Appendix B4

Probable Maximum Flood Study

14-02-REP_Probable Maximum Flood Study

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Report
14-02-REP
v2.0

Susitna-Watana Hydroelectric Project
Probable Maximum Flood Study

AEA11-022

Prepared for:
Alaska Energy Authority
813 West Northern Lights Blvd.
Anchorage, AK 99503

Prepared by:
MWH
1835 South Bragaw St., Suite 350
Anchorage, AK 99508

December 2014

THIS PAGE INTENTIONALLY LEFT BLANK

The following individuals have been directly responsible for the preparation, review and approval of this Report.

Prepared by: John Haapala, P.E., Senior Hydrologic/Hydraulic Engineer

Reviewed by: Jill Gray, Senior Environmental Scientist

Approved by: ______________________________
Howard Lee, P.E., Sr. Technical Reviewer

Approved by: ______________________________
Brian Sadden, P.E., Project Manager

Disclaimer

This document was prepared for the exclusive use of AEA and MWH as part of the engineering studies for the Susitna-Watana Hydroelectric Project, FERC Project No. 14241, and contains information from MWH which may be confidential or proprietary. Any unauthorized use of the information contained herein is strictly prohibited and MWH shall not be liable for any use outside the intended and approved purpose.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

List of Tables

List of Figures

List of Appendices

EXECUTIVE SUMMARY

The purpose of the study was to develop the Watana Dam inflow design flood, which is the Probable Maximum Flood (PMF). The PMF is an industry standard design criterion that federal regulatory authorities apply to large dams like Watana Dam. The PMF is 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), which was also developed as a part of this study, 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 flood passage safety of the dam.

Project Description

The proposed Susitna-Watana Hydroelectric Project (Susitna-Watana Project or the Project), which is currently in the feasibility and licensing phase, will be a major development on the Susitna River some 120 miles north and east of Anchorage and about 140 miles south of Fairbanks. The Project is being developed to provide long-term stable power for generations of Alaskans. Once on line, the Project will be capable of generating about 50 percent of the Railbelt's electricity. The Project's installed power capacity will be 600 megawatts (MW). As proposed, the Susitna-Watana Project would include construction of a dam, reservoir, powerhouse, transmission lines connecting to the existing Railbelt transmission system, and a new access road. Feasibility studies have indicated that the Project appears to be technically feasible using a roller-compacted concrete (RCC) dam and surface powerhouse.

Watershed Description

The watershed is in a remote part of the Susitna River, with Watana Dam located 184 river miles (RM) upstream from Cook Inlet. The drainage area tributary to the Watana Dam site is about 5,180 square miles, which compares to about 20,000 square miles 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 feet, almost 70% of the watershed tributary to the Watana Dam site is below 4,000 feet in elevation and 88% is below 5,000 feet. The predominant types of watershed cover include shrub/scrub, 45%; evergreen forest, 17%; and barren land, 15%. Glaciers and perennial snow cover about 5% of the area and open water and lakes account for about 3% of the area tributary to the Watana Dam site. Streamflow is highly seasonal with over 85% of the annual average flow occurring during the 5-month period of May through September.

Historic Floods

In 60 years of record at the USGS gaging station downstream of the dam site at Gold Creek, which has a drainage area of 6,160 square miles, 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% 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.

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 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. 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 GIS data.

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.

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.

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 only 400 square miles and for durations up to only 24 hours, development of a site-specific PMP was necessary. Derivation of the site specific PMP is detailed in a separate report prepared by MWH sub-consultant Applied Weather Associates, which is included as Appendix A 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 (9 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 were 1.78 inches for 6 hours, 4.40 inches for 24-hours, 7.19 inches for 72 hours, and 10.00 inches for 216 hours. 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.

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.

Data analysis indicated that a snow water equivalent equal to 1.68 times the average October through April total precipitation would be appropriate for the 100-year spring snowpack. Detailed monthly average GIS-based precipitation data was used to develop the distribution of the snow within 1,000-foot elevation bands in each sub-basin. 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.

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 Independent Board of Consultants suggested performing a sun-on-snow PMF case, which was included in the Sensitivity Analysis section of this report.

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, in order 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.

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. 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. 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 with a peak inflow of 310,000 cfs and a 13-day total inflow volume to the reservoir of 3,980,000 acre-feet.

To safely pass the PMF with a maximum reservoir level below El 2065 with a spillway crest at El 2010, a spillway with a total width of 168 feet (4 gates each at 42 feet wide) was required. This spillway size is preliminary and subject to change pending further review of parameter sensitivity. 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 feet above the maximum normal pool level at El 2050 is used for flood control storage with 7.6 feet allocated to the 50-year flood and an additional 6.9 feet 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 ES-1 is a plot of the PMF inflow, total outflow, and reservoir elevation.

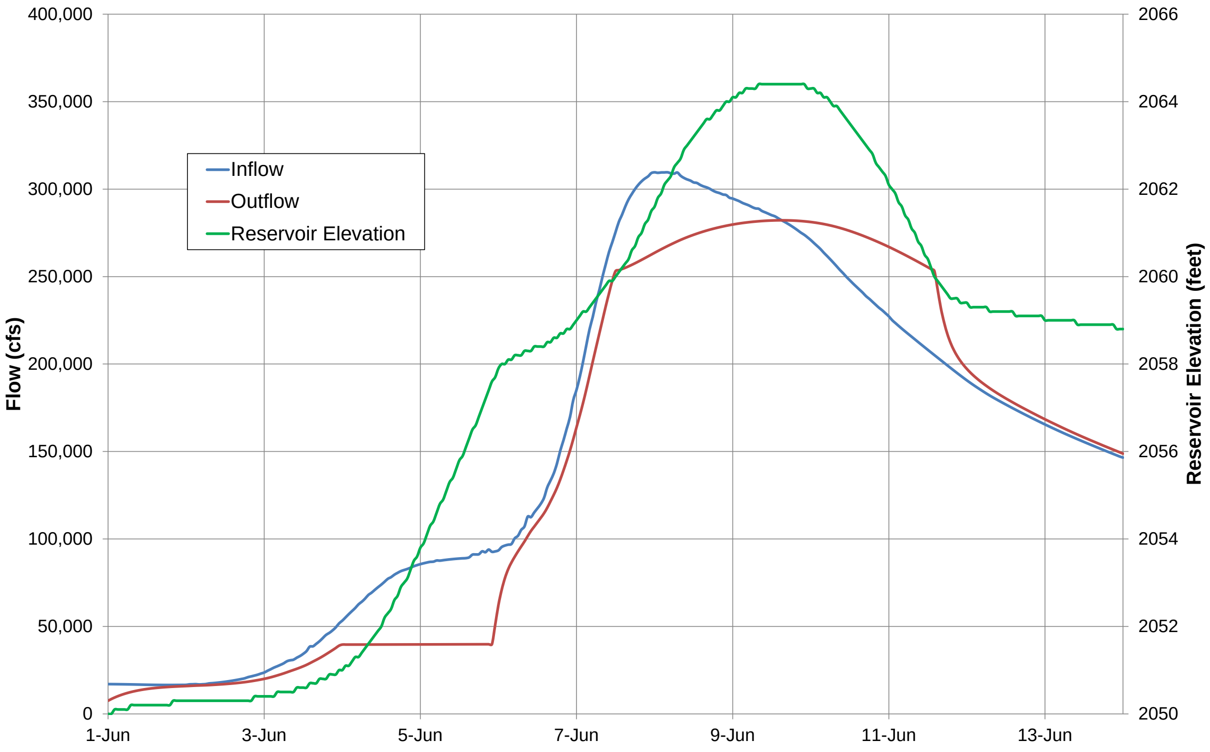


Figure ES-1. PMF Inflow, Outflow, and Reservoir Elevation

1. PROJECT DESCRIPTION

The Susitna-Watana Hydroelectric Project (Susitna-Watana Project or the Project) will be a major development on the Susitna River some 120 miles north and east of Anchorage and about 140 miles south of Fairbanks. The Project is being developed to provide long-term stable power for generations of Alaskans and to help the State of Alaska meet the goal set by the State Legislature of getting 50% of its energy from renewable sources by 2025. It will generate about 50 percent of the Railbelt's electricity, or 2,800,000 megawatt hours (MWh) of annual energy. The Project's installed power capacity will be 600 megawatts (MW).

As proposed, the Susitna-Watana Project would include construction of a dam, reservoir, and related facilities including a powerhouse and transmission lines. Watana Dam would be located in a remote part of the Susitna River, 184 river miles (RM) from Cook Inlet, more than 80 RM beyond Talkeetna and 32 RM above Devils Canyon which acts as a natural impediment to salmon migration. Transmission lines connecting to the existing Railbelt transmission system and an access road would also be constructed.

1.1 Project Data

As an unconstructed project currently in the feasibility phase of project design, all project data is preliminary and subject to change as the design progresses. As currently designed, Watana Dam will be a roller-compacted concrete (RCC) dam with an approximate height of 715 feet above its foundation and a normal maximum operating level (NMOL) at El 2050. At the NMOL, the reservoir area will be 23,500 acres (36.7 square miles) and the total reservoir storage capacity will be 5,170,000 acre-feet. Outlets at the dam would include (1) three turbines; (2) a gated spillway with four bays; (3) several fixed-cone valves; and (4) an emergency low-level outlet that is provided for use only in the event of a dam safety emergency. In accordance with standards of the industry for a dam if its size and economic importance to the Railbelt, the inflow design flood for Watana Dam is the Probable Maximum Flood (PMF). The determination of the design flood inflow hydrograph and the preliminary outlet capacity at the dam is the subject of this report. The results will inform sizing of the main spillway and, at a later date, the determination of the dam crest elevation.

1.2 Basin Hydrologic Data

Fourteen gaging stations have been intermittently operated by the USGS in or near the Susitna River watershed between 1949 and 2013 as shown on Table 1.2-1. The locations of the four gaging stations located in the area tributary to or just downstream of Watana Dam, along with the watershed boundaries are shown on Figure 1.2-1. The four USGS gaging stations shown on

Figure 1.2-1 are the ones used in the current study for calibration of the runoff model. Figure 1.2-2 shows the chronological availability of USGS flow data in the Susitna watershed. The USGS gage records provide an adequate flow record for calibration and verification of the flood runoff model.

Table 1.2-1. USGS Gages in the Susitna River Watershed

USGS Gage Number	Gage Name	Drainage Area (sq.mi)	Latitude	Longitude	Gage Datum (feet)	Available Period of Record
15290000	Little Susitna River near Palmer	62	61°42'37"	149°13'47"	917	1948 - 2013
15291000	Susitna River near Denali	950	63°06'14"	147°30'57"	2,440	1957 - 1976; 1978 - 1986; 2012
15291200	Maclaren River near Paxson	280	63°07'10"	146°31'45"	2,866	1958 - 1986
15291500	Susitna River near Cantwell	4,140	62°41'55"	147°32'42"	1,900	1961 - 1972; 1980 - 1986
15291700	Susitna River above Tsusena Creek	5,160	62°49'24"	147°36'17"	1,500	2013
15292000	Susitna River at Gold Creek	6,160	62°46'04"	149°41'28"	677	1949 - 1996; 2001 - 2013
15292400	Chulitna River near Talkeetna	2,570	62°33'31"	150°14'02"	520	1958 - 1972; 1980 - 1986
15292700	Talkeetna River near Talkeetna	1,996	62°20'49"	150°01'01"	400	1964 - 1972; 1980 - 2013
15292780	Susitna River at Sunshine	11,100	62°10'42"	150°10'30"	270	1981 - 1986; 2012 - 2013
15292800	Montana Creek near Montana	164	62°06'19"	150°03'27"	250	2005 - 2006; 2008 - 2012
15294005	Willow Creek Near Willow	166	61°46'51"	149°53'04"	350	1978 - 1993; 2001 - 2013
15294010	Deception Creek near Willow	48	61°44'52"	149°56'14"	250	1978 - 1985
15294100	Deshka River near Willow	591	61°46'05"	150°20'13"	80	1978 - 1986; 1988 - 2001
15294300	Skwentna River near Skwentna	2,250	61°52'23"	151°22'01"	200	1959 - 1982
15294345	Yentna River near Susitna Station	6,180	61°41'55"	150°39'02	80	1980 - 1986
15294350	Susitna River at Susitna Station	19,400	61°32'41"	150°30'45	40	1974 - 1993

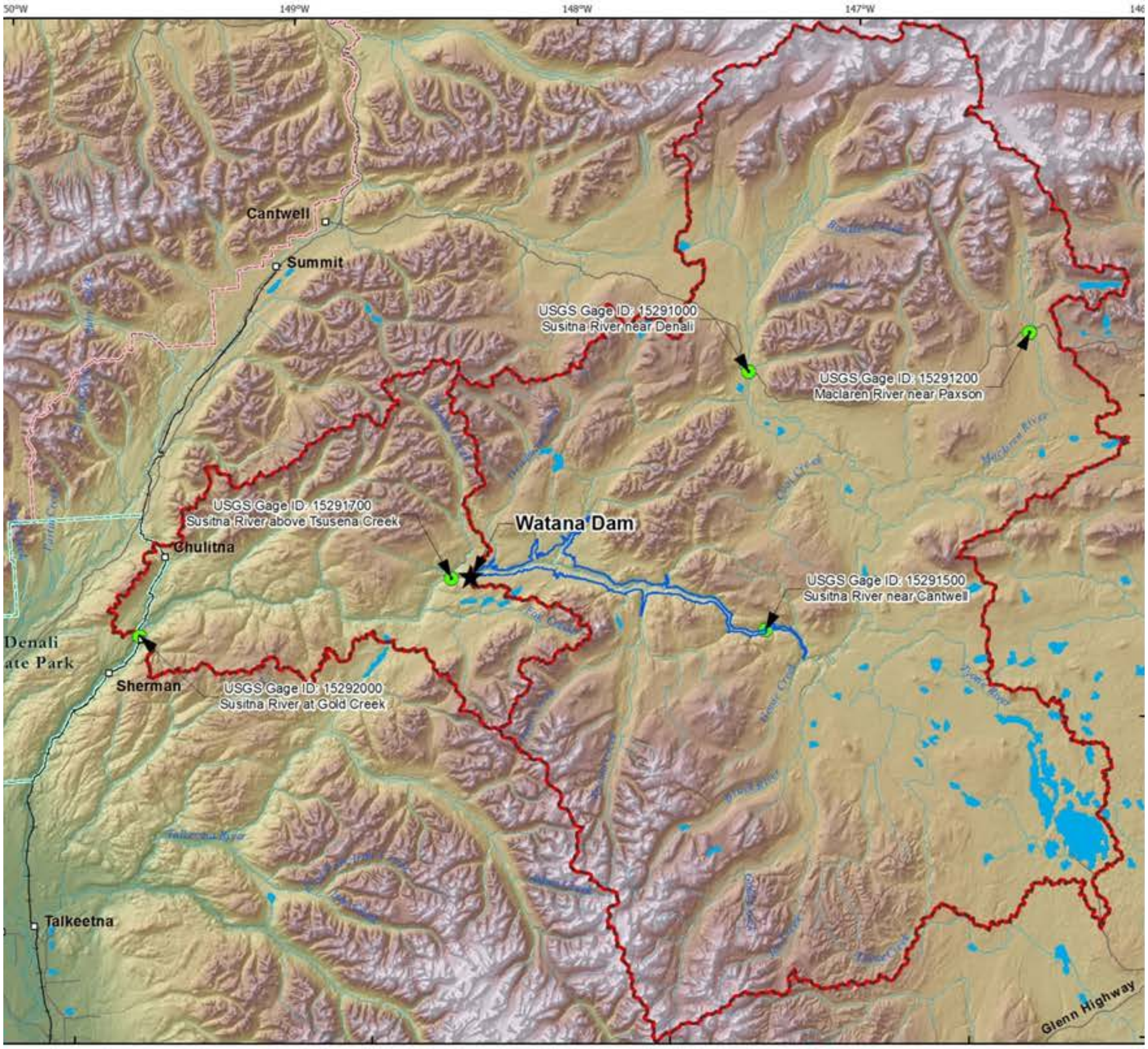


Figure 1.2-1. Susitna Watershed Boundary and USGS Gage Locations

Figure 1.2-2. Susitna Watershed USGS Flow Data – Chronological Availability

1.3 Upstream Dams

There are no dams upstream from the Watana Dam site.

1.4 Field Visit

A field visit was performed on May 29, 2013. The probable maximum precipitation (PMP) and PMF Board of Consultants (BOC) experts and consultants performed a watershed over-flight in a single-engine airplane, beginning and ending at Talkeetna airport. Numerous geo-referenced photographs were taken. All watershed observations were made from the air as no landings were made within the watershed area tributary to Watana Dam.

The field visit occurred at an opportune time because a flood flow that equaled the maximum flow of record occurred at the Gold Creek USGS gaging station just a few days later on June 2, 2013 so water levels were high at the time of the overflight. On May 29, the day of the site visit, the high temperature was 83 degrees at Talkeetna. A colder than average spring was followed by a rapid warming that resulted in a snowmelt flood without significant concurrent rainfall. Figure 1.4-1 shows remnants of a river ice cover following the recent breakup. Figure 1.4-2 shows the Susitna River near the Denali Highway crossing.

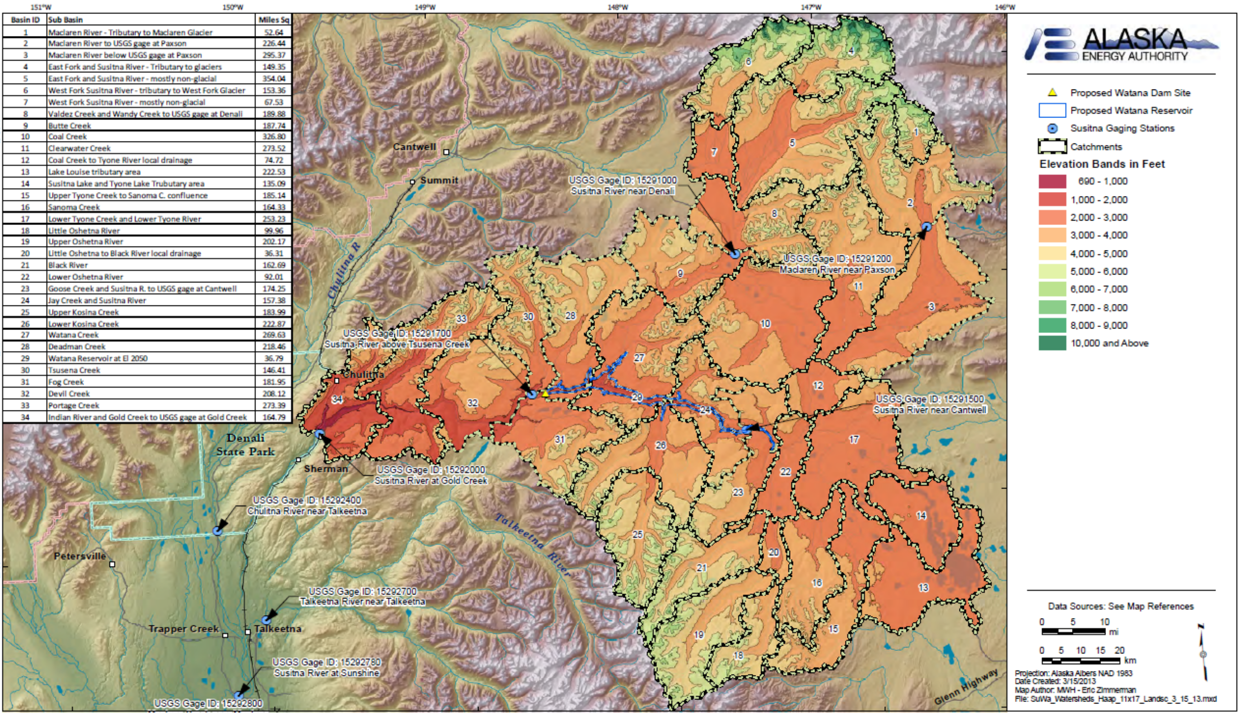
Figure 1.4-1. Susitna River near Deadman Creek on May 29, 2013

Figure 1.4-2. Susitna River near the Denali Highway Crossing on May 29, 2013

1.5 Watershed Description

1.5.1 Watershed Area-Elevation Data

In mountainous regions, snowpack can vary widely with elevation. To account for the variation of snowpack with elevation, the watershed area is divided into 1,000-foot elevation bands. The 1,000-foot elevation bands tributary to Watana Dam and to the USGS gaging station at Gold Creek are graphically depicted on Figure 1.5-1. To account for the areal variation in many parameters, including snowpack, the watershed was divided into 29 sub-basins to the Watana dam site, with 5 additional sub-basins between the Watana dam site and Gold Creek. The sub-basin boundaries are also depicted on Figure 1.5-1.



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 1.5-1. Susitna Watershed Sub-Basins and Elevation Bands

Table 1.5-1 provides the detailed results of the area by 1,000-foot elevation in each sub-basin to the proposed Watana Dam site in with dam condition. The results in Table 1.5-1 are for the PMF study with the constructed dam, with sub-basin 29 being the area of the reservoir itself. This provides the capability of using 136 unique snowpack values for the area tributary to Watana Dam. Table 1.5-2 provides the areas in 1,000-foor elevation bands to Gold Creek under existing without dam conditions.

It is noted that over 69 percent of the watershed tributary to Watana Dam lies within two elevation bands (2000-3000 and 3000-4000 feet) and over 88 percent lies within three elevation bands (adding the 4000-5000 foot level). This means that the snowpack at higher watershed elevations, which may be known with less accuracy, has reduced importance in comparison with the snowpack values at lower watershed elevations. It also means that the temperature lapse rate, applied in 1,000-foot increments to determine snowmelt, cannot have significant error as long as the base temperatures are correct.

Table 1.5-1. Area in Elevation Bands to Watana Dam

Basin	Area in Elevation Bands (sq.mi.) for Model with Reservoir												% of
No.	1-2000	2-3000	3-4000	4-5000	5-6000	6-7000	7-8000	8-9000	9-10000	10-11000	11-14000	Total	Total
1	0.0	0.0	8.7	19.7	8.9	11.3	3.9	0.2	0.0	0.0	0.0	52.7	1.02%
2	0.0	16.4	105.6	65.3	32.3	7.0	0.4	0.0	0.0	0.0	0.0	226.9	4.39%
3	0.0	145.7	139.5	9.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	295.2	5.71%
4	0.0	3.5	18.2	28.5	34.4	32.5	17.1	9.2	3.8	1.4	0.8	149.4	2.89%
5	0.0	90.7	93.0	99.8	48.5	18.5	3.6	0.0	0.0	0.0	0.0	354.2	6.85%
6	0.0	3.6	23.1	39.8	37.0	29.8	14.0	3.4	1.5	0.9	0.4	153.4	2.97%
7	0.0	55.2	9.4	2.1	0.8	0.0	0.0	0.0	0.0	0.0	0.0	67.5	1.31%
8	0.0	54.3	60.4	59.5	15.8	0.1	0.0	0.0	0.0	0.0	0.0	190.1	3.68%
9	0.0	38.5	91.3	52.5	5.3	0.0	0.0	0.0	0.0	0.0	0.0	187.6	3.63%
10	0.0	180.0	113.2	28.1	5.5	0.0	0.0	0.0	0.0	0.0	0.0	326.9	6.32%
11	0.0	72.4	130.2	57.0	13.7	0.4	0.0	0.0	0.0	0.0	0.0	273.6	5.29%
12	0.0	48.7	23.7	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	74.7	1.45%
13	0.0	202.6	20.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	222.6	4.30%
14	0.0	131.5	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	135.2	2.61%
15	0.0	68.0	87.9	29.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	185.2	3.58%
16	0.0	41.6	100.5	22.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	164.4	3.18%
17	0.0	223.2	27.3	2.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	253.3	4.90%
18	0.0	0.1	28.7	48.2	21.2	1.8	0.0	0.0	0.0	0.0	0.0	100.0	1.93%
19	0.0	0.6	45.9	77.9	62.9	14.4	0.5	0.0	0.0	0.0	0.0	202.2	3.91%
20	0.0	16.5	19.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	36.3	0.70%
21	0.0	7.2	48.4	52.3	42.3	11.6	1.0	0.0	0.0	0.0	0.0	162.7	3.15%
22	0.0	76.3	14.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	92.0	1.78%
23	0.0	41.0	88.7	35.1	4.0	0.0	0.0	0.0	0.0	0.0	0.0	168.9	3.27%
24	0.0	51.6	89.5	20.2	1.5	0.0	0.0	0.0	0.0	0.0	0.0	162.8	3.15%
25	0.0	5.3	42.0	72.4	54.0	10.2	0.1	0.0	0.0	0.0	0.0	184.0	3.56%
26	0.0	37.1	115.5	51.0	17.2	2.1	0.0	0.0	0.0	0.0	0.0	222.9	4.31%
27	0.0	141.0	92.5	33.3	2.8	0.1	0.0	0.0	0.0	0.0	0.0	269.6	5.21%
28	0.0	62.2	88.5	61.7	8.8	0.0	0.0	0.0	0.0	0.0	0.0	221.1	4.28%
29	0.0	36.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	36.8	0.71%
Total	0.0	1851.4	1729.1	972.2	417.6	139.8	40.6	12.8	5.3	2.3	1.3	5172.3	100.00%
	0.00%	35.79%	33.43%	18.80%	8.07%	2.70%	0.78%	0.25%	0.10%	0.04%	0.02%	100.00%	

Table 1.5-2. Area in Elevation Bands to Gold Creek

Basin	Area in Elevation Bands (sq.mi.) for Model **without** Reservoir													% of
No.	0-1000	1-2000	2-3000	3-4000	4-5000	5-6000	6-7000	7-8000	8-9000	9-10000	10-11000	11-14000	Total	Total
1	0.0	0.0	0.0	8.7	19.7	8.9	11.3	3.9	0.2	0.0	0.0	0.0	52.7	0.86%
2	0.0	0.0	16.4	105.6	65.3	32.3	7.0	0.4	0.0	0.0	0.0	0.0	226.9	3.69%
3	0.0	0.0	145.7	139.5	9.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	295.2	4.80%
4	0.0	0.0	3.5	18.2	28.5	34.4	32.5	17.1	9.2	3.8	1.4	0.8	149.4	2.43%
5	0.0	0.0	90.7	93.0	99.8	48.5	18.5	3.6	0.0	0.0	0.0	0.0	354.2	5.76%
6	0.0	0.0	3.6	23.1	39.8	37.0	29.8	14.0	3.4	1.5	0.9	0.4	153.4	2.50%
7	0.0	0.0	55.2	9.4	2.1	0.8	0.0	0.0	0.0	0.0	0.0	0.0	67.5	1.10%
8	0.0	0.0	54.3	60.4	59.5	15.8	0.1	0.0	0.0	0.0	0.0	0.0	190.1	3.09%
9	0.0	0.0	38.5	91.3	52.5	5.3	0.0	0.0	0.0	0.0	0.0	0.0	187.6	3.05%
10	0.0	0.0	180.0	113.2	28.1	5.5	0.0	0.0	0.0	0.0	0.0	0.0	326.9	5.32%
11	0.0	0.0	72.4	130.2	57.0	13.7	0.4	0.0	0.0	0.0	0.0	0.0	273.6	4.45%
12	0.0	0.0	48.7	23.7	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	74.7	1.22%
13	0.0	0.0	202.6	20.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	222.6	3.62%
14	0.0	0.0	131.5	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	135.2	2.20%
15	0.0	0.0	68.0	87.9	29.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	185.2	3.01%
16	0.0	0.0	41.6	100.5	22.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	164.4	2.68%
17	0.0	0.0	223.2	27.3	2.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	253.3	4.12%
18	0.0	0.0	0.1	28.7	48.2	21.2	1.8	0.0	0.0	0.0	0.0	0.0	100.0	1.63%
19	0.0	0.0	0.6	45.9	77.9	62.9	14.4	0.5	0.0	0.0	0.0	0.0	202.2	3.29%
20	0.0	0.0	16.5	19.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	36.3	0.59%
21	0.0	0.0	7.2	48.4	52.3	42.3	11.6	1.0	0.0	0.0	0.0	0.0	162.7	2.65%
22	0.0	0.0	76.3	14.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	92.0	1.50%
23	0.0	0.0	41.0	88.7	35.1	4.0	0.0	0.0	0.0	0.0	0.0	0.0	168.9	2.75%
24	0.0	0.0	51.6	89.5	20.2	1.5	0.0	0.0	0.0	0.0	0.0	0.0	162.8	2.65%
25	0.0	0.0	5.3	42.0	72.4	54.0	10.2	0.1	0.0	0.0	0.0	0.0	184.0	2.99%
26	0.0	0.0	37.1	115.5	51.0	17.2	2.1	0.0	0.0	0.0	0.0	0.0	222.9	3.63%
27	0.0	0.0	141.0	92.5	33.3	2.8	0.1	0.0	0.0	0.0	0.0	0.0	269.6	4.39%
28	0.0	0.0	62.2	88.5	61.7	8.8	0.0	0.0	0.0	0.0	0.0	0.0	221.1	3.60%
29	0.0	30.4	6.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	36.8	0.60%
30	0.0	2.5	35.4	39.6	54.8	13.8	0.1	0.0	0.0	0.0	0.0	0.0	146.4	2.38%
31	0.0	12.9	71.6	50.4	34.2	9.5	0.6	0.0	0.0	0.0	0.0	0.0	179.3	2.92%
32	0.0	46.8	60.7	81.4	18.4	0.7	0.0	0.0	0.0	0.0	0.0	0.0	208.1	3.39%
33	1.0	59.9	101.3	56.5	46.7	8.0	0.0	0.0	0.0	0.0	0.0	0.0	273.4	4.45%
34	10.9	71.4	45.3	26.2	10.4	0.5	0.0	0.0	0.0	0.0	0.0	0.0	164.8	2.68%
Total	11.9	224.0	2135.4	1983.2	1136.7	450.1	140.5	40.6	12.8	5.3	2.3	1.3	6144.1	100.00%
	0.19%	3.65%	34.76%	32.28%	18.50%	7.33%	2.29%	0.66%	0.21%	0.09%	0.04%	0.02%	100.00%	

1.5.2 Geology and Soils

The Susitna-Watana area is underlain by a variety of rock units consisting primarily of Cretaceous and Tertiary plutonic and volcanic rocks plus argillaceous and lithic greywacke resulting from the accretion of northwestward drifting tectonic plates onto the North American plate. The region was subjected to repeated glaciation during the late Quaternary. At its glacial maximum, an ice cap covered the Talkeetna Mountains and nearly everything from the crest of the Alaska Range to the Gulf of Alaska. Subsequent advances were not extensive enough to create an ice cap over the Talkeetna Mountains and evidence suggests a series of glaciations of sequentially decreasing extent.

The glaciers advanced from the Alaska Range to the north, the southern and southeastern Talkeetna Mountains, and the Talkeetna Mountains north and northwest of the Susitna River. Glacial flow was predominantly south and southwest, following the regional slope and structural grain. At least three periods of glaciation have been delineated for the region based on the glacial stratigraphy. During the most recent period, glaciers filled the adjoining lowland basins and spread onto the continental shelf. Waning of the ice masses from the Alaska Range and Talkeetna Mountains formed ice barriers which blocked the drainage of glacial meltwater and produced glacial lakes. As a consequence of the repeated glaciation, the Susitna basin is covered by varying thicknesses of till and lacustrine deposits.

Permafrost distribution in the greater Susitna-Watana region has been characterized as "discontinuous" (50-90 percent of the area is underlain by permafrost) except along the immediate river corridor itself, which is characterized as "isolated" (>0-10 percent of the area is underlain by permafrost) (Jorgenson et al. 2008). Based on the subsurface investigations to date, most of which are within two miles of the proposed dam site, permafrost is generally continuous (greater than 90 percent of the area is underlain by permafrost) under north-facing slopes. The frozen ground is typically encountered within 10 feet of the surface and extends to depths of approximately 200 feet. Ground temperatures typically range from 31-32°F.

Hydrologic soil groups provide an initial indication of infiltration rates to be used for runoff modeling. As shown in Table 1.5-3, 90% of the Susitna watershed tributary to the Watana Dam site (Harza-Ebasco 1984) is covered with soils having the lower infiltration rates of Hydrologic Soil Groups C and D. A review of the assignment of soil types to hydrologic soil groups in the previous study (Harza-Ebasco 1984) indicated that generally conservative judgments to lower infiltration soil groups were made. The minimum infiltration rates in Table 1.5-3 for the watershed tributary to the Watana Dam site are from the PMF guidelines (FERC 2001), but it is noted that published USBR (1974) minimum infiltration rates for hydrologic soil group C are given as 0.08 to 0.15 inches/hour, and for hydrologic soil group D the minimum infiltration rates are given as 0.02 to 0.08 inches/hour. Further initial indications of infiltration rates is provided by calibration results from the previous Susitna PMF studies.

Table 1.5-3. Watershed Minimum Infiltration Rates

Hydrologic Soil Group	Range of Minimum Rates (inches/hour)	Area (sq.mi.)	Percent of Area Tributary to Watana
A	0.30 - 0.45	0	0%
B	0.15 - 0.30	526	10%
C	0.05 - 0.15	2,465	48%
D	0.00 - 0.05	2,189	42%

1.5.3 Land Use and Land Cover

Figures 1.5-2 and 1.5-3 show the type and distribution of watershed cover and Table 1.5-4 provides a data summary of cover types for the entire watershed. Table 1.5-5 provides similar information for each sub-basin. Shrub and scrub is the dominant watershed cover type, totaling about 56% of the entire watershed. Forest covers about 18% of the watershed to the Gold Creek USGS gaging station. Barren land makes up about 15% of the watershed cover, while wetlands cover 3.9%, perennial snow/ice is 3.8% and open water covers 2.9% of the watershed.

Table 1.5-4. Watershed Cover

Code	To Gold Creek without Reservoir Description	Area (sq. mi.)	% of Total
52	Shrub/Scrub	2784.0	45.3%
42	Evergreen Forest	996.4	16.2%
31	Barren Land (Rocks/Sand/Clay)	925.9	15.1%
51	Dwarf Scrub	652.9	10.6%
90	Woody Wetlands	238.9	3.9%
12	Perennial Ice/Snow	234.3	3.8%
11	Open Water	180.3	2.9%
43	Mixed Forest	56.4	0.9%
41	Deciduous Forest	54.2	0.9%
72	Sedge/Herbaceous	14.6	0.2%
95	Emergent Herbaceous Wetlands	2.9	0.0%
22	Developed, Low Intensity	1.7	0.0%
71	Grassland/Herbaceous	1.6	0.0%
21	Developed, Open Space	0.1	0.0%
23	Developed, Medium Intensity	0.01	0.0%
	Total	6144.1	100.0%

Table 1.5-5. Watershed Cover by Sub-Basin

Sub-Basin Number	Barren Land	Deciduous Forest	Developed, Low Intensity	Developed, Medium Intensity	Developed, Open Space	Dwarf Scrub	Emergent Herbaceous Wetlands	Evergreen Forest	Grassland/ Herbaceous	Mixed Forest	Open Water	Perennial Ice/Snow	Sedge/ Herbaceous	Shrub/ Scrub	Woody Wetlands	Sub-Basin Total
1	26.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	16.0	8.2	1.8	0.0	52.7
2	77.7	0.0	0.1	0.0	0.0	7.7	0.0	0.0	0.0	0.0	4.4	7.3	0.1	122.7	6.4	226.6
3	5.2	0.9	0.1	0.0	0.0	128.0	0.8	50.4	0.1	0.1	9.7	0.0	0.4	67.4	32.6	295.5
4	60.5	0.0	0.0	0.0	0.0	7.1	0.0	0.0	0.0	0.0	0.1	74.2	0.1	7.3	0.0	149.4
5	91.9	0.1	0.0	0.0	0.0	16.4	0.1	5.7	0.1	0.1	7.3	26.3	0.3	180.5	25.4	354.2
6	50.8	0.0	0.0	0.0	0.0	2.7	0.0	0.0	0.0	0.0	0.2	93.9	1.0	4.7	0.0	153.4
7	12.2	0.0	0.0	0.0	0.0	1.5	0.1	2.4	0.0	0.0	1.4	0.1	0.1	32.7	16.9	67.5
8	40.3	0.2	0.3	0.0	0.0	16.6	0.0	7.3	0.0	0.0	3.4	0.1	0.1	110.3	11.3	189.9
9	25.6	0.2	0.1	0.0	0.0	21.6	0.0	5.4	0.0	0.0	3.9	0.2	0.6	126.5	3.7	187.8
10	18.8	1.5	0.3	0.0	0.0	11.2	0.1	102.5	0.0	0.4	12.5	0.0	0.1	156.0	23.4	326.9
11	37.7	0.7	0.5	0.0	0.0	9.3	0.2	48.7	0.0	0.2	3.0	0.0	0.1	158.7	14.5	273.6
12	0.9	0.4	0.0	0.0	0.0	1.1	0.0	37.1	0.0	0.1	3.6	0.0	0.0	28.9	2.5	74.7
13	0.1	0.7	0.2	0.0	0.0	0.0	0.0	110.4	0.0	0.2	42.4	0.0	0.0	55.9	12.7	222.6
14	0.0	1.1	0.0	0.0	0.0	0.0	0.0	86.8	0.0	0.2	24.4	0.0	0.0	17.8	4.9	135.2
15	0.1	0.3	0.0	0.0	0.0	12.3	0.0	43.2	0.0	0.3	3.9	0.0	0.0	115.1	10.0	185.2
16	0.1	0.1	0.0	0.0	0.0	14.6	0.0	32.9	0.0	0.2	1.6	0.0	0.0	107.1	7.8	164.4
17	0.5	0.7	0.0	0.0	0.0	1.3	0.1	164.7	0.0	0.3	15.8	0.0	0.1	56.5	13.5	253.3
18	11.5	0.0	0.0	0.0	0.0	28.7	0.0	0.1	0.1	0.0	0.0	0.9	0.0	57.2	1.4	100.0
19	48.9	0.0	0.0	0.0	0.0	51.2	0.0	0.3	0.1	0.0	0.2	2.9	0.1	95.3	3.3	202.2
20	0.2	0.1	0.0	0.0	0.0	0.1	0.0	8.4	0.0	0.1	0.8	0.0	0.0	24.0	2.7	36.3
21	52.5	0.0	0.0	0.0	0.0	40.8	0.1	2.2	0.0	0.0	0.5	4.3	0.1	58.3	4.0	162.7
22	0.2	0.8	0.0	0.0	0.0	0.6	0.1	44.7	0.2	0.6	4.7	0.0	0.0	36.2	3.9	92.0
23	4.7	0.7	0.0	0.0	0.0	17.7	0.0	18.0	0.0	1.1	1.3	0.0	0.0	127.1	3.5	174.3
24	6.7	2.3	0.0	0.0	0.0	9.8	0.0	17.0	0.0	2.7	2.1	0.0	0.1	114.5	2.2	157.4
25	76.9	0.0	0.0	0.0	0.0	44.1	0.0	0.2	0.0	0.0	1.7	4.0	0.2	54.7	2.2	184.0
26	37.5	0.3	0.0	0.0	0.0	22.0	0.1	5.6	0.0	0.3	2.9	0.4	0.3	147.5	5.9	222.9
27	28.4	0.4	0.0	0.0	0.0	16.4	0.0	60.7	0.1	1.2	5.4	0.4	0.6	150.4	5.7	269.6
28	41.1	0.1	0.0	0.0	0.0	22.9	0.0	16.7	0.0	0.4	4.0	0.5	0.3	127.5	5.0	218.5
29	2.0	1.5	0.0	0.0	0.0	0.0	0.0	20.7	0.0	2.5	5.9	0.0	0.0	2.9	1.2	36.8
30	54.4	0.1	0.0	0.0	0.0	19.6	0.0	8.2	0.1	0.3	0.7	0.2	0.2	61.0	1.6	146.4
31	30.8	0.1	0.0	0.0	0.0	14.1	0.0	41.9	0.1	1.2	3.6	1.6	0.6	82.8	5.1	181.9
32	8.2	7.2	0.0	0.0	0.0	20.7	0.0	22.8	0.0	11.9	3.7	0.0	0.4	131.3	2.0	208.1
33	55.9	12.3	0.0	0.0	0.0	61.8	0.1	17.5	0.2	18.0	2.8	0.7	0.4	102.3	1.3	273.4
34	17.4	21.4	0.0	0.0	0.1	31.2	1.0	14.1	0.1	14.1	2.3	0.1	0.1	61.0	1.9	164.8
Total	925.9	54.2	1.7	0.0	0.1	652.9	2.9	996.4	1.6	56.4	180.3	234.3	14.6	2784.0	238.9	6144.1

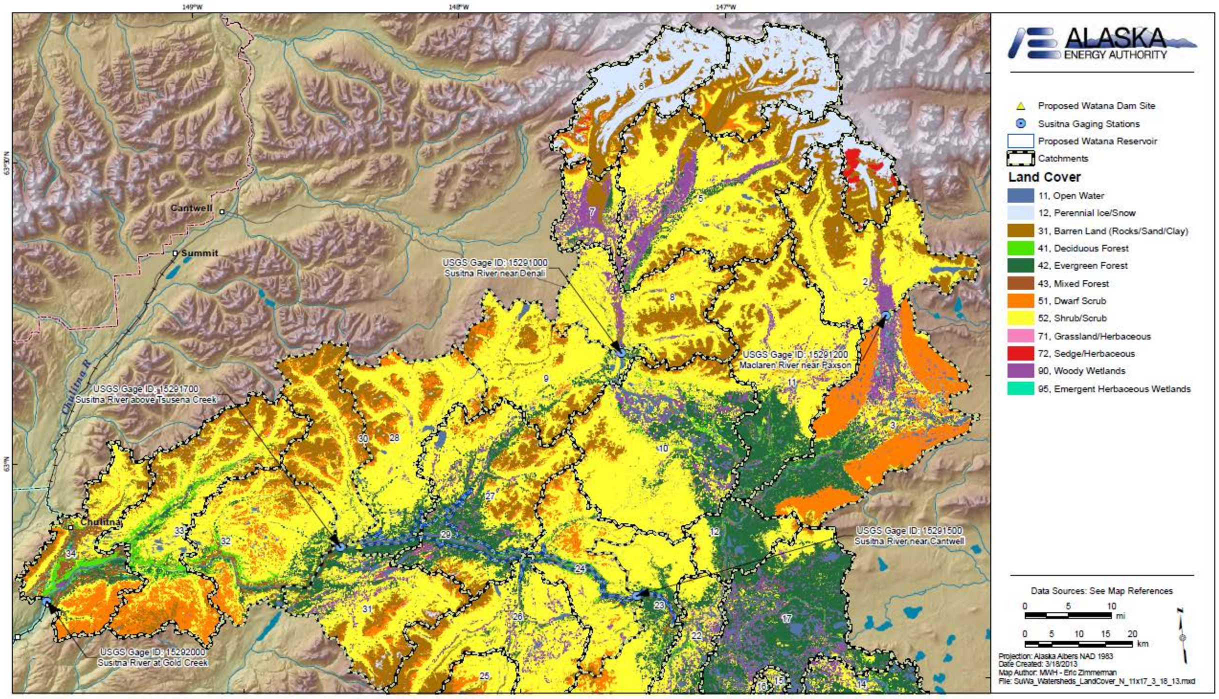


Figure 1.5-2. Susitna Watershed Land Cover – North Half

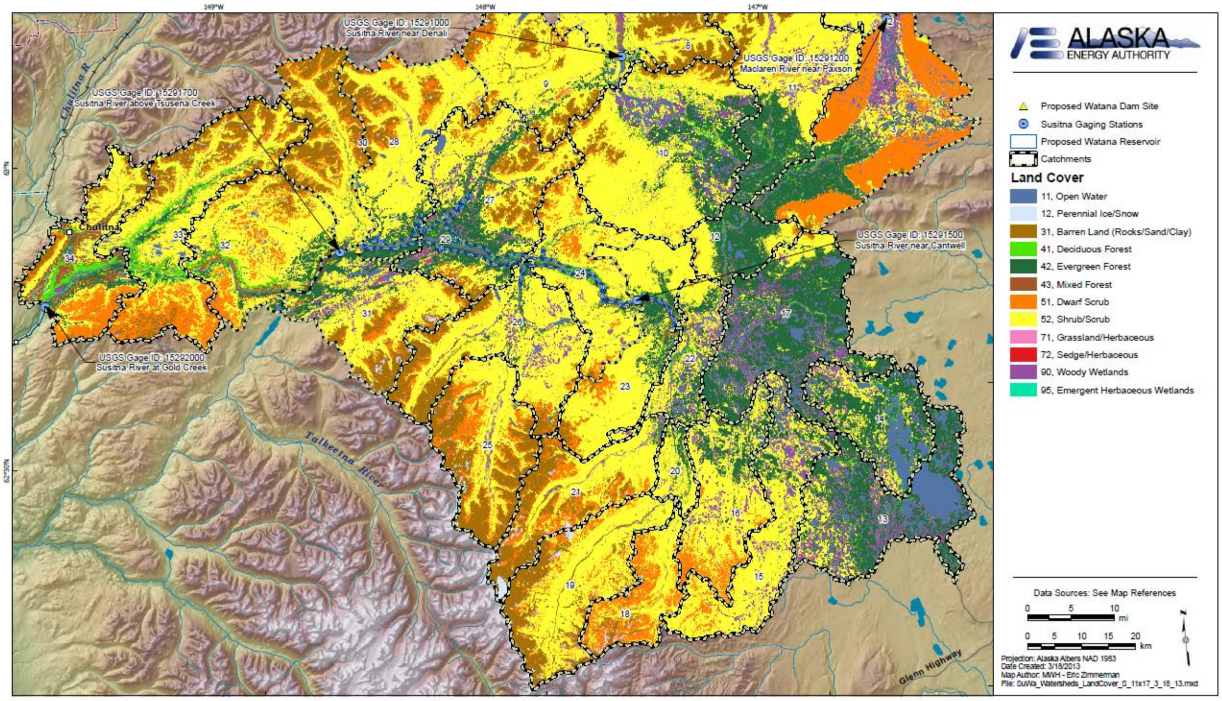


Figure 1.5-3. Susitna Watershed Land Cover – South Half

1.6 Previous Studies

A PMF study was originally performed by the U.S. Army Corps of Engineers for the Watana Dam site and was described in the following two documents:

- U.S. Army Corps of Engineers, 1975. *Interim Feasibility Report, South Central Railbelt Area, Alaska*; Appendix 1, Part 1, Section 4.
- U.S. Army Corps of Engineers, 1979. Supplemental Feasibility Report, South Central Railbelt Area, Alaska.

