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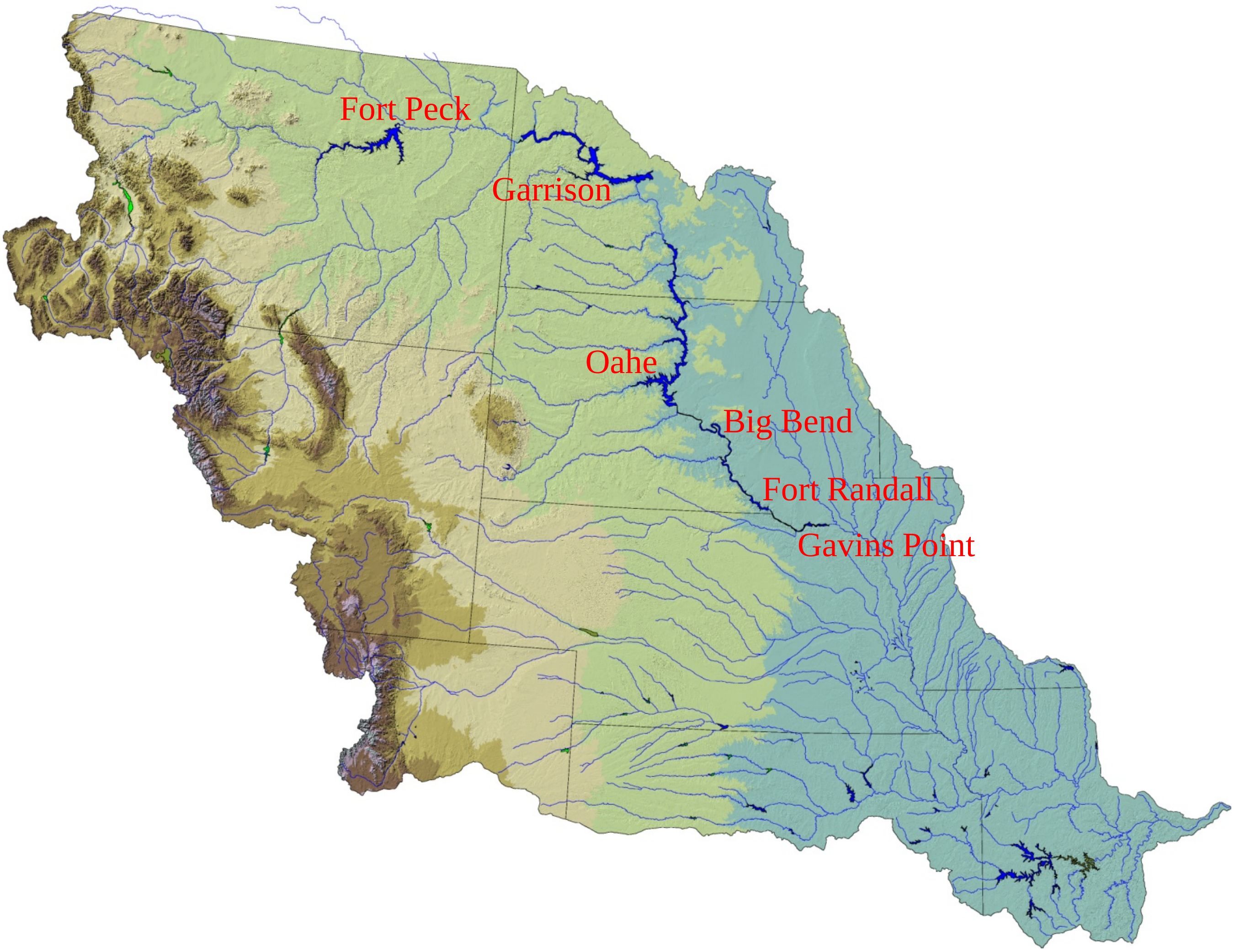
Northwestern Division

Hydrologic Statistics

Technical Report



Missouri River Basin Water Management Division
Omaha, Nebraska

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Missouri River Basin Water Management Division

Technical Report – Hydrologic Statistics, September 2013

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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
ft msl	feet above mean sea level in NGVD29
kAF	1000 acre-feet
LRS	Long Range Study
M	million
MAF	million acre-feet
Master Manual	Master Water Control Manual
MRBWMD	Missouri River Basin Water Management Division
msl	mean sea level
NWD	Corps' Northwestern Division
SWE	snow water equivalent
System	Missouri River Mainstem Reservoir System
T&E	Threatened and Endangered
USBR	U.S. Bureau of Reclamation

DEFINITION OF TERMS

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

Cubic foot per second (cfs) is the rate of discharge representing a volume of 1 cubic foot passing a given point during 1 second and is equivalent to approximately 7.48 gallons per second or 448.8 gallons per minute. The volume of water represented by a flow of 1 cubic foot per second for 24 hours is equivalent to 86,400 cubic feet, approximately 1.983 acre-feet, or 646,272 gallons. Conversely, 1.5 cfs for 24 hours is approximately 1 million gallons; therefore, 1.5 cfs is approximately 1 million gallons per day (MGD).

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

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

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

Drought is three or more consecutive years of below-average calendar year runoff into the Missouri River above Sioux City, IA.

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

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

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

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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 time period was selected because it is the period where regulation decisions most impact the threatened piping plover and endangered least tern (T&E) birds 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 using class interval analysis. Class interval analysis involves subdividing the data into defined class intervals and computing the relative frequency of each class interval based on the number of data within each class.

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.

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. In order 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 current updated study utilized an additional 14 years of historical data from the period 1967-2011. This updated study was completed by the Hydrologic Engineering Branch, Omaha District of the U.S. Army Corps of Engineers and is published as MRBWM Technical Report “Hydrologic Statistics, September 2013”. 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 for 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	1,798	5,293	428
Flood Storage (kAF)	3,675	5,706	4,315	177	2,292	133
Top of Dam* (ft msl)	2280.5	1875.0	1660.0	1440.0	1395.0	1234.0
Maximum Surcharge Pool** (ft msl)	2253.3	1858.5	1644.4	1433.6	1379.3	1221.4
Top of Exclusive FC Pool*** (ft msl)	2250.0	1854.0	1620.0	1423.0	1375.0	1210.0
Top of Annual FC Pool (ft msl)	2246.0	1850.0	1617.0	1422.0	1365.0	1208.0
Base of Flood Control Pool (ft msl)	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

*Feet above mean sea level (ft msl). All elevations in this report are referenced to the NGVD29 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 actually 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, at that time the non-damaging channel capacity, 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, flood storage requirement reductions due to upstream 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 preliminary March-July runoff season volume of the 2011 flood at Sioux City, IA of 48.7 MAF, exceeding the 1881 design volume by 20 percent. The final March-July runoff is 48.4 MAF and does not significantly change the results of this analysis. 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 (130 years).

C. Daily Routing Model (DRM)

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.

The DRM consists of 20 nodes, including the 6 mainstem dams and 14 gaging stations located at: Wolf Point and Culbertson, MT; Williston and Bismarck, ND; Sioux City, IA; Omaha, Nebraska City, and Rulo, NE and St. Joseph, Kansas City, Waverly, Boonville, Hermann, and St. Louis, MO. Input data consist of historic reach inflows, streamflow depletions, evaporation data, downstream flow targets, reservoir characteristics including operational levels, routing factors, operational guide curves, power generation criteria, navigation guide criteria, and endangered species flow criteria.

As part of the Master Manual Review and studies, the regulation of the System at that time was modeled using the DRM and is documented in "Volume 2A: Reservoir Regulation Studies-

Daily Model Studies" dated August 1998. That study, referred to as the Current Water Control Plan (CWCP), contained the experienced hydrologic record extending from 1898 through 1997 and reflected, to the degree possible in long-term studies of this type, regulation criteria at the 1997 level, as well as Missouri Basin water resource development current to the last year of the study which is 1993.

As part of continued use of the DRM, regulation criteria were adjusted to reflect the new water control plan and input files have been updated to include the actual regulation period through 2011. Depletions for each reach upstream from Sioux City were estimated by the U.S. Bureau of Reclamation (USBR) in 2002. These depletions were used to update the DRM input files. Updated CWCP model results were evaluated and used for the analysis in this report as discussed in the next section.

D. 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 releases from Gavins Point Dam for the benefit of the endangered pallid sturgeon.

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 regulations 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 1898 through 2011, representing 114 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 DRM was used in the analysis for this technical study. Daily data are not available before 1929 at all stations used by the model, and as a result the pre-1929 data used in the DRM was estimated based on monthly data available from 1898 to 1929. The data derived in this time period are often referred to as "synthesized" data. Criteria incorporated in these models reflect current regulation criteria to the maximum extent possible. The DRM 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 2002 level of Basin water resource development;

3. The DRM utilizes a consistent set of reservoir regulation criteria throughout the entire period (1898-2011).

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; and

3. Long-term studies do not reflect limits on hydropower generation that occurs during actual regulation due generally to power units being unavailable because of scheduled or unplanned maintenance outages. Changes in weekly energy demand also affect System generation; and

4. 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.

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 CWCP was used for this analysis and the DRM utilized the rule curves established in the Master Manual against the continuous long-term record (1898-2011). The large runoff events of 1975, 1997 and 2011 proved difficult for the DRM to exactly match actual pool elevations and releases while still effectively modeling more normal events at the three upstream projects. This is because in actual operations during 1975, 1997 and 2011 the actual operation did not follow the rule curves exactly (e.g. surcharging reservoirs, maximum project releases). In order to reflect actual operation of the projects during significant high inflow events, Fort Peck, Garrison and Oahe data from 1975, 1997 and 2011 were replaced with observed data from those same years.

Two data sets were used to determine the pool-probability relationships: 1) a graphical analysis of the 114 years (1898-2011) of simulated maximum daily pool elevations from the DRM (that includes observed data from 1975, 1997 and 2011) and 2) a graphical analysis of the 45 years (1967-2011) since the System first filled of observed maximum daily pool elevations based on the historical rank. In this report, the analysis based on the DRM model is also referred to as "Simulated", while the analysis based on the 45 years of observed record is referred to as "Observed". Each graphical analysis was based on the Weibull plotting position formula. Computed probability, expected probability and confidence limit relationships were created for both data sets using the Hydrologic Engineering Center's Statistical Software Package (HEC-SSP 2.0). These relationships were then compared with the adopted pool-probability relationships from the 1999 study to obtain the adopted relationships for this update study. Similar procedures were used to develop the release-probability relationships.

As explained in later sections, the MRBWM technical report "Frequencies of the Upper Missouri Basin Runoff in 2011" was used in this analysis to better approximate the percent chance of exceedance of the 2011 event.

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. Spring pulses from Gavins Point, which are designed to cue pallid sturgeon spawning, are provided in March and May. Flow magnitude, duration and timing are based on System storage, runoff forecast, downstream flow limits and other criteria. Minimum release restrictions and pool fluctuations for fish spawning management generally occur from April 1 to June 30. Nesting of the endangered interior least tern and the threatened piping 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.

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 1967-2011, the pool elevation has ranged from a low of 2196.2 ft msl in March 2007 to a maximum of 2252.3 ft msl in June 2011, a range of over 56 feet. The average annual pool elevation is (1967-2011) 2229.6 ft msl, with a standard deviation of 13.7 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 9,300 cfs since 1967, with a standard deviation of 3,000 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 (1967-2011)

Month	**Pool Elevation (ft msl)**			**Daily Release (cfs)**		
	Maximum	**Minimum**	**Mean**	**Maximum**	**Minimum**	**Mean**
Jan	2245.1	2197.5	2227.8	15,600	4,200	10,600
Feb	2244.4	2196.3	2226.9	15,500	4,100	10,900
Mar	2246.2	2196.2	2227.0	15,600	1,000	7,900
Apr	2247.3	2197.5	2228.1	25,100	0	7,300
May	2248.9	2198.4	2229.2	28,900	2,800	9,100
Jun	2252.3	2199.7	2231.6	65,900	3,000	10,600
Jul	2251.6	2202.3	2233.1	49,900	3,000	10,600
Aug	2250.1	2200.9	2232.3	35,200	3,800	10,200
Sep	2248.5	2,199.8	2231.2	25,200	2,700	9,100
Oct	2248.0	2199.7	2230.6	21,800	2,700	8,000
Nov	2246.3	2199.8	2230.0	22,300	2,700	8,300
Dec	2245.4	2198.9	2229.1	16,000	4,100	9,500
Annual	**2252.3**	**2196.2**	**2229.6**	**65,900**	**0**	**9,300**

B. Pool- and Release-Duration Relationships

Pool-duration and release-duration relationships were developed with data for the period 1898-2011. DRM data were used for all years with the exception of 1975, 1997 and 2011 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

Percent of Time Equaled or Exceeded	Pool Elevation (ft msl)		Release (cfs)	
	Annual	May – Aug	Annual	May – Aug
Maximum	2252.3	2252.3	65,900	65,900
1	2249.0	2250.3	25,000	35,100
5	2246.1	2248.1	14,800	15,900
10	2243.8	2246.5	14,200	14,500
20	2241.0	2244.0	12,500	13,000
50	2235.8	2237.1	8,600	8,600
80	2215.4	2216.0	6,000	6,800
90	2206.5	2207.0	4,800	6,000
95	2201.1	2203.0	4,100	5,600
99	2198.5	2299.1	3,000	4,100
100	2196.2	2198.4	0	2,800

C. Pool-Probability Relationship

The maximum Fort Peck pool elevation of 2252.3 ft msl was recorded in June 2011. In this analysis, the 2011 pool elevation for the DRM and observed data were plotted at approximately 0.8 percent chance of exceedance (130-year return period). The 0.8 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 1.5 percent chance exceedance probability as the second highest pool elevation in 130 years. Extrapolation of the eye-fit curve between the observed and simulated data indicates a reasonable pool-probability relationship. This curve closely resembles the 1999 adopted Fort Peck pool-probability relationship, with only a small increase in expected pool elevation between the 5 and 1 percent chance of exceedance. Therefore, this curve was adopted for the Fort Peck pool-probability relationship. Results are shown in ***Table 4*** and on ***Plate 7***.

Table 4
Fort Peck Pool-Probability Relationship
Pool Elevations ft msl

Percent Chance Exceedance	1976 Study	1999 Study	Observed (1967-2011)	Simulated (1898-2011*)	Adopted
50	2240.0	2241.5	2239.7	2239.7	**2240.0**
20	2246.5	2246.5	2246.8	2246.8	**2246.5**
10	2249.0	2249.0	2249.3	2248.2	**2249.0**
2	2251.0	2251.0	2251.5	2250.0	**2252.0**
1	2252.0	2252.0	2252.0	2252.1	**2252.5**
0.2	2253.0	2253.0	2253.0**	2253.2**	**2253.0**

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

D. Release-Probability Relationship

The 5-month (March-July) inflow volume of the 2011 event at Fort Peck was approximately a 1 percent chance of exceedance event, based on Fort Peck inflow volume-duration probability relationships developed by MRBWM in the "Hydrologic Statistics on Inflows" technical report (February 2005). Using this information and the historical event of 1881, the 2011 release for the DRM and observed data were plotted at approximately 0.8 percent chance of exceedance (130-year return period). The 0.8 percent chance of exceedance probability represents the historical record back to the 1881 flood event, creating a longer period of record.

The maximum observed release from Fort Peck was 65,900 cfs in 2011. Both the observed and simulated data indicated a relatively flat curve at a discharge of approximately 15,000 cfs (near the full powerplant discharge capacity) from the 20 to 50 percent chance of exceedance. A similar flat section in the data occurs near 35,000 cfs from the 2 to 7 percent chance of exceedance. The maximum release observed prior to 2011 and simulated releases were modeled to keep maximum releases near this level.

The Fort Peck release-probability relationship follows the adopted 1999 Fort Peck release-probability relationship from the 20 to 50 percent chance of exceedance. A straight line was assumed from the 0.2 to 20 percent chance of exceedance, matching the observed and simulated data. This relationship defines the adopted Fort Peck release-probability relationship. Results are shown in ***Table 5*** and on ***Plate 8***. DRM 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	1976 Study	1999 Study	Observed (1967-2011)	Simulated (1898-2011*)	Adopted
50	15,000	15,000	13,600	16,300	**15,000**
20	15,000	17,000	15,300	16,600	**17,000**
10	15,000	22,000	21,300	25,000	**25,000**
2	28,000	29,000	48,000	35,000	**48,000**
1	35,000	35,000	60,000	60,000	**60,000**
0.2	50,000	50,000	95,000**	80,000**	**95,000**

* To eliminate the influence of modeled outliers, observed releases were used in 1975, 1997 and 2011.
** 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 1967-2011, the pool elevation has ranged from a low of 1805.8 ft msl in May 2005 to a maximum of 1854.8 ft msl in July 1975, a range of almost 50 feet. The average annual pool elevation since 1967 is 1834.9 ft msl, with a standard deviation of 10.6 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 21,700 cfs since 1967, with a standard deviation of 7,100 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 (1967-2011)

Month	**Pool Elevation (ft msl)**			**Daily Release (cfs)**		
	Maximum	**Minimum**	**Mean**	**Maximum**	**Minimum**	**Mean**
Jan	1845.3	1807.0	1832.6	34,200	12,700	22,600
Feb	1843.6	1806.6	1831.2	36,000	11,000	23,700
Mar	1847.9	1806.9	1831.2	37,800	0	19,100
Apr	1847.7	1806.6	1832.7	39,100	5,000	18,500
May	1853.3	1805.8	1833.5	85,500	9,100	21,400
Jun	1854.5	1809.1	1836.6	150,600	9,500	25,100
Jul	1854.8	1815.2	1839.7	141,700	9,500	26,200
Aug	1854.6	1811.9	1839.0	110,300	12,100	25,200
Sep	1851.3	1809.5	1837.4	61,600	6,000	21,000
Oct	1848.2	1809.3	1836.5	49,700	9,200	19,100
Nov	1847.0	1808.9	1837.5	50,100	9,300	19,900
Dec	1846.8	1807.8	1834.2	39,100	11,300	20,100
Annual	**1854.8**	**1805.8**	**1834.9**	**150,600**	**0**	**21,700**

B. Pool- and Release-Duration Relationships

Pool-duration and release-duration relationships were developed with data for the period 1898-2011. DRM data were used for all years with the exception of 1975, 1997 and 2011 where observed elevations and releases were used to eliminate the influence of modeled outliers. Both ***Plate 12*** and ***Plate 13*** show the simulated data and the observed data. ***Plate 12*** shows the Garrison pool-duration relationship, while ***Plate 13*** shows the release-duration relationship. ***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

Percent of Time Equaled or Exceeded	Pool Elevation (ft msl)		Release (cfs)	
	Annual	May-Aug	Annual	May-Aug
Maximum	1854.8	1854.8	150,600	150,600
1	1851.9	1854.1	59,000	115,400
5	1848.6	1850.6	36,900	40,000
10	1846.9	1849.0	31,400	37,000
20	1844.5	1847.5	27,100	28,900
50	1838.8	1840.3	19,900	20,200
80	1823.8	1825.7	14,700	16,000
90	1816.9	1817.7	12,300	14,100
95	1812.4	1815.7	10,700	13,100
99	1807.6	1808.8	9,800	10,200
100	1805.8	1805.7	0	9,100

C. Pool-Probability Relationship

The maximum Garrison pool elevation recorded was 1854.8 ft msl in July 1975. In July 2011, the second highest pool of record occurred at elevation 1854.6 ft msl. In this analysis, the 1975 pool elevation for the simulated and observed data were both plotted at approximately 0.8 percent chance of exceedance (130-year return period). The 0.8 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 1.5 percent chance exceedance probability as the second highest pool elevation in 130 years. The 1999 Garrison pool-probability relationship closely followed the observed and simulated data. Therefore, the 1999 Garrison pool-probability relationship was adopted as the current version, except for lowering the 50 percent chance exceedance value to match the observed and simulated curves. Results of this analysis are shown in ***Table 8*** and ***Plate 16***.

Table 8
Garrison Pool-Probability Relationship
Pool Elevations ft msl

Percent Chance Exceedance	1976 Study	1999 Study	Observed (1967-2011)	Simulated (1898-2011*)	Adopted
50	1845.0	1848.0	1845.2	1845.0	**1845.0**
20	1850.0	1850.5	1849.5	1850.1	**1850.5**
10	1852.0	1852.0	1851.5	1851.3	**1852.0**
2	1853.5	1854.0	1854.6	1854.4	**1854.0**
1	1854.0	1854.5	1854.8	1854.6	**1854.5**
0.2	1855.0	1855.5	1855.0**	1855.5**	**1855.5**

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

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 described in the MRBWM Technical Report “Frequencies of the Upper Missouri Basin Runoff in 2011”, the 5-month runoff volume from March to July was estimated to have a recurrence interval between 200 and 500 years. 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 130 years.

Addition 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 20 to 50 percent chance of exceedance. The simulated data shows a distinct breakpoint occurring between the 10 to 20 percent chance exceedance range, then flattening again at approximately 60,000 cfs. The adopted Garrison release-probability relationship was based on the computed results from HEC-SSP analysis between the 0.5 to 20 percent chance of exceedance, followed by a straight line fit to the 0.2 percent chance of exceedance. The simulated releases were adopted from the 20 to 50 percent chance of exceedance. Results are shown in ***Table 9*** and ***Plate 17***. DRM and observed data are shown on ***Plate 18*** and ***Plate 19***, respectively.

It should be noted that in assigning a return period to the 2011 runoff event, the Fort Peck reach used the 2005 ”Hydrologic Statistics on Inflows” technical report and the 1881 flood as a guide while the Garrison reach used the “Frequencies of the Upper Missouri Basin Runoff in 2011” technical report. While the runoff into Fort Peck during the 2011 flood was a record, it was not as significant as what was experienced in the Garrison reach and did not approach the 0.2 percent chance of exceedance event (500-year return period).

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	1976 Study	1999 Study	Observed (1967-2011)	Simulated (1898-2011*)	Adopted
50	38,000	39,000	32,000	38,500	**39,000**
20	39,000	42,000	39,000	42,200	**42,000**
10	43,000	45,000	48,000	60,000	**48,000**
2	61,000	68,000	72,000	70,000	**72,000**
1	70,000	76,000	85,000	85,000	**85,000**
0.2	90,000	90,000	150,000	140,000	**150,000**

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

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 1967-2011, the pool elevation has ranged from a low of 1570.2 ft msl in August 2006 to a maximum of 1619.7 ft msl in June 2011, a range of almost 50 feet. The average annual pool elevation since 1967 is 1601.6 ft msl, with a standard deviation of 11.4 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 24,300 cfs since 1967, with a standard deviation of 8,500 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 (1967-2011)

Month	Pool Elevation (ft msl)			Daily Release (cfs)		
	Maximum	**Minimum**	**Mean**	**Maximum**	**Minimum**	**Mean**
Jan	1610.0	1572.8	1598.3	54,000	800	20,800
Feb	1611.2	1571.9	1599.5	45,600	0	18,200
Mar	1617.9	1572.3	1601.6	57,400	0	18,000
Apr	1618.4	1573.5	1603.6	59,100	0	20,800
May	1618.8	1574.8	1604.5	86,300	0	22,200
Jun	1619.7	1575.8	1605.0	160,300	0	27,300
Jul	1619.6	1573.4	1604.8	150,500	0	31,600
Aug	1618.3	1570.2	1603.3	135,100	0	34,100
Sep	1617.5	1570.3	1601.4	80,500	200	29,700
Oct	1616.9	1571.4	1599.9	57,500	0	24,000
Nov	1615.9	1572.7	1599.0	57,700	0	22,600
Dec	1612.5	1572.8	1598.5	56,700	0	21,100
Annual	**1619.7**	**1570.2**	**1601.6**	**160,300**	**0**	**24,300**

B. Pool- and Release-Duration Relationships

Pool-duration and release-duration relationships were developed with data for the period 1898-2011. DRM data were used for all years with the exception of 1975, 1997 and 2011 where observed elevations and releases were used to eliminate the influence of modeled outliers. Both ***Plate 21*** and ***Plate 22*** show the simulated data and the observed data. ***Plate 21*** shows the pool-duration relationship for Oahe; ***Plate 22*** shows the release-duration relationship. ***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

Percent of Time Equaled or Exceeded	Pool Elevation (ft msl)		Release (cfs)	
	Annual	May-Aug	Annual	May-Aug
Maximum	1619.7	1619.7	160,300	160,300
1	1618.1	1618.6	57,800	135,000
5	1616.4	1617.7	46,600	50,000
10	1614.5	1616.9	40,600	44,800
20	1611.1	1615.4	33,800	37,400
50	1605.6	1608.5	22,800	27,400
80	1590.4	1590.9	13,000	16,600
90	1582.2	1585.2	8,200	10,400
95	1576.4	1577.3	4,900	5,900
99	1572.5	1573.6	1,000	700
100	1570.2	1570.2	0	0

C. Pool-Probability Relationship

The maximum Oahe pool elevation recorded for Oahe Reservoir was 1619.7 ft msl during June 2011. In this analysis, the 2011 pool elevation for the simulated and observed data were both plotted at approximately 0.8 percent chance of exceedance (130-year return period). The 0.8 percent chance of exceedance probability represents the historical record back to the 1881 flood event, creating a longer period of record. The 1999 Oahe pool-probability relationship closely followed the observed and simulated data and will remain the adopted relationship. Results of this analysis are shown in ***Table 12*** and on ***Plate 25***.

Table 12
Oahe Pool-Probability Relationship
Pool Elevations in ft msl

Percent Chance Exceedance	1976 Study	1999 Study	Observed (1967-2011)	Simulated (1898-2011*)	Adopted
50	1610.0	1613.0	1611.2	1610.0	**1613.0**
20	1615.0	1617.0	1617.4	1616.5	**1617.0**
10	1617.0	1618.1	1618.5	1617.8	**1618.1**
2	1619.0	1619.5	1619.5	1619.0	**1619.5**
1	1620.0	1620.0	1619.7	1619.5	**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 and 2011.
** Extrapolated: Maximum observed is 1619.7 ft msl.

D. Release-Probability Relationship

The maximum Oahe daily release was 160,300 cfs in June 2011. In some years, maximum daily and maximum hourly releases can vary significantly, since Oahe is operated to meet peak power demands. It is not likely that releases greater than powerplant capacity would be made at Oahe unless required for emergency evacuation of storage or to prevent overtopping of the spillway tainter gates. Although the annual event results in a discharge higher than the listed powerplant capacity of 54,000 cfs, releases in excess of the rated capacity can occur during periods of higher than normal pool elevations or for short durations of high releases not sufficient to fill downstream channel storage and increase the tailwater significantly. Oahe does have six outlet tunnels that allow for an additional 111,000 cfs to be released, in addition to the full powerplant release of 54,000 cfs. Oahe is a significant “peaking” power-generating facility; the hourly discharge can vary significantly to meet peak power demands. This change in hourly discharge normally varies from 30,000 to 40,000 cfs, but can be as high as 58,000 cfs above the average daily release. Maximum hourly releases dating back to 1976 were available for this study.

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 MRBWM Technical Report "Frequencies of the Upper Missouri Basin Runoff in 2011", the 5-month runoff volume from March through July was estimated to have a recurrence interval between 200 and 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 130 years. Addition of these two extreme events creates a better estimation of expected releases between the 1 and 0.2 percent chance of exceedance. The adopted relationship follows the 1999 Oahe release-probability relationship from the 5 to 50 percent chance of exceedance. The adopted relationship then increases to fit the 1881 and 2011 events. The results of this analysis are shown in ***Table 13*** and ***Plate 26***. DRM and observed data are shown on ***Plate 27*** and ***Plate 28***, respectively.

Table 13
Oahe Release-Probability Relationships
Discharge in cfs

Percent Chance Exceedance	1976 Study	1999 Study	Observed (1967-2011)	Simulated (1898-2011*)	Adopted
50	57,500	56,000	46,000	57,000	**56,000**
20	57,500	57,000	54,000	59,000	**57,000**
10	57,500	57,500	55,000	60,000	**57,500**
2	65,000	65,000	80,000	70,000	**70,000**
1	70,000	70,000	90,000	85,000	**90,000**
0.2	85,000	85,000	160,000	160,000	**160,000**

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

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 1967-2011, the pool elevation has ranged from a low of 1414.7 ft msl in September 1967 to a maximum of 1422.1 ft msl in June 1991, a range of about 7 feet. The average annual pool elevation since 1967 is 1420.4 ft msl, 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 23,900 cfs since 1967 with a standard deviation of 8,600 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 (1967-2011)

Month	Pool Elevation (ft msl)			Daily Release (cfs)		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean
Jan	1421.7	1419.0	1420.4	56,500	0	20,400
Feb	1421.4	1419.4	1420.5	57,300	0	18,300
Mar	1421.6	1417.8	1420.4	69,200	0	18,800
Apr	1421.9	1417.7	1420.4	68,000	0	20,800
May	1421.8	1417.4	1420.4	83,900	0	22,300
Jun	1422.1	1417.9	1420.3	166,300	0	27,300
Jul	1421.2	1418.7	1420.2	155,000	0	30,500
Aug	1421.5	1417.8	1420.2	131,000	0	32,900
Sep	1421.8	1414.7	1420.3	74,500	0	28,800
Oct	1421.7	1414.9	1420.3	65,700	0	23,300
Nov	1421.5	1418.8	1420.4	63,700	0	22,300
Dec	1421.4	1418.1	1420.4	58,600	0	20,600
Annual	**1422.1**	**1414.7**	**1420.4**	**166,300**	**0**	**23,900**

B. Pool- and Release-Duration Relationships

Pool-duration and release-duration relationships were developed with the DRM using data from 1898-2010. To create a consistent data set ending in 2011, the observed 2011 elevation and release data were appended to the DRM data. Pool-duration and release-duration relationships were developed using historical daily records for the period of June 1967 through December 2011. ***Plate 30*** shows pool-duration relationships for the observed and simulated data. ***Plate 31*** shows the release-duration relationship based only upon 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

Percent of Time Equaled or Exceeded	Pool Elevation (ft msl)		Release (cfs)	
	Annual	May-Aug	Annual	May-Aug
Maximum	1422.1	1422.1	166,300	166,300
1	1421.2	1421.2	57,600	130,000
5	1421.0	1421.0	46,600	52,400
10	1420.9	1420.8	42,800	47,000
20	1420.7	1420.7	35,300	39,700
50	1420.4	1420.3	23,100	27,600
80	1420.0	1419.9	10,100	12,700
90	1419.8	1419.7	3,800	6,500
95	1419.6	1419.5	100	2,000
99	1419.0	1419.0	0	0
100	1414.7	1414.7	0	0

C. Pool-Probability Relationships

Annual maximum pool elevations at Big Bend have fluctuated only 1.7 feet during the period of 1967-2011, with the maximum pool recorded of 1422.1 ft msl 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 ft msl was plotted at approximately 0.8 percent chance of exceedance (130-year return period). The 0.8 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 ft msl. 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 run-of-the-river project, is operated to follow power-peaking requirements, and generally the pool elevations are maintained in the range from 1420.0-1421.0 ft msl.

Table 16
Big Bend Pool-Probability Relationship
Pool Elevations in ft msl

Percent Chance Exceedance	1976 Study	1999 Study	Observed (1967-2011)	Simulated (1898-2011*)	Adopted
50	--	1421.3	1421.3	1421.2	**1421.3**
20	--	1421.5	1421.5	1421.4	**1421.5**
10	--	1421.8	1421.8	1421.5	**1421.8**
2	--	1422.2	1422.2**	1421.8	**1422.2**
1	1423.0	1422.4	1422.4**	1422.0	**1422.4**
0.2	--	1423.0	1422.7**	1422.5	**1423.0**

* 2011 Observed data were added to the 1898-2010 DRM data set.
** Extrapolated: Maximum observed is 1422.1 ft msl.

