Technical Memorandum

Analysis of Flood Control Storage at Baker River Project

Introduction

This Technical Memorandum presents an analysis that evaluates the flood storage opportunities at the Baker River Project and quantifies potential flood reduction benefits that could be realized on the lower Skagit River floodplain if additional flood control storages at Baker Lake and Lake Shannon were made available.

The Baker River Project (FERC project number 2150) is owned and operated by Puget Sound Energy (PSE) and is currently involved in a FERC relicensing proceeding. This provides an important opportunity for downstream floodplain communities to seek an optimum use of the storages at both reservoirs to benefit Skagit River flood reduction. Skagit County (County) has requested that PSE conduct an analysis of their storage operation for downstream flood reduction and environmental impacts as part of their re-licensing efforts.

Background

The annual average flow recorded at the Baker River gage is 17 percent of the flow recorded at the Skagit River gage near Concrete. This represents a runoff contribution that is proportionately higher than all the other subbasins of the Skagit River. The average annual precipitation in the Baker River basin ranges from about 70 inches at Concrete to greater than 150 inches at higher elevations. The average annual precipitation is approximately 120 inches from the Baker River basin and only 75 inches from the Skagit River basin above the Concrete gage. Between Concrete and Mount Vernon, the Skagit River drainage area increases by 356 square miles with the average annual runoff from this intermediate drainage area at approximately 50 inches.

Baker Lake, above the Upper Baker Dam [at river mile (RM) 9.35], is about 9 miles long and covers a surface area of about 4,800 acres at normal full pool (El. 724.0, NGVD-29 datum used throughout this memorandum). Roughly 285,000 acre-feet of water are stored in Baker Lake at normal full pool. Lake Shannon above the Lower Baker Dam (at RM 1.2) is approximately 7 miles long and covers a surface area of about 2,190 acres at normal full pool (El. 438.6). About 160,000 acre-feet of water are stored in Lake Shannon at normal full pool.

Operation for flood control storage is provided only at Baker Lake and managed by the U.S. Army Corps of Engineers (Corps), as detailed in the Water Control Manual. A compensation agreement between PSE and the Corps was entered into in 1980 and was extended in 2000. The agreement limits the pool level of Baker Lake to El. 720.75[1] from November 1 to March 1 for 16,000 acre-feet of flood control storage, and to El. 707.9 under normal operation conditions from November 15 to March 1 to provide a total of 74,000 acre-feet of flood control storage.

This agreement stipulates that outflows from Baker Lake be maintained equal to inflows until eight hours before Skagit River flow at the Concrete gage is forecasted to reach 90,000 cubic feet per second (cfs). The outflows are then dropped to 5,000 cfs, the approximate maximum turbine flow at Baker Lake.

The 16,000 acre-feet of storage is intended to make up for lost valley storage from the original construction of the Baker River Project. In addition to the current flood control storage total of 74,000 acre-feet, the existing FERC license states that PSE shall provide for flood control in Baker Lake up to a maximum of 26,000 additional acre-feet as may be requested by the Corps under the condition that PSE is compensated for the reservation of flood control storage beyond the 16,000 acre-feet. Therefore, up to 100,000 acre-feet of flood control storage at Baker Lake is available for flood control, if justified and requested by the Corps.

The existing FERC License Article 32 states the following:

> "Article 32. The licensee shall so operate the Upper Baker reservoir as to provide each year 16,000 acre-feet of space for flood regulation between November 1 and March 1 as replacement for the valley storage eliminated by the development. Utilization of this storage space shall be directed by the District Engineer, Corps of Engineers.
>
> "In addition to the above-specified 16,000 acre-feet, the Licensee shall provide in the Upper Baker River reservoir space for flood control during the storage drawdown season (about September 1 to April 15) up to a maximum of 84,000 acre-feet as may be requested by the District Engineer, provided that suitable arrangement shall have been made to compensate the Licensee for the reservation of flood control space other than the 16,000 acre-feet specified herein."

PSE is not required to manage the Lake Shannon pool to provide flood control. The Lower Baker Dam has a total drainage area 38 percent larger than the drainage area above Upper Baker Dam, and passes approximately 35 percent more water in an average year than the Upper Baker Dam. There is not a provision to provide any control over the additional local inflow into

[1] All stages in this technical memorandum are based on NGVD-29.

Lake Shannon. This inflow likely exceeds 10,000 cfs for all events greater than the 25-year flood. Lake Shannon needs to be operated in coordination with Baker Lake in order to provide the most effective flood control operation in Baker Lake.

The high runoff from the Baker River basin and the significance of the locations of Baker Lake and Lake Shannon in respect to the uncontrolled portion of the Skagit River basin, make the operation of the Baker River Project a critical element of flood control. The Baker River Project has historically provided and will continue to provide a significant public benefit to the communities in the Skagit River valley.

The FERC relicensing process requires PSE to develop a Baker River Project relicense application that is best adapted to a comprehensive plan for beneficial public uses including flood control and other purposes. Significant flood control benefits are available with modifications to the Baker River Project. These benefits should be included with other public benefits in the FERC relicensing process. Flood control benefits are maximized with a combination of modifications to the operation and storage of both dams.

Approach

An analysis to optimize flood control benefits from the Baker River system included evaluation of the two dams in isolated condition and in a combined condition. The incremental benefits gained with additional flood control from the Baker River system in this report are limited to benefits in the Skagit River floodplain up to and including Sedro Woolley.

A HEC-5 reservoir operation model, originally developed by the Corps for existing conditions (74,000 acre-feet of storage in Baker Lake and 5,000 cfs minimum flow release) was modified to include various flood control storage levels at each lake to determine flood peak flows and reductions at the Concrete gage of the Skagit River. A HEC-FDA Flood Damage Analysis model, originally developed by the Corps for existing conditions, was applied using the flood peak flows determined from the HEC-5 model runs to quantify the average annual damage and the flood reduction benefits for each of the flood control storages analyzed. The optimum combination of flood control storages at Baker Lake and Lake Shannon was then selected based on the maximizing flood reduction benefits determined consistent with assumptions discussed below.

The Corps' recently revised synthetic flood hydrographs for the 5-, 10-, 25-, 50-, 75-, 100-, 250-, and 500-year floods were provided to Pacific International Engineering (PI Engineering) via email on April 16, 2004. These revised hydrographs include unregulated and regulated hydrographs and are preliminary only. They were reviewed by PSE, the County, and others, and the first round of review comments have been provided to the Corps as part of the Corps Independent Technical Review (ITR) process. The

Corps will finalize these hydrographs when the ITR is complete. These hydrographs were used for the HEC-5 modeling analysis.

The Corps plans to update the HEC-FDA model later this year when the hydrographs are finalized. However, for this analysis, the currently available HEC-FDA model based on the old Corps hydrographs was used to quantify the flood reduction benefits.

Assumptions used to quantify the additional flood control storage above the 74,000 acre-foot storage at Baker Lake are as follows:

- Outflows from Baker Lake will be reduced to the minimum flow of 0 cfs, instead of the 5,000 cfs currently released, when Skagit River flow at the Concrete gage reaches 90,000 cfs.
- Outflows from Lake Shannon will be reduced to the minimum flow of 100 cfs when Skagit River flow at the Concrete gage reaches 90,000 cfs.
- A minimum outflow from Lake Shannon is set at 100 cfs, partly due to dam leakage and partly for fishery flow needs.
- The rate of change of outflow from Baker Lake and Lake Shannon is set at 5,000 cfs per hour.
- The time lag for flow from Lake Shannon to reach the Concrete gage on the Skagit River is set to be one hour.
- The Corps' revised HEC-FDA model will be substantially the same as the Corps' current HEC-FDA model when used to quantify the flood damage reduction benefits.
- The selection of the optimum combination of flood control storage at Baker Lake and Lake Shannon is based on peak flow reductions of flows over 90,000 cfs, as measured at Concrete, and not on protection for the 100-year event.

