9. PROBABLE MAXIMUM PRECIPITATION AND PROBABLE MAXIMUM FLOOD

9.1. Introduction

Due to the size of Watana Dam and the economic importance of the Project to the Railbelt, the Probable Maximum Flood (PMF) was selected as the inflow design flood for Watana Dam. The PMF is an industry standard design criterion that federal regulatory authorities apply to large dams like Watana Dam. The PMF is the highest flood design standard applied to any dam. The PMF is defined as the largest flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in the drainage basin tributary to Watana Dam. The PMF results from the Probable Maximum Precipitation (PMP) and other coincident conditions including snowmelt. The PMF inflow hydrograph was routed through the reservoir with the ultimate purpose of sizing the spillway and outlet works and providing information for selection, at a later date, of a dam crest level that ensures the passage of a flood without jeopardizing the safety of the dam. This section of the report briefly summarizes development of the PMP and PMF. A complete PMF study report, which also includes a complete site-specific PMP report, is included as Appendix B4 to this Engineering Feasibility Report.

9.2. Watershed Description

The watershed is in a remote part of the Susitna River, with Watana Dam located 187 project river miles upstream from Cook Inlet. The drainage area tributary to the Watana Dam site is about 5,180 square miles (sq.mi.), which compares to about 20,000 sq.mi. for the entire Susitna River watershed. The topography upstream from the proposed Watana Dam is mostly rugged, ranging from hilly to mountainous with glaciers. Although watershed elevations reach over 13,000 ft., almost 70 percent of the watershed tributary to the Watana Dam site is below 4,000 ft. in elevation and 88 percent is below 5,000 ft. The predominant types of watershed cover include shrub/scrub, 45 percent; evergreen forest, 17 percent; and barren land, 15 percent. Glaciers and perennial snow cover about five percent of the area and open water and lakes account for about three percent of the area tributary to the Watana Dam site. Streamflow is highly seasonal with over 85 percent of the annual average flow occurring during the five-month period of May through September.

9.3. Historic Floods

In 60 years of historical record at the U.S. Geological Survey (USGS) gaging station downstream of the dam site at Gold Creek, which has a drainage area of 6,160 sq.mi., the peak recorded flow has been 90,700 cfs. The estimated 100-year peak flow at the Watana Dam site is 91,300 cfs. In the 134 station-years of flow data for USGS gages at or upstream from Gold Creek, 100 percent of the annual peak flows have occurred during the months of May through September. Susitna River floods were found to be of two types, those in May or June that primarily result from snowmelt, and those in July, August or September that primarily result from rainfall.

Figure 9.3-1 shows the watershed boundary for the drainage area tributary to Watana Dam, and the boundary of the additional drainage area tributary to Gold Creek where a long-term USGS gaging station is located. The five USGS gaging stations shown on Figure 9.3-1 were the ones used in the current study for calibration of the flood runoff model.