D. Release-Probability Relationships

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 1976-2011. 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 MRBWM Technical Report "Frequencies of the Upper Missouri Basin Runoff in 2011", the 5-month runoff volume from March to July was estimated to have a recurrence interval between 200 and 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 130 years. Addition 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***. DRM 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	1976 Study	1999 Study Average Daily	1999 Study Peak Hourly	Observed (1967-2011)	Adopted Peak Hourly	Adopted Average Daily
50	110,000	55,000	103,000	55,000	**103,000**	**55,000**
20	110,000	61,000	105,000	61,000	**105,000**	**61,000**
10	110,000	65,000	107,000	65,000	**107,000**	**65,000**
2	110,000	72,000	109,000	85,000	**109,000**	**80,000**
1	110,000	75,000	110,000	95,000	**120,000**	**90,000**
0.2	110,000	80,000	110,000	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 1967-2011, the pool elevation has ranged from a low of 1317.9 ft msl in December 1968 to a maximum of 1374.0 ft msl in July 2011, a range of over 56 feet. Since 1971, the pool has drawn down to 1337.5 ft msl 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 ft msl. The average annual pool elevation since 1967 is 1351.2 ft msl, with a standard deviation of 2.3 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 25,200 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 (1967-2011)

Month	Pool Elevation (ft msl)			Daily Release (cfs)		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean
Jan	1351.1	1324.7	1344.4	27,600	4,500	15,100
Feb	1356.4	1338.7	1349.7	25,400	900	13,300
Mar	1362.4	1345.1	1354.9	40,500	500	15,500
Apr	1370.8	1350.8	1357.1	53,000	1,400	21,200
May	1372.2	1349.0	1357.7	76,600	0	25,400
Jun	1373.9	1349.9	1357.8	155,300	500	29,100
Jul	1374.0	1351.9	1357.4	160,000	600	33,300
Aug	1369.3	1350.7	1356.1	149,500	3,100	35,600
Sep	1365.9	1342.3	1353.3	90,200	8,600	34,800
Oct	1357.0	1333.2	1346.8	67,000	3,200	32,300
Nov	1349.9	1318.0	1339.5	67,500	3,200	28,700
Dec	1348.3	1317.9	1339.0	63,000	900	17,400
Annual	**1374.0**	**1317.9**	**1351.2**	**160,000**	**0**	**25,200**

B. Pool- and Release-Duration Relationships

Pool-duration and release-duration relationships were developed using the DRM which used data from 1898-2010. To create a consistent data set ending in 2011, the observed 2011 elevation and release data were appended to the DRM data. Both ***Plate 39*** and ***Plate 40*** show the simulated and observed data. ***Plate 39*** shows the Fort Randall pool-duration relationship and ***Plate 40*** shows the Fort Randall release-duration relationship. ***Table 19*** shows the 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

Percent of Time Equaled or Exceeded	Pool Elevation (ft msl)		Release (cfs)	
	Annual	May-Aug	Annual	May-Aug
Maximum	**1374.0**	**1374.0**	**160,000**	**160,000**
1	1367.8	1371.0	65,700	145,000
5	1361.5	1364.8	49,500	52,000
10	1359.3	1362.1	42,000	45,600
20	1356.8	1359.9	33,500	36,700
50	1353.6	1356.0	24,000	28,200
80	1343.5	1354.6	13,500	21,900
90	1339.6	1353.9	9,800	17,000
95	1338.1	1353.2	7,100	11,600
99	1326.5	1351.6	2,900	2,600
100	1317.9	1349.0	0	0

C. Pool-Probability Relationships

During 2011, the Fort Randall pool reached elevation 1374.0 ft msl, the maximum of record. In this analysis, the 2011 pool elevation for the simulated and observed data were both plotted at approximately 0.8 percent chance of exceedance (130-year return period). The 0.8 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 1.5 percent chance exceedance probability as the second highest pool elevation in 130 years. Results of the DRM 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 DRM does not utilize this project to maximize downstream flood control to the extent that is done in actual practice. Therefore, the adopted relationship was based primarily on an eye-fit of the observed data. Results of this analysis are shown in ***Table 20*** and ***Plate 43***.

Table 20
Fort Randall Pool Probability Relationship
Pool Elevations in ft msl

Percent Chance Exceedance	1976 Study	1999 Study	Observed (1967-2011)	Simulated (1898-2011*)	Adopted
50	1361.5	1360.0	1360.0	1355.5	**1360.0**
20	1364.5	1364.0	1364.0	1357.6	**1364.0**
10	1366.0	1366.0	1367.0	1363.0	**1367.0**
2	1369.0	1372.0	1372	1371.0	**1372.0**
1	1370.0	1375.0	1374.0	1373.0	**1374.0**
0.2	1372.0	1377.0	1377.0**	1376.0**	**1377.0**

* 2011 observed data were added to the 1898-2010 DRM data.
** Extrapolated: Maximum observed is 1374.0 ft msl.

D. Release-Probability Relationships

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 MRBWM Technical Report "Frequencies of the Upper Missouri Basin Runoff in 2011", the 5-month runoff volume from March to July was estimated to have a recurrence interval between 200 and 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 130 years. Addition 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 on the upper end of the curve transitioning to the full powerplant capacity of 44,500 cfs at the 50 percent chance exceedance. Results of this analysis are shown in ***Table 21*** and on ***Plate 44***. DRM 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	1976 Study	1999 Study	Observed (1967-2011)	Simulated (1898-2011*)	Adopted
50	48,000	41,000	37,000	42,000	**45,000**
20	49,000	50,000	47,000	50,000	**50,000**
10	55,000	55,000	56,000	50,000	**56,000**
2	69,000	69,000	81,000	70,000	**84,000**
1	75,000	85,000	95,000	80,000	**100,000**
0.2	88,000	88,000	160,000	160,000	**160,000**

* 2011 observed data were added to the 1898-2010 DRM data set.

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 1967-2011, the pool elevation has ranged from a low of 1199.8 ft msl in March 1969 to a maximum of 1209.7 ft msl in June 2010, a range of about 10 feet. The average annual pool elevation since 1967 is 1206.8 ft msl, with a standard deviation of 1.2 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 27,300 cfs since 1967, with a standard deviation of 9,400 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 (1967-2011)

Month	Pool Elevation (ft msl)			Daily Release (cfs)		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean
Jan	1208.9	1204.1	1207.4	31,000	7,800	17,100
Feb	1209.2	1203.2	1206.9	34,700	7,500	17,300
Mar	1209.2	1199.8	1205.6	42,000	6,000	19,600
Apr	1208.2	1201.5	1205.8	58,000	6,000	25,000
May	1209.5	1204.2	1205.8	77,000	8,000	28,800
Jun	1209.7	1204.3	1206.0	160,700	6,000	32,200
Jul	1208.9	1204.4	1206.5	160,300	6,000	35,100
Aug	1209.4	1204.7	1207.0	151,800	7,000	36,900
Sep	1208.8	1203.9	1207.5	90,100	14,000	36,500
Oct	1209.2	1206.4	1207.7	70,100	7,600	34,400
Nov	1209.0	1204.5	1207.7	70,100	7,500	31,100
Dec	1209.1	1203.9	1207.4	68,000	8,000	19,500
Annual	**1209.7**	**1199.8**	**1206.8**	**160,700**	**6,000**	**27,800**

B. Pool- and Release-Duration Relationships

Pool-duration and release-duration relationships were developed using the DRM which used data from 1898-2010. To create a consistent data set ending in 2011, the observed 2011 elevation and release data were appended to the DRM data. Both ***Plate 48*** and ***Plate 49*** show the simulated data along with the observed data. ***Plate 48*** and ***Plate 49*** shows the pool-duration and release-duration relationships for Gavins Point, respectively. ***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

Percent of Time Equaled or Exceeded	**Pool Elevation (ft msl)**		**Release (cfs)**	
	Annual	**May-Aug**	**Annual**	**May-Aug**
Maximum	**1209.7**	**1209.7**	**160,700**	**160,700**
1	1208.5	1208.4	68,000	150,000
5	1208.2	1208.0	52,000	55,000
10	1208.1	1207.8	43,100	46,000
20	1207.9	1207.2	35,000	37,000
50	1206.9	1206.2	27,000	31,000
80	1205.7	1205.4	16,500	24,600
90	1205.2	1205.1	13,000	21,000
95	1205.0	1205.0	11,000	16,000
99	1204.4	1204.7	8,600	9,000
100	1199.8	1204.2	6,000	6,000

C. Pool-Probability Relationships

Historically, the observed maximum daily pool elevations at Gavins Point have varied only 1.8 feet during the period of 1967-2011 with the maximum pool elevation of 1209.7 ft msl recorded in June 2010. In this analysis, the maximum pool elevations for the simulated and observed data were plotted at approximately 0.8 percent chance of exceedance (130-year return period). The 0.8 percent chance of exceedance probability represents the historical record back to the 1881 flood event, creating a longer period of record.

A pool-probability relationship was not derived for Gavins Point in the 1976 study. However, it was assumed that in 1976 the 1 percent chance exceedance pool elevation would be 1213.0 ft msl, based on incremental runoff occurring coincident with a starting Gavins Point pool exceeding elevation 1204.5 ft msl 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 ft msl with the maximum pool elevation of 1211.0 ft msl assumed to be a 0.2 percent event. This results in a 1 percent pool elevation about three feet lower than that assumed in the 1976 study. The major factor influencing the change is the 30 years of operational history with major runoffs. The 1999 Gavins Point pool-probability relationship 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 ft msl

Percent Chance Exceedance	1976 Study	1999 Study	Observed (1967-1995)	Simulated (1967-2011*)	Adopted
50	--	1208.8	1208.8	1207.5	1208.8
20	--	1209.0	1209.0	1208.4	1209.0
10	--	1209.2	1209.2	1208.6	1209.2
2	--	1209.6	1209.6	1209.0	1209.6
1	1213.0	1210.0	1209.7	1209.2	1210.0
0.2	--	1211.0	1210.5**	1210.0	1211.0

* 2011 observed data were added to the 1898-2010 DRM data set.
** Extrapolated: Maximum observed since 1967 is 1209.7 ft msl.

D. Release-Probability Relationships

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 MRBWM Technical Report "Frequencies of the Upper Missouri Basin Runoff in 2011", the 5-month runoff volume from March to July was estimated to have a recurrence interval between 200 and 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 130 years. Addition of these two extreme events creates a better estimation of expected releases between the 1 and 0.2 percent chance of exceedance.

The development of the final adopted relationship was guided by the expected probability relationship produced from the observed data analysis as it best fit the historical data points on the upper end of the curve transitioning to the 1999 adopted relationship for events with a less than the 10 percent chance of exceedance. Results of this analysis are shown in ***Table 25*** and ***Plate 53***. DRM and observed data are shown on ***Plate 54*** and ***Plate 55***, respectively.

Table 25
Gavins Point Release-Probability Relationship
Discharge in cfs

Percent Chance Exceedance	1976 Study	1999 Study	Observed (1967-2011)	Simulated (1898-2011*)	Adopted
50	37,000	38,000	36,000	44,000	**38,000**
20	47,000	47,000	47,000	55,000	**47,000**
10	54,000	54,000	57,000	60,000	**57,000**
2	72,000	72,000	84,000	75,000	**84,000**
1	80,000	80,000	100,000	85,000	**100,000**
0.2	100,000	100,000	160,000	160,000	**160,000**

* 2011 observed data were added to the 1898-2010 DRM data set.

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 45-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 ft msl

Project	Percent Chance of Exceedance					
	50	20	10	2	1	0.2
Fort Peck	2240.0	2246.5	2249.0	2252.0	2252.2	2253.0
Garrison	1845.0	1850.5	1852.0	1854.0	1854.5	1855.5
Oahe	1613.0	1617.0	1618.1	1619.5	1620.0	1621.0
Big Bend	1421.3	1421.5	1421.8	1422.2	1422.4	1423.0
Fort Randall	1360.0	1364.0	1367.0	1372.0	1374.0	1377.0
Gavins Point	1208.8	1209.0	1209.2	1209.6	1210.0	1211.0

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	15,000	17,000	25,000	48,000	60,000	95,000
Garrison	39,000	42,000	48,000	72,000	85,000	150,000
Oahe	56,000	57,000	57,500	70,000	90,000	160,000
Big Bend	55,000	61,000	65,000	80,000	90,000	160,000
Fort Randall	45,000	50,000	56,000	84,000	100,000	160,000
Gavins Point	38,000	47,000	57,000	84,000	100,000	160,000

XI. SYSTEM REGULATION IN SIGNIFICANT RUNOFF YEARS

This chapter presents a discussion of specific System regulation requirements for a few of the more significant runoff years.

A. Regulation of 1975 Runoff

Runoff during 1975 from the drainage area controlled by the System totaled 35.5 MAF, which ranks as the ninth highest since mainstem regulation began and the tenth highest during the period 1898-2011. 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. All maximum release rates were well below the flow rates that occurred frequently prior to operation of the System and below those that would have occurred on numerous occasions since operation began.

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.

A criticism of overall regulation in 1975 was that pool levels at Fort Peck and Garrison were allowed to rise too high. At Fort Peck, the pool reached elevation 2251.6 ft msl, the highest level reached before 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 Garrison maximum pool level reached elevation 1854.8 ft msl, which is 0.8 foot into the surcharge zone and remains the maximum level ever reached. Maintaining lower levels in the upstream reservoirs would have required substantial increases in the releases from these projects. When it became apparent that utilization of surcharge storage was probable, releases were increased up to the maximum rate believed practicable without causing substantial lowland flooding through the immediate downstream areas. Since encroachment into the surcharge zone of any reservoir project reduces the effectiveness of the project for control of subsequent flood inflows that may occur, consideration is given to the time of year and risk of subsequent floods. If the encroachment had occurred early in the flood season prior to mountain snowmelt, it would have been much more serious and would have required greater project releases. However, actual encroachment occurred when the mountain snowmelt was essentially completed and the normal season of large runoff producing rains in upstream areas had passed. Maintaining relatively higher Fort Peck and Garrison reservoir levels than at downstream projects also served to maintain an overall increased flood control capability of the System by providing additional flood control storage space in downstream projects.

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

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

1. Releases during the period extending from March-May were less than would normally be made with the amount of storage accumulated at Fort Peck. Reasons for this included low forecasts of subsequent runoff, the desire to make large releases during the later irrigation season because of temporary irrigation intake deficiencies, and powerplant maintenance requirements. This combination, coinciding with such an unprecedented amount of runoff, is considered to be remote.

2. Analysis of the release pattern in combination with pool levels indicates that during the 1975 flood there was a several-day delay in increasing releases to all levels, including particularly those that exceeded powerplant capacity. After the event it was noted the maximum release did not cause significant problems to at least the mouth of the Yellowstone River. In future events, this available channel capacity could be fully utilized during the early portions of an event, resulting in lower crest levels than occurred in 1975.

B. Regulation of 1978 Runoff

Above Sioux City, runoff during 1978 totaled 40.6 MAF, the third highest on record. System storage increased rapidly at the beginning of the 1978 navigation season. On March 22, System storage was 54.0 MAF, which increased 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, an upward adjustment of the forecasted annual runoff resulted in the decision to increase navigation levels to full service. 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 ft msl to 1209.2 ft msl, the highest pool elevation until June 2010 (1209.7 ft msl).

Releases from Fort Randall generally paralleled those from Gavins Point with the exception of the flood runoff period and a scheduled weekly cycle that permitted Fort Randall to share the Sunday release sags occasioned by the reduced power loads. Due to the large runoff that began about mid-March, releases were reduced to about 1,000 cfs for one week to limit the pool rise in 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 ft msl 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, drawing the Fort Randall Reservoir down to elevation 1339.3 ft msl by the end of November.

At Oahe, the pool level increased from elevation 1600.6 ft msl at the end of February to its annual peak of 1616.2 ft msl in mid-July. Hour-to-hour and day-to-day releases from both Oahe and Big Bend fluctuated widely to meet varying power loads and to back System releases. Oahe outflows of at least 3,000 cfs were maintained during weekend daylight hours to enhance downstream fishing and recreational use during the recreation season. Oahe releases reached a maximum of 54,300 cfs in September. The Big Bend Reservoir was maintained near elevation 1420.0 ft msl during the entire period.

At the beginning of the period, the Garrison Reservoir level was at elevation 1826.0 ft msl, 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 ft msl 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 ft msl in early March. It rose to elevation 2245.0 ft msl by the end of May and crested at elevation 2249.6 ft msl on July 20. Releases from Fort Peck were reduced from 8,000 cfs to only 3,000 cfs or less during the last two days of March and the first nine days of April to minimize flooding near the mouth of the Milk River as stages in that stream reached record levels. 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 was 36.2 MAF, the seventh highest on record and the sixth highest from 1967-2011. 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. The Oahe Reservoir climbed to a new record high in June, which was not exceeded until 1995. 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 even though Gavins Point releases remained near the winter release level of 18,000 cfs. Missouri River flows continued well above normal during April with near record precipitation. As a result, Gavins Point releases during April averaged only 17,200 cfs, the third lowest monthly average since the System became operational in 1967. Despite these low releases, rains caused the lower river to exceed flood stage at several locations downstream from the Platte River. 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 project 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. Although it was desired to initiate Gavins Point spillway releases in late July, they were delayed to mid-August to facilitate the completion of nesting of least terns and piping plovers. In October, maximum daily releases from Gavins Point reached 45,000 cfs.

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

The Big Bend Reservoir was maintained between a minimum elevation of 1419.5 ft msl and a maximum of 1421.5 ft msl. At the beginning of March, the Oahe Reservoir level was near elevation 1604.0 ft msl, 3.5 feet below the base of Annual Flood Control and Multiple Use Zone. It reached a record elevation of 1618.5 ft msl on May 16, 0.2 foot higher than the previous record set in 1984. This pool level remained the record elevation until it was surpassed in 1995 (1618.6 ft msl) and again in 2011 (1619.7 ft msl).

At the beginning of the runoff period Garrison releases were 28,000 cfs and then were gradually decreased to 14,000 cfs by the end of April. 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 ft msl.

At Fort Peck, the pool was near elevation 2229.1 ft msl at the beginning of the 1986 navigation season. This was 4.9 feet below the base of the Annual Flood Control and Multiple Use Zone and 6.9 feet lower than in 1985. 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 ft msl by the end of December.

D. Regulation of 1993 Runoff

During 1993, runoff above Sioux City, IA totaled 36.2 MAF, the eighth highest on record and seventh highest since System regulation began in 1967. Downstream from Sioux City to the mouth of the Missouri River, runoff during 1993 was an unprecedented 111.8 MAF, which was 255 percent of average. Upstream from Sioux City, runoff was 36.2 MAF, 147 percent of normal. Six consecutive years of below normal runoff in the upper Missouri River Basin ended dramatically in 1993. System storage began 1993 at 42.7 MAF, more than 14.0 MAF below the base of the Annual Flood Control and Multiple Use Zone. System storage for the year crested at 57.2 MAF on September 7. Low System releases to lessen downstream impacts during the Great Flood of 1993 had a significant impact on the accumulation of storage during July through September. The Great Flood of 1993, with its 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. Average monthly releases during May and July were new record lows. Daily average releases varied between 26,000 cfs in late May and 600 cfs in July. At the beginning of the navigation season the Fort Randall pool level was near elevation 1357.0 ft msl, climbing to a crest of 1361.0 ft msl by the end of July.

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

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

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

E. Regulation of 1995 Runoff

Runoff above Sioux City, IA during 1995 totaled 37.2 MAF, the fifth highest year on record (1898-2011). Near the start of the winter season (November 1, 1994) System storage was at the desired level of 57.2 MAF, the base of the Annual Flood Control and Multiple Use Zone. During the winter months, inflows to the System were below normal and the System storage fell slightly to 55.9 MAF. System storage made its 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. Record high pool elevations occurred at Gavins Point, Fort Randall and Oahe. Flood damages prevented exceeded $1.8 billion.

Gavins Point releases were held near 17,000 cfs until mid-March, when flow support for the navigation season began as releases were gradually increased to 26,500 cfs. In April, Gavins Point releases were reduced to 12,000 cfs to reduce the threat of flooding downstream. By the end of May, releases were increased to 25,000 cfs as downstream flooding subsided. By the end of June releases from Gavins Point were increased to 35,000 cfs, 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. In November, the maximum daily release of 56,100 cfs occurred. These high releases were made to evacuate the accumulated flood storage. The Gavins Point Reservoir target elevation was 1206 ft msl throughout the spring and summer of 1995. The Gavins Point reservoir elevation ranged from 1205.8 ft msl to a then record high pool elevation of 1209.5 ft msl in May. This elevation was within 0.5 foot of overtopping the spillway gates (closed position). 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 an elevation of 1367.9 ft msl. The Fort Randall Reservoir elevation was gradually decreased, reaching 1359.4 ft msl by the end of July and 1338.3 ft msl by the end of November as releases were increased to a maximum of 53,000 cfs by November.

At Oahe and Big Bend, daily average releases were well below normal during April through June to prevent flooding downstream. Oahe releases averaged only 1,900 cfs in May, a record low. In June, releases averaged 11,100 cfs. These low releases, in conjunction with high inflows, resulted in a then record high Oahe Reservoir level of 1618.7 ft msl 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. Evacuation of Oahe flood storage gradually brought the pool elevation down to 1608.2 ft msl by the end of December. Big Bend pool levels were maintained between elevations 1419.4 ft msl and 1421.8 ft msl during this period.

Garrison releases averaged 12,300 cfs for the month of April. Releases were cycled from mid-May through early July to prevent threatened and endangered birds from nesting in low areas of sandbars in the reach below Garrison. During May, the cycle was one day at 16,000 cfs followed by two days of 13,000 cfs. The cycling pattern was modified as the Oahe Reservoir continued to climb. By June the cycle was two days at 10,000 cfs followed by one day at 13,000 cfs. During 1995 the Garrison Reservoir level increased over 15 feet to elevation 1851.9 ft msl 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.

Releases from Fort Peck averaged 5,800 cfs in April to support fish spawning below the dam. In May, releases were increased to near 7,000 cfs and remained at this level through the end of July. At the beginning of the navigation season, the elevation of the Fort Peck pool was 2231.5 ft msl. It rose gradually to a peak elevation of 2244.2 ft msl 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 to gradually draw the pool down to elevation 2238.3 ft msl by the end of December.

F. Regulation of 1996 Runoff

Runoff in the Missouri River Basin above Sioux City, IA in 1996 was 35.6 MAF, the ninth highest on record and very near the total runoff experienced in 1975. Runoff was 45 percent above normal. 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 and the System storage was on target to be at the base of the Annual Flood Control and Multiple Use Zone by the first of March. However, 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. While runoff was accumulating in the System, snow was continuing to build in the mountains. The mountain snowpack continued to accumulate into early May peaking nearly 20 percent above the normal peak accumulation.

System storage declined to as low as 58.1 MAF in late January and early February, but 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 were made from February to April in order to create adequate space to manage expected high inflows from the plains and mountain snowpack. Near the end of April, very heavy rain fell across southeastern Missouri, marking the end of a relatively dry period in the lower basin and the beginning of a series of very heavy rainfall events below the System. The heavy rains began in Missouri and gradually moved upstream as the summer progressed with much of the heaviest rain, including several events with as much as 6 to 12 inches, falling along the Missouri River in eastern Nebraska and western Iowa. Gavins Point releases were held near 20,000 cfs until early February and then gradually increased to full 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. Releases were reduced several times during May, June and July as significant downstream rainfall events occurred. Between storms in June, releases reached 50,000 cfs and by July 1, they reached 52,000 cfs and remained at that rate until late fall. The peak System storage of 68.5 MAF occurred on July 7, 0.4 MAF higher than 1995's peak storage. The releases reached 55,000 cfs, the maximum of the year, in early November after tributary flows had declined and cooler water temperatures made the additional increases possible without increasing stages downstream.

Releases from Fort Randall generally paralleled those from Gavins Point. Average daily releases during the year varied between 9,100 cfs in late May 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 ft msl on June 28, 3.5 feet below the base of the Exclusive Flood Control Zone.

The Oahe Reservoir was drawn down to within 0.4 feet of the base of the Annual Flood Control and Multiple Use Zone prior to February’s record runoff. It then rose 3.5 feet to 1611.1 ft msl by March 1. The pool continued on a steady rise 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 ft msl 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 before being cutback prior to the winter freeze-in. The Oahe Reservoir elevation was at 1607.5 ft msl at year’s end, the base of the Annual Flood Control and Multiple Use Zone.

The Garrison Reservoir reached the base of its Annual Flood Control and Multiple Use Zone in early February. High inflows during the month caused the reservoir elevation to climb to 1839.6 ft msl 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 ft msl on July 23, 0.4 feet from the base of the Exclusive Flood Control Zone. Higher-than-normal releases through the summer and fall lowered the pool to 1838.9 ft msl by the end of December, 1.4 feet into the Annual Flood Control and Multiple Use Zone.

The Fort Peck Reservoir was drawn down to within 2.6 feet of the base of the Annual Flood Control and Multiple Use Zone prior to February’s high inflows, but rose to 2238.0 ft msl, 4.0 feet into the Annual Flood Control and Multiple Use Zone by March 1. The pool peaked at 2247.3 ft msl, 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. The Fort Peck Reservoir elevation at year's end was 2236.0 ft msl, 2.0 feet into the Annual Flood Control and Multiple Use Zone.

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 snow pack. 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. Record and near-record inflows occurred during each of the first seven months of the year. The January-February runoff exceeded the maximum set just one year earlier and the March-April total runoff exceeded the 1952 historic maximum. May and June runoff were the fifth and fourth largest monthly runoffs, respectively, in the 114 years for which runoff records have been kept and the three-month May-July runoff was third only to 1975 and the record amount in 2011. The combined runoff for the five-month March-July period, which comprised the second highest runoff period, totaled 36.8 MAF, 17 percent more than the third highest that occurred in 1978. The total annual runoff was 49.0 MAF, second only to the record runoff in 2011. Annual runoff was 194 percent of average and 21 percent greater than the third highest, which was experienced in 1978.

Early in the year, MRBWM forecasted near record reservoir inflows. In response to the expected large inflows, System releases were increased to record levels early in the year and were maintained at rates significantly higher than previous levels. January releases were near historic highs, and by February record high releases began and continued throughout the remainder of the year. For the January-July period System releases were 183 percent of average and 32 percent greater than the previous record for the period set just one year earlier. The Oahe and Fort Randall reservoirs rose into their respective Exclusive Flood Control Zones during March and April, respectively. The pool rises were in response to the unprecedented runoff from the record plains snowpack, whose melt was accelerated by warmer than normal temperatures. Fort Peck and Garrison releases were minimized early in the runoff period, to the extent possible, to stem the rise in Oahe and Fort Randall pools.

The 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 Oahe Reservoir rose from a winter minimum level of 1607.5 ft msl to 1618.6 ft msl by early May, climbing 8.0 feet during the month of March alone. Fort Randall Reservoir climbed from a late winter level of 1353.0 ft msl to a maximum and record of

1372.2 ft msl 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. Releases from Fort Peck and Garrison were increased significantly. Garrison's release was set at 59,000 cfs, at the time the second highest rate of record. Increases at Fort Peck were made later and were at a lower rate to help evacuate Garrison. Both were set at a rate that would result in the evacuation of the flood pool by the beginning of the upcoming flood season.

Fort Peck 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 ft msl, 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 ft msl on July 4, slightly overtopping the closed spillway gates. This elevation was slightly less than the record 1854.8 ft msl experienced in 1975. Fort Peck reached an elevation of 2250.3 ft msl on July 23, 2.0 feet less than the record peak of 2252.3 ft msl, which occurred in 2011. Some of the rise in Fort Peck was due to release reductions to stem the rise at Garrison. In addition, evacuation of flood storage in U.S. Bureau of Reclamation (USBR) Section 7 tributary reservoirs was also delayed to halt Garrison's pool rise.

System releases were maintained at record levels beginning in early February in order to maintain, to the extent possible, sufficient flood storage space to store the forecasted large runoffs. In spite of 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 January-July System release was 83 percent greater than normal and was 32 percent higher than the record set just one year earlier.

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 fourth highest on record.

At the end of 2009, the Missouri River Basin was almost entirely covered by plains snowpack as a result of October and early December snowfall in the plains coupled with colder-than-normal temperatures. Snowfall 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.

Over the course of the winter season, the mountain snowpack accumulation was above average until early December and then lessened to below-average levels and remained there for the season. A cool and wet April and May revived the snowpack accumulation in the reach from Fort Peck to Garrison and delayed the peak mountain SWE until May 13, almost one month from the average April 15 peak. 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. Areas of the basin received well-above average precipitation in all periods; however, much greater than normal precipitation occurred in April through August. Notable rainstorms in eastern Nebraska and South Dakota highlighted the wet year. Montana, parts of North Dakota, and the Rocky Mountain Front Range in Wyoming and Colorado received above average precipitation in the October through December period. In January through March much of Montana and Wyoming were drier than average. From October to December drier-than-average conditions occurred in southern South Dakota, Nebraska, Kansas and Missouri.

Early spring rainfall and plains snowmelt produced a March through May runoff of 13.1 MAF above Sioux City, which was 145 percent of normal. Runoff volumes above Sioux City, IA for June and July were higher than normal, 8.6 MAF (161 percent of normal) and 5.9 MAF (186 percent of normal), respectively. The June-July runoff was a result of mountain snowpack runoff as well as significant rainfall runoff.

Gavins Point January-March releases ranged from 15,000 cfs to 17,000 cfs as below-normal temperatures created river ice issues downstream. 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 ft msl on June 14, the highest pool elevation recorded since 1967, and 0.3 feet below the top of the closed spillway gates. By June 20, the Gavins Point Reservoir reached the month's minimum elevation of 1205.2 ft msl. At the same time, the lower Missouri River was setting record stages. An 18,000 cfs reduction in System releases, from 33,000 cfs to 15,000 cfs, was made on June 22, and the releases were held for two days at 15,000 cfs, in order to reduce peak stages in the lower Missouri River. Releases were increased as downstream stages receded. 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 ft msl to 1361.1 ft msl during March. Runoff from above-normal rainfall upstream and downstream of Fort Randall resulted in the pool elevation reaching a maximum of 1368.1 ft msl on June 22, 3.1 feet into the 10-foot Exclusive Flood Control Zone. Maximum Fort Randall releases reached 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 ft msl in early February. The peak daily release was 56,700 cfs and the peak hourly release was 97,900 cfs.

Oahe began 2010 at 1607.0 ft msl, 0.5 feet below the base of Annual Flood Control and Multiple Use Zone. 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 ft msl, 0.9 feet into its 3-foot Exclusive Flood Control Zone. Releases from Oahe did not exceed powerplant capacity during floodwater evacuation.

Garrison began the 2010 runoff season at 1837.5 ft msl, at the base of Annual Flood Control and Multiple Use Zone. Although inflows were below normal, the Garrison pool rose steadily during March through May due to lower than normal releases. The pool reached 1841.0 ft msl at the end of May. 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 in order to reduce high flows in the lower reaches of the Missouri River downstream of the System. The mountain snowpack runoff resulted in the Garrison pool elevation peaking at 1851.4 ft msl, 1.4 feet into the Exclusive Flood Control Zone. Evacuation releases peaked at 31,200 cfs in November.

The Fort Peck Reservoir level began 2010 at elevation 2221.1 ft msl, 12.9 feet below the base of Annual Flood Control and Multiple Use Zone. 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 ft msl at the end of March to 2233.3 ft msl at the end of June, during the forage fish spawn. High flows on the Milk River allowed for below normal releases while still meeting the needs of downstream irrigation. The reservoir peaked at 2235.8 ft msl, 1.8 foot into the Annual Flood Control and Multiple Use Zone. This marked Fort Peck's recovery from the 2000-2007 drought. Peak releases of 11,500 cfs were made to mitigate the effects of a power transmission issue; the peak daily release associated with normal operations was 8,800 cfs.

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, 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 114-year period of record. The 34.3 MAF of runoff received during that 3-month period exceeded the total annual runoff in 102 of the previous 113 years.

The winter of 2011 marked the third consecutive year of significant plains snowpack. All of the stored floodwaters from 2010 had been evacuated from the System by January 28, 2011 when System storage reach 56.8 MAF, the base of the Annual Flood Control and Multiple Use Zone. Some subsequent plains snowmelt resulted in some early System inflows, resulting in System storage on March 1 of 57.6 MAF, which occupied 0.8 MAF of the 16.3 MAF flood control storage space.

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. In some areas of the basin, particularly in the Milk River basin and the upper James and Big Sioux River basins, the plains snowpack was classified as "very heavy" with SWE amounts exceeding 6 inches. As the System storage increased, as well as mountain snowpack and forecasted inflow, the service level was increased 10,000 cfs (from 35,000 cfs to 45,000 cfs) in early April, another 5,000 cfs in mid-April (to 50,000 cfs), and an additional 10,000 cfs (to 60,000 cfs) in early May. 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. Initial analyses called for releases from the lower five System projects to be increase to 85,000 cfs. On May 25 an additional 1.5-2.0 inches of rain fell in eastern Montana further exacerbating the flooding situation. On May 26, releases for the lower five System dams were forecast to be increased to range from 110,000 cfs to 120,000 cfs, with Fort Peck Dam releases increasing to 50,000 cfs. On May 27, the NWS precipitation forecasts indicated that an additional 2-3 inches over the eastern half of Montana would fall May 30-31. The decision was then made to increase releases on the lower five System projects to 150,000 cfs. System releases were 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).