HEC-5 Analysis of Flood Control Storage

a. Use of Baker Lake Storage in Isolation

The modifications to the Corps' HEC-5 model include: using the latest reservoir storage-elevation curve provided by PSE (dated August 5, 2003); adding overtopping flow above the dam crest to the reservoir total outflow capacities; and adjusting Muskingum flood routing coefficients for the upper Skagit River based on calibration of the Corps' revised 25- and 100-year flood hydrographs at various reaches of the river.

The modified and calibrated HEC-5 model was verified by routing other revised synthetic flood hydrographs for existing conditions: existing Baker Lake flood control storage (74,000 acre-feet with 5,000 cfs outflow discharge) and existing Ross Lake flood control storage (120,000 acre-feet with 5,000 cfs outflow discharge). The routed flood hydrographs from the modified HEC-5 model match well with the Corps' flood hydrographs at the Skagit River gage near Concrete for all of the synthetic floods under existing conditions.

It should be noted, however, that utilization of the HEC-5 model for the existing conditions runs for Upper Baker produces slightly different flows than those calculated by the Corps. This accounts for the slight variation of numbers presented in some of the tables and figures in this report.

The HEC-5 model was then modified for six new rule curve conditions that include flood control storages at 74,000; 80,000; 90,000; 100,000; 110,000; and 120,000 acre-feet, and a minimum of 0 cfs flow release from Baker Lake. It was assumed that flood storage operation at Ross Lake would not change due to a change of the Baker Lake operation rule curve.

The revised synthetic flood hydrographs for the 5-, 10-, 25-, 50-, 75-, 100-, 250-, and 500-year floods were routed for each of the six new rule curve conditions. The results presented in Table 1(a) include a set of exceedance probability values in the HEC-FDA model input format and are based on the modified HEC-5 models and revised synthetic flood hydrographs.

The storage in Baker Lake that approximately maximizes incremental downstream benefits when considered in isolation is identified at 110,000 acre-feet. This calculation was based on the revised synthetic flood hydrographs provided by the Corps.

b. Use of Lake Shannon Storage in Isolation

The modified HEC-5 model, as described above for the Baker Lake storage analysis, was further modified to include likely future modified Lower Baker Dam design and operation configurations. Those configurations were assumed to use 20 existing spillway gates and three new lower spillway gates (replacing the three existing gates with larger gates having a lower crest elevation) for flood control operation. The preliminary dimensions of each of the new spillway gates assumed in this analysis are 7.36 feet wide and 24 feet high, with a crest at El 391.00. The total maximum discharge capacity of these new gates is 19,000 cfs at the normal full pool of El. 438.6.

New spillway gates with lower crest elevation, capable of evacuating Lake Shannon to provide adequate flood storage in a timely manner, are required. This is because all of the 23 existing spillway gates are at higher levels (crest El. 424.87) and can evacuate only a limited amount of storage, particularly when the Baker Lake storage also needs to be evacuated through Lower Baker

Dam between floods. A new probable maximum flood (PMF) study, completed in March 2004 by PI Engineering and submitted to the Corps for ITR, shows that the existing Lower Baker Dam spillway capacity is not adequate to pass the PMF. It is not clear at this time whether or not FERC would require PSE to provide an expansion of the spillway capacity. Potentially, new spillway gates with a crest at a lower level may be required for compliance with the FERC dam-safety requirements in order to pass the PMF. If new spillway gates are required for the PMF, it is possible that they would also provide sufficient capacity to evacuate Lake Shannon and Baker Lake storages for flood control operation.

The HEC-5 model was modified for three new rule curve conditions to include flood control storages at 30,000; 40,000; and 50,000 acre-feet and a minimum 100 cfs flow release from Lake Shannon. It was assumed that flood storage operation at Ross Lake would not change due to a change of the Lake Shannon operation rule curve.

The revised synthetic flood hydrographs for the 5-, 10-, 25-, 50-, 75-, 100-, 250-, and 500-year floods were routed for each of the three new rule curve conditions. A set of the exceedance probability values based on the modified HEC-5 models and revised synthetic flood hydrographs is provided in Table 1(b).

The storage in Lake Shannon that approximately maximizes incremental downstream benefits is identified at 40,000 acre-feet. This calculation is based on the revised synthetic flood hydrographs provided by the Corps.

c. Use of Baker Lake and Lake Shannon Storage in Conjunction

The HEC-5 model, as described above for the Lake Shannon storage analysis, was used to analyze various combinations of flood control storages provided at Baker Lake and Lake Shannon as described below.

1. Lake Shannon flood control storage at 30,000 acre-feet with a minimum release of 100 cfs in conjunction with alternative Baker Lake flood control storages at 74,000; 80,000; 90,000; 100,000; 110,000; 120,000; and 130,000 acre-feet with a minimum release of 0 cfs. A total of seven new rule curve conditions were developed.

2. Lake Shannon flood control storage at 40,000 acre-feet with a minimum release of 100 cfs in conjunction with alternative Baker Lake flood control storages at 74,000; 80,000; 90,000; 100,000; 110,000; 120,000; and 130,000 acre-feet with a minimum release of 0 cfs. A total of seven new rule curve conditions were developed.

3. Lake Shannon flood control storage at 50,000 acre-feet with a minimum release of 100 cfs in conjunction with alternative Baker

Lake flood control storages at 100,000; 110,000; 120,000; and 130,000 acre-feet with a minimum release of 0 cfs. A total of four new rule curve conditions were developed.

The HEC-5 model was modified for all eighteen new rule curve conditions developed above. It was assumed that flood storage operation at Ross Lake would not change due to a change of the operation rule curve at either Baker Lake or Lake Shannon.

The revised synthetic flood hydrographs provided by the Corps for the 5-, 10-, 25-, 50-, 75-, 100-, 250-, and 500-year floods were routed for each of the eighteen new rule curve conditions. A set of the exceedance probability values based on the modified HEC-5 models and synthetic flood hydrographs is provided in Table 1(c).

Table 1(a) Upper Baker Dam Optimization in Isolation, HEC-5 Results: Peak Flow for the Skagit River at Concrete

Return Interval	Exceedance Probability	74,000 AF 5,000 cfs Min. Outflow Discharge (cfs)	74,000 AF 0 cfs Min. Outflow Discharge (cfs)*	80,000 AF 0 cfs Min. Outflow Discharge (cfs)	90,000 AF 0 cfs Min. Outflow Discharge (cfs)	100,000 AF 0 cfs Min. Outflow Discharge (cfs)	110,000 AF 0 cfs Min. Outflow Discharge (cfs)	120,000 AF 0 cfs Min. Outflow Discharge (cfs)
1	0.999							
2	0.5	73,605	73,605	73,605	73,605	73,605	73,605	73,605
5	0.2	96,821	91,821	91,821	91,821	91,821	91,821	91,821
10	0.1	121,242	116,248	116,220	116,220	116,220	116,220	116,220
25	0.04	158,826	153,828	153,828	153,828	153,828	153,828	153,828
50	0.02	191,321	187,696	186,287	186,287	186,287	186,287	186,287
75	0.013	213,688	215,663	212,861	209,351	208,099	208,099	208,099
100	0.01	233,028	236,338	233,696	229,870	227,481	225,033	224,573
250	0.004	322,583	325,943	322,529	317,795	314,881	309,955	303,529
500	0.002	401,175	400,534	400,214	400,113	396,010	391,910	387,537
1000	0.001							

* Regulated synthetic flood hydrographs from HEC-5 model

Table 1(b) Lower Baker Dam Optimization in Isolation, HEC-5 Results: Peak Flow for the Skagit River at Concrete

