Draft Upper and Lower Baker Dams Probable Maximum Flood Study Report

Skagit River Flood Damage Reduction and Ecosystem Restoration Project Feasibility Study
Skagit County Public Works

PACIFIC
INTERNATIONAL
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Skagit County Public Works

Prepared for:

Skagit County Public Works
Mt. Vernon, Washington

Prepared by:

Pacific International Engineering
Edmonds, Washington

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PACIFIC INTERNATIONAL ENGINEERING PLLC
POST OFFICE BOX 1599 • 123 SECOND AVENUE SOUTH • EDMONDS, WASHINGTON • 98020

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Background

The Baker River Hydroelectric Project (Project), Federal Energy Regulatory Commission (FERC) project number 2150, is owned and operated by Puget Sound Energy (PSE). The Project consists of two hydroelectric generating developments, both located on the Baker River, in Washington State. Construction of the Lower Baker Development was completed in 1925 prior to the enactment of the Federal Power Act. In 1927, the Federal Power Commission (now known as FERC) issued a license to Puget Sound Power & Light Company (now known as PSE) to operate the Lower Baker Development. The Federal Power Commission subsequently issued a license in 1956 to construct the Upper Baker Development. The license combined the operations of both developments into a single federal license for the Project. PSE's 50-year license for the Project expires on May 1, 2006. PSE plans to file an application to re-license the Project on or before April 30, 2004.

The Skagit River Flood Damage Reduction and Ecosystem Restoration Project Feasibility Study (Flood Reduction Study) presently being studied by the U.S. Army Corps of Engineers – Seattle District (Corps), includes an evaluation of the Baker River Dams flood control storage operation as one of several potential flood reduction measures. Skagit County (County), as the local sponsor of the Flood Reduction Study, has requested that Pacific International Engineering (PI Engineering) conduct that evaluation, as well as a probable maximum flood (PMF) study for the Upper and Lower Baker Dams as part of that evaluation. This report summarizes the PMF study. The report outline presented herein is in general accordance with the FERC Engineering Guidelines, Chapter VIII – Gaged Basins.

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I. Project Description

A. Project Data

The Baker River Hydroelectric Project (Project) is located on the Baker River, approximately one mile from the town of Concrete, in the northwest corner of Washington State (Figure 1).

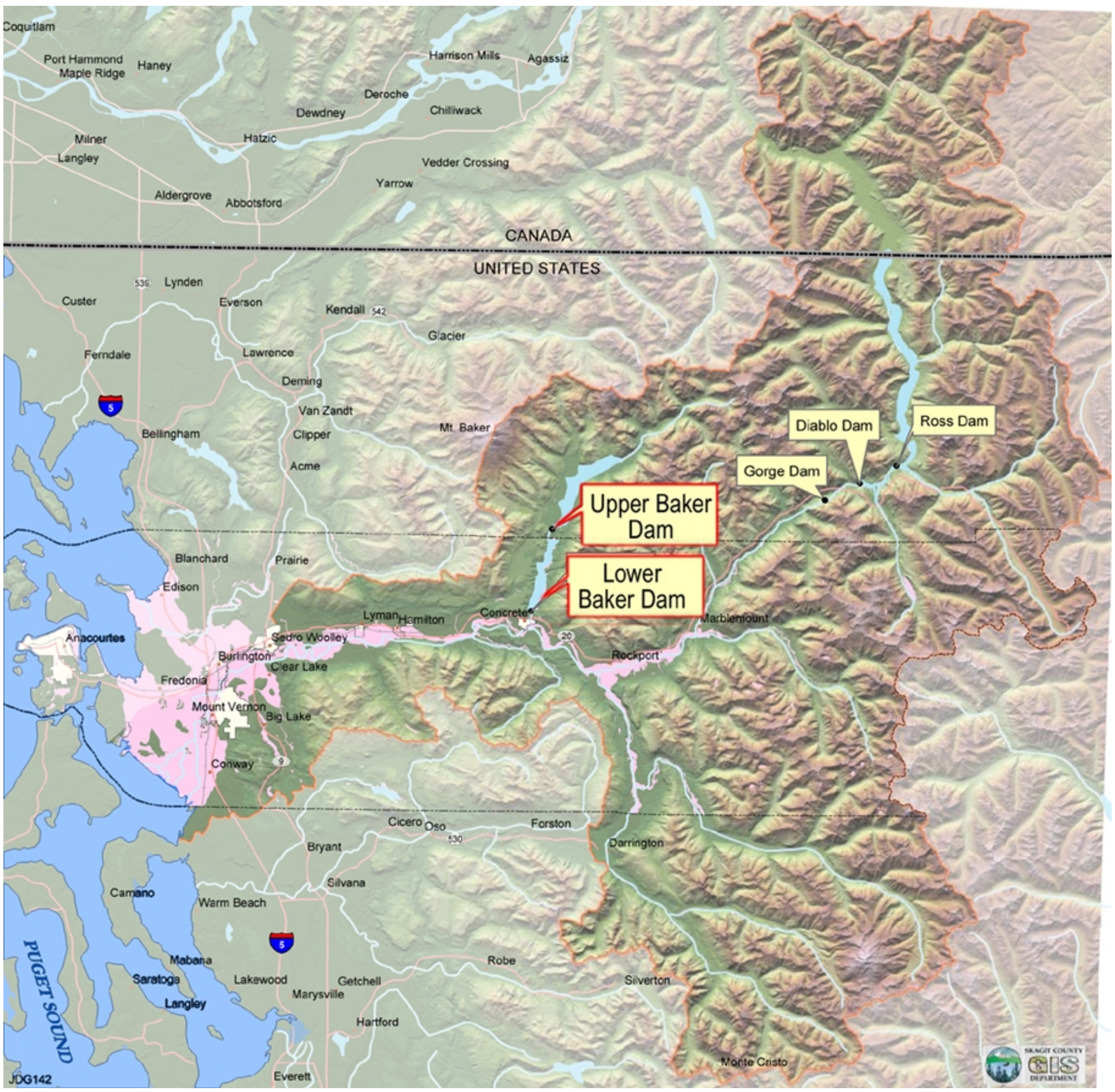

Figure 1 Location map, Upper and Lower Baker Dams PMF Study

The Upper Baker Dam and reservoir are operated and maintained primarily for power supply and flood control. The Lower Baker Dam and reservoir are operated only for power supply and not available for flood control capacity at the present time.

1. Upper Baker Dam

The Upper Baker Dam (Figures 2 and 3), a concrete gravity dam, consists of a three-radial-gate spillway, a reservoir, and a powerhouse containing two turbine-generator units with a total 90.7 MW capacity. The spillway capacity is 48,000 cubic feet per second (cfs) at normal full pool elevation (El.) 727.77 feet (NAVD 88[1]). Baker Lake, the reservoir formed by Upper Baker Dam, is approximately nine miles long and covers an area of about 4,980 acres at normal full pool. Roughly 274,202 acre-feet of water are stored in Baker Lake at full pool, including about 180,128 acre-feet of active storage above the minimum generating level (Puget Sound Energy 2003). The top of Upper Baker Dam is at El. 735.77 feet (NAVD 88) and water is released through the turbine intakes or through the dam spillway. Under normal operating conditions, Baker Lake is held near full pool during the summer months. Minimum reservoir elevations are typically attained from November through March or early April.

Operation for flood control storage is provided only at Baker Lake, under an agreement between the Corps and PSE. It limits the pool level of Baker Lake to El. 724.50 (NAVD 88) from November 1 to March 1 for 16,000 acre-feet of flood control storage, and to El. 711.56 (NAVD 88) 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 as equal to inflows until eight hours before Skagit River flow at the Concrete gage is forecasted to reach 90,000 cfs. The outflows are then dropped to 5,000 cfs 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 Project. In addition to the agreed upon 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 a total maximum of 100,000 acre-feet of flood control storage at Baker Lake would be provided, if justified and requested.

[1] In late spring of 2003, PSE reconciled most datum discrepancies by converting elevations based on 1929 datum (NGVD 29) to GIS-based datum of 1988 (NAVD 88). Although most new elevations have been converted, not all conversions have been completed. The text notes whether elevations are based on NGVD 29 or NAVD 88. For Lower Baker Dam, NGVD 29 plus 3.75 feet equals NAVD 88. For Upper Baker Dam, NGVD 29 plus 3.77 feet equals NAVD 88. Calculations for this report were based on NGVD 29 elevations.

