Memorandum

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DATE: 15 June 2010 PROJECT: 21739
TO: Lorna Ellestad
COMPANY/AGENCY: Skagit County
FROM: Pat Flanagan and Malcolm Leytham
SUBJECT: Skagit River GI Study – Seasonality Assessment of Flood Storage

We have completed a preliminary assessment of the impact of seasonal variation in flood storage on regulated flood hydrographs as defined in Task Order #4 (Amendment 1). This memorandum describes our analysis and the impact to regulated flows in the Skagit River at Concrete.

1.0 Introduction

According to the current Water Control Manuals (WCMs), the flood control storage required at Upper Baker and Ross reservoirs varies seasonally as shown in Table 1:

Table 1: Flood control storage requirements at Upper Baker and Ross

Upper Baker	
Date	(ac-ft)
October 1	0
November 1	16,000
November 15	74,000
March 1	74,000
April 1	0

Ross	
Date	(ac-ft)
October 1	0
October 15	20,000
November 1	43,000
November 15	60,000
December 1	120,000
March 15	120,000

As noted in Section 2.0, the flood storage requirements for Upper Baker, as described in the WCM, is slightly different from the requirement under the current FERC project license. All analyses described in this memo have assumed the flood control storage requirements per the WCM.

Hydrologic analyses of existing condition regulated flows conducted to date have ignored the seasonal variation of flood control storage and have assumed that the required maximum amount of storage (74,000 ac-ft at Upper Baker and 120,000 ac-ft at Ross) is available for all floods, regardless of the date of occurrence. The full amount of flood storage is not required at Upper Baker until November 15 and at Ross until December 1. The purpose of the work described in this memo was to assess the impact of lower flood control storage requirements prior to December 1 on regulated peak flows on the Skagit River near Concrete (i.e. downstream from the Baker River confluence).

2.0 Reservoir Record Analysis

Daily time series of reservoir elevations for Upper Baker and Ross were obtained from PSE (via Skagit County), the USGS, and the Corps. For Upper Baker, gaps in the USGS daily data were filled with the PSE data to create a continuous record for water years 1977 through 2009. For Ross, the USGS daily data were filled with data from the Corps to create a continuous record for water years 1962 through 2009. The reservoir elevation time series were converted to time series of reservoir storage using elevation/storage data provided in the WCMs.

It is recognized that the period of historic reservoir elevation or storage data obtained for this work (1977 through 2009 at Upper Baker, and 1962 through 2009 at Ross) may not be representative of future project operations. Accordingly, discussions were held with representatives from both Puget Sound Energy (PSE) and Seattle City Light (SCL) to determine what period of historic reservoir elevation or storage data is expected to be most representative of future conditions, especially in the early part of the flood control season.

Upper Baker

According to representatives from PSE, prior to 1984, flood control operations at Upper Baker provided 16,000 acre-ft of storage on 1 November and 74,000 acre-ft on 15 November, with more of a "stair-step" change in flood control storage between those two dates than at present. Since 1984, project operations have assumed a linear transition in the storage required between those two dates, hence providing more assured flood control early in the flood control season.

Operations at Upper Baker have also deviated from expected future operations since 2004. In accordance with the requirements of a relicensing agreement, an Interim Protection Plan (IPP) was introduced in 2004 to improve fish habitat in the Baker River by reducing rapid fluctuations in flow. Under IPP-related project operations, more storage than required would be available in the Baker River project early in the flood control season. IPP operations are expected to continue until approximately 2012 when new turbine units will be installed at the project.

Under the terms of Article 107c of the new FERC license, PSE is required to "develop means and operational changes to operate the Project reservoirs in a manner addressing imminent flood events". These changes may include "additional reservoir drawdown below the maximum established flood pool". It is anticipated that any operational changes to address "imminent floods" would take place after about 2012; the nature and impact of any such changes is not yet known.

A further change affecting flood control performance has been the implementation by PSE since about 2006 of flood control pool buffers at both Upper Baker and Lower Baker. The buffers provide additional storage above that required for flood control operations per the operating license. At Upper Baker, this additional storage is 26,000 acre-ft, so that the bottom of the buffer is approximately 7 ft below the maximum permissible pool elevation in the flood control season. At Lower Baker, the bottom of the buffer is approximately 5 ft below the spillway crest elevation, representing approximately 9,850 acre-ft of storage below the spillway crest. The purpose of the buffers is to provide PSE with operational flexibility while avoiding, to the extent possible, incursion into the formal flood control storage space at Upper Baker. PSE operates the reservoirs to try to maintain water levels toward the low end of these buffers (water levels are generally maintained 2 to 3 feet above the bottom of the buffer), however there is no formal operating policy for the buffers. It should also be noted that the Corps only manages flood control space at the Upper Baker project.

It was noted in the course of discussion with PSE staff that the flood control storage requirements at Upper Baker as described in the WCM differ slightly from the storage required per the project's FERC license. Under the FERC license, which PSE views as the controlling document, 16,000 acre-feet of storage is required at Upper Baker between 15 October and 1 November. Under the current WCM, flood control storage would be increased from 0 acre-feet on 1 October to 16,000 acre-feet on 1 November. Comment from the Corps (e-mail from Dan Johnson dated 7 June 2010) confirms that PSE will be required to provide 16,000 acre-feet of storage in Upper Baker by 15 October per the current license.

While future operations at Upper Baker are expected to differ from past operations in a number of respects, for current purpose it is assumed that future operations will be most similar to operations in the 20-year period 1984-2003.

Ross

The situation at Ross is less clear than at Upper Baker. As discussed later in this section, Ross Reservoir often provides significantly greater storage early in the flood control season than is required under the terms of its operating license. According to a representative from SCL, Ross reservoir elevations in the early fall are driven by a combination of factors including summer/fall weather conditions, energy demand, fisheries compliance requirements, and conditions in the energy market in general. SCL stressed that while no significant changes in operational practices were anticipated in the foreseeable future, there was also no guarantee that early flood control season storage at Ross would be greater than required in the future. Considering trends in energy demand, SCL suggested that reservoir data from the period 1990 through present would be more indicative of future operations than data from earlier periods.

Data for the periods 1984-2003 at Upper Baker and 1990-2009 at Ross were analyzed to produce summary "hydrographs" and duration curves of reservoir elevation and available storage. Summary hydrographs are provided in Figures 1 through 4, while duration curves are provided in Figures 5 through 8.

The summary hydrographs (Figures 1 through 4) show percentiles of stage or available volume on a given day of the year, as well as the required flood storage. The Upper Baker plots show that from October 1 to November 15 the median available flood storage is much less than the full

74,000 ac-ft required after November 15. While this is consistent with the requirements of the 2000 Baker WCM, it demonstrates that it is inappropriate to assume that full flood control storage is available for all floods regardless of their date of occurrence. The plots for Ross show that for most of October, the median available flood storage is close to or exceeds the full 120,000 ac-ft required after December 1. The plots for Ross also show that in many years, the storage available greatly exceeds the flood control requirements.