The Fort Peck Reservoir was in or above its Exclusive Flood Control Zone for 71 days, from May 26 through August 4, and was in the surcharge zone for 35 days, from June 3 through July 7. Garrison Reservoir was in or above its Exclusive Flood Control Zone for 79 days, from May 22 through August 8, and was in the surcharge zone for 23 days, from June 20 through July 12. Oahe Reservoir was its Exclusive Flood Control Zone for 78 days, from May 21 through August 6. Fort Randall Reservoir was in its Exclusive Flood Control zone for 60 days, from June 19 through August 17.

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 inflow exceeded the previous June maximum daily inflow into Fort Peck of 80,000 cfs for total of ten days. The average 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 release from Fort Peck was established on June 15, 2011 at 65,900 cfs. The previous record maximum was 35,400 cfs (July 1975), which was exceeded for 46 days in 2011. The highest record Fort Peck Reservoir level of 2252.3 ft msl occurred on June 15, 2011, eclipsing the previous reservoir level of 2251.6 ft msl 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 daily average inflows exceeded the previous June maximum daily inflow into Garrison of 125,000 cfs for a total of 39 days. Included in this inflow where the releases from Fort Peck. The record maximum daily Garrison release of 150,600 cfs was established on June 25. The previous maximum was 65,200 cfs (July 1975), which was exceeded for 100 days in 2011. The Garrison Reservoir pool elevation peaked at 1854.6 ft msl 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 ft msl 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, and included Garrison’s release. The daily average inflows exceeded the previous June maximum daily inflow into Oahe of 103,000 cfs for a total of 73 days. Included in this inflow were the releases from Garrison. The record maximum daily release from Oahe occurred on June 20, 2011 at 160,300 cfs. Previously the record was 59,300 cfs, which was established in July 1997. The old record release was exceeded for 122 days in 2011. The highest Oahe Reservoir level during 2011 occurred on June 26 at 1619.7 ft msl. The peak reservoir elevation set a record for the highest peak pool since the System first became fully operational in 1967. The prior record was 1618.7 ft msl, 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, and included Oahe’s releases. The previous record inflow of

79,000 cfs occurred in June 1997. The previous inflow record was exceeded for 92 days in 2011. Included in this inflow were the releases from Oahe. 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. The 2011 the previous record was exceeded for 98 days. As a run-of-the-river 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 total of 218,000 cfs occurred on June 21 and more than doubled the previous June maximum daily record of 95,000 cfs. This inflow included Big Bend's release. The 95,000 cfs prior record was exceeded for 88 days in 2011. Included in this inflow were the releases from Big Bend. 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 and was exceeded on 119 days in 2011. The highest Fort Randall Reservoir level during 2011 occurred on July 7 at 1374.0 ft msl, which exceeded the previous record high of 1372.2, set in May 1997.

At Gavins Point, the maximum daily inflow of 168,000 cfs occurred on June 27. This inflow exceeded the prior maximum June daily inflow in 1997 of 61,000 cfs for 127 days. The prior annual maximum record was 74,000 cfs, which also occurred in 1997. This higher level was exceeded in 116 days in 2011. 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, which was exceeded for 119 days in 2011. The highest Gavins Point Reservoir level in 2011 was 1208.6 ft msl, reach on February 11. This was not a record pool elevation. As is the case with Big Bend, Gavins Point is considered a run-of-the-river project used to smooth out releases from Fort Randall with a small amount of flood control storage available to manage local inflows.

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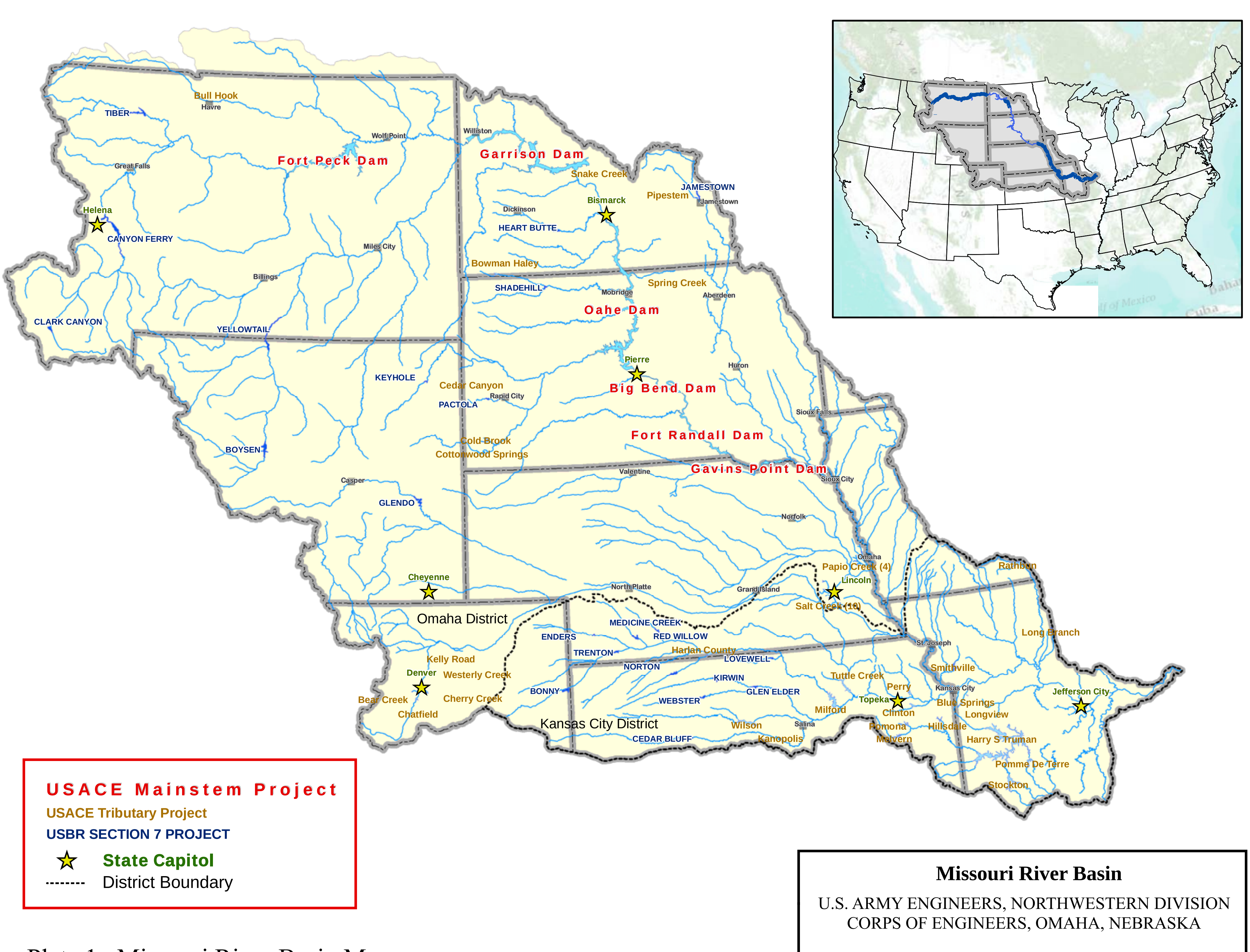

Plate 1. Missouri River Basin Map

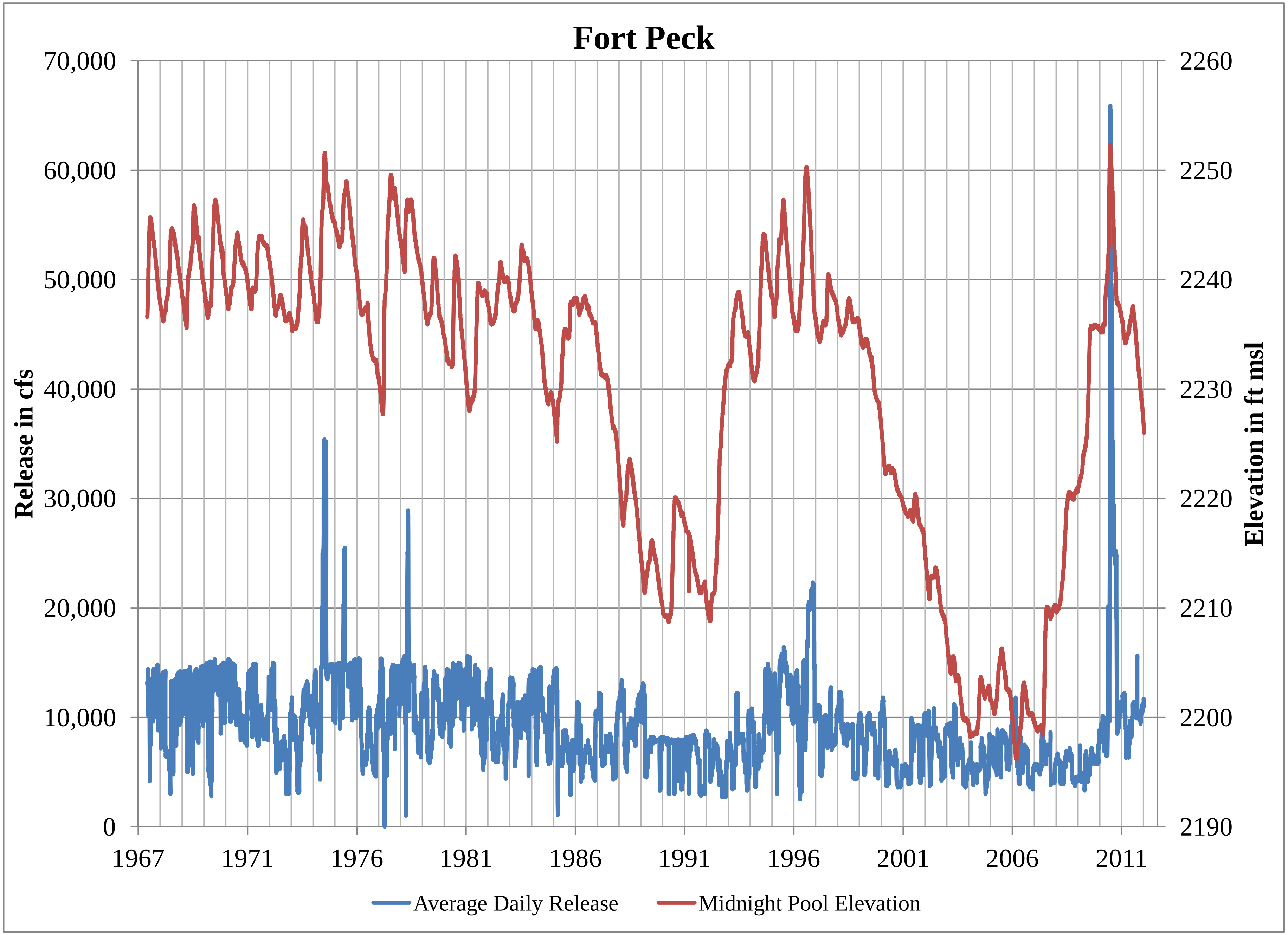

Plate 2. Fort Peck Daily Releases and Elevations.

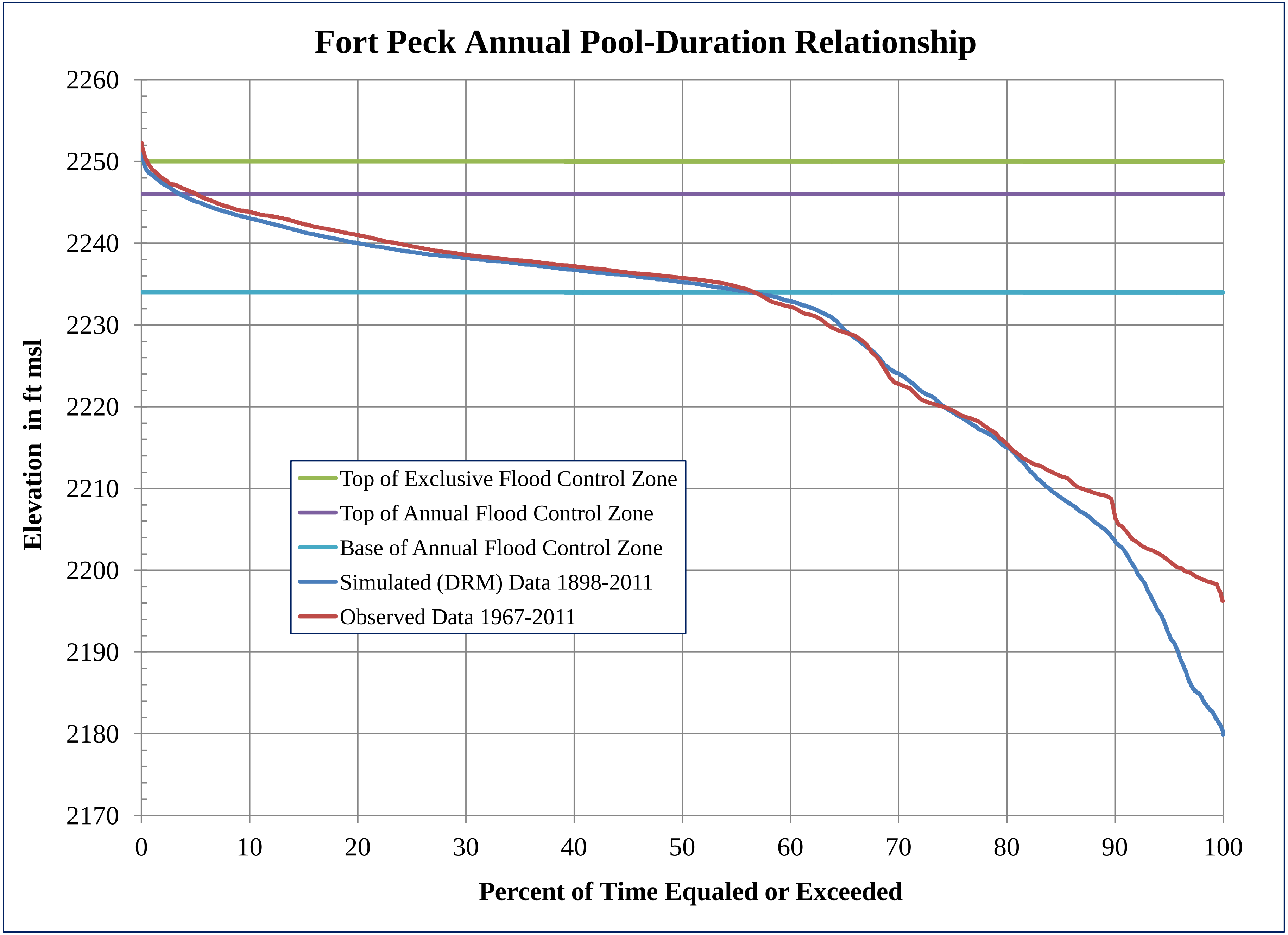

Plate 3. Fort Peck Annual Pool-Duration Relationship.

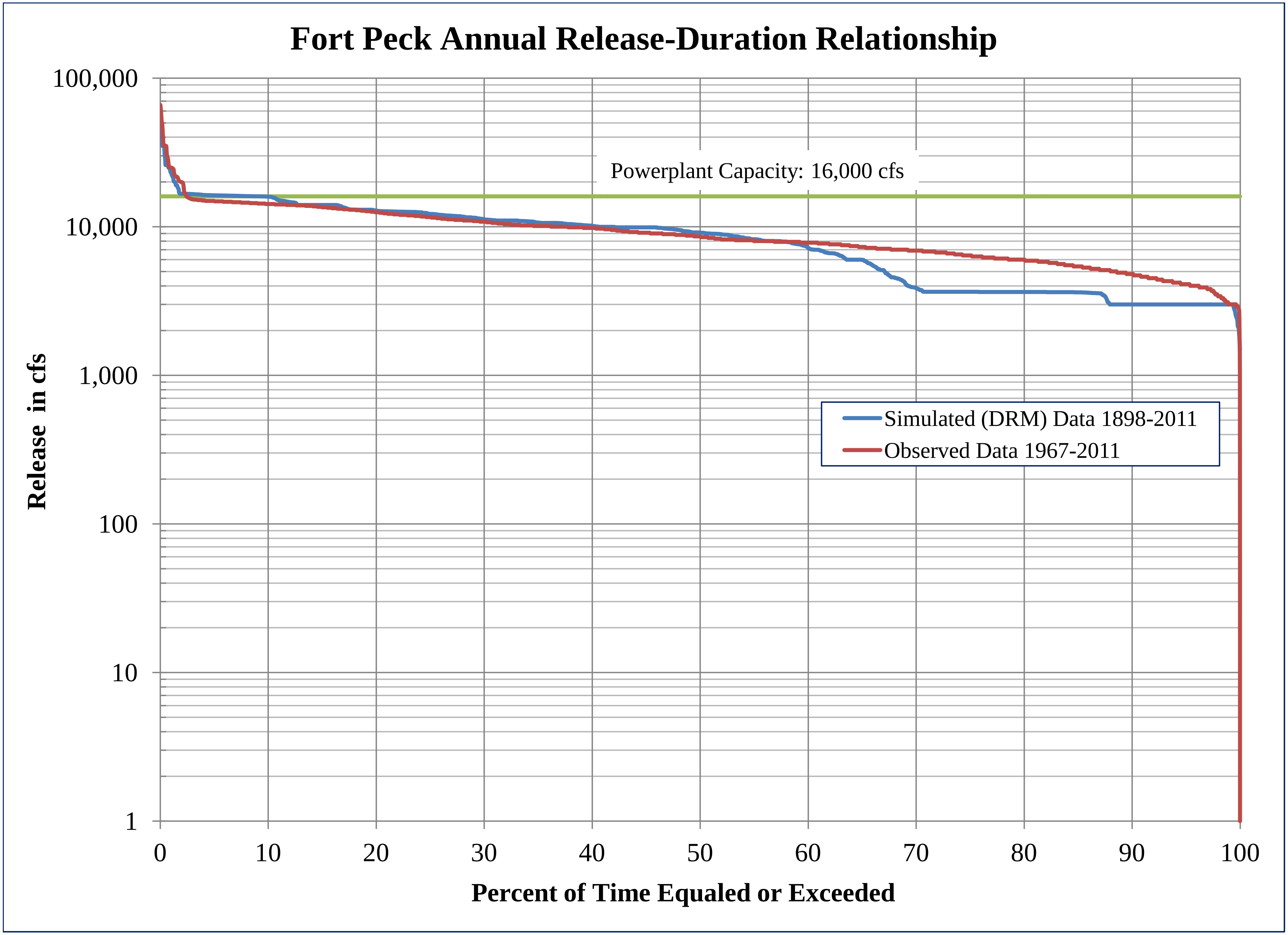

Plate 4. Fort Peck Annual Release-Duration Relationship.

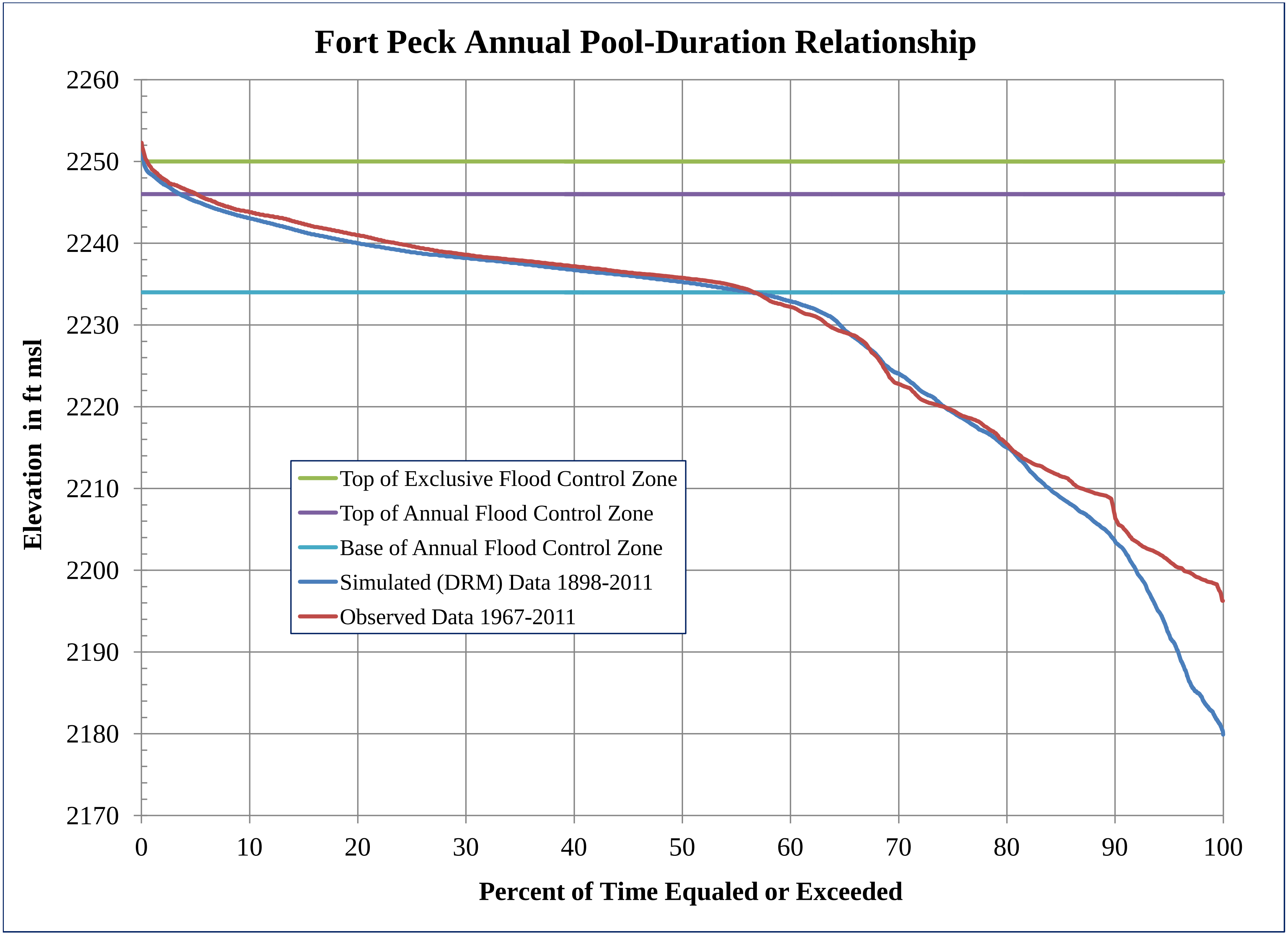

Plate 5. Fort Peck Pool-Duration Relationship (May-August).

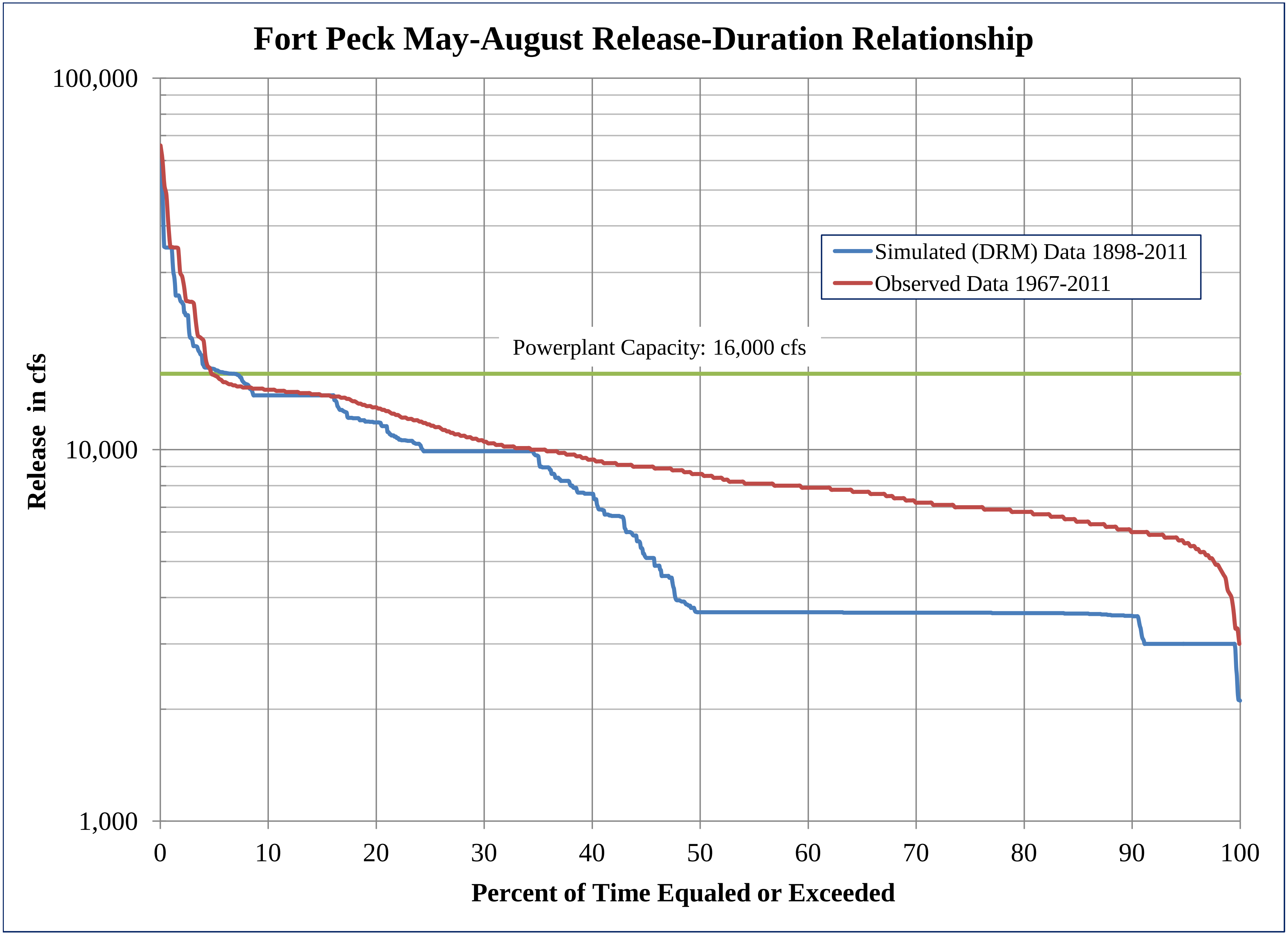

Plate 6. Fort Peck Release-Duration Relationship (May-August).

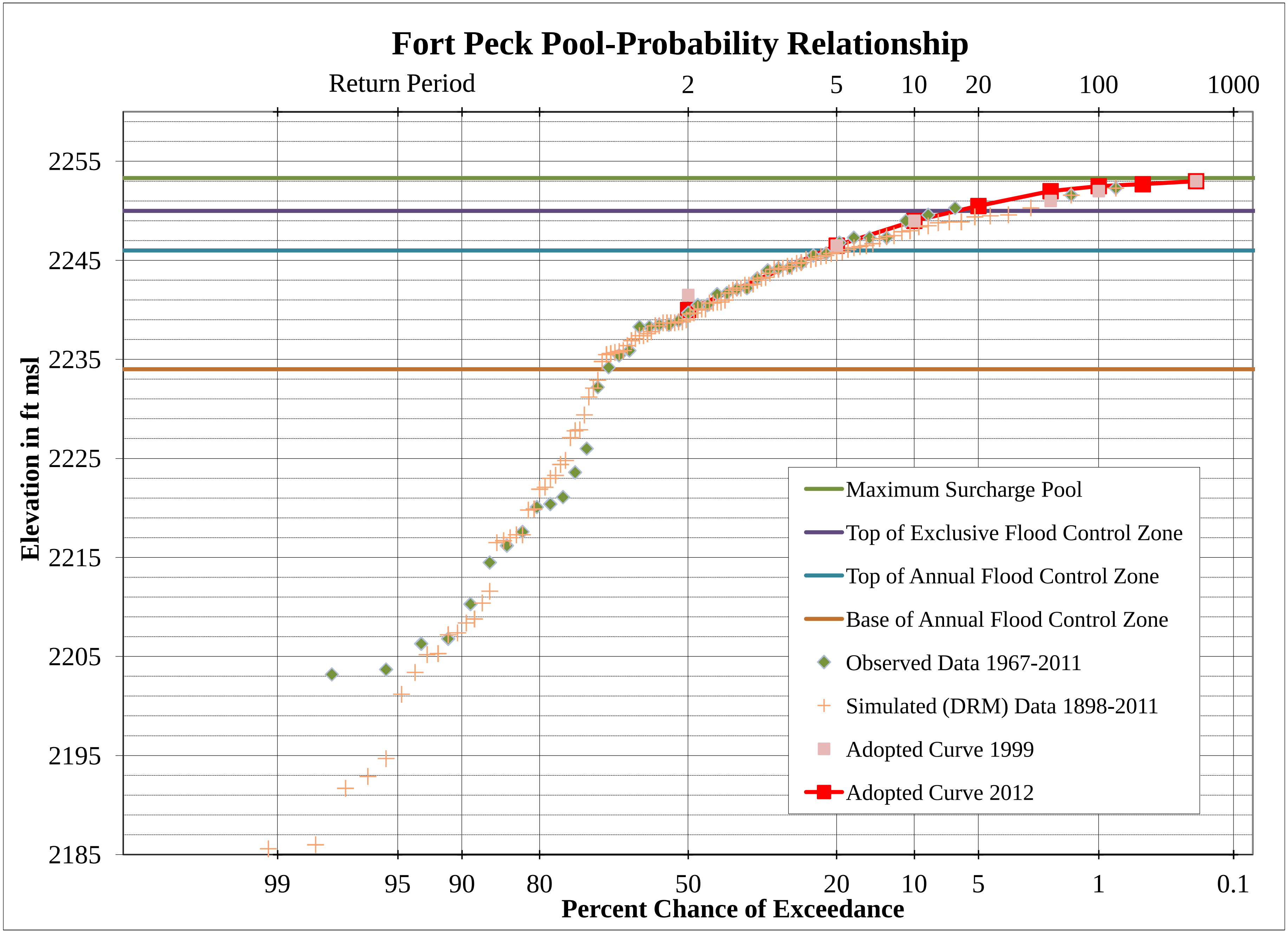

Plate 7. Fort Peck Pool-Probability Relationship.

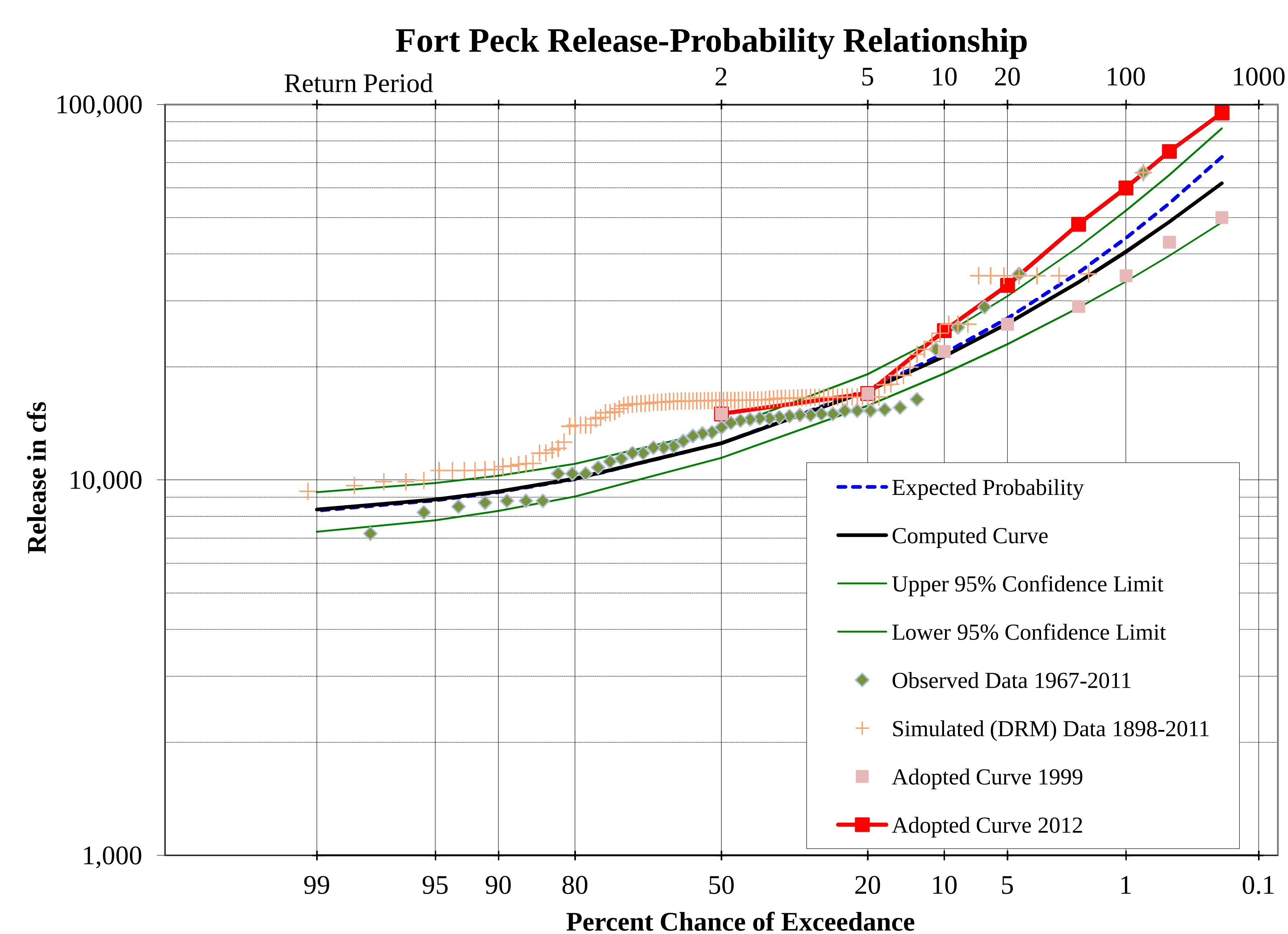

Plate 8. Fort Peck Release-Probability Relationship.