Figure 2 Upper Baker Dam spillway evacuating Baker Lake

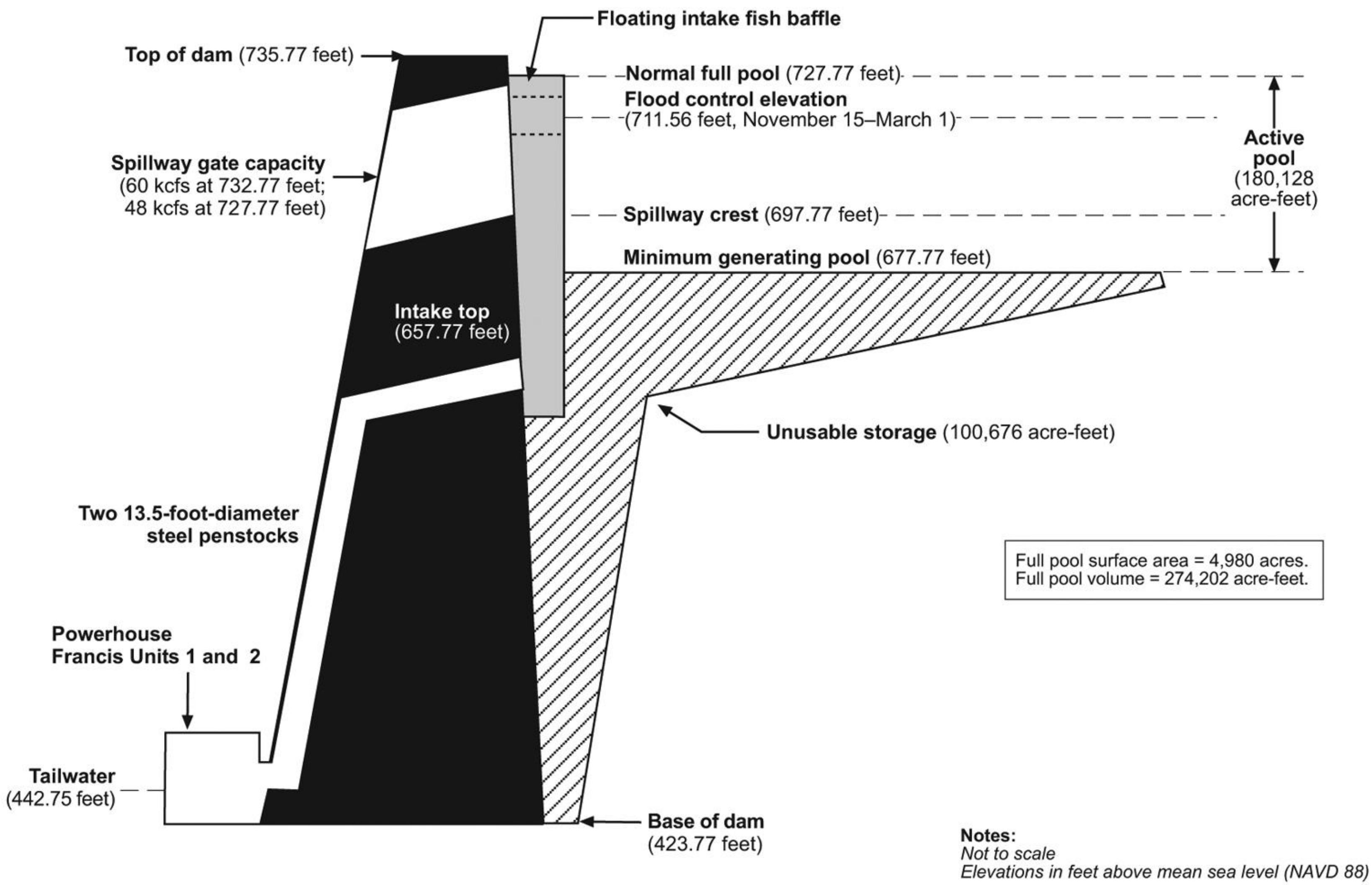

Figure 3 Upper Baker Dam cross-section (Source: Puget Sound Energy, 2003)

2. Lower Baker Dam

Lower Baker Dam (Figures 4 and 5) is located on the Baker River approximately one-half mile north of the confluence of the Baker and Skagit Rivers. The Lower Baker Dam, a semi-gravity arch dam, consists of a 23-gate spillway with a discharge capacity of 41,000 cfs at normal full pool [El. 442.35 feet (NAVD 88)] and a one-unit 79.3 MW powerhouse. The development also includes a reservoir and associated facilities.

Lake Shannon, the reservoir formed by Lower Baker Dam, is approximately seven miles long and covers a surface area of about 2,278 acres at normal full pool. At normal full pool, Lake Shannon has an estimated storage capacity of 146,279 acre-feet [plus unknown additional storage between El. 343.75 and El. 373.75 (NAVD 88)]. The reservoir has an active storage capacity of approximately 116,770 acre-feet above the minimum generating pool level of 373.75 feet (NAVD 88) (Puget Sound Energy 2003). The top of Lower Baker Dam is at El. 450.62 feet (NAVD 88). Water is released through the turbine intake or through the dam spillway. Under normal operating conditions, Lake Shannon is held at full pool during the summer months. Minimum reservoir elevations are typically attained from November through March or early April. The Lower Baker Dam has a drainage area 38 percent larger than the area above Upper Baker Dam, and passes approximately 35 percent more water in an average year than does the Upper Baker Dam. Lake Shannon can be operated in coordination with Baker Lake to provide flood control protections, but there is no formal agreement governing Lake Shannon operations to limit the pool level in order to provide flood control storage operation.

Figure 4 Lower Baker Dam spillway discharge evacuating Lake Shannon

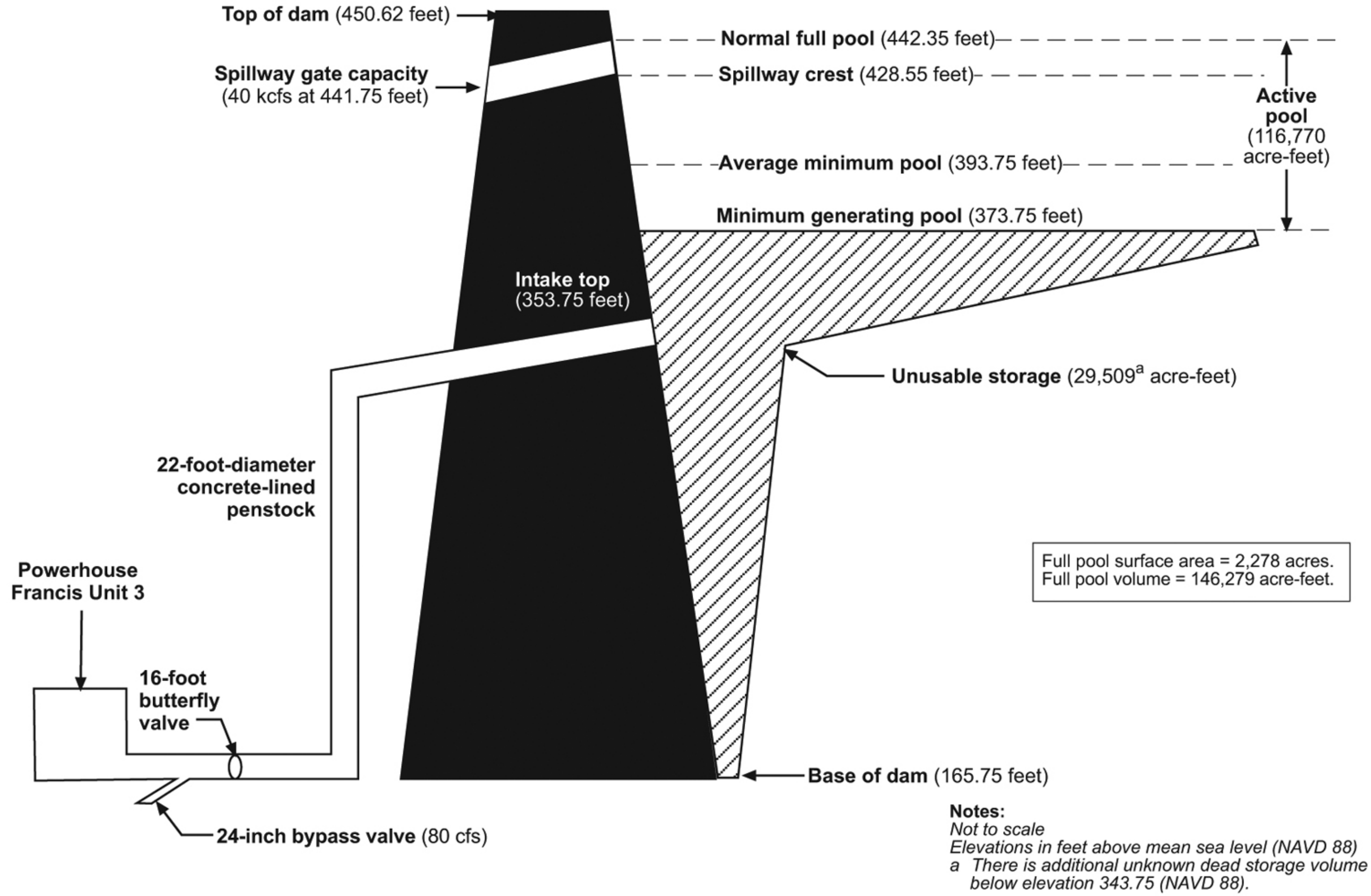

Figure 5 Lower Baker Dam cross-section (Source: Puget Sound Energy, 2003)

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3. Powerhouse

The powerhouse at Upper Baker Dam is an integral structure consisting of two generating units. The total flow through the two units at rated net head and best gate position is about 4,200 cfs and the normal maximum total turbine capacity is 5,050 cfs. The powerhouse at Lower Baker Dam consists of one generating unit. The flow through the turbine is 4,000 cfs at rated net head, and the normal maximum turbine capacity is 4,200 cfs.

4. Standard Operating Procedures

The Project is operated as a multi-purpose facility. It is managed for hydropower generation, flood control, recreation, and fisheries. Water levels in both reservoirs (Baker Lake and Lake Shannon) fluctuate seasonally in response to operational objectives, flood control requirements, and variations in natural inflows to the reservoirs.

The plant is operated in a semi-automatic mode. Units are started by the operator and then controlled by a computerized load center in the powerhouse. Operation varies seasonally, but is generally run-of-river. Most routine maintenance is performed in the fall, when water flow has diminished.

The reservoir level at Upper Baker Dam is generally maintained at the planned minimal flood control pool level at El. 711.56 (NAVD 88) at the beginning of flood season. The reservoir level is controlled by flow through the three spillway gates during reservoir operation. The reservoir level at Lower Baker Dam is normally held at full pool [El. 442.35 (NAVD 88)] during the summer months. Water is released through the turbine intake or through the 23-gate dam spillway.

B. Basin Hydrologic Data

1. Drainage Area

Baker River, the second largest tributary to the Skagit River, originates in the glacial fields of Mt. Baker and Mt. Shuksan and has an average annual flow of 2,110 (cfs) (U.S. Geological Survey 2000). From its headwaters, the Baker River flows toward the southwest and reaches the valley floor after about five miles. From this point, the Baker River valley continues in a southwesterly to southerly direction for about 25 miles to its confluence with the Skagit River. The Baker River watershed is generally very steep, with slopes from 20 to 40 percent over most of its area, with the exception of the valley bottom along the Baker River channel and some of its major tributary streams. The lower basin consists of a wide, unconfined valley floor composed of glacial and stream sediments, into which the Baker River has carved a narrow canyon up to 500 feet deep.

Lake Shannon occupies much of this canyon. The middle portion of the basin, site of Baker Lake, is a more confined valley where glacial and stream sediments have been covered by mudflows and recent alluvial deposits. The upper basin is a narrow rock canyon with a valley floor of recent deposits of sand and gravelly material. The main access into the watershed is afforded by the Baker Lake Highway (also known as Baker River Highway and U.S. Forest Service Road 11), which begins at the junction with the North Cascades Highway about six miles west of Concrete.