Return Interval	Exceedance Probability	Upper Dam: 74,000 AF 5,000 cfs Outflow Lower Dam: 0 AF Existing Conditions Discharge (cfs)*	Upper Dam: 74,000 AF 5,000 cfs Outflow Lower Dam: 30,000 AF Discharge (cfs)	Upper Dam: 74,000 AF 5,000 cfs Outflow Lower Dam: 40,000 AF Discharge (cfs)	Upper Dam: 74,000 AF 5,000 cfs Outflow Lower Dam: 50,000 AF Discharge (cfs)
1	0.999				
2	0.5	73,605	73,605	73,605	73,605
5	0.2	96,821	90,000	90,000	90,000
10	0.1	121,242	112,165	112,165	112,165
25	0.04	158,826	148,630	148,630	148,630
50	0.02	191,321	180,174	180,174	180,174
75	0.013	213,688	213,327	201,409	201,409
100	0.01	233,028	243,297	237,613	234,068
250	0.004	322,583	327,639	326,502	326,463
500	0.002	401,175	397,948	397,968	397,295
1000	0.001				

* Regulated synthetic flood hydrographs from HEC-5 model

Table 1(c) Upper and Lower Baker Dams in Conjunction, HEC-5 Results: Peak Flow for the Skagit River at Concrete
(continued on next page)

Lower Baker Storage: 30,000 AF

Return Interval	Exceedance Probability	Upper Dam: 74,000 AF Lower Dam: 0 AF 5,000 cfs Outflow Existing Conditions Discharge (cfs)*	Upper Dam: 74,000 AF Lower Dam: 30,000 AF 100 cfs Outflow Discharge (cfs)	Upper Dam: 80,000 AF Lower Dam: 30,000 AF 100 cfs Outflow Discharge (cfs)	Upper Dam: 90,000 AF Lower Dam: 30,000 AF 100 cfs Outflow Discharge (cfs)	Upper Dam: 100,000 AF Lower Dam: 30,000 AF 100 cfs Outflow Discharge (cfs)	Upper Dam: 110,000 AF Lower Dam: 30,000 AF 100 cfs Outflow Discharge (cfs)	Upper Dam: 120,000 AF Lower Dam: 30,000 AF 100 cfs Outflow Discharge (cfs)	Upper Dam: 130,000 AF Lower Dam: 30,000 AF 100 cfs Outflow Discharge (cfs)
1	0.999								
2	0.5	73,605	73,605	73,605	73,605	73,605	73,605	73,605	73,605
5	0.2	96,821	90,000	90,000	90,000	90,000	90,000	90,000	90,000
10	0.1	121,242	112,165	112,165	112,165	112,165	112,165	112,165	112,165
25	0.04	158,826	148,630	148,630	148,630	148,630	148,630	148,630	148,630
50	0.02	191,321	180,174	180,174	180,174	180,174	180,174	180,174	180,174
75	0.013	213,688	219,701	212,250	201,409	201,409	201,409	201,409	201,409
100	0.01	233,028	243,789	231,778	218,528	217,393	217,393	217,393	217,393
250	0.004	322,583	326,510	326,502	326,499	326,493	326,481	324,050	321,033
500	0.002	401,175	398,448	397,968	397,456	396,825	396,519	396,117	395,461
1000	0.001								

Lower Baker Storage: 40,000 AF

Return Interval	Exceedance Probability	Upper Dam: 74,000 AF Lower Dam: 0 AF 5,000 cfs Outflow Existing Conditions Discharge (cfs)*	Upper Dam: 74,000 AF Lower Dam: 40,000 AF 100 cfs Outflow Discharge (cfs)	Upper Dam: 80,000 AF Lower Dam: 40,000 AF 100 cfs Outflow Discharge (cfs)	Upper Dam: 90,000 AF Lower Dam: 40,000 AF 100 cfs Outflow Discharge (cfs)	Upper Dam: 100,000 AF Lower Dam: 40,000 AF 100 cfs Outflow Discharge (cfs)	Upper Dam: 110,000 AF Lower Dam: 40,000 AF 100 cfs Outflow Discharge (cfs)	Upper Dam: 120,000 AF Lower Dam: 40,000 AF 100 cfs Outflow Discharge (cfs)	Upper Dam: 130,000 AF Lower Dam: 40,000 AF 100 cfs Outflow Discharge (cfs)
1	0.999								
2	0.5	73,605	73,605	73,605	73,605	73,605	73,605	73,605	73,605
5	0.2	96,821	90,000	90,000	90,000	90,000	90,000	90,000	90,000
10	0.1	121,242	112,165	112,165	112,165	112,165	112,165	112,165	112,165
25	0.04	158,826	148,630	148,630	148,630	148,630	148,630	148,630	148,630
50	0.02	191,321	180,174	180,174	180,174	180,174	180,174	180,174	180,174
75	0.013	213,688	217,005	201,409	201,409	201,409	201,409	201,409	201,409
100	0.01	233,028	236,641	223,063	217,393	217,393	217,393	217,393	217,393
250	0.004	322,583	326,493	326,502	325,909	325,317	324,050	317,199	312,862
500	0.002	401,175	397,456	397,415	396,968	396,454	396,117	395,735	395,395
1000	0.001								

Table 1(c) Upper and Lower Baker Dams in Conjunction, HEC-5 Results: Peak Flow for the Skagit River at Concrete
(continued from previous page)

Lower Baker Storage: 50,000 AF

Return Interval	Exceedance Probability	Upper Dam: 74,000 AF Lower Dam: 0 AF 5,000 cfs Outflow Existing Conditions Discharge (cfs)*	Upper Dam: 100,000 AF Lower Dam: 50,000 AF 100 cfs Outflow Discharge (cfs)	Upper Dam: 110,000 AF Lower Dam: 50,000 AF 100 cfs Outflow Discharge (cfs)	Upper Dam: 120,000 AF Lower Dam: 50,000 AF 100 cfs Outflow Discharge (cfs)	Upper Dam: 130,000 AF Lower Dam: 50,000 AF 100 cfs Outflow Discharge (cfs)
1	0.999					
2	0.5	73,605	73,605	73,605	73,605	73,605
5	0.2	96,821	90,000	90,000	90,000	90,000
10	0.1	121,242	112,165	112,165	112,165	112,165
25	0.04	158,826	148,630	148,630	148,630	148,630
50	0.02	191,321	180,174	180,174	180,174	180,174
75	0.013	213,688	201,409	201,409	201,409	201,409
100	0.01	233,028	217,393	217,393	217,393	217,393
250	0.004	322,583	318,703	313,072	305,929	304,885
500	0.002	401,175	396,098	395,395	391,615	390,627
1000	0.001					

* Regulated synthetic flood peak from HEC-5 model

Summary of HEC-FDA Analysis

The HEC-FDA analysis was performed by Alexander Aaron, Inc. under a subconsultant agreement with PI Engineering. Results of the HEC-FDA analysis are documented in the report “Upper and Lower Baker Dam Storage Evaluation – Flood Inundation Damage Reduction, June 2004” and are shown in Figure 1. Figure 1 shows annual damage reduction and corresponding net present value based on the current federal discount rate over a 50-year project life.

Selection of Optimum Flood Control Storage at Baker River Project

As presented in Figure 1, the HEC-FDA run results show that additional flood control storage at the Baker River Project is estimated to provide up to $10.8 million annual flood reduction benefits if the additional storage is provided in Baker Lake and Lake Shannon. The HEC-FDA analysis demonstrates that the combination of Baker Lake and Lake Shannon flood control storage should total 130,000 acre-feet to 140,000 acre-feet to obtain optimum benefits. Many risks and uncertainties exist during actual flood events, including: accuracy of flood forecast and analysis; potential operational problems such as gate failure, debris, power outages, gage failure, etc.; and the frequent occurrence of double peak flood events. A total capacity of 140,000 acre-feet was selected as the optimum for Baker Lake and Lake Shannon combined flood control storage.