Fort Peck Simulated (DRM) Peak Elevations and Releases

Year	Elevation	Release	Year	Elevation	Release	Year	Elevation	Release
1898	2247.4	19,000	1939	2205.2	15,980	1980	2239.6	16,340
1899	2249.4	35,000	1940	2192.9	15,110	1981	2240.8	16,580
1900	2243.3	14,000	1941	2185.6	14,560	1982	2243.0	16,310
1901	2242.2	12,620	1942	2207.4	9,900	1983	2246.1	16,260
1902	2242.2	11,080	1943	2232.9	16,510	1984	2243.2	16,270
1903	2239.7	12,150	1944	2237.8	10,600	1985	2238.4	14,000
1904	2244.4	16,120	1945	2237.6	10,860	1986	2245.9	16,200
1905	2237.1	12,030	1946	2235.6	16,600	1987	2240.8	14,680
1906	2238.7	16,570	1947	2238.7	14,000	1988	2235.5	16,620
1907	2248.9	17,930	1948	2245.7	26,000	1989	2223.3	16,640
1908	2249.5	35,000	1949	2238.8	16,340	1990	2217.3	16,550
1909	2247.2	16,230	1950	2240.7	16,310	1991	2219.9	16,640
1910	2242.5	23,390	1951	2244.1	16,310	1992	2211.6	9,330
1911	2239.0	16,520	1952	2246.3	21,620	1993	2229.4	16,610
1912	2245.2	16,350	1953	2246.7	18,990	1994	2236.4	11,060
1913	2247.5	35,000	1954	2235.9	16,620	1995	2244.8	16,270
1914	2245.5	16,280	1955	2231.2	16,640	1996	2247.9	16,320
1915	2246.4	16,310	1956	2227.9	16,640	1997	2250.3	22,300
1916	2249.6	35,000	1957	2223.0	16,630	1998	2245.4	16,240
1917	2248.8	35,000	1958	2227.1	16,640	1999	2240.0	11,000
1918	2243.7	16,290	1959	2224.4	16,650	2000	2235.7	9,980
1919	2237.4	15,210	1960	2221.9	15,980	2001	2232.1	13,910
1920	2235.8	10,600	1961	2216.5	16,410	2002	2224.8	16,630
1921	2240.1	16,500	1962	2219.8	9,670	2003	2217.0	16,510
1922	2240.7	15,480	1963	2227.8	16,620	2004	2208.8	16,200
1923	2240.1	16,330	1964	2236.9	10,600	2005	2205.3	16,020
1924	2241.7	16,330	1965	2244.7	24,590	2006	2207.2	16,130
1925	2244.2	16,260	1966	2241.0	14,000	2007	2203.4	10,650
1926	2238.4	15,880	1967	2245.1	16,310	2008	2210.4	10,670
1927	2248.0	35,000	1968	2242.5	16,430	2009	2222.1	10,600
1928	2248.5	16,210	1969	2244.4	16,300	2010	2238.7	9,900
1929	2242.6	16,230	1970	2248.4	16,100	2011	2252.3	65,900
1930	2238.7	16,360	1971	2245.1	26,000			
1931	2234.8	16,640	1972	2245.8	18,000			
1932	2216.7	16,510	1973	2238.8	11,790			
1933	2217.3	15,970	1974	2242.0	16,240			
1934	2208.4	15,920	1975	2251.6	35,400			
1935	2194.7	10,900	1976	2244.1	26,000			
1936	2191.7	15,120	1977	2237.4	16,610			
1937	2186.0	11,810	1978	2248.9	16,100			
1938	2201.2	15,780	1979	2246.5	20,000			

Plate 9. Fort Peck Simulated (DRM) Data 1898-2011.
Peak Elevations in ft msl, Peak Releases in cfs

Fort Peck Observed Peak Elevations and Releases

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

Plate 10. Fort Peck Observed Data 1967-2011.

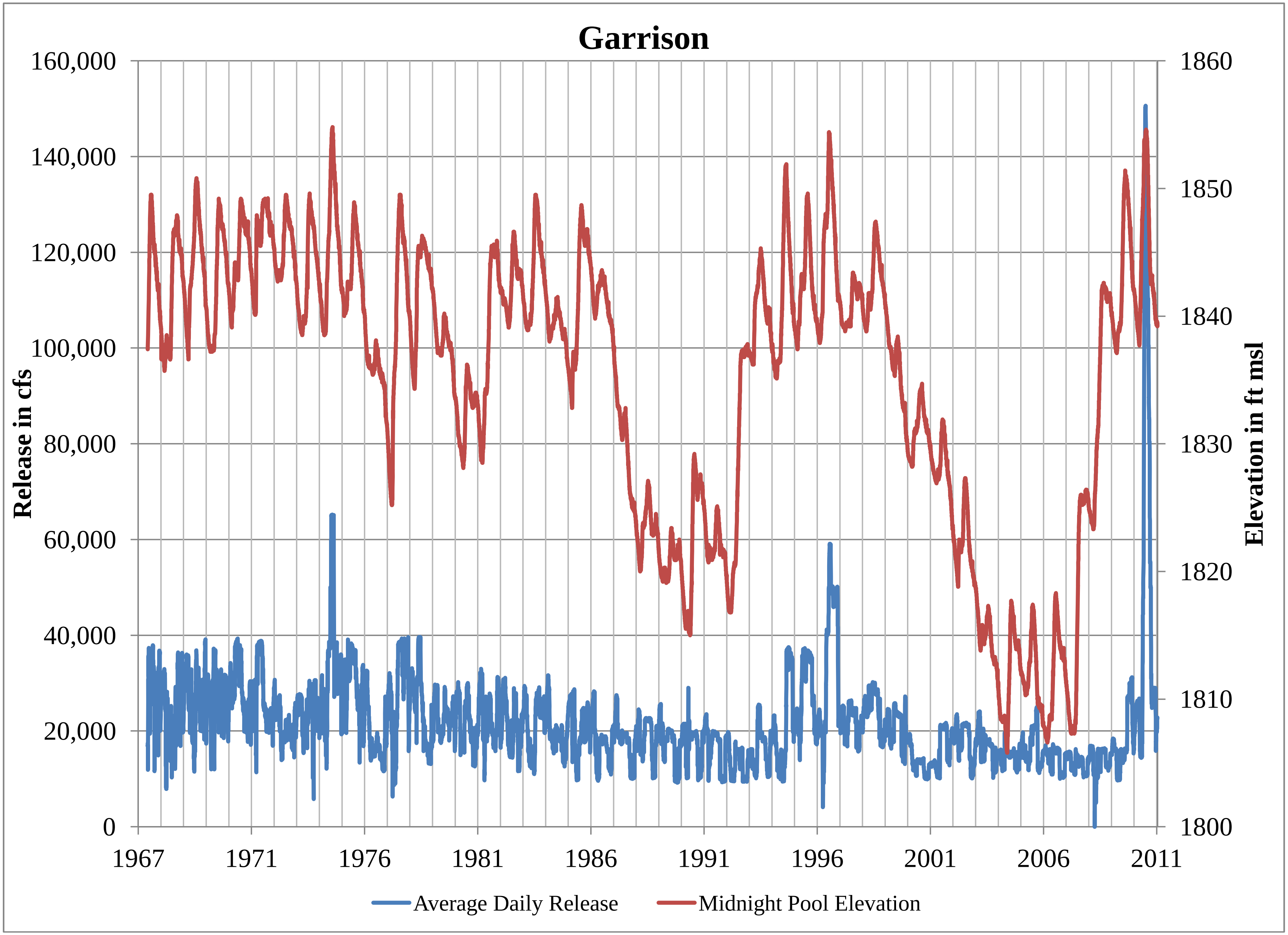

Plate 11. Garrison Daily Releases and Elevations.

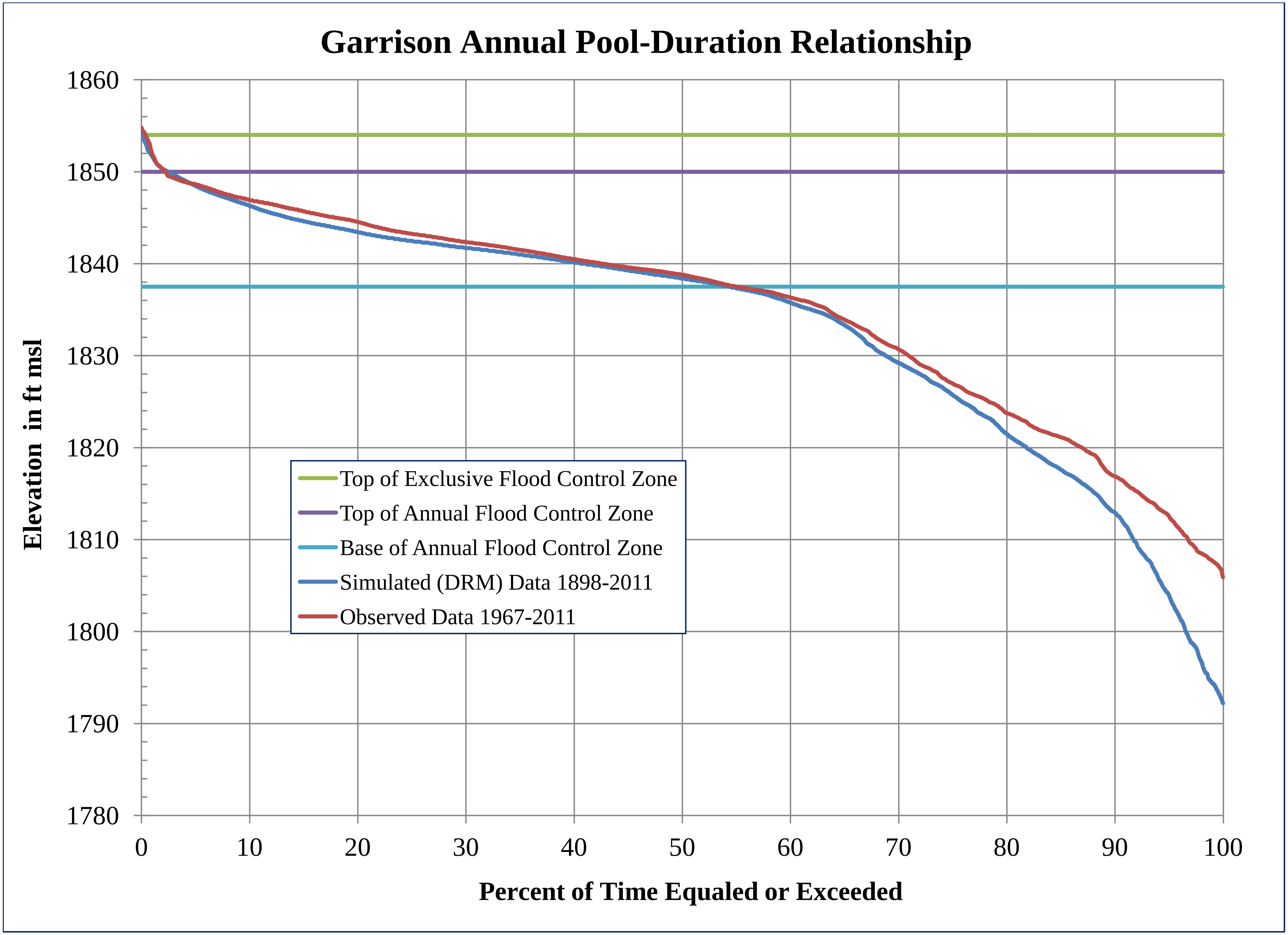

Plate 12. Garrison Annual Pool-Duration Relationship.

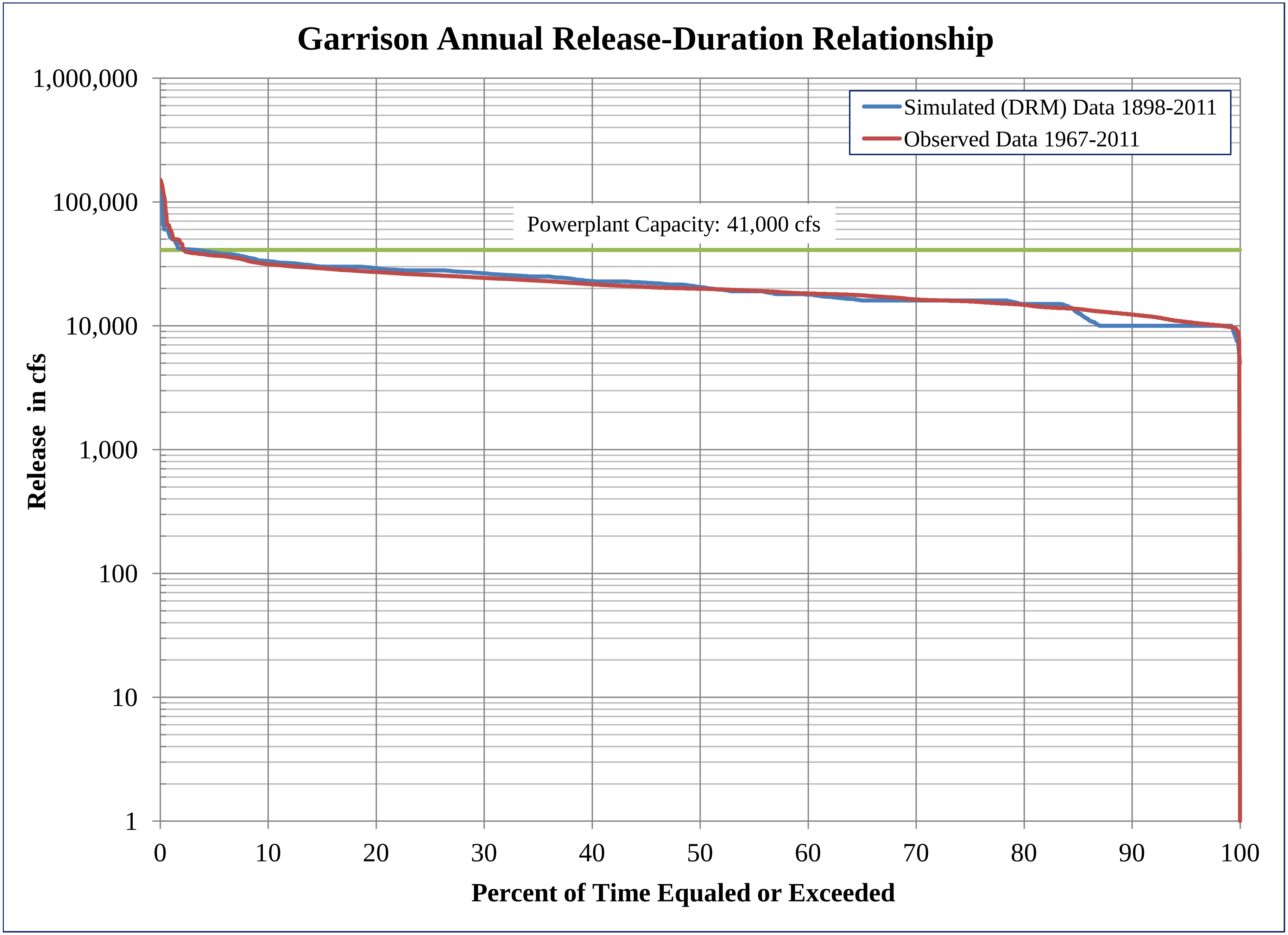

Plate 13. Garrison Annual Release-Duration Relationship.

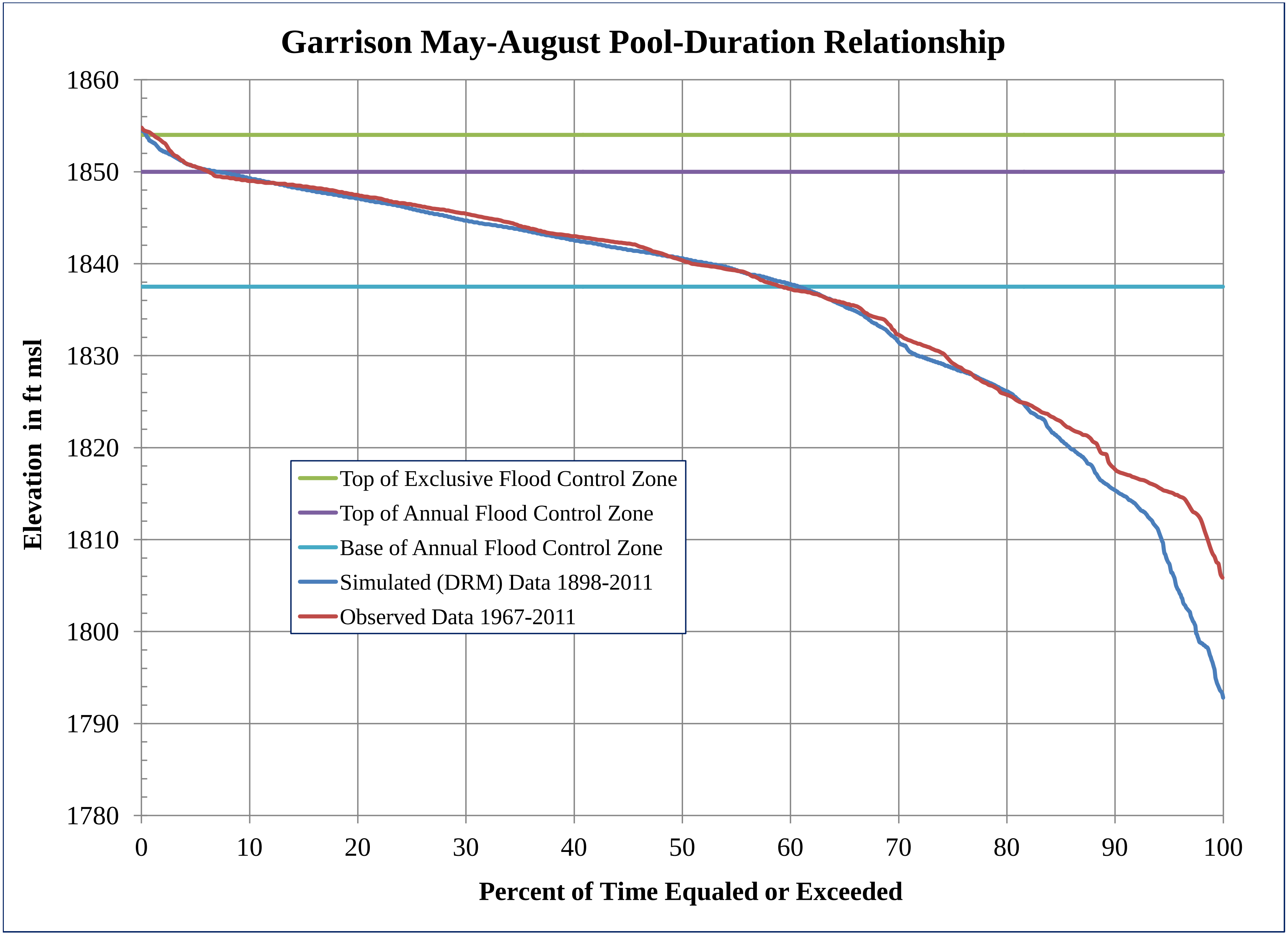

Plate 14. Garrison Pool-Duration Relationship (May-August).

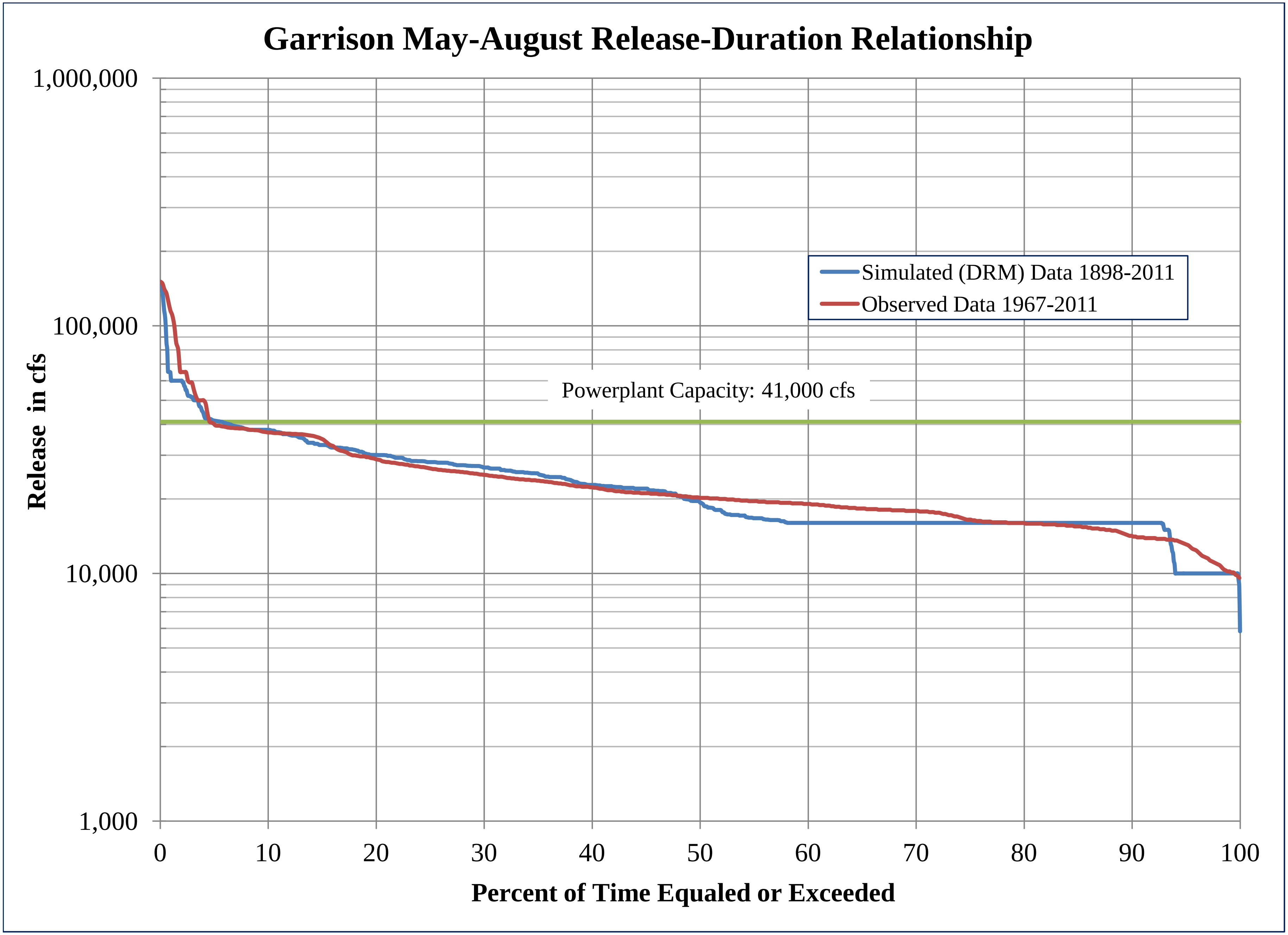

Plate 15. Garrison Release-Duration Relationship (May-August).

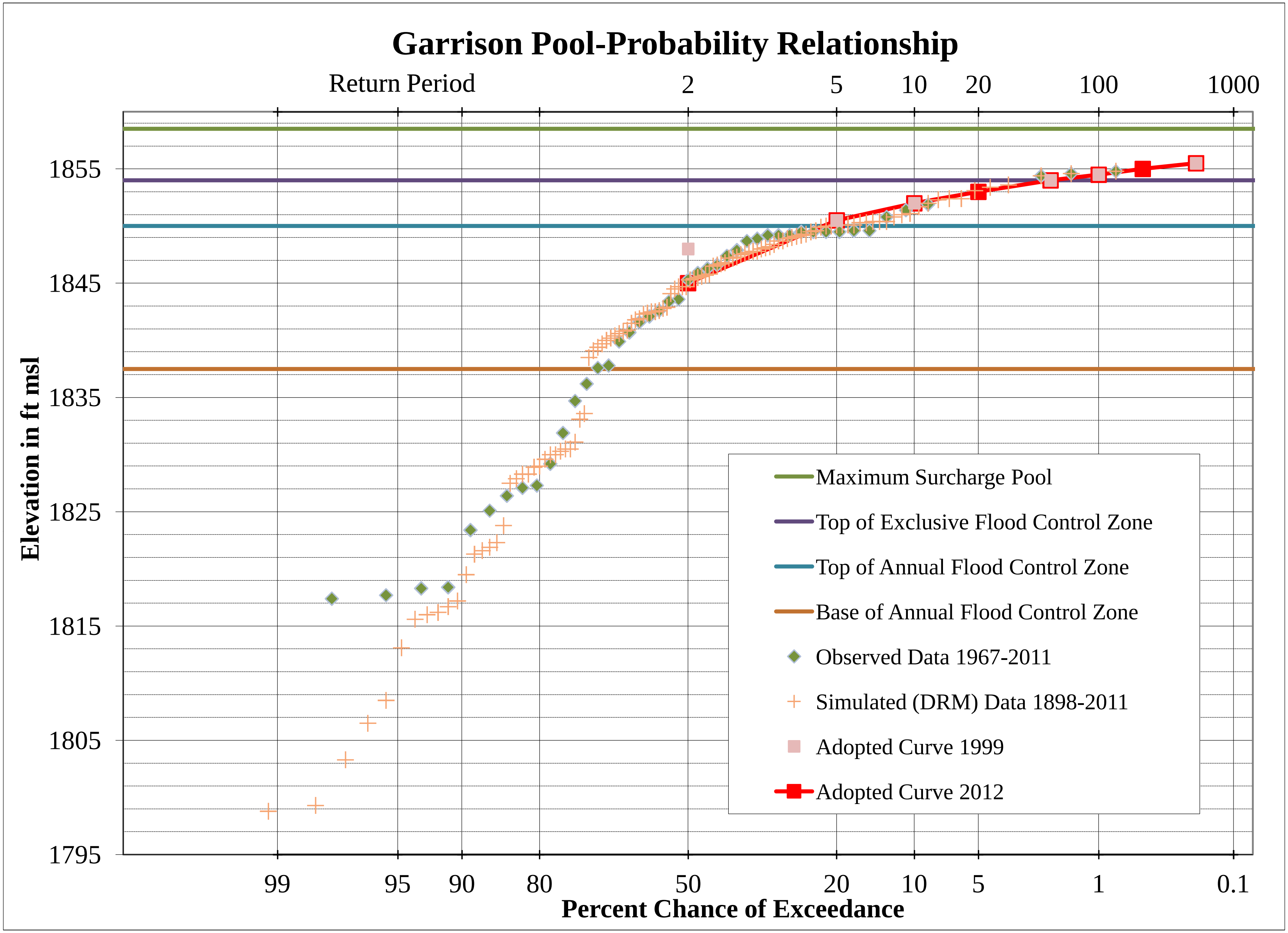

Plate 16. Garrison Pool-Probability Relationship.

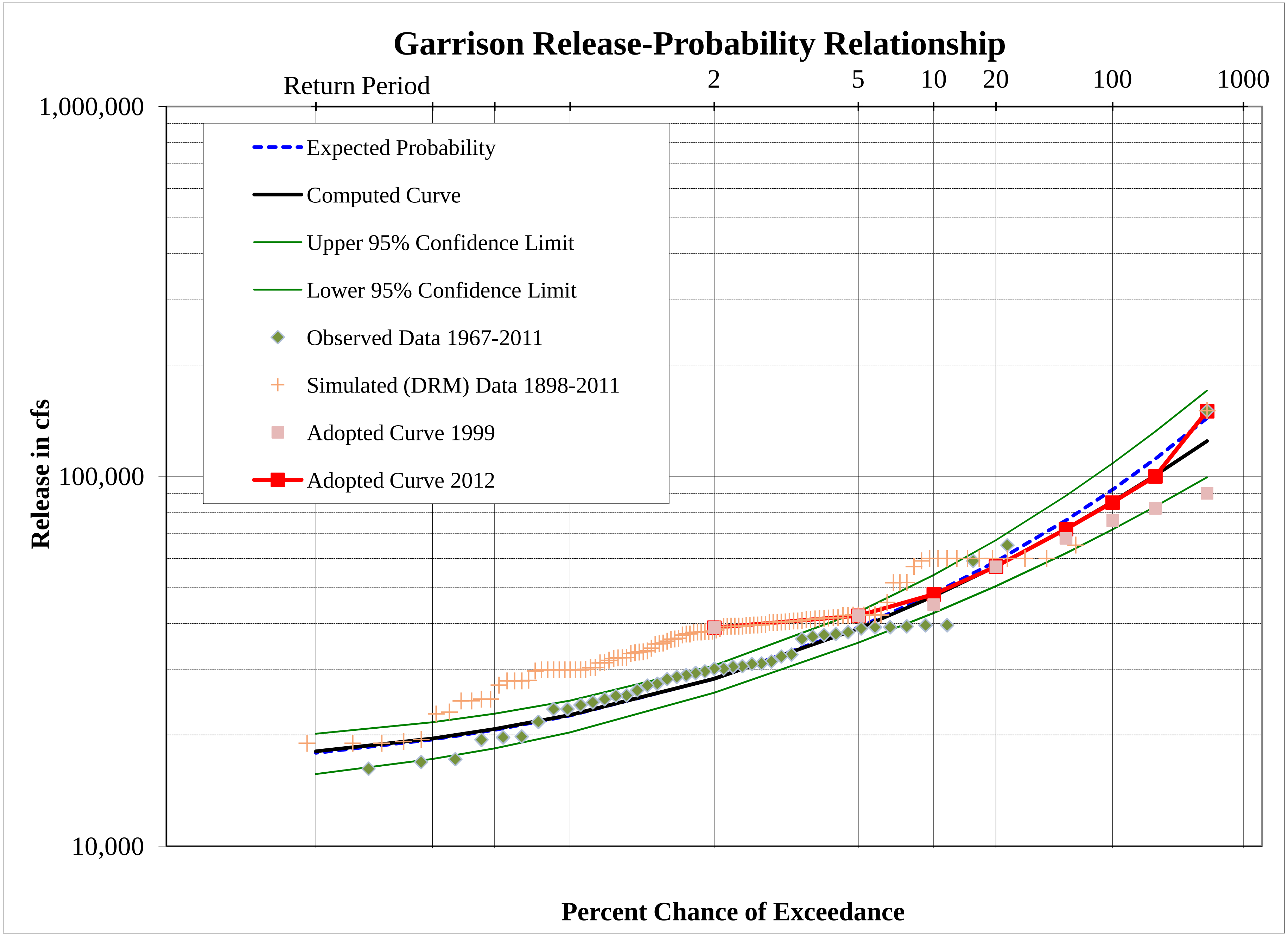

Plate 17. Garrison Release-Probability Relationship.

