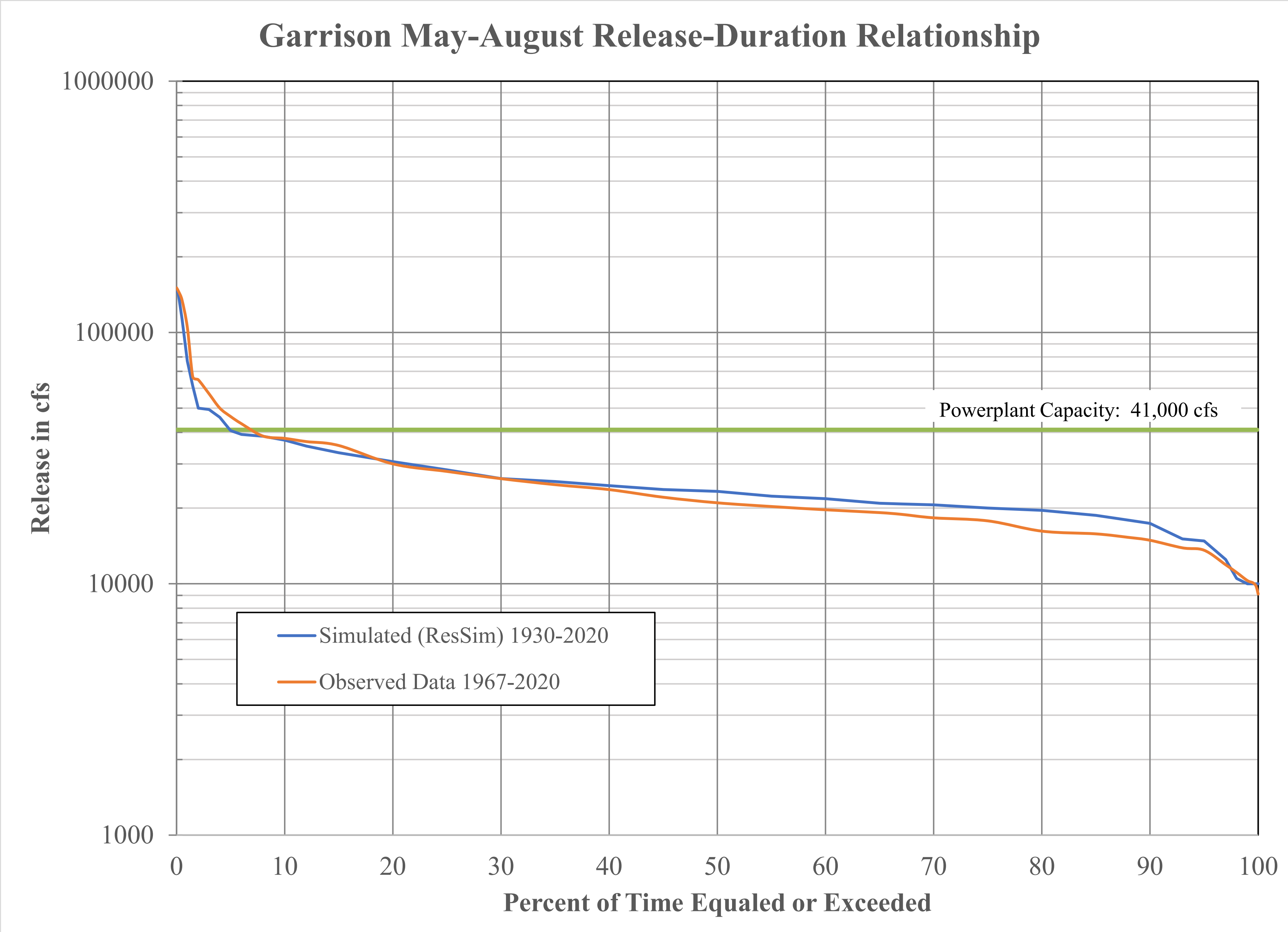

Plate 15. Garrison Release-Duration Relationship (May-August).
MRBWM Technical Report - Hydrologic Statistics, May 2022

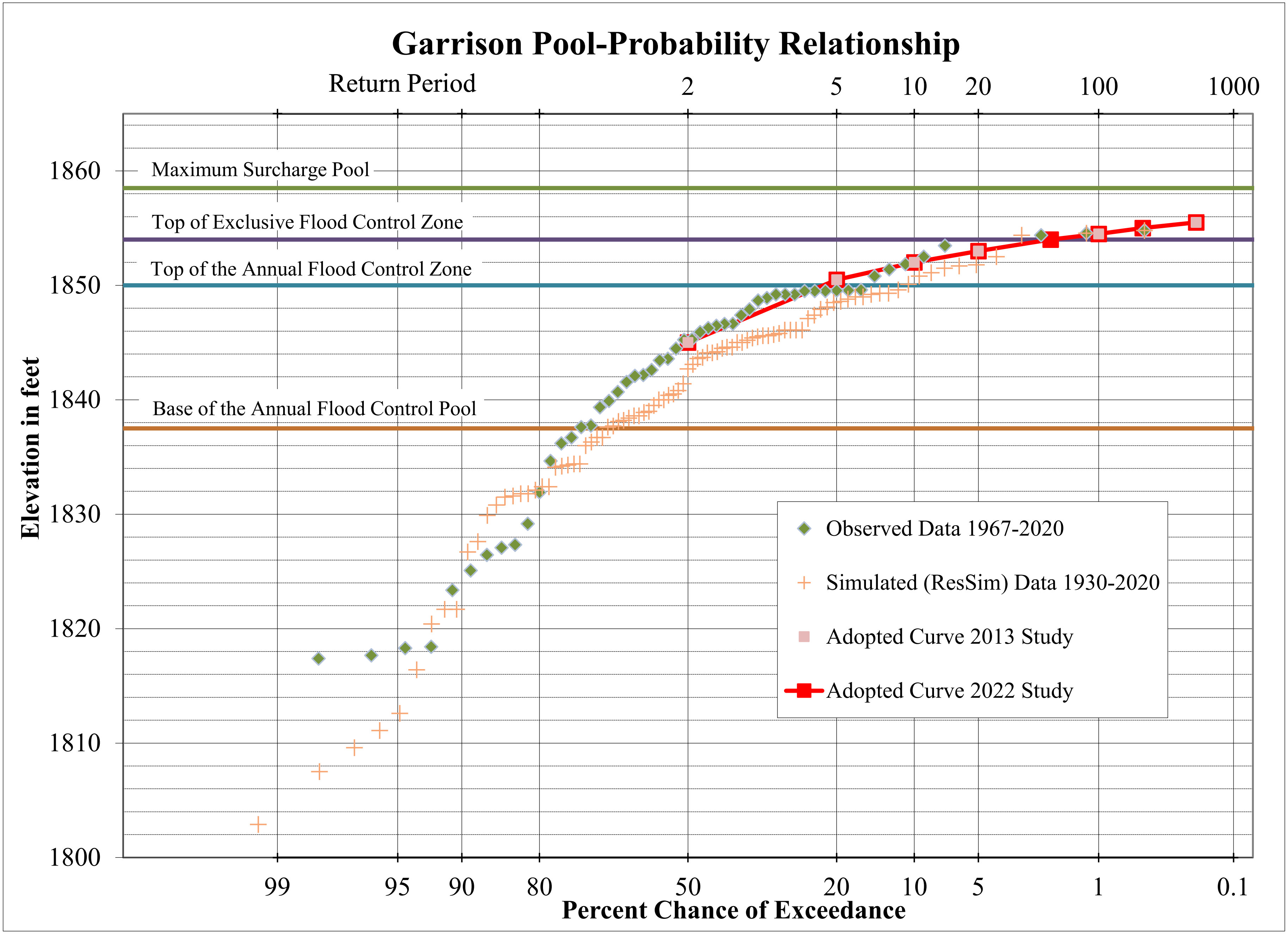

Plate 16. Garrison Pool-Probability Relationship.

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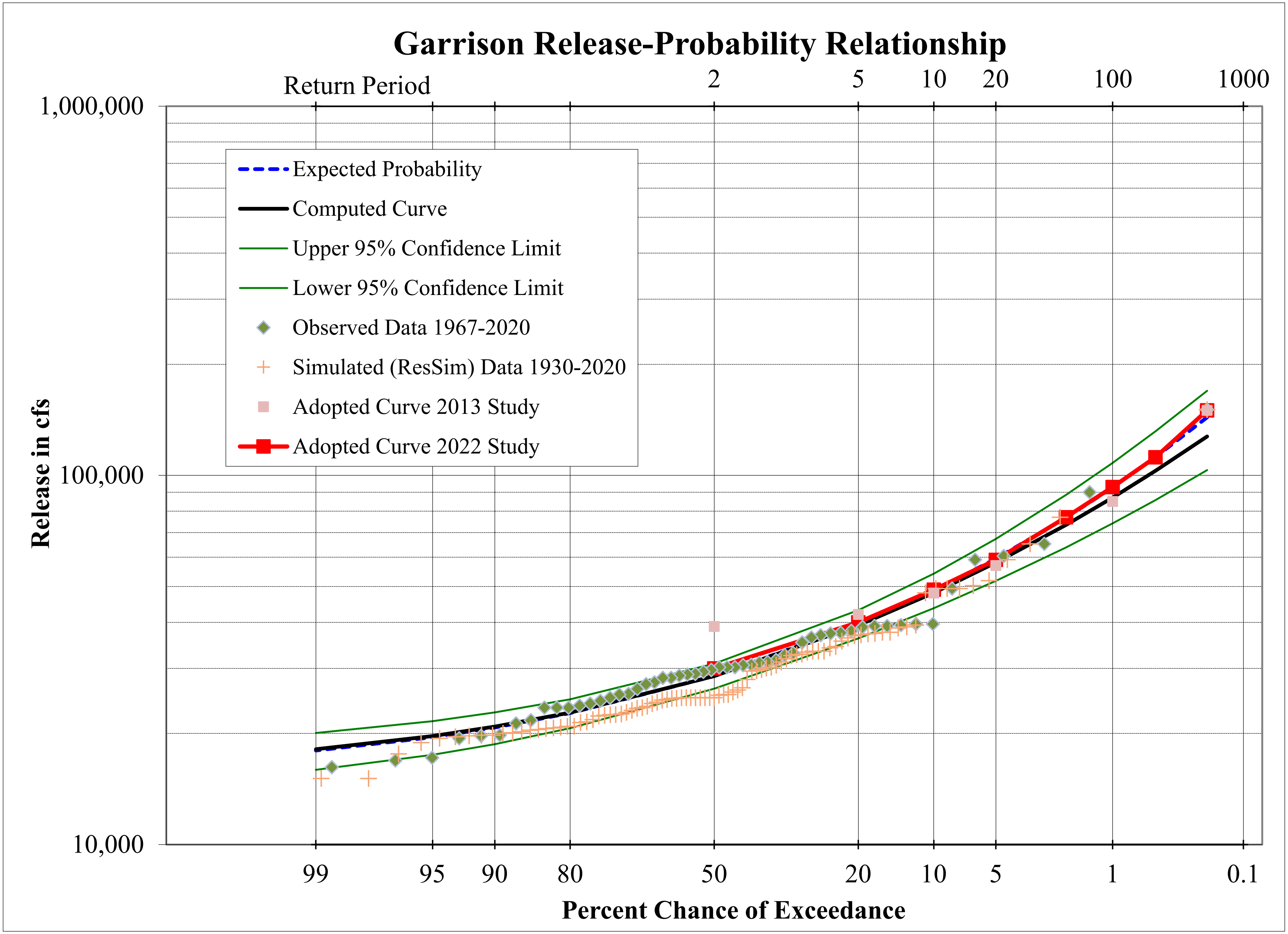

Plate 17. Garrison Release-Probability Relationship.

Garrison Simulated (ResSim Model) Peak Elevations and Releases

Year	Elevation	Release	Year	Elevation	Release	Year	Elevation	Release
1930	1840.4	26,200	1962	1837.6	19,400	1994	1843.7	25,900
1931	1834.2	20,700	1963	1844.6	25,000	1995	1849.6	35,600
1932	1830.8	20,600	1964	1843.1	30,100	1996	1849.3	37,600
1933	1831.8	21,500	1965	1850.8	51,900	1997	1854.4	59,100
1934	1821.7	21,400	1966	1839.5	22,500	1998	1844.5	34,100
1935	1812.6	20,400	1967	1850.1	33,400	1999	1847.9	32,800
1936	1807.5	22,300	1968	1846.1	31,200	2000	1840.0	23,500
1937	1802.9	15,100	1969	1848.6	36,800	2001	1837.7	19,700
1938	1816.4	15,100	1970	1849.3	34,400	2002	1834.4	20,900
1939	1820.4	24,700	1971	1849.0	38,900	2003	1834.1	20,500
1940	1809.6	23,100	1972	1849.0	37,300	2004	1826.7	20,200
1941	1811.1	20,100	1973	1846.1	23,700	2005	1832.1	17,600
1942	1821.7	20,000	1974	1848.1	30,600	2006	1831.6	19,800
1943	1844.1	36,300	1975	1854.8	65,200	2007	1832.4	19,800
1944	1847.1	24,600	1976	1846.1	39,300	2008	1838.6	19,600
1945	1845.2	24,300	1977	1838.1	21,800	2009	1848.5	29,600
1946	1841.4	25,500	1978	1851.8	48,100	2010	1851.1	37,600
1947	1847.4	30,200	1979	1845.6	38,600	2011	1854.6	150,600
1948	1848.8	32,700	1980	1838.4	25,000	2012	1840.5	25,400
1949	1844.1	29,800	1981	1838.9	25,500	2013	1838.6	23,400
1950	1845.5	29,500	1982	1846.1	50,300	2014	1845.6	33,400
1951	1845.0	37,200	1983	1845.8	37,000	2015	1845.0	25,000
1952	1851.7	49,400	1984	1845.7	31,900	2016	1840.8	22,400
1953	1843.6	26,600	1985	1840.0	25,000	2017	1845.4	33,200
1954	1839.0	25,000	1986	1849.2	49,400	2018	1851.5	77,000
1955	1836.7	32,500	1987	1842.7	24,100	2019	1852.5	49,400
1956	1836.0	33,400	1988	1838.2	22,600	2020	1844.6	28,000
1957	1836.7	22,800	1989	1831.8	20,900			
1958	1832.4	22,500	1990	1829.9	20,800			
1959	1834.4	25,000	1991	1836.3	24,900			
1960	1834.3	25,000	1992	1831.5	24,900			
1961	1827.6	18,900	1993	1844.2	25,000			

Plate 18. Garrison Simulated (ResSim Model) Data 1930-2020.
Peak elevations in feet, peak releases in cfs.

Garrison Observed Peak Elevations and Releases

Year	Elevation	Release	Year	Elevation	Release
1967	1849.5	37,900	1994	1845.3	25,500
1968	1847.9	36,400	1995	1851.9	37,500
1969	1850.8	39,100	1996	1849.6	37,300
1970	1849.2	36,900	1997	1854.4	59,100
1971	1849.2	39,300	1998	1843.5	26,400
1972	1849.2	38,800	1999	1847.4	30,200
1973	1849.5	30,700	2000	1840.7	27,200
1974	1849.6	30,600	2001	1834.7	19,400
1975	1854.8	65,200	2002	1831.9	21,700
1976	1848.9	39,100	2003	1827.3	23,500
1977	1839.9	32,600	2004	1818.4	24,100
1978	1849.5	39,600	2005	1817.7	19,700
1979	1846.3	39,600	2006	1817.4	25,000
1980	1842.1	29,700	2007	1818.3	17,200
1981	1836.2	30,200	2008	1826.5	16,200
1982	1845.9	33,000	2009	1842.6	16,900
1983	1846.6	31,100	2010	1851.4	31,200
1984	1849.5	29,400	2011	1854.6	150,600
1985	1841.6	31,600	2012	1839.34	28,300
1986	1848.7	28,700	2013	1836.7	23,800
1987	1843.6	28,300	2014	1846.5	30,200
1988	1837.6	27,500	2015	1845.2	23,500
1989	1827.1	24,500	2016	1842.2	21,300
1990	1823.4	25,600	2017	1846.7	35,300
1991	1829.2	29,000	2018	1853.5	60,500
1992	1825.1	23,500	2019	1852.5	49,400
1993	1837.8	19,800	2020	1844.5	28,900

Plate 19. Garrison Observed Data 1967-2020.
Peak elevations in feet, peak releases in cfs.