The annual flood reduction benefit for this storage combination was estimated to be $10.6 million [Figure 1(a)]. This storage combination could reduce flood damages by $177 million [Figure 1(b)] on a net present value based on the current federal discount rate over a 50-year project life.

At the selected combined total storage of 140,000 acre-feet, the split between Baker Lake and Lake Shannon can be between 100,000 and 110,000 acre-feet, and between 30,000 and 40,000 acre-feet, respectively. However, the larger the better for storage provided in Lake Shannon, as it needs to regulate not only the peak flow contribution from the intermediate drainage area between Upper and Lower Baker Dams, but also potential peak flow spilling from Baker Lake. It is therefore recommended that the split of the combined total of 140,000 acre-feet be 100,000 acre-feet in Baker Lake and 40,000 acre-feet in Lake Shannon.

Based on the selected flood storage combination, downstream flood reductions at Concrete and Mount Vernon were analyzed and presented in the following discussion.

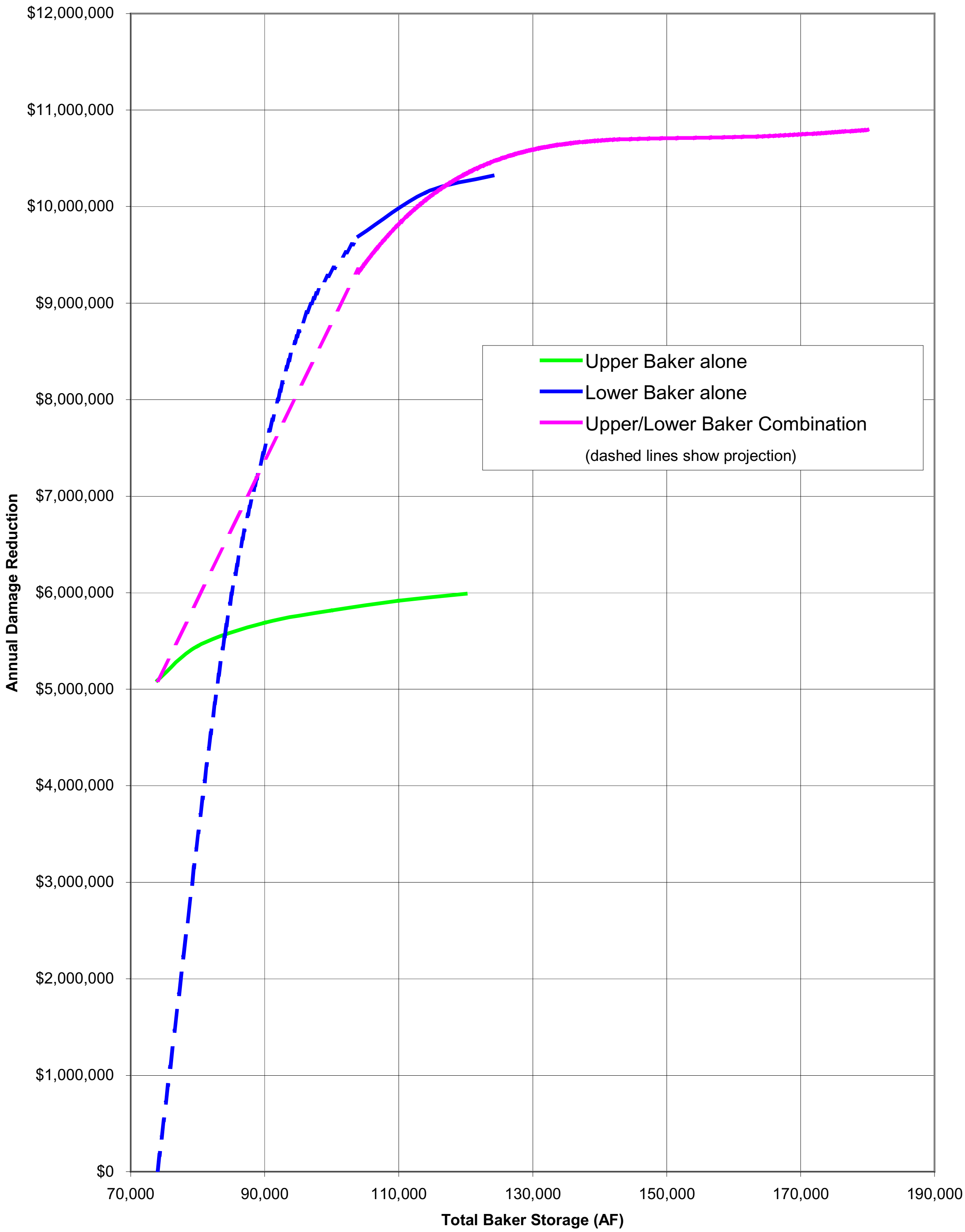

Figure 1(a) Annual damage reduction, HEC-FDA results

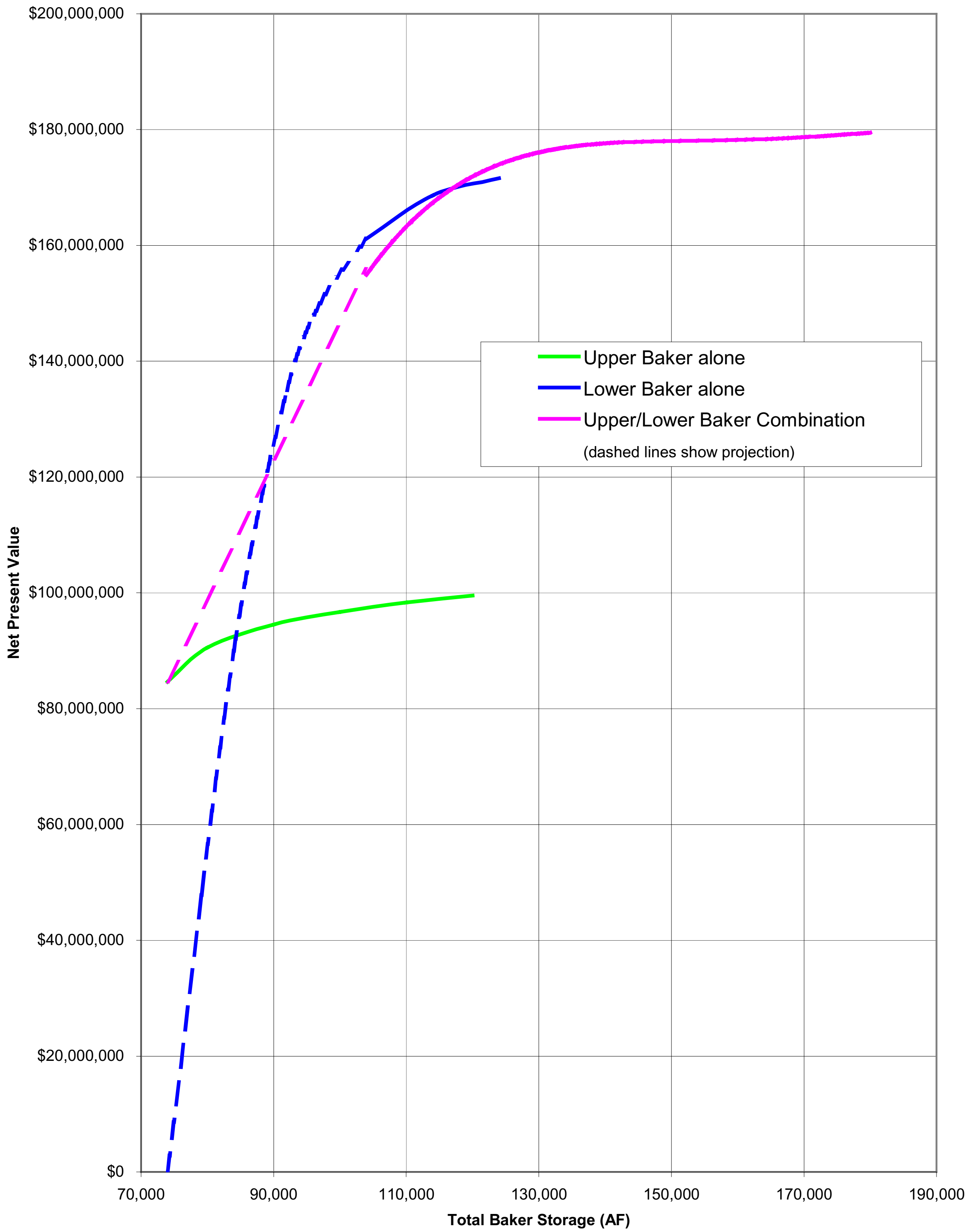

Figure 1(b) Net present value over 50-year project life

Skagit River Flood Reductions at Concrete

Table 2(a) shows potential reductions of the Skagit River flood stage and peak flow at the Concrete gage for the four synthetic floods of 10-, 25-, 50, and 100-year events if the selected flood control storages were provided at the Baker River Project. Shown in Table 2(b) are the potential stage and flow for the most recent four floods: the two November 1990 floods, the November 1995 flood, and the October 2003 floods. The flood stage reductions range from 0.64 to 1.67 feet on the Skagit River at the Concrete gage. The peak flow reductions are approximately 3 to 8 percent of the Skagit River flood peaks. The peak flows of the 10-, 25-, 50-, and 100-year synthetic events would be reduced using the additional storage-to-flow values that approximately represent 8-, 20-, 40-, and 80-year events, respectively. The four historical floods with recurrence intervals ranging from 19 to 30 years, would be reduced to 14- to 26-year flood events.

Figures 2, 3, 4, and 5 show plots of lake levels and flow hydrographs for Baker River and Skagit River at the gage near Concrete for the two November 1990 floods, the November 1995 flood, and the October 2003 flood.

Assuming that 90,000 cfs at the Concrete gage is targeted for the storage operation, the total flood control storages required at the Baker River Project to maximize downstream protection during these four historical flood events were estimated to be between 82,800 and 123,100 acre-feet, and are listed in Table 3 [Table 3(c)]. Also shown in Table 3, the split of these total flood control storages between Baker Lake [Table 3(a)] and Lake Shannon [Table 3(b)] were estimated to be 65,500 to 99,100 acre-feet, and 17,300 to 45,400 acre-feet, respectively.

Table 2(a) Potential Skagit River Flood Reductions at Concrete Gage - Synthetic Events

Flood	With Current FC Storage at Baker Lake (1)			With Additional FC Storage at Baker Lake and Lake Shannon (2)			Reductions		
	Max. Stage El. (ft) (a)	Peak Flow (cfs) (b)	Return Interval (year)	Max. Stage El. (ft) (a)	Peak Flow (cfs)	Return Interval (year)	Max. Stage (ft)	Peak Flow (cfs)	Return Interval (year)