The Upper Baker and Lower Baker Dams are located 9.35 river miles and 1.2 river miles above the mouth of Baker River, respectively. The total drainage area for Baker River above the Baker River U.S. Geological Survey (USGS) gage near Concrete (USGS No. 12193500), located at river mile (RM) 0.7 upstream from its confluence with Skagit River, is 297 square miles. Approximately 214 square miles of the drainage basin lie upstream of Upper Baker Dam, and 83 square miles are between the two dams. The Baker River drainage area is approximately 11 percent of the drainage area (2,737 square miles) at the Skagit River streamflow gage near Concrete (Pacific International Engineering 2003a). The annual average flow recorded at the Baker River gage is 18 percent of that recorded at the Skagit River gage near Concrete, a runoff contribution proportionately higher than any other major subbasin of the Skagit River on a unit drainage area basis (Puget Sound Energy 2003).

2. Topography

Baker River lies in the Baker River valley. Elevations in the Baker River drainage area range from El. 300 feet (NAVD 88) near Lower Baker Dam to over El. 10,778 feet (NAVD 88) at Mt. Baker, sitting astride the western boundary of the Baker River Basin. The Upper and Lower Baker Dam drainages have a mean elevation of El. 3,698 feet and El. 3,365 feet (NGVD 29), respectively.

3. Soil Types

The Baker River valley in the vicinity of Baker Lake is geologically quite different from most of the other Skagit River tributaries. This is largely due to the influence of Mt. Baker, a volcanic cone.

Soil maps within the Baker River drainage area were obtained from USDA Natural Resources Conservation Service (NRCS). The main soil types from datasets SSURGO and STATSGO are WA240, WA242, WA243, WA248, WA249, and WA299. The equivalent hydrologic soil group for the drainage area is between B and C.

4. Land Use and Land Cover

Land ownership and management in the Baker River watershed are dominated by federal government holdings in the Mt. Baker-Snoqualmie National Forest (55.6 percent of the total watershed area) and in North Cascades National Park (30.4 percent). Private and state holdings account for the remaining 14 percent of the watershed's area. The private and state holdings are primarily confined to the lower watershed tributaries entering Lake Shannon and to the lower Baker River downstream of Lake Shannon.

Consistent with the dominance of federal ownership, 49 percent of the watershed is managed as wilderness, roadless areas, or national park. Recreation and management of lands for protection of natural values are the predominant land uses in the watershed. Most of the 14 percent of land in private and state ownership has been extensively harvested and is managed for silviculture (Puget Sound Energy 2003).

Land use and vegitative cover information for the drainage area was obtained from EPA Land Use and Land Cover (LULC) datasets. Most areas are forest land. The LULC types and distribution calculations are shown in Table 1.

Table 1 Land Use and Land Cover Calculations

Land Type	Area (sq. mi.)	Percent
Evergreen Forest Land	210.95	71.03%
Perennial Snowfields	14.13	4.76%
Glaciers	14.04	4.73%
Shrub & Brush Rangeland	14.02	4.72%
Mixed Forest Land	11.12	3.75%
Reservoirs	10.69	3.60%
Mixed Rangeland	6.88	2.32%
Bare Ground	6.88	2.32%
Shrub and Brush Tundra	4.47	1.51%
Mixed Tundra	1.78	0.60%
Bare Exposed Rock	0.95	0.32%
Lakes	0.46	0.16%
Residential	0.24	0.08%
Forested Wetland	0.15	0.05%
Strip Mines	0.12	0.04%
Trans, Comm, Util	0.08	0.03%
Streams and Canals	0.02	0.01%
Commercial and Service	0.02	0.01%
Cropland and Pasture	0.00	0.00%
Total	297.00	100.00%

5. Climate

The major factors influencing the climate of the Skagit River basin are terrain, proximity of the Pacific Ocean, and the position and intensity of semi-permanent high and low pressure centers over the north Pacific.

The watershed lies in a convergence zone between Pacific weather systems from the west and Arctic weather systems form the north. During the summer, the Pacific systems dominate and bring periods of generally clear weather and reduced precipitation. During the winter, the Arctic systems usually dominate, with the winter storms and increased precipitation. Lower temperatures at higher elevations in the watershed result in heavy snow in winter, a portion of which is stored in ice fields and glaciers.

Westerly air currents from the ocean prevail in the latitude bringing the region considerable moisture, cool summers, and comparatively mild winters. Annual precipitation throughout the basin varies markedly due to elevation and topography. Major storm activity occurs during the winter when the basin is subject to rather frequent ocean storms that include heavy frontal rains associated with cyclonic disturbances generated by the semi-permanent Aleutian Low. During the summer months, the weather is relatively warm and dry due to the increased influence of the semi-permanent Hawaiian high-pressure system.

The mean annual temperature varies from 40.1 degrees Fahrenheit (F) at Mt. Baker Lodge [El. 4,150 feet (NGVD 29)] to 50.7 F at Concrete [El. 195 feet (NGVD 29)]. Normal monthly temperatures vary in January from 26.9 F at Mt. Baker Lodge to 36 F at Concrete, and in August from 56.7 F at Mt. Baker Lodge to 64.3 F at Concrete.

Average annual precipitation in the Baker River basin ranges from about 70 inches at Concrete to greater than 150 inches at some of the higher elevations. The average annual runoff is approximately 120 inches from the Baker River basin and 75 inches from the Skagit River basin above the Concrete gage. Approximately 75 percent of this amount falls during the six-month period, October through March. Storm studies indicate that 5 to 6 inches of rainfall in a 24-hour period have occurred over much of the Skagit River basin. Between Concrete and Mount Vernon, the Skagit River drainage area increases by 356 square miles. The average annual runoff from this intermediate drainage area is approximately 50 inches.

Snowfall in the Skagit River basin is dependent upon elevation and proximity to the moisture supply of the Pacific Ocean. The mean annual snowfall is 525.3 inches at Mt. Baker Lodge.

Surface wind speed in the basin is the result of the pressure gradient between high and lower pressure cells, storm intensity, and topographic effects. In the upper valley above Concrete, the airflow is subject to topographic funneling effects and is generally up the valley in the winter and down slope in the summer. In the winter season, storm winds often range from 20 to 30 miles per hour (mph).

6. Streamflow Records

Continuous long-term streamflow and water surface stage records available to-date and used in the watershed model development are from three USGS gages located on the Baker River. These are: Baker River streamflow Gage No. 12193500 near Concrete below the Lower Baker Dam; Baker Lake stage Gage No. 12191600 above the Upper Baker Dam; and Lake Shannon stage Gage No. 12193000 above the Lower Baker Dam. These gages began operation in 1910, 1959, and 1925, respectively. There is also a long-term streamflow gage (USGS No. 12194000) on the Skagit River near Concrete, below the confluence of Baker River.

7. Floods of Record

The streamflow records at Baker River near Concrete are affected by regulations at Upper and Lower Baker Dams. A summary of the flood peaks of record and dates of occurrence are shown in Table 2.

Table 2 Largest Floods of Record for Skagit and Baker Rivers

	Baker River near Concrete Gage No. 12193500		Skagit River near Concrete Gage No. 12194000	
Rank	Peak (cfs)	Date	Peak (cfs)	Date
1	30,700	Oct. 21, 2003	164000	Oct. 21, 2003
2	29,400	Nov. 28, 1995	160000	Nov. 29, 1995
3	35,200	Nov. 27, 1949*	154000	Nov. 27, 1949
4	22,500	Nov. 13, 1990	149000	Nov. 10, 1990
5	21,400	Dec. 26, 1980	148700	Dec. 26, 1980
6			147000	Feb. 27, 1932
7	29,700	Feb. 10, 1951*	139000	Feb. 10, 1951
8	31,200	Dec. 18, 1979*	135800	Dec. 18, 1979
9			131000	Jan. 25, 1935
10	26,900	Dec. 05, 1975*	122000	Dec. 04, 1975
11	21,300	Dec. 15, 1989	119000	Dec. 04, 1989
12			116000	Nov. 13, 1932
13	36,600	Nov. 19, 1962*	114000	Nov. 20, 1962

*Occurred before the current 74,000 acre-feet flood control operation began in 1980 at Upper Baker Dam

All flood peaks recorded after 1980 were affected by the flood control storage operations at the Upper Baker Dam. Most major historical floods for Baker River and Skagit River occur during the winter season from October to February, and occasionally in the spring season, primarily during general storm rain on snow.

C. Previous Study

The Spillway Design Flood (SDF) inflow for the Upper Baker Dam was developed for PSE by Hydrocomp International in 1969 using probable maximum precipitation (PMP) values and maximum snowpack for the Baker River Basin (U.S. Army Corps of Engineers 2000a). This study estimated the peak inflow at the Upper Baker Dam to be 118,200 cfs. The Corps routed the inflow through Baker Lake, assuming the lake to be drafted down to the minimum flood control pool of El. 707.93 feet (NGVD 29) following an antecedent flood prior to the SDF. This SDF reservoir routing determined the maximum regulated pool elevation to be El. 727.32 feet (NGVD 29), and the maximum discharge to be 56,000 cfs. A five-day volume was determined to be 241,200 acre-feet. No other previous study pertaining to the PMF is available for either the Upper or Lower Baker Dam.

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II. Watershed Model and Subdivision

A. Watershed Model Methodology

A watershed rainfall-runoff model for two subbasins of the Baker River drainage area was developed through application of the HEC-1 program (U.S. Army Corps of Engineers 1991). These two subbasins are: the drainage above the Upper Baker Dam; and the intermediate drainage between Upper and Lower Baker Dams. The watershed model was based on the Clark unit hydrograph method. The HEC-1 modeling requires input of subbasin drainage geometric data, meteorological data, and hydrological parameters including Clark unit hydrograph parameters, ground losses, and base flow estimates. The HEC-1 optimization process for preliminary determination of the two Clark unit hydrograph parameters [time of concentration (Tc) and basin storage coefficient (R)] and ground loss rates was initially carried out for the entire Baker River Basin. The optimized hydrological parameters were then adjusted for application to the two subbasins by comparison of subbasin drainage geometric data including drainage area, slope, and stream length.