During feasibility studies performed for the Alaska Power Authority in the 1980's, two additional PMF studies were performed as described in the following two documents:

- Acres American Inc., 1982. *Feasibility Report, Susitna Hydroelectric Project*, Volume 4, Appendix A, Hydrological Studies, Final Draft.
- Harza-Ebasco Susitna Joint Venture, January 1984. *Probable Maximum Flood for Watana and Devil Canyon Sites*, Susitna Hydroelectric Project, Draft Report, Document No. 457.

The Acres and Harza-Ebasco PMF studies were reviewed and some information from the previous studies was used where applicable and advantageous to the current study. The current study is independent and substantially different from any previous study because of watershed sub-basin delineation, calibration and verification of unit hydrographs, the probable maximum precipitation, snowpack and snowmelt, and other parameters.

2. WATERSHED MODEL AND SUBDIVISION

2.1 Watershed Model Methodology

Three flood hydrology models were considered for performing the PMF study including:

- Streamflow Synthesis and Reservoir Routing (SSARR). This model was developed by the U.S. Army Corps of Engineers (USACE), North Pacific Division. The SSARR model was used for the 1982 Susitna PMF study. In addition to its use by the USACE, the SSARR model was used occasionally by consultants for flood simulation on major watersheds, particularly in the Pacific Northwest. The SSARR model is no longer in general use. The latest version of SSARR was modified in 1991 to run on IBM-compatible personal computers. The USACE has noted that there will be no further program updates or modifications to the SSARR files by the USACE, and no user support is available.

- Flood Hydrograph Package (HEC-1). This model was developed by the Hydrologic Engineering Center (HEC) of the USACE and was (possibly still is) the most widely used model in PMF studies. HEC-1 is one of the two rainfall-runoff models recommended for PMF studies (FERC 2001). Compared to other models, HEC-1 has the advantage of including the recommended energy budget snowmelt method as well as fully documented equations for calculating snowmelt in the model.

- Hydrologic Modeling System (HEC-HMS). This model was also developed by the HEC and is the Windows-based successor to HEC-1. HEC-HMS contains many of the same methods as HEC-1 and is the other model recommended for PMF studies (FERC 2001). Snowmelt in the HEC-HMS model is based on a method that uses temperature data only.

Flood hydrology model selection was reviewed with the BOC during the initial BOC meeting on November 2, 2012. With BOC input from that review, the HEC-1 Flood Hydrograph Package was selected as the rainfall-runoff model for developing the PMF inflow and routing of the PMF through the reservoir. The SSARR model is generally no longer in use outside of the USACE. HEC-1 includes the preferred energy budget method of snowmelt computation (FERC 2001) that is unavailable in HEC-HMS and much experience data is available for HEC-1 that is unavailable particularly for snowmelt coefficients in HEC-HMS.

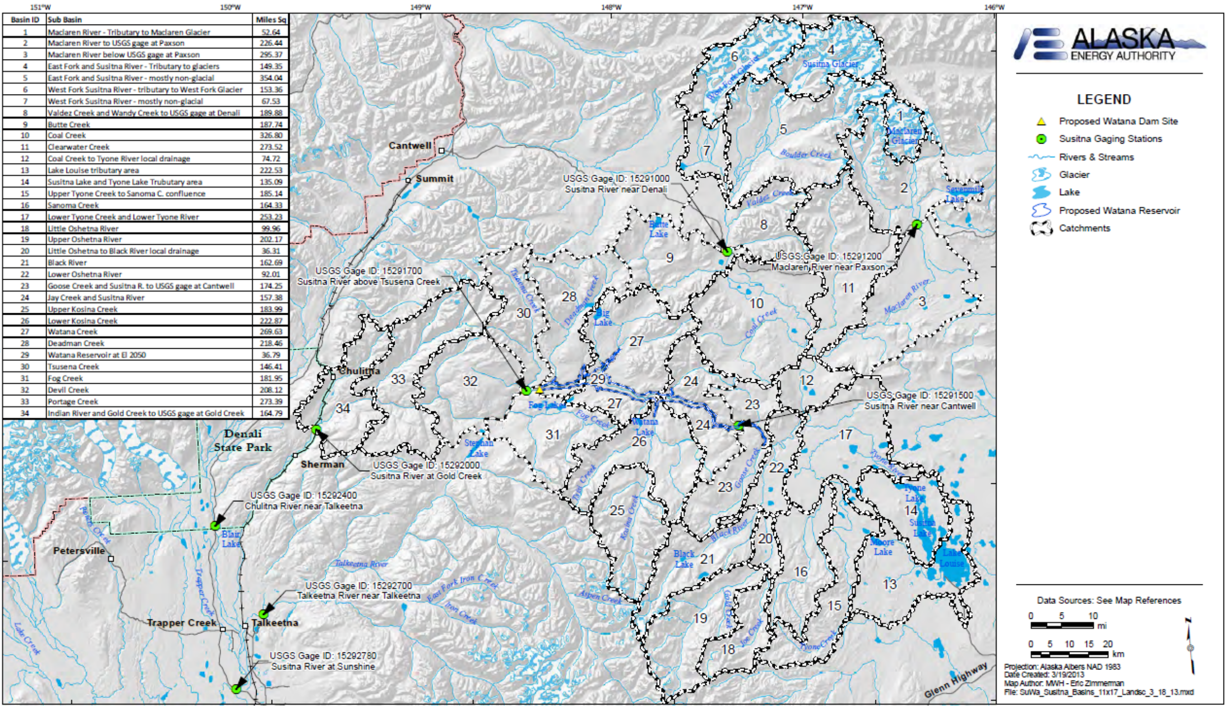
The Clark unit hydrograph method was used along with uniform infiltration losses. The Clark method parameters tc (time of concentration) and R (a storage coefficient) were developed by calibration. The ratio R/(Tc + R) has been found in a number of studies to be fairly constant on a regional basis (ASCE 1997; FERC 2001, pg. 36). This relationship was used as a means of initially estimating the parameters. Snowmelt was accomplished within the HEC-1 program using the energy budget method.

2.2 Sub-Basin Definition

The segmentation of the watershed into sub-basins included a number of factors, including the following:

- The USGS gaging stations would be included as the downstream boundary of sub-basins to facilitate model calibration.
- The major tributaries should be sub-basins.
- The major glaciers should have sub-basins.
- Watana reservoir would be included as a separate sub-basin to model the post-project reservoir properties and to set a computation point at the proposed dam site.
- There should be sufficient sub-basins to account for the areal variation of historic precipitation and the probable maximum precipitation.
- There should be sufficient sub-basins to account for the elevation distribution of the watershed.
- The objectives should be accomplished without an excessive number of sub-basins that would cause unwarranted difficulty in model calibration and data preparation.

Using the above factors as guidelines, Figure 2.2-1 outlines the selected 29 sub-basins tributary to Watana Dam and the 5 additional sub-basins between Watana Dam and the USGS gaging station at Gold Creek, which is the downstream limit of the PMF study. The average sub-basin size was about 180 square miles. Previous experience with PMF studies that included significant snowmelt contributions has shown that sub-basin sizes of about 200 square miles has been sufficient to develop acceptable model calibration and verification and a reliable estimate of the PMF.



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 2.2-1. Susitna Watershed Sub-Basins

2.3 Channel Routing Method

Level pool routing was used for routing through Watana reservoir. Although Watana reservoir is relatively large, it may not be large enough to have a significant routing effect on the PMF as the inflow PMF volume will be many times greater than the reservoir volume available to attenuate the inflow flood.

The Muskingham-Cunge method was used for channel routing. Flood attenuation of the PMF through channel routing is generally not substantial. For areas downstream from Watana Dam, previously surveyed cross-sectional data and channel lengths were available that were abstracted into the 8-point Muskingum-Cunge cross-section form. For areas upstream from Watana Dam, cross-sectional data and channel lengths were developed from available Google Earth information.

3. HISTORIC FLOOD RECORDS

3.1 Stream Gages

As previously presented in Table 1.2-1, long-term streamflow records exist at three USGS gaging stations within the watershed upstream from the proposed Watana Dam site, plus the long-term USGS gage downstream at Gold Creek at a gage having a drainage area about 19% greater than at the dam site. An additional USGS gaging station was established beginning in water year 2012 on the Susitna River above Tsusena Creek, just below the Watana Dam site. Continuous streamflow data are reported by the USGS, but when ice covers are present on the river, daily streamflow data must be estimated by the USGS.

3.2 Historic Floods

For the four USGS gages upstream or near the proposed Watana Dam site, the ranked highest ten peak flows of record for the Susitna River at Gold Creek, Cantwell, near Denali, and for the Maclaren River near Paxson have been summarized in Tables 3.2-1 through Table 3.2-4, respectively. Floods for the same date at different stations have been highlighted in the same color. Floods with the largest recorded peaks at the most gages are favored for selection as flood hydrograph calibration and verification floods. As would be expected, there is some variation in the flood rankings from gage to gage, in part due to the period of record available for each gage.

Table 3.2-1. Recorded Peak Flows – Susitna River at Gold Creek – 60 Years of Record

Rank	Date	Peak Flow (cfs)	cfs/sq.mi.
1	June 7, 1964	90,700	14.7
1	June 1, 2013	90,700	14.7
3	August 10, 1971	87,400	14.2
4	June 17, 1972	82,600	13.4
5	June 15, 1962	80,600	13.1
6	August 15, 1967	80,200	13.0
7	September 22, 2012	78,500	12.7
8	July 12, 1981	64,900	10.5
9	June 6, 1966	63,600	10.3
10	August 25, 1959	62,300	10.1

Table 3.2-2. Recorded Peak Flows – Susitna River at Cantwell – 18 Years of Record

Rank	Date	Peak Flow (cfs)	cfs/sq.mi.
1	August 10, 1971	55,000	13.3
2	June 8, 1964	51,200	12.4
3	June 15, 1962	46,800	11.3
4	June 17, 1972	44,700	10.8
5	August 14, 1967	38,800	9.4
6	June 16, 1984	33,400	8.1
7	July 18, 1963	32,000	7.7
8	August 14, 1981	30,900	7.5
9	June 23, 1961	30,400	7.3
10	July 29, 1980	28,500	6.9

Table 3.2-3. Recorded Peak Flows – Susitna River near Denali – 28 Years of Record

Rank	Date	Peak Flow (cfs)	cfs/sq.mi.
1	August 10, 1971	38,200	40.2
2	August 14, 1967	28,200	29.7
3	July 28, 2003	27,800	29.3
4	September 21, 2012	25100	26.4
5	July 28, 1980	24,300	25.6
6	August 9, 1981	23,200	24.4
7	August 4, 1976	22,100	23.3
8	July 12, 1975	21,700	22.8
9	June 7, 1957	18,700	19.7
10	July 7, 1983	18,700	19.7

Table 3.2-4. Recorded Peak Flows – Maclaren River near Paxson – 28 Years of Record

Rank	Date	Peak Flow (cfs)	cfs/sq.mi.
1	August 11, 1971	9,260	33.1
2	September 13, 1960	8,920	31.9
3	August 14, 1967	7,460	26.6
4	July 18, 1963	7,300	26.1
5	July 2, 1985	7,190	25.7
6	June 16, 1972	7,070	25.3
7	August 10, 1981	6,650	23.8
8	August 5, 1961	6,540	23.4
9	June 14, 1962	6,540	23.4
10	June 7, 1964	6,400	22.9

3.2.1 Flood Frequency

Peak annual flows have been recorded by the USGS at Gold Creek for the unusually long period of 60 years, as summarized in Table 3.2-5. Peak flow rates provided by the USGS include both average daily values and instantaneous peaks.

Peak flows for return periods up to 10,000 years were estimated for the Susitna River at Gold Creek. Peak flows were estimated for various return periods by fitting recorded peak flow data with a Log Pearson Type III distribution according to methods in Bulletin 17B (IACWD, 1982). Estimated peak flows for the Susitna River at Gold Creek are presented in Table 3.2-6.

The quality of the fit of the parameterized Log Pearson Type III distribution to the observed data is evaluated by plotting the data and the parameterized distribution together. A good fit is indicated by data points for observed annual peaks which are close to and randomly distributed above and below the computed Log Pearson Type III curve. The probability values assigned to each data point, called plotting positions, and the scale of the x-axis, are selected so that the Log Pearson Type III distribution appears as a straight line when the skew value is zero.

The fitted distribution and resulting estimated peak flows at specified return periods are approximations. The ability to fit a distribution depends on the size and the variability within the sample. Confidence limits around the computed distribution curve provide a measure of the uncertainty for the predicted discharge at a specified exceedance probability.

Figure 3.2-1 below shows the fitted Log Pearson Type III distribution as a solid line, 5 percent and 95 percent upper and lower confidence limits on the distribution as dashed lines, the observed annual peak flow data, and return periods for which peak flows were estimated in Table 3.2-6.

Table 3.2-5. Peak Annual Flows in the Susitna River at Gold Creek

Date	Peak Flow (cfs)	Date	Peak Flow (cfs)	Date	Peak Flow (cfs)
June 21, 1950	34,000	June 30, 1970	33,400	September 15, 1990	50,300
June 8, 1951	37,400	August 10, 1971	87,400	June 23, 1991	35,300
June 17, 1952	44,700	June 17, 1972	82,600	July 19, 1992	33,300
June 7, 1953	38,400	June 16, 1973	54,100	September 3, 1993	36,300
August 4, 1954	42,400	May 29, 1974	37,200	June 22, 1994	46,600
August 26, 1955	58,100	June 3, 1975	47,300	June 25, 1995	37,800
June 9, 1956	51,700	June 12, 1976	35,700	August 26, 1996	26,100
June 8, 1957	42,200	June 15, 1977	54,300	August 1, 2001	40,200
August 3, 1958	49,600	June 23, 1978	25,000	August 23, 2002	36,200
August 25, 1959	62,300	July 16, 1979	41,300	July 28, 2003	51,700
September 13, 1960	41,900	July 29, 1980	51,900	May 8, 2004	43,400
June 23, 1961	54,000	July 12, 1981	64,900	June 19, 2005	50,200
June 15, 1962	80,600	June 21, 1982	37,900	August 20, 2006	59,800
July 18, 1963	49,000	June 3, 1983	37,300	May 28, 2007	30,800
June 7, 1964	90,700	June 17, 1984	59,100	July 30, 2008	34,400
June 28, 1965	43,600	May 28, 1985	40,400	May 5, 2009	40,400
June 6, 1966	63,600	June 18, 1986	29,100	July 22, 2010	37,400
August 15, 1967	80,200	July 31, 1987	47,300	May 29, 2011	46,300
May 22, 1968	41,800	June 16, 1988	43,600	September 21, 2012	72,000
May 25, 1969	28,400	June 15, 1989	46,800	June 1, 2013	90,700

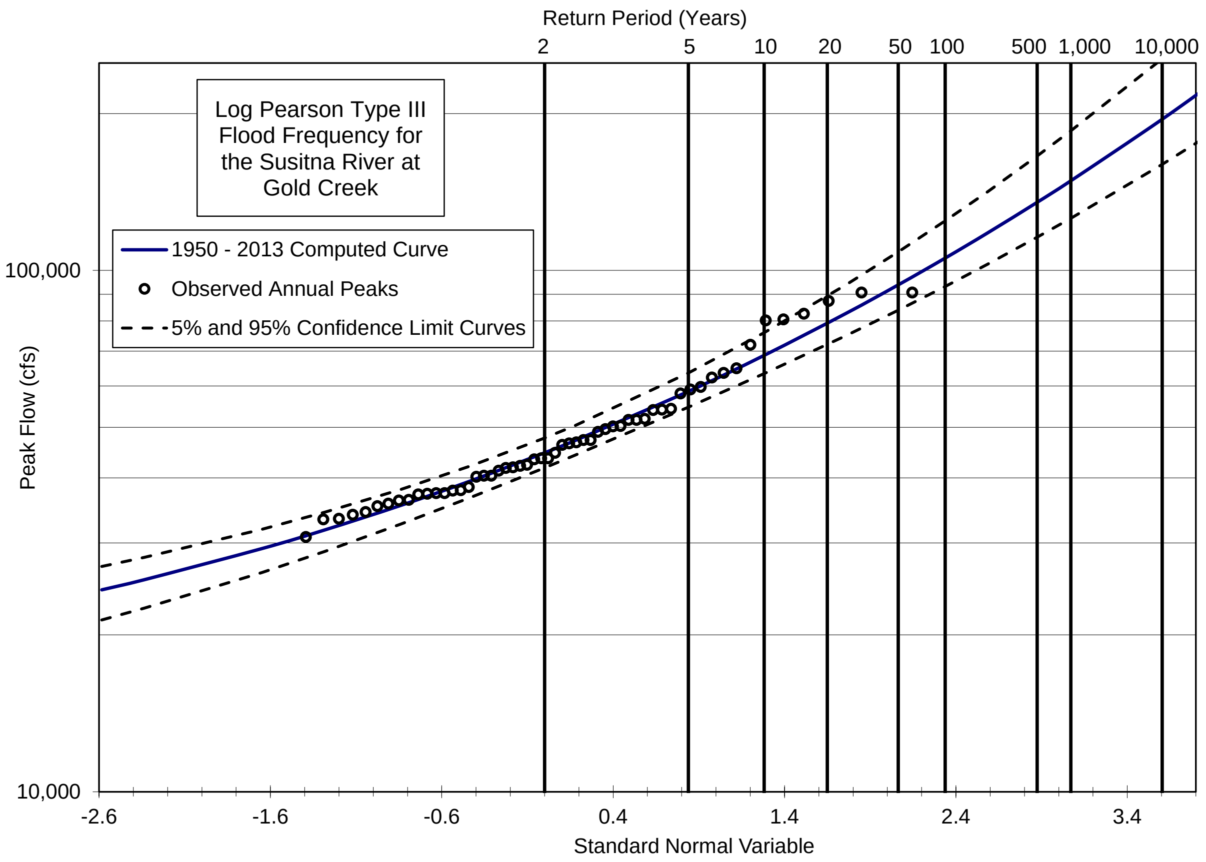


Figure 3.2-1. Log Pearson Type III Flood Frequency Plot for the Susitna River at Gold Creek

Table 3.2-6. Calculated Flood Frequency for the Susitna River at Gold Creek

Return Period (Years)	Flow (cfs)
2	44,700
5	58,600
10	68,700
25	82,700
50	93,800
100	106,000
200	118,000
500	135,000
1,000	149,000
10,000	195,000

Peak flows were estimated for return periods up to 10,000 years at the Watana Dam site by transposing peak flow analysis results at Gold Creek to Watana according to the following equation:

$$Q_{Watana} = Q_{Gold\ Creek} \times \left(\frac{A_{Watana}}{A_{Gold\ Creek}}\right)^{0.86}$$

In the above equation, A is the drainage area for each site. Peak flows are frequently adjusted from a gaged to an ungaged location by the ratio of the square root of the drainage areas. A USGS publication on the *Flood Characteristics of Alaskan Streams* (Water Resources Investigations 78-129, indicates that the exponent of the drainage area ratio should be at about the selected 0.86 value. The estimated flood frequency values for Watana Dam are presented in Table 3.2-7.

Table 3.2-7. Estimated Peak Annual Flows in the Susitna River at Watana Dam

Return Period (Years)	Flow (cfs)
2	38,500
5	50,500
10	59,200
20	68,300
25	71,300
50	80,800
100	91,300
500	116,300
1,000	128,400
10,000	168,000

3.2.2 Seasonal Flood Distribution

The determination of a 100-year snowpack for every month of the year is unnecessary because of the highly seasonal nature of Susitna River flow. With 59 years of daily flow data available, the USGS streamflow gage at Gold Creek provides an excellent long-term record of the seasonality of Susitna River flow. Table 3.2-8 provides the maximum daily flow of record at Gold Creek for each month. During the coldest months of November through March, a daily flow of as much as 10,000 cfs has never been recorded, indicating that these five months can be eliminated as potentially maximum flood producing months.

Table 3.2-8. Maximum Daily Flows for Each Month at Gold Creek

Gold Creek USGS Gage Maximum Daily Flow (cfs)	
January	2,900
February	3,700
March	2,400
April	24,000
May	55,500
June	85,900
July	60,800
August	77,700
September	70,800
October	36,200
November	8,940
December	4,400

Table 3.2-9 summaries the month of occurrence of the annual peak flow at each of the four USGS gages in or near the watershed tributary to the Watana Dam site. For the gaging stations nearest the Watana Dam site, Gold Creek and Cantwell, June is the month during which the annual maximum flows most frequently occur and the same is true at the Maclaren gage. The Denali gage is most heavily influenced by glacier melt and annual peak flows occur most frequently at Denali during July or August. In 134 gage-years of daily flow data, an annual peak flow has never been recorded during the months of October through April.

Additional flow frequency data at Gold Creek is provided on Figure 3.2-2. April and May are the months with the lowest reservoir elevations, and April flows exceed 10,000 cfs less than 1 percent of the time, April can be eliminated from further consideration as the critical PMF month for Watana Dam. Although October has never had an annual maximum flow, the reservoir levels would be higher and it was therefore retained for further consideration as a potentially critical month for the PMF.

Table 3.2-9. Monthly Distribution of Annual Peak Flows

Month	Gold Creek Gage		Cantwell Gage		Denali Gage		Maclaren Gage		Total of All Gages	
	Annual Peaks	% of Total	Annual Peaks	% of Total	Annual Peaks	% of Total	Annual Peaks	% of Total	Annual Peaks	% of Total
January	0	0%	0	0%	0	0%	0	0%	0	0%
February	0	0%	0	0%	0	0%	0	0%	0	0%
March	0	0%	0	0%	0	0%	0	0%	0	0%
April	0	0%	0	0%	0	0%	0	0%	0	0%
May	8	14%	1	6%	0	0%	1	4%	10	7%
June	28	47%	8	44%	3	10%	12	43%	51	38%
July	9	15%	5	28%	12	41%	6	21%	32	24%
August	10	17%	4	22%	12	41%	7	25%	33	25%
September	4	7%	0	0%	2	7%	2	7%	8	6%
October	0	0%	0	0%	0	0%	0	0%	0	0%
November	0	0%	0	0%	0	0%	0	0%	0	0%
December	0	0%	0	0%	0	0%	0	0%	0	0%
Total	59	100%	18	100%	29	100%	28	100%	134	100%

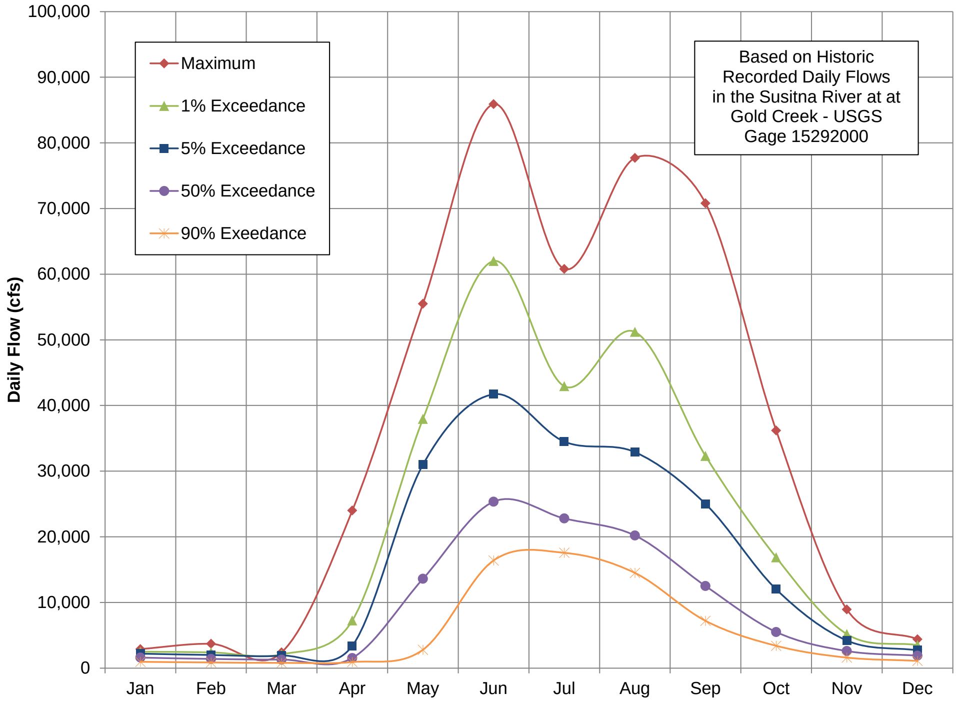


Figure 3.2-2. Historic Flow Frequency at the USGS Gold Creek Gage

3.2.3 Volume Frequency Analysis

A volume frequency analysis of historic streamflow records serves two purposes, which are (1) to serve as a potential substitute for the 100-year runoff of glaciated areas, and (2) for comparison to the PMF hydrograph volumes of previous PMF studies. The location of the major glaciers tributary to the Watana Dam site is shown on Figure 3.2-3.

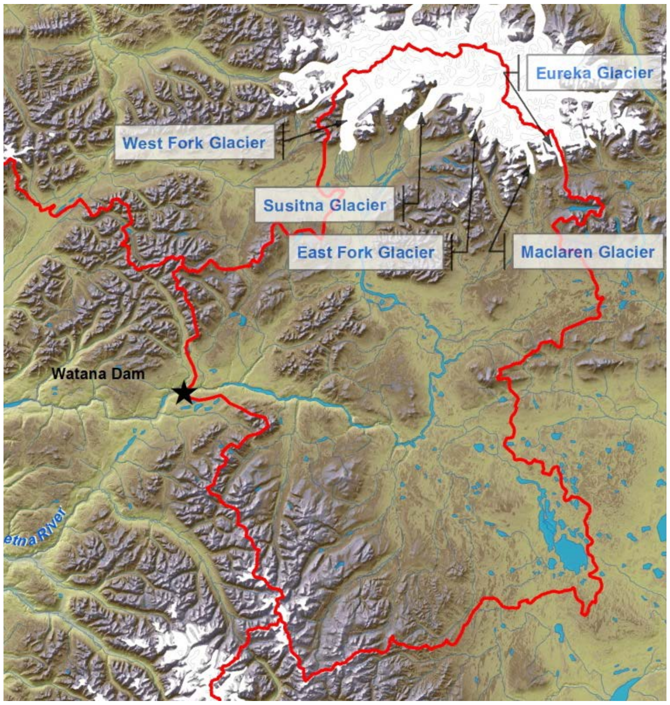


Figure 3.2-3. Susitna Watershed Glaciers

The 100-year 3-day average runoff is a potential alternative or comparison value for the 100-year snowpack runoff. Table 3.2-10 presents the monthly maximum recorded and 100-year calculated 3-day average runoff at the USGS gaging stations and for the area tributary to Watana Dam.

Table 3.2-10. 3-Day Average Flows at USGS Gages and Watana Dam Site

Station	Data Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	cfs/sq.mi.
Maclaren	Max. Recorded	200	150	130	170	5,977	6,153	7,000	7,257	5,823	1,607	483	300	7,257	25.9
Maclaren	100-Year Calc.	231	167	148	215	7,778	6,799	7,608	8,416	5,942	1,792	502	316	8,564	30.6
Denali	Max. Recorded	543	380	320	600	9,040	16,433	21,900	30,433	14,833	3,933	1,263	680	30,433	32.0
Denali	100-Year Calc.	569	435	366	567	11,572	17,526	24,258	31,536	17,448	4,571	1,483	809	30,857	32.5
Cantwell	Max. Recorded	1,800	1,500	1,500	2,467	25,767	48,367	31,667	49,667	19,133	9,667	3,600	1,967	49,667	12.0
Cantwell	100-Year Calc.	2,165	2,023	1,848	2,865	31,209	59,494	36,071	62,017	23,876	11,487	4,220	2,358	62,155	15.0
Gold Creek	Max. Recorded	2,867	3,567	2,333	17,000	43,567	81,900	54,533	72,733	66,271	30,267	8,627	4,400	81,900	13.3
Gold Creek	100-Year Calc.	2,730	2,848	2,377	15,237	45,345	80,134	51,647	75,610	55,687	28,384	7,126	4,019	84,712	13.8
Watana (1)	Max. Recorded	2,292	2,866	1,869	13,838	34,464	69,370	44,349	62,563	38,134	24,869	7,005	3,551	69,370	13.1
Watana (1)	100-Year Calc.	2,269	2,336	1,934	12,441	35,923	66,256	42,693	62,662	33,783	23,374	5,846	3,331	70,147	13.3

Note (1): Based on USGS synthesized 61-year record from October 1949 through September 2010.

The principal influences of glaciers include a delay of the maximum seasonal flow and storage of spring snowmelt in the form of liquid water for release later in the year (Fountain and Tangborn 1985). These influences appear to be at least partially responsible for the occurrence of the maximum recorded flows (highlighted in yellow on Table 3.2-10) in August rather than June at the most upstream gages in the Susitna River watershed.

Table 3.2-11 presents the 20-day average and peak flows for the PMF hydrographs from the 1980s Susitna PMF studies and also includes maximum recorded results for the long-term USGS streamflow record at Gold Creek and the estimated 100-year 20-day average flow at Watana Dam. The 100-year volumes from USGS records are of interest because they are likely to primarily result from snowmelt and the 100-year snowpack is the primary contributor to the 20-day volume of the PMF hydrograph. One striking result of this comparison is that the Acres 1982 PMF volume appears to be far too high, which means that the estimated antecedent 100-year snowpack was far too great in that study.

Table 3.2-11. 20-Day Average Flows and Peak Flows

Study	Location	Data Type	Avg. cfs	Total Acre-Feet	Peak cfs
Current (1)	Watana Dam	100-Year	50,200	1,990,000	86,600
USGS Records	Gold Creek	Maximum	59,280	2,350,000	90,700
Acres 1982	Watana Dam	PMF	220,600	8,750,000	325,000
Harza-Ebasco 1984 - **May**	Watana Dam	PMF	106,900	4,240,000	309,000
Harza-Ebasco 1984 - **June**	Watana Dam	PMF	76,900	3,050,000	254,000
Harza-Ebasco 1984 - **July-Aug**	Watana Dam	PMF	59,000	2,340,000	267,000

Note (1): 20-day maximums are based on USGS synthesized 61-year record

3.2.4 Spring Breakup Timing Effects on Maximum Floods

A timing analysis of the beginning of spring high flows has revealed a correlation between maximum floods and a late start to the spring breakup high flows. This is a key observation because it provides a mechanism for rapid melting of large snowpacks during late spring when higher temperatures are possible. Although this type of cold, late spring with a rapid June warming has been advanced as a PMF producing mechanism in a previous Susitna PMF study (Acres 1982) and for a PMF study of the Yukon River (Weather Bureau 1966), no recorded data was presented in these studies confirming the historic existence of this scenario for production of maximum floods.

In the current analysis, it was assumed that the first day of the calendar year having a flow of 5,000 cfs or more at Gold Creek would serve as a proxy for the beginning of the spring breakup high flows. As shown on Table 3.2-12, the two years that are tied for the highest flow of record, 1964 and 2013, had the latest and third latest start to high spring flows in the 60 years of peak flow records. It is noted that the 2013 flows are preliminary and subject to change by the USGS. Figure 5 presents a flood frequency curve for the USGS gage at Gold Creek that indicates the 90,700 cfs maximum flow of record has about a 2.5 percent chance of occurrence in any given year (about a 40-year return period). These historic records are a strong indicator of maximum flood producing mechanism.

Table 3.2-12. Initiation of Spring Breakup during Historic Large Flood Years

Flood Peak Rank	Flood Peak Date	Peak Flow (cfs)	Date of Initial 5,000 cfs Flow	Rank Order of Initial 5,000 cfs Flow (of 60 years)
1 (tie)	June 7, 1964	90,700	May 27	1 - Latest
1 (tie)	June 2, 2013	90,700	May 24	3 (tie)
3	August 10, 1971	87,400	May 24	3 (tie)
4	June 17, 1972	82,600	May 5	35
5	June 15, 1962	80,600	May 16	12

3.2.5 May – June 2013 Flood Analysis

Because a cold, late spring followed by a rapid June warm up is potentially a PMF producing temperature scenario, the 2013 May-June flood, which had a record maximum peak flow, was examined in more detail as an example maximum flood scenario. In addition, the FERC Board of Consultants performed a site visit on May 29, 2013, providing some brief first-hand observations and photographic evidence on flow, meteorological, and snow conditions.

Figure 3.2-4 shows the Susitna River preliminary flow data for April 1 through June 30. No Susitna River flow data are available through May 19 due to ice cover. Gaged flow data begins on May 20. Figure 3.2-4 also shows the daily average temperature departure from normal at the Talkeetna airport weather station. For most of April through May 22, temperatures were below normal, far below normal at times. Beginning on May 19, there was a rapid rise in temperatures at Talkeetna beginning at 13 degrees below normal and peaking at 13 degrees above normal on May 29. Daily average flows at Gold Creek rose rapidly, peaking on June 2. Subsequent even higher temperatures in June did not result in flows nearly as high as the June 2 peak, probably because the snowpack had already been mostly melted.

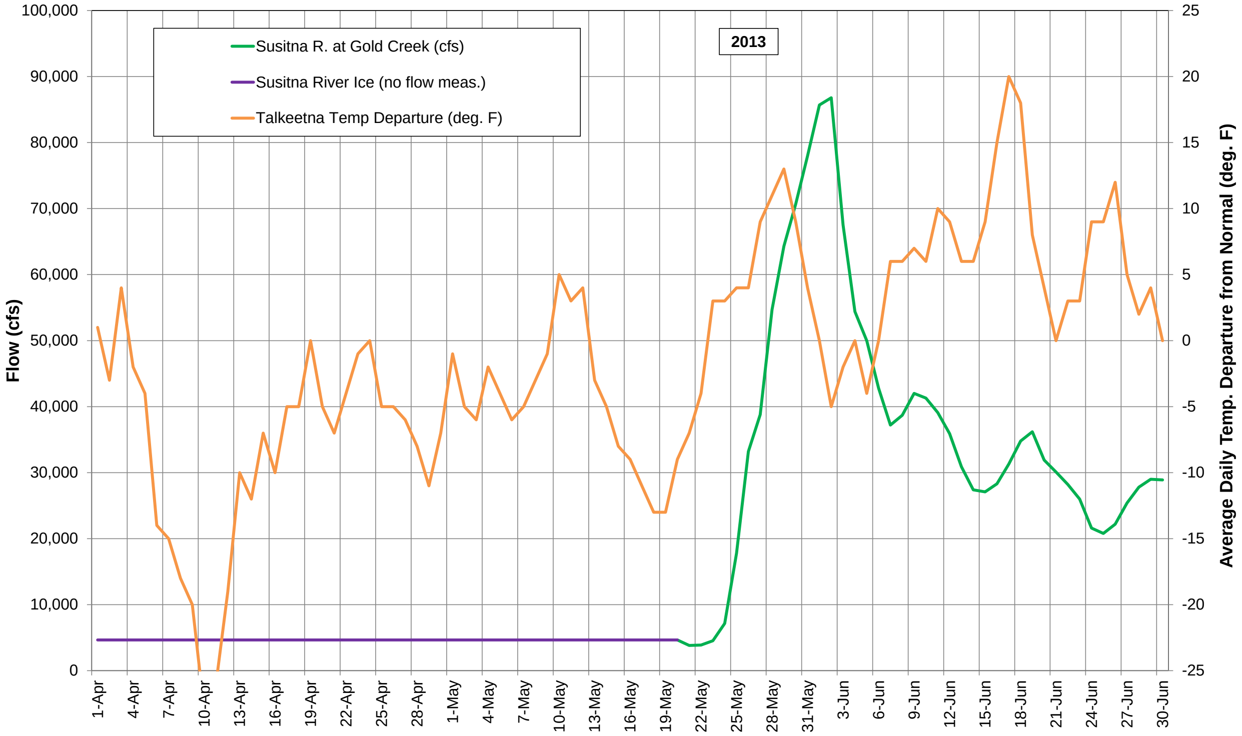


Figure 3.2-4. April – June 2013 Flow and Temperature Departure from Normal

Figure 3.2-5 also shows temperature data at Talkeetna for the same period, but the temperature data is presented as the daily maximum and minimum temperatures. The maximum recorded temperature prior to the peak flow was 83 degrees on May 29. Figure 3.2-6 shows recorded precipitation at Talkeetna in addition to the Gold Creek flows, which shows that the rise in Susitna River flows to record levels occurred during a rain-free period. Recorded rainfall on the day of the peak was too late to have any significant effect on flows. Snowpack records indicate that 2013 was a near normal winter.

