PCWA-L-213

Placer County Water Agency

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July 14, 2005

Mr. Takeshi Yamashita, Regional Engineer
FEDERAL ENERGY REGULATORY COMMISSION
901 Market Street, Suite 350
San Francisco, CA 94103-1778

Attention: Mr. John Onderdonk

RE: FERC Project No. 2079 - CA
Middle Fork American River Project
LL Anderson Dam PMF Study Supplement

Dear Mr. Yamashita:

In response to your March 31, 2005 letter, our consultant Mead & Hunt has reevaluated their June 2003 L.L. Anderson (French Meadows) PMF Study based on the comments provided by FERC in the letter. The enclosed study is entitled "Supplement to the June 2003 Probable Maximum Flood Study, L.L Anderson Dam", and is dated July 2005. Three copies are provided. Your letter of May 24, 2005 granted us a time extension to July 15, 2005 to complete this study.

In the enclosed study, Mead & Hunt addresses the first four items in your March 31, 2005 letter. The fifth item relates to our semi-annual progress reports, which we have agreed to provide. The most recent progress report was submitted to FERC on June 22, 2005.

As a result of performing analyses requested in the first item in your March 31, 2005 letter, Mead & Hunt has recommended that the PMF inflow for French Meadows Reservoir be increased from 52,800 cfs to 59,100 cfs. Mead & Hunt considers the US Army Corps of Engineer's (COE) Energy-Budget method as an appropriate alternative to the Degree-Day method originally used in the Mead & Hunt 2003 study. The analyses performed by Mead & Hunt use the Energy-Budget method including HMR No.58, with the exception that, for the Mead & Hunt recommended PMF, local wind speed data from the Hell Hole area is used, rather than the more generalized wind speed criteria given in HMR No. 58, which Mead & Hunt considers excessive for the French Meadows basin. The revised Mead & Hunt PMF does not use the Bureau of Reclamation's Snow-Water Budget method, which Mead & Hunt considers to have unnecessary additional conservatism for this study. The Probable Maximum Storm is now considered to occur in March, due to the increased snowmelt contribution of the Energy-Budget method.

The second item in your March 31, 2005 letter addressed temporal rainfall distribution. Mead & Hunt performed a sensitivity analysis that showed that shifting the peak precipitation to later in

FEDERAL ENERGY REGULATORY COMMISSION
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SAN FRANCISCO, CALIFORNIA

the storm event had an insignificant effect on the PMF inflow, but did result in somewhat higher peak reservoir storage, so the shift to a later peak was adopted.

The third item in your March 31, 2005 letter discussed spillway submergence, which will be considered in the final design of the PMF modifications to the spillway, including physical model testing currently planned by the COE.

The fourth item in the letter, recalculation of the spillway outflow rating curve, is not considered necessary by Mead & Hunt, since there is no evidence that submergence affecting the ogee discharge occurred during the 1997 storm. Further, hydraulic analysis by both Mead & Hunt and our independent Part 12 consultant indicates that it is very unlikely that submergence effects could have affected the 1997 spillway discharge.

It is PCWA's objective to maintain a safe facility that will withstand the effects of extreme flood events, while making efficient use of the project's resources. To that end, PCWA feels that the approach reflected in the Mead & Hunt Supplement strikes an appropriate balance, utilizing conservative assumptions where necessary, and empirical/historical data where appropriate.

Please call me at (530) 885-6917, if you have any questions.

Sincerely,

PLACER COUNTY WATER AGENCY

Stephen J. Jones
Power System Manager

Enclosure

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PCWA-L-213

Final Report

Supplement to the June 2003 Probable Maximum Flood Study L.L. Anderson Dam

FERC Project No. 2079

Prepared for:

pcwa
Placer County Water Agency

Prepared by:

MEAD & HUNT

July 2005

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Exhibits

Executive Summary

This report documents supplemental analyses made at the request of Federal Energy Regulatory Commission (FERC) reviewers of Mead & Hunt's June 2003 *Probable Maximum Flood Study for the L.L. Anderson Dam.* In reviewing the 2003 report, FERC staff questioned three general aspects of the study: the timing of the probable maximum precipitation (PMP); the methodology and assumptions used to compute snowmelt concurrent with the PMP; and the calculation of flow through the spillway gates and channel downstream of the gates. To respond to these issues, Mead & Hunt reviewed the spillway rating curve calculations and revised the watershed model with respect to the time distribution of precipitation and snowmelt.

