Susitna-Watana Hydroelectric Project Document
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PART C – ATTACHMENT 1: FINAL DRAFT PROBABLE MAXIMUM FLOOD STUDY REPORT

SUSITNA-WATANA HYDRO

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Report
14-02-REP
v1.0

Susitna-Watana Hydroelectric Project
Probable Maximum Flood Study

FINAL DRAFT

AEA11-022

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May 2014

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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.

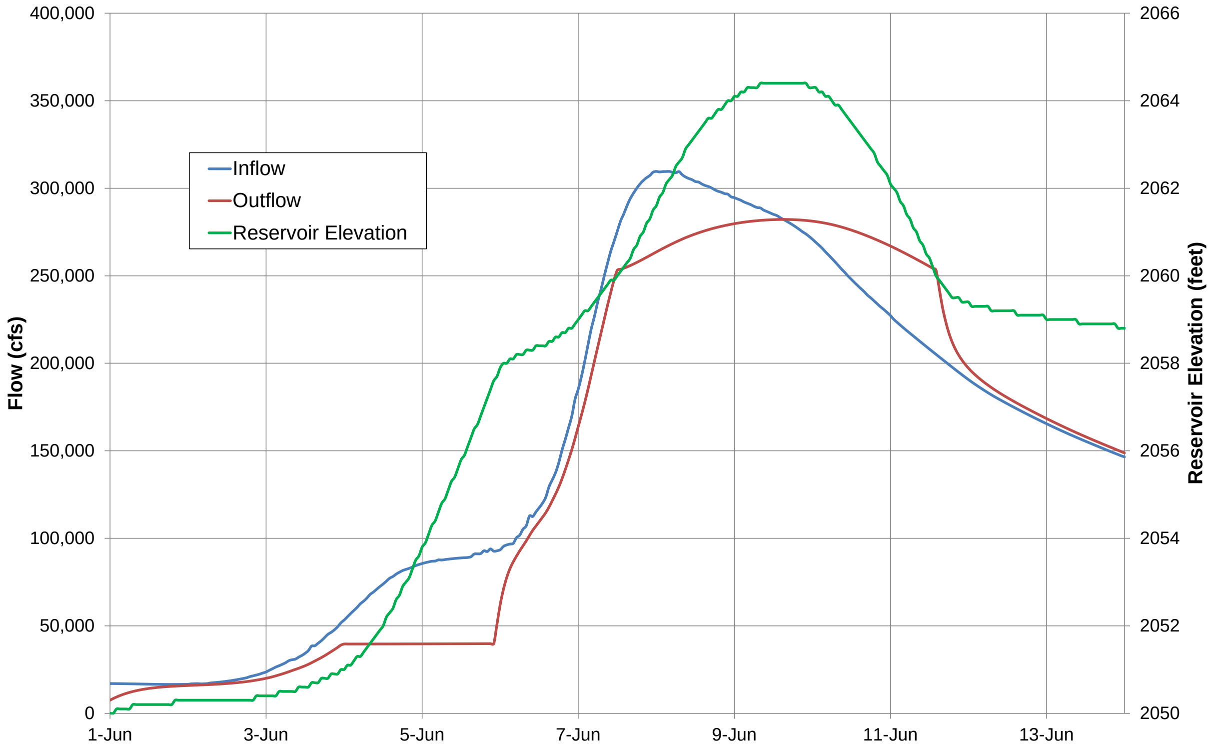


Figure ES-1. PMF Inflow, Outflow, and Reservoir Elevation

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 three 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

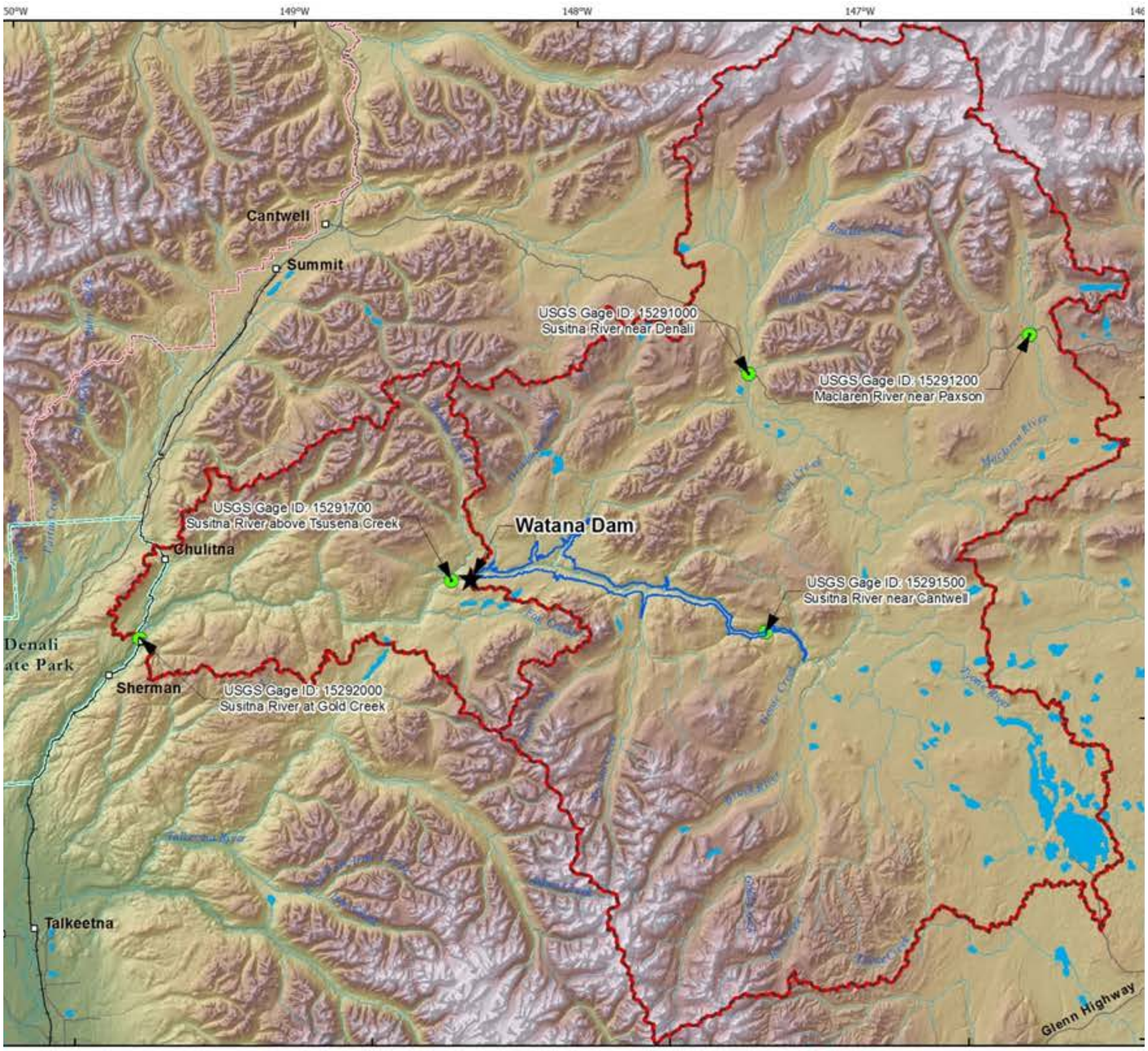


Figure 1.2-1. Susitna Watershed Boundary and USGS Gage Locations

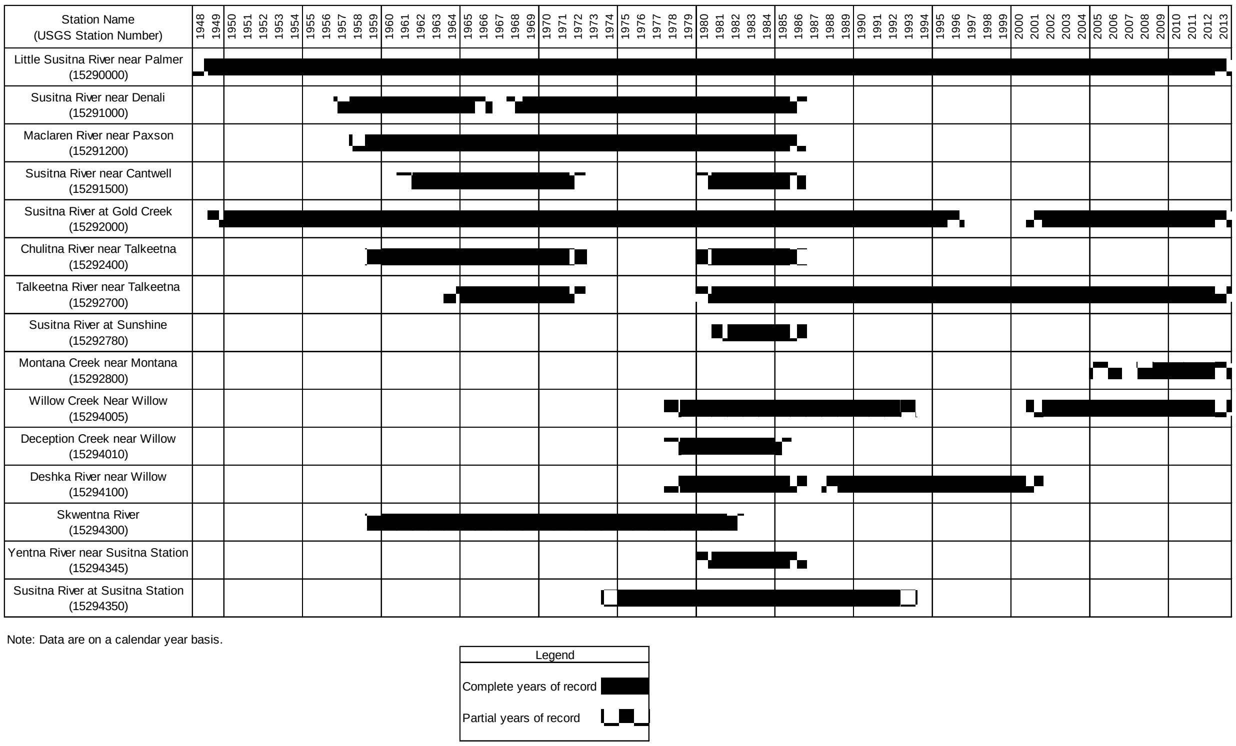


Figure 1.2-2. Susitna Watershed USGS Flow Data – Chronological Availability

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.

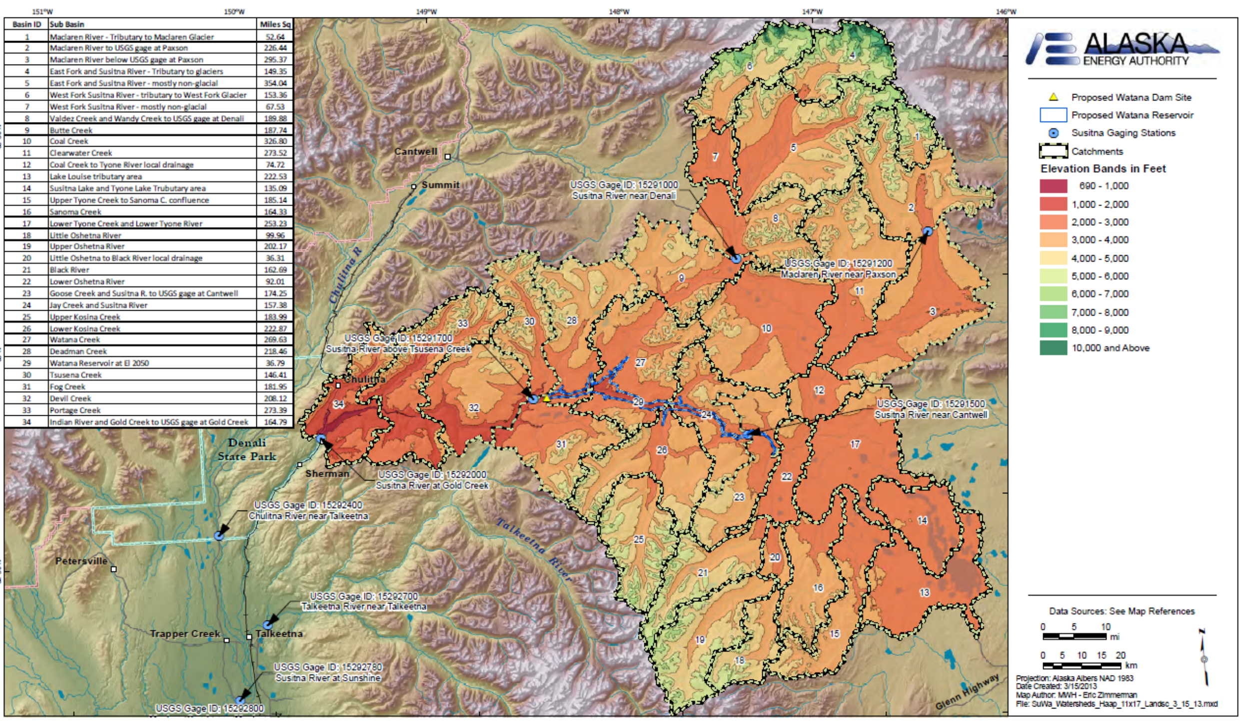


Figure 1.5-1. Susitna Watershed Sub-Basins and Elevation Bands

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

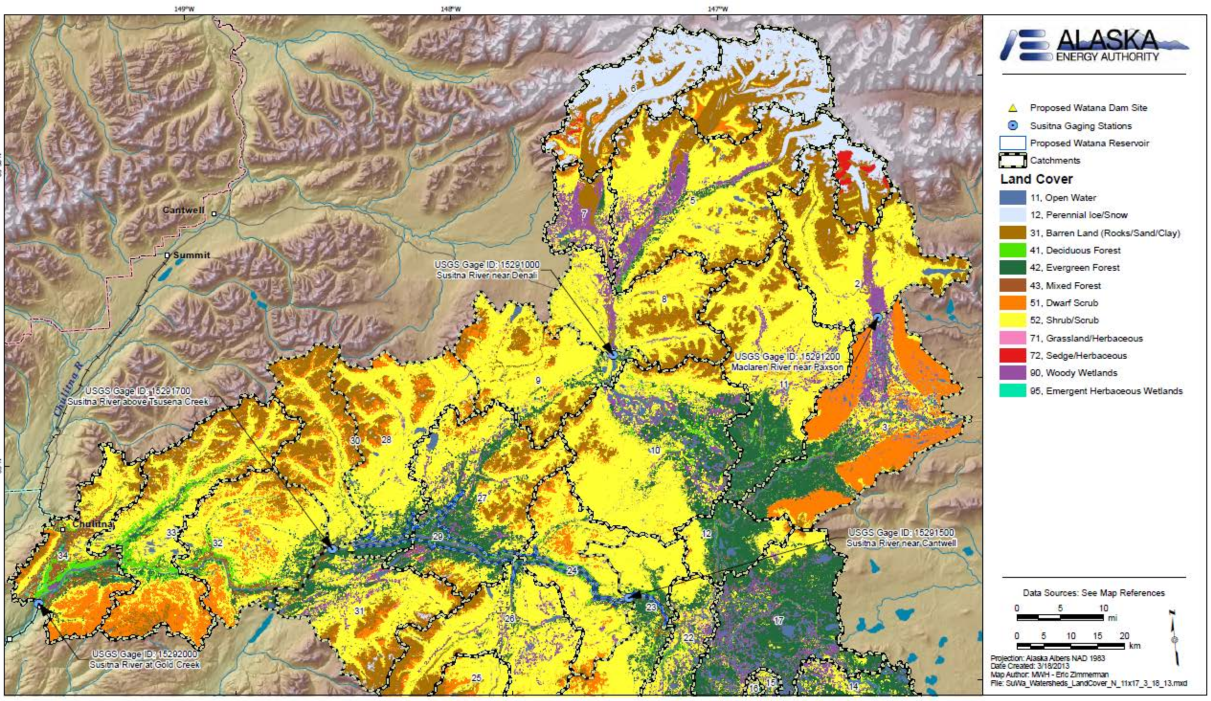
Figures 1.5-2 and 1.5-3 show the type and distribution of watershed cover and Table 1.5-4 provides a data summary of cover types for the entire watershed. Table 1.5-5 provides similar information for each sub-basin. Shrub and scrub is the dominant watershed cover type, totaling about 56% of the entire 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%

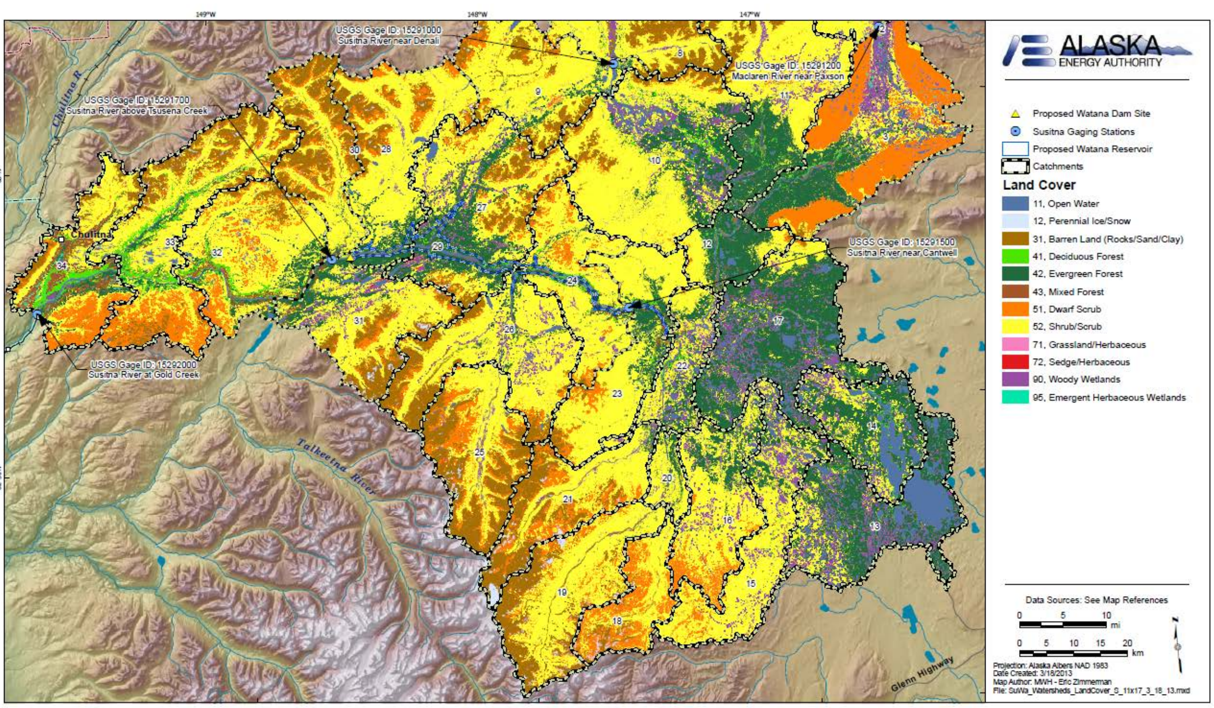
Table 1.5-5. Watershed Cover by Sub-Basin

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



Northern Upper Susitna Land Cover

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



Southern Upper Susitna Land Cover

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.

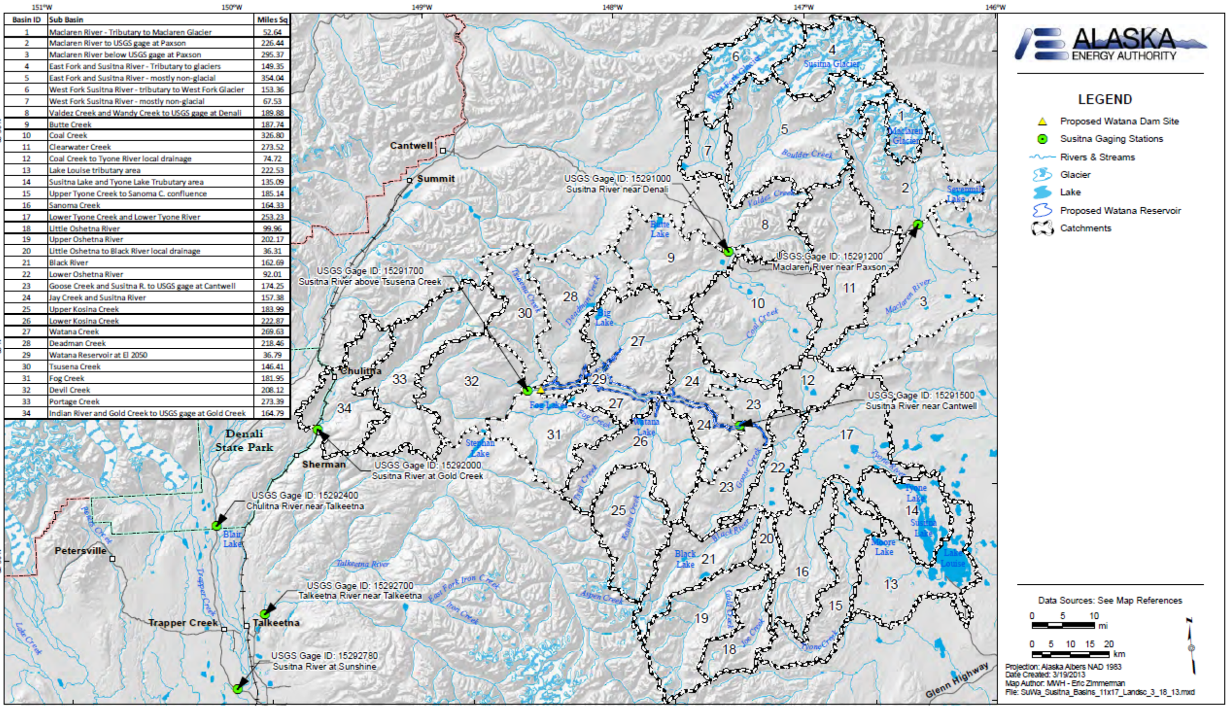
The Clark unit hydrograph method was used along with uniform infiltration losses. The Clark method parameters tc (time of concentration) and R (a storage coefficient) were developed by calibration. The ratio R/(Tc + R) has been found in a number of studies to be fairly constant on a regional basis (ASCE 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.

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 – 59 Years of Record

Rank	Date	Peak Flow (cfs)	cfs/sq.mi.
1	June 7, 1964	90,700	14.7
2	August 10, 1971	87,400	14.2
3	June 17, 1972	82,600	13.4
4	June 15, 1962	80,600	13.1
5	August 15, 1967	80,200	13.0
6	September 21, 2012	72,900	11.8
7	July 12, 1981	64,900	10.5
8	June 6, 1966	63,600	10.3
9	August 25, 1959	62,300	10.1
10	August 20, 2006	59,800	9.7

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	90,500

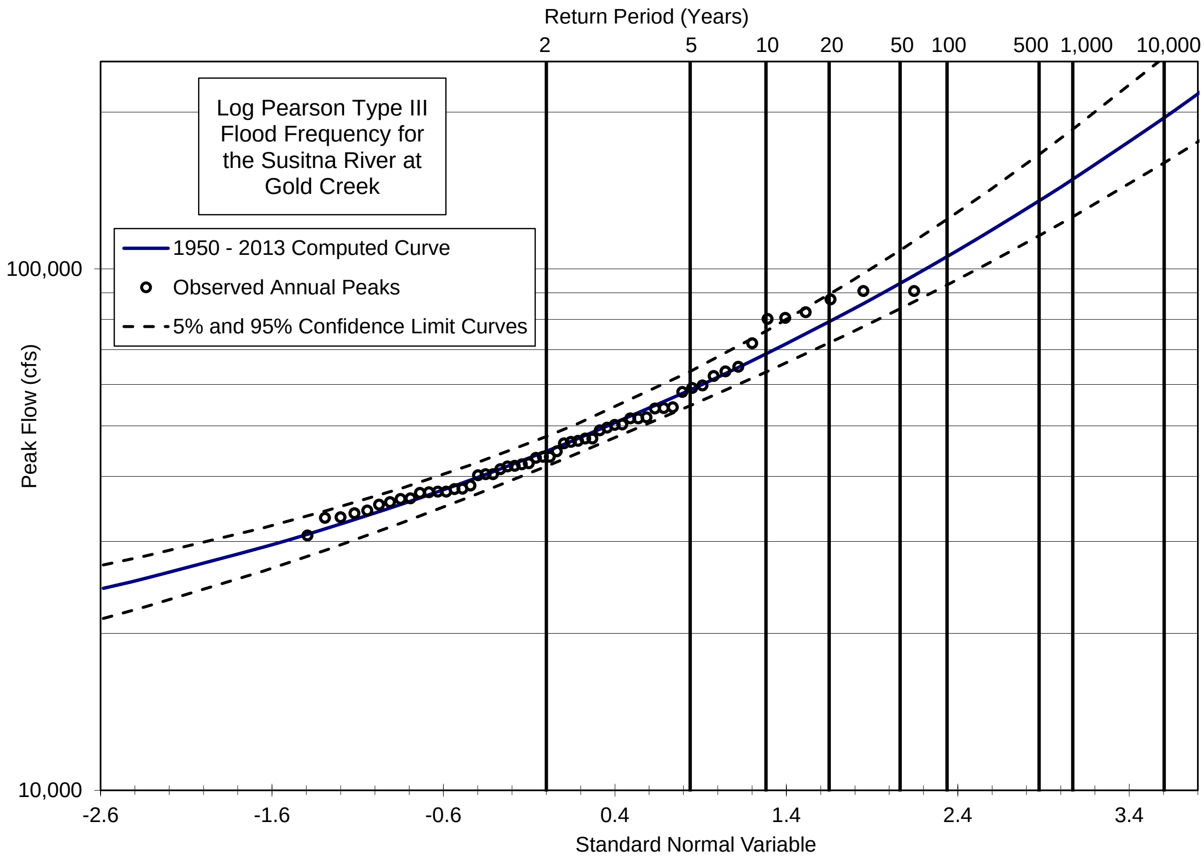


Figure 3.2-1. Log Pearson Type III Flood Frequency Plot for the Susitna River at Gold Creek

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 1,000 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%

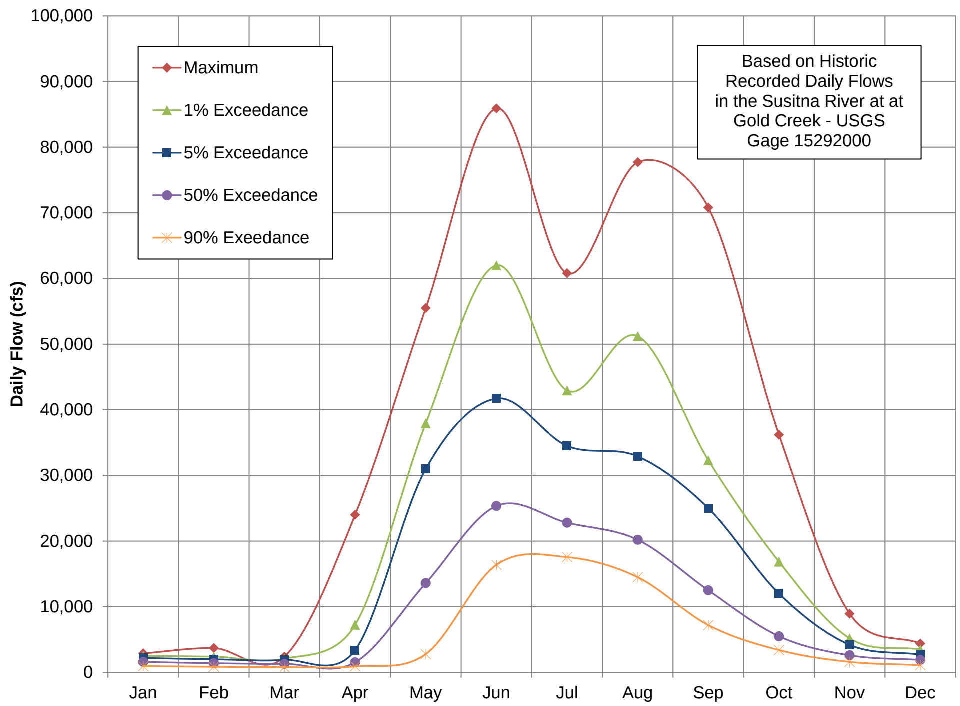


Figure 3.2-2. Historic Flow Frequency at the USGS Gold Creek Gage

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.

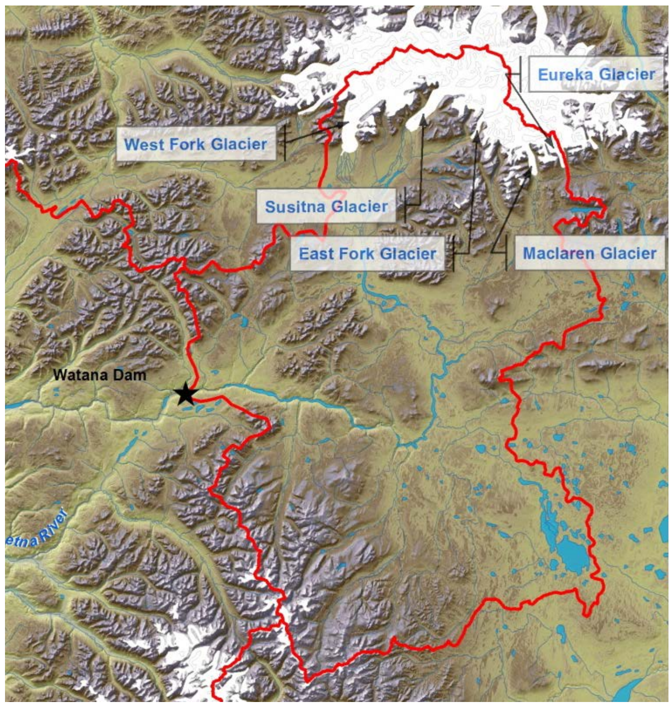


Figure 3.2-3. Susitna Watershed Glaciers

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.

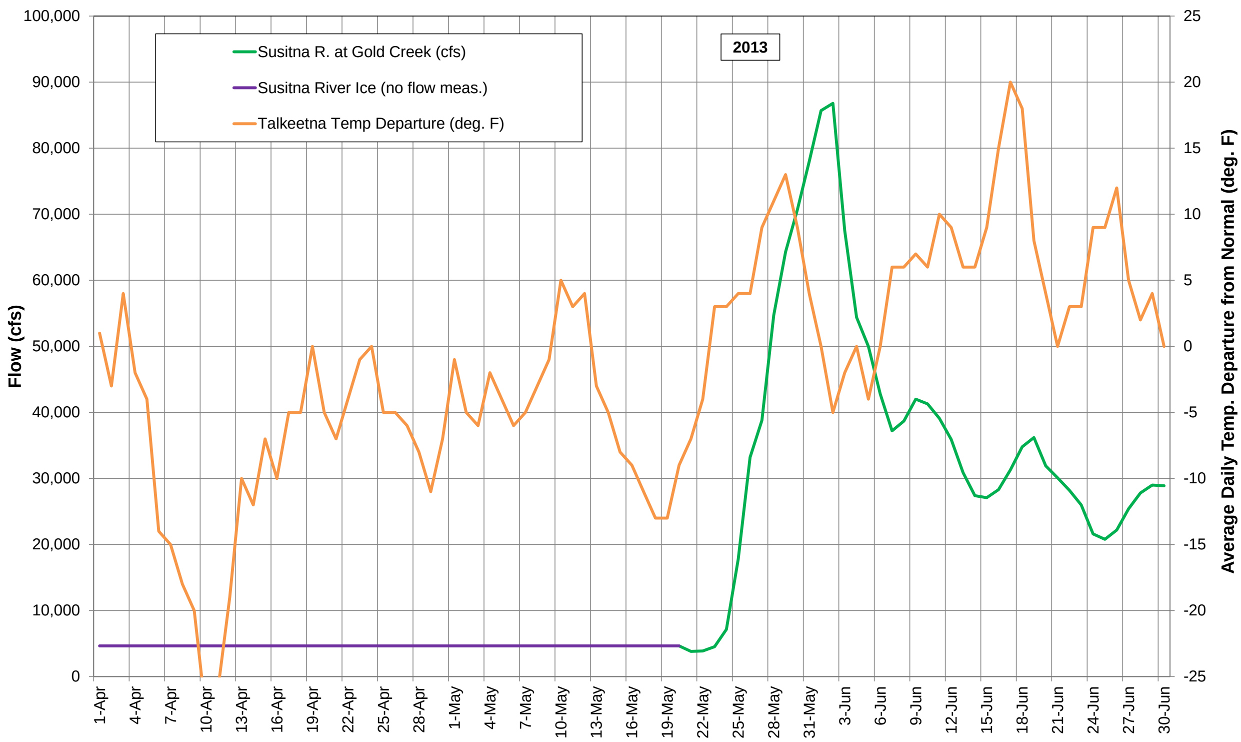


Figure 3.2-4. April – June 2013 Flow and Temperature Departure from Normal

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.

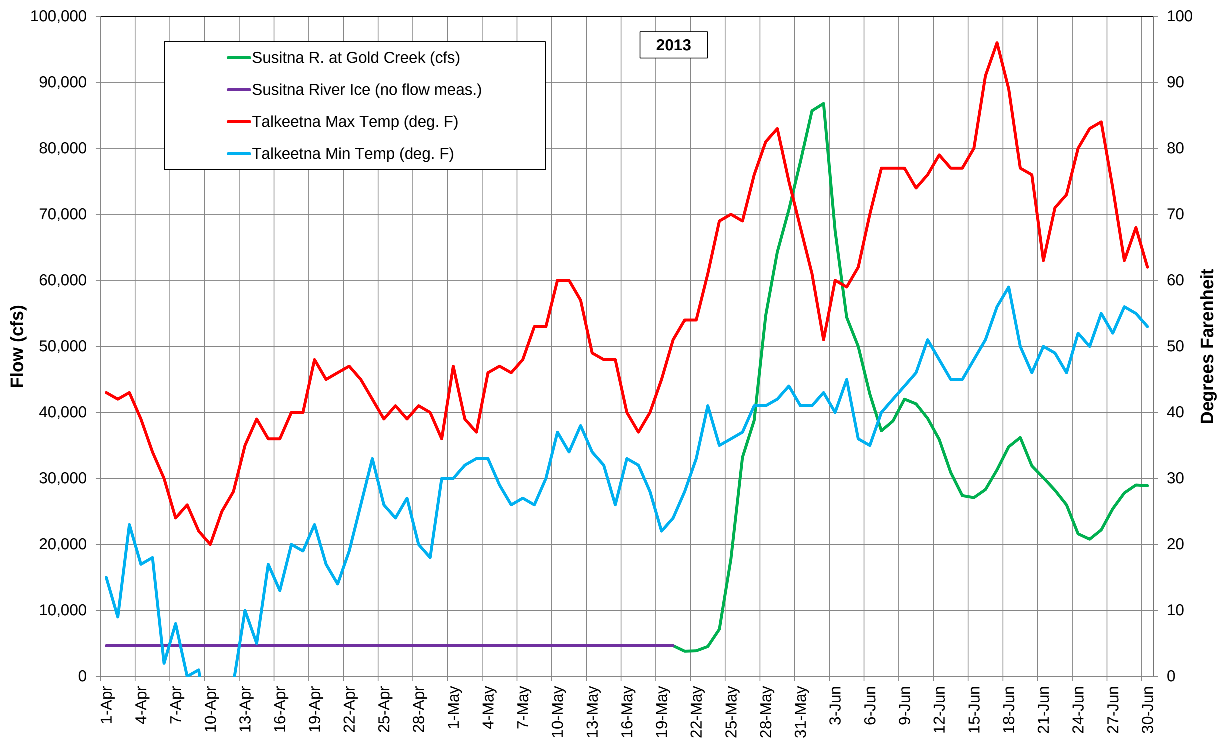


Figure 3.2-5. April – June 2013 Flow and Temperatures

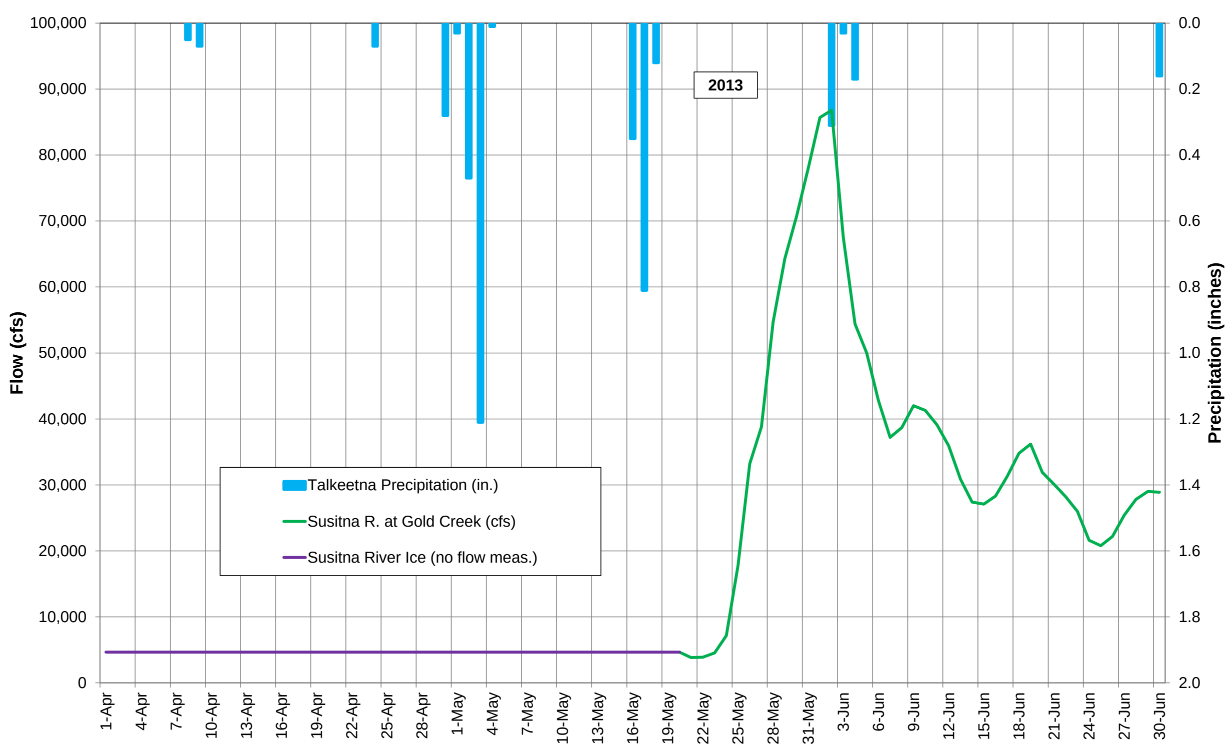


Figure 3.2-6. April – June 2013 Flow and Precipitation

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) (inches)	Maximum SWE (2) Date	Earliest Day with Snowpack	Latest Day with Snowpack	Years of Available Snowpack Data In the Period of Record
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.

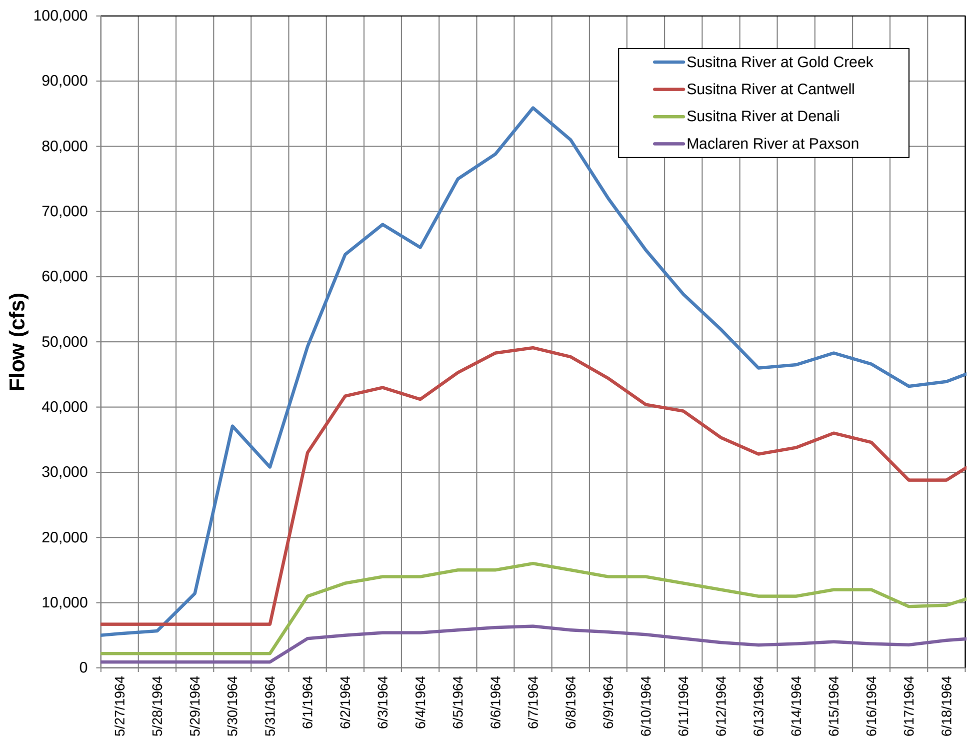


Figure 4.1-1. June 1964 Recorded Flows at USGS Gages

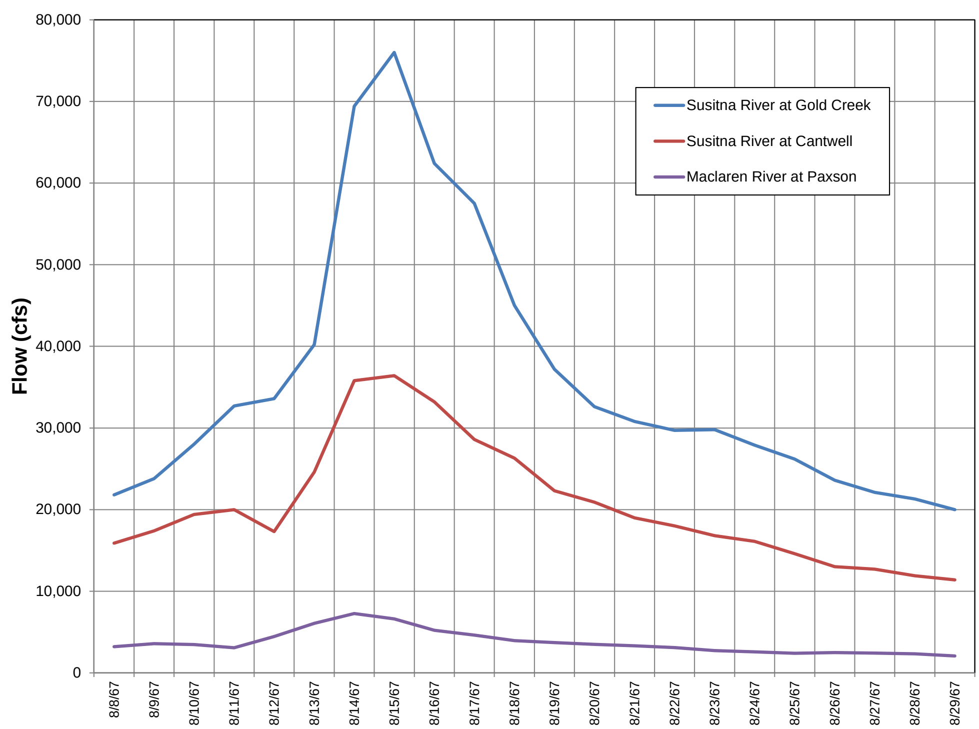


Figure 4.1-2. August 1967 Recorded Flows at USGS Gages

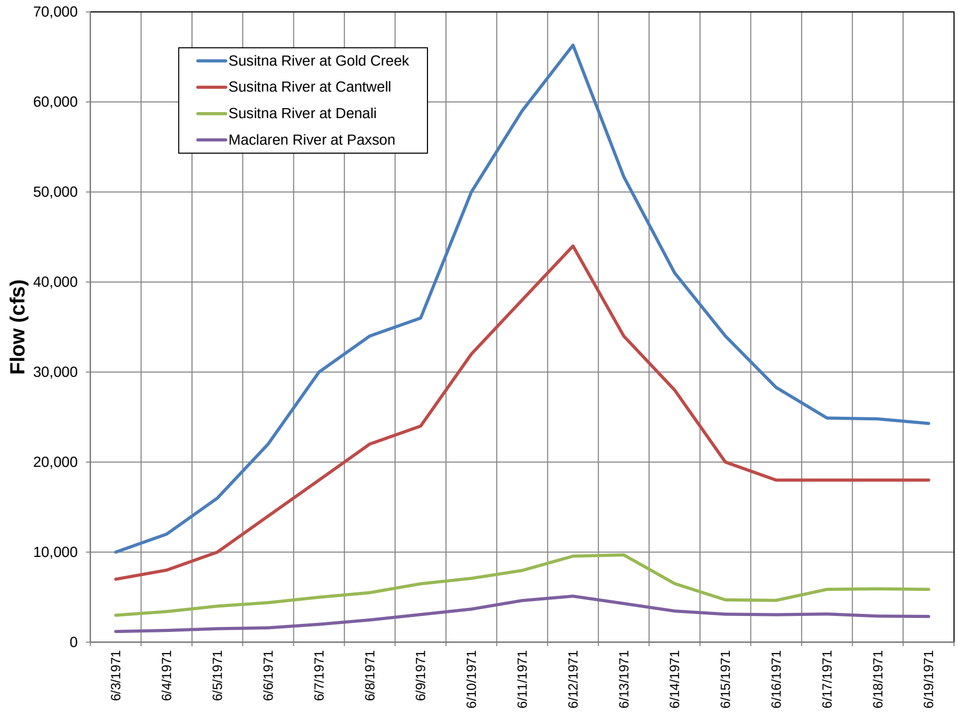


Figure 4.1-3. June 1971 Recorded Flows at USGS Gages

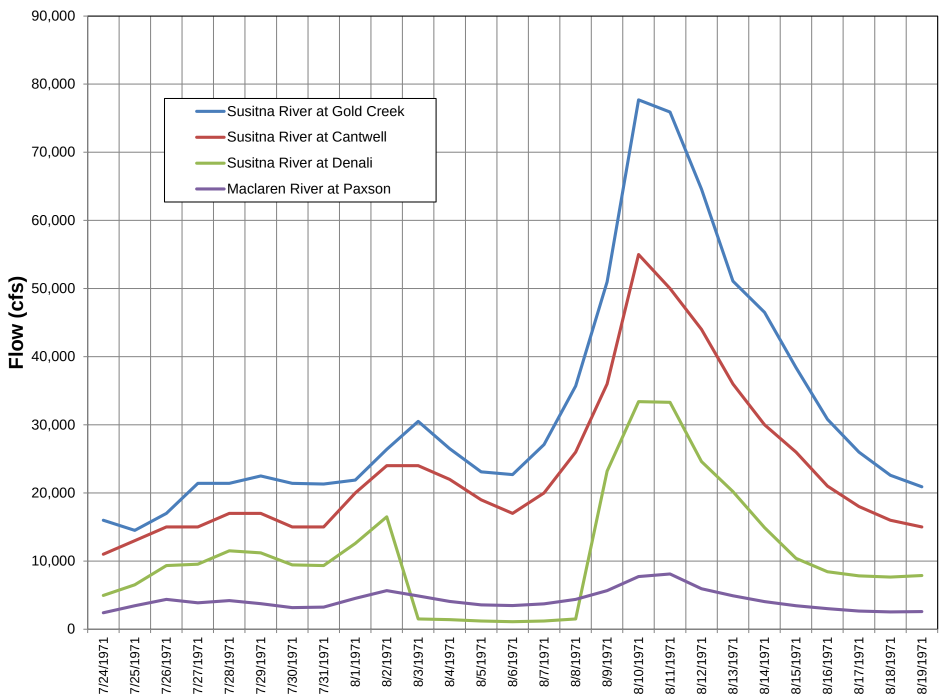


Figure 4.1-4. August 1971 Recorded Flows at USGS Gages

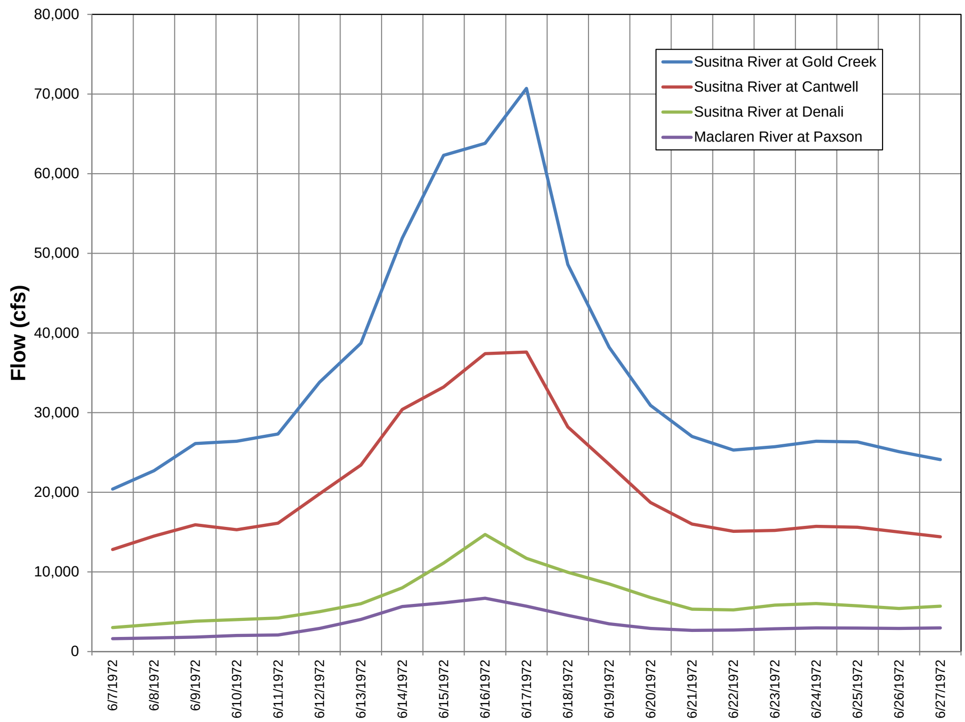


Figure 4.1-5. June 1972 Recorded Flows at USGS Gages

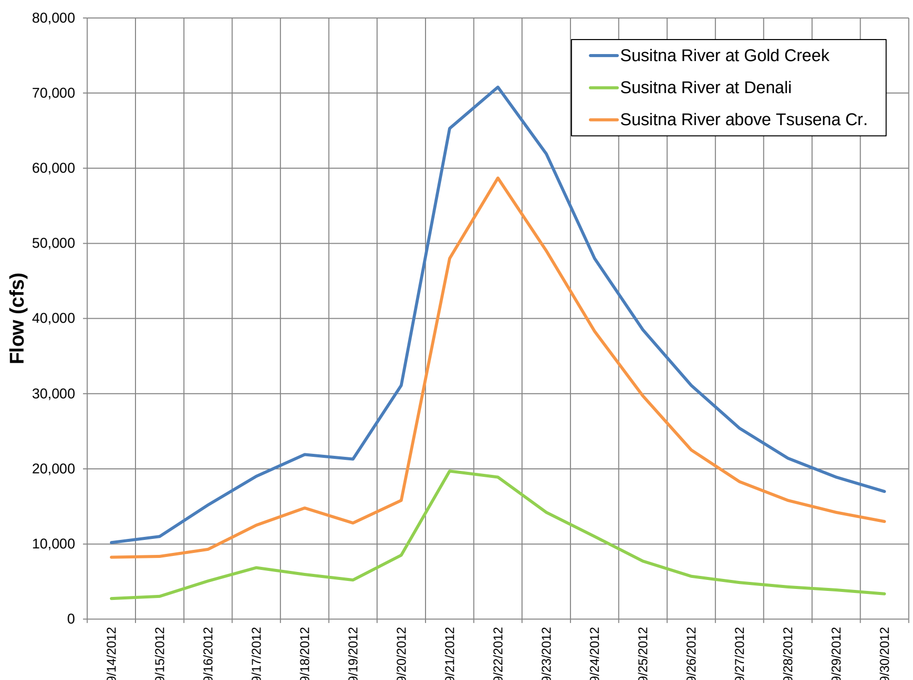


Figure 4.1-6. September 2012 Recorded Flows at USGS Gages

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.

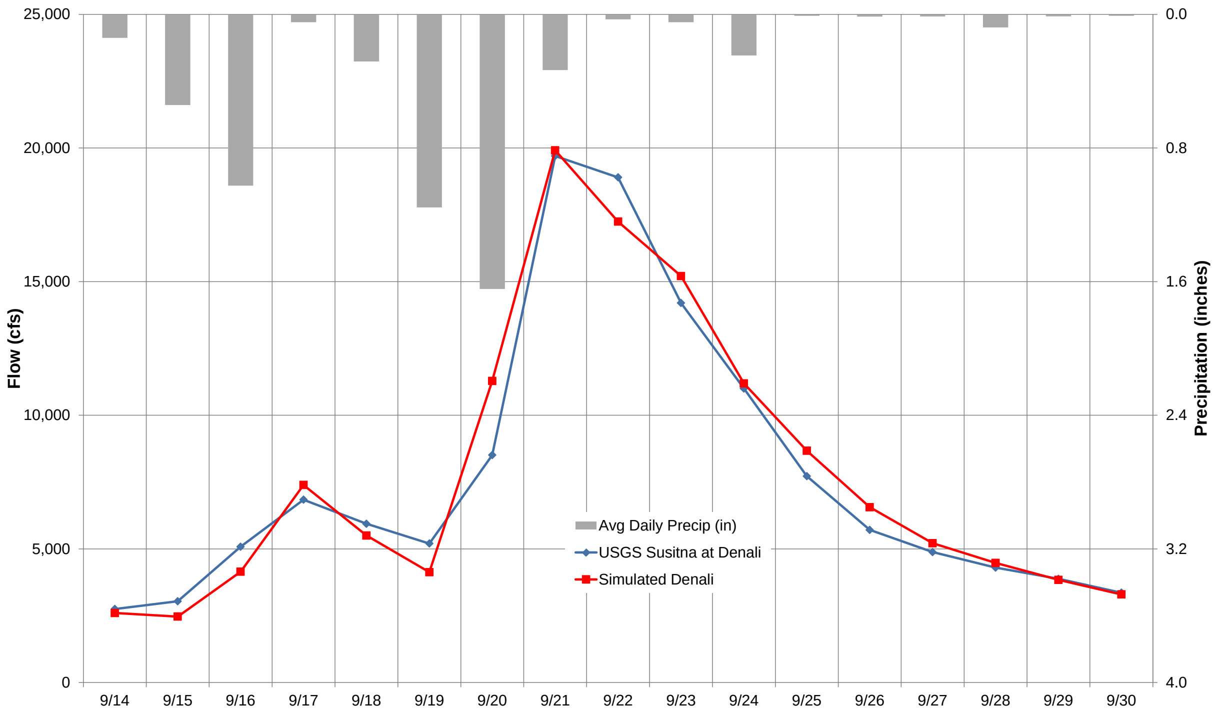


Figure 4.4-1. September 2012 Calibration, Susitna River near Denali

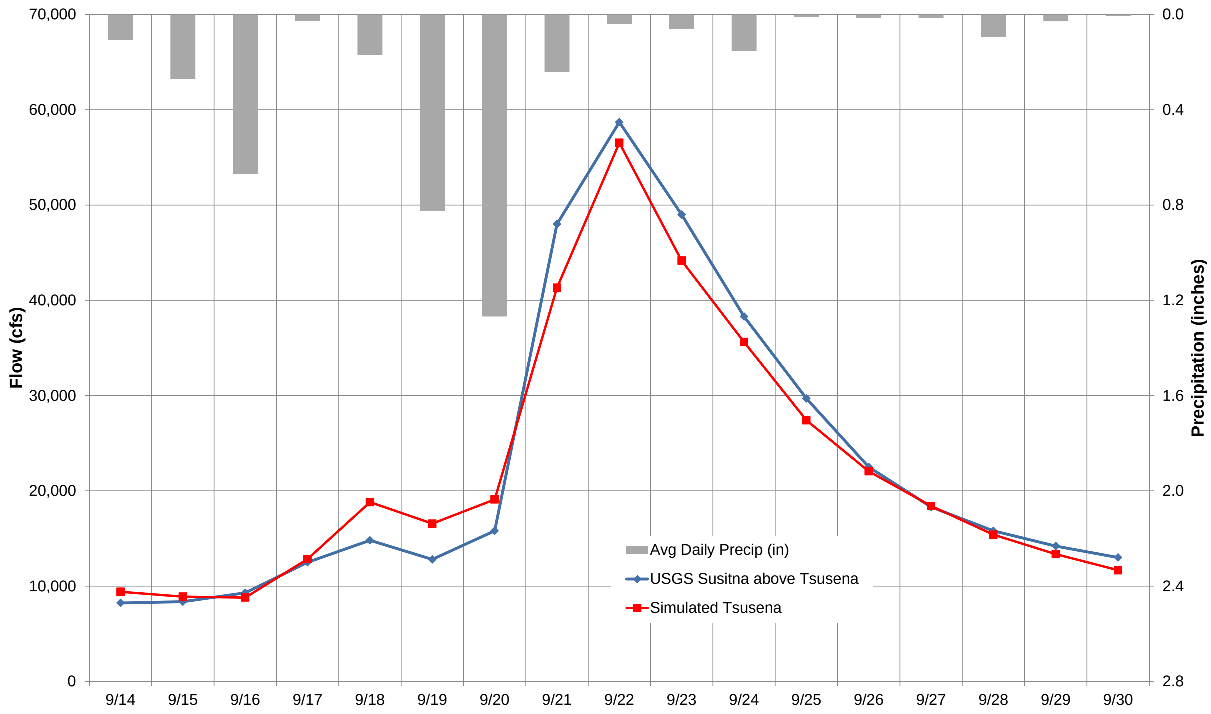


Figure 4.4-2. September 2012 Calibration, Susitna River above Tsusena Creek

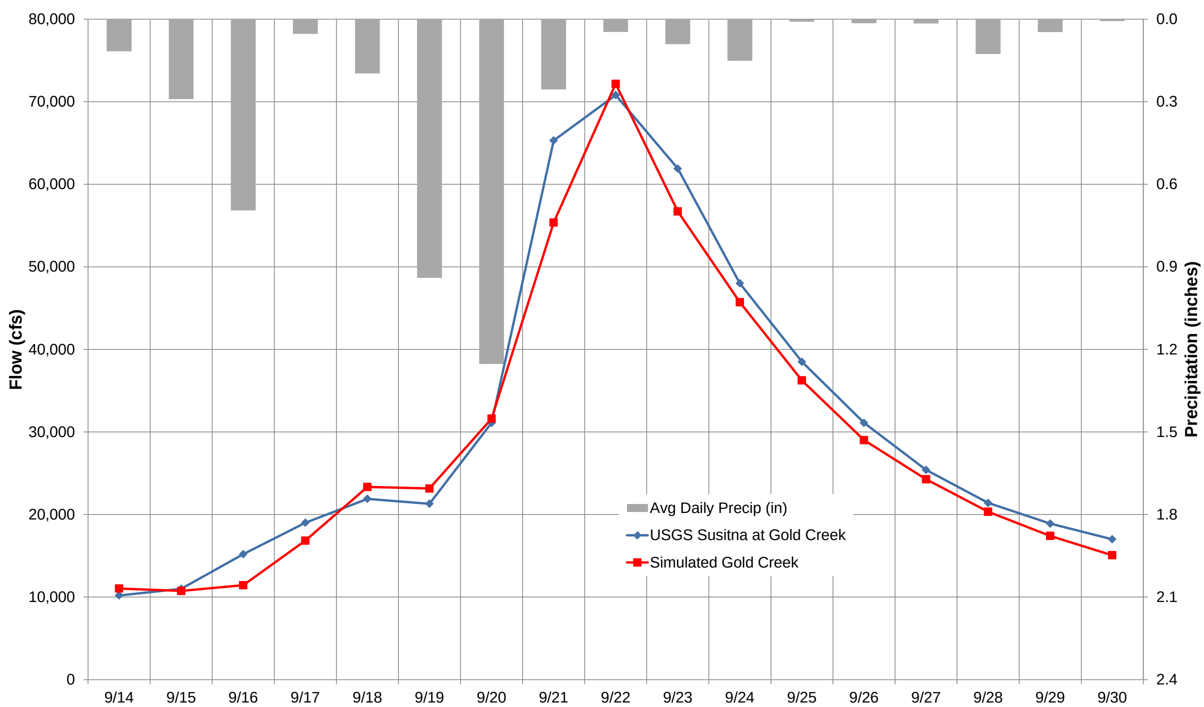


Figure 4.4-3. September 2012 Calibration, Susitna River at Gold Creek

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.

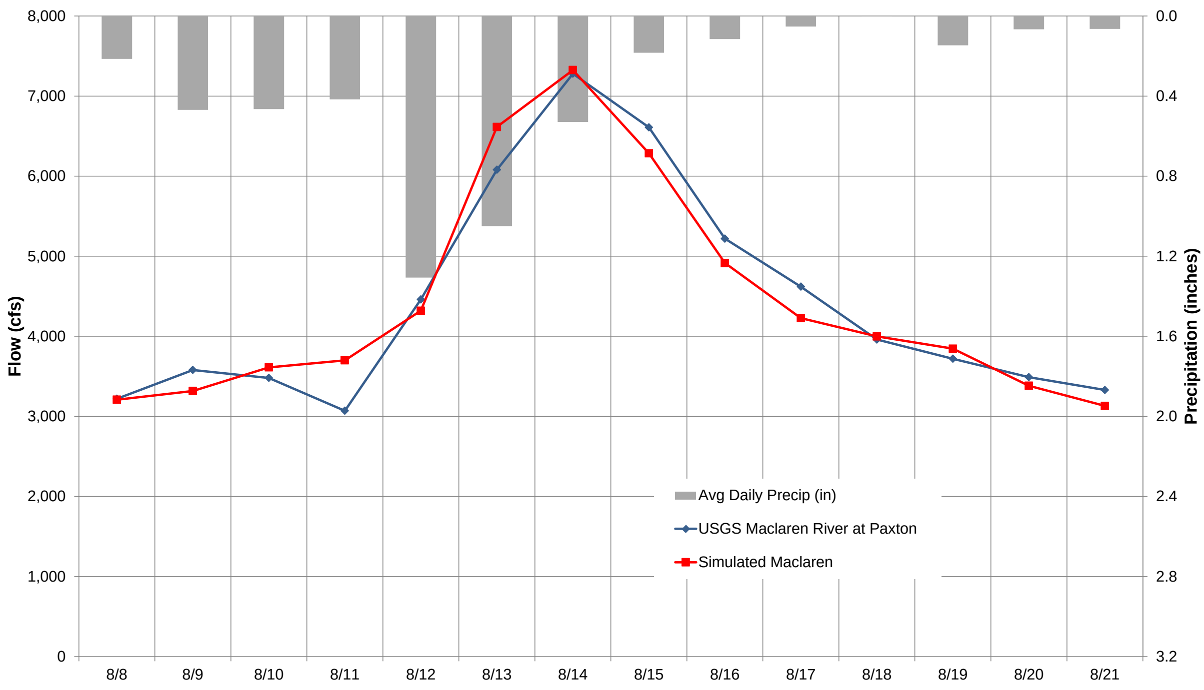


Figure 4.4-4. August 1967 Calibration, Maclaren River near Paxson

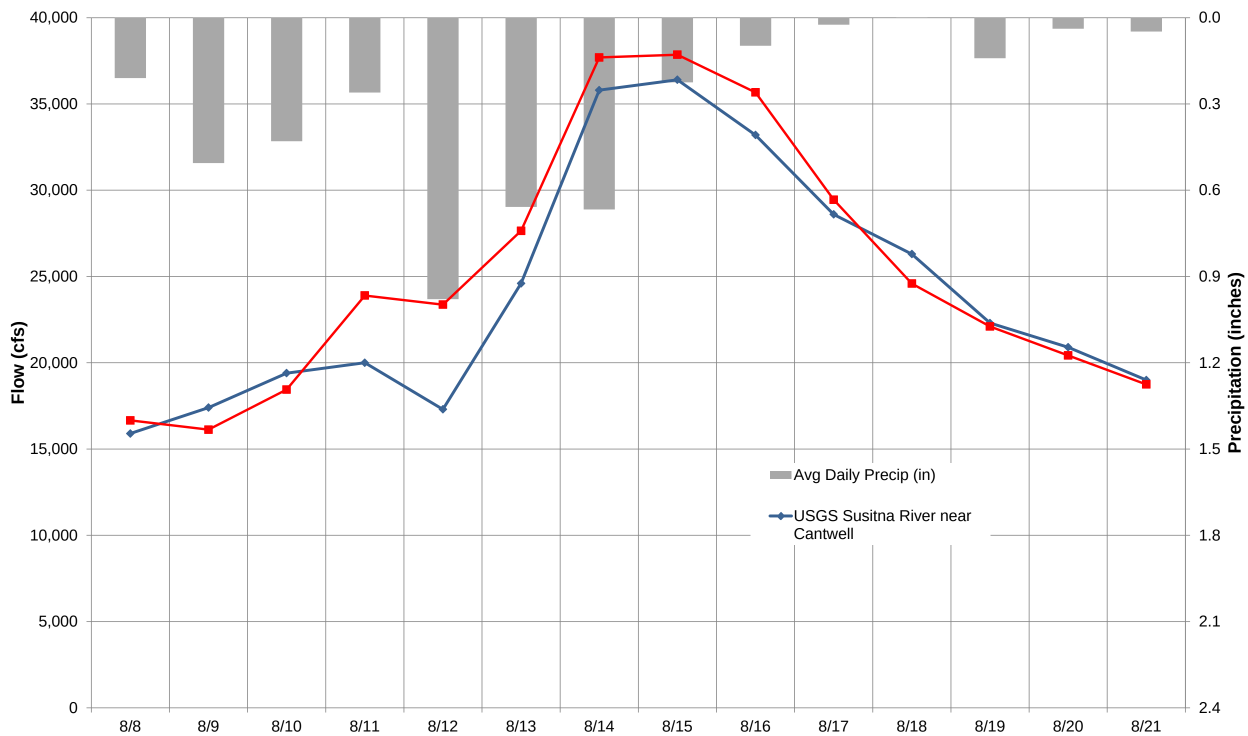


Figure 4.4-5. August 1967 Calibration, Susitna River near Cantwell

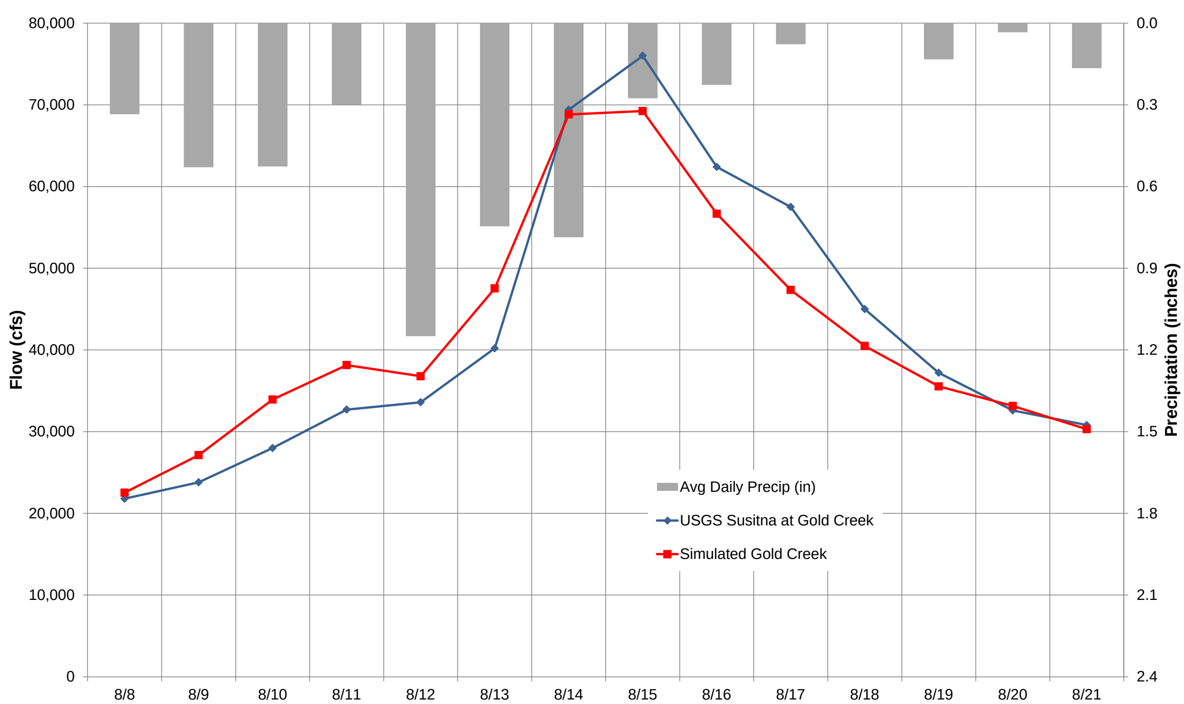


Figure 4.4-6. August 1967 Calibration, Susitna River at Gold Creek

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.

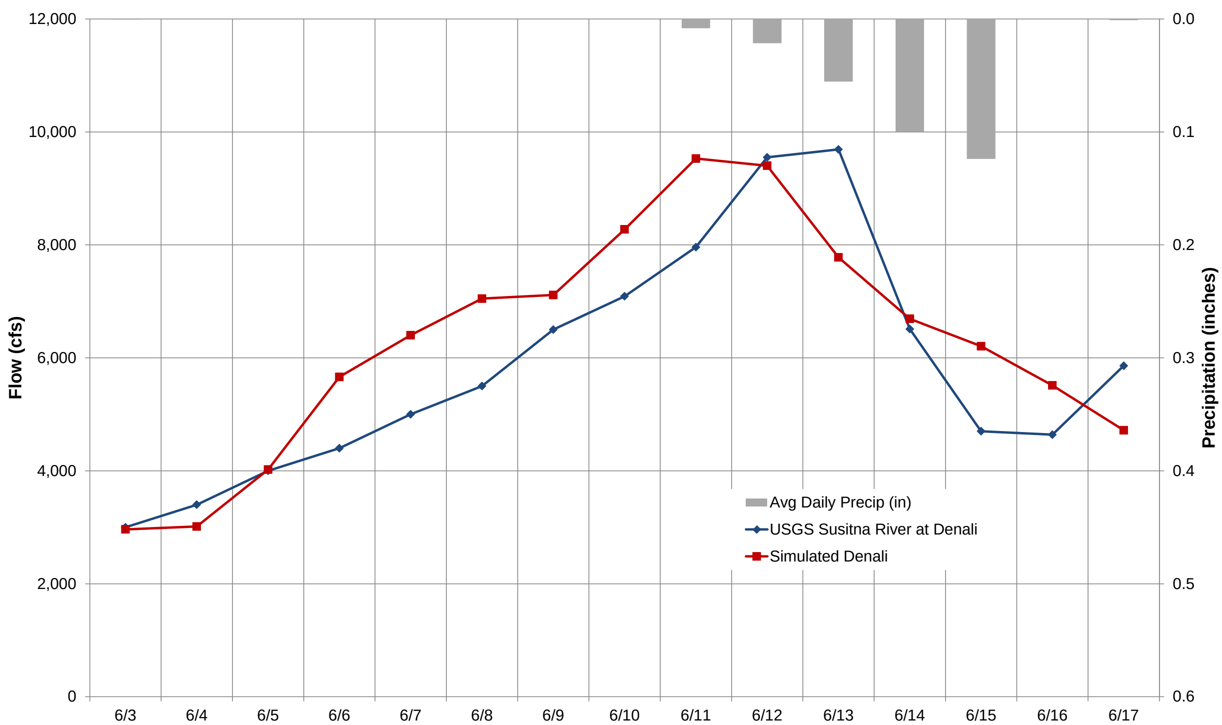


Figure 4.5-1. June 1971 Calibration, Susitna River near Denali

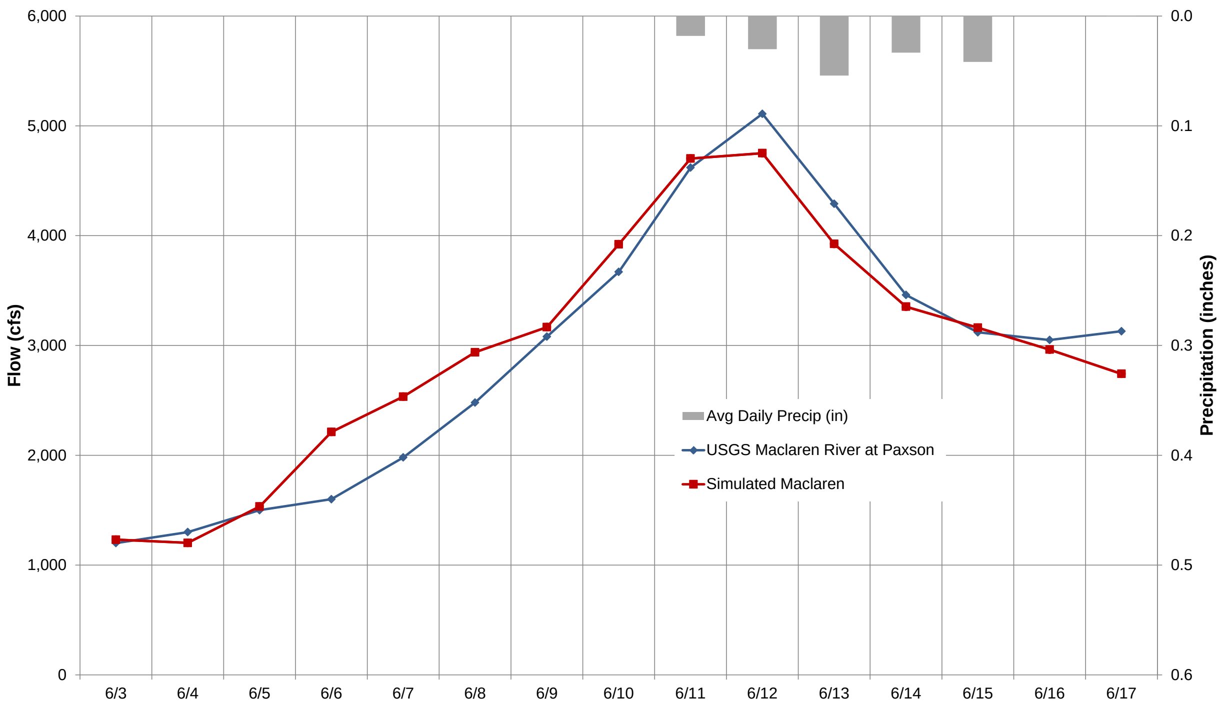


Figure 4.5-2. June 1971 Calibration, Maclaren River near Paxson

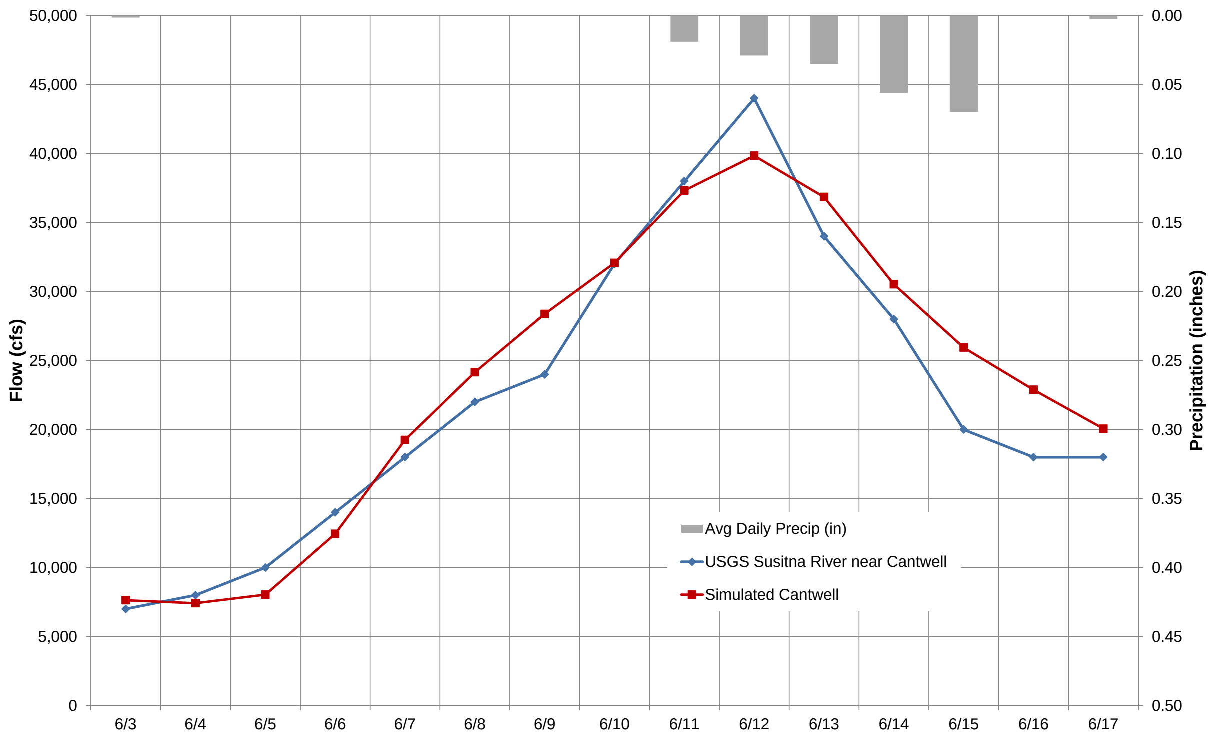


Figure 4.5-3. June 1971 Calibration, Susitna River near Cantwell

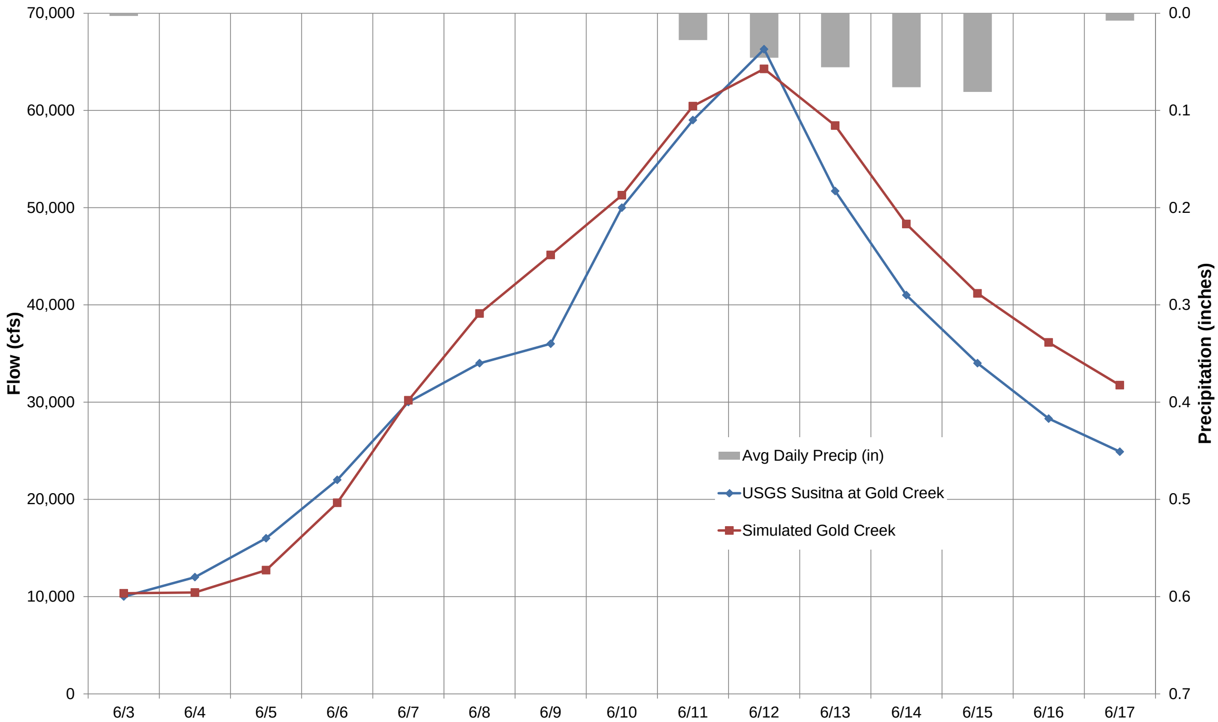


Figure 4.5-4. June 1971 Calibration, Susitna River at Gold Creek

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.