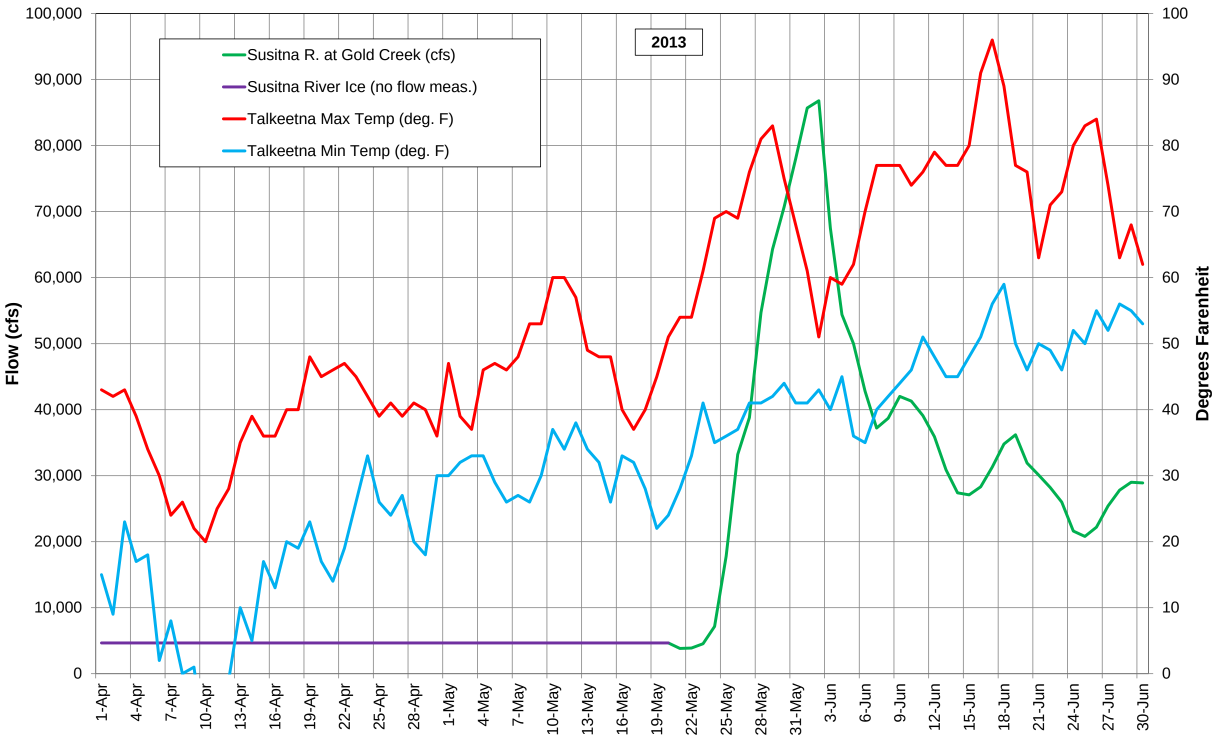


Figure 3.2-5. April – June 2013 Flow and Temperatures

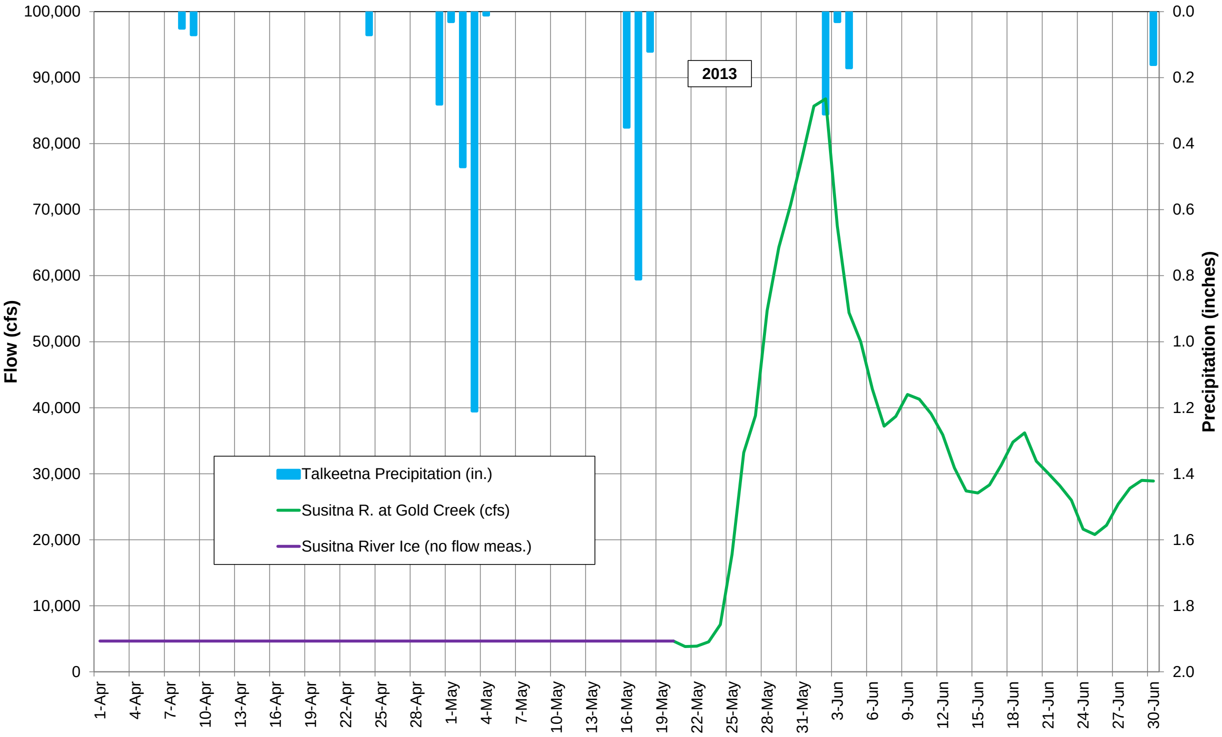


Figure 3.2-6. April – June 2013 Flow and Precipitation

3.3 Precipitation Associated with Historic Floods

The Storm Precipitation Analysis System (SPAS) was used to develop historical precipitation data for the Susitna River watershed upstream from the USGS gage at Gold Creek. SPAS is a state-of-the-science hydrometeorological tool used to characterize the magnitude, temporal, and spatial details of precipitation events. A more complete discussion of the development of historic precipitation for use in runoff model calibration is included in Appendix A.

Historical data was acquired to develop meteorological time series for use in rain on snow PMF modeling. Information from six storms was used in the runoff model calibration efforts. Daily and hourly time series were developed for meteorological parameters (i.e. temperature, dew point, wind) required for snow melt modeling using data from surrounding weather stations (e.g. NWS COOP, RAWS, SNOTEL, and various other networks).

3.4 Snowpack and Snowmelt During Historic Floods

Normally three floods are selected for calibration and verification of unit hydrograph parameters and loss rates. Because the Susitna River is subject to two distinctly different types of floods, snowmelt dominated floods in the spring and rainfall dominated floods in the summer, three historic floods of each type were selected for analysis. The flood periods selected for calibration and verification of hydrograph parameters are:

1. June 1964 (spring)
2. August 1967 (summer)
3. June 1971 (spring)
4. August 1971 (summer)
5. June 1972 (spring)
6. September 2012 (summer)

There is no SNOTEL data available at any gage for the August 1967 and August 1971 floods. The snow course sites do not begin measurement until the end of January. For the September 2012 flood, all of the SNOTEL sites show zero antecedent snowpack, except for Independence Mine, which had 0.4 inch snow water equivalent (SWE) on September 19, then zero on September 20. Independence Mine is at El 3550 and is far to the south. Table 3.4-1 summarizes the earliest and latest recorded dates for snowpack at the SNOTEL stations. To be counted as snowpack, the recorded snow on the ground must persist on a seasonal basis. There is no evidence of a snowpack existing for the August and September calibration storms, other than snow and ice on glaciers.

Table 3.4-1. Earliest and Latest Snowpack at SNOTEL Stations

Station Name	Station Number	In Susitna R. Watershed (1)	Elevation (feet)	Maximum SWE (2)		Earliest Day with Snowpack	Latest Day with Snowpack	Years of Available Snowpack Data In the Period of Record
				(inches)	Date			
Anchorage Hillside	1070	No	2,080	18.4	4/12/2012	10/6/2009	5/31/2012	8 years: 2006 - 2013
Bentalit Lodge	1086	Yes	150	12.1	4/2/2012	10/10/2009	5/8/2008	8 years: 2006 - 2013
Fairbanks F.O.	1174	No	450	11.2	4/26/1991	9/12/1992	5/20/2013	31 years: 1983 - 2013
Granite Creek	963	No	1,240	7.7	4/16/1991	9/12/1992	5/14/2013	26 years: 1988 - 2013
Independence Mine	1091	Border	3,550	23.5	5/17/2001	10/1/2002	6/13/2013	16 years: 1998 - 2013
Indian Pass	946	No	2,350	40.1	5/13/2001	9/17/1992	6/27/1985	34 years: 1980 - 2013
Monohan Flat (3)	1094	**Border**	2,710	N/A	N/A	10/4/2008	5/25/2013	6 years: 2008 - 2013
Mt. Alyeska	1103	No	1,540	69.1	5/13/1998	10/1/1993	7/3/1980	40 years: 1973 - 2013
Munson Ridge	950	No	3,100	18.4	4/15/1991	9/11/1992	6/2/1982	33 years: 1981 - 2013
Susitna Valley High	967	Yes	375	18.7	4/1/1990	10/1/1997	5/21/1999	27 years: 1988 - 2013
Tokositna Valley	1089	Yes	850	20.7	4/27/2008	10/8/2009	6/3/2013	8 years: 2006 - 2013

Notes:

(1) Items in bold indicate the location is tributary to Watana Dam. Border indicates the station is on or near the watershed border.

(2) SWE is snow water equivalent, the depth of melted snow in a snowpack.

(3) Snow water equivalent data is unavailable for the Monahan Flat SNOTEL site.

The lowest level of the Susitna watershed glaciers are at about El 3000. It was assumed that there is zero antecedent snow below El 3000, and then essentially unlimited snow (glacier) above El 4000 feet in the sub-basins that have glaciers. The other sub-basins with higher elevations without glaciers would be assumed to have zero snow water equivalents for the August and September calibration floods.

Because snow course data antecedent to the individual June calibration floods showed considerable variation relative to the average October through April precipitation, several individual snow course stations were used to distribute the June calibration flood antecedent snowpack in conjunction with the precipitation maps. Table 3.4-2 presents a summary of the antecedent snowpack used for the June calibration storms. Because snow course data is not available after about May 1, and because no data is available at the SNOTEL gages for the time period of the calibration floods, snowpack is considered to be a calibration parameter.

Table 3.4-2. Antecedent Snowpack Snow Water Equivalent as a Percent of Average Oct-April Precipitation

Sub-Basin Number	June 1964	June 1971	June 1972
1	85%	110%	120%
2	85%	110%	120%
3	85%	110%	120%
4	85%	110%	120%
5	85%	110%	120%
6	85%	110%	120%
7	85%	110%	120%
8	85%	110%	120%
9	85%	110%	120%
10	50%	110%	150%
11	70%	110%	150%
12	50%	90%	150%
13	90%	70%	150%
14	90%	70%	150%
15	90%	70%	150%
16	90%	70%	150%
17	90%	70%	150%
18	85%	90%	90%
19	85%	90%	90%
20	85%	70%	90%
21	85%	90%	90%
22	85%	70%	120%
23	85%	70%	120%
24	85%	70%	120%
25	85%	90%	120%
26	85%	90%	120%
27	50%	100%	120%
28	50%	100%	120%
29	50%	100%	120%
30	50%	90%	120%
31	50%	90%	120%
32	50%	70%	120%
33	50%	70%	120%
34	50%	70%	120%

4. UNIT HYDROGRAPH DEVELOPMENT

4.1 Approach and Tasks

The Susitna River basin is considered to be a case where sufficient streamflow data of satisfactory quality are available for confidence in developing unit hydrographs. Five USGS gages have been in operation for various periods within or not far downstream of the area tributary to Watana Dam. All five USGS gages were used in the calibration and verification of unit hydrograph parameters. Snowpack data is available at several stations (see section 3.4 and 8.3) and is considered to be adequate. Although long-term meteorological stations (precipitation, temperature, and wind speed data) are absent within the watershed tributary to Watana Dam, a sophisticated meteorological model provided adequate data using stations near the watershed. As discussed in Section 2.1, the HEC-1 Flood Hydrograph Package (USACE HEC, 1998) was chosen as the watershed model to perform the calibration and verification runs and the final PMP runoff and PMF routing runs.

Eleven floods were considered for runoff model calibration and verification, with six being selected. Because the Susitna River is subject to floods having two distinctly different predominant origins, snowmelt in the spring and rainfall in the summer, three floods of each type were selected for calibration and verification. Preference for selection of historic floods for calibration and verification was based on:

- the largest floods of record
- the floods with data at the most USGS gages
- the floods with the most complete flow data near the peak flow
- distribution of floods in the May through October potential flood season

The floods selected for calibration included the following:

- Spring floods – June 1964, June 1971, and June 1972
- Summer floods – August 1967, August 1971, and September 2012

The available USGS gaging station data for these floods are plotted on Figures 4.1-1 through 4.1-6. These plots provide an indication of the relative magnitude and timing of flows at the various gaging stations for the period both before and after the peak flows.

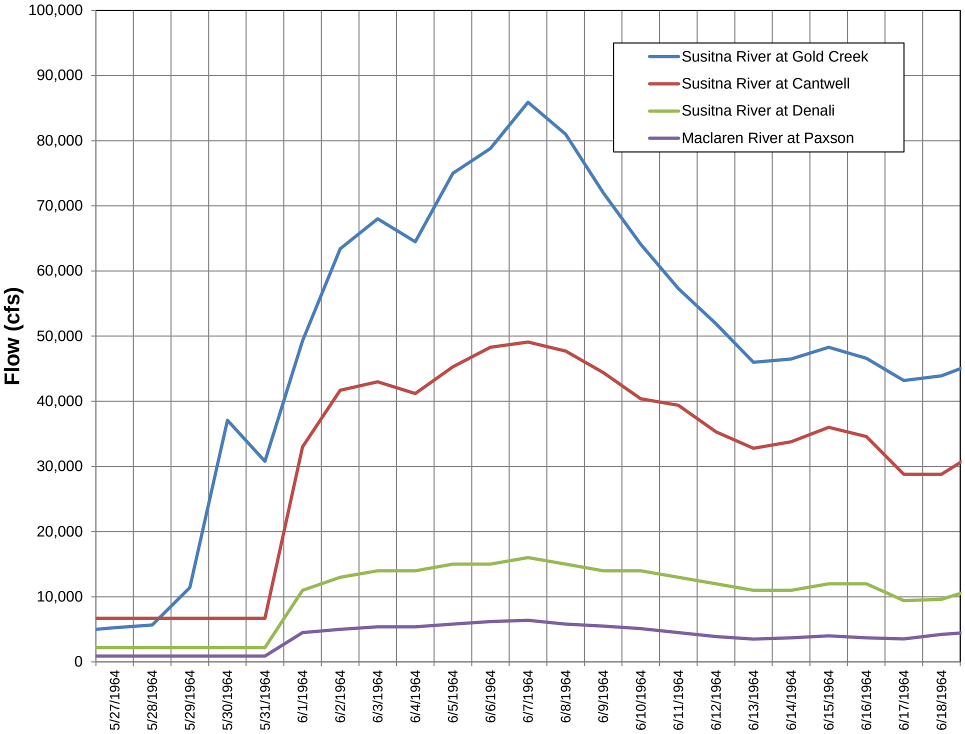


Figure 4.1-1. June 1964 Recorded Flows at USGS Gages

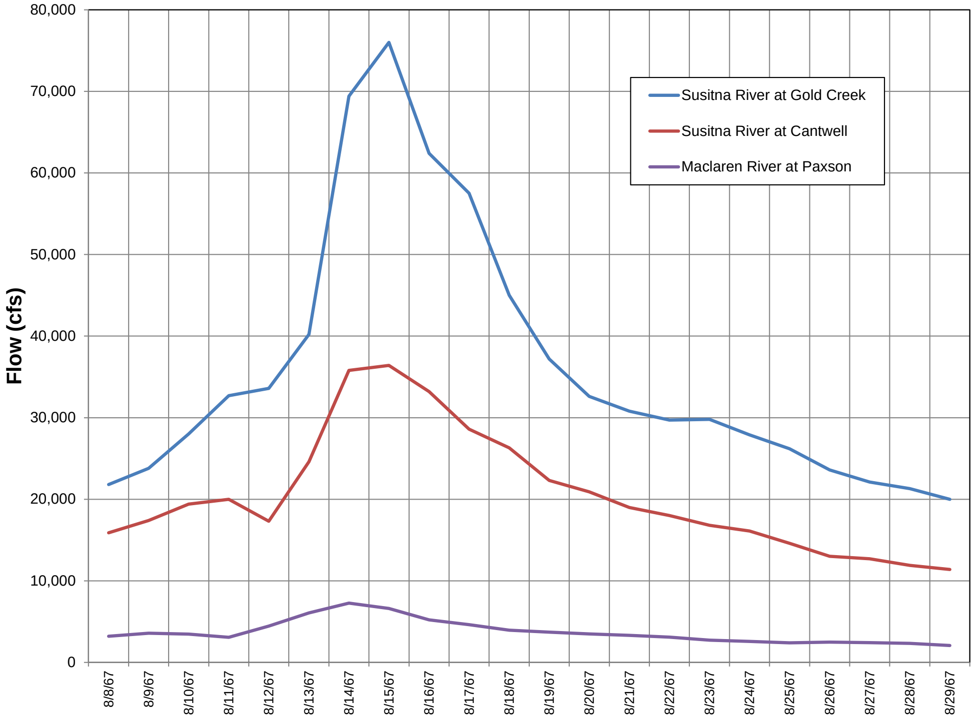


Figure 4.1-2. August 1967 Recorded Flows at USGS Gages

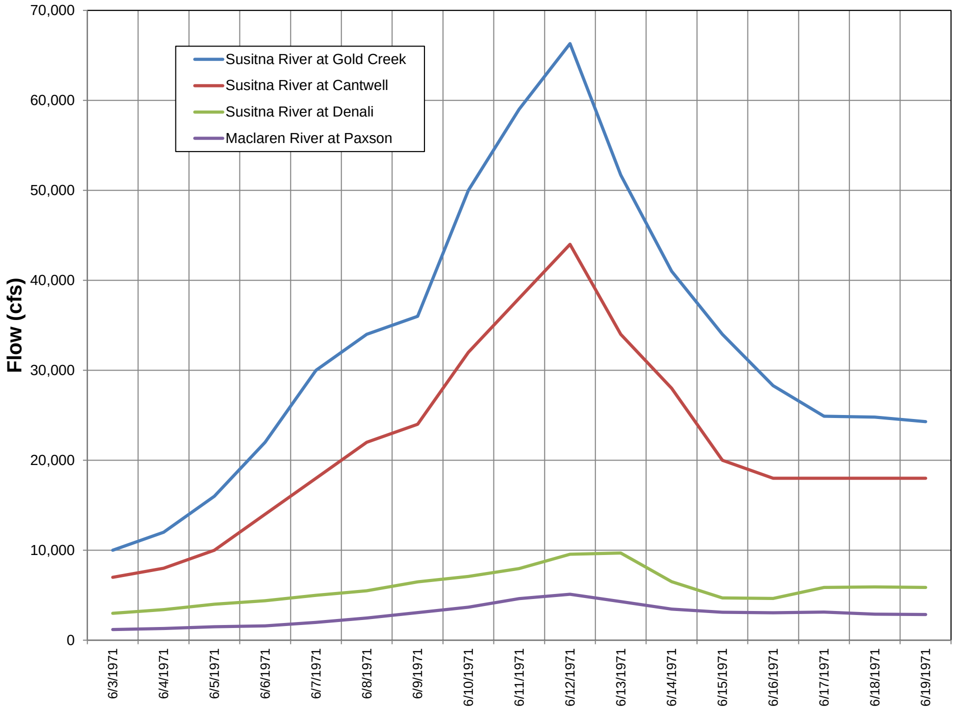


Figure 4.1-3. June 1971 Recorded Flows at USGS Gages

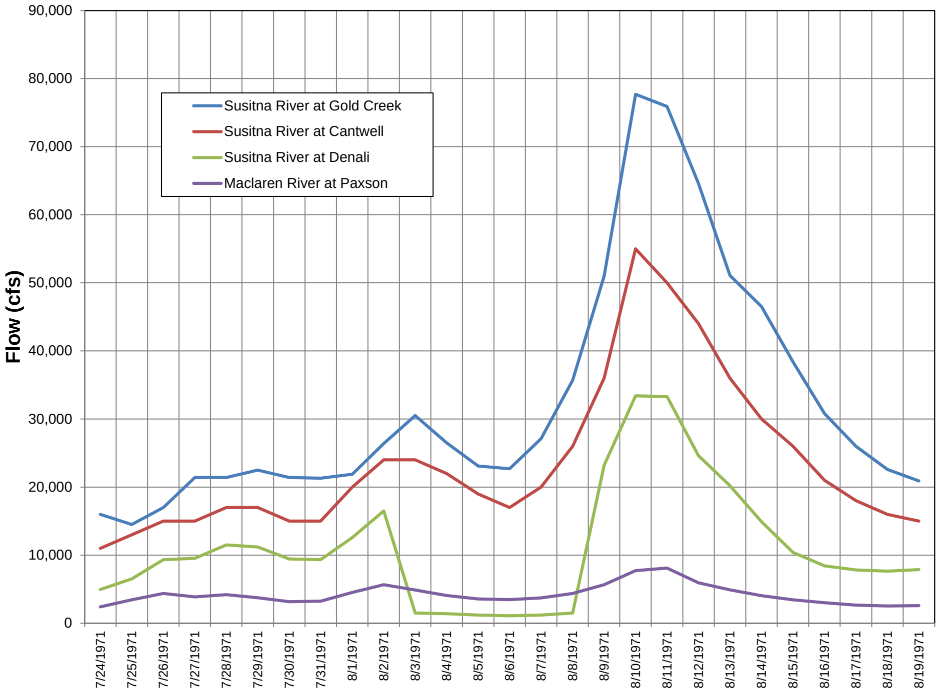


Figure 4.1-4. August 1971 Recorded Flows at USGS Gages

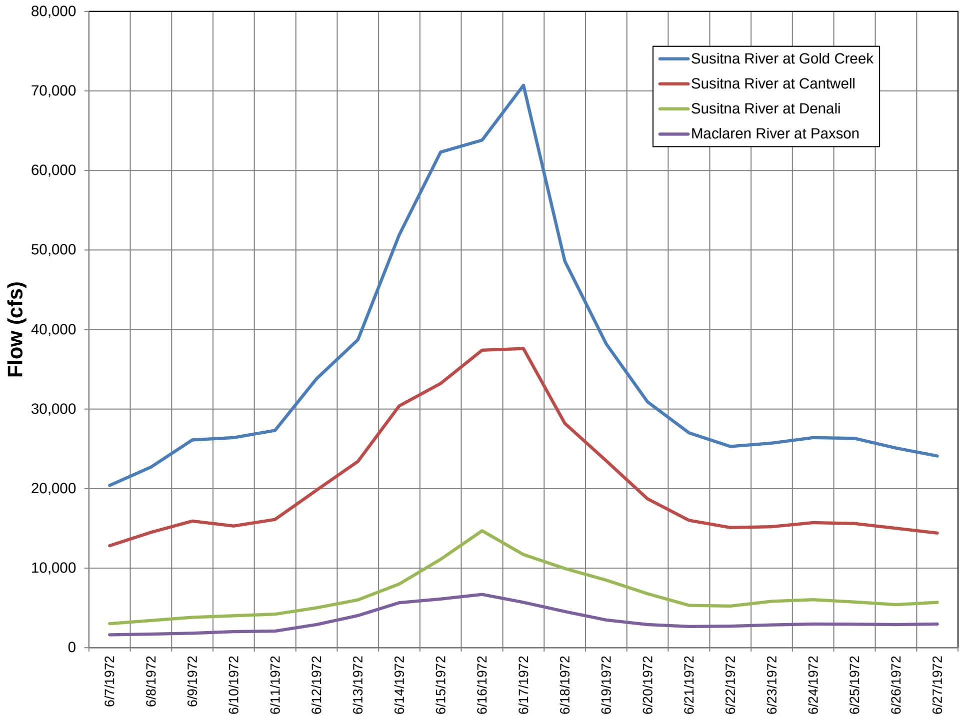


Figure 4.1-5. June 1972 Recorded Flows at USGS Gages

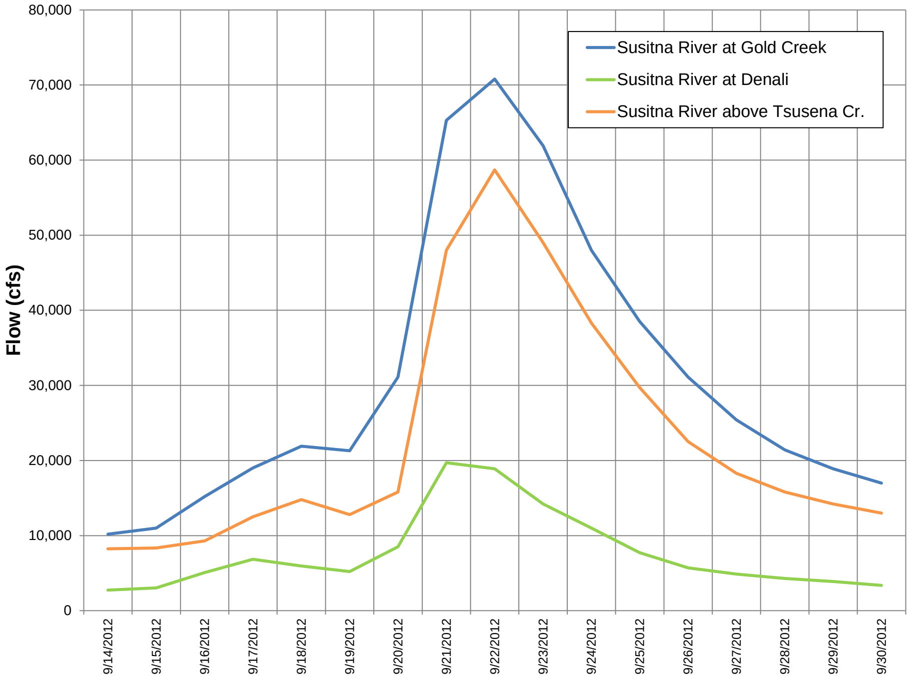


Figure 4.1-6. September 2012 Recorded Flows at USGS Gages

4.2 Preliminary Estimates of Clark Parameters

Preliminary estimates of Clark parameters were available at some locations from previous studies. Initial estimates for the Clark parameters were made by approximately simulating the results of the previous Susitna PMF studies. However, the calibration and verification process for the unit hydrographs provided revised Clark parameter values. The preliminary estimates for Clark parameters were not used in the final studies.

4.3 Estimate of Infiltration During Historic Floods

The initial abstraction and uniform loss rate method of simulating infiltration was used for the rainfall dominated summer floods and the exponential loss rate method was used for the snowmelt dominated spring floods. Initial abstractions of 0.06 to 0.08 inch and uniform loss rates of 0.02 to 0.04 inch/hour were used for most of the sub-basins. As shown in Table 1.5-3, 90% of the Susitna watershed tributary to the Watana Dam site (Harza-Ebasco 1984) is covered with soils having the lower infiltration rates (USBR 1974) of Hydrologic Soil Groups C and D. The initial abstraction and uniform loss rate parameters are very low for soils of these types and would represent wet antecedent conditions in the watershed.

4.4 Summer Sub-Basin Unit Hydrograph Parameters

Development of unit hydrograph parameters for the Clark unit hydrograph method involves the two parameters Tc (time of concentration) and R (a storage coefficient). A frequently used concept for calibration is that the ratio R/(Tc + R) tends to be fairly constant on a regional basis. Due to the diverse topography and other factors in the Susitna River basin, a constant ratio was not always the result in the calibration. The final Clark unit hydrograph parameters resulting from the calibration effort are summarized in Table 4.4-1. The same final Clark unit hydrograph parameters were used for all floods, both spring and summer.

On all of the figures in this section, USGS recorded flow data is in blue and simulated flow is in red. Average daily precipitation for the area tributary to the gage is shown at the top of the plots. Scale differences in precipitation between the spring and summer floods should be noted. For all summer runs, snowpack is included only in glaciated areas.

Recorded USGS streamflow data is available for the September 2012 flood at the Denali, Tsusena Creek, and Gold Creek gages. The Tsusena Creek gage is essentially at the Watana Dam site and because it was recently established, September 2012 is the only calibration and verification flood that has data at the Tsusena Creek gage. At the time of its occurrence, the September 2012 flood was the largest recorded flood at Gold Creek in the previous 40 years, the 6th largest flood of record at Gold Creek, and by far the largest flood ever recorded in September at the Gold Creek gage. The September 2012 flood was the 4th highest flood of record at the Denali gage.

As shown on Figures 4.4-1 through 4.4-3, the agreement between recorded and simulated peak flows, hydrograph volumes, timing of the peak flows, and general hydrograph shape are all notably excellent. In addition, no adjustments were made to precipitation, wind speed, temperature, or snowpack in any sub-basin. It is noted that the September 2012 flood is the only calibration or verification flood with available precipitation radar data (NEXRAD) and has the best available meteorological data. From this a significant conclusion is made; highly accurate data input results in the best runoff model simulations.

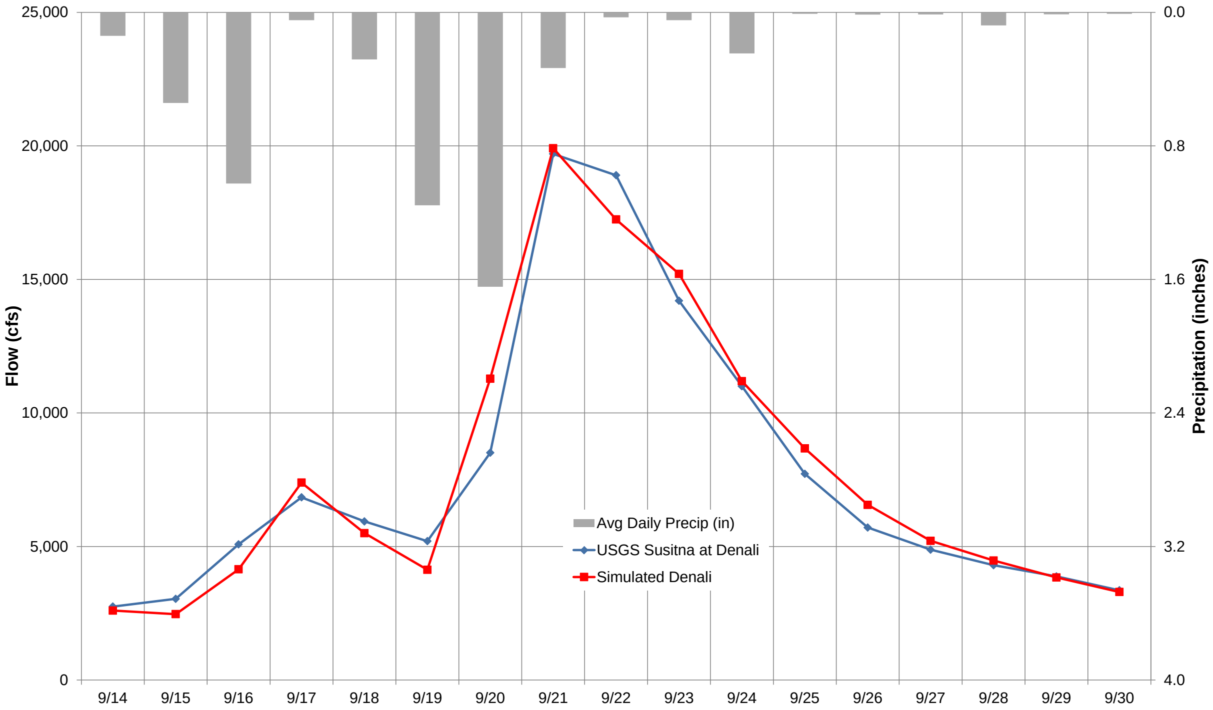


Figure 4.4-1. September 2012 Calibration, Susitna River near Denali

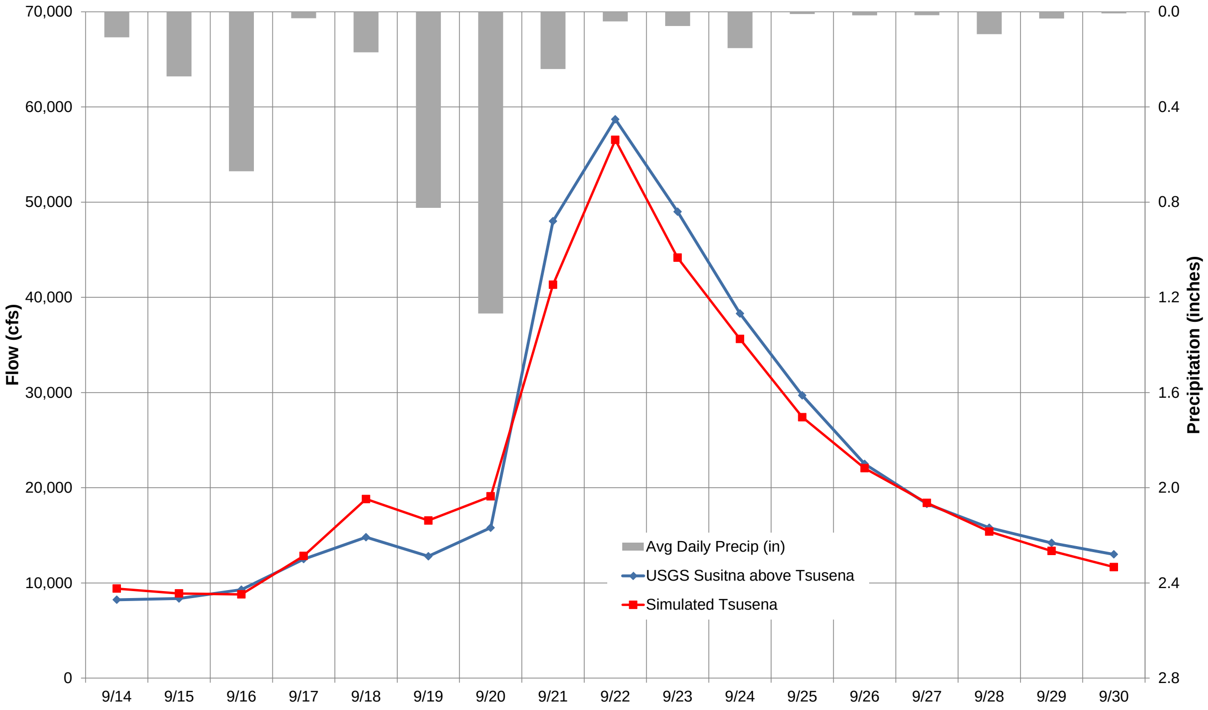


Figure 4.4-2. September 2012 Calibration, Susitna River above Tsusena Creek

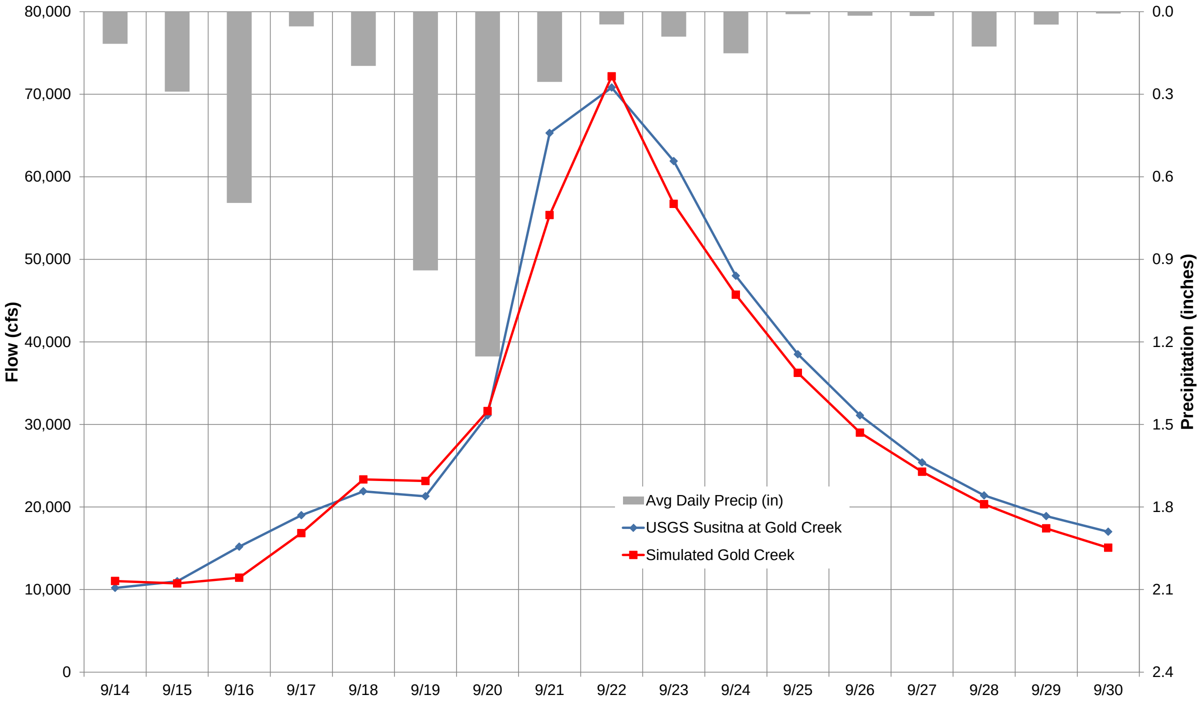


Figure 4.4-3. September 2012 Calibration, Susitna River at Gold Creek

The August 1967 flood was the 5th highest peak flow at Gold Creek and Cantwell, and the third highest peak recorded on the Maclaren River. The August 1967 storm was also significant because it became the controlling storm for development of the Probable Maximum Precipitation both in regards to development of total precipitation depth and for the critical temporal distribution of the precipitation.

As shown on Figures 4.4-4 through 4.4-6, the agreement between simulated and recorded peak flows, hydrograph volume, and general hydrograph shape is good at all three locations. The most notable differences appear to be on the rising limb of the hydrograph, but the overall calibration is certainly acceptable. Precipitation was factored upwards from initial estimates for sub-basins at higher elevations, an effect noted as needed for runoff model calibration by others independently doing Susitna River runoff model studies (Wolken 2013). A factored adjustment means that all data in a time-series were adjusted by the same factor.