10-year	166.46	119,600	10	165.26	110,600	8	1.20	9,000	2
25-year	171.16	157,000	25	169.95	147,000	20	1.21	10,000	5
50-year	174.94	190,700	50	173.71	179,500	40	1.23	11,200	10
100-year	179.42	232,800	100	177.75	216,900	80	1.67	15,700	20

(1) 74,000 AF flood control storage and 5,000 cfs minimum flow at Baker Lake.
(2) 100,000 AF flood control storage and 0 cfs minimum flow at Baker Lake, and 40,000 AF flood control storage and 100 cfs minimum flow at Lake Shannon.
(a) Based on USGS stage-discharge rating curve with logarithmic extension.
(b) Regulated synthetic flood peak from Corps provided spreadsheet routing model.

Note: All stages are based on NGVD-29. USGS gage readings at Concrete are NGVD-29 stages, minus 130 feet.

Table 2(b) Potential Skagit River Flood Reductions at Concrete Gage - Historical Events

Flood	With Current FC Storage at Baker Lake (1)			With Additional FC Storage at Baker Lake and Lake Shannon (2)			Reductions		
	Max. Stage El. (ft) (a)	Peak Flow (cfs) (a)	Return Interval (year)	Max. Stage El. (ft) (b)	Peak Flow (cfs)	Return Interval (year)	Max. Stage (ft)	Peak Flow (cfs)	Return Interval (year)
Nov 8 to Nov 15, 1990	170.18	149,000	21	169.16	140,600	17	1.02	8,400	4
Nov 21 to Nov 28, 1990	169.79	146,000	19	168.37	134,250	14	1.42	11,750	5
Nov 26 to Dec 3, 1995	171.43	159,000	26	170.24	149,400	21	1.19	9,600	5
Oct 16 to Oct 22, 2003	172.04	164,000	30	171.40	158,550	26	0.64	5,450	4

(1) 74,000 AF flood control storage and 5,000 cfs minimum flow at Baker Lake.
(2) 100,000 AF flood control storage and 0 cfs minimum flow at Baker Lake, and 40,000 AF flood control storage and 100 cfs minimum flow at Lake Shannon.
(a) USGS published data.
(b) Interpolated from USGS published hydrographs.

Note: All stages are based on NGVD-29. USGS gage readings at Concrete are NGVD-29 stages, minus 130 feet.

Table 3(a) Flood Control (FC) Storage Requirements* at Baker Lake – Historical Floods

Historical Flood Event	Observed FC Storage Used at Baker Lake (Ac-Ft)	Estimated Additional FC Storage at Baker Lake (Ac-Ft)	Total FC Storage at Baker Lake (Ac-Ft)
Nov. 8 to Nov. 15, 1990	84,600	14,500	99,100
Nov. 21 to Nov. 28, 1990	59,800	14,500	74,300
Nov. 26 to Dec. 3, 1995	51,200	14,300	65,500
Oct. 16 to Oct. 22, 2003	66,100	11,600	77,700

* Based on the targeted 90,000 cfs at the Skagit River Concrete gage

Table 3(b) Flood Control (FC) Storage Requirements* at Lake Shannon – Historical Floods

Historical Flood Event	Observed FC Storage Used at Lake Shannon (Ac-Ft)	Estimated Additional FC Storage at Lake Shannon (Ac-Ft)	Total FC Storage at Lake Shannon (Ac-Ft)
Nov. 8 to Nov. 15, 1990	0	21,600	21,600
Nov. 21 to Nov. 28, 1990	0	19,200	19,200
Nov. 26 to Dec. 3, 1995	0	17,300	17,300
Oct. 16 to Oct. 22, 2003	31,600	13,800	45,400

* Based on the targeted 90,000 cfs at the Skagit River Concrete gage

Table 3(c) Flood Control (FC) Storage Requirements* at Baker Lake and Lake Shannon – Historical Floods

Historical Flood Event	Observed Total FC Storage Used at Baker Lake and Lake Shannon (Ac-Ft)	Estimated Total Additional FC Storage at Baker Lake and Lake Shannon (Ac-Ft)	Total FC Storage at Baker Lake and Lake Shannon (Ac-Ft)
Nov. 8 to Nov. 15, 1990	84,600	36,100	120,700
Nov. 21 to Nov. 28, 1990	59,800	33,700	93,500
Nov. 26 to Dec. 3, 1995	51,200	31,600	82,800
Oct. 16 to Oct. 22, 2003	97,700	25,400	123,100