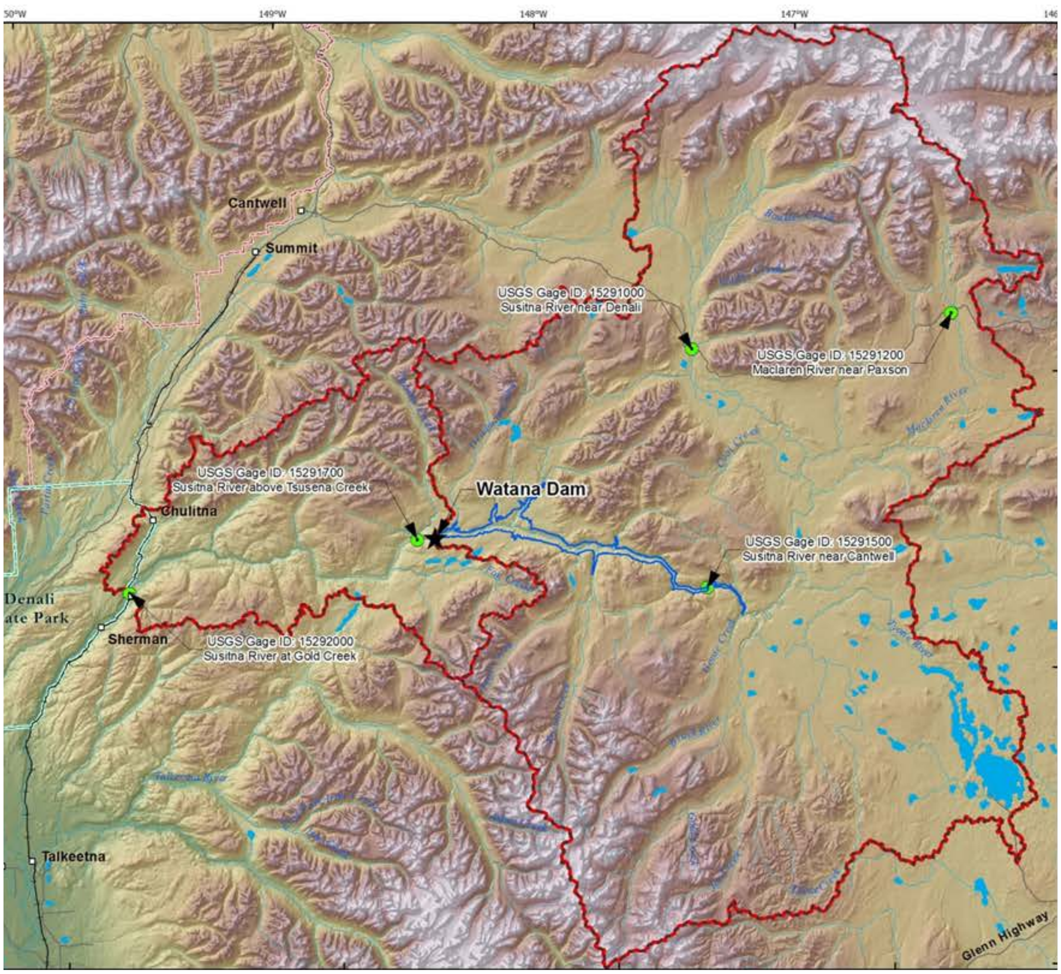
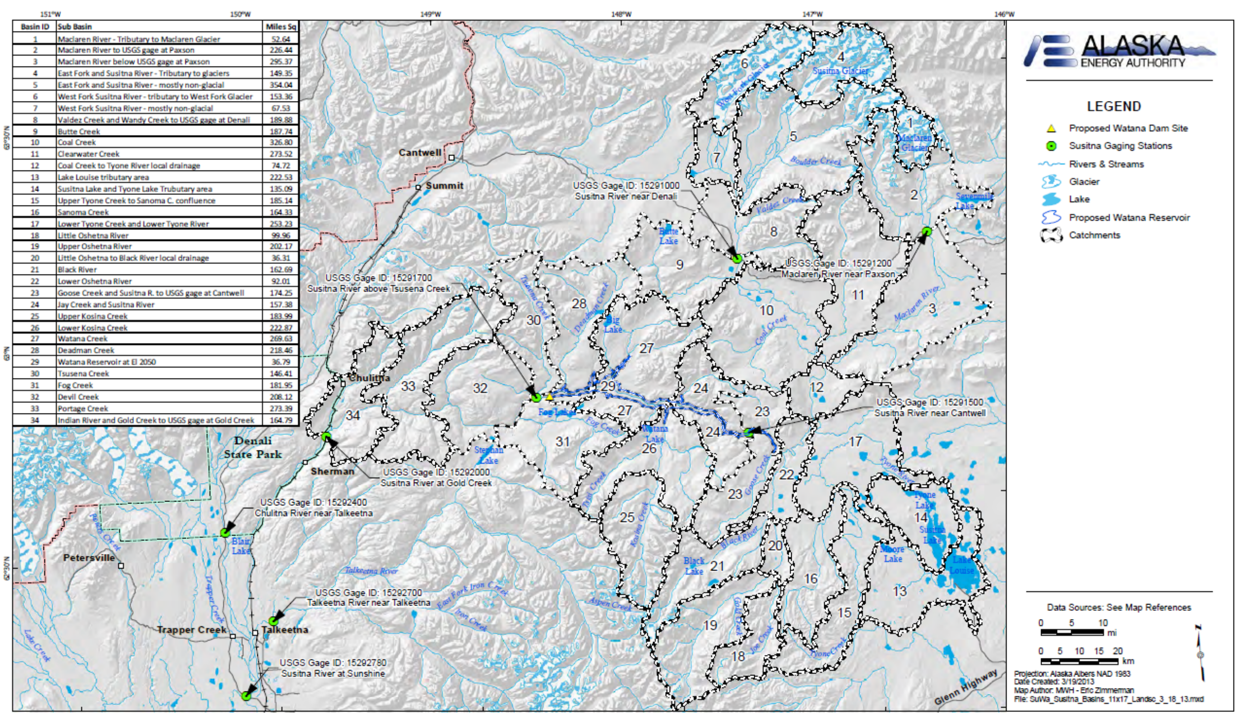