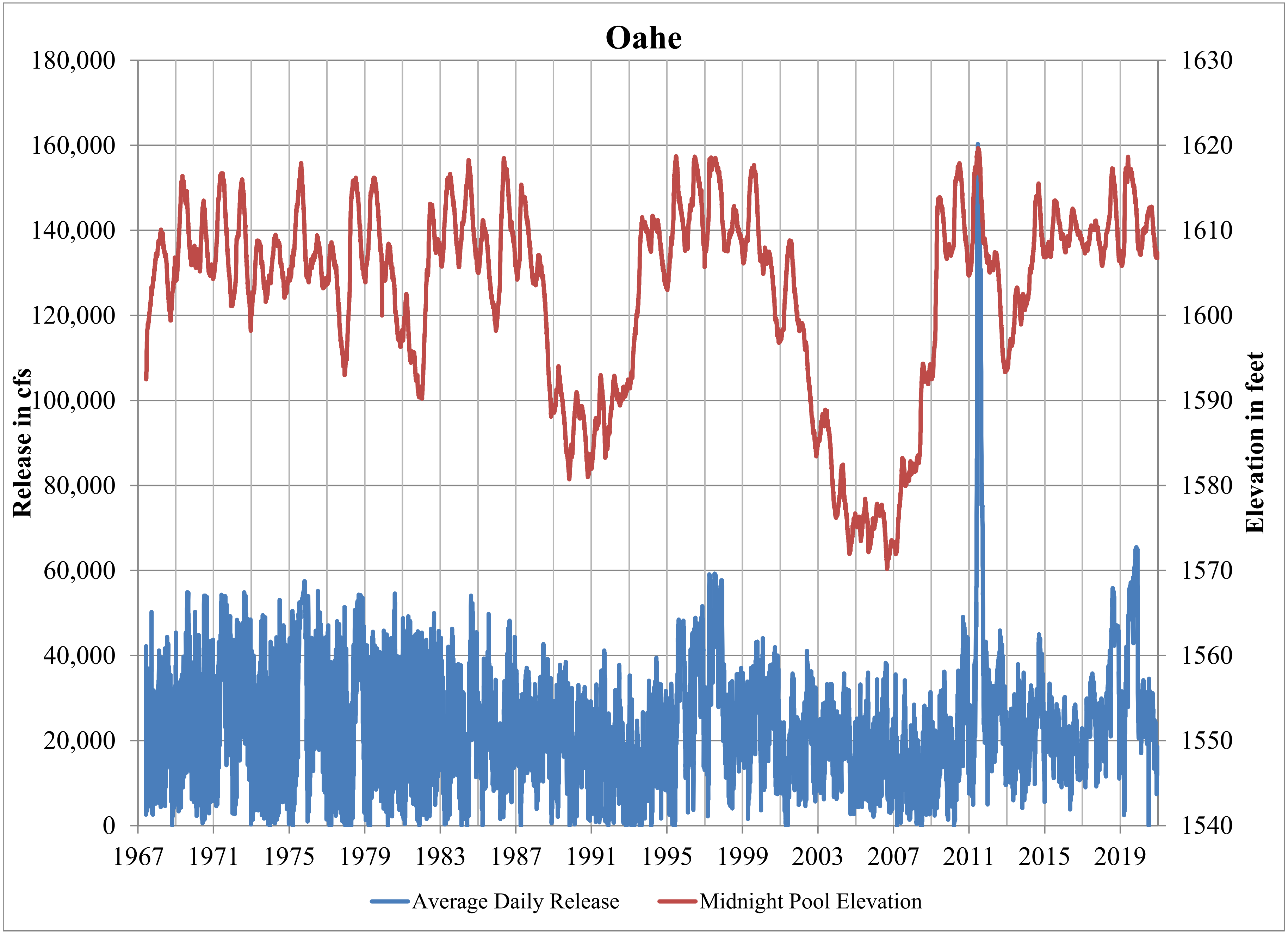

Plate 20. Oahe Daily Releases and Elevations.
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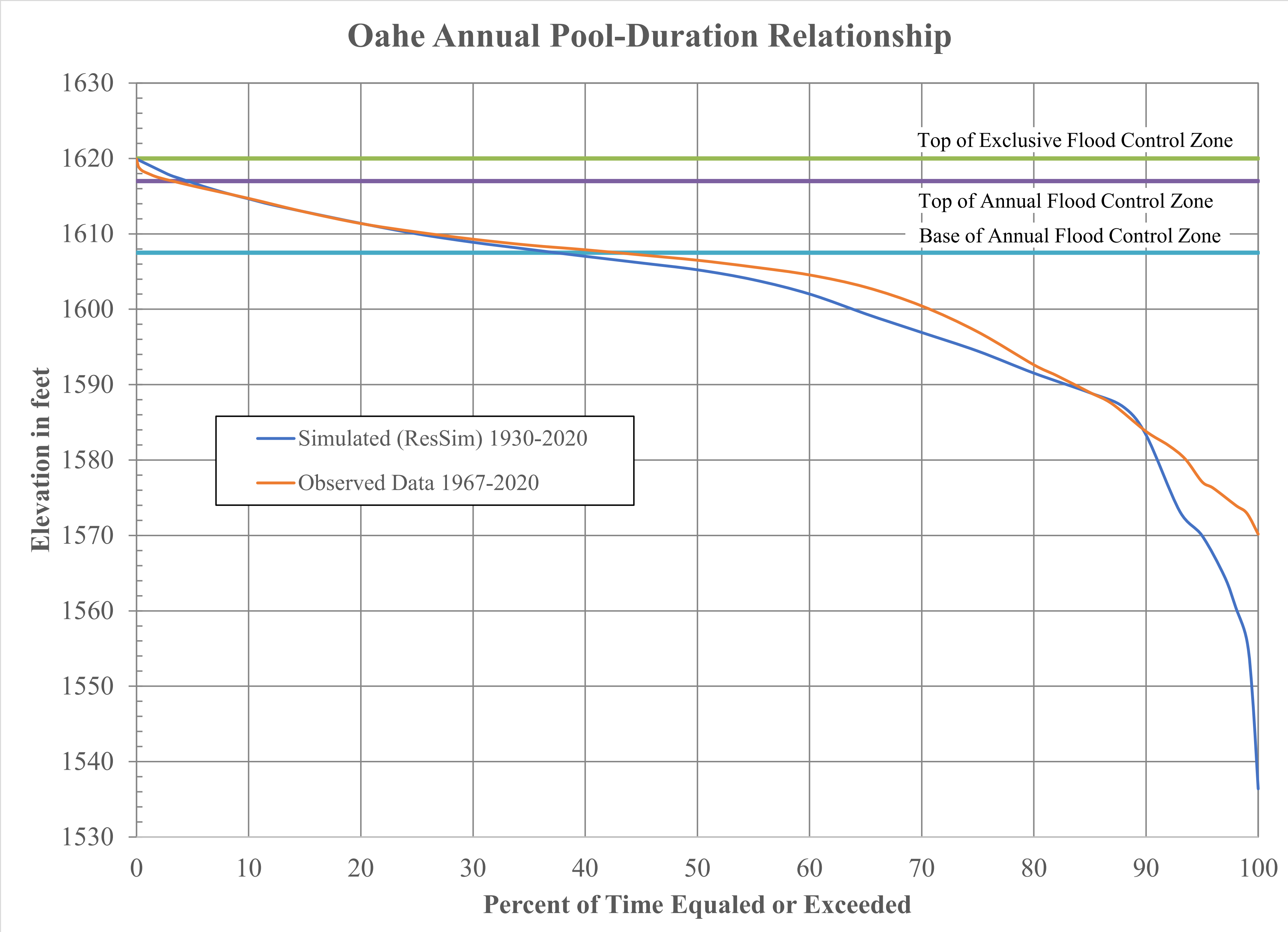

Plate 21. Oahe Annual Pool-Duration Relationship.
MRBWM Technical Report - Hydrologic Statistics, May 2022

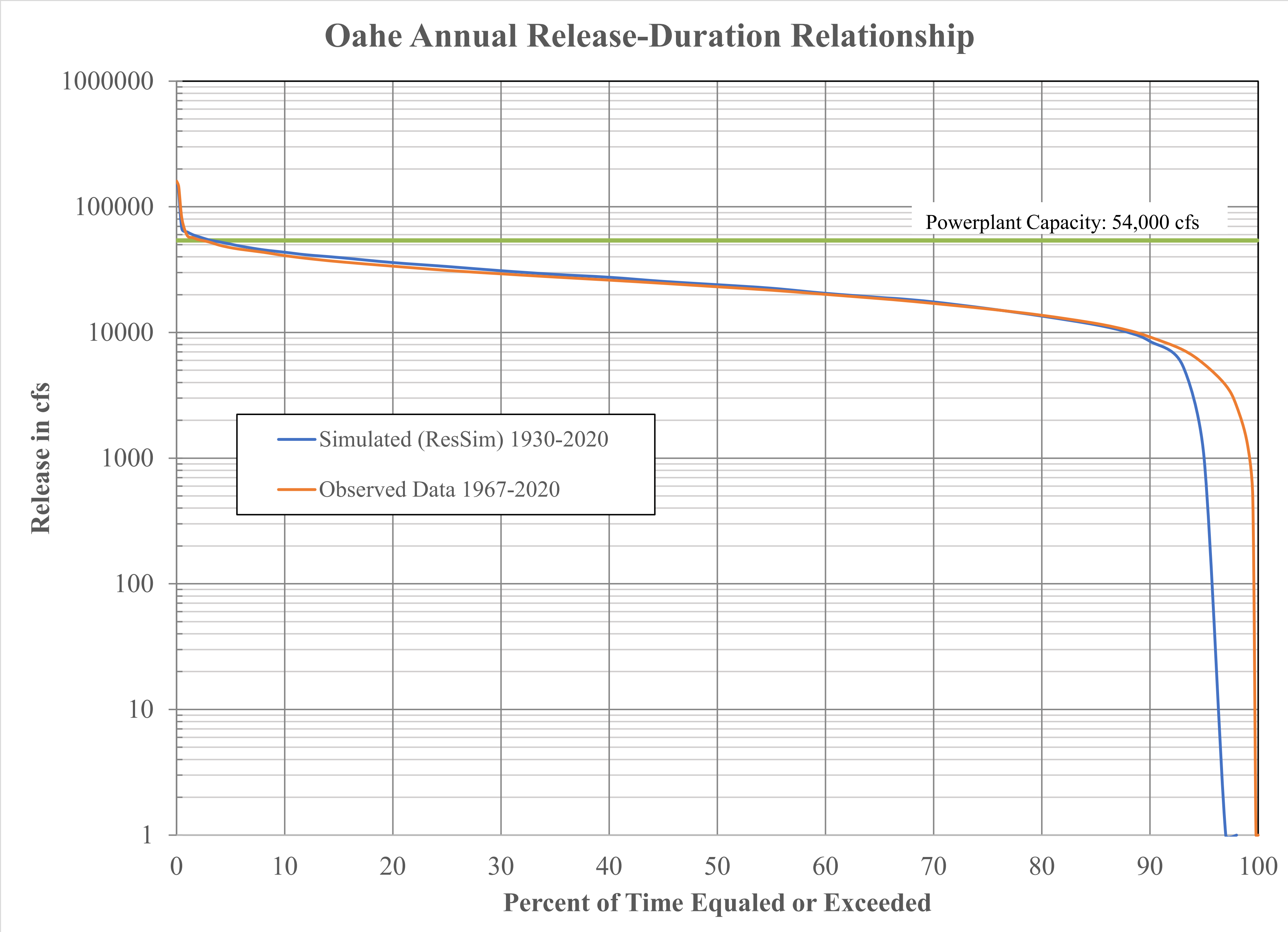

Plate 22. Oahe Annual Release-Duration Relationship.
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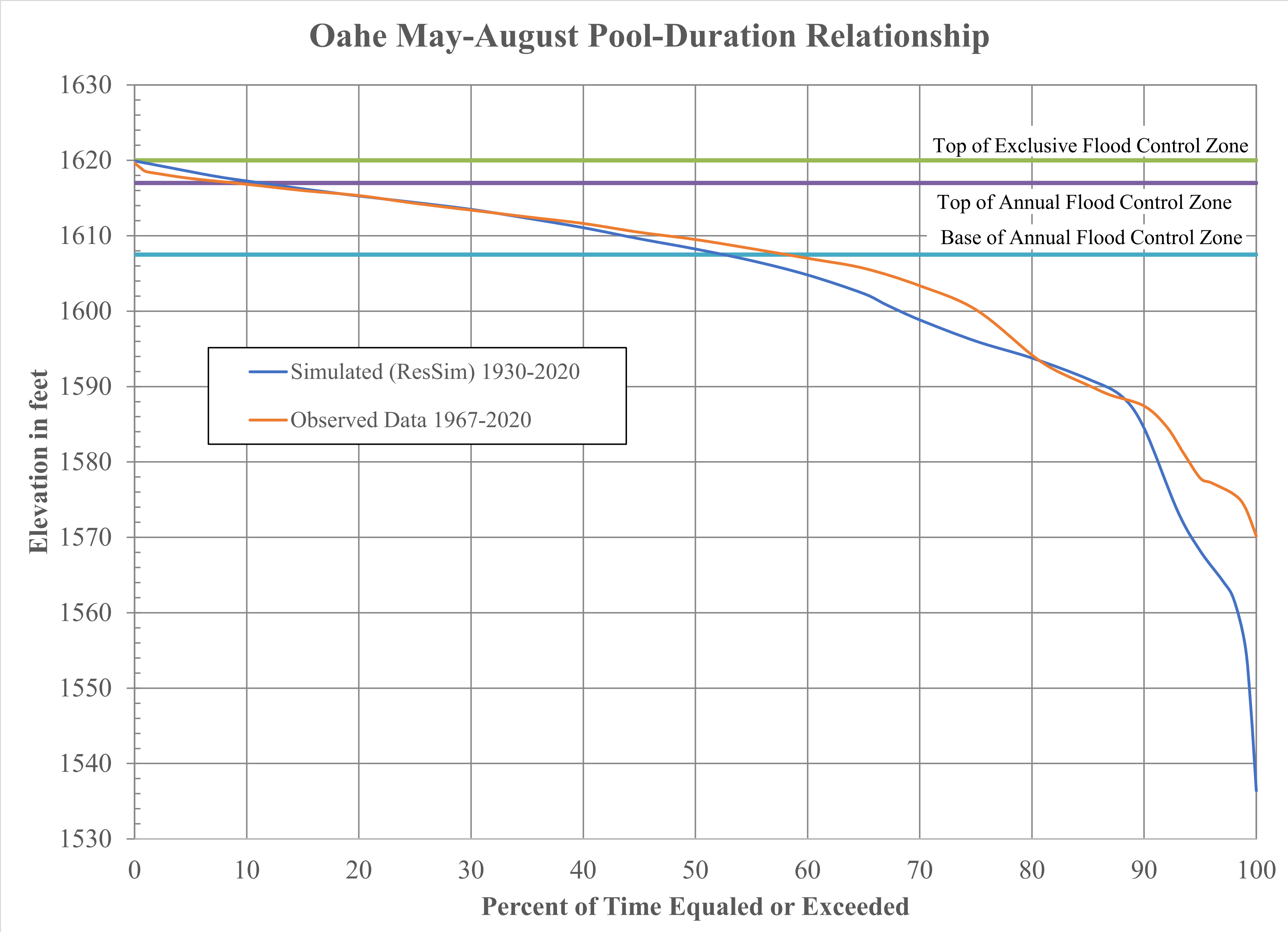

Plate 23. Oahe Pool-Duration Relationship (May-August).