* Based on the targeted 90,000 cfs at the Skagit River Concrete gage

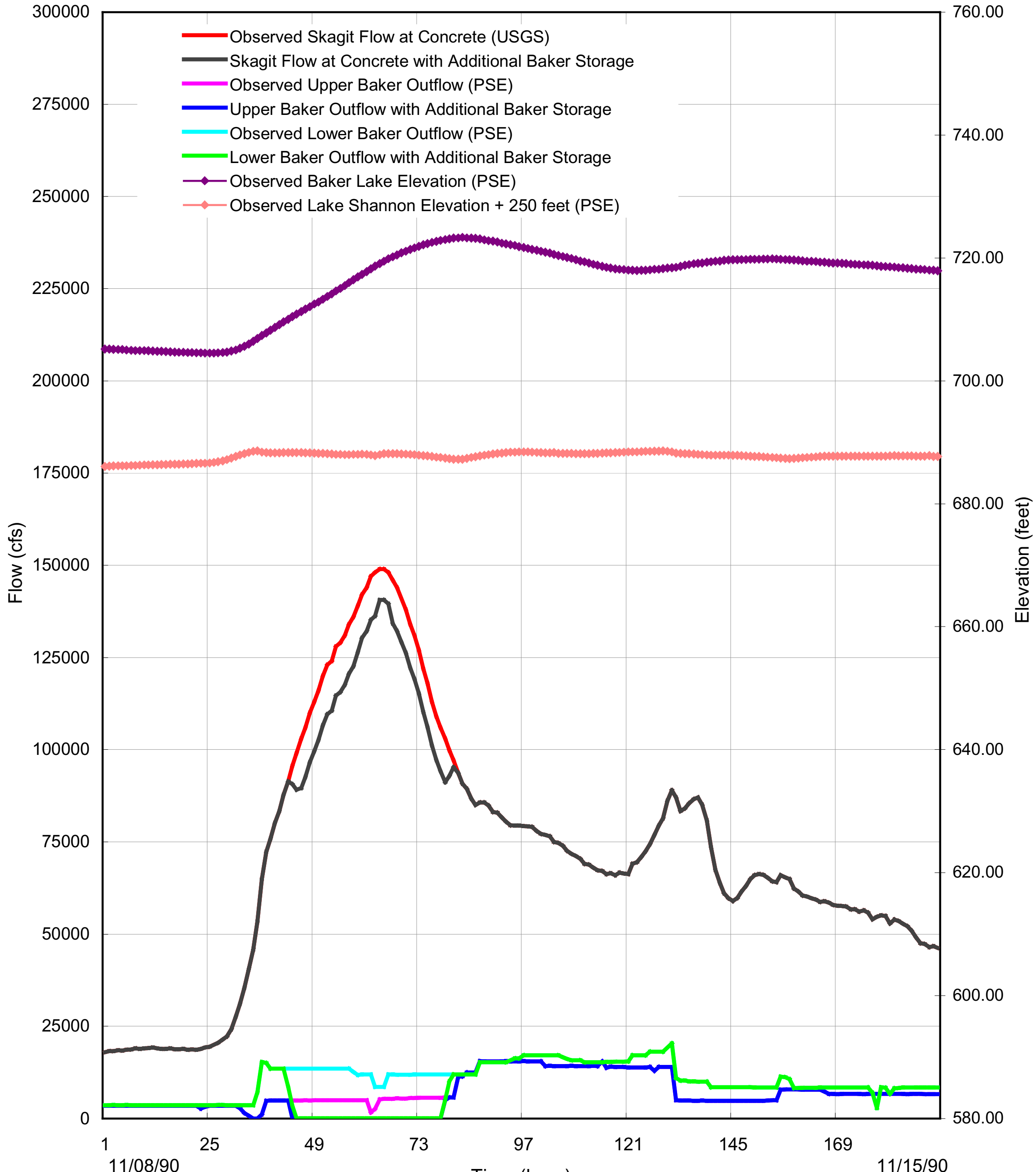

Figure 2 Flow hydrographs for Baker River and Skagit River at the gage near Concrete for November 8, 1990 flood

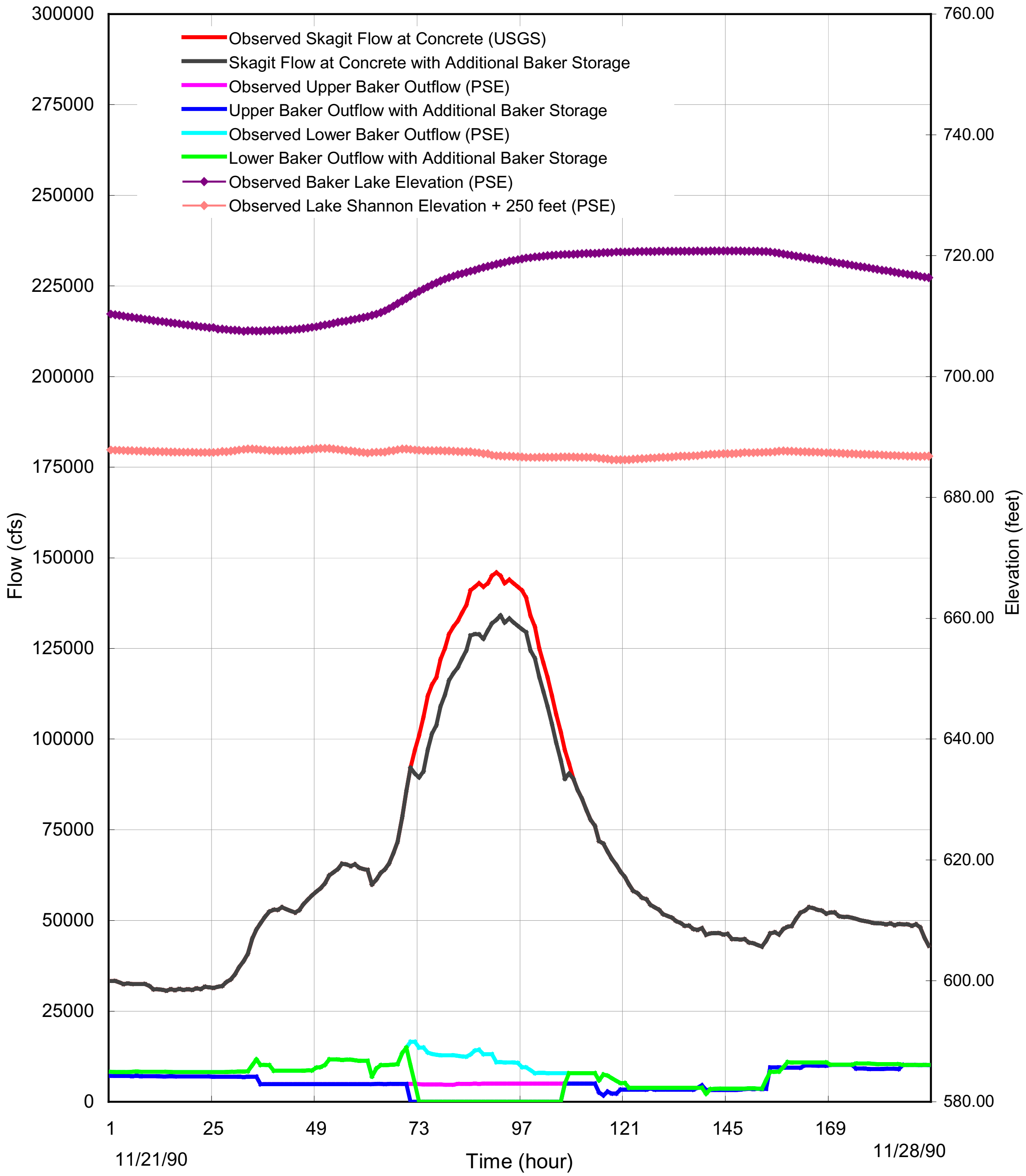

Figure 3 Flow hydrographs for Baker River and Skagit River at the gage near Concrete for November 21, 1990 flood