The new analyses showed that the probable maximum flood (PMF) inflow peak is insensitive to the timing of the peak precipitation, but the peak stage and outflow at the dam do increase as the maximum precipitation increments are shifted later in the storm. The computed snowmelt contribution to the flood is quite sensitive to the method and assumptions used. The largest snowmelt flood is computed using a U.S. Bureau of Reclamation (USBR) methodology, assuming that the snowpack is saturated with meltwater before the probable maximum storm (PMS) begins and releases the free water along with the melt. A less extreme estimate uses the energy budget equations presented in the U.S. Army Corps of Engineers' manuals. This method, when used with a wind pattern based on maximum observed winds at a Forest Service station near L.L. Anderson Dam, yields a PMF inflow peak of 59,100 cubic feet per second (cfs), which is 12 percent more than the 2003 estimate, almost three times the flood of record, and almost four times the peak flow of January 1997. Given the rarity and severity of all assumed concurrent hydrometeorological conditions, this hydrograph should be adopted as the PMF inflow hydrograph.

Supplement to the June 2003
Probable Maximum Flood
L.L. Anderson Dam
FERC Project No. 2079

1. Background for the Study

In June 2003, the Placer County Water Agency submitted the report titled *Probable Maximum Flood Study, L.L. Anderson Dam* to the Federal Energy Regulatory Commission (FERC) and the California Division of Dam Safety. The report, prepared by Mead & Hunt, Inc., concluded that the all-season Probable Maximum Flood (PMF) at the project would have a peak inflow of 52,800 cubic feet per second (cfs) and a peak outflow of 37,500 cfs, and would overtop the dam. In comparison, the flood of record at the dam site (which occurred in 1963, a year before the dam was completed) peaked at 21,500 cfs. Mead & Hunt's PMF was substantially larger than the previous (1988) estimate of the PMF, which had an inflow of 34,500 cfs.

One motivation for reanalyzing the PMF in 2003 was the completion in 2001 by the U.S. Army Corps of Engineers (USACE) of a PMF study for Folsom Dam, which is downstream of the Placer County Water Agency's hydroelectric projects. The USACE study suggested that the PMF would overtop and possibly cause a failure of the L.L. Anderson Dam. In 2004, the USACE refined its estimate of the PMF specifically for the L.L. Anderson Dam, concluding that the peak PMF inflow would be 67,100 cfs. Differences between Mead & Hunt's approach and results and those of the USACE were cited in the FERC's letter to the Placer County Water Agency (PCWA) requesting a revised analysis.

Both studies conclude that there is a need for additional spillway capacity, and various alternatives have been evaluated by both the PCWA and the USACE. These design studies, if implemented, would change the storage-outflow relationship for the dam. Therefore, this report focuses on the PMF inflow hydrograph. The outflow hydrograph will follow from this inflow hydrograph and the selected design solution.

The issues raised by the FERC reviewers and addressed in the following paragraphs are as follows:

- The calculation of the gated spillway capacity, in particular whether a correction for submergence in the downstream channel is necessary. The FERC posed this question in relation to both the computed PMF outflows and the use of back-routing to compute inflows for the January 1997 calibration event.

- The time distribution of the probable maximum precipitation (PMP). In Mead & Hunt's study, the peak precipitation occurred slightly ahead of the midpoint of the storm. The FERC suggested that a delayed peak rainfall might produce a more critical runoff sequence.