Duration curves (Figures 5 through 8) were developed for two-week periods in October and November, as well as for the balance of the flood control season from December through February. The duration curves show that in early October, the full flood storage has historically only been provided about 10% of the time at Upper Baker and 45% of the time at Ross. After December 1, the full flood storage has historically been available over 90% of the time at both projects. While these data show that project operations are consistent with the respective WCMs, the duration curves again serve to demonstrate that it is inappropriate to assume that the full amount of flood control storage is available early in the flood control season.

3.0 Impact of Reduced Flood Storage on Regulated Peak Flows

10- and 100-year flood hydrographs were routed through Upper Baker and Ross to the Skagit River USGS gage near Concrete using the Corps reservoir routing spreadsheet "model"[1]. To represent the seasonally varying flood control storage requirements, simulations were conducted for two week periods from October 1 to November 30, and for the remainder of the flood control season after December 1, when the full amount of flood control storage is required at both projects. The initial conditions in the two reservoirs were set to the required flood storage on the middle date of each two week period.

The "average" regulating scheme previously used by the Corps was assumed. This assumes that outflow at both projects would be restricted before the **unregulated** flow at Concrete reaches the flood damage threshold of 90,000 cfs. Upper Baker releases were set to the minimum of 5000 cfs[2] three hours before the 90,000 cfs threshold flow was reached at Concrete, while Ross releases were set to 0 cfs eight hours before the threshold flow was reached at Concrete[3]. These releases are maintained until reservoir levels rise to a point which triggers greater releases as specified under the respective Spillway Gate Regulation Schedules. Simulation results are provided in Table 2 on the following page.

[1] Flood hydrographs for this purpose were those included in the Corps spreadsheet model and were based on unregulated 10-year and 100-year winter peak flows on the Skagit River near Concrete of 154,000 cfs and 299,000 cfs respectively. The May 2008 Draft Revised Flood Insurance Study reports 10-year and 100-year unregulated peak discharges of 159,000 cfs and 278,000 cfs respectively.

[2] There is a perception in some quarters that a release of 5,000 cfs from the Baker project is required to generate power to operate the project for flood control. The actual minimum release required to generate power for station operation for a single turbine is about 1,600 cfs. There is no operational reason why the release from Upper Baker cannot be reduced below the current 5000 cfs minimum if desirable.

[3] Note that some Corps routing simulations for Ross assume a release of 0 cfs, while other simulations assume 5,000 cfs. It is not clear how this restricted release rate was determined for any particular simulation.

Table 2: Reservoir routing by two-week period

Two-Week Period	10-year Event			100-year Event			Starting Flood Storage			
	Contribution to Regulated Peak Discharge at Concrete (cfs)		Regulated Peak Discharge, Skagit River near Concrete (cfs)[a]	Contribution to Regulated Peak Discharge at Concrete (cfs)		Regulated Peak Discharge, Skagit River near Concrete (cfs)[a]	Upper Baker		Ross	
	From Upper Baker	From Ross		From Upper Baker	From Ross		ft, NAVD88	ac-ft	ft, NAVD88	ac-ft
10/1 to 10/15	17,000	13,000	142,000	34,000	34,000	281,000	727.04	3,700	1603.63	10,100
10/16 to 10/31	15,000	10,000	137,000	34,000	28,000	276,000	725.42	11,700	1601.80	31,600
11/1 to 11/15	5,000	7,000	125,000	29,000	28,000	269,000	718.12	46,100	1600.09	51,500
11/16 to 11/30	5,000	0	118,000	11,000	21,000	244,000	711.70	74,000	1596.72	90,100
Full Storage (Routed by NHC)	5,000	0	118,000	11,000	12,000	239,000	711.70	74,000	1594.09[b]	119,900
Full Storage (Routed by COE)	n/a	n/a	118,000	n/a	n/a	232,000	711.70	74,000	1594.13[b]	119,500

a. Unregulated 10-yr and 100-yr winter peak flows for this analysis would be 154,000 and 299,000 cfs respectively.

b. There are minor inconsistencies in the Skagit WCM with regard to both the stage/storage relationship at Ross and the pool elevation corresponding to the December 1 flood control storage requirement.

Modifications to the Corps spreadsheets' representation of the Spillway Gate Regulation Schedules (SGRSs) were made for both Upper Baker and Ross[4]. The SGRSs from the 2001 Skagit WCM and the 2000 Baker WCM were implemented in the spreadsheet model to determine required releases from the projects at high pool levels. The SGRSs control the release from both projects during large events based on the reservoir pool elevation and the rate of rise (or reservoir inflow if known). The differences in SGRS representation between the Corps spreadsheets and NHC's analysis result in slightly different regulated peak discharge at Concrete for the 100-year event (see last two rows in Table 2[5]).

The simulation results in Table 2 show a 20% increase in both 10-year and 100-year regulated peak flow at Concrete for an event occurring in early October instead of December when full flood storage is required to be available. The SGRS curves control the outflow at both projects in both the 10- and 100-year events when less than the full amount of flood storage is available at the start of the simulation. The SGRS are not activated during the 10-year event when full flood storage is available.

4.0 Impact of Reduced Flood Storage on Flood Risk

The analysis described in Section 3 indicates that a nominal 10-year or 100-year winter flood event occurring in the first two weeks of October would result in a regulated peak at Concrete some 20% higher than for similar events occurring after December 1, when the full amount of flood control storage is available at both Ross and Upper Baker. However, to gain insight into the effect of reduced flood storage on flood risk, one obviously also has to consider the probability of damaging floods occurring early in the flood season.

Ideally for this type of analysis one would determine 10-year and 100-year unregulated flood hydrographs for each two-week window within the flood season and then route those flows to produced 10-year and 100-year regulated flows for each two-week period. However, the unregulated flood hydrographs available are based on analysis of annual maximum winter (i.e. October through March) flows[6] only; more detailed analyses of unregulated flows by month or by two-week window are not available.

In the absence of more detailed information, our assessment of risk is based on a simple analysis of the temporal distribution of annual maximum winter flows within the flood control season. Examination of the reconstructed record of unregulated 1-day winter peak flows for the Skagit River near Concrete shows that 42% of winter floods occur prior to 1 December. The seasonal distribution of unregulated 1-day peak flows is illustrated in Figure 9 and tabulated in Table 3.

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[4] Modifications were made to: 1) simplify the computational procedure used in the spreadsheet for the Upper Baker SGRSs, and 2) add relevant portions of the Ross SGRSs (the spreadsheet originally provided by the Corps did not include the Ross SGRSs).

[5] Note that analyses from the Corps are only available for the "Full Storage" scenario.

[6] More specifically the analysis is based on annual maximum winter (defined as October through March) flows for those years in which the annual maximum flow occurred in the winter. There are four years in the period of record (water years 1931, 1937, 1992, and 1993) in which the annual maximum flow did not occur in the period October through March and which are consequently excluded from analysis. This results in some slight underrepresentation of dry years in the flood frequency analyses.