Figure 9.3-1. Susitna Watershed Boundary and USGS Gage Locations

9.4. Hydrologic Model

The HEC-1 Flood Hydrograph Package was chosen as the rainfall-runoff model to develop the PMF because it is one of the models recommended by the Federal Energy Regulatory Commission (FERC) specifically for this purpose, it includes the preferred energy budget method for snowmelt, and a wealth of experience data is available for this model. This model was developed by the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers and has been (and possibly still is) the most widely used model in PMF studies.

As shown on Figure 9.4-1, the watershed was divided into 29 sub-basins tributary to the Watana Dam site plus five additional sub-basins tributary to the USGS gage at Gold Creek that were necessary for model calibration. The area of each sub-basin in 1,000-foot elevation bands and the sub-basin area for each watershed cover type were determined from geographic information system (GIS) data.



Basin ID	Sub Basin	Miles Sq
1	Maclaren River - Tributary to Maclaren Glacier	52.64
2	Maclaren River to USGS gage at Paxson	226.44
3	Maclaren River below USGS gage at Paxson	295.37
4	East Fork and Susitna River - Tributary to glaciers	149.35
5	East Fork and Susitna River - mostly non-glacial	354.04
6	West Fork Susitna River - tributary to West Fork Glacier	153.36
7	West Fork Susitna River - mostly non-glacial	67.53
8	Valdez Creek and Wandy Creek to USGS gage at Denali	189.88
9	Butte Creek	187.74
10	Coal Creek	326.80
11	Clearwater Creek	273.52
12	Coal Creek to Tyone River local drainage	74.72
13	Lake Louise tributary area	222.53
14	Susitna Lake and Tyone Lake Trubutary area	135.09
15	Upper Tyone Creek to Sanoma C. confluence	185.14
16	Sanoma Creek	164.33
17	Lower Tyone Creek and Lower Tyone River	253.23
18	Little Oshetna River	99.96
19	Upper Oshetna River	202.17
20	Little Oshetna to Black River local drainage	36.31
21	Black River	162.69
22	Lower Oshetna River	92.01
23	Goose Creek and Susitna R. to USGS gage at Cantwell	174.25
24	Jay Creek and Susitna River	157.38
25	Upper Kosina Creek	183.99
26	Lower Kosina Creek	222.87
27	Watana Creek	269.63
28	Deadman Creek	218.46
29	Watana Reservoir at El 2050	36.79
30	Tsusena Creek	146.41
31	Fog Creek	181.95
32	Devil Creek	208.12
33	Portage Creek	273.39
34	Indian River and Gold Creek to USGS gage at Gold Creek	164.79

Figure 9.4-1. Susitna Watershed Sub-Basins

Streamflow data for model calibration and verification were available at four relatively long-term Susitna River USGS gages at Gold Creek, Cantwell, and Denali, and on the tributary Maclaren River at Paxson. The recently established USGS gaging station above Tsusena Creek, near the Watana Dam site, also contributed data for one flood. Because Susitna River floods of two different types have been noted (primarily from spring snowmelt and primarily from summer rainfall), three spring floods and three summer floods were selected for runoff model calibration and verification. Preference was given to selecting floods of the greatest magnitude that had recorded data at the most USGS gaging stations that would also satisfy the spring/summer distribution. Although selecting a total of three floods for calibration and verification is more typical, the flood characteristics of the Susitna River and the magnitude of the Susitna-Watana Project provided justification for using six floods. Based on the near maximum sunny weather flood that occurred during May-June 2013, consideration was also given to a variation of the spring snowmelt flood herein called a sun-on-snow PMF. After calibrating the model to the May-June 2013 flood, maximum temperatures without rainfall were used to derive a sun-on-snow PMF.

Runoff model calibration challenges included a general lack of historical meteorological data (precipitation, temperature, wind) within the watershed tributary to the Watana Dam site and the lack of historical snowpack data concurrent with the spring floods. Given these limitations, the watershed model calibration was in all cases considered to be within the normal range of acceptable results.