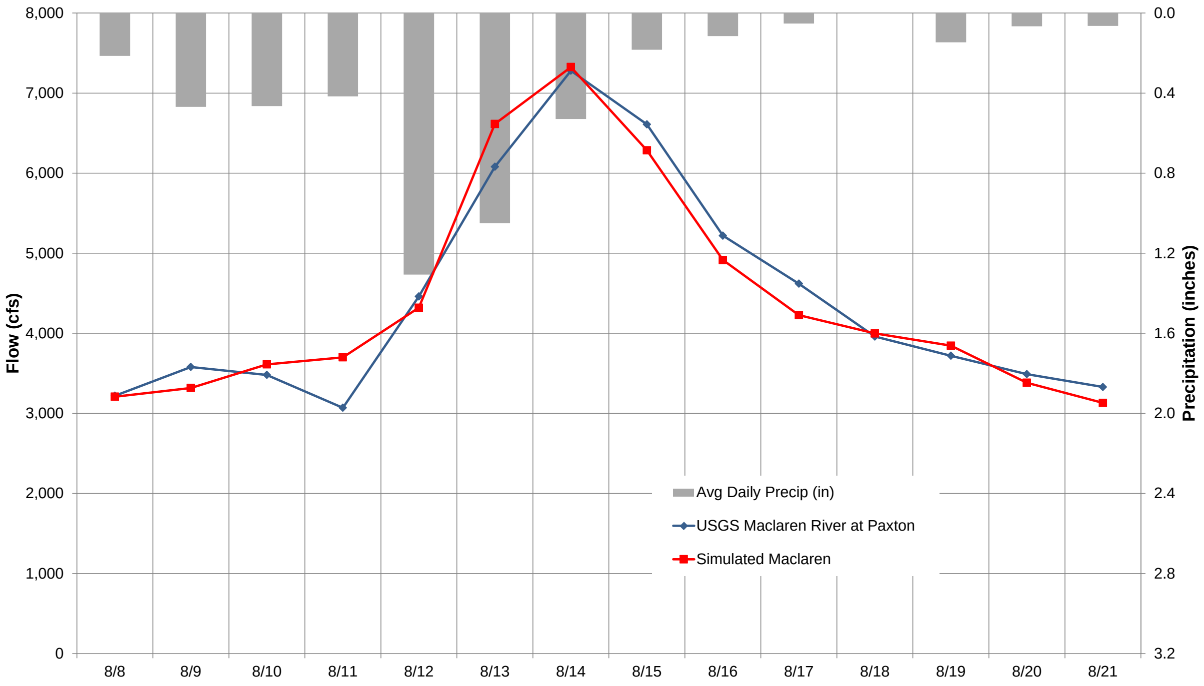


Figure 4.4-4. August 1967 Calibration, Maclaren River near Paxson

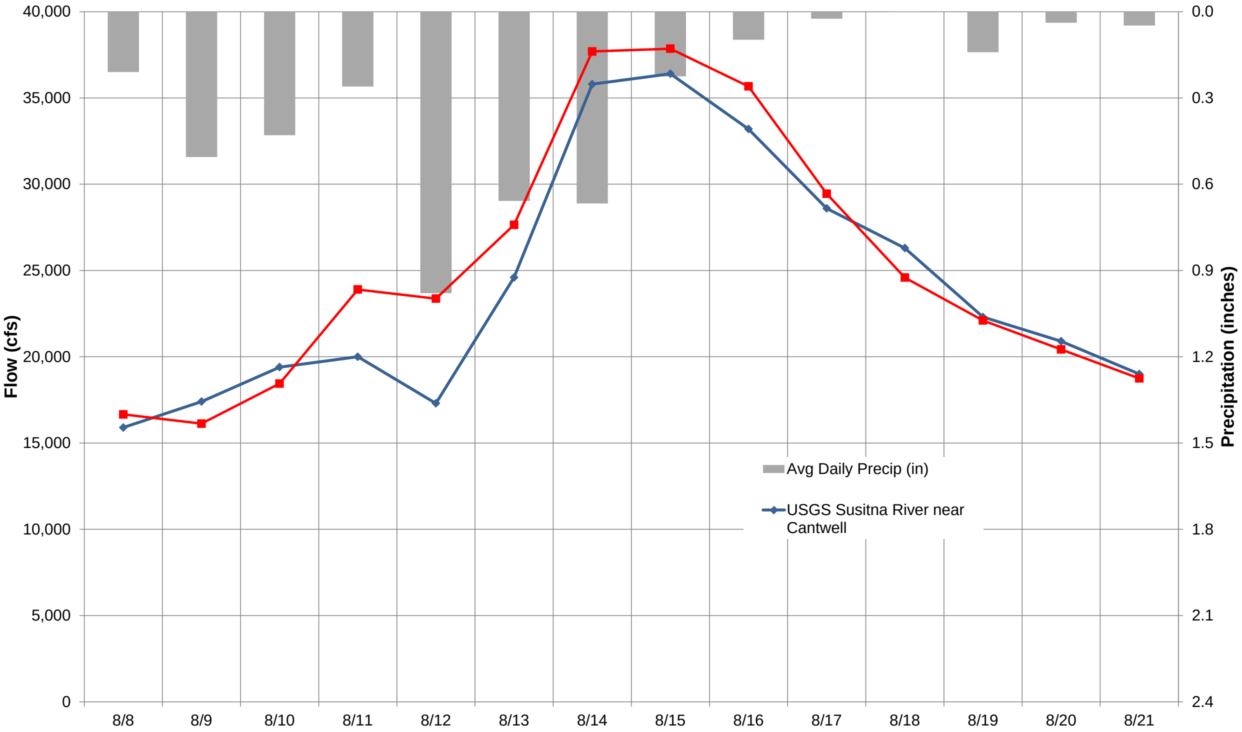


Figure 4.4-5. August 1967 Calibration, Susitna River near Cantwell

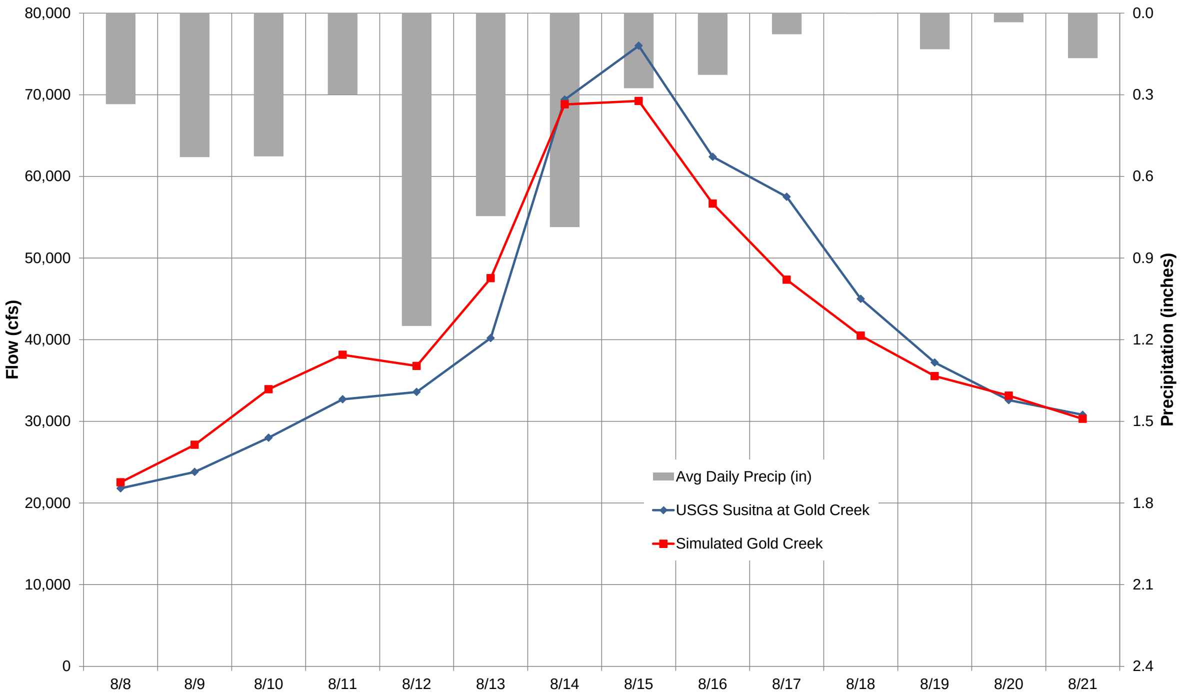


Figure 4.4-6. August 1967 Calibration, Susitna River at Gold Creek

Table 4.4-1. Clark Unit Hydrograph Parameters by Sub-Basin

Sub-Basin	Tc	R	R/(Tc + R)
1	25.6	31	0.55
2	25.6	31	0.55
3	38.6	41	0.52
4	16.0	39	0.71
5	16.0	39	0.71
6	16.0	39	0.71
7	22.0	53	0.71
8	10.0	24	0.71
9	62.9	44	0.41
10	62.9	44	0.41
11	83.9	35	0.29
12	64.0	54	0.46
13	72.3	61	0.46
14	72.3	61	0.46
15	64.0	68	0.52
16	64.0	68	0.52
17	72.3	61	0.46
18	43.8	37	0.46
19	43.8	37	0.46
20	43.8	37	0.46
21	43.8	37	0.46
22	43.8	37	0.46
23	87.5	46	0.34
24	35.0	29	0.45
25	27.7	23	0.45
26	35.0	29	0.45
27	35.0	29	0.45
28	35.0	29	0.45
29	26.2	22	0.46
30	39.0	21	0.35
31	39.0	21	0.35
32	39.0	21	0.35
33	30.8	17	0.36
34	30.8	17	0.36

4.5 Spring Sub-Basin Unit Hydrograph Parameters

Final Clark unit hydrograph parameters were the same for both the summer and spring calibration floods. Streamflow data was available for all four of the long-term USGS gages for the June 1971 flood. The June 1971 flood is the 7th largest partial duration flood (considers all floods of record, not just annual peak flows) of record at Gold Creek and has the 3rd highest partial duration flow of record at Cantwell. The recorded floods generally exhibit a classic hydrograph shape.

From Figures 4.5-1 through 4.5-4, it is clear that precipitation is a negligible factor in the peak flow as total precipitation is quite small and most of it occurs after the peak of the hydrograph. The great majority of the runoff must result from snowmelt. The agreement between peak flows, hydrograph volume, and hydrograph shape are generally good. Timing of the simulated peak flow at Denali is a little early, but it makes no significant difference at downstream stations. Adjustments were made to the initial estimate of snowpack, as well as factored adjustments to precipitation, and wind speed for several sub-basins.

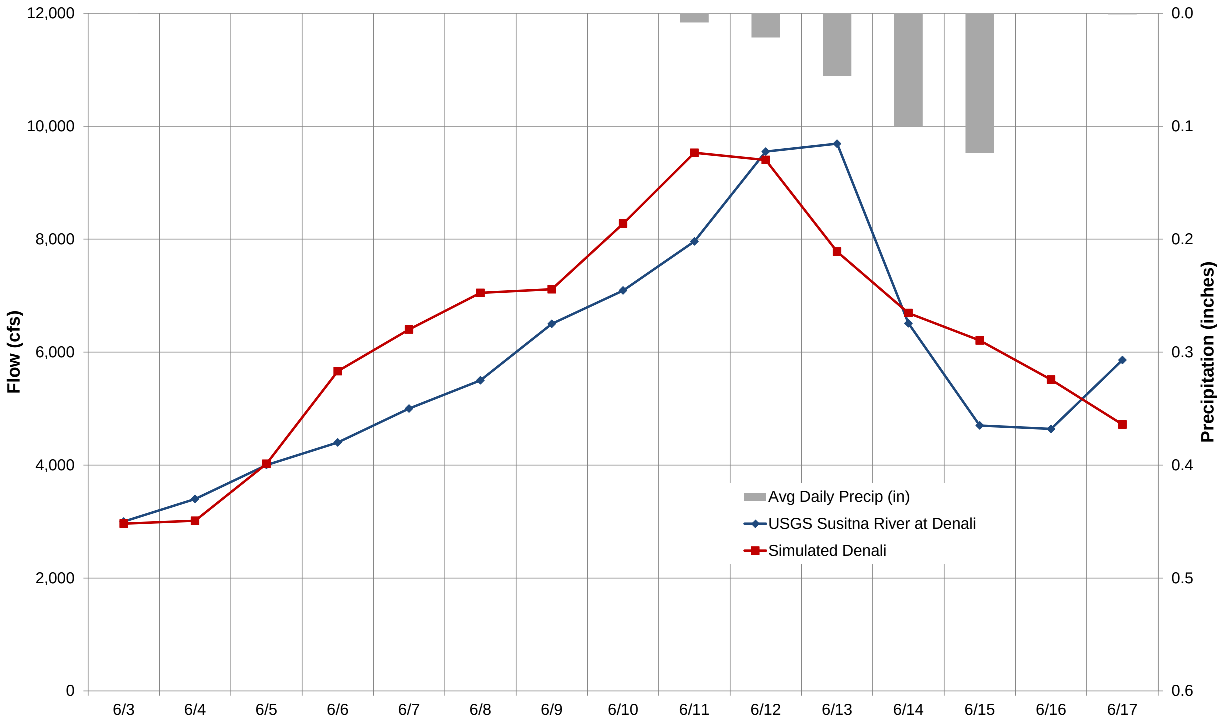


Figure 4.5-1. June 1971 Calibration, Susitna River near Denali

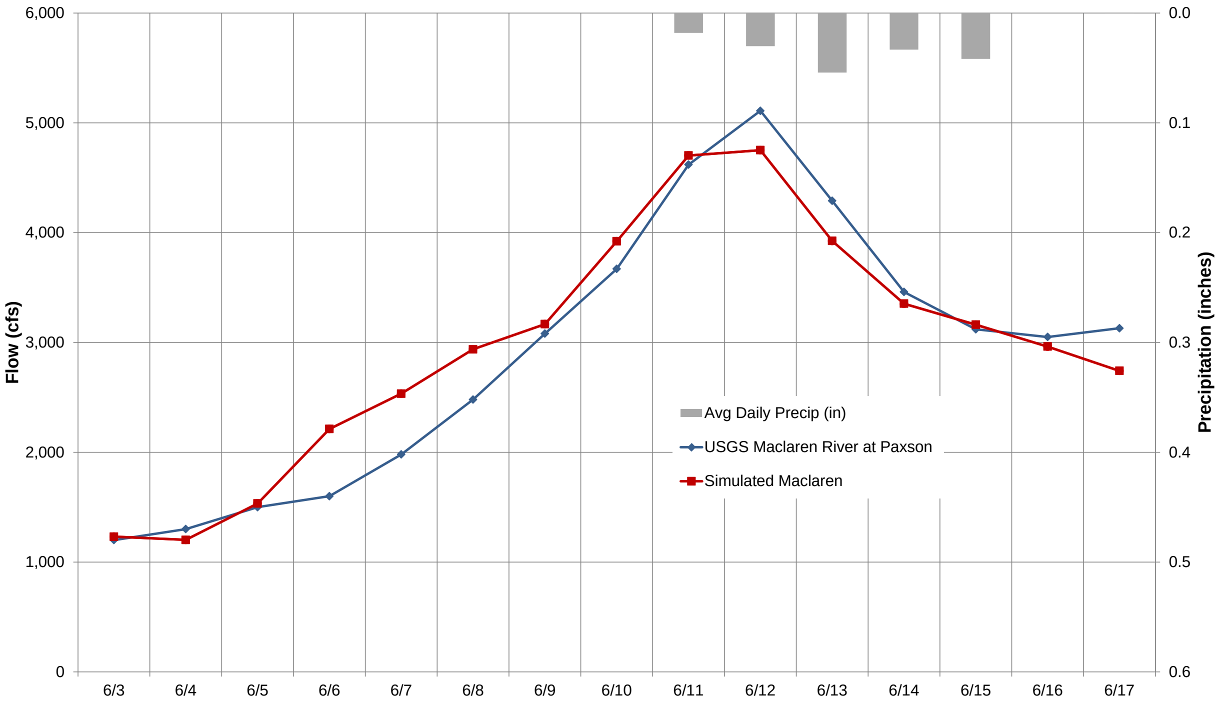


Figure 4.5-2. June 1971 Calibration, Maclaren River near Paxson

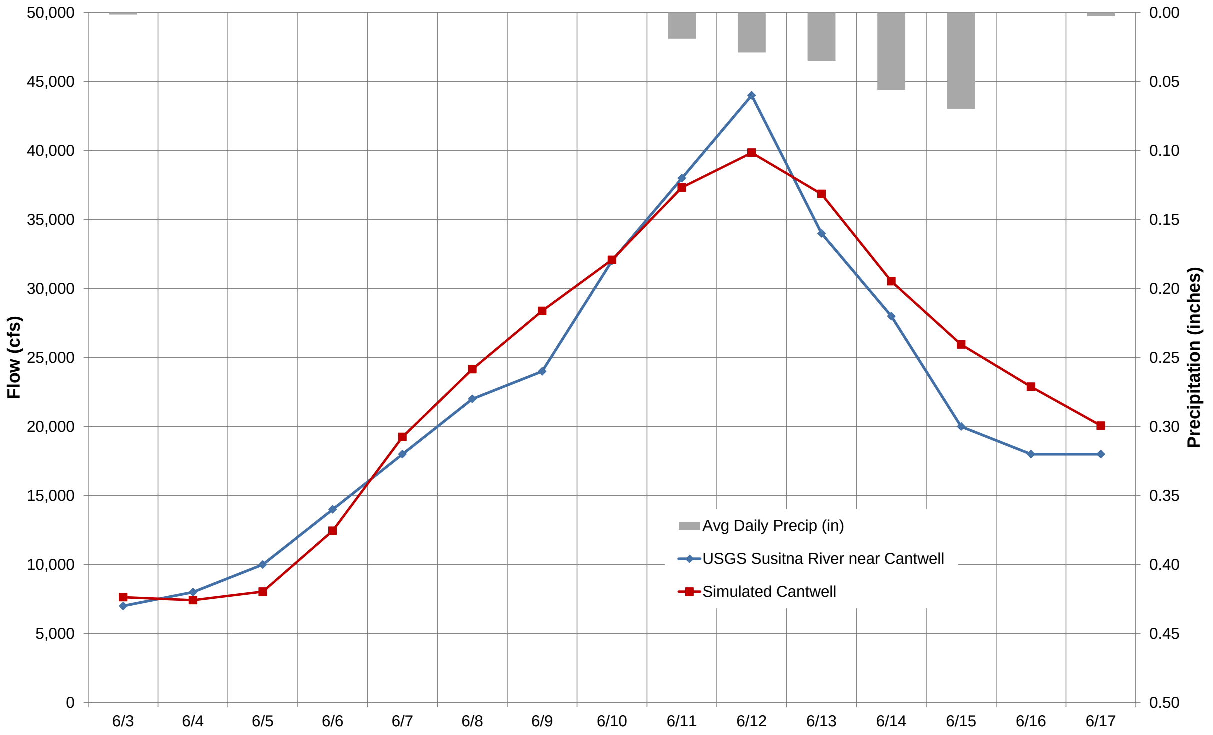


Figure 4.5-3. June 1971 Calibration, Susitna River near Cantwell

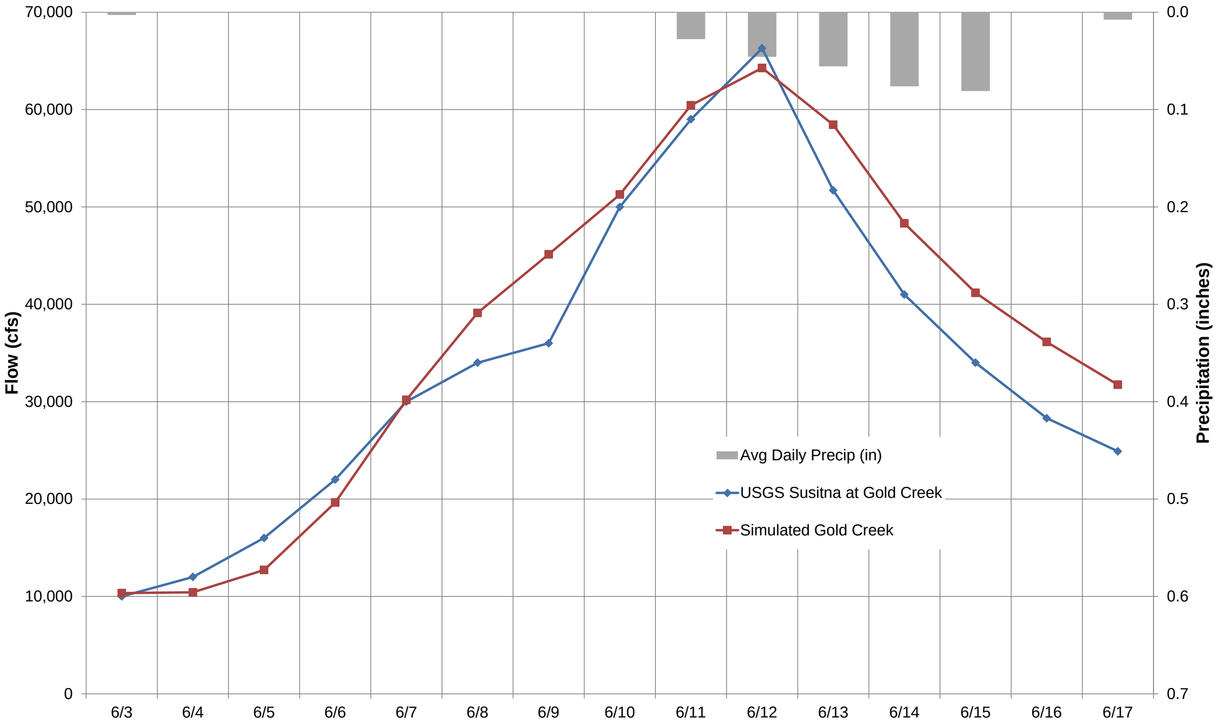


Figure 4.5-4. June 1971 Calibration, Susitna River at Gold Creek

Streamflow data was available for all four of the long-term USGS gages for the June 1972 flood. The June 1972 flood represents the 3rd largest peak flow of record at Gold Creek, the 4th largest at Cantwell, and the 6th largest on the Maclaren River.

From Figures 4.5-5 through 4.5-8 it can be seen that precipitation is not a major factor in the flood hydrograph as most of the runoff results from snowmelt. The agreement between simulated and recorded peak flows at all four gages is good. The simulation of hydrograph shape at the downstream stations at Cantwell and Gold Creek is better than at the upstream stations at Denali and on the Maclaren River where glacier melt would be a more significant factor. It is noted that the HEC-1 program does not have a specific glacier simulation routine, only snowmelt simulation methods. Adjustments were made to the initial estimate of snowpack, as well as factored adjustments to precipitation, and wind speed for several sub-basins. The overall simulation of the June 1972 flood was considered to be acceptable.

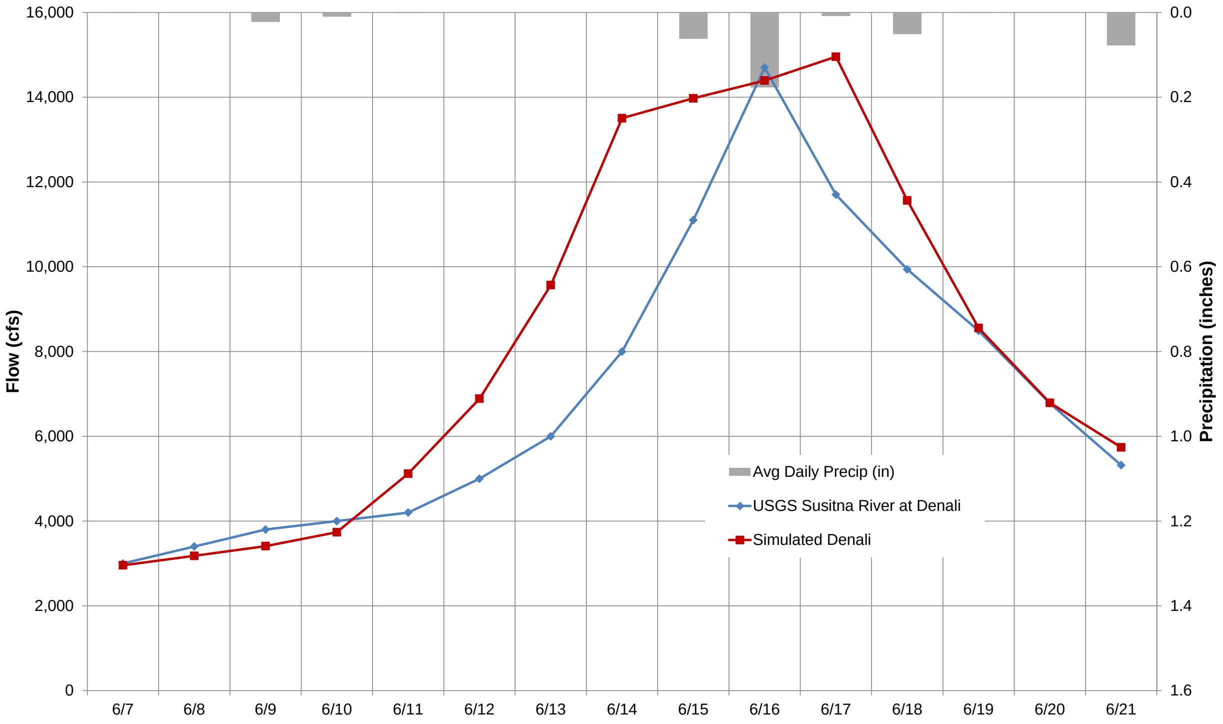


Figure 4.5-5. June 1972 Calibration, Susitna River near Denali

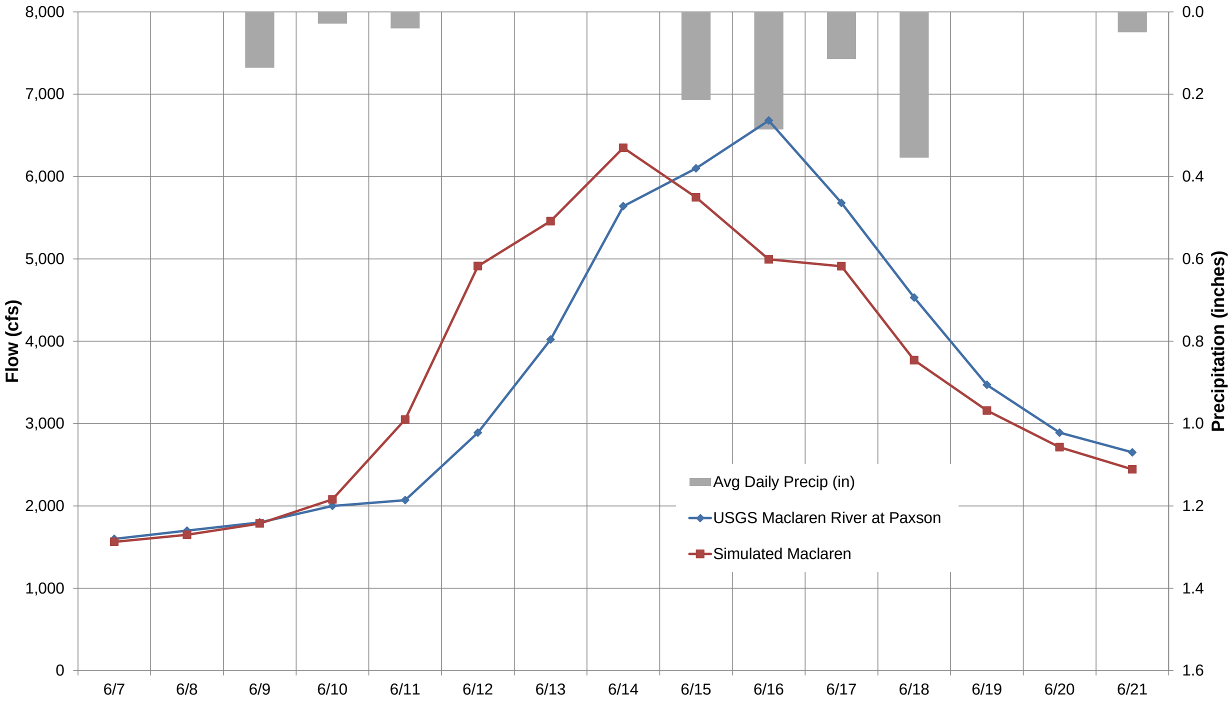


Figure 4.5-6. June 1972 Calibration, Maclaren River near Paxson

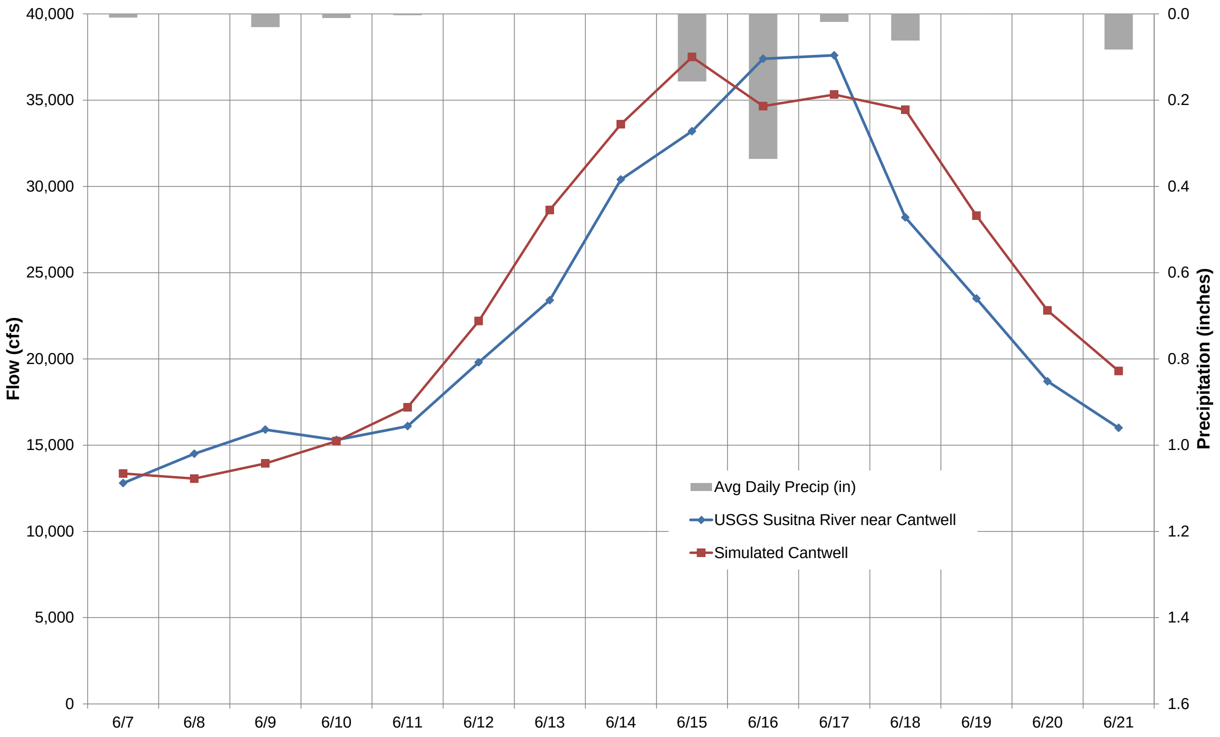


Figure 4.5-7. June 1972 Calibration, Susitna River near Cantwell

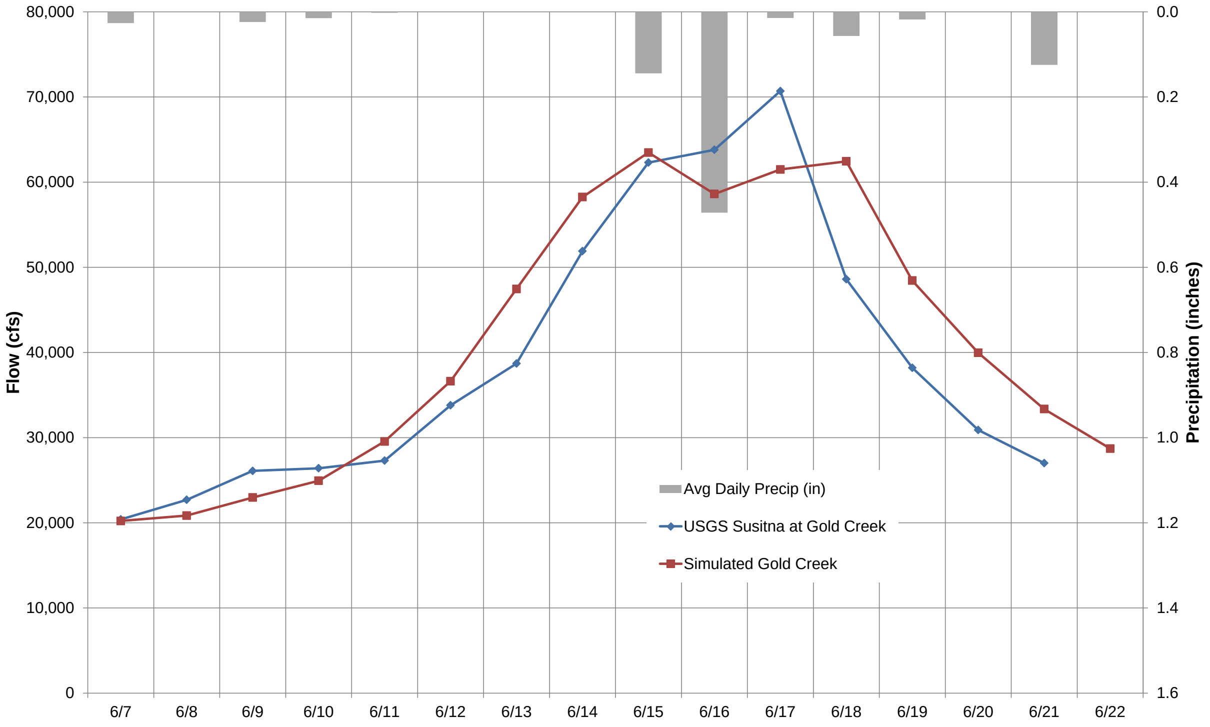


Figure 4.5-8. June 1972 Calibration, Susitna River at Gold Creek

5. UNIT HYDROGRAPH VERIFICATION

5.1 Summer Flood

Verification HEC-1 model runs for both the summer and spring floods were made without any changes to unit hydrograph parameters or loss rates that were used for the corresponding season in the calibration runs. On all of the figures in this section, USGS recorded flow data is in blue and simulated flow is in red. Average daily precipitation for the area tributary to the gage is shown at the top of the plots. Scale differences in precipitation between the spring and summer floods should be noted. A factored adjustment to increase the initial estimate of precipitation to sub-basins tributary to the Maclaren and Denali gages was made, with a slight reduction to precipitation at a few lower elevation sub-basins.

Streamflow data is available at four USGS gages for the August 1971 flood. The August 1971 flood was significant in that it was the largest flood of record at the Cantwell, Denali, and Maclaren River gages, and the third largest flood of record at Gold Creek (including the 2013 flood). As shown on Figures 5.1-1 through 5.1-4, agreement between simulated and recorded peaks and volumes were generally very good, with the exception of the first few days of the rising limb of the hydrograph at the Denali gage. During August 4-8, there may have been a process occurring above the Denali gage such as an ice dam that is beyond the simulation capability of the runoff model. Based on the verification run, the unit hydrograph parameters were accepted.

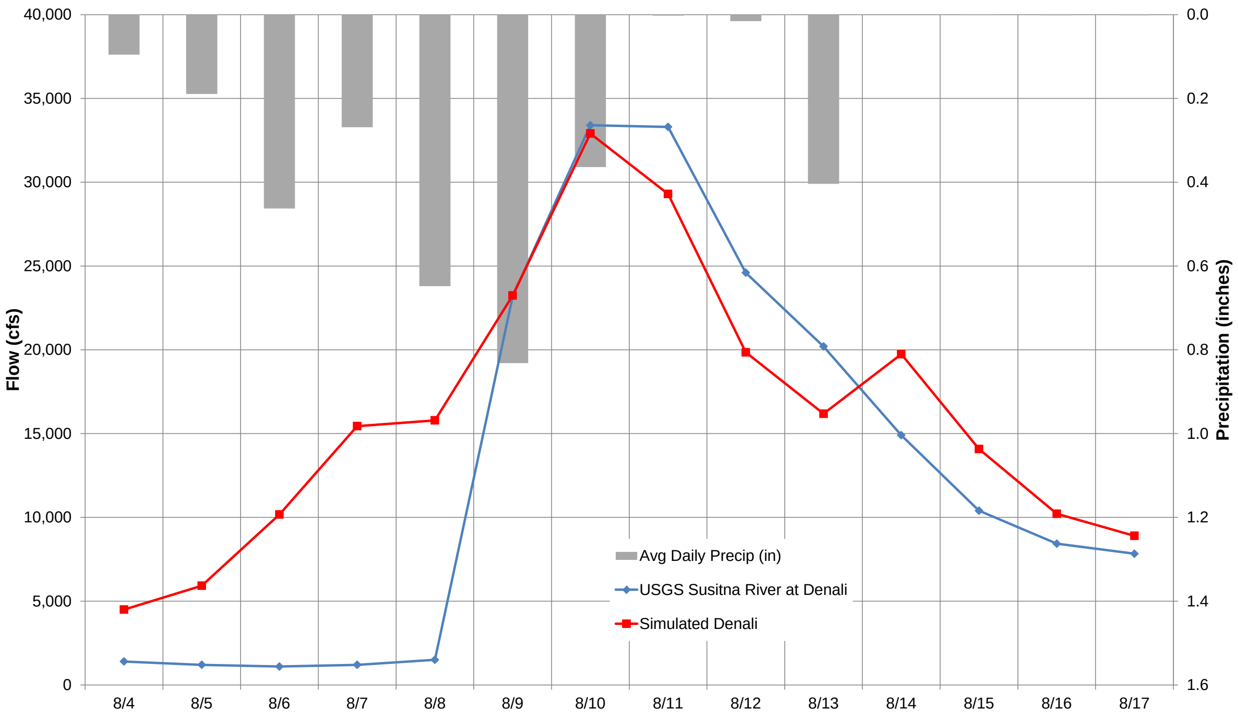


Figure 5.1-1. August 1971 Verification, Susitna River near Denali

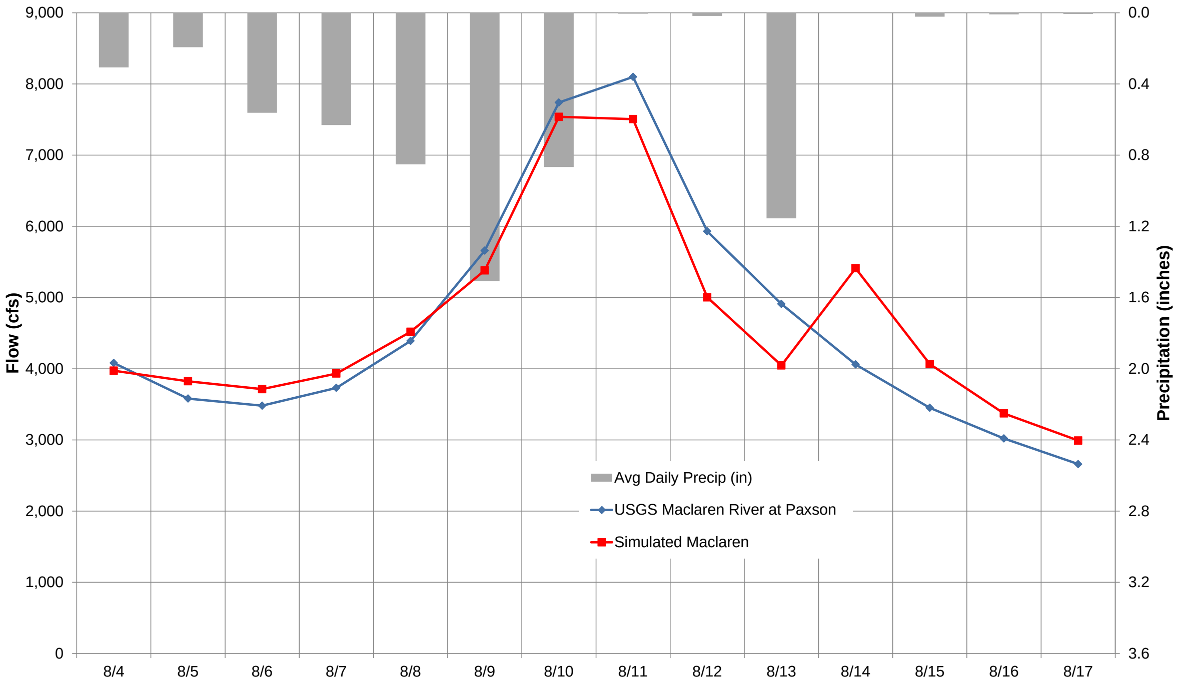


Figure 5.1-2. August 1971 Verification, Maclaren River near Paxson

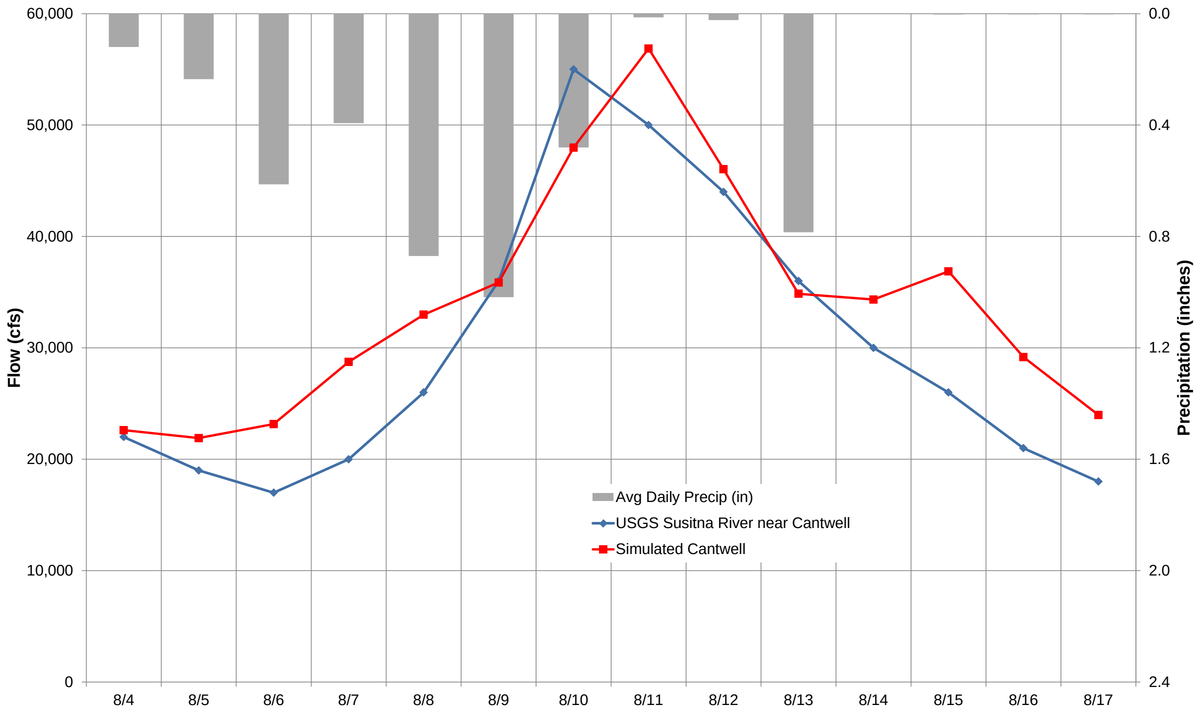


Figure 5.1-3. August 1971 Verification, Susitna River near Cantwell

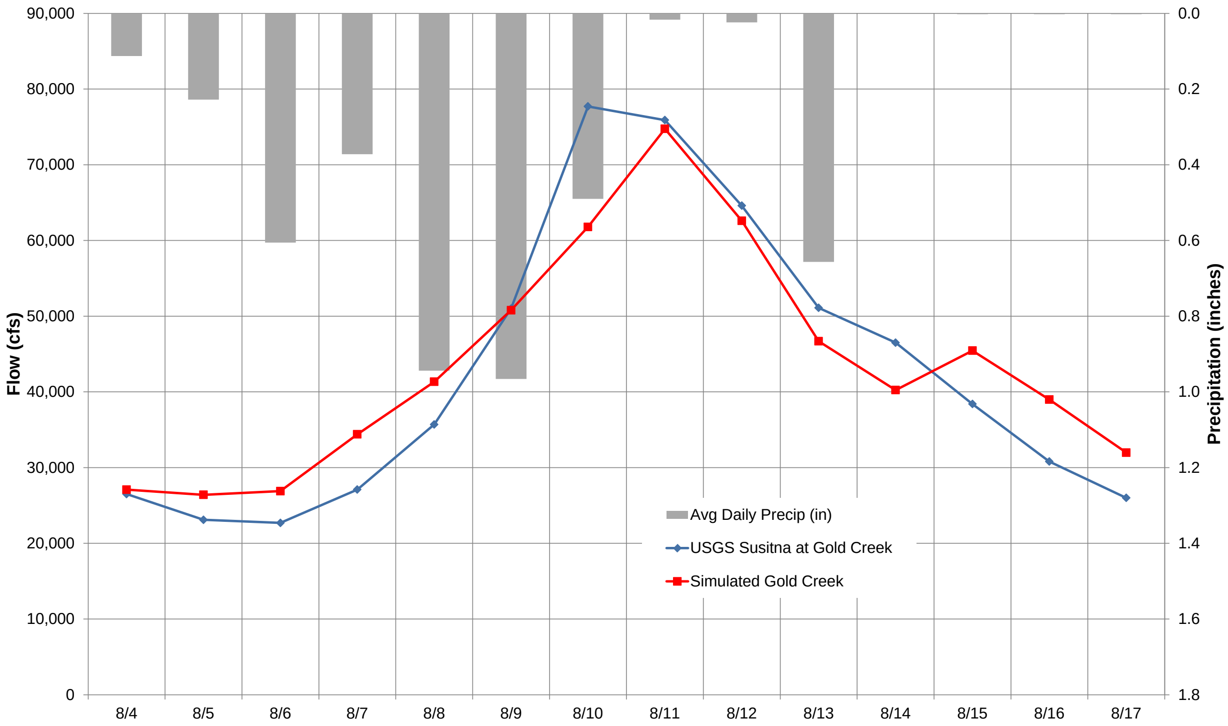


Figure 5.1-4. August 1971 Verification, Susitna River at Gold Creek

5.2 Spring Flood

Streamflow data was available at four USGS gages for the June 1964 verification flood. The June 1964 flood is significant because it was the largest peak flow and the largest daily average flow of record at the Gold Creek gage and it was the second largest flood of record at Cantwell. It was also the 10th largest flood of record on the Maclaren River, and the largest flow of the year at Denali.