The recorded hourly streamflows at the Baker River stream gage near Concrete (USGS No. 12193500) were unregulated based on storage changes in Baker Lake and Lake Shannon. The unregulated flows were used for the basin parameter optimization.

B. Subbasin Definition

Figure 6 shows the two subbasins delineated in the watershed model. They are: one above Lower Baker Dam; and the other between Upper and Lower Baker Dams. Both were delineated by application of the HEC-GeoHMS program (U.S. Army Corps of Engineers, 2000b) using the USGS ten-meter Digital Elevation Model (DEM). Drainage sizes for these subbasins are listed in Table 3.

Table 3 Subbasin Drainage Sizes

Subbasin	Drainage Size (sq. mi.)
Above Upper Baker Dam	214
Between Upper and Lower Baker Dams	83

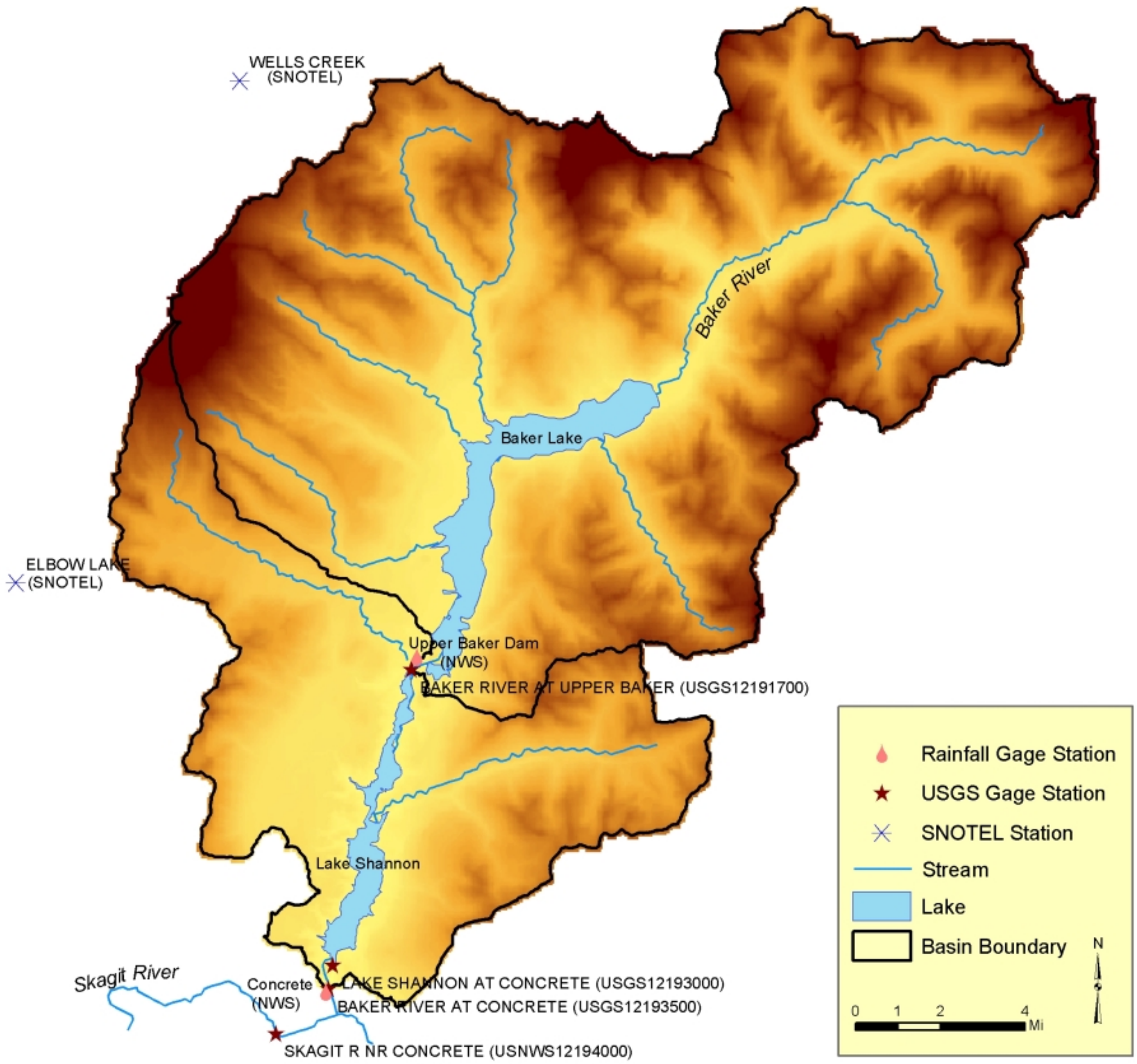


Figure 6 Baker River Basin map, Upper and Lower Baker Dams PMF Study

III. Historic Flood Records

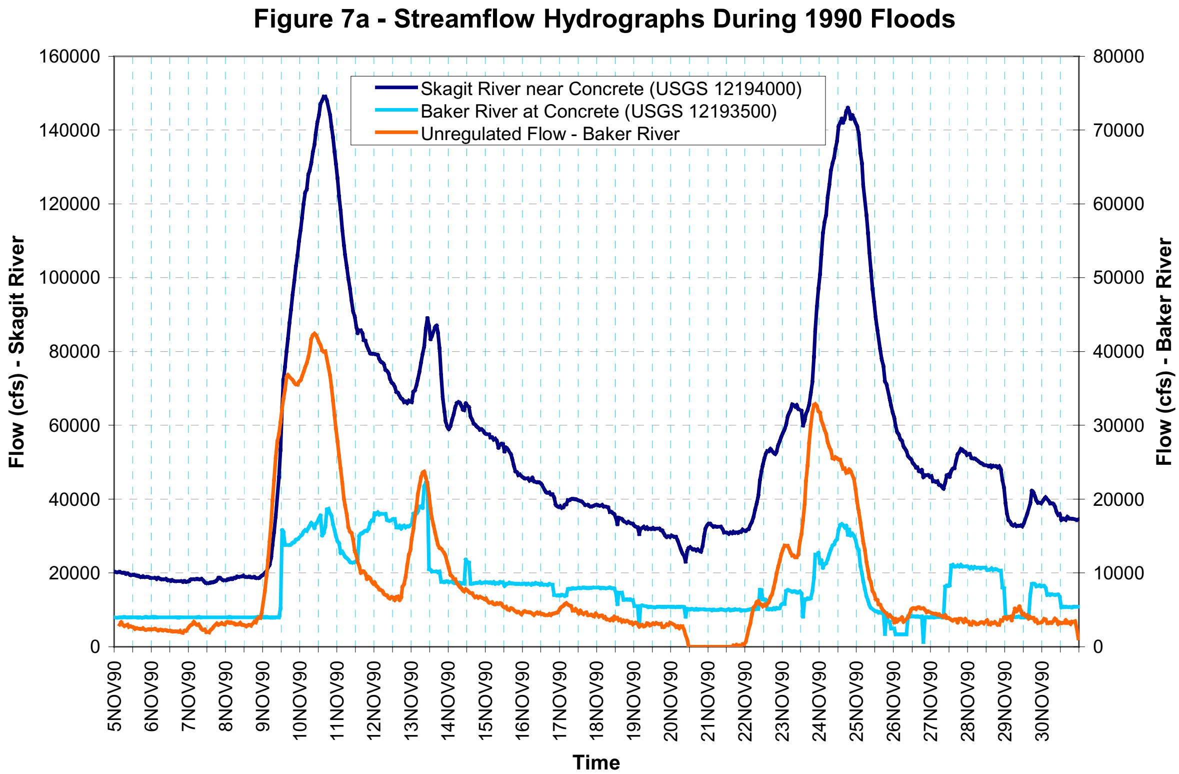
A. Stream Gages and Stage Gages

Information is provided in Section I.B.6. Streamflow Records.

B. Historic Floods

In this PMF study, three recent floods, two in 1990 and one in 1995 were selected for calibration and verification of the watershed model.

The flood peaks recorded at the Skagit River stream gage near Concrete (USGS No. 12194000) on November 10 and 24, 1990, and November 29, 1995 are 149,000 cfs, 146,000 cfs, and 160,000 cfs, respectively. These floods are approximately the 25- to 30-year events. Plots of the recorded hourly stream flows and hourly water surface elevations of Baker Lake and Lake Shannon during these floods are shown in Figures 7 and 8. Also shown in these figures are the estimated Baker River unregulated flow hydrographs during these events.