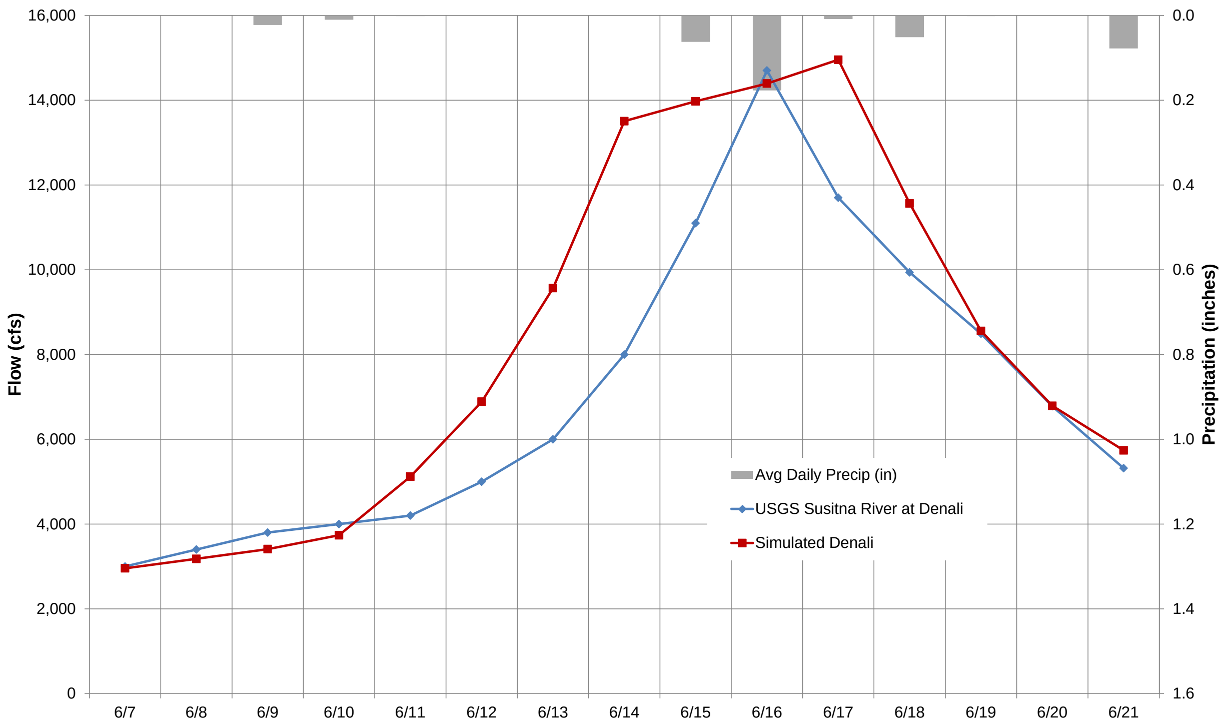


Figure 4.5-5. June 1972 Calibration, Susitna River near Denali

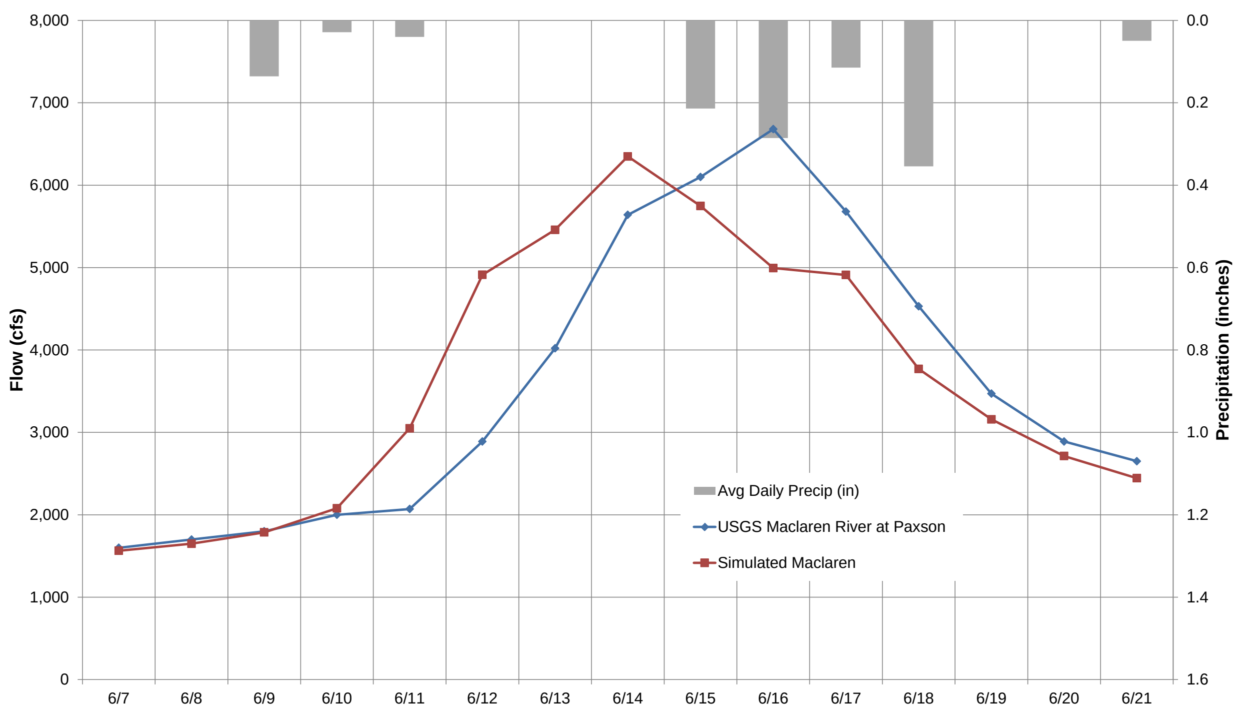


Figure 4.5-6. June 1972 Calibration, Maclaren River near Paxson

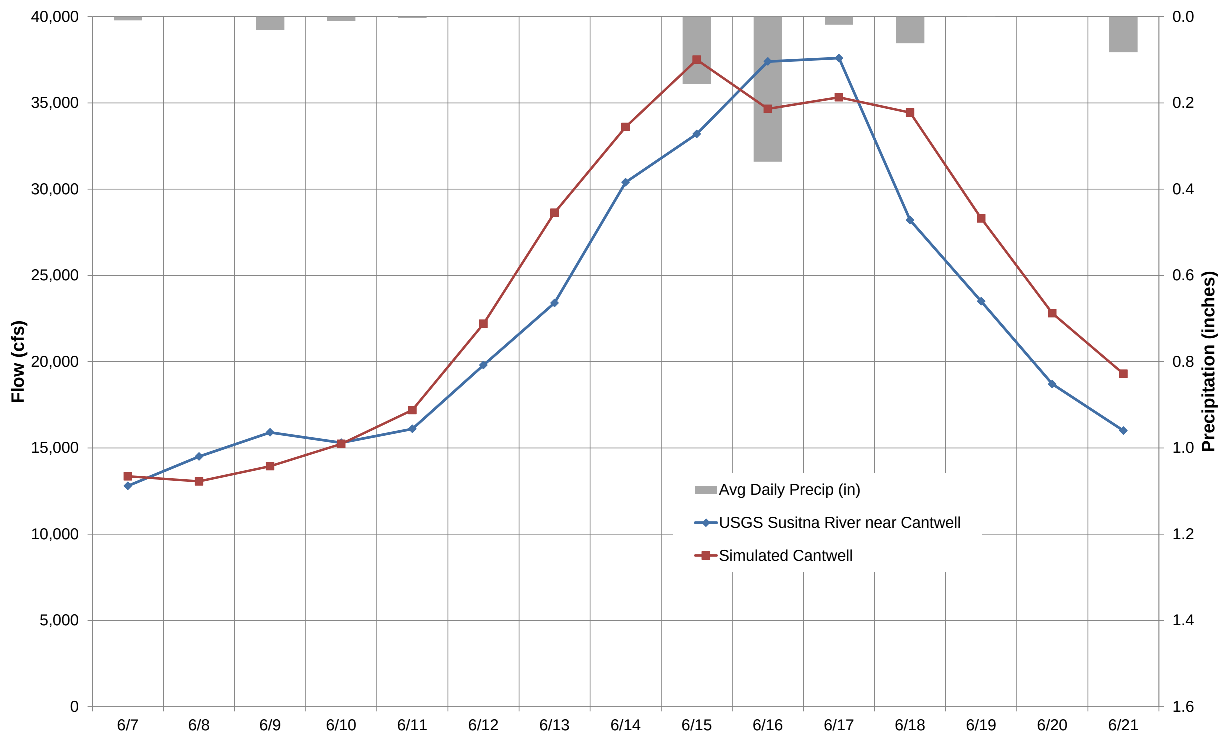


Figure 4.5-7. June 1972 Calibration, Susitna River near Cantwell

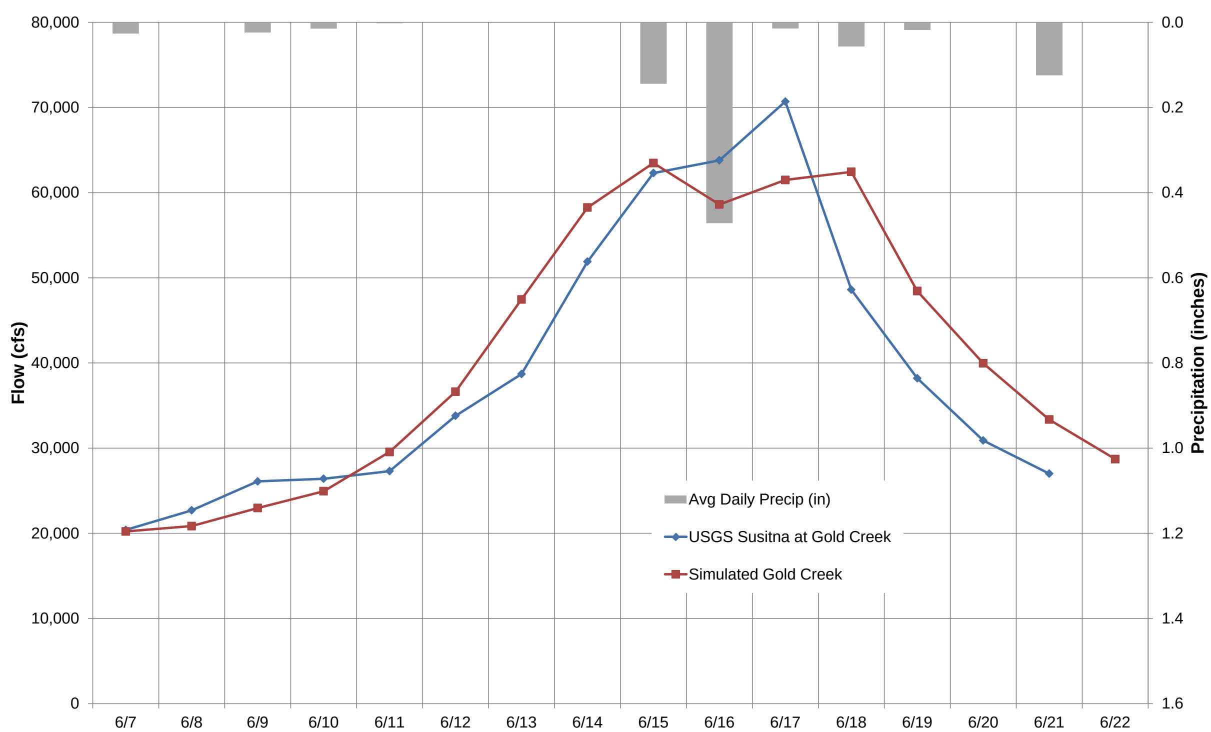


Figure 4.5-8. June 1972 Calibration, Susitna River at Gold Creek

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.

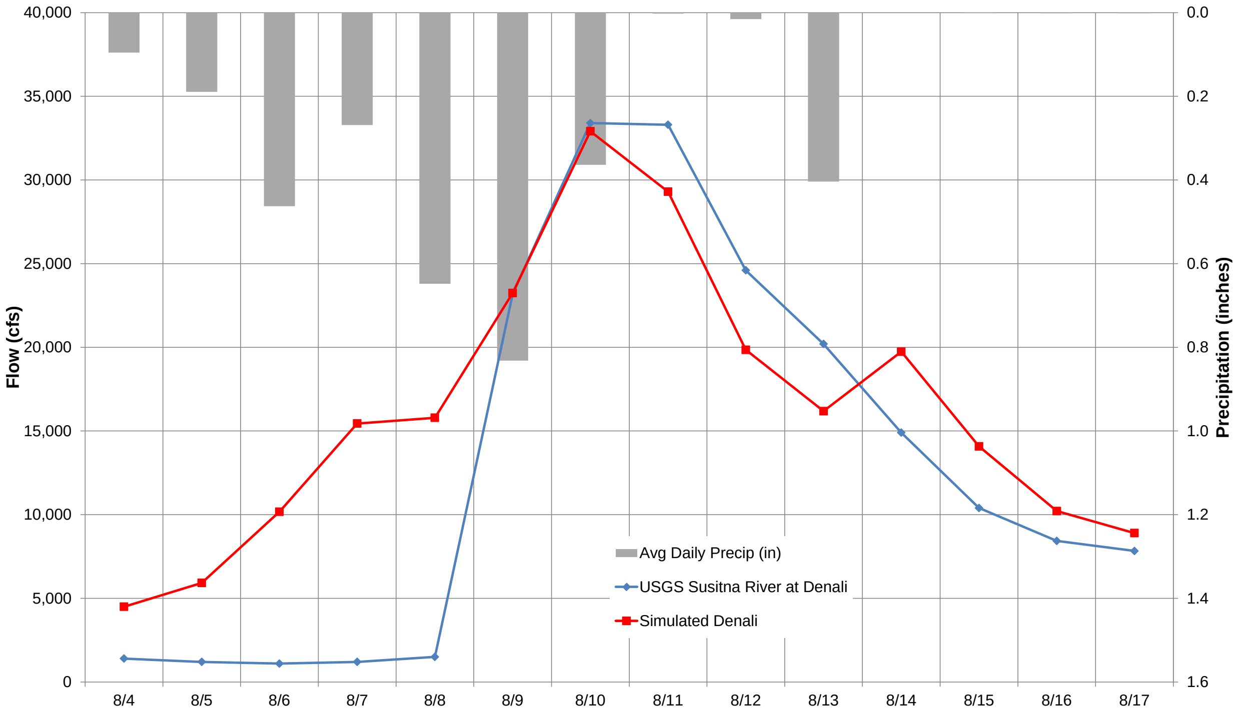


Figure 5.1-1. August 1971 Verification, Susitna River near Denali

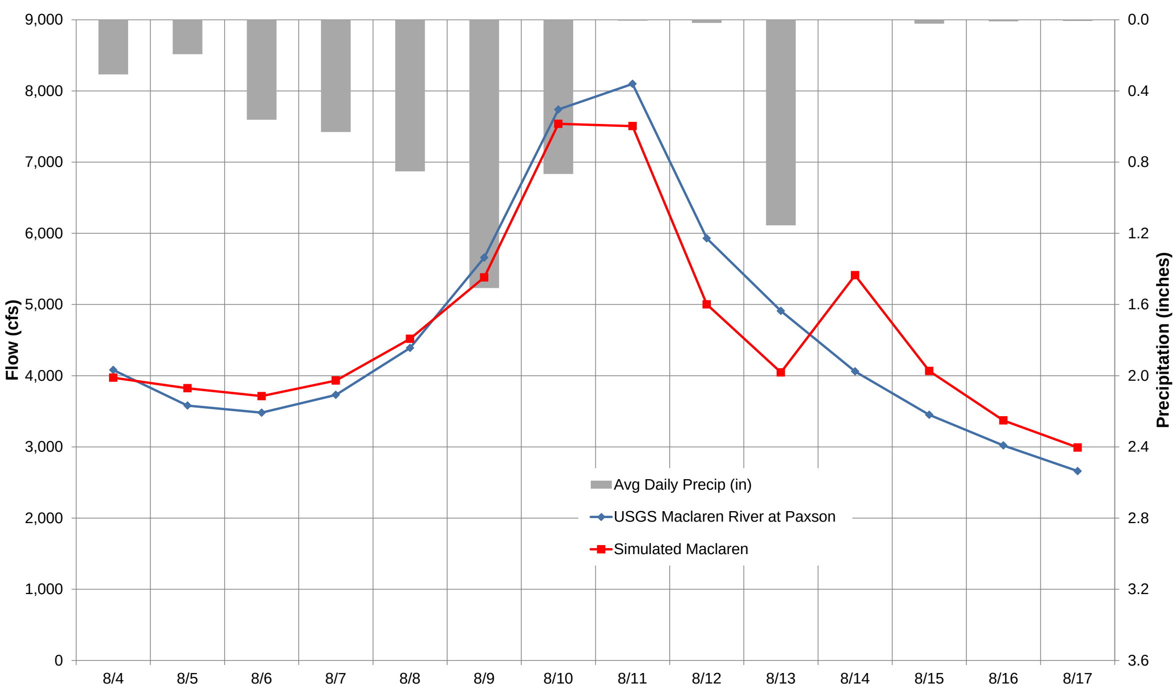


Figure 5.1-2. August 1971 Verification, Maclaren River near Paxson

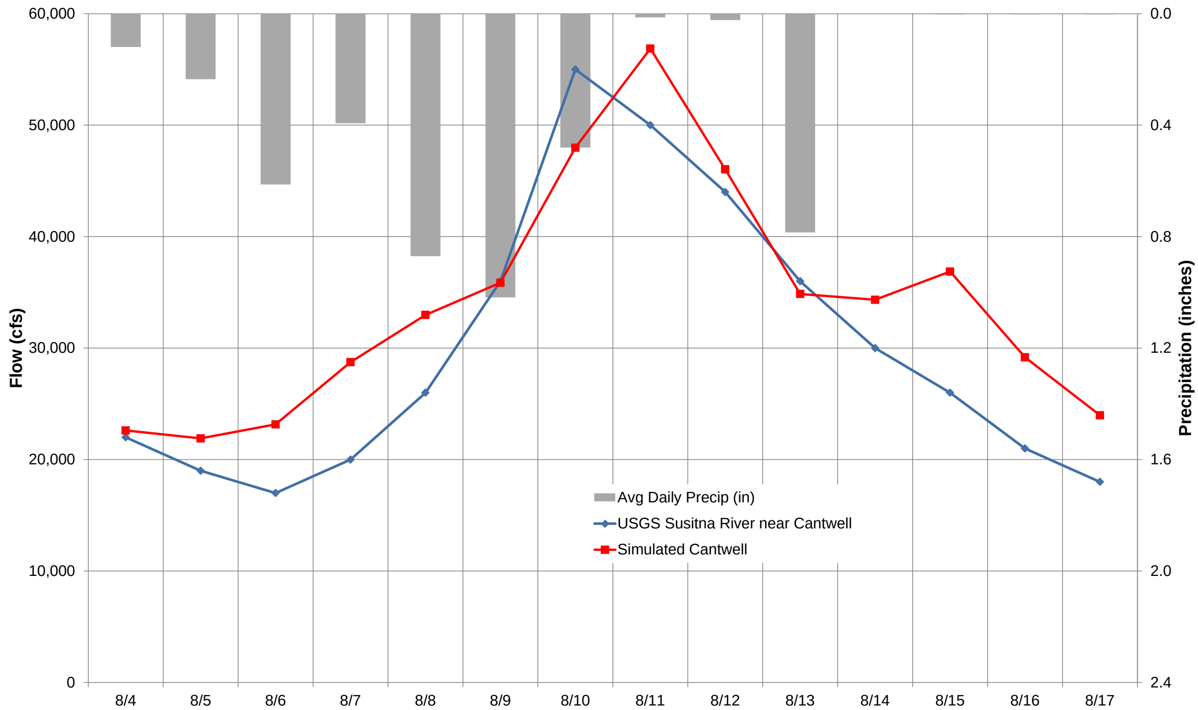


Figure 5.1-3. August 1971 Verification, Susitna River near Cantwell

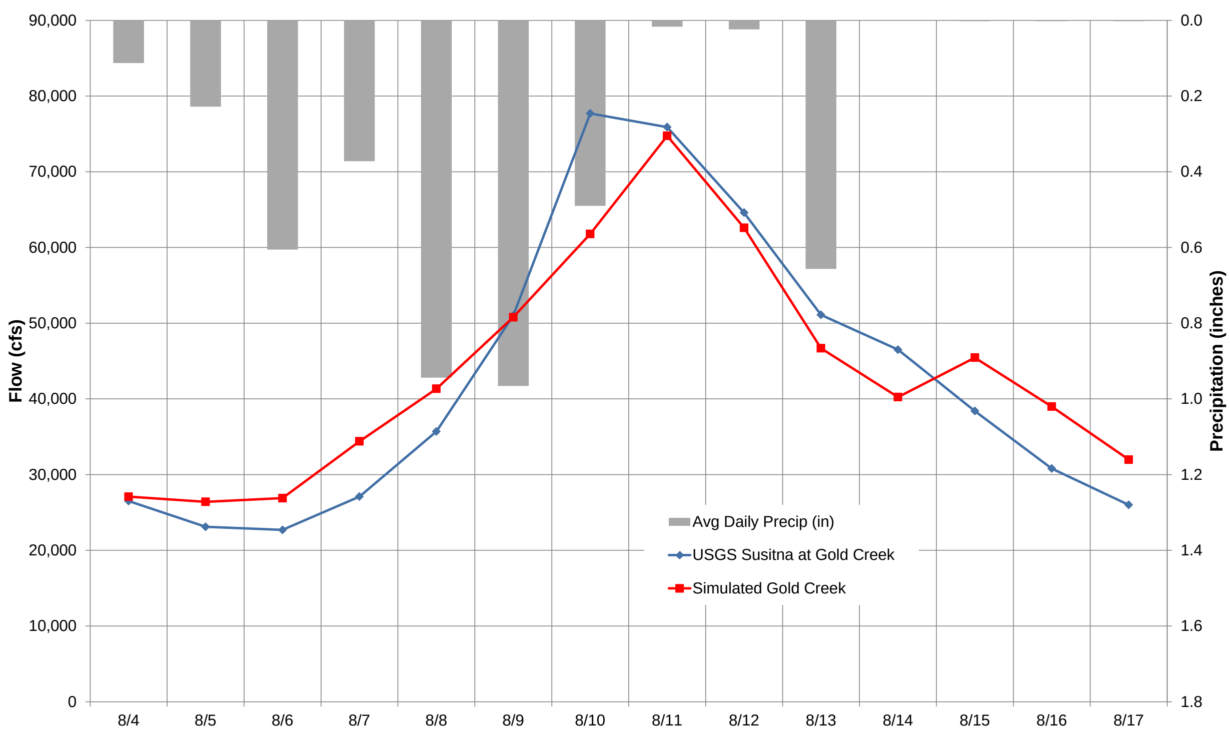


Figure 5.1-4. August 1971 Verification, Susitna River at Gold Creek

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.

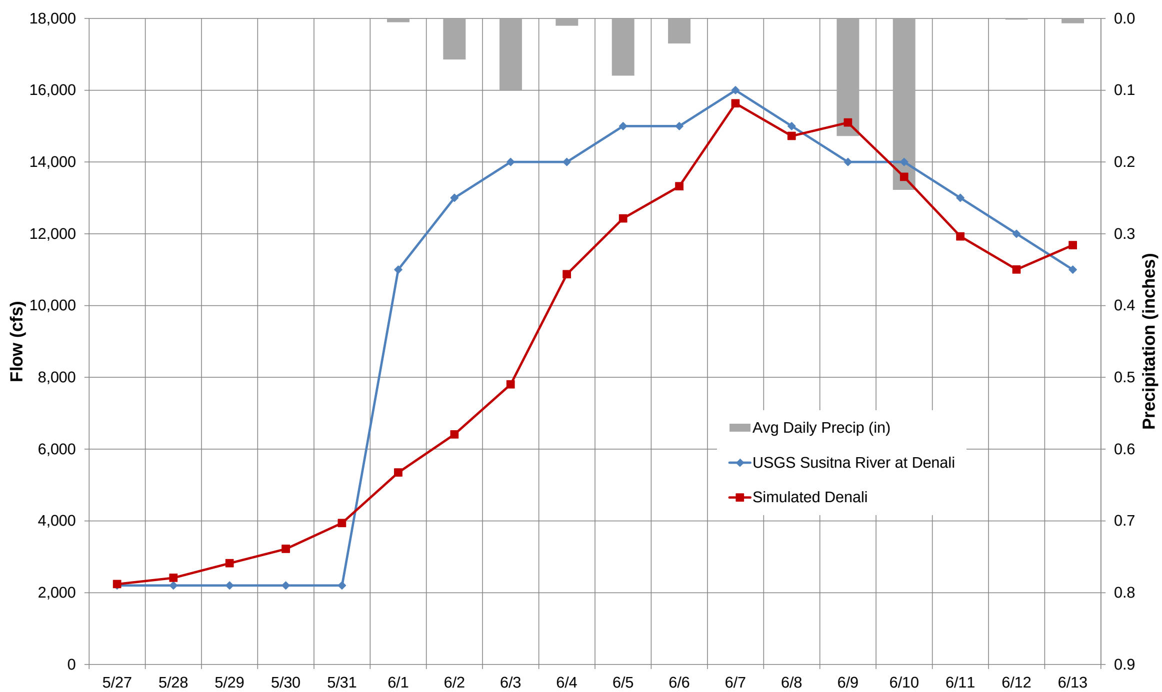


Figure 5.2-1. June 1964 Verification, Susitna River near Denali

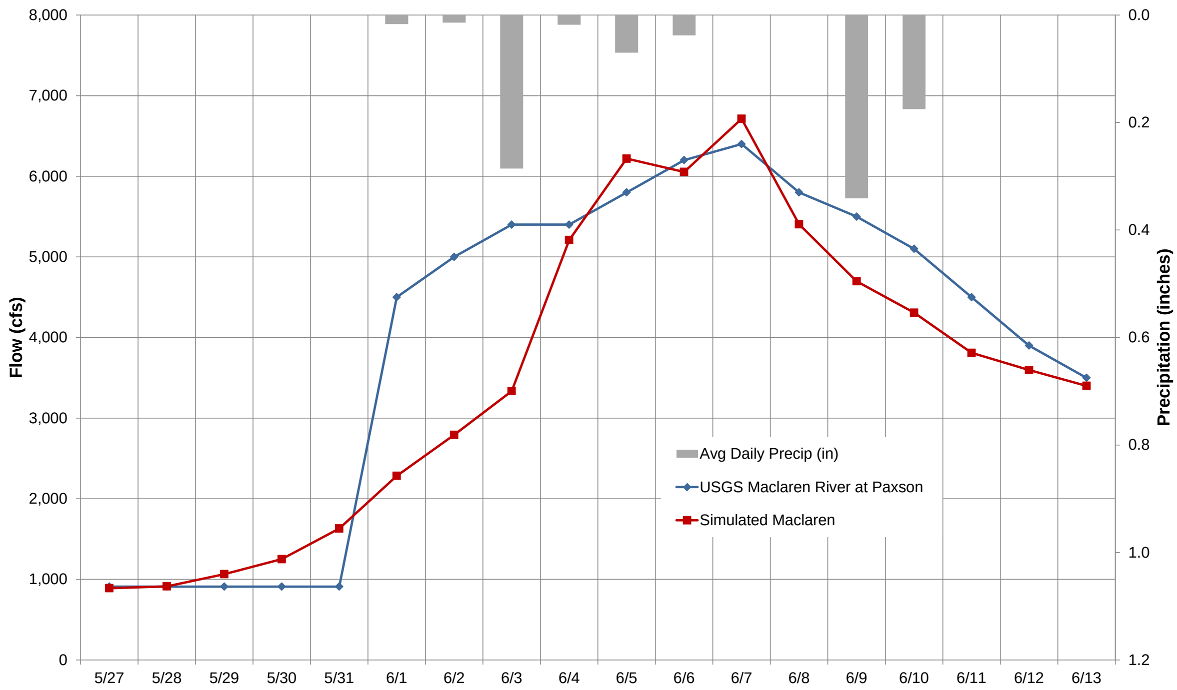


Figure 5.2-2. June 1964 Verification, Maclaren River near Paxson

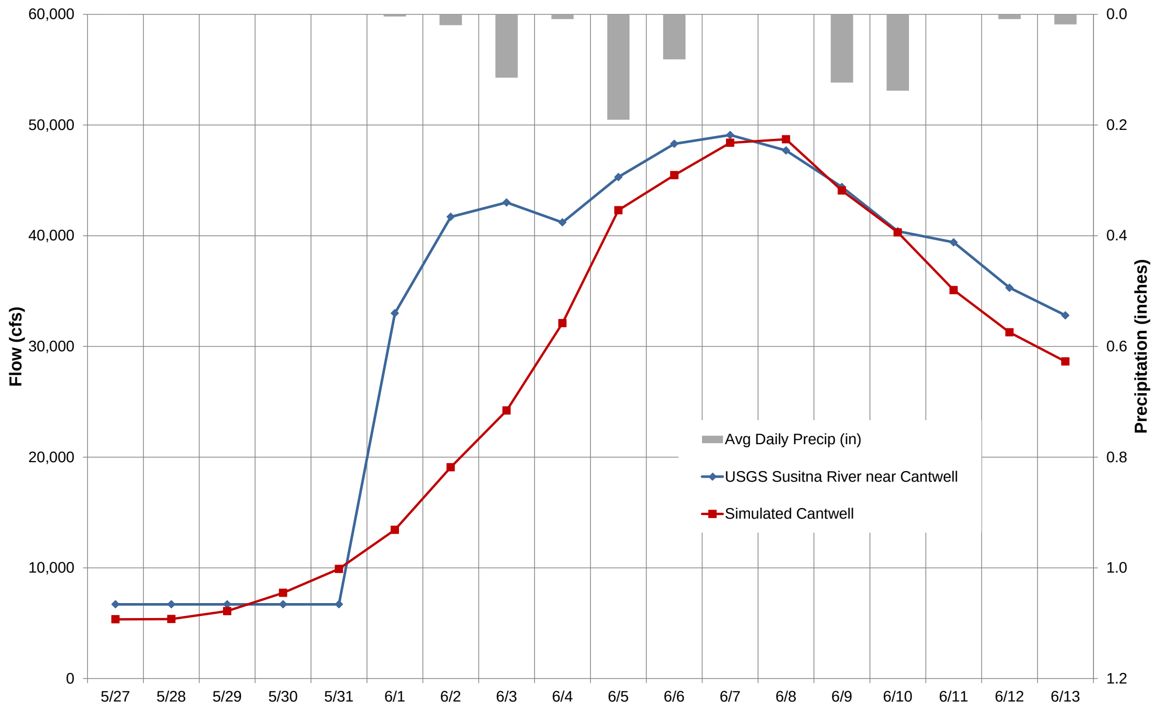


Figure 5.2-3. June 1964 Verification, Susitna River near Cantwell

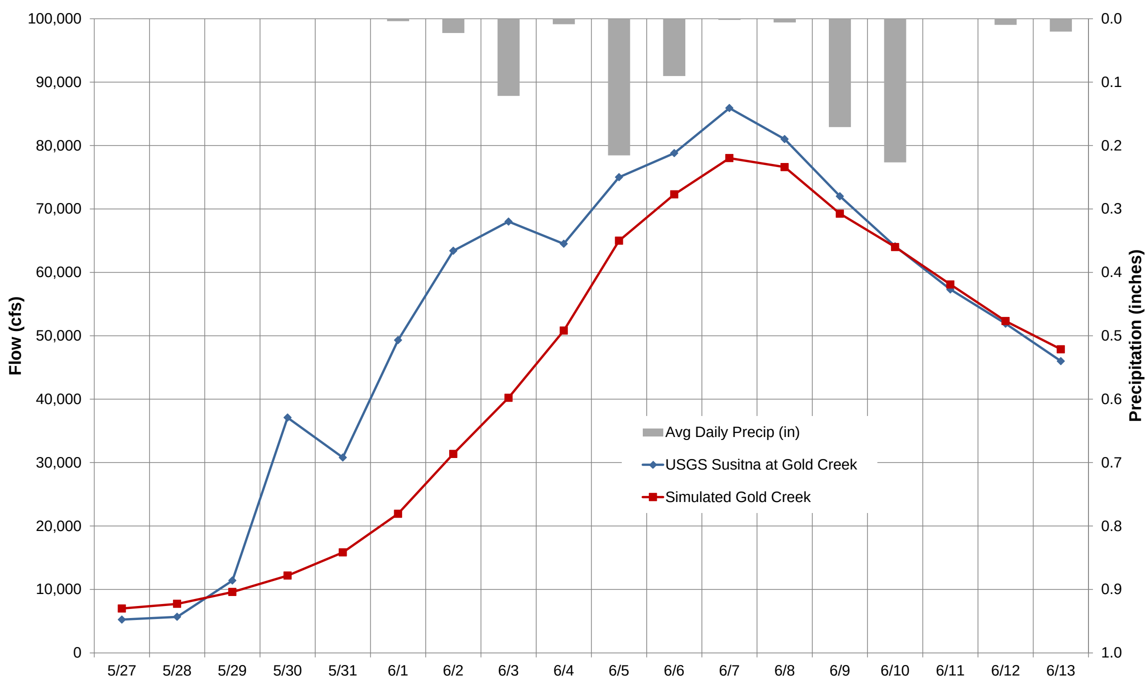


Figure 5.2-4. June 1964 Verification, Susitna River at Gold Creek

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 is 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

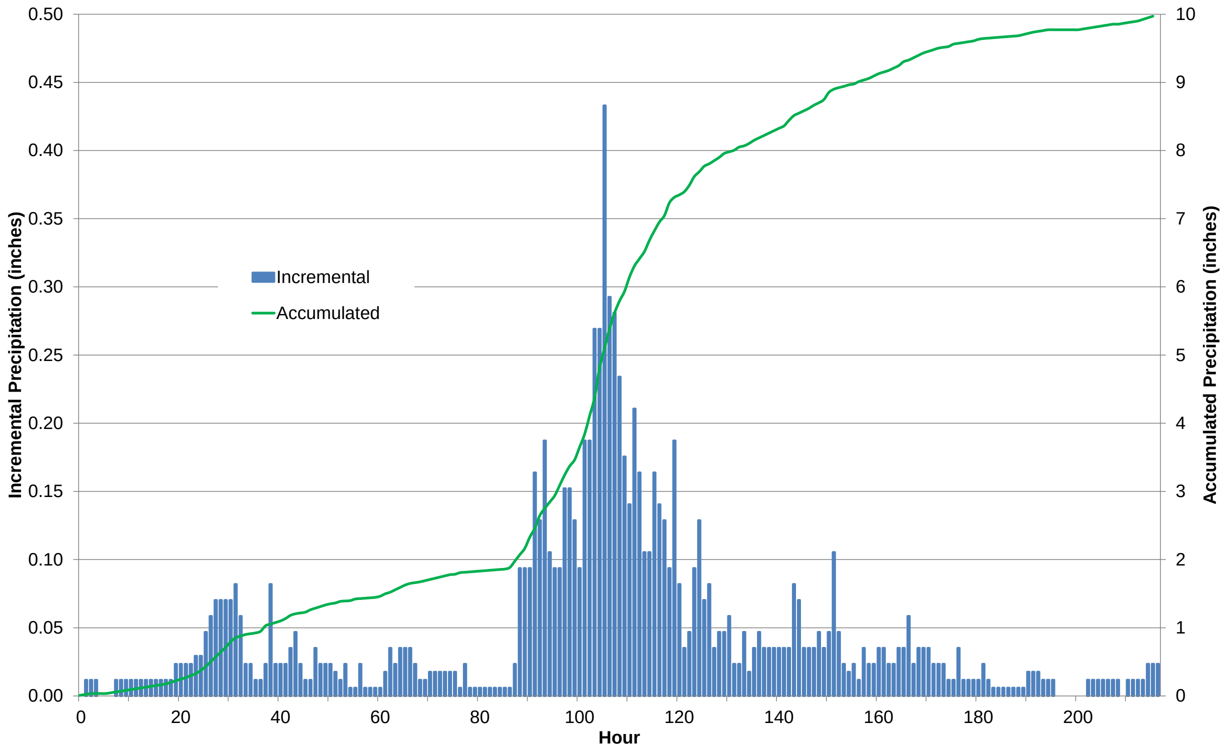


Figure 6.1-1. Incremental and Accumulated All Season PMP – August 1967 Temporal Distribution

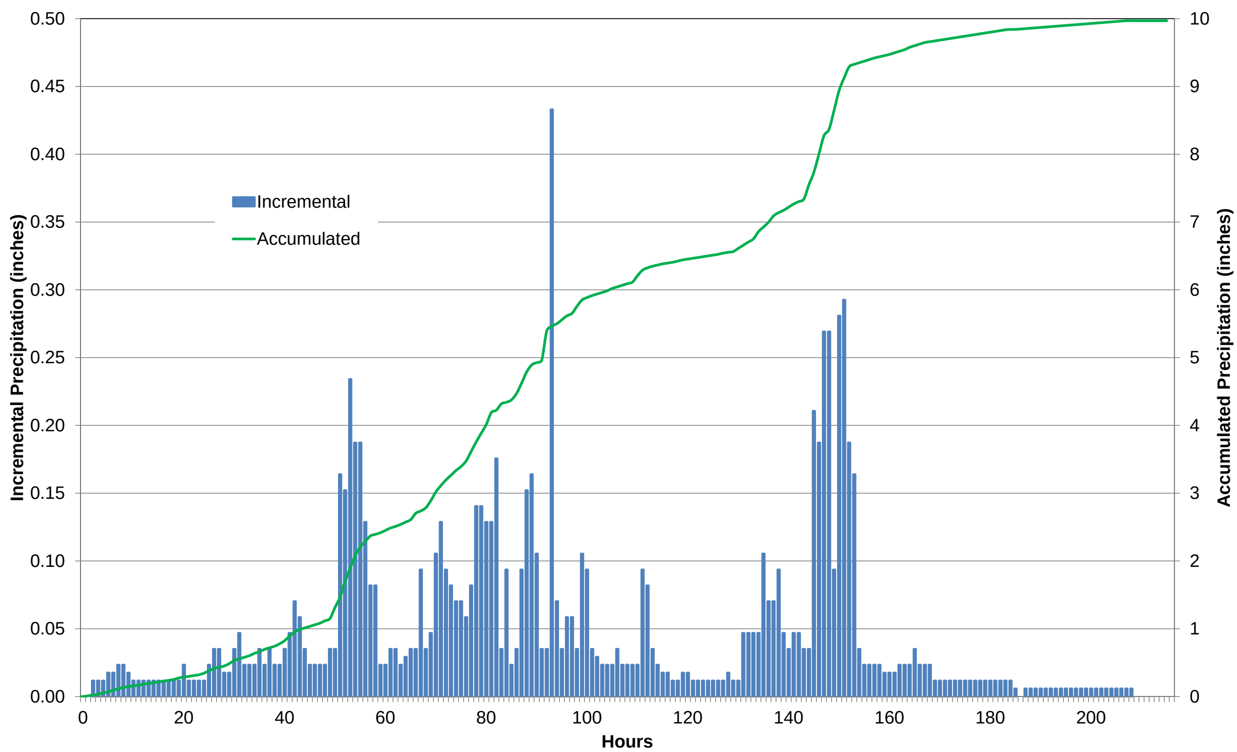


Figure 6.1-2. Incremental and Accumulated All Season PMP – August 1955 Temporal Distribution

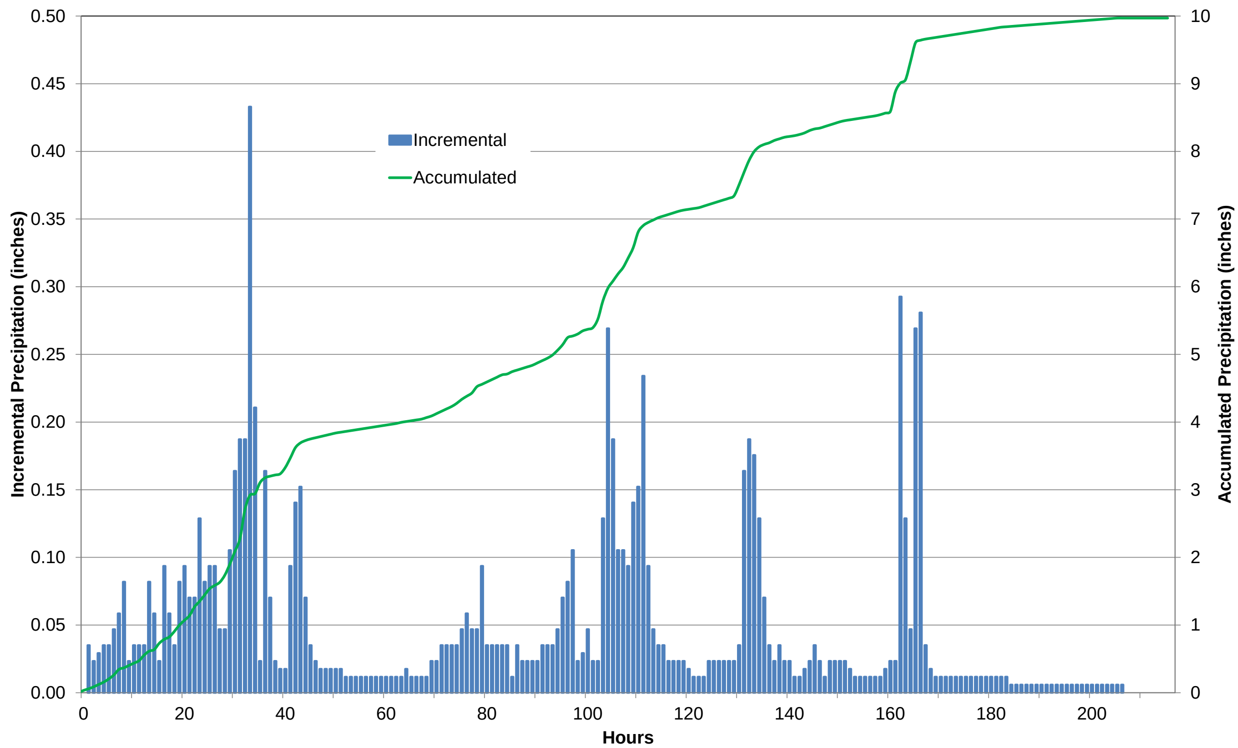


Figure 6.1-3. Incremental and Accumulated All Season PMP – September 2012 Temporal Distribution

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, the lowest 1,000-foot elevation band tributary to Watana. 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.

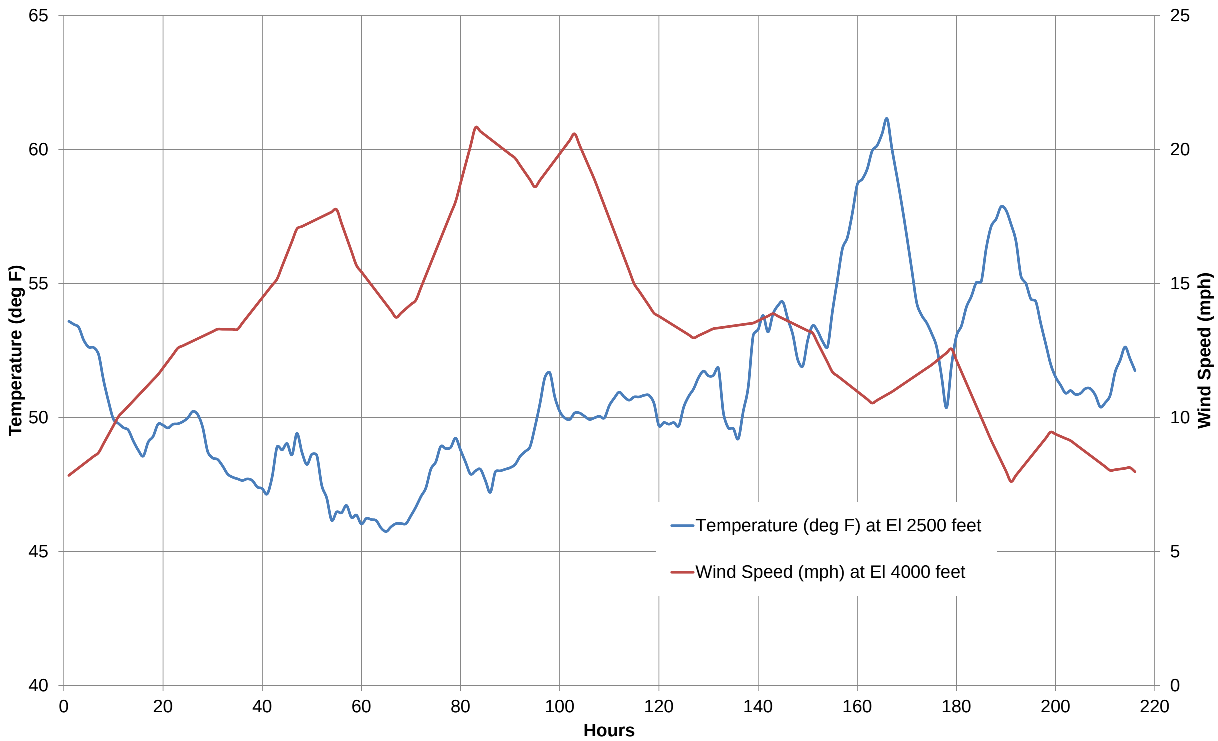


Figure 6.1-4. Temperature and Wind Speed for Period of PMP Rainfall for Seasonality Ratios of 1.00

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.

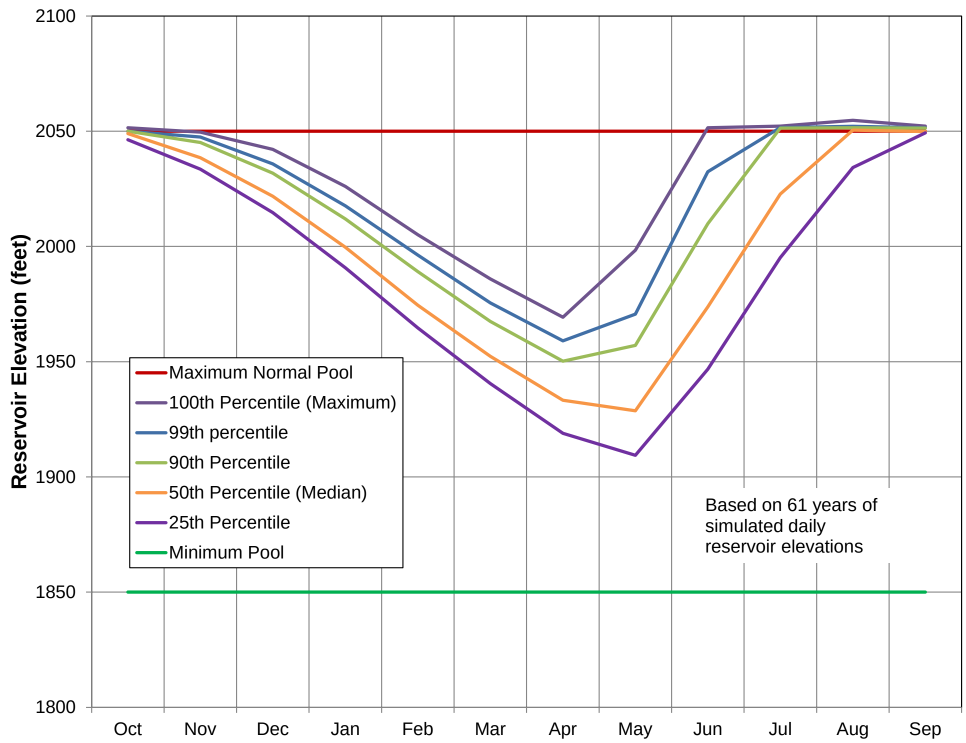


Figure 8.1-1. Reservoir Elevation Frequency – Maximum Load

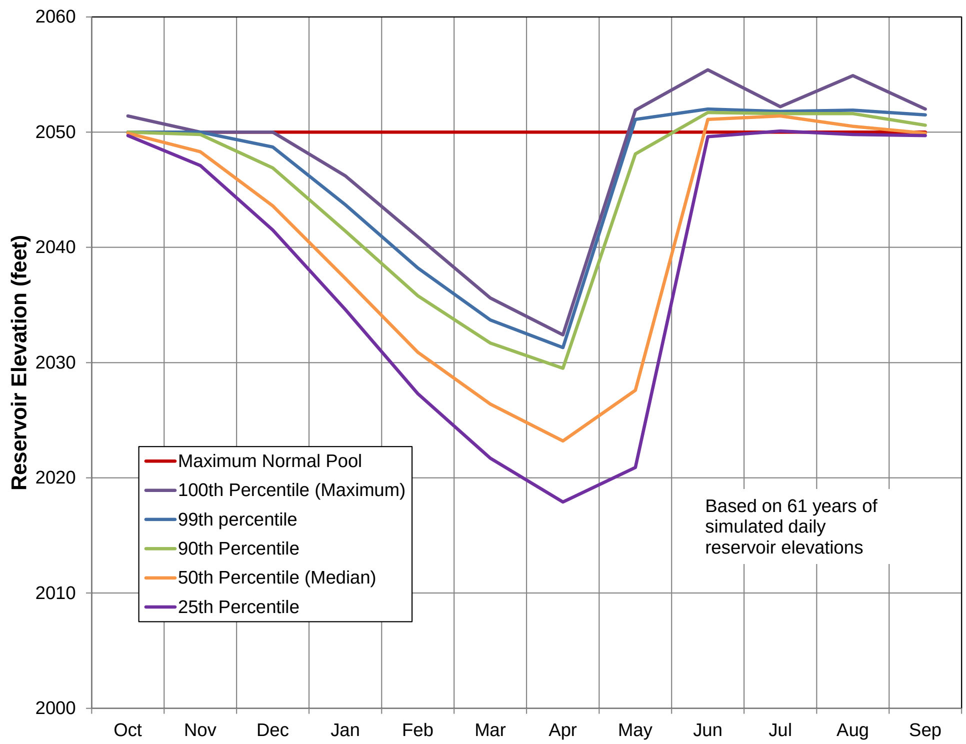


Figure 8.1-2. Reservoir Elevation Frequency – 50% Load

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.

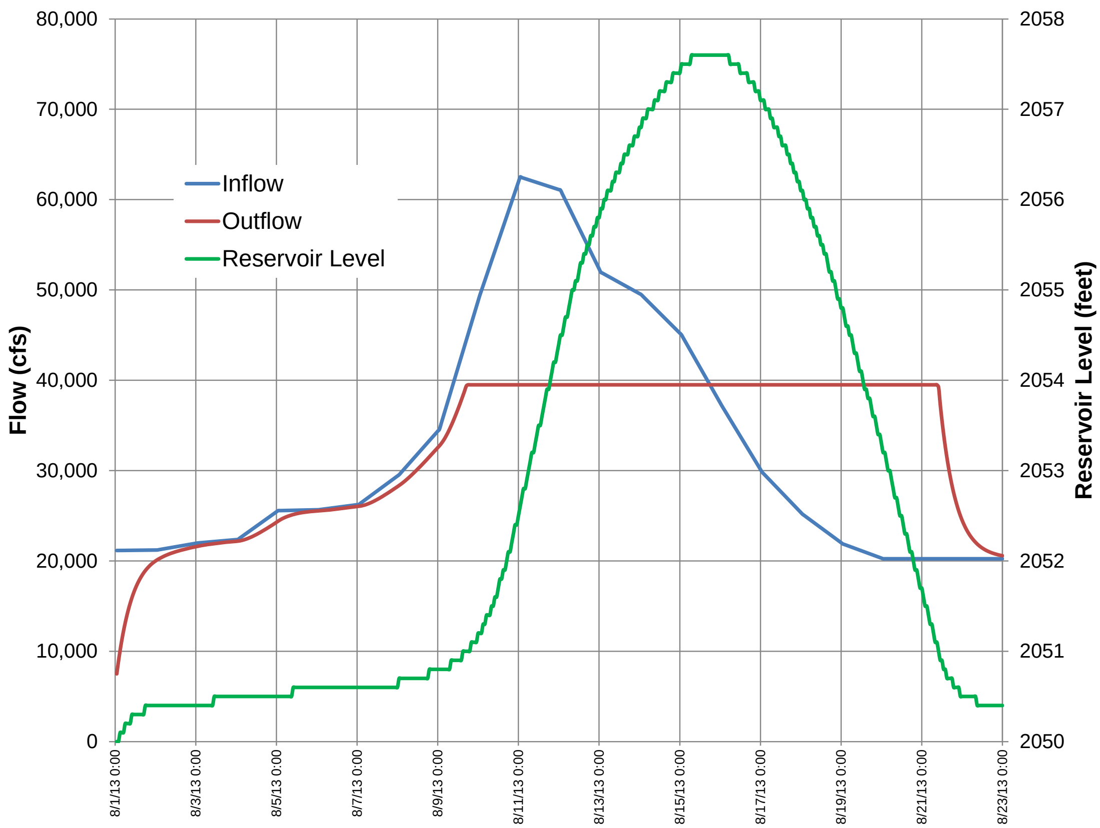


Figure 8.1-3. 50-Year Flood Routing with 8 Fixed-Cone Valves

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) (inches)	Maximum SWE (2) Date	Earliest Day (3) with Snowpack	Latest Day (3) with Snowpack	Years of Available Snowpack Data In the Period of Record
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.

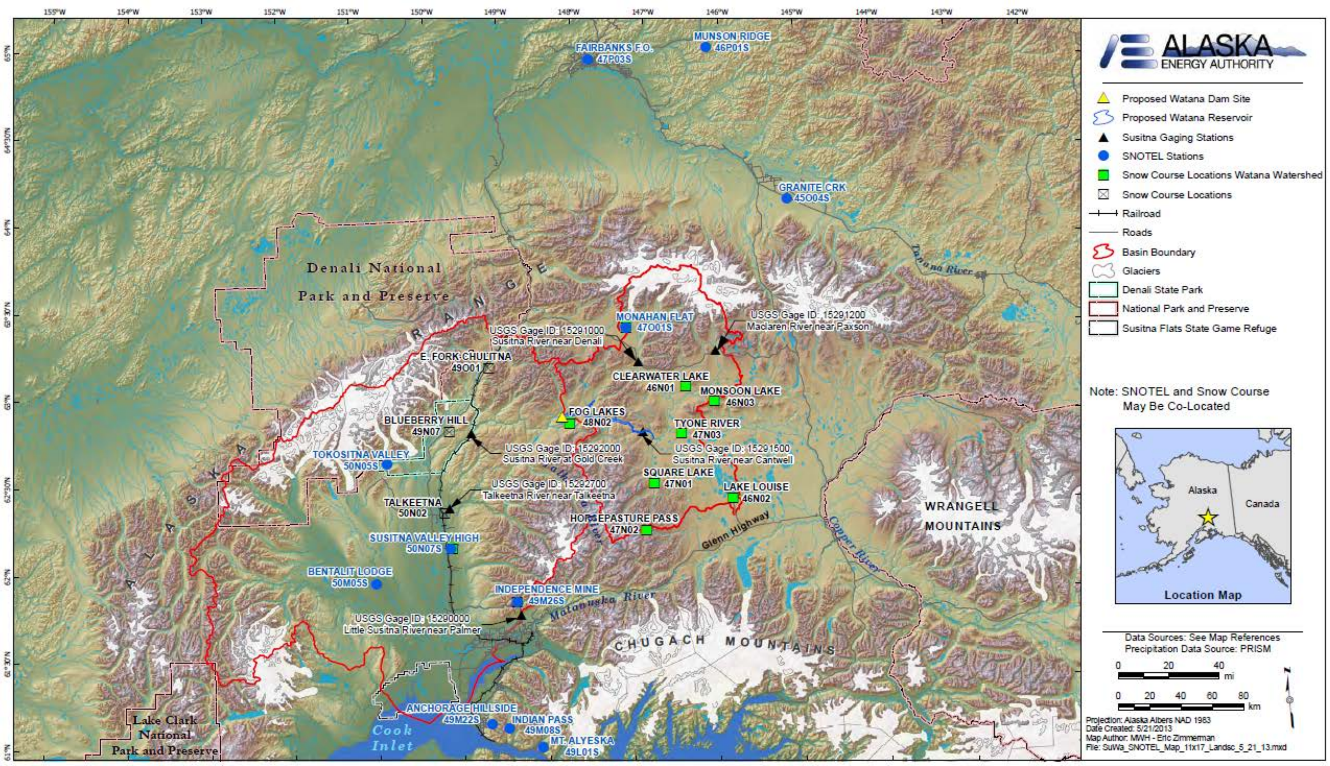


Figure 8.3-1. Location of Snow Courses and SNOTEL Stations

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.

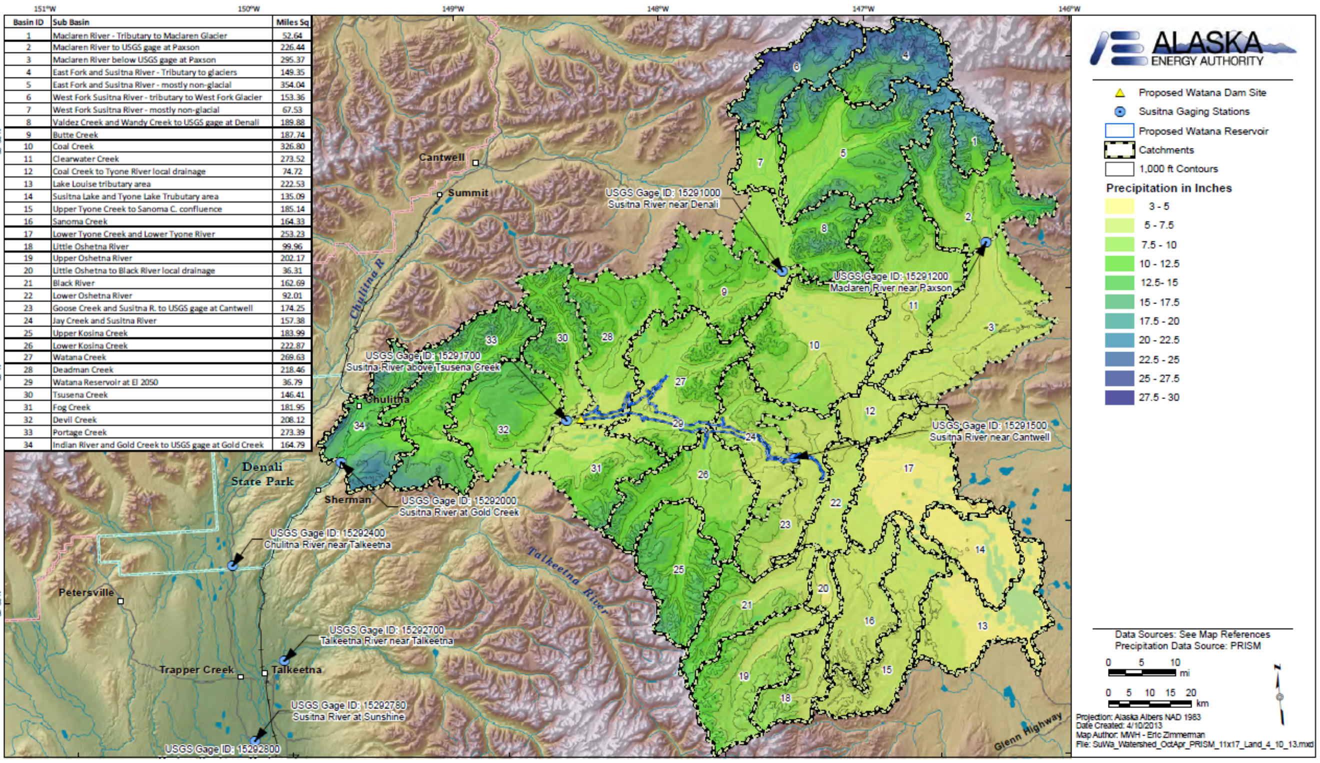


Figure 8.3-2. Average October through April Precipitation

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	Basin Area	Average Precipitation (inches)														Oct-Apr
Number	(sq.mi.)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Oct-Apr	% of Year
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 snowpacks 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 the 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 (shaded cells)

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.

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	281,000	2064.4
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

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.