No changes were made to unit hydrograph parameters or loss rates from those used in the spring calibration floods. Adjustments to the initial estimate of snowpack, or factored adjustments to temperature or wind speeds are acceptable within appropriate ranges. Agreement between simulated and recorded peak flow is generally very good, but the rising limb of the hydrograph exhibited a sharp one-day rise in flow that could not be replicated with the model. The constant flow rates at USGS gages through May 31 give the appearance of being estimated data. Based on the verification run, the unit hydrograph parameters were accepted.

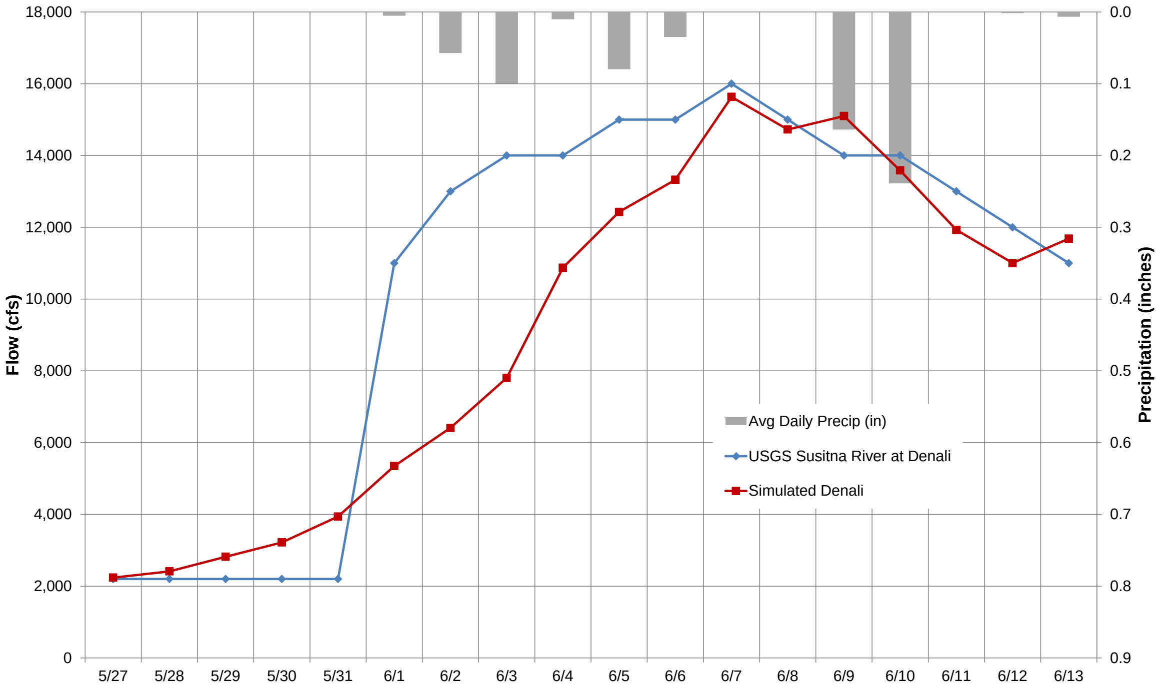


Figure 5.2-1. June 1964 Verification, Susitna River near Denali

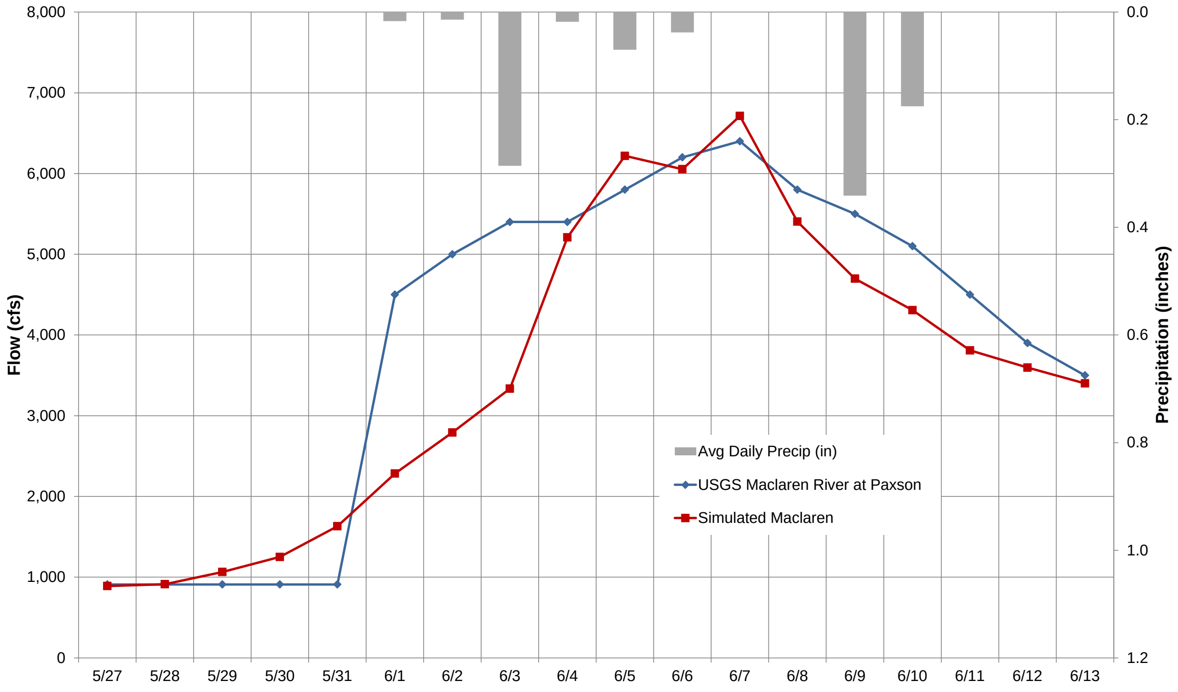


Figure 5.2-2. June 1964 Verification, Maclaren River near Paxson

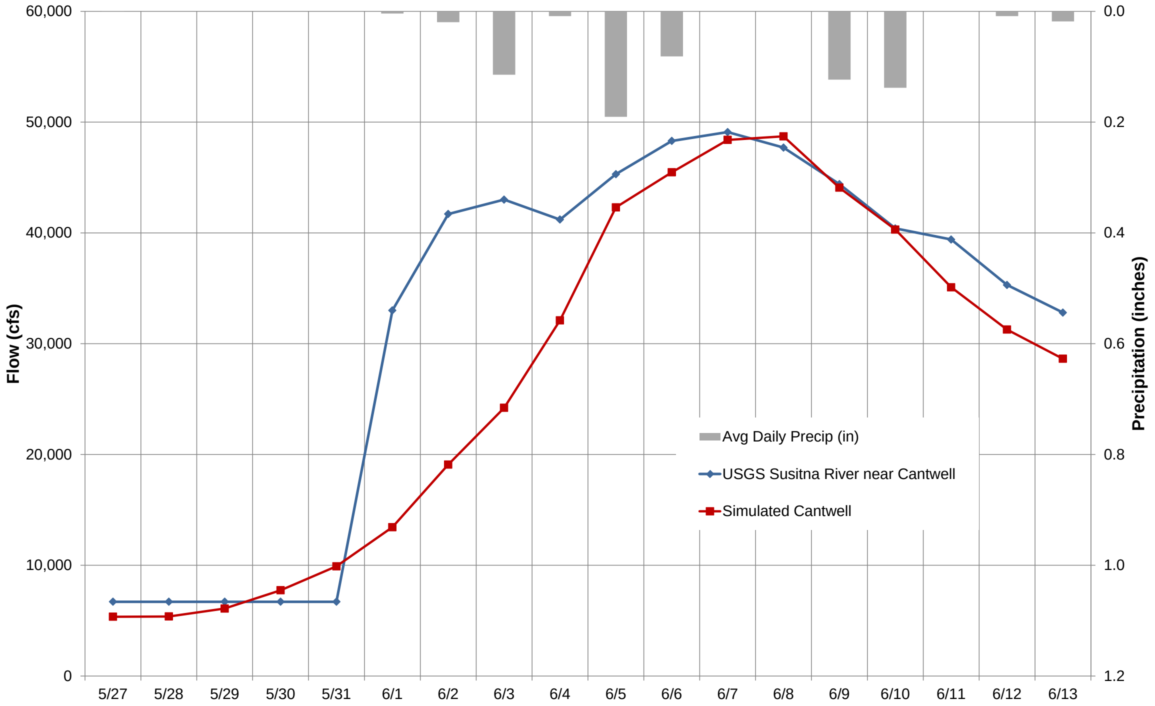


Figure 5.2-3. June 1964 Verification, Susitna River near Cantwell

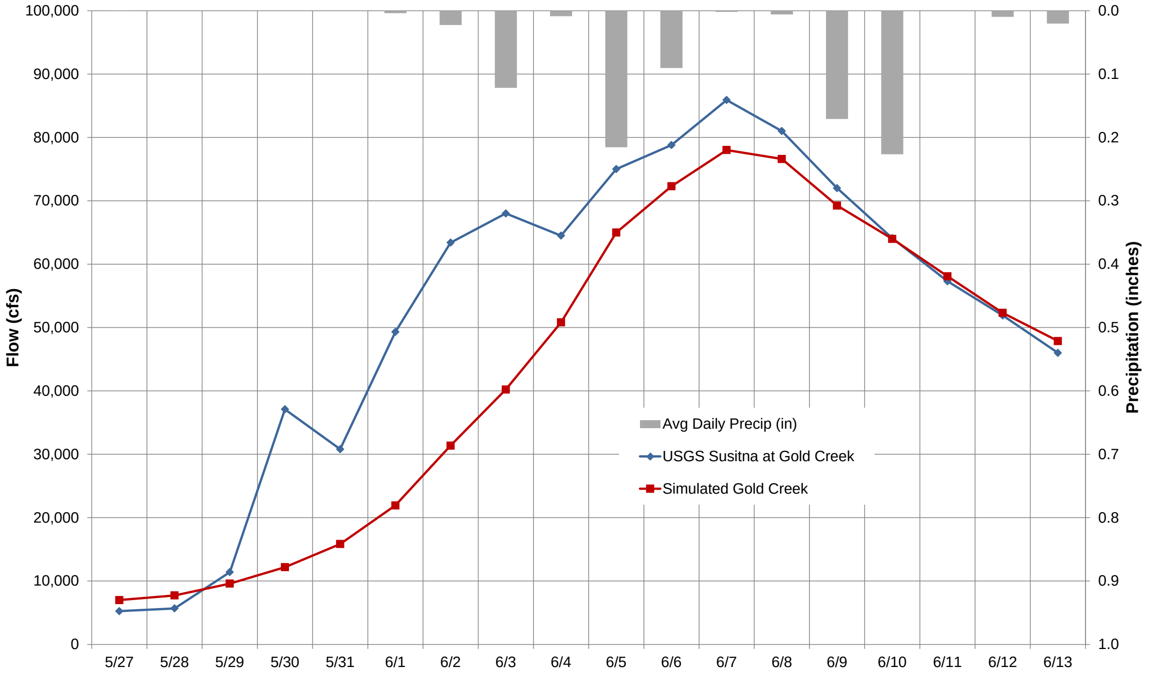


Figure 5.2-4. June 1964 Verification, Susitna River at Gold Creek

6. PROBABLE MAXIMUM PRECIPITATION

The applicable available National Weather Service (formerly the U.S. Weather Bureau) Probable Maximum Precipitation (PMP) guidance document is Probable Maximum Precipitation and Rainfall-Frequency Data for Alaska, Technical Paper No. 47 (Weather Bureau 1963). Technical Paper No. 47 is applicable to areas up to 400 square miles and durations up to 24 hours. Because the drainage area at the Watana Dam site is over 5,000 square miles and current standards call for the PMP to have a duration of at least 72 hours, development of a site-specific PMP was necessary.

The site-specific PMP was developed by Applied Weather Associates, working under subcontract to MWH. This section briefly summarizes the results of the site specific PMP analysis. A complete report on development of the site-specific PMP is included as Appendix A.

6.1 Probable Maximum Precipitation Data

The applicable PMP for any watershed will vary by season, duration, and areal extent. There is a seasonal variation of the PMP and the month or season having the greatest depth is referred to as the “all season” PMP. The all season PMP applies from mid-July through mid-August period for the Susitna River basin. The monthly reduction factors or ratios of the PMP for other months to the all season PMP are summarized on Table 6.1-1.

Table 6.1-1. Mid-Month PMP Seasonality Ratios

Month	Ratio
Jan	-----
Feb	-----
Mar	0.30
Apr	0.60
May	0.83
Jun	0.94
Jul	1.00
Aug	1.00
Sep	0.92
Oct	0.80
Nov	0.65
Dec	-----

The Susitna-Watana PMP was developed for a period of 216 hours (9 days). The all season PMP depths for three alternative temporal distributions for various durations from 1-hour to 216 hours by sub-basin are presented in Table 6.1-2 through Table 6.1-4. The temporal and accumulated precipitation for the three alternative distributions of the PMP are shown on Figure 6.1-1 through Figure 6.1-3. The rainfall is concentrated near the center of the time sequence developed from the August 1967 storm in a manner that should be critical for development of the PMF.

Table 6.1-2. All Season PMP by Sub-Basin for Various Durations – August 1967 Temporal Distribution

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

Table 6.1-3. All Season PMP by Sub-Basin for Various Durations – August 1955 Temporal Distribution

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	1.93	3.83	7.64	13.83
2	226.4	0.50	1.59	3.16	6.31	11.41
3	295.4	0.37	1.20	2.37	4.73	8.56
4	149.3	0.56	1.81	3.58	7.15	12.93
5	354.0	0.44	1.40	2.79	5.56	10.06
6	153.4	0.48	1.54	3.06	6.10	11.03
7	67.5	0.32	1.03	2.04	4.06	7.35
8	189.9	0.39	1.25	2.48	4.95	8.95
9	187.7	0.41	1.33	2.63	5.25	9.50
10	326.8	0.39	1.26	2.51	5.00	9.04
11	273.5	0.41	1.31	2.59	5.17	9.35
12	74.7	0.36	1.15	2.27	4.54	8.21
13	222.5	0.34	1.09	2.16	4.32	7.81
14	135.1	0.33	1.06	2.11	4.21	7.62
15	185.1	0.36	1.17	2.32	4.63	8.38
16	164.3	0.37	1.18	2.35	4.69	8.48
17	253.2	0.35	1.13	2.25	4.49	8.12
18	100.0	0.43	1.39	2.77	5.52	9.98
19	202.2	0.50	1.60	3.17	6.33	11.45
20	36.3	0.37	1.20	2.37	4.73	8.56
21	162.7	0.50	1.61	3.19	6.37	11.52
22	92.0	0.36	1.15	2.28	4.56	8.25
23	174.2	0.41	1.33	2.64	5.27	9.53
24	157.4	0.43	1.39	2.76	5.51	9.96
25	184.0	0.61	1.98	3.92	7.82	14.15
26	222.9	0.54	1.74	3.46	6.91	12.49
27	269.6	0.47	1.52	3.01	6.00	10.85
28	218.5	0.52	1.67	3.31	6.61	11.96
29	36.8	0.43	1.37	2.72	5.42	9.80
Total/Avg.	5168.2	0.43	1.40	2.77	5.53	10.00

Table 6.1-4. All Season PMP by Sub-Basin for Various Durations – September 2012 Temporal Distribution

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	1.79	3.77	6.40	13.83
2	226.4	0.50	1.47	3.11	5.28	11.41
3	295.4	0.37	1.11	2.33	3.96	8.56
4	149.3	0.56	1.67	3.52	5.99	12.93
5	354.0	0.44	1.30	2.74	4.66	10.06
6	153.4	0.48	1.42	3.00	5.11	11.03
7	67.5	0.32	0.95	2.00	3.40	7.35
8	189.9	0.39	1.16	2.44	4.15	8.95
9	187.7	0.41	1.23	2.59	4.40	9.50
10	326.8	0.39	1.17	2.46	4.19	9.04
11	273.5	0.41	1.21	2.55	4.33	9.35
12	74.7	0.36	1.06	2.23	3.80	8.21
13	222.5	0.34	1.01	2.13	3.62	7.81
14	135.1	0.33	0.98	2.07	3.53	7.62
15	185.1	0.36	1.08	2.28	3.88	8.38
16	164.3	0.37	1.09	2.31	3.93	8.48
17	253.2	0.35	1.05	2.21	3.76	8.12
18	100.0	0.43	1.29	2.72	4.62	9.98
19	202.2	0.50	1.48	3.12	5.30	11.45
20	36.3	0.37	1.11	2.33	3.96	8.56
21	162.7	0.50	1.49	3.14	5.34	11.52
22	92.0	0.36	1.06	2.25	3.82	8.25
23	174.2	0.41	1.23	2.59	4.41	9.53
24	157.4	0.43	1.29	2.71	4.61	9.96
25	184.0	0.61	1.83	3.85	6.55	14.15
26	222.9	0.54	1.61	3.40	5.78	12.49
27	269.6	0.47	1.40	2.96	5.03	10.85
28	218.5	0.52	1.54	3.26	5.54	11.96
29	36.8	0.43	1.27	2.67	4.54	9.80
Total/Avg.	5168.2	0.43	1.29	2.72	4.63	10.00

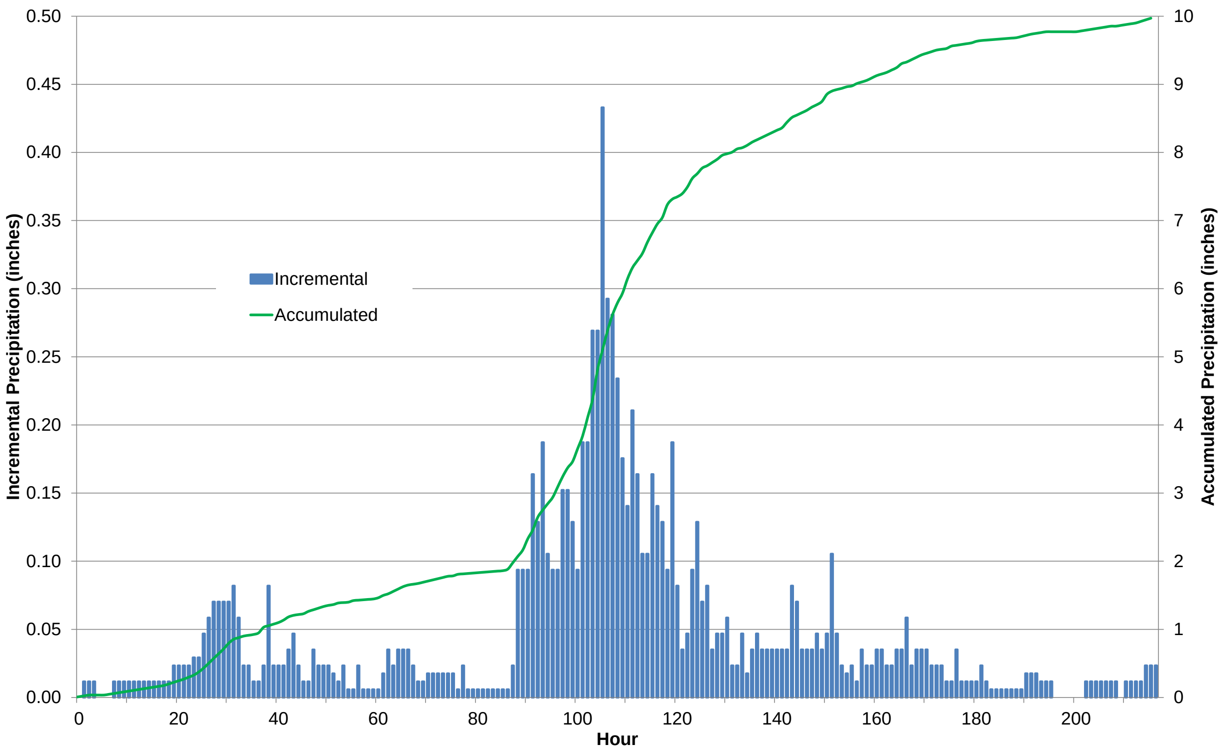


Figure 6.1-1. Incremental and Accumulated All Season PMP – August 1967 Temporal Distribution

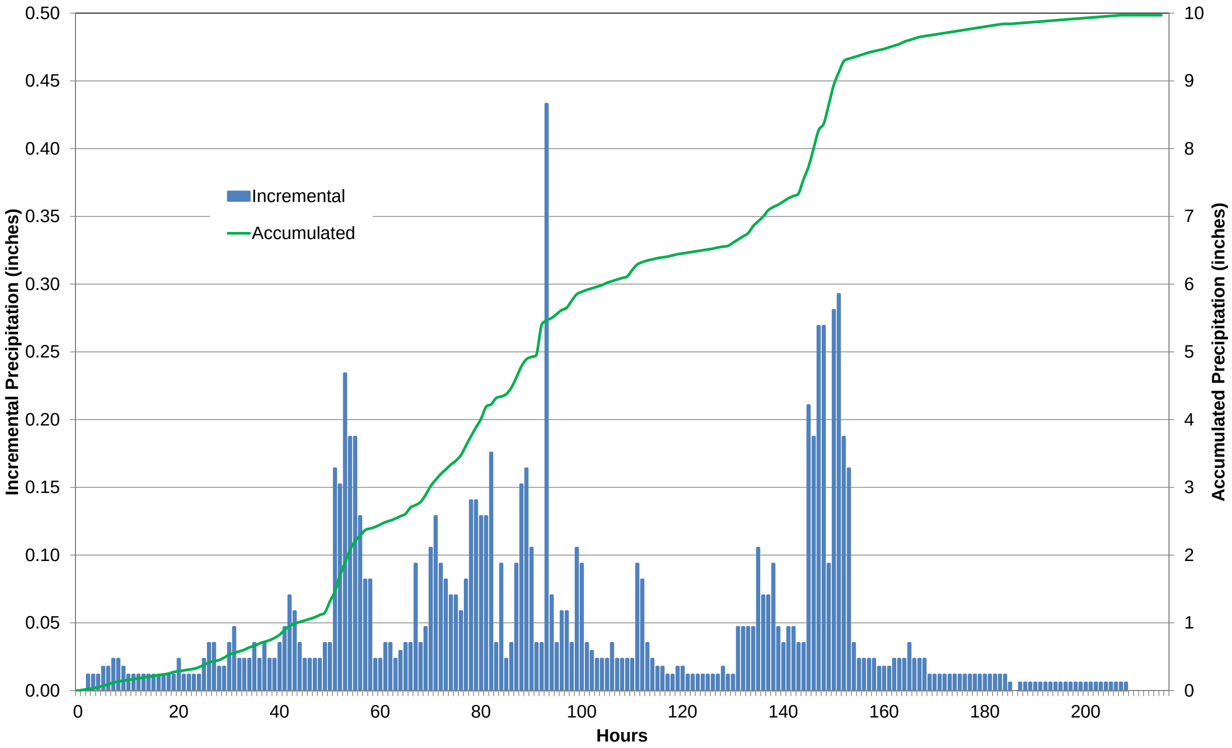


Figure 6.1-2. Incremental and Accumulated All Season PMP – August 1955 Temporal Distribution

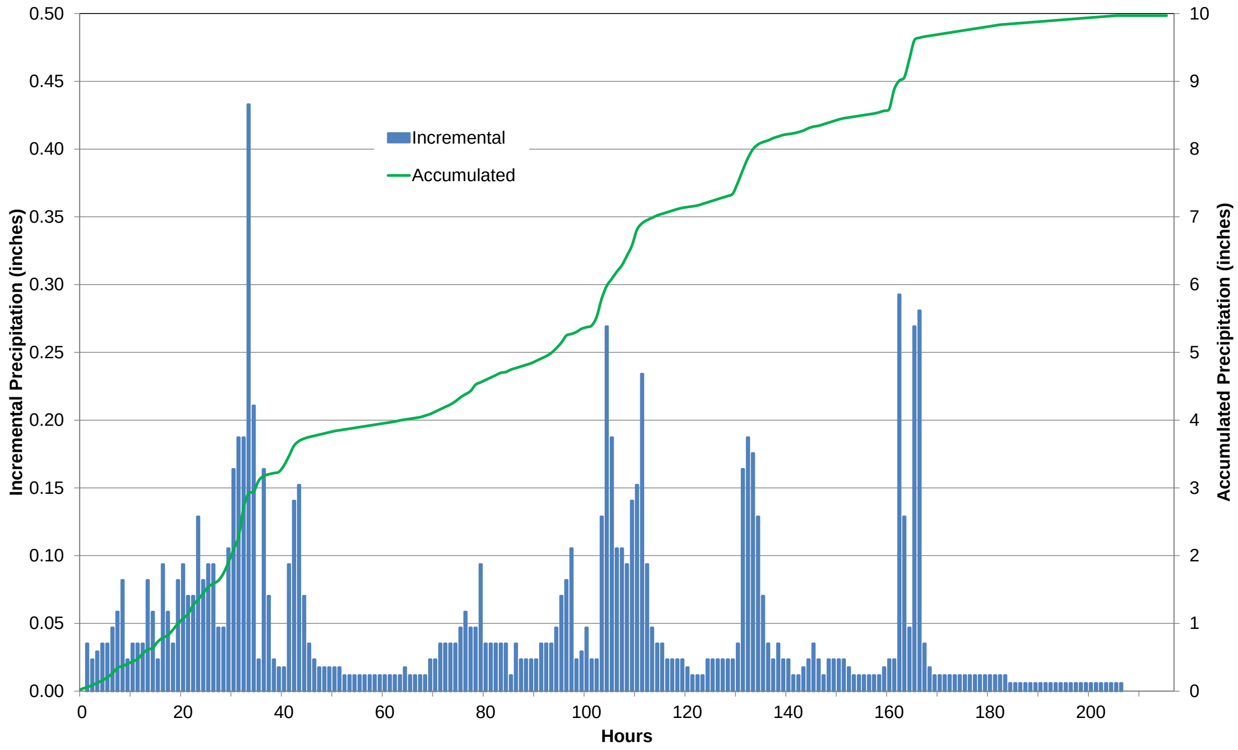


Figure 6.1-3. Incremental and Accumulated All Season PMP – September 2012 Temporal Distribution

Temperature and wind speed are important factors in determining snowmelt rates for the energy budget method. The 216-hour time-series of temperature and wind speed coincident with the PMP time sequences are plotted on Figure 6.1-4. Temperature, which decreases by about 2.6 degrees per 1,000-feet in elevation, is plotted for elevation 2500 feet, which is the mid-point of the lowest 1,000-foot elevation band within the Watana basin. Wind speed, which increases with elevation, is plotted for an elevation near the average for the watershed at 4,000 feet.

In a manner similar to the variation of the PMP by month, the seasonality ratios for air temperature and dew point are summarized on Table 6.1-5 and the seasonality ratios for wind speeds are summarized on Table 6.1-6. The ratios become multiplication factors applied to the all season sequences of air temperature, dew point, and wind speed.

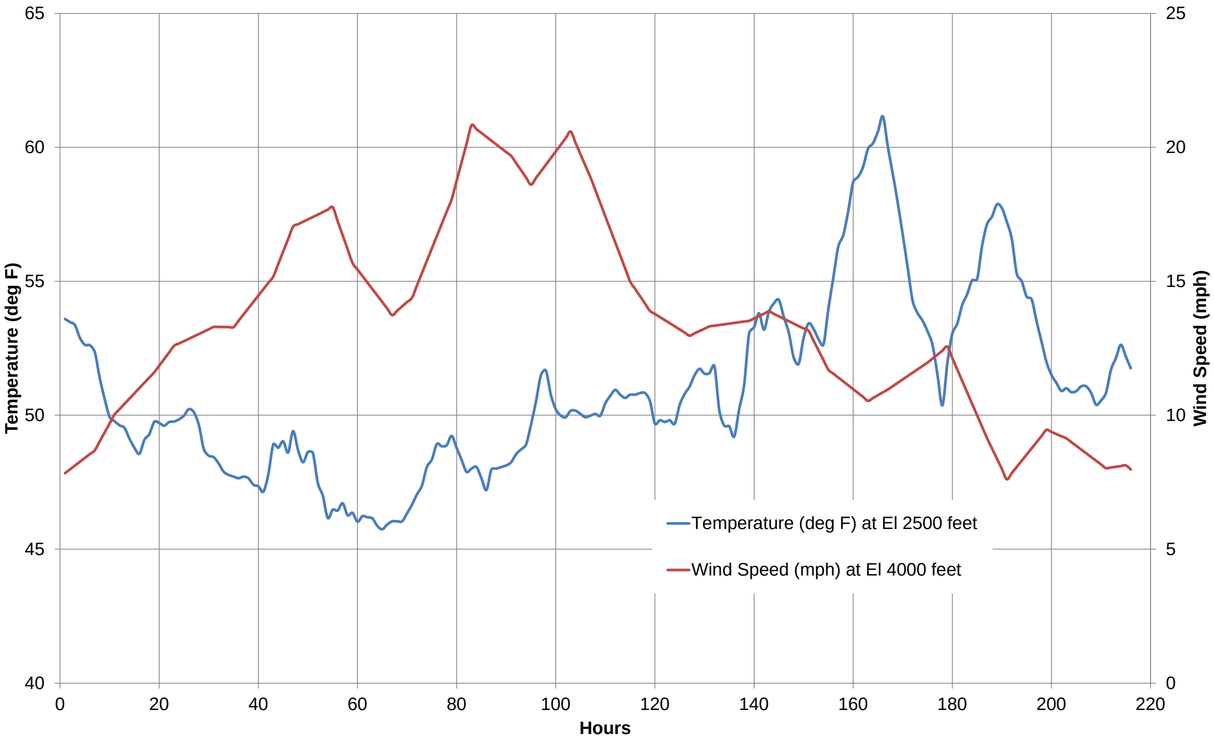


Figure 6.1-4. Temperature and Wind Speed for Period of PMP Rainfall for Seasonality Ratios of 1.00

Table 6.1-5. Air Temperature and Dew Point Seasonality Ratios

Date	Ratio
1-Apr	0.39
15-Apr	0.55
1-May	0.69
15-May	0.80
1-Jun	0.90
15-Jun	0.95
1-Jul	1.00
15-Jul	1.00
1-Aug	1.00
15-Aug	1.00
1-Sep	0.94
15-Sep	0.86
1-Oct	0.77
15-Oct	0.64
1-Nov	0.51

Table 6.1-6. Wind Speed Seasonality Ratios

Date	Ratio
15-Jan	-----
15-Feb	-----
15-Mar	1.45
15-Apr	1.25
15-May	1.06
15-Jun	0.87
15-Jul	0.92
15-Aug	1.00
15-Sep	1.15
15-Oct	1.25
15-Nov	1.28
15-Dec	-----

6.2 Candidate Storms for the PMF

Based on PMF guidelines, (FERC 2001), the evaluation of two PMF scenarios is required in the area west of the Continental Divide. This includes (a) PMP on 100-yr snowpack, and (b) 100-yr precipitation on Probable Maximum Snowpack (FERC, 2001, pg. 68). PMP seasonality ratios are presented in Table 6.1-1. Because the PMP, 100-year snowpack, factors affecting snowmelt, and reservoir initial level can all vary from month to month, the PMF was computed for the critical months that cannot be logically eliminated by evaluation of the PMP, coincident meteorological data, snowpack, initial reservoir level, and historical flood distribution. Development of the 100-year snowpack is discussed in Section 8.3.4. Development of the 100-year precipitation is discussed in Section 8.5.

7. LOSS RATES

The initial loss and uniform loss rate method of simulating interception of rainfall and infiltration into the ground and the uniform loss rate method for combined rainfall and snowmelt losses were used for calibration of summer floods and for summer PMF runs. As used in a runoff event model such as HEC-1, loss rates effectively means any rainfall or snowmelt that does not reach the river within the time frame of the simulation.

Loss rates were initially based on those used in the Harza-Ebasco 1984 study, which identified soil types based on a Soil Conservation Service (1979) study. More current digital soil type classification files are unavailable for the area tributary to the Watana Dam site. As used in the PMF runs, sub-basin 29 had zero losses as it represents the Watana Reservoir water surface area. The rainfall uniform loss rates ranged from 0.02 inch/hour to 0.04 inch/hour. The previous study (Harza-Ebasco 1984) has determined that 48% of the watershed is composed of type C soils, with about 42% of the watershed in type D soils. The Harza-Ebasco assignment of soils to hydrologic soil groups appears to have been done in a conservative manner. For example, a common soil type described as very gravelly, loamy (SO16) or even very gravelly (SO15) was assigned to the type C soil group. Soils described as loamy or clayey without other soil descriptors (IQ1, IQ2) were classified as type D soils. Other soils described as very gravelly without other soil descriptors (IU2, IU3) were classified as type B soils. The soils in the most mountainous areas (RM1) were classified as type D. The recommended range of minimum infiltration rates (FERC 2001) are 0.05 to 0.15 inch/hour for type C soils and 0.00 to 0.05 inch/hour for type D soils (see section 1.5.2). The uniform infiltration rates for the summer floods were confirmed using the HEC-1 during the unit hydrograph calibration.

The exponential loss rate method was used for calibration of spring floods and for spring PMF runs. The results of the exponential loss rate method can best be explained from the actual losses calculated during the June 1 PMF run when loss rates would be at their maximum. For the 216-hour PMP storm period, total loss rates (precipitation losses plus snowmelt losses in the HEC-1 output) for the sub-basins averaged 0.032 inch/hour, with a range of 0.018 to 0.044 inch/hour. For the 72-hour period of the most intense PMP rainfall, total loss rates averaged 0.060 inch/hour, with a range of 0.039 to 0.076 inch/hour. These loss rates exclude the reservoir surface area (sub-basin 29), which has zero losses.

8. COINCIDENT HYDROMETEOROLOGICAL AND HYDROLOGICAL CONDITIONS FOR THE PROBABLE MAXIMUM FLOOD

A common definition for the PMF is the flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in the drainage basin under study (FERC 2001). A distinction is drawn between the PMF and the "maximum possible flood" which would result from simultaneously maximizing every possible flood producing factor. The maximum possible flood is not in current use as an inflow design flood in the USA. This chapter addresses conditions coincident to the PMP designed to avoid compounding of conservatism and to provide a reasonable PMF hydrograph given the limitations of basic hydrologic and meteorological data.

8.1 Reservoir Level

For Watana Dam, initial reservoir level considerations include both the starting reservoir at the beginning of the PMP, as discussed in the next section, and the reservoir level at which the spillway gates begin to open. The reservoir level at which the spillway gates begin to open is determined in the following Intermediate Flood Operation section.

8.1.1 Starting Reservoir Level

As a large storage reservoir with highly seasonal inflows and an electricity demand load that is completely out of phase with the annual Susitna River flow patterns (i.e. reservoir inflows), Watana Reservoir will experience large seasonal fluctuations in water levels. The reservoir will most frequently be full to the maximum normal operating level at El 2050 during the months of August through October and will typically reach its lowest levels during April or May.

The reservoir levels will also be dependent on the load (demand for generation) that is placed on Watana. Figure 8.1-1 is a monthly elevation-frequency plot, based on daily simulated elevation data under the assumption that generation demand from Watana is at the maximum annual level that can be sustained with acceptable reliability. Figure 8.1-2 shows similar elevation-frequency data except that the load placed on Watana is half the maximum load. Note that there is a significant difference between reservoir elevation ranges (the y-axis) as shown on the two plots. The elevation-frequency data on Figure 8.1-2 could also correspond to a situation where an extended outage has occurred, or to a situation where for whatever reason, generation from Watana has been replaced by generation from another source.

Based on these plots, the assumed starting reservoir level for the PMF model runs for the months of June through October will be at the maximum normal pool level at El 2050. A sensitivity run will be performed for June at an initial reservoir level below El 2050 because under the maximum load scenario, the reservoir would frequently be less than full in June. It is noted that for a final PMF model run with a starting reservoir below El 2050, it would be necessary to route a 100-year flood through the reservoir three days prior to the start of the PMP. This requirement would typically result in a full reservoir anyway.