The one-day maximum winter discharges for the period of record are also plotted against time of occurrence in Figure 10. The record used for this analysis comprises the four historic events (water years 1898, 1910, 1918 and 1922) and the systematic record from water years 1925 through 2007, for a total of 83 events, as obtained from Corps HEC-FFA input files dated February 2008.

Table 3: Distribution of 1-Day Winter Peak Flows

Period	No. of Events in Period	Cumulative Percentage to End of Period
Oct 1-15	3	4
Oct 16-31	14	20
Nov 1-15	9	31
Nov 16-30	9	42
Dec 1-15	14	59
Dec 16-31	7	67
Jan 1-15	8	77
Jan 16-31	9	88
Feb 1-15	4	93
Feb 16-28	3	96
Mar 1-15	2	99
Mar 16-31	1	100
Total	83	

One approach to estimate the impact of the seasonal variation of flood storage on 100-year regulated flow is to simply weight the regulated flows from Table 2 on the basis of the historic frequency of occurrence of annual maximum winter flows within each of the two-week windows used for analysis, as shown in Table 4 below.

Table 4: Weighted Estimates of Regulated Discharges, Skagit River near Concrete

Period	Percentage of Winter Floods Occurring in Period	Regulated Peak Flow from 10-yr Event (cfs)	Weighted 10-yr Discharge (cfs)	Regulated Peak Flow from 100-yr Event (cfs)	Weighted 100-yr Discharge (cfs)
Oct 1-15	4	142,000	5,680	281,000	11,240
Oct 16-31	16	137,000	21,920	276,000	44,160
Nov 1-15	11	125,000	13,750	269,000	29,590
Nov 16-30	11	118,000	12,980	244,000	26,840
After Dec 1	58	118,000	68,440	239,000	138,620
		Sum	**122,770**		**250,450**
	Ratio to Discharge w Full Storage		**1.040**		**1.048**

5.0 Conclusion and Recommendations

Table 4 indicates that consideration of the seasonal variation of flood control storage would increase estimates of the 10-year and 100-year peak flow quantiles for the Skagit River near Concrete by about 4% and 5% respectively.

These estimates are probably slightly high for several reasons:

1) The required flood control storage amounts at Upper Baker are assumed to follow the WCM. This is inconsistent with the FERC license under which PSE operates. The FERC license provides somewhat more storage (up to 8,000 acre ft) in the 1 October – 1 November period than indicated in the WCM manual.

2) The weighting approach used here assumes that the probability of an extreme flood occurring in a particular 2-week window can be determined from the percentage of annual winter peak flows occurring in that window. This approach probably overstates the risk of extreme floods at the start of the flood control season (especially in the 1-15 October period) where dry antecedent moisture conditions have a significant influence on storm runoff. On the other hand, the record of flows on the Skagit only shows 1 event greater than 150,000 cfs occurring after 1 January. Inclusion of smaller post 1 January events in the analysis may have the effect of diluting the percentage of large floods that occur prior to the availability of full flood control storage.

3) The above analysis strictly follows the WCM flood control storage curves. As indicated in Figure 4, the storage available at Ross is often significantly greater than required throughout the flood control season.

The impact of the seasonal variation of flood control storage on flood damage estimates has not been determined.

Our recommendations are as follows:

1) The Baker Project WCM should be updated to show flood control storage requirements per the current FERC license. Future updates to the WCM should be anticipated and coordinated with PSE to reflect operational changes adopted as a result of future implementation of new FERC license conditions.
2) In view of the apparently modest impact that the seasonal variation of flood control storage has on flood quantiles, we recommend that this effect NOT be incorporated directly into the analysis and characterization of existing condition Skagit River hydrology.
3) The hydrology technical documentation should clearly document assumptions regarding the seasonal variation of flood control storage and the approximate impact of those assumptions on flood quantile estimates.
4) Any analyses undertaken of the value of additional storage at the Baker or Skagit Projects should recognize and account for the limitations in the analysis of existing condition hydrology. The analysis presented in this memo indicates that modification of operations to require full flood storage earlier in the flood control season, could reduce weighted average flood quantiles by about 5%.
5) Consideration should be given to including the effects of seasonal variation of flood control storage when describing uncertainty in project performance for flood damage analyses using HEC-FDA.
6) This analysis should be revisited if Climate Change impacts are to be considered for future with or without project conditions.