9.5. Probable Maximum Precipitation

Because the existing standard U.S. Weather Bureau (now National Weather Service) PMP guidance document for Alaska is applicable to drainage areas up to 400 sq.mi. and for durations up to 24 hours, development of a site-specific PMP was necessary. Derivation of the site specific PMP is fully detailed in a separate report prepared by MWH sub-consultant Applied Weather Associates, which is included in Appendix B4 to this report. The site-specific all-season (maximum) PMP was found to occur in July or August and was derived on an hourly basis for a 216 hour (nine day) time sequence for each of the 29 sub-basins tributary to the Watana Dam site.

Alternative temporal distributions for the PMP were evaluated. The critical basin-wide all-season average PMP values are shown on Table 9.5-1. All-Season PMP by Sub-Basin for Various Durations values averaged over the watershed tributary to Watana Dam were 1.78 inches for six hours, 4.40 inches for 24-hours, 7.19 inches for 72 hours, and 10.00 inches for 216 hours. The temporal and accumulated precipitation for the critical distribution of the PMP, which was based on the August 1967 storm, is shown on Figure 9.5-1.

Associated concurrent meteorological data (temperature, wind speed, dew point) were also derived for the 216 hour PMP period plus 24 hours prior to and 72 hours subsequent to the PMP for a total of 312 hours. Because snowpack and snowmelt are significant hydrologic conditions in the Susitna River watershed that affect the estimated PMF, seasonal PMP and meteorological data were derived for the period from April through October based on different factors applied to the all-season data. The data sets for various seasonal time periods and sensitivity runs form cases from which the PMF can be determined.

Table 9.5-1. All-Season PMP by Sub-Basin for Various Durations

Sub-basin	Drainage Area (sq.mi.)	All Season 1-hr PMP (inches)	All Season 6-hr PMP (inches)	All Season 24-hr PMP (inches)	All Season 72-hr PMP (inches)	All Season 216-hr PMP (inches)
1	52.6	0.60	2.47	6.09	9.95	13.83
2	226.4	0.50	2.04	5.02	8.21	11.41
3	295.4	0.37	1.53	3.77	6.16	8.56
4	149.3	0.56	2.31	5.69	9.31	12.93
5	354.0	0.44	1.79	4.43	7.24	10.06
6	153.4	0.48	1.97	4.86	7.94	11.03
7	67.5	0.32	1.31	3.23	5.29	7.35
8	189.9	0.39	1.60	3.94	6.44	8.95
9	187.7	0.41	1.69	4.18	6.83	9.50
10	326.8	0.39	1.61	3.98	6.51	9.04
11	273.5	0.41	1.67	4.12	6.73	9.35
12	74.7	0.36	1.46	3.61	5.90	8.21
13	222.5	0.34	1.39	3.44	5.62	7.81
14	135.1	0.33	1.36	3.35	5.48	7.62
15	185.1	0.36	1.50	3.69	6.03	8.38
16	164.3	0.37	1.51	3.73	6.10	8.48
17	253.2	0.35	1.45	3.57	5.84	8.12
18	100.0	0.43	1.78	4.39	7.18	9.98
19	202.2	0.50	2.04	5.04	8.24	11.45
20	36.3	0.37	1.53	3.77	6.16	8.56
21	162.7	0.50	2.06	5.07	8.29	11.52
22	92.0	0.36	1.47	3.63	5.93	8.25
23	174.2	0.41	1.70	4.19	6.86	9.53
24	157.4	0.43	1.78	4.38	7.17	9.96
25	184.0	0.61	2.52	6.23	10.18	14.15
26	222.9	0.54	2.23	5.50	8.99	12.49
27	269.6	0.47	1.94	4.78	7.81	10.85
28	218.5	0.52	2.13	5.26	8.60	11.96
29	36.8	0.43	1.75	4.31	7.05	9.80
Total/Avg.	5168.2	0.43	1.78	4.40	7.19	10.00