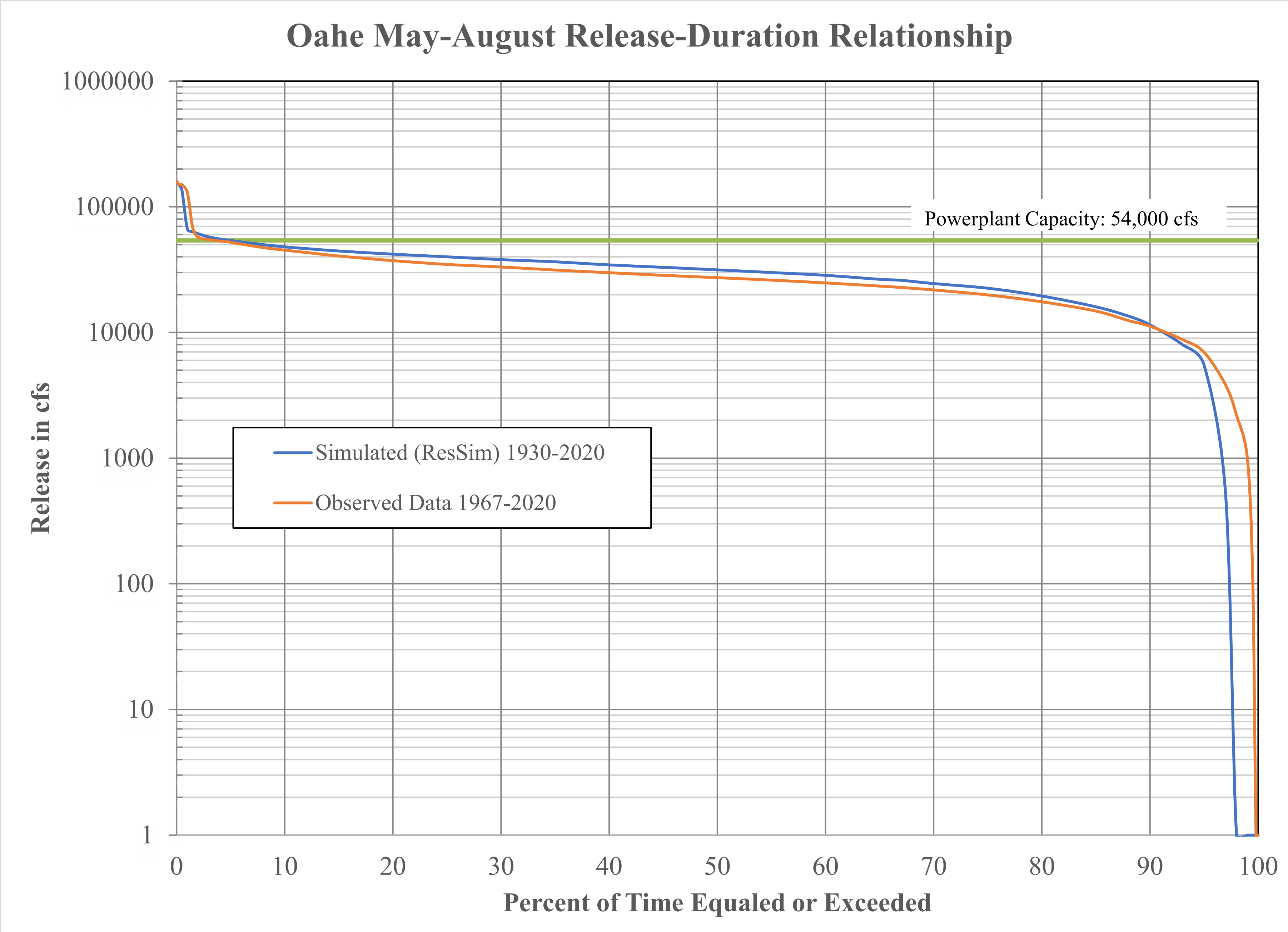

Plate 24. Oahe Release-Duration Relationship (May-August).
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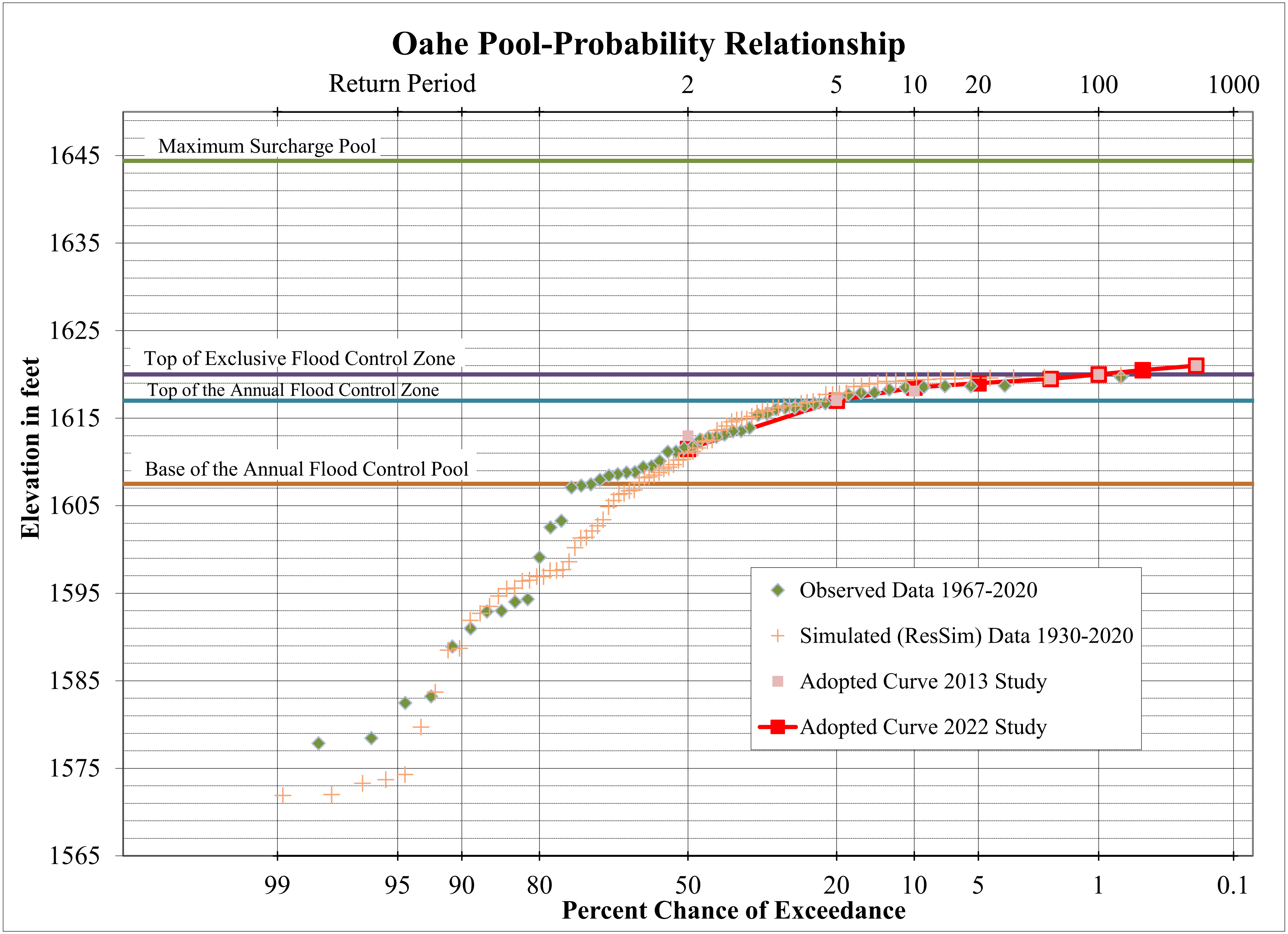

Plate 25. Oahe Pool-Probability Relationship.
MRBWM Technical Report - Hydrologic Statistics, May 2022

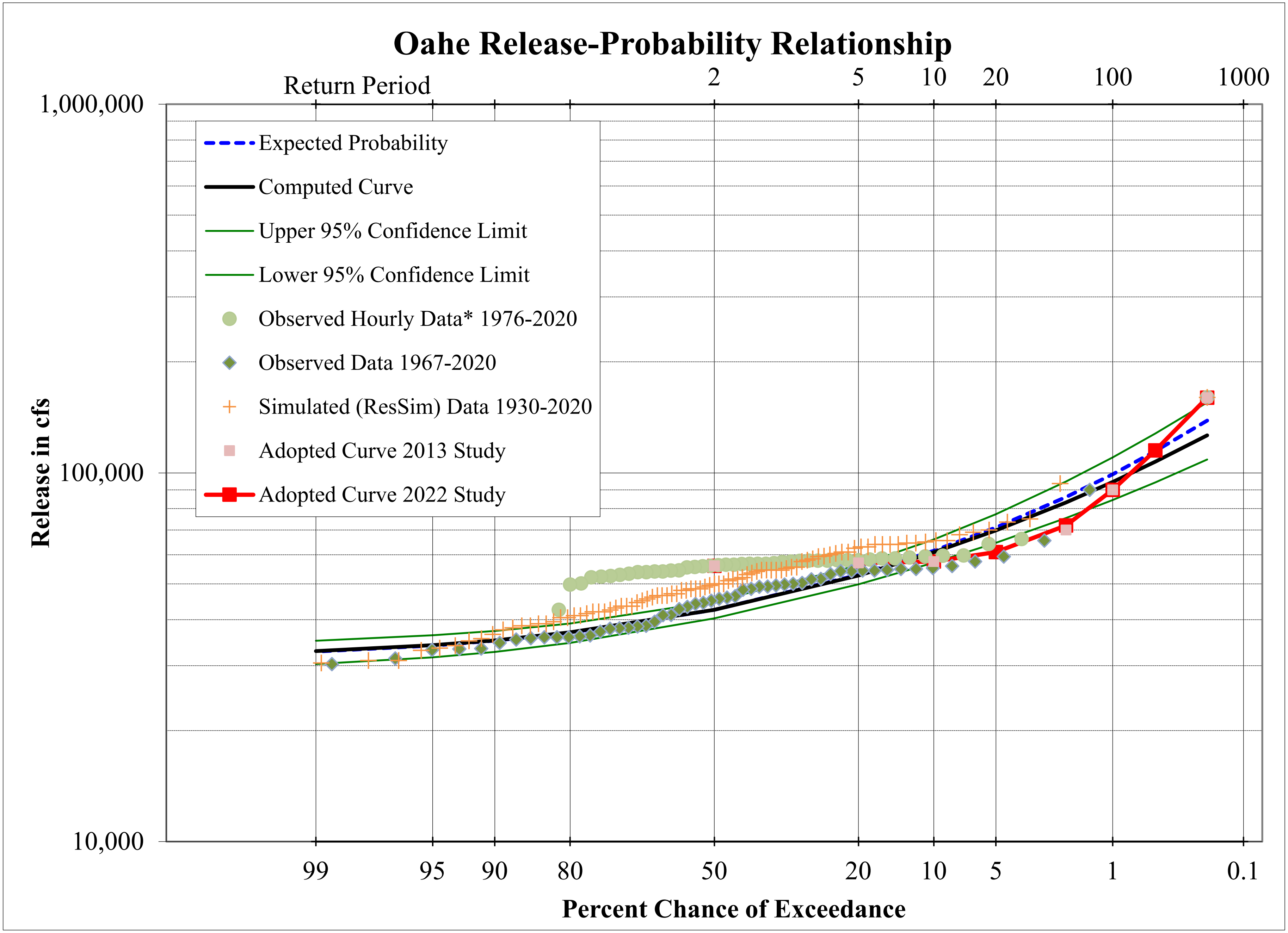

Plate 26. Oahe Release-Probability Relationship.
* Refer to Section VI. D. for details regarding hourly releases.
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Oahe Simulated (ResSim Model) Peak Elevations and Releases

Year	Elevation	Release	Year	Elevation	Release	Year	Elevation	Release
1930	1609.7	50,000	1962	1612.5	48,500	1994	1614.9	42,000
1931	1602.1	44,500	1963	1605.6	51,000	1995	1619.3	69,000
1932	1594.7	43,500	1964	1606.4	48,000	1996	1616.9	54,000
1933	1591.9	48,500	1965	1611.2	61,000	1997	1618.6	59,300
1934	1588.7	51,500	1966	1614.1	48,500	1998	1617.8	64,000
1935	1574.3	46,500	1967	1614.8	64,000	1999	1615.6	64,500
1936	1572.0	53,500	1968	1609.4	49,000	2000	1610.2	41,000
1937	1573.7	30,500	1969	1619.2	64,500	2001	1616.9	42,000
1938	1579.7	31,000	1970	1613.7	62,500	2002	1603.4	40,500
1939	1583.7	47,000	1971	1615.9	60,000	2003	1596.9	35,500
1940	1573.3	50,000	1972	1615.8	53,000	2004	1595.5	33,000
1941	1571.9	31,000	1973	1616.2	47,000	2005	1595.6	34,000
1942	1588.5	38,500	1974	1611.0	54,500	2006	1597.6	39,000
1943	1596.9	52,000	1975	1617.9	57,500	2007	1602.7	33,500
1944	1615.2	55,000	1976	1606.8	58,000	2008	1608.3	35,000
1945	1616.4	49,500	1977	1608.5	38,000	2009	1619.9	73,500
1946	1608.2	63,000	1978	1617.7	65,000	2010	1619.5	64,000
1947	1614.9	63,000	1979	1612.3	50,000	2011	1619.7	160,300
1948	1612.4	54,500	1980	1609.2	46,000	2012	1608.8	42,000
1949	1616.4	51,500	1981	1604.9	46,500	2013	1606.7	37,500
1950	1618.9	65,500	1982	1619.0	93,500	2014	1616.4	54,500
1951	1619.4	70,000	1983	1619.4	54,500	2015	1617.7	48,000
1952	1619.6	75,000	1984	1619.2	55,500	2016	1616.2	36,500
1953	1616.7	64,000	1985	1611.6	41,500	2017	1613.6	60,500
1954	1606.3	54,500	1986	1619.6	68,000	2018	1614.6	61,000
1955	1601.3	55,500	1987	1619.5	43,500	2019	1618.7	65,500
1956	1592.7	45,000	1988	1610.3	46,500	2020	1616.8	58,500
1957	1593.5	43,500	1989	1598.6	42,500			
1958	1597.7	39,500	1990	1596.5	38,500			
1959	1596.4	40,500	1991	1600.2	41,000			
1960	1607.6	45,500	1992	1601.4	43,000			
1961	1597.6	39,000	1993	1619.7	59,500			

Plate 27. Oahe Simulated (ResSim Model) Data 1930-2020.
Peak elevations in feet, peak releases in cfs.

Oahe Observed Peak Elevations and Releases

Year	Elevation	Release	Hourly Release	Year	Elevation	Release	Hourly Release
1967	1607.3	50,300		1994	1611.7	39,500	55,400
1968	1610.1	44,400		1995	1618.7	48,500	56,700
1969	1616.4	54,900		1996	1618.7	51,600	58,000
1970	1613.5	54,100		1997	1618.6	59,300	64,200
1971	1616.7	54,300		1998	1612.9	37,900	56,600
1972	1616.0	54,900		1999	1617.7	43,300	57,500
1973	1608.8	49,500		2000	1608.0	44,100	58,600
1974	1609.5	53,100		2001	1608.8	35,800	58,600
1975	1617.9	57,500		2002	1599.1	41,100	56,000
1976	1609.4	55,200	58,000	2003	1588.9	33,300	53,800
1977	1608.6	51,400	56,200	2004	1582.5	35,800	53,800
1978	1616.2	54,300	57,800	2005	1578.4	36,000	52,300
1979	1616.2	45,600	56,700	2006	1577.9	38,300	53,300
1980	1608.4	54,600	56,400	2007	1583.2	35,600	54,000
1981	1602.5	49,200	57,300	2008	1594.3	31,400	49,800
1982	1613.1	50,000	58,200	2009	1613.9	36,200	59,400
1983	1616.6	46,300	54,000	2010	1617.9	49,100	59,700
1984	1618.3	54,100	56,700	2011	1619.7	160,300	160,500
1985	1611.2	49,800	56,900	2012	1607.5	45,900	57,704
1986	1618.5	48,200	57,800	2013	1603.3	38,000	55,818
1987	1615.4	37,100	57,800	2014	1615.5	45,000	58,963
1988	1607.1	42,700	56,400	2015	1613.5	33,400	52,537
1989	1594.0	38,500	55,600	2016	1612.6	30,300	42,519
1990	1591.0	33,100	54,300	2017	1611.2	35,800	58,007
1991	1593.0	41,200	54,400	2018	1617.3	55,900	59,624
1992	1592.9	37,800	52,100	2019	1618.7	65,500	66,156
1993	1611.6	35,300	52,900	2020	1612.8	34,600	50,137

Plate 28. Oahe Observed Data 1967-2020.

Peak Elevations in feet, Peak Releases in cfs

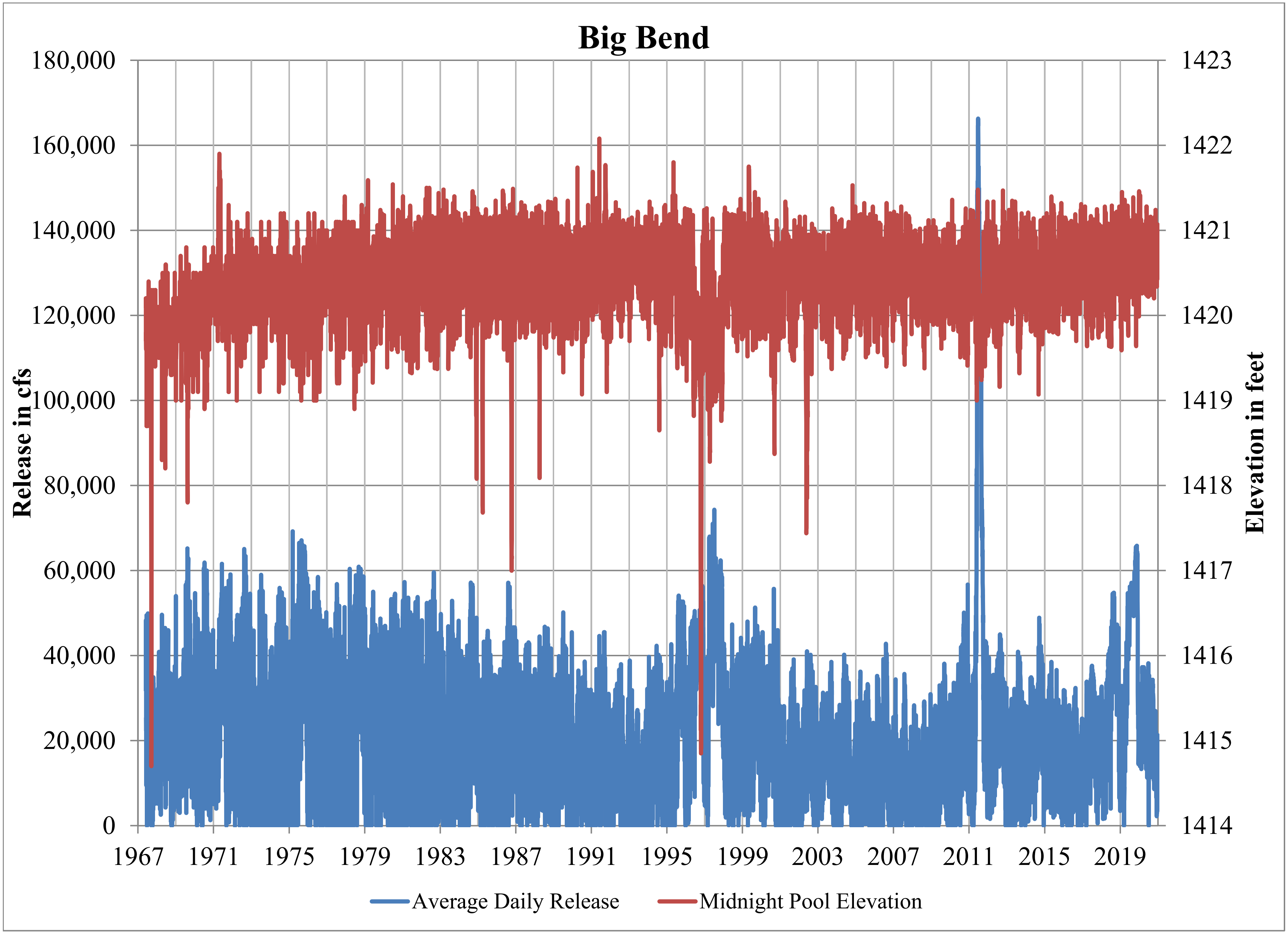

Plate 29. Big Bend Daily Releases and Elevations.