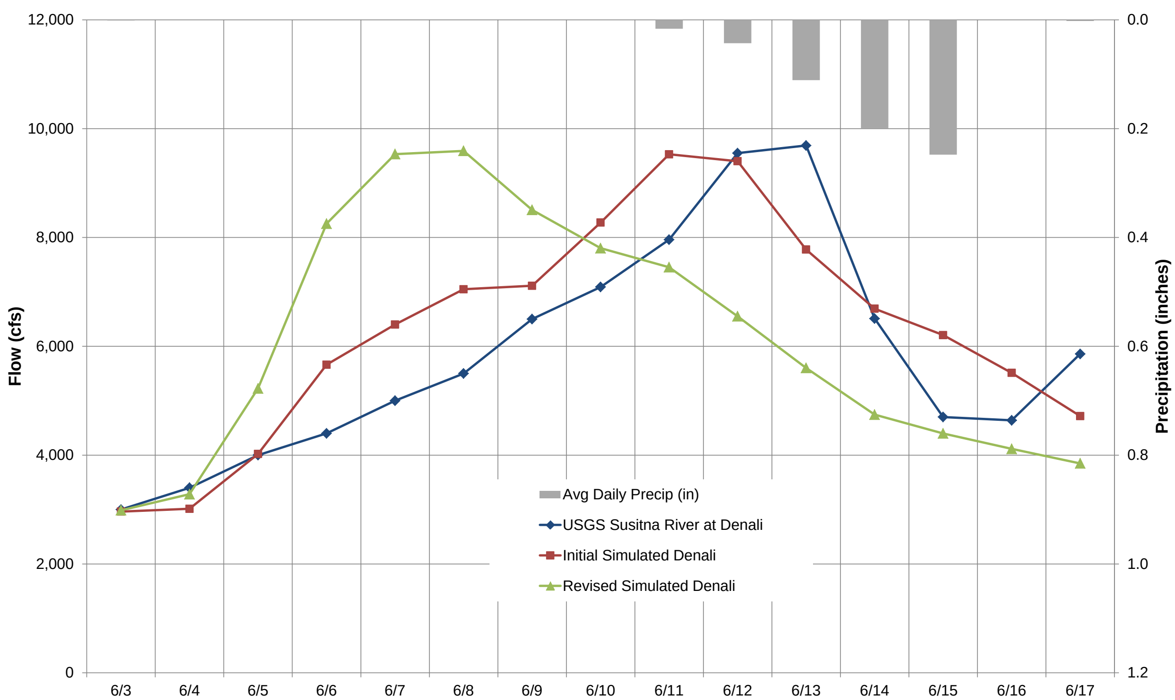


Figure 9.2-1. June 1971 Reanalysis, Susitna River near Denali

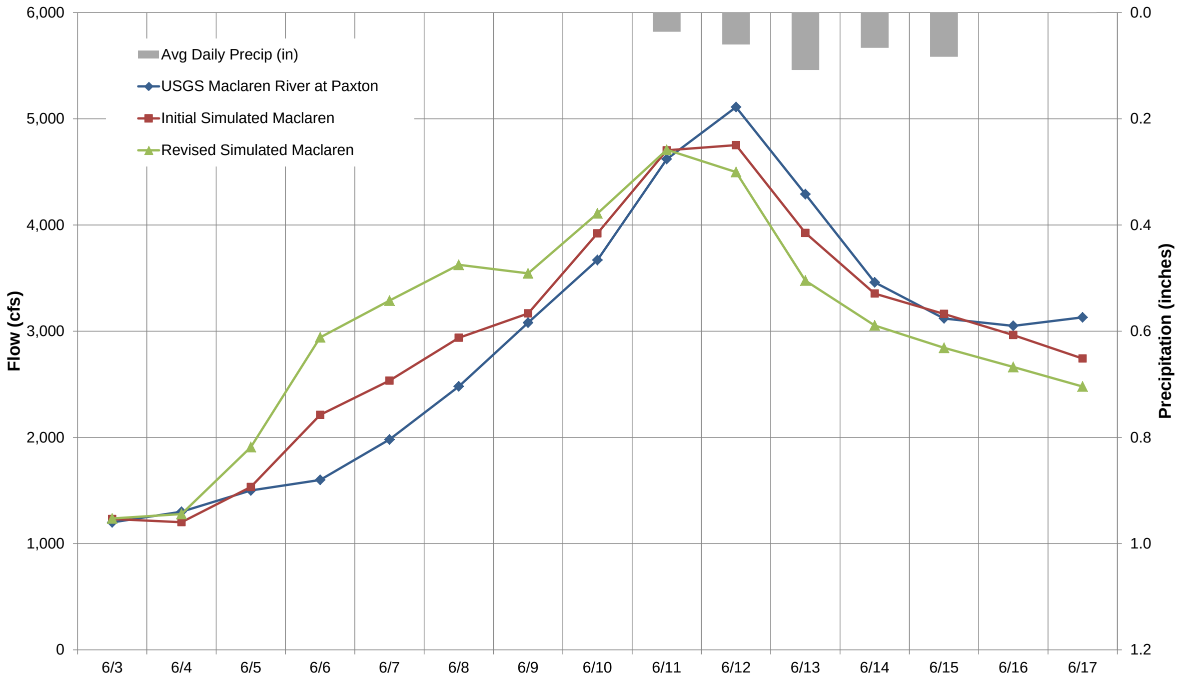


Figure 9.2-2. June 1971 Reanalysis, Maclaren River near Paxson

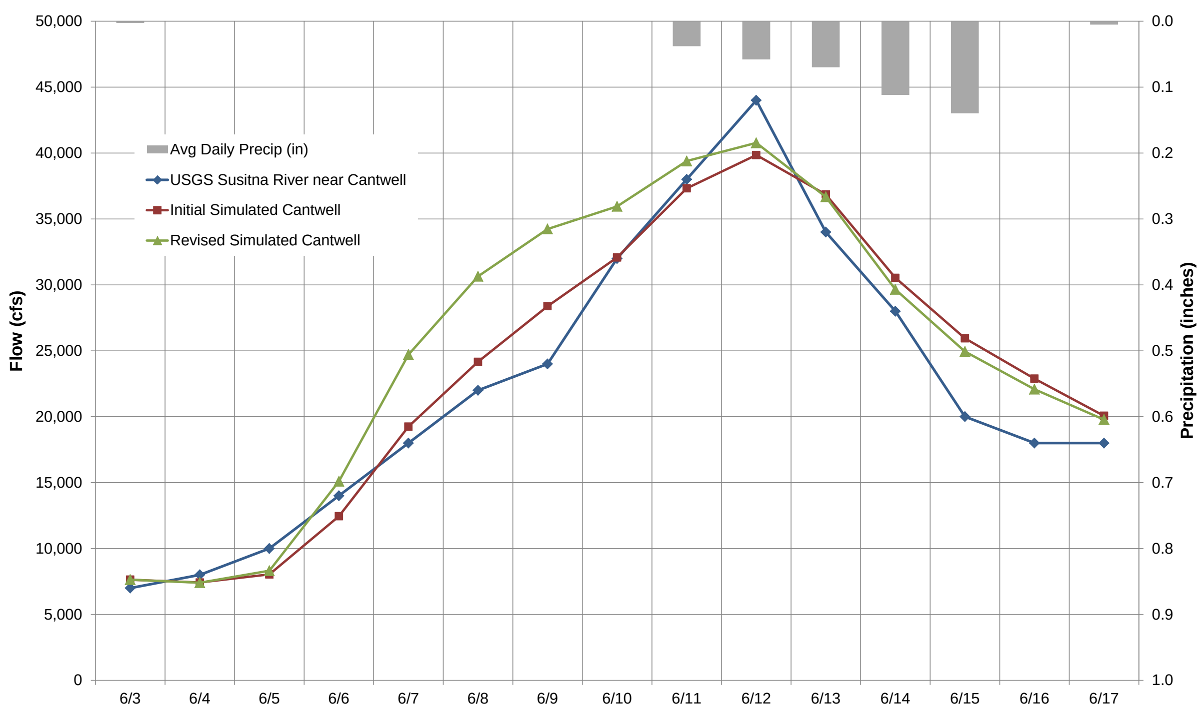


Figure 9.2-3. June 1971 Reanalysis, Susitna River near Cantwell

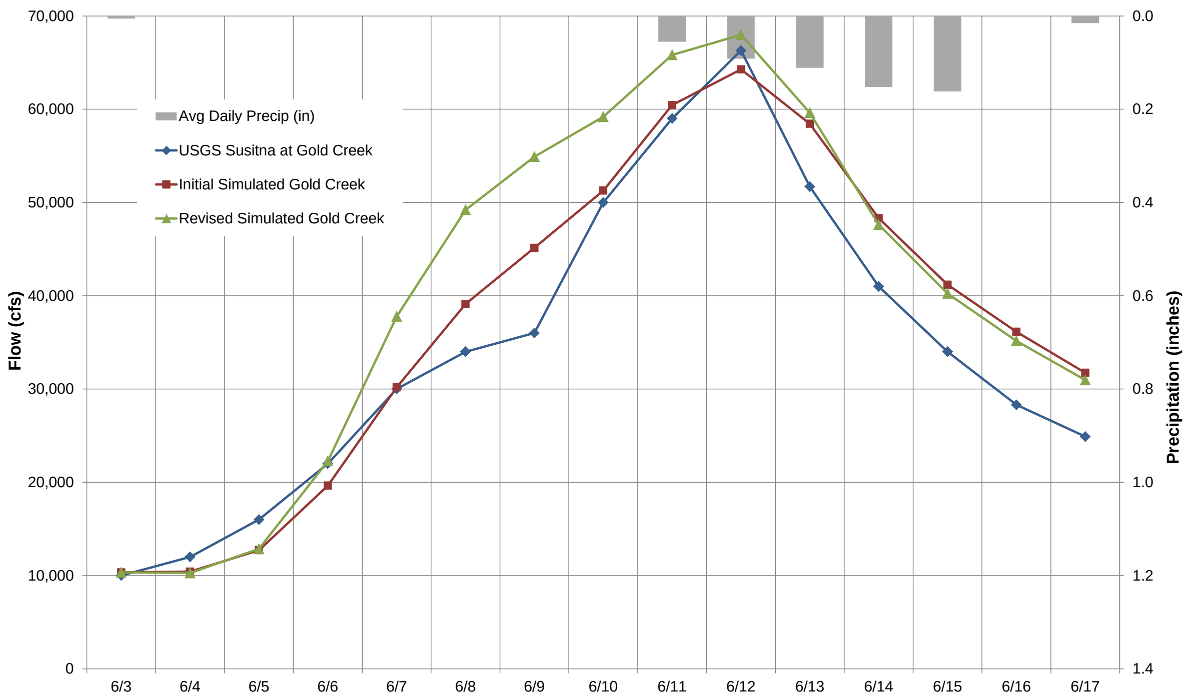


Figure 9.2-4. June 1971 Reanalysis, Susitna River at Gold Creek

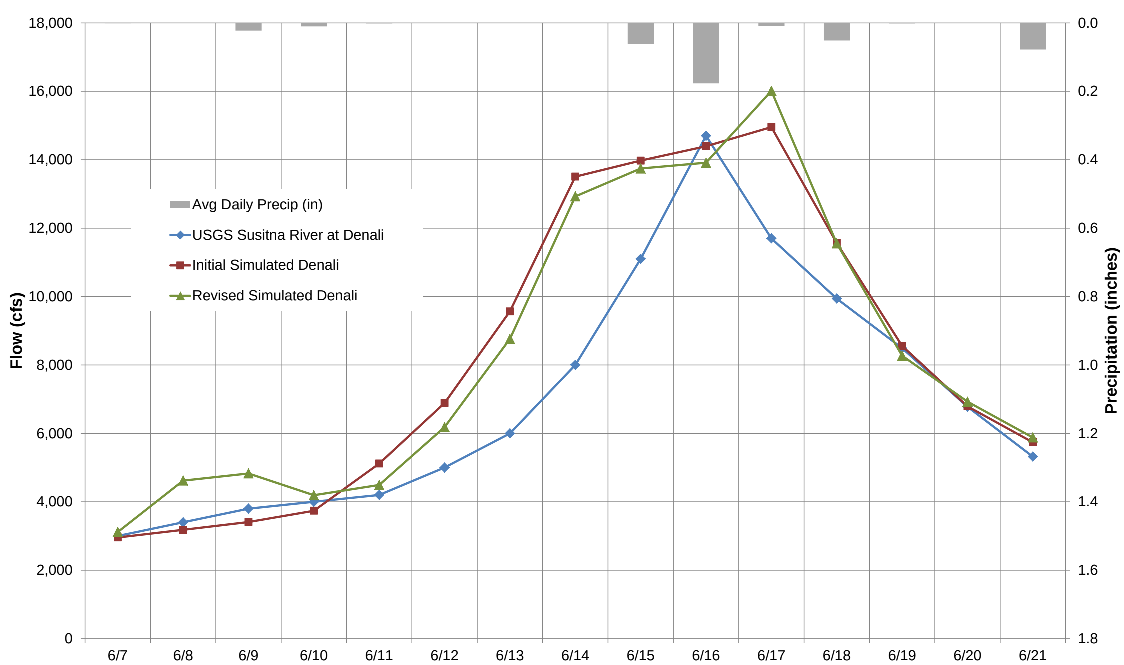


Figure 9.2-5. June 1972 Reanalysis, Susitna River near Denali

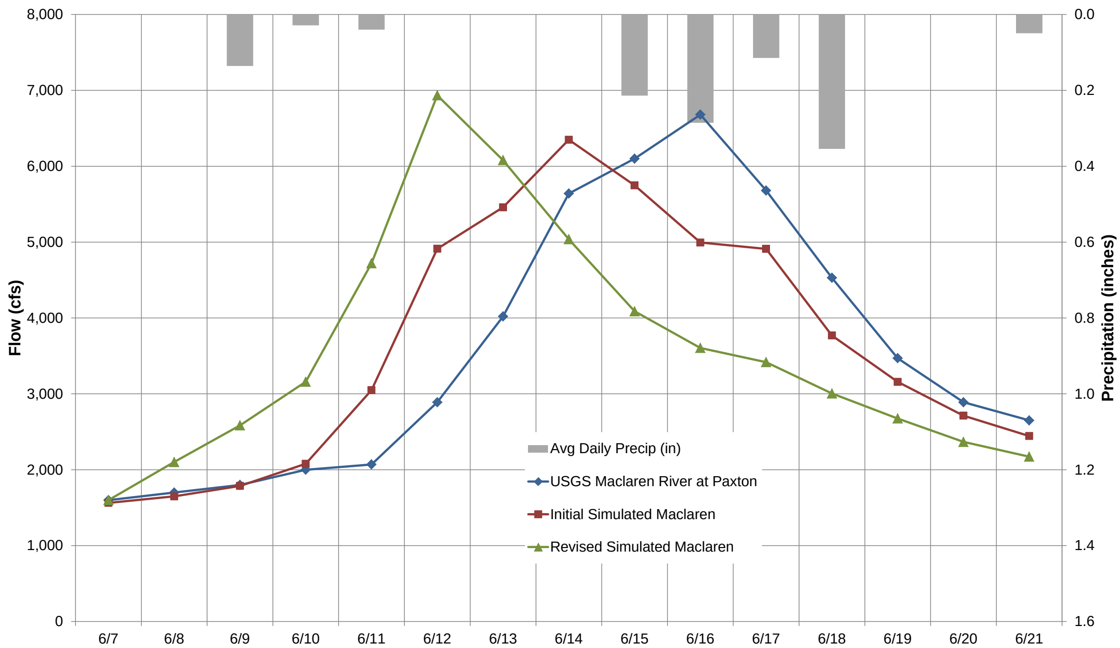


Figure 9.2-6. June 1972 Reanalysis, Maclaren River near Paxson

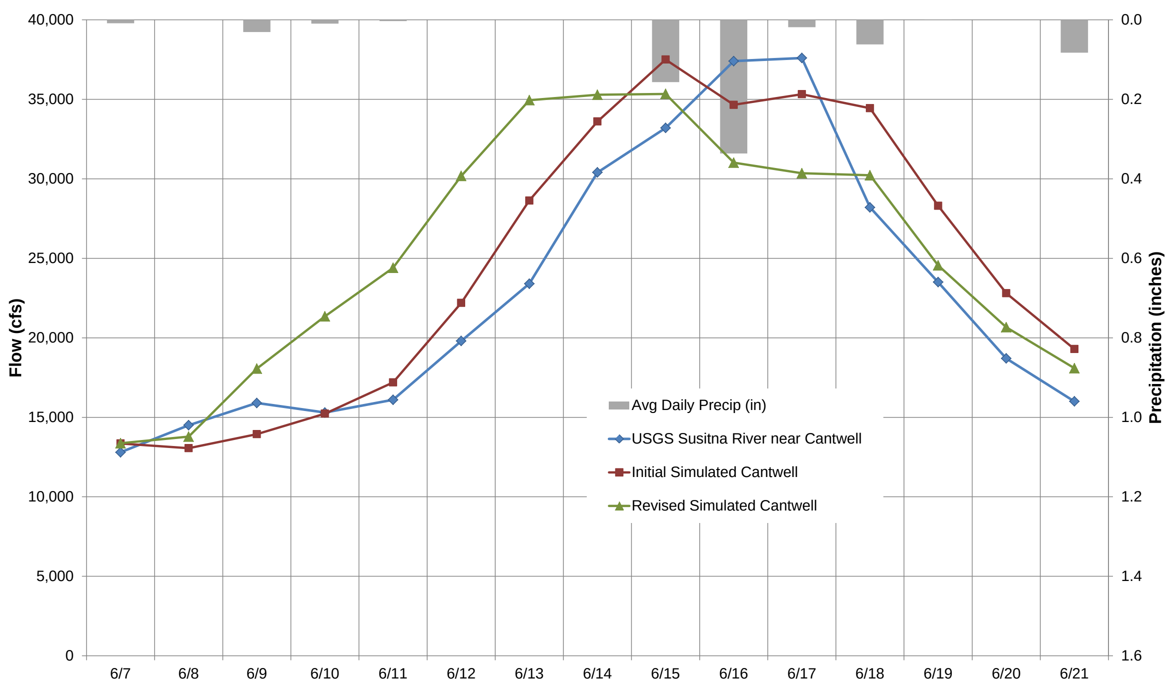


Figure 9.2-7. June 1972 Reanalysis, Susitna River near Cantwell

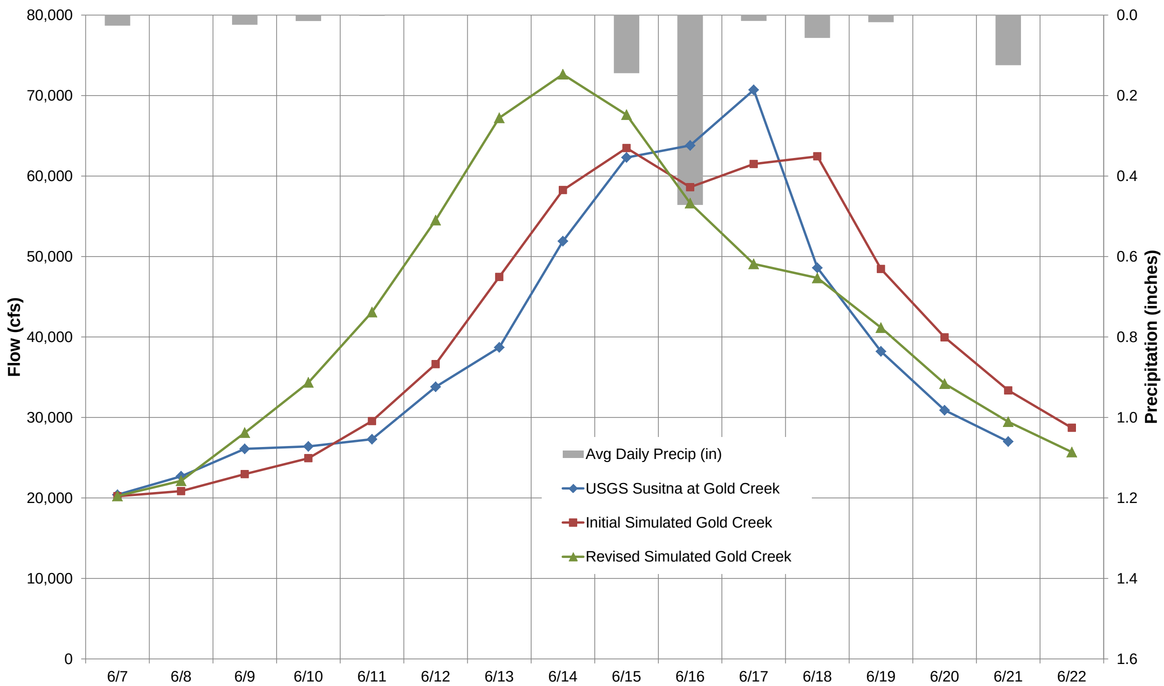


Figure 9.2-8. June 1972 Reanalysis, Susitna River at Gold Creek

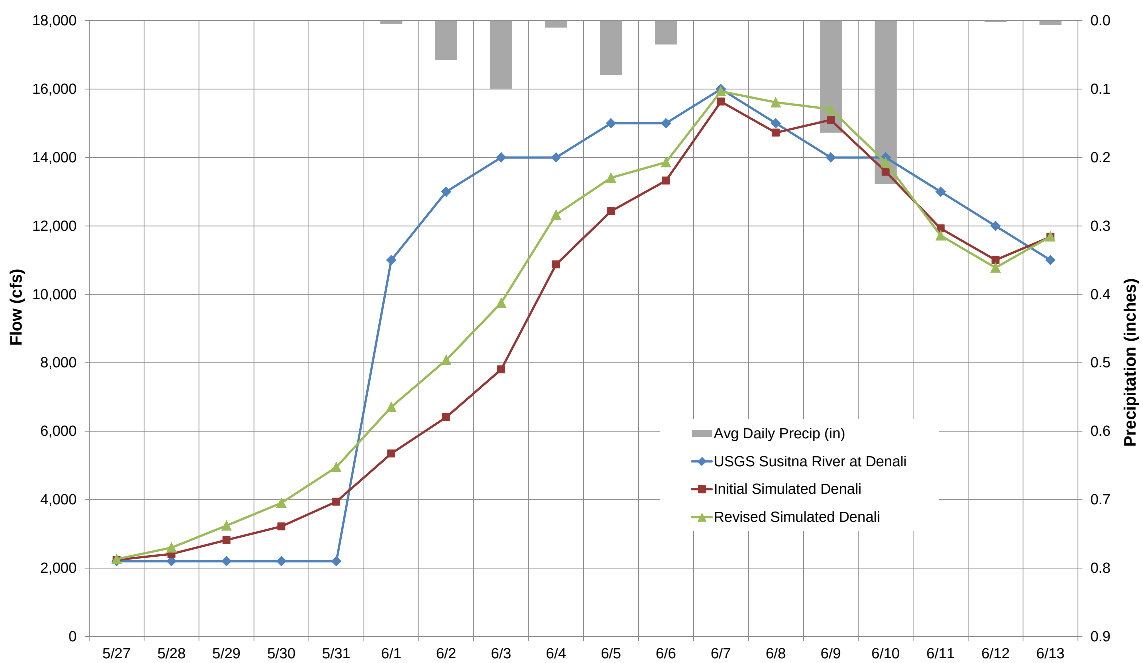


Figure 9.2-9. June 1964 Reanalysis, Susitna River near Denali

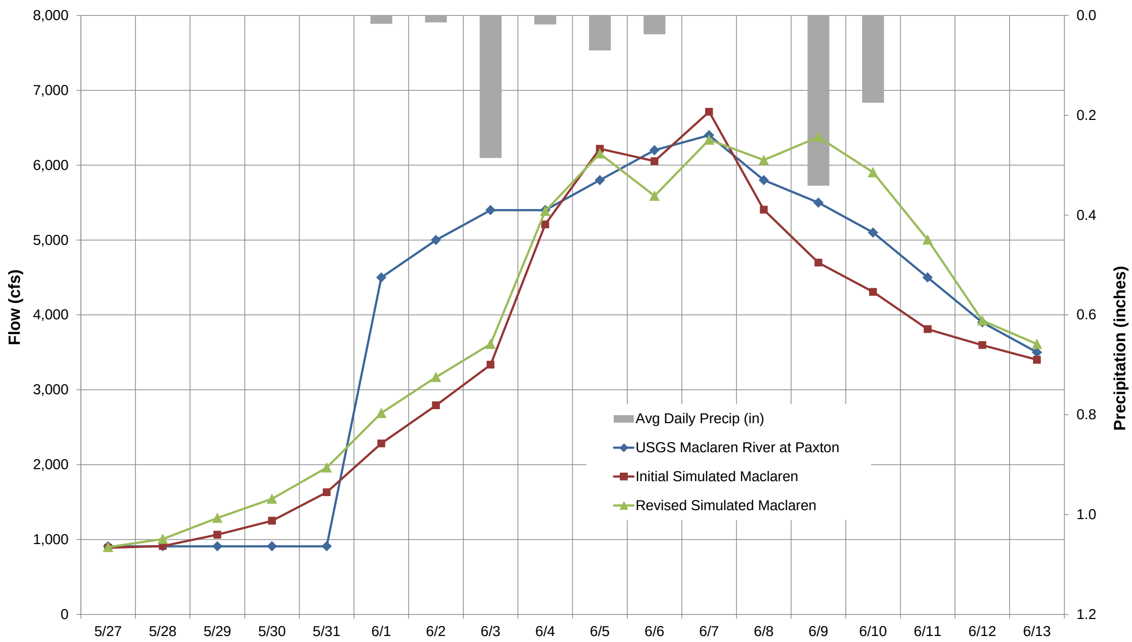


Figure 9.2-10. June 1964 Reanalysis, Maclaren River near Paxson

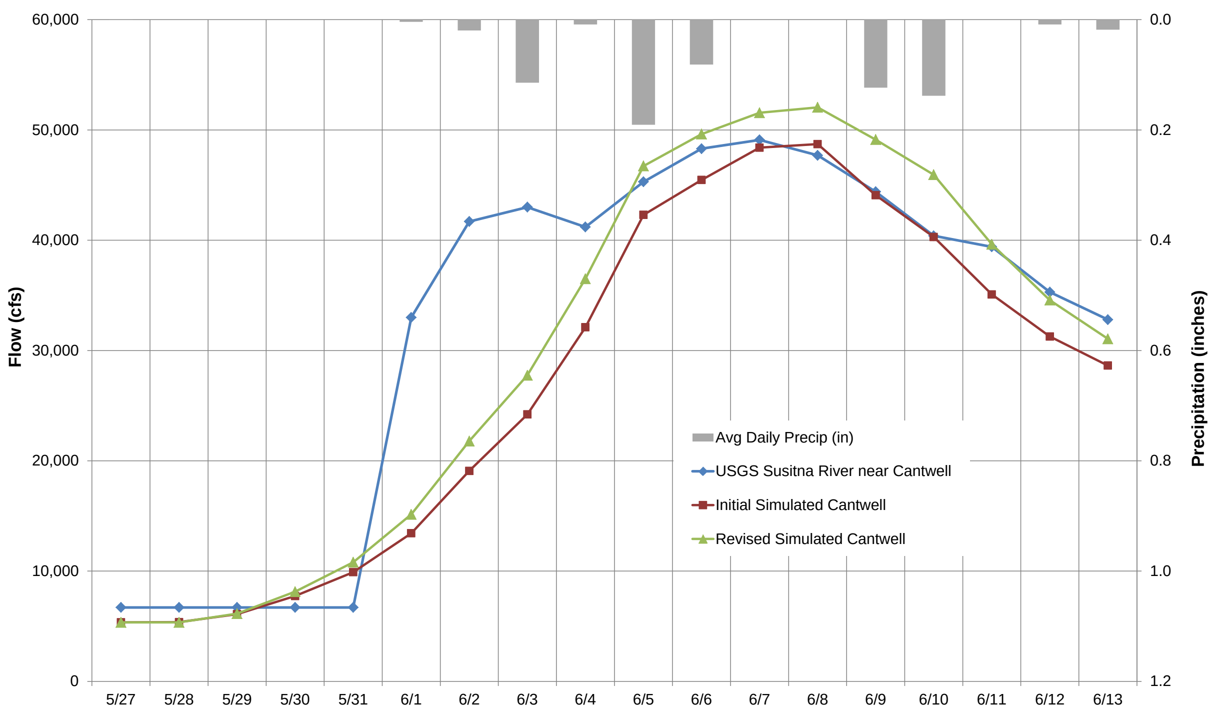


Figure 9.2-11. June 1964 Reanalysis, Susitna River near Cantwell

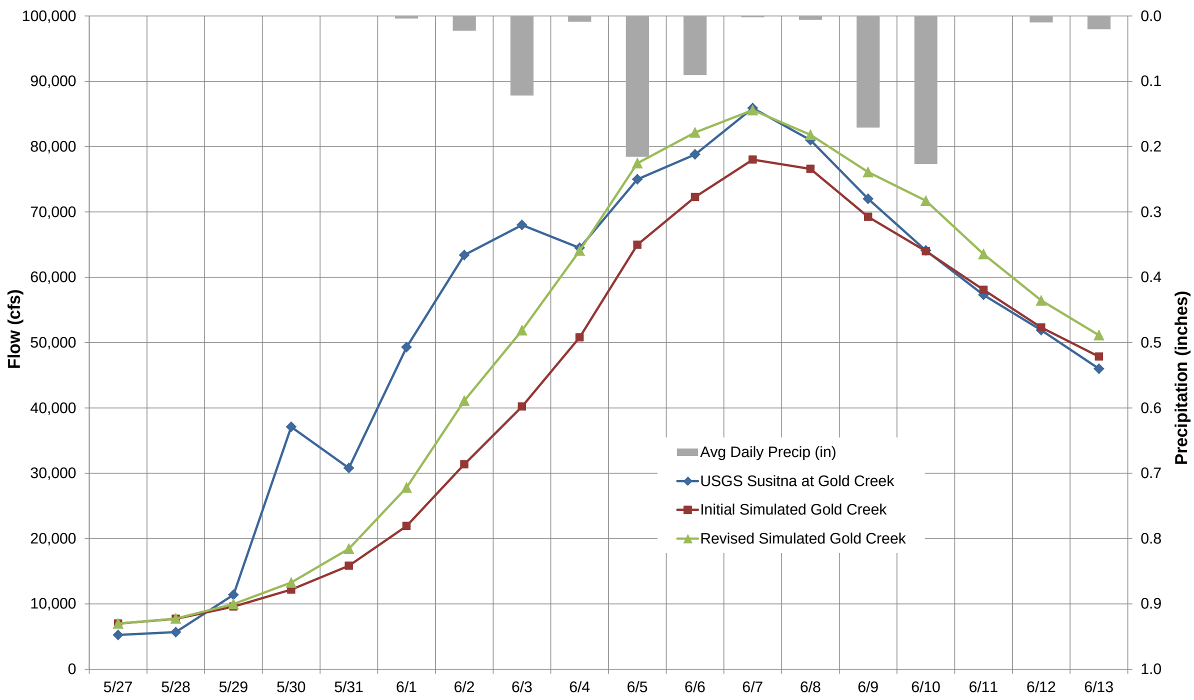


Figure 9.2-12. June 194 Reanalysis, Susitna River at Gold Creek

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.

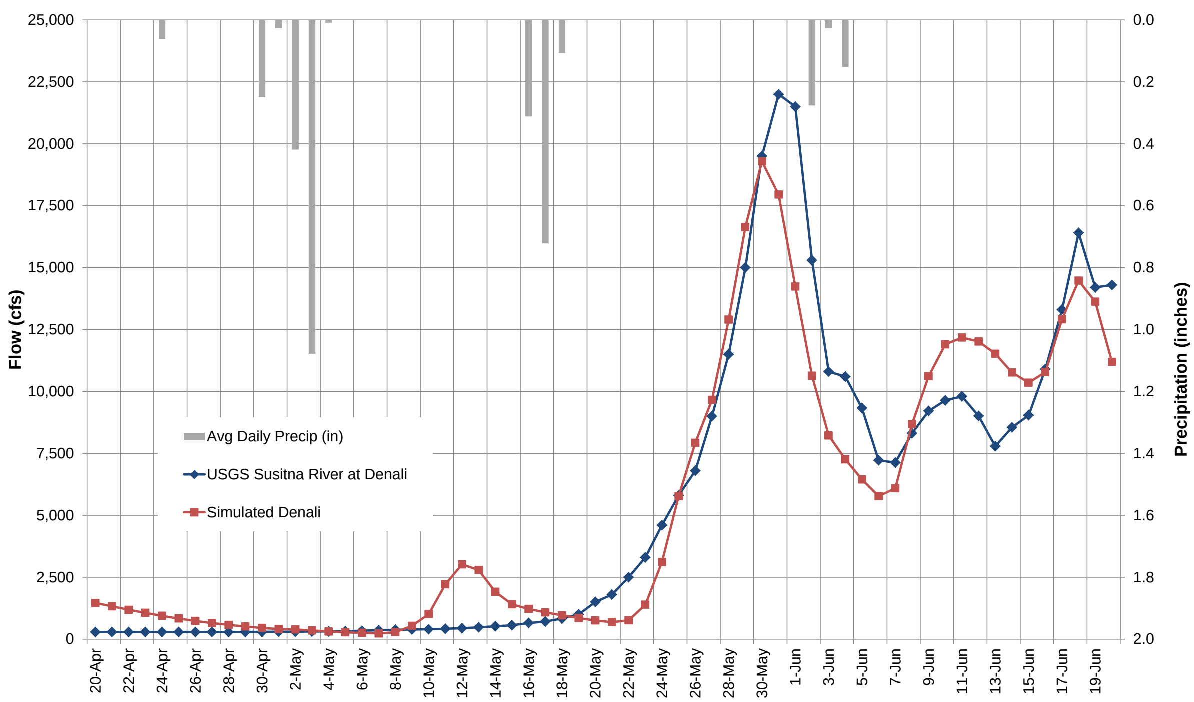


Figure 9.2-13. May-June 2013 Simulation, Susitna River near Denali

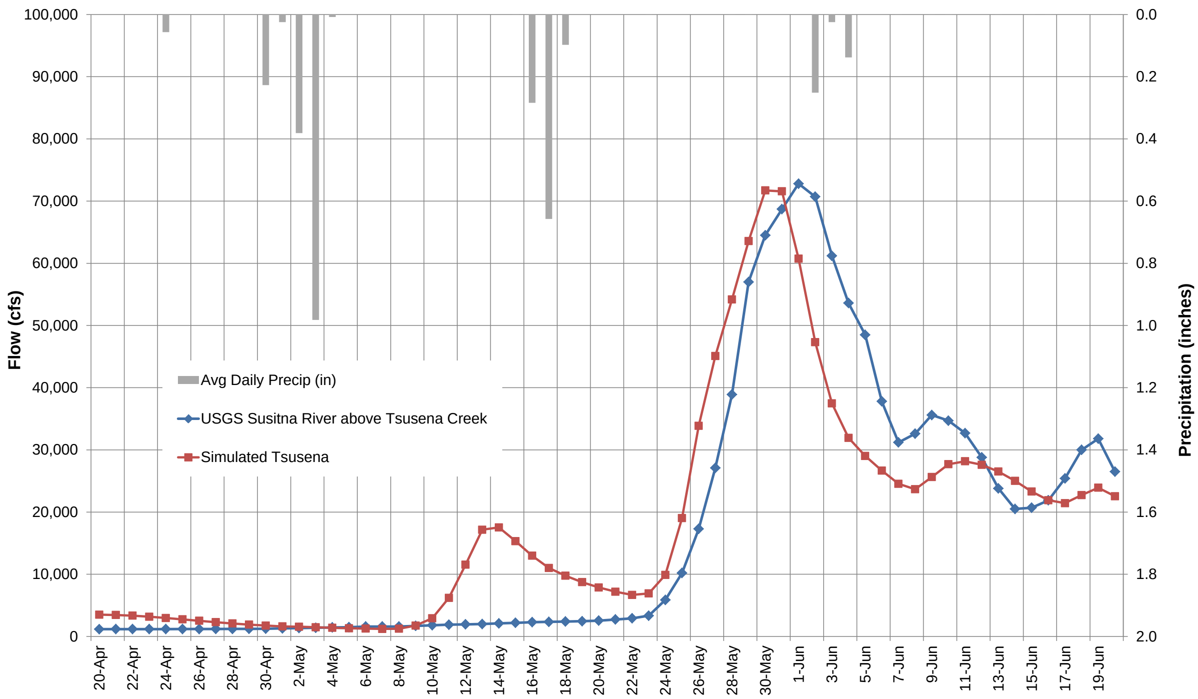


Figure 9.2-14. May-June 2013 Simulation, Susitna River above Tsusena Creek

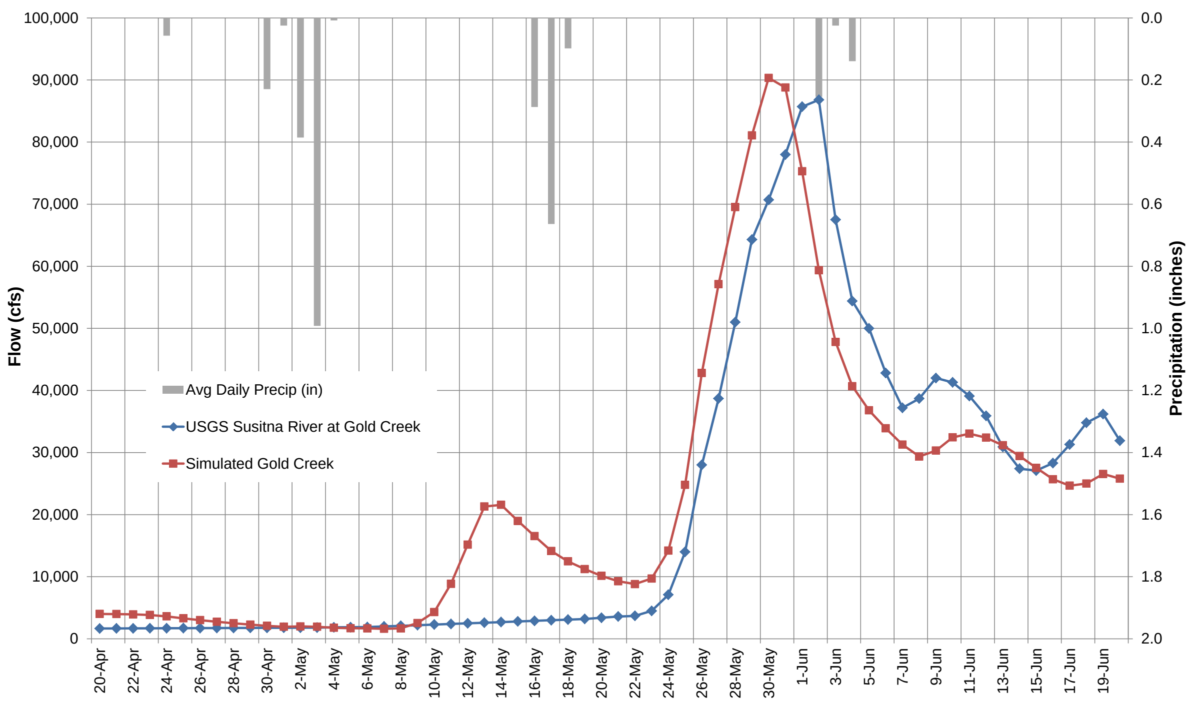


Figure 9.2-15. May-June 2013 Simulation, Susitna River at Gold Creek

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.

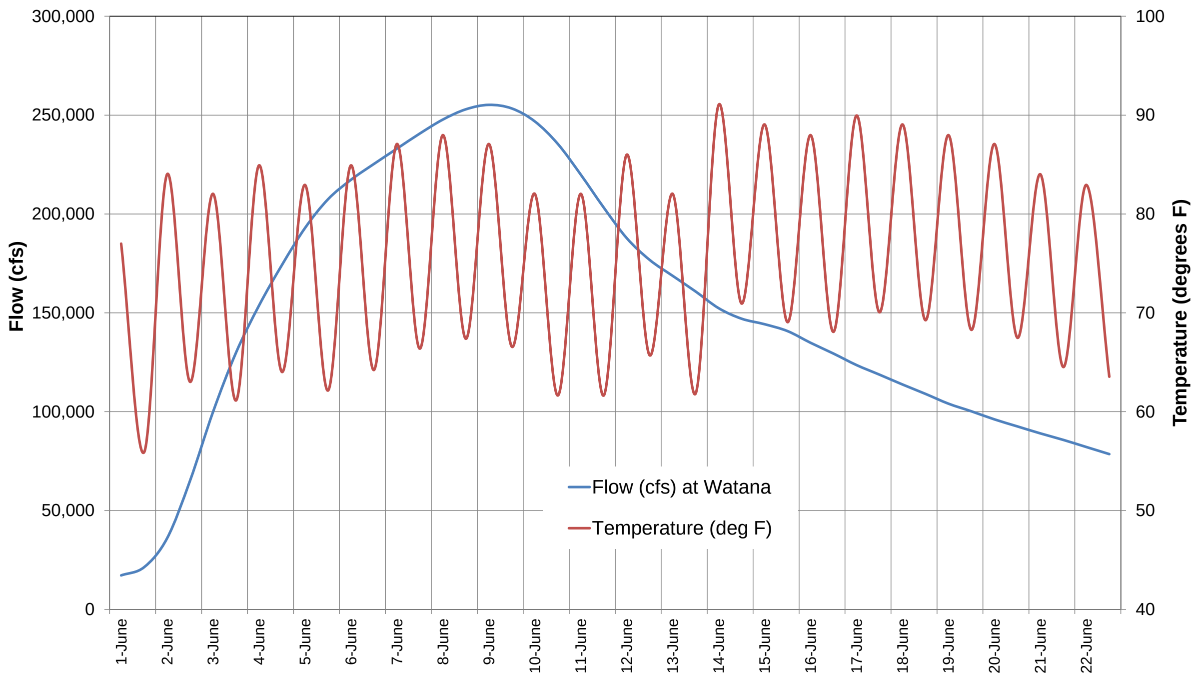


Figure 9.2-16. Sun-on-Snow PMF and Air Temperatures

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.

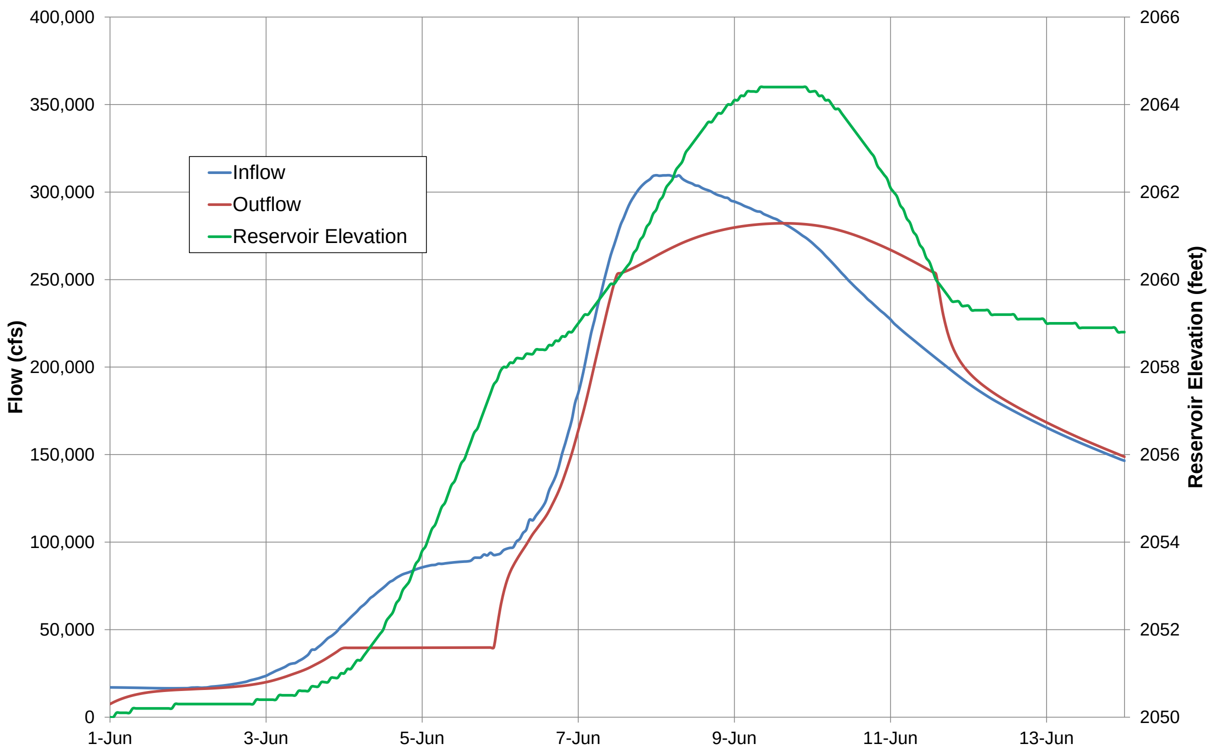


Figure 9.3-1. Watana Dam PMF Inflow, Outflow, and Reservoir Elevation

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	Watnana 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.

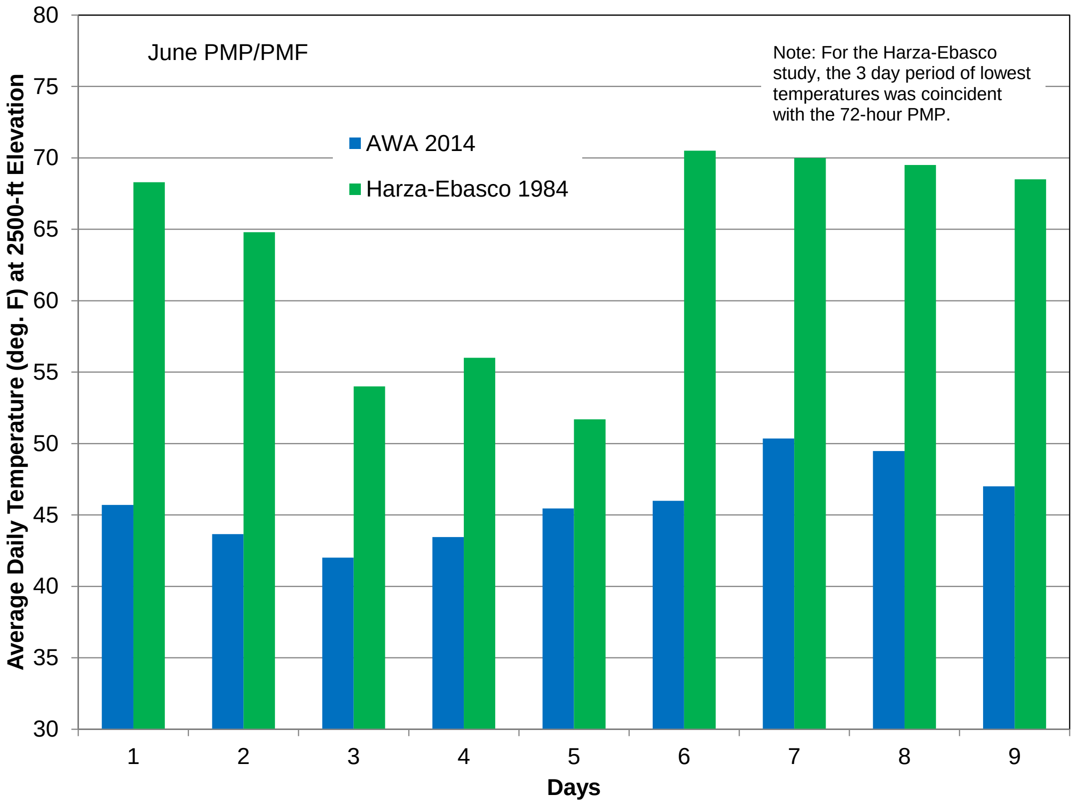


Figure 9.4-1. Temperature Comparison – June PMF

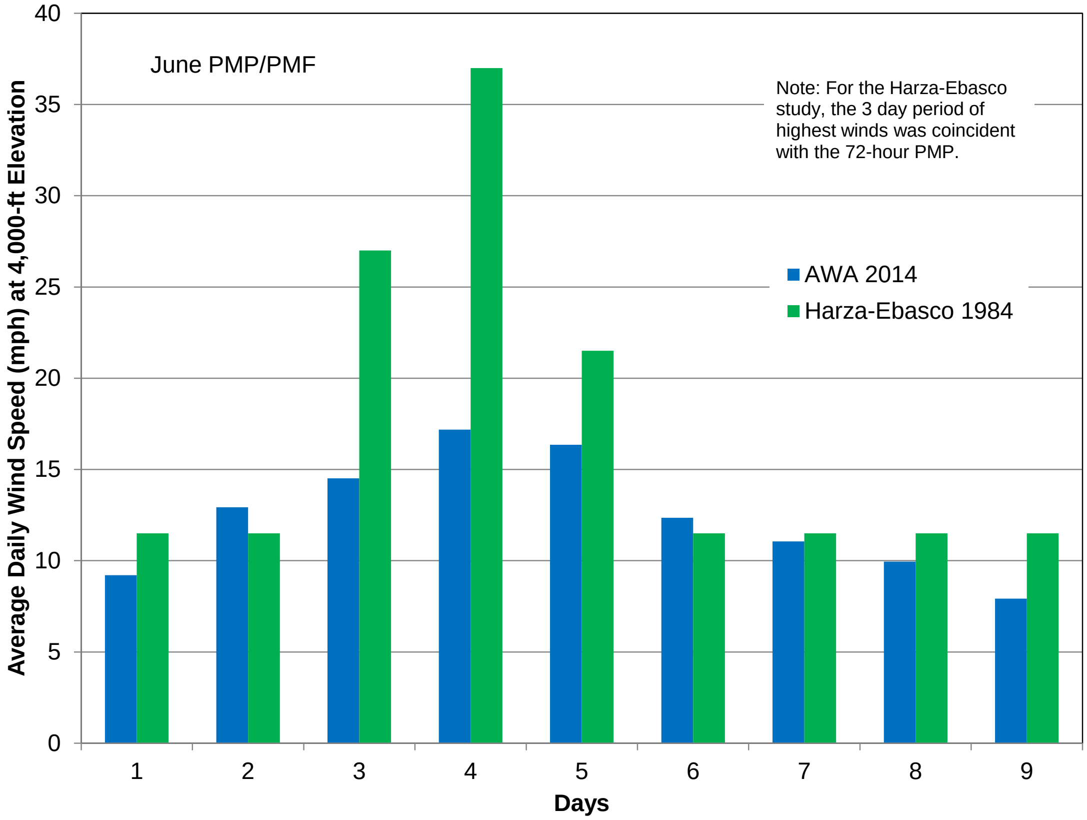


Figure 9.4-2. Wind Speed Comparison – June PMF

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

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PART C – ATTACHMENT 1: FINAL DRAFT PROBABLE MAXIMUM FLOOD STUDY REPORT

APPENDIX A: PROBABLE MAXIMUM PRECIPITATION STUDY

APPENDIX B: INTERMEDIATE FLOOD ROUTING TECHNICAL MEMORANDUM

Appendix A

Probable Maximum Precipitation Study

14-07-REP

by

Applied Weather Associates

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Report
14-07-REP
v1.0

Susitna-Watana Hydroelectric Project
Probable Maximum Precipitation Study

FINAL DRAFT

AEA11-022

Prepared for:
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May 2014

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TABLE OF CONTENTS

List of Attachments

List of Tables

List of Figures

EXECUTIVE SUMMARY

Applied Weather Associates (AWA) has completed a site-specific Probable Maximum Precipitation (SSPMP) study for the Susitna River basin located south of the Alaska Range and north east of Anchorage in Alaska. The purpose of the study was to determine PMP values specific to the watershed, taking into account topography, climate and storm types that affect the region.

The approach used in this study was consistent with those used in the numerous PMP studies that AWA has completed since 1996. This is a storm-based approach similar to the methods and processes employed by the National Weather Service (NWS) in the development of the various Hydrometeorological Reports (HMRs) to the extent the data and current understanding of meteorological processes supports those previous methods. The World Meteorological Organization (WMO) manual for PMP determination (WMO 2009) recommends this storm-based approach when sufficient data are available. This approach identified extreme rainfall events that have occurred over a wide region around southern Alaska from Fairbanks to the Gulf of Alaska west to the Aleutians Island and east to the northern Alaska Panhandle. These storms have meteorological and topographical characteristics similar to extreme rainfall storms that could occur over the Susitna-Watana basin. The largest of these rainfall events were selected for detailed analyses and PMP development.

Nine rainfall events were identified as having similar characteristics to PMP-type events that could potentially occur over the Susitna River basin and could potentially influence the PMP values. Each of these storms were analyzed by AWA for this study using the Storm Precipitation Analysis System (SPAS). Some storms had more than one Depth-Area-Duration (DAD) zone analyzed by SPAS. A total of 13 unique DAD zones were used in the final PMP development for this study.

The general concepts employed to derive the SSPMP values from rainfall maximization, storm transpositioning, and elevation moisture adjustments were consistent with those used in HMR 57 (Hansen et al. 1994) and in the numerous PMP studies completed by AWA (Tomlinson et al. 2006-2013, Kappel et al. 2011-2014). Further, information and processes detailed in Technical Paper 47 (1963), as well as the United States Army Corps of Engineers (USACE) (1975) and Acres (1982) feasibility studies, were used where appropriate. New techniques and databases were used in the study to increase accuracy and reliability, while adhering to the basic approach used in the HMRs and in the WMO Manual. Two updated analysis methodologies were utilized in this study. The first was the use of the Orographic Transposition Factor (OTF), which objectively quantifies the effects of terrain on rainfall enhancement and depletion. This process replaces the NWS K factor/Storm Separation Method (see HMR 57 Section 6 and 8), and allows the unique and highly variable topography at both the in-place storm location and the Susitna River basin to be properly represented in the PMP values and subsequent Probable Maximum Flood (PMF) modeling. The second was the use of the HYSPLIT trajectory model (Draxler and Rolph 2010), which was used to evaluated the general location of the moisture source regions originating over water. These regions were identified using a NWS reanalysis interface.

New storm maximization factors were computed for each storm of the nine most significant storms using an updated sea surface temperature (SST) climatology and a ship report/satellite SST database (Reynolds et al. 2007 and Kent et al. 2007, NCDC DS 540.0). Each historic extreme rainfall event used for PMP development was maximized, transpositioned, and orographically adjusted to a series grid points covering the entire Susitna River basin using methods consistent with HMR 57 and previous AWA PMP studies when possible and modified to work on a gridded basis. The governing equation used for computation of the SSPMP values for the Susitna River basin is shown in Equation ES.1.

$$PMP_{xhr} = P_{xhr} * IPMF * MTF * OTF \qquad \text{ES.1}$$

where:

PMP_{nhr} is the SSPMP value at the x-hour duration for the 5,131-square mile Susitna River basin (target location);

P_{xhr} is the x-hour 5,131-square mile precipitation observed at the historic in-place storm location (source location);

In-Place Maximization Factor (*IPMF*) is the adjustment factor that increases a storm's maximum amount of atmospheric moisture that could have been present to the storm for rainfall production. It is the ratio of the maximum amount to the actual amount of atmospheric moisture that was available to the storm;

Moisture Transposition Factor (MTF) is the adjustment factor which accounts for the difference in available moisture between the location where the storm occurred and the Susitna-Watana basin;

Orographic Transposition Factor (OTF) is obtained from the results of the comparison of the 24-hour precipitation frequency characteristics between the storm target and source locations. The OTF accounts for differences between orographic effects at the historic in-place storm location and the grid point being evaluated within the Susitna-Watana basin.

A total of 4,767 grid cells, at a resolution of .025° decimal degrees x .025° decimal degrees, were analyzed over the Susitna-Watana basin. The resulting values were analyzed hourly for a total of 216-hours and provided by sub-basin average for use in PMF modeling. These data were distributed spatially the precipitation climatology from NOAA Atlas 14 Volume 7 (Perica et al. 2012). The temporal distribution of the hourly rainfall accumulations followed the temporal pattern of three historic storms, each with a distinct accumulation pattern. This procedure is preferred compared to moving each storm to the centroid of the basin because it captures the spatial and temporal variability of PMP rainfall as it would occur over the complex terrain of the Susitna-Watana basin. Values were derived for the all-season period, extending from July 1-August 15, with an additional set of seasonality adjustments for use in defining the PMP rainfall from April 1 through October 31.

The last component of the PMP determination process was the development of the meteorological time series used for snowmelt calculations prior to, coincident with, and after the PMP rainfall period. Hourly values for temperatures, dew points, and wind speeds were derived using historic observed conditions during similar rainfall periods. These values were then maximized to represent the expected conditions during the PMP rainfall. Values were derived representing July 1-August 15, with an additional set of seasonality adjustments for use in defining the meteorological time series from April 1 through October 31.

1. INTRODUCTION

This study provides the Site-Specific Probable Maximum Precipitation (SSPMP) values and development procedures for use in the computation of the Probable Maximum Flood (PMF) for the Susitna River basin in the southern Alaska.

1.1 Background

Definitions of Probable Maximum Precipitation (PMP) are found in most of the Hydrometeorological Reports (HMRs) issued by the National Weather Service (NWS). The definition used in the most recently published HMR is "theoretically, the greatest depth of precipitation for a given duration that is physically possible over a given storm area at a particular geographical location at a certain time of the year." (HMR 59, pg. 5). Since the mid-1940s, several government agencies have been developing methods to calculate PMP in various regions of the United States. The NWS (formerly the U.S. Weather Bureau) and the Bureau of Reclamation have been the primary agencies involved in this activity. PMP values from their reports are used to calculate the PMF, which, in turn, is often used for the design of significant hydraulic structures.

The generalized PMP studies currently in use in the conterminous United States include: HMR 49 (1977) for the Colorado River and Great Basin drainage; HMRs 51 (1978), 52 (1982) and 53 (1980) for the U.S. east of the 105th meridian; HMR 55A (1988) for the area between the Continental Divide and the 103rd meridian; HMR 57 (1994) for the Pacific Northwest states west of the Continental Divide; and HMR 58 (1998) and 59 (1999) for the state of California (Figure 1.1). The Susitna-Watana basin is located outside the domain of the HMRs and therefore a SSPMP is required to derive quantifiable and reproducible PMP values.

In addition to these HMRs, numerous Technical Papers and Reports deal with specific subjects concerning precipitation (e.g. NOAA Tech. Report NWS 25 1980 and NOAA Tech. Memorandum NWS HYDRO 45 1995). Topics include maximum observed rainfall amounts, return periods for various rainfall amounts, and specific storm studies. Climatological Atlases (e.g. Technical Paper No. 40 1961; Short Duration Rainfall Frequency Relations for the Western United States 1986; NOAA Atlas 2 1973; NOAA Atlas 14 2002-2014) are available for use in determining precipitation return periods. A number of specialized and regional studies (e.g. Technical Paper 47; Tomlinson 1993; Tomlinson et al. 2002-2013, Kappel et al. 2011-2014) augment generalized PMP reports for specific basins and regions included in the large areas addressed by the various HMRs (Tomlinson and Kappel 2009). TP 47 provides PMP values for Alaska for area sizes up to 400 square miles and durations up to 24 hours.

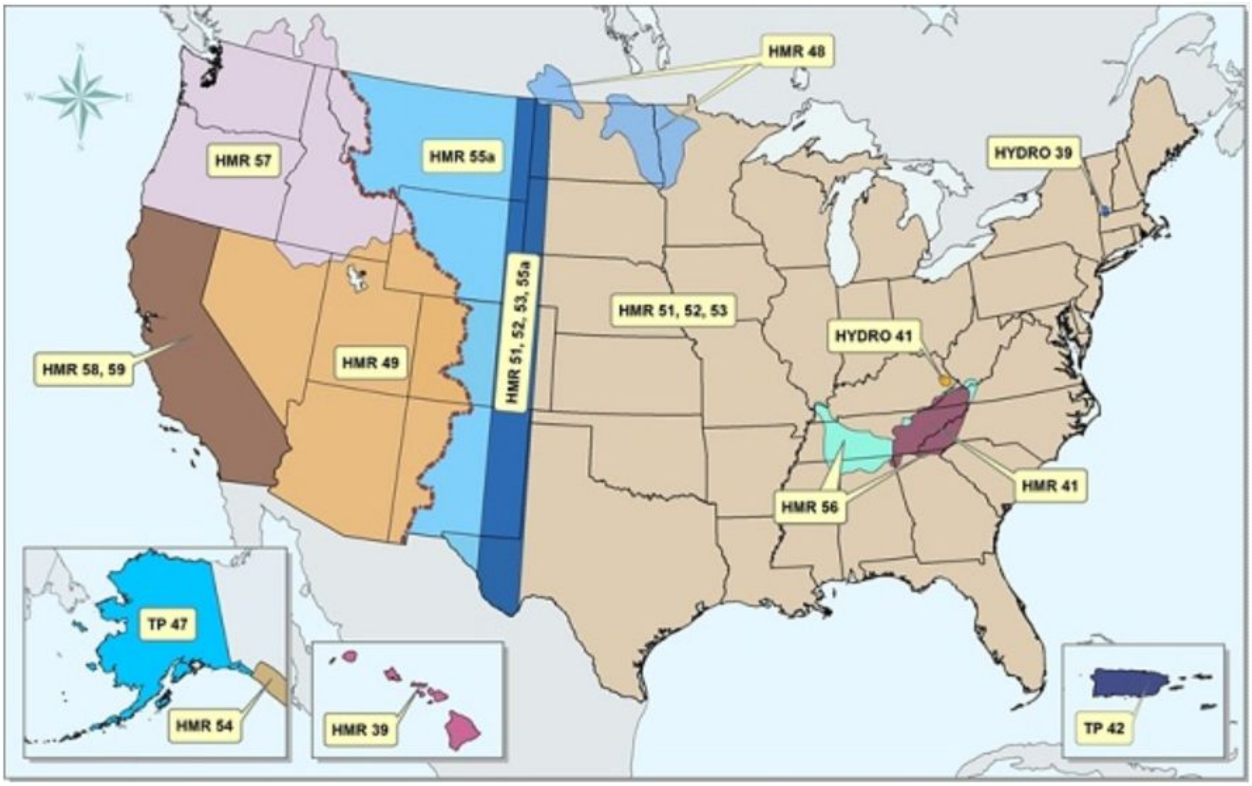

Figure 1.1. Coverage of NWS HMRs as of 2012 (from http://www.nws.noaa.gov/oh/hdsc/studies/pmp.html).

The meteorological and topographical settings within and surrounding the large Susitna River basin create unique effects on precipitation and other meteorological variables that can only be resolved through a detailed analysis specific to the basin. Each of the NWS HMR studies addressing PMP over specific regions also recognized that SSPMP studies could incorporate more site-specific considerations and provide improved PMP estimates. Additionally, by periodically updating storm data and incorporating advances in meteorological concepts, PMP analysts can make improved PMP estimates (HMR 57 Section 14 and Section 15.2 Steps 8-9).

Previous site-specific and regional PMP projects completed by AWA provide examples of PMP studies that explicitly consider the topography of the basins and characteristics of historic extreme rainfall storms over climatologically similar regions surrounding the basins (see Figure 1.2). These site-specific PMP studies have received extensive review and the results have been used in computing the PMF for the watersheds and regions covered. This study follows many of the same procedures used in those studies to determine SSPMP values for the Susitna-Watana basin. These procedures, together with Storm Precipitation Analysis System (SPAS) rainfall analyses[1] are used to compute PMP values using a .025 x .025 decimal degree grid over the Susitna-Watana basin. The grid based approach provides improvements in the spatial evaluation of the historic storm

[1] Appendix D contains a complete description of the SPAS program and its development.

rainfall patterns and how the PMP storm would occur over the highly variable topography unique to the Susitna-Watana basin. In addition, storm specific and generalized temporal distributions can be applied.

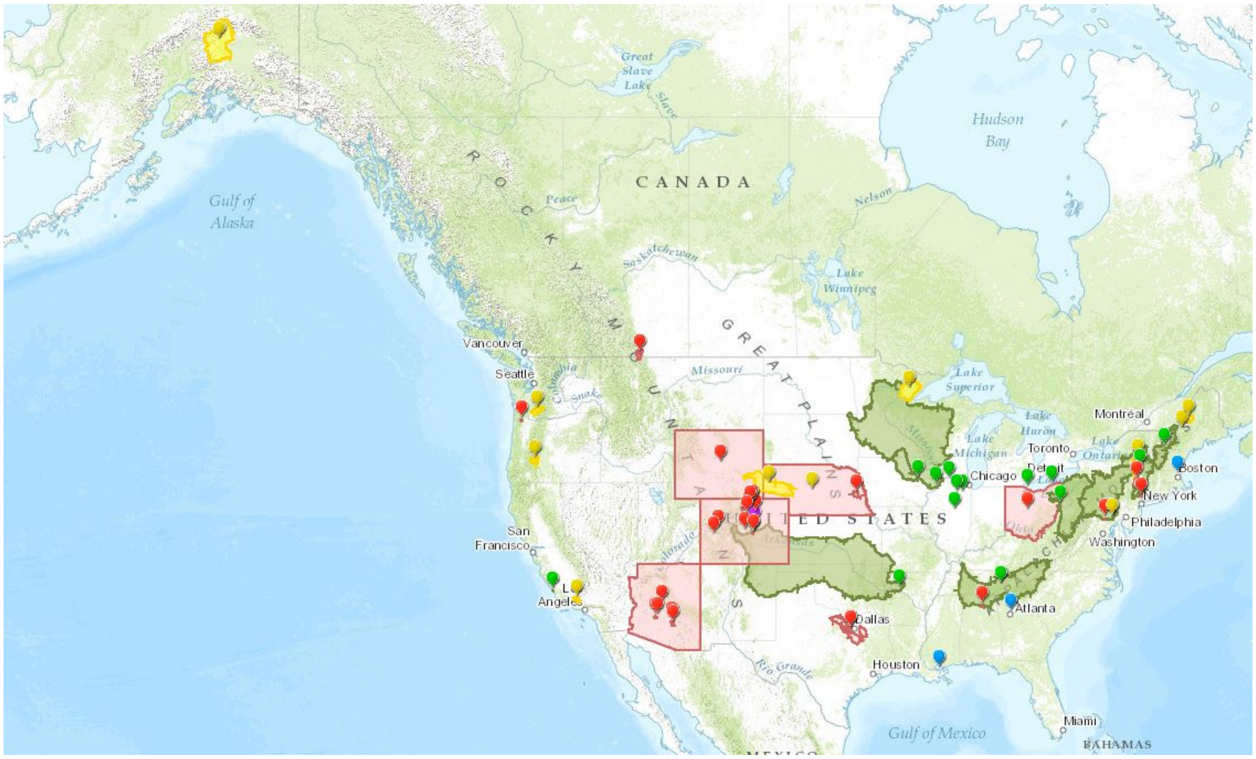

Figure 1.2. Locations of AWA PMP studies as of March 2013.

1.2 Objective

The objective of this study was to perform a site-specific study to determine reliable estimates of PMP values for the Susitna-Watana basin, as well as develop coincident meteorological time series data (temperature, dew point, and wind speed) for use in snow melt calculation. In addition, guidance was provided on the seasonality of both the PMP values and the meteorological time series values because it was critical to provide information on how those values vary beyond the all-season (July-August for PMP) for PMF modeling. This is because it is very likely that the PMF would result at a time when some amount less than the full PMP could accumulate and be augmented by melting snow pack to produce a larger volume of flood runoff versus the time of the year when the full PMP could accumulate but have significantly less snow melt runoff. This all-season PMP would therefore produce a smaller flood volume than the lesser amount of rainfall but higher amount of snow melt. The most reliable methods and data currently available have been used, with new techniques and data used where appropriate.

1.3 Approach

The approach used in this study is consistent with the majority of the procedures that were used in the development of the HMRs, with updated procedures implemented where appropriate. These procedures were applied considering the site-specific characteristics of the Susitna River basin and the unique effects of the topography both in the surrounding region and in the basin. Terrain characteristics are addressed as they specifically affect rainfall patterns, both spatially and in magnitude within the basin. The weather and climate of the region are discussed in Section 2. The process of identifying extreme storms is discussed in Section 3. Procedures used to analyze storms are discussed in Section 4. Adjustments for storm maximization, storm moisture transposition, and orographic transposition are presented in Sections 5, 6, 7 and 8. The meteorological time series and seasonality of PMP development are provided in Section 9. Results are presented in Section 10. Discussions on sensitivities are provided in Section 11 and the recommendations for application are in Section 12.

Procedures used in this study maintained consistency with the general methods used in the HMRs and the previous PMP studies completed by AWA while deviations were incorporated when justified by developments in meteorological analyses and available data. The basic approach identifies major storms that occurred within the region surrounding the Susitna River basin that are PMP storm type (see Section 2.0). This includes the region from central Alaska west to the Bering Strait to the Gulf of Alaska through the Alaska Panhandle (see Section 5.0). The moisture content of each of these storms is increased to a climatological maximum to provide worst case rainfall estimation for each storm at the location where it occurred had all atmospheric process resulting in rainfall production been optimum. The storms are then transpositioned to the Susitna River basin to the extent supportable by similarity of topographic and meteorological conditions. Finally, the largest rainfall amounts from these maximized and transpositioned storms provide the basis for deriving the SSPMP values. Figure 1.3 shows the flow chart of the major steps used in a site-specific storm-based PMP derivation process. Note that the final process used during this study incorporated the use of a grid cell by grid cell delineation and detailed evaluation of orographic effects on rainfall within the basin. The details are included in Equation 1 and Figure 1.4.

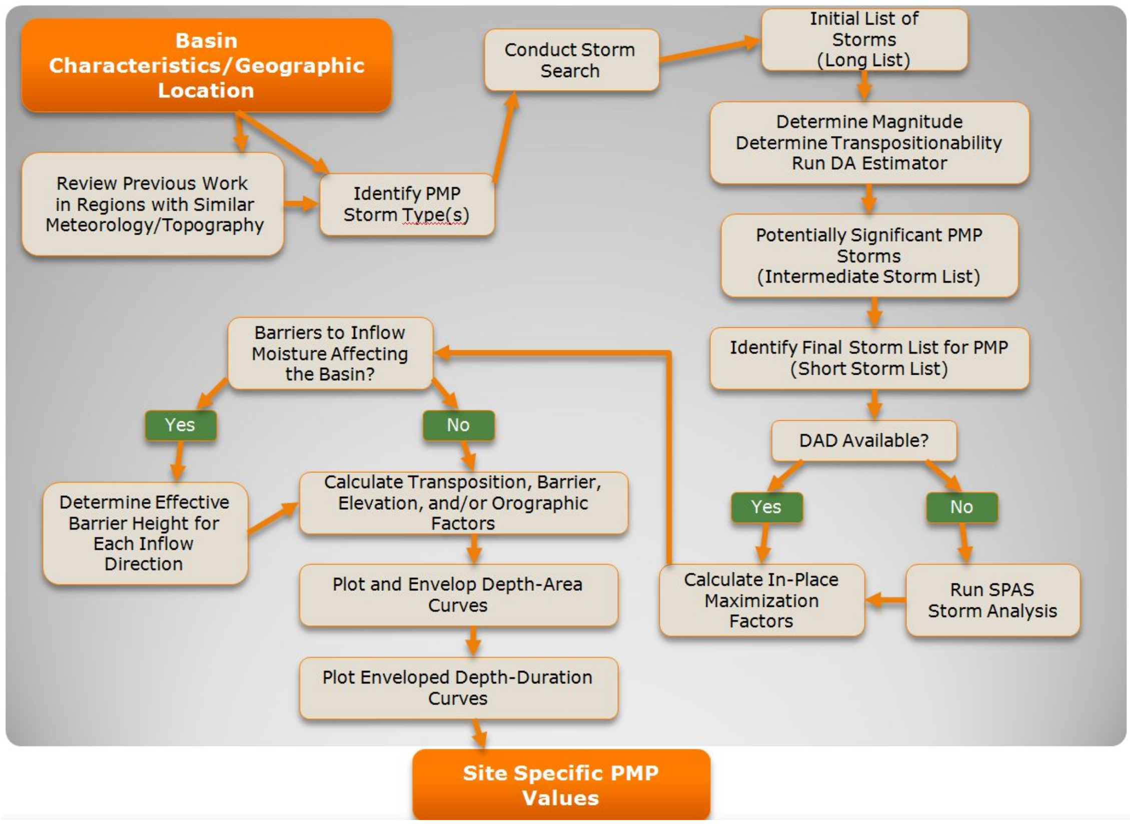

Figure 1.3. Flow chart showing the major steps involved in site-specific PMP development.

For some of the processes used to derive PMP, this study applied standard methods (e.g. WMO 2009 and Hansen et al. 1994), while for others, new techniques were developed. A major advancement utilized during this study was the ability to analyze rainfall and climate data on a gridded basis in a GIS environment. This allowed for in-place maximizations, horizontal moisture transpositioning, and orographic transpositioning using a data grid over the basin. The original SPAS gridded rainfall amounts were analyzed at each storm's in-place location to provide values used for the PMP calculations (see Equation 1.1). The largest of the total adjusted rainfall values at each hour were distributed spatially and temporally over the Susitna-Watana basin. The spatial distribution proved to be very effective in quantifying the unique effects of the highly variable topography on the storm at both the in-place storm location and the Susitna-Watana basin. This process uses the Orographic Transposition Factor (OTF) to quantify the effects of topography on rainfall production and spatial distribution. The OTF is determined by comparing the NOAA Atlas 14 Volume 7 precipitation frequency data (Perica et al. 2012) at the in-place storm location versus the precipitation frequency values at each grid point over the basin. The relationship through a range of precipitation frequency values between the two locations results in a ratio indicating if the in-place storm center location is more or less effective at enhancing rainfall versus the grid point over the basin. The OTF is then combined with the in-place maximization factor and the moisture transposition factor to produce the total adjustment factor for that grid point, for a given storm, for a given duration. This process is then repeated for all grid points in the basin for all duration analyzed. The assumption in the OTF process is that the NOAA Atlas 14 precipitation frequency values adequately represent the expected effects of topography at a given grid point and by upwind and surrounding topography as reflected in the numerous precipitation events that have occurred at that location and within the region used to produce the precipitation frequency estimates.

This process replaces the use of the NWS Storm Separation Method (SSM). A detailed description of the NWS SSM method can be found in HMR 55A Section 7, with updates to the method in HMR 57 Section 6. The OTF is discussed in Section 6.2 with example results and calculations given in Section 7.3.

Figure 1.4 shows a flow chart of the processes that were used during this study to derive the SSPMP values. Note that most of the processes displayed in Figure 1.3 are included, however the flow chart in Figure 1.4 includes the processes that are unique to this SSPMP study.

The governing equation used for computation of the SSPMP values for the Susitna River basin is:

$$PMP_{xhr} = P_{xhr} * IPMF * MTF * OTF \quad \text{Equation 1.1}$$

where:

PMP_{xhr} is the SSPMP value at the x-hour duration for the 5,131-square mile Susitna River basin (target location);

P_{xhr} is the x-hour 5,131-square mile precipitation observed at the historic in-place storm location (source location);

In-Place Maximization Factor (*IPMF)* is the adjustment factor determined using the maximum amount of atmospheric moisture that could have been present to the storm for rainfall production;

Moisture Transposition Factor (MTF) is the adjustment factor which accounts for the difference in available moisture between the location where the storm occurred and the Susitna-Watana basin;

Orographic Transposition Factor (OTF) is obtained from the results of the calculation which compares the x-hour precipitation frequency characteristics between the basin grind points and the in-place storm location. The OTF accounts for differences between orographic effects at the historic in-place storm location and the Susitna-Watana basin.

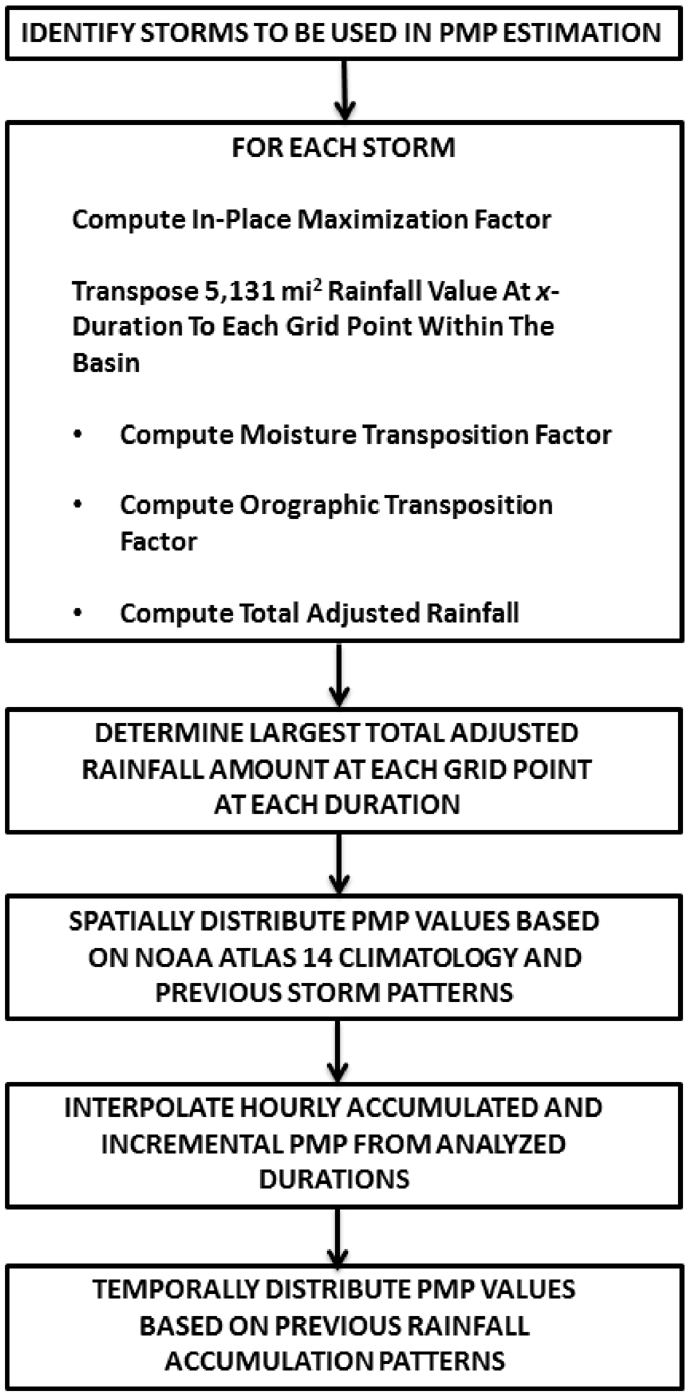

Figure 1.4. Major Components in Computation of Site-Specific PMP for Susitna-Watana Basin.

Advanced computer-based technologies, Weather Service Radar WSR-88D NEXt generation RADar (NEXRAD), and HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model trajectories were used for storm rainfall analyses for all storms used in PMP development. New technology and data were incorporated into the study when they improved reliability. This approach provides the most complete scientific application compatible with the engineering requirements of consistency and reliability for credible PMP estimates.

Storm maximization (also called moisture maximization) analyses have historically used monthly maximum observed 12-hour persisting dew points as published in the *Climatic Atlas of the United States* by the Environmental Data Services, Department of Commerce (1969). However, use of surface based dew points (either persisting or average) is only valid for storms where atmospheric moisture can be quantified using land based, surface dew point observations. In this study, sea surface temperature (SST) values were used in-place of dew point temperatures. SSTs were used in HMRs 57 and 59 as well as several site-specific PMP studies completed by AWA where inflow moisture source regions were located over the Atlantic or Pacific Ocean.

As part of this study, an updated maximum SST climatology was developed replacing the Marine Climate Atlas of the World (U.S. Navy 1981) used in HMRs 57 and 59. This updated climatology includes monthly mean and +2-sigma maps for the Pacific Ocean from the coastline of the United States to 180°W and from 15°N to the southern Alaska coast. In conjunction with the +2-sigma climatological maps, daily SST maps based on ship and buoy reports used in deriving the storm representative SST values for each storm event (NOAA 2011, Kent et al. 2007, Reynolds et al. 2007, and Worley et al. 2005).

The ESRI ArcGIS, version 10.2 geographic information system (GIS) software environment was used extensively in the study to analyze storms, evaluate climatology data, complete the OTF analyses, delineate the characteristics of the Susitna-Watana basin, identify unique characteristics and terrain features of the region, and produce basin and regional maps.

SPAS provided gridded storm rainfall analyses. The SPAS analyses produced high-resolution gridded maximum rainfall datasets at hourly intervals over the spatial extent for the entire duration of each storm used in this study.

1.4 Basin Location and Description

The Susitna River basin is located in southern Alaska. The area of the drainage basin is approximately 5,131-square miles. The average elevation within the basin is 3,643 feet and varies from 1,456 feet at the proposed dam site to 13,134 feet in the Alaska Range. Figure 1.5 shows the basin location and surrounding topography. Figure 1.6 shows the topography within the basin and the thirty-four major sub-basins.

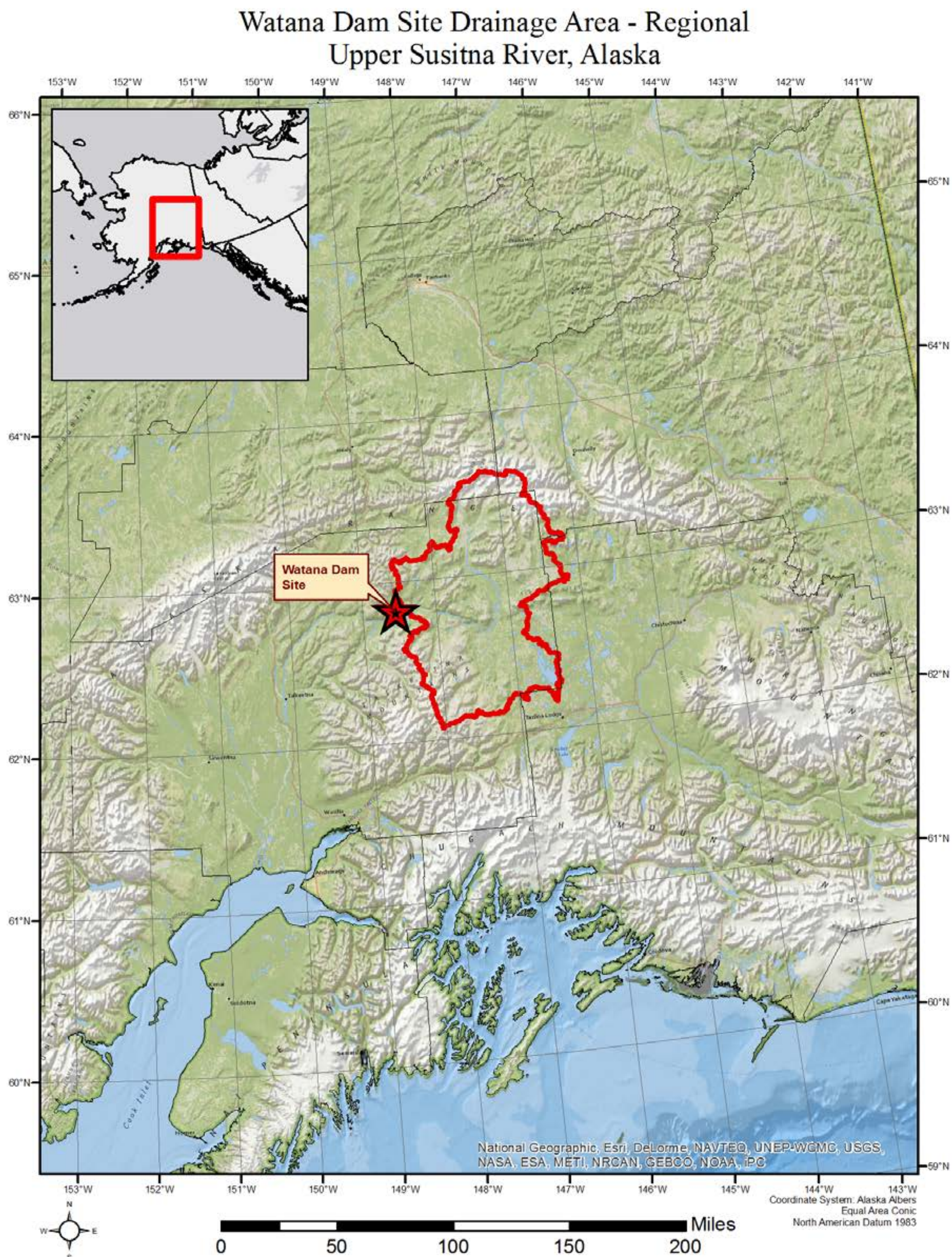

Figure 1.5. Susitna-Watana basin location and surrounding topography.

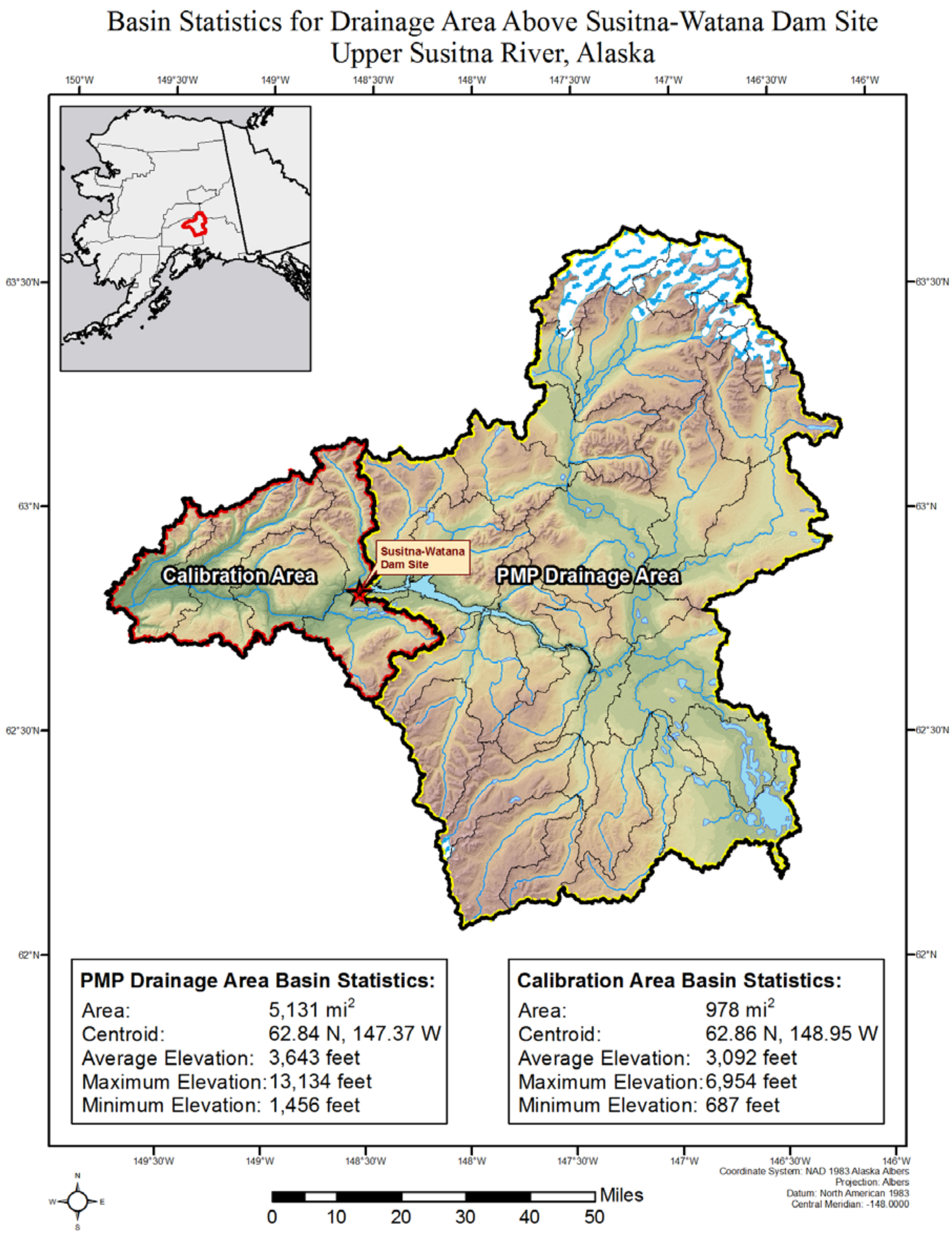

Figure 1.6. Susitna-Watana basin, subbasins, and major hydrologic features.

2. WEATHER AND CLIMATE OF THE SUSITNA-WATANA REGION

2.1 Seasonal Patterns

The weather and climate around the Susitna River basin is known for its extreme seasonality and high variability of weather patterns. Moisture feeding rainfall events in the basin arrives on southerly wind flows, with westerly components sometimes involved. The basin is located between two highly contrasting air mass types. Relatively mild and very moist air masses originated from the Gulf of Alaska and Pacific Ocean contrast with dry and cold Polar air masses from the north. Depending on which air mass is dominating the weather at any given time determines the resulting weather conditions. In addition, the basin is large enough that each of these air masses may be affecting different portions of the basin at the same time. During the months from November through March, temperatures are cold enough that rainfall is rare, and when it occurs it is light enough that flooding is not produced. Starting in April, a rapid transition takes places as warmer temperatures and higher levels of moisture begin to affect the region. Chances for rain increase across the lower elevations closer to the Gulf of Alaska. For most of April and often into May, significant snow pack remains. Over the interior and higher elevations of the basin, significant snow pack often stays well into June. This combination of rain on snow has resulted in some of the largest flood of record for the basin.

The peak season for rainfall occurs from July through early September as the storm track from the Pacific Ocean and Gulf of Alaska intensifies and combines with the highest amount of atmospheric moisture. In rare instances, remnant Tropical Storm moisture becomes entrained in these storms and enhances the rainfall across southern and interior Alaska. An excellent example of this scenario was the Great Fairbanks Flood of August 1967[2]. Rare heavy rainfall events, such as the September 2012 and October 1986, provide examples when the rain season is extended beyond expected time frames.

2.2 Orographic Influences

Rainfall in the region of the Susitna River basin is controlled by the orographic effect associated with the steep rise in elevation from sea level to over 12,000 feet south of the basin along the coastal mountains which intercepts most of the moisture moving in from the Gulf of Alaska. However, a major gap in the mountainous terrain occurs through the Cook Inlet and up the Susitna River valley. This allows significant amounts of low level moisture to move into the lower reaches of the Susitna River basin and into the western portions of the basin. In addition, as this moisture encounters the rising elevations of the Alaska Range around Denali as well as the higher elevation at the edge of the basin, it is forced to rise and precipitation enhancement occurs. In combination, all these upwind and along basin higher elevation serve to limit the amount of low-level moisture

[2] http://en.wikipedia.org/wiki/History_of_Fairbanks,_Alaska

reaching into the basin, especially the middle and eastern interior portions. Therefore, average precipitation amounts fall off very quickly within the basin, especially for elevation below 5,000 ft (the majority of the area within the basin). This effect is known as a rainshadow and it is imperative that the PMP value reflect this phenomena. Because of the unique topographic situations both upstream and within the basin, PMP-type rainfall is rare within the basin, but common at upwind locations. Therefore, extensive evaluations were completed to quantify the effects of topography on rainfall spatially and in magnitude, and to provide information on how storms are transpositioned the basin.