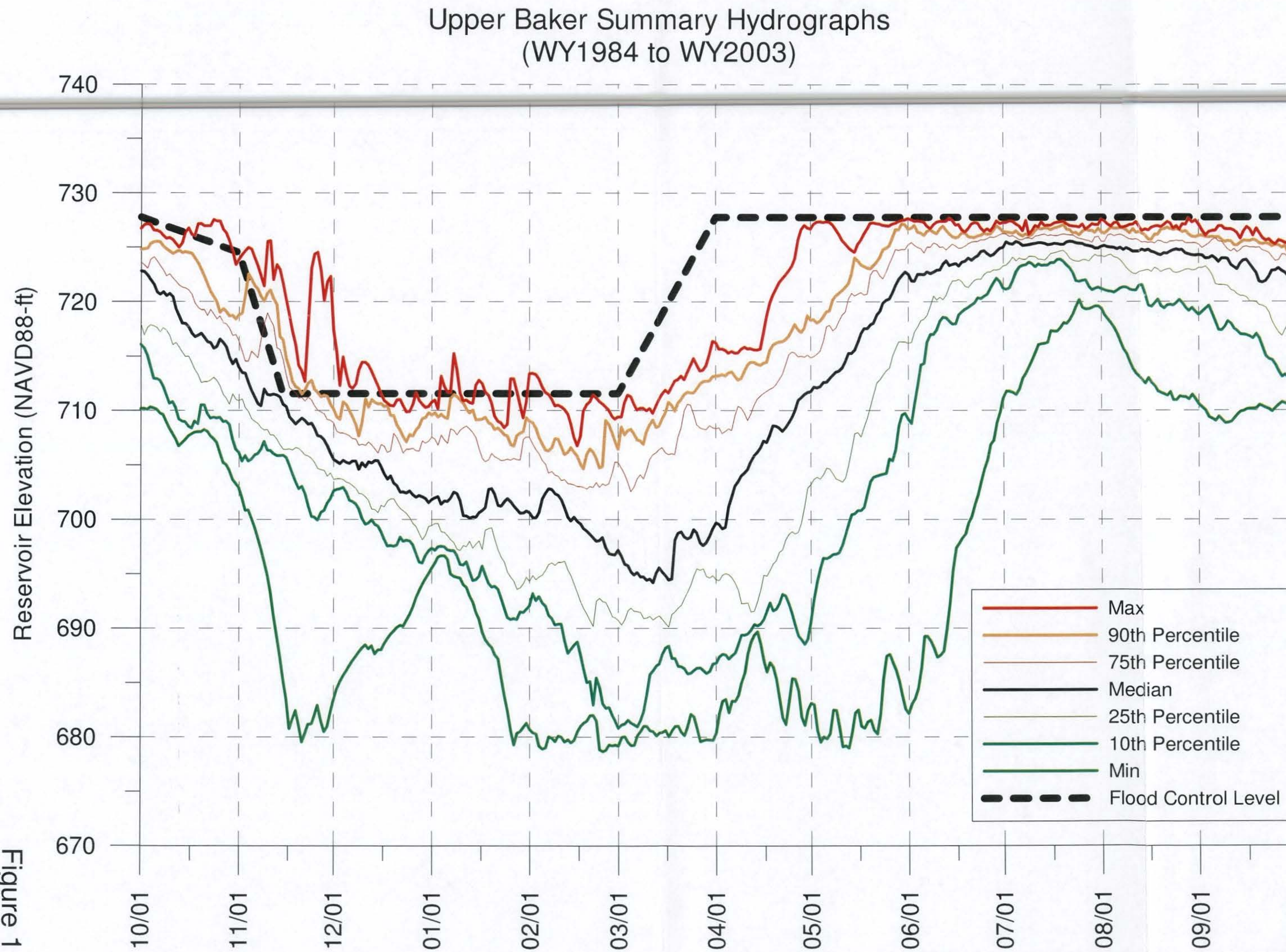
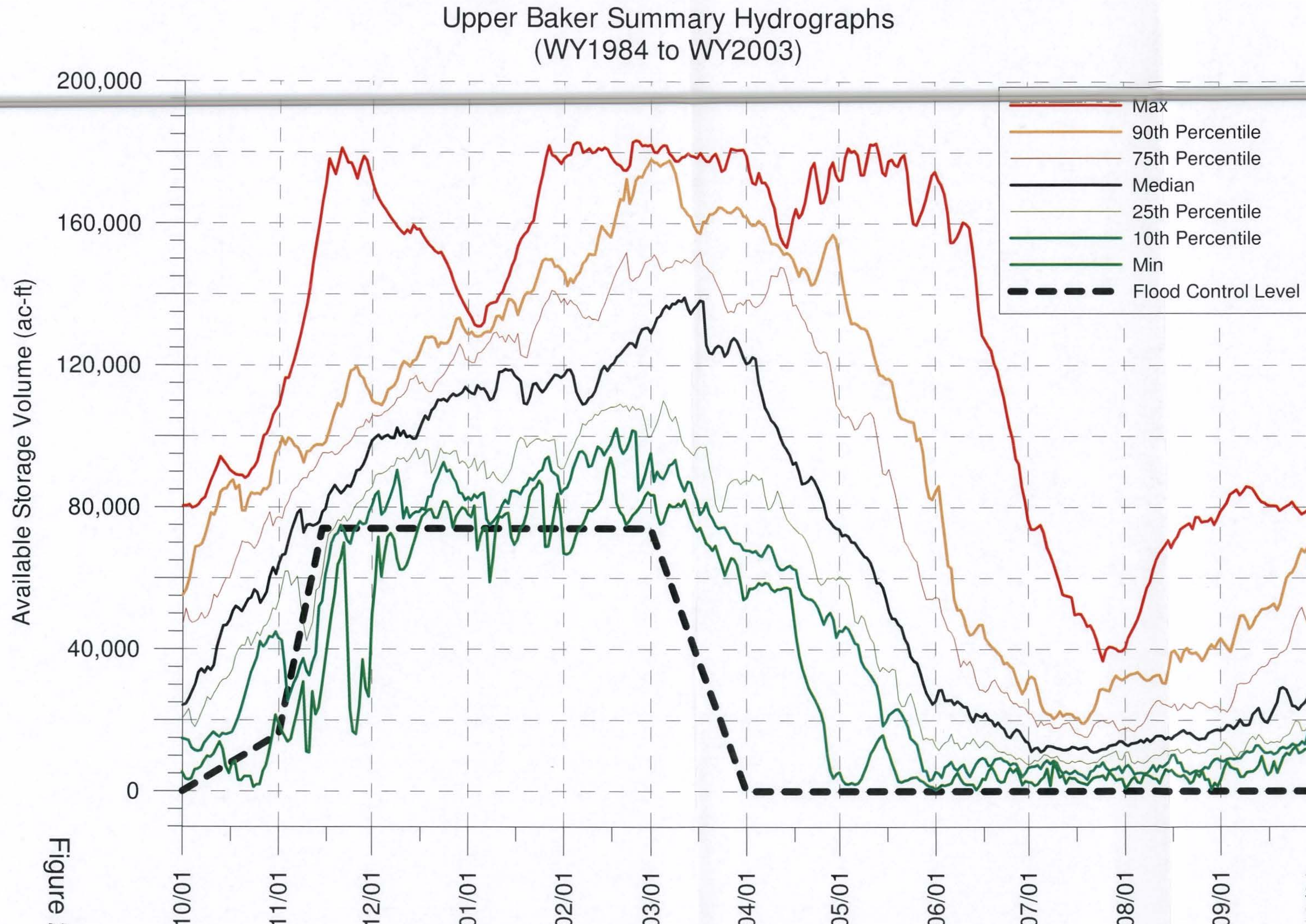

Upper Baker Summary Hydrographs
(WY1984 to WY2003)
Reservoir Elevation (NAVD88-ft)
740
730
720
710
700
690
680
670
10/01
11/01
12/01
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
Max
90th Percentile
75th Percentile
Median
25th Percentile
10th Percentile
Min
Flood Control Level

Figure 1



Upper Baker Summary Hydrographs
(WY1984 to WY2003)
Available Storage Volume (ac-ft)
200,000
160,000
120,000
80,000
40,000
0
10/01
11/01
12/01
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
Max
90th Percentile
75th Percentile
Median
25th Percentile
10th Percentile
Min
Flood Control Level