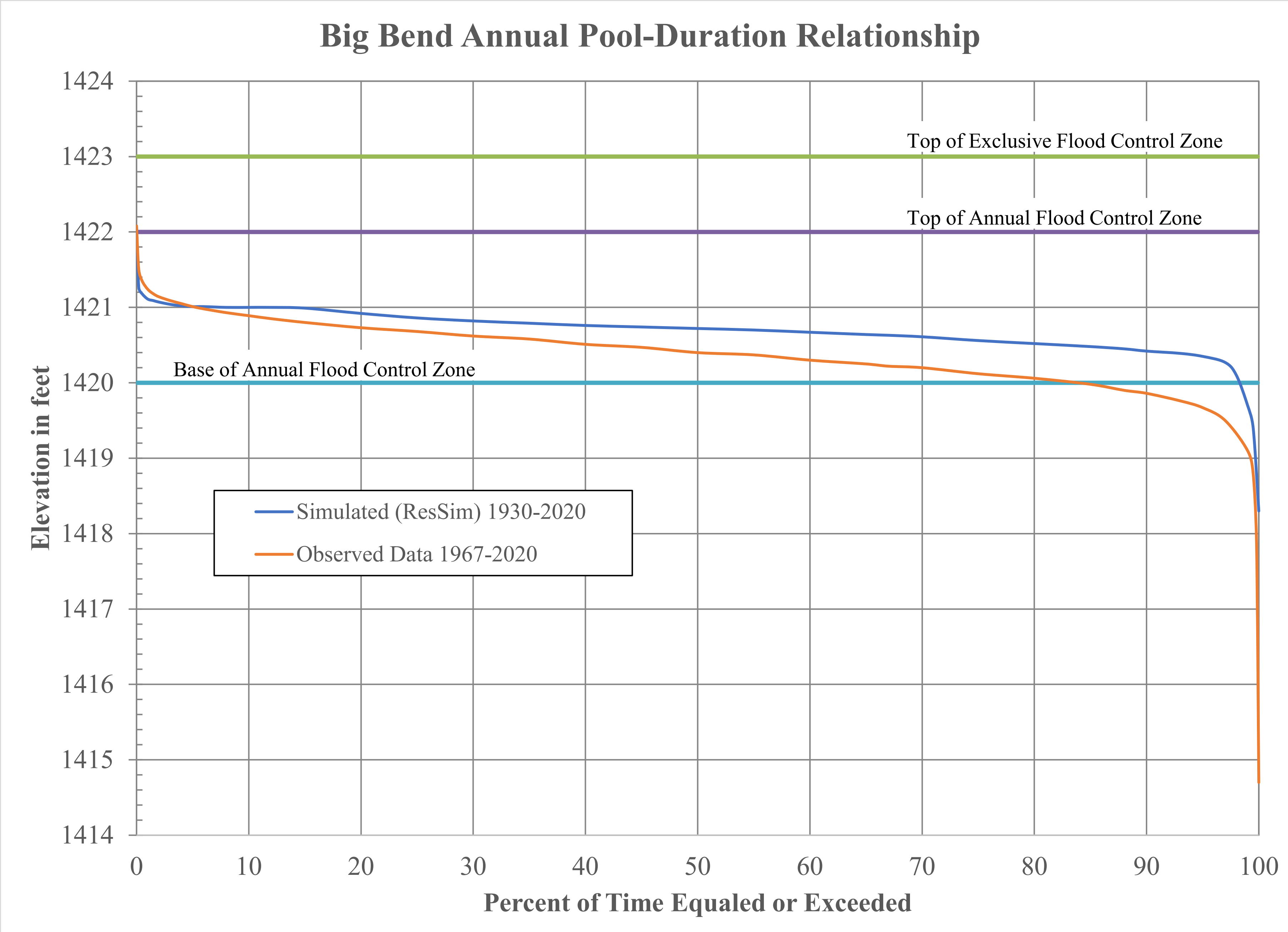

Plate 30. Big Bend Annual Pool-Duration Relationship.
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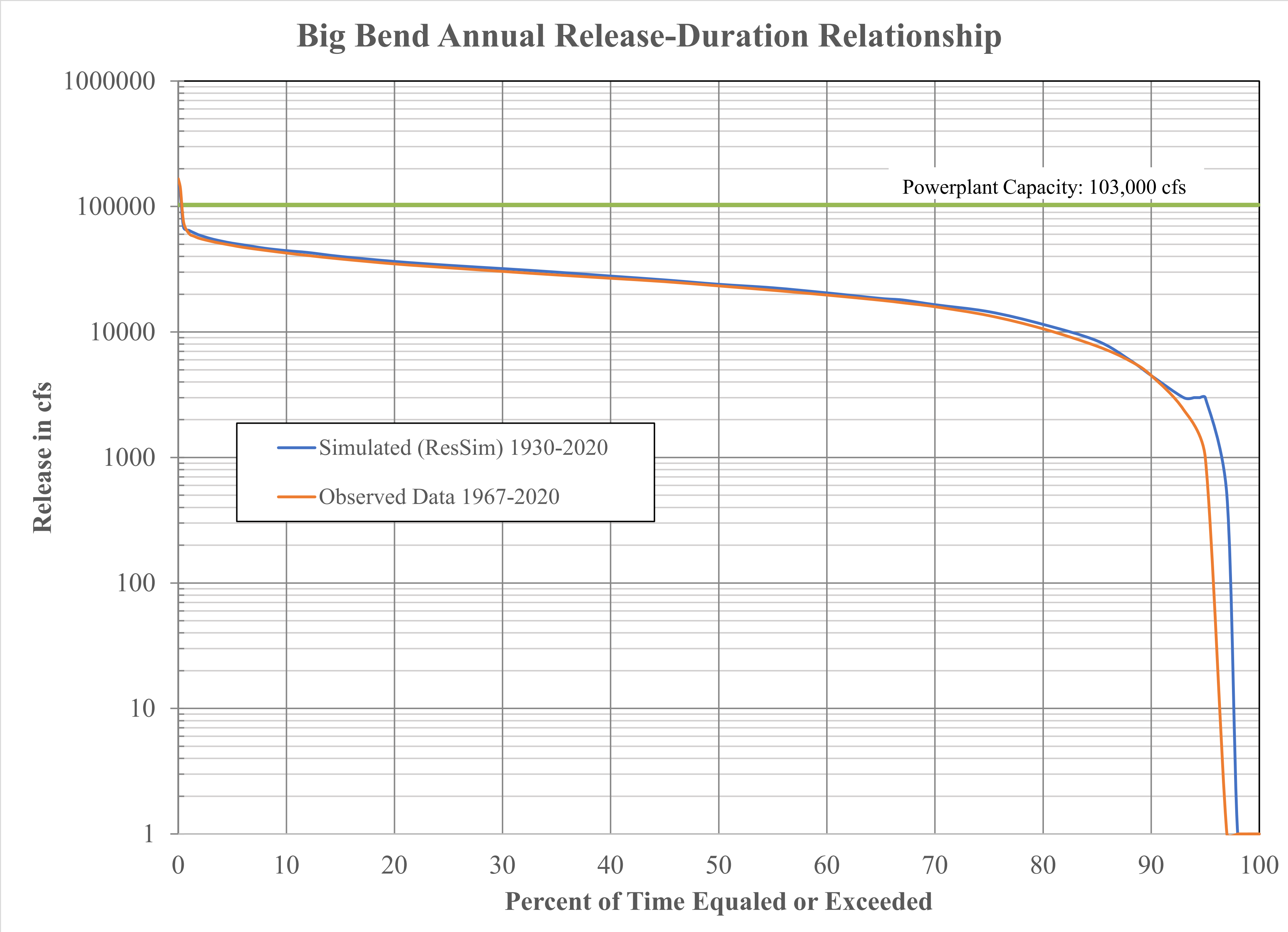

Plate 31. Big Bend Annual Release-Duration Relationship.
MRBWM Technical Report - Hydrologic Statistics, May 2022

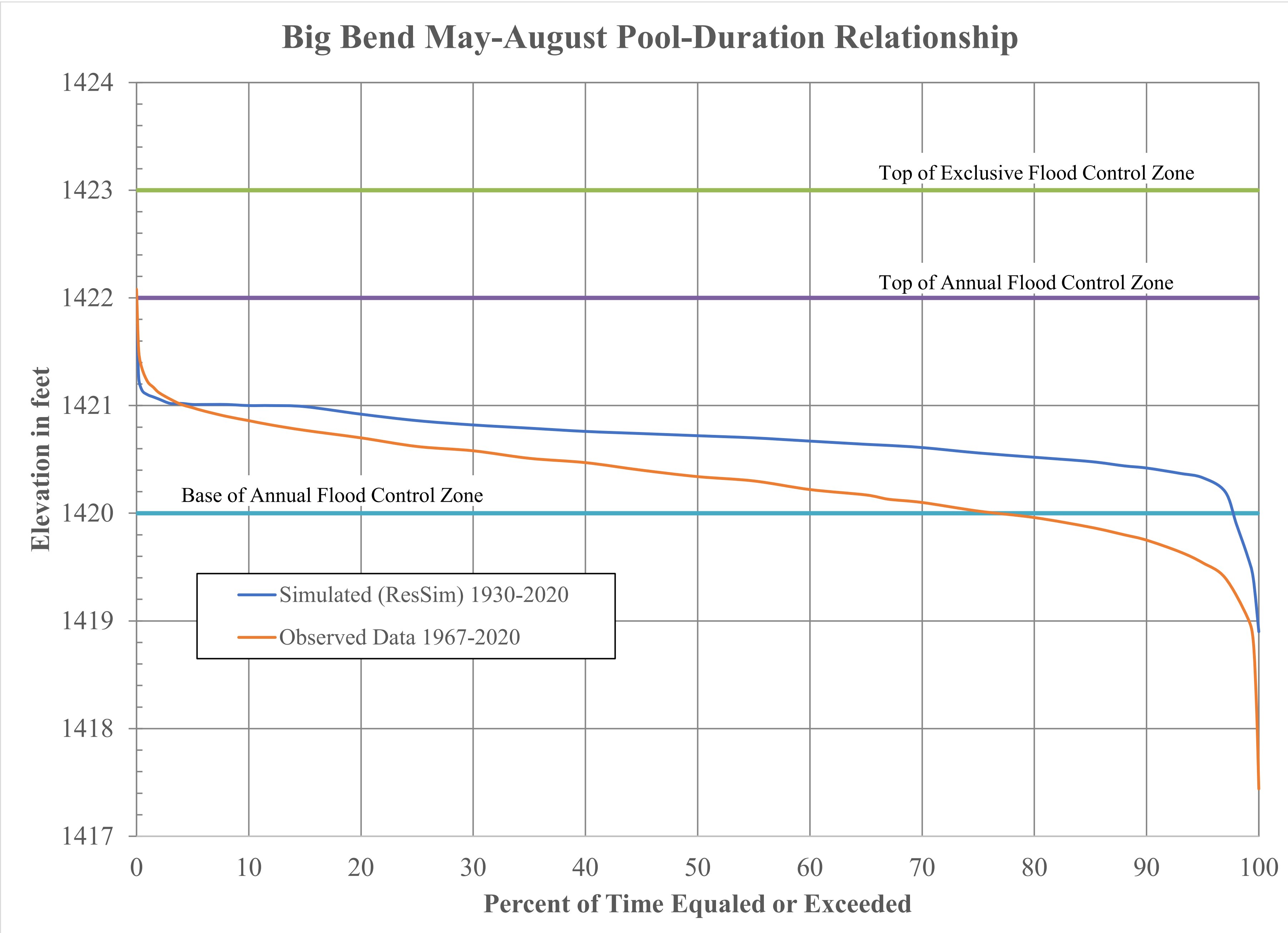

Plate 32. Big Bend Pool-Duration Relationship (May-August).
MRBWM Technical Report - Hydrologic Statistics, May 2022

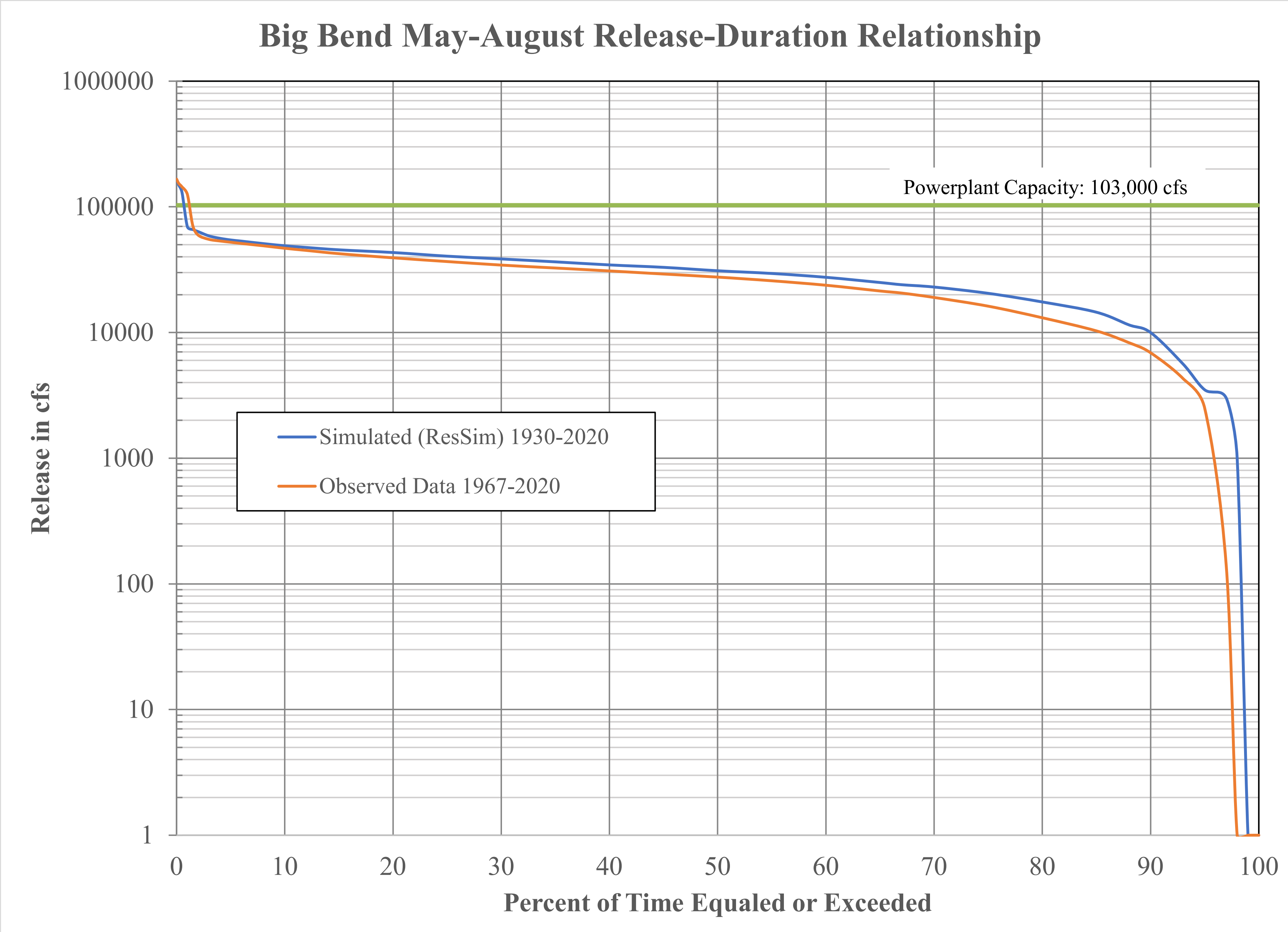

Plate 33. Big Bend Release-Duration Relationship (May-August).
MRBWM Technical Report - Hydrologic Statistics, May 2022