- The methodology used to compute snowmelt. Mead & Hunt's choice of a simple temperature index in 2003 was based on the lack of data (especially wind data) for testing more complex energy-budget methods, and because the method performed well in the watershed model calibration to the flood of January 1997. The degree-day method produced a moderate snowmelt contribution, about 2.6 inches of runoff above the rain-induced runoff. Energy budget methods, used with extreme wind speeds and precipitation rates, have the potential to produce substantially more melt than a degree-day method. The FERC's letter indicated that the PMF should be computed using the same methodology used in the USACE calculation of the PMF. The USACE calculation, in addition to computing melt by an energy budget equation, assumed that during the storm, both the newly melted snow and the maximum possible amount of stored free water were released. These assumptions produce a larger snowmelt flood than either the degree-day method or the application of the energy-budget method contained in the HEC-1 watershed model.

The HEC-1 watershed model used for the 2003 study was used with modifications as needed, to make the calculations discussed in this report. The electronic HEC-1 model input file and supporting spreadsheet calculations accompany this report (Appendix A).

2. Seasonality of the Probable Maximum Flood

The 2003 study concluded that a PMF occurring in November would be the worst-case event. However, the PMFs computed for February and March were almost equally large (52,400 and 52,500 cfs, respectively, compared to 52,800 cfs in November). All months from November to March are considered capable of producing the all-season PMP. Because of the increased importance of snowmelt and a saturated, late-season type of snowpack in the USBR melt methodology used by the USACE, the probable maximum storm (PMS) was assumed to occur in March for the analyses described in this report. Furthermore, even when using a straight HEC-1 energy budget method, the March wind speeds specified in Hydrometeorological Report No. 58 (HMR 58) are significantly higher than those in November. Mid-winter (December to February) PMF calculations would be expected to be very similar to those reported here for March, reflecting slightly lower temperatures and slightly higher wind speeds.

3. Submergence of the Gated Spillway

At a reservoir level of 5270 feet (approximately the highest level at which weir flow persists in the gated spillway) Mead & Hunt computed an outflow of 19,600 cfs, whereas the USACE computed an outflow of about 15,500 cfs, citing a correction for tailwater submergence in the downstream channel. The FERC's review letter stated that the HEC-RAS model used by Mead & Hunt should be revised to begin upstream of the gate, run through the gate using the ogee crest routine, and end in the downstream channel, thus providing the appropriate submergence correction. Furthermore, the FERC asked that the routing of the 1997 calibration flood be revised to reflect the reduced spillway outflow.

We chose not to use HEC-RAS to model flow through the gate, because the model is primarily designed to compute water surface profiles on a much larger scale than the immediate spillway area. Spillway rating curve details such as variations from design head, pier contractions, and weir-orifice transitions can be handled more accurately in a separate calculation, as was provided in Mead & Hunt's 2003 report. In that study, the HEC-RAS model was used for the downstream channel to confirm that supercritical conditions persisted throughout the spillway channel and to identify the depth of flow at the toe of the spillway ogee. With respect to the FERC's concerns about submergence of the spillway, we consulted two references. The first was the USBR and USACE submergence charts presented in Chow's "Open Channel Hydraulics" textbook. These charts (used with the tailwater depths predicted by the HEC-RAS model) indicated that when flow in the downstream channel reaches 20,000 cfs, a submergence correction of 6 to 8 percent may be appropriate. We also consulted the equations for weir submergence used in the National Weather Service DAMBRK and FLDWAV models. In these equations, submergence does not begin until the height of the tailwater is approximately two-thirds the height of the headwater, with both being measured in height above the weir crest. This condition does not apply to the L.L. Anderson spillway when the headwater is at 5270 feet, the tailwater at 5247 feet, and the weir crest at 5244.5 feet.

Our reviews suggest that if a tailwater submergence correction applies at all, it is only at the highest spillway flows and is only a fraction of that used by the USACE. While the two references we consulted show that there is no single calculation method, a submergence correction certainly would not apply for the peak outflow of about 4,100 cfs observed in the 1997 calibration flood. The spillway rating curve also has no bearing on the determination of the PMF inflow hydrograph, and will change depending on the adopted design for increasing capacity. Therefore, we recommend that this issue be resolved, if necessary, as part of the spillway design.