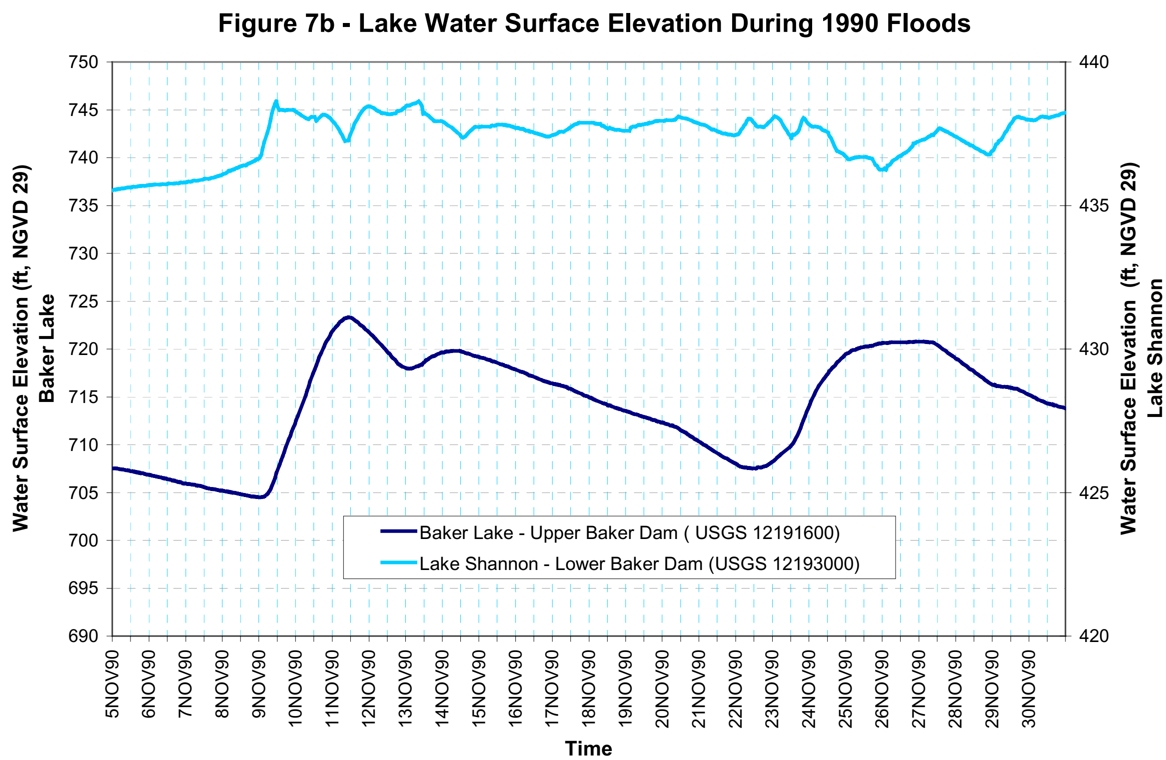
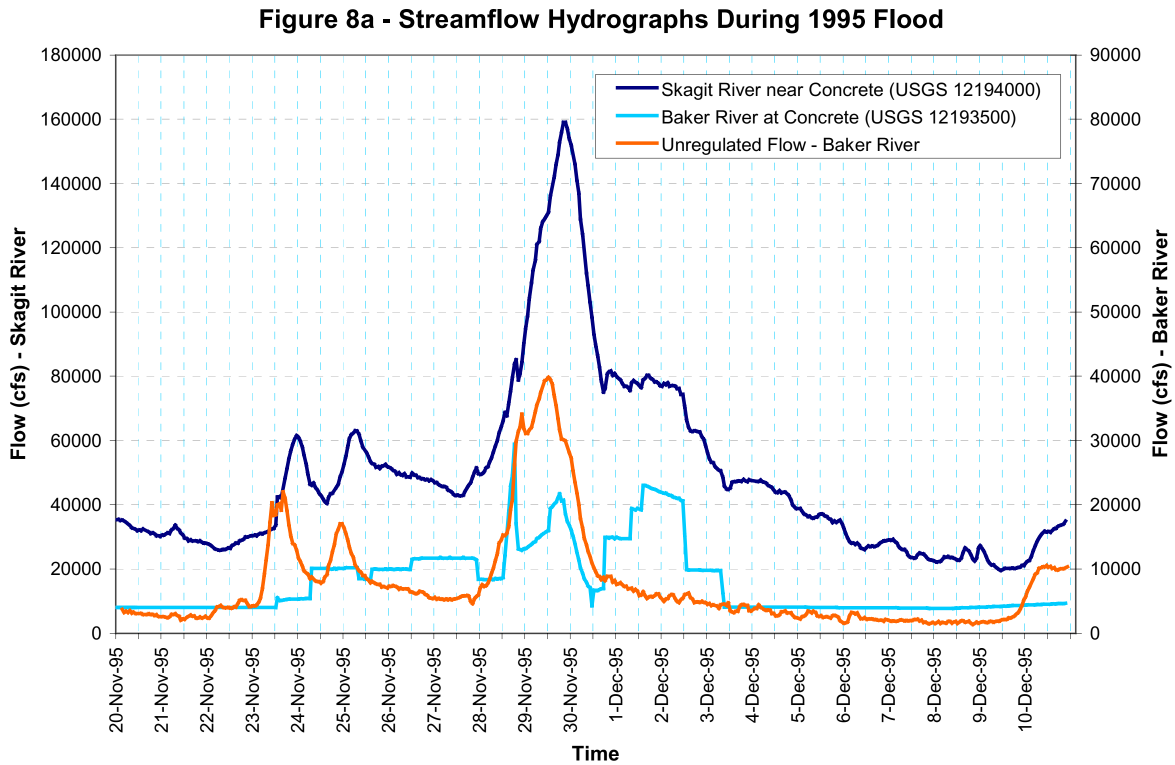


Figure 7 Streamflow and lake water surface elevation hydrographs for 1990 floods



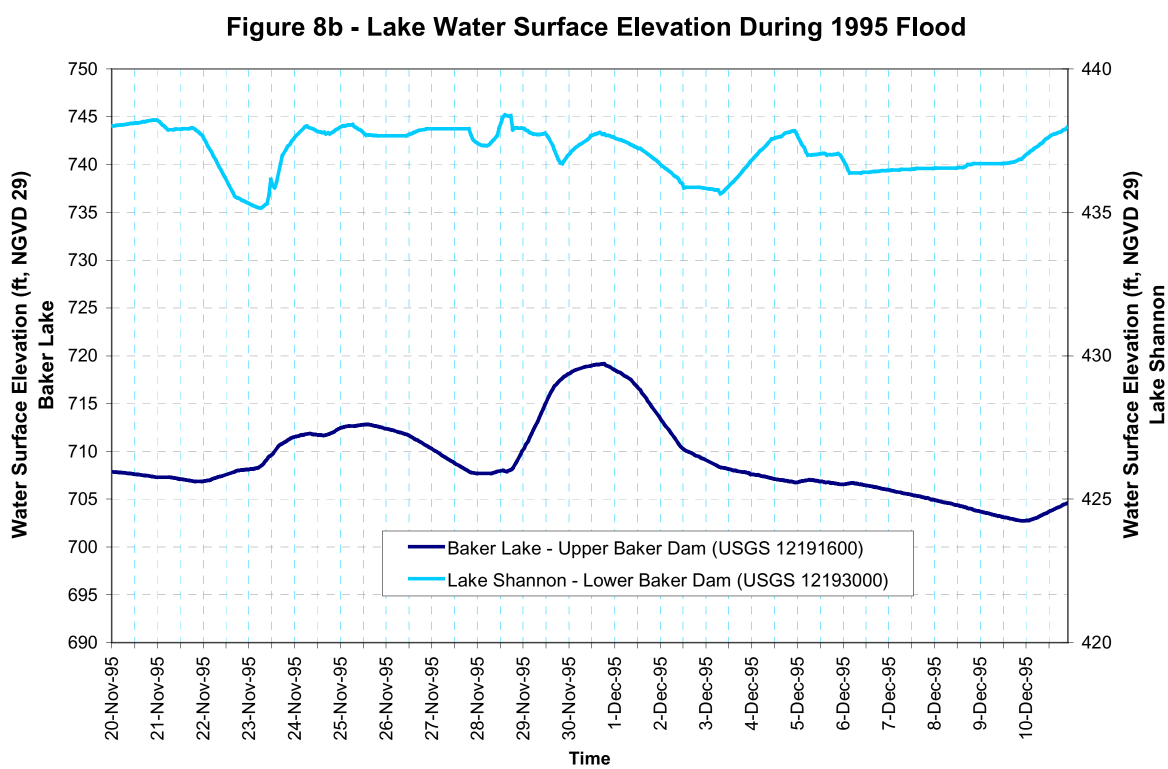


Figure 8 Streamflow and lake water surface elevation hydrographs for 1995 flood

C. Precipitation Associated with Historic Floods

Weather stations and available data pertaining to this study are listed in Table 4. Recorded precipitation data at Upper Baker Dam during the selected three flood events are shown in Figures 9 and 10. These data obtained from National Weather Service (National Weather Service 1994) and NRCS, were used in the watershed model development.

Table 4 Precipitation and Snowpack Stations

Station Name	Elevation (ft, NGVD 29)	Data Type	Data Available
Upper Baker Dam	690	Hourly	Precipitation
Sea-Tac Airport	400	3-hour	Precipitation, Temperature, Dew Point
Concrete	270	Daily	Precipitation
Wells Creek	4,200	Daily	Precipitation, Snow, Temperature
Elbow Lake	3,200	Daily	Precipitation, Snow, Temperature
Thunder Creek	4,200	Daily	Precipitation, Snow, Temperature
Rainy Pass	4,780	Daily	Precipitation, Snow, Temperature