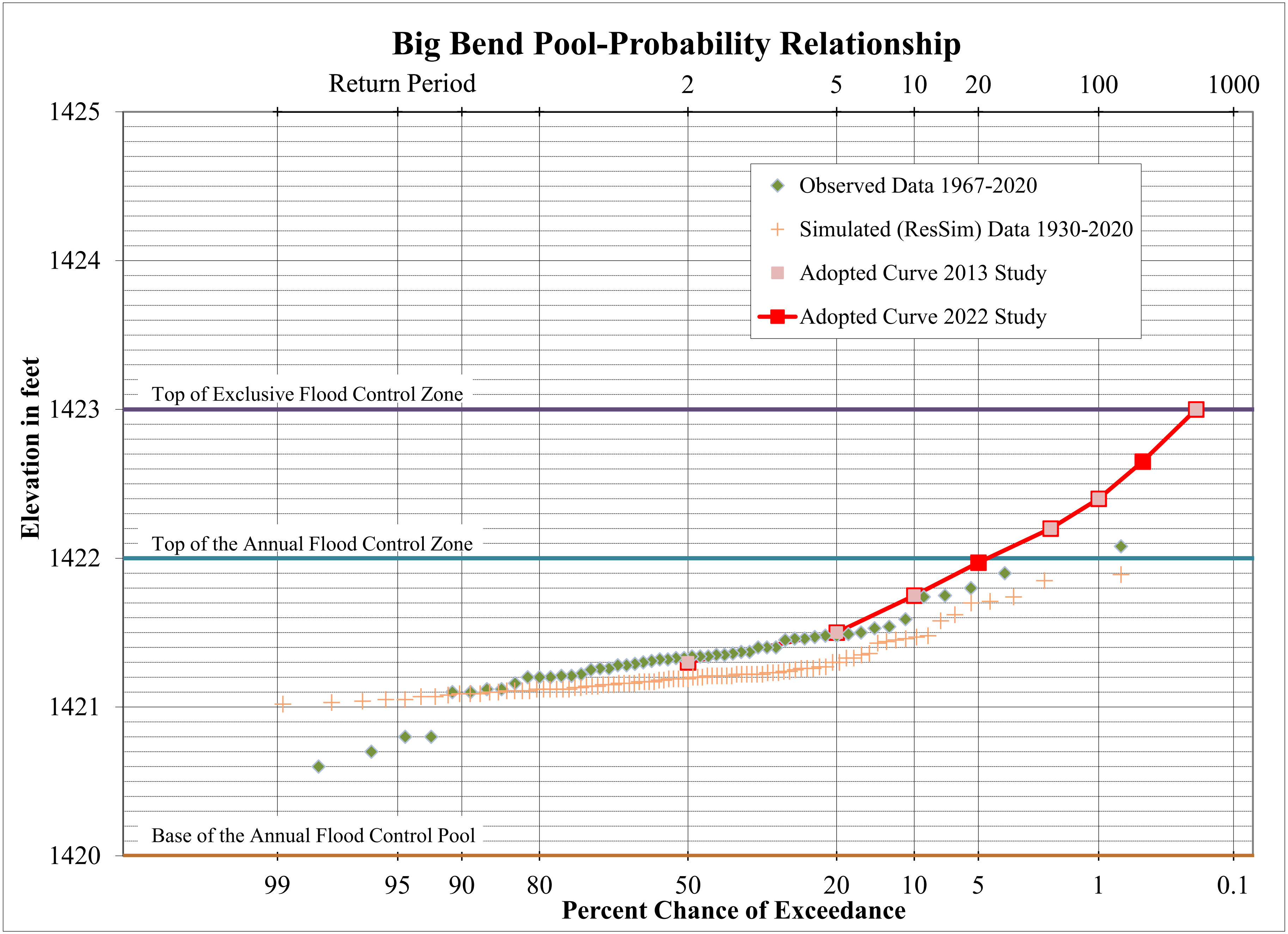

Plate 34. Big Bend Pool-Probability Relationship.
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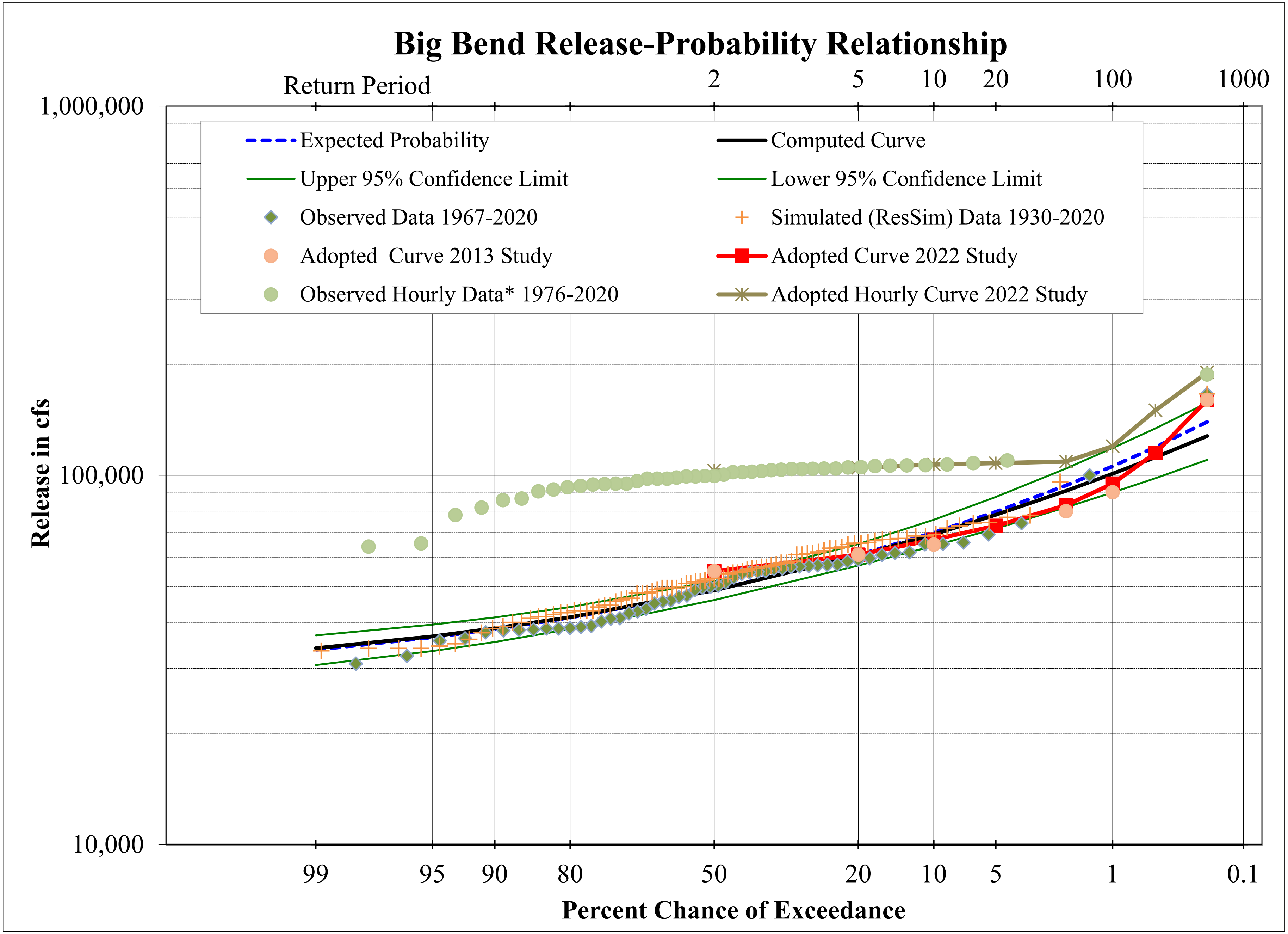

Plate 35. Big Bend Release-Probability Relationship.
* Refer to Section VII. D. for details regarding hourly releases.

Big Bend Simulated (ResSim Model) Peak Elevations and Releases

Year	Elevation	Release	Year	Elevation	Release	Year	Elevation	Release
1930	1421.1	52,500	1962	1421.1	51,500	1994	1421.3	44,500
1931	1421.1	48,000	1963	1421.2	54,000	1995	1421.9	77,000
1932	1421.2	46,500	1964	1421.3	52,000	1996	1421.1	56,500
1933	1421.3	51,000	1965	1421.1	64,000	1997	1421.3	74,300
1934	1421.2	54,500	1966	1421.4	51,000	1998	1421.3	67,500
1935	1421.2	49,000	1967	1421.4	67,000	1999	1421.1	67,500
1936	1421.2	56,500	1968	1421.1	51,500	2000	1421.2	43,000
1937	1421.2	33,500	1969	1421.2	67,000	2001	1421.2	43,000
1938	1421.1	34,000	1970	1421.0	63,500	2002	1421.2	41,500
1939	1421.2	49,500	1971	1421.0	63,500	2003	1421.2	37,500
1940	1421.2	52,500	1972	1421.0	56,000	2004	1421.2	34,000
1941	1421.4	34,000	1973	1421.3	50,000	2005	1421.4	35,000
1942	1421.6	41,500	1974	1421.2	56,000	2006	1421.2	40,000
1943	1421.1	55,000	1975	1421.1	69,200	2007	1421.2	34,500
1944	1421.1	58,000	1976	1421.1	61,000	2008	1421.2	36,000
1945	1421.1	52,500	1977	1421.1	40,000	2009	1421.7	74,500
1946	1421.1	65,500	1978	1421.7	68,500	2010	1421.7	65,000
1947	1421.2	65,500	1979	1421.1	52,500	2011	1421.5	166,300
1948	1421.1	57,500	1980	1421.1	48,500	2012	1421.2	43,000
1949	1421.2	54,500	1981	1421.2	49,500	2013	1421.2	39,000
1950	1421.5	68,500	1982	1421.9	96,000	2014	1421.2	55,500
1951	1421.1	73,000	1983	1421.1	58,000	2015	1421.2	49,500
1952	1421.6	78,000	1984	1421.3	61,500	2016	1421.3	38,500
1953	1421.2	66,500	1985	1421.2	44,000	2017	1421.2	61,500
1954	1421.1	57,000	1986	1421.5	72,000	2018	1421.2	61,000
1955	1421.1	58,500	1987	1421.3	46,000	2019	1421.5	65,800
1956	1421.1	48,000	1988	1421.2	49,500	2020	1421.2	62,000
1957	1421.2	46,500	1989	1421.2	44,500			
1958	1421.1	42,500	1990	1421.2	41,000			
1959	1421.2	43,000	1991	1421.2	42,500			
1960	1421.1	48,000	1992	1421.2	45,500			
1961	1421.2	42,000	1993	1421.3	62,500			

Plate 36. Big Bend Simulated (ResSim Model) Data 1930-2020.
Peak elevations in feet, peak releases in cfs.

Big Bend Observed Peak Elevations and Releases

Year	Elevation	Release	Hourly Release	Year	Elevation	Release	Hourly Release
1967	1420.7	49,900		1994	1421.3	42,300	99,600
1968	1420.6	49,600		1995	1421.8	54,100	103,600
1969	1420.8	65,200		1996	1421.3	56,400	104,100
1970	1420.8	61,900		1997	1421.3	74,300	106,400
1971	1421.9	61,600		1998	1421.4	47,300	102,300
1972	1421.2	65,100		1999	1421.8	51,300	108,000
1973	1421.1	59,000		2000	1421.2	55,700	102,000
1974	1421.2	55,900		2001	1421.3	39,100	99,400
1975	1421.1	69,200		2002	1421.2	41,000	99,300
1976	1421.2	58,500	106,600	2003	1421.3	38,500	91,600
1977	1421.4	56,800	109,800	2004	1421.5	40,200	92,900
1978	1421.3	60,900	104,100	2005	1421.3	36,200	93,600
1979	1421.6	55,000	106,300	2006	1421.3	42,800	96,500
1980	1421.5	54,600	105,100	2007	1421.3	35,700	95,000
1981	1421.4	57,300	105,200	2008	1421.1	30,900	98,000
1982	1421.5	59,600	106,000	2009	1421.1	38,100	85,700
1983	1421.5	52,900	103,300	2010	1421.4	56,700	97,900
1984	1421.5	57,200	104,200	2011	1421.5	166,300	187,700
1985	1421.4	45,800	100,500	2012	1421.5	45,000	86,552
1986	1421.5	57,100	104,300	2013	1421.4	40,900	97,933
1987	1421.3	43,500	107,000	2014	1421.2	48,900	94,768
1988	1421.3	46,800	102,100	2015	1421.4	38,500	81,772
1989	1421.4	50,200	102,800	2016	1421.3	32,400	64,119
1990	1421.7	38,600	99,600	2017	1421.3	37,600	65,420
1991	1422.1	45,500	104,400	2018	1421.3	54,800	78,059
1992	1421.3	38,000	98,700	2019	1421.5	65,800	94,920
1993	1421.2	38,800	90,600	2020	1421.5	38,200	94,510

Plate 37. Big Bend Observed Data 1967-2020.

Peak Elevations in feet, Peak Releases in cfs

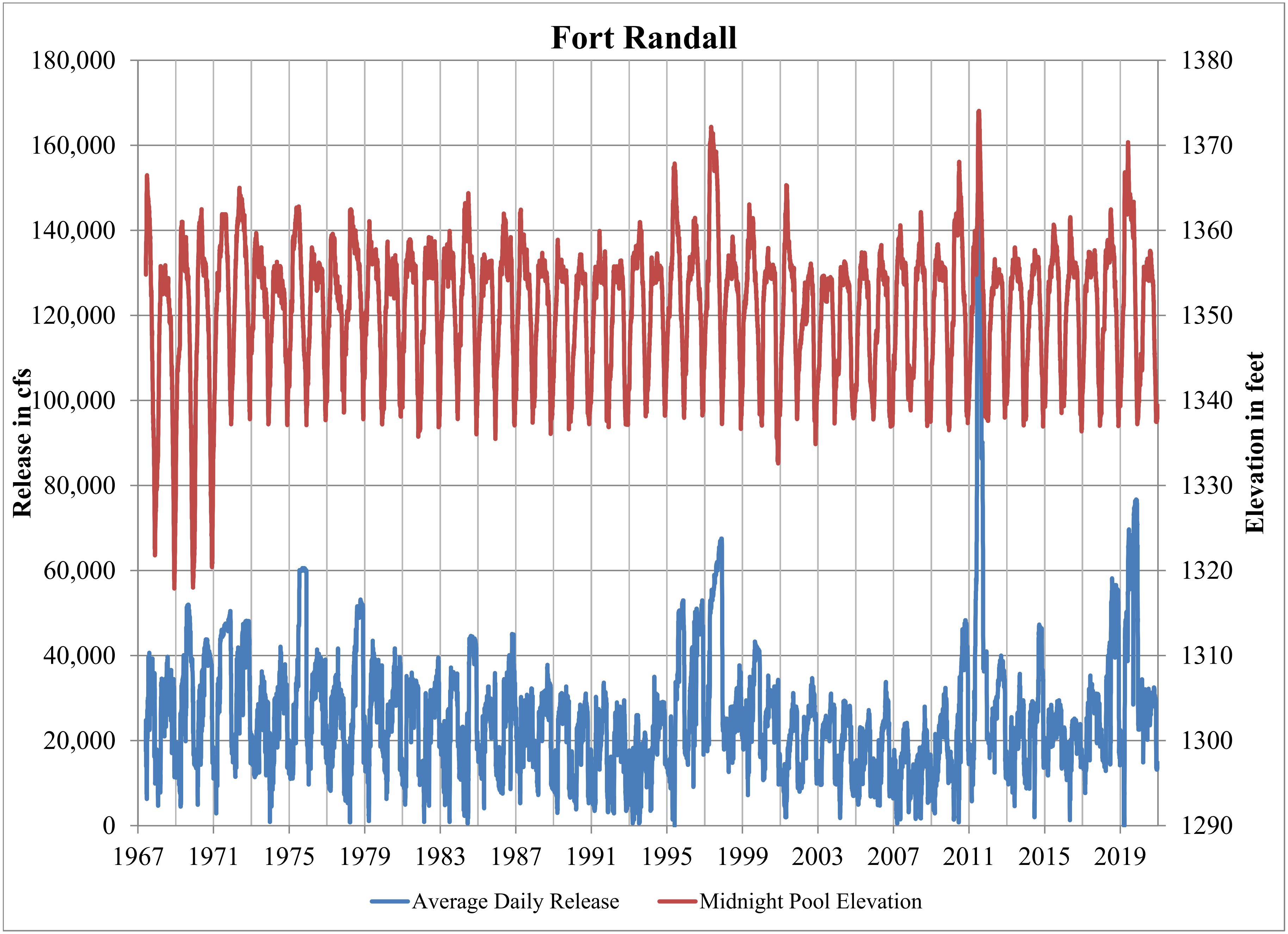

Plate 38. Fort Randall Daily Releases and Elevations.

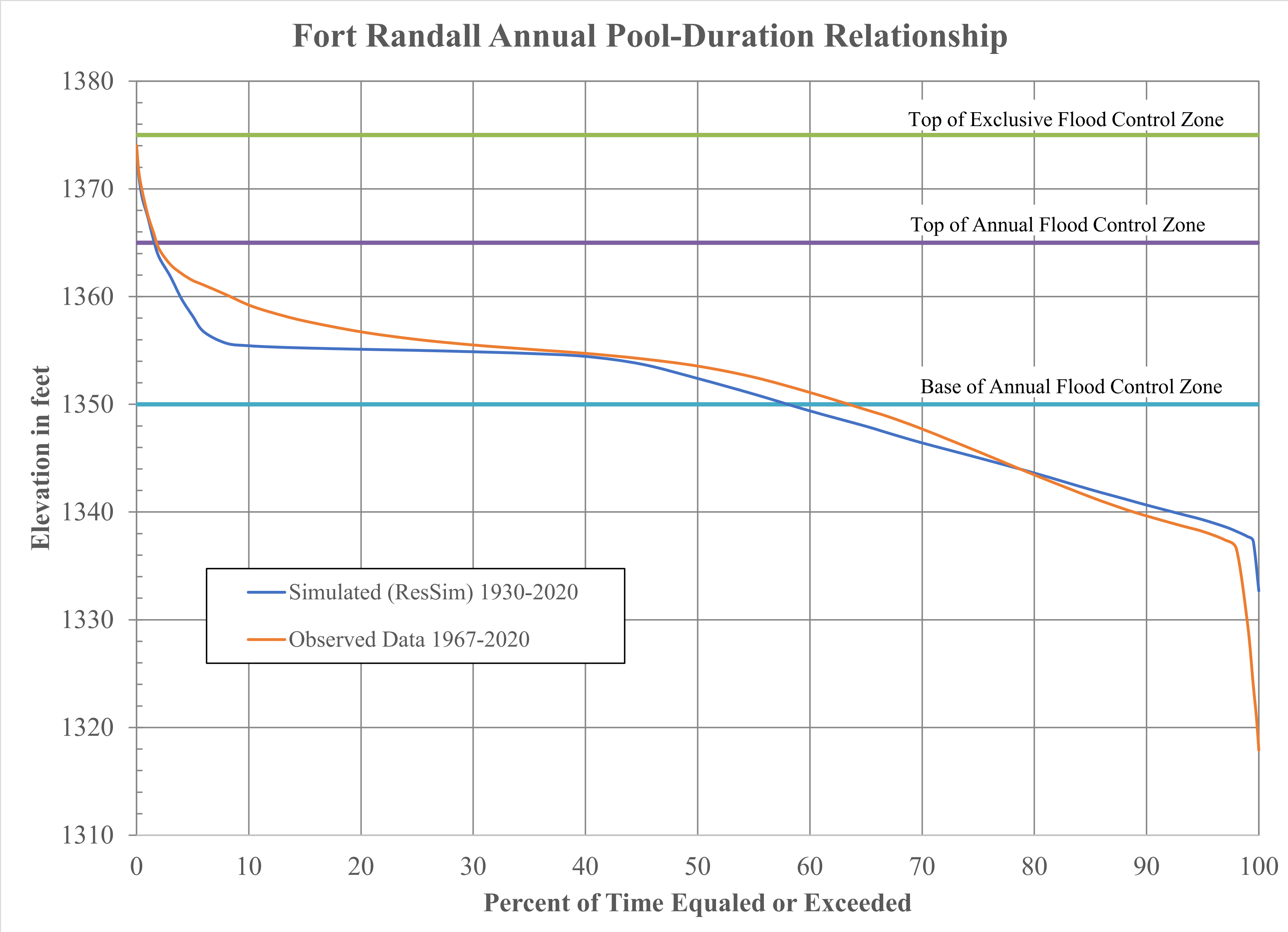

Plate 39. Fort Randall Annual Pool-Duration Relationship.
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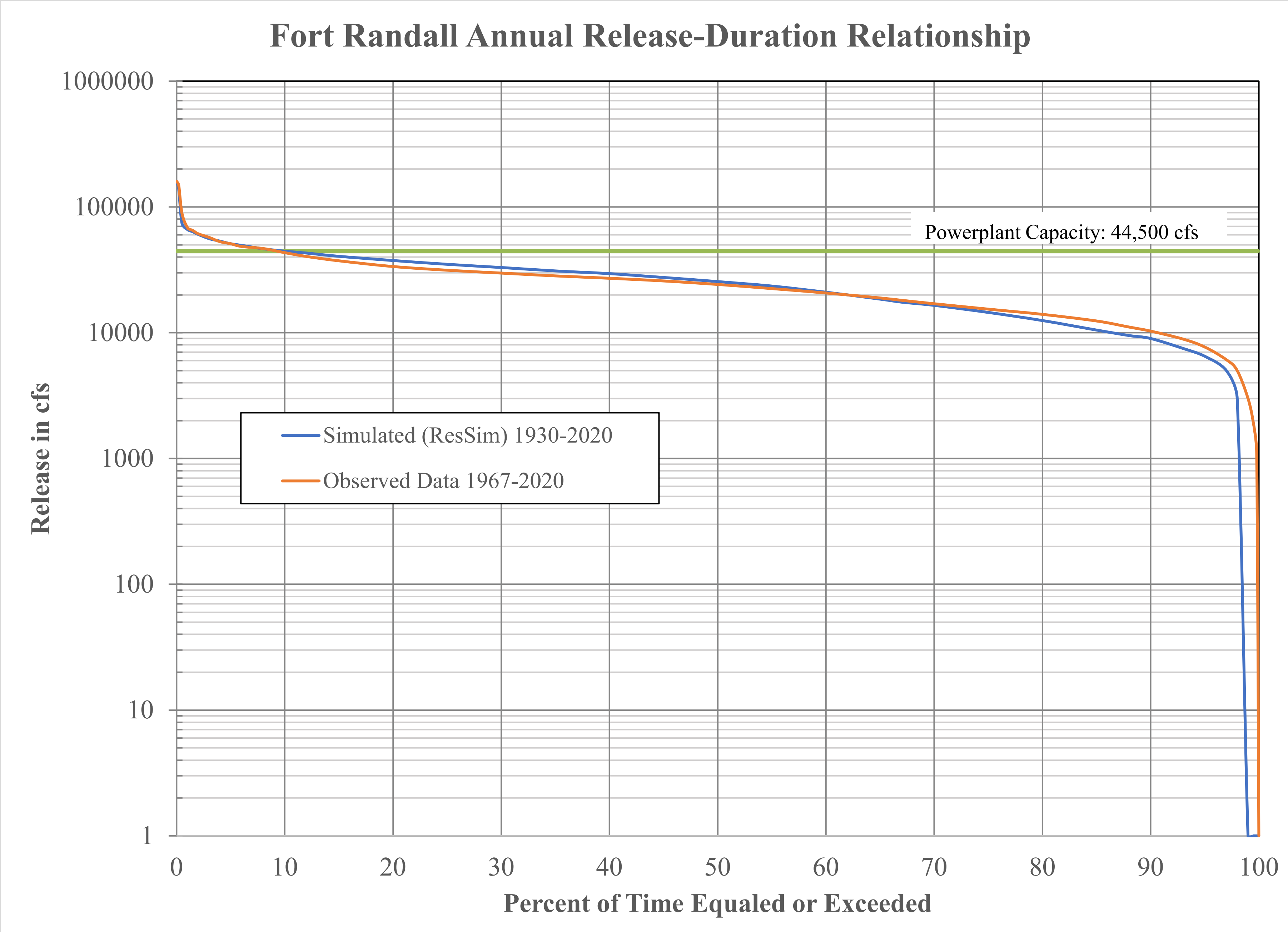