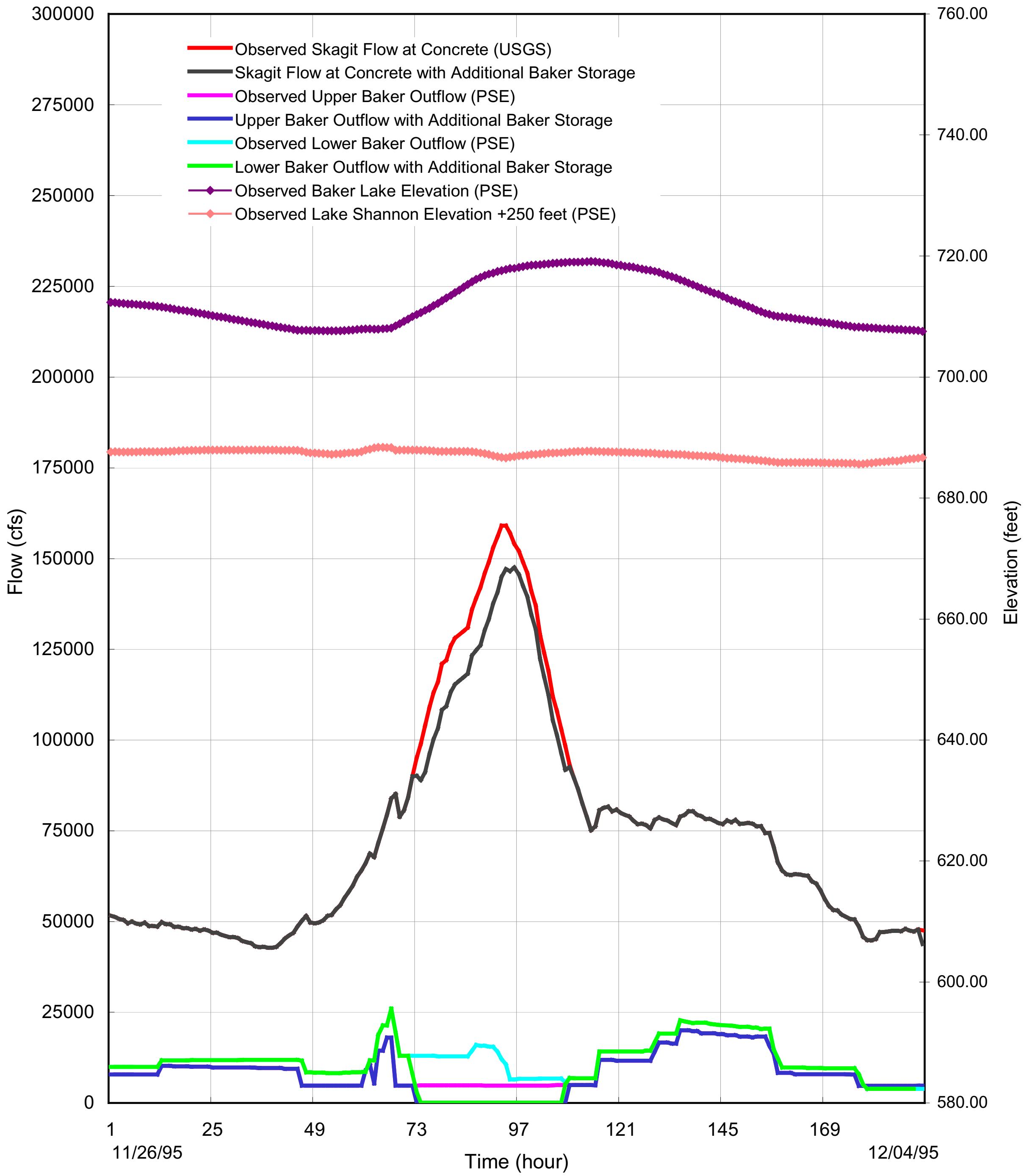

Figure 4 **Flow hydrographs for Baker River and Skagit River at the gage near Concrete for November 26, 1995 flood**

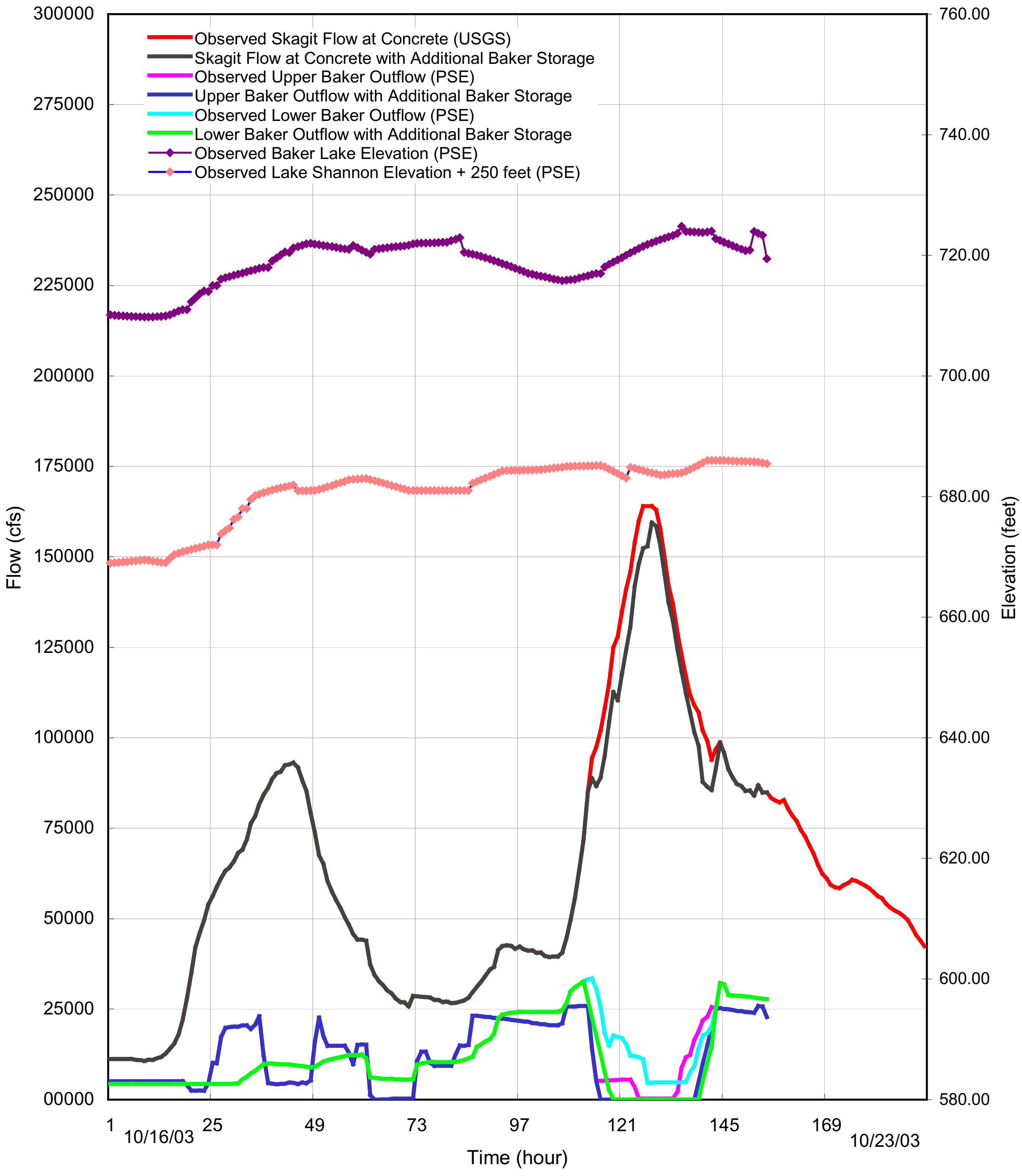

Figure 5 Flow hydrographs for Baker River and Skagit River at the gage near Concrete for October 20, 2003 flood

Skagit River Flood Reductions at Mt. Vernon

Hydrographs of the 10-, 25-, 50-, and 100-year synthetic floods for the current Baker Lake flood control storage operation conditions (74,000 acre-feet of storage at Baker Lake only), as well as conditions with the selected optimum flood control storages (100,000 acre-feet of storage at Baker Lake and 40,000 acre-feet of storage at Lake Shannon) were routed downstream to assess reduction in flood levels in Mount Vernon.