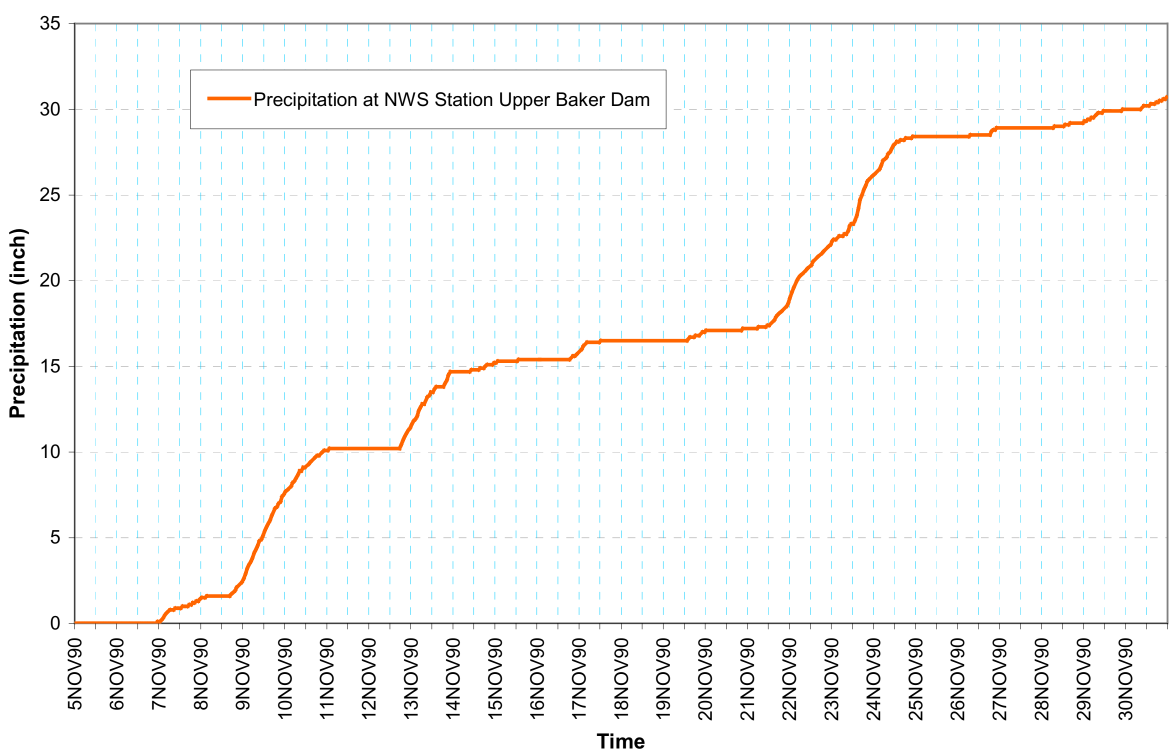


Figure 9 Cumulative precipitation recorded at Upper Baker Dam during 1990 floods

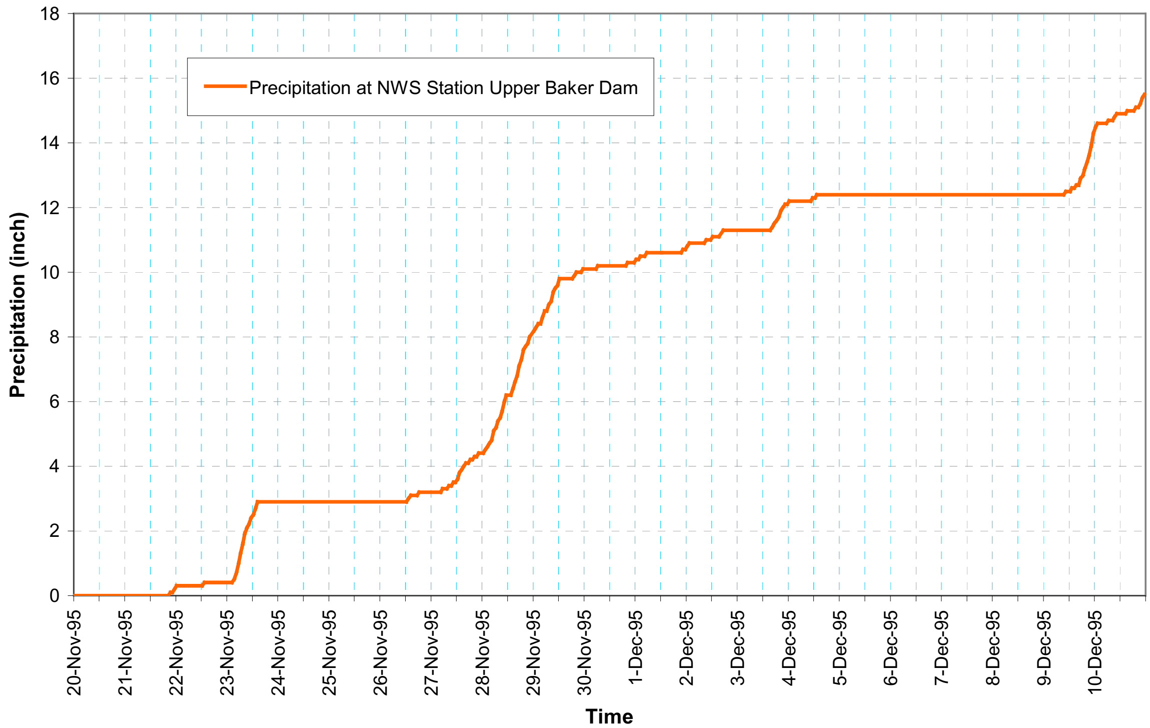


Figure 10 Cumulative precipitation recorded at Upper Baker Dam during 1995 flood

D. Snowpack and Snowmelt During Historic Floods

Snow data recorded at NRCS SNOTEL stations (Table 4 and Figure 6) were used to estimate the snow and water equivalent during floods. The mountain snowpack near the basin during the winters of 1990 and 1995 was not abnormally high. The recorded water equivalent content in November 1990 and 1995 at SNOTEL stations are listed in Table 5.

Table 5 Water Equivalent (in inches) Snowpack Record

Station Name	Elevation	11/10/90	11/24/90	11/29/95
Wells Creek	4,200			1.5
Elbow Lake	3,200			1.0
Thunder Creek	4,200	1.0	0.0	7.0
Rainy Pass	4,780	6.0	12.0	11.5

From the recorded data, the amount of snow melt contributing to flow is insignificant for the flood events in 1990 and 1995. The floods were primarily a result of intensive storm rainfall.

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IV. Unit Hydrograph Development

A. Approach

Two separate PMFs, one for Upper Baker Dam, and the other for Lower Baker Dam, were developed by application of the Clark unit hydrograph procedure with rainfall and snowmelt excesses. A Clark unit hydrograph was developed (Bureau of Reclamation 1987) for each of the two delineated subbasins, one being the drainage area above Upper Baker Dam, and the other, the intermediate drainage area between Upper and Lower Baker Dams. The November 24, 1990 and November 29, 1995 flood hydrographs were used for the watershed model parameter optimization. Preliminary watershed parameters based on average values of the optimized parameters for these two floods were used to verify the November 10, 1990 flood hydrographs. The recorded snowpack, temperature, dew point, wind speed, and precipitation data in the area were used in the model parameter optimization and verification.

A HEC-5 (U.S. Army Corps of Engineers 1998c) model developed for the Skagit River Basin was provided by the Corps (U.S. Army Corps of Engineers 1998a). This model was modified to route the PMF hydrographs through Baker Lake and Lake Shannon assuming a coincident flood corresponding to the 500-year flood at Concrete, as requested by the Corps (U.S. Army Corps of Engineers 2003), over the rest of the Skagit River Basin. A 50 percent PMF in the Baker River with a 25-year coincident flood over the rest of the Skagit River Basin was assumed as the antecedent condition approximately five days prior to the start of each of the two PMFs. The 500-year and other synthetic flood hydrographs used in this study were provided by the Corps (U.S. Army Corps of Engineers 1998d).

B. Baseflow Separation

Baseflows were separated from the unregulated flood hydrographs for the entire Baker River Basin to obtain the surface runoff hydrographs.

The baseflows for the two subbasins (above Upper Baker Dam, and between Upper and Lower Baker Dams) were estimated based on the area ratio of each subbasin to the total area of the Baker River Basin.

C. Preliminary Estimates of Clark Parameters for Baker River Basin

The Clark unit hydrograph parameters determined from the HEC-1 unit hydrograph parameter optimization procedures are listed in Table 6 for the total Baker River drainage area for the three historical floods (two events in November 1990, and the November 1995 event).

Table 6 Clark Unit Hydrograph Parameters for Total Baker River Drainage Area

Flood	Time of Concentration (Tc), hrs	Storage Coefficient (R), hrs	R/(R+Tc)
Nov. 24, 1990	8.35	15.65	0.65
Nov. 29, 1995	7.72	13.03	0.63
Nov. 10, 1990	8.04	14.30	0.64

D. Estimate of Infiltration During Historic Floods

The equivalent uniform infiltration loss rates for the total Baker River drainage area were determined through the HEC-1 unit hydrograph optimization procedures to be 0.074 inch per hour for the November 24, 1990 flood; 0.070 inch per hour for the November 29, 1995 flood; and 0.077 inch per hour for the November 10, 1990 flood.

E. Subbasin Unit Hydrograph Parameters

The Clark unit hydrograph parameters, Tc and R, adjusted and adapted for the two subbasins are listed in Table 7. These parameters were based on the model calibration and verification of the three selected historical floods, and then further adjusted by applying a conservative reduction factor of 90 percent to the PMF development.

Table 7 Adapted Clark Unit Hydrograph Parameters for Subbasins

Subbasin	Tc (hr)	R (hr)
Sub-drainage Above Upper Baker Dam	7.20	12.80
Sub-drainage Between Upper and Lower Baker Dams	5.60	10.00

V. Unit Hydrograph Verification

The unit hydrograph parameters determined from optimization of the November 24, 1990 and November 29, 1995 flood hydrographs were verified for the flood occurring in November 10, 1990. The verification indicated that the historical flood hydrographs reproduced by the watershed model have sufficient accuracy for the study basin (Pacific International Engineering 2003b). The HEC-1 output for the unit hydrograph calibration and verification runs, as well as for the PMF study runs is provided in a separate document package.

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VI. Probable Maximum Precipitation

A. Probable Maximum Precipitation Data

Upper and Lower Baker Dams have a drainage area of 214 and 297 square miles, respectively. Major reservoirs within the basin include Baker Lake and Lake Shannon. The general storm probable maximum precipitation (PMP) for the 214-square-mile basin above Upper Baker Dam and for the 297-square-mile basin above Lower Baker Dam was derived in accordance with the procedure outlined in HMR 57. The 72-hour general storm PMP was derived for November through February with snowmelt.

Historically, November through February have produced extreme floods with rain and rain on snow. November is the most critical month to produce PMP on snow because the 12-hour maximum persisting 1,000-millibar (mb) dew point is the highest among these four months (National Weather Service 1994). Therefore, the November PMP values, adequate basin snowpack, and ambient temperature conditions were used to provide snowmelt for the duration of the entire storm event.

The analysis resulted in a basin-average November 72-hour PMP value of 30.31 inches for the basin above Upper Baker Dam and 28.58 inches for the basin above Lower Baker Dam.

The local storm (or thunderstorm) PMP was also derived in accordance with HMR 57 procedures. The analysis resulted in a warm season 6-hour thunderstorm PMP of 2.31 inches for the 214-square-mile basin above Upper Baker Dam, and 1.89 inches for the 297-square-mile-basin above Lower Baker Dam. These PMP values are much less than the 6-hour general storm PMP values of 6.65 inches for the basin above Upper Baker Dam, and 6.19 inches for the basin above Lower Baker Dam, respectively.

B. Candidate Storms for PMF

The candidate storm considered for the Upper and Lower Baker Dam PMFs is thus, the November 72-hour general storm PMP with snowmelt. These PMP values, derived in accordance with HMR 57 procedures, are presented in Table 8. Two corresponding PMFs, based on the HEC-1 modeling, were developed for the 214-square-mile basin above Upper Baker Dam, and the 297-square-mile basin above Lower Baker Dam.