Garrison Simulated (DRM) Peak Elevations and Releases

Year	Elevation	Release	Year	Elevation	Release	Year	Elevation	Release
1898	1850.1	57,070	1939	1817.2	38,190	1980	1842.5	28,000
1899	1853.6	60,000	1940	1803.3	35,850	1981	1839.1	40,400
1900	1848.7	38,000	1941	1799.3	35,440	1982	1846.6	39,710
1901	1847.7	28,000	1942	1821.6	31,310	1983	1846.5	31,840
1902	1845.4	30,000	1943	1841.8	41,040	1984	1850.1	33,760
1903	1844.7	30,000	1944	1849.6	42,120	1985	1841.9	23,060
1904	1848.1	30,000	1945	1842.9	30,000	1986	1850.4	41,450
1905	1844.7	29,790	1946	1839.7	40,420	1987	1844.5	25,000
1906	1849.1	30,000	1947	1845.7	35,210	1988	1840.0	34,330
1907	1852.4	60,000	1948	1847.3	37,500	1989	1827.9	39,260
1908	1852.4	60,000	1949	1841.5	30,000	1990	1823.8	38,830
1909	1852.3	60,000	1950	1848.0	37,500	1991	1828.3	39,390
1910	1846.8	41,370	1951	1845.6	38,000	1992	1821.3	19,200
1911	1842.6	30,000	1952	1851.1	60,000	1993	1833.1	19,000
1912	1850.0	42,180	1953	1848.4	31,360	1994	1842.4	19,440
1913	1852.0	45,660	1954	1840.6	40,650	1995	1850.1	30,410
1914	1847.5	36,510	1955	1831.1	39,640	1996	1850.8	60,000
1915	1850.3	42,210	1956	1830.0	39,380	1997	1854.4	59,100
1916	1853.4	60,000	1957	1829.0	30,090	1998	1849.2	41,180
1917	1853.1	60,000	1958	1829.6	39,580	1999	1851.0	51,650
1918	1849.3	42,030	1959	1830.5	39,670	2000	1842.5	40,800
1919	1840.8	40,540	1960	1830.3	24,730	2001	1833.6	30,000
1920	1848.2	25,000	1961	1821.9	36,300	2002	1830.0	39,570
1921	1848.7	32,320	1962	1828.9	19,000	2003	1828.3	39,360
1922	1844.7	37,260	1963	1838.5	40,680	2004	1816.7	28,110
1923	1846.7	41,500	1964	1840.9	22,800	2005	1819.5	38,420
1924	1849.5	39,350	1965	1847.2	41,300	2006	1816.2	37,880
1925	1848.9	32,340	1966	1844.1	27,270	2007	1815.6	19,000
1926	1842.8	41,050	1967	1847.8	40,320	2008	1822.3	32,200
1927	1851.7	60,000	1968	1847.2	33,220	2009	1839.4	35,280
1928	1850.0	51,610	1969	1847.6	41,440	2010	1849.0	24,720
1929	1850.4	42,220	1970	1849.9	42,170	2011	1854.6	150,600
1930	1842.3	32,390	1971	1850.3	42,210			
1931	1840.4	40,350	1972	1850.1	42,190			
1932	1830.5	39,780	1973	1845.8	28,000			
1933	1827.5	39,300	1974	1845.5	30,440			
1934	1816.0	37,950	1975	1854.8	65,200			
1935	1813.1	37,960	1976	1847.8	33,580			
1936	1806.5	33,510	1977	1840.2	40,320			
1937	1798.8	36,340	1978	1850.4	60,000			
1938	1808.5	33,370	1979	1845.3	51,640			

Plate 18. Garrison Simulated (DRM) Data 1898-2011.
Peak Elevations in ft msl, Peak Releases in cfs

Garrison Observed Peak Elevations and Releases

Year	Elevation	Release	Year	Elevation	Release
1967	1849.5	37,900	1990	1823.4	25,600
1968	1847.9	36,400	1991	1829.2	29,000
1969	1850.8	39,100	1992	1825.1	23,500
1970	1849.2	36,900	1993	1837.8	19,800
1971	1849.2	39,300	1994	1845.3	25,500
1972	1849.2	38,800	1995	1851.9	37,500
1973	1849.5	30,700	1996	1849.6	37,300
1974	1849.6	30,600	1997	1854.4	59,100
1975	1854.8	65,200	1998	1843.4	26,400
1976	1848.9	39,100	1999	1847.4	30,200
1977	1839.9	32,600	2000	1840.7	27,200
1978	1849.5	39,600	2001	1834.7	19,400
1979	1846.3	39,600	2002	1831.9	21,700
1980	1842.1	29,700	2003	1827.3	23,500
1981	1836.2	30,200	2004	1818.4	24,100
1982	1845.9	33,000	2005	1817.7	19,700
1983	1846.6	31,100	2006	1817.4	25,000
1984	1849.5	29,400	2007	1818.3	17,200
1985	1841.6	31,600	2008	1826.4	16,200
1986	1848.7	28,700	2009	1842.6	16,900
1987	1843.6	28,300	2010	1851.4	31,200
1988	1837.6	27,500	2011	1854.6	150,600
1989	1827.1	24,500			

Plate 19. Garrison Observed Data 1967-2011.

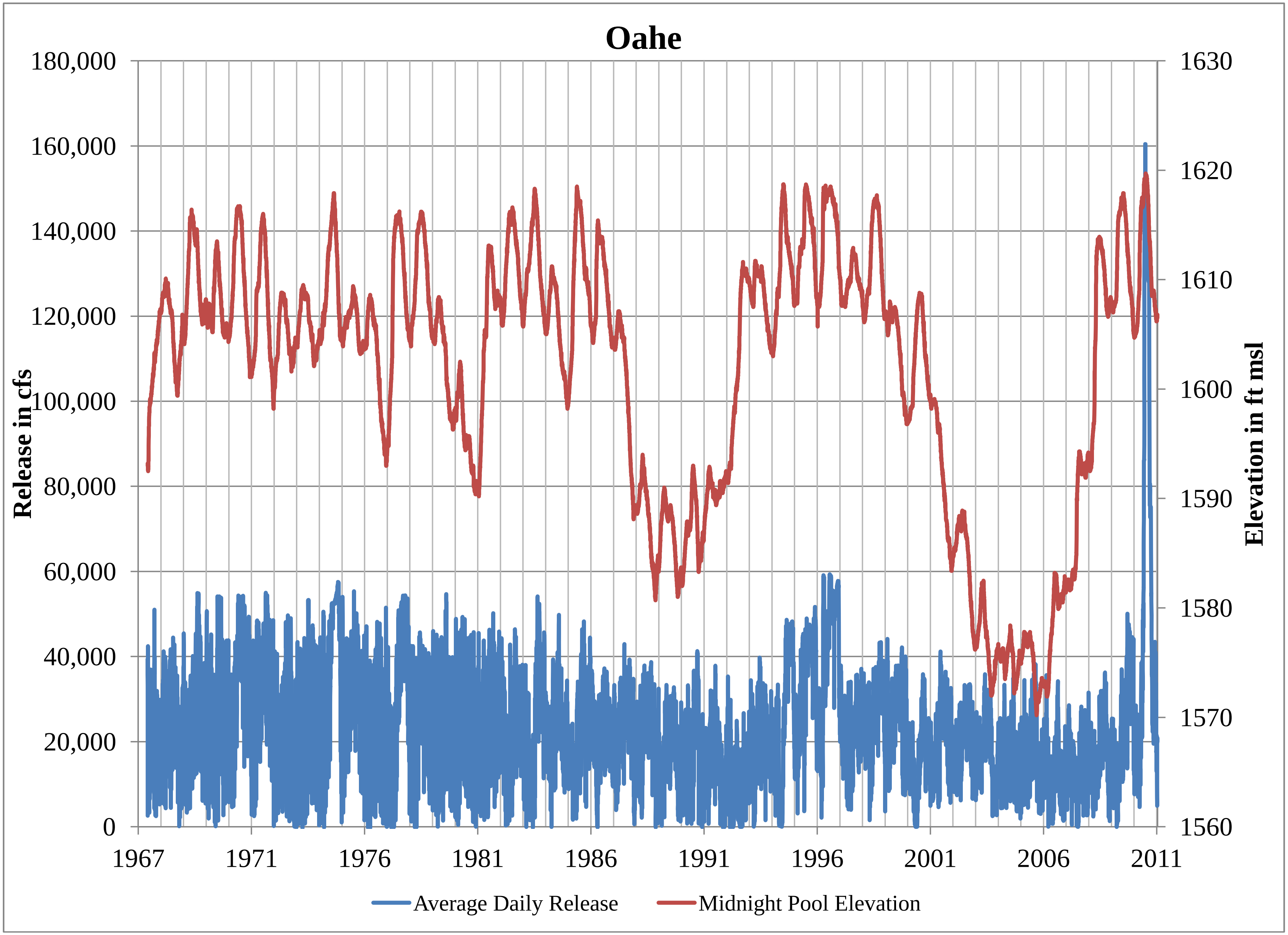

Plate 20. Oahe Daily Releases and Elevations.

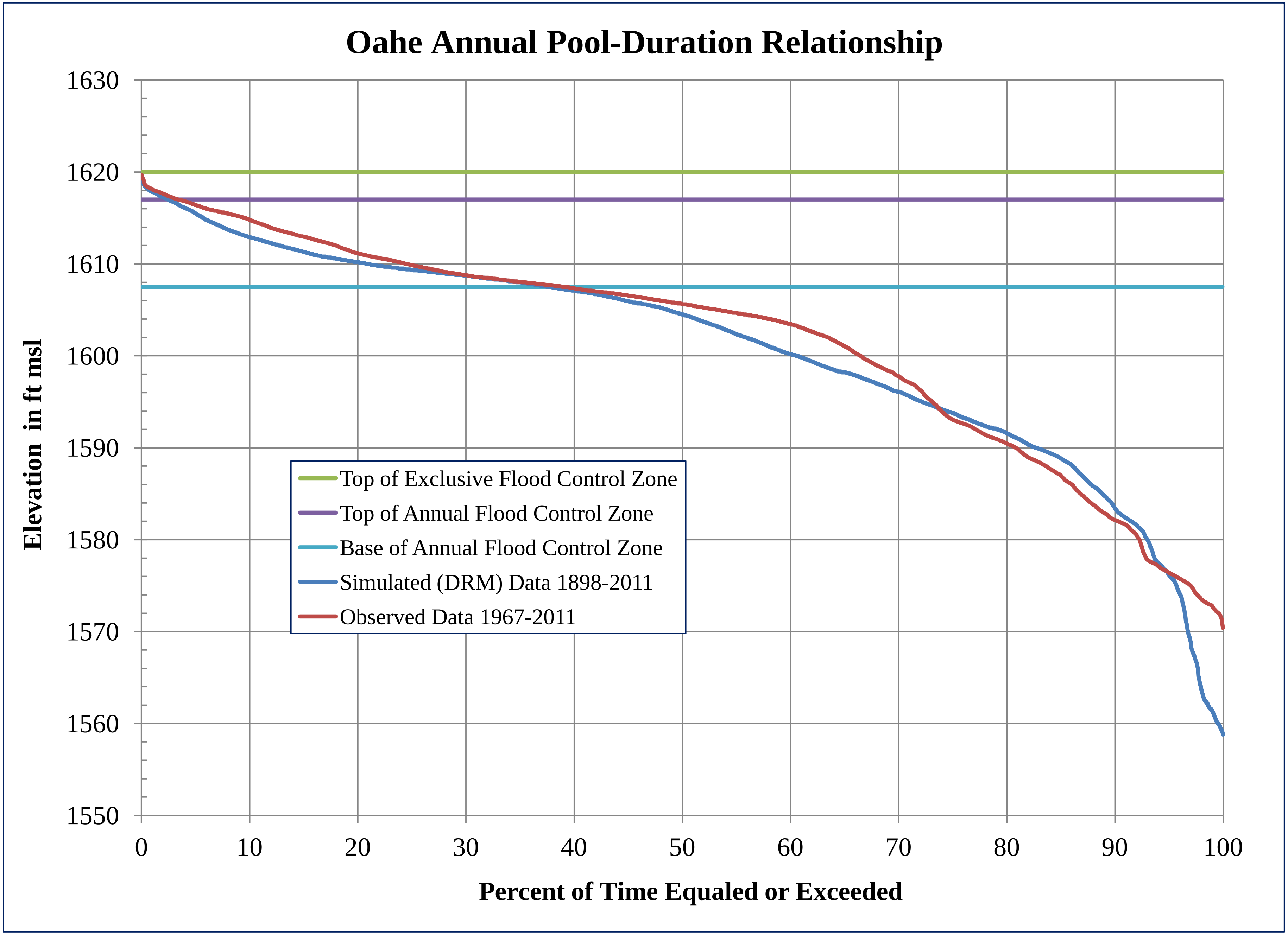

Plate 21. Oahe Annual Pool-Duration Relationship.

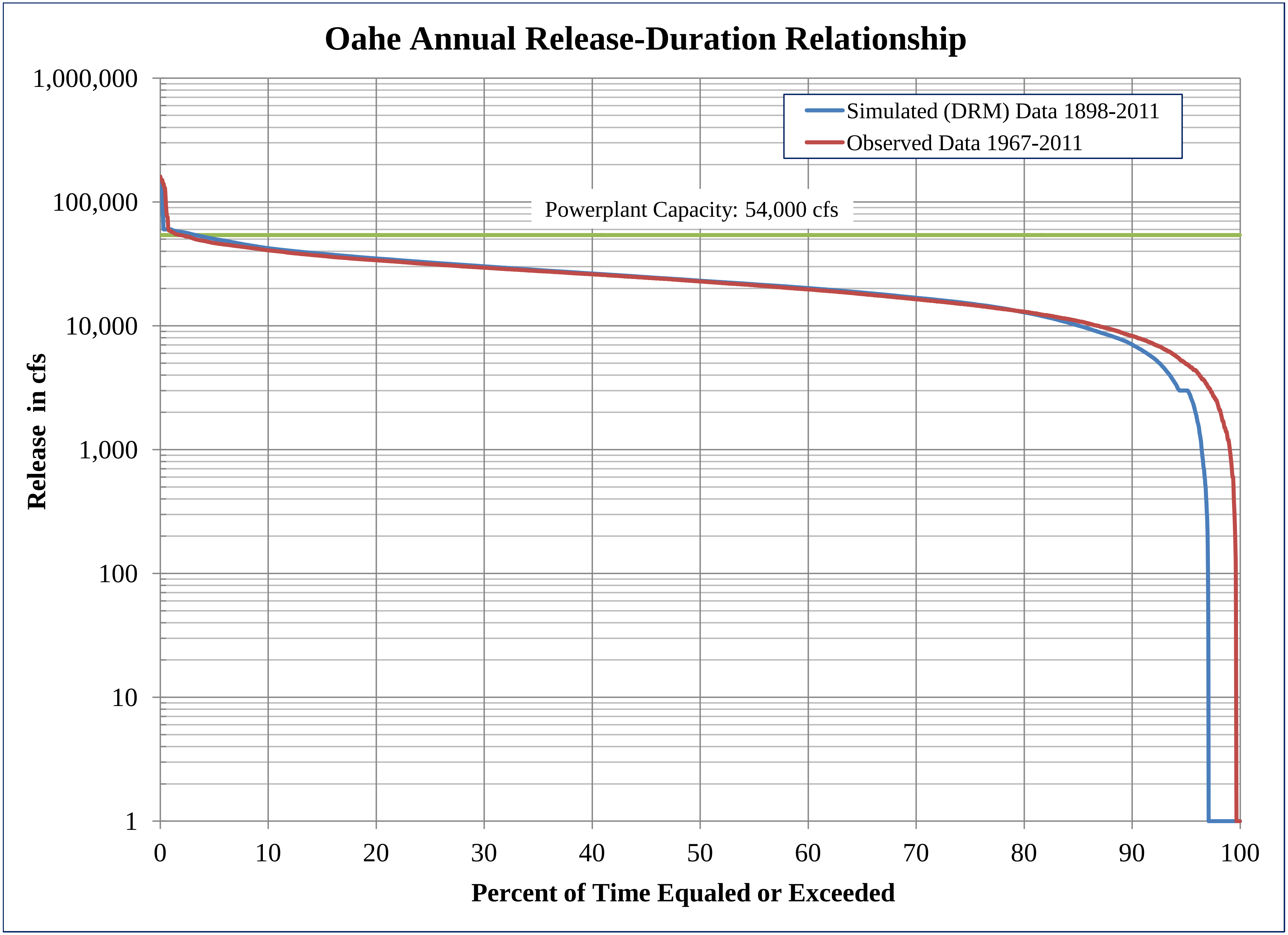

Plate 22. Oahe Annual Release-Duration Relationship.

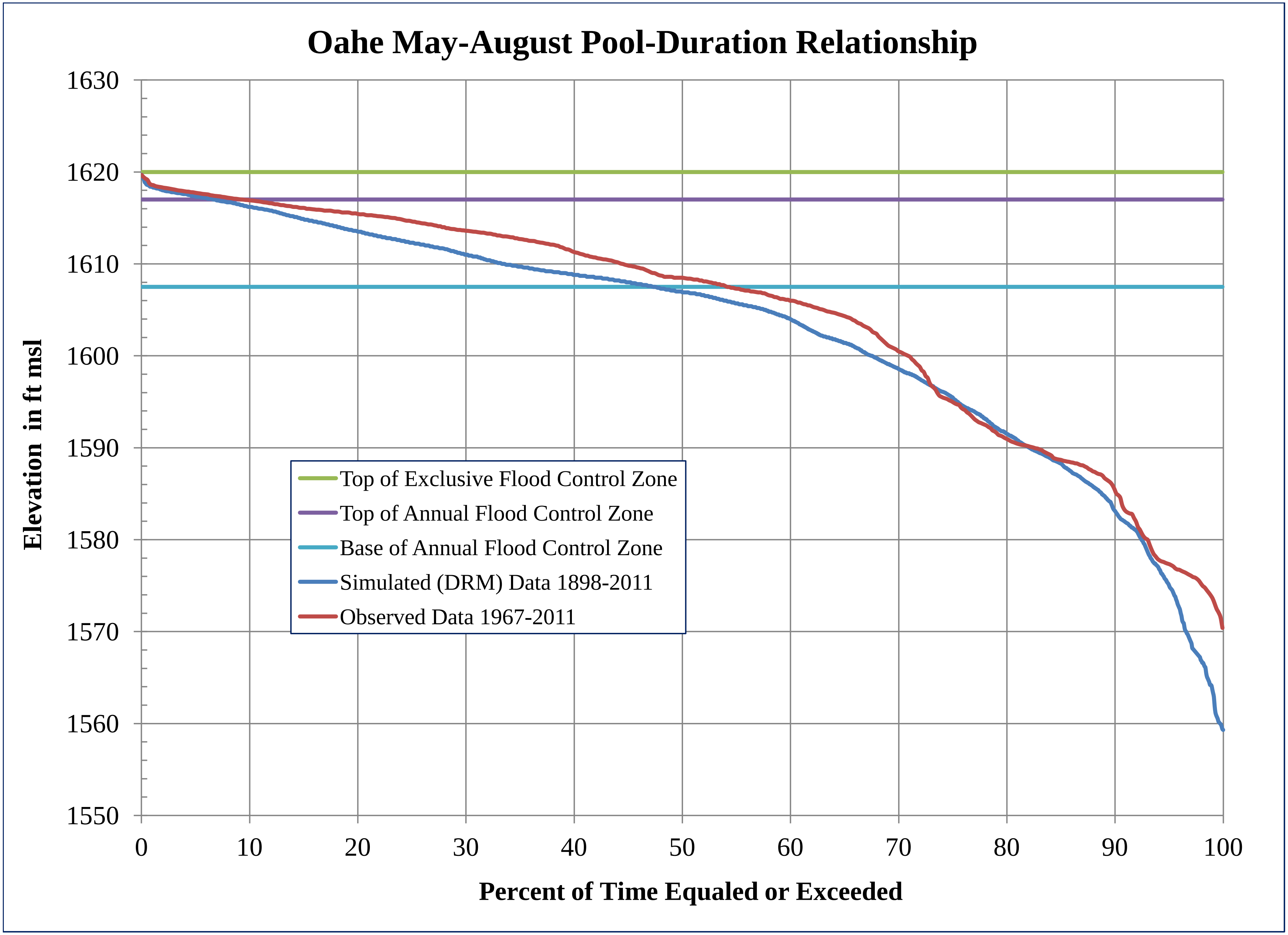

Plate 23. Oahe Pool-Duration Relationship (May-August).

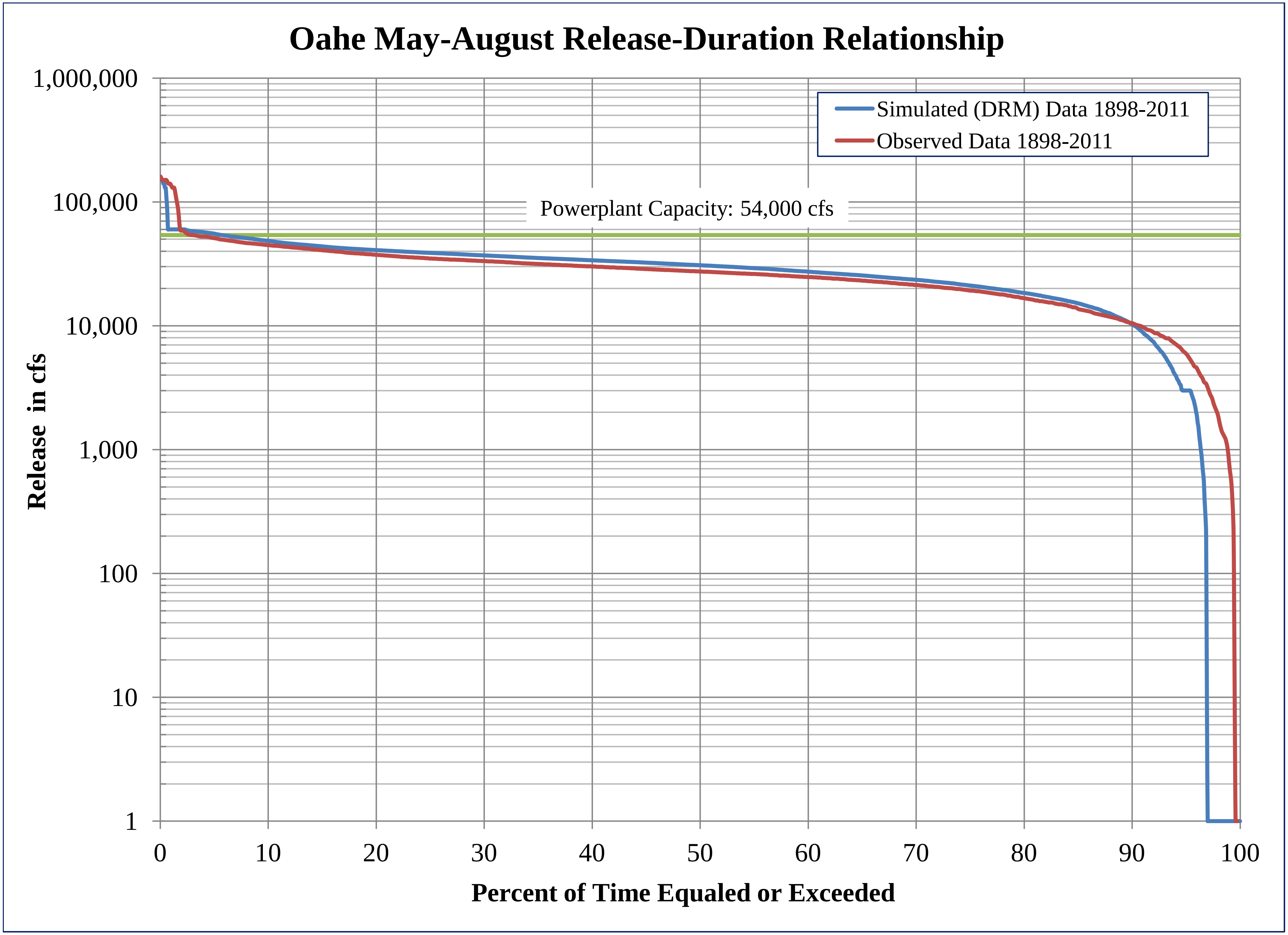

Plate 24. Oahe Release-Duration Relationship (May-August).

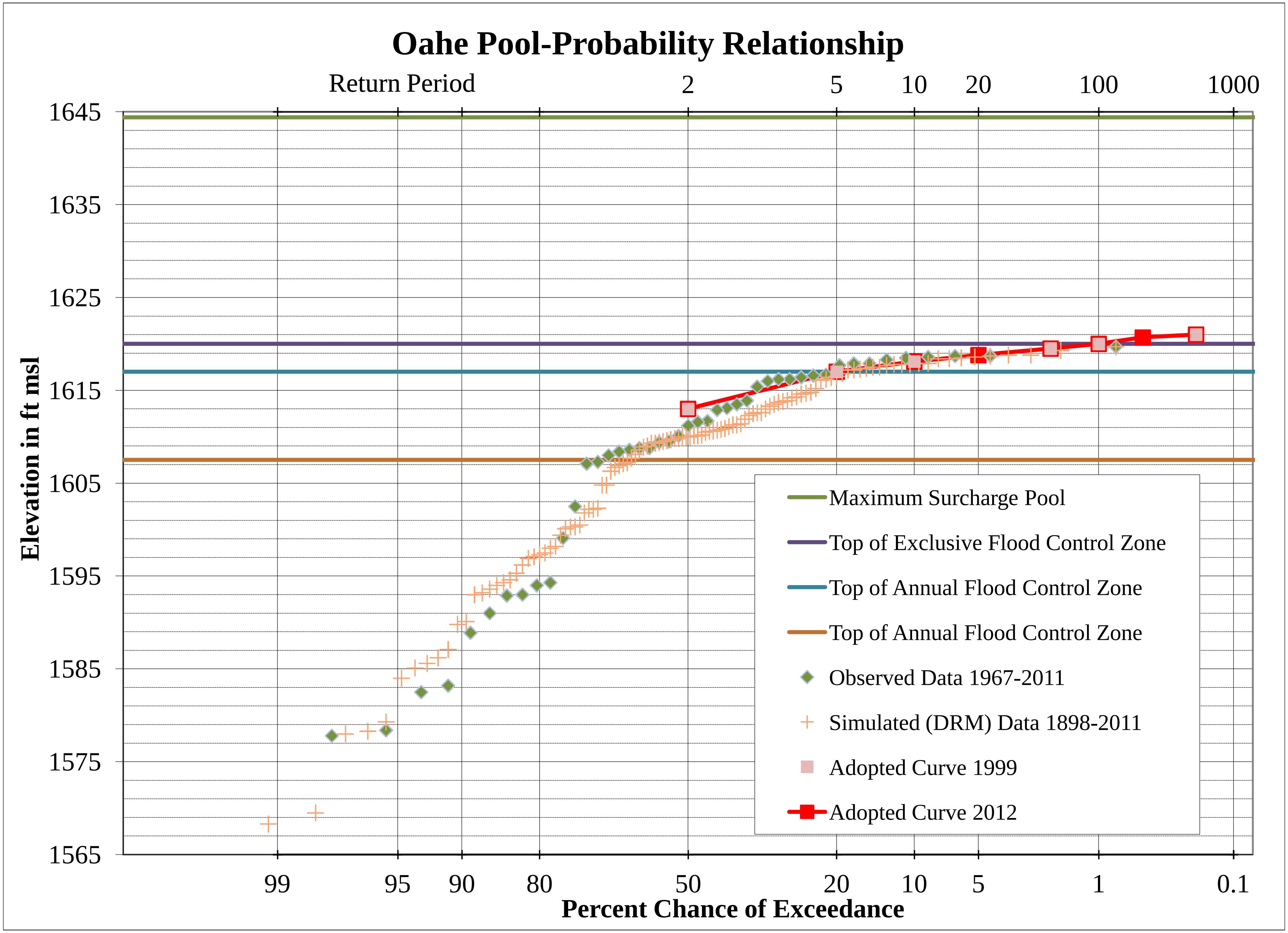

Plate 25. Oahe Pool-Probability Relationship.

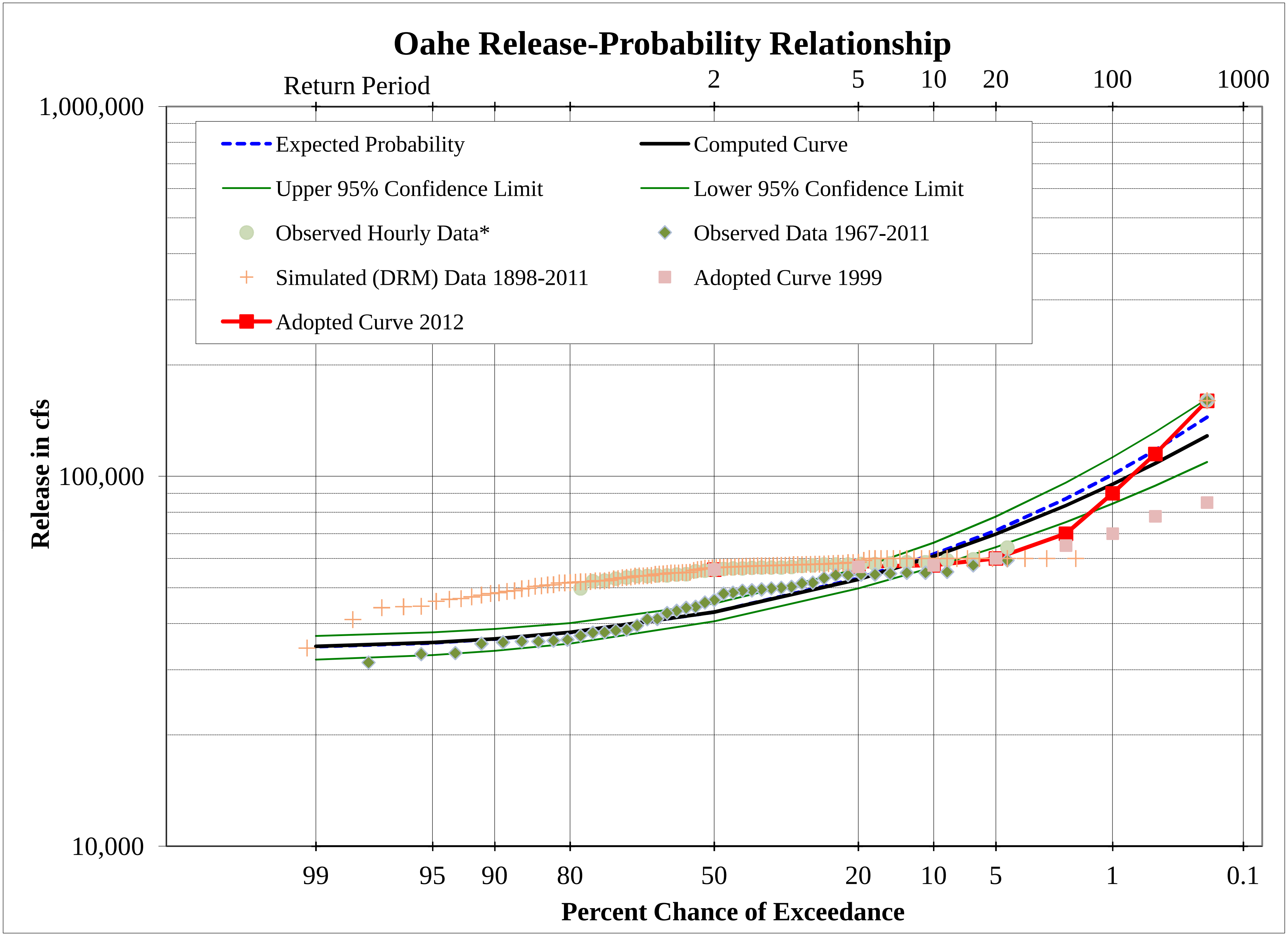

Plate 26. Oahe Release-Probability Relationship.

* Refer to Section VI. D. for details regarding hourly releases.