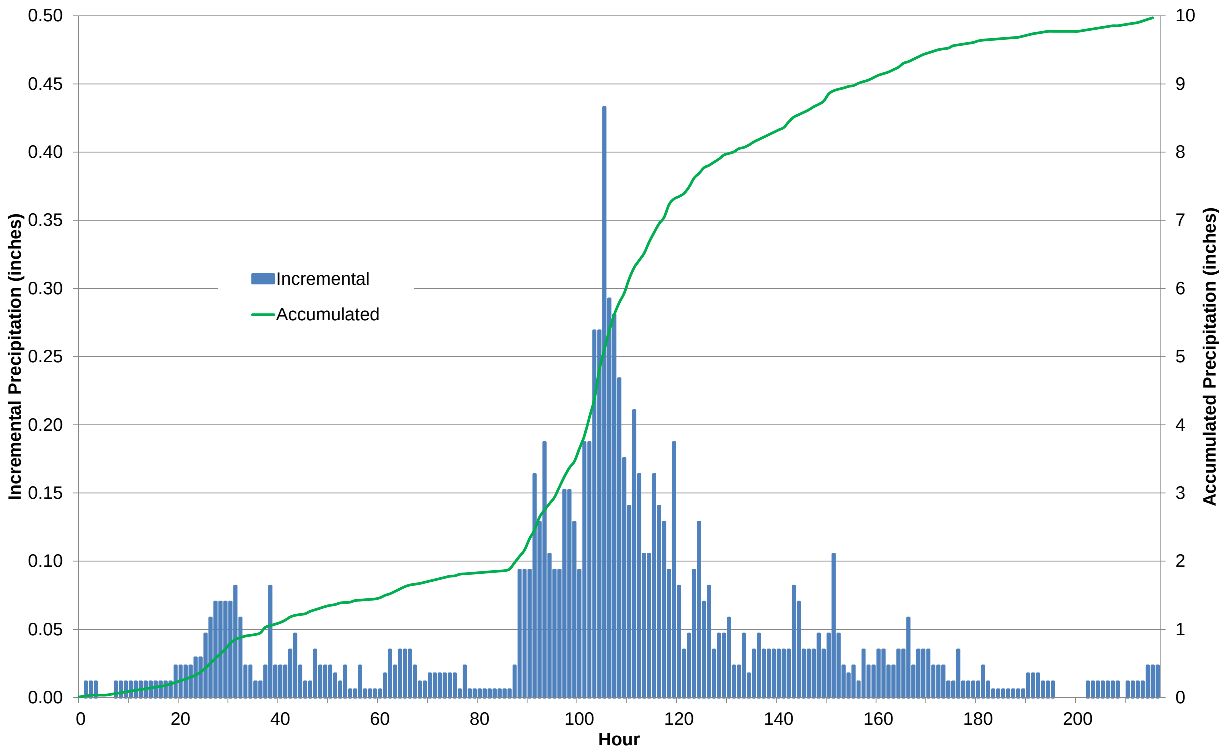


Figure 9.5-1. Incremental and Accumulated All-Season PMP – August 1967 Temporal Distribution

9.6. Snowpack

Snowmelt is an important and potentially a controlling component of the PMF for Watana Dam. Snow course data (measured monthly during the winter) is available at several locations within the area tributary to Watana Dam, and SNOTEL data (measured daily) is available near the watershed boundaries and in nearby watersheds. This data was generally adequate for developing the necessary snow water equivalent values antecedent to the seasonal PMP sequences.

Table 9.6-1 presents the calculated 100-year snow water equivalent (SWE) values on or about the first of the month from February through May. Also shown is the October through April average total precipitation at the snow course locations. The last column of Table 9.6-1 shows the ratio of the calculated May 1, 100-year SWE values to the October through April total average precipitation. These are the key values used to distribute the 100-year snowpack over the watershed.

The last column ratios in Table 9.6-1 for snow courses in areas tributary to Watana Dam (not highlighted in red) range from 1.51 to 1.94 and average 1.68. The data for the snow courses highlighted in red, which are all outside the area tributary to Watana Dam, are all outside the

1.51 to 1.94 range and have therefore been eliminated from further consideration. Therefore, the tributary area average factor of 1.68 times the average October through April total precipitation was selected and was used to develop the 100-year May and June snowpacks. Due to the potential for cold weather to persist from April up to the start of June, the May and June snowpacks were considered to be equal. The precipitation that falls during May would essentially offset any snowmelt that occurs.

Table 9.6-2 presents the 100-year snowpack SWE averaged by sub-basin. It is noted that the 100-year SWE tributary to Watana Dam that averages 15.7 inches substantially exceeds the 100-year all-season PMP average of 10.0 inches at Watana Dam. The runoff model separates the 100-year SWE values within each sub-basin by 1000-foot elevation bands. Based on a Weather Bureau study for the Yukon River, the probable maximum spring snowpack was estimated to yield a snow water equivalent equal to 3.0 times the average October through April total precipitation.