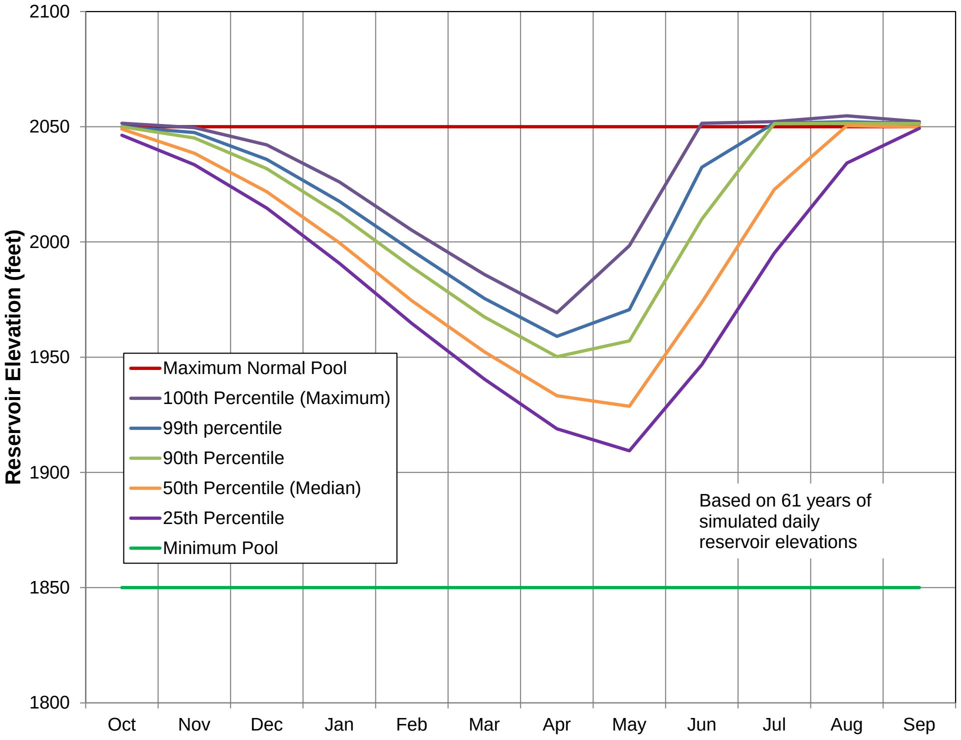


Figure 8.1-1. Reservoir Elevation Frequency – Maximum Load

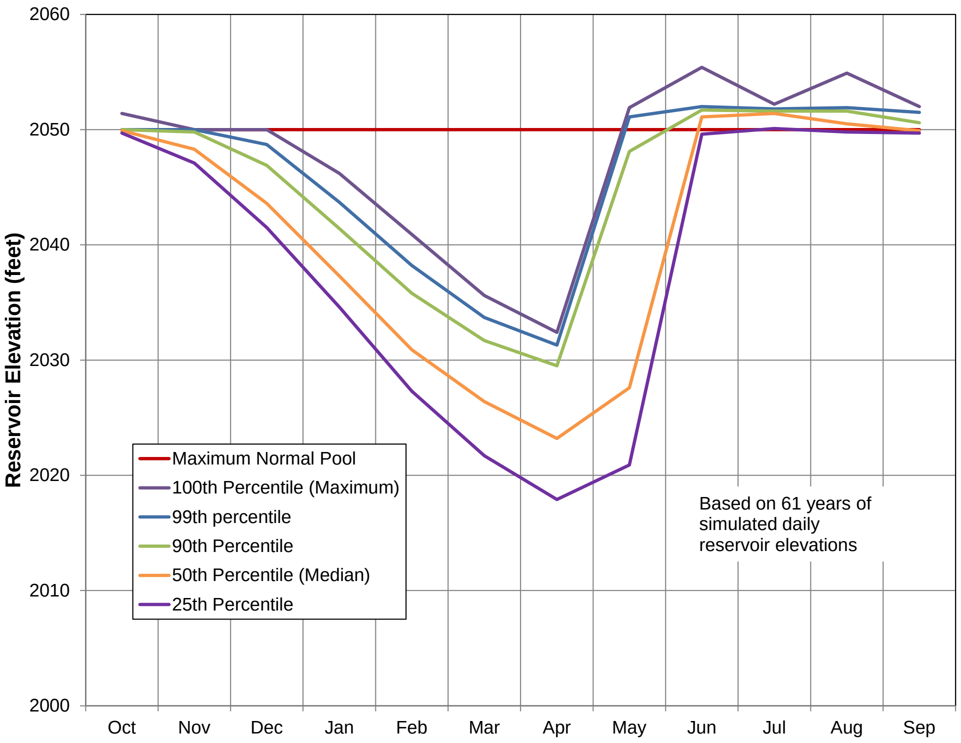


Figure 8.1-2. Reservoir Elevation Frequency – 50% Load

8.1.2 Intermediate Flood Operation

To limit the frequency of spillway operation, which may result in undesirable downstream gas super-saturation, an operating criterion is being adopted such that the Project should be able to pass floods up to the 50-year flood (the “intermediate flood”) without opening the spillway gates. Facilities that will be used to pass the 50-year flood include the powerhouse turbines and the fixed-cone valves in the low-level outlet works (LLOW) as well as surcharge storage in the reservoir above the maximum normal operating level at El 2050. Floods larger than the 50-year flood ranging up to the PMF would require usage of the main spillway in addition to the LLOW.

For the purposes of determining LLOW operation with an intermediate flood, the flood frequency was based on historic peak flows and flood volumes during the months of July through September when the reservoir is most likely to be full. In actual operation, there would be no attempt to determine the flood frequency of the inflow flood, the spillway gates would simply begin to open at the pre-determined reservoir level. The 50-year flood includes both the 50-year peak flow and the 50-year volume. The shape of the 50-year flood hydrograph was based on the August 1971 historical flood. Assuming that the reservoir is full at the start of even a July through September should give a conservatively high peak reservoir level because there is some realistic chance that the reservoir will not actually be full at the start of the 50-year flood.

A range of the number of valves in the LLOW was considered with eight valves being selected. Each valve has a capacity of about 4,000 cfs with the reservoir at El 2050, for a total capacity of 32,000 cfs in the LLOW. During routing of the intermediate flood, the turbines were assumed to be passing a total of 7,500 cfs, which is about 40% of their capability at El 2050, which gives a total outflow capability of 39,500 cfs. As shown on Figure 8.1-3, the maximum water level during routing of the intermediate flood was at El 2057.6. During routing of the PMF, the spillway gates do not begin to open until the reservoir level reaches El 2057.6, which is also the reservoir level at which the turbines are assumed to be completely shut down. The LLOW continues to operate through the PMF routing. Additional detail regarding the intermediate flood operation is provided in a technical memorandum that is included as Appendix B to this report.

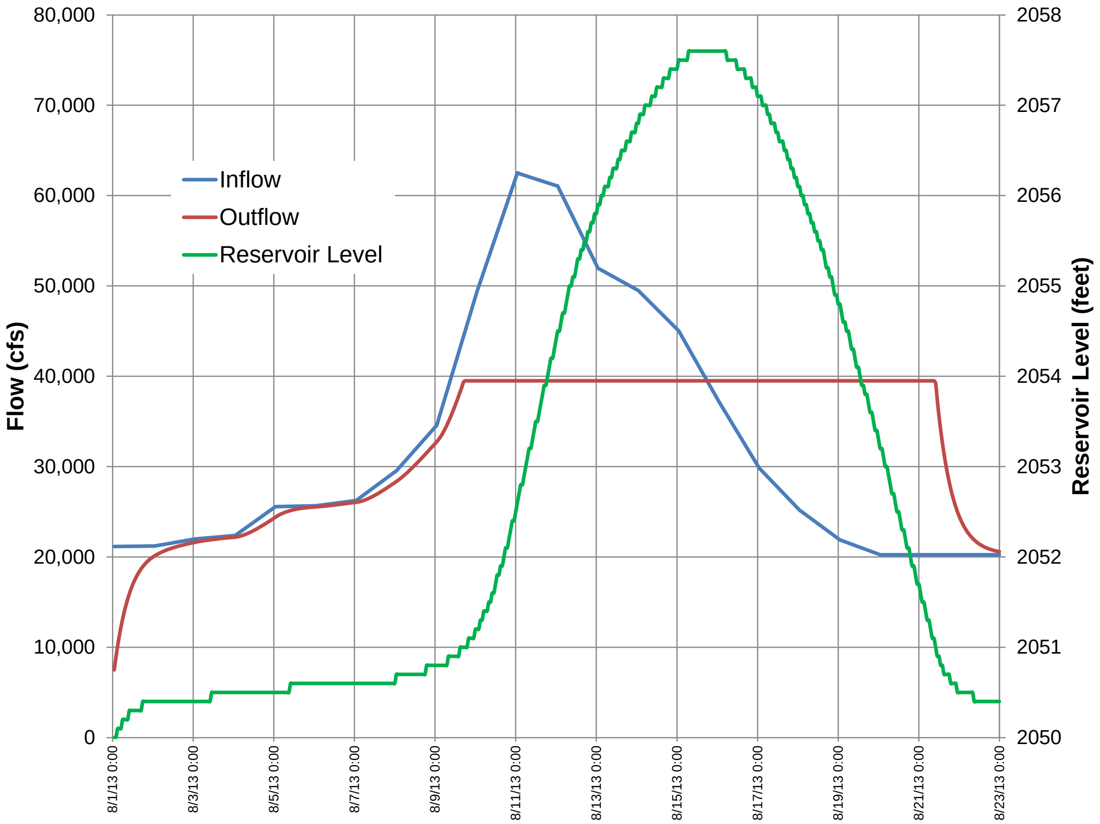


Figure 8.1-3. 50-Year Flood Routing with 8 Fixed-Cone Valves

8.2 Baseflow

Baseflow can be estimated from the average monthly flow coincident with the PMP or as recorded prior to historic maximum floods. The baseflow used in the current study is based on the flows antecedent to the maximum values used for the corresponding spring or summer calibration and verification floods.

8.3 Snowpack

Snowmelt is an important and potentially a controlling component of the PMF because of the substantial snowpack that can occur in the Susitna River basin. This section summarizes the available snowpack data, develops a methodology to develop extreme snowpack data, and determines the required 100-year snowpack and probable maximum snowpack for the Susitna River tributary to Watana Dam.

8.3.1 Available Historical Snowpack Data

Snowpack data is available at a number of stations either in the vicinity of or within the Susitna River watershed. Two types of snow data stations are available. SNOTEL stations have daily measurements, but only one SNOTEL station is located in the watershed tributary to Watana Dam, and it has a short record with missing data during much of 2013. Snow course data is available at several stations tributary to Watana Dam and the periods of record are generally longer than for SNOTEL stations, but typically only four measurements per year are available for the snow courses, taken roughly around the first of the month from February 1 through May 1. Snow course data measurements are not available for June. Table 8.3-1 summarizes identifiers, location, elevation, and period of record information for the SNOTEL and snow course stations for which data was gathered. The location of the various snowpack stations is shown on Figure 8.3-1.

Table 8.3-1. Snow Course and SNOTEL Stations In or Near the Susitna Watershed

Station Name	Station Number	Station Type	In Susitna R. Watershed (1)	Latitude (deg:min)	Longitude (deg:min)	Elevation (feet)	Maximum SWE (2)		Earliest Day (3) with Snowpack	Latest Day (3) with Snowpack	Years of Available Snowpack Data In the Period of Record
							(inches)	Date			
Anchorage Hillside	1070	SNOTEL	No	N 61:07	W 149:40	2,080	18.4	4/12/2012	10/6/2009	5/31/2012	8 years: 2006 - 2013
Bentalit Lodge	1086	SNOTEL	Yes	N 61:56	W 150:59	150	12.1	4/2/2012	10/10/2009	5/8/2008	8 years: 2006 - 2013
Fairbanks F.O.	1174	SNOTEL	No	N 64:51	W 147:48	450	11.2	4/26/1991	9/12/1992	5/20/2013	31 years: 1983 - 2013
Granite Creek	963	SNOTEL	No	N 63:57	W 145:24	1,240	7.7	4/16/1991	9/12/1992	5/14/2013	26 years: 1988 - 2013
Independence Mine	1091	SNOTEL	Border	N 61:48	W 149:17	3,550	23.5	5/17/2001	10/1/2002	6/13/2013	16 years: 1998 - 2013
Indian Pass	946	SNOTEL	No	N 61:04	W 149:29	2,350	40.1	5/13/2001	9/17/1992	6/27/1985	34 years: 1980 - 2013
Monohan Flat (4)	1094	SNOTEL	**Border**	N 63:18	W 147:39	2,710	N/A	N/A	10/4/2008	5/25/2013	6 years: 2008 - 2013
Mt. Alyeska	1103	SNOTEL	No	N 60:58	W 149:05	1,540	69.1	5/13/1998	10/1/1993	7/3/1980	40 years: 1973 - 2013
Munson Ridge	950	SNOTEL	No	N 64:51	W 146:13	3,100	18.4	4/15/1991	9/11/1992	6/2/1982	33 years: 1981 - 2013
Susitna Valley High	967	SNOTEL	Yes	N 62:08	W 150:02	375	18.7	4/1/1990	10/1/1997	5/21/1999	27 years: 1988 - 2013
Tokositna Valley	1089	SNOTEL	Yes	N 62:38	W 150:47	850	20.7	4/27/2008	10/8/2009	6/3/2013	8 years: 2006 - 2013
Blueberry Hill	49N07	Snow Course	Yes	N 62:48	W 149:59	1,200	27.6	3/30/1990	-----	-----	26 years: 1988 - 2013
Clearwater Lake	46N01	Snow Course	**Yes**	N 62:56	W 146:57	2,650	9.4	4/27/1972	-----	-----	47 years: 1964 - 2013
E. Fork Chulitna River	47N02	Snow Course	Yes	N 63:08	W 149:27	1,800	27.7	4/28/2005	-----	-----	26 years: 1988 - 2013
Fog Lakes	48N02	Snow Course	**Yes**	N 62:47	W 148:28	2,120	11.2	3/28/1991	-----	-----	50 years: 1964 - 2013
Horsepasture Pass	47N02	Snow Course	**Border**	N 62:08	W 147:38	4,300	11.8	3/30/2005	-----	-----	46 years: 1968 - 2013
Independence Mine	49M26	Snow Course	Border	N 61:48	W 149:17	3,550	41.0	5/2/1990	-----	-----	25 years: 1989 - 2013
Lake Louise	46N02	Snow Course	**Yes**	N 62:16	W 146:31	2,400	7.6	4/2/1993	-----	-----	50 years: 1964 - 2013
Monohan Flat	47O01	Snow Course	**Border**	N 63:18	W 147:39	2,710	14.8	3/31/2005	-----	-----	49 years: 1964 - 2013
Monsoon Lake	46N03	Snow Course	**Border**	N 62:50	W 146:37	3,100	10.3	3/30/1990	-----	-----	29 years: 1985 - 2013
Square Lake	47N01	Snow Course	**Yes**	N 62:24	W 147:28	2,950	7.2	4/26/1982	-----	-----	50 years: 1964 - 2013
Susitna Valley High	50N07	Snow Course	Yes	N 62:08	W 150:02	375	18.1	3/30/1990	-----	-----	19 years: 1988 - 2012
Talkeetna	50N02	Snow Course	Yes	N 62:19	W 150:05	350	18.3	3/26/1990	-----	-----	47 years: 1967 - 2013
Tyone River	47N03	Snow Course	**Yes**	N 62:40	W 147:08	2,500	6.2	3/29/2000	-----	-----	21 years: 1981 - 2011

Notes:

(1) Items in bold indicate the location is tributary to Watana Dam. Border indicates the station is on or near the watershed border.

(2) SWE is snow water equivalent, the depth of melted snow in a snowpack.

(3) Snow course measurements are infrequent and insufficient to determine the earliest and latest days with a snowpack.

(4) Snow water equivalent data is unavailable for the Monahan Flat SNOTEL site.

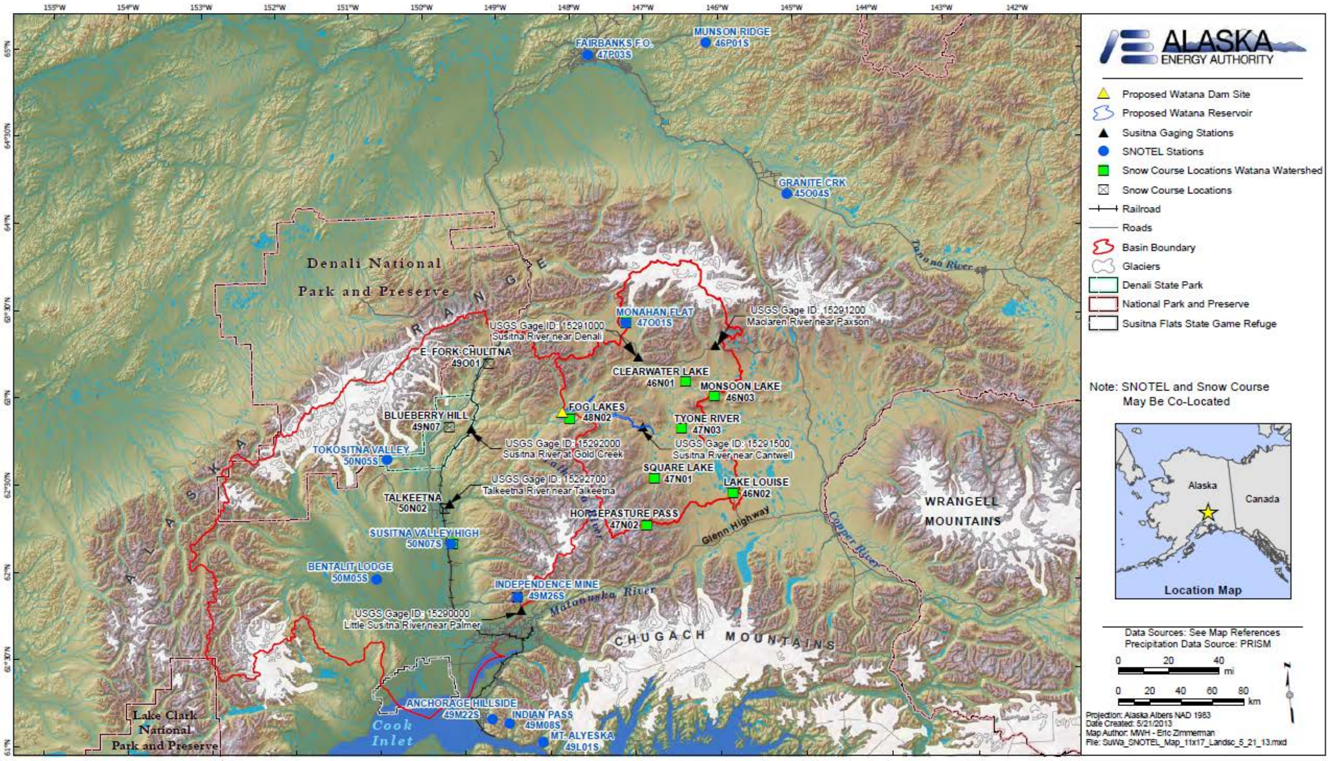


Figure 8.3-1. Location of Snow Courses and SNOTEL Stations

8.3.2 Methodology Used to Determine the Estimated PMF Snowpack

The seasonal 100-year snowpack coincident with the corresponding seasonal PMP is required by the FERC guidelines (2001, pg. 68) for the determination of the PMF. The 100-year snowpack, or preferably the snow water equivalent (SWE) data, must be refined in three ways:

- The 100-year SWE data must be seasonal (by month), for May through October.
- The 100-year SWE data must be separated into 1000-ft elevation bands for each sub-basin.
- The 100-year SWE data should vary by location in the watershed to account for the areal differences in precipitation, if appropriate. Due to large variations in average annual precipitation in the watershed above Watana Dam, the SWE in a single elevation band would not be the same throughout the watershed.

For areas where snowmelt may be a significant contributor to the PMF, the FERC guidelines (pg. 68) also require a second PMF scenario, which is the 100-year precipitation on a Probable

Maximum Snowpack. Alternative methods to develop these PMF input data needs are discussed in the following paragraphs.

Method 1 – Use Only Historic Snow Course and SNOTEL Data

Using historic recorded data, the historic snowpack can be summarized for each month of the year at each location where data is available. Where the available data is only inches of snowpack, assume a starting SWE of 30 percent (FERC pg. 68). Fit a distribution to the recorded monthly data and estimate the 100-year snowpack at each location for each month. From the various stations, develop snowpack data in each elevation band for each month. Develop separate 100-year data sets for different snow course locations. Assign sub-basins to appropriate snowpack data locations. This is a method previously used by MWH in PMF studies, but for smaller watersheds, and with more snowpack data stations relative to the watershed area.

Advantages: If data is adequate, this could be the most direct method.

Disadvantages: The available historic recorded data is probably inadequate to directly use this as the preferred method, particularly with regards to areal variation.

Method 2 – Combine Historic SWE Data and the Seasonal Precipitation Map

Historic snowpack data at available SNOTEL and snow course stations can be used to develop the 100-year snowpack by season. The snowpack would be spatially distributed in the sub-basins based on the area in 1000-ft elevation zones and the GIS-based seasonal precipitation map. The preferred alternative would be to use an October thru April average precipitation map to distribute the snowpack. The same ratio of the 100-year snowpack at a given snow course station (or stations) for a given month to the seasonal precipitation (Oct-April) would be used to develop the 100-year snowpack at all locations. Different ratios would be used for different months. For example, if the 100-year SWE at a snow course station (or stations) for May was equal to 120 percent of the October through April average precipitation at the snow course station (or stations) as determined from GIS precipitation maps, then the 100-year SWE at all locations in the watershed for May would be equal to 120 percent of the Oct-Apr precipitation.

Advantages: The available data is adequate for this method. Adequate data may be available at several snow course and SNOTEL locations from which a more localized ratio could be developed. A method similar to this is given in the FERC PMF guidelines (pg. 24).

Disadvantages: May lack accuracy at lower elevations where a higher percentage of annual precipitation would be rain instead of snow, but inaccuracy for the extreme 100-year snowpack may not be significant. Snow course data ends at about May 1.

Method 3 – Assume an Unlimited SWE

An unlimited SWE as used herein means more SWE than can be melted during the PMP storm sequence at any elevation. In effect, this method was apparently applied in one of the previous PMF studies (Acres 1982), where the minimum initial snowpack for any sub-basin was 27 inches in the Tyone River sub-basin. The snowpack values in the 1982 PMF study are apparently SWE, based on an approximate reconstruction of the 1982 PMF with HEC-1. The 27 inches of SWE are enough to contribute snowmelt to the PMF peak over the entire watershed such that unlimited SWE would not increase the peak flow of the PMF.

Advantages: The FERC PMF guidelines (pg. 68) allow use of this assumption when no snowpack data are available. It would be the easiest method to apply.

Disadvantages: Using this method for the Susitna-Watana watershed would probably represent compounding of conservatism during any month at the lower watershed elevations that constitute the majority of the watershed. It certainly represents compounding of conservatism at lower elevations during the summer months. FERC PMF guidelines (pg. 2) specifically caution against compounding of conservatism in developing the PMF.

Method 4 – Combine Historic Flood Data with the Assumption of Unlimited Snowpack

Due to compounding of conservatism at lower elevations for the assumption of an unlimited SWE, use historic flood data to estimate snowmelt contributions from the lower elevations while using an unlimited SWE at the higher elevations. The FERC PMF guidelines (pg. 68) indicate that seasonal 3-day average 100-year flood discharges may be used in lieu of the snowmelt component in non-mountainous regions if snowpack data is inadequate. For example, it could be assumed that elevations below 4,000 feet (or alternative elevation) are non-mountainous, but these lower elevations constitute about 69 percent of the watershed tributary to Watana Dam. For areas below 4,000 feet, the snowmelt component would be included as constant base seasonal flow proportioned by the area below 4,000 feet. For elevations above 4,000 feet, the assumption of unlimited snowpack would apply.

In Design of Small Dams (1987, pg. 52-53), the USBR has suggested development of the 100-year snowmelt flood based on a frequency analysis of the maximum annual snowmelt flood volume. The usual period of runoff selected was 15 days. The 100-year snowmelt flood is then distributed over time using the largest recorded snowmelt flood as the basis for distribution.

Advantages: This method would limit the snowmelt runoff in the areas where unlimited snowpack is an unfounded assumption. Proportioning the seasonal 100-year flood runoff provides a method for seasonal variation of the snowmelt runoff from 69 percent of the watershed. Data is adequate for this method.

Disadvantages: There is some inherent uncertainty in the assumption that the 3-day average 100-year flood flow corresponds to the 100-year snowmelt runoff. Proportioning the 100-year runoff by drainage area is an approximation, but is probably conservative. The assumption of unlimited snowpack is always conservative and is probably excessively conservative.

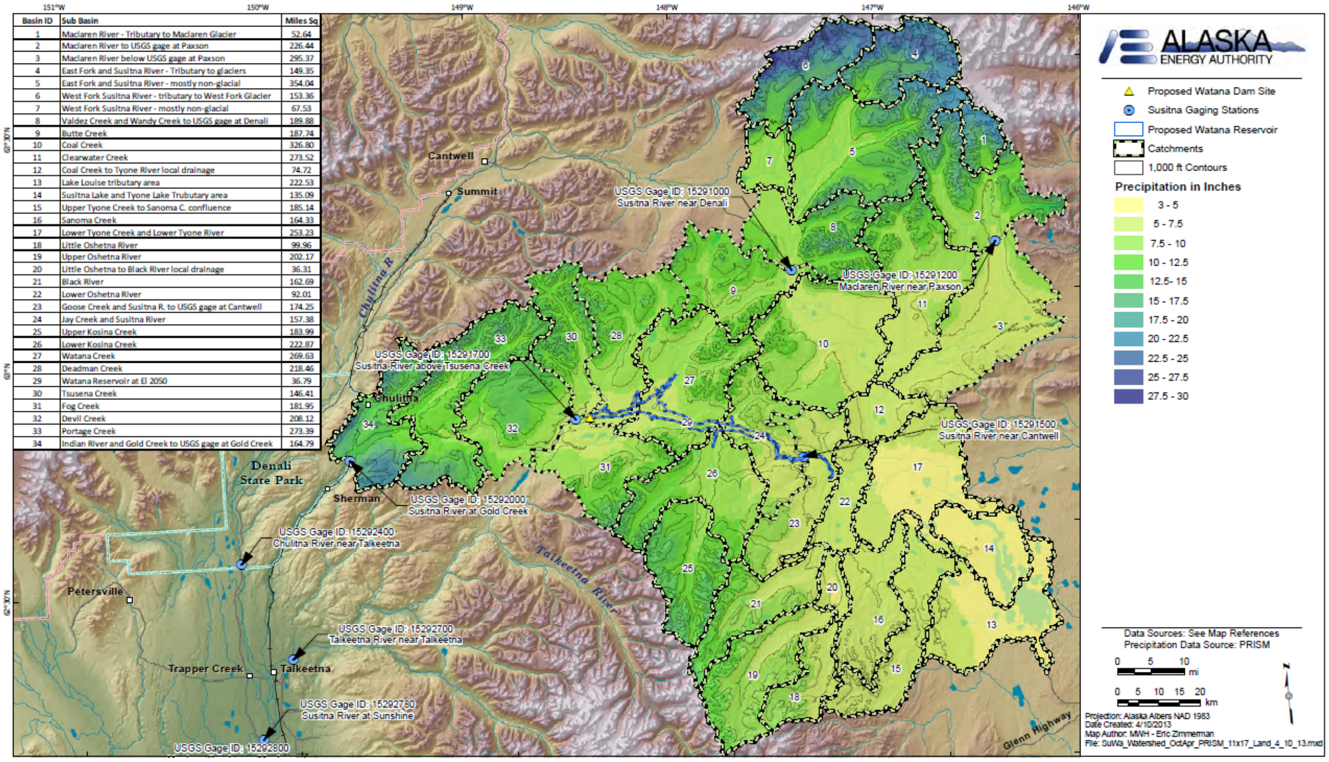
Selected Method: Historic SWE Data Combined with Seasonal Precipitation Mapping

Method 2 described above is selected for development of the Susitna-Watana snowpack data because it maximizes the use of both historic snowpack data and the available precipitation mapping. The availability of GIS-based monthly precipitation maps and data is an advantage of this method for the areal and elevation distribution of snowpack that was not available during the 1980s PMF studies. This method should also avoid excessive conservatism that could be included in other methods.

8.3.3 Seasonal Precipitation

Maximum snowpack distribution data was developed in proportion to the October through April average precipitation as has been previously suggested for the Yukon River (Weather Bureau 1966). GIS-based monthly precipitation was prepared using PRISM (Parameter-elevation Regressions on Independent Slopes Model) an analytical tool developed at Oregon State University that uses point data, a digital elevation model, and other spatial data sets to generate gridded estimates of monthly, yearly, and event-based climatic parameters, such as precipitation, temperature, and dew point.

Figure 8.3-2 graphically depicts the October through April average precipitation for the drainage area above the Gold Creek USGS gaging station. This figure clearly shows the wide variation in precipitation with lower total precipitation in the southeast part of the watershed and higher precipitation in the northern and western portions of the watershed.



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 8.3-2. Average October through April Precipitation

Table 8.3-2 provides the monthly average precipitation for each sub-basin and for the annual and October through April totals. Also shown is the area-weighted average precipitation to Watana Dam and to each of the four USGS gaging stations. The months of maximum precipitation are July through September with April being the month with the minimum precipitation. The average October through April precipitation varies from a maximum of almost 20 inches for the West Fork Susitna River (sub-basin 6) to a minimum of 4.32 inches in the area tributary to Susitna Lake and Tyone Lake (sub-basin) 14.

Table 8.3-2. Monthly Average Precipitation by Month and Sub-Basin

Sub-Basin Number	Basin Area (sq.mi.)	Average Precipitation (inches)														Oct-Apr % of Year
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Oct-Apr	
1	52.6	1.73	2.61	2.07	1.54	1.67	3.46	4.36	5.85	5.61	4.32	2.01	2.64	37.88	16.92	44.7%
2	226.4	1.26	1.79	1.40	1.11	1.34	2.86	3.75	4.60	4.15	3.30	1.44	1.95	28.94	12.24	42.3%
3	295.4	0.81	0.71	0.61	0.59	1.10	2.34	2.93	2.85	2.19	1.92	0.84	1.18	18.08	6.66	36.8%
4	149.3	2.38	2.73	2.49	1.60	1.76	3.72	4.84	6.29	5.83	4.44	2.43	3.14	41.66	19.22	46.1%
5	354.0	1.61	1.97	1.55	1.14	1.37	3.04	4.10	4.73	4.21	3.29	1.62	2.26	30.91	13.45	43.5%
6	153.4	2.67	2.60	2.21	1.65	1.62	3.83	5.39	6.31	5.79	4.68	2.33	3.74	42.84	19.90	46.4%
7	67.5	1.43	1.24	0.92	0.81	1.11	2.93	3.98	3.59	2.78	2.35	1.14	1.65	23.93	9.54	39.9%
8	189.9	1.35	1.67	1.29	1.01	1.28	2.87	3.85	4.35	3.85	2.96	1.41	1.88	27.76	11.57	41.7%
9	187.7	1.42	1.32	1.00	0.97	1.30	3.11	4.20	4.24	3.57	2.75	1.34	1.72	26.93	10.50	39.0%
10	326.8	0.94	0.97	0.72	0.76	1.13	2.35	3.24	3.70	2.94	2.36	0.90	1.31	21.31	7.96	37.3%
11	273.5	1.02	1.06	0.87	0.84	1.17	2.57	3.33	3.71	3.18	2.62	1.07	1.47	22.91	8.95	39.1%
12	74.7	0.69	0.57	0.54	0.51	1.08	2.28	2.86	2.69	2.01	1.61	0.79	1.12	16.76	5.84	34.9%
13	222.5	0.54	0.45	0.44	0.32	1.04	2.31	2.68	1.82	1.55	1.22	0.77	1.05	14.20	4.79	33.7%
14	135.1	0.47	0.41	0.38	0.26	1.06	2.34	2.70	1.75	1.64	1.25	0.66	0.90	13.81	4.32	31.3%
15	185.1	0.61	0.56	0.60	0.44	1.14	2.48	2.94	2.18	1.68	1.32	0.95	1.28	16.17	5.75	35.6%
16	164.3	0.60	0.50	0.58	0.51	1.18	2.53	3.02	2.36	1.85	1.44	0.95	1.30	16.83	5.88	34.9%
17	253.2	0.57	0.47	0.51	0.35	1.05	2.24	2.71	2.17	1.71	1.32	0.79	1.08	14.97	5.09	34.0%
18	100.0	0.69	1.00	0.89	0.75	1.45	3.01	3.57	2.92	2.35	1.75	1.03	1.40	20.81	7.52	36.1%
19	202.2	0.77	1.01	0.91	1.15	1.99	3.30	3.84	3.35	3.19	2.33	1.12	1.55	24.52	8.85	36.1%
20	36.3	0.52	0.46	0.47	0.63	1.26	2.49	3.03	2.72	2.21	1.58	0.76	1.04	17.15	5.45	31.8%
21	162.7	0.79	0.81	0.78	1.29	1.87	2.94	3.84	3.71	4.08	2.70	1.21	1.57	25.59	9.15	35.8%
22	92.0	0.56	0.46	0.49	0.54	1.05	2.24	2.83	2.73	2.05	1.59	0.77	1.08	16.40	5.50	33.6%
23	174.2	0.67	0.58	0.57	0.86	1.39	2.57	3.34	3.57	3.02	2.21	0.90	1.22	20.91	7.02	33.6%
24	157.4	0.86	0.75	0.63	0.85	1.23	2.48	3.45	3.86	3.04	2.46	0.99	1.28	21.89	7.84	35.8%
25	184.0	1.16	1.02	0.80	1.66	1.76	3.50	4.72	5.59	5.76	3.96	1.72	1.92	33.57	12.24	36.5%
26	222.9	1.02	0.92	0.75	1.32	1.40	2.99	4.35	4.72	4.06	3.07	1.46	1.60	27.67	10.14	36.6%
27	269.6	1.08	1.04	0.84	0.94	1.18	2.62	3.66	4.00	3.19	2.28	1.39	1.42	23.63	8.99	38.0%
28	218.5	1.20	1.23	1.03	0.99	1.22	2.89	4.05	4.44	3.71	2.15	1.78	1.66	26.35	10.04	38.1%
29	36.8	0.76	0.73	0.60	0.75	0.99	2.19	2.99	3.25	2.58	1.78	1.03	1.06	18.70	6.71	35.9%
30	146.4	1.32	1.42	1.23	1.20	1.36	2.91	4.22	4.79	4.12	2.19	2.16	1.88	28.78	11.40	39.6%
31	181.9	1.03	1.08	0.87	1.29	1.30	3.05	4.05	4.77	4.14	2.27	1.64	1.37	26.87	9.55	35.6%
32	208.1	1.02	1.48	1.39	1.53	1.52	2.86	3.85	4.69	4.10	1.75	2.59	1.72	28.49	11.47	40.3%
33	273.4	1.57	1.67	1.59	1.49	1.48	2.97	4.13	5.04	4.40	2.16	2.57	2.21	31.29	13.26	42.4%
34	164.8	2.07	1.98	1.87	1.48	1.21	3.04	4.57	6.27	5.45	3.69	2.28	2.69	36.60	16.06	43.9%
To Gold Creek Gage	6,143	1.11	1.17	1.01	0.99	1.32	2.80	3.70	3.97	3.45	2.46	1.40	1.67	25.04	9.80	39.1%
To Watana Dam	5,168	1.05	1.10	0.93	0.91	1.31	2.77	3.61	3.76	3.26	2.48	1.24	1.61	24.03	9.32	38.8%
To Denali Gage	914	1.85	2.08	1.71	1.25	1.44	3.24	4.37	5.09	4.56	3.57	1.79	2.53	33.50	14.79	44.2%
To Maclaren Gage	279	1.35	1.94	1.52	1.19	1.40	2.97	3.86	4.84	4.42	3.49	1.55	2.08	30.62	13.12	42.8%
To Cantwell Gage	4,079	1.05	1.13	0.96	0.85	1.30	2.74	3.51	3.58	3.10	2.42	1.17	1.62	23.44	9.20	39.3%

8.3.4 100-Year Snowpack Antecedent to the PMP

PMF combined events criteria call for using a 100-year snowpack coincident with the PMP appropriate for the same month. The 100-year snow water equivalent was developed at several stations based on monthly snowpack statistics and the following equation:

$$SWE = M + KS$$

where: SWE is the 100-year snow water equivalent (inches)

M is the mean snow water equivalent for a month (inches)

S is the standard deviation of the monthly snow water equivalent (inches)

K is a factor corresponding to a 100-year return period and the calculated skew of the monthly snow water equivalent

Table 8.3-3 presents the calculated 100-year snow water equivalent 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 as obtained from PRISM data. The last column of

Table 8.3-3 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 8.3-3 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 8.3-4 presents the 100-year snowpack SWE averaged by sub-basin. The runoff model separates the 100-year SWE values within each sub-basin by 1000-foot elevation bands.

Table 8.3-3. 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.

As presented in the previous section, July, August and September have no historic evidence of snowpack accumulation in the Susitna watershed. The only 100-year snowpack SWE for these months would be in glaciated areas, which are assumed to have an essentially unlimited snowpack above 4,000 feet.

Although there is no historic evidence of maximum floods occurring during October, and there is little evidence of any snowpacks forming during October, the possibility of the critical PMF occurring during October has been retained for completeness. No snow course data is available for October and no SNOTEL data with SWE measurements are available within the watershed tributary to Watana Dam. The 100-year October snowpack was estimated as being equal to the average precipitation for the entire month of October. This is considered to be a conservative assumption, since the maximum snow accumulation would not occur until the end of the month, but the maximum temperatures would occur near the beginning of the month.

Table 8.3-4. 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

8.3.5 Probable Maximum Snowpack

The evaluation of a 100-year precipitation on a Probable Maximum Snowpack is required in areas where snowpack may make a significant contribution to the PMF (FERC 2001). In many cases, it can be enough to simply assume an unlimited snowpack and if the resulting PMF is less than for the PMP on 100-year snowpack case, then the Probable Maximum Snowpack scenario can be dismissed, which is the usual result. A more reasonable Probable Maximum Snowpack is developed for Watana Dam in this section.

The Yukon River watershed lies to the north and east of the Susitna River watershed and is in places adjacent to the Susitna River watershed. The Weather Bureau (1966) has prepared a hydrometeorological report (HMR 42) for the Yukon River and preparation of a Probable Maximum Snowpack for the Yukon River was a major part of the report. Results of HMR 42 are applicable to the Susitna River watershed.

The HMR 42 Yukon River final result was that the Probable Maximum Snowpack was equal to 3.0 times the October through April cumulative average precipitation, based on an enveloping analysis of historic October through April precipitation data. The Susitna River watershed tributary to Watana Dam lacks this type of long-term precipitation data. In terms of May 1 recorded snow course SWE as a ratio to October through April average precipitation, the maximum recorded year value for the area tributary to Watana Dam is 1.73 at Monohan Flat. The maximum ratio in the Susitna watershed vicinity is 2.35 for the East Fork Chulitna River snow course. Although it is a very approximate comparison, a snowpack of 3.0 times the average snowpack on May 1 would be more rare than a calculated 10,000-year event at many of the snow course stations, which would be appropriately rare for a probable maximum event.

The adopted Probable Maximum Snowpack for the watershed tributary to Watana Dam will be 3.0 times the average October through April precipitation. The method of snowpack distribution over the watershed will be the same as for the 100-year snowpack. The average Probable Maximum Snowpack SWE for each sub-basin is presented on Table 8.3-5. The average Probable Maximum Snowpack SWE in the area tributary to Watana Dam is 27.9 inches, which compares to the Weather Bureau result of 15.7 inches Probable Maximum Snowpack for the upper Yukon River.

Table 8.3-5. Probable Maximum Snowpack Snow Water Equivalent

Sub-Basin Number	Basin Area (sq.mi.)	Annual Precip. (inches)	Oct-Apr Precip. (inches)	PMS SWE (inches)
1	52.6	37.9	16.9	50.8
2	226.4	28.9	12.2	36.7
3	295.4	18.1	6.7	20.0
4	149.3	41.7	19.2	57.7
5	354.0	30.9	13.5	40.4
6	153.4	42.8	19.9	59.7
7	67.5	23.9	9.5	28.6
8	189.9	27.8	11.6	34.7
9	187.7	26.9	10.5	31.5
10	326.8	21.3	8.0	23.9
11	273.5	22.9	9.0	26.9
12	74.7	16.8	5.8	17.5
13	222.5	14.2	4.8	14.4
14	135.1	13.8	4.3	13.0
15	185.1	16.2	5.8	17.3
16	164.3	16.8	5.9	17.6
17	253.2	15.0	5.1	15.3
18	100.0	20.8	7.5	22.6
19	202.2	24.5	8.8	26.5
20	36.3	17.1	5.4	16.3
21	162.7	25.6	9.2	27.5
22	92.0	16.4	5.5	16.5
23	174.2	20.9	7.0	21.1
24	157.4	21.9	7.8	23.5
25	184.0	33.6	12.2	36.7
26	222.9	27.7	10.1	30.4
27	269.6	23.6	9.0	27.0
28	218.5	26.3	10.0	30.1
29	36.8	18.7	6.7	20.1
30	146.4	28.8	11.4	34.2
31	181.9	26.9	9.6	28.7
32	208.1	28.5	11.5	34.4
33	273.4	31.3	13.3	39.8
34	164.8	36.6	16.1	48.2
To Gold Creek Gage	6,143	25.0	9.8	29.4
To Watana Dam	5,168	24.0	9.3	27.9
To Denali Gage	914	33.5	14.8	44.4
To Maclaren Gage	279	30.6	13.1	39.4
To Cantwell Gage	4,079	23.4	9.2	27.6

8.4 Snowmelt

Snowmelt was determined within the HEC-1 program using the energy budget method. The input data used to determine snowmelt within HEC-1 includes snowpack water equivalent, snowmelt temperature, air and dew point temperature, insolation, and wind speed. The snowpack water equivalent was developed in the previous section. The snowmelt temperature was taken as 32 degrees Fahrenheit. The air and dew point temperatures were as developed in the PMP study (Appendix A) for the appropriate month. Temperatures were reduced for elevation at a rate of 2.6 degrees per 1,000 feet. Insolation was developed from Figure 7-1 of a PMF study for the Yukon River (Weather Bureau 1966).

The energy budget snowmelt method in HEC-1 includes a snowmelt coefficient input value that the HEC-1 User’s Manual (USACE 1998) indicates usually has a value of about 1.0. The HEC-1 snowmelt coefficient can be used to account for differences from the general snowmelt equation included in HEC-1 that applies most directly to partly forested areas (10% to 60% forest cover). Based on calibration results, the snowmelt coefficient input value was 1.25 for open sub-basins (<10% forest cover), 1.00 for partly forested sub-basins (10% to 60% forest cover), and 0.90 for forested sub-basins (>60% forest cover). The general rationale for the variation of the snowmelt coefficients is that more open (less forested) areas are more exposed to winds that increase snowmelt.

8.5 100-Year Precipitation

Based on PMF study guidelines (FERC 2001, pg. 68), the evaluation of two PMF scenarios is required in the area west of the Continental Divide, which would include Alaska. This includes (a) PMP on 100-yr snowpack, and (b) 100-yr precipitation on Probable Maximum Snowpack.

The published data for Alaska that includes the 100-year precipitation (Weather Bureau 1963; Weather Bureau 1965; National Weather Service, et al. 2012) focuses on point precipitation values and none of the publications contains areal reduction factors for areas greater than 400 square miles. Only Technical Paper No. 47 (Weather Bureau 1963) for Alaska includes an estimate of the PMP, and it also includes a map of the ratio of the PMP to the 100-year rainfall for a 6-hour duration. For the drainage area tributary to Watana Dam, the ratio of the PMP to the 100-year precipitation averages about 4, with the ratio approaching 3 near the mountainous borders of the watershed.