4. Probable Maximum Precipitation Time Distribution

In the 2003 study, the maximum 6-hour increment of the PMS was assumed to occur during the fifth of 12, 6-hour periods. The HEC-1 model's sensitivity to this assumption was tested by shifting the peak precipitation to the seventh 6-hour period, with the maximum rainfall occurring in hour 40. Other increments of rainfall were arranged in decreasing order around this peak, preserving the depth-duration relationships developed from HMR 58. The sensitivity test was conducted using the HEC-1 model from the 2003 study. Although the shift in timing had an insignificant effect on the peak inflow (52,438 and 52,432 cfs for the earlier and later peaking storms, respectively), it did result in an increased peak reservoir stage and outflow because the peak inflow arrived when the reservoir was already relatively full. The peak stage and outflow were 5275.4 feet and 36,600 cfs, respectively, for the earlier-peaking storm and 5275.6 feet and 38,800 cfs, respectively, for the later-peaking storm. Based on these results, the later-peaking pattern was used for subsequent snowmelt analyses.

5. Snowmelt

Snowmelt during the PMS was computed using various methods and assumptions in order to assess the sensitivity of the computed snowmelt, and the PMF as a whole, to these procedures. In addition to the degree-day method, in which the only change since the 2003 study was the shift in precipitation timing, two other approaches were assessed. The first was the energy budget equations as described in the USACE “Runoff from Snowmelt” manual (EM 110-2-1406, published in 1960). This methodology may be used directly in the HEC-1 model. The second approach was the USBR methodology reported in the USACE *L.L. Anderson Dam Study*, in which the same energy budget equations are used, along with a procedure for computing the release of stored free water as the snowpack melts. The USBR methodology is described in the 1966 USBR Engineering Monograph No. 35, “Effect of Snow Compaction on Runoff from Rain on Snow.” The calculations for the USBR methodology were made in a Microsoft Excel spreadsheet outside of the HEC-1 model, and the computed “drainage” from the snowpack in each elevation interval was area-averaged and returned to the HEC-1 model as precipitation.

The effect of wind on the energy budget snowmelt calculation is significant during the PMF, but is difficult to test or calibrate. The USACE reports that for the L.L. Anderson study, wind speeds for calibration were adopted from records at Blue Canyon in 1986, and ranged from 5 to 26 miles per hour. (In contrast, HMR 58 specifies surface wind speeds during the PMS of more than 60 miles per hour.) Even less wind data was available for the 1997 storm.

The energy budget equation in the HEC-1 model contains an embedded assumption about the coefficient representing the basin’s exposure to wind. The model documentation states that this coefficient is appropriate to partially forested areas, but the degree to which the forest cover, orientation, and topography of the L.L. Anderson Dam basin affect the wind coefficient cannot readily be assessed. Therefore, methods using the energy budget equations cannot really be calibrated. To test the sensitivity of the computed PMF to the assumed wind speed, the HEC-1 energy budget simulations were made using a zero wind speed, the HMR 58 wind speeds, and wind speeds derived from a U.S. Forest Service wind recorder near Hell Hole Dam, about 5 miles south of L.L. Anderson Dam at an elevation of 5240 feet.

The Hell Hole hourly wind speed records extend from 1995 to the present, but the first 2 years contain many missing data (including the first one-third of the 1997 storm). This data set was reviewed to provide a basis for comparing observed winds in the basin area to the design winds provided in HMR 58. The most critical 3-day wind sequence in the record occurred in November 2002, and was associated with intermittent rainfall totaling about 1 inch. The winds associated with the last two-thirds of the 1997 storm were around 10 miles per hour.

An envelope wind speed sequence was then constructed around the November 2002 wind data (Exhibit 1). This envelope sequence, including a 24-hour period of 40-mph wind speeds, was entered into the HEC-1 model. The Hell Hole winds were not adjusted further for basin elevation, as the wind recorder is situated on an exposed ridge that would experience exceptionally high winds relative to the basin as a whole.