Plate 40. Fort Randall Annual Release-Duration Relationship.
MRBWM Technical Report - Hydrologic Statistics, May 2022

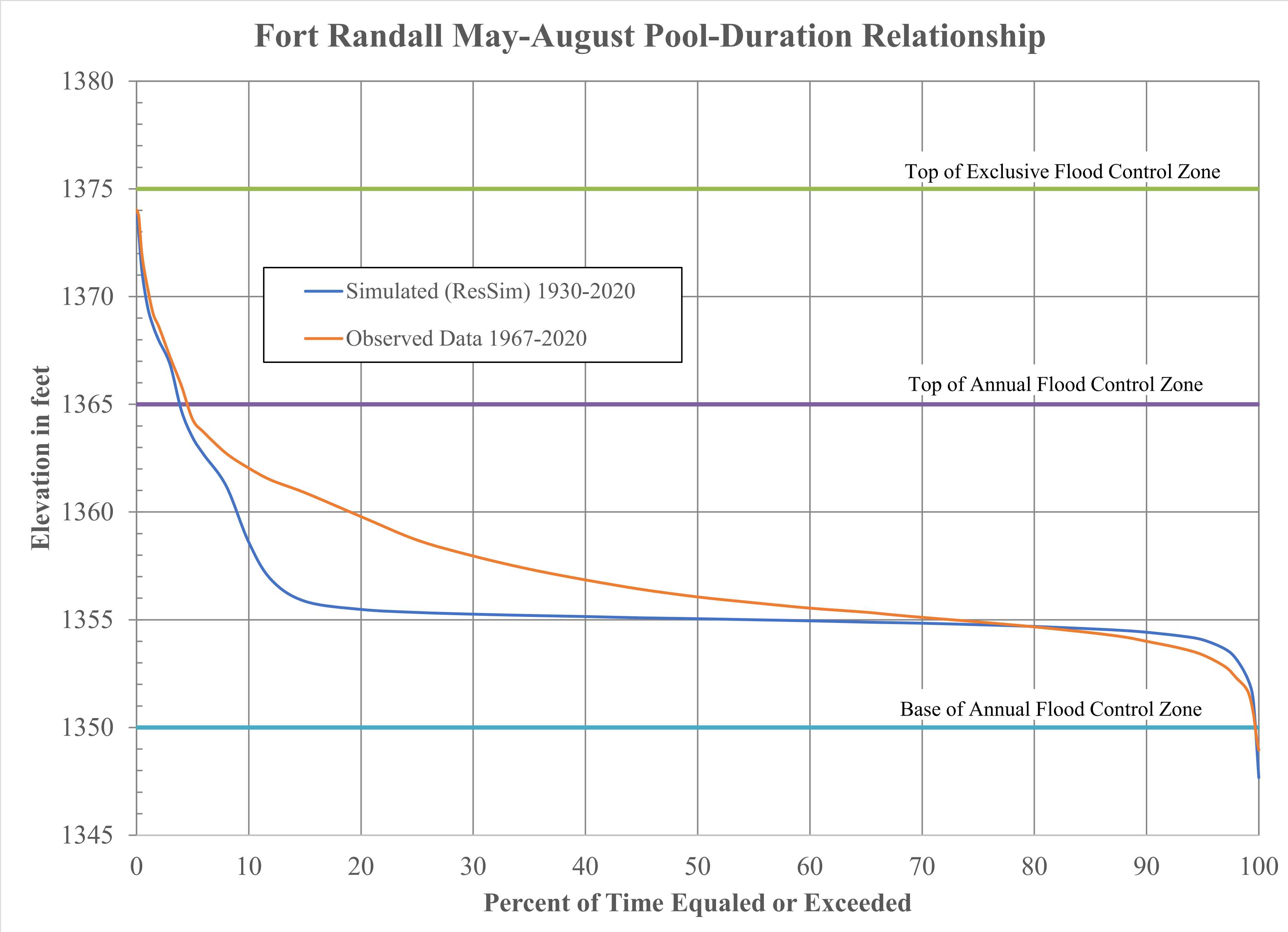

Plate 41. Fort Randall Pool-Duration Relationship (May-August).

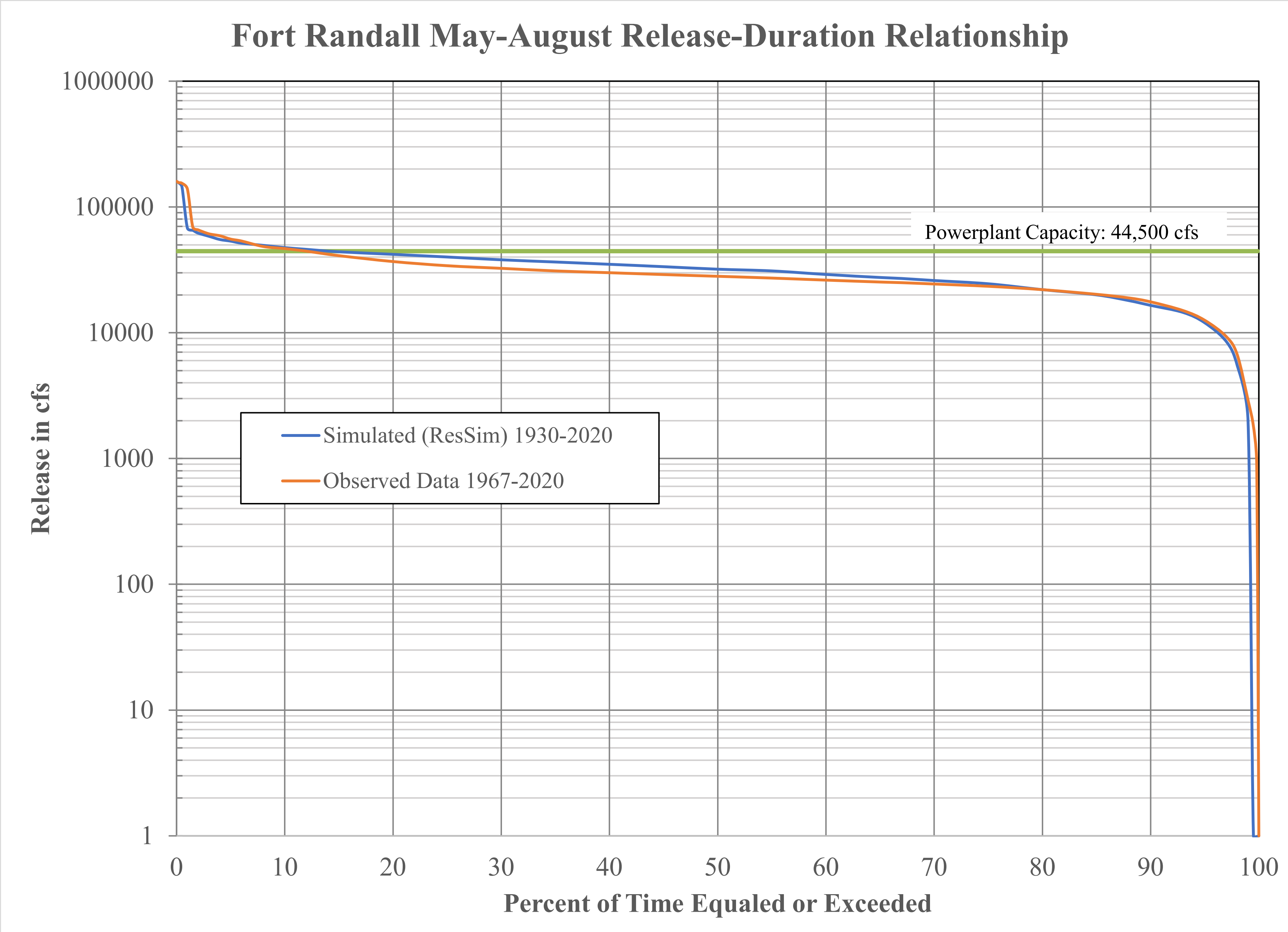

Plate 42. Fort Randall Release-Duration Relationship (May-August).

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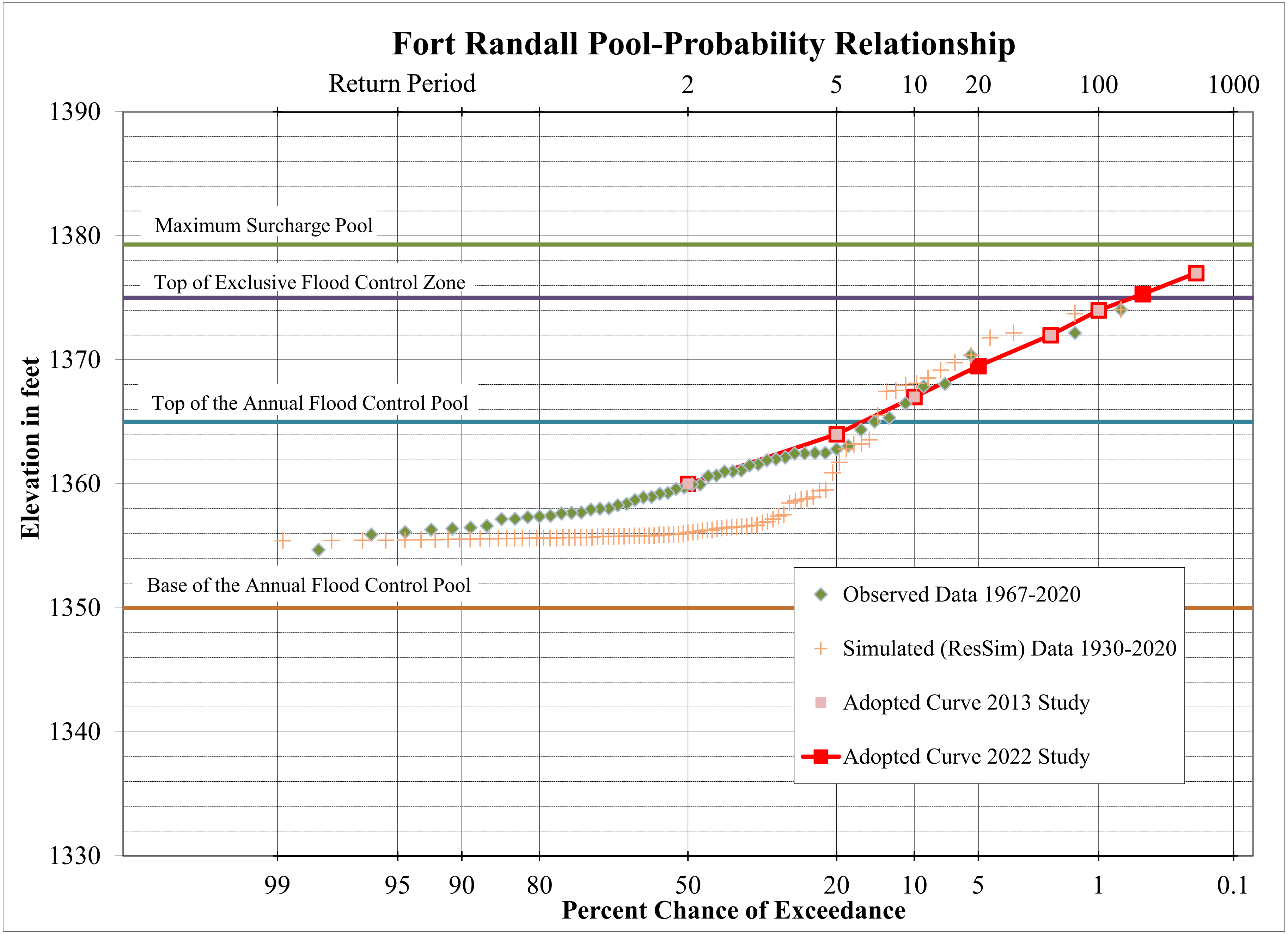

Plate 43. Fort Randall Pool-Probability Relationship.
MRBWM Technical Report - Hydrologic Statistics, May 2022

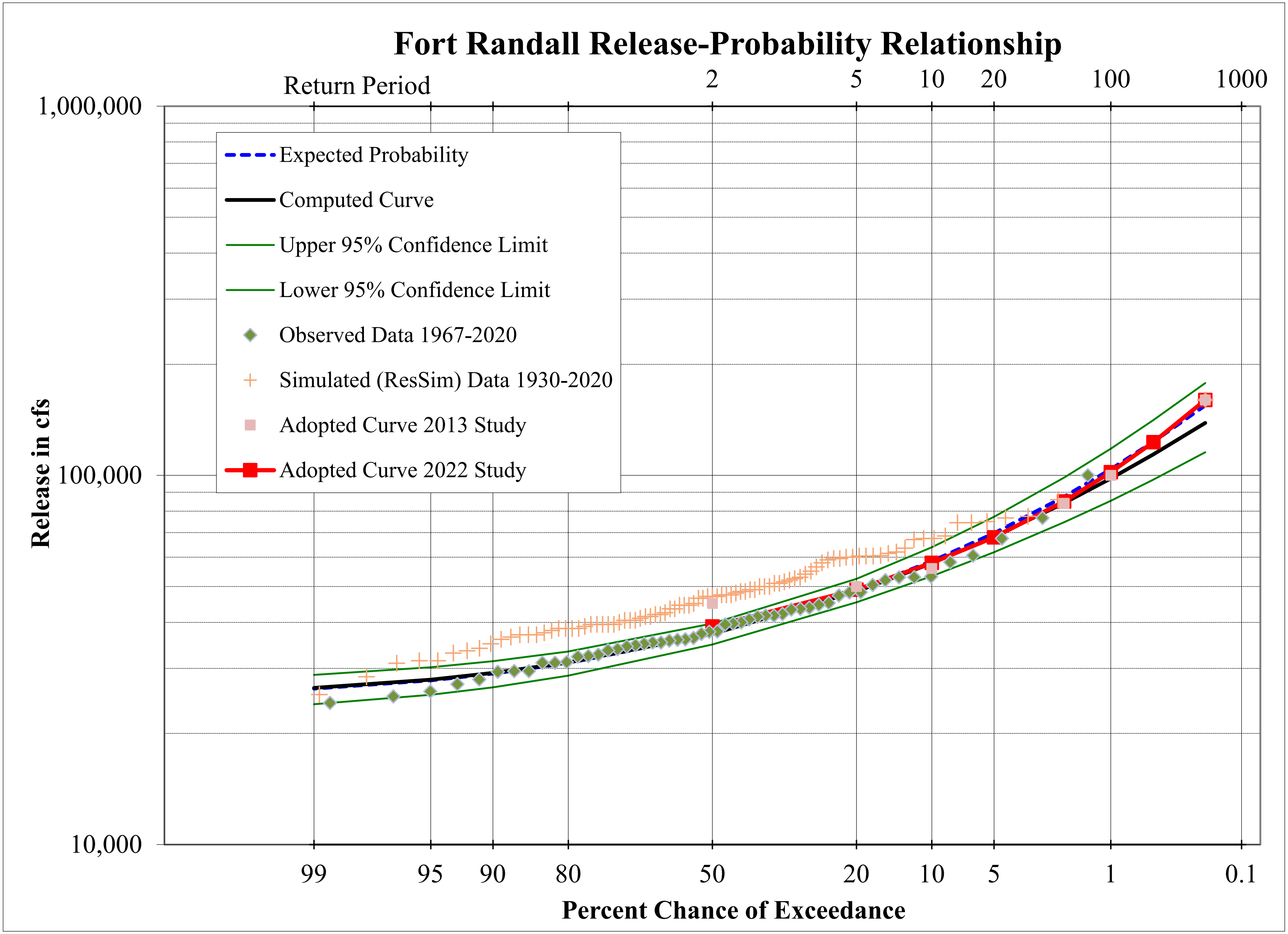

Plate 44. Fort Randall Release-Probability Relationship.
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Fort Randall Simulated (ResSim Model) Peak Elevations and Releases