The topography within the basin also creates distinct rainfall patterns with extreme variations within the basin. The heaviest precipitation occurs at the western edge of the basin and along the higher elevation of the northern portion of the basin along the Alaska Range. Mean annual precipitation varies from just over 10 inches in the lower elevations of the southeastern portion of the basin to over 60 inches in the Alaska Range in the northeastern portion of the basin (Figure 2.1). At elevations above 5,000 ft, precipitation can be in the form of snow any time of the year.

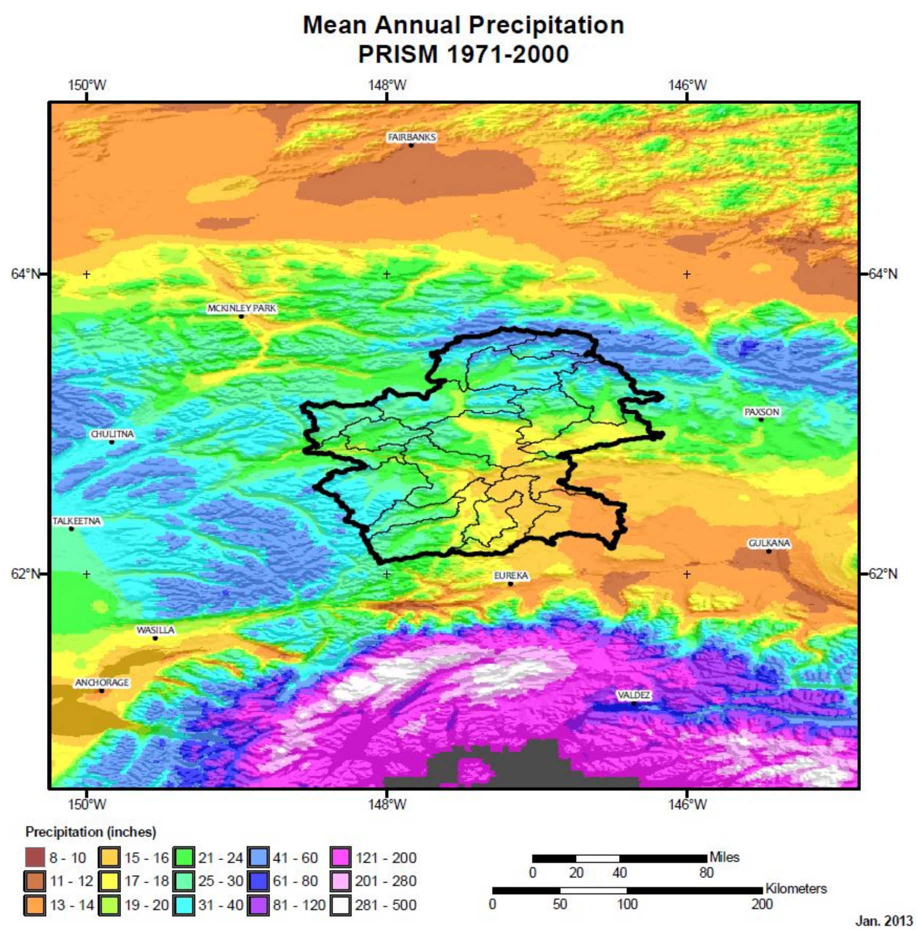

Figure 2.1. Mean annual precipitation based on PRISM 1971-2000 climatology.

2.3 Susitna River Basin PMP Storm Type

The region around the basin is directly influenced by strong areas of low pressure (mid-latitude cyclones) moving in from the Pacific Ocean and Gulf of Alaska. These storms, referred to as synoptic storms, often bring with them very active storm dynamics (lift) and high levels of moisture from locations as far south as the subtropics north of Hawaii and points westward. This combination of enhanced lift and moisture often produces widespread heavy rainfall that may last three or more days. When these storms are able to tap into high levels of moisture supplied by the subtropical regions in and around the central Pacific Ocean, extreme rainfalls can occur. This type of scenario is known as an Atmospheric River. On the upslope regions upwind of the Susitna-Watana basin, the storms are further enhanced by orographic processes associated with the steep terrain encountered as they move onshore and are forced to rise over the slopes of the Coastal Range and Alaska Range. As discussed in the previous section, much of this atmospheric moisture precipitates on the upwind slopes, thereby eliminating much of the low-level atmospheric moisture by the time it reaches the basin. Therefore, extreme rainfall events are rare in the basin and rainfall amounts are generally less than areas to the west and south of the basin. Synoptic storms cover large areas and produce heavy rains over relatively long periods. This storm type is most common from late June through early October.

2.3.1 Atmospheric Rivers and Mid-Latitude Cyclones

An Atmospheric River is an elongated, narrow, water vapor transport band located in the warm sector of a mid-latitude cyclone, often enhanced by convergence of local moisture (Bao et al. 2006). Atmospheric Rivers contain warm temperatures relative to normal in the surrounding air mass, enhanced water vapor and a strong low-level jet approximately 5,000 ft above the surface (Zhu and Newell 1998, Neiman et al. 2001, 2008, 2008, 2011, Ralph et al. 2003, 2004, 2005, 2006, 2011). Ralph (2004) demonstrated that more than 90% of the total meridional water vapor flux in the mid-latitudes is attributed to Atmospheric Rivers.

With this type of storm, flooding can be exacerbated antecedent snowpack, especially in the spring season. This scenario is most common between late May and late June after a cooler than normal spring has allowed higher than normal amounts of snowpack to remain over the basin. High levels of moisture and relatively warm temperatures associated with the Atmospheric River events emanating from the subtropical regions of the central Pacific Ocean result in heavy rainfall on a quickly melting snowpack producing increased runoff. These two factors lead to the largest flood events in the region.

2.4 Storm Types Seasonality

The most likely time for a PMP type storm event to occur in the Susitna River basin is from July through early September. However, extreme storms occur as early as May and as late as October.

Figure 2.2 displays the month of occurrence of the individual storm events from the storm search that were considered for PMP development (see Section 3.0). It should be noted that although the heaviest amounts of rainfall occur in the summer months, the higher amounts of snow pack available to combine with the rainfall runoff are likely to produce the largest volumes of flood runoff. Therefore, it is likely that the PMF would result from a combination of rainfall and snowmelt in May or early June.

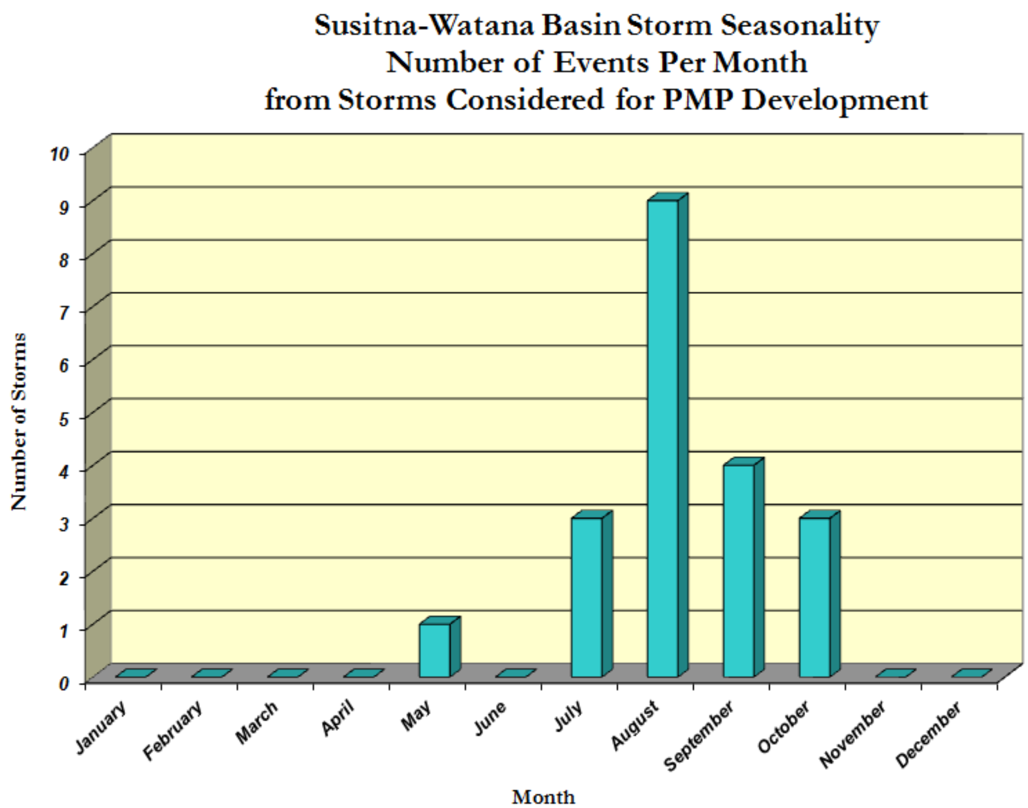

Figure 2.2. Storm seasonality for the Susitna River basin using all storm events from the long storm list.

3. EXTREME STORM IDENTIFICATION

3.1 Storm Search Area

A comprehensive storm search was conducted for this study and included an analysis of all the storms in meteorologically and topographically similar regions to the Susitna-Watana basin. Previous work and documents which discussed and analyzed storm events in the region were also reviewed. These included the reports from the NWS offices in Anchorage and Fairbanks, as well as HMR 57, the Acres (1982) study, and the Harza-Ebasco (1984) PMP work. Nine new storms were identified from the storm search which required full SPAS storm analyses for use in PMP development (Section 4). The primary search area included all geographic locations where extreme rainfall storms similar to those that could occur over the Susitna River basin have been observed. The search area extended from the Alaska Panhandle region (~54°N) to southern interior Alaska (~65°N) and from the Pacific Ocean coastline to northwestern interior Alaska (Figure 3.1). This ensured a large enough area was included in the storm search to capture all significant storms that could potentially influence final PMP values for the basin.

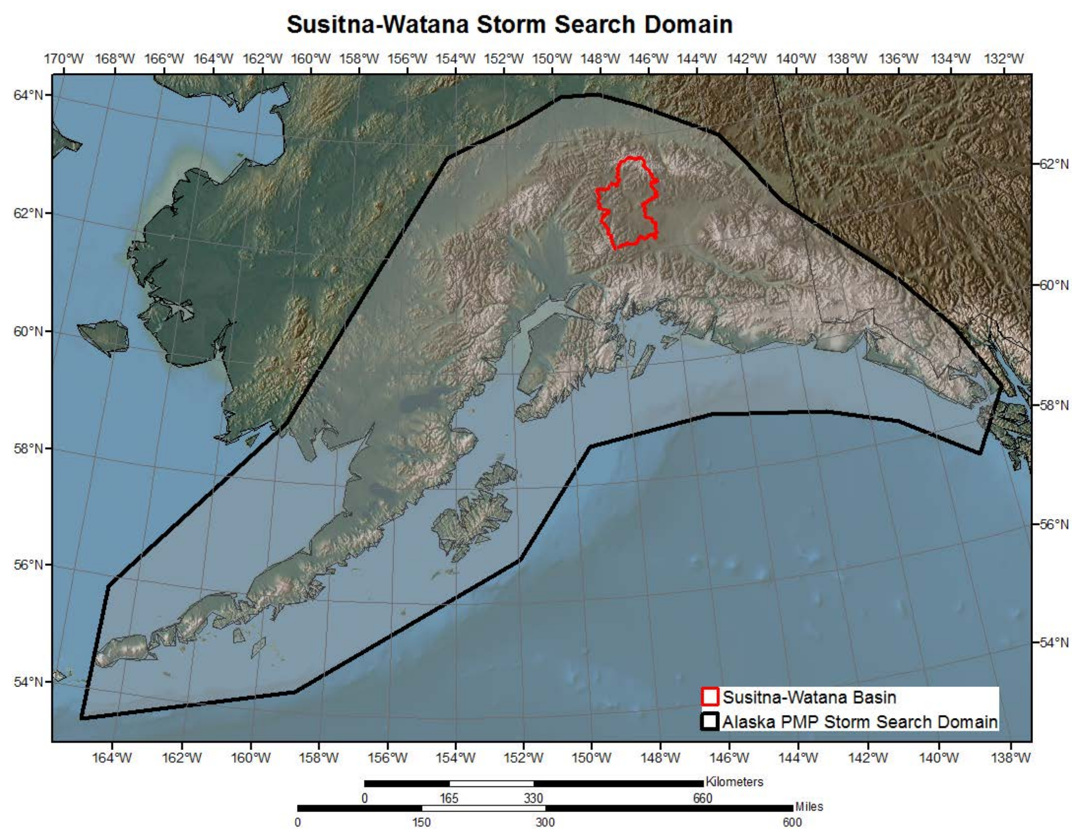

Figure 3.1. Susitna-Watana storm search domain.

3.2 Data Sources

The storm search was conducted using a dataset that included rainfall data from several sources. The primary data sources are listed below:

1. Cooperative Summary of the Day / TD3200 through 2013. These data are published by the National Climatic Data Center (NCDC).
2. Hourly Weather Observations published by NCDC, U.S. Environmental Protection Agency, and Forecast Systems Laboratory (now National Severe Storms Laboratory).
3. NCDC Recovery Disk
4. Hydrometeorological Reports
5. Corps of Engineers Storm Studies
6. Other data published by the Alaska State climate office
7. American Meteorological Society journals
8. Personal communications with various members of the Board of Consultants and others involved in this study
9. Watana and Devil Canyon Sites Probable Maximum Flood Report
10. Susitna Hydroelectric Project v4 Appendix A

3.3 Storm Search Method

The primary search began with identifying hourly and daily stations that have reliable rainfall data within the storm search area described previously. These stations were evaluated to identify the largest 1, 3, and 7 observational-day precipitation totals. Other reference sources such as HMRs and USACE storm reports and USGS flood studies (e.g. Smith 1950, USACE 1975, ACRES 1982, Harza-Ebasco 1984, HMR 42 1966) were reviewed to identify other dates with large rainfall amounts within the storm search domain. The criteria for storms to make the initial list of significant storms (referred to as the long storm list) were events that exceeded the 100-year return frequency value for the specified duration at the storm location.

The resulting long storm list was extensively quality controlled to ensure that only the highest storm rainfall values for each event were selected. Each storm was analyzed to verify its precipitation reports and compare it with rainfall amounts associated with other storms.

These storms values were plotted to ensure they occurred over similar meteorological and topographic regions as the Susitna River basin and could, therefore be used in the next steps of the PMP analysis. Table 3.1 is the long storm list and represents an initial assessment of all the storms found during the initial storm search. Quality control checks eliminated storms with duplicate rainfall centers, rainfall amounts which were accumulations, smaller rainfall centers associated with the same storm event, and storms that were deemed not transpositionable to the Susitna-Watana basin, etc.

Table 3.1. Long storm list from the storm search. Rainfall values shown are the highest point values in inches over the total storm duration.

Name	ST	Lat	Lon	Year	Mon	Day	Total Rainfall
COAL HARBOR	AK	55.400	-160.817	1900	4	23	10.00
COAL HARBOR	AK	55.400	-160.817	1909	4	3	8.00
CORDOVA WB A	AK	60.500	-145.500	1912	9	26	19.75
CORDOVA WB A	AK	60.500	-145.500	1917	9	9	9.40
CORDOVA WB A	AK	60.500	-145.500	1925	9	20	15.69
CORDOVA WB A	AK	60.500	-145.500	1925	10	6	24.12
CHIGNIK	AK	56.300	-158.400	1927	8	15	14.99
CHIGNIK	AK	56.300	-158.400	1927	9	19	15.43
CHIGNIK	AK	56.300	-158.400	1929	9	8	16.38
CHIGNIK	AK	56.300	-158.400	1930	5	9	18.93
CHIGNIK	AK	56.300	-158.400	1930	5	25	15.78
DENALI NP	AK	63.038	-150.471	1955	8	22	13.75
CORDOVA	AK	60.646	-145.554	1955	8	22	21.67
CAPE SPENCER	AK	58.200	-136.633	1956	11	24	20.93
MT SPURR	AK	61.346	-152.329	1958	7	25	6.62
LITTLE SUSITNA	AK	61.854	-149.229	1959	8	18	13.05
CAPE HINCHINBROOK	AK	60.233	-146.650	1962	4	13	20.50
CAPE HINCHINBROOK	AK	60.233	-146.650	1962	5	9	29.95
CAPE HINCHINBROOK	AK	60.233	-146.650	1962	5	25	13.75
CAPE SPENCER	AK	58.200	-136.633	1966	11	23	15.80
DENALI NP	AK	62.846	-150.513	1967	8	2	12.45
FAIRBANKS	AK	65.521	-147.329	1967	8	2	12.45
HOMER	AK	59.871	-150.563	1967	8	2	12.45
CHIGNIK	AK	56.300	-158.400	1969	6	4	14.81
CAPE HINCHINBROOK	AK	60.233	-146.650	1969	7	24	22.90
CHIGNIK	AK	56.300	-158.400	1969	10	12	14.68
BLACK RAPIDS	AK	63.471	-145.479	1971	8	5	12.17
SUTTON	AK	61.904	-148.863	1971	8	5	11.39
PORTAGE	AK	61.004	-148.663	1971	8	5	12.17
DENALI NP	AK	62.954	-150.079	1980	7	24	7.33
ANGOON PWR	AK	57.499	-134.586	1982	10	12	15.20
DENALI NP	AK	62.829	-151.138	1986	10	8	11.01
SEWARD	AK	60.113	-149.513	1986	10	8	20.80
OUZINKIE	AK	57.933	-152.500	1991	11	1	10.76
WHITTIER	AK	60.713	-148.779	1995	9	19	26.03
SEWARD	AK	60.117	-149.450	1995	9	20	9.81
BIG RIVER LA	AK	60.817	-152.300	1996	3	22	7.50
ELFIN COVE	AK	58.200	-136.667	1996	9	25	8.61
CANNERY CREEK	AK	60.696	-145.688	2003	9	29	23.69
PELICAN	AK	57.950	-136.233	2005	11	17	26.87
BLACK RAPIDS	AK	63.465	-145.685	2006	8	17	16.12
CANNERY CREEK	AK	60.696	-145.688	2006	10	7	23.63
OLD TYONEK	AK	61.260	-151.860	2012	9	15	15.91
KENAI FJORDS NP	AK	59.610	-150.220	2012	9	15	33.96

3.4 Developing the Intermediate List of Extreme Storms

A multiple step process was followed to develop the list of storms used to define the PMP values. For PMP development, this final list of storms (known as the short storm list) is required to be comprehensive and include all storms which could possibly affect PMP values for the basin. At the same time, there must be a balance to eliminate smaller events that would not be significant for determining PMP values at any area size or duration after all adjustments were applied. Initially, all storms previously analyzed during the ACRES 1982, Harza-Ebasco 1984 or by the USACE were moved to the short storm list. The remaining storms were sorted by maximum rainfall amount. This eliminated events based on different locations reporting rainfall amounts associated with the same event. Further analysis was conducted to verify that each storm was transpositionable to the Susitna-Watana basin. Other checks were performed to see whether conditions within the basin during a storm event would have produced snow instead of rain, whether the storm had enough data available to complete an analysis, and whether the storm was within at least 35% of maximum values from other storms. Table 3.2 displays the results of this iterative analysis, including the reason for elimination or inclusion of each storm. In Table 3.2, the columns highlighted with a green header display the various parameters which were analyzed to determine whether a storm could be moved from the long storm list to the intermediate storm list. Each storm was analyzed going from left to right on the table. Once a storm met or did not meet one of the criteria, no further evaluation using the remaining criteria was completed. A notation was entered into the appropriate column associated with a particular selection criterion (i.e. a “yes” or “no”) with all other selection criteria cells associated with a particular storm left blank. The results of this analysis comprised the short storm list as described in the following section.

Table 3.2. Long storm list storm selection criteria used to derive the intermediate storm list.

Name	ST	Lat	Lon	Year	Mon	Day	Total Rainfall	AWA Storm Analysis	Transpositionable to Basin	Snow in the basin	Larger Storm in Similar Location	No Rain in basin or region	Data to Complete Analysis	More than 35% of Max Storm amount (>12.00")
COAL HARBOR	AK	55.400	-160.817	1900	4	23	10.00							No
COAL HARBOR	AK	55.400	-160.817	1909	4	3	8.00							No
CORDOVA WB A	AK	60.500	-145.500	1912	9	26	19.75						No	
CORDOVA WB A	AK	60.500	-145.500	1917	9	9	9.40							No
CORDOVA WB A	AK	60.500	-145.500	1925	9	20	15.69				Yes			
CORDOVA WB A	AK	60.500	-145.500	1925	10	6	24.12						No	
CHIGNIK	AK	56.300	-158.400	1927	8	15	14.99		No			Yes	No	
CHIGNIK	AK	56.300	-158.400	1927	9	19	15.43		No			Yes		
CHIGNIK	AK	56.300	-158.400	1929	9	8	16.38		No				No	
CHIGNIK	AK	56.300	-158.400	1930	5	9	18.93		No				No	
CHIGNIK	AK	56.300	-158.400	1930	5	25	15.78		No			Yes		
DENALI NP	AK	63.038	-150.471	1955	8	22	13.75	Yes						
CORDOVA	AK	60.646	-145.554	1955	8	22	21.67	Yes						
CAPE SPENCER	AK	58.200	-136.633	1956	11	24	20.93		No					
MT SPURR	AK	61.346	-152.329	1958	7	25	6.62	Yes						
LITTLE SUSITNA	AK	61.854	-149.229	1959	8	18	13.05	Yes						
CAPE HINCHINBROOK	AK	60.233	-146.650	1962	4	13	20.50		No	Yes				
CAPE HINCHINBROOK	AK	60.233	-146.650	1962	5	9	29.95		No					
CAPE HINCHINBROOK	AK	60.233	-146.650	1962	5	25	13.75				Yes			
CAPE SPENCER	AK	58.200	-136.633	1966	11	23	15.80		No					
DENALI NP	AK	62.846	-150.513	1967	8	2	12.45	Yes						
FAIRBANKS	AK	65.521	-147.329	1967	8	2	12.45	Yes						
HOMER	AK	59.871	-150.563	1967	8	2	12.45	Yes						
CHIGNIK	AK	56.300	-158.400	1969	6	4	14.81		No			Yes		
CAPE HINCHINBROOK	AK	60.233	-146.650	1969	7	24	22.90		No					
CHIGNIK	AK	56.300	-158.400	1969	10	12	14.68			Yes		Yes		
BLACK RAPIDS	AK	63.471	-145.479	1971	8	5	12.17	Yes						
SUTTON	AK	61.904	-148.863	1971	8	5	11.39	Yes						
PORTAGE	AK	61.004	-148.663	1971	8	5	12.17	Yes						
DENALI NP	AK	62.954	-150.079	1980	7	24	7.33	Yes						
ANGOON PWR	AK	57.499	-134.586	1982	10	12	15.20		No					
DENALI NP	AK	62.829	-151.138	1986	10	8	11.01	Yes						
SEWARD	AK	60.113	-149.513	1986	10	8	20.80	Yes						
OUZINKIE	AK	57.933	-152.500	1991	11	1	10.76			Yes				
WHITTIER	AK	60.713	-148.779	1995	9	19	26.03		No					
SEWARD	AK	60.117	-149.450	1995	9	20	9.81							No
BIG RIVER LA	AK	60.817	-152.300	1996	3	22	7.50							No
ELFIN COVE	AK	58.200	-136.667	1996	9	25	8.61							No
CANNERY CREEK	AK	60.696	-145.688	2003	9	29	23.69		No					
PELICAN	AK	57.950	-136.233	2005	11	17	26.87		No					
BLACK RAPIDS	AK	63.465	-145.685	2006	8	17	16.12	Yes						
CANNERY CREEK	AK	60.696	-145.688	2006	10	7	23.63		No			Yes		
OLD TYONEK	AK	61.260	-151.860	2012	9	15	15.91	Yes						
KENAI FJORDS NP	AK	59.610	-150.220	2012	9	15	33.96	Yes						

3.5 Short Storm List

Each of the storms on the short storm list were evaluated in detail using the SPAS program. Results of these analysis included the development of storm isohyetals and Depth-Area-Duration tables (DADs). Each of these storms was maximized in-place, transpositioned to each grid point comprising the basin. The storm center locations of the various SPAS DAD analyses are plotted for reference in Figure 3.2. Table 3.3 list the final short list of storms.

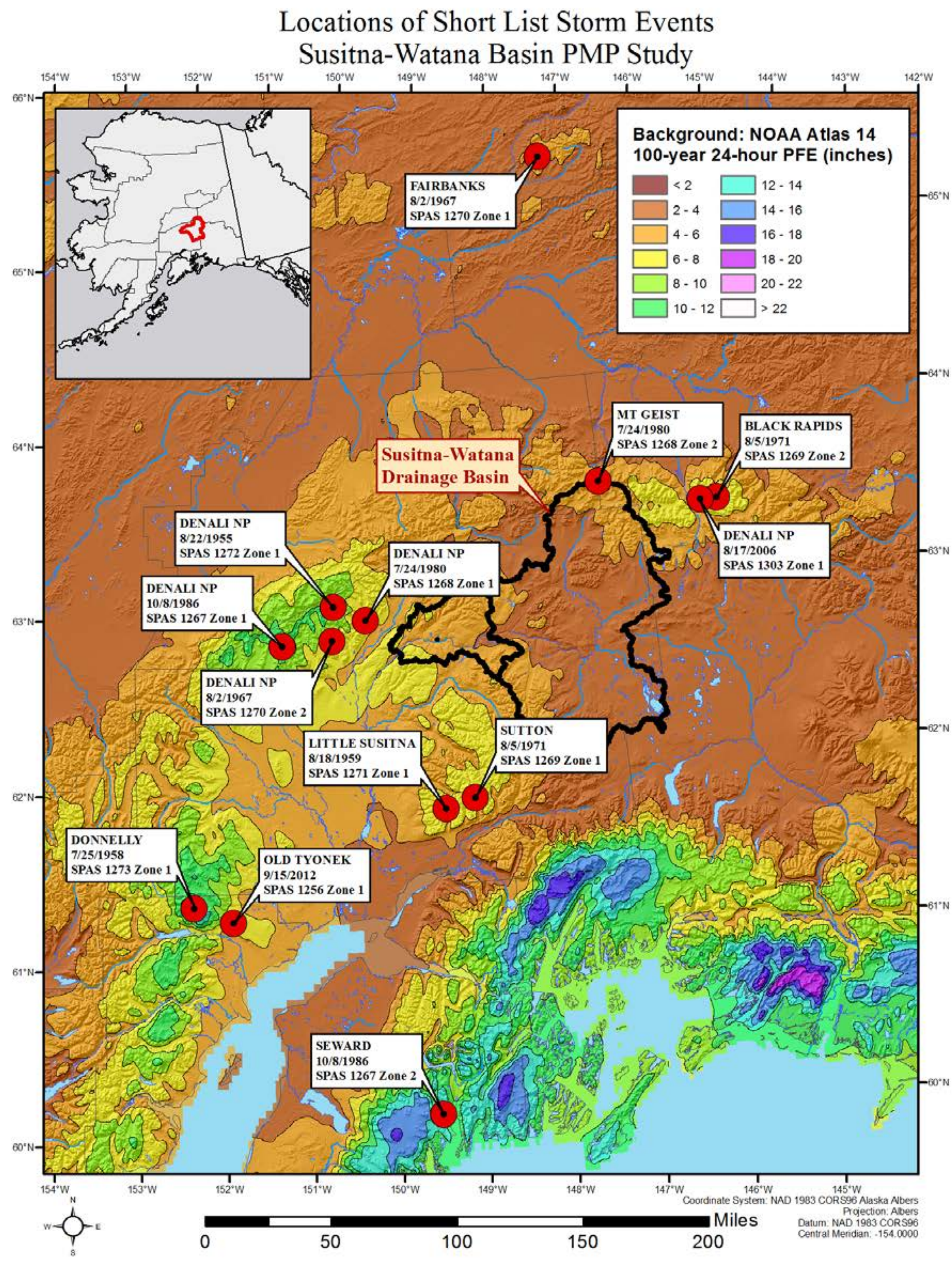

Figure 3.2. Short storm list storm locations.

Table 3.3. Susitna-Watana short storm list used in the SSPMP analysis. Rainfall values are the maximum rainfall totals produced the SPAS storm analyses.

Name	ST	Lat	Lon	Year	Mon	Day	Total Rainfall	Precipitation Source
DENALI NP	AK	63.038	-150.471	1955	8	22	13.75	SPAS 1272 Zone 1
MT SPURR	AK	61.346	-152.329	1958	7	25	6.62	SPAS 1273 Zone 1
LITTLE SUSITNA	AK	61.854	-149.229	1959	8	18	13.05	SPAS 1271 Zone 1
DENALI NP	AK	62.846	-150.513	1967	8	2	12.45	SPAS 1270 Zone 2
FAIRBANKS	AK	65.521	-147.329	1967	8	2	12.45	SPAS 1270 Zone 1
BLACK RAPIDS	AK	63.471	-145.479	1971	8	5	12.17	SPAS 1269 Zone 2
SUTTON	AK	61.904	-148.863	1971	8	5	11.39	SPAS 1269 Zone 1
MT GEIST	AK	63.638	-146.971	1980	7	24	5.26	SPAS 1268 Zone 2
DENALI NP	AK	62.954	-150.079	1980	7	24	7.33	SPAS 1268 Zone 1
DENALI NP	AK	62.829	-151.138	1986	10	8	11.01	SPAS 1267 Zone 1
SEWARD	AK	60.113	-149.513	1986	10	8	20.80	SPAS 1267 Zone 2
BLACK RAPIDS	AK	63.465	-145.685	2006	8	17	16.12	SPAS 1303 Zone 1
OLD TYONEK	AK	61.260	-151.860	2012	9	15	15.91	SPAS 1256 Zone 1

4. STORM DEPTH-AREA-DURATION (DAD) ANALYSES

Gridded rainfall values are required for PMP calculations. Therefore, all storms on the short storm list (see Section 3.5) were required to be analyzed using the SPAS program. This program computed the required rainfall values, along with several other products such as mass curves, isohyetal patterns, analysis statistics, and quality control analyses. Detailed results of each of these analyses are included in Appendix C.

There are two main steps in the SPAS DAD analysis: 1) The creation of high-resolution hourly rainfall grids and 2) the computation of Depth-Area (DA) rainfall amounts for various durations. The reliability of the results from step 2) depends on the accuracy of step 1) (Jones 1969, Gou et al 2001, Duchon and Essenberg 2001). Before this process was automated using SPAS, the storm rainfall analyses were very labor intensive and highly subjective. SPAS utilizes a GIS to create spatially-oriented and highly accurate results in an efficient manner. Furthermore, the availability of NEXRAD data allows SPAS to better account for the spatial and temporal variability of storm precipitation for events occurring since the early 1990s. Prior to NEXRAD, the NWS developed and used a method based on Weather Bureau Technical Paper No. 1 (U.S. Weather Bureau 1946). Because this process has been the standard for many years (all DAD produced by the NWS in all the HMRs used this procedure) and holds merit, the SPAS DAD analysis process used in this study attempts to apply the NWS procedure as much as possible. By adopting this approach, some level of consistency between the newly analyzed storms and the hundreds of storms already analyzed by the NWS is achieved. Comparisons between the NWS DAD results and those computed using the SPAS method for two storms (Westfield, MA 1955 and Ritter, IA 1953) produced very similar results (see Appendix D for complete discussion, comparisons, and results).

4.1 Data Collection

The areal extent of a storm's rainfall was evaluated using existing maps and documents along with plots of total storm rainfall. Based on the storm's spatial domain (longitude-latitude box), hourly and daily rainfall data were extracted from our in-house database for specified areas, dates, and times. Rainfall amounts are either observed and recorded each hour (hourly) or once a day (daily). To account for the temporal variability in observation times at daily reporting stations, the extracted hourly data must capture the entire observational period of all daily station reports. For example, if a station takes daily observations at 8:00 AM local time, then the hourly data need to be complete from 8:00 AM local time the day prior. As long as the hourly data are sufficient to capture all of the daily station observations, the hourly variability in the daily observations can be properly addressed.

The daily rainfall database is comprised of data from National Climatic Data Center (NCDC) TD-3206 (pre 1948) and TD-3200 (generally 1948 through present). The hourly rainfall database is comprised of data from NCDC TD-3240 and NOAAs Meteorological Assimilation Data Ingest System (MADIS). The daily supplemental database is largely comprised of data from "bucket surveys," local rain gauge networks (e.g. ALERT, USGS, etc.) and daily gauges with accumulated data.

4.2 Mass Curves

The most complete rainfall observational dataset available is compiled for each storm. To obtain temporal resolution to the nearest hour in the DAD results, it is necessary to distribute the daily precipitation observations (at daily stations) into hourly values. This process has traditionally been accomplished by anchoring each of the daily stations to a single hourly timer station. However, this may introduce biases and may not correctly represent hourly precipitation at locations between hourly stations. A preferred approach is to anchor the daily station to some set of the nearest hourly stations. This is accomplished using a spatially based approach that is called the spatially based mass curve (SMC) process.

4.3 Hourly or Sub-hourly Precipitation Maps

At this point, SPAS can either operate in its standard mode or in NEXRAD-mode to create high resolution hourly or sub-hourly (for NEXRAD storms) grids. In practice both modes are run when NEXRAD data are available so that a comparison can be made between the methods. Regardless of the mode, the resulting grids serve as the basis for the DAD computations.

4.3.1 Standard SPAS Mode

The standard SPAS mode requires a full listing of all the observed hourly rainfall values, as well as the newly created estimated hourly values from daily and daily supplemental stations. This is done by creating an hourly file that contains the newly created hourly mass curve precipitation data (from the daily and supplemental stations) and the "true" hourly mass curve precipitation. The option of incorporating basemaps was used in this study. If base maps were not used, the individual hourly precipitation values would simply be plotted and interpolated to a raster with an inverse distance weighting (IDW) interpolation routine or some other mathematical scheme using GIS.

4.3.2 NEXRAD Mode

Radar has been in use by meteorologists since the 1960s to estimate rainfall depth. In general, most current radar-derived rainfall techniques rely on an assumed relationship between radar reflectivity and rainfall rate. This relationship is described by the equation (4.1) below:

$$Z = aR^b \qquad \text{Equation 4.1}$$

Where Z is the radar reflectivity, measured in units of dBZ (dBZ stands for decibels of Z), R is the rainfall rate, *a* is the "multiplicative coefficient" and *b* is the "power coefficient". Both *a* and *b* are related to the drop size distribution (DSD) and the drop number distribution (DND) within a cloud (Martner et al. 2005).

The NWS uses this relationship to estimate rainfall through the use of their network of NEXRAD sites located across the United States. A standard default Z-R algorithm of $Z = 300R^{1.4}$ is the primary algorithm used throughout the country and has proven to produce highly variable results. The variability in the results of Z vs. R is a direct result of differing DSD and DND, and differing air mass characteristics across the United States (Dickens 2003). The DSD and DND are determined by a complex interaction of microphysical processes in a cloud. They fluctuate hourly, daily, seasonally, regionally, and even within the same cloud (see Appendix D for a more detailed description).

Although SPAS uses Equation 4.1 to determine rainfall rates, the *a* and *b* coefficients are explicitly determined for each hour of the storm using a calibration technique. Hourly rain gauge data are used with hourly NEXRAD data in the calibration calculations.

4.4 Depth-Area-Duration Program

The DAD extension of SPAS runs from within a Geographic Resource Analysis Support System (GRASS) GIS environment[3] and utilizes many of the built-in functions for calculation of area sizes and average depths. The following is the general outline of the procedure:

1. Given a duration (e.g. x-hours) and cumulative precipitation, sum up the appropriate hourly or sub-hourly precipitation grids to obtain an x-hour total precipitation grid starting with the first x-hour moving window.

2. Determine x-hour precipitation total and its associated areal coverage. Store these values. Repeat for various lower rainfall thresholds. Store the average rainfall depths and area sizes.

3. The result is a table of depth of precipitation and associated area sizes for each x-hour duration. Summarize the results by moving through each of the area sizes and choosing the maximum precipitation amount. A log-linear plot of these values provides the depth-area curve for the x-hour duration.

4. Based on the log-linear plot of the rainfall depth-area curve for the x-hour duration, determine rainfall amounts for the standard area sizes for the final DAD table. Store these values as the

[3] Geographic Resource Analysis Support System, commonly referred to as GRASS, this is free Geographic Information System (GIS) software used for geospatial data management and analysis, image processing, graphics/maps production, spatial modeling, and visualization. GRASS is currently used in academic and commercial settings around the world, as well as by many governmental agencies and environmental consulting companies. GRASS is an official project of the Open Source Geospatial Foundation.

rainfall amounts for the standard sizes for the x-duration period. Determine if the x-hour duration period is the longest duration period being analyzed. If it is not, analyze the next longest duration period and return to step 1.

5. Construct the final DAD table with the stored rainfall values for each standard area for each duration period.

5. STORM MAXIMIZATION

Storm maximization (also called moisture maximization in the HMRs) is the process of increasing rainfall associated with an observed extreme storm. In this process, it is assumed the storms being maximized and the PMP storm would have the same storm efficiency (ability to convert moisture in the atmosphere to precipitation). Therefore, the only variable that would increase or decrease the amount of precipitation produced from a given storm would be the amount of moisture available. During the storm maximization process, a quantification of the amount of additional moisture which could have been available to the storm and would have increased the rainfall production in calculated. This is quantified by comparing the storm representative dew points (or SSTs for all storms used in this study) to some climatological maximum and calculating the enhanced rainfall amounts that could potentially have been produced had the climatological maximum value been present versus what actually occurred (Bolsenga 1965). An additional consideration is usually applied that selects the climatological maximum dew point (or SST for this study) for a date two weeks towards the climatological maximum warm season from the date that the storm actually occurred. This procedure assumes that the storm could have occurred two weeks earlier or later in the year when maximum dew points or SSTs are higher. Calculations for each storm used in this study are shown in Appendix C.

5.1 New Procedures Used in the Storm Maximization Process

The HYSPLIT trajectory model (Draxler and Rolph 2003, 2010) provides detailed analyses of upwind trajectories of atmospheric moisture that was advected into the storm systems. Using these trajectories, the atmospheric moisture source locations are determined. The procedures followed are similar to the approach used in HMRs 57 and 59. However, by utilizing the HYSPLIT model trajectories, much of the subjectivity is eliminated. Further, details of each evaluation can be explicitly provided and the results are reproducible.

Using SSTs for in-place maximization and storm transpositioning (discussed Section 6) followed the same procedure used with land based surface dew points. Use of the HYSPLIT trajectory model provided a significant improvement in determining the inflow wind vectors originating over the ocean compared to older methods of extrapolating coastal wind observations and estimating moisture advection from synoptic features. This more objective procedure is especially useful for situations where a long distance is involved to reach warmer ocean regions. Timing is not as critical for inflow wind vectors extending over the oceans since SSTs change very slowly with time compared to dew point values over land. Changing wind directions are of greater importance, especially for situations where there is curvature in the wind fields. Any changes in wind curvature and variations in timing are inherently captured in the HYSPLIT trajectories.

5.1.1 HYSPLIT Trajectory Model

The HYSPLIT trajectory model was used during the analysis of each of the rainfall events included on the short storm list when available (1948-present from the National Centers for Environmental Prediction (NCEP) Global Reanalysis fields) (Mesinger et al. 2006). Use of a trajectory model provides increased confidence for determining inflow moisture vectors and storm representative SSTs. The HYSPLIT model trajectories have been used to analyze the moisture inflow vectors in other PMP studies completed by AWA over the past several years. During these analyses, the model trajectory results were verified and the utility explicitly evaluated (e.g. Tomlinson et al. 2006-2011, Kappel et al. 2012-2013).

Instead of subjectively determining the moisture inflow trajectory, the HYSPLIT analysis was used to determine the trajectory of the moisture inflow for various levels in the atmosphere associated with the storm's rainfall production. The HYSPLIT software was run for trajectories at several levels of the lower atmosphere to help determine the moisture source for each storm event. These included 700mb (approximately 10,000 ft), 850mb (approximately 5,000 ft), and storm center location surface elevation[4].

For the majority of the analyses, a combination of all three levels was used to identify the upwind moisture source location. It is important to note that the resulting HYSPLIT model trajectories are only used as a general guide of where to evaluate the moisture source for storms in space and time. The final determination of the storm representative SST and its location is determined following the standard procedures used by AWA in previous PMP studies and as outlined in the HMRs and WMO manuals. Appendix C of this report lists each of the HYSPLIT trajectories used for each storm. As an example, Figures 5.1 show the HYSPLIT trajectories used to determine the inflow moisture vector from the October 1986 rainfall event.

[4] These are standard elevations for atmospheric analysis. Further, the majority of atmospheric moisture available for rainfall production occurs below the 700mb level.

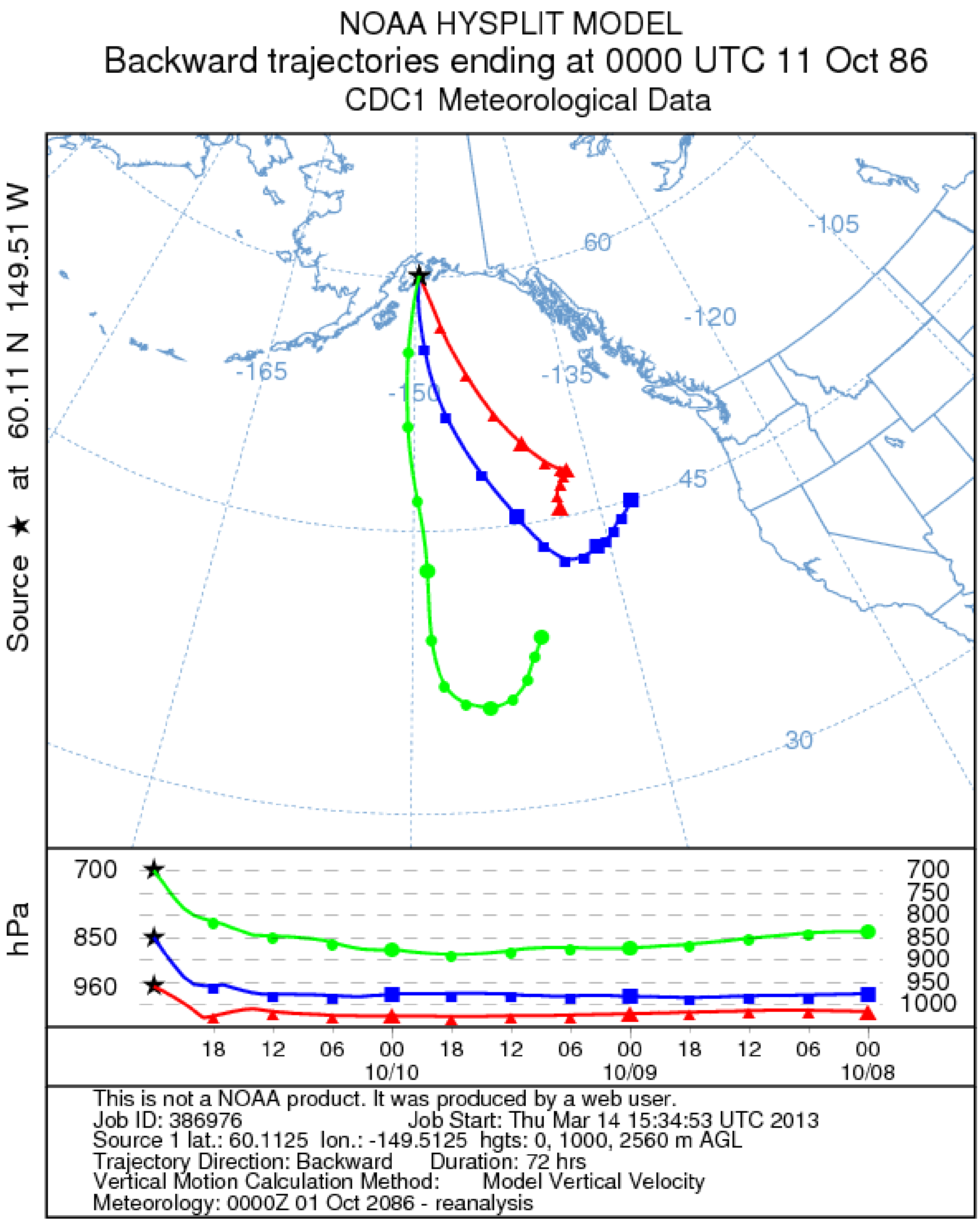

Figure 5.1. Surface (960mb), 850mb, and 700mb HYSPLIT trajectory model results for the October 1986 storm event.

5.1.2 Sea Surface Temperatures (SSTs)

The second data set used in storm analyses contained SSTs derived from the various databases available from NOAA. Daily values were generated from the following sources:

1985 – Present: http://dss.ucar.edu/datasets/ds277.7/
1946 - 1985: http://dss.ucar.edu/datasets/ds195.1/
Prior to 1946: http://dss.ucar.edu/datasets/ds540.0/

Observations were taken from ships, buoys (moored and drifting), automated coastal fixed platforms and drilling rigs, and satellite observations of SSTs (Woodruff et al. 2005). Analyses are archived to the nearest 0.1°F, with a spatial resolution of 1° in both latitude and longitude. For storm analyses, daily SSTs were used to determine the storm representative SST for each storm event on the short storm list. Figure 5.2 is an example daily SST map for the October 1986 storm event.

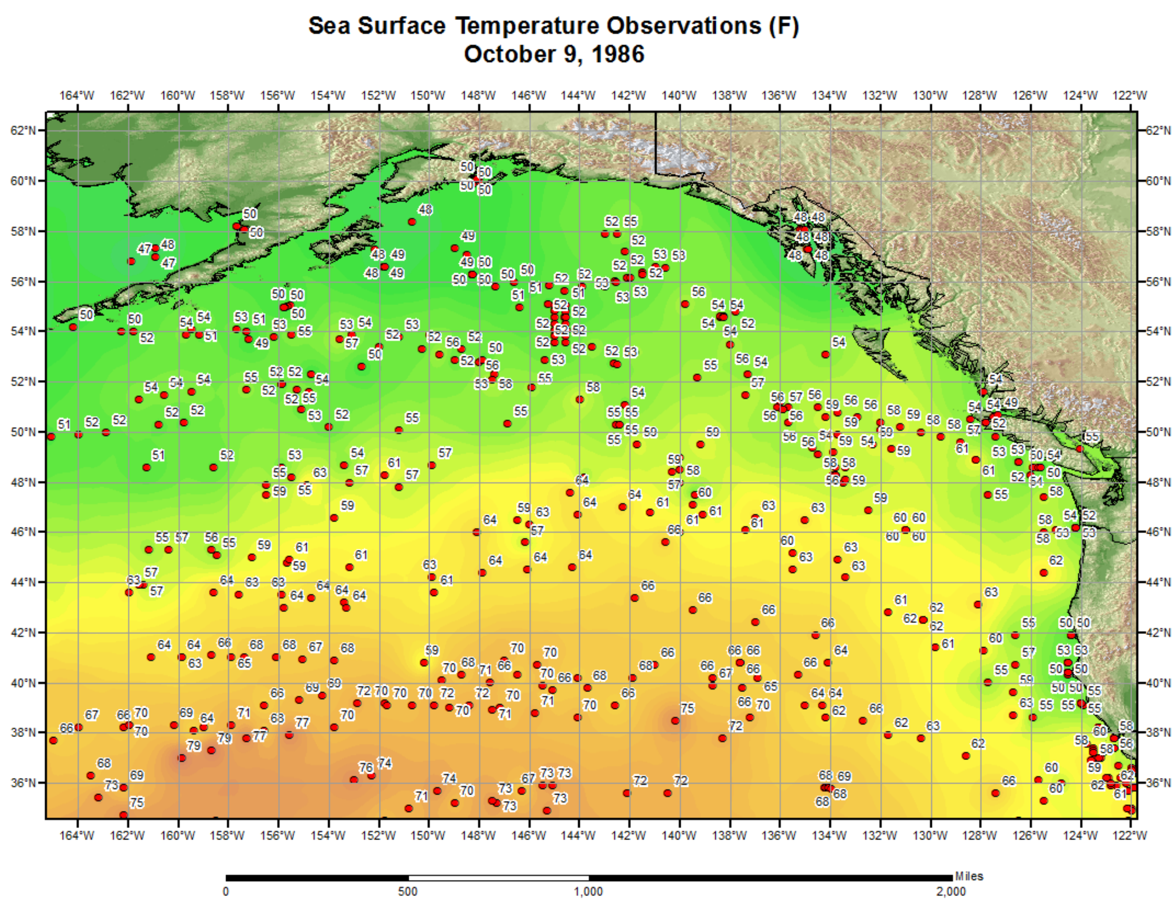

Figure 5.2. Daily sea surface temperatures for October 9, 1986 over the upwind domain used to determine the storm representative sea surface temperature.

For computing the maximization factors, a climatology of SSTs was computed for every 1° latitude and longitude, based on data from 1982 through 2012[5]. The standard deviation for each cell was calculated and plus two standard deviations (+2-sigma) were added to the monthly mean SST values for each cell. Monthly maps were produced to provide spatial analyses of the mean plus 2-sigma (two standard deviations warmer than the mean) SSTs. Use of the mean plus 2-sigma SSTs is consistent with the NWS procedure used in HMRs 57 and 59. Figure 5.3 is an example monthly map for October.

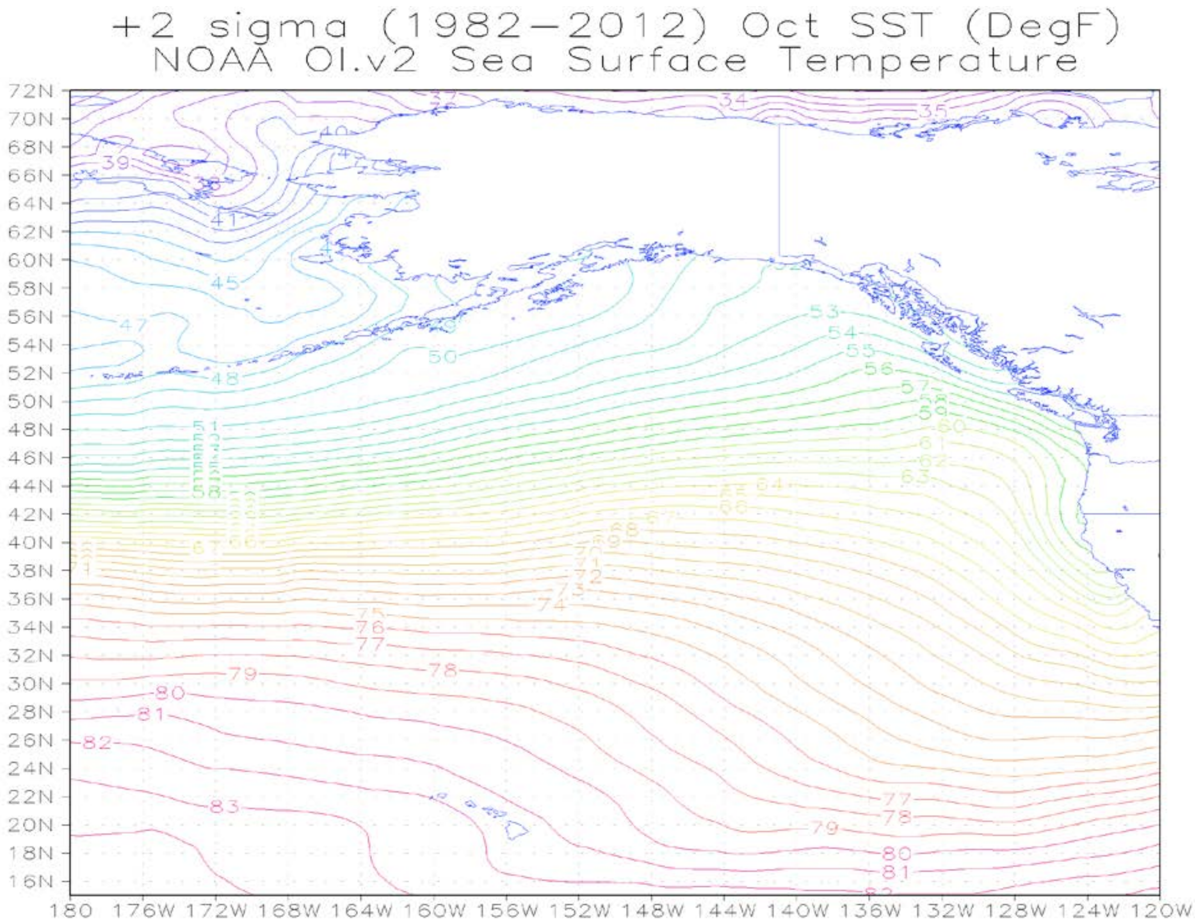

Figure 5.3. +2-sigma sea surface temperature map for October.

Dew point observations are not generally available over ocean regions. When the source region of atmospheric moisture feeding an extreme rainfall event originates over the ocean, a substitute for dew points observations is required. The NWS adopted a procedure for using SSTs as surrogates for dew points over the ocean. The value used as the maximum SST in the PMP calculations is determined using the SSTs plus two standard deviations (+2-sigma) warmer than the mean SST.

[5] From NOAA_OI_SST_V2, http://www.esrl.noaa.gov/psd/

This provides a value for the maximum SST that has a probability of occurrence of about 0.025, i.e. about the 40-year return frequency value (see Section 5.1.2.1 for more detail).

Following the NWS procedure (e.g. HMR 57) and previous AWA PMP work (Tomlinson et al. 2008-2013, Kappel et al. 2011-2014), storm representative SSTs were substituted for dew points. All storms on the short list were reanalyzed to determine the storm representative SST and the +2-sigma SST. These SST values are then treated the same as dew points and the same process is followed for storm maximization as if the SST values were dew point values taken from land based stations.

Where cold currents affect ocean temperatures adjacent to the coast, use of the cold SSTs is inappropriate to represent the storm atmospheric moisture source region. The procedure that selects a storm representative SST in the region that is the primary source of atmospheric moisture available to the storm is then employed. This procedure requires extending the inflow wind vector over the region of colder SSTs along the immediate coastline and selecting a location over the warmer water of the moisture source region. Daily SSTs are then analyzed over this general region, using HYSPLIT as guidance when available, to determine a homogenous region of SSTs in space and time. Generally, this area should show less than a 1°F temperature change in a 1° latitude x 1° longitude box. This value is the storm representative SST.

For storm maximization, the value for the maximum SST is determined using the mean plus 2-sigma SST for that location for a date two weeks before or after the storm date (which ever provides the climatologically warmer 2-sigma SST values). Storm representative SSTs and the mean plus 2-sigma SSTs are used in the same manner as storm representative dew points and maximum dew points in the maximization and transpositioning procedure.

The NWS states in HMR 57 that the two standard deviations warmer values are approximately equal to a 0.02 probability of occurrence. Specifically, HMR 57 Section 4.3, pp 43-44, states that two standard deviations represent about 98 percent of normally distributed values and this "…places the magnitude of this parameter at about the level of other estimates used in this study, e.g. the 100-year frequency values." For the +2-sigma probability, there is 0.05 out of 1.00 that is not included under the normal distribution curve. The 0.05 is divided between the extremes on the upper and lower ends of the normal distribution curve. Since only the high end (i.e. SST plus two standard deviations warmer) is used, only half of the 0.05 is excluded from under the normal distribution curve, i.e. 0.025. Hence 0.975 or 97.5% is included under the normal distribution curve. Figure 5.4 shows the normal distribution curve with the +1-sigma and +2-sigma values.

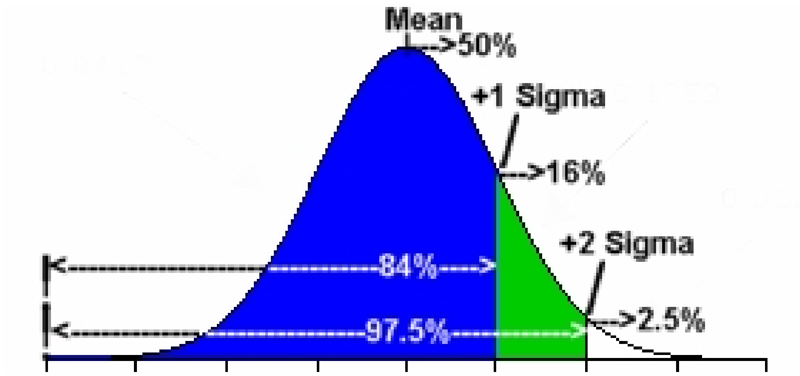

Figure 5.4. Normal distribution curve with +1-sigma and +2-sigma values shown

It appears, for reasons that are not clear in HMR 57, that the NWS increased the value of 0.975 to 0.99 and then concluded that this represents the 100-year frequency value. Therefore, it is important to note that without any adjustments, 0.975 is approximately equal to a 40-year return frequency value.

6. STORM TRANSPOSITIONING

Extreme rain events in meteorologically homogeneous regions surrounding a watershed are an important part of the historical evidence for a basin PMP estimate. Since most basin locations have a limited period of record and number of recording stations for rainfall data collected within the basin boundaries, the number of extreme storms that have been observed over the basin is often limited. This lack of data is especially prevalent for the Susitna River basin because of its remote location. To overcome this, storms that have been observed within similar meteorological and topographic regions are analyzed and adjusted to provide information describing the storm rainfall as if that storm had occurred over the basin being studied. Transfer of a storm from where it occurred to a location that is meteorologically and topographically similar is called storm transpositioning. The underlying assumption is that storms transposed to the basin could occur over the basin under similar meteorological conditions. To properly relocate such storms, it is necessary to address issues of similarity as they relate to meteorological conditions (moisture availability) and topography (difference in elevation and orographic influence) between the in-place storm location and the basin location.

Using ArcGIS, a gridded network was placed over the Susitna-Watana basin. The adopted grid cell resolution for this study is 0.025 x 0.025 decimal degrees in latitude and longitude (90 arc-seconds). The area of the grid cells varies with latitude, averaging approximately 1.4-square miles at the basin location. There are a total of 4,013 grid cells/grid points within the domain. This universal grid provides a consistent template for the grid cell by grid cell analysis. Figure 6.1 shows the grid over the Susitna-Watana basin.

Each of the short list storms were transposed from the storm center location to each of the 4,013 grid points within the Susitna-Watana basin. The transposition process includes a moisture transposition component and an orographic transposition component. The moisture transposition component closely follows the procedures in HMR 57 and previous AWA studies. The orographic transposition process leverages the NOAA Atlas 14 (Perica et al. 2012) 10 to 1,000-year precipitation frequency values to quantify the differences in extreme rainfall between the historic storm centers and the basin, which is primarily a function of elevation and topography. For moisture transpositioning, only the horizontal difference in available moisture between the storm center and the basin grid points is explicitly accounted for. The vertical component, which accounts for the difference in elevation between the two locations, was not calculated as part of the storm (also called moisture) transposition factor. Instead, this component was accounted for in the derivation of the orographic transposition component: the rainfall values used to derive the ratio at the in-place similar area to the Susitna-Watana basin inherently have the elevation component incorporated. The transposition procedures are defined in the following sections.

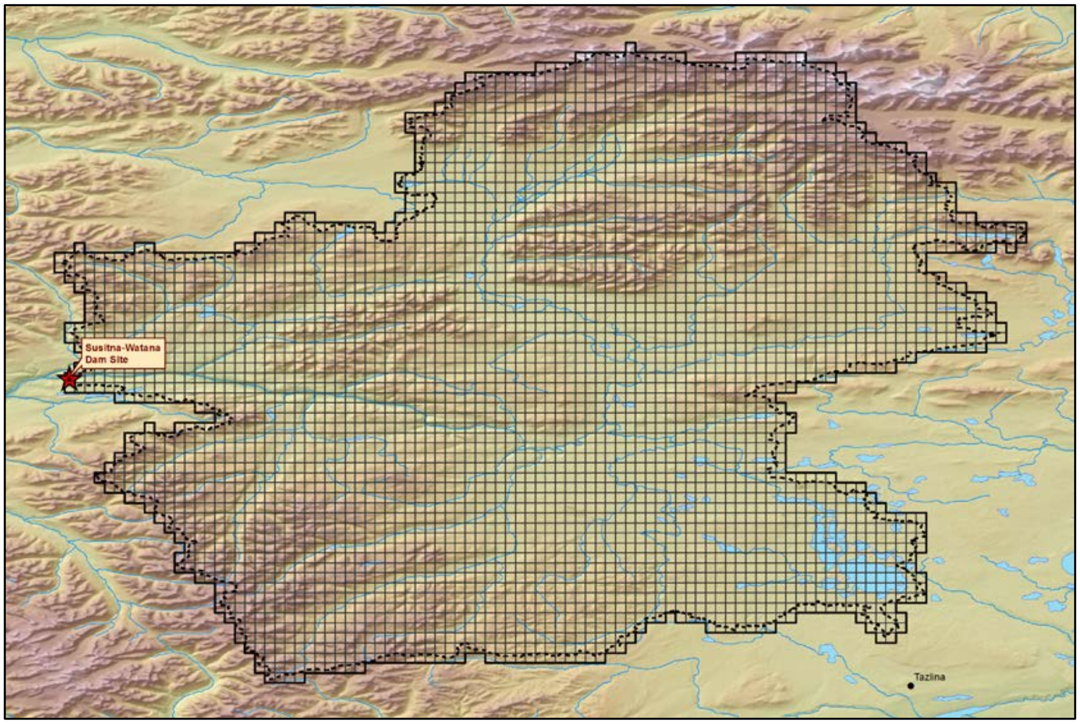

Figure 6.1. The universal 90 arc-second grid network placed over the Susitna-Watana drainage basin.

6.1 Moisture Transposition

The general procedure for storm maximization has been discussed in Section 5. The same data sets used for maximum SSTs are used in the storm transpositioning procedure. The wind inflow vector connecting the storm location with the storm representative SST location was transpositioned to each grid point within the basin. Figure 6.2 shows an example of inflow vector transpositioning for the August 1967, Fairbanks, Alaska storm center. The upwind end of the vector identifies the transposition maximum SST location. The value of the maximum SST at that location provided the transpositioned maximum SST value used to compute the transposition adjustment for relocating the storm to each grid point within the basin. The primary effect of storm transpositioning is to adjust storm rainfall amounts to account for enhanced or reduced atmospheric moisture made available to the storm at the transposed location versus the in-place storm location. The ratio of precipitable water due to available atmospheric moisture (as determined by the SST) at the basin target location to the in-place storm location is expressed as the moisture transposition factor (MTF). Figure 6.2 shows the august +2σ SST as a background grid. The SST grid resolution is 1° x 1° decimal degree; therefore a bilinear interpolation is used to extract the SST value at each grid point with a greater degree of precision.

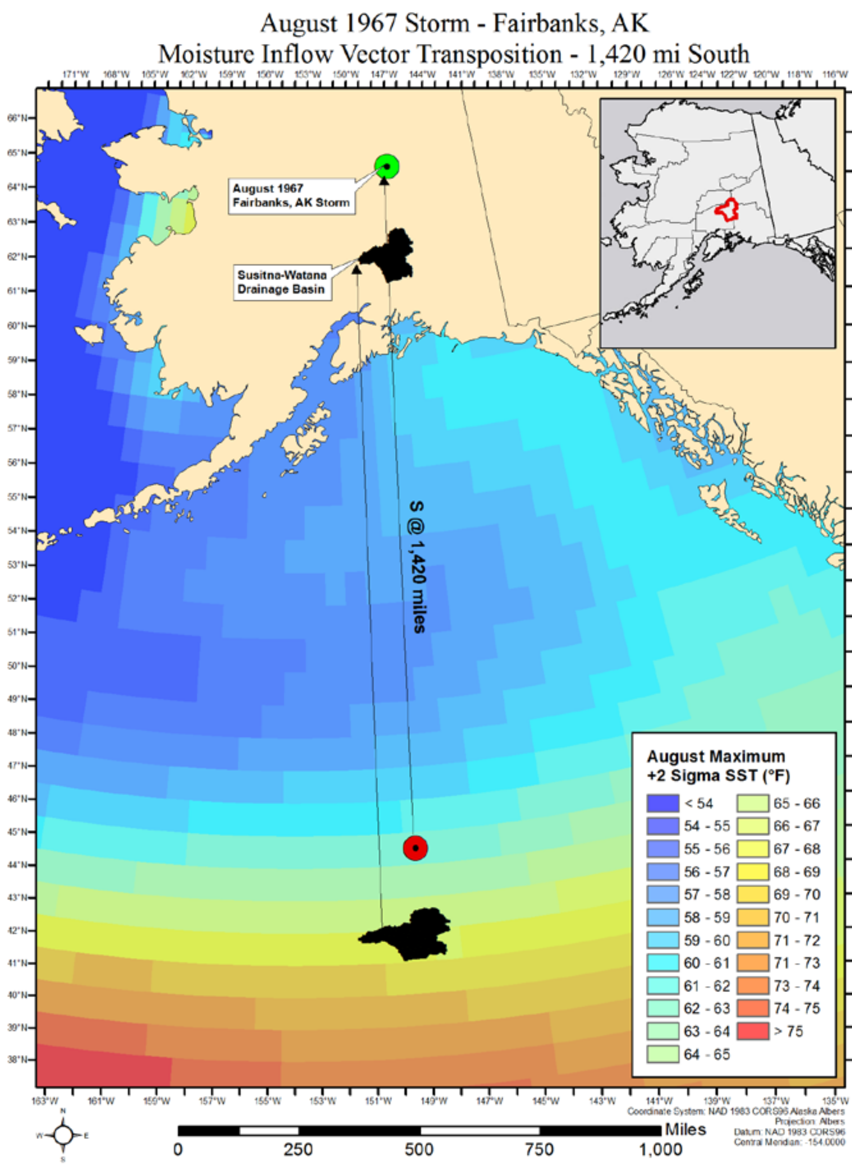

Figure 6.2. An example of inflow wind vector transpositioning for August 1967, Fairbanks storm. The storm representative SST location is ~1,420 miles south of the storm location.

6.2 Orographic Transposition

6.2.1 Topographic Effect on Rainfall

The terrain within the Susitna River basin and the surrounding region is complex, often over relatively short distances (Figure 6.3). When a basin has intervening elevated terrain features that deplete some of the atmospheric moisture available to storms before reaching a basin, these must be taken into account during the storm maximization process. Conversely, when a basin includes terrain which enhances the lift in the atmosphere and increases the conversion of moisture to liquid and ice particles, precipitation processes are enhanced. To account for the enhancements and reductions of precipitation by terrain features, called orographic effects, explicit evaluations were performed using the OTF calculation. The OTF evaluation of the orographic effect in this study is significantly more objective and reproducible than the HMR procedure.

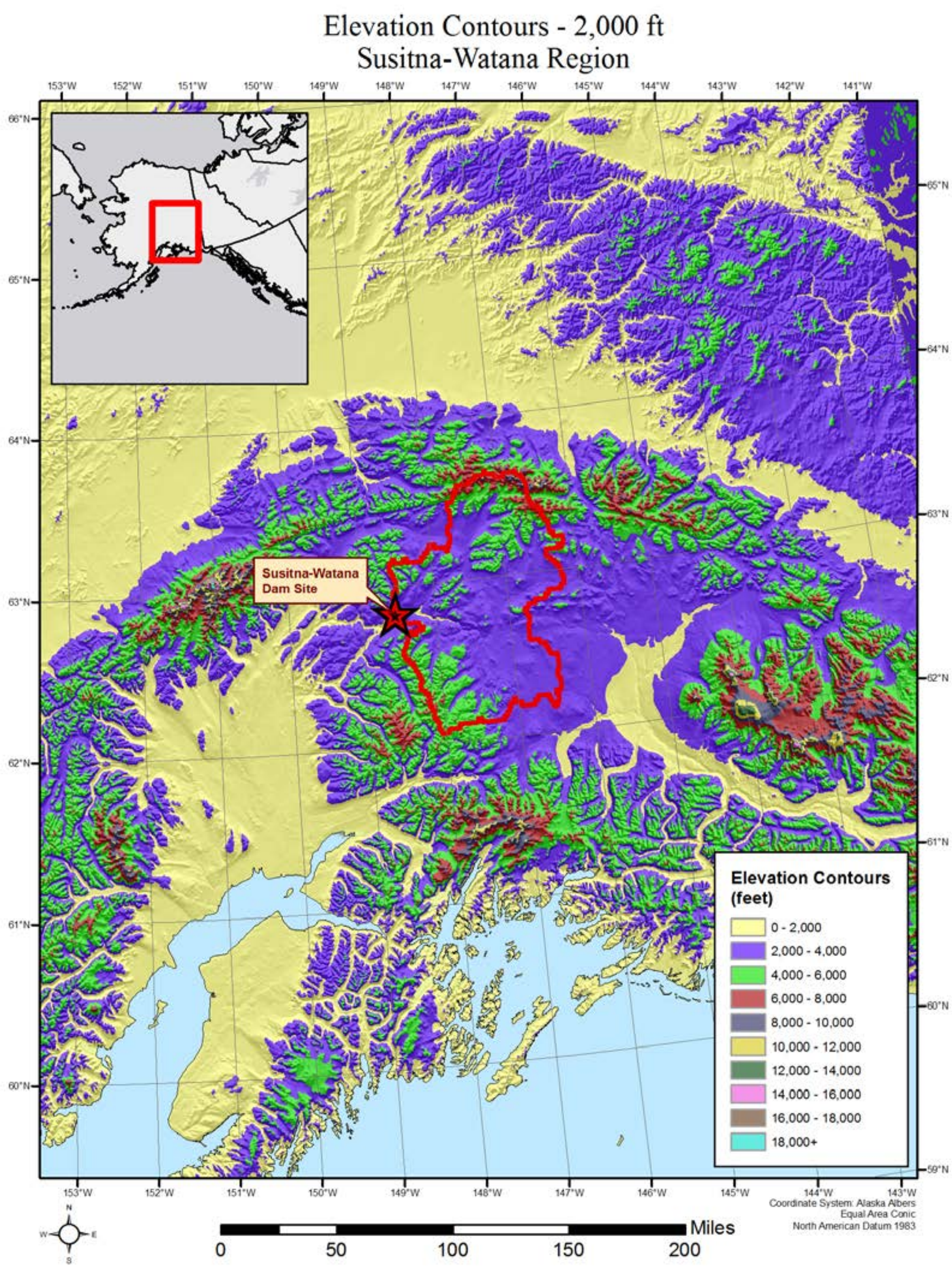

Figure 6.3. 2,000-foot elevation contours over the Susitna-Watana region.

Orographic effects on rainfall are explicitly captured in the NOAA Atlas 14 precipitation frequency climatological analyses. Although the orographic effects at a particular location may vary from storm to storm, the overall effect of the topographic influence is inherent in the climatology of storms that have occurred over various locations, assuming that the climatology is based on storms of the same type being analyzed. The NOAA Atlas 14 analysis should adequately reflect the differences in topographic influences at different locations at durations appropriate to the storm type in similar meteorological and topographical settings.

The procedure used in this study to account for orographic effects assesses the differences between the NOAA Atlas 14 data at the in-place storm location and each grid point within the Susitna-Watana basin. By evaluating the rainfall values for a range of return frequencies at both locations, a relationship between the two locations was established. For this study, precipitation frequency datasets developed as part of NOAA Atlas 14, Volume 7 (Perica et al. 2012) were used to evaluate the orographic effects. Figure 6.4 illustrates the 100-year 24-hour NOAA Atlas 14 precipitation coverage. The spatial distribution clearly exhibits the anchoring of the majority of rainfall to the coastal topography, particularly on the upwind side, while inland regions (such as the Susitna-Watana basin) are under a significant rain shadow effect and experience relatively low rainfall.

The NOAA Atlas 14 precipitation frequency estimates utilize data from the mean annual maximum grids developed using the Oregon State University Climate Group's PRISM system to help spatially distribute the values between data points. PRISM is a peer-reviewed modeling system that combines statistical and geospatial concepts to evaluate gridded rainfall with particular effectiveness in orographic areas (Daly et al. 1994, 1997). NOAA Atlas 14 precipitation frequency estimates implicitly express orographic controls through the adoption of the PRISM system. This study assumes the relationship between precipitation frequency values in areas of similar atmospheric characteristics reveal a quantifiable orographic effect and that terrain influence drives the variability in the relationship between NOAA Atlas 14 values at two distinct point locations.

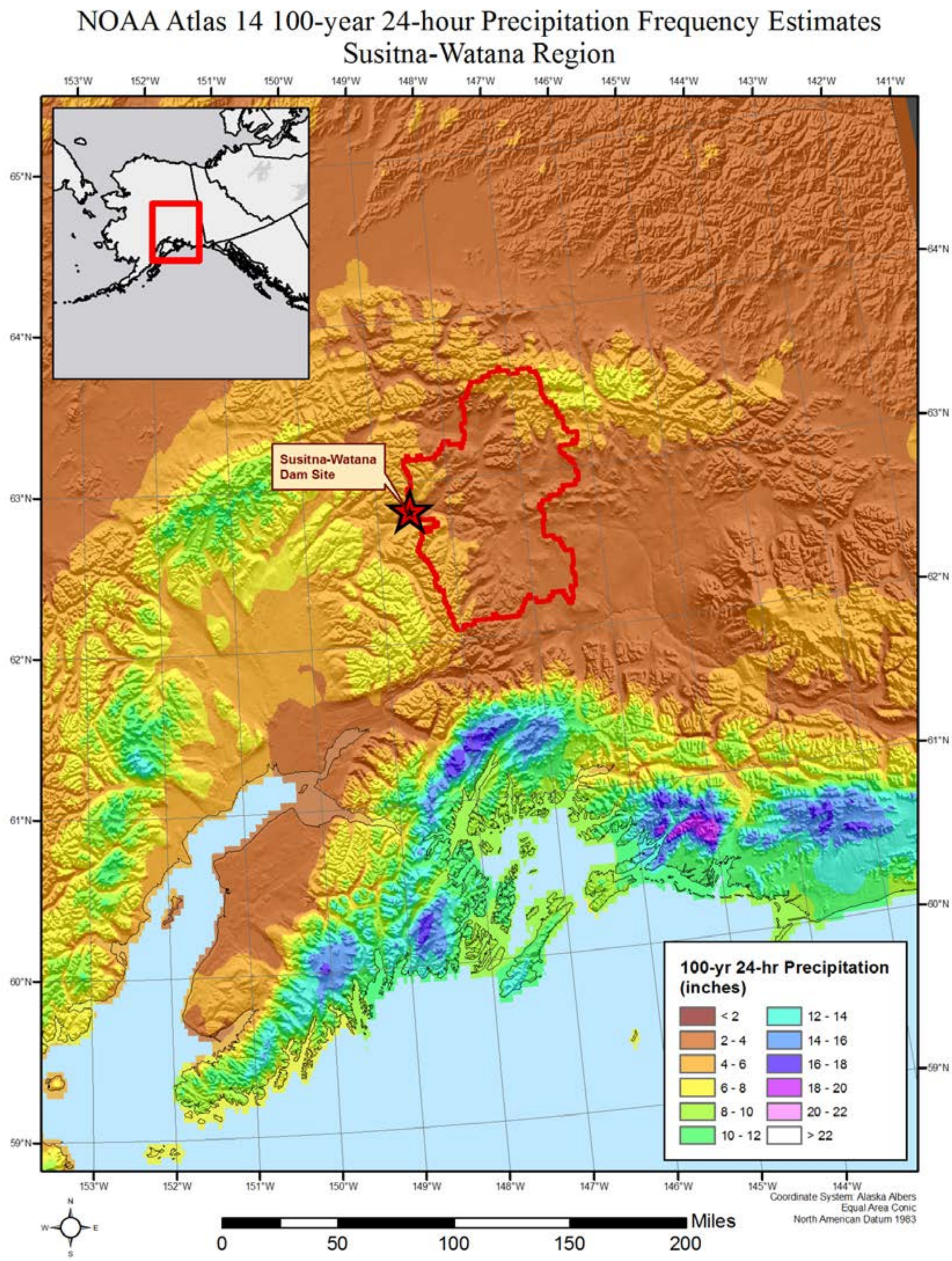

Figure 6.4. 100-year 24-hour NOAA Atlas 14 precipitation over the Susitna-Watana region.

6.2.2 Orographic Transpositioning Procedure

The orographically adjusted rainfall values for a given storm at a target location (grid cell) within the basin are calculated by applying a coefficient of proportionality, determined by the relationship between a NOAA Atlas 14 data series at the source storm location and the corresponding NOAA Atlas 14 values at the target location. For the transposition of a single grid cell at a given duration, the orographic relationship is defined as the linear relationship between the NOAA Atlas 14 values, at that duration, over a range of recurrence intervals. This study evaluates the trend of precipitation frequency estimates through the 10-, 25-, 50-, 100-, 200-, 500-, and 1,000-year average recurrence intervals. The relationship between the target and the source can be expressed as a linear function with P_o as the independent variable and P_i as the dependent variable as shown in Equation 6.1.

$$P_o = mP_i + b \qquad \text{Equation 6.1}$$

where,

P_o	=	orographically adjusted rainfall (target)
P_i	=	in-place rainfall (source)
m	=	proportionality coefficient (slope)
b	=	transposition offset (y-intercept)

Equation 6.1 provides the orographically transpositioned rainfall depth, as a function of the in-place rainfall depth. The in-place rainfall depth used to calculate the orographically transpositioned rainfall use NOAA Atlas 14 values. The 24-hour duration is appropriate for all storms in the short list. To express the orographic effect as a ratio, or OTF, the orographically adjusted rainfall (P_o) is divided by the original source in-place rainfall depth (P_i). It is assumed the orographic effect for a given transposition scenario will remain constant over the durations analyzed. Therefore, the 24-hour OTF is valid for any other duration a storm.