In the 2003 analysis, a 100-year snowpack was assumed to be in place at the beginning of the PMS. This assumption proved to be irrelevant, as the maximum potential melt is much lower than the 100-year snowpack. In the present study, snowpack water equivalents similar to those adopted by the USACE (and based on the 1997 flood) were used. In only one case – the USBR methodology – was the snow in the lowest elevation band completely melted by the end of the storm. All of the analyses adopted the March temperature sequence provided by HMR 58, in which the base-level temperature is 47.5 degrees in the peak 6 hours of the PMP. The lapse rate, or decrease in temperature per 1,000-foot elevation rise above the base level, was 2.8 degrees in all cases.

Table 1 summarizes the snowmelt analyses. All HEC-1 model input and the spreadsheets used to compute wind, temperature, and USBR snowpack drainage are submitted electronically with this report. The HEC-1 energy budget was run three times to test model sensitivity to wind speed.

The USBR analyses were performed twice to test the sensitivity to the assumed density of the snowpack at the outset of the storm. In the first case, a snowpack density of 40 percent (the “threshold” density, similar to that assumed by the USACE) was assumed. The 40 percent was the net density produced by water equivalent in snow and free water stored in the snowpack. In this case, drainage begins immediately. In the second USBR analysis, a dry snow density of 20 percent was assumed with no free stored water. The second case actually resulted in a higher peak inflow (due to the delay of melt until precipitation runoff was also peaking) but a significantly smaller volume than the first case.

The PMF inflow hydrographs associated with the entries in Table 1 are shown in Exhibit 2. Also shown is an estimate, based on the recorded peak flow and daily average flows, of the flood of record. The flood of record occurred in December 1963, before the dam was completed, and peaked at 21,500 cfs. The estimated peak inflow in the 1997 flood, 16,000 cfs, is also shown for comparison.

Table 1
Comparison of Snowmelt Calculations

Methodology	Snowmelt Process Assumptions	Wind Speed Assumptions	Peak Inflow to French Meadows Reservoir (cfs)	Maximum 72-hour Runoff Volume (acre feet)
No snowmelt	None – base case	–	51,400	110,000
Degree-day melt	Rate of snowmelt is proportional to air temperature	None	52,500	113,500

Table 1
Comparison of Snowmelt Calculations

Methodology	Snowmelt Process Assumptions	Wind Speed Assumptions	Peak Inflow to French Meadows Reservoir (cfs)	Maximum 72-hour Runoff Volume (acre feet)
Energy budget	Rate of snowmelt is a function of air temperature, precipitation rate, wind speed	No wind	55,700	117,500
		Wind speeds up to 40 mph, based on maximum recorded wind speeds at Hell Hole weather station	59,100	127,600
		Wind distributed as directed in HMR 58; maximum 1-hour surface wind speed = 65 mph	60,700	133,100
USBR (Energy budget with snow compaction and free water drainage)	Rate of snowmelt is a function of air temperature, precipitation rate, wind speed, but melt also releases free water held in a previously saturated snowpack	Wind distributed as directed in HMR 58; maximum 1-hour surface wind speed = 65 mph	66,800	147,500
	Snowpack is at 20-percent density, not saturated, before storm begins		72,700	139,300

6. Interpretation of Model Results

The analyses summarized in Table 1 indicate that a range of PMF hydrograph volumes and shapes are possible, depending on the assumptions made about concurrent hydrometeorological conditions and the methodology used to track those conditions. A change to energy-budget based snowmelt calculations accounts, at a minimum, for the additional heat added to the snowpack due to intense precipitation, and we concur that this is a reasonable modification to the procedure – although none of the energy-budget snowmelt methods are really testable for this watershed. Beyond that, the question remains as to the appropriate assumptions about wind speed, wind exposure, and snowpack. The questions in identifying the appropriate PMF hydrograph are not which method is technically correct; it is how severe a set of concurrent hydrometeorological conditions is "reasonably possible," and how much faith should be put in an uncalibratable model. For example, the USBR approach combines a set of conditions so extreme that the computed snowmelt component alone is more than the total estimated inflow during the flood of January 1997.