Figure 2

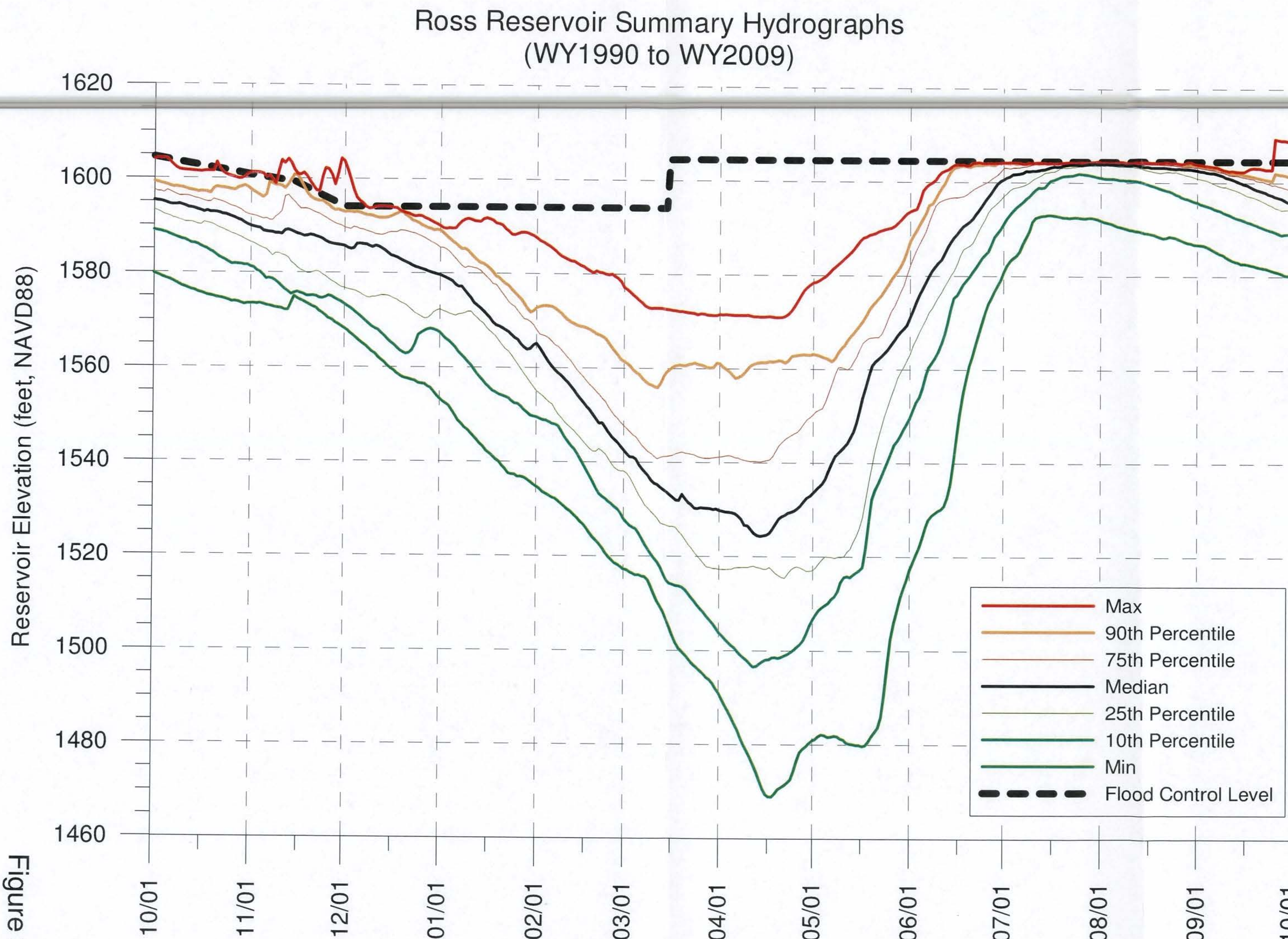
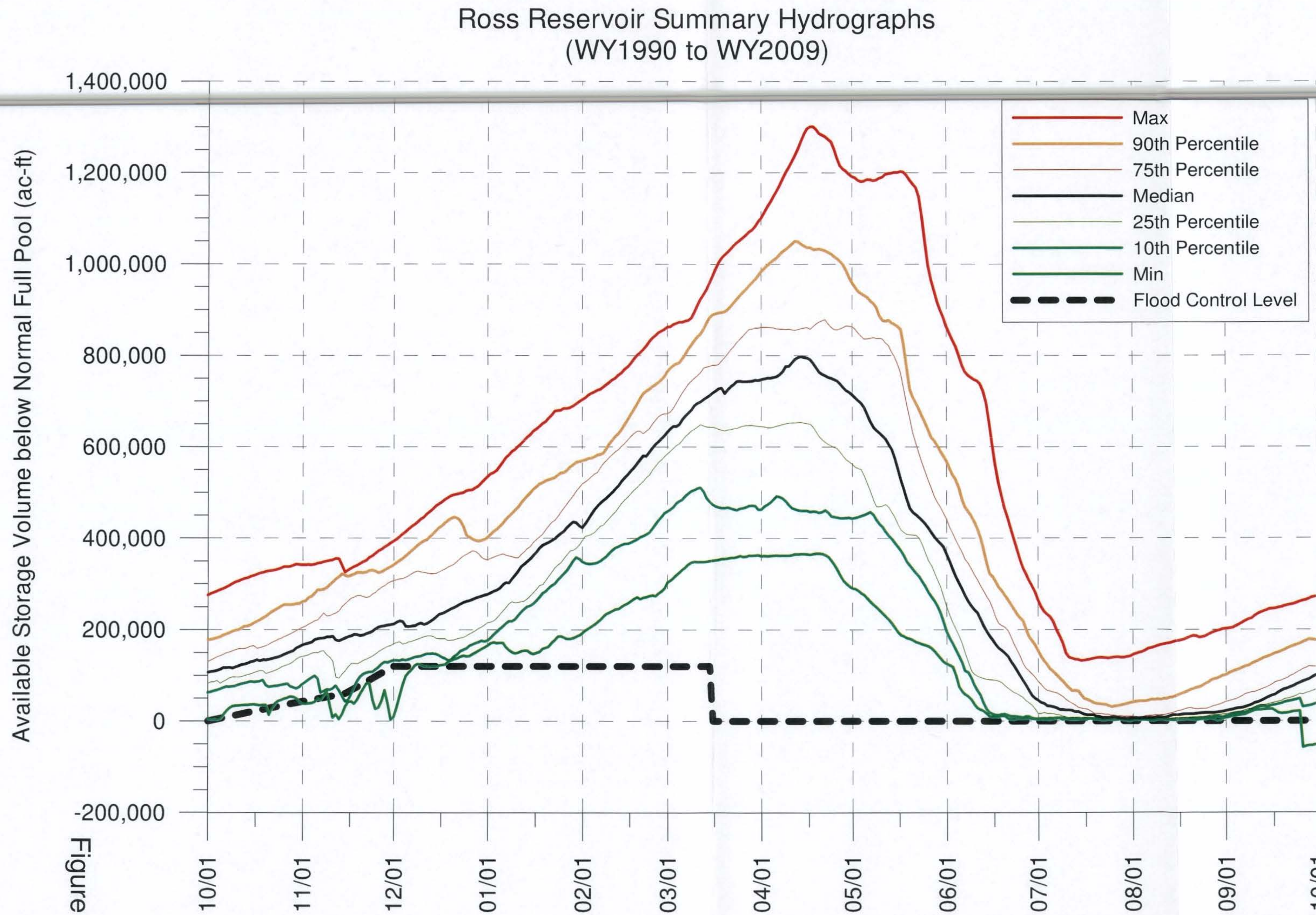
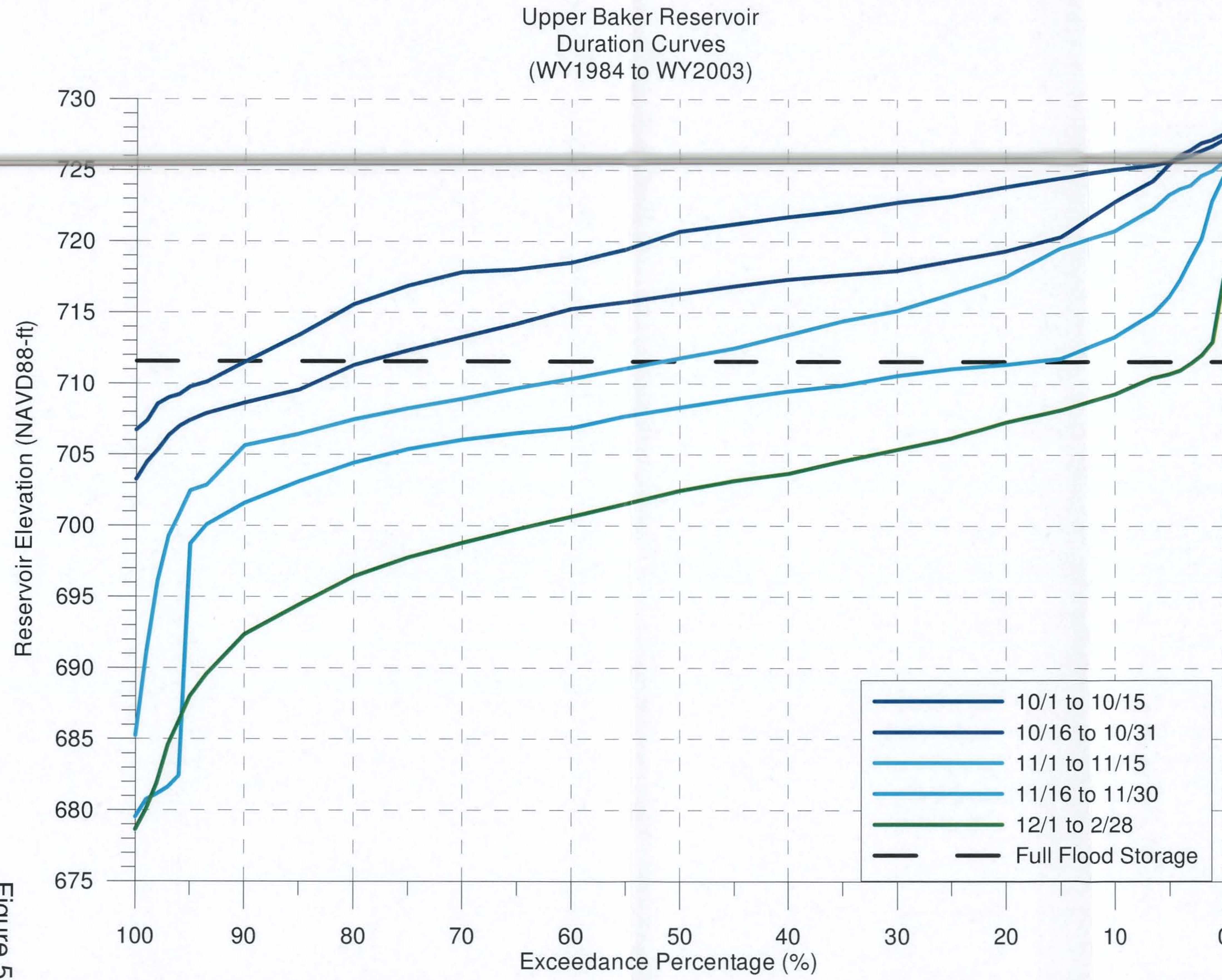