The orographic relationship can be visualized by plotting the average NOAA Atlas 14 depths for the grid point at the source location on the *x*-axis and the NOAA Atlas 14 depths for the grid point at the target location on the *y*-axis, then drawing a best-fit linear trend line among the seven return frequency value points. The trend line describes the general relationship between the NOAA Atlas 14 values at the grid location and the values at the storm location. As an alternative to producing the best-fit linear trendline graphically, linear regression can be used to apply the function mathematically. The mathematical method was applied, in Excel spreadsheets, to efficiently calculate the OTF for each of the basin grid points, for each storm. An example of the determination of the orographic relationship and development of the OTF is given in Section 7.3.

7. PMP CALCULATION PROCEDURES

PMP depths were calculated by comparing the total adjusted rainfall values for all transpositionable storm events for each grid point and taking the largest value, a process comparable to the envelopment of all transpositionable events. In this case, envelopment occurs because the largest PMP depth for a given duration is derived after analyzing all storms for each grid point location for each duration over the Susitna-Watana basin.

The adjusted rainfall at a grid point, for a given storm event, was determined by applying a Total Adjustment Factor (TAF) to the SPAS analyzed rainfall depth value corresponding to the basin area size of 5,131 mi^2, at each analyzed duration. The TAF is the product of the three separate storm adjustment factors, the IPMF, the MTF, and the OTF. In-place maximization and moisture transposition are described in Section 6.1. Orographic transposition is described in Section 6.2. These calculations were completed for all transpositionable storm centers, for each of the 4,013 basin grid cells.

An Excel storm adjustment spreadsheet was produced for each of the transpositionable storm centers. These spreadsheets are designed to perform the initial calculation of each of the three adjustment factors, along with the final TAF. The spreadsheet format allows for the large number of data calculations to be performed correctly and consistently in an efficient template format. Information such as the basin NOAA Atlas 14 data, coordinate pairs, grid point elevation values, equations, and the precipitable water lookup table remain constant from storm to storm and remain static within the spreadsheet template. The spreadsheet contains a final adjusted rainfall tab with the adjustment factors, including the TAF, listed for each grid point. A table holding the TAF for each basin grid point was exported to a GIS feature class for each storm. A Python-language scripted GIS tool receives the storm TAF feature classes and the corresponding DAD tables for each of the 13 SPAS DAD zones as input, along with a basin outline feature layer as a model parameter. The tool then calculates and compares the total adjusted rainfall at each grid point within the basin and determines the PMP depth at each duration up to 216-hours. The tool produces gridded PMP datasets for each duration and a point shapefile holding PMP values for all durations.

The following sections describe the procedure for calculating the IPMF, the MTF, the OTF, and the TAF for the creation of the storm adjustment feature classes. The August 1967, Fairbanks, Alaska event controls PMP at each duration. Examples of calculations using the data from this storm are provided.

7.1 In-Place Maximization Factor

In-place storm maximization is applied to each storm event using the methodology described above. Storm maximization is quantified by applying the IPMF, calculated using Equation 7.2.

$$IPMF = \frac{W_{p,max}}{W_{p,rep}} \qquad \text{Equation 7.2}$$

where,

$W_{(p,max)}$ = precipitable water for the maximum +2σ monthly SST
$W_{(p,rep)}$ = precipitable water for the representative SST

EXAMPLE:

Using the storm representative SST temperature and storm center elevation as input, the precipitable water lookup table returns the depth, in inches, used in Equation 7.2. The storm representative SST is 61.0°F, calculated using the procedures described in Section 5. The storm center elevation is approximated at 7,500 feet at the storm center of 65.52 N, 147.33 W. The storm representative precipitable water value ($W_{p,rep}$) is calculated:

$$W_{p,rep} = W(@60.0°)_{p,30,000'} - W(@60.0°)_{p,7,500'}$$

$$W_{p,rep} = 1.45" - 0.89"$$

$$\boldsymbol{W_{p,rep} = 0.560"}$$

The temporal transposition date for the August 1967, Fairbanks event is August 15th, therefore the August +2σ SST climatology is appropriate for use to determine the maximum precipitable water. The August climatological maximum +2σ SST at the upwind storm representative location is 62.5°F. The storm location climatological maximum available moisture at the storm in-place elevation of 7,500' ($W_{p,max}$) is calculated:

$$W_{p,max} = W(@62.5°)_{p,30,000'} - W(@62.5°)_{p,7,500'}$$

$$W_{p,max} = 1.56" - 0.945$$

$$\boldsymbol{W_{p,max} = 0.615"}$$

The ratio of climatological maximum moisture ($W_{p,max}$) to the in-place storm representative moisture ($W_{p,rep}$) yields the in-place maximization factor using Equation 7.2:

$$IPMF = \frac{0.615}{0.560}$$

$$\boldsymbol{IPMF = 1.10}$$

7.2 Moisture Transposition Factor

The change in available atmospheric moisture between the storm center location and the basin target grid point is quantified using the MTF. This MTF represents the change in available atmospheric moisture due to horizontal distance only and is calculated at the storm center elevation. The change in atmospheric moisture due to vertical displacement is quantified in the OTF, described in the next section. The MTF is calculated as the ratio of moisture for the climatological maximum SST at the target grid cell location to the moisture for the climatological maximum SST at the storm center elevation.

$$MTF = \frac{W_{p,trans}}{W_{p,max}} \qquad \text{Equation 7.3}$$

where,

$W_{(p,trans)}$ = maximum precipitable water at the basin grid cell
$W_{(p,max)}$ = maximum precipitable water at the storm center location

EXAMPLE:

The transpositioned climatological maximum available moisture must be determined for each target grid point within the basin domain. There are 4,013 grid cells within the basin domain. Only the first grid cell #1, at 62.075° N, 148.050° W (in the southwest corner of the basin), is discussed in this example. The August climatological maximum SST temperature, at the moisture inflow vector upwind from grid point #1 is 69.0°F. The precipitable water for this SST is adjusted to the in-place storm center elevation of 7,500 ft[6]. The horizontally transpositioned climatological maximum available moisture ($W_{p,trans}$) is calculated.

$$W_{p,trans} = W(@69.0°)_{p,30,000'} - W(@69.0°)_{p,7,500'}$$

$$W_{p,trans} = 2.14'' - 1.21''$$

[6] Note: Although the elevation at grid point #1 is at 6,500 ft, the elevation of the storm center is used to remove the vertical component of the moisture transposition which will be included in the orographic transposition factor.

$$W_{p,trans} = 0.930''$$

The storm location climatological maximum available moisture ($W_{p,\ max}$) was calculated above for the IPMF:

$$W_{p,max} = 0.615''$$

The MTF is calculated as the ratio of moisture for the climatological maximum SST for the grid cell location ($W_{p,\ trans}$) to the moisture for the climatological maximum SST for the storm center location ($W_{p,\ max}$), from Equation 7.3:

$$MTF = \frac{0.930}{0.615}$$

$$MTF = 1.51$$

7.3 Orographic Transposition Factor

Section 6.2 provides detail on the methods used in this study to define the orographic effect on rainfall. The OTF is calculated by taking the ratio of orographically affected rainfall at the storm in-place location to orographically affected rainfall at the basin grid cell location.

$$OTF = \frac{P_o}{P_i} \qquad \text{Equation 7.4}$$

where,

P_o = orographically adjusted rainfall (target)
P_i = SPAS-analyzed in-place rainfall

The orographically adjusted rainfall is determined by applying Equation 7.5 to the SPAS-analyzed rainfall depth. The 24-hour duration was used for P_i to be consistent with the 24-hour duration of the precipitation frequency datasets.

$$P_o = mP_i + b \qquad \text{Equation 7.5 (from Equation 6.1)}$$

where,

P_o = orographically adjusted rainfall (target)
P_i = SPAS-analyzed in-place rainfall
m = proportionality coefficient (slope)
b = proportionality variation offset (y-intercept)

EXAMPLE:

Table 7.1 gives an example using NOAA Atlas 14 24-hour values (in inches) at both the storm center grid cell location (source) and a basin grid cell location (target) used to determine the orographic relationship.

Table 7.1. 24-hour NOAA Atlas 14 Precipitation Frequency values at the storm center (source) and grid cell #1 (target) locations.

	10 year	25 year	50 year	100 year	200 year	500 year	1000 year
SOURCE (X-axis)	3.05	3.73	4.27	4.85	5.46	6.32	7.02
TARGET (Y-axis)	2.99	3.65	4.17	4.71	5.28	6.07	6.70

When the NOAA Atlas 14 values are plotted, a best fit trendline can be constructed to provide a visualization of the relationship between the NOAA Atlas 14 values at the source and target locations (Figure 7.1). In this example, the values for the source grid point nearest the Fairbanks, Alaska (August 1967) storm center are plotted on the *x*-axis while the target values for the first grid point in basin are plotted on the *y*-axis.

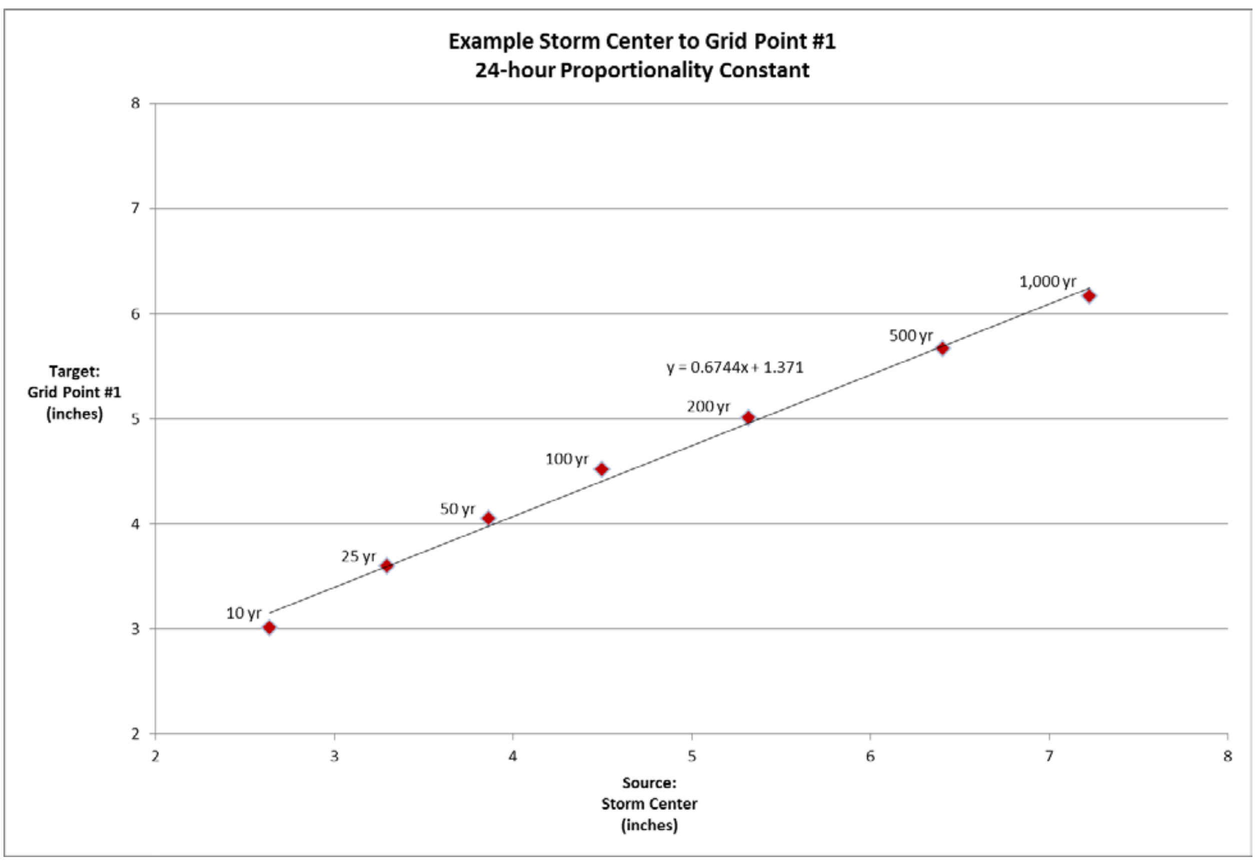

Figure 7.1. Example of NOAA Atlas 14 proportionality between the Fairbanks, 1967 DAD Zone 1 storm center and the Susitna River basin grid cell #1.

The orographically adjusted rainfall at the target location can be determined using the equation of the best fit trendline in slope-intercept form. This linear trendline equation corresponds to equation 7.5.

The slope, *m* is the proportionality coefficient, representing the direct relationship between the source and target cells. The *y*-intercept, *b,* is used to correct for variability in the precipitation frequency estimate recurrence intervals between the source and target locations. The equation for the SPAS 1270_1 24-hour orographically adjusted rainfall transpositioned to grid point #1, based on the linear trendline in Figure 7.5 is:

$$P_o = 0.6744m + 1.371$$

The maximum SPAS analyzed 24-hour point rainfall value of 5.36" is entered as the *Po* value to estimate the target *y*-value, or orographically adjusted rainfall (P_o) of 4.99".

$$P_o = 0.6744(5.36'') + 1.371''$$

$$\boldsymbol{P_o = 4.99''}$$

The ratio of the orographically adjusted rainfall (P_o) to the in-place SPAS analyzed 24-hour rainfall (P_i) yields the orographic transposition factor (OTF).

$$OTF = \frac{4.99''}{5.36''}$$

$$\boldsymbol{OTF = 0.93}$$

The OTF to grid cell #1 of the basin is 0.93, or a 7% rainfall reduction from the storm center location due to terrain effects. The OTF is then considered to be a temporal constant for the spatial transposition between that specific source/target grid point pair, for that storm only, and can then be applied to the other durations for the given storm.

7.4 Total Adjusted Rainfall

The TAF is a product of the linear multiplication of the IPMF, MTF, and OTF. The TAF is a combination of the total moisture and terrain influences on the SPAS analyzed rainfall when maximized and transpositioned to the target grid cell.

$$TAF = IPMF * MTF * OTF \qquad \text{Equation 7.7}$$

EXAMPLE:

For grid point #1, the TAF is calculated as shown in Equation 7.7 using the IPMF from Section 7.1, the MTF from Section 7.2, and the OTF from Section 7.3:

$$TAF = 1.10 * 1.51 * 0.93$$

$$TAF = 1.54$$

To calculate the total adjusted rainfall, the TAF is applied to the SPAS analyzed rainfall depth at the basin area size (5,131 mi^2). For the Fairbanks, Alaska event, the 216-hour SPAS analyzed rainfall depth at the basin size is 8.52”. Therefore, the total adjusted rainfall for this storm at grid point #1 is:

$$Total\ Adj.Rainfall_{216-hr} = TAF * Rainfall_{216-hr}$$

$$Total\ Adj.Rainfall_{216-hr} = 1.54 * 8.52''$$

$$Total\ Adj.Rainfall_{216-hr} = 13.12''$$

7.5 Gridded PMP Calculation and Envelopment

The total adjusted rainfall values are computed for each of the 4,013 grid cells in the basin. These calculations are made for a series of index durations sufficient to provide a framework for the temporal distribution of PMP over the basin through a 9-day period. For this study, the index durations are 1-, 6-, 12-, 24-, 48-, 72-, 96-, 120-, 144-, 168-, 192-, and 216-hour durations.

Once the total adjusted rainfall values have been calculated for each of the basin grid cells, the process is repeated for each SPAS DAD zone on the short list. Then the total adjusted rainfall values for all storms at a given grid point are compared and the largest becomes the PMP. When this comparison is made at a grid by grid basis for all storms, the result is an envelopment of adjusted rainfall values. The PMP at each grid point will be derived from whichever storm, after maximization and transposition, produces the largest rainfall. After the total adjusted rainfall had been calculated for all grid points in the basin, for all storms, the Fairbanks, Alaska event of August 1967 produced the largest depths, at all durations.

The resulting gridded PMP values for each index duration are contained within GIS files in both raster and vector (point) datasets. Due to the large amounts of calculations needed to create the PMP grids, a scripted ArcGIS tool was created using the Python language. The tool performs the following tasks:

1) Calculates the basin size
2) Looks up the SPAS analyzed rainfall depths at the basin size
3) Applies the rainfall depths to the total adjusted rainfall factor for each storm
4) Compares the adjusted rainfall values for all storms to get PMP
5) Outputs the PMP to GIS files
6) Repeats the process for each duration

8. SPATIAL AND TEMPORAL DISTRIBUTION OF PMP

8.1 Spatial Distribution

The spatial distribution of the Susitna-Watana PMP is dependent on a combination of the variation of the gridded OTF and MTF values over the basin. Therefore, the spatial distribution is largely dependent on variation in terrain, which is represented by the 10- through 1,000-year 24-hour NOAA Atlas 14 precipitation frequency spatial distribution over the basin, and to a lesser extent, variation in moisture which is controlled by the gradient of sea surface temperatures at the source location for the controlling storm event.

The variation in available moisture is a smooth gradient with larger values at the southern end of the basin transitioning to smaller values at the northern end. A map of the MTF over the basin (Figure 8.1) illustrates the distribution due to moisture.

As discussed in Section 6.2.1, the topography of the basin and surrounding region is dynamic and varies greatly over the surface of the basin. Therefore, it is expected that the effect of mountainous terrain would be the defining factor in the spatial distribution. The variation of rainfall due to orography, as a result of slope, elevation, and rain shadow effect is inherently represented in the OTF due to it being a function of the NOAA Atlas 14 precipitation frequency relationship between each grid point in the basin and a constant location at the storm center. A map of the OTF over the basin (Figure 8.2) illustrates the spatial distribution due to terrain.

The spatial distribution pattern, due to the variation in terrain and moisture is apparent in the gridded basin PMP maps. Figures 8.3a, 8.3b, and 8.3c show the basin 24-hour, 72-hour, and 216-hour PMP, respectively.

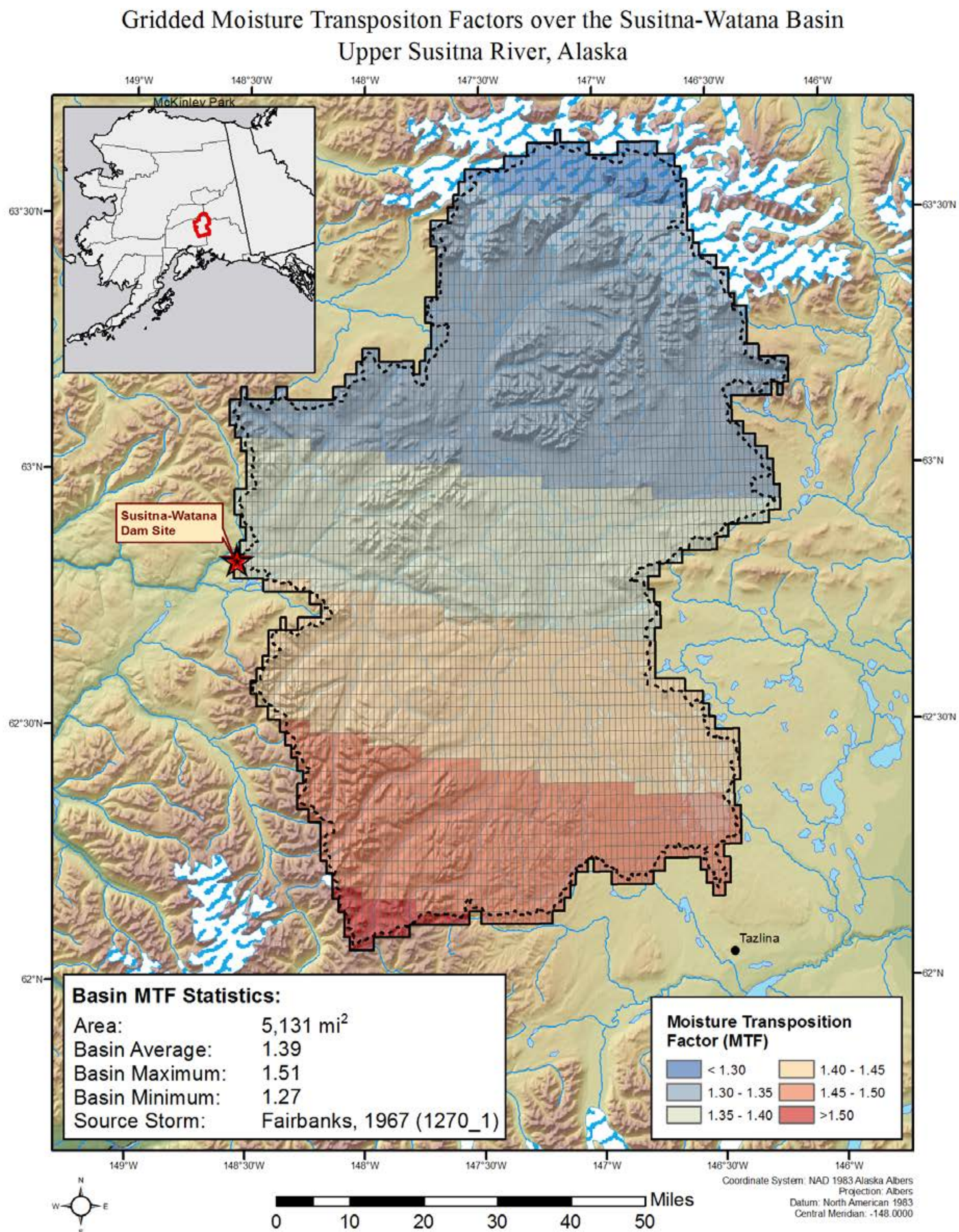

Figure 8.1. Moisture Transposition Factors over the basin.

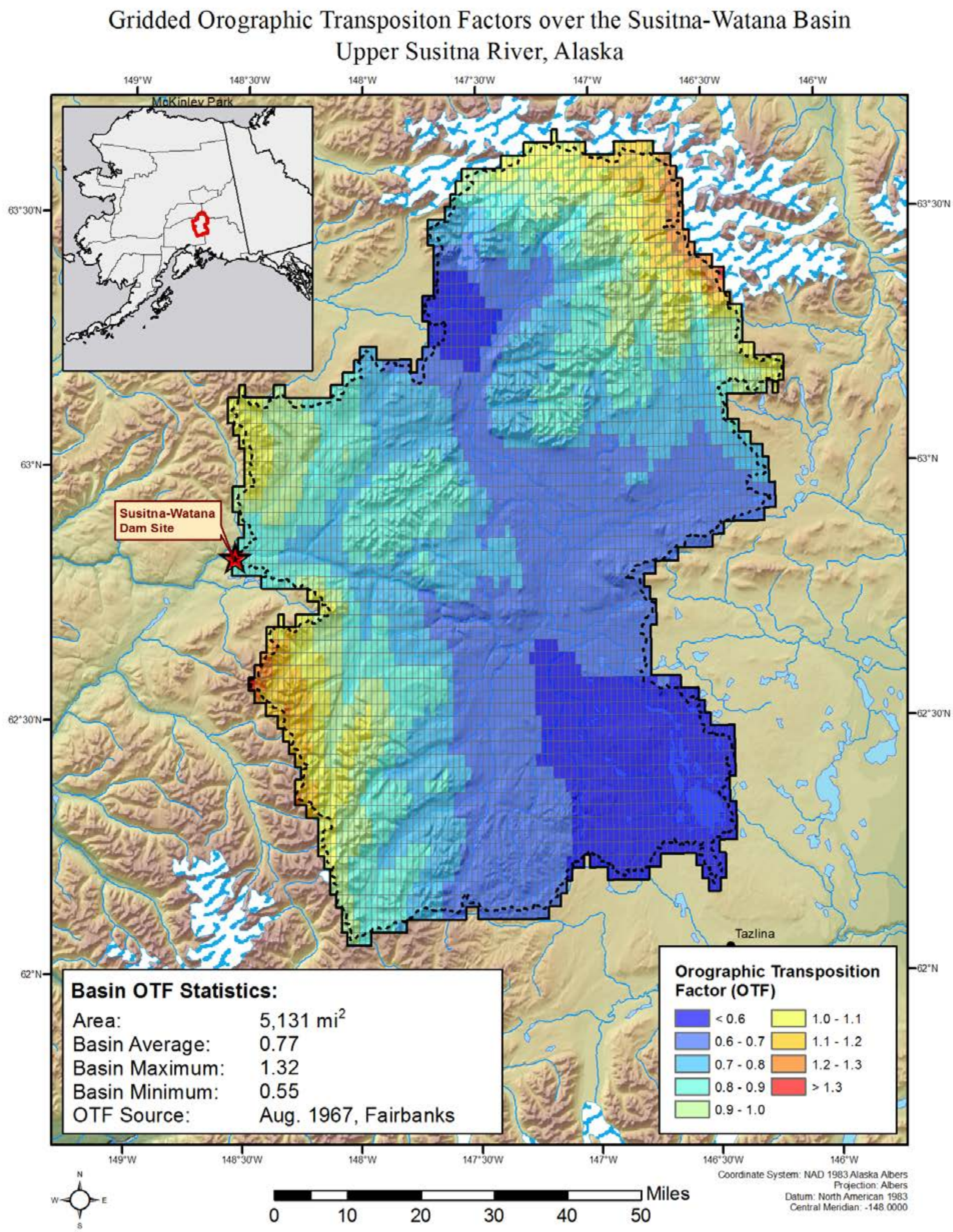

Figure 8.2. Orographic Transposition Factors over the basin.

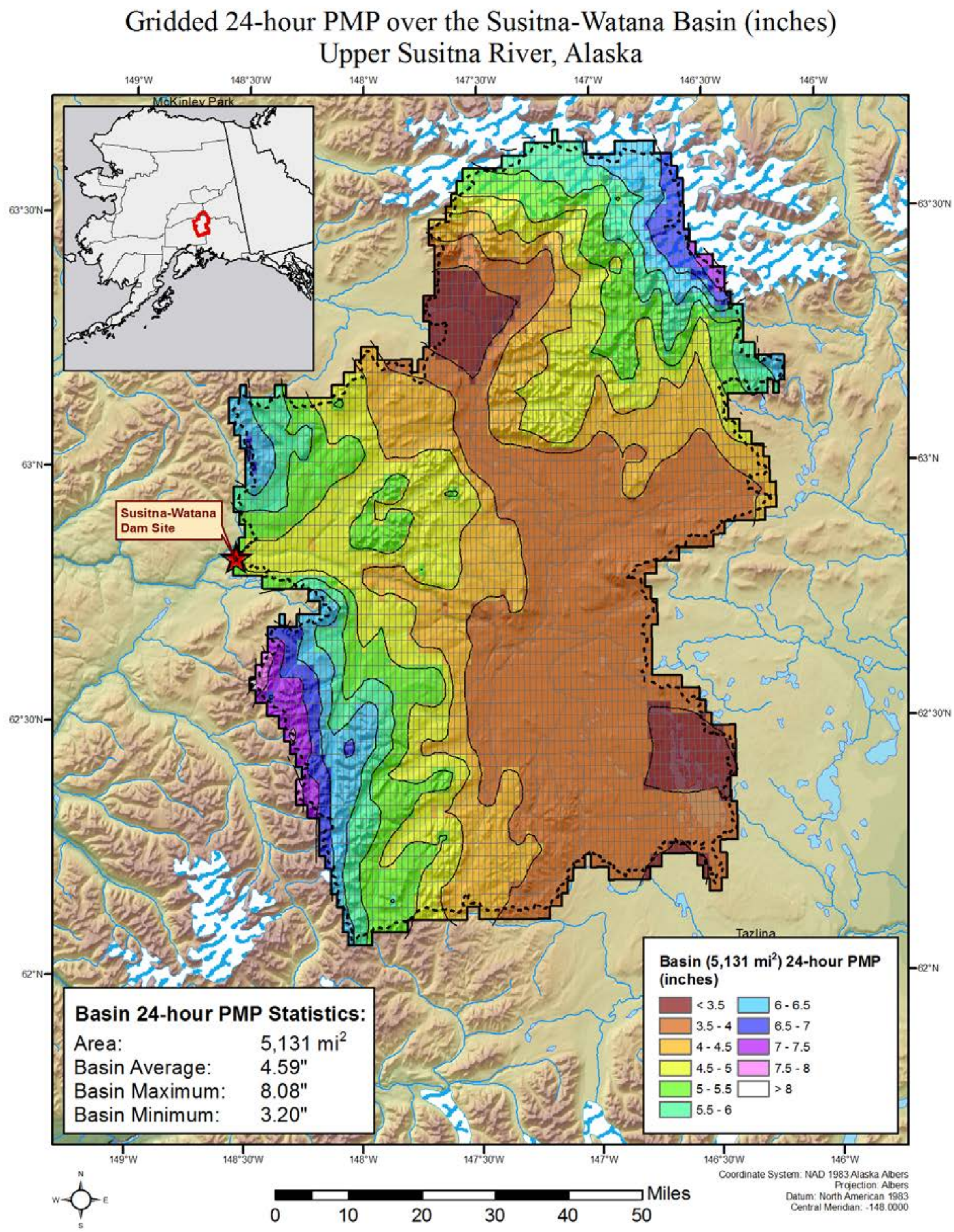

Figure 8.3a. Susitna River basin 24-hour gridded PMP.

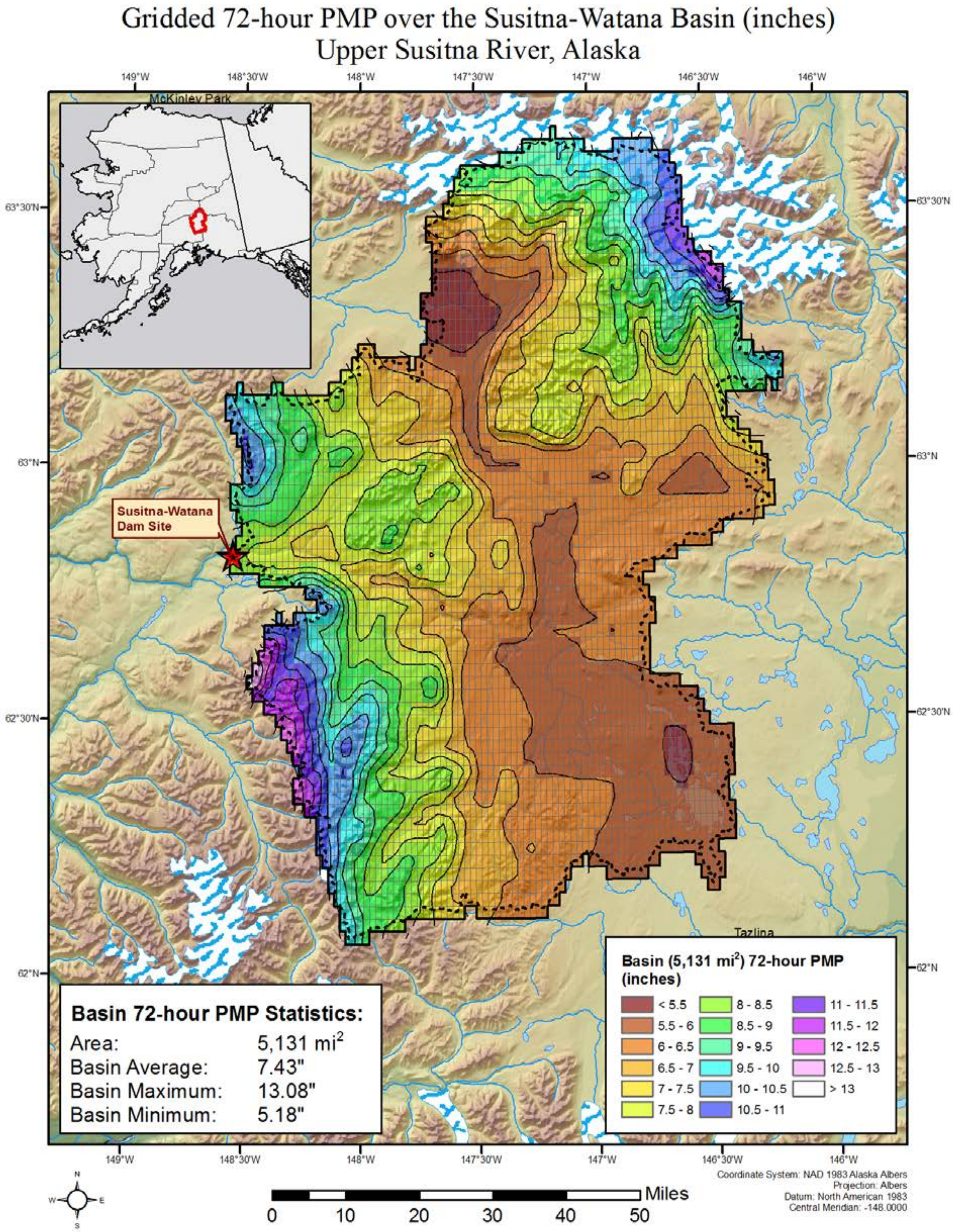

Figure 8.3b. Susitna River basin 72-hour gridded PMP.

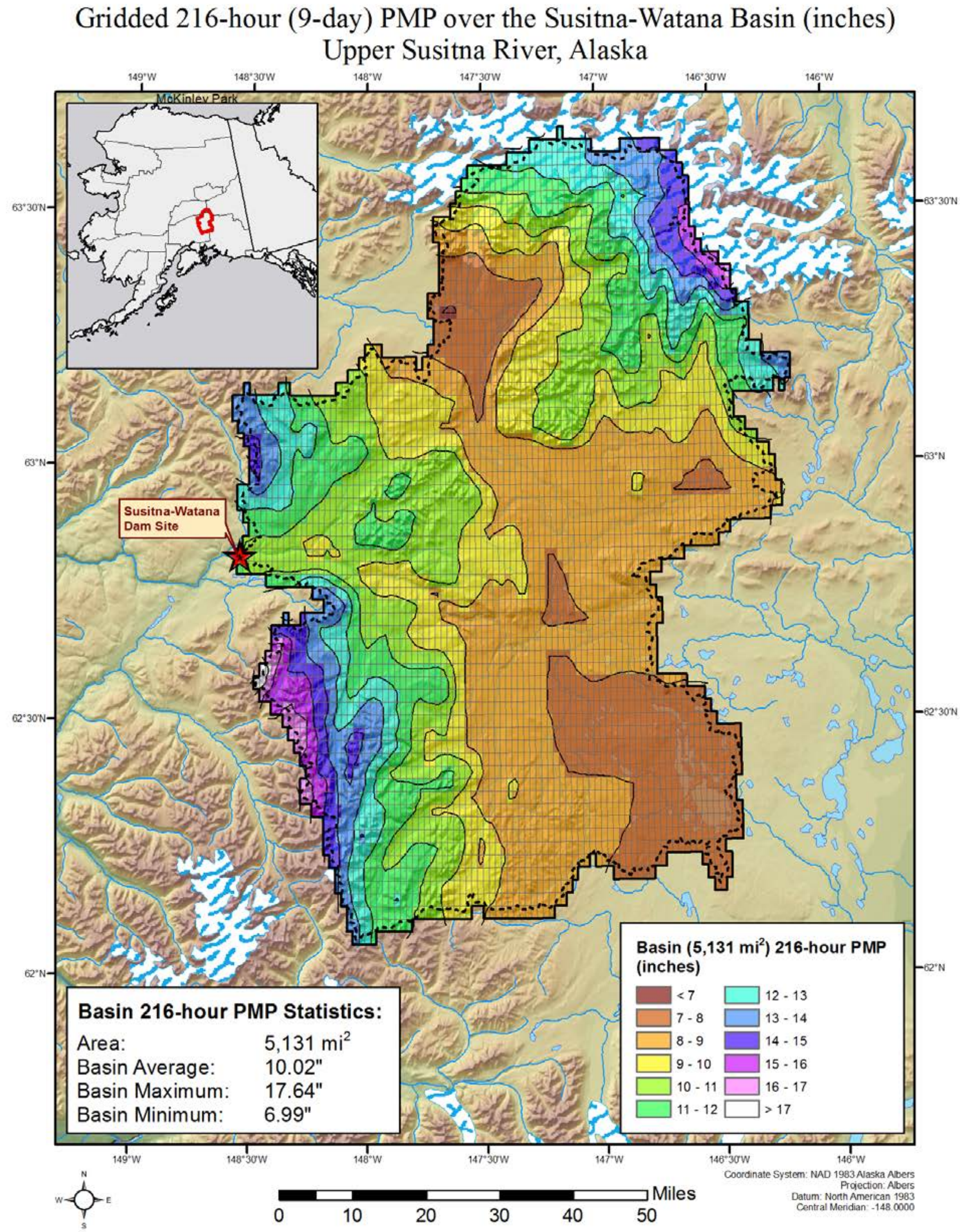

Figure 8.3c. Susitna River basin 216-hour gridded PMP.

8.2 Temporal Distribution

Hourly accumulated PMP depths for each grid point were determined by plotting the basin average PMP values, for each index duration, on a graph. A smooth curve was drawn through each index duration, 1-hour through 216-hour. Using this curve, the PMP accumulations at each hourly interval were estimated. The hourly incremental PMP values could then be calculated from the accumulated PMP values. This process follows the general procedure outlined in HMR 57, however, here it has been scaled up to 1-hour (instead of 6-hour intervals), and extends to a total duration of 216-hour (instead of 72-hours).

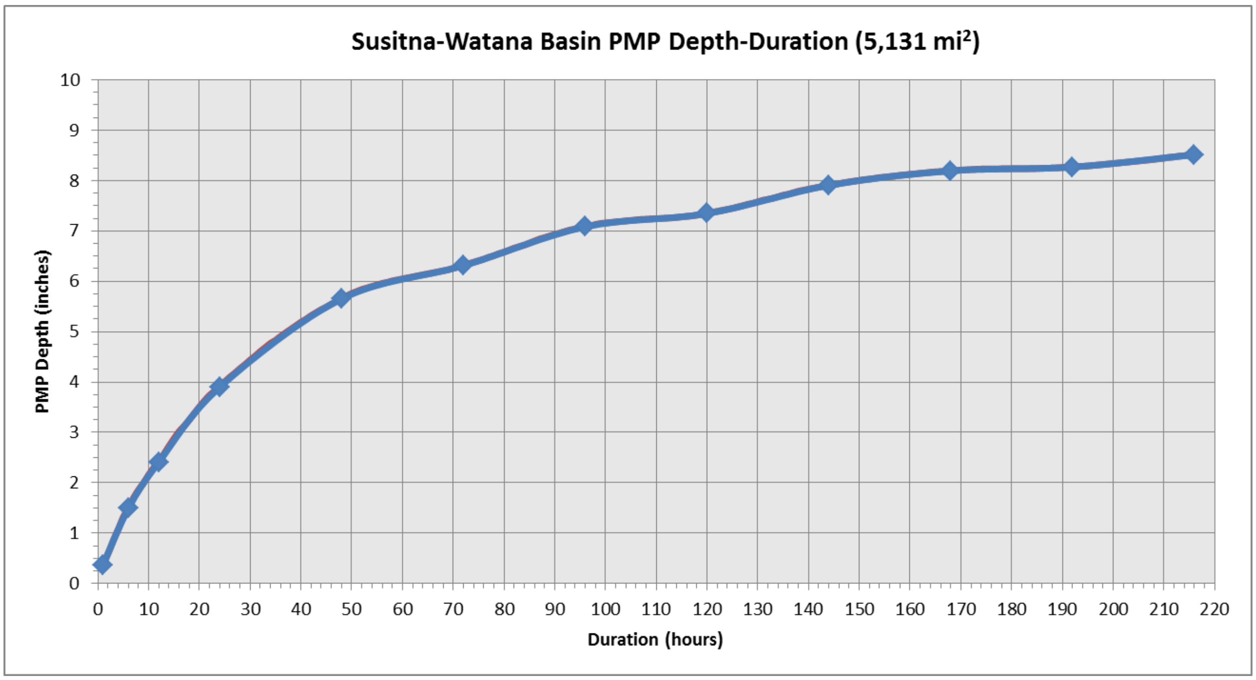

Figure 8.4. Depth-Duration PMP curve used to interpolate accumulated PMP at hourly intervals.

To temporally distribute the gridded PMP values, the incremental depths are re-ordered to mirror the mass curve of three separate storm events: August 1955, Denali N.P. (SPAS 1272) DAD zone 1; August 1967, Fairbanks (SPAS 1270) DAD zone 1; and August 2012, Old Tyonek (SPAS 1256) DAD zone 1.

The temporal distribution pattern for August 1955, Denali N.P. (SPAS 1272) DAD zone 1 applied to the total basin average PMP is shown in Figure 8.5.

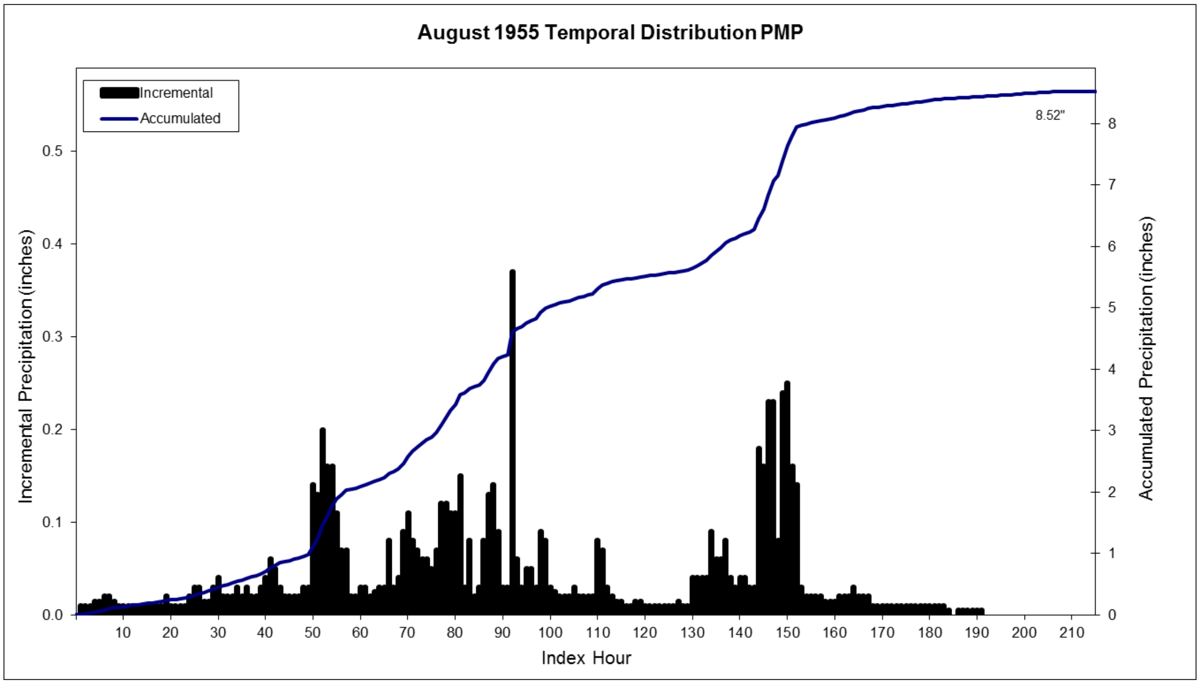

Figure 8.5. August 1955, Denali NP mass curve pattern used for the temporal distribution of the Susitna-Watana PMP.

The temporal distribution pattern for August 1967, Fairbanks (SPAS 1270) DAD zone 1 as applied to the total basin average PMP is shown in Figure 8.6.

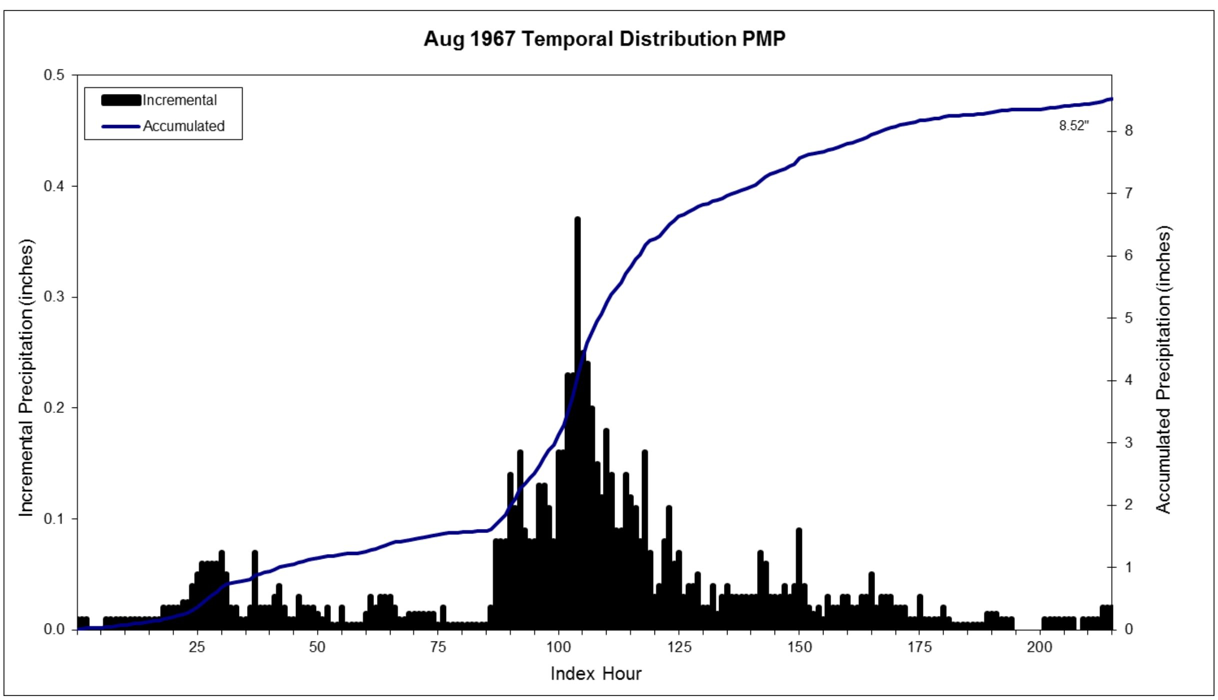

Figure 8.6. August 1967, Fairbanks storm zone 1 mass curve pattern used for the temporal distribution of the Susitna-Watana PMP.

The temporal distribution pattern for August 2012, Old Tyonek (SPAS 1256) DAD zone 1 as applied to the total basin average PMP is shown in Figure 8.7.

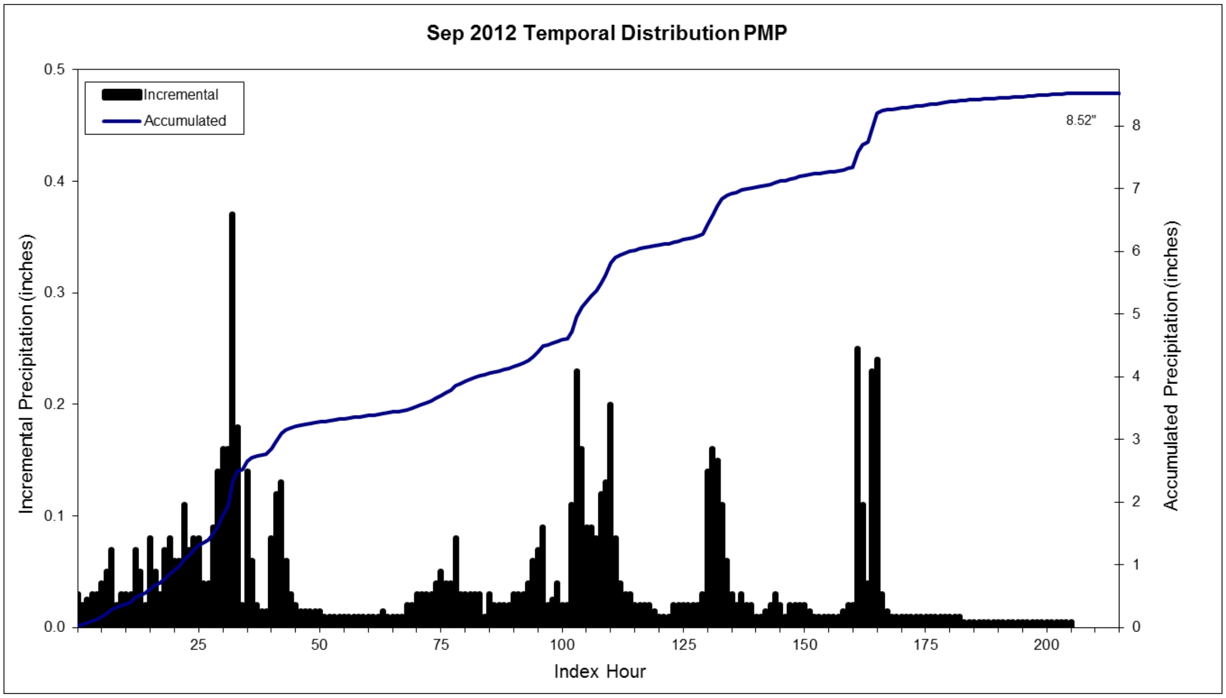

Figure 8.7. August 2012, Old Tyonek storm mass curve pattern used for the temporal distribution of the Susitna-Watana PMP.

9. PMP METEOROLOGICAL TIME SERIES DEVELOPMENT

Hourly meteorological time series were developed for the six calibration events (see Table 12.2.1) over the Susitna River basin in order to aid the hydrologic modeling to best represent expected conditions that would be associated with the PMP rainfall. Meteorological time series parameters have been derived for temperature, dew point temperature and wind speed over the Susitna-Watana basin. The hydrologic model requirements are a single temperature and dew point temperature time series at a given base elevation and wind speed at 1,000-foot increments from 0-feet to 15,000-feet. Temperature lapse rates were estimated using observed surface temperature data for stations in and around the Susitna-Watana basin and Fairbanks radiosonde data.

Vertical wind speed profiles at 1,000-foot increments were derived base on wind speed data from the Fairbanks radiosonde and observed surface wind speed data for stations in and around the Susitna-Watana basin. The radiosonde wind speeds represents free atmospheric winds (unobstructed flow). This free-air data were adjusted to surface wind speeds based on comparisons of anemometer level wind speeds with concurrent free-air wind speeds. The wind speed derivation methodology was based on methods described in HMR 42 (Weather Bureau 1966). HMR 42 measured winds at Gulkana glacier (4,800 ft) and compared to free-air winds at Fairbanks, the study found that average winds on the glacier was 0.60 that of the free-air. In this updated analysis, comparisons were made using both Anchorage and Fairbanks radiosonde data. This analysis showed the Anchorage radiosonde data were not as representative of the surface wind speeds over the basin based on comparisons made to the September 2012 storm event. Instead, the Fairbanks data better represented the timing and magnitude of the observed surface wind speeds.

All six storms were normalized to have a similar index period of 312-hours (see Figure 9.1). For each storm, the index time of the maximum 216-hour accumulated precipitation was determined; this represents the PMP rainfall accumulation window. Then, the 216-hour mid-point was determined by shifting the maximum 216-hour accumulated precipitation index hour 108-hours earlier. Finally, the 108-hour mid-point was used to determine the start and end times of the 216-hour PMP analysis window. The 312-hour window was completed with 24-hours added at the beginning and 72-hours added at the end of the 216-hour PMP window. Hourly temperatures, dew point temperatures, and vertical wind speeds were derived for each of these events for the 312-hour time frame. Figure 9.2 shows the indexed temperature and dew point temperature for the six storm events (base elevation of 2,500 ft).

Once the proper 312-hour window was identified for each of the six storm events, the 312-hour time series data were grouped by month (i.e. all June events grouped together, all August events grouped, and all September events grouped together). For each monthly grouping, an average time series was created based on averaging the individual hourly station meteorological data. Since the all-season PMP event is more conducive to the rainfall associated with the September and August storm events, an average time series was created based on averaging the September and August storm events time series values. The monthly averaged temperature and dew point temperature profiles for June, August, September and average August/September events are shown in Figure 9.3. The final temperature, dew point temperature and wind speed information were based on the average profiles for August/September (Figure 9.4 and 9.5).

The averaged September and August meteorological time series was selected because it best represents the expected conditions that would be associated with the PMP rainfall. The final PMP temperature and dew point temperature have a base elevation of 2,500-ft, the lapse rate used to adjust PMP temperature and dew point temperature to other elevations was -2.63°F per 1,000 ft. The -2.63°F lapse rate was based on the average of all August (1967 and 1971) and September (2012) storm event lapse rates (-2.87°F, -2.85°F, -2.70°F = 2.63°F).

The final vertical wind speed values were based on the average of all August (1967 and 1971) and September (2012) storm events anemometer height wind speeds.

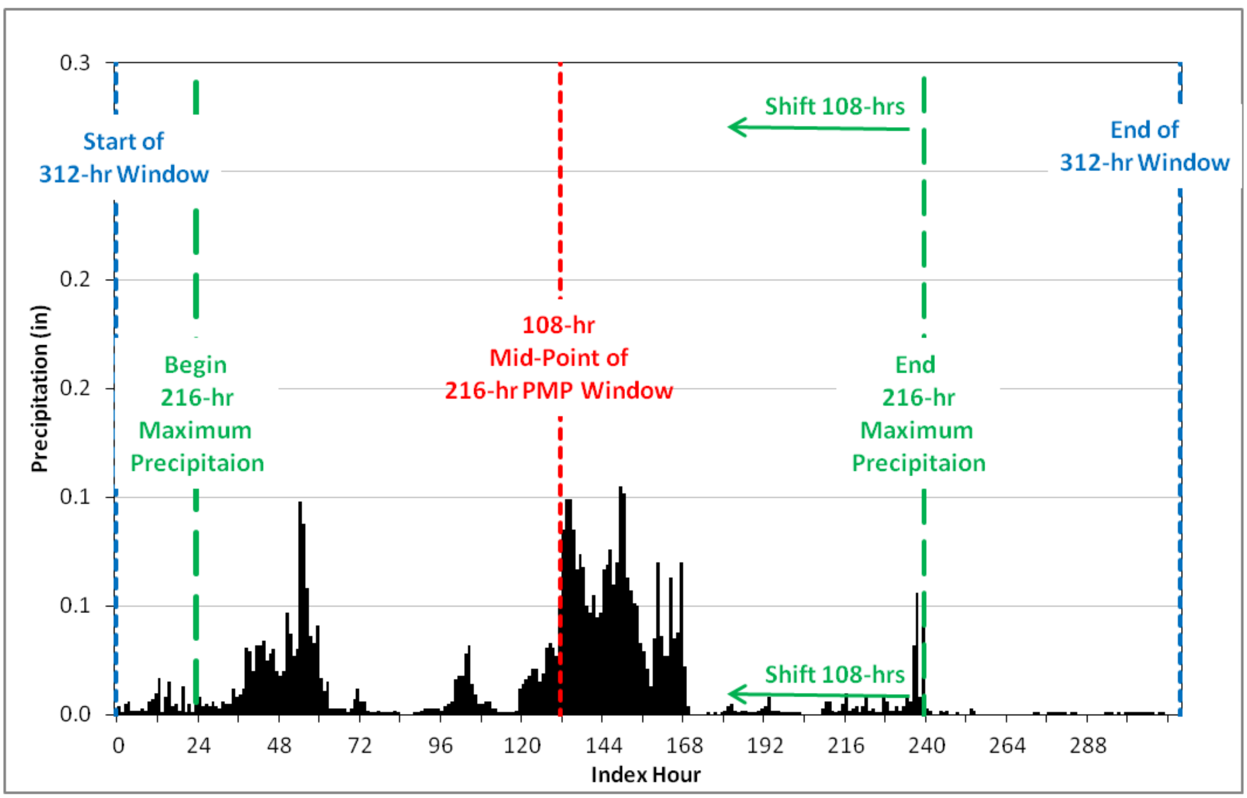

Figure 9.1. Methodology used to create the normalized 312-hour meteorological time series. Maximum 216-hour accumulated precipitation (green line). Mid-point of the 216-hour window basin on the 108-hour shift from the maximum 216-hour accumulation (red line). Start and end point of the 312-hour duration used in this example analysis (blue lines).

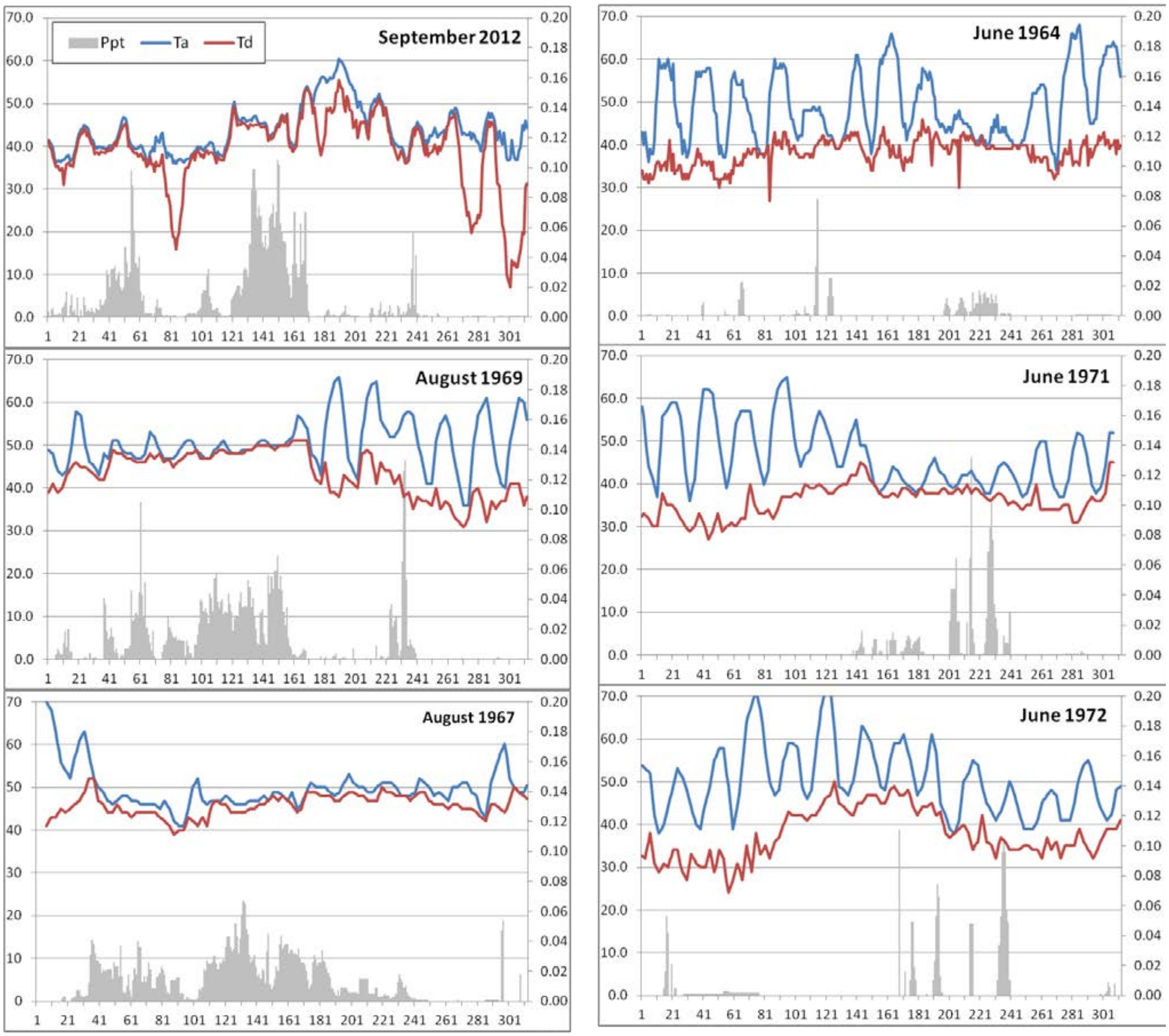

Figure 9.2. Indexed temperature and dew point temperature for the six storm events for a base elevation of 2,500 feet.

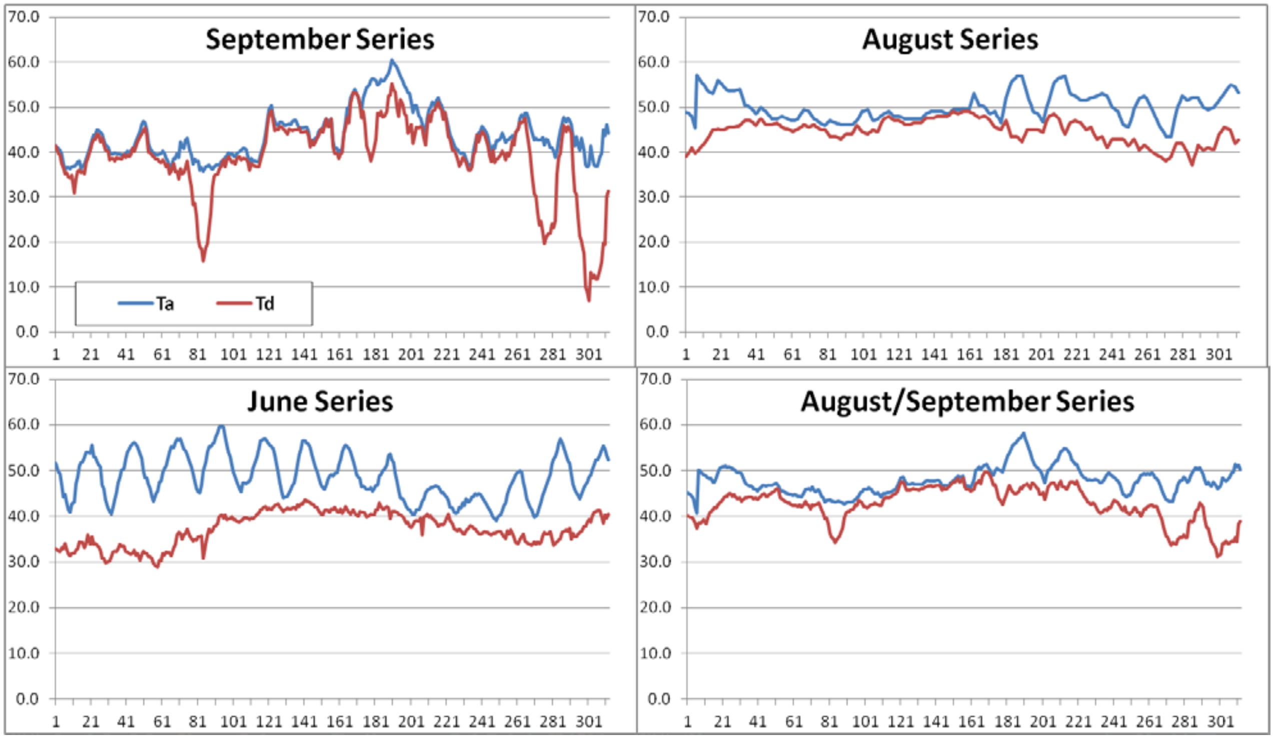

Figure 9.3. Indexed monthly averaged profiles for June, August, September and average August/September for a base elevation of 2,500 feet.

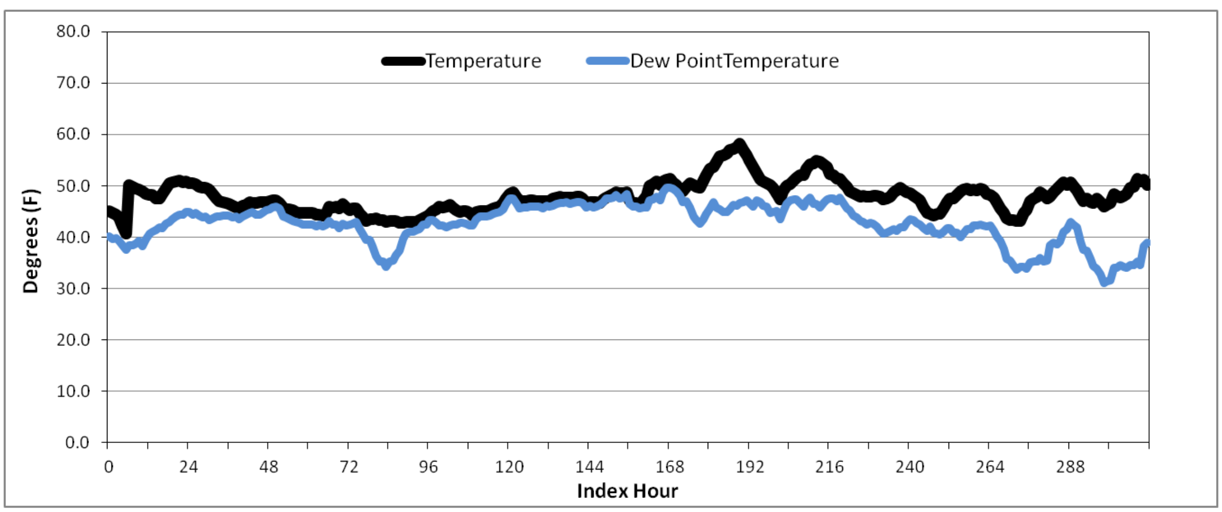

Figure 9.4. PMP non-maximized temperature and dew point temperature data based on the average profiles for August/September for a base elevation of 2,500 feet and lapse rate of -2.63°F per 1,000 feet.

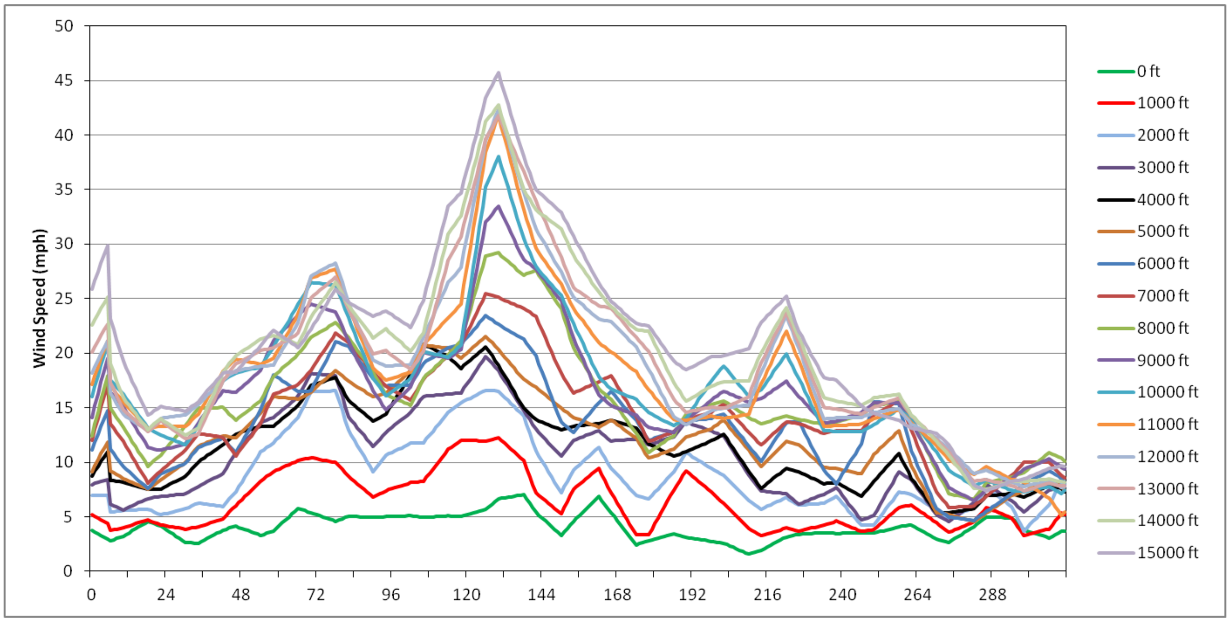

Figure 9.5. Final PMP wind speed values based on the average profiles for August/September for a base elevation of 2,500 feet.

9.1 PMP Temperature Time Series Maximization

The storm representative SST temperature and climatological maximum SST temperature associated with each of the short list storms were analyzed to derive the average difference between the two values in degrees Fahrenheit. The values associated with the storms which control the PMP values were averaged and the resulting value was then applied to each hourly temperature and dew point temperature value. The value derived from this process was 3.0°F. This was the value applied in the maximization process of the temperature and dew point temperature time series used for the snow melt calculations. This was done for all hourly data (in 216-hour window) in order to provide a consistent maximization of the temperature and dew point temperature time series that would be expected to occur during a cool-season PMP rainfall event.

An example of the maximized PMP temperature and dew point temperature data for a PMP event is shown below and the temperature and dew point temperature results displayed in Figure 9.6.

Storm rep SST for = 54.0°F
August 15[7] 2-sigma SST at the storm rep location = 57.0°F
September 15 2-sigma SST at the storm rep location = 56.5°F
Maximization Value = 57.0°F – 54.0°F = 3.0°F

[7] A combination of August and September +2-sigma SST values was used following the procedure of moving a storm two week towards the warmer season for maximization purposes. Because the example event occurred on September 15, the storm is moved to September 1 for storm analysis purposes.

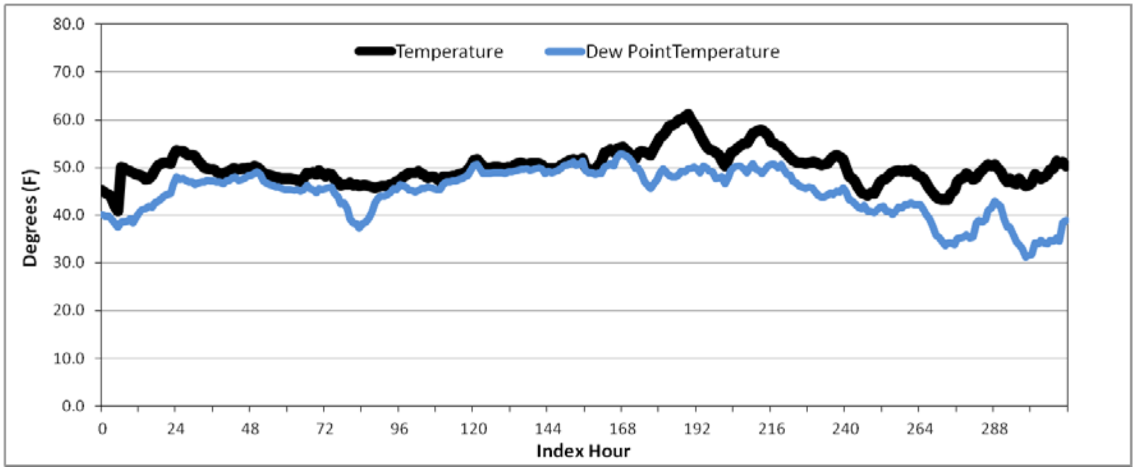

Figure 9.6. Final maximized PMP temperature and dew point temperature data based on the average profiles for August/September for a base elevation of 2,500 feet and lapse rate of -2.63°F per 1,000 feet.

9.2 Seasonality Adjustments for Moving to Other Months

Investigations of the seasonal variation in the Susitna-Watana PMP/PMF required that the maximized PMP temperature, dew point temperature, and wind speed time series values be moved, with appropriate adjustments to the other months when a lesser amount of these values could combine with a great snow melt runoff to produce a larger PMF. Three adjustment factors were determined: i) moving the maximized temperature and dew point temperature time series to other months, ii) moving the wind speed time series to other months, and iii) moving the all-season PMP to other months.

9.2.1 Temperature Seasonality Adjustments

Daily surface climate normal data (1981-2010) were acquired for ten stations (Table 9.1) for a period of April 1 to October 31. For each day, the average temperature was calculated from the ten stations. The average daily temperature for the Susitna-Watana basin, based on ten stations 30-year climate normal is shown in Figure 9.7. The maximum daily average temperature was computed to be 56.6°F. The maximum daily average temperature was used to scale the daily average temperature on a scale of 0.0 to 1.0, with 1.0 equal to 56.6°F. The 1st and 15th of each month scaled daily average temperature were extracted from April to November. The temperatures for July and August were set to 1.00, based on the small changes in temperature and this period represents the all season PMP months. The final seasonality adjustment factors to apply to the all-season PMP temperature and dew point temperature time series are shown in Table 9.2. The adjustment factors should be applied to move the all-season temperature and dew point temperature time series to other months. For example, moving the all-season temperature and dew point temperature from July 15 to May 15 would reduce the time series data by 0.80 (see example below).

July 15 all-season PMP at index hour 1 has a T_a of 45.1°F and T_d of 40.2°F
July 15 to May 15 adjustment = 0.80
May 15 PMP at index hour 1 T_a is 36.1°F and T_d is 32.2°F

Table 9.1 Stations used for temperature and dew point temperature seasonality adjustments.

Station	Elevation (ft)
Anchorage	130
Fairbanks	433
Talkeetna	350
Gulkana	1560
Chulitna River	1355
Paxson	2700
Lake Susitna	2375
Cantwell 2E	2130
Tahneta Pass	2620
Sutton 1W	550

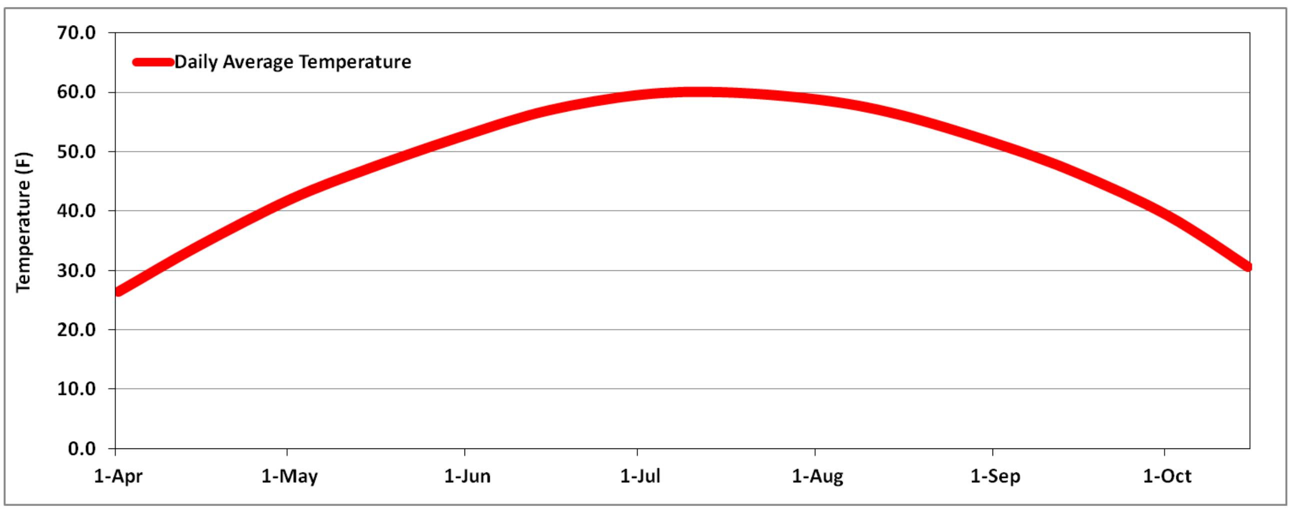

Figure 9.7. Daily average temperature based on ten stations 30-year climate normal around the Susitna-Watana basin.

Table 9.2. Seasonality adjustments to all season PMP temperature and dew point temperature time series.

Ta Td Time Series Seasonality	
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

9.2.2 Wind Speed Seasonality Adjustments

Daily average wind speed data was acquired from the Global Historical Climatology Network (GHCN) daily database at four stations (Table 9.3) surrounding the Susitna-Watana basin. The entire period of record for each station was extracted and analyzed. The average daily wind speed for each station was grouped by month; the monthly values were used to identify the monthly average maximum wind speed and average wind speed.

Table 9.3. Stations used for wind speed seasonality adjustments.

Station	Elevation (ft)
Gulkana	1560
Talkeetna	350
Anchorage	433
Fairbanks	500

A final average monthly maximum and average wind speed was calculated based on each of the four stations monthly values. For example, the August average monthly wind speed of 17.2 mph was calculated with the four stations maximum daily wind speed as:

Station		August Wind Speed
Talkeetna	=	14.8
Gulkana	=	23.7
Fairbanks	=	17.0
Anchorage	=	13.2
Average	*=*	*17.2*

The August average wind speed was computed to be 17.2 mph. The August average wind speed was used to scale the monthly maximum wind speed on a scale of 0.0 to 1.0, with 1.0 equal to 17.2 mph. The final seasonality adjustment factors to apply to the all-season PMP wind speed time series are shown in Table 9.4. The adjustment factors should be applied to the move the all-season wind speed time series to other months. For example, moving the all-season wind speed from August 15 to May 15 would increase the time series data by 1.06 (see example below).

August 15 all-season PMP at index hour 1 and 5000 ft has a Ws of 9.1 mph
August 15 to May 15 adjustment = 1.06
May 15 PMP at index hour 1 and 5000 ft Ws is 9.7 mph

Table 9.4. Seasonality adjustments to all season PMP wind speed time series.

Ws PMP Seasonality	
Month	**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	-

9.2.3 PMP Seasonality Adjustments

Monthly maximum 1-day precipitation data was acquired from the Alaska Climate Research Center for four stations (Table 9.2.5) surrounding the Susitna-Watana basin. Each stations maximum 1-day precipitation was used to scale each stations monthly 1-day maximum precipitation from 0.0 to 1.0. For example, Fairbanks monthly 1-day maximum precipitation was 3.42 inches and occurred in August, the scaled maximum precipitation data at Fairbanks is 1.0 for the month of August. The average of each four stations monthly scaled maximum precipitation was used to initially identify the PMP seasonality adjustment. The all-season PMP is for the months of July and August, these months had a seasonality adjustment of 1.0. All other months had a reduction based on the average scaled maximum 1-day precipitation. The final PMP seasonality adjustment are shown in Table 9.6.