Table 9.6-1. 100-Year Snowpack at Snow Course Stations

Station Name	Is Station Area Tributary to Watana Dam (1)	Elevation (feet)	100-Year Snow Water Equivalent				Oct-Apr Avg. Total Precip. (inches)	Ratio May 1 100-Year / Oct-Apr (2)
			Feb. 1 (inches)	Mar. 1 (inches)	Apr. 1 (inches)	May 1 (inches)		
Blueberry Hill	No	1,200	24.0	32.8	36.5	33.8	16.9	2.01
Clearwater Lake	Yes	2,650	8.1	8.2	9.8	11.6	6.0	1.94
E. Fork Chulitna River	No	1,800	23.6	28.8	31.5	34.3	11.8	2.90
Fog Lakes	Yes	2,120	11.6	12.1	12.9	11.9	6.7	1.78
Horsepasture Pass	Yes/Border	4,300	9.4	11.8	12.5	12.8	7.0	1.82
Independence Mine	No	3,550	39.6	48.1	50.1	50.1	24.5	2.05
Lake Louise	Yes	2,400	6.7	7.1	8.2	7.2	4.4	1.63
Monohan Flat	Yes/Border	2,710	12.7	13.8	14.7	12.0	8.5	1.40
Monsoon Lake	Yes/Border	3,100	8.3	9.6	10.8	-----	6.0	1.79
Square Lake	Yes	2,950	6.0	6.5	7.4	7.2	4.8	1.51
Susitna Valley High	No	375	13.6	15.5	16.5	19.0	13.3	1.43
Talkeetna	No	350	11.3	15.9	18.4	16.7	12.0	1.39
Tyone River	Yes	2,500	5.7	6.2	7.3	-----	4.8	1.53
							Average of non-red values	1.68

Notes:

(1) Border indicates that the stations are on or near the watershed boundary.

(2) Where May 1 data is missing, April 1 data was used.

Values in the red boxes were not used to determine the 100-year snowpack.

Table 9.6-2. 100-Year All-Season Snowpack Snow Water Equivalent

Sub-Basin Number	Basin Area (sq.mi.)	Annual Precip. (inches)	Oct-Apr Precip. (inches)	100-Year SWE (inches)
1	52.6	37.9	16.9	28.4
2	226.4	28.9	12.2	20.6
3	295.4	18.1	6.7	11.2
4	149.3	41.7	19.2	32.3
5	354.0	30.9	13.5	22.6
6	153.4	42.8	19.9	33.4
7	67.5	23.9	9.5	16.0
8	189.9	27.8	11.6	19.4
9	187.7	26.9	10.5	17.6
10	326.8	21.3	8.0	13.4
11	273.5	22.9	9.0	15.0
12	74.7	16.8	5.8	9.8
13	222.5	14.2	4.8	8.0
14	135.1	13.8	4.3	7.3
15	185.1	16.2	5.8	9.7
16	164.3	16.8	5.9	9.9
17	253.2	15.0	5.1	8.5
18	100.0	20.8	7.5	12.6
19	202.2	24.5	8.8	14.9
20	36.3	17.1	5.4	9.2
21	162.7	25.6	9.2	15.4
22	92.0	16.4	5.5	9.2
23	174.2	20.9	7.0	11.8
24	157.4	21.9	7.8	13.2
25	184.0	33.6	12.2	20.6
26	222.9	27.7	10.1	17.0
27	269.6	23.6	9.0	15.1
28	218.5	26.3	10.0	16.9
29	36.8	18.7	6.7	11.3
30	146.4	28.8	11.4	19.1
31	181.9	26.9	9.6	16.1
32	208.1	28.5	11.5	19.3
33	273.4	31.3	13.3	22.3
34	164.8	36.6	16.1	27.0
To Gold Creek Gage	6,143	25.0	9.8	16.5
To Watana Dam	5,168	24.0	9.3	15.7
To Denali Gage	914	33.5	14.8	24.9
To Maclaren Gage	279	30.6	13.1	22.0
To Cantwell Gage	4,079	23.4	9.2	15.5

9.7. Coincident and Antecedent Conditions

The primary coincident conditions to be evaluated are several cases formed by seasonal combinations of the 100-year snowpack and the PMP. Coincident seasonally varying temperatures and wind speeds are also important factors. The combination of the probable maximum snowpack and the 100-year precipitation is another case that was evaluated. Based on the historic near maximum Susitna River flood of May-June 2013 that occurred with little to no contributing rainfall, the FERC Independent Board of Consultants suggested performing a sun-on-snow PMF case. The sun-on-snow PMF case is detailed in the Sensitivity Analysis section of the PMF report in Appendix B1, but it did not become the critical PMF case.