Year	Elevation	Release	Year	Elevation	Release	Year	Elevation	Release
1930	1355.6	48,500	1962	1363.2	38,000	1994	1355.6	41,000
1931	1355.8	42,500	1963	1355.9	47,000	1995	1371.8	67,500
1932	1355.5	39,500	1964	1356.4	47,000	1996	1357.4	56,500
1933	1355.6	50,000	1965	1356.0	67,000	1997	1372.2	67,500
1934	1356.2	46,500	1966	1355.5	47,000	1998	1355.7	68,500
1935	1355.8	46,500	1967	1358.8	58,000	1999	1356.7	49,000
1936	1355.6	49,000	1968	1356.5	47,500	2000	1355.4	38,500
1937	1355.8	28,500	1969	1359.0	60,500	2001	1363.2	39,500
1938	1355.5	25,500	1970	1355.8	60,000	2002	1355.6	38,500
1939	1355.7	43,500	1971	1355.6	61,500	2003	1355.7	36,500
1940	1356.3	47,500	1972	1355.8	52,500	2004	1355.7	31,500
1941	1355.5	31,500	1973	1355.8	51,000	2005	1356.6	33,000
1942	1363.5	35,000	1974	1356.6	50,000	2006	1355.9	37,500
1943	1355.8	54,000	1975	1362.8	60,600	2007	1356.9	33,500
1944	1358.7	48,500	1976	1355.9	48,000	2008	1359.5	31,000
1945	1357.0	41,500	1977	1355.8	39,500	2009	1368.5	60,500
1946	1355.5	51,000	1978	1361.7	74,500	2010	1369.8	62,000
1947	1357.2	60,500	1979	1356.4	50,000	2011	1374.0	160,000
1948	1356.1	51,500	1980	1355.4	40,500	2012	1355.6	41,500
1949	1358.6	52,000	1981	1355.6	39,000	2013	1356.1	36,000
1950	1360.9	55,000	1982	1355.9	86,000	2014	1357.5	47,500
1951	1359.4	74,500	1983	1368.0	59,500	2015	1355.7	44,500
1952	1373.7	75,000	1984	1367.5	53,000	2016	1358.5	39,500
1953	1356.3	63,500	1985	1356.5	39,500	2017	1355.7	43,500
1954	1355.8	44,500	1986	1369.2	77,500	2018	1356.1	59,500
1955	1355.8	60,000	1987	1368.1	40,500	2019	1370.4	76,700
1956	1355.7	42,000	1988	1355.7	45,000	2020	1356.7	42,000
1957	1355.9	40,500	1989	1355.6	38,500			
1958	1355.5	37,000	1990	1355.5	37,000			
1959	1355.6	40,000	1991	1356.5	38,500			
1960	1365.5	44,500	1992	1355.6	34,000			
1961	1355.5	37,000	1993	1367.5	59,000			

Plate 45. Fort Randall Simulated (ResSim Model) Data 1930-2020.
Peak elevations in feet, peak releases in cfs.
MRBWM Technical Report - Hydrologic Statistics, May 2022

Fort Randall Observed Peak Elevations and Releases

Year	Elevation	Release	Year	Elevation	Release
1967	1366.5	40,700	1994	1357.3	35,000
1968	1355.9	39,700	1995	1367.9	53,000
1969	1361.0	52,000	1996	1361.5	53,000
1970	1362.5	43,800	1997	1372.2	67,500
1971	1361.9	50,500	1998	1359.3	37,700
1972	1365.0	48,200	1999	1363.1	43,300
1973	1359.7	36,300	2000	1357.9	35,300
1974	1356.3	42,100	2001	1365.3	31,200
1975	1362.8	60,600	2002	1356.1	34,700
1976	1358.0	41,400	2003	1354.7	31,100
1977	1359.6	41,700	2004	1356.4	29,400
1978	1362.5	53,200	2005	1357.4	27,200
1979	1361.1	43,500	2006	1358.3	33,800
1980	1358.7	41,700	2007	1360.6	24,200
1981	1358.9	36,000	2008	1362.1	28,000
1982	1359.2	39,500	2009	1358.4	32,400
1983	1359.9	37,200	2010	1368.1	48,300
1984	1364.4	44,600	2011	1374.0	160,000
1985	1357.2	35,900	2012	1356.6	40,000
1986	1362.0	45,100	2013	1358.0	35,700
1987	1362.4	32,300	2014	1357.7	47,300
1988	1357.4	37,800	2015	1360.7	29,500
1989	1358.9	32,700	2016	1361.6	25,200
1990	1357.2	31,100	2017	1357.7	35,300
1991	1360.0	33,600	2018	1362.5	58,200
1992	1356.5	29,500	2019	1370.4	76,700
1993	1361.0	26,000	2020	1357.6	34,400

Plate 46. Fort Randall Observed Data 1967-2020.
Peak elevations in feet, peak releases in cfs.
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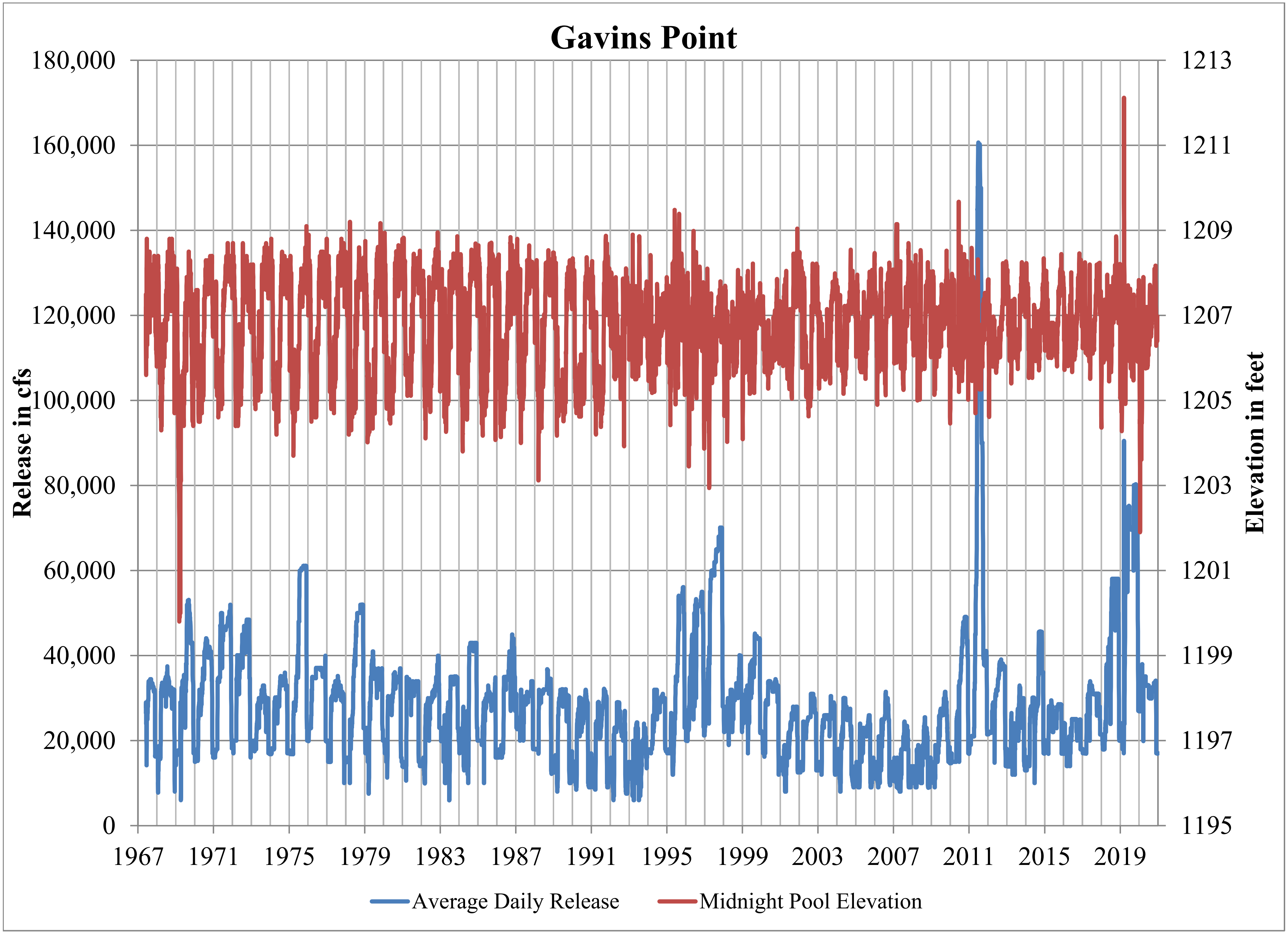

Plate 47. Gavins Point Daily Releases and Elevations.

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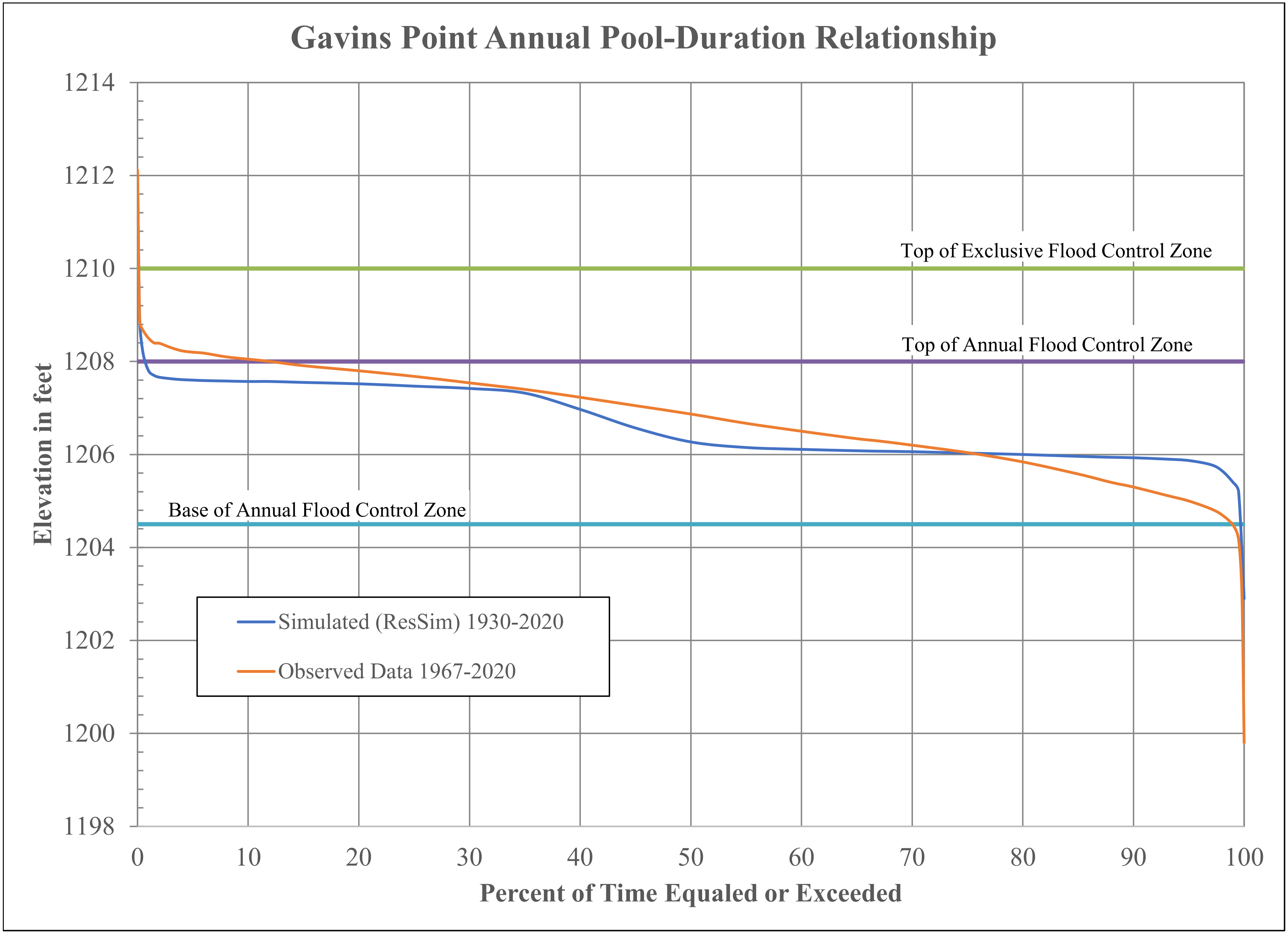

Plate 48. Gavins Point Annual Pool-Duration Relationship.
MRBWM Technical Report - Hydrologic Statistics, May 2022

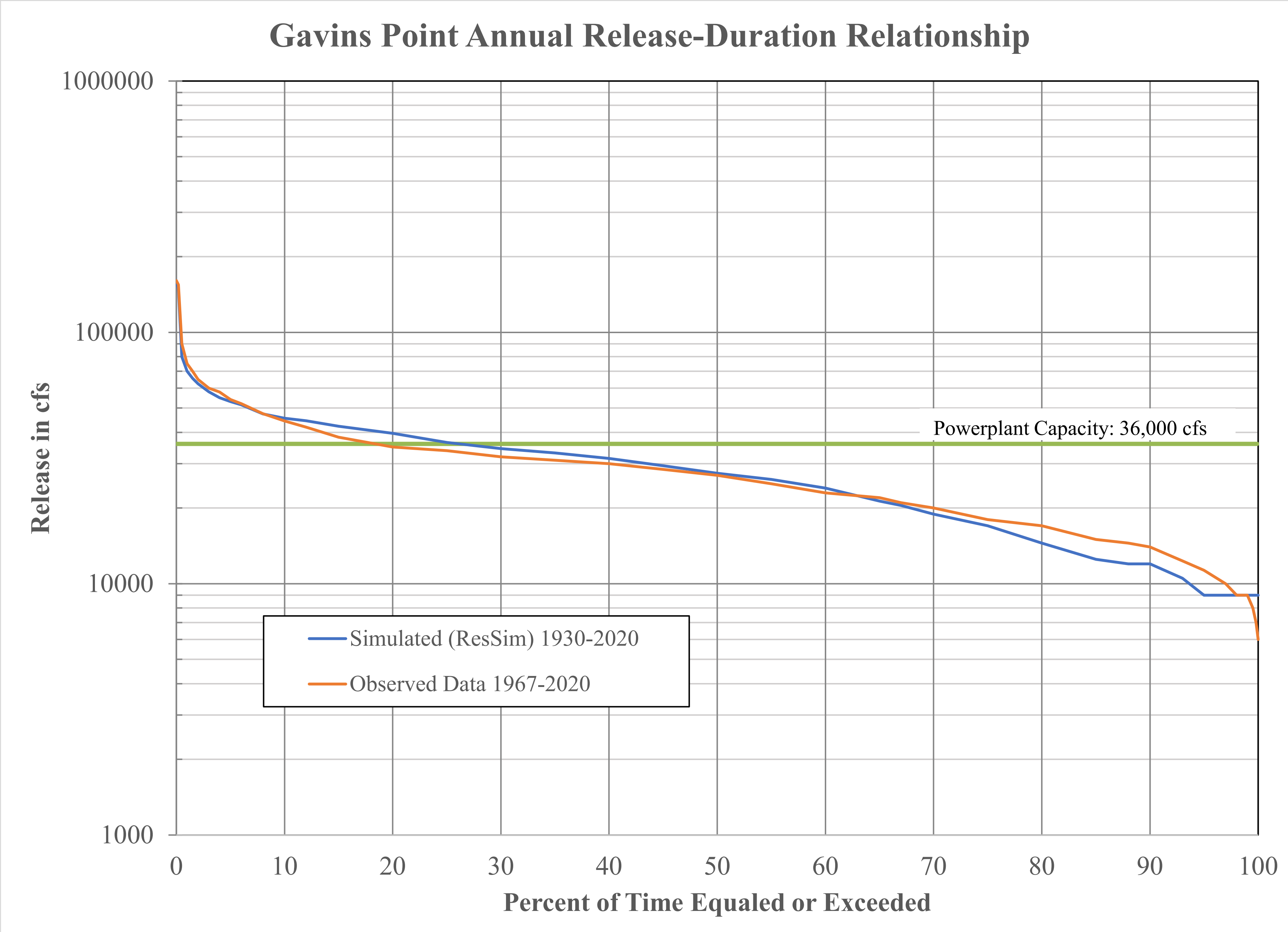

Plate 49. Gavins Point Annual Release-Duration Relationship.
MRBWM Technical Report - Hydrologic Statistics, May 2022

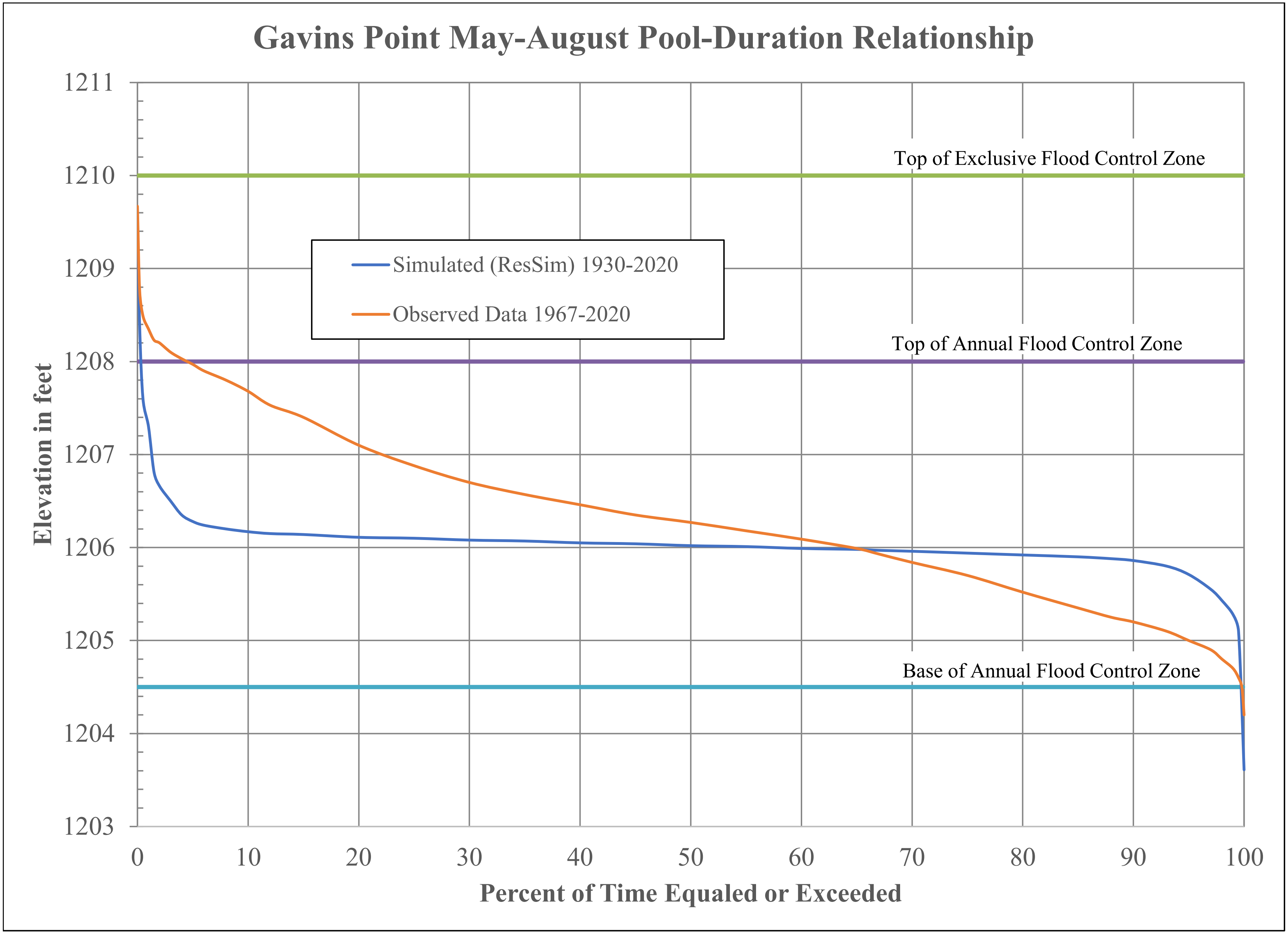

Plate 50. Gavins Point Pool-Duration Relationship (May-August).
MRBWM Technical Report - Hydrologic Statistics, May 2022