Ross Reservoir Summary Hydrographs
(WY1990 to WY2009)
Reservoir Elevation (feet, NAVD88)
1620
1600
1580
1560
1540
1520
1500
1480
1460
10/01
11/01
12/01
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
Max
90th Percentile
75th Percentile
Median
25th Percentile
10th Percentile
Min
Flood Control Level

Figure 3



Ross Reservoir Summary Hydrographs
(WY1990 to WY2009)
Available Storage Volume below Normal Full Pool (ac-ft)
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
-200,000
10/01
11/01
12/01
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
Max
90th Percentile
75th Percentile
Median
25th Percentile
10th Percentile
Min
Flood Control Level

Figure 4



Upper Baker Reservoir
Duration Curves
(WY1984 to WY2003)
Reservoir Elevation (NAVD88-ft)
730
725
720
715
710
705
700
695
690
685
680
675
100
90
80
70
60
50
40
30
20
10
0
Exceedance Percentage (%)
10/1 to 10/15
10/16 to 10/31
11/1 to 11/15
11/16 to 11/30
12/1 to 2/28
Full Flood Storage

Figure 5

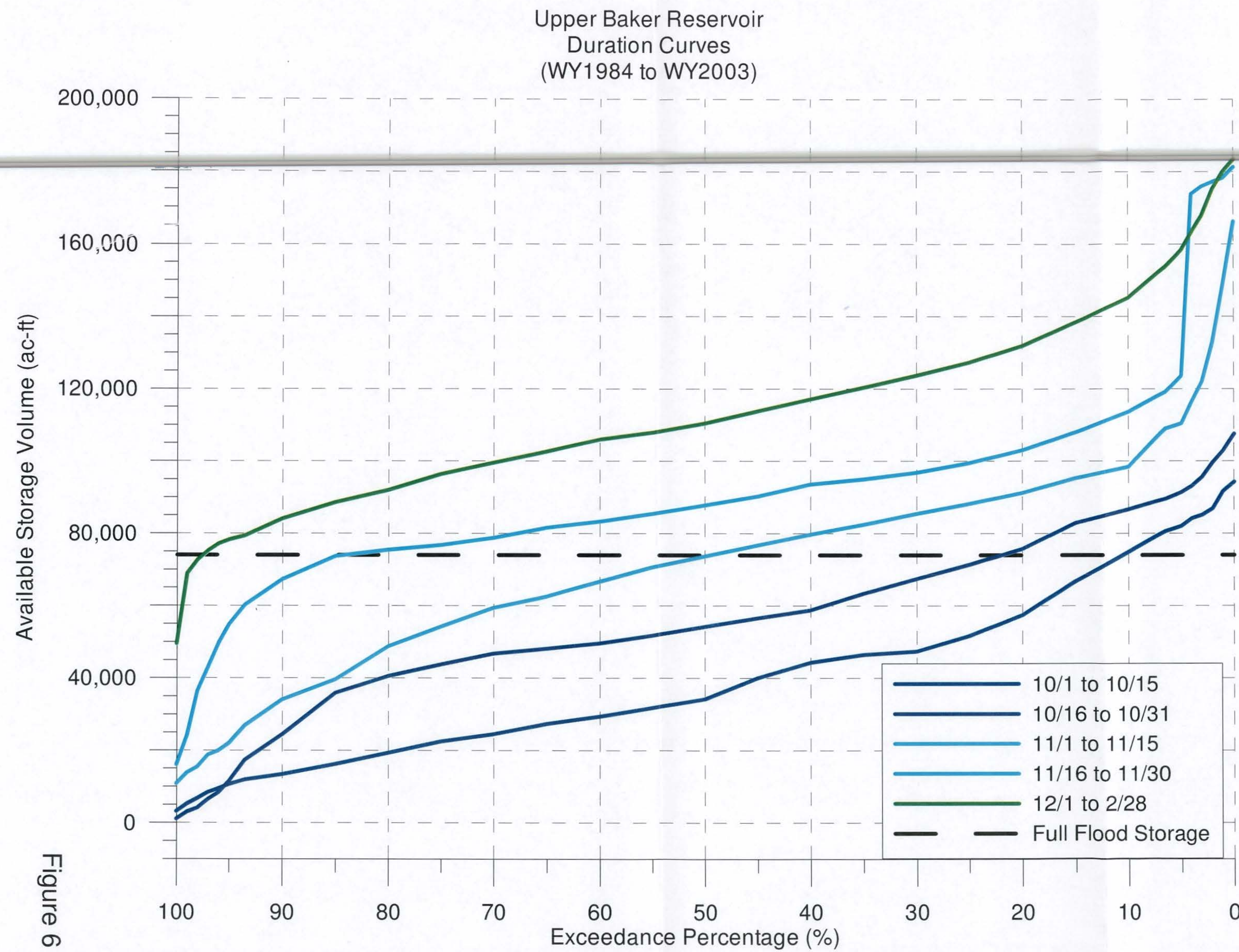

Upper Baker Reservoir
Duration Curves
(WY1984 to WY2003)
Available Storage Volume (ac-ft)
200,000
160,000
120,000
80,000
40,000
0
100
90
80
70
60
50
40
30
20
10
0
Exceedance Percentage (%)
10/1 to 10/15
10/16 to 10/31
11/1 to 11/15
11/16 to 11/30
12/1 to 2/28
Full Flood Storage

Figure 6

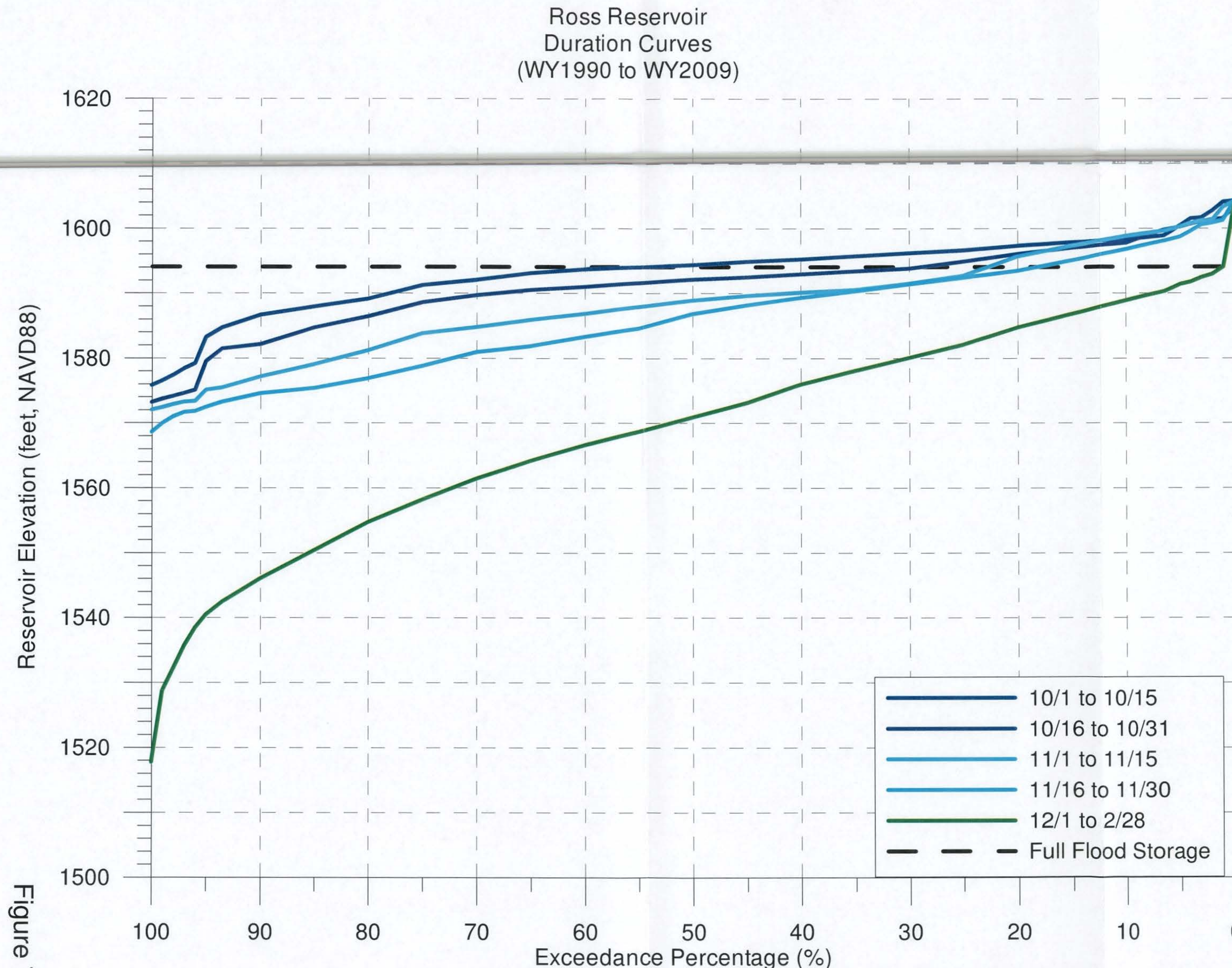
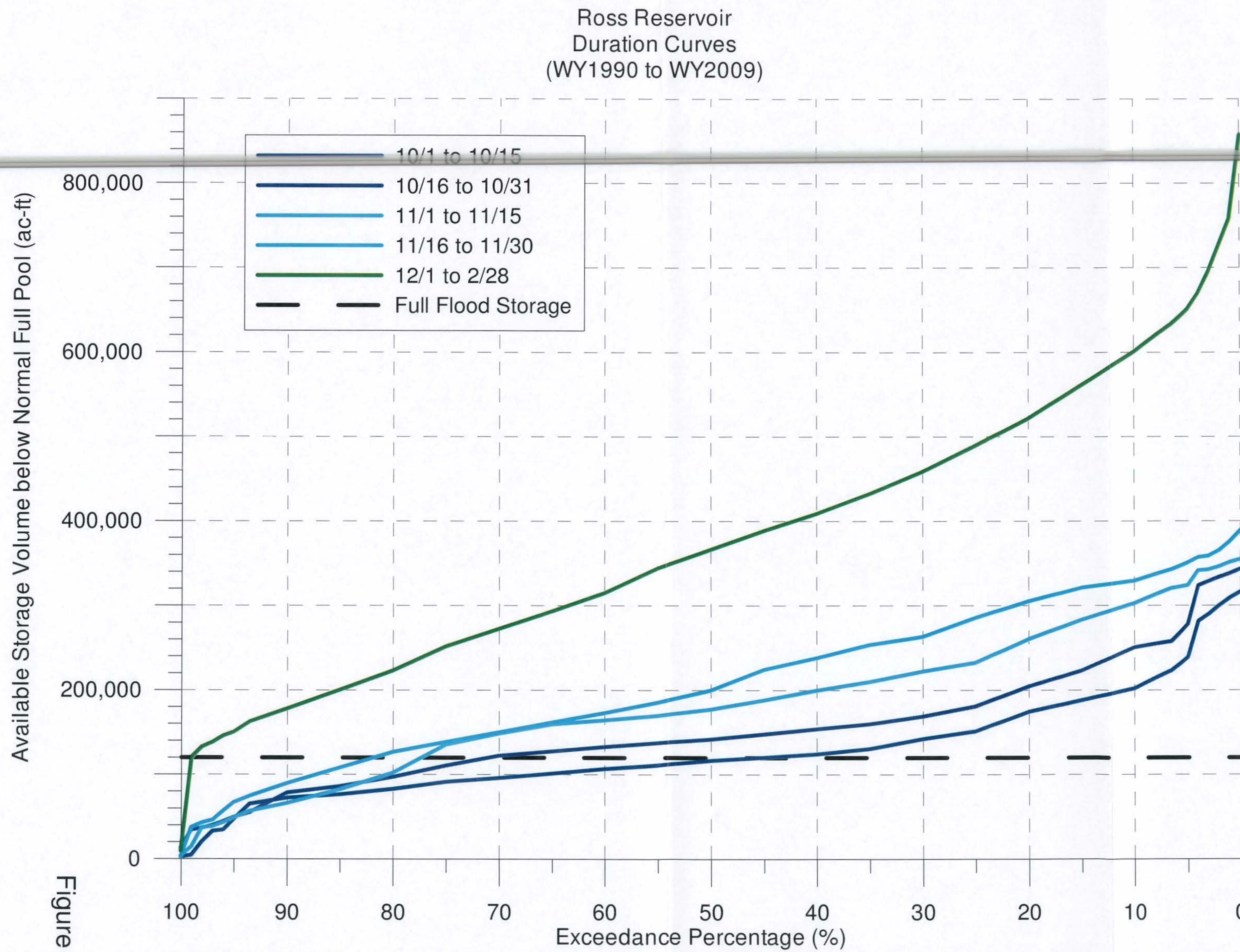