Table 8 November Cumulative General Storm PMP Values

	November Cumulative General Storm PMP Without Snowmelt	
Duration (hr)	214-square-mile basin above Upper Baker Dam (in)	297-square-mile basin above Lower Baker Dam (in)
1	1.58	1.48
6	6.65	6.19
24	16.92	15.88
48	25.48	23.98
72	30.31	28.58

The basin-average 72-hour snowmelt values were estimated for heavy forested drainage area. Seventy-five percent snowmelt availability was assumed during the snowmelt calculations. The 72-hour snowmelt values are 4.79 inches (75 percent of 6.38 inches) for the basin area above Upper Baker Dam, and 4.91 inches (75 percent of 6.54 inches) for the basin area above Lower Baker Dam, while the snow water equivalent of the seven-year average cumulative for the season through November 30 is 4.24 inches (1.3 to 8.5 inches) at Elbow Lake, and 4.31 inches (2.3 to 8.2 inches) at Wells Creek.

The 72-hour total PMP plus snowmelt values were thus determined to be 35.10 inches for the 214-square-mile basin above Upper Baker Dam, and 33.49 inches for the 297-square-mile basin above Lower Baker Dam.

VII. Loss Rates

A. Discussion of Loss Rate Methodology

Loss rates in the subbasin above Lower Baker Dam were developed for the watershed model as discussed in Section IV.C. Losses are the difference between total storm precipitation/snowmelt and storm runoff. Based on reconstruction of historical hydrographs, the loss rates optimized by HEC-1 were an equivalent 0.074-inch-per-hour for the November 24, 1990 flood event, 0.070-inch-per-hour for the November 29, 1995 flood event, and 0.077-inch-per-hour for the November 10, 1990 flood event. Variation of loss rates among these floods is relatively small. To be conservative, a reduced loss rate of 0.065 inch per hour was chosen for the PMF development.

B. Warm-Season

The areas above both Upper and Lower Baker Dams contributing surface runoff are heavily forested. As such, unfrozen ground conditions during the November PMP for the saturated soil infiltration rates were assumed for the PMF development. Snowmelt contributed insignificantly to the major historical floods, and added less than five inches of runoff to the November general storm PMF for the basin.

C. Cool-Season

Frozen ground conditions would not be applicable for the November PMF development.

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VIII. Coincident Hydrometeorological and Hydrological Conditions for the PMF

A. Reservoir Level

The November normal maximum operating elevations of El. 707.93 feet (NGVD 29) for Upper Baker Dam, and El. 438.60 feet (NGVD 29) for Lower Baker Dam, were assumed to be the starting water surface levels during the PMF. Baker Lake provides 74,000 acre-feet of flood control storage at the assumed starting level. The assumed antecedent condition of a 50 percent PMF approximately five days prior to the PMF start would not result in a higher starting Baker Lake level during the PMF. Lake Shannon does not provide any flood control storage. The starting reservoir levels at the dams would not significantly affect the results of the PMF routing through the reservoirs.

B. Baseflow

The base flows selected for various portions of the basin during the PMF are based on the average conditions for historical floods in 1990 and 1995. These values, initially during the PMFs, are 2,500 cfs and 970 cfs for the subbasin above Upper Baker Dam, and the subbasin between Upper and Lower Baker Dams, respectively. These base flow values were not critical to the PMF runoff contribution.

C. Snowpack

There is a reasonable probability that some snowpack will be available in November for melt during the PMF. The snowpack conditions providing snowmelt were assumed to coincide with the PMP.

D. Snowmelt

The Corps' Engineering Manual EM 1110-2-1406 (U.S. Army Corps of Engineers 1998b) was used to compute snowmelt during the PMP. Temperature data developed from HMR 57, together with rainfall and wind speed were used as input for the snowmelt calculations. The snowmelt runoff contribution to the PMF was computed assuming basin-average snowpack conditions. The 72-hour total snowmelt during the PMP was computed to be 4.79 and 4.91 inches for the 214-square-mile basin above Upper Baker Dam and the 297-square-mile basin above Lower Baker Dam, respectively.

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IX. PMF Hydrographs

A. Inflow and Outflow PMF Hydrographs

The PMF inflow computations were made for the November 72-hour general storm PMP with snowmelt using the HEC-1 model. The associated flood routings through the dams were made using HEC-5 models. The time interval of the HEC-1 rainfall-runoff model computations is one hour. The computational time interval of the HEC-5 reservoir routing model is also one hour. Total outflows at Upper and Lower Baker Dams in the HEC-5 routing include flows through the gated spillway and turbine(s), and flows overtopping dams.

The Upper Baker Dam PMF inflow hydrograph computed by the HEC-1 rainfall-runoff model for the 214-square-mile basin above Upper Baker Dam and the assumed coincident flood hydrograph for the intermediate subbasin between Upper and Lower Baker Dams are presented in Figure 11. The Lower Baker Dam PMF hydrographs computed by the HEC-1 model for the basin above Upper Baker Dam and the intermediate basin between Upper and Lower Baker Dams are presented in Figure 12.

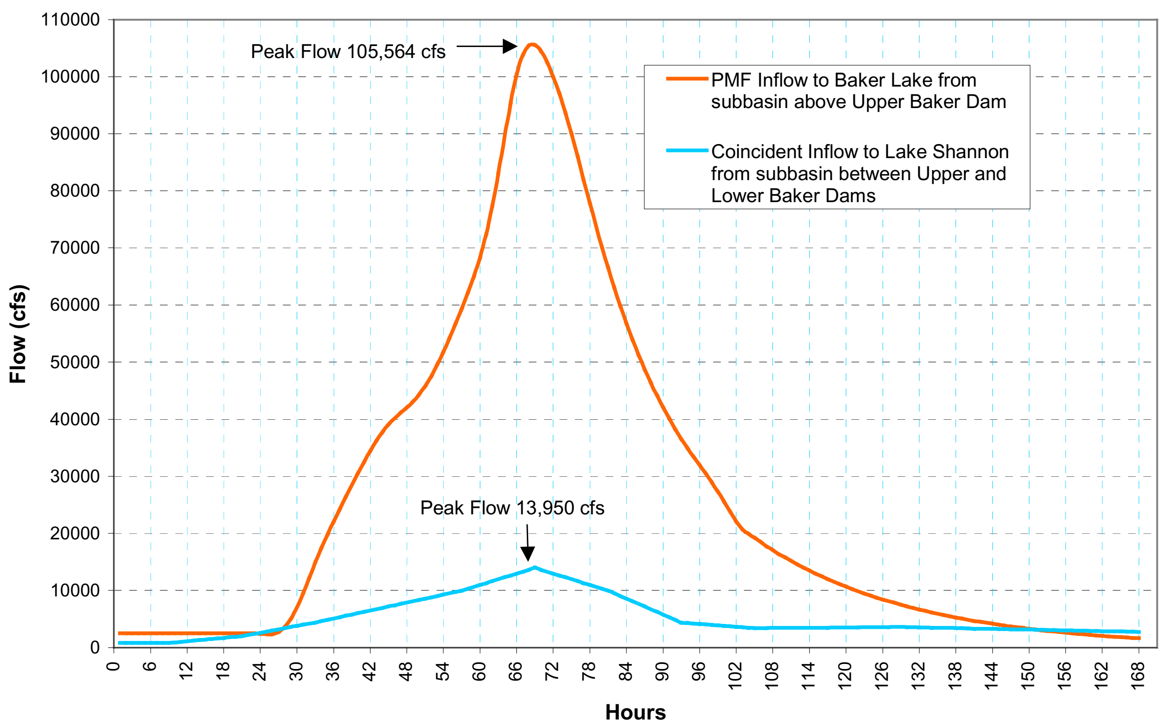

Figure 11 Subbasin inflow hydrographs for Upper Baker Dam PMF

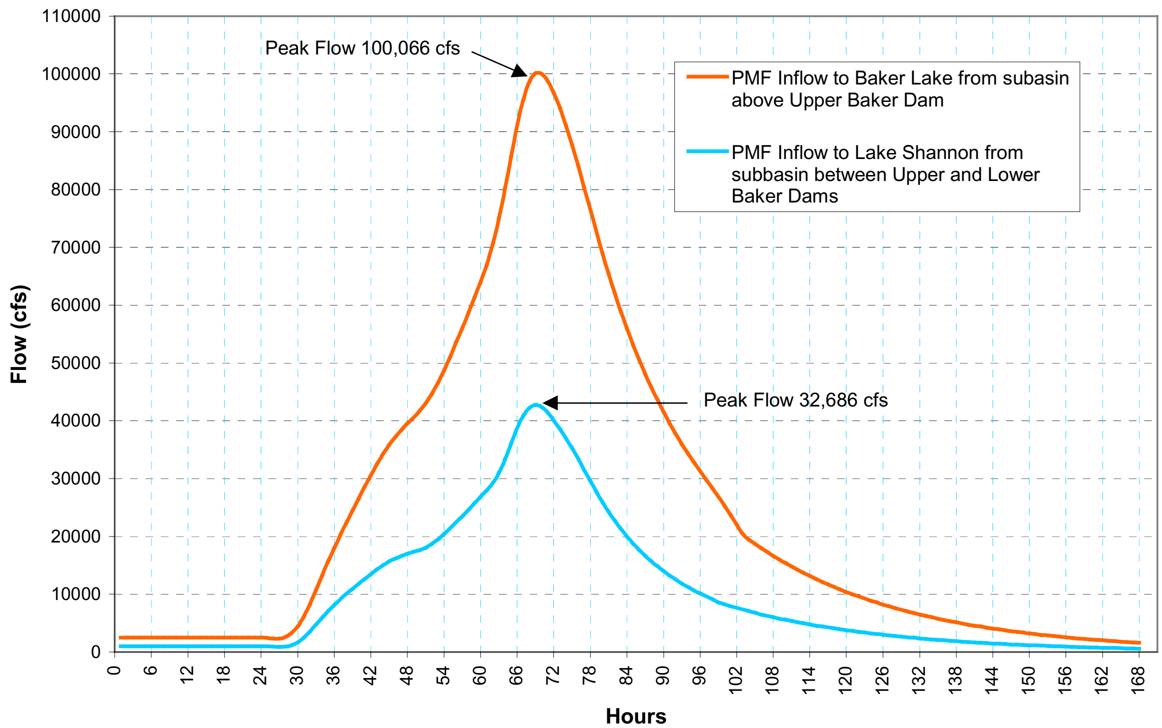

Figure 12 Subbasin inflow hydrographs for Lower Baker Dam PMF

The PMF hydrographs routed by the HEC-5 reservoir routing model through Baker Lake and Lake Shannon are presented in Figures 13 and 14 for the Upper Baker Dam PMF and the Lower Baker Dam PMF, respectively. The PMF peak flows, lake water surface elevations , and dam overtopping results are provided in Table 9.