Oahe Simulated (DRM) Peak Elevations and Releases

Year	Elevation	Release	Year	Elevation	Release	Year	Elevation	Release
1898	1614.8	60,000	1939	1585.6	53,850	1980	1610.1	54,700
1899	1617.8	60,000	1940	1578.0	51,870	1981	1599.4	52,220
1900	1611.3	49,090	1941	1569.5	44,440	1982	1612.5	57,910
1901	1610.0	51,770	1942	1593.6	34,360	1983	1614.6	56,660
1902	1608.9	52,190	1943	1607.1	57,090	1984	1618.7	60,000
1903	1606.7	56,630	1944	1611.3	60,000	1985	1610.5	57,490
1904	1612.6	57,840	1945	1610.9	57,350	1986	1617.9	60,000
1905	1609.6	50,590	1946	1602.3	55,710	1987	1618.8	57,350
1906	1609.4	53,890	1947	1608.1	56,480	1988	1606.3	52,900
1907	1617.3	60,000	1948	1606.9	56,890	1989	1597.3	45,960
1908	1616.2	60,000	1949	1610.2	57,450	1990	1596.2	54,380
1909	1618.5	60,000	1950	1611.9	57,740	1991	1594.3	44,180
1910	1613.0	50,450	1951	1614.2	58,040	1992	1598.0	53,720
1911	1604.8	49,860	1952	1617.8	60,000	1993	1609.8	51,530
1912	1609.7	57,330	1953	1609.3	56,170	1994	1616.1	58,260
1913	1611.1	57,320	1954	1604.8	55,000	1995	1618.8	60,000
1914	1613.8	57,980	1955	1601.8	54,860	1996	1619.3	60,000
1915	1617.5	60,000	1956	1598.2	49,680	1997	1618.6	59,300
1916	1616.4	60,000	1957	1596.9	47,250	1998	1613.9	60,000
1917	1617.5	60,000	1958	1597.5	53,830	1999	1618.4	60,000
1918	1614.7	58,180	1959	1594.6	50,880	2000	1612.6	57,790
1919	1610.0	51,510	1960	1602.2	52,400	2001	1610.6	57,510
1920	1609.3	48,240	1961	1595.3	46,520	2002	1602.2	52,830
1921	1608.6	50,940	1962	1600.5	48,890	2003	1597.1	54,520
1922	1610.1	46,740	1963	1600.3	54,820	2004	1593.2	53,460
1923	1609.8	55,070	1964	1600.1	54,820	2005	1585.1	53,230
1924	1615.2	54,440	1965	1610.8	57,070	2006	1586.2	48,490
1925	1613.3	57,880	1966	1613.7	56,460	2007	1587.1	53,980
1926	1610.0	56,740	1967	1611.4	57,160	2008	1589.8	51,930
1927	1617.7	60,000	1968	1609.0	55,990	2009	1612.3	56,950
1928	1616.8	60,000	1969	1617.2	58,500	2010	1618.4	60,000
1929	1614.3	58,210	1970	1610.6	57,720	2011	1619.7	160,300
1930	1610.7	57,610	1971	1617.8	58,490			
1931	1600.3	51,610	1972	1617.4	58,570			
1932	1594.0	47,770	1973	1613.5	57,730			
1933	1593.0	54,950	1974	1607.7	57,270			
1934	1590.1	51,960	1975	1617.9	57,500			
1935	1578.3	52,210	1976	1609.5	57,170			
1936	1584.0	53,290	1977	1607.2	56,830			
1937	1568.3	41,020	1978	1616.5	60,000			
1938	1579.3	44,570	1979	1617.2	56,890			

Plate 27. Oahe Simulated (DRM) Data 1898-2011.

Peak Elevations in ft msl, Peak Releases in cfs

Oahe Observed Peak Elevations and Releases

Year	Elevation	Release	Year	Elevation	Release
1967	1607.3	50,300	1990	1591.0	33,100
1968	1610.1	44,400	1991	1593.0	41,200
1969	1616.4	54,900	1992	1592.9	37,800
1970	1613.5	54,100	1993	1611.6	35,300
1971	1616.7	54,300	1994	1611.7	39,500
1972	1616.0	54,900	1995	1618.7	48,500
1973	1608.8	49,500	1996	1618.7	51,600
1974	1609.5	53,100	1997	1618.6	59,300
1975	1617.9	57,500	1998	1612.9	37,900
1976	1609.4	55,200	1999	1617.7	43,300
1977	1608.6	51,400	2000	1608.0	44,100
1978	1616.2	54,300	2001	1608.8	35,800
1979	1616.2	45,600	2002	1599.1	41,100
1980	1608.4	54,600	2003	1588.9	33,300
1981	1602.5	49,200	2004	1582.5	35,800
1982	1613.1	50,000	2005	1578.4	36,000
1983	1616.6	46,300	2006	1577.8	38,300
1984	1618.3	54,100	2007	1583.2	35,600
1985	1611.2	49,800	2008	1594.3	31,400
1986	1618.5	48,200	2009	1613.9	36,200
1987	1615.4	37,100	2010	1617.9	49,100
1988	1607.1	42,700	2011	1619.7	160,300
1989	1594.0	38,500			

Plate 28. Oahe Observed Data 1967-2011.

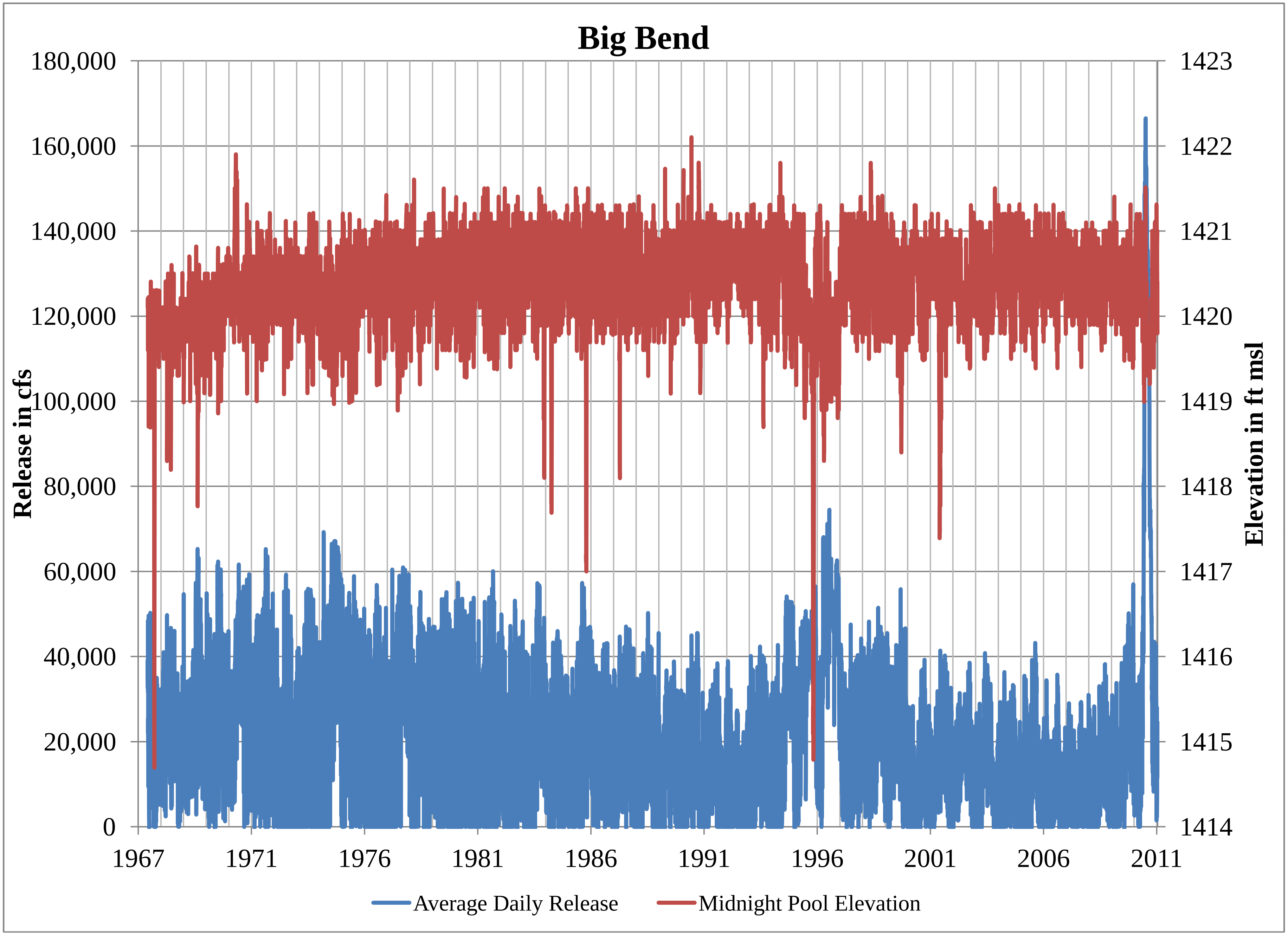

Plate 29. Big Bend Daily Releases and Elevations.

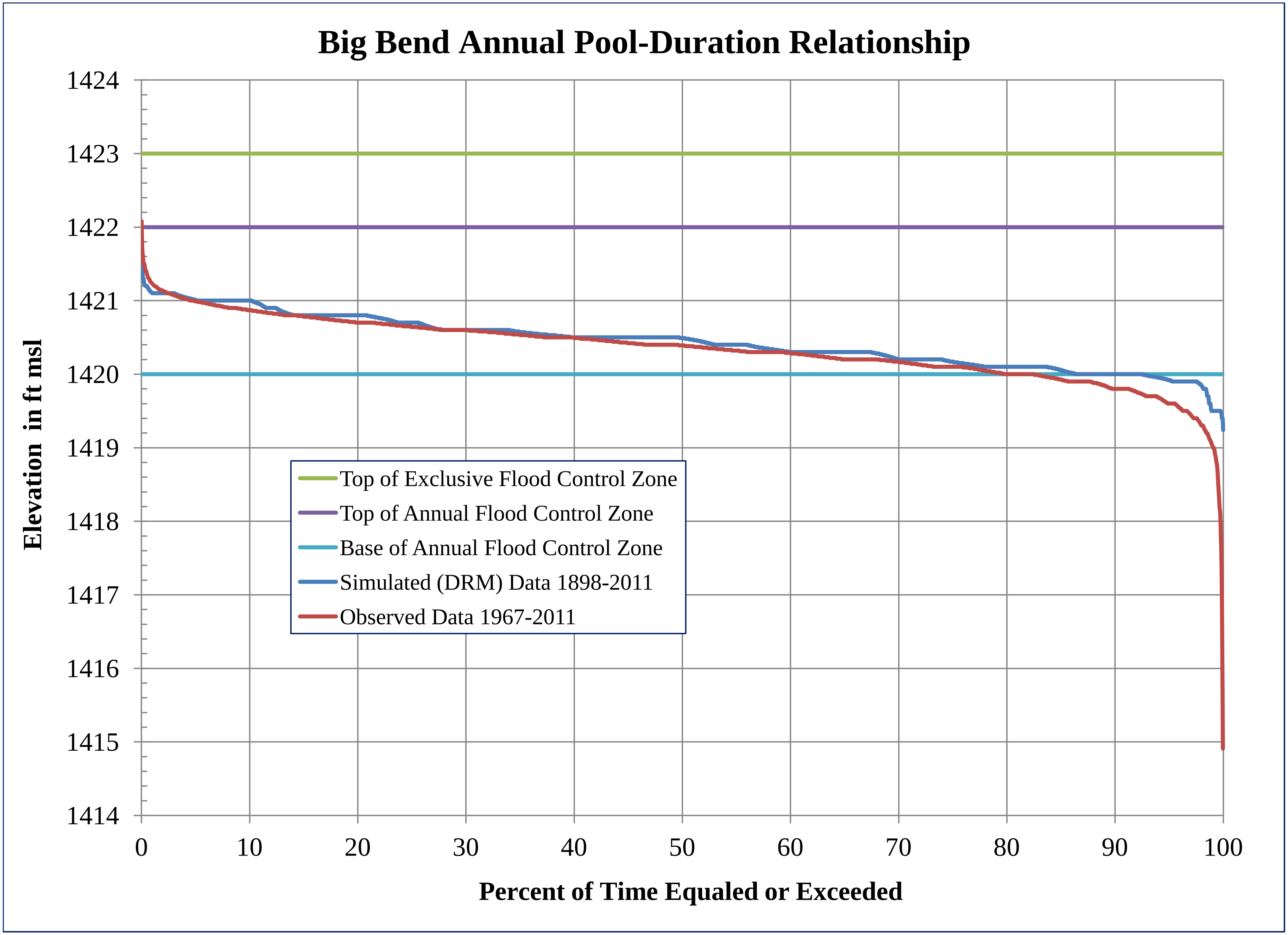

Plate 30. Big Bend Annual Pool-Duration Relationship.

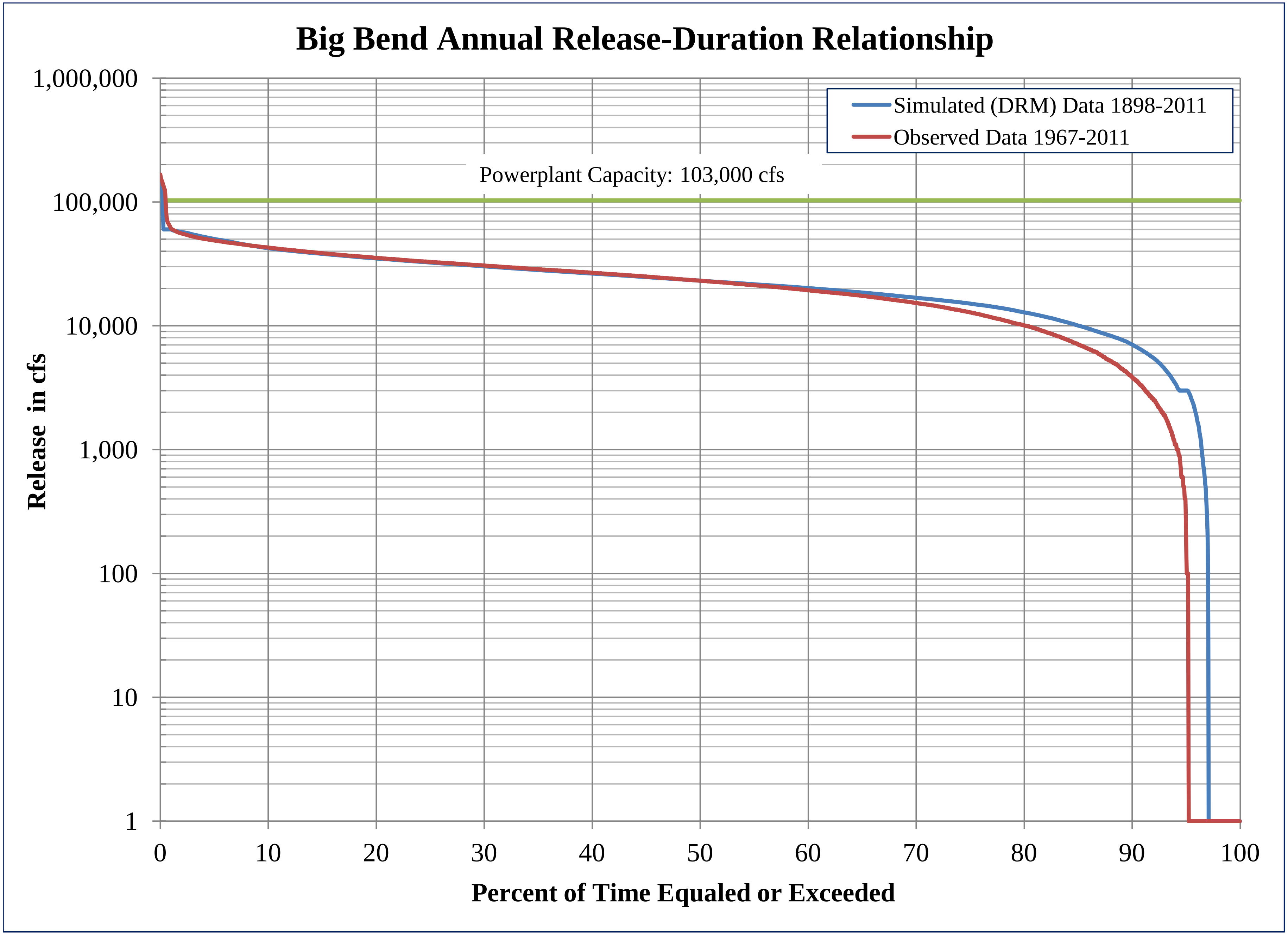

Plate 31. Big Bend Annual Release-Duration Relationship. Note: Daily release data was used.

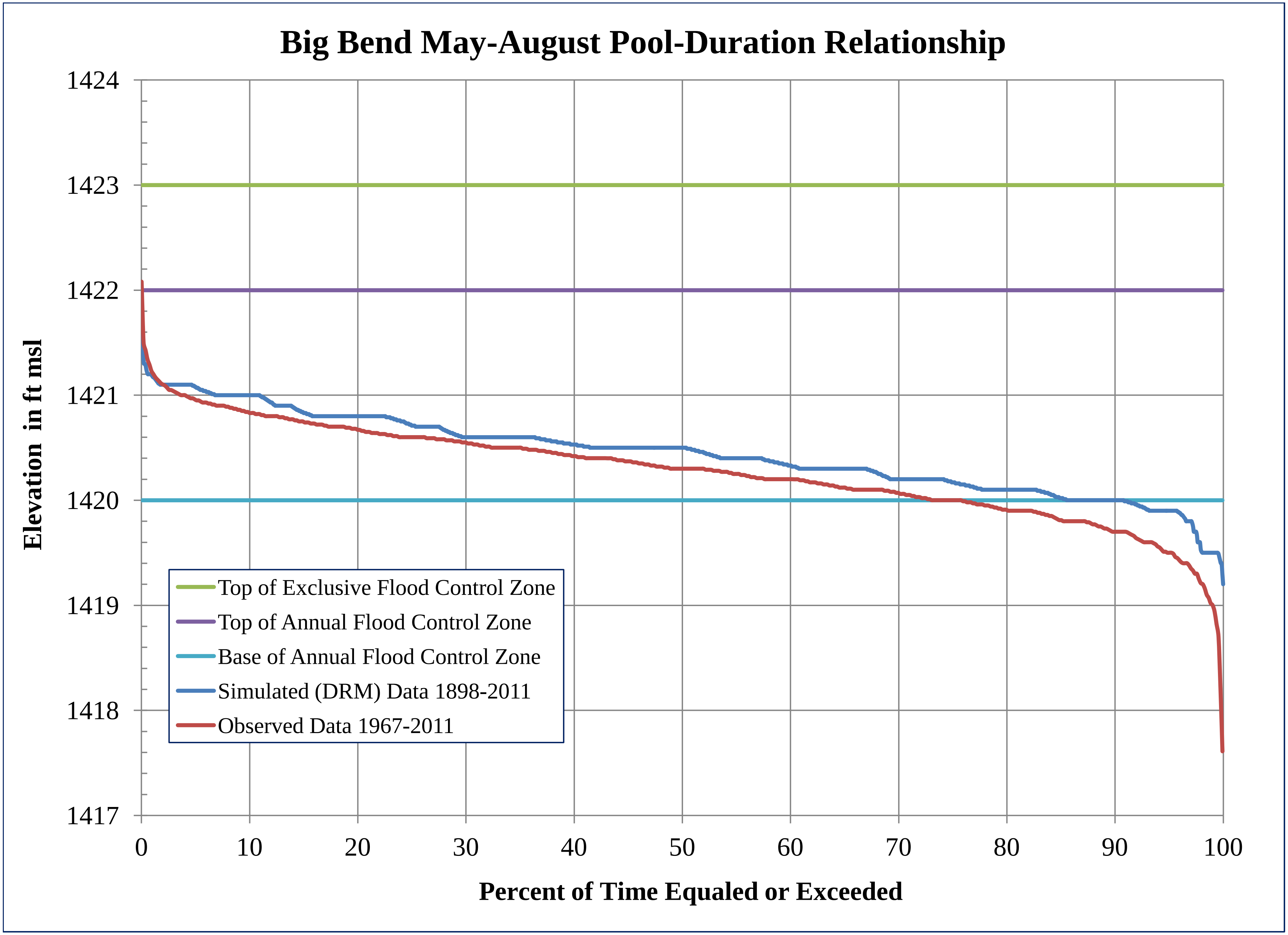

Plate 32. Big Bend Pool-Duration Relationship (May-August).

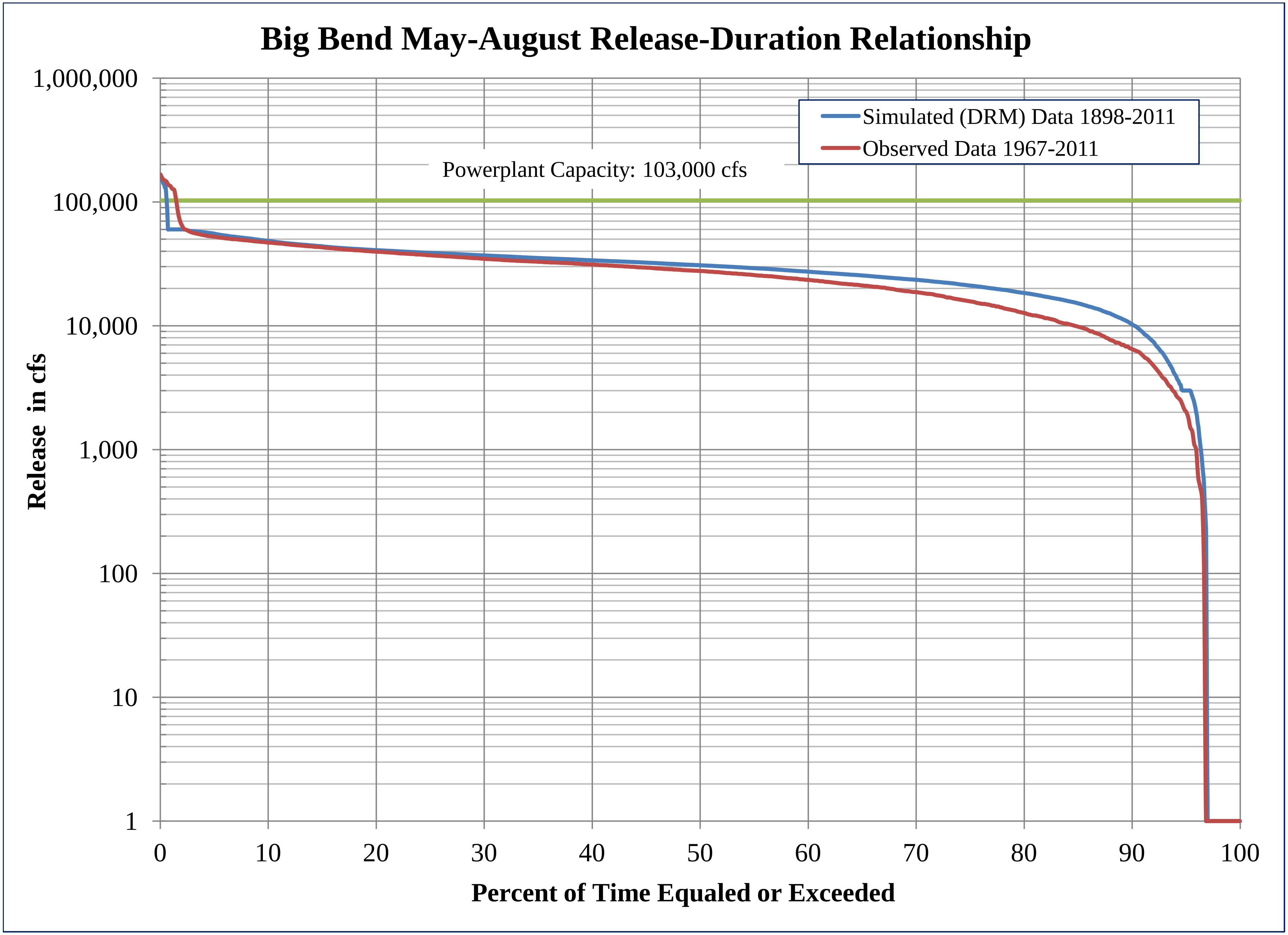

Plate 33. Big Bend Release-Duration Relationship (May-August). Note: Daily release data was used.

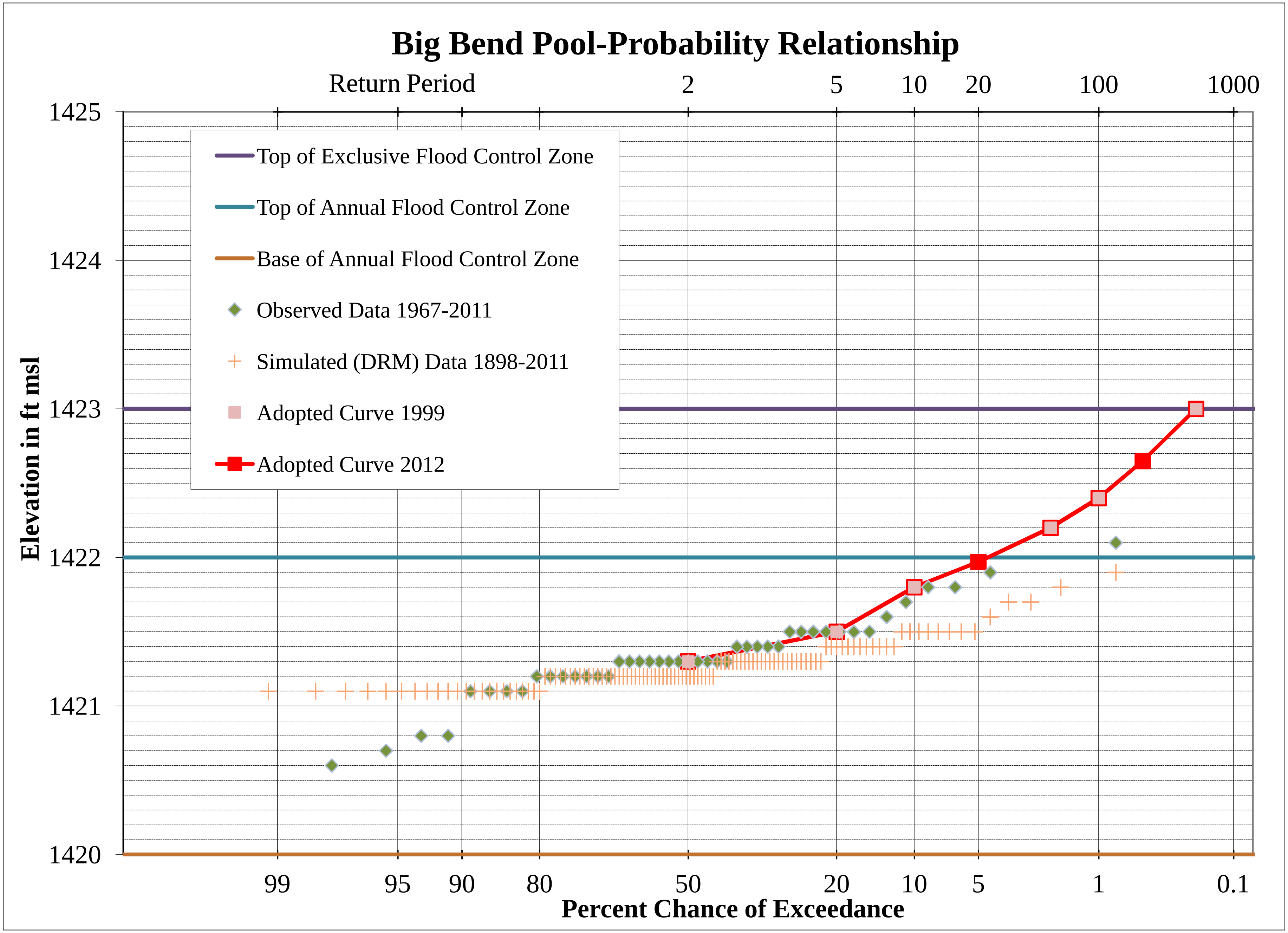

Plate 34. Big Bend Pool-Probability Relationship.

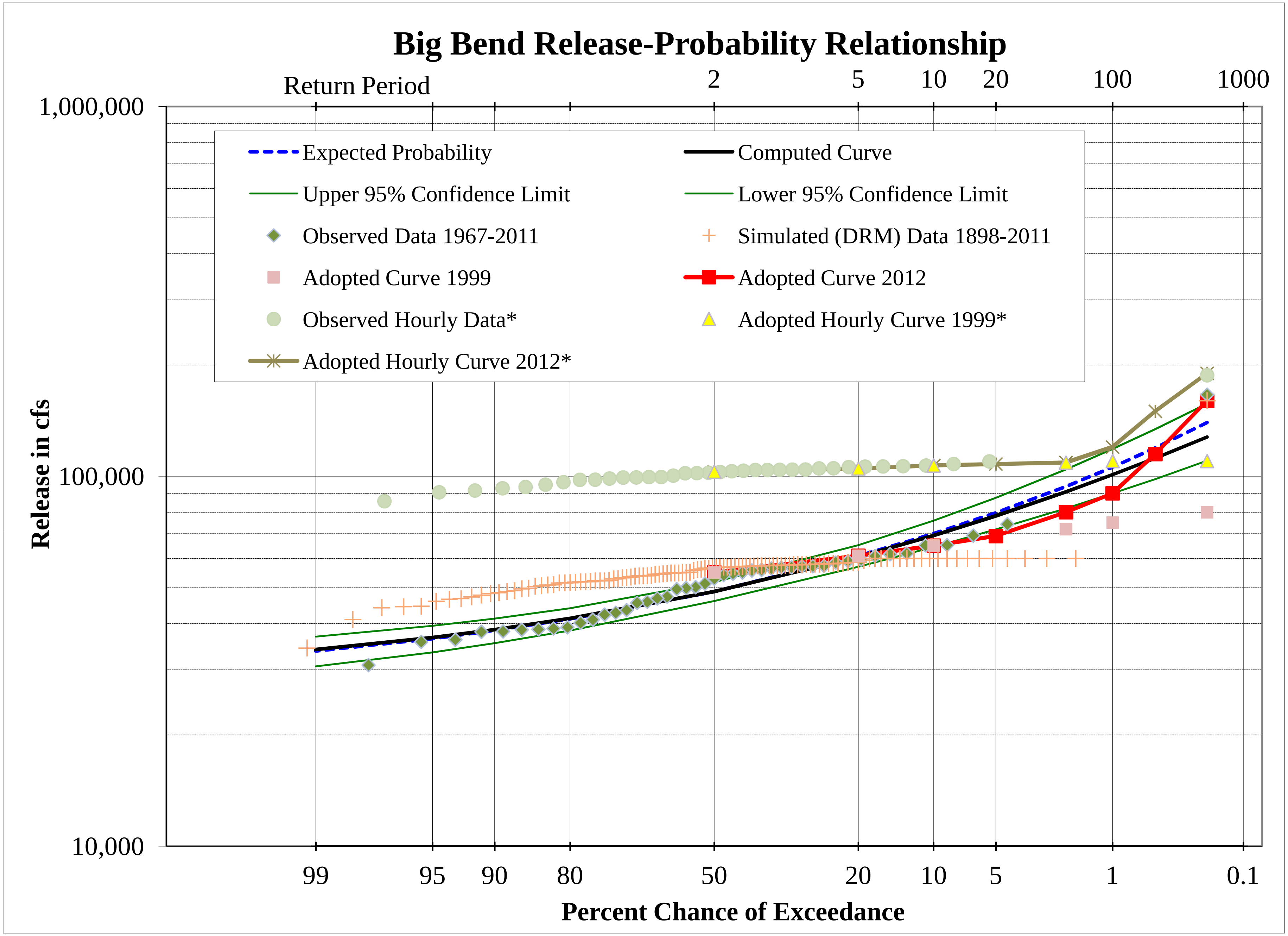

Plate 35. Big Bend Release-Probability Relationship.

* Refer to Section VII. D. for details regarding hourly releases.