For the 48 adjacent United States area, maps of the ratio of the PMP for 10 square miles to the 100-year frequency rainfall (both for 24-hour durations) have been developed. These PMP/100-yr rainfall ratios range between 2 and 6 (Committee on Safety Criteria for Dams 1985). In the 48 adjacent states, there are indications that the PMP to 100-year precipitation ratio is frequently about 3 in mountainous areas.

As a part of the current site-specific PMP study, Applied Weather Associates has determined the ratio of the 24-hour point PMP values from the current study to the corresponding recent National Weather Service (2012) 100-year, 24-hour point precipitation values. For the area tributary to Watana Dam site, the ratio of the PMP to 100-year values averaged 1.74 (see Appendix A for additional detail). The 1.74 ratio represents the most current data and methods and will result in the most conservative estimate of the 100-year precipitation. Therefore, for the PMF scenario developed with the 100-year precipitation on the probable maximum snowpack, the 100-year precipitation was developed as the seasonal PMP divided by 1.74.

8.6 Freeboard

Freeboard is the vertical distance between a specified stillwater reservoir surface elevation and the top of the dam. Watana Dam will be designed to provide two types of freeboard: (1) normal freeboard, which is defined as the difference in elevation between the top of the dam (i.e. dam crest) and the normal maximum pool elevation, and (2) minimum freeboard, which is defined as the difference in pool elevation between the top of the dam and the maximum reservoir water surface that would result from routing the PMF through the reservoir.

The Federal Energy Regulatory Commission (FERC 1993) has referenced the U.S. Bureau of Reclamation ACER TM No. 2 (USBR 1992) for guidelines that provide criteria for freeboard computations. The USBR freeboard policy has been developed for three categories of dam types relative to their age and erodibility including (1) new concrete dams, (2) new embankment dams, and (3) existing concrete and embankment dams. Regarding new concrete dams, the guideline (USBR 1992) states that the standard 3.5-foot high solid parapet entirely above the elevation of the non-overflow section (dam crest) provides for minimum freeboard in the event of the PMF. ACER TM No. 2 further states that due to the ability of concrete dams to resist erosion, this is ordinarily the only type of freeboard necessary to consider (no criteria for normal freeboard were provided). To ensure that exceptional circumstances do not point to a need for additional freeboard, normal freeboard based on the 100 mph maximum wind speed specified for a new embankment dam has been analyzed along with the wind speed protection provided by the 3.5-foot parapet wall coincident with the peak of the PMF.

The significant wave height (average of the highest one-third of the waves) is commonly used for freeboard design of dams that are erosion resistant. The calculated effective fetch for the reservoir is 2.87 miles. For wave runup on a vertical dam face, the results are summarized in Table 8.6-1.

Table 8.6-1. Freeboard Parameters

Parameter	Wind Speed (mph)		
	40	50	100
Significant wave height (feet)	2.8	3.7	8.7
Wave period (seconds)	3.0	3.3	4.3
Wave length (feet)	45.2	54.2	95.1
Wave runup (feet)	3.08	4.06	9.52
Wind setup (feet)	0.01	0.01	0.03
Wave runup + wind setup (feet)	3.09	4.07	9.55

9. PMF HYDROGRAPHS

Under FERC guidelines, in planning a project of this type, evaluation of two PMF scenarios is required including (a) PMP on 100-year snowpack, and (b) 100-year precipitation on probable maximum snowpack. This chapter also includes three sets of PMF runs that determine (1) the critical temporal distributions of the PMP, (2) the critical seasonal PMF in combination with seasonal PMPs and meteorological conditions, and (3) PMF sensitivity runs that determine the potential effects of both more conservative and less conservative values for key parameters. From among the three sets of PMF runs a preliminary determination of the critical PMF inflow hydrograph was made and preliminary spillway sizing was performed. A final section of this chapter compares results of the current studies with results of previous Susitna PMF studies. Precipitation, temperature, wind speed, and dew point data were used directly as provided by Applied Weather Associates for all PMF cases.

A review of previous Susitna PMF studies indicated that a reasonable objective for the PMF maximum water level would be about 15 feet above the maximum normal pool level at El 2050. To provide a common basis for comparison of the various PMF case runs summarized in this section and for selection of the critical PMF case, a common spillway crest level at El 2000 and a common spillway width of 126 feet (3 gates each at 42 feet wide) were used for all initial case runs. The 126-foot spillway width limits the critical PMF hydrograph to a maximum water level below El 2065.

Based on comments received at the Fourth Meeting of the Independent Board of Consultants during April 2-4, 2014, the spillway crest level was subsequently raised by 10 feet to El 2010. As described in Section 9.3, the total gate width was increased to keep the maximum routed critical PMF level below El 2065 with the raised spillway crest. The spillway sizing is preliminary and subject to additional future optimization. No dam crest level was determined herein by the PMF study.

9.1 PMF Inflow and Outflow Hydrographs

As shown on Figures 6.1-1, 6.1-2, and 6.1-3, three alternative temporal distributions were available for the PMP. Because it is not known in advance with complete certainty which PMP distribution will be critical (results in the highest reservoir elevation), all three distributions were run for both spring and summer conditions. As shown on Table 9.1-1, the PMP temporal distribution based on the August 1967 storm resulted in the critical maximum reservoir water surface elevation for both the spring (El 2059.3) and summer (El 2059.6) PMF. As can be seen on Figure 6.1-1, the August 1967 temporal distribution had the most concentrated rainfall, which generally produces the critical condition. Therefore, all subsequent PMF runs used the August 1967 temporal distribution of the PMP.

Table 9.1-1. PMP Temporal Distribution Cases

Case Number	Season	Based on Storm	Peak Inflow (cfs)	Peak Outflow (cfs)	Maximum Reservoir W.S. Elev. (feet)
T1	Spring	Aug-67	196,000	195,000	2059.3
T2	Spring	Aug-55	180,000	179,000	2059.1
T3	Spring	Sep-12	158,000	157,000	2058.9
T4	Summer	Aug-67	222,000	218,000	2059.6
T5	Summer	Aug-55	159,000	157,000	2058.9
T6	Summer	Sep-12	130,000	126,000	2058.6

Table 9.1-2 shows the list of seasonal model runs that were made with variations in PMP, temperature and dew point, wind speed, and snowpack. Normally seasonal PMF runs are only considered on a monthly basis, but because temperature and dew point data were available on a half-month basis, PMP values and wind speeds were interpolated to also provide half month values. The comment column of Table 9.1-2 provides reasons for eliminating runs for various half-month periods because they cannot produce the controlling results.

Table 9.1-2. PMF Seasonal Run Selection

Date	PMP Ratio	Temp. and Dew Point Ratio	Wind Speed Ratio	Snowpack	Comment
January	-----	-----	-----	-----	Eliminated by lack of historic floods, low temperatures, etc.
February	-----	-----	-----	-----	
1-Mar	-----	-----	-----	-----	
15-Mar	0.300	-----	1.450	-----	
1-Apr	0.450	0.39	1.350	-----	Eliminated by lack of historic floods, low antecedent reservoir levels, low PMP, and low temperatures.
15-Apr	0.600	0.55	1.250	-----	
1-May	0.715	0.69	1.155	100-year	Run only if May 15 appears be controlling
15-May	0.830	0.80	1.060	100-year	Case M1
1-Jun	0.885	0.90	0.965	100-year	Case M2
15-Jun	0.940	0.95	0.870	Reduced	Eliminated - snowpack reduced compared to June 1
1-Jul	0.970	1.00	0.895	Glacier only	Eliminated - no snowpack, less than All-Season PMP
15-Jul	1.000	1.00	0.920	Glacier only	Eliminated - August 15 is more critical due to wind speed
1-Aug	1.000	1.00	0.960	Glacier only	Eliminated - August 15 is more critical due to wind speed
15-Aug	1.000	1.00	1.000	Glacier only	Case M3
1-Sep	0.960	0.94	1.075	Glacier only	Case M4
15-Sep	0.920	0.86	1.150	Glacier only	Case M5
1-Oct	0.860	0.77	1.200	50% Avg. Sep Precip.	Case M6
15-Oct	0.800	0.64	1.250	Avg. Oct Precip.	Eliminated - lower temperatures and PMP than October 1
1-Nov	0.725	0.51	1.265	Avg. Oct Precip.	Eliminated - less critical than October 15.
15-Nov	0.650	-----	1.280	-----	Eliminated by low temperatures and low PMP.
December	-----	-----	-----	-----	Eliminated by lack of historic floods, low temperatures, etc.

Interpolated ▨

Table 9.1-3 provides the PMF inflow, outflow, and reservoir elevations for the seasonal model runs selected for analysis on Table 9.1-2. Results for the set of seasonal PMF cases indicates that Case M3, the August 15 PMF forms the maximum PMF reservoir water level condition, but Case M2, the June 1 PMF yields almost the same maximum reservoir level.

One additional run, the probable maximum snowpack with the 100-year rainfall is also included as Case M7. The 100-year rainfall was based on a PMP/100-year rainfall ratio of 1.74 that was estimated in the Applied Weather Associates PMP study (see Appendix A). The relatively low PMP/100-year rainfall ratio (a conservative value for estimating the 100-year rainfall) is associated with higher elevations where general storm, long duration precipitation is prevalent. The results show that Case M7 is not the controlling PMF condition.

Although references indicate that a perfect ogee-crested spillway coefficient could be slightly higher, the selected spillway coefficient value of 3.90 that was used in all cases is a more achievable actual construction value. The ogee-crest of the spillway was at El 2000 feet in all cases.

Table 9.1-3. PMF Routing Results at Watana Dam

Case Number	Starting Date (1)	Peak Inflow (cfs)	Peak Outflow (cfs)	Maximum Reservoir W.S. Elev. (feet)
M1	15-May	96,000	96,000	2058.2
M2	1-Jun	196,000	195,000	2059.3
M3	15-Aug	222,000	218,000	2059.6
M4	1-Sep	206,000	201,000	2059.4
M5	15-Sep	163,000	158,000	2058.9
M6	1-Oct	92,000	92,000	2058.2
M7	1-Jun (2)	136,000	134,000	2058.6

Notes
(1) See Table 9.1-2 for the elimation of some months.
(2) Probable maximum snowpack with 100-year rain.

9.2 Sensitivity Analysis

FERC PMF guidelines indicate that the first computed inflow PMF hydrograph should be considered as preliminary pending review of the assumptions considered to have a significant effect on the PMF and a determination of the sensitivity of individual parameters on the magnitude of the PMF. A sensitivity analysis is made to determine the degree the PMF is affected by key parameters even if conservative parameters for those parameters were assumed.

9.2.1 PMF Cases

Previous studies have indicated that the critical PMF inflow hydrograph occurs in the spring, in contrast to the results in Table 9.1-3 that show that the August 15 PMF results in the maximum reservoir water level. Therefore, the sensitivity analysis focuses primarily on the spring maximum June 1 PMF. Lowering the loss rates is a typical sensitivity case. Case S2 substitutes the summer loss rates into the spring runs and also lowers the initial loss to the corresponding hourly loss rate. Case S3 lowers the loss rate to a minimal 0.02 in/hr with zero initial losses. As shown on Table 9.2-1, both of these lowered loss rate cases resulted in maximum reservoir water levels higher than the August 15 PMF case.

Cases S4, S5, and S6 focus on the sensitivity of the June 1 PMF to adjustments in wind speed and temperature. Case S4 represents a relatively large 10 mph increase in all wind speeds. Case S5 represents a 3 degree F increase in all temperatures. Case S6 substitutes in the 1980s Harza-Ebasco PMF Study temperature and wind values while using all the other parameters from the current study. This case is particularly notable because it produces essentially the same peak PMF inflow as was determined in the Harza-Ebasco study.

Case S7 represents a less conservative case wherein the initial reservoir level would be 20 feet below the maximum normal pool level. Results of Case S7 are essentially unchanged from Case S1 because the volume of the inflow flood greatly exceeds the reservoir volume available for flood attenuation.

A sensitivity run was also performed for the August 15 PMP (Case M3 in Table 9.1-3). Case S8 for the August 15 PMP uses the same 0.02 in/hr with zero initial losses that was used in Case S3. Results for Case S8 show that it is a smaller flood than Case S3, which emphasizes the high sensitivity to the snowmelt loss rates that were applicable for the entire watershed with the 100-year snowpack in Case S3, but snowmelt loss rates were only a minor factor from the glaciers for the August 15 Case S8. The Sun-on-Snow PMF is covered in Section 9.2.3.

Table 9.2-1. 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

9.2.2 Spring Flood Loss Rate Reanalysis

The sensitivity runs indicated a high degree of sensitivity to loss rates, wind speeds and temperature. Wind speeds in particular have a relatively high degree of uncertainty associated with them. On many other PMF studies, the conservatism associated with the PMF is primarily embodied in the PMP (as much as 60 inches in 72 hours in some places in the USA), such that it overwhelms the sensitivity that may occur in all other parameters. Because the Susitna-Watana PMP is 10 inches over 216 hours, the sensitivity to other parameters particularly those associated with snowmelt can significantly affect the PMF results. Primarily due to both the sensitivity and uncertainty associated with input data affecting snowmelt runoff, it was considered appropriate to lower the previously calibrated loss rates to a minimal 0.02 inch per hour and add a measure of additional conservatism to the PMF analysis. Because adding excessive conservatism to parameters is unacceptable, this section focuses on a reanalysis of the spring calibration and verification floods to determine the acceptability of using the constant 0.02 inch/hour loss rate.

Results for the historic spring flood reanalysis are presented on Figures 9.2-1 through 9.2-12. On all of the figures, the USGS recorded daily flows are in blue, the initially simulated flows are in red, and the reanalysis flows are in green, with the basin average precipitation to the point of flow measurement in gray at the top of the plots. No adjustments were made to the originally estimated precipitation and temperature values for any sub-basin in any of the three historic flood periods. Some adjustments were made to the notably low originally estimated wind speeds for the June 1964 flood. Adjustments to initial snowpack were considered to be acceptable within a reasonable range considering the uncertainty associated with this parameter.

Although the results of the spring flood loss rate reanalysis generally indicate that the original calibration was of better quality, it does not provide any reason to consider the 0.02 inch per hour loss rate to be excessively conservative. Therefore, the 0.02 inch/hour loss rate was accepted for use with the PMF.

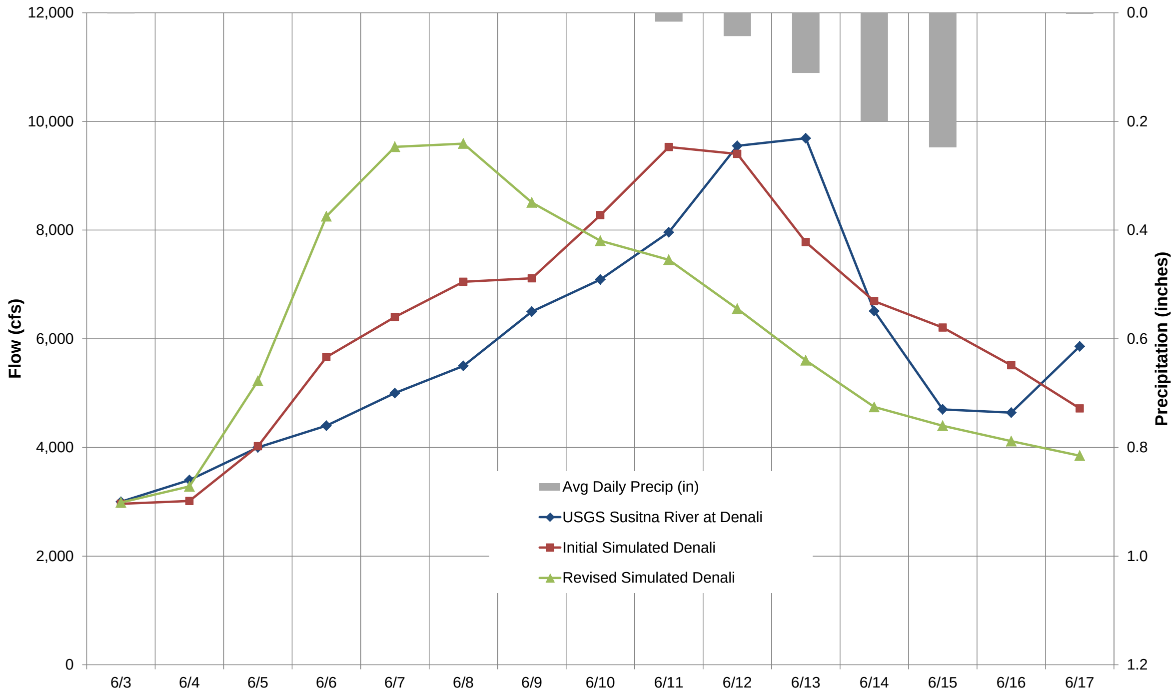


Figure 9.2-1. June 1971 Reanalysis, Susitna River near Denali

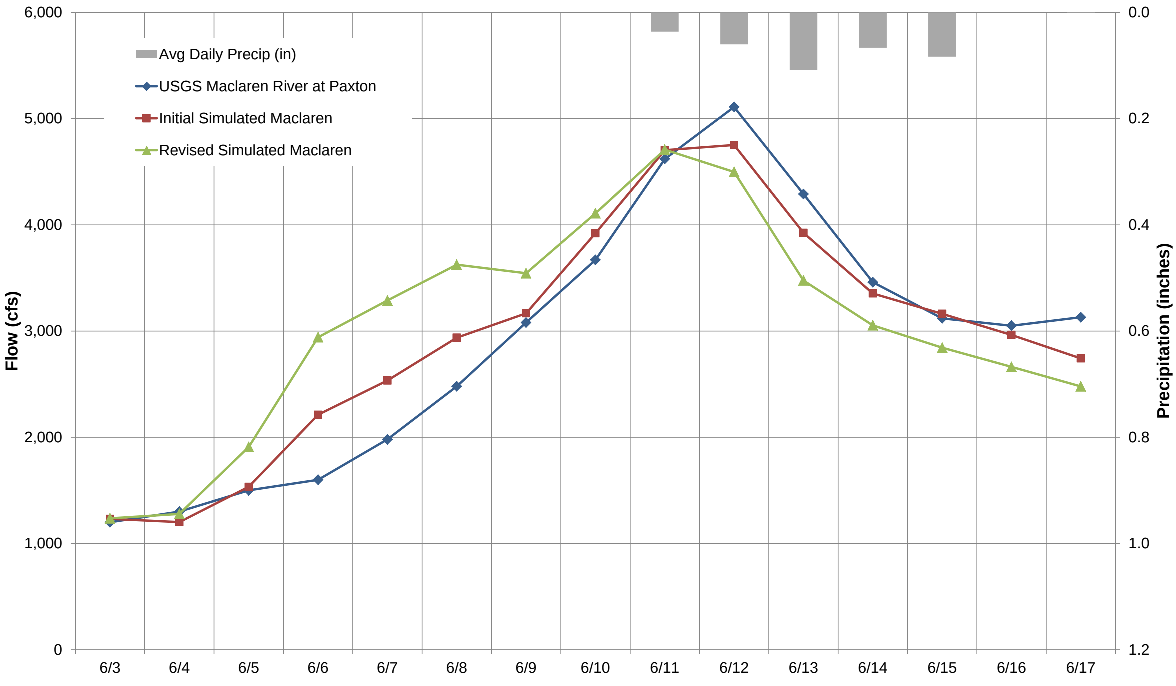


Figure 9.2-2. June 1971 Reanalysis, Maclaren River near Paxson

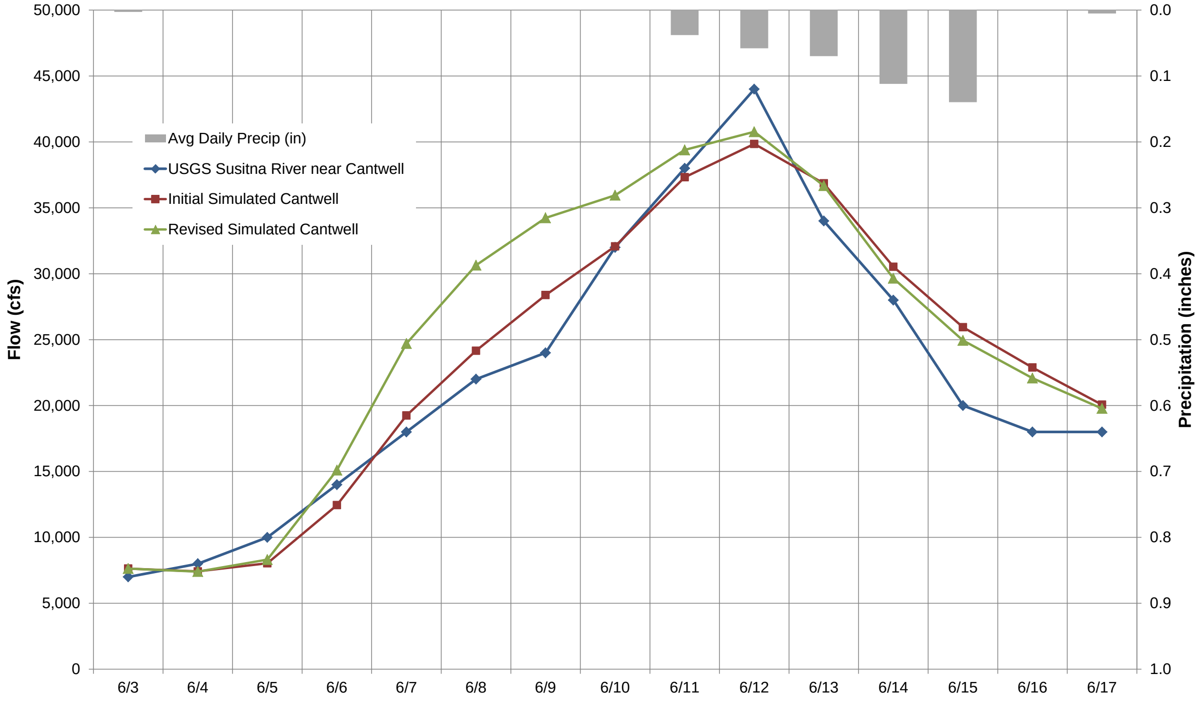


Figure 9.2-3. June 1971 Reanalysis, Susitna River near Cantwell

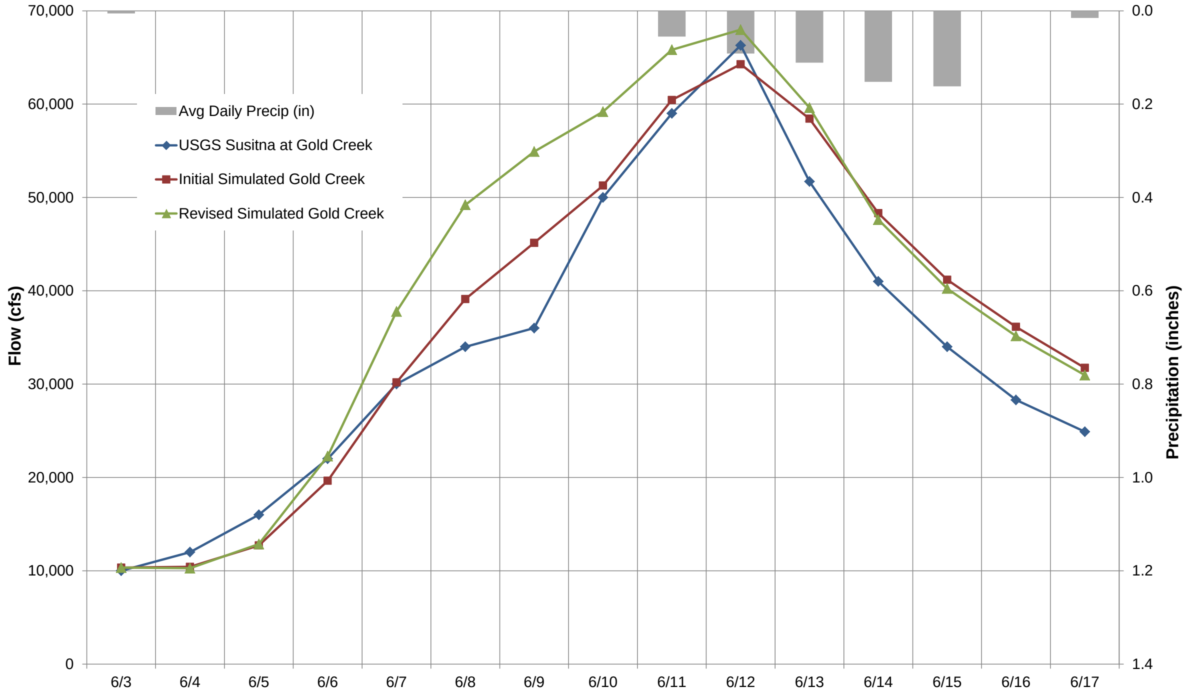


Figure 9.2-4. June 1971 Reanalysis, Susitna River at Gold Creek

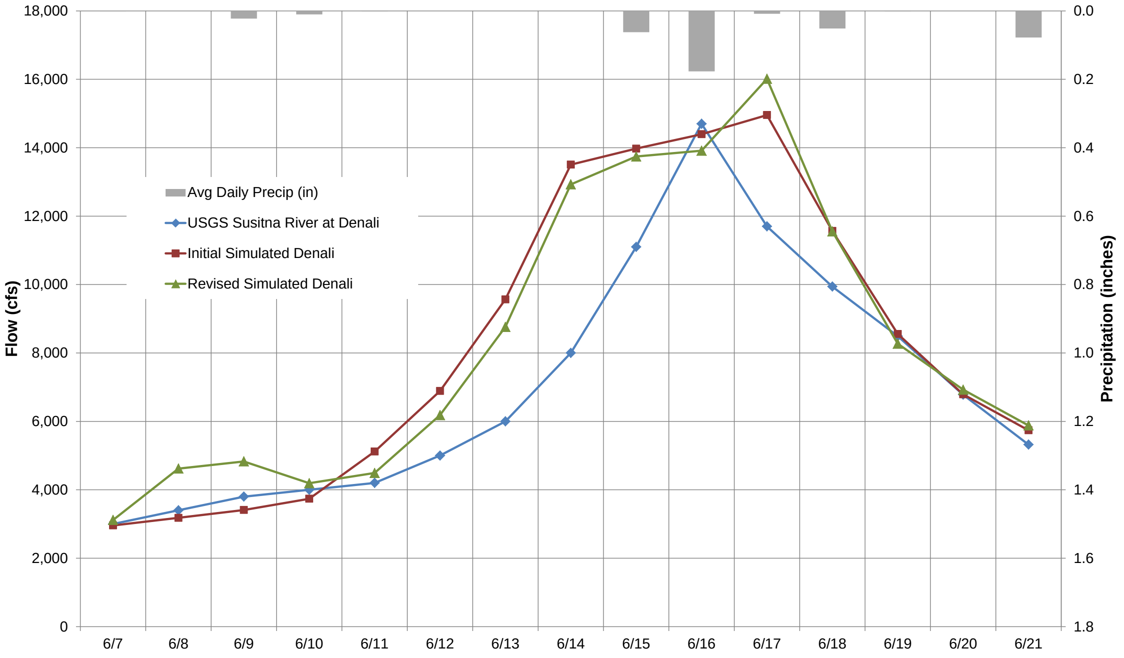


Figure 9.2-5. June 1972 Reanalysis, Susitna River near Denali

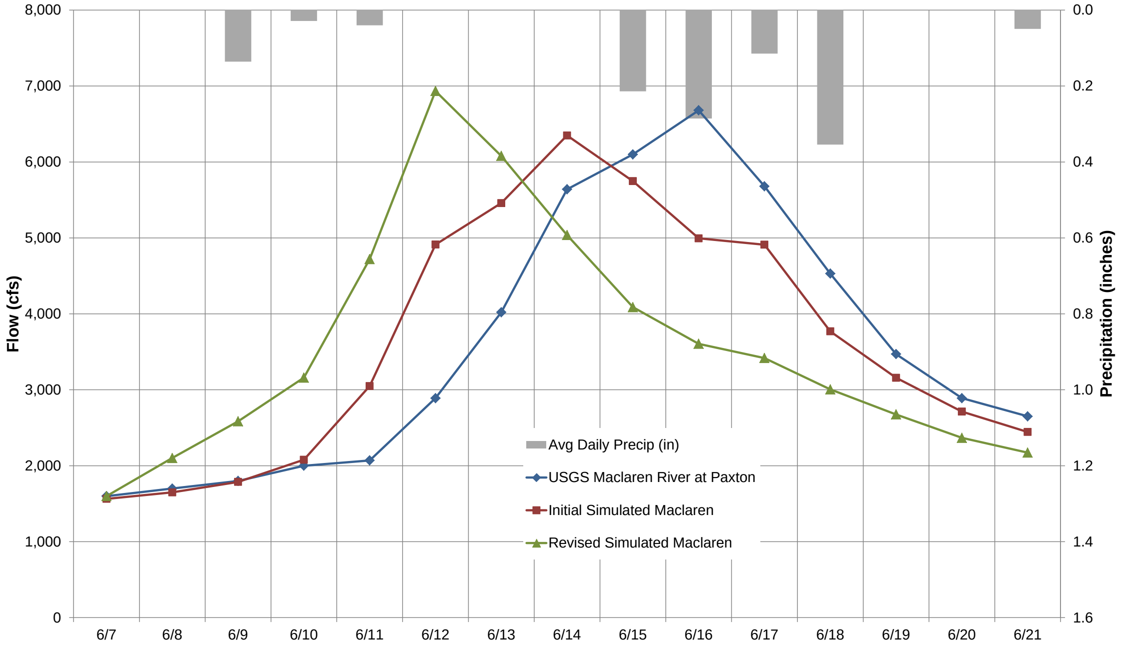


Figure 9.2-6. June 1972 Reanalysis, Maclaren River near Paxson

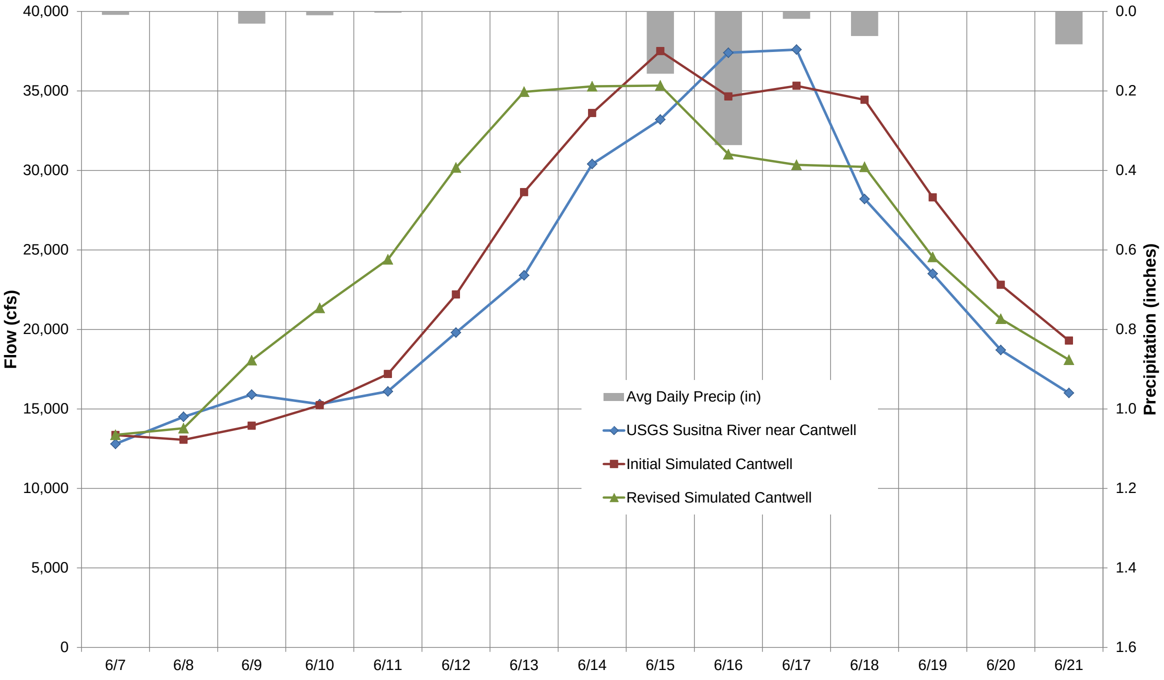


Figure 9.2-7. June 1972 Reanalysis, Susitna River near Cantwell

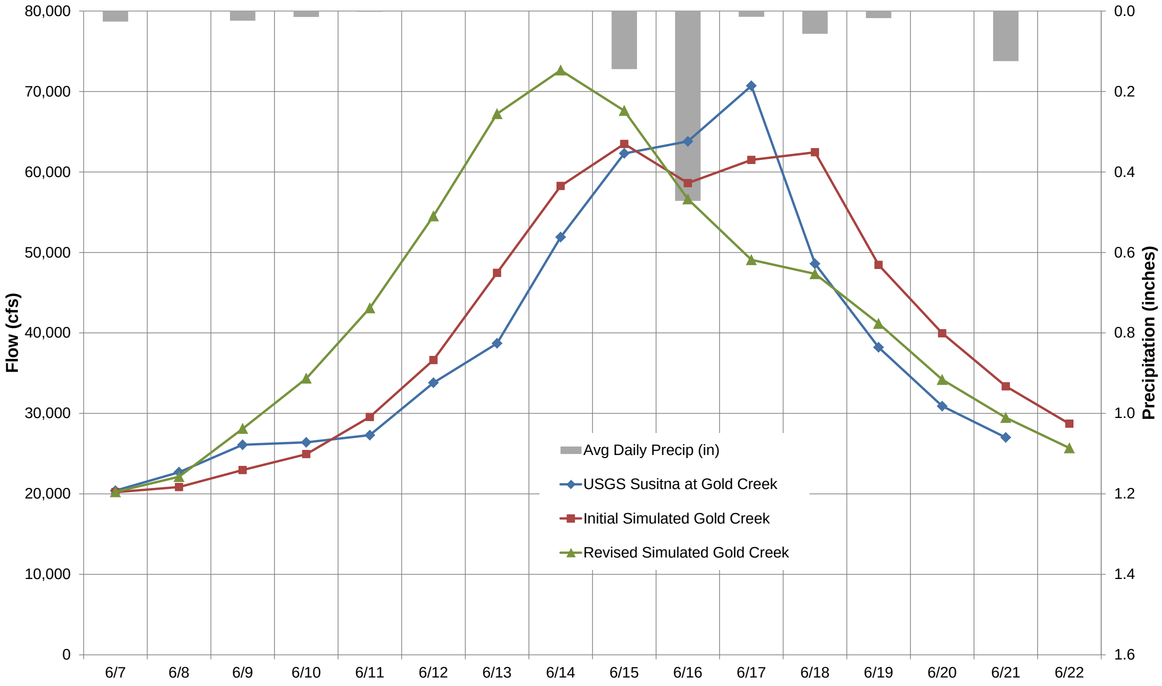


Figure 9.2-8. June 1972 Reanalysis, Susitna River at Gold Creek

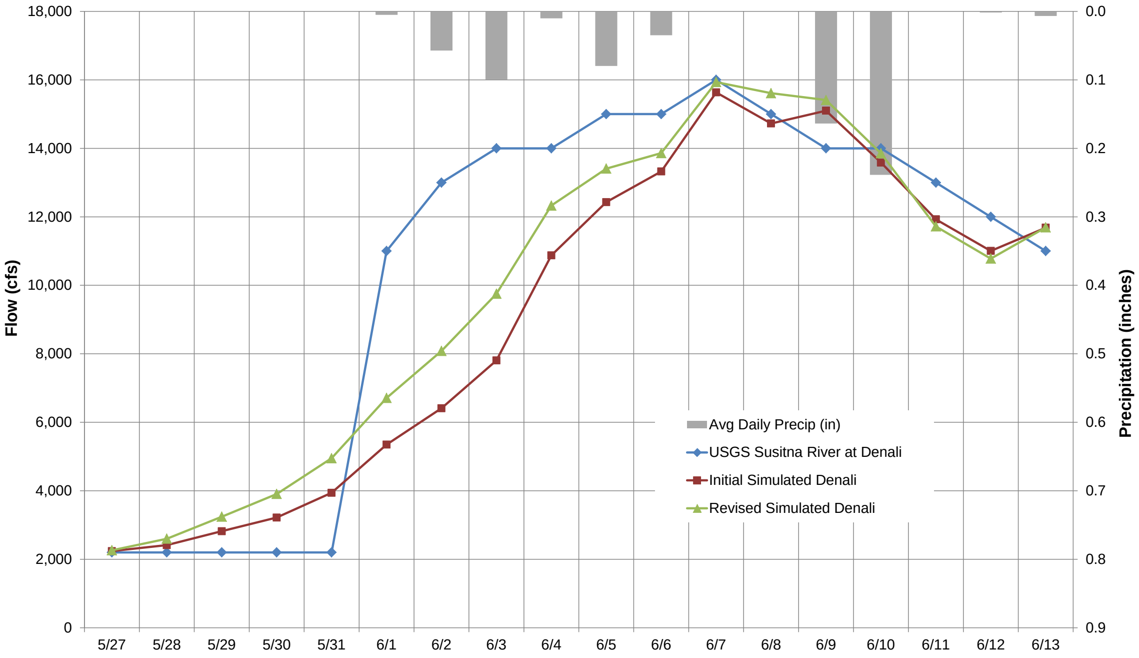


Figure 9.2-9. June 1964 Reanalysis, Susitna River near Denali

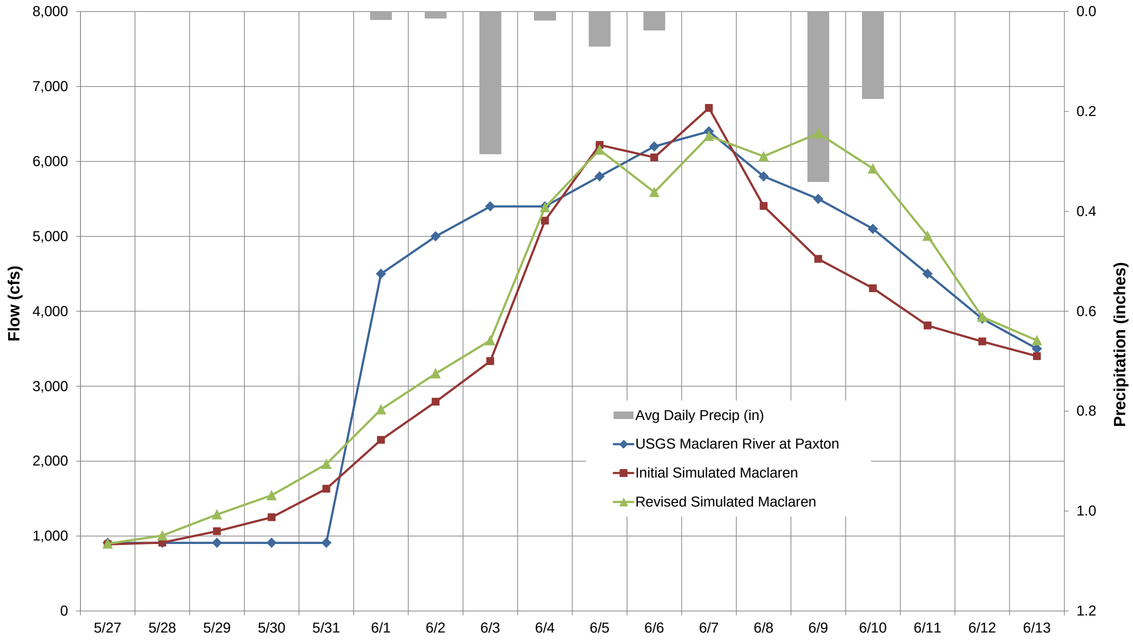


Figure 9.2-10. June 1964 Reanalysis, Maclaren River near Paxton

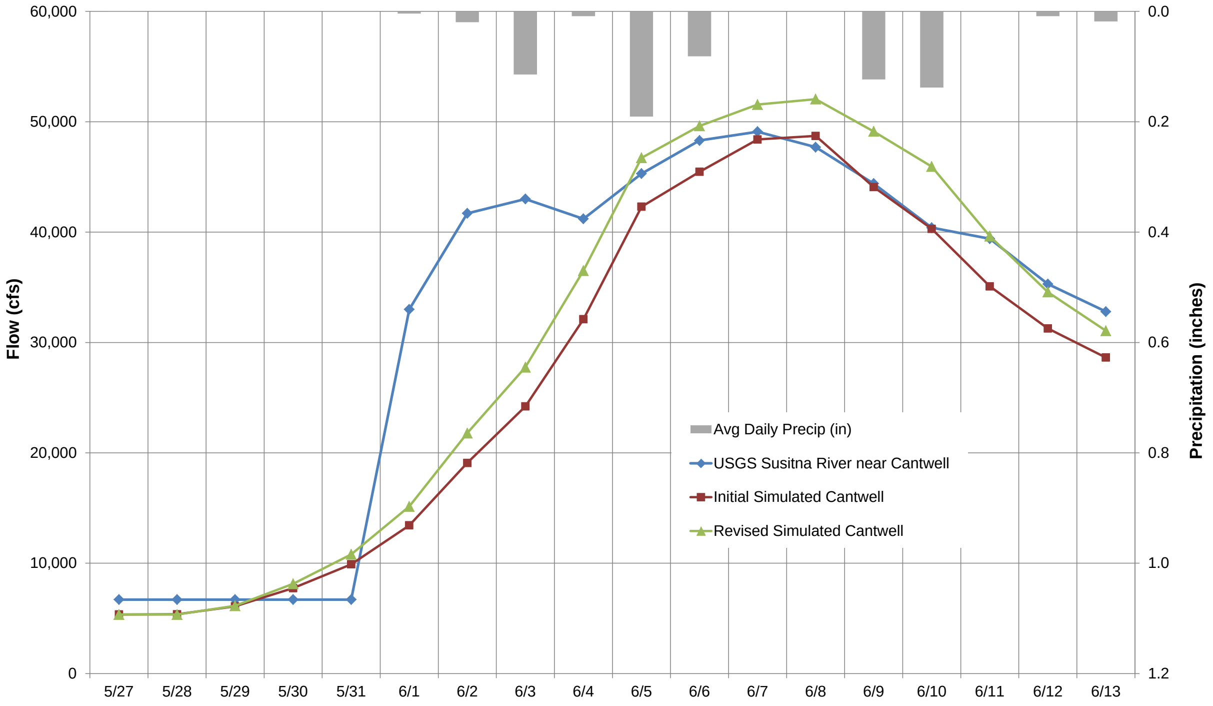


Figure 9.2-11. June 1964 Reanalysis, Susitna River near Cantwell

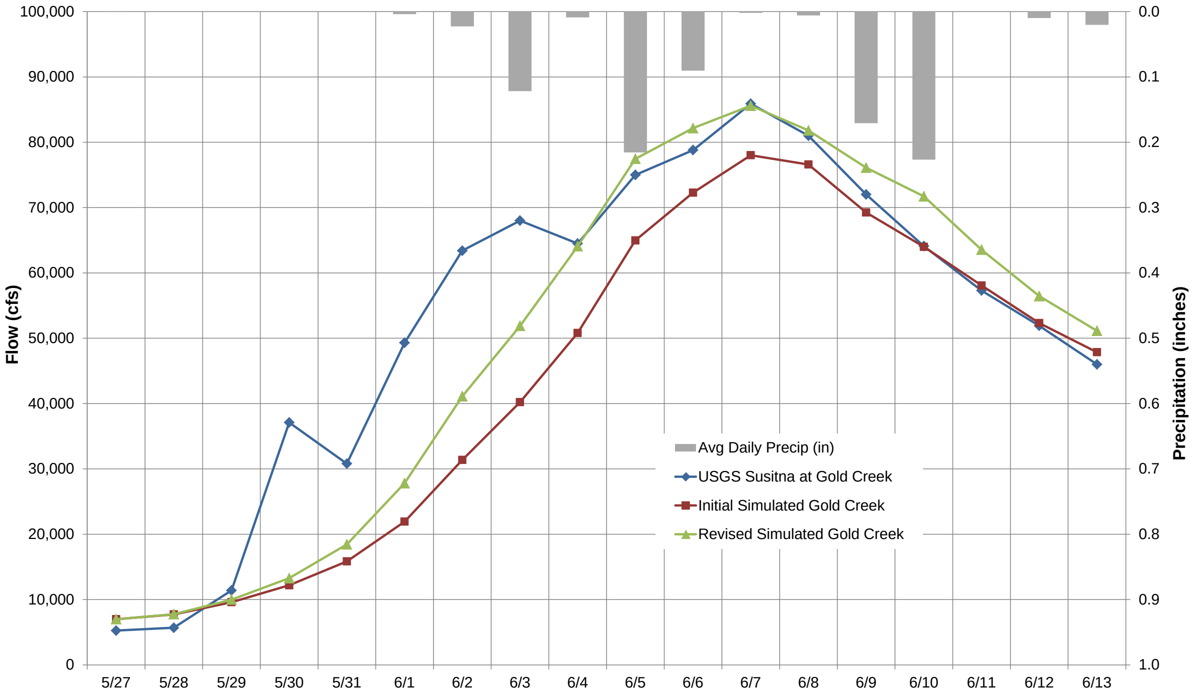


Figure 9.2-12. June 1964 Reanalysis, Susitna River at Gold Creek

9.2.3 Sun-on-Snow PMF

Section 3.2.5 presented recorded flow, precipitation, and temperature data for the near record Susitna River flood that peaked at Gold Creek on June 2, 2013. This flood provided actual data that confirmed the hypothesis that a colder than normal spring followed by a later than normal rapid warmup to near record temperatures around the first of June presented at least some of the conditions that could result in maximum flood generation on the Susitna River.