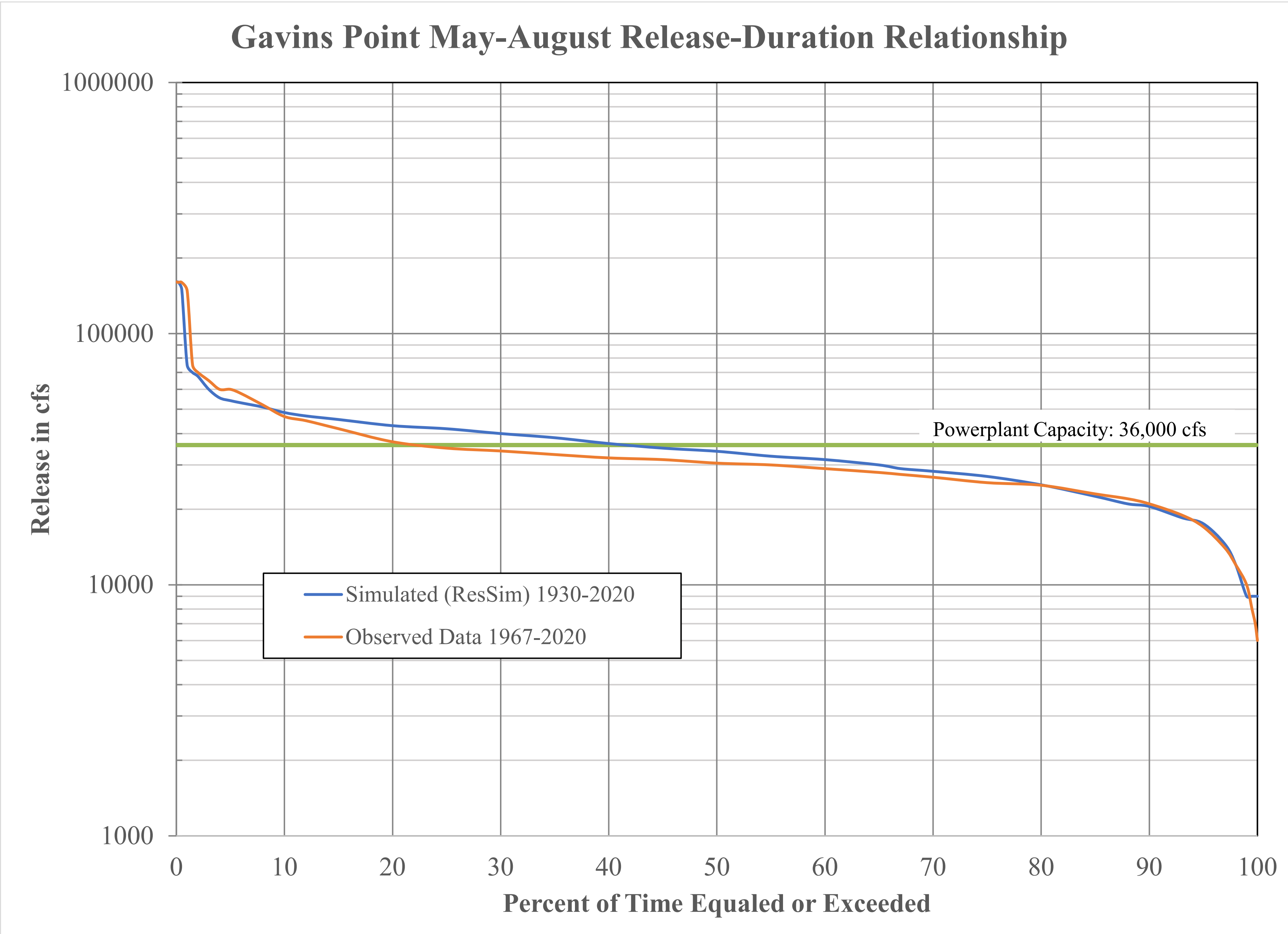

Plate 51. Gavins Point Release-Duration Relationship (May-August).
MRBWM Technical Report - Hydrologic Statistics, May 2022

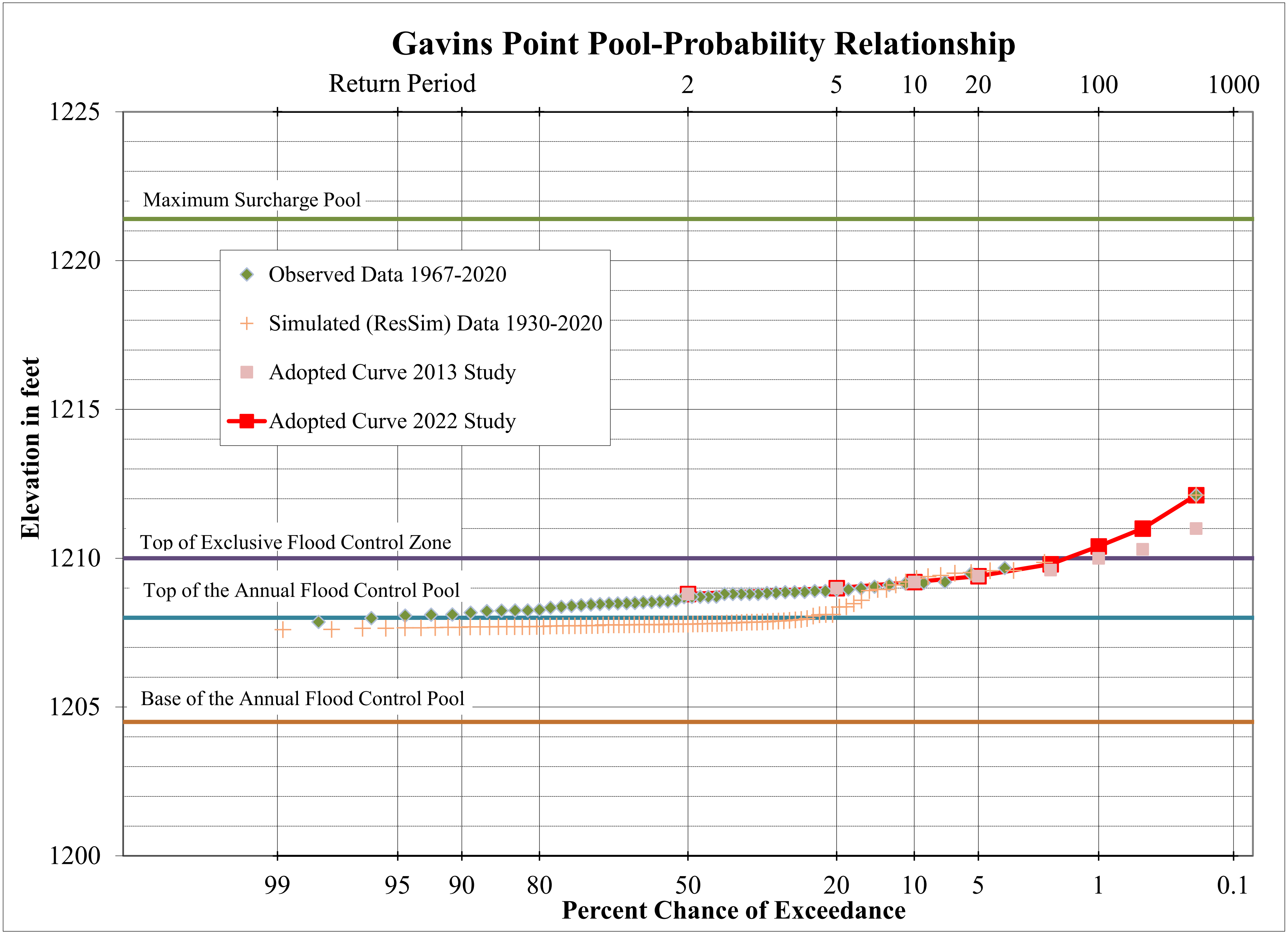

Plate 52. Gavins Point Pool-Probability Relationship.

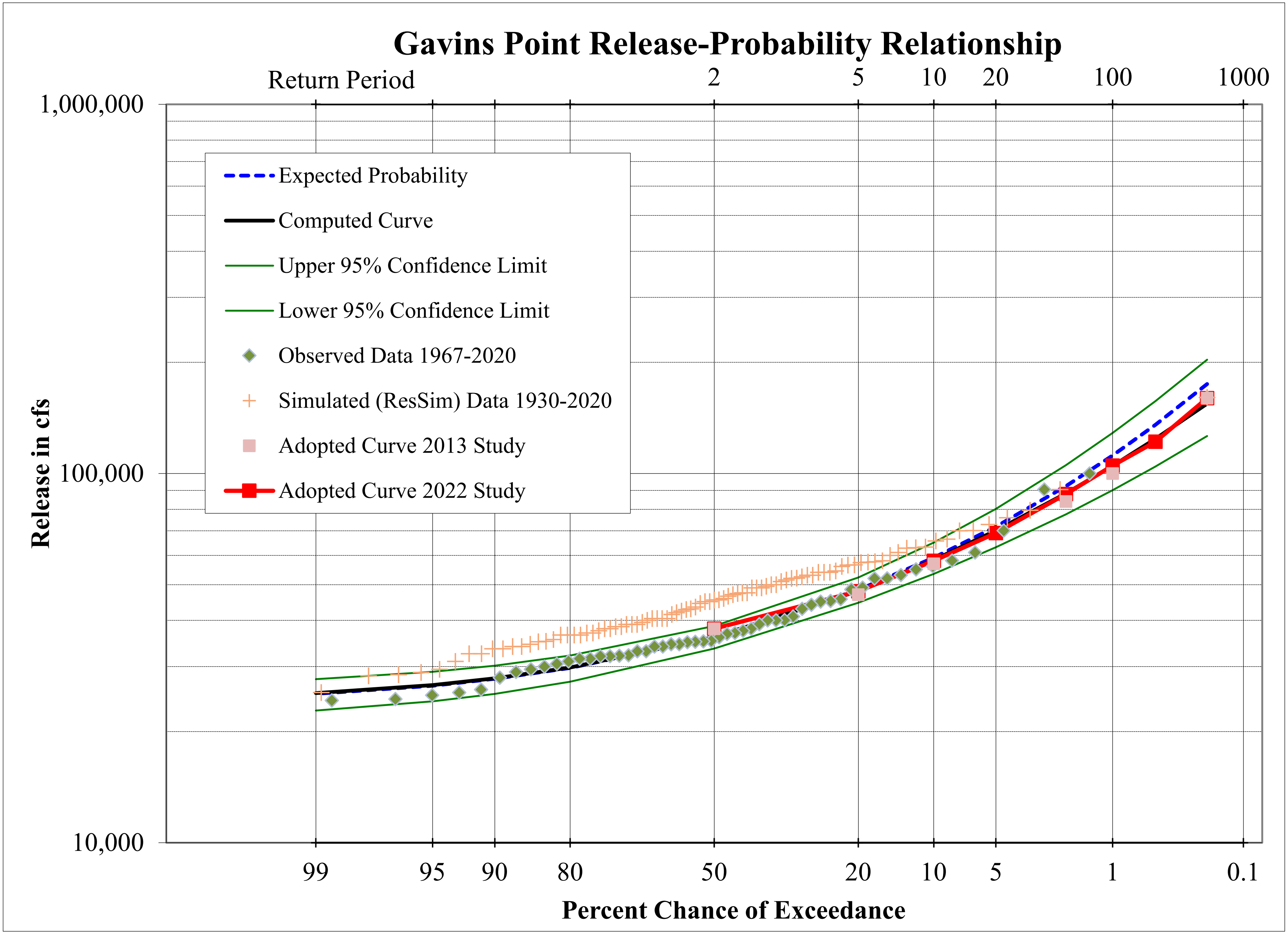

Plate 53. Gavins Point Release-Probability Relationship.
MRBWM Technical Report - Hydrologic Statistics, May 2022

Gavins Point Simulated (ResSim Model) Peak Elevations and Releases

Year	Elevation	Release	Year	Elevation	Release	Year	Elevation	Release
1930	1207.8	50,000	1962	1209.6	35,100	1994	1207.8	36,500
1931	1207.7	41,500	1963	1207.9	54,000	1995	1207.8	62,800
1932	1207.7	39,500	1964	1207.8	45,000	1996	1207.7	57,700
1933	1207.7	56,500	1965	1207.6	49,000	1997	1208.1	70,100
1934	1207.7	51,000	1966	1207.8	43,500	1998	1207.7	65,700
1935	1207.7	53,000	1967	1208.0	49,500	1999	1207.8	45,900
1936	1209.5	38,000	1968	1208.1	54,500	2000	1207.8	38,000
1937	1207.7	32,500	1969	1207.8	54,000	2001	1207.9	34,500
1938	1207.7	25,500	1970	1208.1	53,000	2002	1207.8	35,500
1939	1207.8	45,500	1971	1207.9	49,000	2003	1207.7	35,000
1940	1207.7	51,500	1972	1207.7	50,000	2004	1207.8	29,500
1941	1207.7	32,500	1973	1207.7	44,500	2005	1207.8	28,500
1942	1209.5	38,500	1974	1207.9	47,000	2006	1207.7	34,000
1943	1207.8	57,500	1975	1209.1	61,100	2007	1209.0	28,300
1944	1207.9	54,000	1976	1207.8	46,500	2008	1207.9	31,000
1945	1207.7	40,500	1977	1207.7	38,500	2009	1207.8	56,000
1946	1207.9	47,500	1978	1209.4	63,200	2010	1207.8	57,400
1947	1207.9	70,000	1979	1208.1	45,000	2011	1208.6	160,700
1948	1208.4	52,000	1980	1207.7	40,000	2012	1207.8	40,500
1949	1208.4	43,000	1981	1207.7	37,000	2013	1207.7	33,500
1950	1209.0	58,000	1982	1207.7	75,900	2014	1207.8	45,400
1951	1207.6	56,600	1983	1209.6	52,100	2015	1207.9	36,500
1952	1209.4	79,500	1984	1208.5	47,300	2016	1207.9	33,500
1953	1207.7	60,000	1985	1207.9	37,000	2017	1207.8	42,400
1954	1207.8	49,000	1986	1209.2	66,400	2018	1207.8	52,500
1955	1207.7	63,000	1987	1209.3	40,500	2019	1212.1	90,500
1956	1207.8	47,500	1988	1207.7	42,000	2020	1207.8	42,800
1957	1207.8	36,500	1989	1207.8	39,000			
1958	1207.8	34,000	1990	1207.8	36,500			
1959	1207.7	39,000	1991	1207.7	39,000			
1960	1209.9	40,500	1992	1207.8	28,900			
1961	1207.8	37,500	1993	1208.9	72,800			

Plate 54. Gavins Point Simulated (ResSim Model) Data 1930-2020.
Peak elevations in feet, peak releases in cfs.

Gavins Point Observed Peak Elevations and Releases

Year	Elevation	Release	Year	Elevation	Release
1967	1208.8	34,500	1994	1208.4	32,000
1968	1208.8	37,500	1995	1209.5	56,100
1969	1208.5	53,100	1996	1209.0	55,000
1970	1208.4	44,100	1997	1208.1	70,100
1971	1208.7	52,000	1998	1208.1	40,100
1972	1208.7	48,500	1999	1208.2	45,200
1973	1208.7	33,000	2000	1207.9	34,500
1974	1208.8	36,000	2001	1209.0	28,000
1975	1209.1	61,100	2002	1208.5	31,000
1976	1208.9	40,000	2003	1208.0	30,500
1977	1208.8	35,200	2004	1208.6	30,000
1978	1209.2	52,000	2005	1208.5	26,000
1979	1209.2	41,000	2006	1208.2	31,500
1980	1208.9	37,000	2007	1209.2	24,500
1981	1208.8	35,000	2008	1208.5	25,500
1982	1209.0	40,000	2009	1208.5	31,500
1983	1208.9	35,100	2010	1209.7	49,100
1984	1208.7	43,000	2011	1208.6	160,700
1985	1208.7	34,900	2012	1208.3	39,100
1986	1208.8	45,000	2013	1208.3	33,000
1987	1208.8	34,000	2014	1208.3	45,700
1988	1208.5	36,800	2015	1208.4	29,500
1989	1208.5	32,100	2016	1208.5	25,100
1990	1208.4	32,000	2017	1208.3	34,000
1991	1208.9	32,200	2018	1208.9	58,100
1992	1208.1	29,000	2019	1212.1	90,500
1993	1208.9	24,300	2020	1208.2	38,000

Plate 55. Gavins Point Observed Data 1967-2020.
Peak elevations in feet, peak releases in cfs.