Big Bend Simulated (DRM) Peak Elevations and Releases

Year	Elevation	Release	Year	Elevation	Release	Year	Elevation	Release
1898	1614.8	60,000	1939	1585.6	53,850	1980	1610.1	54,700
1899	1617.8	60,000	1940	1578.0	51,870	1981	1599.4	52,220
1900	1611.3	49,090	1941	1569.5	44,440	1982	1612.5	57,910
1901	1610.0	51,770	1942	1593.6	34,360	1983	1614.6	56,660
1902	1608.9	52,190	1943	1607.1	57,090	1984	1618.7	60,000
1903	1606.7	56,630	1944	1611.3	60,000	1985	1610.5	57,490
1904	1612.6	57,840	1945	1610.9	57,350	1986	1617.9	60,000
1905	1609.6	50,590	1946	1602.3	55,710	1987	1618.8	57,350
1906	1609.4	53,890	1947	1608.1	56,480	1988	1606.3	52,900
1907	1617.3	60,000	1948	1606.9	56,890	1989	1597.3	45,960
1908	1616.2	60,000	1949	1610.2	57,450	1990	1596.2	54,380
1909	1618.5	60,000	1950	1611.9	57,740	1991	1594.3	44,180
1910	1613.0	50,450	1951	1614.2	58,040	1992	1598.0	53,720
1911	1604.8	49,860	1952	1617.8	60,000	1993	1609.8	51,530
1912	1609.7	57,330	1953	1609.3	56,170	1994	1616.1	58,260
1913	1611.1	57,320	1954	1604.8	55,000	1995	1618.8	60,000
1914	1613.8	57,980	1955	1601.8	54,860	1996	1619.3	60,000
1915	1617.5	60,000	1956	1598.2	49,680	1997	1618.6	59,300
1916	1616.4	60,000	1957	1596.9	47,250	1998	1613.9	60,000
1917	1617.5	60,000	1958	1597.5	53,830	1999	1618.4	60,000
1918	1614.7	58,180	1959	1594.6	50,880	2000	1612.6	57,790
1919	1610.0	51,510	1960	1602.2	52,400	2001	1610.6	57,510
1920	1609.3	48,240	1961	1595.3	46,520	2002	1602.2	52,830
1921	1608.6	50,940	1962	1600.5	48,890	2003	1597.1	54,520
1922	1610.1	46,740	1963	1600.3	54,820	2004	1593.2	53,460
1923	1609.8	55,070	1964	1600.1	54,820	2005	1585.1	53,230
1924	1615.2	54,440	1965	1610.8	57,070	2006	1586.2	48,490
1925	1613.3	57,880	1966	1613.7	56,460	2007	1587.1	53,980
1926	1610.0	56,740	1967	1611.4	57,160	2008	1589.8	51,930
1927	1617.7	60,000	1968	1609.0	55,990	2009	1612.3	56,950
1928	1616.8	60,000	1969	1617.2	58,500	2010	1618.4	60,000
1929	1614.3	58,210	1970	1610.6	57,720	2011	1619.7	160,300
1930	1610.7	57,610	1971	1617.8	58,490			
1931	1600.3	51,610	1972	1617.4	58,570			
1932	1594.0	47,770	1973	1613.5	57,730			
1933	1593.0	54,950	1974	1607.7	57,270			
1934	1590.1	51,960	1975	1617.9	57,500			
1935	1578.3	52,210	1976	1609.5	57,170			
1936	1584.0	53,290	1977	1607.2	56,830			
1937	1568.3	41,020	1978	1616.5	60,000			
1938	1579.3	44,570	1979	1617.2	56,890			

Plate 36. Big Bend Simulated (DRM) Data 1898-2011.
Peak Elevations in ft msl, Peak Daily Releases in cfs

Year	Elevation	Release	Year	Elevation	Release
1967	1420.7	49,900	1990	1421.7	38,600
1968	1420.6	49,600	1991	1422.1	45,500
1969	1420.8	65,200	1992	1421.3	38,000
1970	1420.8	61,900	1993	1421.2	38,800
1971	1421.9	61,600	1994	1421.3	42,300
1972	1421.2	65,100	1995	1421.8	54,100
1973	1421.1	59,000	1996	1421.2	56,400
1974	1421.2	55,900	1997	1421.3	74,300
1975	1421.1	69,200	1998	1421.4	47,300
1976	1421.2	58,500	1999	1421.8	51,300
1977	1421.4	56,800	2000	1421.2	55,700
1978	1421.3	60,900	2001	1421.3	39,100
1979	1421.6	55,000	2002	1421.2	41,000
1980	1421.5	54,600	2003	1421.3	38,500
1981	1421.4	57,300	2004	1421.5	40,200
1982	1421.5	59,600	2005	1421.3	36,200
1983	1421.5	52,900	2006	1421.3	42,800
1984	1421.5	57,200	2007	1421.3	35,700
1985	1421.3	45,800	2008	1421.1	30,900
1986	1421.5	57,100	2009	1421.1	38,100
1987	1421.3	43,500	2010	1421.4	56,700
1988	1421.3	46,800	2011	1421.5	166,300
1989	1421.4	50,200			

Plate 37. Big Bend Observed Data 1967-2011.

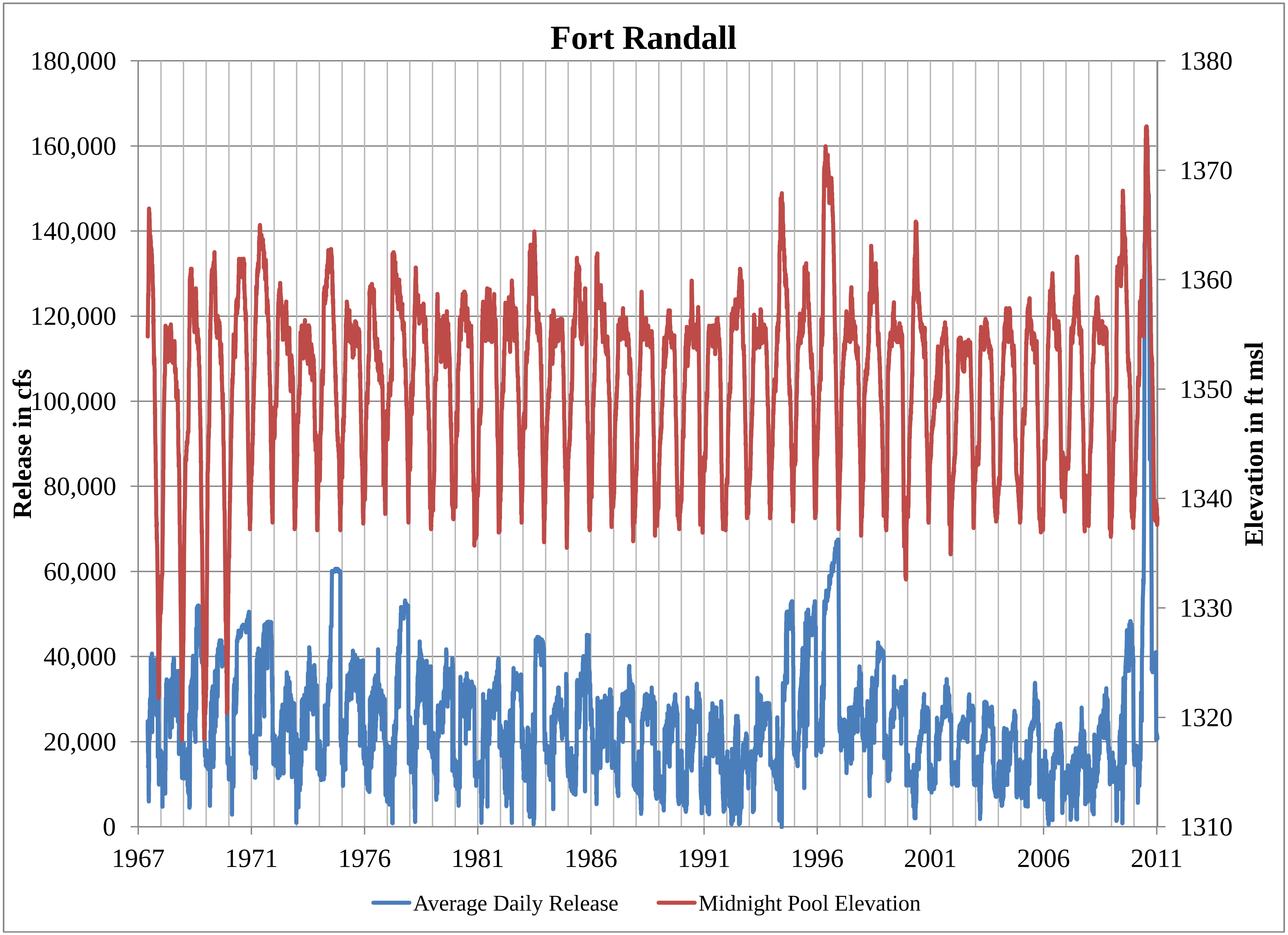

Plate 38. Fort Randall Daily Releases and Elevations.

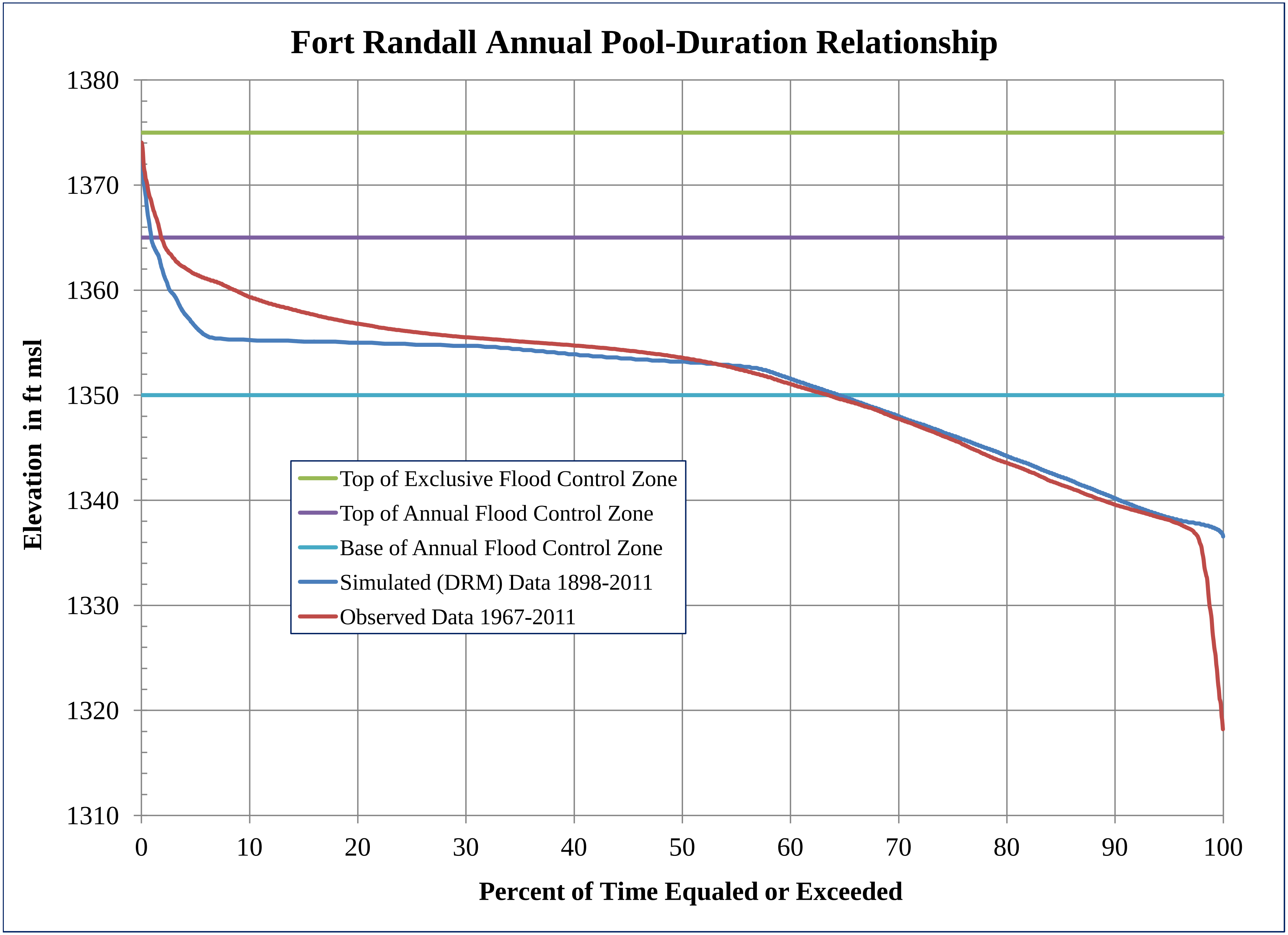

Plate 39. Fort Randall Annual Pool-Duration Relationship.

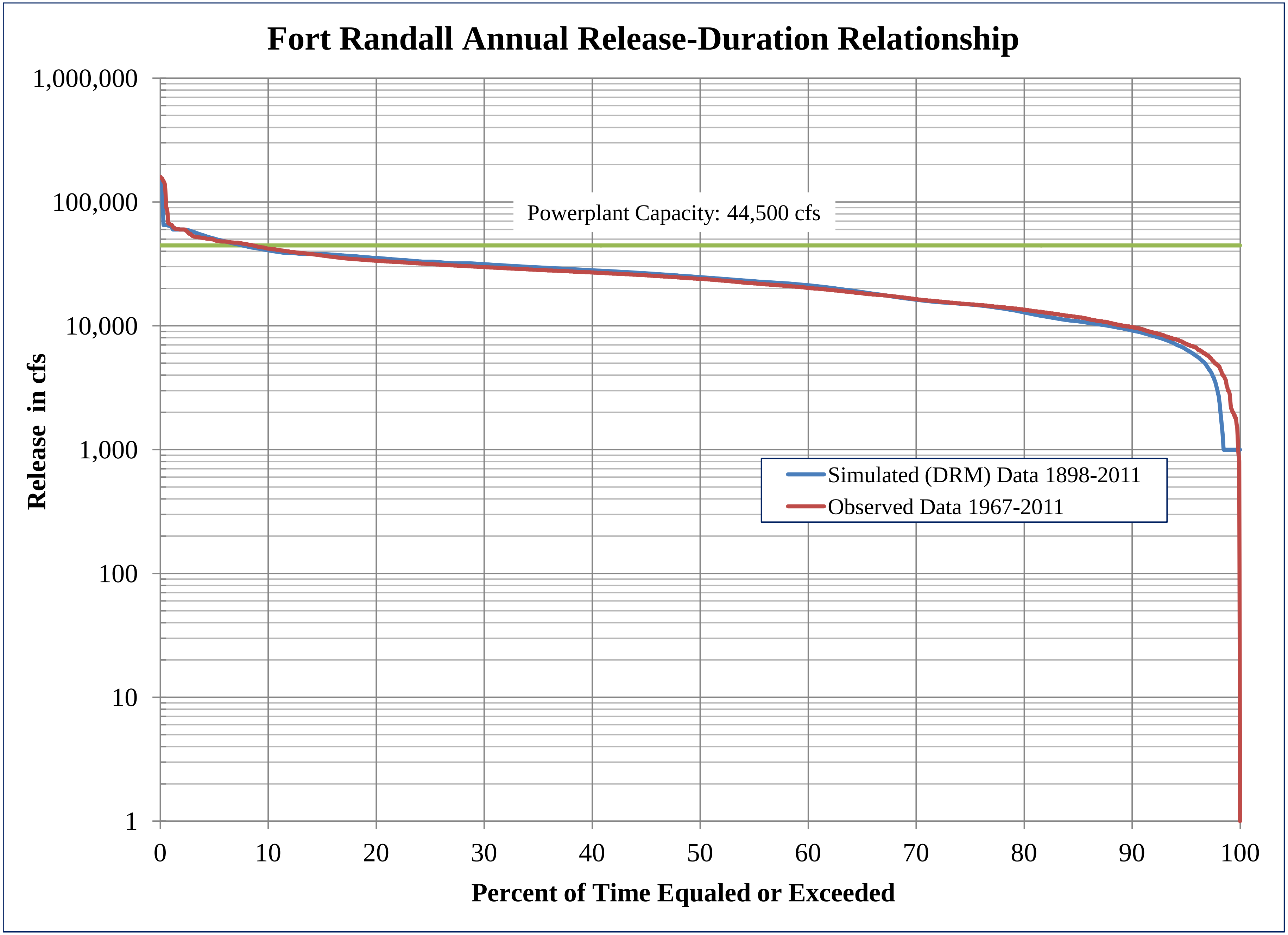

Plate 40. Fort Randall Release-Duration Relationship.

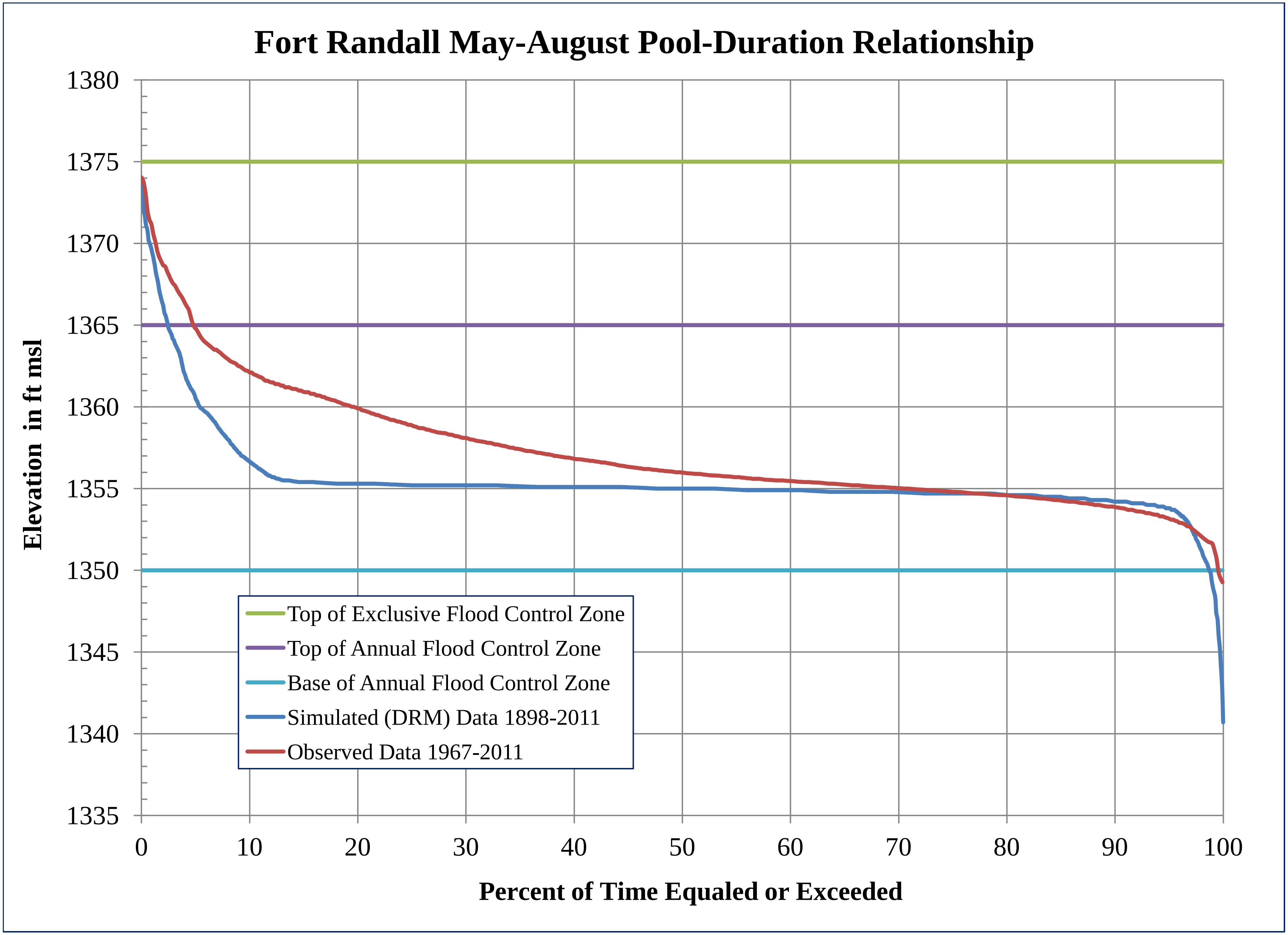

Plate 41. Fort Randall Pool-Duration Relationship (May-August).

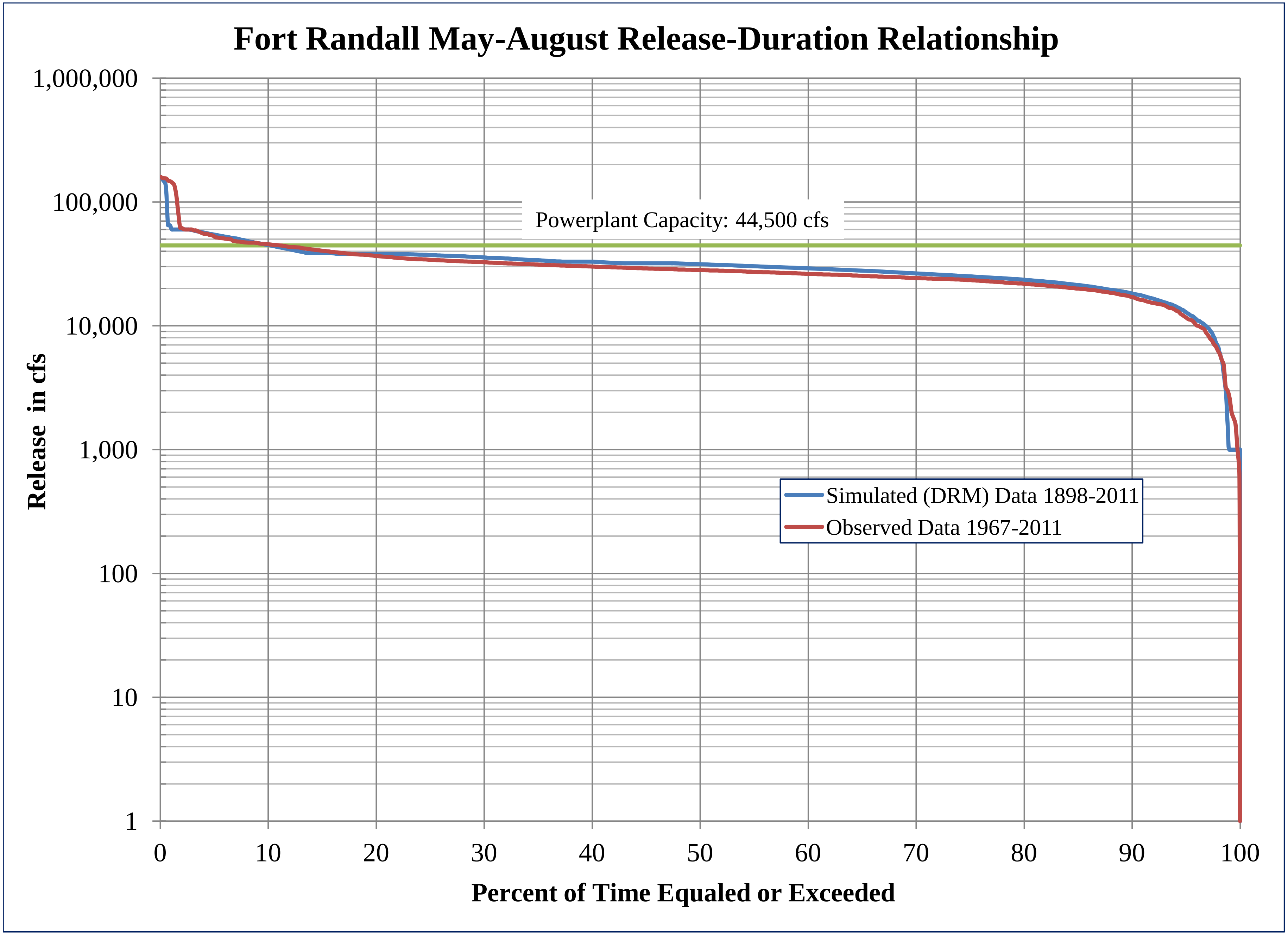

Plate 42. Fort Randall Release-Duration Relationship (May-August).

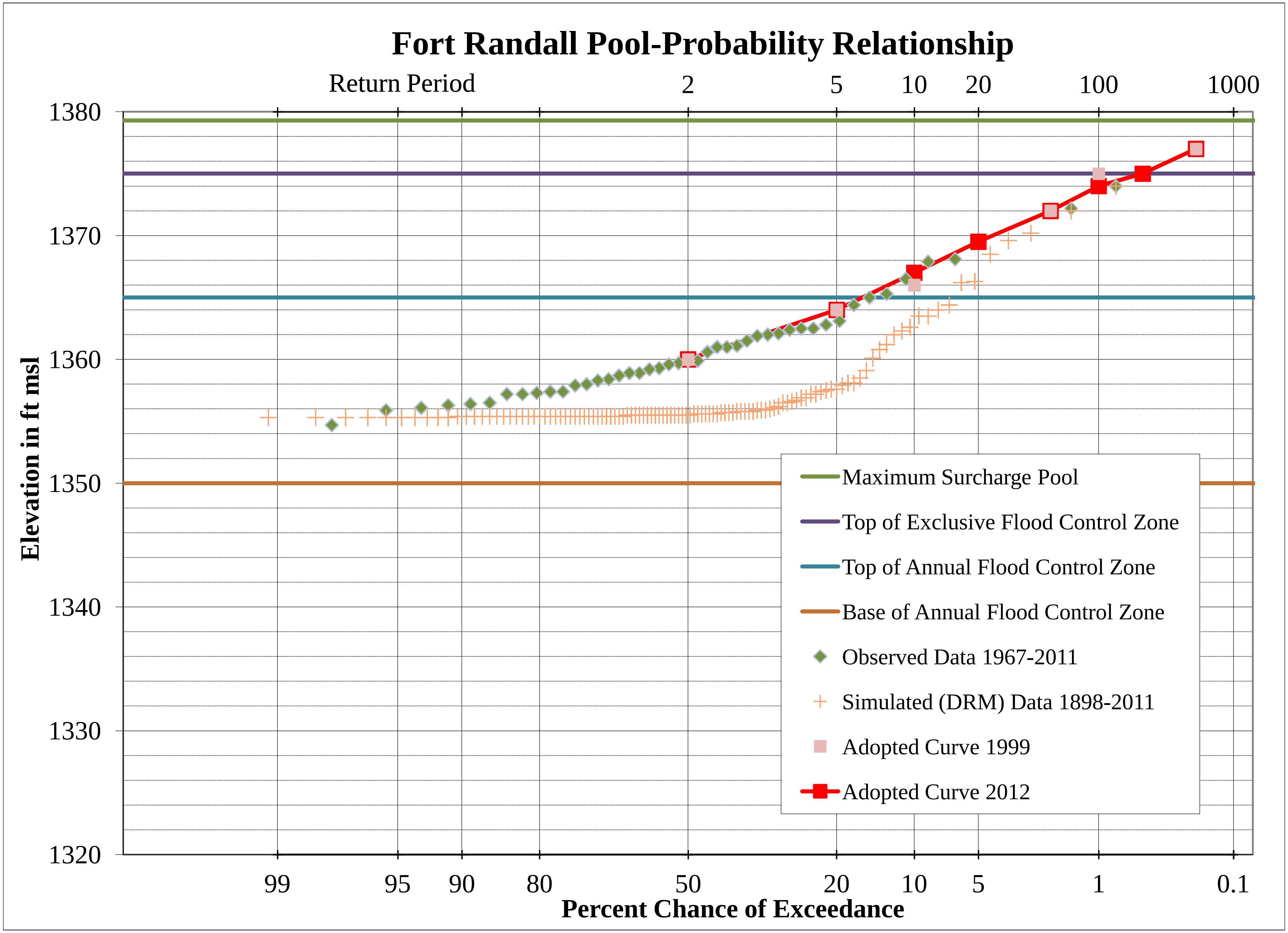

Plate 43. Fort Randall Pool-Probability Relationship.

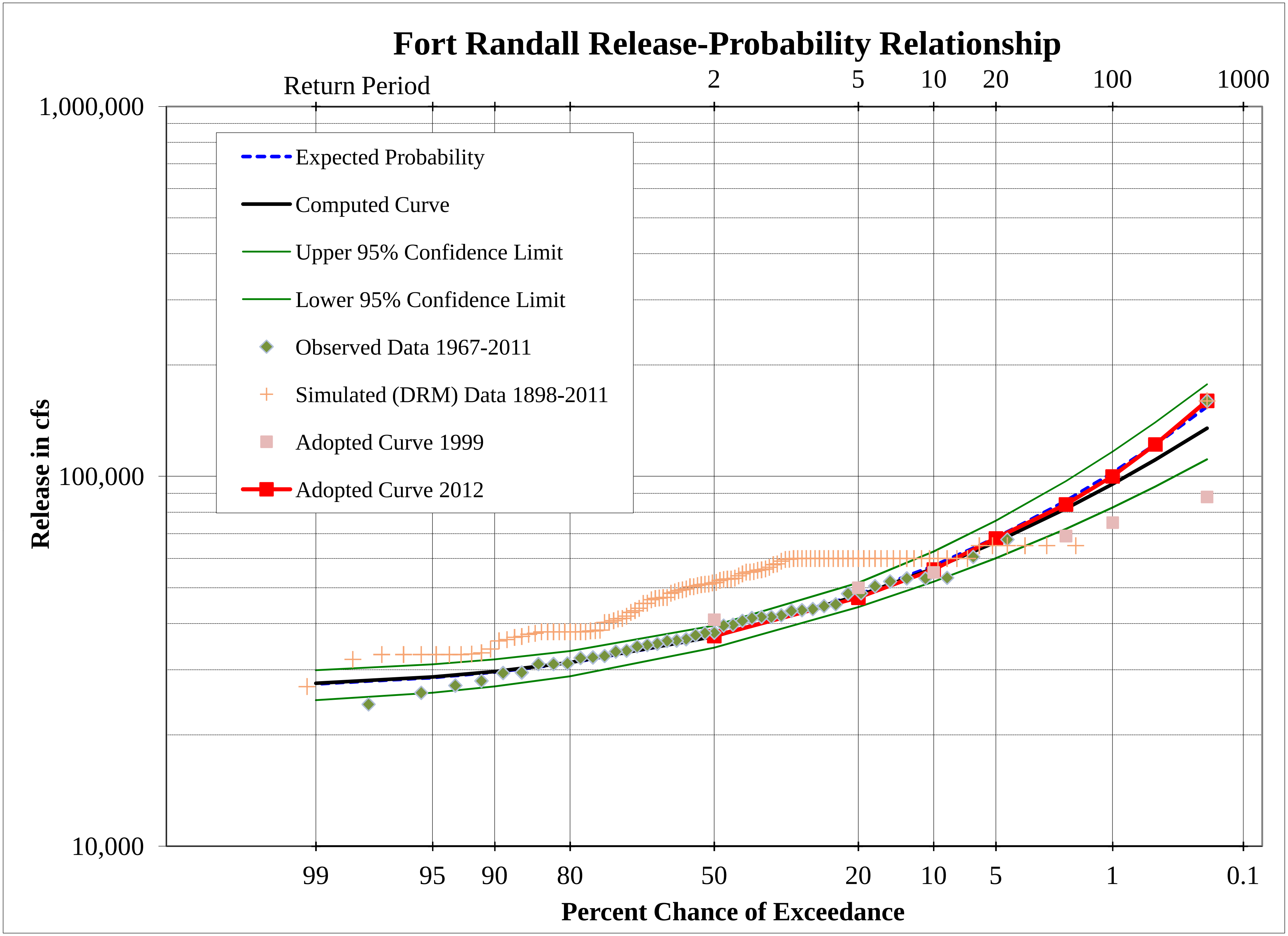

Plate 44. Fort Randall Release-Probability Relationship.