A HEC-RAS unsteady flow routing model, converted from the Corps' originally developed UNET model and modified by PI Engineering to add more routing reaches for the Nookachamps Creek and floodplain area, was used in the flood routing analysis. The HEC-RAS model assumes no levee failure, nor overtopping under potential future levee conditions. It also assumes no debris blocking at any bridges for modeling the synthetic floods. Routing results were compared between existing conditions and future conditions with the optimized flood control storages.

Table 5(a) provides the potential reductions of the Skagit River flood peak flows and stages at the Mount Vernon gage for the 10-, 25-, 50-, and 100-year synthetic flood events. Flood stage reductions range from 1.01 to 1.73 feet on the Skagit River at Mount Vernon. Peak flow reductions range from 6 to 7 percent at Mount Vernon.

The hydrographs for the two November 1990 floods, the November 1995 flood, and the October 2003 floods were also routed by the HEC-RAS model for the current Baker Lake flood control storage operation conditions, as well as for conditions with the optimized flood control storages at Baker Lake and Lake Shannon. The potential reductions of the Skagit River flood peak flows and stages at Mount Vernon for these four historical floods are provided in Table 5(b). Flood stage reductions range from 0.71 to 0.84 feet on the Skagit River at Mount Vernon during these four historical floods. Peak flow reductions range from 6 to 7 percent at Mount Vernon.

Table 5(a) Potential Skagit River Flood Reductions at Mt. Vernon Gage - Synthetic Events

Flood	With Current FC Storage at Baker Lake (1)		With Additional FC Storage at Baker Lake and Lake Shannon (2)		Reductions	
	Max. Stage El. (ft) (a)	Peak Flow (cfs) (a)	Max. Stage El. (ft) (b)	Peak Flow (cfs)	Max. Stage (ft)	Peak Flow (cfs)
10-year	34.89	117,400	33.86	109,700	1.03	7,700
25-year	38.24	148,000	37.14	138,500	1.10	9,500
50-year	40.95	175,700	39.84	164,700	1.11	11,000
100-year	45.27	223,000	43.54	206,400	1.73	16,600

(1) 74,000 AF flood control storage and 5,000 cfs minimum flow at Baker Lake.
(2) 100,000 AF flood control storage and 0 cfs minimum flow at Baker Lake, and 40,000 AF flood control storage and 100 cfs minimum flow at Lake Shannon.
(a) Regulated synthetic flood peaks developed and routed to Mount Vernon by Corps.
(b) Interpolated from Corps synthetic flood hydrographs.
Note: All stages are based on NGVD-29.

Table 5(b) Potential Skagit River Flood Reductions at Mt. Vernon Gage - Historical Events

Flood	With Current FC Storage at Baker Lake (1)		With Additional FC Storage at Baker Lake and Lake Shannon (2)		Reductions	
	Max. Stage El. (ft) (a)	Peak Flow (cfs) (a)	Max. Stage El. (ft) (b)	Peak Flow (cfs)	Max. Stage (ft)	Peak Flow (cfs)
Nov 8 to Nov 15, 1990	36.61	142,000	35.90	132,650	0.71	9,350
Nov 21 to Nov 28, 1990	37.37	152,000	36.65	142,400	0.72	9,600
Nov 26 to Dec 3, 1995	37.33	141,000	36.49	131,850	0.84	9,150
Oct 20 to Oct 22, 2003	36.18	129,000	35.36	121,100	0.82	7,900

(1) 74,000 AF flood control storage and 5,000 cfs minimum flow at Baker Lake.
(2) 100,000 AF flood control storage and 0 cfs minimum flow at Baker Lake, and 40,000 AF flood control storage and 100 cfs minimum flow at Lake Shannon.
(a) USGS published data.
(b) Interpolated from USGS published hydrographs.
Note: All stages are based on NGVD-29.

Conclusions and Recommendations

It is concluded from the above analysis that additional flood control storage at the Baker River Project, above the currently provided 74,000 acre-foot storage at Baker Lake, will provide very significant additional flood reduction benefits on the Skagit River floodplain below Concrete.

The preceding discussion presents an analytical and economic evaluation identifying the reduction of water surface elevation at Mount Vernon and the reduction of damage costs from flooding as a result of additional storage in the Baker River System. Several combinations of additional storage between Baker Lake and Lake Shannon were evaluated. The evaluation demonstrates that the combination of additional storage should total 140,000 acre-feet to obtain benefits on an incrementally justified basis. This additional storage will reduce damages by $177 million on a net present value over the life of 50 years or the equivalent annualized amount of $10.6 million per year. The additional storage will reduce the water surface elevation for the 25-year flood by 1.1 foot and the 100-year flood by 1.7 feet at Mount Vernon.

The preferred relationship between the reservoirs for flood control storage is 100,000 acre-feet in Baker Lake and 40,000 acre-feet in Lake Shannon. Additional storage in Lake Shannon has more value than additional storage in Baker Lake because Lake Shannon regulates flow contribution from 297 square miles of watershed, whereas Upper Baker regulates flow contribution from 215 square miles of watershed. Three other criteria are necessary to achieve the benefits of additional storage: flood control storage operation rule curve; reservoir release regulation during flood events; and new spillway gates on Lower Baker Dam.

Flood Control Storage Operation Rule Curve

The recommended flood control storages of 100,000 acre-feet and 40,000 acre-feet in Baker Lake and Lake Shannon, respectively, shall be maintained between October 15 and March 1 each year during flood season.

Reservoir Releases During Flood Events

The additional storage needs to be available during the peak flow period of the flood. This is accomplished by maintaining the reservoir flood control elevations by releasing all inflows to both reservoirs until maximum peak flow reduction in the Skagit River at Concrete can be achieved, with the outflows from the spillways and hydro plants of both reservoirs reduced to zero.

Spillway Gates on Lower Baker Dam.

New spillway gates need to be added that have adequate capacity to evacuate the water stored in Lake Shannon in a timely manner between flood events in coordination with the necessary release from Baker Lake. The new gates are necessary to assure that the required flood control storage in Lake Shannon can be maintained until the Skagit River reaches 90,000 cfs.

The County is actively engaged in an engineering analysis with the Corps to identify a flood control project to protect the existing cities and communities from flood damage. A recently completed Baseline Economic Study by the Corps includes an estimate that the threatened community would experience $1 billion in damages in a 100-year flood event. The County is planning to construct several measures to manage or control the water associated with the 100-year event as it passes through the community. These measures include modification or rehabilitation of up to 40 miles of levees, modification to several bridges, the evaluation of an emergency overflow structure, and use of floodplain storage. The cost of each of these structures can be significantly impacted by a change of water surface level of 1.7 feet during the 100-year flood. Although the cost savings associated with a 1.7-foot flood stage reduction has not been completed in detail, the incremental cost is estimated to amount to tens of millions of dollars.