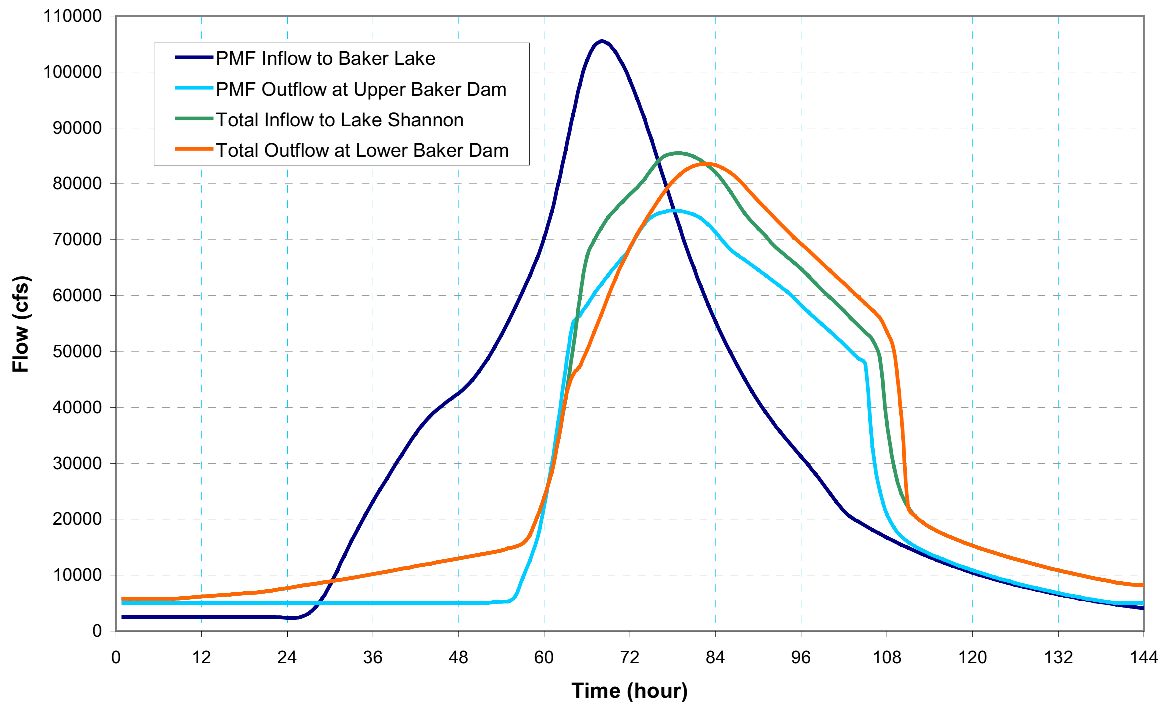

Figure 13 Inflow and outflow hydrographs for Upper Baker Dam PMF

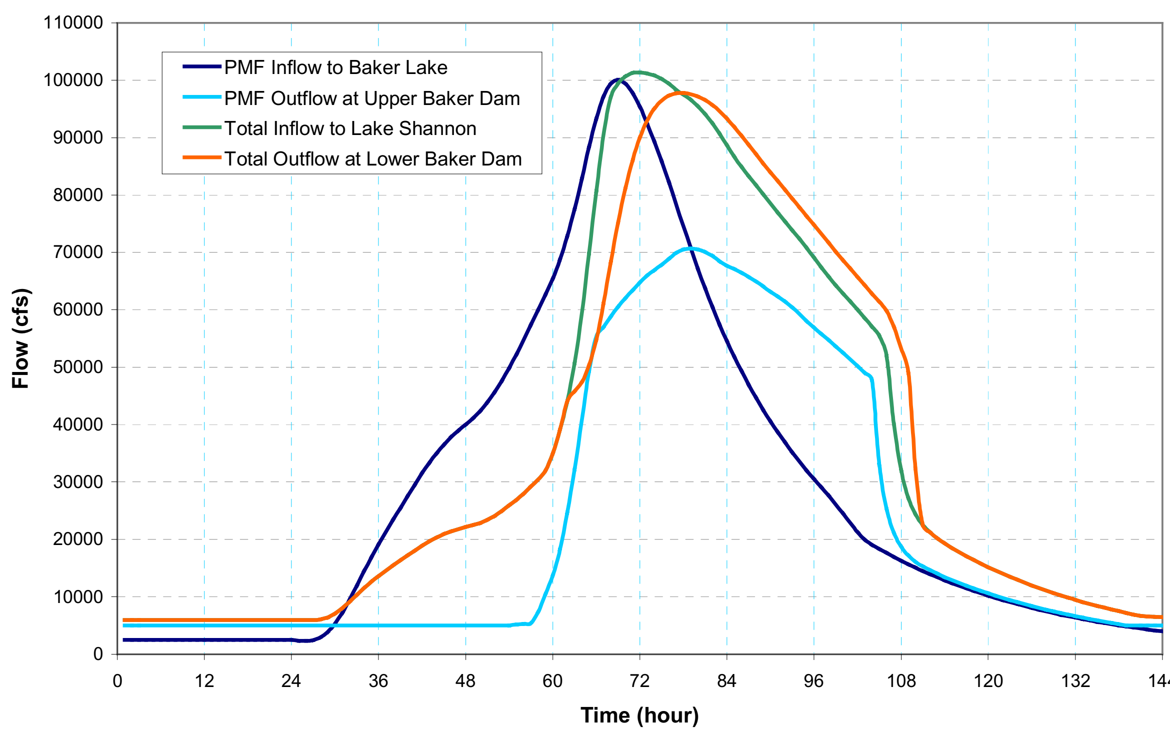

Figure 14 Inflow and outflow hydrographs for Lower Baker Dam PMF

Table 9 PMF Peak Flows and Lake Levels

Location Description	PMF Peak Flow/Stage and Dam Overtopping	
	For Upper Baker Dam PMF	For Lower Baker Dam PMF
Inflow to Baker Lake	105,564 cfs	100,066 cfs
Max. Baker Lake Elevation (NGVD 29)	733.44 ft	732.47 ft
Overtopping Upper Baker Dam (732.0 ft, NGVD 29), depth/duration	1.44 ft / 15 hr	0.47 ft / 8 hr
Outflow at Upper Baker Dam	75,225 cfs	70,679 cfs
Inflow to Lake Shannon	85,491 cfs	101,361 cfs
Max. Lake Shannon Elevation (NGVD 29)	444.81 ft	446.61 ft
Overtopping Lower Baker Dam Parapet Wall (439.87 ft, NGVD 29), depth/duration	4.94 ft / 42 hr	6.74 ft / 43 hr
Outflow at Lower Baker Dam	83,561 cfs	97,804 cfs

For the Upper Baker Dam PMF, the modeled peak inflow to Baker Lake is 105,564 cfs, and the routed peak outflow at Upper Baker Dam is 75,225 cfs. The subsequently routed peak inflow to Lake Shannon and peak outflow at Lower Baker Dam are 85,491 cfs and 83,561 cfs, respectively, under the assumed coincident flow conditions for the lower basin. The maximum Baker Lake level during the PMF is at El. 733.44 feet (NGVD 29), overtopping Upper Baker Dam by 1.44 feet for 15 hours. The maximum Lake Shannon level during the PMF is at El. 444.81 (NGVD 29), overtopping Lower Baker Dam by 4.94 feet (over the dam parapet wall) for 42 hours.

For the Lower Baker Dam PMF, the modeled peak inflow to Baker Lake is 100,066 cfs, and the routed peak outflow at Upper Baker Dam is 70,679 cfs. The subsequently routed peak inflow to Lake Shannon and peak outflow at Lower Baker Dam are 101,361 cfs and 97,804 cfs, respectively, during the PMF. The maximum Baker Lake level during this PMF is at El. 732.47 feet (NGVD 29), overtopping Upper Baker Dam by 0.47 feet for 8 hours. The maximum Lake Shannon level during this PMF is at El. 446.61 (NGVD 29), overtopping Lower Baker Dam by 6.74 feet (over the dam parapet wall) for 43 hours.

B. Sensitivity Analysis

Both the Upper and the Lower Baker Dam PMFs were developed by application of the Clark unit hydrograph procedure with the PMP and snowmelt excesses. The Clark unit hydrograph parameters, Tc, and R, used in the rainfall-runoff watershed model were developed based on optimization of historical flood hydrographs. Uncertainty exists in direct application of these parameters to the PMF development. This is due to the fact that the PMF values for the Upper and Lower Baker Dams basins are significantly higher than any historical floods recorded at the USGS gages in the basin.

A sensitivity analysis was performed by applying adjustment factors for all subbasins to the optimized Clark unit hydrograph parameters Tc and R. The PMF values are sensitive to these parameters. The adjustment factor was applied to the PMF modeling by multiplying the optimized Tc and R values by the factor to reduce the time of concentration and the storage coefficient. Table 10 presents results of the sensitivity analysis using the adjustment factors of 100, 90, and 80 percent. Use of the 100 percent adjustment factor represents the case directly using the optimized Tc and R values to the PMF modeling. The final PMF hydrographs selected for Upper and Lower Baker Dams are based on the 90 percent factor, which was judged to be reasonable.

Table 10 Results of Sensitivity Analysis

Peak PMF	Adjustment Factor Applied to Tc and R		
	100%	90%	80%
Upper Baker Inflow (cfs) (Upper Baker Dam PMP)	101,663	105,564	110,636
Lower Baker inflow (cfs) (Lower Baker Dam PMF)	41,171	42,686	44,354

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