Fort Randall Simulated (DRM) Peak Elevations and Releases

Year	Elevation	Release	Year	Elevation	Release	Year	Elevation	Release
1898	1355.4	60,000	1939	1355.4	55,110	1980	1355.4	44,000
1899	1355.7	65,000	1940	1355.3	52,340	1981	1355.4	37,430
1900	1355.5	38,000	1941	1355.8	38,210	1982	1355.6	50,300
1901	1355.4	40,350	1942	1368.5	27,030	1983	1357.4	42,890
1902	1355.4	38,000	1943	1362.0	60,000	1984	1359.1	60,000
1903	1355.4	38,000	1944	1356.6	60,000	1985	1355.4	38,000
1904	1355.6	51,170	1945	1355.5	50,350	1986	1360.8	60,000
1905	1355.3	38,000	1946	1355.4	60,000	1987	1363.5	45,350
1906	1355.4	36,940	1947	1355.8	60,000	1988	1355.5	40,730
1907	1357.2	65,000	1948	1355.6	60,000	1989	1355.5	38,270
1908	1355.7	60,000	1949	1355.5	60,000	1990	1355.4	37,660
1909	1366.2	65,000	1950	1356.7	55,750	1991	1355.9	43,350
1910	1355.4	41,310	1951	1355.8	55,930	1992	1355.5	32,000
1911	1355.5	46,410	1952	1369.6	60,000	1993	1357.2	33,000
1912	1355.3	60,000	1953	1356.9	60,000	1994	1357.6	38,000
1913	1355.3	60,000	1954	1355.5	50,700	1995	1370.2	55,300
1914	1355.4	60,000	1955	1356.2	60,000	1996	1362.6	58,020
1915	1355.6	65,000	1956	1355.3	54,530	1997	1372.0	65,000
1916	1355.4	60,000	1957	1355.5	47,060	1998	1356.5	60,000
1917	1358.1	60,000	1958	1355.4	60,000	1999	1366.3	55,130
1918	1355.3	60,000	1959	1355.4	49,160	2000	1355.5	38,400
1919	1355.4	38,000	1960	1364.4	41,900	2001	1364.0	36,730
1920	1355.5	33,350	1961	1355.9	47,070	2002	1355.5	34,150
1921	1355.4	38,000	1962	1361.2	49,640	2003	1355.4	36,220
1922	1355.5	41,200	1963	1355.4	52,670	2004	1355.6	33,000
1923	1355.7	60,000	1964	1355.7	48,720	2005	1355.8	33,000
1924	1355.4	59,670	1965	1355.9	57,750	2006	1355.5	33,110
1925	1355.5	50,990	1966	1356.0	52,790	2007	1356.9	33,000
1926	1355.4	45,420	1967	1357.6	60,000	2008	1358.5	33,000
1927	1362.3	65,000	1968	1355.5	51,140	2009	1355.6	33,000
1928	1355.4	60,000	1969	1357.9	58,990	2010	1363.5	51,680
1929	1355.4	60,000	1970	1355.3	60,000	2011	1374.0	160,000
1930	1358.1	56,810	1971	1355.4	60,000			
1931	1355.3	48,320	1972	1355.4	59,740			
1932	1355.6	46,900	1973	1355.8	52,810			
1933	1357.5	49,380	1974	1355.5	46,790			
1934	1355.4	56,190	1975	1355.3	60,000			
1935	1355.4	51,510	1976	1355.3	53,860			
1936	1356.1	60,000	1977	1355.4	38,040			
1937	1355.4	35,930	1978	1360.1	60,000			
1938	1355.4	40,280	1979	1356.5	53,050			

Plate 45. Fort Randall Simulated (DRM) Data 1898-2011.
Peak Elevations in ft msl, Peak Releases in cfs

Fort Randall Observed Peak Elevations and Releases

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

Plate 46. Fort Randall Observed Data 1967-2011.

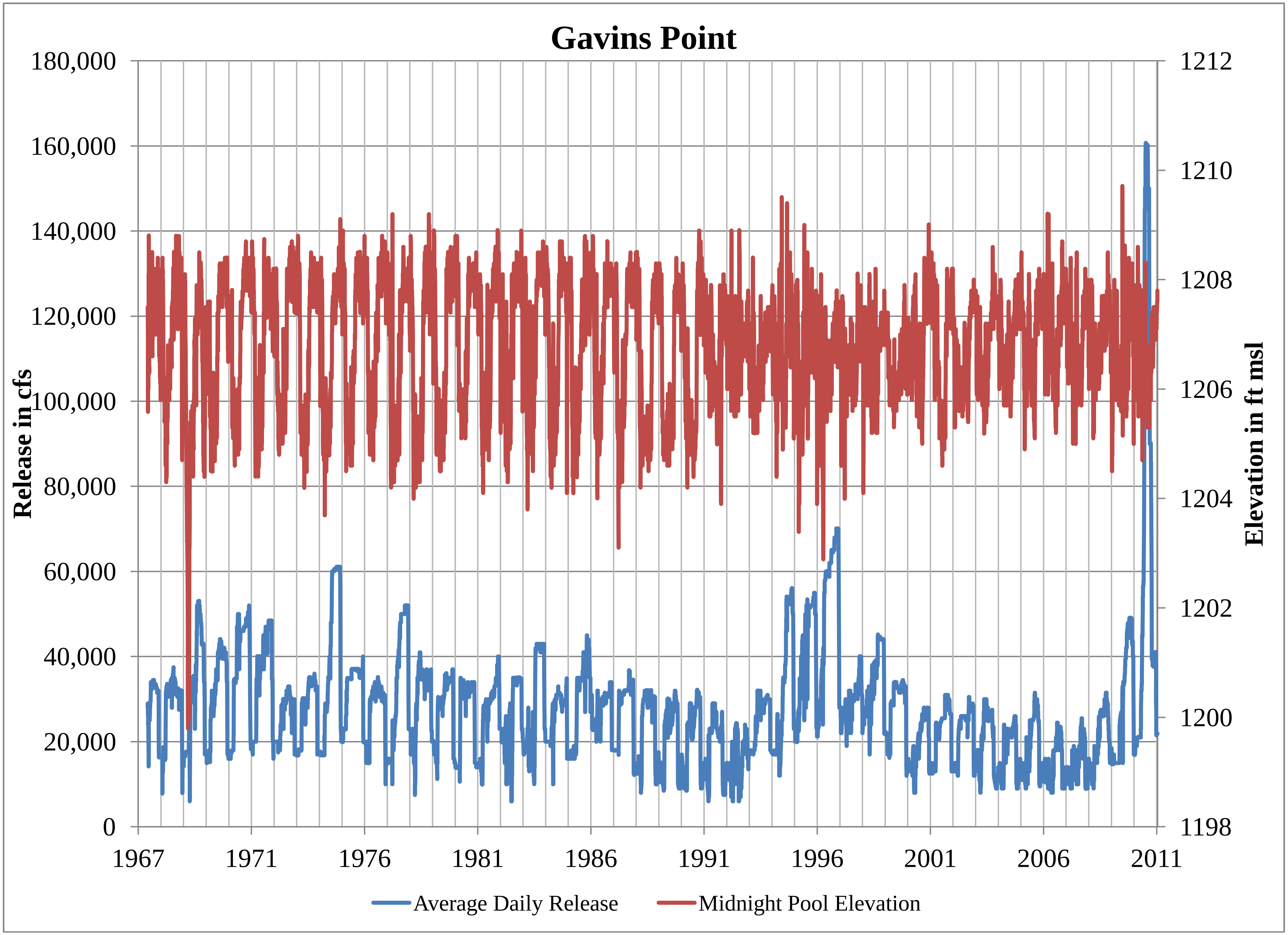

Plate 47. Gavins Point Daily Releases and Elevations.

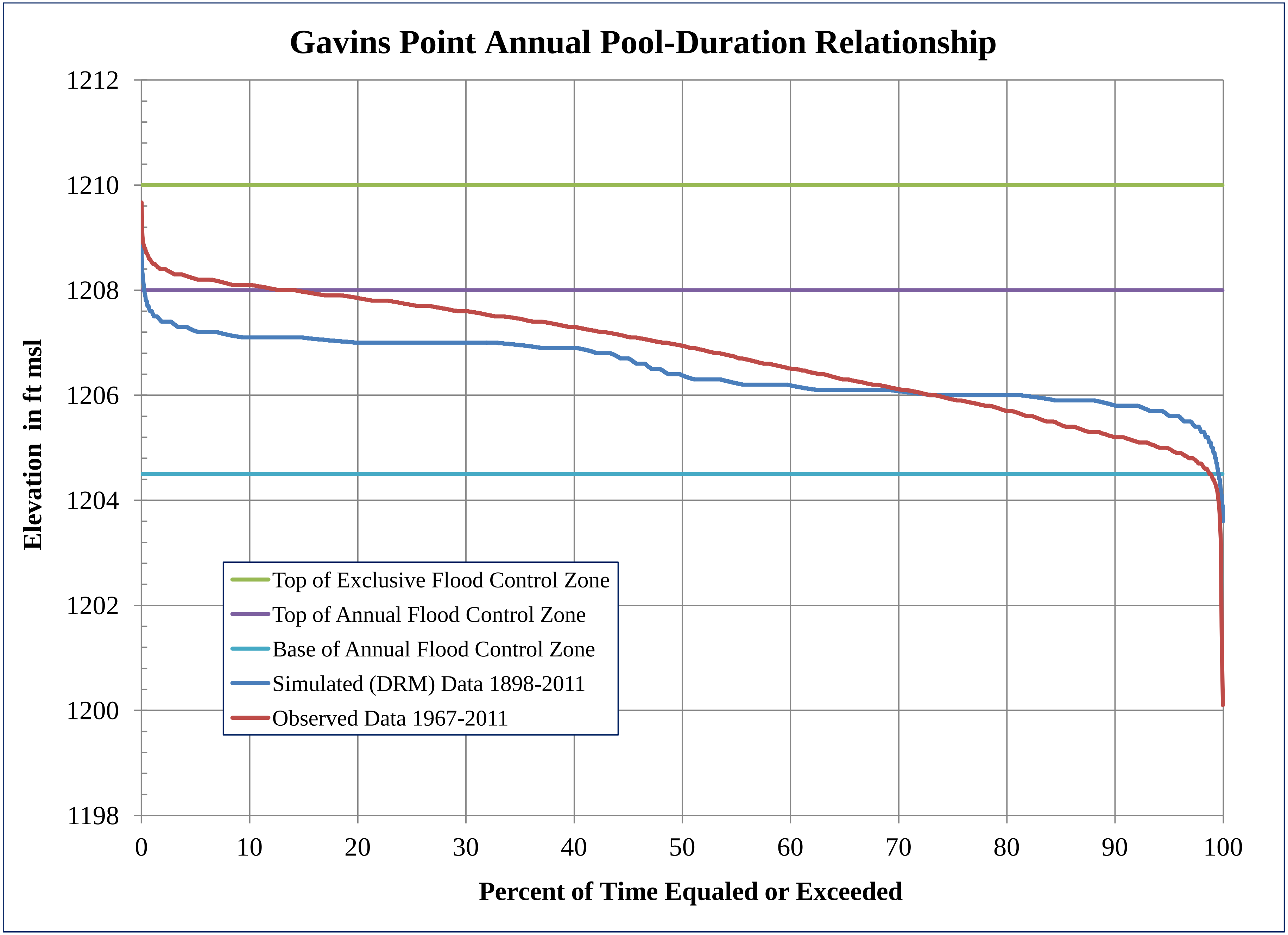

Plate 48. Gavins Point Annual Pool-Duration Relationship.

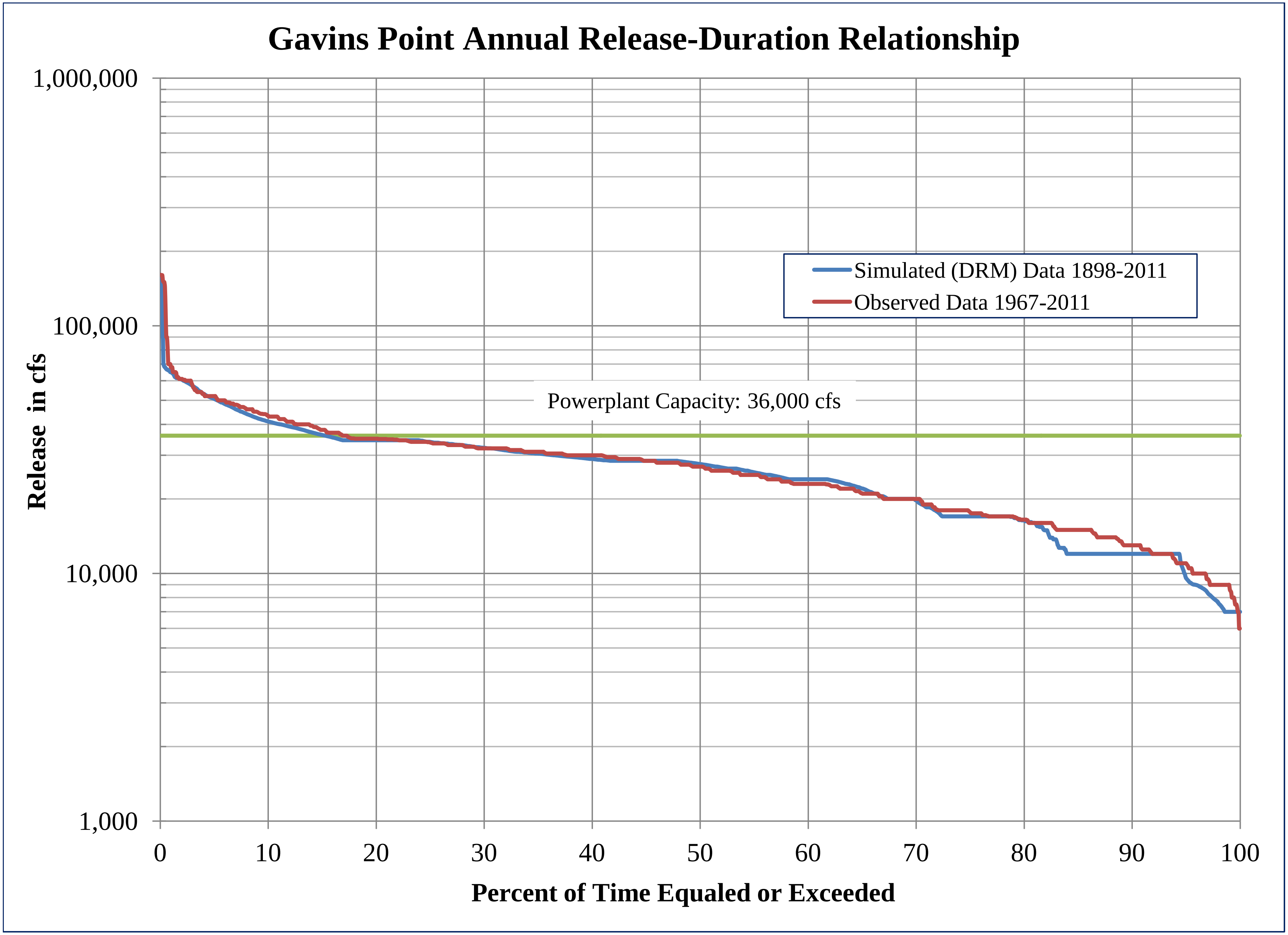

Plate 49. Gavins Point Annual Release-Duration Relationship.

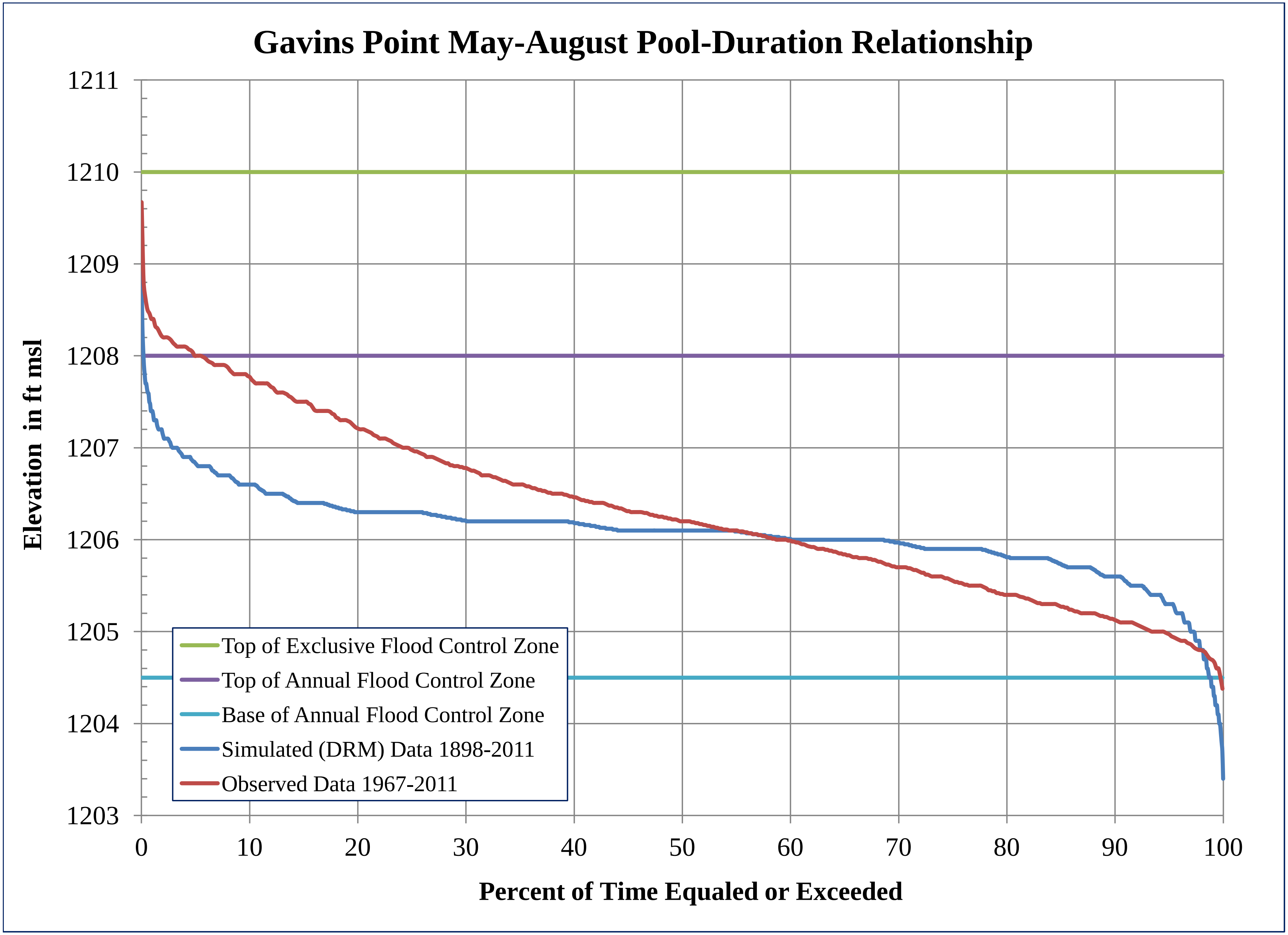

Plate 50. Gavins Point Pool-Duration Relationship (May-August).

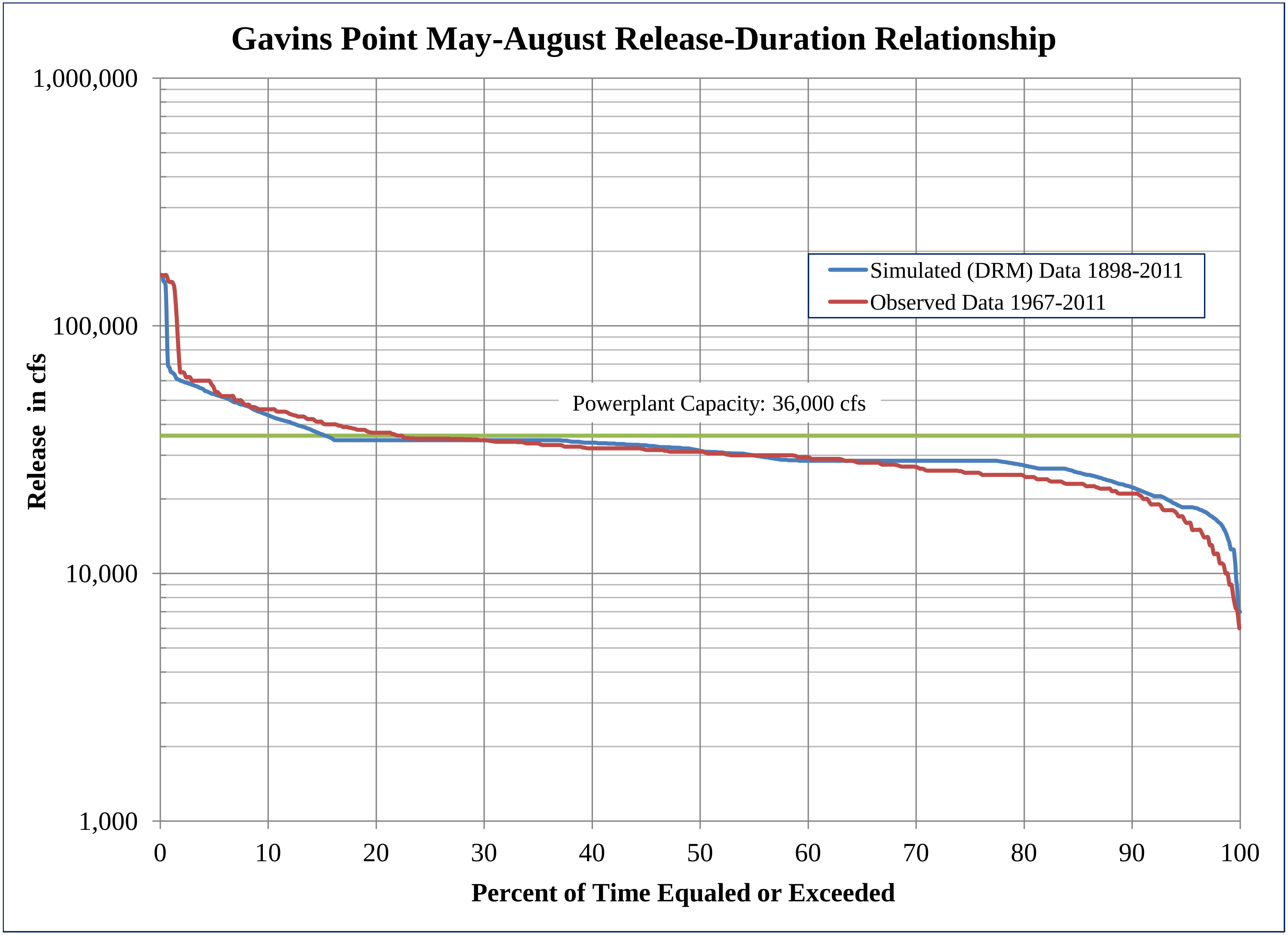

Plate 51. Gavins Point Release-Duration Relationship (May-August).

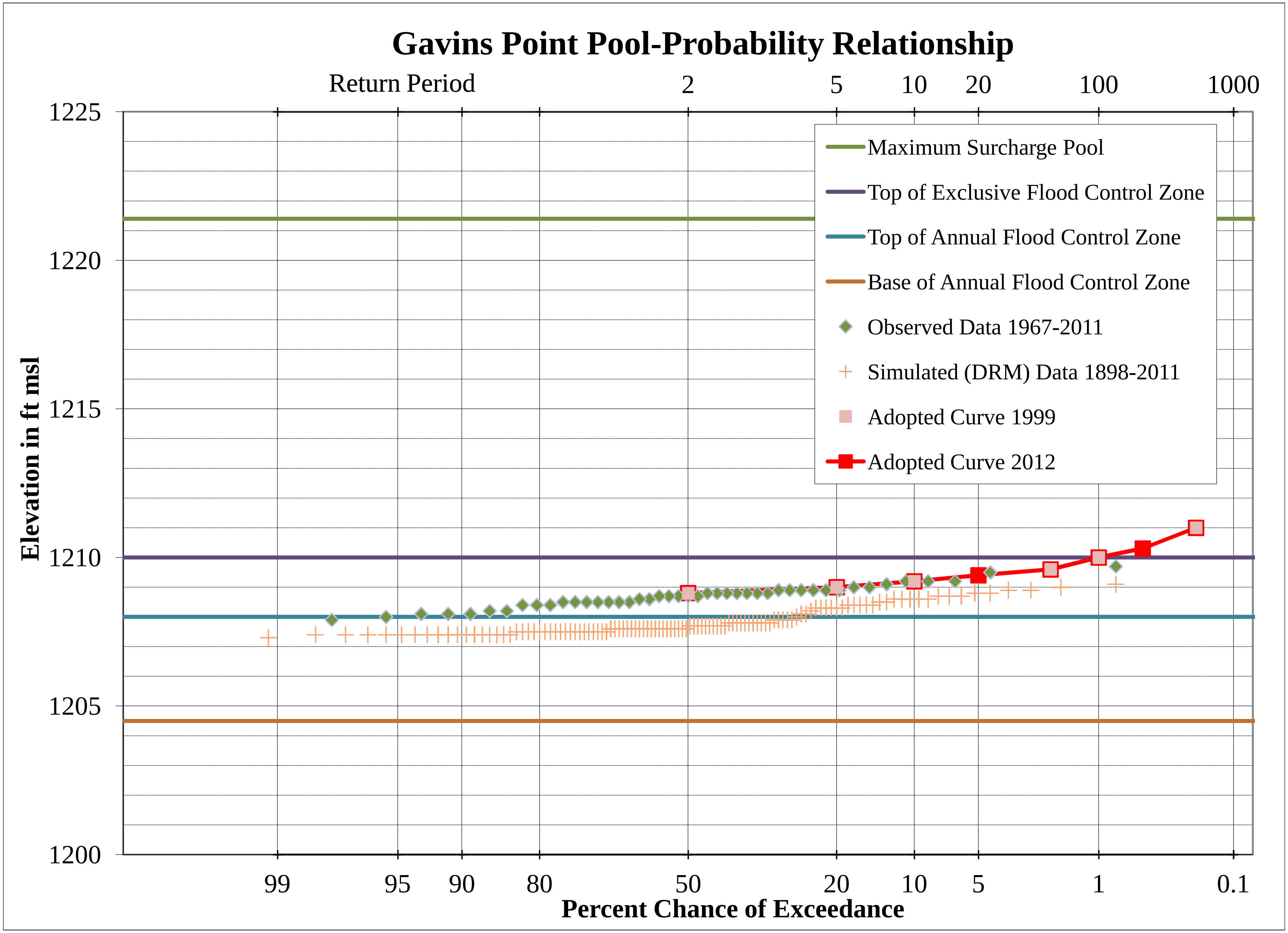

Plate 52. Gavins Point Pool-Probability Relationship.

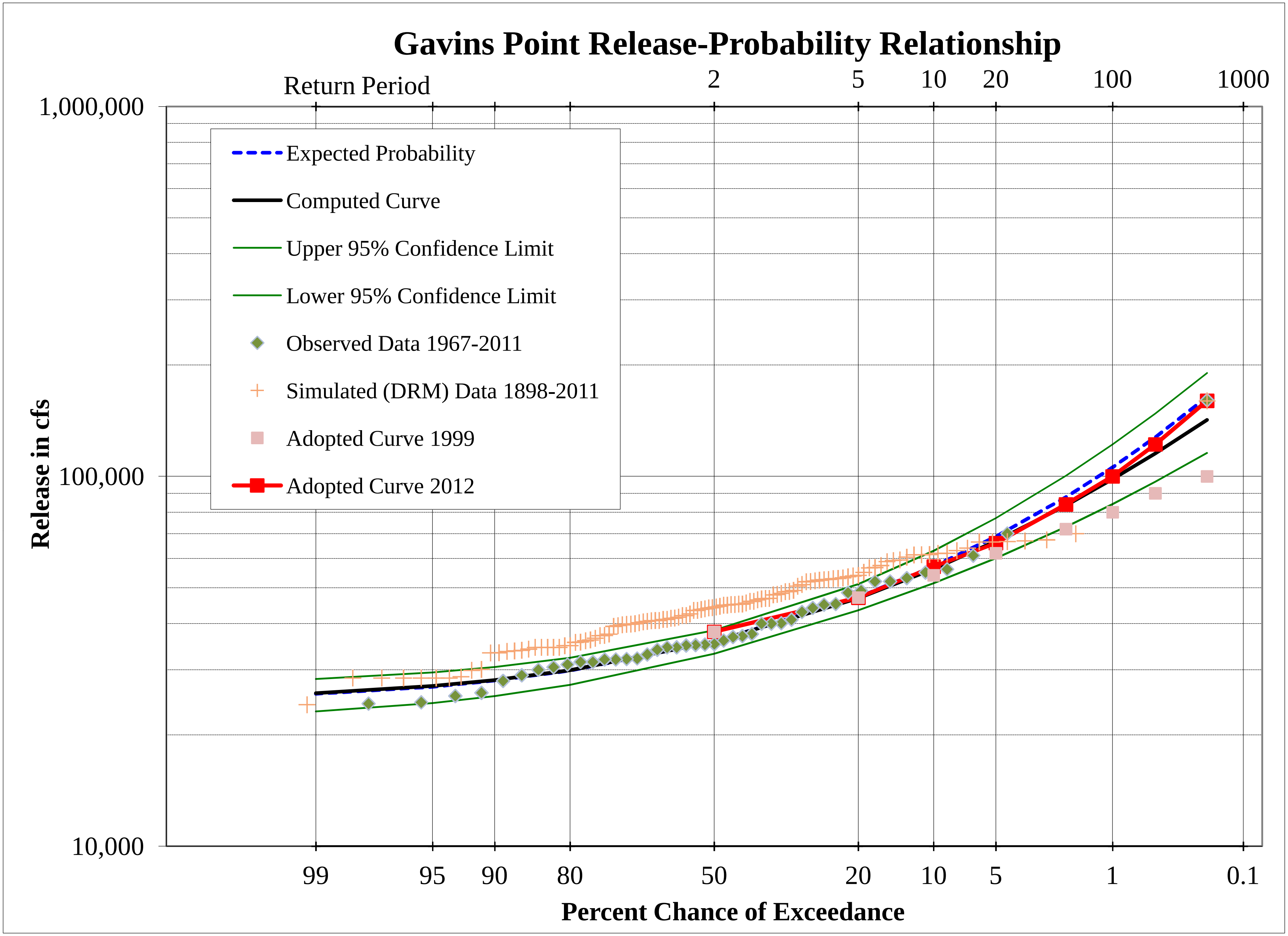

Plate 53. Gavins Point Release-Probability Relationship.

Gavins Point Simulated (DRM) Peak Elevations and Releases

Year	Elevation	Release	Year	Elevation	Release	Year	Elevation	Release
1898	1207.6	59,250	1939	1208.5	43,840	1980	1208.2	40,420
1899	1207.8	66,500	1940	1207.8	45,940	1981	1207.4	35,660
1900	1207.4	34,500	1941	1207.4	35,590	1982	1207.6	46,800
1901	1207.4	39,700	1942	1208.6	24,150	1983	1207.6	39,970
1902	1207.5	34,500	1943	1208.1	49,180	1984	1208.6	48,780
1903	1207.4	36,130	1944	1207.9	46,650	1985	1207.6	37,100
1904	1207.5	44,100	1945	1207.8	44,180	1986	1208.6	64,000
1905	1207.4	34,500	1946	1208.3	54,000	1987	1208.6	39,510
1906	1207.4	33,760	1947	1208.4	56,690	1988	1207.6	40,570
1907	1207.5	66,930	1948	1207.9	46,380	1989	1207.5	39,840
1908	1207.5	61,360	1949	1209.1	47,830	1990	1207.5	34,860
1909	1207.5	66,500	1950	1208.7	44,570	1991	1207.6	41,060
1910	1207.4	39,880	1951	1208.8	52,980	1992	1207.6	28,500
1911	1207.4	42,060	1952	1208.8	63,000	1993	1208.3	28,500
1912	1207.5	59,440	1953	1207.7	51,010	1994	1207.6	34,500
1913	1207.4	55,040	1954	1207.5	43,430	1995	1208.3	52,010
1914	1207.4	52,590	1955	1207.8	53,560	1996	1208.1	56,600
1915	1207.9	67,370	1956	1207.6	45,080	1997	1207.8	70,000
1916	1207.5	62,000	1957	1207.6	39,320	1998	1208.4	61,390
1917	1207.5	61,940	1958	1207.7	45,150	1999	1207.8	52,180
1918	1207.5	48,280	1959	1207.7	44,390	2000	1207.7	37,480
1919	1207.4	36,520	1960	1209.0	41,400	2001	1208.4	34,130
1920	1207.4	33,630	1961	1207.7	40,210	2002	1207.5	29,900
1921	1207.4	34,860	1962	1208.9	41,050	2003	1207.7	33,370
1922	1207.4	40,770	1963	1207.6	44,890	2004	1207.4	28,730
1923	1207.6	61,500	1964	1208.0	42,500	2005	1207.7	30,090
1924	1207.6	51,900	1965	1207.8	45,950	2006	1207.5	28,510
1925	1207.4	45,180	1966	1207.6	42,040	2007	1208.4	28,500
1926	1207.6	40,780	1967	1208.4	45,480	2008	1208.3	28,500
1927	1207.5	66,640	1968	1207.8	43,690	2009	1207.7	28,500
1928	1207.6	58,840	1969	1208.3	52,670	2010	1208.7	48,870
1929	1207.7	53,170	1970	1207.7	50,480	2011	1208.6	160,700
1930	1207.6	40,730	1971	1207.6	53,800			
1931	1207.8	45,020	1972	1207.9	52,920			
1932	1207.6	41,340	1973	1208.3	44,890			
1933	1208.9	35,950	1974	1207.5	41,630			
1934	1208.7	46,760	1975	1207.5	60,500			
1935	1207.3	37,150	1976	1207.8	47,970			
1936	1207.6	52,410	1977	1207.9	34,500			
1937	1207.5	33,880	1978	1208.5	57,410			
1938	1207.5	33,340	1979	1207.8	43,410			

Plate 54. Gavins Point Simulated (DRM) Data 1898-2011.
Peak Elevations in ft msl, Peak Releases in cfs

Gavins Point Observed Peak Elevations and Releases

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

Plate 55. Gavins Point Observed Data 1967-2011.