For Watana Dam, initial reservoir level considerations include both the starting reservoir level at the beginning of the PMP sequence and the reservoir level at which the spillway gates begin to open. Low-level outlet works valves are assumed to be used to make reservoir releases until the peak 50-year flood reservoir level has been exceeded, to limit the frequency of spillway operation and the potential for downstream gas super-saturation in the Susitna River which might adversely affect fish. Potential variations in the initial reservoir level were evaluated with sensitivity runs.

9.8. Probable Maximum Flood Hydrograph

After evaluating all of the candidate cases for the PMF including alternative temporal, seasonal, and sensitivity runs, including the sun-on-snow PMF case, it was apparent that there is significant sensitivity in the results to infiltration loss rates, wind speed and temperature input data. Several PMF routing sensitivity runs are summarized on Table 9.8-1. Given the sensitivity in these parameters, the critical PMF case used for spillway sizing was found to be formed by a spring PMP combined with the 100-year snowpack and with conservative low loss rates (Case S3 in Table 9.8-1). The conservative low loss rates were confirmed with reanalysis of the spring historic calibration and verification floods. For the critical PMF case, the maximum reservoir level was at El. 2064.5 ft. with a peak inflow of 310,000 cfs and a 13-day total inflow volume to the reservoir of 3,980,000 acre-ft.

To safely pass the PMF with a maximum reservoir level below El. 2065 ft. with a spillway crest at El. 2010 ft., a spillway with a total width of 168 ft. (four gates each at 42 ft. wide) was required. This spillway size is preliminary and subject to change pending further review. Including a total outflow of 32,000 cfs through eight fixed-cone valves and a peak outflow of 250,000 cfs through the spillway, the total peak PMF outflow was estimated to be 282,000 cfs based on HEC-1 model results. A total of 14.5 ft. above the maximum normal operating pool level at El. 2050 ft. is used for flood control storage with 7.6 ft. allocated to the 50-year flood and an additional 6.9 ft. allocated to safely pass the PMF. With the inclusion of a standard 3.5-foot high parapet wall on top of the dam crest, the required freeboard would be provided for both normal and flood conditions. Figure 9.8-1 is a plot of the PMF inflow, total outflow, and reservoir elevation.

The 310,000 cfs PMF peak inflow is about 3.4 times the estimated 100-year flood at the Watana Dam site. The 3.4 ratio of the PMF to the 100-year flood is within a typically expected range.

One additional safety check is the ability of the dam to pass the 10,000-year flood (estimated to be 168,000 cfs) with one gate stuck shut. Because the total outflow capability of Watana Dam spillway would be 190,000 cfs at El. 2065 ft. with one gate shut, and the Project would have the capability to pass an additional 32,000 cfs through the low-level outlets, it was determined that the peak inflow of the 10,000-year flood could be passed with one spillway gate shut.

The spillway gates will be capable of being controlled by a microprocessor based controller (or programmable logic controller) using inputs of upstream reservoir water level and spillway gate position. Preliminary flood operating guidelines can be summarized as follows:

1. If the reservoir water level exceeds El. 2050 ft., all flows would be diverted through the turbines and low-level outlets until the reservoir reaches El. 2057.6 ft. The low-level outlets operate at all levels above El. 2050 ft. and the turbines would operate to the maximum extent possible. For the PMF study, the turbines were assumed to operate at 7,500 cfs to reservoir El. 2057.6 ft., with turbine shutdown necessary above reservoir El. 2057.6 ft.

2. If the reservoir water level rises above El. 2057.6 ft., the spillway gates would begin to open. The spillway gates should be fully open at reservoir El. 2060 ft.

3. The sequence of gate opening would begin with two of the four spillway gates opening as needed until they reach 80 percent open, at which point the other two spillway gates would begin to open.

4. If all gates were to reach 80 percent open with the reservoir level still rising, two gates would be fully opened and the other two gates would close slightly. If the reservoir level continues to rise, all four gates would be fully open at reservoir El. 2060 ft.