Ross Reservoir
Duration Curves
(WY1990 to WY2009)
Reservoir Elevation (feet, NAVD88)
1620
1600
1580
1560
1540
1520
1500
100
90
80
70
60
50
40
30
20
10
0
Exceedance Percentage (%)
10/1 to 10/15
10/16 to 10/31
11/1 to 11/15
11/16 to 11/30
12/1 to 2/28
Full Flood Storage

Figure 7



Ross Reservoir
Duration Curves
(WY1990 to WY2009)
10/1 to 10/15
10/16 to 10/31
11/1 to 11/15
11/16 to 11/30
12/1 to 2/28
Full Flood Storage
Available Storage Volume below Normal Full Pool (ac-ft)
800,000
600,000
400,000
200,000
0
100
90
80
70
60
50
40
30
20
10
0
Exceedance Percentage (%)

Figure 8

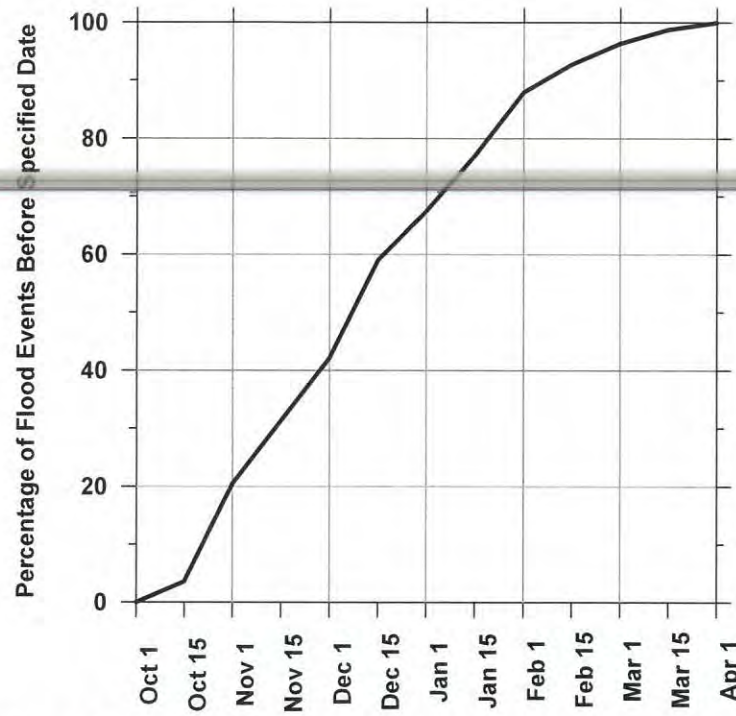


Figure 9: Cumulative seasonal distribution of winter floods.

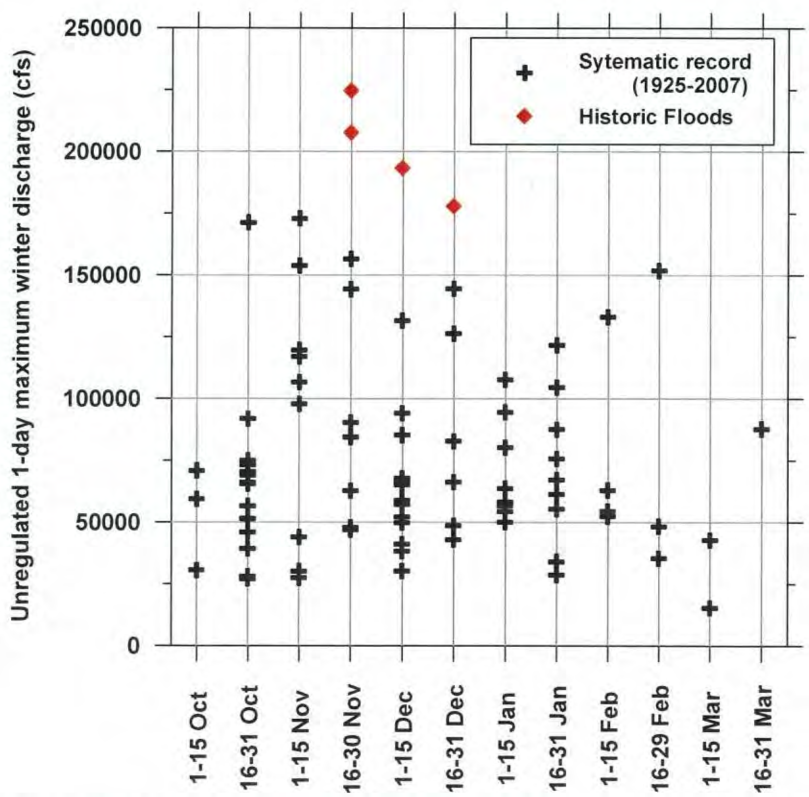


Figure 10: Magnitude and seasonal distribution of winter floods.