At the Fourth Meeting of the Independent Board of Consultants (BOC) held April 2-4, 2014, written recommendations from the BOC included the following:

> "The near-record flood of June 2013 raises the possibility of a "sun-on-snow" PMF. In light of the fact that the PMP rainfall is relatively small and is associated with temperatures substantially lower than the temperatures that may occur in late spring/early summer with no cloud cover, the BOC suggests investigating the snowmelt-only event in at least enough depth to confirm it cannot control the PMF. This investigation would involve two elements:
>
> - Apply the HEC-1 model to the June 2013 event to confirm that it can replicate this type of flood;
> - Consider whether a probable maximum snowpack combined with unusually high temperatures, with no rain, could produce a controlling PMF."

The results from the above BOC recommendation are presented in this section, which also included a change in snowmelt methodology for modeling the sun-on-snow floods.

9.2.3.1 Snowmelt Methodology for Sun-on-Snow Conditions

Two snowmelt methodologies are available in the HEC-1 Flood Hydrograph Package, which are (1) the energy budget method, and (2) the degree-day method. In the FERC Engineering Guidelines, Chapter VIII, "Determination of the Probable Maximum Flood", the following excerpt is taken from page 67 (where PMS refers to the probable maximum storm, also known as the PMP):

> "Snowmelt during the PMF should be computed using the energy-budget method available in the HEC-1 Flood Hydrograph Package. The energy-budget method is preferable to the degree-day (temperature index) method because the degree-day method was developed specifically for rain-free periods. The energy budget method, on the other hand, was developed for either rain-on-snow or rain-free periods. In the case of a PMS, the heat added to the snow pack by the rain is an important (and sometimes even dominant) melt factor."

The energy budget snowmelt method has been used in all other flood simulations presented herein. Because the BOC requested new PMF case is for a rain-free PMF, for which degree-day method was developed, it should be considered as an acceptable method for this case. Because the degree-day snowmelt method requires only temperature and snowpack as input data, it is much easier to apply than the energy budget method that also requires the more difficult to estimate wind speed and dew point data as input. If the degree-day method results clearly indicate that a rain-free PMF could not be the controlling case, it should provide sufficient documentation to eliminate the rain-free PMF as the controlling PMF case.

9.2.3.2 May-June 2013 Simulation

Recorded temperature and precipitation at the Talkeetna Airport (elevation 350 feet) provided the basic meteorological data needed for the May-June 2013 flood simulation. Recorded Talkeetna precipitation was adjusted to the sub-basins based on the ratio of average May precipitation in each sub-basin to the average Talkeetna precipitation for the same period. Hourly temperatures at Talkeetna were estimated from the maximum and minimum daily values and adjusted to the sub-basin snowpack based on a 2.6 degree per 1,000-ft lapse rate. The initial snowpack snow water equivalent in all sub-basins was estimated to be equal to the average total precipitation for the October through April period. The loss rate was 0.02 inches per hour in all sub-basins and all unit hydrograph parameters remained the same as developed in the calibration and verification process. The HEC-1 model was operated on an hourly time increment.

Recorded and simulated daily average flow data for the three USGS gaging stations that were operating during 2013 are presented on Figures 9.2-13 through 9.2-15. The daily precipitation on the plots represents average precipitation for the area tributary to the USGS gages. No adjustments were made to any recorded data. A small adjustment was made to the estimated snowpack above Denali to make it be slightly above average.

The general agreement between the simulated and recorded flows at all three USGS gages is very good and acceptable. The initial rise in simulated flows, peaking in the May 12-14 period, occurred during a period when the remaining winter ice cover prevented direct flow measurements at the USGS gages. The contribution of rainfall to the peak flow was negligible as the non-snow precipitation occurred on the same day of or after the peak flow. The results of the May-June 2013 simulation confirm that the degree-day snowmelt method is acceptable for rain-free flood simulation on the Susitna River and increases confidence in the validity of the results for the hypothetical sun-on-snow PMF simulations.

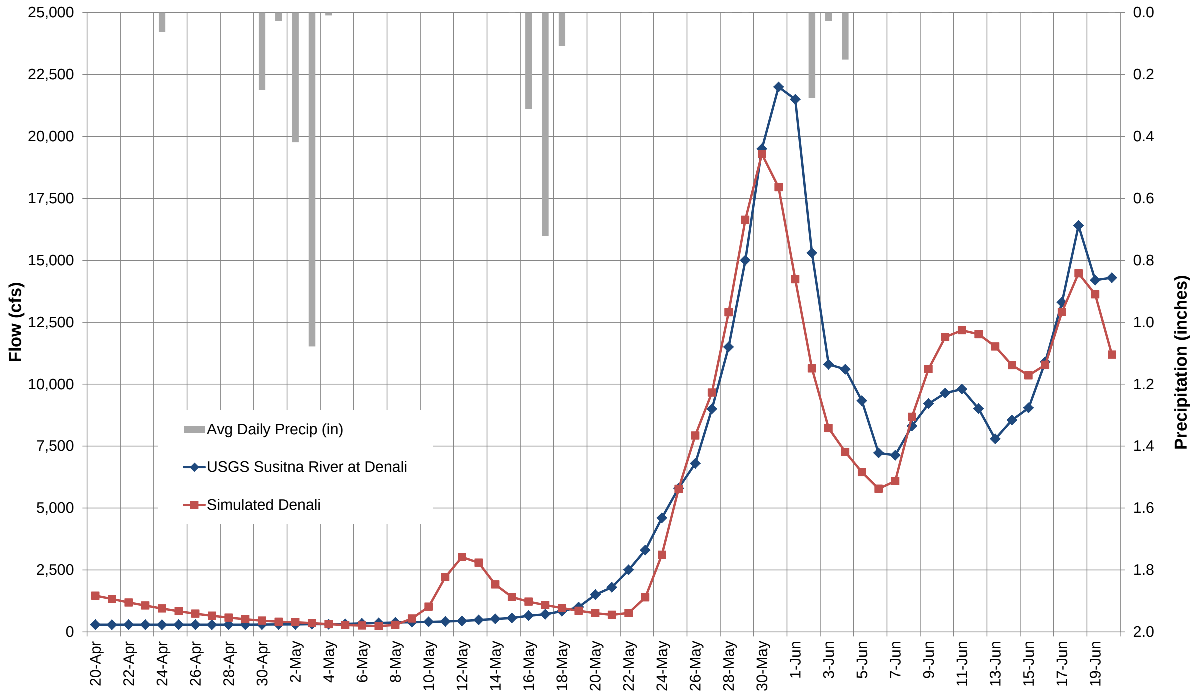


Figure 9.2-13. May-June 2013 Simulation, Susitna River near Denali

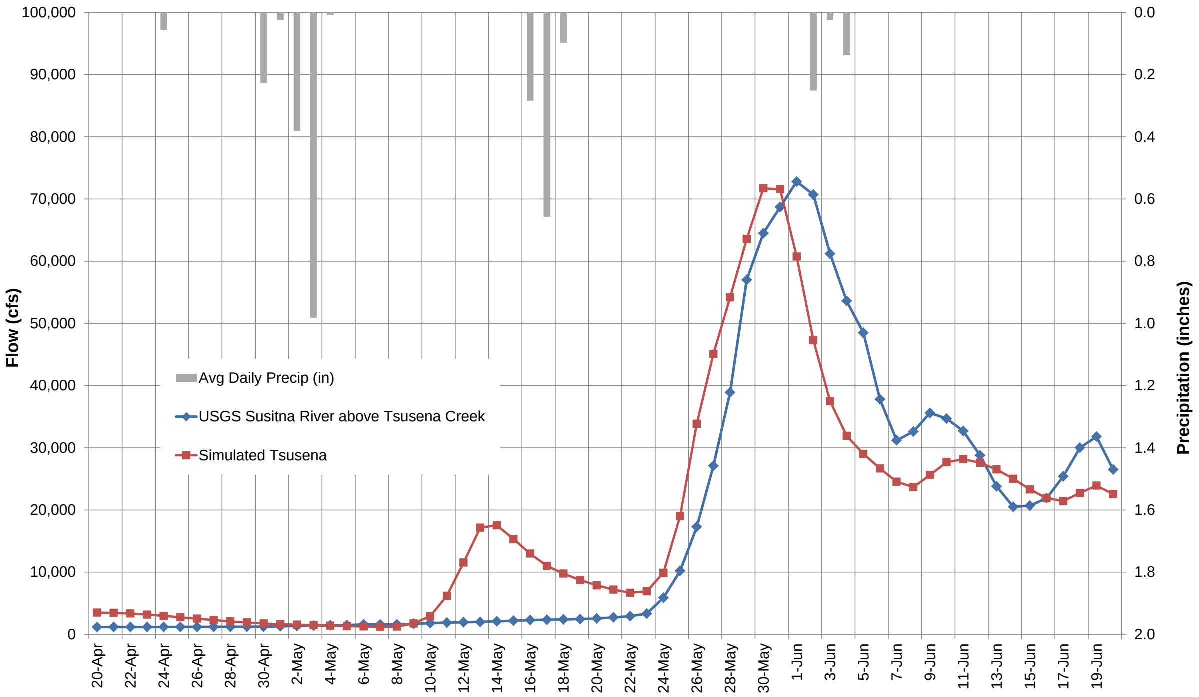


Figure 9.2-14. May-June 2013 Simulation, Susitna River above Tsusena Creek

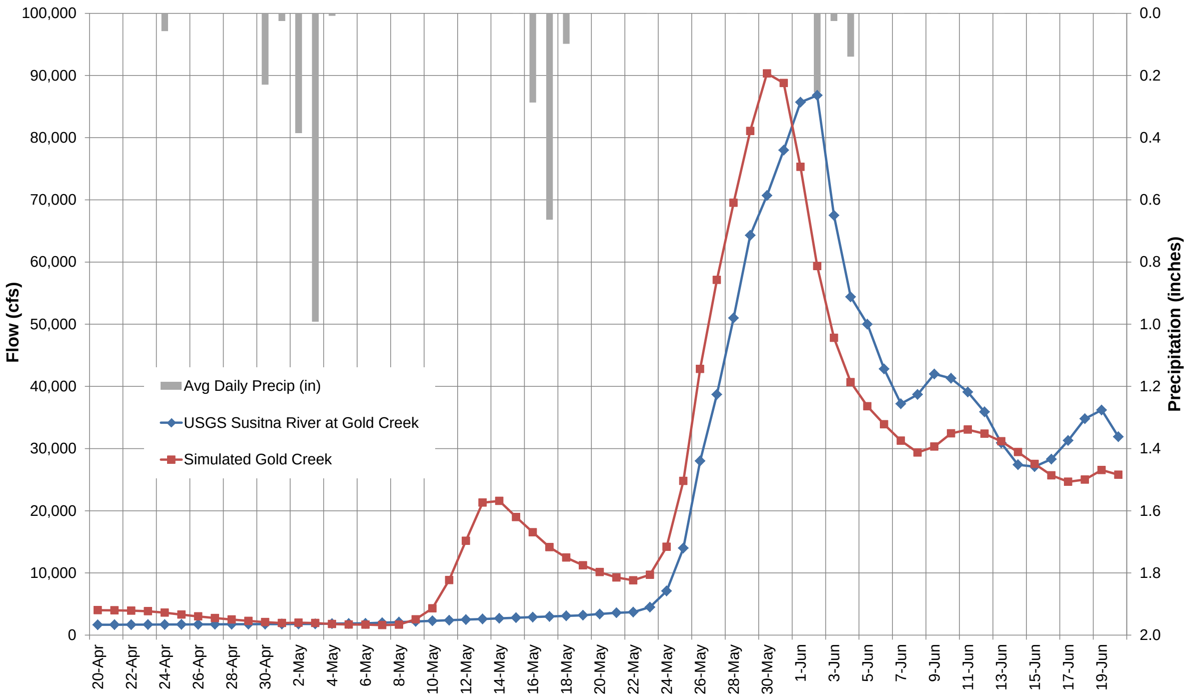


Figure 9.2-15. May-June 2013 Simulation, Susitna River at Gold Creek

9.2.3.3 Sun-on-Snow PMF Evaluation

The sun-on-snow PMF was developed from a combination of the probable maximum snowpack and maximum historic temperatures beginning on June 1. To develop the maximum temperatures, sunny weather was assumed without any precipitation. With over 90 years of maximum and minimum daily temperature records, Talkeetna provides the longest weather record within the Susitna River watershed. The maximum temperature of the day in the PMF simulation was assumed to be the maximum recorded temperature for the day from the entire period of record. The nighttime low temperatures were based on the daily diurnal temperature change normals at Talkeetna, which ranged from about 19 to 22 degrees F for the corresponding days. The calculated lows should be conservatively high because clear weather should result in above average temperature ranges. The hourly variation in temperature was then interpolated from the daily maximum and minimum temperatures.

This method should give roughly the 100-year maximum temperatures for any given single day and probably even more rare average daily temperatures. Having a sequence of these maximum temperatures for 22 consecutive days would represent a heat wave far more rare than a 100-year event. Because the PMF combined events criteria include a probable maximum event combined with a 100-year event (the PMP and the 100-year snowpack; or the probable maximum snowpack and the 100-year rainfall), combining the probable maximum snowpack with a temperature sequence far more rare than the 100-year event is very conservative. A more detailed meteorological evaluation would probably result in a lower temperature sequence. Loss rates were 0.02 in/hr for all sub-basins.

Watana Dam site inflows and temperatures at Talkeetna are plotted on Figure 9.2-16. Temperatures were adjusted to other elevations in the watershed using a lapse rate of 2.6 degrees per 1,000 feet of elevation. The resulting peak inflow at the Watana Dam site was 255,000 cfs, and the peak water surface elevation was at El 2060.1, which indicates that the sun-on-snow PMF would not result in the controlling PMF inflow for Watana. The 22-day volume of snowmelt was equivalent to 114% of the average annual runoff at the Watana Dam site, or an average of 24 inches of snowmelt runoff over the entire watershed tributary to Watana. The controlling PMF has a higher peak inflow and resulting peak water surface elevation, as described in the following section.

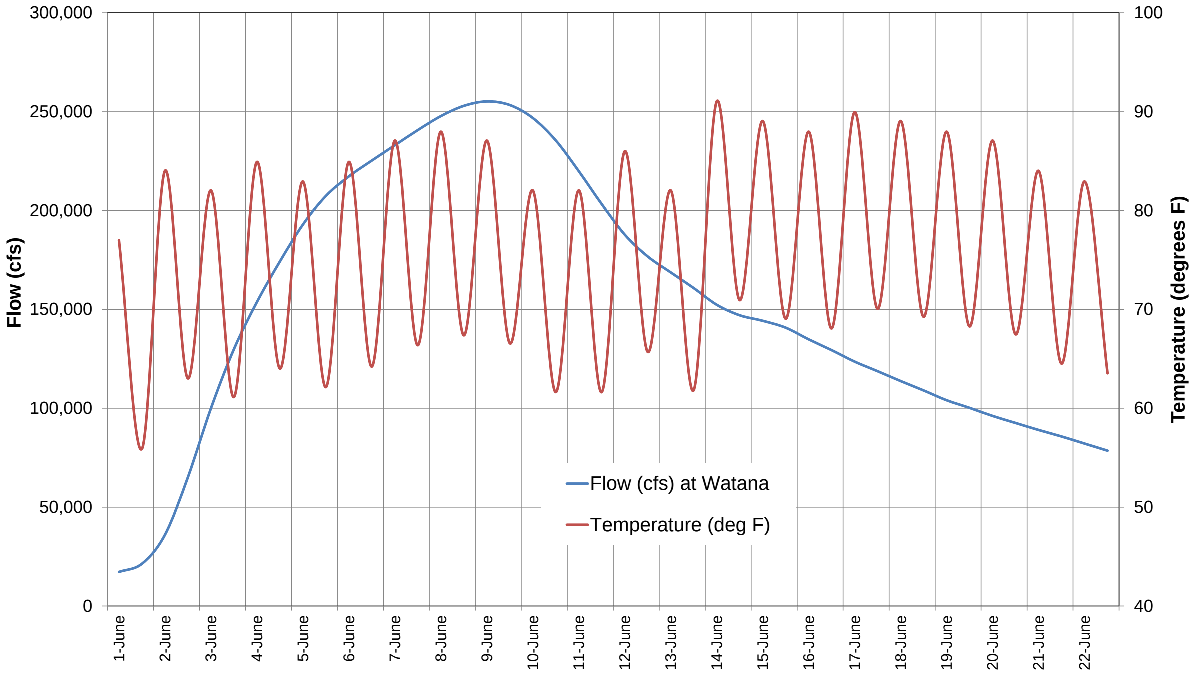


Figure 9.2-16. Sun-on-Snow PMF and Air Temperatures

Although the previously described combined events of snowpack and temperature represent a case with at least the rarity necessary for a PMF scenario, additional HEC-1 runs were made to define a temperature sequence necessary to develop a peak reservoir water level equal to the controlling PMF case. It was found that all temperatures in the previously described scenario would have to be increased by about 7 degrees F, resulting in a peak inflow of 297,000 cfs and a peak reservoir level at El 2064.8. This type of temperature sequence that is totally unprecedented in both duration and magnitude, and must also be coincident with a probable maximum snowpack that should exert a cooling influence on temperatures, is considered to represent excessive conservatism and is eliminated as a potentially controlling PMF case.

9.3 Selected PMF and Spillway Sizing

With consideration given to all PMF case runs and to the notably high sensitivity to loss rates, wind speed and temperature input data, Case S3 was determined to be the critical PMF case and was selected for spillway sizing. Based on a recommendation from the FERC Independent Board of Consultants, the spillway crest level used in the PMF case runs was raised by 10 feet from El 2000 to El 2010. The spillway width was sized with the Case S3 critical PMF to provide essentially the same spillway capacity as was used in all of the PMF case runs.

The peak PMF inflow was estimated to be 310,000 cfs, the peak reservoir outflow was 282,000 cfs, and the maximum reservoir water surface elevation was at El 2064.5. The PMF inflow hydrograph, outflow hydrograph, and reservoir level for the spillway with crest at El 2010 are plotted on Figure 9.3-1. The 13-day volume of the PMF inflow hydrograph was 3,980,000 acre-feet, which compares to a total reservoir storage volume from El 2050.0 to El 2064.5 (14.5-foot rise) of about 345,000 acre-feet. This means that attenuation of the PMF inflow hydrograph will not be great. For additional comparison, the reservoir active storage between El 1850 and El 2050 would be about 3,380,000 acre-feet. With a spillway crest at El 2010, a total spillway width of 168 feet (4 gates each at 42 feet wide) is necessary to pass the PMF with a reservoir level below the selected maximum level at El 2065. The 168-ft total spillway width is preliminary and subject to change as a result of further design refinements.

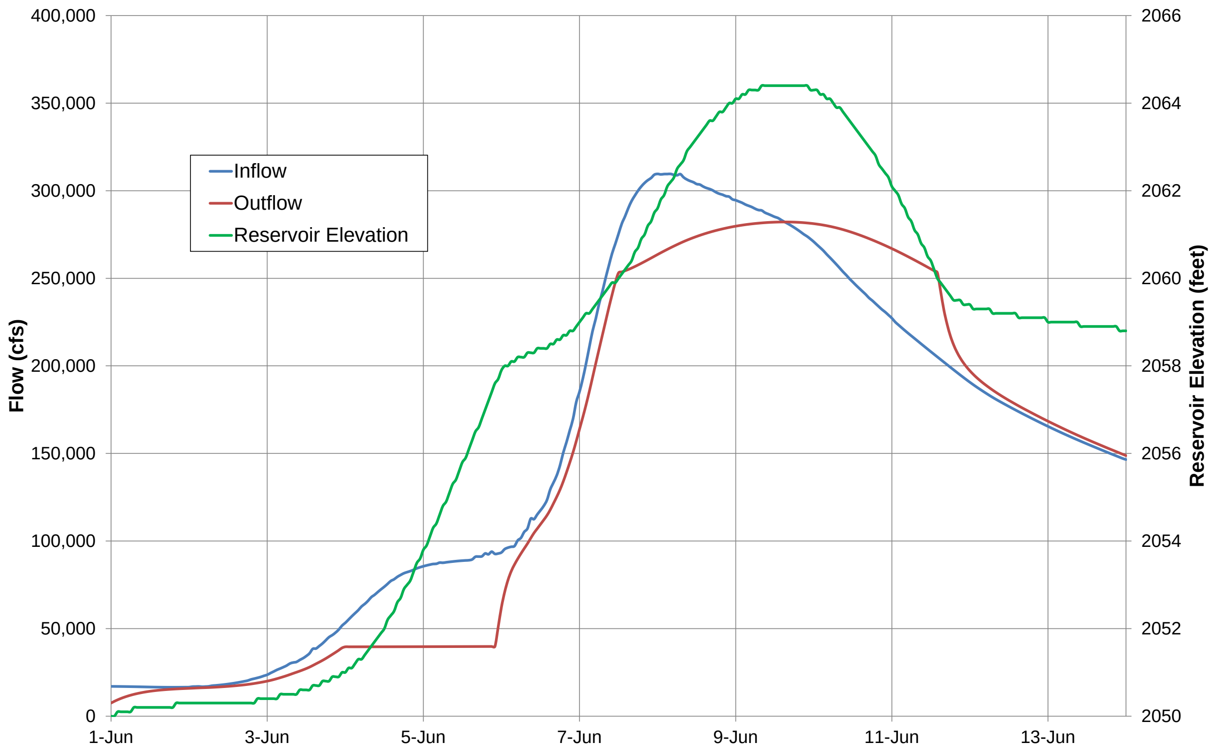


Figure 9.3-1. Watana Dam PMF Inflow, Outflow, and Reservoir Elevation

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 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.

9.4 Comparison with Previous PMF Studies

9.4.1 Snowpack

A comparison of the current study snowpack results to those obtained during the 1980s Susitna PMF studies performed by both Acres and Harza-Ebasco is instructive. Table 9.4-1 shows that the 1982 Acres June PMF had a 51 inch SWE in the area tributary to Watana Dam site, and a 49 inch SWE even after eliminating the glacier areas that were assigned an essentially unlimited 99 inch SWE. The Harza-Ebasco May (maximum) snowpack shown on Table 9.4-2 has an average SWE of 16.8 inches, which is comparable to the 15.7 inch May-June 100-year snowpack developed for the current study. The 1982 Acres PMF snowpack SWE appears to be the result of excessive conservatism as it is about 75 percent greater than the Probable Maximum Snowpack as determined in the current study and 5.5 times the average October through April precipitation.

Table 9.4-1. 1982 Acres PMF Snowpack Snow Water Equivalent Estimate

Acres Sub-Basin Number	Sub-Basin Name	Local Area (sq.mi.)	Average SWE (inches)
10	Susitna R. near Denali - Glacial	221	99
20	Susitna R. near Denali - Non-Glacial	694	81
80	Susitna R. local drainage area above Denali	312	35
210	Maclaren near Paxson - Glacial	44	99
220	Maclaren near Paxson - Non-Glacial	232	62
280	Maclaren R. local above Susitna R. confluence	307	30
180	Susitna R. local above Maclaren confluence	477	32
330	Lake Louise and Susitna Lake	48	30
340	Tyone R. basin	1,047	27
380	Oshetna R. and Goose Creek	735	59
480	Watana and Deadman Creek local	1,045	57
To Watana Dam Site		5,162	51
To Watana Dam Site Without Glacier Areas		4,897	49

Table 9.4-2. 1984 Harza-Ebasco May PMF Estimate

Harza-Ebasco Sub-basin Number	Drainage Area (sq.mi.)	Sub-Basin Vicinity	Wtd. Avg. SWE (inches)
2	460	Watana Creek	15.8
3	580	Kosina Creek	17.1
4	725	Black River	18.1
5	1,060	Tyone River	14.6
6	790	Coal Creek	15.7
7	188	W. Fork Susitna to Denali	17.0
8	762	Susitna R. above Denali	19.7
9	335	Maclaren R. below USGS gage	14.9
10	280	Maclaren R. above USGS gage	19.6
Total	5,180	Weighted Average	16.8

9.4.2 Probable Maximum Precipitation

A comparison of the PMP totals for the watershed tributary to the Watana Dam site from among the three available PMP studies is summarized in Table 9.4-3. It is noted that although the Acres 1982 study showed the highest all-season (August) PMP, an August PMF was not developed in that study. The PMP values shown in Table 9.4-3 are similar among the three studies, with the current study PMP values being slightly higher.

Table 9.4-3. PMP Study Comparison

PMP Duration	All-Season PMP (inches)			June PMP (inches)		
	Acres 1982	H-E 1984	AWA 2014	Acres 1982	H-E 1984	AWA 2014
24 hours	3.07	4.10	4.40	2.15	3.80	4.14
72 hours	6.59	6.80	7.19	4.61	6.30	6.76
PMP total (days)	12.5 (10 days)	N/A	10.00 (9 days)	8.7 (10 days)	N/A	9.4 (9 days)

The available National Weather Service (formerly the U.S. Weather Bureau) PMP guidance document Technical Paper No. 47 (Weather Bureau 1963) indicates 24-hour point PMP values for the Watana Dam watershed ranging from slightly less than 10 inches to about 18 inches. These Technical Paper 47 PMP values are now considered to be superseded.

9.4.3 Temperature and Wind

Temperature and wind speed input data is used to determine snowmelt in the energy budget method. Daily average temperature and wind speed is available for the Harza-Ebasco 1984 PMF study. Figure 9.4-1 is a plot of average daily temperature at the 2500-ft level for a 9 day (216 hour) period used for the PMP in the current study. Figure 9.4-2 provides a plot of average daily wind speeds at the 4000-ft level for the same 9 day period. The Harza-Ebasco study used a 72-hour PMP that would occur on days 3, 4, and 5 on the two plots, corresponding to the periods of highest wind speeds and lowest temperatures. The plots highlight generally higher temperatures and higher wind speeds coincident with the PMP in the Harza-Ebasco study in comparison with those used in the current study.

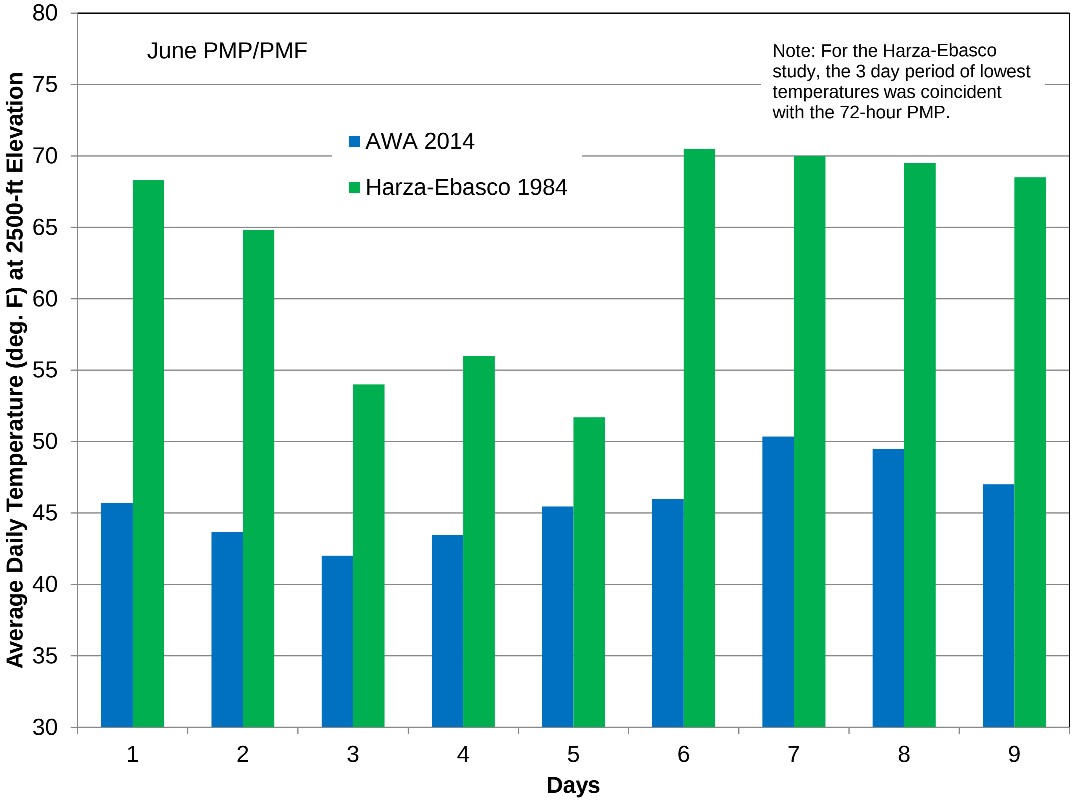


Figure 9.4-1. Temperature Comparison – June PMF

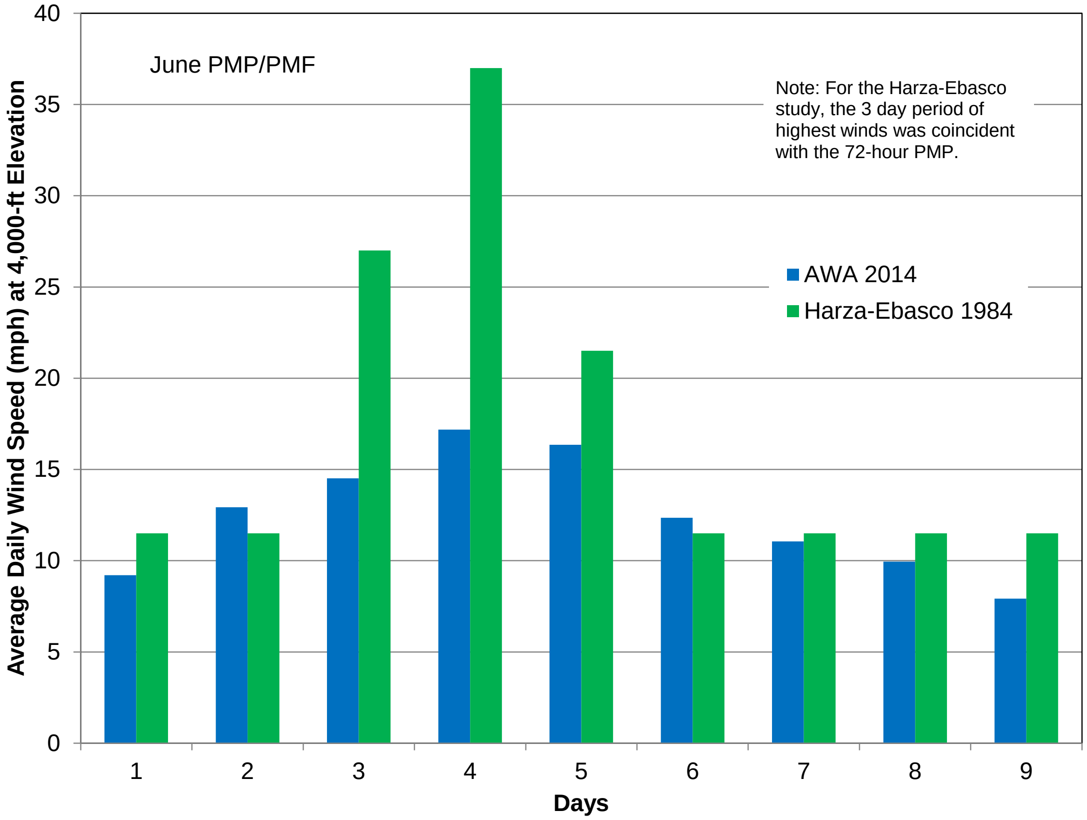


Figure 9.4-2. Wind Speed Comparison – June PMF

9.4.4 Probable Maximum Flood

A comparison of PMF peak inflow and outflow rates from among the three available PMF studies are shown in Table 9.4-4. This basic comparison shows little variation among the three studies regarding peak inflow. The relatively high inflow volume estimated in the 1982 Acres PMF results primarily from the high estimated watershed snow water equivalent antecedent to the PMF as noted in Section 9.4.1, which has since been determined to be unrealistic.

Table 9.4-4. PMF Inflow and Outflow Comparison

Parameter	1982 Acres PMF	1984 Harza-Ebasco PMF	2014 MWH PMF
PMF peak inflow (cfs)	326,000	309,000	310,000
PMF peak outflow (cfs)	302,400	N/A	282,000
13-Day Maximum Inflow Volume (acre-feet)	6,480,000	3,980,000	3,980,000
Fixed-cone valves total capacity (cfs)	24,000	N/A	32,000
Spillway capacity at PMF surcharge (cfs)	278,400	N/A	250,000

Table 9.4-5 provides a dam and reservoir elevation comparison with the 1985 Stage I and Stage III Watana Dams and with the current design for Watana Dam. Although the maximum normal pool level is different for all three cases, the comparisons of primary note are the total flood storage and the normal and minimum freeboard values. Freeboard values are preliminary for the current Watana Dam feasibility design. Total flood control storage is similar for all three dams, which reflects the similarity of the inflow PMF and total outflow capacities. The normal and freeboard values are greater for the 1985 Stage I and Stage III Watana Dam because the dam-type was rockfill. The current design calls for a roller-compacted concrete dam that requires less minimum freeboard.

Table 9.4-5. Dam and Reservoir Elevation Comparison

Parameter	1985 (1) Watana Stage I	1985 (1) Watana Stage III	2014 Watana AEA
Maximum normal pool elevation (feet)	2000.0	2185.0	2050.0
50-year flood peak reservoir elevation (feet)	2011.0	2191.5	2057.6
Elevation that spillway begins to operate (feet)	2014.0	2193.0	2057.6
PMF peak reservoir elevation (feet)	2017.1	2199.3	2064.5
Total flood control storage (feet)	17.1	14.3	14.5
Normal freeboard (feet)	25.0	25.0	> 15
Minimum freeboard for PMF (feet)	7.9	10.7	> 3.5

Note: (1) Data from 1985 FERC License Application

10. REFERENCES

Acres American Inc., 1982. *Feasibility Report, Susitna Hydroelectric Project*, Volume 4, Appendix A, Hydrological Studies, Final Draft.

American Society of Civil Engineers, 1997. *Flood-Runoff Analysis*, Technical Engineering and Design Guides as Adapted from the U.S. Army Corps of Engineers, No. 19.

Committee on Safety Criteria for Dams, 1985. *Safety of Dams, Flood and Earthquake Criteria*, Water Science and Technology Board, Commission on Engineering and Technical Systems, National Research Council, published by National Academy Press.

Federal Energy Regulatory Commission, October 1993. *Engineering Guidelines for the Evaluation of Hydroelectric Projects*, Chapter II, "Selecting and Accommodating Inflow Design Floods for Dams".

Federal Energy Regulatory Commission, September 2001. *Engineering Guidelines for the Evaluation of Hydroelectric Projects*, Chapter VIII, "Determination of the Probable Maximum Flood".

Fountain, A. G., and W. V. Tangborn, 1985. "The Effect of Glaciers on Streamflow Variations", *Water Resources Research*, 21(4), 579-586.

Harza-Ebasco Susitna Joint Venture, January 1984. *Probable Maximum Flood for Watana and Devil Canyon Sites*, Susitna Hydroelectric Project, Draft Report, Document No. 457.

Jorgenson, T., and others, 2008, *Permafrost Characteristics of Alaska*, Institute of Northern Engineering, University of Alaska, Fairbanks.

National Weather Service and University of Alaska Fairbanks, 2012. *Precipitation Frequency Atlas of the United States*, NOAA Atlas 14, Volume 7 Version 2.0: Alaska, U.S. Department of Commerce, NOAA.

Soil Conservation Service, February 1979. *Exploratory Soil Survey of Alaska*, United States Department of Agriculture.

U.S. Army Corps of Engineers, Hydrologic Engineering Center, 1998. *HEC-1 Flood Hydrograph Package, User's Manual*, June.

U.S. Army Corps of Engineers, 1998. *Runoff from Snowmelt*, EM 1110-2-1406, March 31.

U.S. Bureau of Reclamation (USBR), 1974. *Design of Small Dams*, Revised Reprint, Second Edition, United States Department of the Interior.

U.S. Bureau of Reclamation (USBR), 1987. *Design of Small Dams*, Third Edition, United States Department of the Interior.

U.S. Bureau of Reclamation (USBR), 1992. *ACER Technical Memorandum No. 2, Freeboard Criteria and Guidelines for Computing Freeboard Allowances for Storage Dams*, United States Department of the Interior, original publication 1981, revised 1992.

U.S. Weather Bureau, 1963. *Probable Maximum Precipitation and Rainfall-Frequency Data for Alaska, Technical Paper No. 47*, U.S. Department of Commerce.

U.S. Weather Bureau, 1965. *Two- to Ten-Day Precipitation for Return Periods of 2 to 100 Years in Alaska, Technical Paper No. 52*, U.S. Department of Commerce.

U.S. Weather Bureau, May 1966. *Meteorological Conditions for the Probable Maximum Flood on the Yukon River Above Rampart, Alaska, Hydrometeorological Report No. 42*, U.S. Department of Commerce, Environmental Science Services Administration, Office of Hydrology, Hydrometeorological Branch.

Wolken, Dr. Gabriel, 2013. “Glacier and Runoff Changes Update”, presentation at Technical Workgroup Meeting, September 25, 2013, Alaska Division of Geological & Geophysical Surveys.