Table 9.8-1. PMF Routing Sensitivity Analysis Results

Case Number	Modification (if any) to June 1 or August 15 PMF	Peak Inflow (cfs)	Peak Outflow (cfs)	Maximum Reservoir W.S. Elev. (feet)
S1	No modification to June 1 PMF	196,000	195,000	2059.3
S2	June 1 PMF with summer loss rates	241,000	239,000	2059.8
S3	June 1 PMF with constant 0.02 in/hr loss rates	310,000	282,000	2064.5
S4	June 1 PMF with +10 mph winds	232,000	231,000	2059.7
S5	June 1 PMF with +3 degree F temperatures	235,000	234,000	2059.8
S6	June 1 PMF with Harza-Ebasco temp and wind	312,000	277,000	2063.7
S7	June 1 PMF with initial reservoir level at El 2030	196,000	191,000	2059.3
S8	August 15 PMF with constant 0.02 in/hr loss rates	246,000	244,000	2059.9
Sun-on-Snow	Sun-on-snow PMF - No rainfall, maximum temperatures	255,000	254,000	2060.1

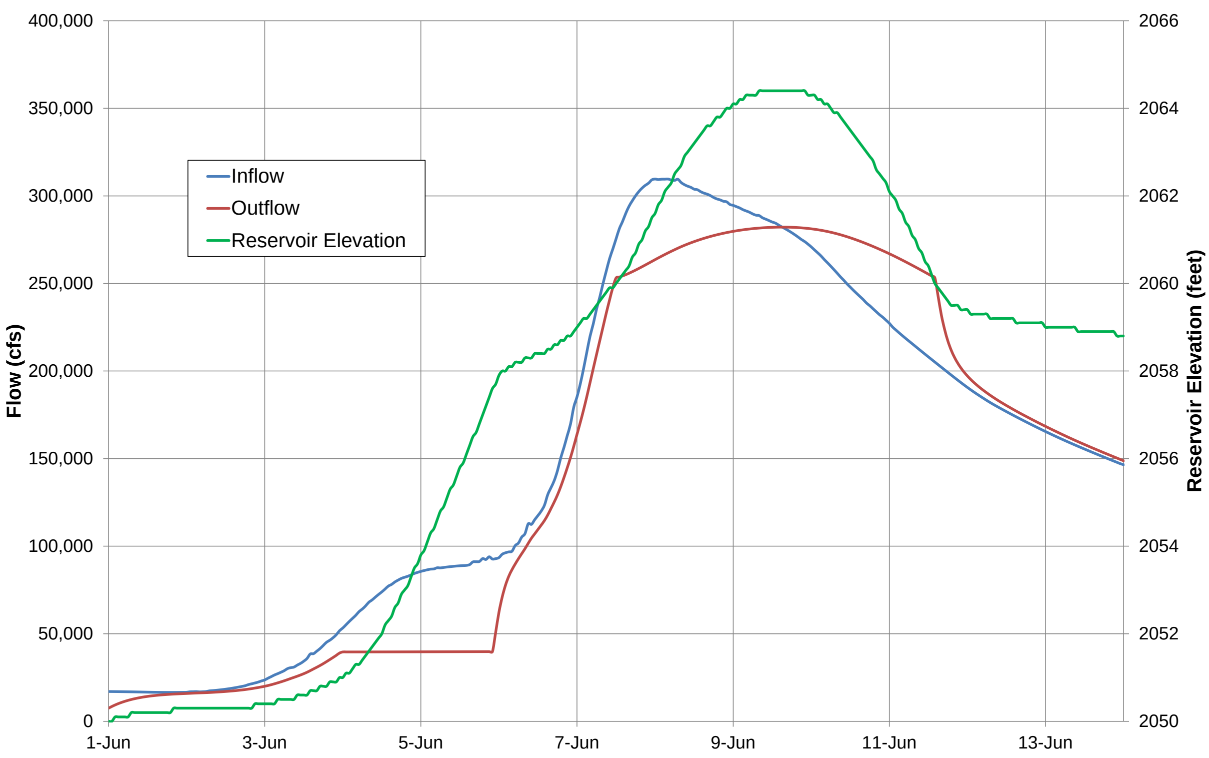


Figure 9.8-1. PMF Inflow, Outflow, and Reservoir Elevation