Table 9.5. Stations used for PMP seasonality adjustments.

Station	Elevation (ft)
Gulkana	1560
Talkeetna	350
Anchorage	433
Fairbanks	500

The adjustment factors should be applied to the move the all-season PMP to other months. For example, moving the all-season PMP from August 15 to May 15 would reduce the PMP magnitude by 0.83 (see example below).

August 15 sub-basin 1 average all-season PMP at 72-hours is 9.95 inches
August 15 to May 15 adjustment = 0.83
May 15 PMP sub-basin 1 72-hour PMP would be 8.26 inches

Table 9.6. Seasonality adjustments to all season PMP.

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

10. RESULTS

10.1 Site-Specific PMP Values

This study produced site-specific PMP values for use in computing the PMF for the Susitna-Watana basin. Values for durations from 1- through 216-hours have been computed for each grid cell within the basin. After all adjustments were applied to all the storms on the short storm list, the Fairbanks August, 1967 storm event resulted in the largest values at all area sizes and all durations. The spatial and temporal patterns associated with the three storms from the storm list with different temporal patterns were then used to distribute the PMP rainfall. Finally, the gridded hourly PMP values were averaged by sub-basin.

Results of this analysis are displayed in Tables 10.1a-c, one for each of the temporal distributions applied. These include the all-season PMP values for each sub-basin as a sub-basin average amount at the x-duration. The total basin (5,131 mi^2) is also included and used for comparisons to previous work in the region.

Table 10.1a. Site-specific PMP values for Susitna-Watana basin using the August, 1967 storm 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 10.1b. Site-specific PMP values for Susitna-Watana basin using the August, 1955 storm 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 10.1c. Site-specific PMP values for Susitna-Watana basin using the September, 2012 storm 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

10.2 PMP Comparison with Previous Studies

There have been previous studies investigating PMP over the Upper Susitna drainage basin: the Susitna Hydroelectric Project Feasibility Report (Acres 1982) and the Harza-Ebasco Susitna Joint Venture (1984). The PMP calculation procedures and tools employed in this study have significantly evolved since the publication of these PMP studies. However, the generalized approach of storm maximization and transposition is similar. Furthermore, despite the occurrence and analysis of recent precipitation events that have occurred since these studies, the August 1967 (the Great Fairbanks Flood) event remains the controlling storm for PMP.

The Harza-Ebasco study reported an all-season basin average 72-hour PMP of 6.85” for 5,180 mi^2. A seasonality factor of 0.93 was applied to June 15th and a factor of 0.73 was applied to May 15th. The 72-hour PMP from the Harza-Ebasco study is summarized in Table 10.2.

Table 10.2. Harza-Ebasco 1984 Susitna 72-hour Basin PMP and spring season adjustments.

	72-hour PMP: Harza-Ebasco	
Season	Factor	PMP
All-season	1.00	6.85
15-Jun	0.93	6.37
15-May	0.73	5.00

The Acres study reported an all-season basin average 72-hour PMP of 5.90” for 5,180 mi^2. A seasonality factor of 0.70 was applied to June 15th. The Acres study did not seasonally adjust PMP to May. At the 216-hour duration, a basin average PMP of 12.54” was reported. The 72-hour PMP from the Acres study is summarized in Table 10.3 and the 216-hour PMP is summarized in Table 10.4.

Table 10.3. Acres 1982 Susitna 72-hour Basin PMP and spring season adjustments.

	72-hour PMP: Acres	
Season	Factor	PMP
All-season	1.00	5.90
15-Jun	0.70	4.13
15-May	N/A	N/A

Table 10.4. Acres 1982 Susitna 216-hour Basin PMP and spring season adjustments.

	216-hour PMP: Acres	
Season	Factor	PMP
All-season	1.00	12.54
15-Jun	0.70	8.90
15-May	N/A	N/A

The gridded basin average 72-hour PMP provided by AWA in this study is 7.43” for 5,132 mi^2, before the application of the various storm-based temporal distribution patterns. A seasonality factor of 0.94 was applied to June 15th and a seasonality factor of 0.83 was applied to May 15th. At the 216-hour duration, a basin average PMP of 12.54” was calculated. The 72-hour PMP from this study is summarized in Table 10.5 and the 216-hour PMP is summarized in Table 10.6

Table 10.5. AWA Susitna-Watana 72-hour Basin PMP and spring season adjustments

	72-hour PMP: AWA	
Season	Factor	PMP
All-season	1.00	7.43
15-Jun	0.94	6.98
15-May	0.83	6.17

Table 10.6. AWA Susitna-Watana 216-hour Basin PMP and spring season adjustments

Season	216-hour PMP: AWA	
	Factor	PMP
All-season	1.00	10.02
15-Jun	0.94	9.42
15-May	0.83	8.32

The ratio of AWA PMP to the Acres (72-hour and 216-hour) and Harza-Ebasco (216-hour) is shown in Table 10.7.

Table 10.7. Ratios of AWA PMP to the Acres and Harza-Ebasco studies.

Season	Ratio of AWA PMP to:		
	Acres (72hr)	Acres (216hr)	Harza-Eb.
All-season	1.26	0.80	1.08
15-Jun	1.69	1.06	1.10
15-May	N/A	N/A	1.23

Generally, the AWA PMP magnitudes are somewhat larger than previous estimates, particularly for the Acres study at 72-hours. There are numerous factors contributing to the differences stemming from both the source data and methods applied. There are several methodologies and data sets employed by the AWA PMP study that differ from previous studies and may contribute to differences in PMP. These include; high spatial and temporal resolution SPAS analyses for each storm and the resulting DAD tables and mass curves, updated storm maximization using SST data, improved geospatial technologies that allow for improved analysis of source moisture and storm maximization, gridded analysis of moisture and orographic transposition over the basin, availability of NOAA Atlas 14 values, and improved temperature-time series and seasonality relations. It is also likely that there are differences in the basin boundary delineation.

10.3 Comparison of PMP with NOAA Atlas 14

NOAA Atlas 14 Volume 7 provides gridded partial duration and annual maximum precipitation data over Alaska. In addition to return frequency analysis, these data can provide an accurate representation of the relationship between historical rainfall and terrain. PMP values were compared with 100-year rainfall values as a general check for reasonableness. The ratio of the PMP to the 24-hour 100-year return period rainfall amounts is generally expected to range between two and four, with values as low as 1.7 and as high as 5.5 found in HMRs 57 and 59 (Hansen et al. 1994, Corrigan et al. 1999). In HMR 59 it is stated "…*the comparison indicates that larger ratios are in lower elevations where short-duration, convective precipitation dominates, and smaller ratios in higher elevations where general storm, long duration precipitation is prevalent*". Therefore, it would be reasonable to expect the ratios for the Susitna River basin to be in the low end of the range.

A gridded basin comparison was made between the 24-hour AWA PMP values and the 24-hour NOAA Atlas 14 precipitation frequency datasets. The NOAA Atlas 14 precipitation depths are considered point values and have no areal reduction applied. For this reason, the 24-hour basin PMP was calculated with the minimum SPAS resolution (0.20 mi^2) to approximate point values, instead of the basin size of 5,131 mi^2. The ratio of 24-hour PMP to NOAA Atlas 14 precipitation was calculated for the 100-year return period. Table 10.8 shows the basin average NOAA Atlas 14 precipitation for 10-year through 1,000-year events. The 100-year basin average is 3.65" over 24-hours. The basin average 0.20 mi^2 PMP is 6.34" for a 24-hour period (Table 10.8). This indicates a factor of 1.74 times the 100-year NOAA Atlas 14 depth (Table 10.9). The largest ratio for all of the 4,013 grid points was 1.86 and the smallest ratio was 1.58, indicating a fairly low amount of variation over the basin.

Table 10.8. Gridded basin average 24-hour NOAA Atlas 14 precipitation for the 10-1,000 year return periods. Gridded basin average 24-hour point PMP.

	10-year	25-year	50-year	**100-year**	200-year	500-year	1,000-year
24-hr Precip. Frequency (NOAA Atlas 14)	2.37	2.85	3.24	**3.65**	4.11	4.73	5.19
Gridded Basin Average 24-hour PMP (0.2sqmi)				6.34			

Table 10.9. Ratio of 24-hour PMP to 100-year NOAA Atlas 14 precipitation.

Average Basin Ratio (24hr PMP:NOAA Atlas 14 100-yr)	**1.74**
Max. Basin Ratio (24hr PMP:NOAA Atlas 14 100-yr)	1.86
Min. Basin Ratio (24hr PMP:NOAA Atlas 14 100-yr)	1.58

It should also be noted that the 24-hour basin average 1,000-year rainfall is 5.19", putting the basin average PMP of 6.34" well above the 1,000 return frequency.

11. DISCUSSION OF PMP PARAMETERS

In the process of deriving SSPMP values, various assumptions and subjective judgments were made which affect the PMP values. In addition, specific procedures were used which could be derived from a range of possible alternatives and result in different values. Therefore, it is important to understand how the assumptions and choice of procedures used could potentially affect certain aspects of the SSPMP calculations.

11.1 Assumptions

11.1.1 Saturated Storm Atmospheres

The atmospheric air masses that provide moisture to both the historic storms and the PMP storm are assumed to be saturated through the entire depth of the atmosphere and to contain the maximum moisture possible based on the surface dew point. This assumes moist pseudo-adiabatic temperature profiles for both the historic storms and the PMP storm. Limited evaluation of this assumption in the EPRI Michigan/Wisconsin PMP study (Tomlinson 1993) and the Blenheim Gilboa (Tomlinson et al. 2008) study indicated that historic storm atmospheric profiles are generally not entirely saturated and contain somewhat less precipitable water than is assumed in the PMP procedure. It follows that the PMP storm (if it were to occur) would also have somewhat less precipitable water available than the assumed saturated PMP atmosphere would contain. What is used in the PMP procedure is the *ratio* of precipitable water associated with each storm. If the precipitable water values for each storm are both slightly overestimated, the ratio of these values will be essentially unchanged. For example, consider the case where instead of a historic storm with a storm representative dew point of 70^{o}F degrees having 2.25 inches of precipitable water assuming a saturated atmosphere, it actually had 90% of that value or about 2.02 inches. The PMP procedure assumes the same type of storm with similar atmospheric characteristics for the maximized storm but with a higher dew point, say 76 ^{o} F degrees. The maximized storm, having similar atmospheric conditions, would have about 2.69 inches of precipitable water instead of the 2.99 inches associated with a saturated atmosphere with a dew point of 76^{o}F degrees. The maximization factor computed using the assumed saturated atmospheric values would be 2.99/2.25 = 1.33. If both storms were about 90% saturated instead, the maximization factor would be 2.69/2.02 = 1.33. Therefore potential inaccuracy of assuming saturated atmospheres (whereas the atmospheres may be somewhat less than saturated) should have a minimal impact on storm maximization and subsequent PMP calculations.

11.1.2 Maximum Storm Efficiency

The assumption is made that if a sufficient period of record is available for rainfall observations, at least a few storms would have been observed that attained the maximum efficiency possible for converting atmospheric moisture to rainfall for regions with similar meteorology and topography. The further assumption is made that if additional atmospheric moisture had been available, the storm would have maintained the same efficiency for converting atmospheric moisture to rainfall. The ratio of the maximized rainfall amounts to the actual rainfall amounts would be the same as the ratio of the precipitable water in the atmospheres associated with each storm.

There are two issues to be considered. First is the assumption that a storm has occurred that has a rainfall efficiency close to the maximum possible. Unfortunately, state-of-the-science in meteorology does not support a theoretical evaluation of storm efficiency. However, if the period of record is considered (generally over 100 years), along with the extended geographic region with transpositionable storms, it is accepted that there should have been at least one storm with dynamics that approach the maximum efficiency for rainfall production.

The other issue is the assumption that storm efficiency does not change if additional atmospheric moisture is available. Storm dynamics could potentially become more efficient or possibly less efficient depending on the interaction of cloud microphysical processes with the storm dynamics. Offsetting effects could indeed lead to the storm efficiency remaining essentially unchanged. For the present, the assumption of no change in storm efficiency is accepted.

11.2 Parameters

This discussion applies to both dew points and SSTs although only SSTs will be addressed in this sections as SSTs are used as substitutes for land based dew points for all storms in this study for inflow vectors that originate over ocean regions and have the same sensitivity considerations.

The maximization factor depends on the determination of storm representative SSTs, along with maximum historical SST values. The magnitude of the maximization factor varies depending on the values used for the storm representative SST and the maximum SST. Holding all other variables constant, the maximization factor is smaller for higher storm representative SSTs as well as for lower maximum SST values. Likewise, larger maximization factors result from the use of lower storm representative SSTs and/or higher maximum SSTs. The magnitude of the change in the maximization factor varies dependent on the SST values. For the range of SST values used in most PMP studies, the maximization factor for a particular storm will change about 5% for every 1^{o}F difference between the storm representative and maximum SST values. The same sensitivity applies to the transposition factor, with about a 5% change for every 1^{o}F change in either the in-place maximum SST or the transposition maximum SST.

For example, consider the following case:

Storm representative SST:	75^{o}F	Precipitable water:	2.85”
Maximum SST:	79^{o}F	Precipitable water:	3.44”

Maximization factor = 3.44”/2.85” = 1.21

If the storm representative SST were 74^{o}F with precipitable water of 2.73”,
Maximization factor = 3.44”/2.73” = 1.26 (an increase of approximately 4%)

If the maximum SST were 78^{o}F with precipitable water of 3.29”,
Maximization factor = 3.29”/2.85” = 1.15 (a decrease of approximately 5%)

12. RECOMMENDATIONS FOR APPLICATION

12.1 Site-Specific PMP Applications

Site-specific PMP values have been computed that provide rainfall amounts for use in computing the PMF. The study addressed several issues that could potentially affect the magnitude of the PMP storm over the Susitna-Watana basin.

The HMRs use a procedure for locating the largest amounts of rainfall associated with the PMP storm, such that the largest volume of rain falls within the watershed boundaries, either using the 100-year 24-hour isopercental analysis or using a significant storm over the basin and the judgment of the user (HMR 57 Section 15.2, Step 9). As the authors of HMR 57 explicitly state in that section of the report, "It is left to a future study to resolve the issue of how to distribute general storm PMP…" This study has directly addressed this issue by using the gridded approach and developing spatial and temporal patterns based on the largest historic storm events that have occurred over the basin. Further, the temperature time series developed for this study explicitly addresses the antecedent and within-storm temperature profile that would be expected during a PMP storm over the basin, thereby eliminating much of the subjectivity employed in previous HMRs (e.g. HMR 57 Section 15.2 Step 10). These updated applications, based on actual data specific to the storms which affect this basin, allows the PMP rainfall to be distributed in a pattern that is physically possible based on the unique topography and climate of the basin. It is recommended that the use of the gridded approach to spatially distribute the PMP rainfall at each duration at each grid point be used to derive the PMF as presented in this report for the Susitna-Watana basin.

The storm search and selection of storms for the short list emphasized storms with the largest rainfall values that occurred over areas that are both meteorologically and topographically similar to the Susitna-Watana drainage basin. Results of this study should not be used for watersheds where meteorological and/or topographical parameters are different from the Susitna-Watana drainage basin without further evaluation.

12.2 Calibration Storm Events

AWA utilized the SPAS to analyze rainfall over the Susitna-Watana basin. Six storm events were selected for calibration of the PMF hydrologic model (Table 12.1). AWA analyzed a sufficiently large storm domain that included sufficient hourly rain gauge observations to calibrate the NEXRAD data if available over larger domain that included the Susitna-Watana region. Quality controlled NEXRAD data was acquired from Weather Decisions Technologies, Inc. Non-radar events utilized climatological basemaps to aid in the spatial distribution of precipitation.

Table 12.1. Six storm events were selected for hydrologic model calibration.

Hydrologic Calibration Events Selected

SPAS #	Date	Radar
1256	Sep-12	Yes
1269	Aug-71	No
1270	Aug-67	No
6008	Jun-64	No
6009	Jun-71	No
6010	Jun-72	No

The rainfall analysis results were provided on a 1/3mi^2 grid with a temporal frequency of 60-minutes. In addition to the rainfall grids, clipped to the Susitna-Watana drainage, sub-basin average rainfall statistics were provided for all 34 sub-basins. Note, the calibration analysis included six extra sub-basins for calibration purposes to include the region immediately downstream of the dam site to the Gold Creek USGS gage.

12.2.1 September 14-30, 2012 Precipitation

The hourly precipitation grids derived from the SPAS 1256 analysis were used in conjunction with SPAS-Lite 6007 as the basis for the Susitna-Watana calibration. SPAS-Lite 6007 was utilized to fill in a longer duration than what was analyzed for SPAS 1256, the calibration period is referenced as SPAS 1256. The SPAS 1256 analysis encompassed the 34 sub-basins of Susitna-Watana. The SPAS 1256 hourly grids were clipped to each of the Susitna-Watana sub-basins, the sub-basin average statistics were calculated and added to an Excel spreadsheet used for hydrologic calibration. The calibration deliverables are based on the SPAS hourly precipitation data for 9/14-30/2012. In general, between 0.80 and 10.30 inches of rain fell across the Susitna-Watana drainage (Figure 12.1 - 12.3).

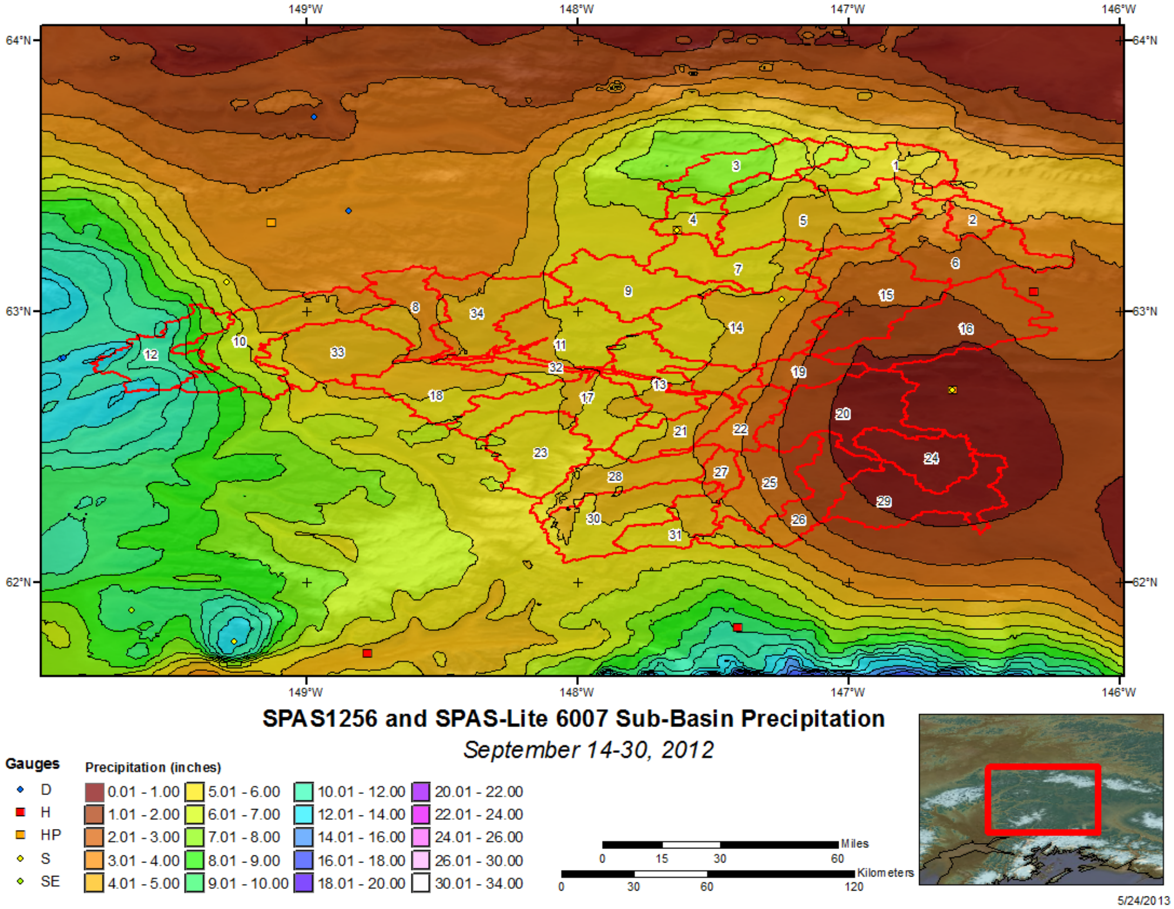

Figure 12.1. Total storm rainfall for SPAS 1256 across Susitna-Watana drainage.

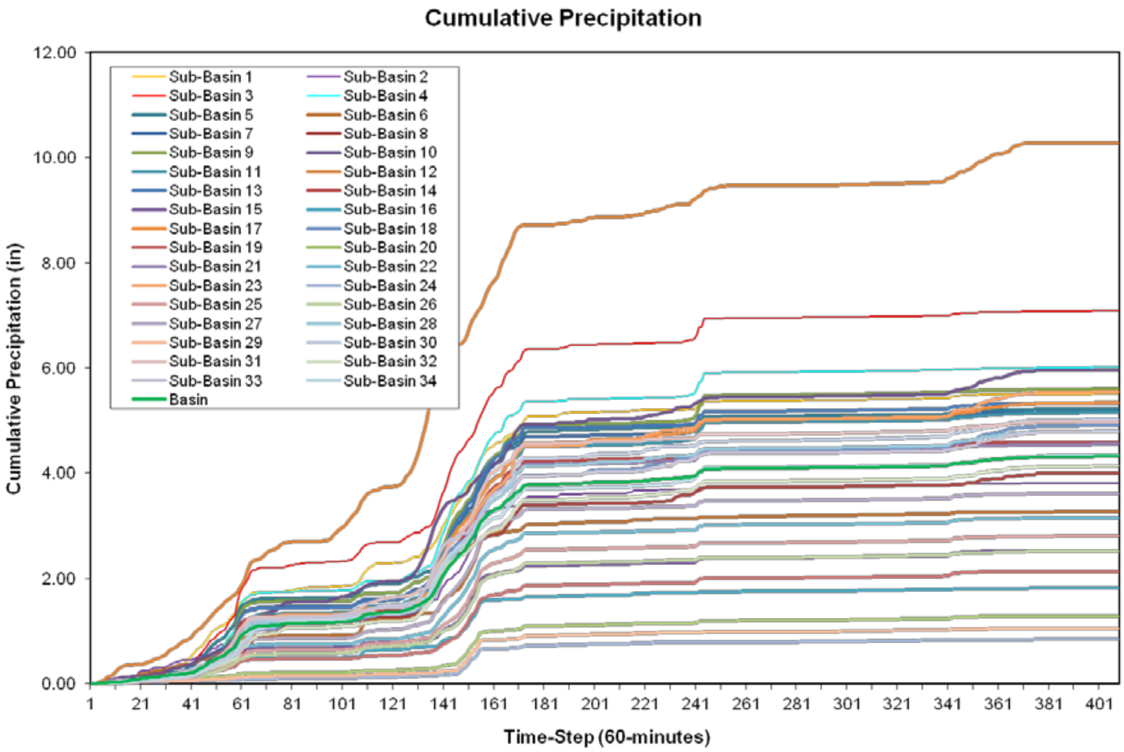

Figure 12.2. Susitna-Watana sub-basin average accumulated rainfall SPAS 1256.

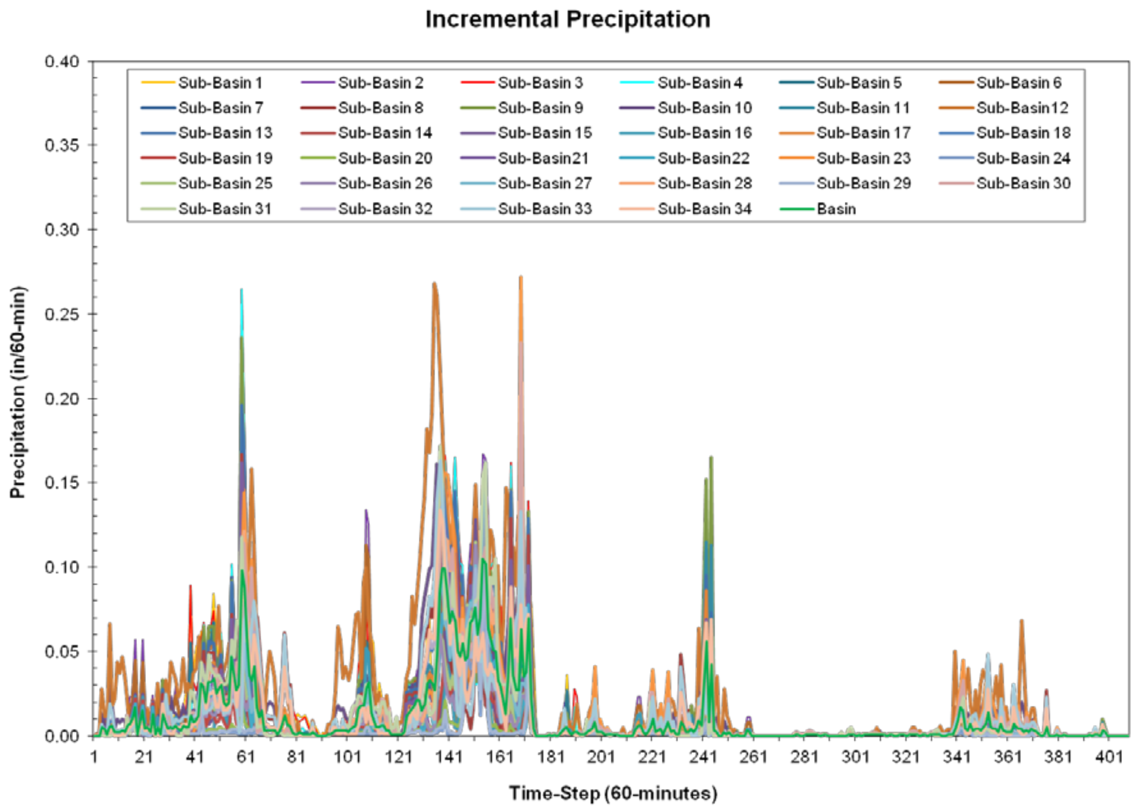

Figure 12.3. Susitna-Watana sub-basin average incremental rainfall SPAS 1256.

12.2.2 August 14-17, 1971 Precipitation

The hourly precipitation grids derived from the SPAS 1269 analysis were used in conjunction with SPAS-Lite 6001 as the basis for the Susitna-Watana calibration. SPAS-Lite 6001 was utilized to fill in a longer duration than what was analyzed for SPAS 1269, the calibration period is referenced as SPAS 1269. The SPAS 1269 analysis encompassed the 34 sub-basins of Susitna-Watana. The SPAS 1269 hourly grids were clipped to each of the Susitna-Watana sub-basins, the sub-basin average statistics were calculated and added to an Excel spreadsheet used for hydrologic calibration. The calibration deliverables are based on the SPAS hourly precipitation data for 8/4-17/1971. In general, between 1.50 and 5.80 inches of rain fell across the Susitna-Watana drainage (Figure 12.4 - 12.6).

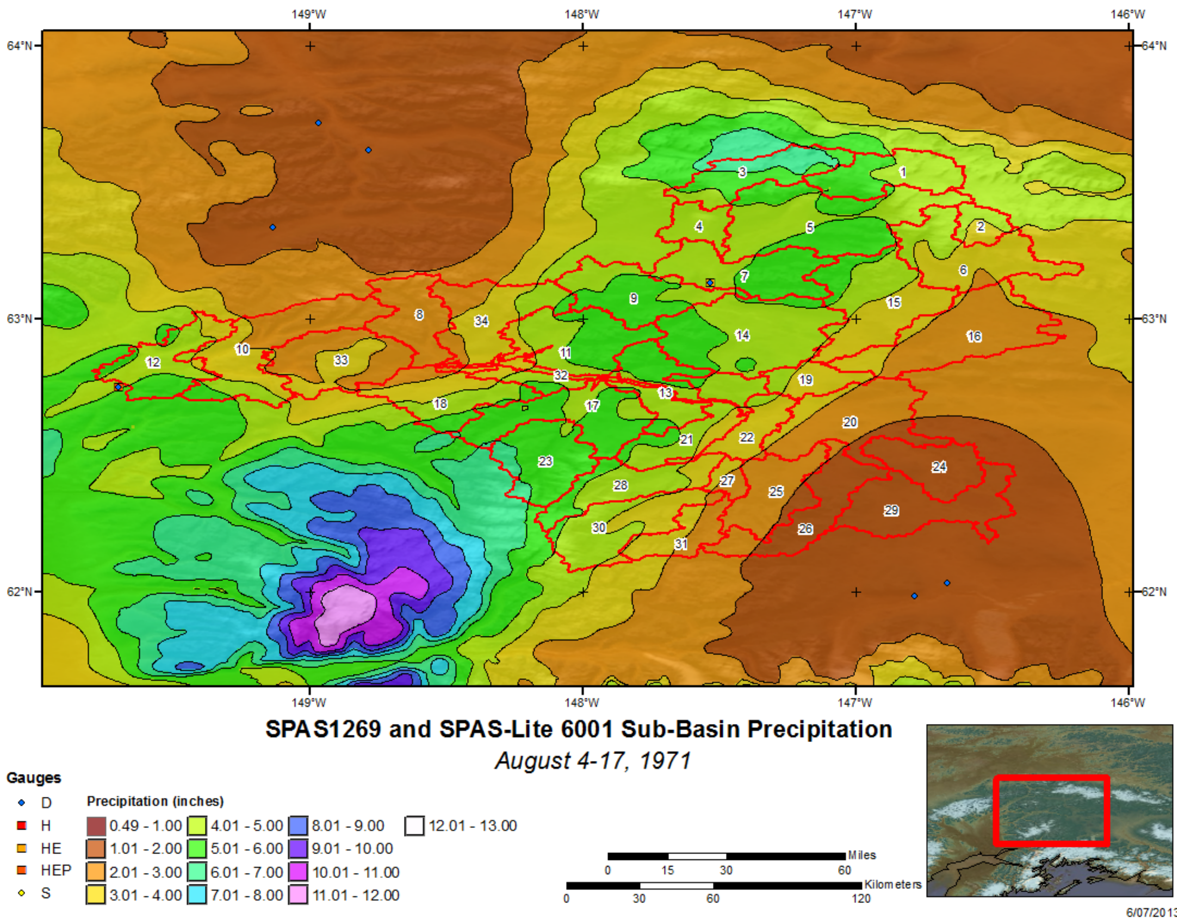

Figure 12.4. Total storm rainfall for SPAS 1269 across Susitna-Watana drainage.

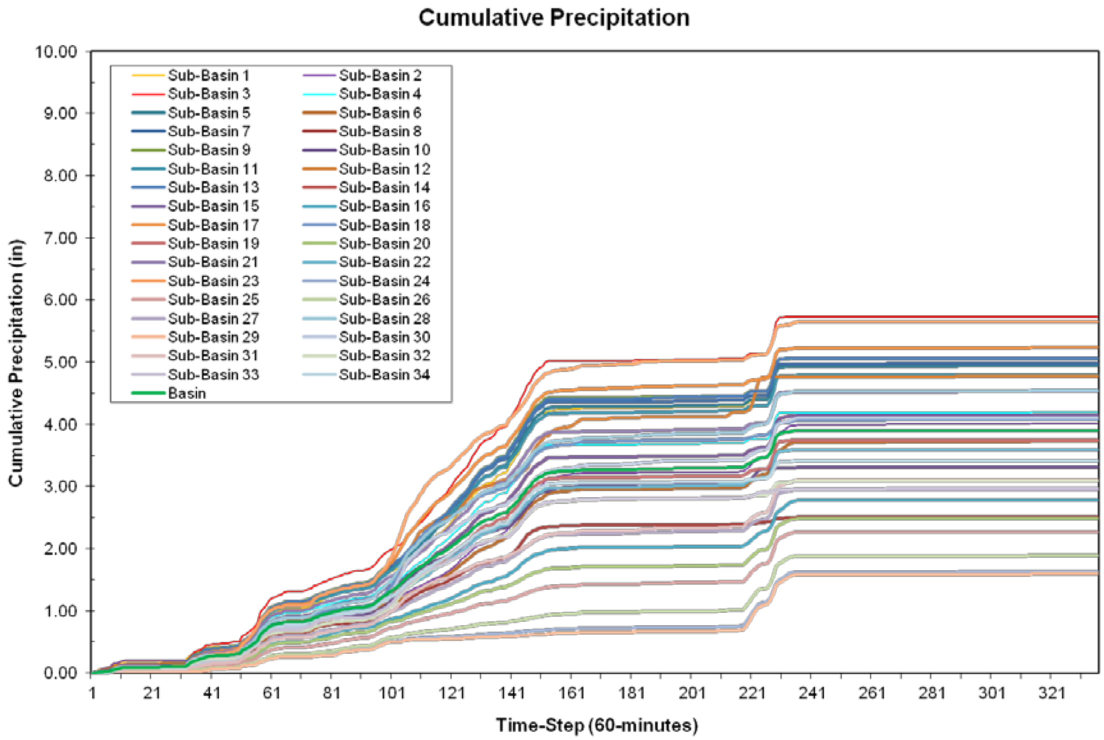

Figure 12.5. Susitna-Watana sub-basin average accumulated rainfall SPAS 1269.

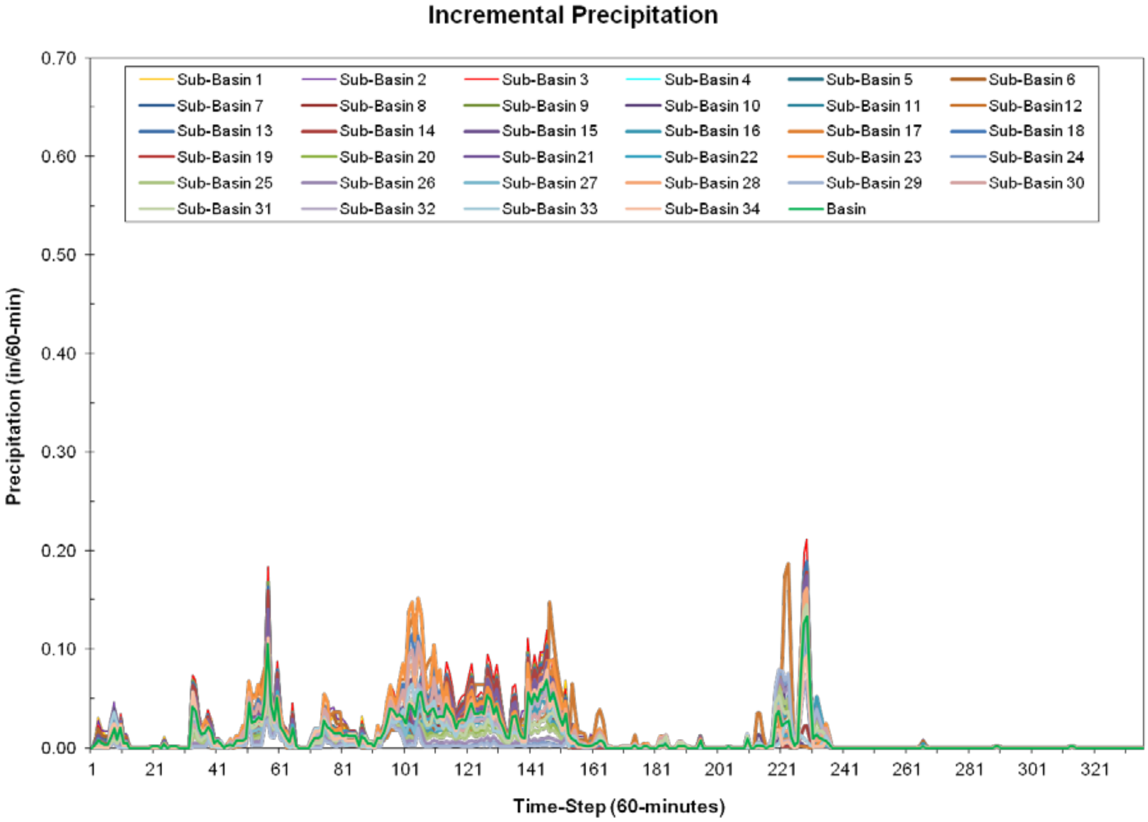

Figure 12.6. Susitna-Watana sub-basin average incremental rainfall SPAS 1269.

12.2.3 August 8-21, 1967 Precipitation

The hourly precipitation grids derived from the SPAS 1270 analysis were used in conjunction with SPAS-Lite 6002 as the basis for the Susitna-Watana calibration. SPAS-Lite 6002 was utilized to fill in a longer duration than what was analyzed for SPAS 1270, the calibration period is referenced as SPAS 1270. The SPAS 1270 analysis encompassed the 34 sub-basins of Susitna-Watana. The SPAS 1270 hourly grids were clipped to each of the Susitna-Watana sub-basins, the sub-basin average statistics were calculated and added to an Excel spreadsheet used for hydrologic calibration. The calibration deliverables are based on the SPAS hourly precipitation data for 8/8-21/1967. In general, between 0.50 and 7.20 inches of rain fell across the Susitna-Watana drainage (Figure 12.7 - 12.9).

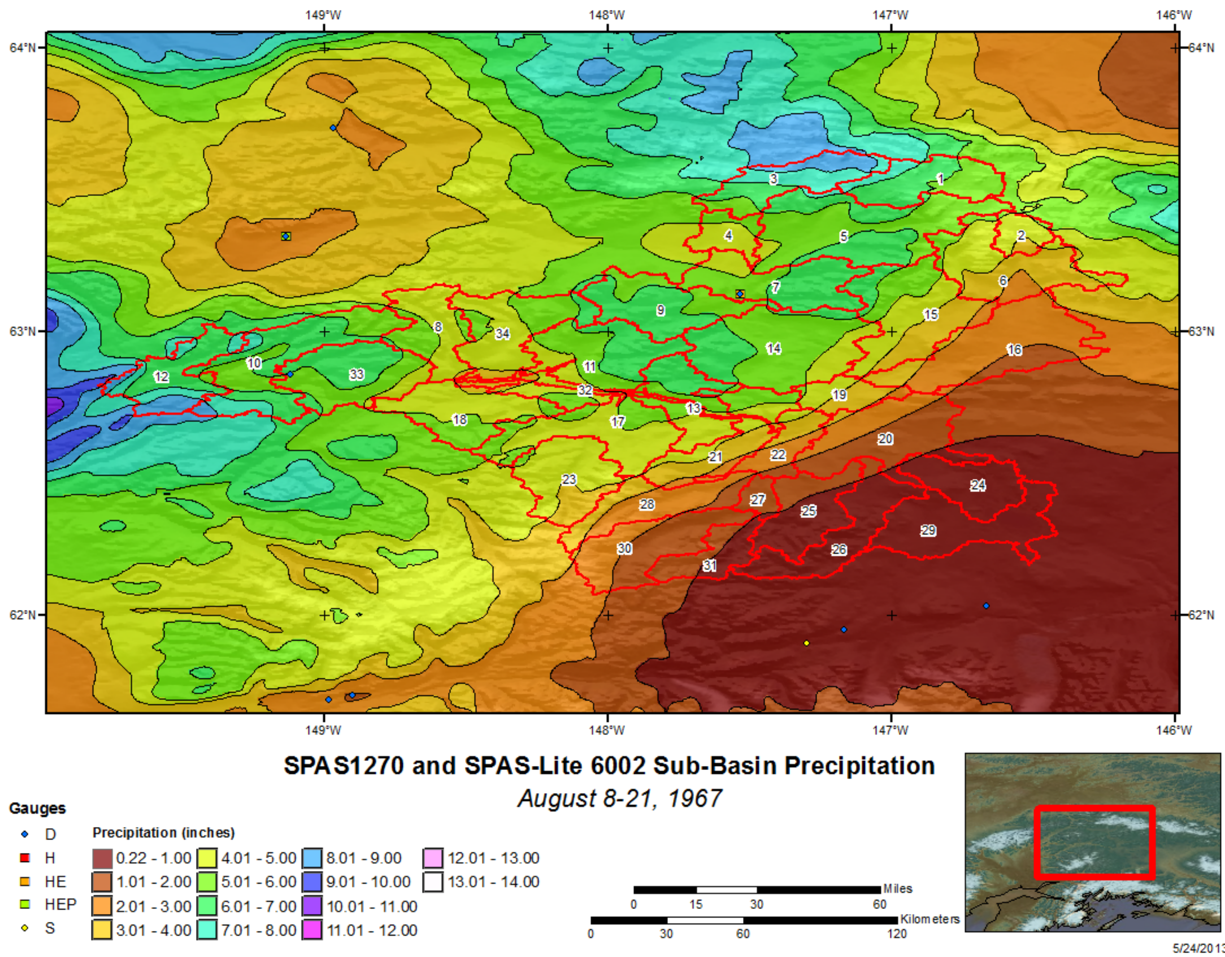

Figure 12.7. Total storm rainfall for SPAS 1270 across Susitna-Watana drainage.

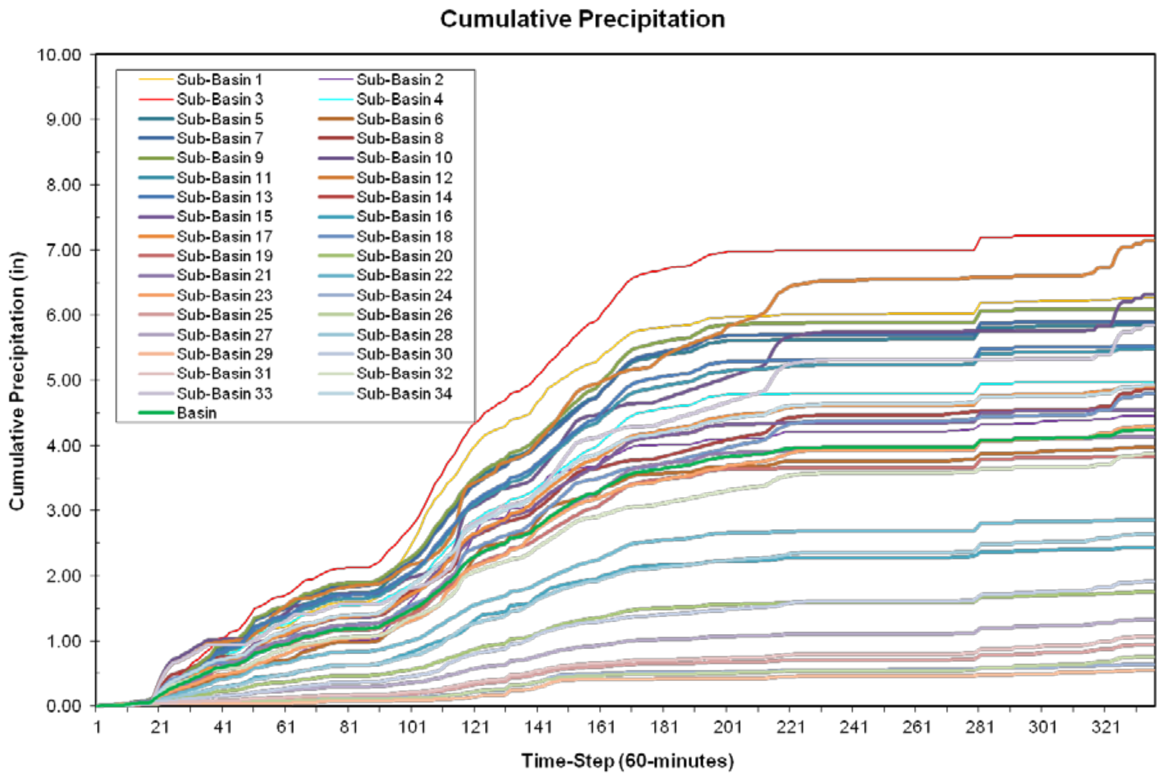

Figure 12.8. Susitna-Watana sub-basin average accumulated rainfall SPAS 1270.

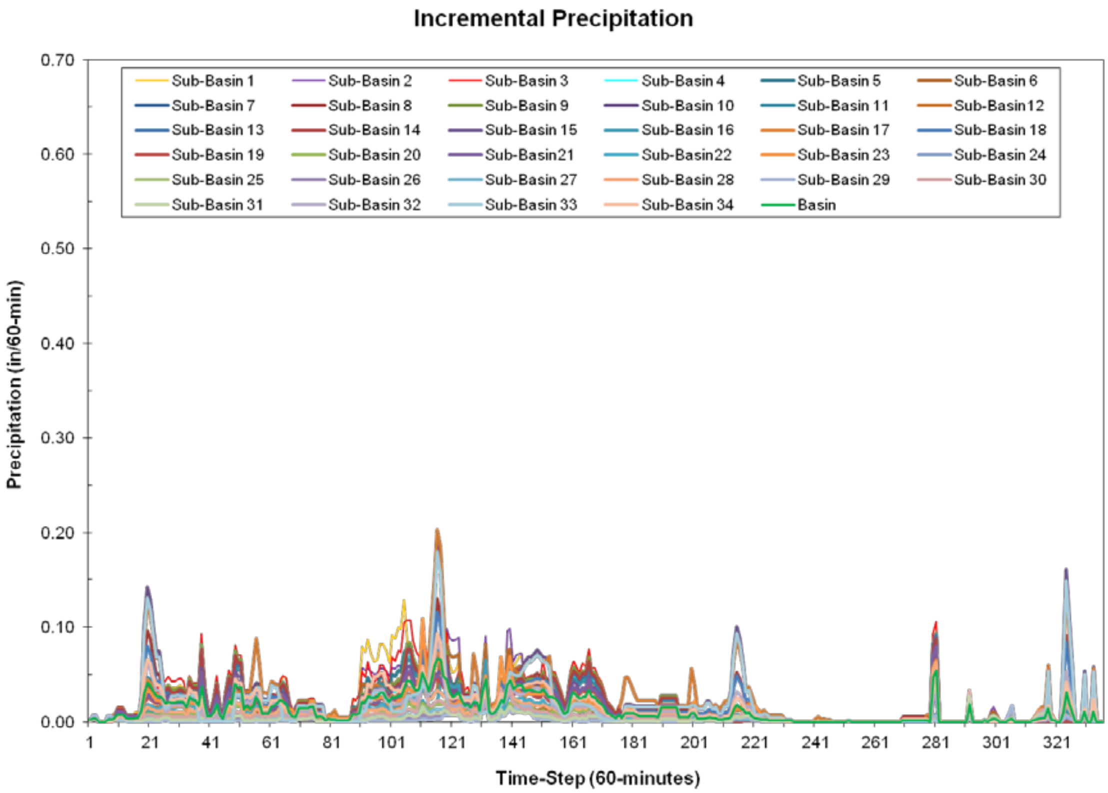

Figure 12.9. Susitna-Watana sub-basin average incremental rainfall SPAS 1270.

12.2.4 May 27, 1964 - June 13, 1964 Precipitation

The hourly precipitation grids derived from the SPAS-Lite 6008 analysis were used as the basis for the Susitna-Watana basin calibration. The SPAS-Lite 6008 analysis encompassed the 34 sub-basins of Susitna-Watana. The SPAS-Lite 6008 hourly grids were clipped to each of the Susitna-Watana sub-basins, the sub-basin average statistics were calculated and added to an Excel spreadsheet used for hydrologic calibration. The calibration deliverables are based on the SPAS hourly precipitation data for 5/27/1964 - 6/13/1964. In general, between 0.20 and 1.50 inches of rain fell across the Susitna-Watana drainage (Figure 12.10 - 12.12).

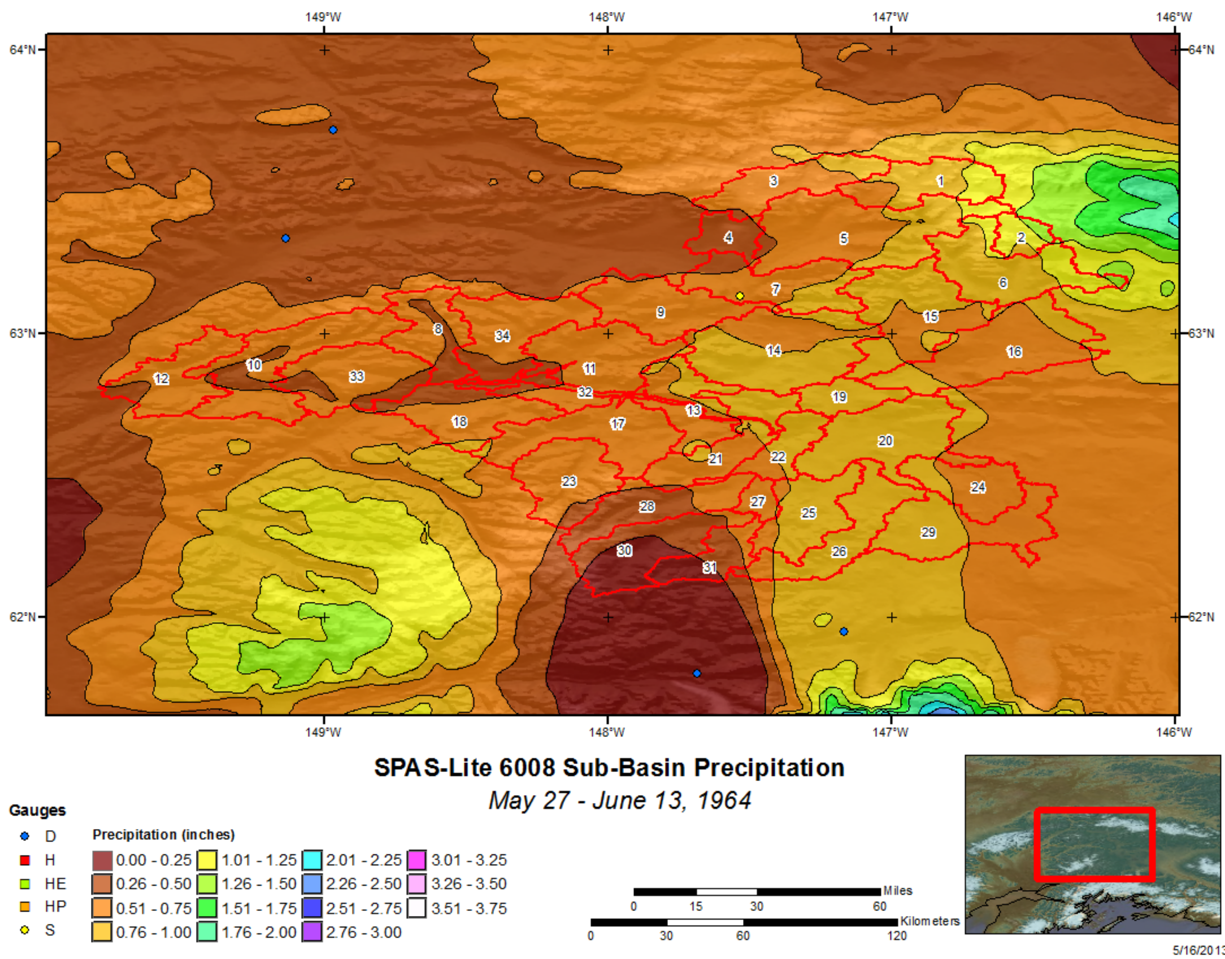

Figure 12.10. Total storm rainfall for SPAS 6008 across Susitna-Watana drainage.

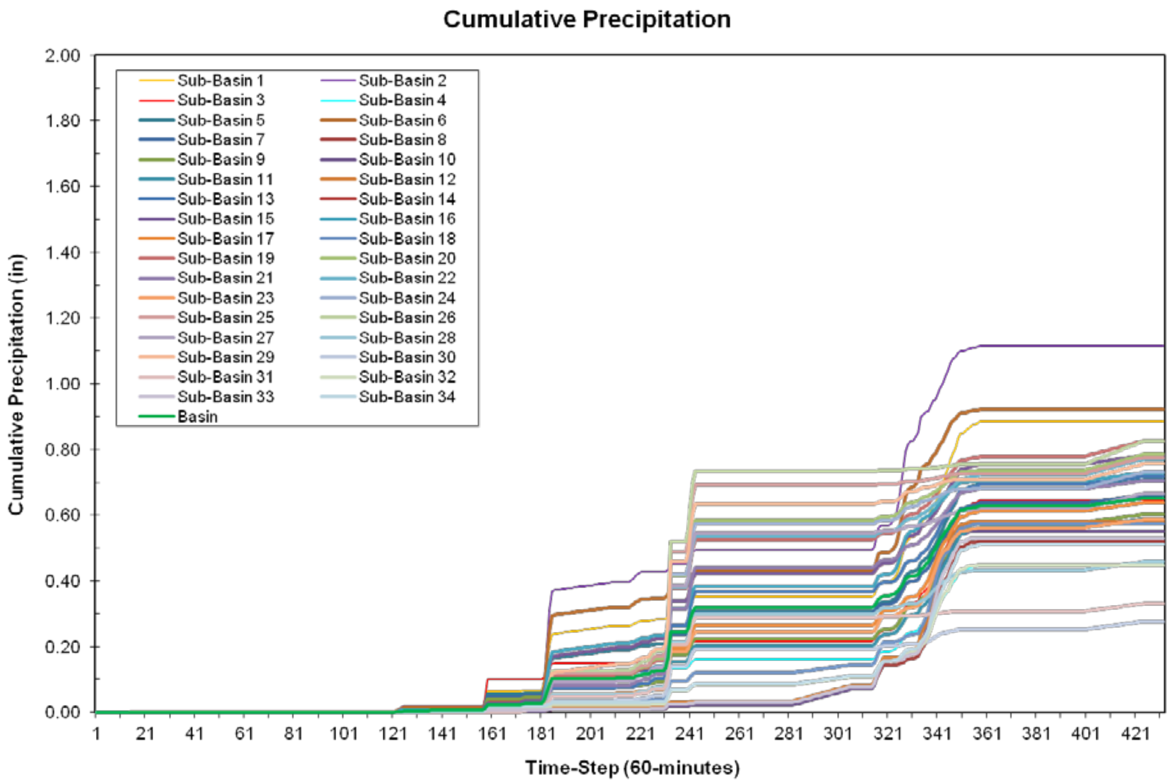

Figure 12.11. Susitna-Watana sub-basin average accumulated rainfall SPAS 6008.

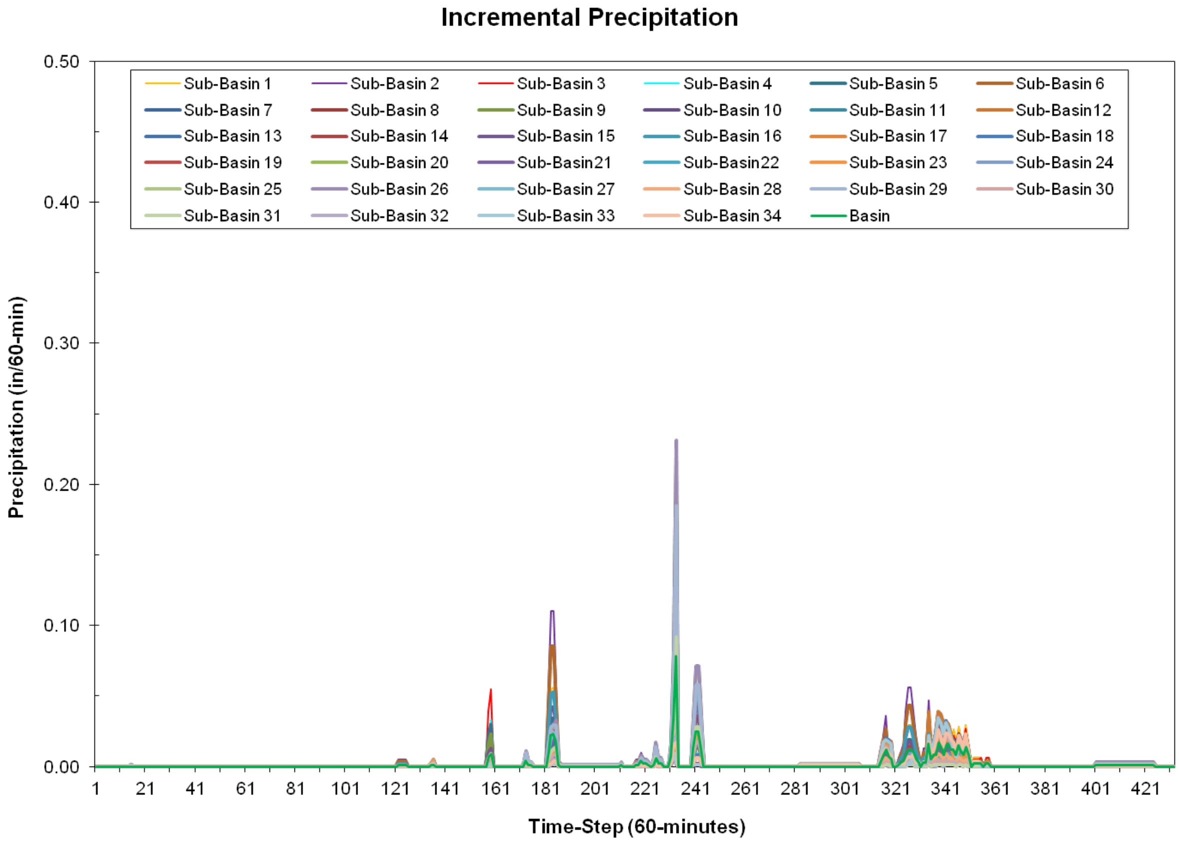

Figure 12.12. Susitna-Watana sub-basin average incremental rainfall SPAS 6008.

12.2.5 June 3-17, 1971 Precipitation

The hourly precipitation grids derived from the SPAS-Lite 6009 analysis were used as the basis for the Susitna-Watana basin calibration. The SPAS-Lite 6009 analysis encompassed the 34 sub-basins of Susitna-Watana. The SPAS-Lite 6009 hourly grids were clipped to each of the Susitna-Watana sub-basins, the sub-basin average statistics were calculated and added to an Excel spreadsheet used for hydrologic calibration. The calibration deliverables are based on the SPAS hourly precipitation data for 6/3-17/1971. In general, between 0.20 and 1.30 inches of rain fell across the Susitna-Watana drainage (Figure 12.13 - 12.15).

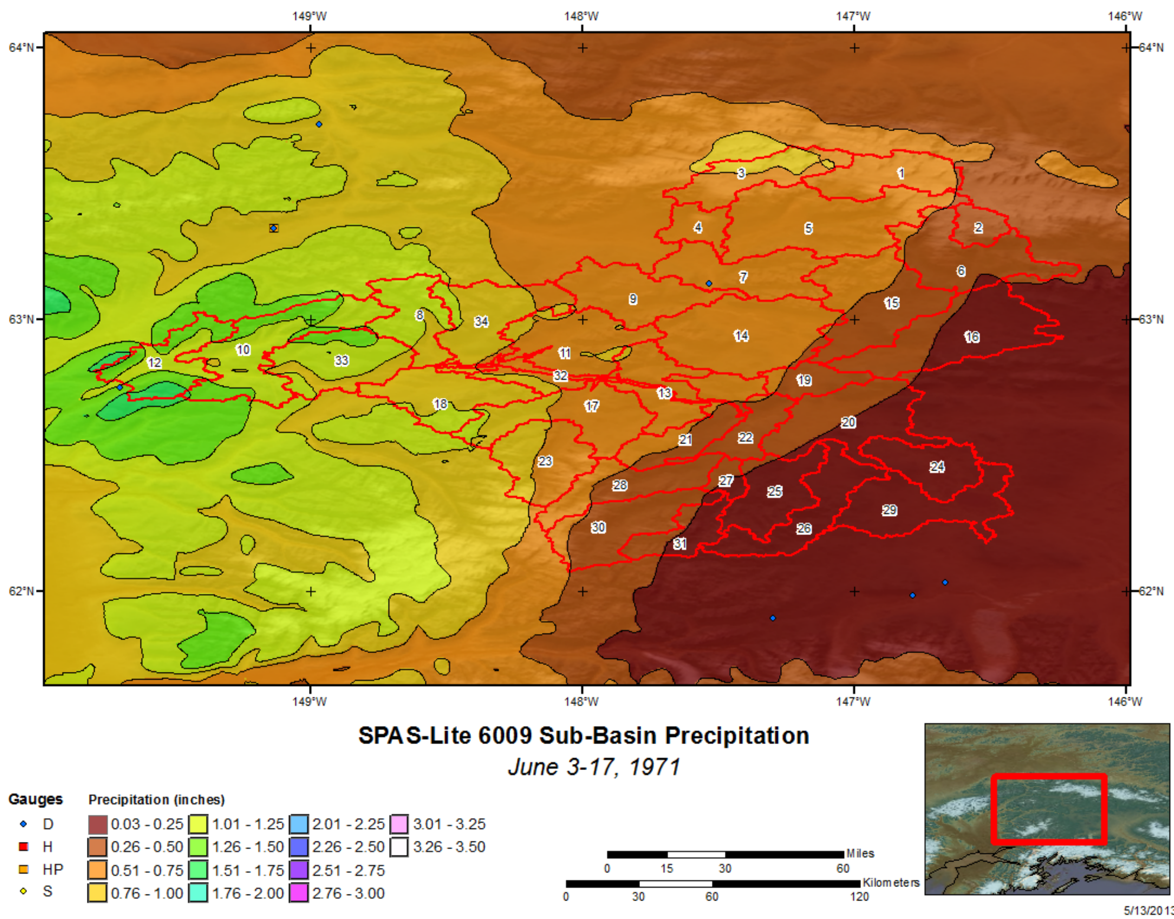

Figure 12.13. Total storm rainfall for SPAS 6009 across Susitna-Watana drainage.

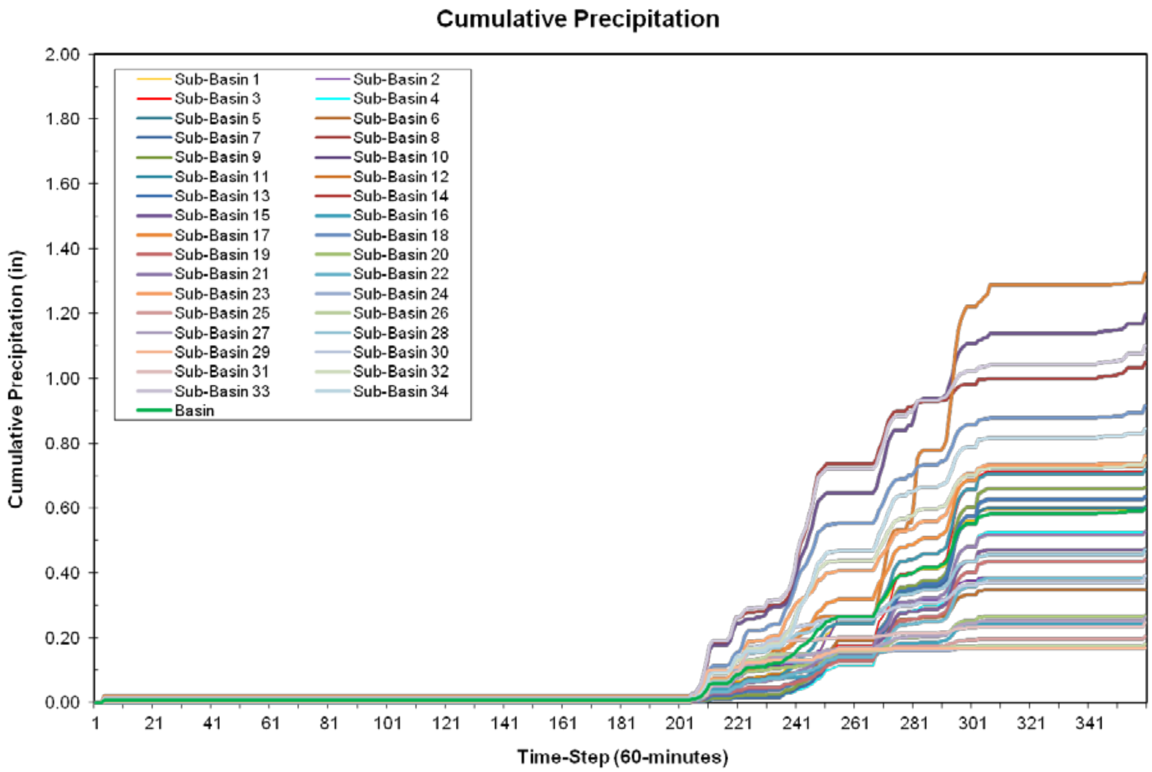

Figure 12.14. Susitna-Watana sub-basin average accumulated rainfall SPAS 6009.

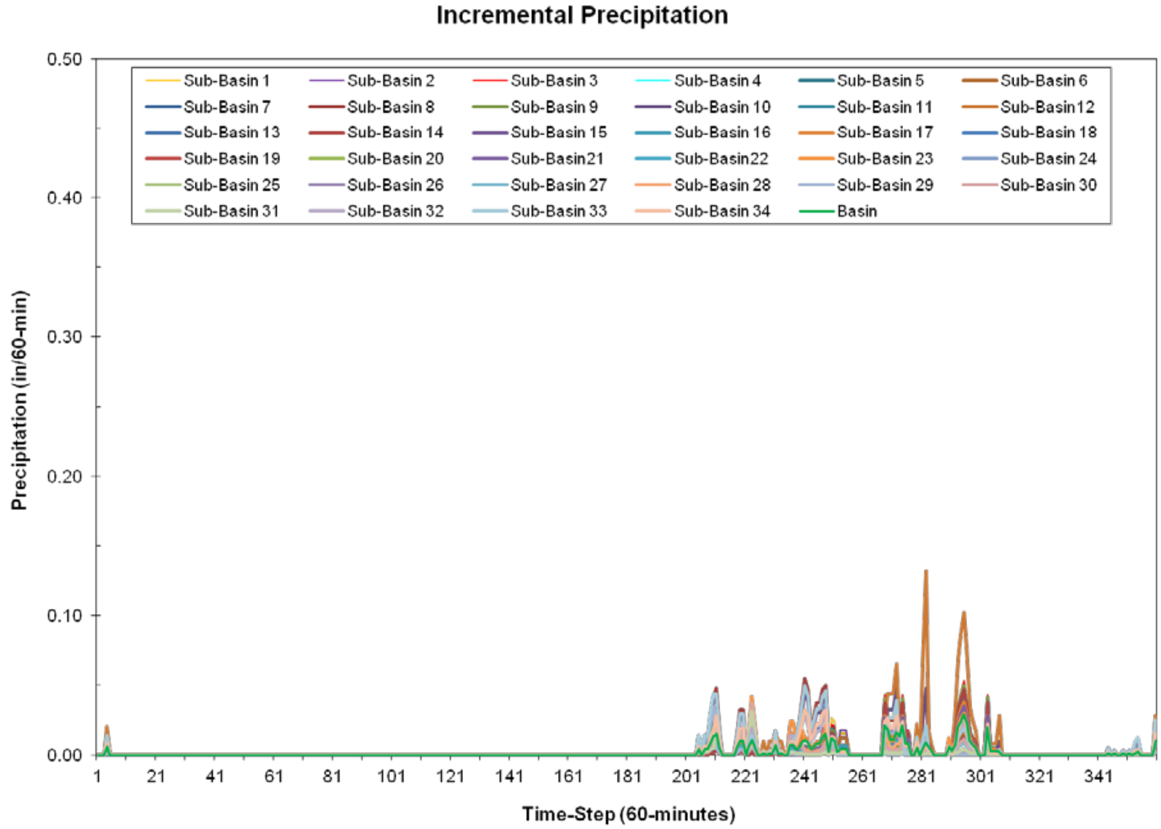

Figure 12.15. Susitna-Watana sub-basin average incremental rainfall SPAS 6009.

12.2.6 June 7-22, 1972 Precipitation

The hourly precipitation grids derived from the SPAS-Lite 6010 analysis were used as the basis for the Susitna-Watana basin calibration. The SPAS-Lite 6010 analysis encompassed the 34 sub-basins of Susitna-Watana. The SPAS-Lite 6010 hourly grids were clipped to each of the Susitna-Watana sub-basins, the sub-basin average statistics were calculated and added to an Excel spreadsheet used for hydrologic calibration. The calibration deliverables are based on the SPAS hourly precipitation data for 6/7-22/1972. In general, between 0.50 and 1.50 inches of rain fell across the Susitna-Watana drainage (Figure 12.16 - 12.18).

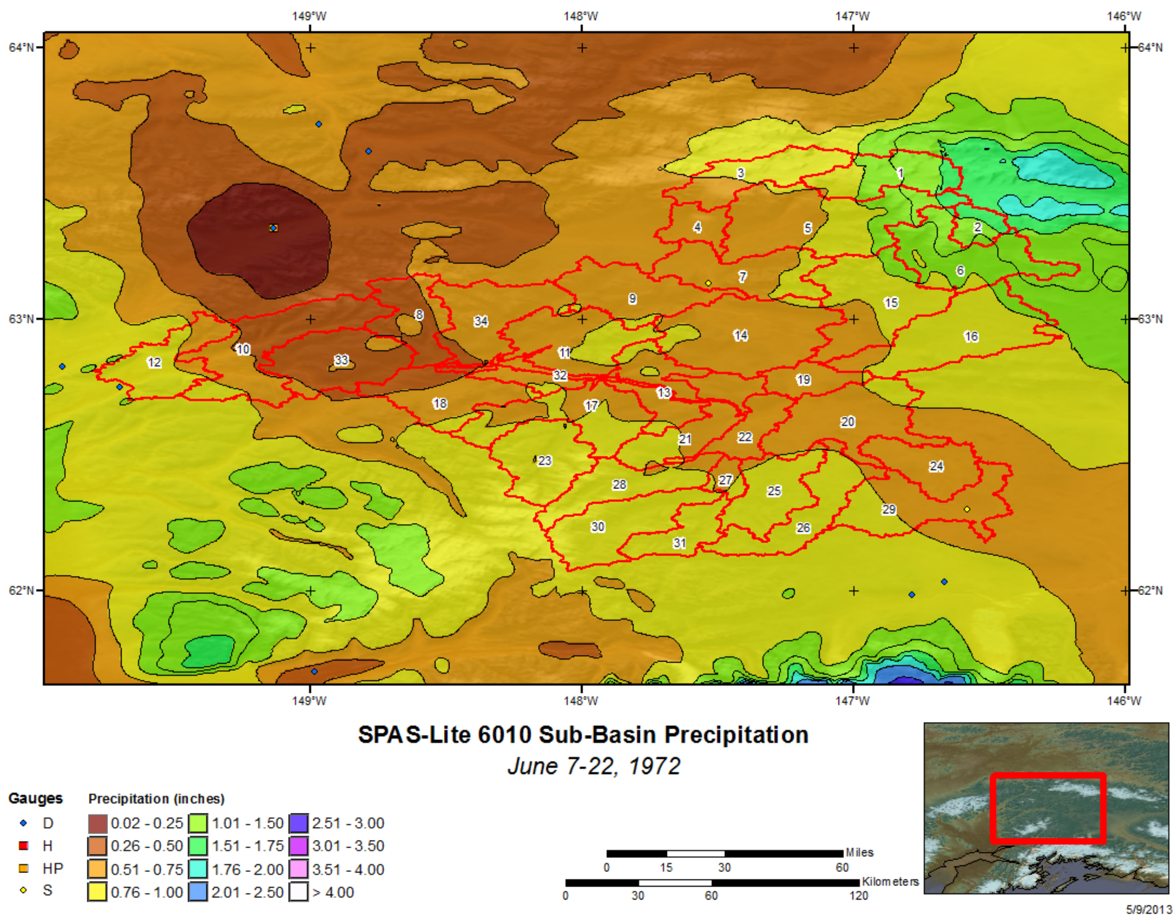

Figure 12.16. Total storm rainfall for SPAS 6010 across Susitna-Watana drainage.

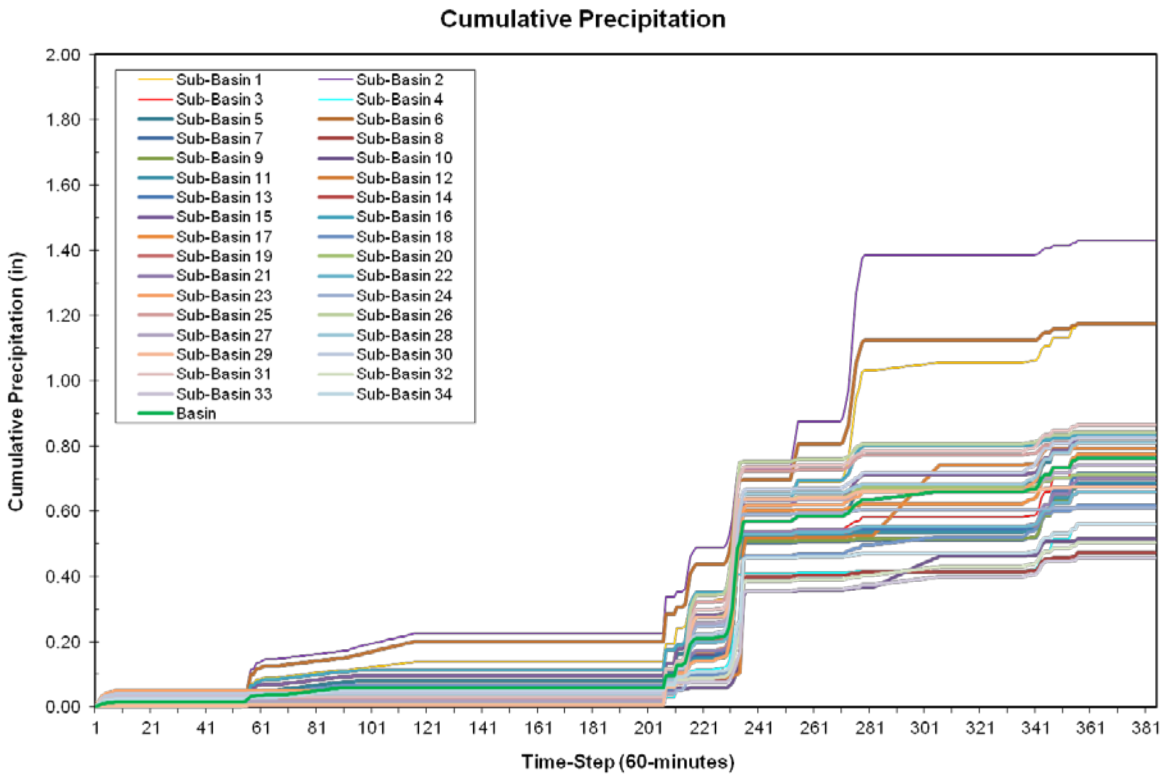

Figure 12.17. Susitna-Watana sub-basin average accumulated rainfall SPAS 6010.

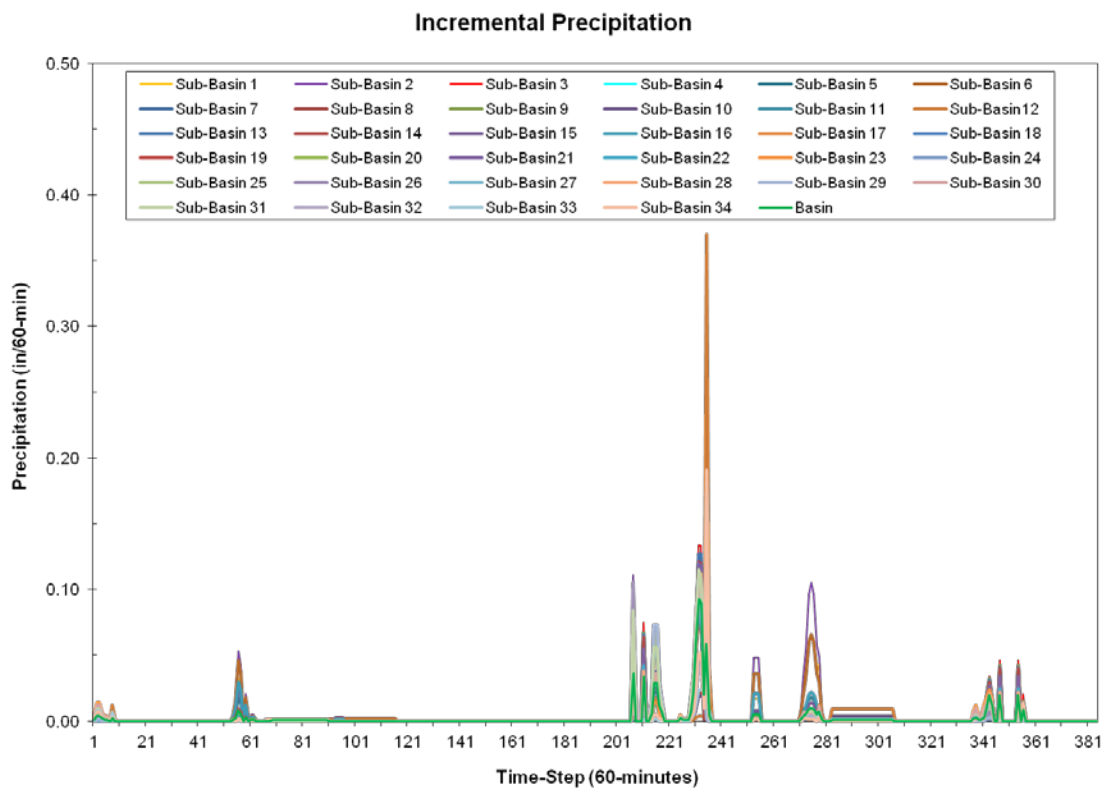

Figure 12.18. Susitna-Watana sub-basin average incremental rainfall SPAS 6010.