As a result of these analyses, we recommend that the adopted PMF hydrograph be the one generated from the HEC-1 energy budget snowmelt method, using the maximum Hell Hole wind speed envelope. This hydrograph, which peaks at 59,100 cfs, reflects extremely severe precipitation and temperatures. The wind sequence is also a very rare one and would be extremely unlikely to occur simultaneously with the PMS. It is not, however, as extraordinary as the sequence provided by HMR 58, which includes a 1-hour wind that is one-and-a-half-times larger than the maximum observed at the Hell Hole station. Our recommended set of assumptions also does not include the additional conservatism of a "primed" snowpack. The hourly ordinates of the PMF inflow hydrograph are attached as Exhibit 3.

The PMF of 59,100 cfs represents an extremely unlikely combination of events. HMR 59 indicates that the PMP alone is approximately two times the 100-year storm. The probability of such an event is extremely small. In addition, the development of the PMF peaking at 59,100 cfs requires that the storm:

- Is centered exactly on the basin in question.
- Falls on a deep snowpack.
- Occurs in conjunction with exceptionally high temperatures.
- Includes near-record wind speeds occurring simultaneously with the PMP.

The peak inflow associated with the PMF as presented here is almost three times the historic peak inflow, and the 72-hour PMF volume is 3.4 times the 72-hour volume associated with the flood of record. In our opinion, more conservative design assumptions than these would increase the estimated PMF but would not, in practice, lead to a significant reduction in the risk of dam overtopping.