12.3 Meteorological Time Series for Calibration Events

Hourly meteorological time series were developed for the six calibration events (see Table 12.1). The meteorological time series parameters derived were temperature, dew point temperature and wind speed over the Susitna-Watana basin. The hydrologic model requirements were a single temperature and dew point temperature time series at a given base elevation and wind speed at 1,000-ft increments from 0 - 15,000-ft. Temperature lapse rates were estimated using observed surface temperature data for stations in and around the Susitna River basin and the Fairbanks and Anchorage radiosonde data.

Vertical wind speed profiles at 1,000-ft increments were derived based on wind speed data from the Fairbanks radiosonde data and observed surface wind speed data for stations in and around the Susitna-Watana basin. The radiosonde wind speed represents free atmospheric wind (unobstructed flow). The free-air data were adjusted to surface wind speeds based on comparisons of anemometer level wind speeds with concurrent free-air wind speeds. The wind speed derivation methodology was based on methods described in HMR 42 (Weather Bureau 1966). HMR 42 measured winds at Gulkana glacier (4,800 ft) and compared them to free-air winds at Fairbanks; the study found that average wind on the glacier was 0.60 that of the free-air. In this updated analysis, comparisons were made using both Anchorage and Fairbanks radiosonde data. This analysis showed the Anchorage radiosonde data were not as representative of the surface wind speeds over the basin based on comparisons made to the September 2012 storm event. Instead, the Fairbanks data better represented the timing and magnitude of the observed surface wind speeds.

12.3.1 September 14-30, 2012 Meteorological Time Series

Temperature lapse rates were estimated using observed surface temperature data for stations in and around the Susitna-Watana basin. Lapse rates were derived each hour using observed surface data at two locations. Station based lapse rates were calculated between: i) Independence Mine and Talkeetna, ii) PAZK and Talkeetna, iii) PAZK and Renee, and iv) Monahan Flats and McKinley. The hourly lapse rates were used to calculate an average lapse rate for the entire calibration period and an average lapse rate based on when rain was occurring during the calibration event (Table 12.2).

Station data were also used to derive an average station based lapse rate for each hour of the storm event. The stations used for this analysis were PAZK, PANC, Blair Lakes, Dunkle Hills, Eielson VC, Paxson, Renee, Toklat, Independence Mine, Monahan Flat, Susitna VH, Tokositna Valley, Fairbanks, Ft Greeley, Gulkana, McKinley NP, Palmer, and Talkeetna. The station average lapse rate was derived using linear regression between temperature and elevation. Based on the hourly station data linear relationship, a lapse rate (regression slope) was calculated for each hour of the analysis period. The average of the station based lapse rates (based on linear regression) was compared to individual station (station 1 @ X elevation compared to station 2 @ X elevation) based lapse rates discussed above (Table 12.2).

Vertical temperature at 1,000-foot increments from 0 - 6,000-ft were derived base on temperature data from the Fairbanks radiosonde. The Fairbanks radiosonde lapse rate data were used to calculate an average lapse rate for the entire calibration period (Table 12.2). The radiosonde wind speed represents free atmospheric winds, unobstructed flow, the free-air data were adjusted to surface wind speeds based on comparisons of anemometer level wind speeds with concurrent free-air wind speeds. Surface wind speeds were compared at six locations with varying elevations across the Susitna River basin to the Fairbanks free-air wind speeds. The average free-air adjustment for the six stations was 0.620 with a maximum of 0.968 and a minimum of 0.385 (Table 12.3). In order to convert free-air wind speed data to anemometer level wind speeds the adjustment/ratio is applied to the free-air data. For example, at 1,000-foot elevation free-air wind speed is 45-mph would be 30-mph at the anemometer level (45-mph * 0.666 = 30-mph). The radiosonde data are measured every 12-hours (0-UTC and 12-UTC), the 12-hour data were interpolated to hourly data using the bounding hourly data and a linear relationship.

Table 12.2. Station based and radiosonde based lapse rates for September 14-30, 2012.

Station Comparisons	Hourly Average	Hourly Rainfall Average	FAI Radiosonde
Indep. Mine vs. Talkeetna	-2.50	-1.98	-
PAZK vs. Talkeetna	-2.17	-1.69	-
PAZK vs. Renee	-3.10	-3.64	-
Monahan Flat vs. McKinley	-1.73	-2.53	-
All Stations	-2.40	-2.38	-
Average	-2.38	-2.44	-2.43

Table 12.3. Fairbanks radiosonde free-air wind speed conversion ratio to anemometer height wind speed for September 14-30, 2012.

Station	Elevation (ft)	FAI Radiosonde Ratio
Gulkana	1500	0.968
McKinley	1500	0.471
Talkeetna	500	0.769
PAZK	3500	0.385
Renee	2500	0.623
Eielson	3500	0.505
	Average	*0.620*
	Maximum	0.968
	Minimum	0.385

The final temperature and dew point temperature series were based on surface data at Monahan Flats, Alaska with a base elevation of 2,700-ft (Figure 12.19). The Monahan Flats station data were selected because it was within the Susitna River basin and provided a complete and representative profile of temperature and dew point temperature. The lapse rate used to adjust temperature and dew point temperature to other elevations was -2.40°F. The -2.40°F lapse rate was based on the average of all station comparisons. The final vertical wind speed data were based on Fairbanks free-air wind speeds with an adjustment ratio of 0.620 applied to represent anemometer level wind speeds (Figure 12.20).

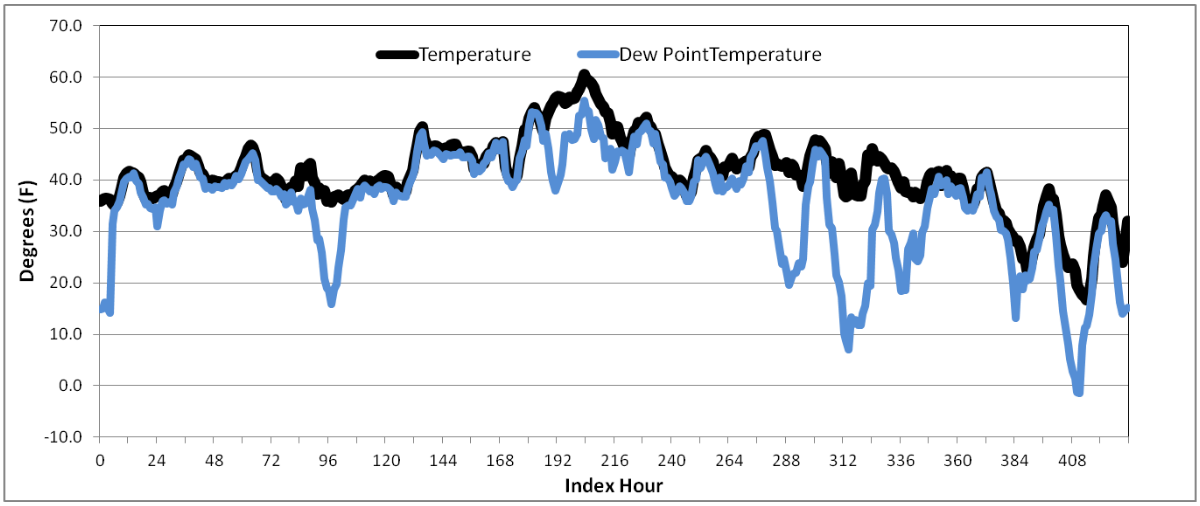

Figure 12.19. Temperature and dew point time series based on surface data at Summit, Alaska with a base elevation of 2,400-ft and lapse rate of -2.40°F for September 14-30, 2012.

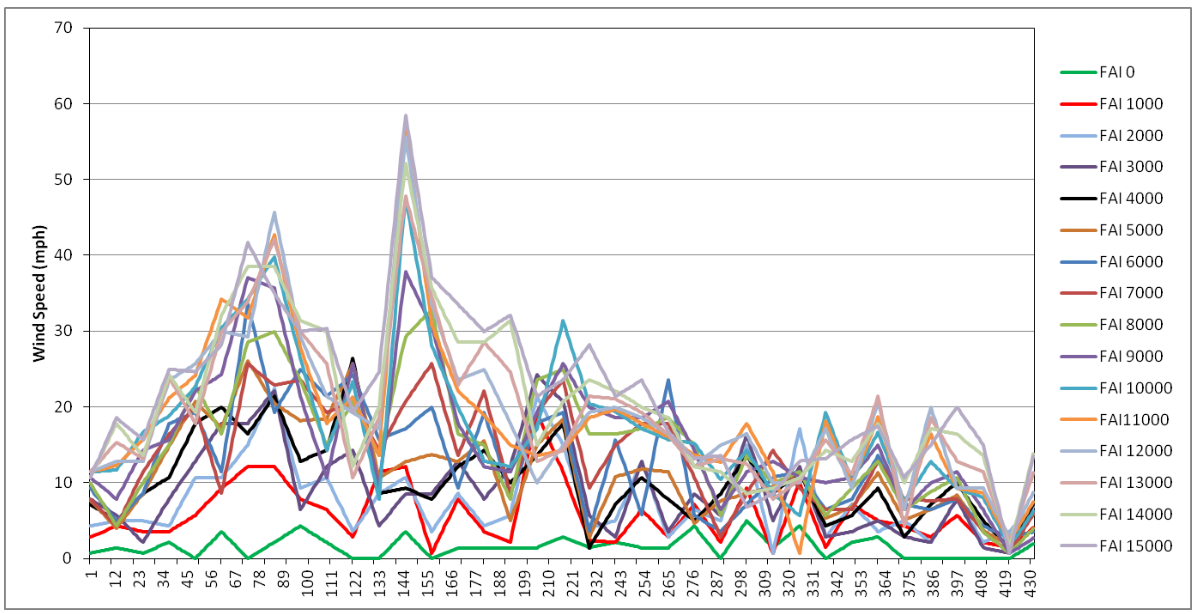

Figure 12.20. Wind speed data based on Fairbanks free-air wind speeds with an adjustment ratio of 0.62 applied to represent anemometer level wind speeds for September 14-30, 2012.

12.3.2 August 4-17, 1971 Meteorological Time Series

Temperature lapse rates were estimated using observed surface temperature data for stations in and around the Susitna-Watana basin. Lapse rates were derived each hour using observed surface data at two locations. Station based lapse rates were calculated between: i) Talkeetna and Summit, ii) Anchorage and Gulkana, iii) Ft Greeley and Summit, and iv) Ft Greeley and Fairbanks. The hourly lapse rates were used to calculate an average lapse rate for the entire calibration period and an average lapse rate based on when rain was occurring during the calibration event (Table 12.4).

Station data were also used to derive an average station based lapse rate for each hour of the storm event. The stations used for this analysis were PANC, Anchorage, Fairbanks, Ft Greeley, Gulkana, Summit, and Talkeetna. The station average lapse rate was derived using linear regression between temperature and elevation. Based on the hourly station data linear relationship, a lapse rate (regression slope) was calculated for each hour of the analysis period. The average of the station based lapse rates (based on linear regression) was compared to individual station (station 1 @ X elevation compared to station 2 @ X elevation) based lapse rates discussed above (Table 12.4).

Vertical temperature at 1,000-foot increments from 0 - 6,000-ft were derived base on temperature data from the Fairbanks radiosonde. The Fairbanks radiosonde lapse rate data were used to calculate an average lapse rate for the entire calibration period (Table 12.4).

Table 12.4. Station based and radiosonde based lapse rates for August 4-17, 1971.

Station Comparisons	Hourly Average	Hourly Rainfall Average	FAI Radiosonde
Talkeetna vs. Summit	-3.31	-2.62	-
Anchorage vs. Gulkana	-0.86	0.17	-
Ft Greely vs. Summit	-3.34	-5.15	-
Ft Greely vs. Fairbanks	-2.47	-2.18	-
All Stations	-2.27	-2.11	-
Average*	-2.85	-3.01	-3.40

* Comparison excludes Anchorage vs. Gulkana lapse rate

The radiosonde wind speed represents free atmospheric winds, unobstructed flow, the free-air data were adjusted to surface wind speeds elevations based on comparisons of anemometer level wind speeds with concurrent free-air wind speeds. Surface wind speeds were compared at six locations with varying elevations across the Susitna River basin to the Fairbanks free-air wind speeds (Table 12.5). The average free-air adjustment for the six stations was 0.666 with a maximum of 0.895 and a minimum of 0.390. In order to convert free-air wind speed data to anemometer level wind speeds the adjustment/ratio is applied to the free-air data. For example, at 1,000-foot elevation free-air wind speed is 45-mph would be 30-mph at the anemometer level (45-mph * 0.666 = 30-mph). The radiosonde data are measured every 12-hours (0-UTC and 12-UTC), the 12-hour data were interpolated to hourly data using the bounding hourly data and a linear relationship.

Table 12.5. Fairbanks radiosonde free-air wind speed conversion ratio to anemometer height wind speed for August 4-17, 1971.

Station	Elevation (ft)	FAI Radiosonde Ratio
Gulkana	1500	0.768
Summit	2500	0.608
Talkeetna	500	0.390
Anchorage	0	0.869
Ft Greely	1500	0.468
Fairbanks	500	0.895
	Average	*0.666*
	Maximum	0.895
	Minimum	0.390

The final temperature and dew point temperature series were based on surface data at Summit, Alaska with a base elevation of 2,400-ft (Figure 12.21). The Summit station data were selected because it was in close proximity to the Susitna River basin and provided a complete and representative profile of temperature and dew point temperature. The lapse rate used to adjust temperature and dew point temperature to other elevations was -2.85°F. The -2.85°F lapse rate was based on the average of all station comparison except the Anchorage and Gulkana comparison. The final vertical wind speed data were based on Fairbanks free-air wind speeds with an adjustment ratio of 0.666 applied to represent anemometer level wind speeds (Figure 12.22).

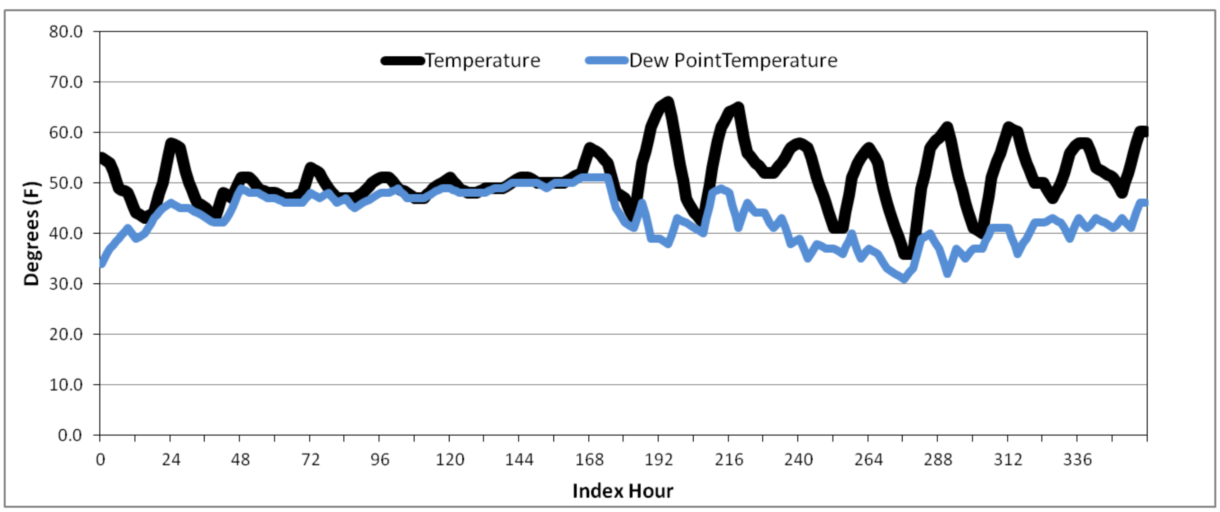

Figure 12.21. Temperature and dew point temperature series based on surface data at Summit, Alaska with a base elevation of 2,400-ft and lapse rate of -2.85°F for August 4-17, 1971.

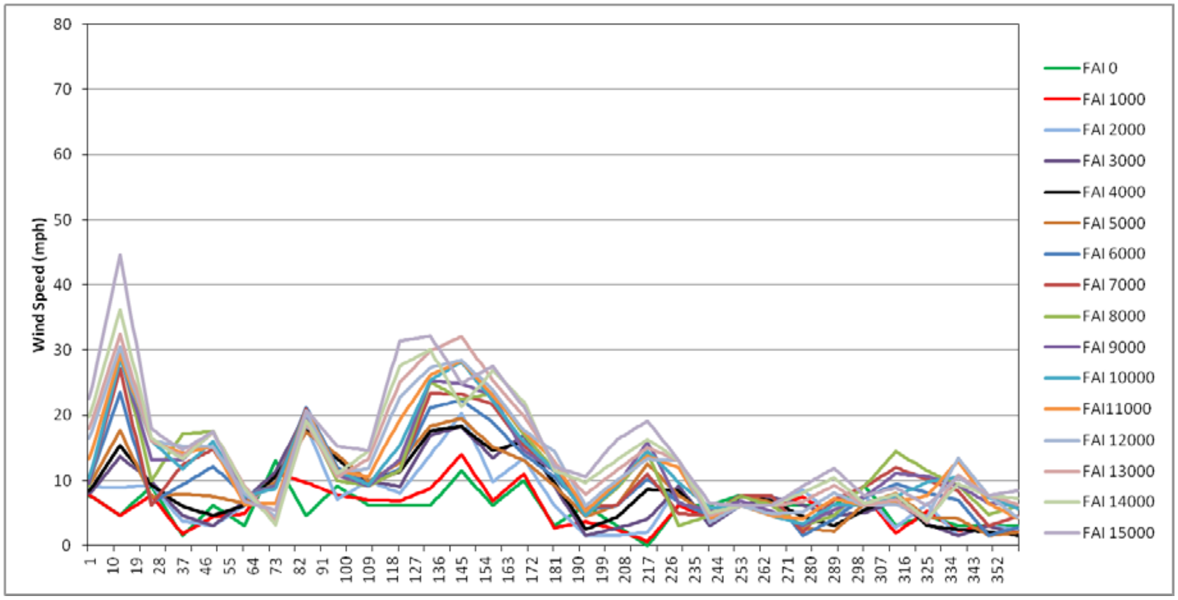

Figure 12.22. Wind speed data based on Fairbanks free-air wind speeds with an adjustment ratio of 0.666 applied to represent anemometer level wind speeds for August 4-17, 1971.

12.3.3 August 8-21, 1967 Meteorological Time Series

Temperature lapse rates were estimated using observed surface temperature data for stations in and around the Susitna-Watana basin. Lapse rates were derived each hour using observed surface data at two locations. Station based lapse rates were calculated between: i) Talkeetna and Summit, ii) Anchorage and Gulkana, iii) Ft Greeley and Summit, and iv) Ft Greeley and Fairbanks. The hourly lapse rates were used to calculate an average lapse rate for the entire calibration period and an average lapse rate based on when rain was occurring during the calibration event (Table 12.6).

Station data were also used to derive an average station based lapse rate for each hour of the storm event. The stations used for this analysis were KINR, Anchorage, Cordova, Fairbanks, Ft Greeley, Gulkana, Nenana, Summit, and Talkeetna. The station average lapse rate was derived using linear regression between temperature and elevation. Based on the hourly station data linear relationship, a lapse rate (regression slope) was calculated for each hour of the analysis period. The average of the station based lapse rates (based on linear regression) was compared to individual station (station 1 @ X elevation compared to station 2 @ X elevation) based lapse rates discussed above (Table 12.6).

Vertical temperature at 1,000-foot increments from 0 - 6,000-ft were derived base on temperature data from the Fairbanks radiosonde. The Fairbanks radiosonde lapse rate data were used to calculate an average lapse rate for the entire calibration period (Table 12.6).

Table 12.6. Station based and radiosonde based lapse rates for August 8-21, 1967.

Station Comparisons	Hourly Average	Hourly Rainfall Average	FAI Radiosonde
Talkeetna vs. Summit	-3.51	-3.83	-
Anchorage vs. Gulkana	-1.72	-2.13	-
Ft Greely vs. Summit	-7.33	-7.22	-
Ft Greely vs. Fairbanks	0.46	0.17	-
All Stations	-1.39	-1.35	-
Average*	-2.70	-2.87	-3.25

* -2.87 was used based on testing lapse rate at Summit to Anchorage and Nenana

The radiosonde wind speed represents free atmospheric winds, unobstructed flow, the free-air data were adjusted to surface wind speeds elevations based on comparisons of anemometer level wind speeds with concurrent free-air wind speeds. Surface wind speeds were compared at six locations with varying elevations across the Susitna River basin to the Fairbanks free-air wind speeds (Table 12.7). The average free-air adjustment for the six stations was 0.610 with a maximum of 0.813 and a minimum of 0.337. In order to convert free-air wind speed data to anemometer level wind speeds the adjustment/ratio is applied to the free-air data. For example, at 1,000-ft elevation free-air wind speed is 45-mph would be 30-mph at the anemometer level (45-mph * 0.620 = 27.5-mph). The radiosonde data are measured every 12-hours (0-UTC and 12-UTC), the 12-hour data were interpolated to hourly data using the bounding hourly data and a linear relationship.

Table 12.7. Fairbanks radiosonde free-air wind speed conversion ratio to anemometer height wind speed for August 8-21, 1967.

Station	Elevation (ft)	FAI Radiosonde Ratio
Gulkana	1500	0.813
Summit	2500	0.643
Talkeetna	500	0.662
Cordova	0	0.337
Ft Greely	1500	0.411
Fairbanks	500	0.519
	Average*	*0.610*
	Maximum	0.813
	Minimum	0.337

* Average excludes Cordova

The final temperature and dew point temperature series were based on surface data at Summit, Alaska with a base elevation of 2,400-ft (Figure 12.23). The Summit station data were selected because it was in close proximity to the Susitna River basin and provided a complete and representative profile of temperature and dew point temperature. The lapse rate used to adjust temperature and dew point temperature to other elevations was -2.87°F. The final vertical wind speed data were based on Fairbanks free-air wind speeds with an adjustment ratio of 0.610 applied to represent anemometer level wind speeds (Figure 12.24).

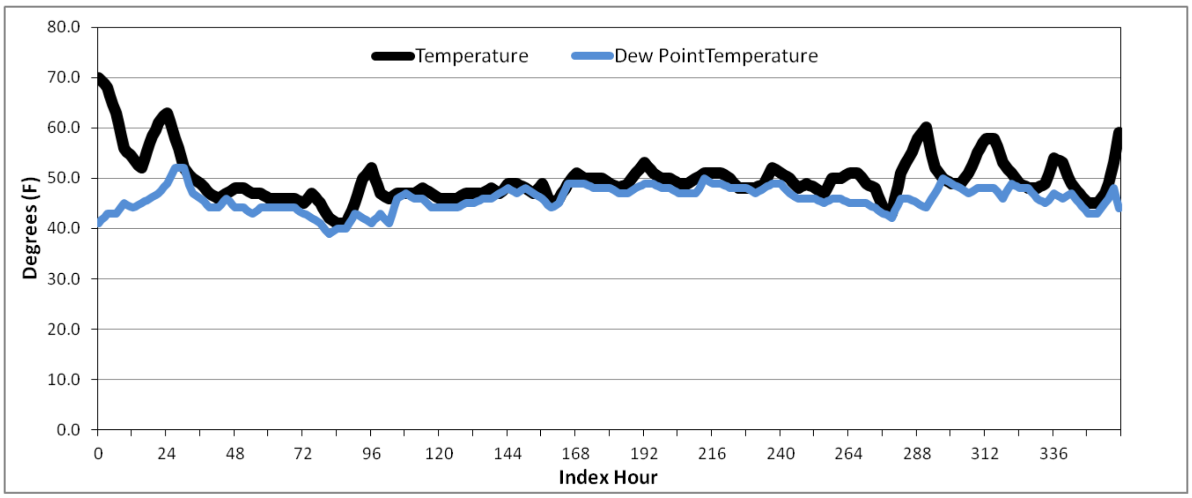

Figure 12.23. Temperature and dew point temperature series based on surface data at Summit, Alaska with a base elevation of 2,400-ft and lapse rate of -2.87°F for August 8-21, 1967.

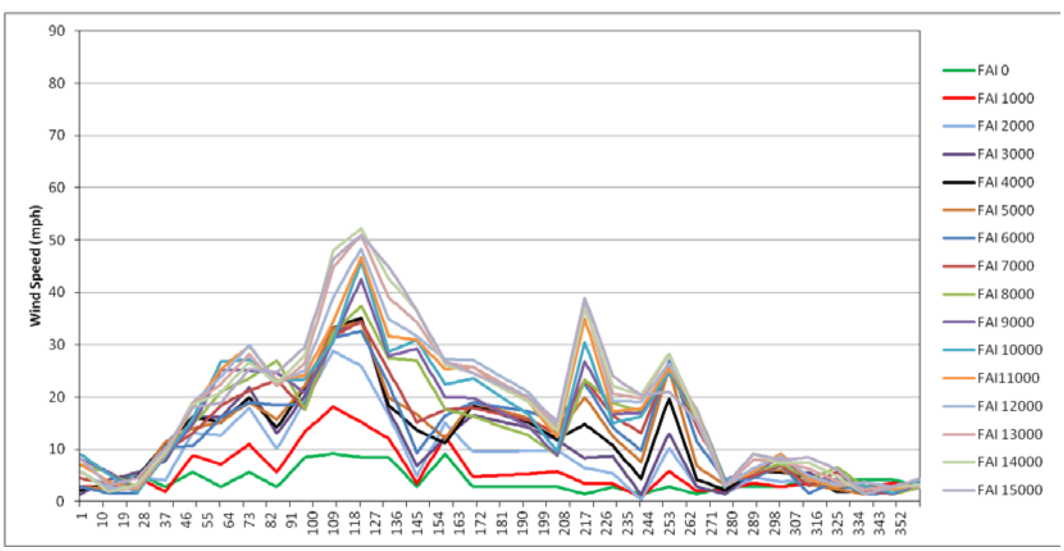

Figure 12.24. Wind speed data based on Fairbanks free-air wind speeds with an adjustment ratio of 0.610 applied to represent anemometer level wind speeds for August 8-21, 1967.

12.3.4 May 27, 1964 - June 13, 1964 Meteorological Time Series

Temperature lapse rates were estimated using observed surface temperature data for stations in and around the Susitna-Watana basin. Lapse rates were derived each hour using observed surface data at two locations. Station based lapse rates were calculated between: i) Talkeetna and Summit, ii) Anchorage and Gulkana, iii) Ft Greeley and Summit, and iv) Ft Greeley and Fairbanks. The hourly lapse rates were used to calculate an average lapse rate for the entire calibration period and an average lapse rate based on when rain was occurring during the calibration event (Table 12.8).

Station data were also used to derive an average station based lapse rate for each hour of the storm event. The stations used for this analysis were PANC, Anchorage, Fairbanks, Ft Greeley, Gulkana, Summit, and Talkeetna. The station average lapse rate was derived using linear regression between temperature and elevation. Based on the hourly station data linear relationship, a lapse rate (regression slope) was calculated for each hour of the analysis period. The average of the station based lapse rates (based on linear regression) was compared to individual station (station 1 @ X elevation compared to station 2 @ X elevation) based lapse rates discussed above (Table 12.8).

Vertical temperature at 1,000-foot increments from 0 - 6,000-ft were derived base on temperature data from the Fairbanks radiosonde. The Fairbanks radiosonde lapse rate data were used to calculate an average lapse rate for the entire calibration period (Table 12.8).

Table 12.8 Station based and radiosonde based lapse rates for May 27 - June 13, 1964.

Station Comparisons	Hourly Average	Hourly Rainfall Average	FAI Radiosonde
Talkeetna vs. Summit	-4.17	-4.09	-
Anchorage vs. Gulkana	0.02	1.35	-
Ft Greely vs. Summit	-5.93	-7.36	-
Ft Greely vs. Fairbanks	-1.18	-0.27	-
All Stations	-3.01	-2.08	-
Average*	-3.57	-3.45	-3.54

* Comparison excludes Anchorage vs. Gulkana lapse rate

The radiosonde wind speed represents free atmospheric winds, unobstructed flow, the free-air data were adjusted to surface wind speeds elevations based on comparisons of anemometer level wind speeds with concurrent free-air wind speeds. Surface wind speeds were compared at six locations with varying elevations across the Susitna River basin to the Fairbanks free-air wind speeds (Table 12.9). The average free-air adjustment for the six stations was 0.614 with a maximum of 0.839 and a minimum of 0.448. In order to convert free-air wind speed data to anemometer level wind speeds the adjustment/ratio is applied to the free-air data. For example, at 1,000-ft elevation free-air wind speed is 45-mph would be 30-mph at the anemometer level (45-mph * 0.614 =

27.6-mph). The radiosonde data are measured every 12-hours (0-UTC and 12-UTC), the 12-hour data were interpolated to hourly data using the bounding hourly data and a linear relationship.

Table 12.9. Fairbanks radiosonde free-air wind speed conversion ratio to anemometer height wind speed for May 27 – June 13, 1964.

Station	Elevation (ft)	FAI Radiosonde Ratio
Gulkana	1500	0.571
Summit	2500	0.615
Talkeetna	500	0.448
Anchorage	0	0.839
Ft Greely	1500	0.525
Fairbanks	500	0.685
	Average	*0.614*
	Maximum	0.839
	Minimum	0.448

The final temperature and dew point temperature series were based on surface data at Summit, Alaska with a base elevation of 2,400-ft (Figure 12.25). The Summit station data were selected because it was in close proximity to the Susitna River basin and provided a complete and representative profile of temperature and dew point temperature. The lapse rate used to adjust temperature and dew point temperature to other elevations was -3.57°F. The -3.57°F lapse rate was based on the average of all station comparison except the Anchorage and Gulkana comparison. The final vertical wind speed data were based on Fairbanks free-air wind speeds with an adjustment ratio of 0.614 applied to represent anemometer level wind speeds (Figure 12.26).

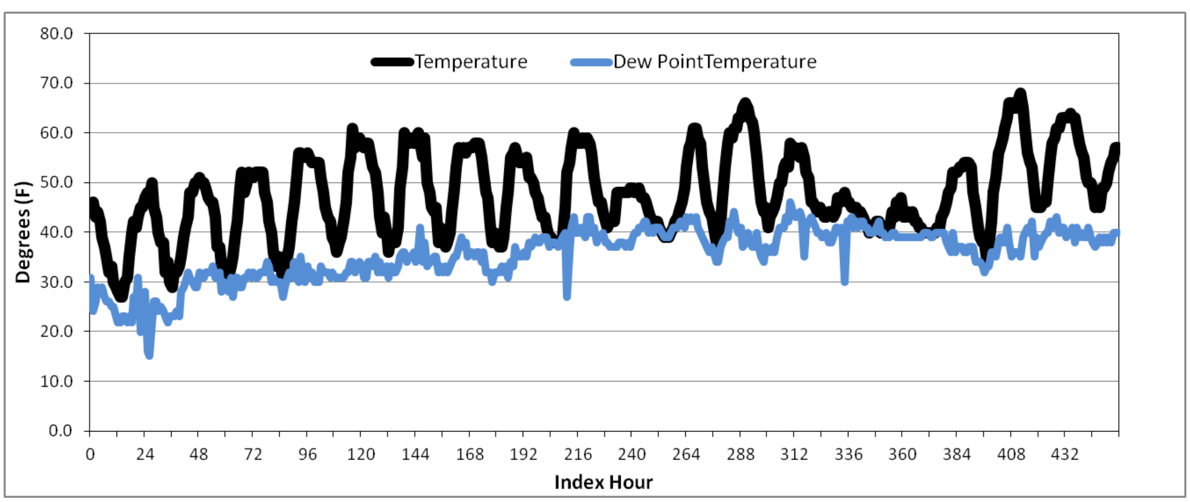

Figure 12.25. Temperature and dew point temperature series based on surface data at Summit, Alaska with a base elevation of 2,400-ft and lapse rate of -3.57°F for May 27 - June 13, 1964.

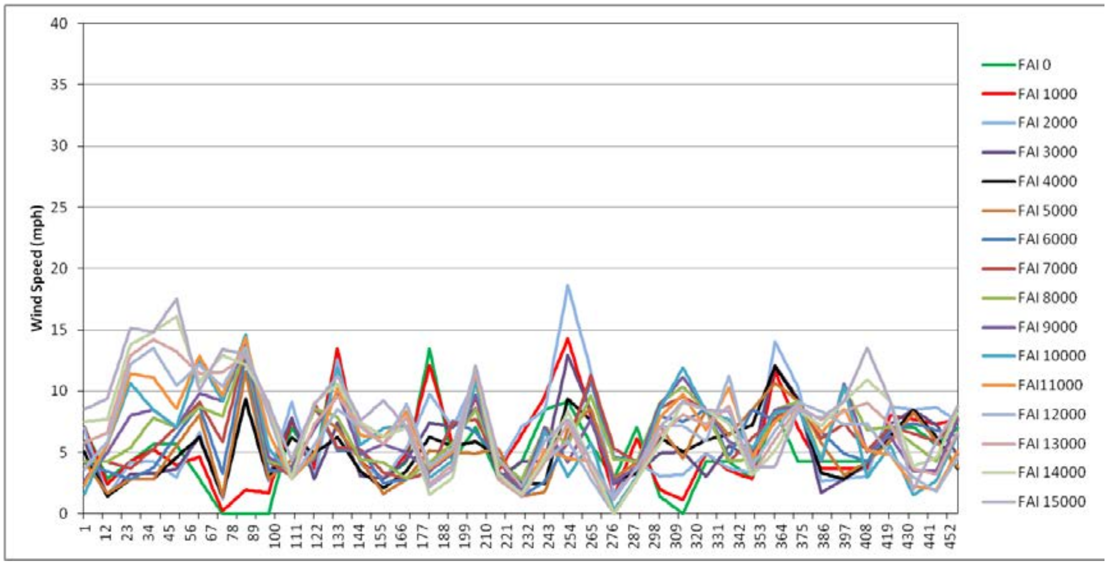

Figure 12.26. Wind speed data based on Fairbanks free-air wind speeds with an adjustment ratio of 0.614 applied to represent anemometer level wind speeds for May 27 - June 13, 1964.

12.3.5 June 3-17, 1971 Meteorological Time Series

Temperature lapse rates were estimated using observed surface temperature data for stations in and around the Susitna-Watana basin. Lapse rates were derived each hour using observed surface data at two locations. Station based lapse rates were calculated between: i) Talkeetna and Summit, ii) Anchorage and Gulkana, iii) Ft Greeley and Summit, and iv) Ft Greeley and Fairbanks. The hourly lapse rates were used to calculate an average lapse rate for the entire calibration period and an average lapse rate based on when rain was occurring during the calibration event (Table 12.10).

Station data were also used to derive an average station based lapse rate for each hour of the storm event. The stations used for this analysis were PANC, Anchorage, Fairbanks, Ft Greeley, Gulkana, Summit, and Talkeetna. The station average lapse rate was derived using linear regression between temperature and elevation. Based on the hourly station data linear relationship, a lapse rate (regression slope) was calculated for each hour of the analysis period. The average of the station based lapse rates (based on linear regression) was compared to individual station (station 1 @ X elevation compared to station 2 @ X elevation) based lapse rates discussed above (Table 12.10).

Vertical temperature at 1,000-foot increments from 0 - 6,000-ft were derived base on temperature data from the Fairbanks radiosonde. The Fairbanks radiosonde lapse rate data were used to calculate an average lapse rate for the entire calibration period (Table 12.10).

Table 12.10. Station based and radiosonde based lapse rates for June 3-17, 1971.

Station Comparisons	Hourly Average	Hourly Rainfall Average	FAI Radiosonde
Talkeetna vs. Summit	-3.89	-3.44	-
Anchorage vs. Gulkana	1.99	0.92	-
Ft Greely vs. Summit	-12.35	-11.15	-
Ft Greely vs. Fairbanks	-3.39	-2.83	-
All Stations	-2.05	-2.49	-
Average*	-3.11	-2.92	-3.76

* Comparison excludes Anchorage vs. Gulkana lapse rate
* Comparison excludes Ft Greeley vs. Summit lapse rate

The radiosonde wind speed represents free atmospheric winds, unobstructed flow, the free-air data were adjusted to surface wind speeds elevations based on comparisons of anemometer level wind speeds with concurrent free-air wind speeds. Surface wind speeds were compared at six locations with varying elevations across the Susitna River basin to the Fairbanks free-air wind speeds (Table 12.11). The average free-air adjustment for the six stations was 0.785 with a maximum of 0.946 and a minimum of 0.493. In order to convert free-air wind speed data to anemometer level wind speeds the adjustment/ratio is applied to the free-air data. For example, at 1,000-ft elevation free-air wind speed is 45-mph would be 30-mph at the anemometer level (45-mph * 0.785 = 35.3-mph). The radiosonde data are measured every 12-hours (0-UTC and 12-UTC), the 12-hour data were interpolated to hourly data using the bounding hourly data and a linear relationship.

Table 12.11. Fairbanks radiosonde free-air wind speed conversion ratio to anemometer height wind speed for June 3-17, 1971.

Station	Elevation (ft)	FAI Radiosonde Ratio
Gulkana	1500	0.895
Summit	2500	0.719
Talkeetna	500	0.493
Anchorage	0	0.909
Ft Greely	1500	0.910
Fairbanks	500	0.946
	Average*	*0.785*
	Maximum	0.946
	Minimum	0.493

* Average excludes Anchorage

The final temperature and dew point temperature series were based on surface data at Summit, Alaska with a base elevation of 2,400-ft (Figure 12.28). The Summit station data were selected because it was in close proximity to the Susitna River basin and provided a complete and representative profile of temperature and dew point temperature. The lapse rate used to adjust temperature and dew point temperature to other elevations was -2.90°F. The -2.90°F lapse rate was based on the average of all station comparison except the Anchorage and Gulkana comparison and Ft Greeley and Summit comparison. The final vertical wind speed data were based on Fairbanks free-air wind speeds with an adjustment ratio of 0.785 applied to represent anemometer level wind speeds (Figure 12.28).

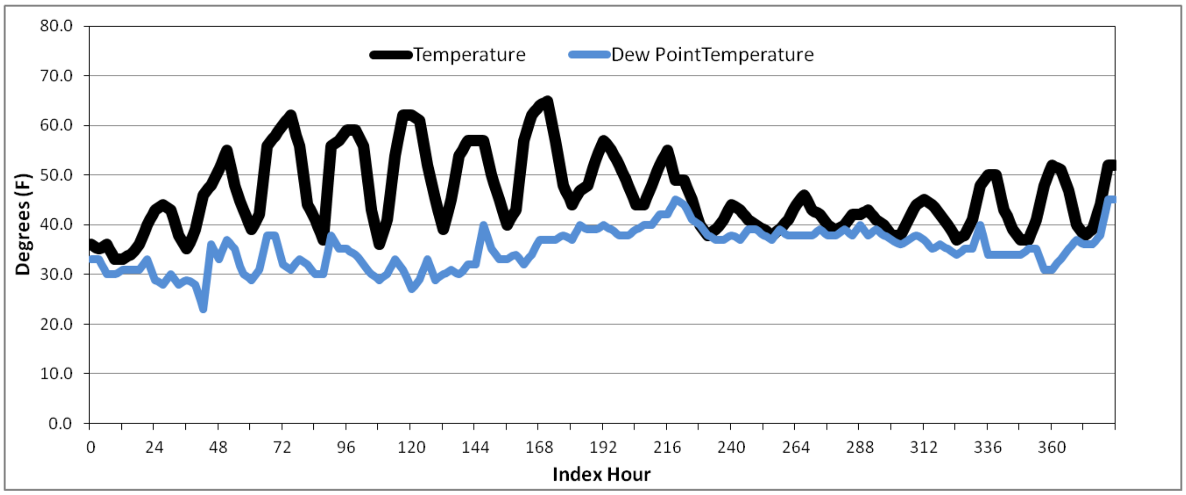

Figure 12.27. Temperature and dew point temperature series based on surface data at Summit, Alaska with a base elevation of 2,400-ft and lapse rate of -2.90°F for June 3-17, 1971.

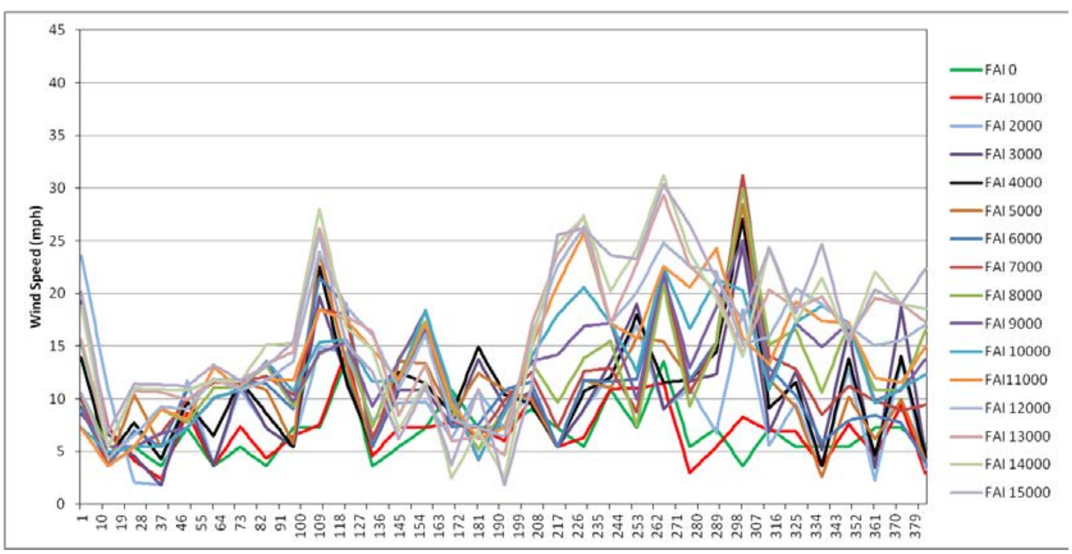

Figure 12.28. Wind speed data based on Fairbanks free-air wind speeds with an adjustment ratio of 0.785 applied to represent anemometer level wind speeds for June 3-17, 1971.

12.3.6 June 7-22, 1972 Meteorological Time Series

Temperature lapse rates were estimated using observed surface temperature data for stations in and around the Susitna-Watana basin. Lapse rates were derived each hour using observed surface data at two locations. Station based lapse rates were calculated between: i) Talkeetna and Summit, ii) Anchorage and Gulkana, iii) Ft Greeley and Summit, and iv) Ft Greeley and Fairbanks. The hourly lapse rates were used to calculate an average lapse rate for the entire calibration period and an average lapse rate based on when rain was occurring during the calibration event (Table 12.12).

Station data were also used to derive an average station based lapse rate for each hour of the storm event. The stations used for this analysis were PANC, Anchorage, Fairbanks, Ft Greeley, Gulkana, Summit, and Talkeetna. The station average lapse rate was derived using linear regression between temperature and elevation. Based on the hourly station data linear relationship, a lapse rate (regression slope) was calculated for each hour of the analysis period. The average of the station based lapse rates (based on linear regression) was compared to individual station (station 1 @ X elevation compared to station 2 @ X elevation) based lapse rates discussed above (Table 12.12).

Vertical temperature at 1,000-foot increments from 0 - 6,000-ft were derived base on temperature data from the Fairbanks radiosonde. The Fairbanks radiosonde lapse rate data were used to calculate an average lapse rate for the entire calibration period (Table 12.12).

Table 12.12. Station based and radiosonde based lapse rates for June 7-22, 1972.

Station Comparisons	Hourly Average	Hourly Rainfall Average	FAI Radiosonde
Talkeetna vs. Summit	-3.20	-2.16	-
Anchorage vs. Gulkana	1.06	0.84	-
Ft Greely vs. Summit	-5.19	-6.53	-
Ft Greely vs. Fairbanks	-1.36	-2.13	-
All Stations	-1.65	-1.30	-
Average*	-2.85	-3.03	-3.52

* Comparison excludes Anchorage vs. Gulkana lapse rate

The radiosonde wind speed represents free atmospheric winds, unobstructed flow, the free-air data were adjusted to surface wind speeds elevations based on comparisons of anemometer level wind speeds with concurrent free-air wind speeds. Surface wind speeds were compared at six locations with varying elevations across the Susitna River basin to the Fairbanks free-air wind speeds (Table 12.13). The average free-air adjustment for the six stations was 0.887 with a maximum of 0.979 and a minimum of 0.748. In order to convert free-air wind speed data to anemometer level wind speeds the adjustment/ratio is applied to the free-air data. For example, at 1,000-ft elevation free-air wind speed is 45-mph would be 30-mph at the anemometer level (45-mph * 0.887 = 39.9-mph). The radiosonde data are measured every 12-hours (0-UTC and 12-UTC), the 12-hour data were interpolated to hourly data using the bounding hourly data and a linear relationship.

Table 12.13. Fairbanks radiosonde free-air wind speed conversion ratio to anemometer height wind speed for June 7-22, 1972.

Station	Elevation (ft)	FAI Radiosonde Ratio
Gulkana	1500	0.979
Summit	2500	0.914
Talkeetna	500	0.886
Anchorage	0	0.929
Ft Greely	1500	0.748
Fairbanks	500	0.868
	Average	*0.887*
	Maximum	0.979
	Minimum	0.748

The final temperature and dew point temperature series were based on surface data at Summit, Alaska with a base elevation of 2,400-ft (Figure 12.29). The Summit station data were selected because it was in close proximity to the Susitna River basin and provided a complete and representative profile of temperature and dew point temperature. The lapse rate used to adjust temperature and dew point temperature to other elevations was -2.85°F. The -2.85°F lapse rate was based on the average of all station comparison except the Anchorage and Gulkana comparison. The final vertical wind speed data were based on Fairbanks free-air wind speeds with an adjustment ratio of 0.887 applied to represent anemometer level wind speeds (Figure 12.30).

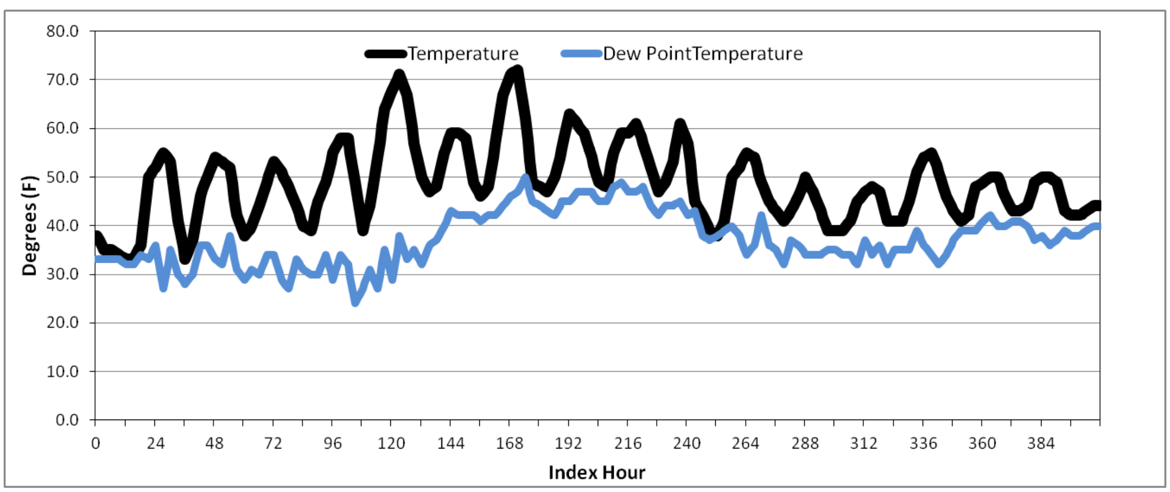

Figure 12.29. Temperature and dew point temperature series based on surface data at Summit, Alaska with a base elevation of 2,400-ft and lapse rate of -2.85°F for June 7-22, 1972.

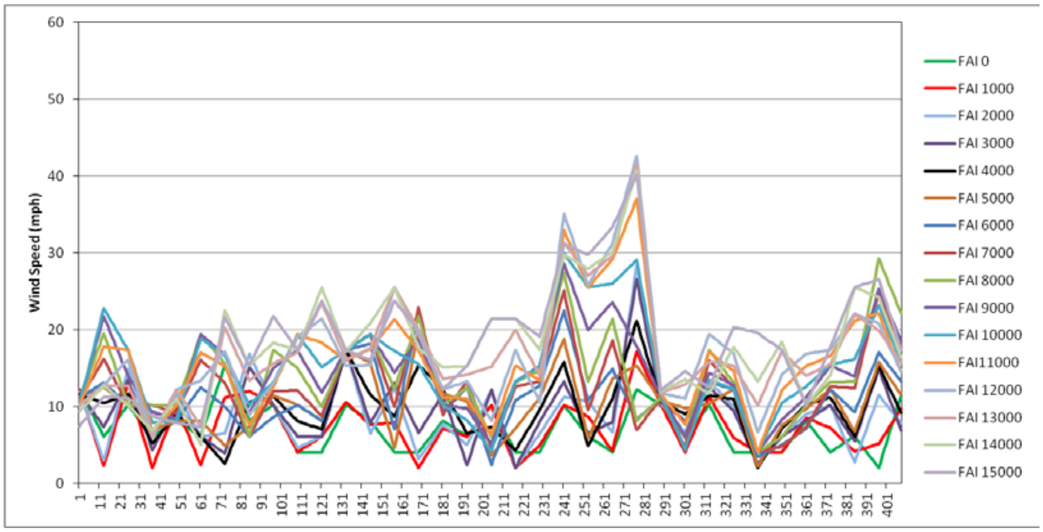

Figure 12.30. Wind speed data based on Fairbanks free-air wind speeds with an adjustment ratio of 0.887 applied to represent anemometer level wind speeds for June 7-22, 1972.

GLOSSARY

Adiabat: Curve of thermodynamic change taking place without addition or subtraction of heat. On an adiabatic chart or pseudo-adiabatic diagram, a line showing pressure and temperature changes undergone by air rising or condensation of its water vapor; a line, thus, of constant potential temperature.

Adiabatic: Referring to the process described by adiabat.

Advection: The process of transfer (of an air mass property) by virtue of motion. In particular cases, advection may be confined to either the horizontal or vertical components of the motion. However, the term is often used to signify horizontal transfer only.

Air mass: Extensive body of air approximating horizontal homogeneity, identified as to source region and subsequent modifications.

Barrier: A mountain range that partially blocks the flow of warm humid air from a source of moisture to the basin under study.

Basin centroid: The point at the exact center of the drainage basin as determined through geographical information systems calculations using the basin outline.

Cold front: Front where relatively colder air displaces warmer air.

Convergence: Horizontal shrinking and vertical stretching of a volume of air, accompanied by net inflow horizontally and internal upward motion.

Cyclone: A distribution of atmospheric pressure in which there is a low central pressure relative to the surroundings. On large-scale weather charts, cyclones are characterized by a system of closed constant pressure lines (isobars), generally approximately circular or oval in form, enclosing a central low-pressure area. Cyclonic circulation is counterclockwise in the northern hemisphere and clockwise in the southern. (That is, the sense of rotation about the local vertical is the same as that of the earth's rotation.)

dBZ: It is a meteorological measure of equivalent reflectivity (Z) of a radar signal reflected off a remote object. The reference level for Z is 1 $mm^6\ m^{-3}$, which is equal to 1 μm^3. It is related to the number of drops per unit volume and the sixth power of drop diameter.

Depth-Area curve: Curve showing, for a given duration, the relation of maximum average depth to size of area within a storm or storms.

Depth-Area-Duration: The precipitation values derived from Depth-Area and Depth-Duration curves at each time and area size increment analyzed for a PMP evaluation.

Depth-Area-Duration values: The combination of depth-area and duration-depth relations. Also called depth-duration-area.

Decimal Degrees: Latitude and longitude geographic coordinates as decimal fractions and are used in many Geographic Information Systems (GIS). Decimal degrees are an alternative to using degrees, minutes, and seconds. As with latitude and longitude, the values are bounded by ±90° and ±180° each. Positive latitudes are north of the equator, negative latitudes are south of the equator. Positive longitudes are east of Prime Meridian, negative longitudes are west of the Prime Meridian. Latitude and longitude are usually expressed in that sequence, latitude before longitude.

Depth-Duration curve: Curve showing, for a given area size, the relation of maximum average depth of precipitation to duration periods within a storm or storms.

Dew point: The temperature to which a given parcel of air must be cooled at constant pressure and constant water vapor content for saturation to occur.

Envelopment: A process for selecting the largest value from any set of data. In estimating PMP, the maximum and transposed rainfall data are plotted on graph paper, and a smooth curve is drawn through the largest values.

Front: The interface or transition zone between two air masses of different parameters. The parameters describing the air masses are temperature and dew point.

General storm: A storm event, that produces precipitation over areas in excess of 500-square miles, has a duration longer than 6 hours, and is associated with a major synoptic weather feature.

HYSPLIT: HYbrid Single-Particle Lagrangian Integrated Trajectory. A complete system for computing parcel trajectories to complex dispersion and deposition simulations using either puff or particle approaches. Gridded meteorological data, on one of three conformal (Polar, Lambert, or Mercator latitude-longitude grid) map projections, are required at regular time intervals. Calculations may be performed sequentially or concurrently on multiple meteorological grids, usually specified from fine to coarse resolution.

In-Place Maximization Factor: The adjustment factor representing the maximum amount of atmospheric moisture that could have been present to the storm for rainfall production

Isohyets: Lines of equal value of precipitation for a given time interval.

Isohyetal Pattern: The pattern formed by the isohyets of an individual storm.

Jet Stream: A strong, narrow current concentrated along a quasi-horizontal axis (with respect to the earth's surface) in the upper troposphere or in the lower stratosphere, characterized by strong vertical and lateral wind shears. Along this axis it features at least one velocity maximum (jet streak). Typical jet streams are thousands of kilometers long, hundreds of kilometers wide, and several kilometers deep. Vertical wind shears are on the order of 10 to 20 mph per kilometer of altitude and lateral winds shears are on the order of 10 mph per 100 kilometer of horizontal distance.

Mass curve: Curve of cumulative values of precipitation through time.

Mid-latitude frontal system: An assemblage of fronts as they appear on a synoptic chart north of the tropics and south of the polar latitudes. This term is used for a continuous front and its characteristics along its entire extent, its variations of intensity, and any frontal cyclones along it.

Moisture Transposition Factor: The adjustment factor which accounts for the difference in available moisture between the location where the storm occurred and the Susitna River basin

Observational day: The 24-hour time period between daily observation times for two consecutive days at cooperative stations, e.g., 6:00PM to 6:00PM.

One-hundred year rainfall event: The point rainfall amount that has a one-percent probability of occurrence in any year. Also referred to as the rainfall amount that on the average occurs once in a hundred years or has a 1 percent chance of occurring in any single year.

Orographic Rainfall: Rainfall enhancement resulting mainly from the forced lifting of moisture-laden air masses by elevated terrain, when combined with unstable atmospheric conditions often results in heavy (high intensity, long duration) rainfall at rates higher than what would be experienced if the elevated terrain were not present.

Orographic Transposition Factor: A factor obtained from the results of the proportionality constant calculation which compares the 24-hour precipitation frequency characteristics between the storm target and source locations

Polar front: A semi-permanent, semi-continuous front that separates tropical air masses from polar air masses.

Precipitable water: The total atmospheric water vapor contained in a vertical column of unit cross-sectional area extending between any two specified levels in the atmosphere; commonly expressed in terms of the height to which the liquid water would stand if the vapor were completely condensed and collected in a vessel of the same unit cross-section. The total precipitable water in the atmosphere at a location is that contained in a column or unit cross-section extending from the earth's surface all the way to the "top" of the atmosphere. The 30,000 foot level (approximately 300mb) is considered the top of the atmosphere in this study.

Persisting dew point: The dew point value at a station that has been equaled or exceeded throughout a specific period of time. Commonly durations of 12 or 24 hours are used, though other durations may be used at times.

Probable Maximum Precipitation (PMP): Theoretically, the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographic location at a certain time of the year.

Pseudo-adiabat: Line on thermodynamic diagram showing the pressure and temperature changes undergone by saturated air rising in the atmosphere, without ice-crystal formation and without exchange of heat with its environment, other than that involved in removal of any liquid water formed by condensation.

Pseudo-adiabatic: Referring to the process described by the pseudo-adiabat.

Rainshadow: The region, on the lee side of a mountain or mountain range, where the precipitation is noticeably less than on the windward side.

PMP storm pattern: The isohyetal pattern that encloses the PMP area, plus the isohyets of residual precipitation outside the PMP portion of the pattern.

Saturation: Upper limit of water-vapor content in a given space; solely a function of temperature.

Short list of storms: The short list of storms is the final list of storms used to derive the site-specific PMP values for the basin. The list represents the most extreme historic storms of record that are considered to be PMP-type storm events.

Spatial distribution: The geographic distribution of precipitation over a drainage according to an idealized storm pattern of the PMP for the storm area.

Storm maximization: The process of adjusting observed precipitation amounts upward based upon the hypothesis of increased moisture inflow to the storm. (Also referred to as "moisture maximization" in HMR 57.)

Storm transposition: The hypothetical transfer, or relocation of storms, from the location where they occurred to other areas where they could occur. The transfer and the mathematical adjustment of storm rainfall amounts from the storm site to another location is termed "explicit transposition." The areal, durational, and regional smoothing done to obtain comprehensive individual drainage estimates and generalized PMP studies is termed "implicit transposition" (WMO, 1986).

Synoptic: Showing the distribution of meteorological elements over an area at a given time, e.g., a synoptic chart. Use in this report also means a weather system that is large enough to be a major feature on large-scale maps (e.g., of the continental U.S.).

Temporal distribution: The time order in which incremental PMP amounts are arranged within a PMP storm.

Tropical Storm: A cyclone of tropical origin that derives its energy from the ocean surface.

Transposition limits: The outer boundaries of the region surrounding an actual storm location that has similar, but not identical, climatic and topographic characteristics throughout. The storm can be transpositioned within the transposition limits with only relatively minor modifications to the observed storm rainfall amounts.

ACRONYMS AND ABBREVIATIONS USED IN THIS REPORT

ALERT: Automated Local Evaluation in Real Time

AWA: Applied Weather Associates, LLC

DA: Depth-Area

DAD: Depth-Area-Duration

.dbf: Database file extension

DD: Depth-Duration

dd: decimal degrees

DEM: Digital elevation model

DND: drop number distribution

DSD: drop size distribution

EPRI: Electric Power Research Institute

F: Fahrenheit

FERC: Federal Energy Regulatory Commission

ft: feet

GIS: Geographical Information System

GRASS: Geographic Resource Analysis Support System

HMR: Hydrometeorological Report

HYSPLIT: Hybrid Single Particle Lagrangian Integrated Trajectory Model

IPMF: In-Place Maximization Factor

mb: millibar

mph: Mile per hour

MTF: Moisture Transposition Factor

NCAR: National Center for Atmospheric Research

NCDC: National Climatic Data Center

NCEP: National Centers for Environmental Prediction

NESDIS: National Environmental Satellite, Data, and Information Service

NEXRAD: National Weather Service 88-D Next Generation Radar

NOAA: National Oceanic and Atmospheric Administration

NWS: National Weather Service

PMF: Probable Maximum Flood

OTF: Orographic Transposition Factor

PMP: Probable Maximum Precipitation

PW: Precipitable water

QC: Quality control

R: Rainfall rate

RAWS: Remote Automated Weather Station

SNOTEL: Snow Telemetry station

SPAS: Storm Precipitation and Analysis System

SPP: Storm Precipitation Period

SSPMP: Site-specific Probable Maximum Precipitation

SST: Sea Surface Temperature

USACE: US Army Corps of Engineers

USGS: United States Geological Survey

WMO: World Meteorological Organization

Z: Radar reflectivity, measured in units of dBZ

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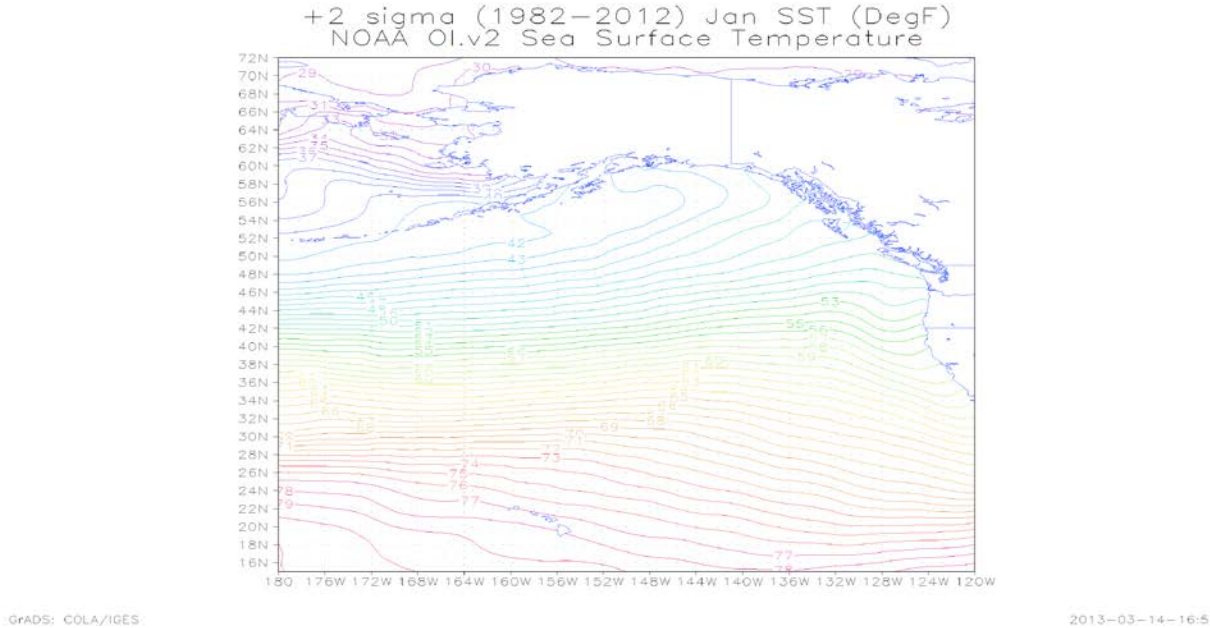
Appendix A

Sea Surface Temperatures Climatology Maps


+2 sigma (1982–2012) Jan SST (DegF)
NOAA OI.v2 Sea Surface Temperature
72N 70N 68N 66N 64N 62N 60N 58N 56N 54N 52N 50N 48N 46N 44N 42N 40N 38N 36N 34N 32N 30N 28N 26N 24N 22N 20N 18N 16N
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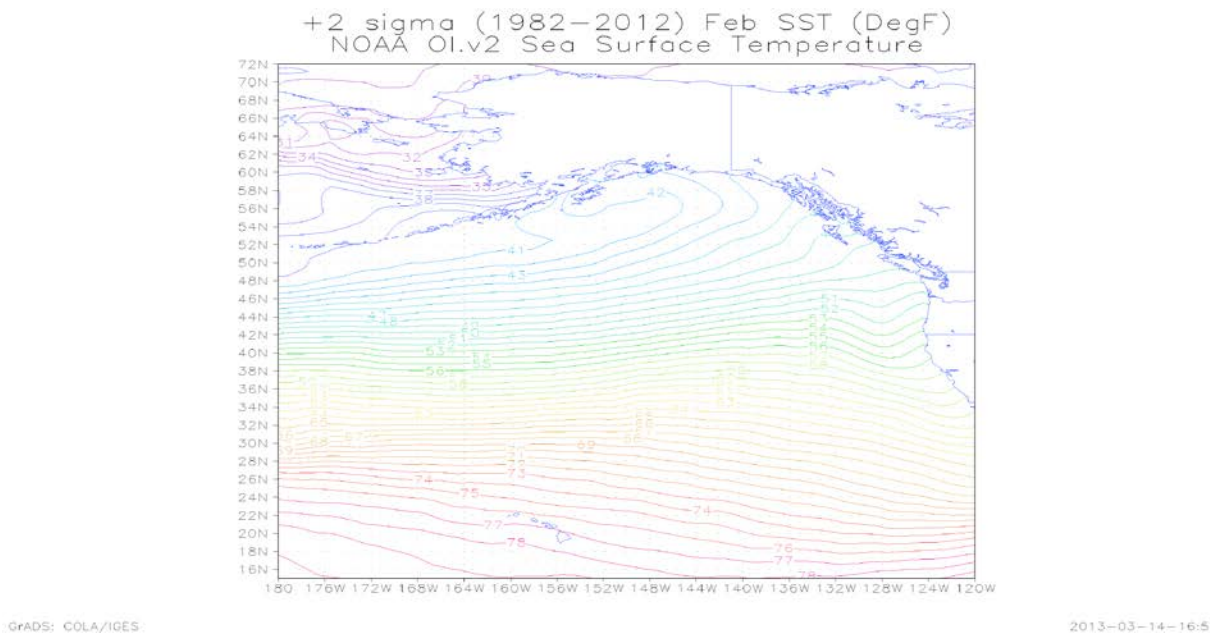
GrADS: COLA/IGES
2013–03–14–16:51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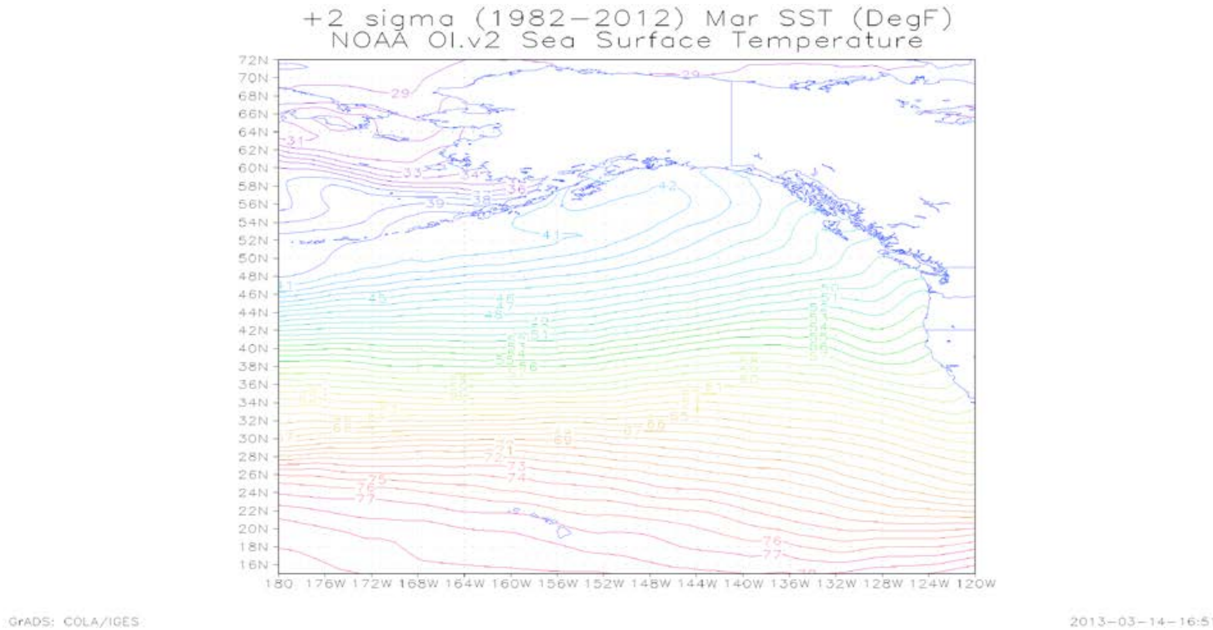
GrADS: COLA/IGES
2013–03–14–16:51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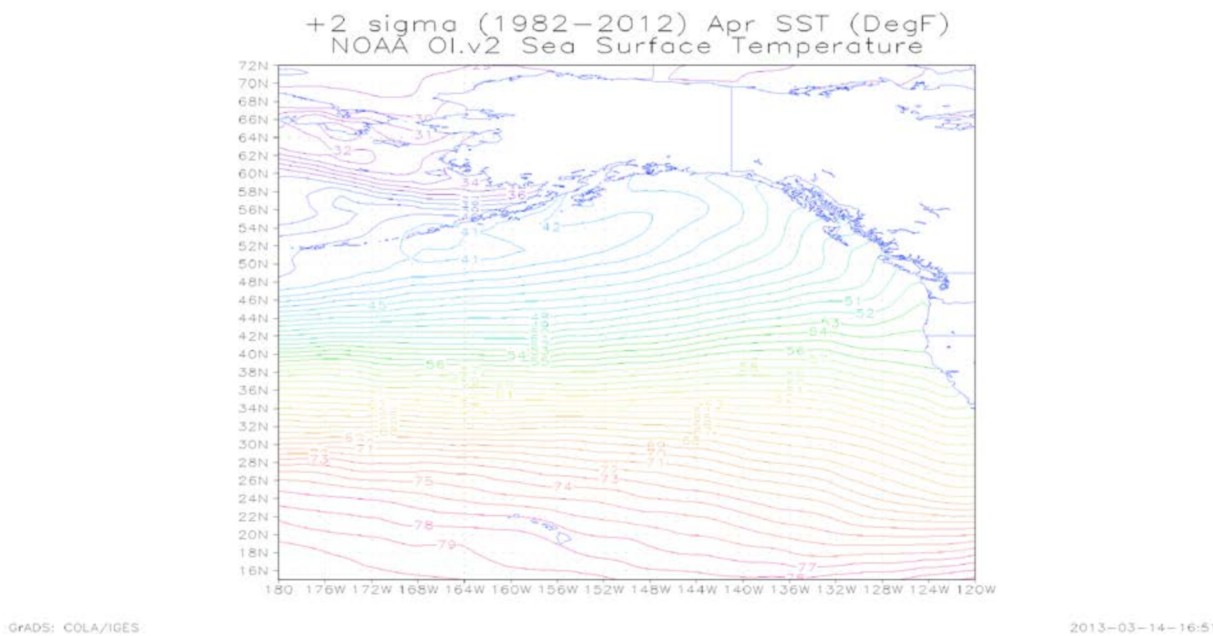
NOAA OI.v2 Sea Surface Temperature
72N 70N 68N 66N 64N 62N 60N 58N 56N 54N 52N 50N 48N 46N 44N 42N 40N 38N 36N 34N 32N 30N 28N 26N 24N 22N 20N 18N 16N
180 176W 172W 168W 164W 160W 156W 152W 148W 144W 140W 136W 132W 128W 124W 120W
GrADS: COLA/IGES
2013-03-14-16:51


+2 sigma (1982-2012) Apr SST (DegF)
NOAA OI.v2 Sea Surface Temperature
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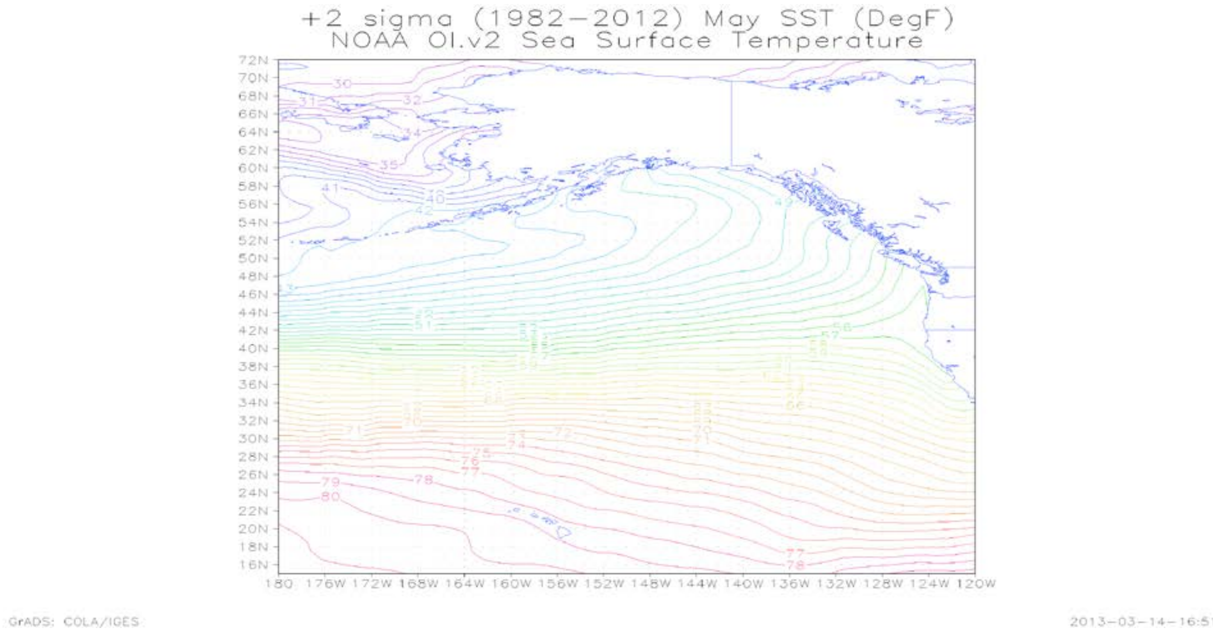
180 176W 172W 168W 164W 160W 156W 152W 148W 144W 140W 136W 132W 128W 124W 120W
GrADS: COLA/IGES
2013-03-14-16:51