Exhibit 1. Wind Pattern Based on Hell Hole Wind Records

Exhibit 1: PMF wind pattern based on maximum recorded Hell Hole sequence

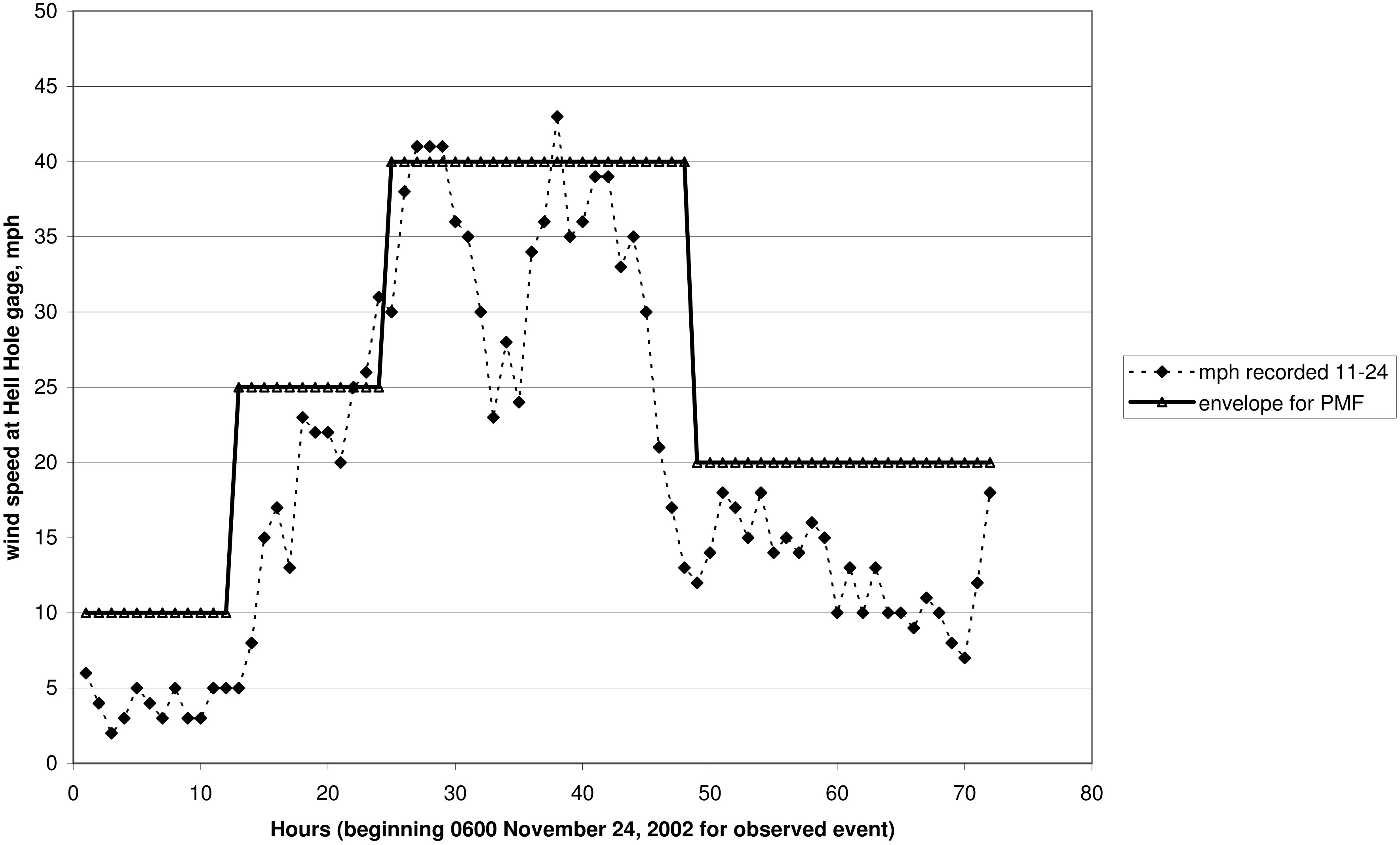

Exhibit 2. Simulated Flood Hydrographs

Exhibit 2: Flood hydrographs

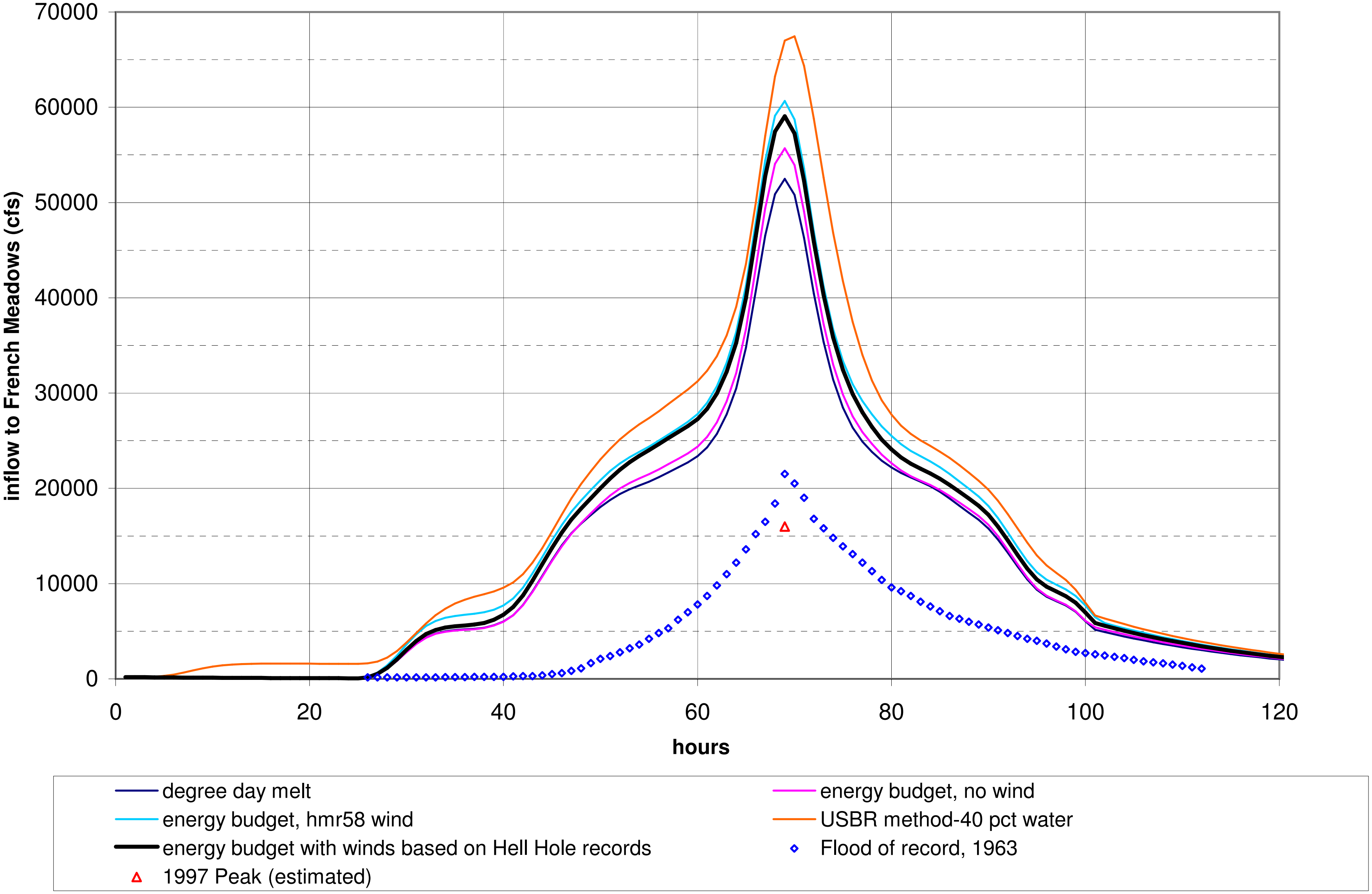

Exhibit 3. PMF Hydrograph Ordinates

Exhibit 3
PMF Hydrograph Ordinates

Hour	Inflow (cfs)		Hour	Inflow (cfs)		Hour	Inflow (cfs)
1	192		49	18948		97	9166
2	183		50	20014		98	8690
3	174		51	21039		99	7984
4	166		52	21961		100	6964
5	158		53	22738		101	5854
6	150		54	23401		102	5575
7	143		55	24017		103	5310
8	136		56	24644		104	5057
9	130		57	25276		105	4816
10	124		58	25891		106	4587
11	118		59	26520		107	4368
12	112		60	27279		108	4160
13	107		61	28346		109	3962
14	102		62	29945		110	3774
15	97		63	32248		111	3594
16	92		64	35270		112	3423
17	88		65	39979		113	3260
18	84		66	46430		114	3105
19	80		67	52783		115	2957
20	76		68	57452		116	2816
21	72		**69**	**59067**		117	2682
22	69		70	57252		118	2554
23	66		71	52286		119	2432
24	63		72	45890		120	2317
25	60		73	40276		121	2206
26	164		74	35851		122	2101
27	521		75	32459		123	2001
28	1166		76	29902		124	1906

Exhibit 3
PMF Hydrograph Ordinates

Hour	Inflow (cfs)		Hour	Inflow (cfs)		Hour	Inflow (cfs)
29	2052		77	27970		125	1815
30	3045		78	26454		126	1729
31	3981		79	25111		127	1646
32	4696		80	24093		128	1568
33	5134		81	23245		129	1493
34	5383		82	22588		130	1422
35	5525		83	22070		131	1354
36	5612		84	21572		132	1290
37	5694		85	21013		133	1229
38	5861		86	20361		134	1170
39	6201		87	19643		135	1114
40	6727		88	18931		136	1061
41	7551		89	18172		137	1011
42	8769		90	17218		138	963
43	10310		91	15999		139	917
44	12032		92	14548		140	873
45	13765		93	13013		141	832
46	15363		94	11576		142	792
47	16726		95	10437		143	754
48	17874		96	9668		144	718