+2 sigma (1982−2012) May SST (DegF)
NOAA OI.v2 Sea Surface Temperature
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180 176W 172W 168W 164W 160W 156W 152W 148W 144W 140W 136W 132W 128W 124W 120W
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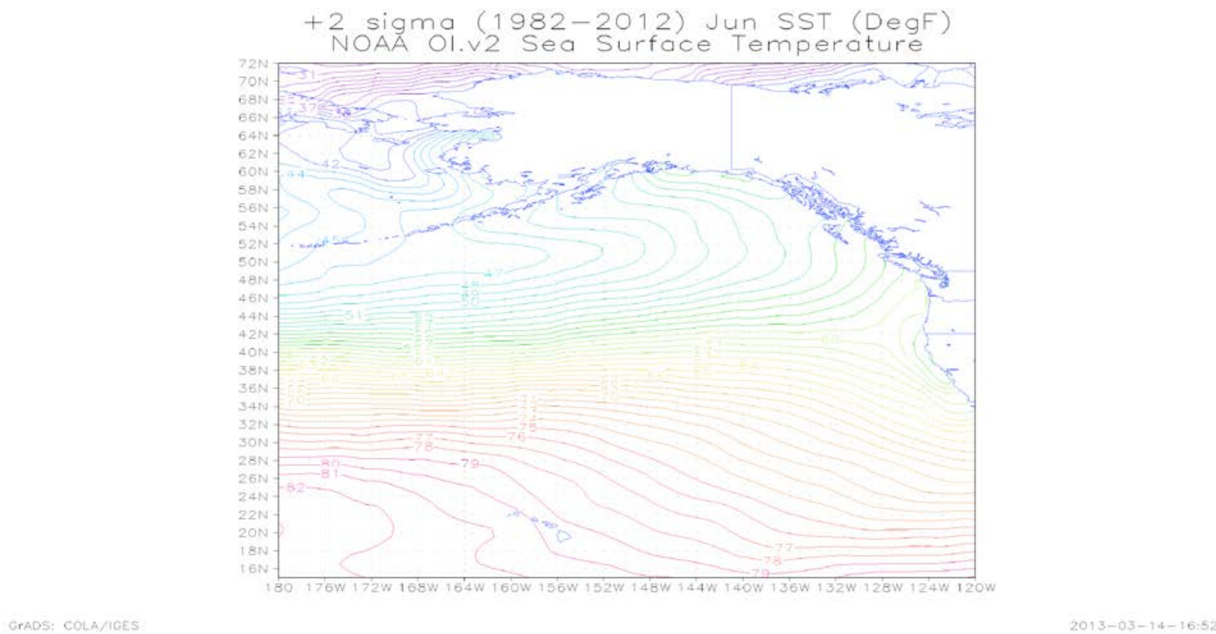
2013−03−14−16:51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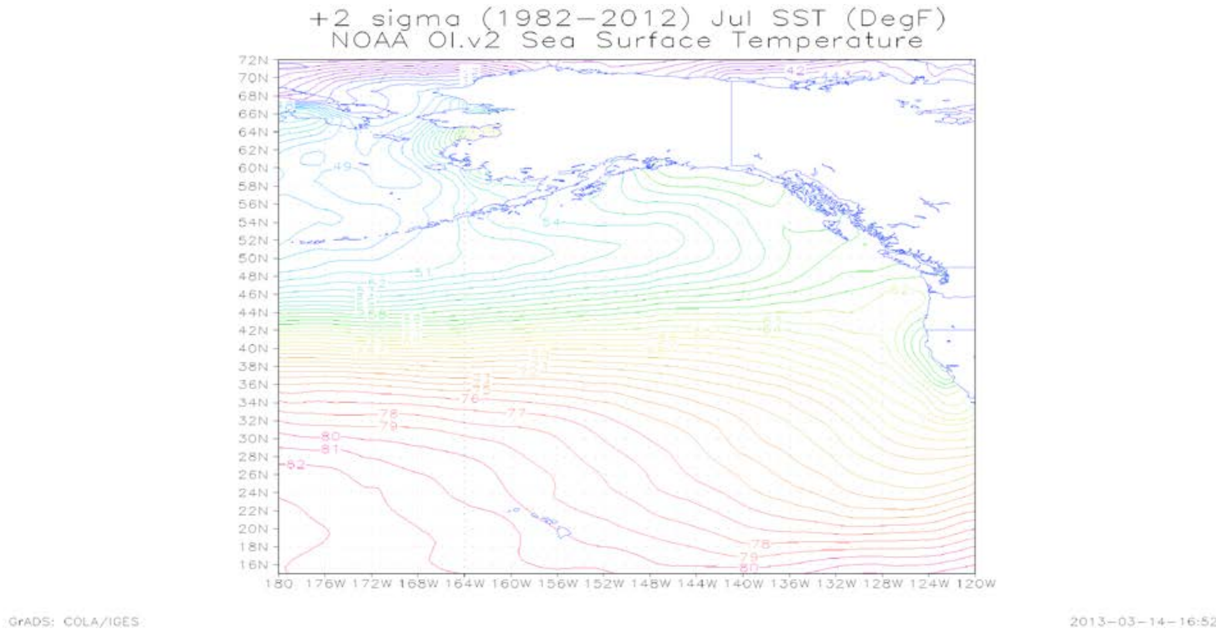
GrADS: COLA/IGES
2013−03−14−16:52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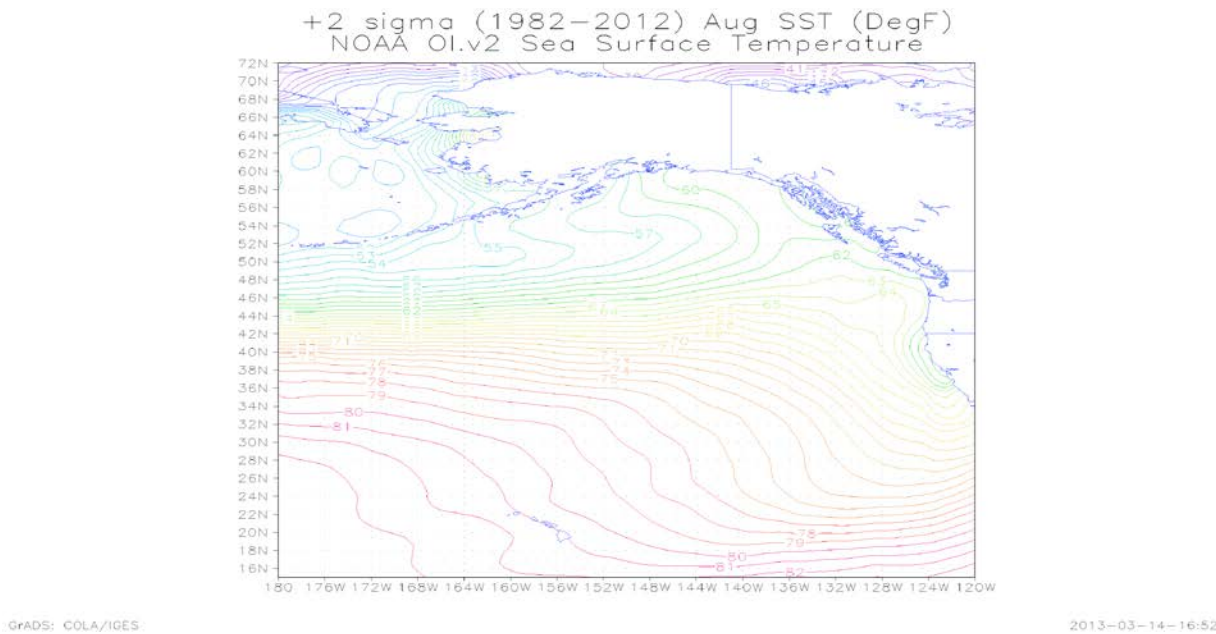
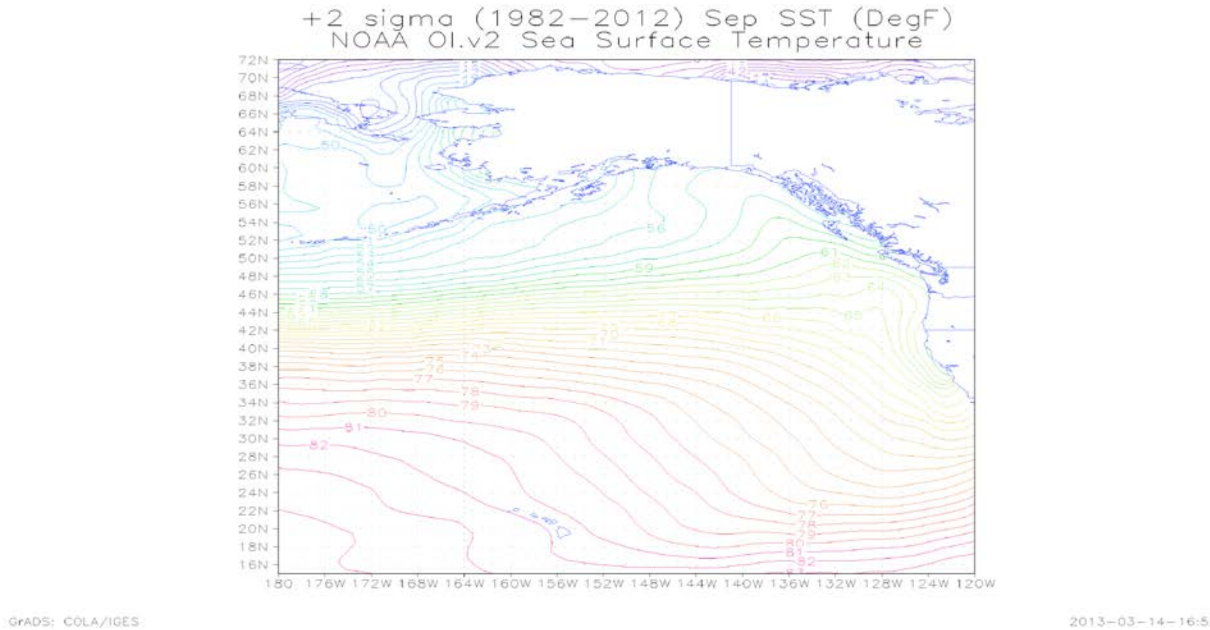
GrADS: COLA/IGES
2013–03–14–16:52


+2 sigma (1982–2012) Aug SST (DegF)
NOAA OI.v2 Sea Surface Temperature
GrADS: COLA/IGES
2013–03–14–16:52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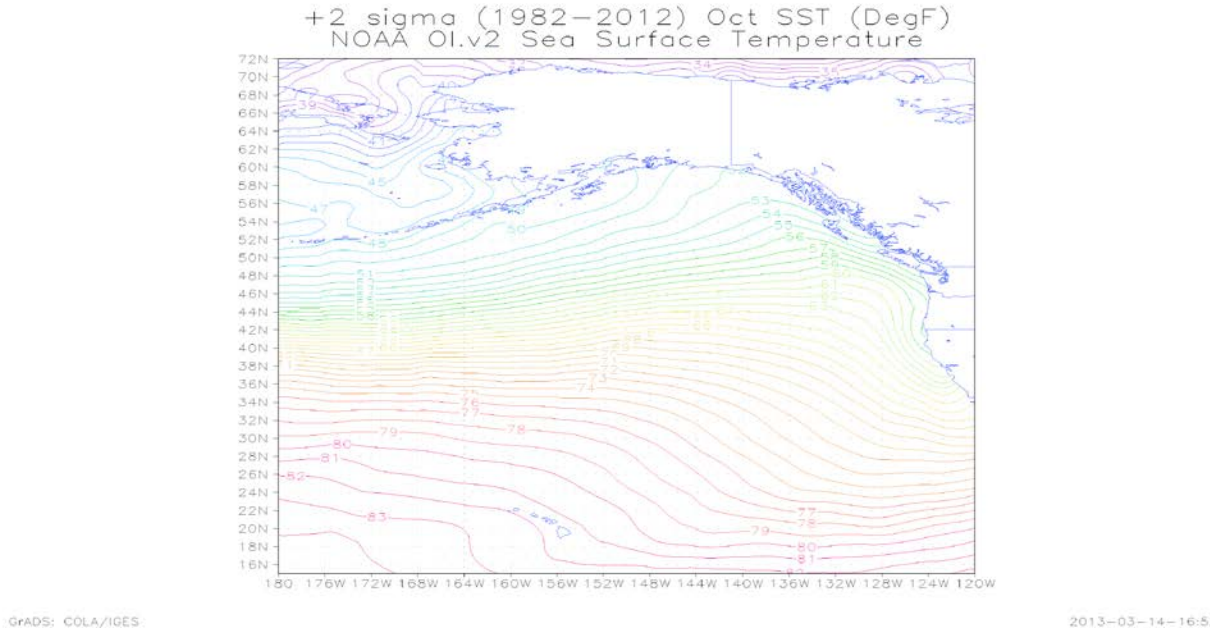
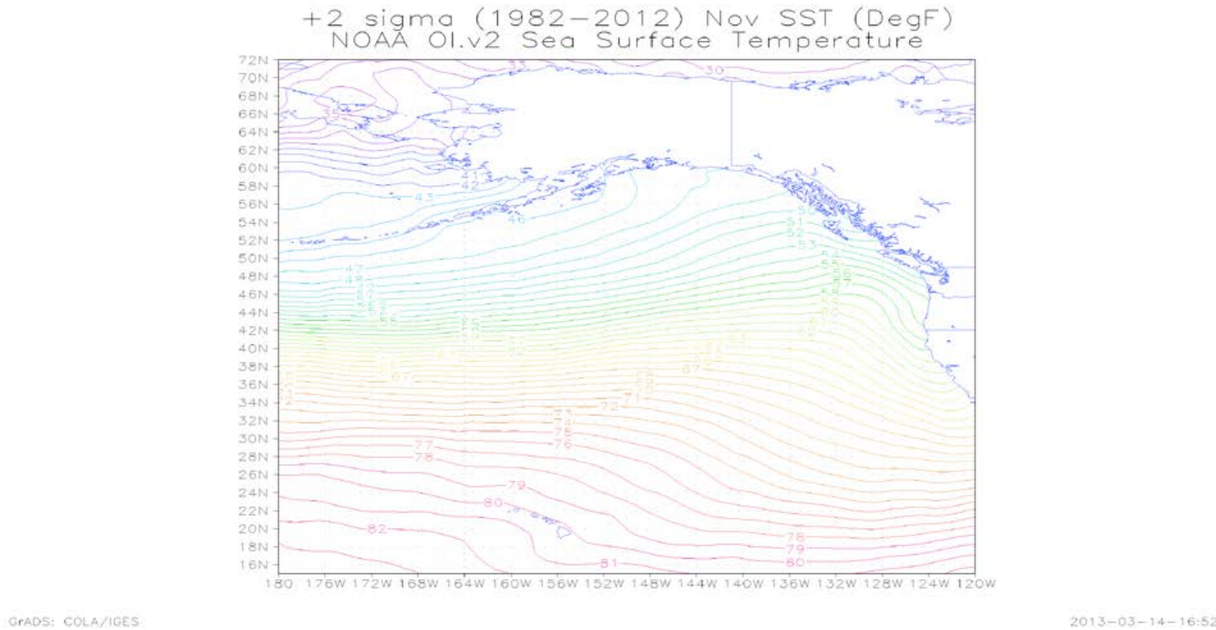
GrADS: COLA/IGES
2013–03–14–16:52


+2 sigma (1982–2012) Oct SST (DegF)
NOAA OI.v2 Sea Surface Temperature
GrADS: COLA/IGES
2013–03–14–16:52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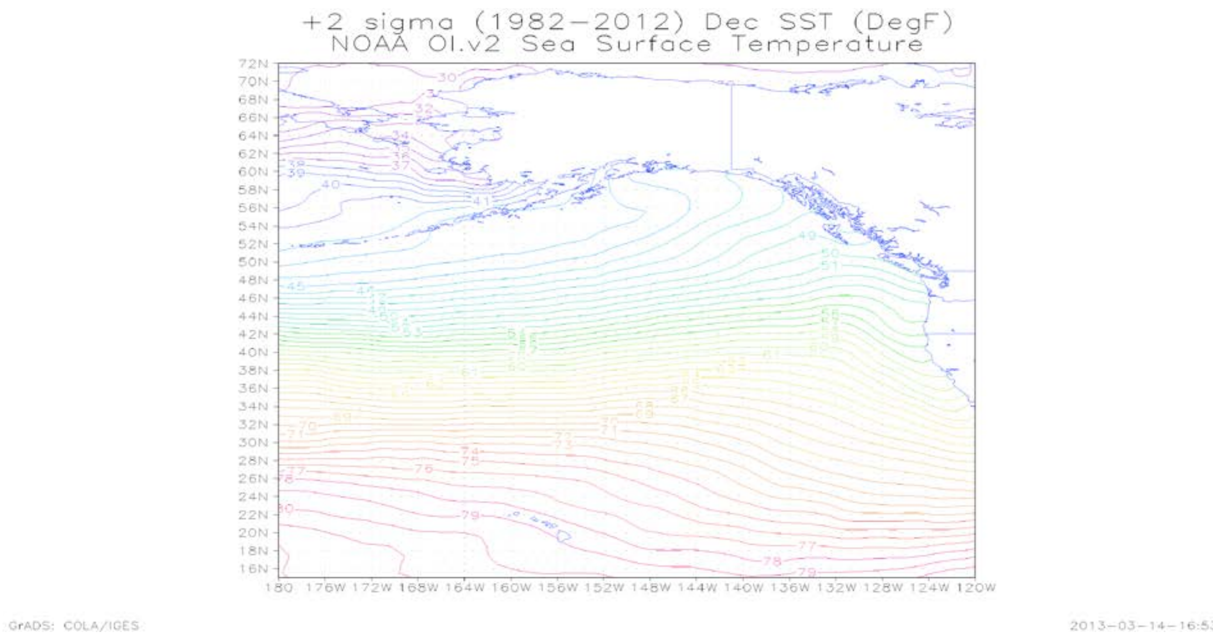
NOAA OI.v2 Sea Surface Temperature
GrADS: COLA/IGES
2013–03–14–16:52


+2 sigma (1982–2012) Dec SST (DegF)
NOAA OI.v2 Sea Surface Temperature
GrADS: COLA/IGES
2013–03–14–16:53

Appendix B

PYTHON Code for ArcGIS PMP Calculation Tool

```
''' ---------------------------------------------------------------------------
Name: PMP_Calc.py
Version: 1.00
ArcGIS Version: ArcGIS Desktop 10.2 SP1 (2013)
Author: Applied Weather Associates
Usage:  The tool is designed to be executed within the ArcMap or ArcCatalog desktop environment.
Required Arguments:
- A basin outline polygon shapefile or feature class
- Directory location path of the "PMP_Evaluation_Tool" folder
- String of durations to analyze.
Description:
  This tool calculates PMP depths for a given drainage basin for the
specified durations.  PMP values are
calculated (in inches) for each grid point (spaced at 90 arc-second intervals)
within (or adjacent to) the drainage basin. A GRID raster layer is created over
the basin from the grid point PMP values.
---------------------------------------------------------------------------'''
###############################################################################
## import Python modules
import sys
import arcpy
from arcpy import env
import arcpy.management as dm
import arcpy.conversion as con
arcpy.env.overwriteOutput = True                          # Set overwrite option
###############################################################################
## get input parameters
basin = arcpy.GetParameter(0)                            # get AOI Basin Shapefile
home = arcpy.GetParameterAsText(1)                           # get location of 'PMP' Project Folder
durInput = arcpy.GetParameter(2)                          # get durations (string)
dadGDB = home + "\\Input\\DAD_Tables.gdb"                       # location of DAD tables
adjFactGDB = home + "\\Input\\Storm_Adj_Factors.gdb"                 # location of feature datasets containing total adjustment
factors
def pmpAnalysis(aoiBasin, stormType):
  ###############################################################################
  ## Create PMP Point Feature Class from points within AOI basin and add fields
  def createPMPfc():
    global outPath
    env.workspace = outPath + "PMP.gdb"                          # set environment workspace
    arcpy.AddMessage("\nCreating feature class: PMP_Points...")
    dm.MakeFeatureLayer(home + "\\Input\Non_Storm_Data.gdb\\Vector_Grid\\Vector_Grid_AZ", "vgLayer")    # make a feature
layer of vector grid cells
    dm.SelectLayerByLocation("vgLayer", "INTERSECT", aoiBasin)                    # select the vector grid cells that
intersect the aoiBasin polygon
    dm.MakeFeatureLayer(home + "\\Input\Non_Storm_Data.gdb\\Vector_Grid\\Grid_Points_AZ", "gpLayer")    # make a feature
layer of grid points
    dm.SelectLayerByLocation("gpLayer", "HAVE_THEIR_CENTER_IN", "vgLayer")               # select the grid points
within the vector grid selection
    con.FeatureClassToFeatureClass("gpLayer", env.workspace, "PMP_Points")              # save feature layer as
"PMP_Points" feature class
    arcpy.AddMessage("(" + str(dm.GetCount("gpLayer")) + " grid points will be analyzed)")
    # Add PMP Fields
    for dur in durList:
```

```
        arcpy.AddMessage("\n\t...adding field: PMP_" + str(dur))
        dm.AddField("PMP_Points", "PMP_" + dur, "DOUBLE")
    # Add STORM Fields (this string values identifies the driving storm by SPAS ID number)
    for dur in durList:
        arcpy.AddMessage("\n\t...adding field: STORM_" + str(dur))
        dm.AddField("PMP_Points", "STORM_" + dur, "TEXT", "", "", 16)
  def getAOIarea():
    sr = arcpy.Describe(aoiBasin).SpatialReference          # Determine aoiBasin spatial reference system
    srname = sr.name
    srtype = sr.type
    srunitname = sr.linearUnitName                          # Units
    arcpy.AddMessage("\nAOI Basin Spatial Reference:  " + srname + "\nUnit Name: " + srunitname + "\nSpatial Ref. type: " +
srtype)

    aoiArea = 0.0
    rows = arcpy.SearchCursor(aoiBasin)
    for row in rows:
        feat = row.getValue("Shape")
        aoiArea += feat.area
    if srtype == 'Geographic':                              # Must have a surface projection
        arcpy.AddMessage("\nThe basin shapefile's spatial reference '" + srtype + "' is not supported.  Please use a 'Projected'
shapefile or feature class.\n")
        raise SystemExit
    elif srtype == 'Projected':
        if srunitname == "Meter":
            aoiArea = aoiArea * 0.000000386102              # Converts square meters to square miles
        elif srunitname == "Foot" or "Foot_US":
            aoiArea = aoiArea * 0.00000003587               # Converts square feet to square miles
        else:
            arcpy.AddMessage("\nThe basin shapefile's unit type '" + srunitname + "' is not supported.")
            sys.exit("Invalid linear units")                # Units must be meters or feet

    aoiArea = round(aoiArea, 3)
    arcpy.AddMessage("\nArea of interest: " + str(aoiArea) + " square miles.")

    # aoiArea = 100     ## Enable a constant area size
    arcpy.AddMessage("\n***Area used for PMP analysis: " + str(aoiArea) + " sqmi***")
    return aoiArea
  ###########################################################################
  ##  Define dadLookup() function:
  ##  The dadLookup() function determines the DAD value for the current storm
  ##  and duration according to the basin area size.  The DAD depth is interpolated
  ##  linearly between the two nearest areal values within the DAD table.
  def dadLookup(stormLayer, duration, area):                # dadLookup() accepts the current storm layer name (string), the current
duration (string), and AOI area size (float)
    #arcpy.AddMessage("\t\tfunction dadLookup() called.")
    durField = "H_" + duration                              # defines the name of the duration field (eg., "H_06" for 6-hour)
    dadTable = dadGDB + "\\" + stormLayer
    rows = arcpy.SearchCursor(dadTable)

    try:
        row = rows.next()                                   # Sets DAD area x1 for basins that are smaller than the smallest DAD area.
        x1 = row.AREASQMI
        y1 = row.getValue(durField)
```

```
        xFlag = "FALSE"                     # Sets DAD area x2 for basins that are larger than the largest DAD area.
    except RuntimeError:                    # return if duration does not exist in DAD table
        return

    #arcpy.AddMessage("\nInitial x1 = " + str(x1) + "\ny1 = " + str(y1))

    row = rows.next()
    i = 0
    while row:                              # iterates through the DAD table - assiging the bounding values directly above and
below the basin area size
        i += 1
        if row.AREASQMI < area:
            x1 = row.AREASQMI
            y1 = row.getValue(durField)
        else:
            xFlag = "TRUE"
            x2 = row.AREASQMI
            y2 = row.getValue(durField)
            #arcpy.AddMessage("\nLoop " + str(i)+ "\nx1 = " + str(x1) + "\ny1 = " + str(y1) + "\nx2 = " + str(x2))
            break

        row = rows.next()
    del row, rows, i
    if xFlag == "FALSE":
        x2 = area                           # If x2 is equal to the basin area, this means that the largest DAD area is smaller than
the basin and the resulting DAD value must be extrapolated.
        #arcpy.AddMessage("x2 = " + str(x2))
        arcpy.AddMessage("\n\tThe basin area size: " + str(area) + " sqmi is greater than the largest DAD area: " + str(x1) + " sqmi.
DAD value is estimated by extrapolation.")    # In this case, y (the DAD depth) is estimated by extrapolating the DAD area to the
basin area size.
        y = x1 / x2 * y1
        return y                            # The extrapolated DAD depth (in inches) is returned.
    # arcpy.AddMessage("\nArea = " + str(area) + "\nx1 = " + str(x1) + "\nx2 = " + str(x2) + "\ny1 = " + str(y1) + "\ny2 = " + str(y2))

    x = area                                # If the basin area size is within the DAD table area range, the DAD depth is interpolated
    deltax = x2 - x1                        # to determine the DAD value (y) at area (x) based on next lower (x1) and next higher
(x2) areas.
    deltay = y2 - y1
    diffx = x - x1
    y = y1 + diffx * deltay / deltax
    return y                                # The interpolated DAD depth (in inches) is returned.
  ###########################################################################################
  ##  Define updatePMP() function:
  ##  This function updates the 'PMP_XX_' and 'STORM_XX' fields of the PMP_Points
  ##  feature class with the largest value from all analyzed storms stored in the
  ##  pmpValues list.
  def updatePMP(pmpValues, stormID, duration):                  # Accepts four arguments: pmpValues - largest
adjusted rainfall for current duration (float list); stormID - driver storm ID for each PMP value (text list); and duration (string)
    pmpfield = "PMP_" + duration
    stormfield = "STORM_" + duration
    gridRows = arcpy.UpdateCursor(outPath + "PMP.gdb\\PMP_Points")          # iterates through PMP_Points rows
    i = 0
    for row in gridRows:
```

```
        row.setValue(pmpfield, pmpValues[i])                    # Sets the PMP field value equal to the Max Adj.
Rainfall value (if larger than existing value).
        row.setValue(stormfield, stormID[i])                    # Sets the storm ID field to indicate the driving storm
event
        gridRows.updateRow(row)
        i += 1
      del row, gridRows, pmpfield, stormfield
      arcpy.AddMessage("\n\t" + duration + "-hour PMP values update complete. \n")
      return
  def outputPMP():
      global outPath
      pmpPoints = outPath + "PMP.gdb\\PMP_Points"               # Location of 'PMP_Points' feature class which will provide
data for output

      arcpy.AddMessage("\nBeginning PMP Raster Creation...")
      for dur in durList:                                       # This code creates a raster GRID from the current PMP point
layer
        durField = "PMP_" + dur
        outLoc = outPath + "GRIDs.gdb\\pmp_" + dur
        arcpy.AddMessage("\n\tInput Path: " + pmpPoints)
        arcpy.AddMessage("\tOutput raster path: " + outPath)
        arcpy.AddMessage("\tField name: " + durField)
        con.FeatureToRaster(pmpPoints, durField, outLoc, "0.025")
        arcpy.AddMessage("\tOutput raster created...")
      del durField
      outFile = open(outPath + "Text_Output\\PMP_Distribution.txt", 'w')
      arcpy.AddMessage("\nPMP Raster Creation complete.")

      ######  This section applies the metadata templates to the output GIS files ######
      pointMetaLoc = home + "\\Input\\Metadata_Templates\\PMP_Points_Metadata_FGDC.xml"          # Location of
'PMP_Points' feature class metadata template
      rasMetaLoc = home + "\\Input\\Metadata_Templates\\PMP_Raster_Metadata_FGDC.xml"            # Location
of 'PMP_XX' raster file metadata template
      arcpy.AddMessage("\nAdding metadata to output files...")
      arcpy.AddMessage("\n\tPMP_Points feature class")
      con.MetadataImporter(pointMetaLoc, pmpPoints)                                               # Applies metadata to
'PMP_Points' feature class
      for dur in durList:                                       # Applies metadata to 'PMP_XX' GRIDs
        targetPath = outPath + "GRIDs.gdb\\pmp_" + dur
        arcpy.AddMessage("\tPMP_" + str(dur) + " feature class")
        con.MetadataImporter(rasMetaLoc, targetPath)
      arcpy.AddMessage("\nOutput metadata import complete.")
  ###########################################################################
  ##  This portion of the code iterates through each storm feature class in the
  ##  'Storm_Adj_Factors' geodatabase (evaluating the feature class only within
  ##  the Local, Tropical, or general feature dataset).  For each duration,
  ##  at each grid point within the aoi basin, the transpositionality is
  ##  confirmed.  Then the DAD precip depth is retrieved and applied to the
  ##  total adjustement factor to yield the total adjusted rainfall.  This
  ##  value is then sent to the updatePMP() function to update the 'PMP_Points'
  ##  feature class.
##~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~##
  desc = arcpy.Describe(basin)                                  # Check to ensure AOI input shape is a Polygon. If not - exit.
```

```
    basinShape = desc.shapeType
    if desc.shapeType == "Polygon":
        arcpy.AddMessage("\nBasin shape type: " + desc.shapeType)
    else:
        arcpy.AddMessage("\nBasin shape type: " + desc.shapeType)
        arcpy.AddMessage("\nError: Input shapefile must be a polygon!\n")
        sys.exit()

    createPMPfc()                                        # Call the createPMPfc() function to create the PMP_Points feature 
class.
    env.workspace = adjFactGDB                           # the workspace environment is set to the 'Storm_Adj_Factors' 
file geodatabase
    aoiSQMI = round(getAOIarea(),2)                      # Calls the getAOIarea() function to assign area of AOI 
shapefile to 'aoiSQMI'

    for dur in durList:
        stormList = arcpy.ListFeatureClasses("", "Point", stormType)          # List all the total adjustment factor feature classes 
within the storm type feature dataset.
        arcpy.AddMessage("\n*****************************************************************\nEvaluating " + dur + "-hour duration...")
        pmpList = []
        driverList = []
        gridRows = arcpy.SearchCursor(outPath + "PMP.gdb\\PMP_Points")
        try:
            for row in gridRows:
                pmpList.append(0.0)                      # creates pmpList of empty float values for each grid point to 
store final PMP values
                driverList.append("STORM")               # creates driverList of empty text values for each grid point to 
store final Driver Storm IDs
            del row, gridRows
        except UnboundLocalError:
            arcpy.AddMessage("\n***Error: No data present within basin/AOI area.***\n")
            sys.exit()
        for storm in stormList:
            arcpy.AddMessage("\n\tEvaluating storm: " + storm + "...")
            dm.MakeFeatureLayer(storm, "stormLayer")                  # creates a feature layer for the current storm
            dm.SelectLayerByLocation("stormLayer", "HAVE_THEIR_CENTER_IN", "vgLayer")   # examines only the grid points that lie 
within the AOI
            gridRows = arcpy.SearchCursor("stormLayer")
            pmpField = "PMP_" + dur
            i = 0
            try:
                dadPrecip = round(dadLookup(storm, dur, aoiSQMI),3)
                arcpy.AddMessage("\t\t" + dur + "-hour DAD value:  " + str(dadPrecip) + chr(34))
            except TypeError:                            # In no duration exists in the DAD table - move to the next storm
                arcpy.AddMessage("\t***Duration '" + str(dur) + "-hour' is not present for " + str(storm) + ".***\n")
                continue
            arcpy.AddMessage("\t\tComparing " + storm + " adjusted rainfall values against current driver values...\n")
            for row in gridRows:
                if row.TRANS == 1:                       # Only continue if grid point is transpositionable ('1' is transpostionable, '0' 
is not).
                    try:                                 # get total adj. factor if duration exists
                        maxAdjRain = round(dadPrecip * row.TAF,2)
                        if maxAdjRain > pmpList[i]:
                            pmpList[i] = maxAdjRain
```

```
                driverList[i] = storm
            except RuntimeError:
                arcpy.AddMessage("\t\t   *Warning* PMP value failed to set for row " + str(row.CNT))
                break
            i += 1
        del row
    del storm, stormList, gridRows, dadPrecip
    updatePMP(pmpList, driverList, dur)           # calls function to update "PMP Points" feature class
  del dur, pmpList

  arcpy.AddMessage("\n'PMP_Points' Feature Class 'PMP_XX' fields update complete for all '" + stormType + "' storms.")

  outputPMP()                    # calls outputPMP() function

##~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~##
type = "General"
durList = durInput
outPath = home + "\\Output\\General\\"
arcpy.AddMessage("\nRunning PMP analysis for storm type: " + type)
pmpAnalysis(basin, type)         # Calls the pmpAnalysis() function to calculate the General storm PMP
arcpy.AddMessage("\nGeneral storm analysis
complete...\n*****************************************************************************************************")
```

Appendix C

Short List Storm Analysis Data Used for PMP Development

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Report
14-07-REP – Appendix C
v1.0

Susitna-Watana Hydroelectric Project
Site-Specific Probable Maximum Precipitation Study
Appendix C – Short List Storm Analyses

FINAL DRAFT

AEA11-022

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May 2014

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.

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APPENDIX C:

SHORT STORM LIST STORM ANALYSES

Storm files were made for 13 SPAS DAD zones which comprised the short storm list (Table C.1). Applied Weather Associates (AWA) analyzed each of these storms to determine the storm representative SST for in-place maximization using the updated SST climatologies. Each storm was then transpositioned and adjusted using the OTF process as description in Section 7 and 8 of the report. The data used to analyze and develop the adjusted DAD table for each of these storms is included in this appendix so that a user is able to understand how each of the storms was adjusted and allow for the process to replicated/reproduced if required.

Table C.1. Alaska Short Storm List

Name	ST	Lat	Lon	Year	Mon	Day	Total Rainfall	Precipitation Source
DENALI NP	AK	63.038	-150.471	1955	8	22	13.75	SPAS 1272 Zone 1
MT SPURR	AK	61.346	-152.329	1958	7	25	6.62	SPAS 1273 Zone 1
LITTLE SUSITNA	AK	61.854	-149.229	1959	8	18	13.05	SPAS 1271 Zone 1
DENALI NP	AK	62.846	-150.513	1967	8	2	12.45	SPAS 1270 Zone 2
FAIRBANKS	AK	65.521	-147.329	1967	8	2	12.45	SPAS 1270 Zone 1
SUTTON	AK	61.904	-148.863	1971	8	5	11.39	SPAS 1269 Zone 1
BLACK RAPIDS	AK	63.471	-145.479	1971	8	5	12.17	SPAS 1269 Zone 2
MT GEIST	AK	63.638	-146.971	1980	7	24	5.26	SPAS 1268 Zone 2
DENALI NP	AK	62.954	-150.079	1980	7	24	7.33	SPAS 1268 Zone 1
DENALI NP	AK	62.829	-151.138	1986	10	8	11.01	SPAS 1267 Zone 1
SEWARD	AK	60.113	-149.513	1986	10	8	20.80	SPAS 1267 Zone 2
BLACK RAPIDS	AK	63.465	-145.685	2006	8	17	16.12	SPAS 1303 Zone 1
OLD TYONEK	AK	61.260	-151.860	2012	9	15	15.91	SPAS 1256 Zone 1

Denali NP, AK, SPAS 1272 Zone 1
August 22, 1955

Storm Name:	SPAS 1272 Denali NP, DAD Zon	Storm Adjustment for Susitna-Watana
Storm Date:	8/21-29/1955	
AWA Analysis Date:	2/19/2013	

Temporal Transposition Date	15-Aug	
	Lat	Long
Storm center location	63.04 N	150.47 W
Storm Rep SST location	53.00 N	152.00 W
Transposition SST location	NA	NA
Basin location	62.84 N	147.37 W

Moisture Inflow Direction:	SSW @ 700	miles
Basin Elevation	3,650	feet
Storm Elevation	7,500	feet
Storm Duration	24	hours
Effective Barrier Height	1,483	feet

The storm representative SST is	54.0 F	with total precipitable water above sea level of			1.02	inches.
The in-place maximum SST is	57.0 F	with total precipitable water above sea level of			1.19	inches.
The transpositioned maximum SST is	NA	with total precipitable water above sea level of			4.44	inches.
The in-place storm elevation is	7,500	which subtracts	0.67	inches of precipitable water at	54.0 F	
The in-place storm elevation is	7,500	which subtracts	0.76	inches of precipitable water at	57.0 F	
The transposition storm elevation at	3,650	which subtracts	xx	inches of precipitable water at	NA	
The moisture inflow barrier height is	1,483	which subtracts	xx	inches of precipitable water at	NA	

The in-place maximization factor is	1.23
The transposition/elevation factor is	#VALUE!
The barrier adjustment factor is	#VALUE!
The total adjustment factor is	#VALUE!

Notes: Storm representative SST value was based on SST values for August 21-22, 1955 along HYSPLIT trajectory data. Values were selected in region where temperature did not vary more than a 1-degree over a large area.

Observed Storm Depth-Area-Duration

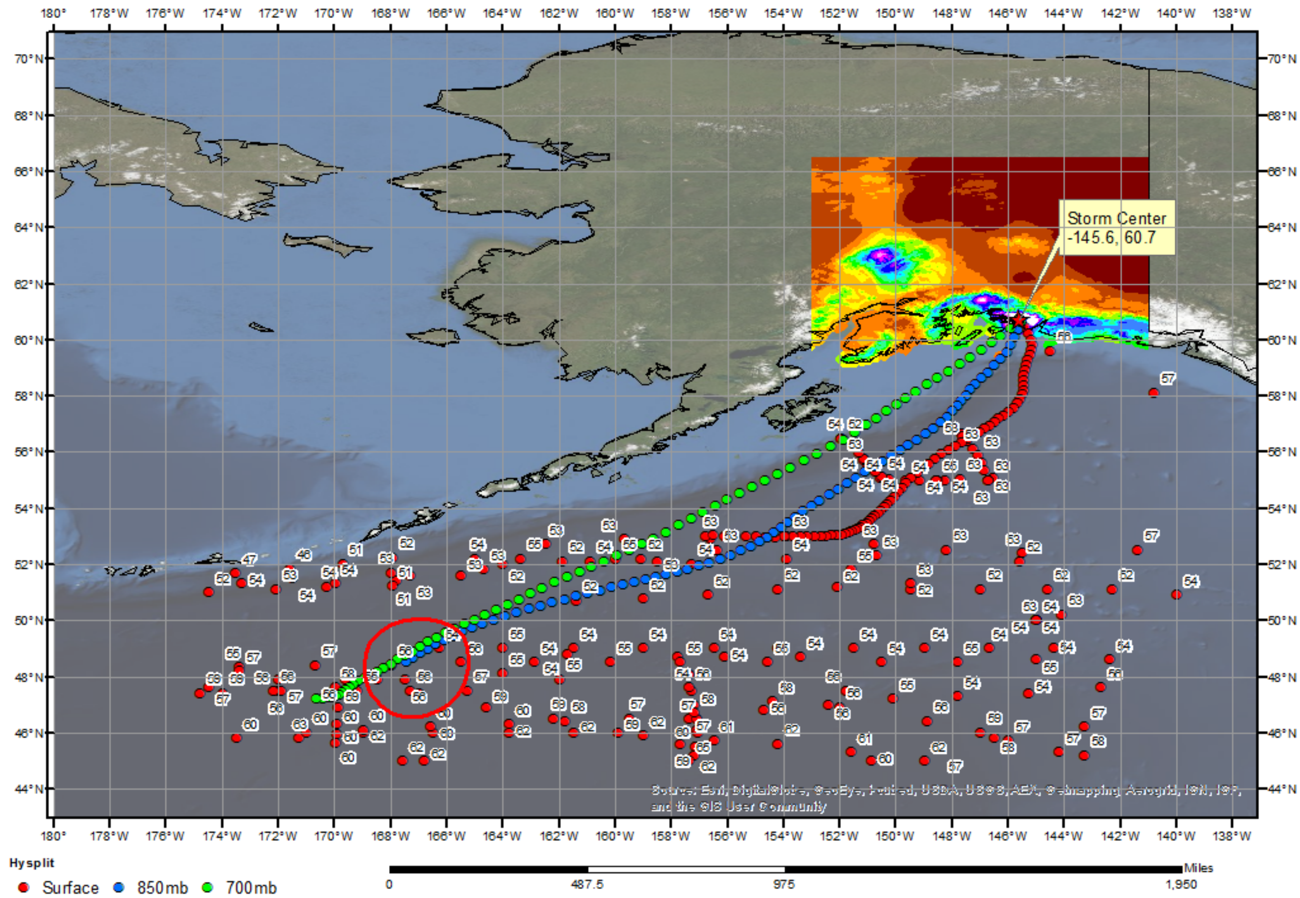
	6 Hours	12 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours	168 Hours
10 sq miles	1.3	2.2	2.8	3.6	6.1	7.9	9.7	12.2	13.1	13.4
100 sq miles	1.3	2.1	2.8	3.5	6.0	7.7	9.5	12.1	12.9	13.1
200 sq miles	1.2	2.0	2.7	3.4	5.8	7.4	9.2	11.7	12.4	12.7
500 sq miles	1.2	1.9	2.6	3.2	5.5	7.1	8.7	11.1	11.8	12.1
1000 sq miles	1.1	1.8	2.4	3.1	5.2	6.7	7.9	10.4	11.2	11.4
2000 sq miles	1.0	1.7	2.3	2.8	4.7	6.2	7.5	9.5	10.3	10.5
5000 sq miles	0.9	1.5	1.9	2.4	4.0	4.8	6.0	7.1	7.9	8.7
10000 sq miles	0.8	1.2	1.7	2.0	3.4	4.2	5.1	5.8	6.7	7.2
20000 sq miles	0.6	0.9	1.3	1.5	2.6	3.4	4.1	4.8	5.4	5.7

Adjusted Storm Depth-Area-Duration

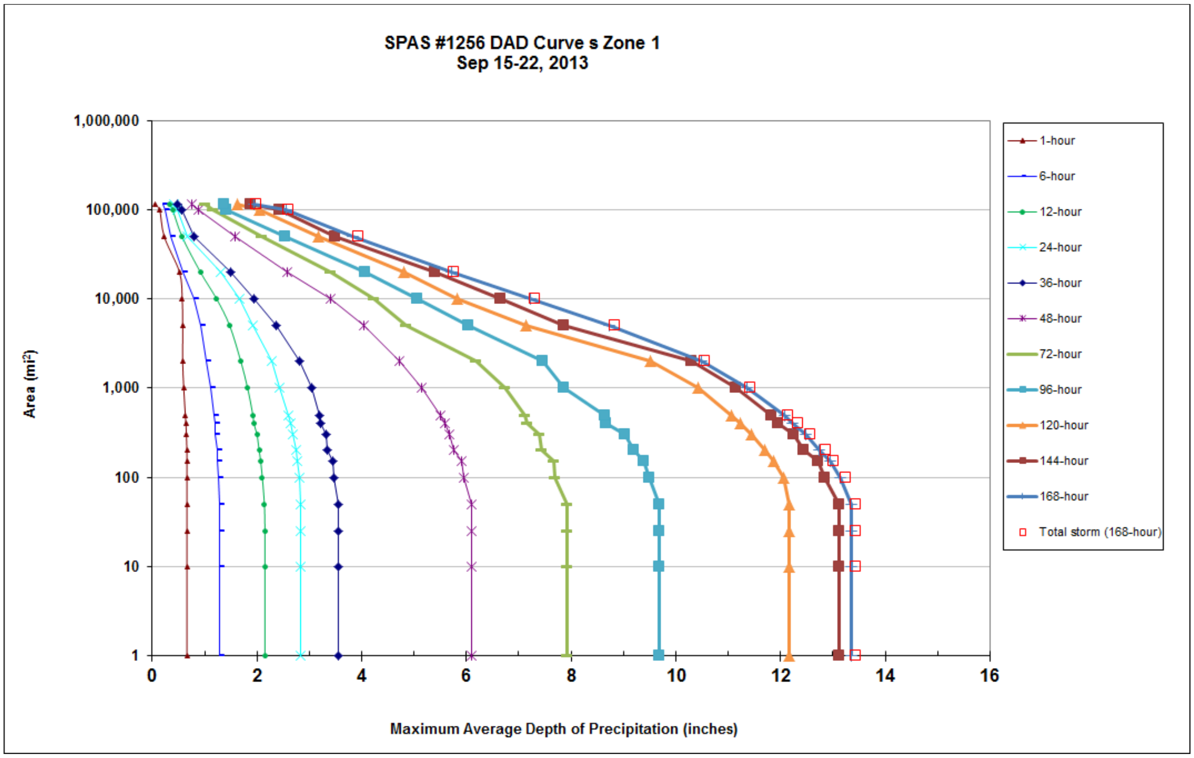
	6 Hours	12 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours	60 Hours	72 Hours
10 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
100 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
200 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
500 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
1000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
2000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
5000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
10000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
20000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!

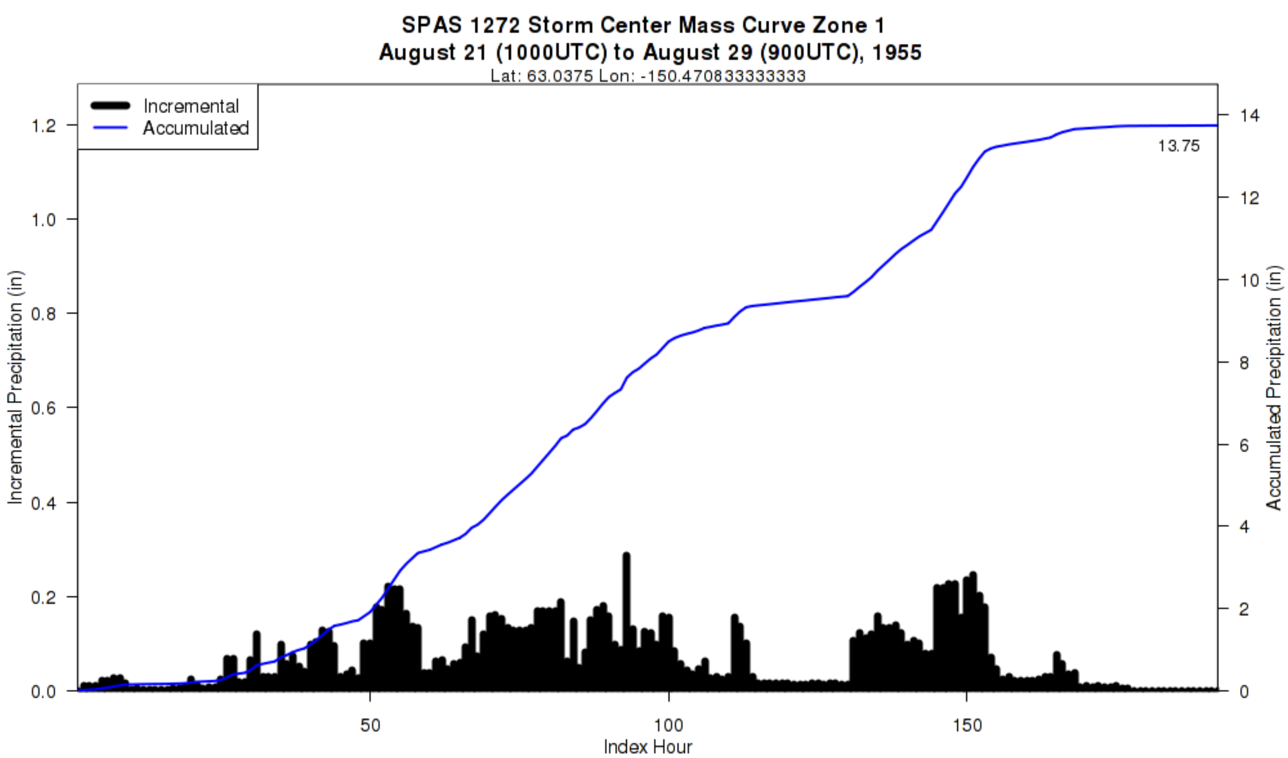
Storm or Storm Center Name	SPAS 1272 Denali NP, DAD Zone 1		
Storm Date(s)	8/21-29/1955		
Storm Type	Atmospheric River		
Storm Location	63.04 N	150.47 W	
Storm Center Elevation	7500		
Precipitation Total & Duration	13.75 inches in 168 hours -DAD Zone 1		
Storm Representative SST	54.0 F		
Storm Representative SST Location	53.00 N	152.00 W	15-Aug
In-place Maximum SST	57.0 F		57
Moisture Inflow Vector	SSW @ 700		
In-place Maximization Factor	1.23		
Temporal Transposition (Date)	15-Aug		
Transposition SST Location	NA	NA	
Transposition Maximum SST	NA		
Transposition Adjustment Factor	#VALUE!		
Average Basin Elevation	3,650		
Highest Elevation in Basin	13,131		
Inflow Barrier Height	1,483		
Elevation Adjustment Factor	#VALUE!		
Total Adjustment Factor	#VALUE!		

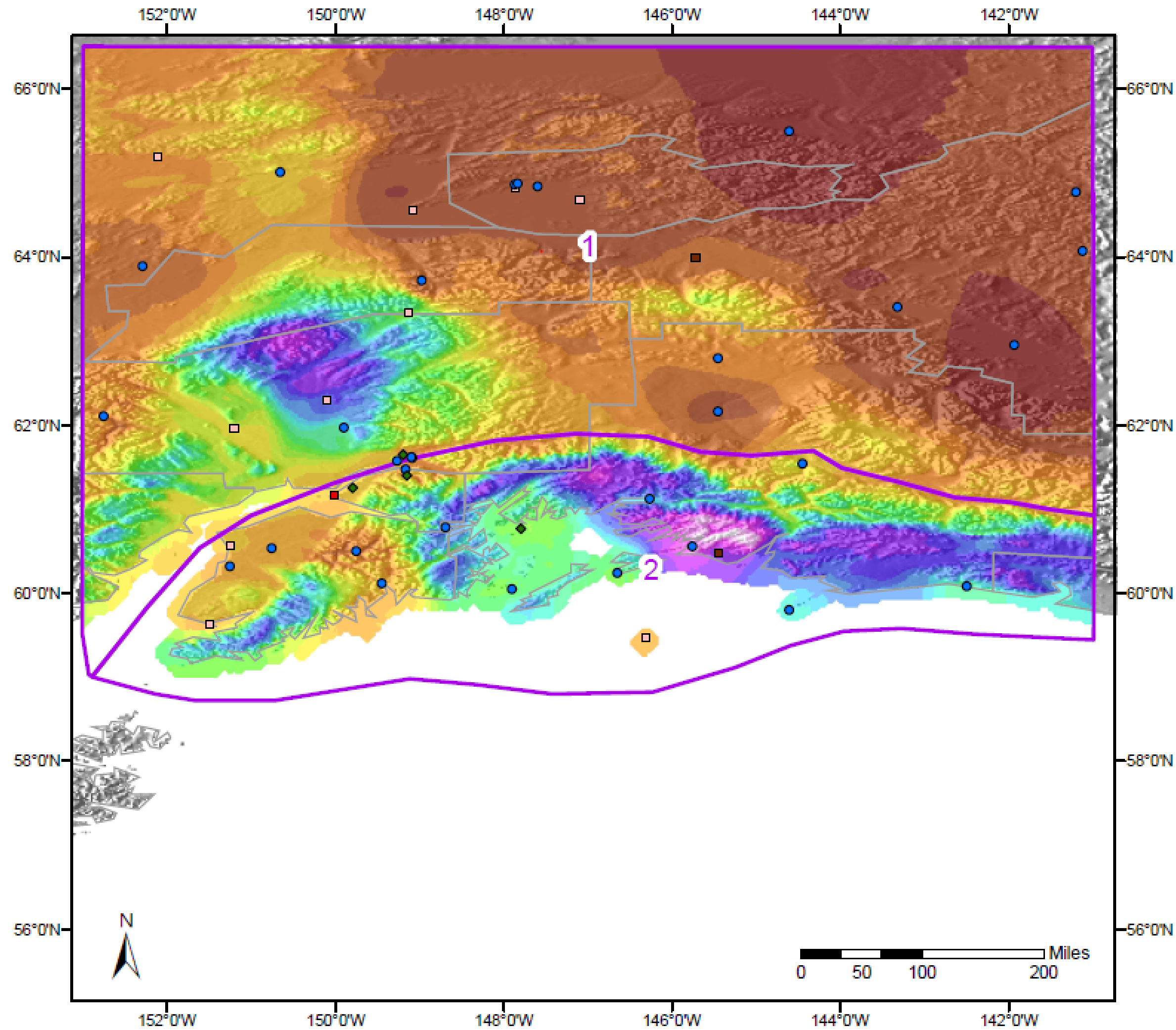
SPAS 1272 Cordova, AK Storm Analysis
August 21 - 29, 1955



Storm 1272 - Aug. 21 (1000 UTC) - Aug. 28 (0900 UTC), 1955											
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)											
	Duration (hours)										
Area (mi^2)	1	6	12	24	36	48	72	96	120	144	168	Total
0.2	0.71	1.32	2.18	2.94	3.63	6.27	8.14	9.92	12.48	13.42	13.67	13.75
1	0.66	1.29	2.15	2.83	3.55	6.09	7.92	9.68	12.16	13.12	13.35	13.43
10	0.66	1.29	2.15	2.83	3.55	6.09	7.92	9.68	12.16	13.12	13.35	13.43
25	0.66	1.29	2.15	2.83	3.55	6.09	7.92	9.68	12.16	13.12	13.35	13.43
50	0.66	1.29	2.14	2.83	3.55	6.09	7.92	9.68	12.16	13.12	13.35	13.43
100	0.66	1.27	2.1	2.82	3.46	5.95	7.7	9.5	12.06	12.85	13.14	13.25
150	0.66	1.25	2.07	2.78	3.44	5.9	7.67	9.39	11.86	12.71	12.94	13.01
200	0.66	1.24	2.04	2.74	3.35	5.76	7.44	9.19	11.7	12.44	12.73	12.86
300	0.65	1.21	2	2.69	3.32	5.68	7.39	9.02	11.45	12.25	12.49	12.57
400	0.64	1.19	1.94	2.65	3.22	5.6	7.15	8.66	11.23	11.95	12.22	12.34
500	0.63	1.18	1.92	2.61	3.2	5.51	7.11	8.65	11.07	11.83	12.07	12.15
1,000	0.6	1.11	1.82	2.43	3.05	5.15	6.74	7.86	10.42	11.15	11.36	11.42
2,000	0.58	1.04	1.69	2.29	2.82	4.73	6.18	7.45	9.51	10.29	10.48	10.56
5,000	0.58	0.92	1.48	1.93	2.37	4.04	4.84	6.03	7.14	7.85	8.72	8.83
10,000	0.57	0.79	1.23	1.66	1.95	3.4	4.23	5.05	5.82	6.65	7.22	7.31
20,000	0.52	0.59	0.92	1.3	1.5	2.57	3.41	4.07	4.8	5.4	5.71	5.77
50,000	0.23	0.35	0.57	0.68	0.8	1.59	2.1	2.54	3.17	3.49	3.82	3.94
100,000	0.14	0.24	0.39	0.49	0.56	0.89	1.15	1.41	2.04	2.44	2.56	2.60
116,206	0.05	0.21	0.34	0.42	0.49	0.75	1	1.37	1.62	1.87	1.95	1.98


SPAS #1256 DAD Curve s Zone 1
Sep 15-22, 2013
Area (mi²)
Maximum Average Depth of Precipitation (inches)
1-hour
6-hour
12-hour
24-hour
36-hour
48-hour
72-hour
96-hour
120-hour
144-hour
168-hour
Total storm (168-hour)

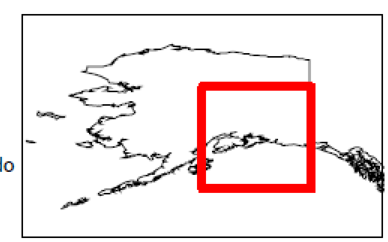

SPAS 1272 Storm Center Mass Curve Zone 1
August 21 (1000UTC) to August 29 (900UTC), 1955
Lat: 63.0375 Lon: -150.470833333333
Incremental
Accumulated
13.75
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour



Total Storm (192-hour) Precipitation (inches)
August 21-28, 1955
SPAS #1272

Precipitation (inches)

0.12 - 0.50	3.01 - 3.50	6.01 - 6.50	12.01 - 14.00	Daily
0.51 - 1.00	3.51 - 4.00	6.51 - 7.00	14.01 - 16.00	Hourly
1.01 - 1.50	4.01 - 4.50	7.01 - 8.00	16.01 - 18.00	Hourly Est.
1.51 - 2.00	4.51 - 5.00	8.01 - 9.00	18.01 - 20.00	Hourly Est. Pseudo
2.01 - 2.50	5.01 - 5.50	9.01 - 10.00	20.01 - 22.00	Supplemental
2.51 - 3.00	5.51 - 6.00	10.01 - 12.00		



METSTAT, Inc. 02/28/2013

Mt. Spurr, AK, SPAS 1273 Zone 1
July 25, 1958

Storm Name:	SPAS 1273-AK Storm 1 and 2, Zone	**Storm Adjustment for Susitna-Watana**
Storm Date:	July 25 - August 5, 1958	
AWA Analysis Date:	3/4/2014	

Temporal Transposition Date	15-Aug	
	Lat	Long
Storm Center Location	61.35 N	152.33 W
Storm Rep SST Location	50.00 N	145.00 W
Transposition SST Location	NA	NA
Basin Location	*	*

Moisture Inflow Direction	SSE @ 830	miles
Basin Average Elevation	NA	feet
Storm Center Elevation	9,200	feet
Storm Analysis Duration	24	hours
Effective Barrier Height	N/A	feet

The storm representative SST is	56.0 F	with total precipitable water above sea level of			1.11	inches.
The in-place maximum SST is	59.0 F	with total precipitable water above sea level of			1.31	inches.
The transpositioned maximum SST is	NA	with total precipitable water above sea level of			4.08	inches.
The in-place storm elevation is	9,200	feet which subtracts	0.83	inches of precipitable water at	56.0 F	
The in-place storm elevation is	9,200	feet which subtracts	0.97	inches of precipitable water at	59.0 F	
The transposition storm elevation at	NA	feet which subtracts	NA	inches of precipitable water at	NA	
The moisture inflow barrier height is	N/A	feet which subtracts	NA	inches of precipitable water at	NA	

The in-place maximization factor is	1.21
The transposition factor is	#VALUE!
The elevation/barrier adjustment factor is	#VALUE!
The total adjustment factor is	#VALUE!

Notes: Storm representative SST value was based on SST values for July 26-August 2 along the surface HYSPLIT trajectory data. Values were selected in region where temperature did not vary more than a 1-degree over a large area and was as closest to the storm center.

Observed Storm Depth-Area-Duration

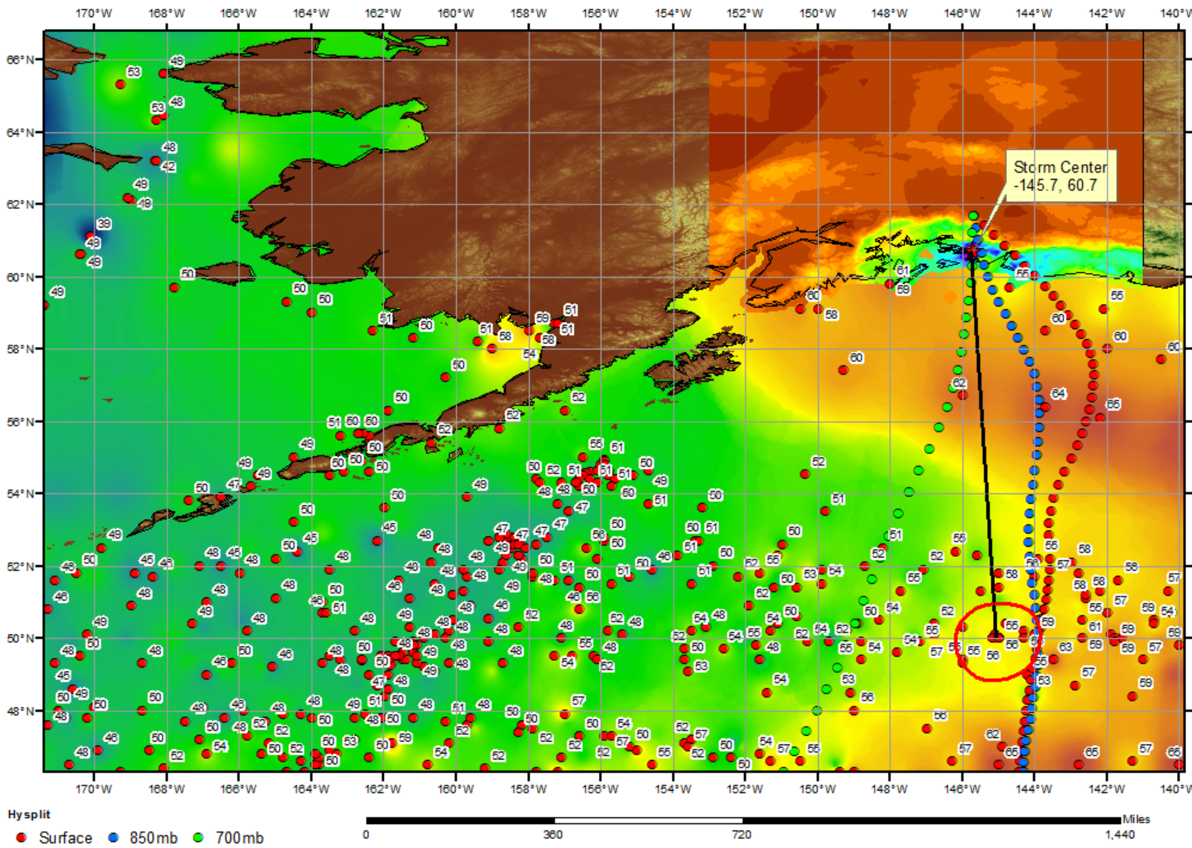
	1 Hours	6 Hours	12 Hours	18 Hours	24 Hours	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours	168 Hours	192 Hours	216 Hours	240 Hours	264 Hours	288 Hours
1 sq miles	0.5	1.8	2.4	2.7	2.7	3.1	3.3	4.0	4.9	5.3	6.0	6.1	6.1	6.4	6.5	6.5
10 sq miles	0.5	1.8	2.4	2.7	2.7	3.1	3.3	4.0	4.9	5.3	6.0	6.1	6.1	6.4	6.5	6.5
100 sq miles	0.4	1.8	2.4	2.7	2.7	3.1	3.2	3.7	4.6	5.0	5.7	5.8	5.8	6.0	6.4	6.4
200 sq miles	0.4	1.7	2.3	2.7	2.7	3.1	3.1	3.6	4.4	4.7	5.4	5.5	5.5	5.7	6.2	6.3
500 sq miles	0.4	1.7	2.2	2.6	2.6	3.0	3.0	3.3	4.0	4.3	4.9	5.1	5.2	5.4	5.9	6.0
1000 sq miles	0.4	1.6	2.2	2.6	2.6	2.9	2.9	3.1	3.7	3.9	4.4	4.8	4.9	5.2	5.7	5.7
2000 sq miles	0.3	1.5	2.1	2.4	2.4	2.8	2.8	2.9	3.3	3.6	4.2	4.5	4.7	4.9	5.4	5.5
5000 sq miles	0.3	1.3	1.8	2.1	2.1	2.4	2.5	2.7	3.0	3.3	3.7	4.1	4.1	4.5	4.9	4.9
10000 sq miles	0.3	1.1	1.6	1.8	1.8	2.1	2.3	2.5	2.6	2.9	3.3	3.6	3.7	4.0	4.4	4.4
20000 sq miles	0.2	0.8	1.4	1.6	1.6	1.8	2.0	2.2	2.4	2.6	3.0	3.2	3.4	3.5	3.8	3.9

Adjusted Storm Depth-Area-Duration

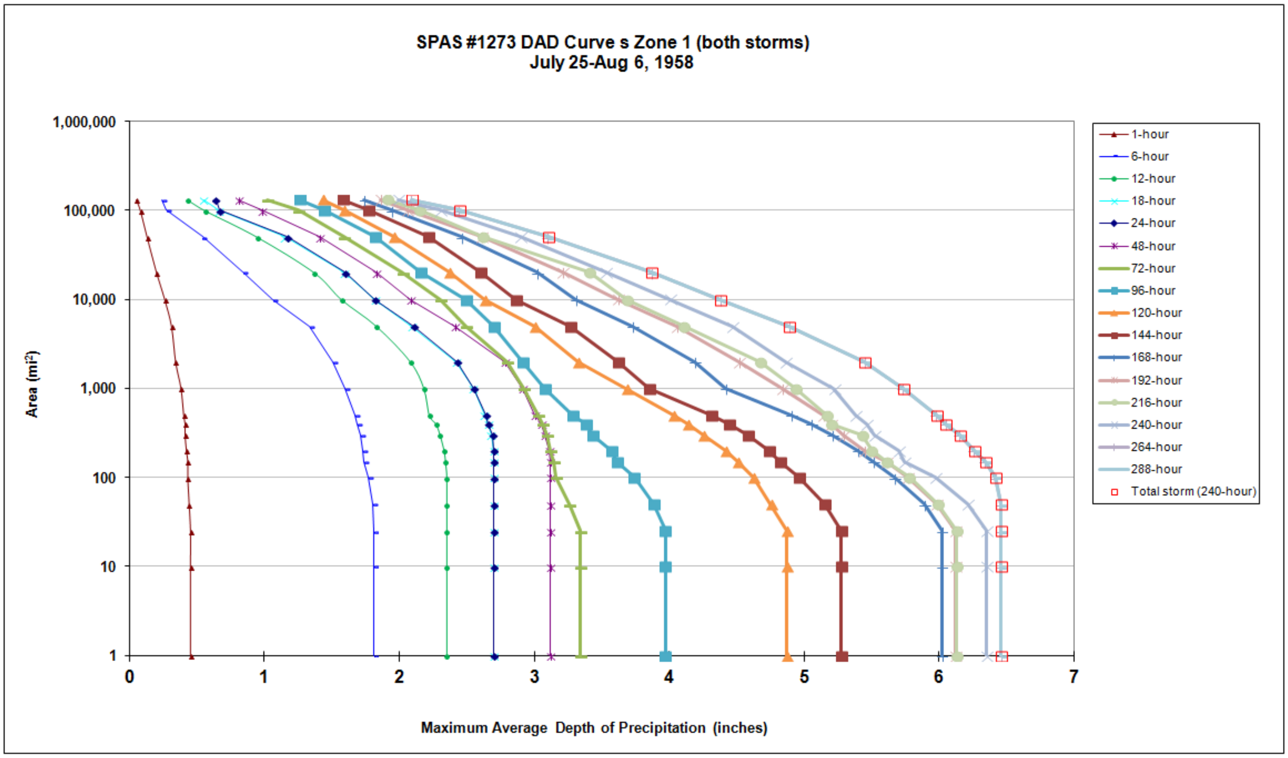
	1 Hours	6 Hours	12 Hours	18 Hours	24 Hours	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours	168 Hours	192 Hours	216 Hours	240 Hours	264 Hours	288 Hours
1 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
10 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
100 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
200 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
500 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
1000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
2000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
5000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
10000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
20000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!

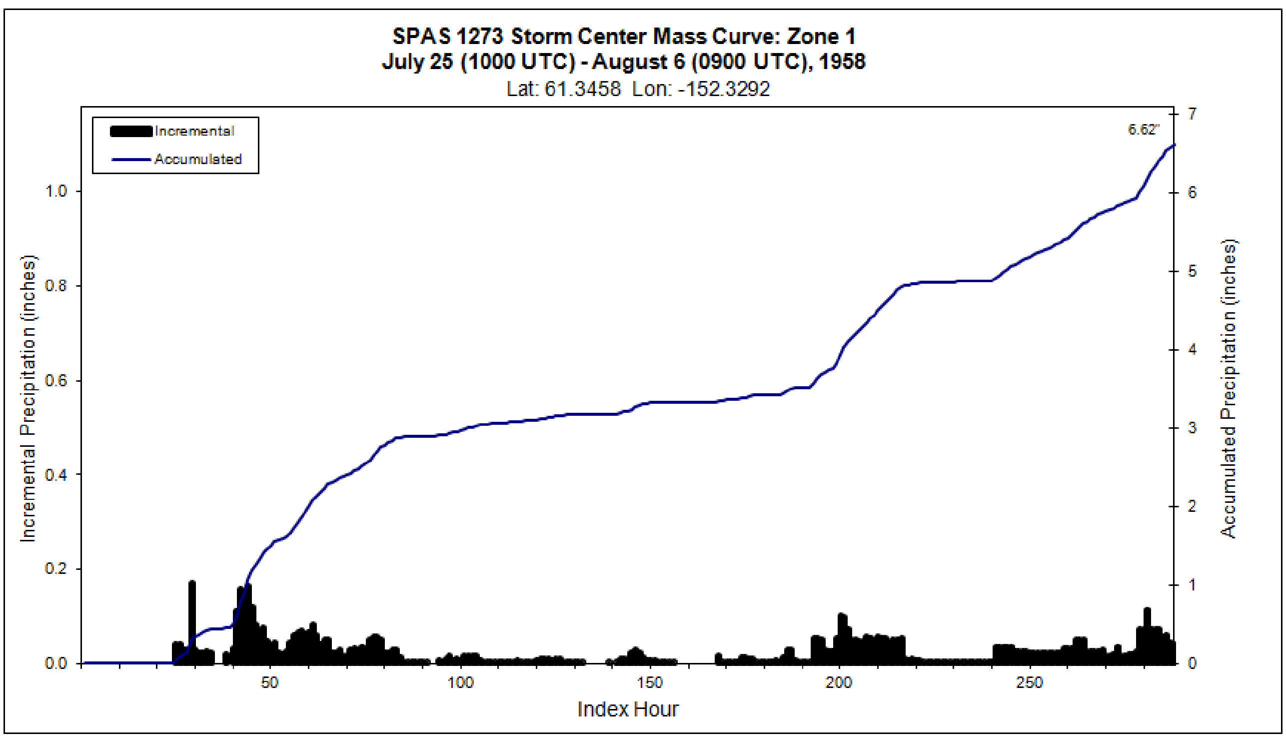
Storm or Storm Center Name	**SPAS 1273-AK Storm 1 and 2, Zone 1**	
Storm Date(s)	July 25 - August 5, 1958	
Storm Type	Series of low pressure systems	
Storm Location	61.35 N	152.33 W
Storm Center Elevation	9,200	
Precipitation Total & Duration (10 sq mi)	6.62 inches at 288 hours	
Storm Representative SST	56.0 F	
Storm Representative SST Location	50.00 N	145.00 W
Maximum SST	59.0 F	
Moisture Inflow Vector	SSE @ 830	
In-place Maximization Factor	**1.21**	
Temporal Transposition (Date)	15-Aug	
Transposition SST Location	NA	NA
Transposition Maximum SST	NA	
Transposition Adjustment Factor	#VALUE!	
Average Basin Elevation	NA	
Highest Elevation in Basin	NA	
Inflow Barrier Height	N/A	
Elevation Adjustment Factor	#VALUE!	
Total Adjustment Factor	#VALUE!	

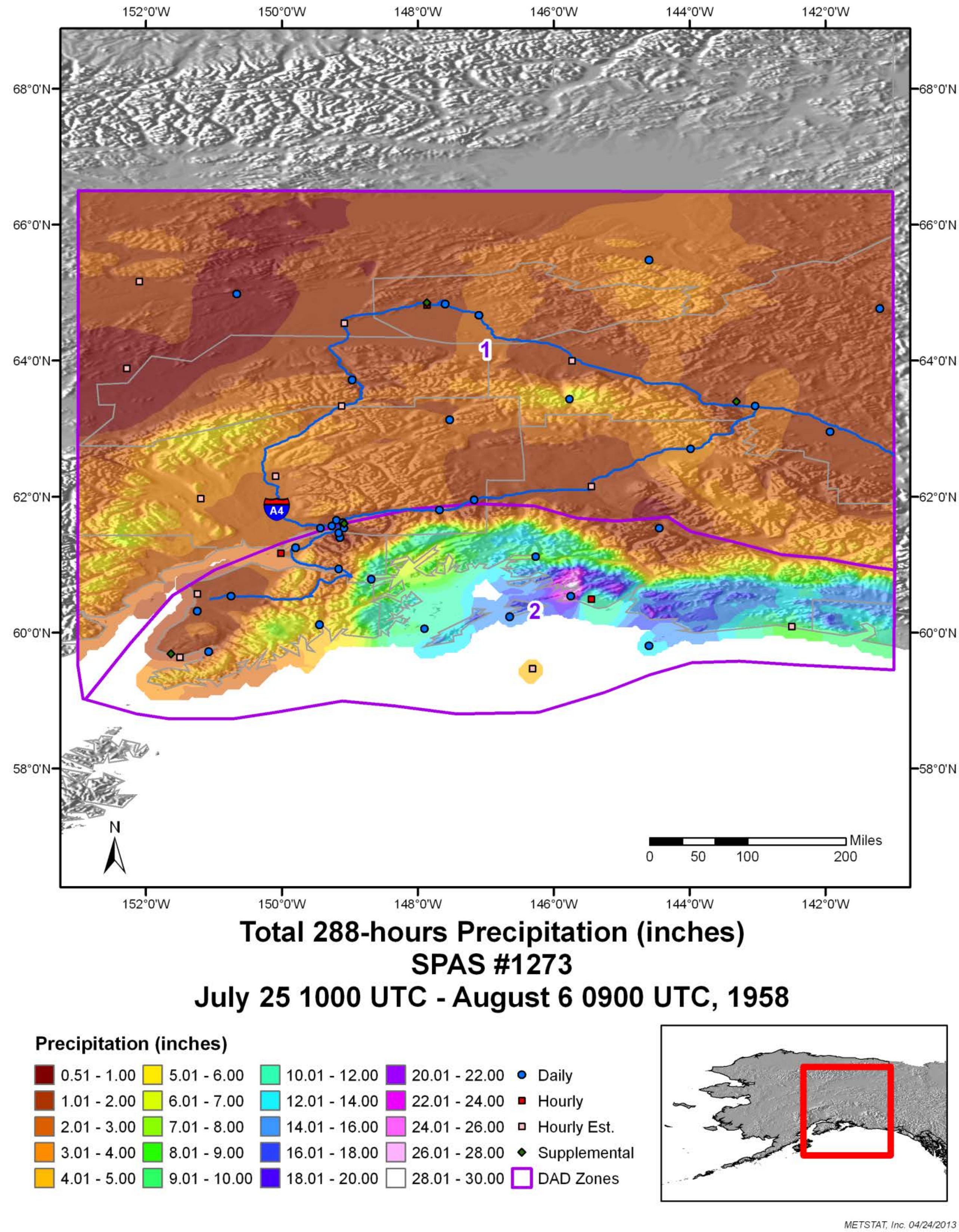
SPAS 1273 South-central AK Storm Analysis
July 26 - August 2, 1958



Storm 1273 - Jul. 25 (1000 UTC) - Aug. 6 (0900 UTC), 1958																	
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)																	
	Duration (hours)																
Area (mi^2)	1	6	12	18	24	48	72	96	120	144	168	192	216	240	264	288	Total
0.2	0.45	1.84	2.41	2.81	2.81	3.23	3.44	4.07	5.02	5.4	6.18	6.28	6.29	6.52	6.62	6.62	6.62
1	0.45	1.81	2.35	2.7	2.7	3.12	3.34	3.97	4.87	5.27	6.02	6.12	6.13	6.35	6.46	6.46	6.46
10	0.45	1.81	2.35	2.7	2.7	3.12	3.34	3.97	4.87	5.27	6.02	6.12	6.13	6.35	6.46	6.46	6.46
25	0.45	1.81	2.35	2.7	2.7	3.12	3.34	3.97	4.87	5.27	6.02	6.12	6.13	6.35	6.46	6.46	6.46
50	0.44	1.8	2.35	2.7	2.7	3.12	3.26	3.88	4.75	5.15	5.89	5.98	5.99	6.21	6.46	6.46	6.46
100	0.43	1.77	2.35	2.7	2.7	3.12	3.16	3.74	4.62	4.96	5.67	5.77	5.78	5.97	6.35	6.42	6.42
150	0.43	1.74	2.34	2.7	2.7	3.12	3.14	3.61	4.51	4.82	5.51	5.61	5.61	5.74	6.3	6.34	6.34
200	0.42	1.73	2.33	2.7	2.7	3.11	3.12	3.57	4.42	4.74	5.4	5.45	5.5	5.7	6.21	6.26	6.26
300	0.41	1.71	2.3	2.68	2.69	3.08	3.09	3.43	4.25	4.58	5.21	5.29	5.43	5.52	6.04	6.15	6.15
400	0.41	1.69	2.27	2.66	2.66	3.05	3.06	3.38	4.14	4.44	5.05	5.2	5.2	5.46	6.03	6.05	6.05
500	0.4	1.67	2.22	2.63	2.64	3	3.03	3.28	4.03	4.31	4.9	5.14	5.17	5.38	5.88	5.98	5.98
1,000	0.38	1.6	2.18	2.55	2.55	2.91	2.92	3.08	3.68	3.85	4.42	4.84	4.94	5.22	5.68	5.73	5.73
2,000	0.34	1.51	2.08	2.42	2.43	2.78	2.8	2.91	3.32	3.62	4.19	4.52	4.67	4.86	5.35	5.45	5.45
5,000	0.31	1.33	1.83	2.09	2.11	2.41	2.49	2.7	3	3.27	3.73	4.06	4.11	4.47	4.89	4.89	4.89
10,000	0.26	1.06	1.57	1.82	1.82	2.08	2.3	2.49	2.63	2.86	3.31	3.62	3.69	4.01	4.37	4.38	4.38
20,000	0.2	0.84	1.37	1.59	1.6	1.83	2.02	2.16	2.37	2.6	3.02	3.21	3.41	3.53	3.82	3.87	3.87
50,000	0.13	0.54	0.95	1.15	1.17	1.41	1.59	1.82	1.96	2.21	2.46	2.61	2.62	2.9	2.98	3.1	3.10
100,000	0.08	0.27	0.56	0.66	0.67	0.98	1.25	1.44	1.59	1.77	1.94	2.06	2.15	2.3	2.38	2.44	2.44
132,242	0.05	0.24	0.43	0.55	0.64	0.81	1.02	1.26	1.43	1.58	1.74	1.86	1.91	1.99	2.09	2.09	2.09


SPAS #1273 DAD Curve s Zone 1 (both storms)
July 25-Aug 6, 1958
Area (mi²)
Maximum Average Depth of Precipitation (inches)
1-hour
6-hour
12-hour
18-hour
24-hour
48-hour
72-hour
96-hour
120-hour
144-hour
168-hour
192-hour
216-hour
240-hour
264-hour
288-hour
Total storm (240-hour)


SPAS 1273 Storm Center Mass Curve: Zone 1
July 25 (1000 UTC) - August 6 (0900 UTC), 1958
Lat: 61.3458 Lon: -152.3292
Incremental
Accumulated
6.62"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour



Total 288-hours Precipitation (inches)
SPAS #1273
July 25 1000 UTC - August 6 0900 UTC, 1958

Little Susitna, AK, SPAS 1271 Zone 1
August 18, 1959

Storm Name:	Little Susitna-SPAS 1271 Zone 1	Storm Adjustment for Susitna-Watana
Storm Date:	8/18-26/1959	
AWA Analysis Date:	3/28/2013	

Temporal Transposition Date	15-Aug	
	Lat	Long
Storm center location	61.85 N	149.23 W
Storm Rep SST location	52.00 N	154.00 W
Transposition SST location	NA	NA
Basin location	42.76 N	74.12 W

Moisture Inflow Direction:	SSW @ 700	miles
Basin Elevation	NA	feet
Storm Elevation	5,150	feet
Storm Duration	24	hours
Effective Barrier Height	NA	feet

The storm representative SST is	52.0 F	with total precipitable water above sea level of			0.92	inches.
The in-place maximum SST is	56.0 F	with total precipitable water above sea level of			1.13	inches.
The transpositioned maximum SST is	NA	with total precipitable water above sea level of			4.44	inches.
The in-place storm elevation is	5,150	which subtracts	0.48	inches of precipitable water at	52.0 F	
The in-place storm elevation is	5,150	which subtracts	0.56	inches of precipitable water at	56.0 F	
The transposition storm elevation at	NA	which subtracts	xx	inches of precipitable water at	NA	
The moisture inflow barrier height is	NA	which subtracts	xx	inches of precipitable water at	NA	

The in-place maximization factor is	1.30
The transposition/elevation factor is	#VALUE!
The barrier adjustment factor is	#VALUE!
The total adjustment factor is	#VALUE!

Notes: Storm representative SST value was based on SST values for August 21-22, 1959 along the HYSPLIT trajectory data. Values were selected in region where temperature did not vary more than a 1-degree over a large area and had temperature recordings throughout the period.

Observed Storm Depth-Area-Duration

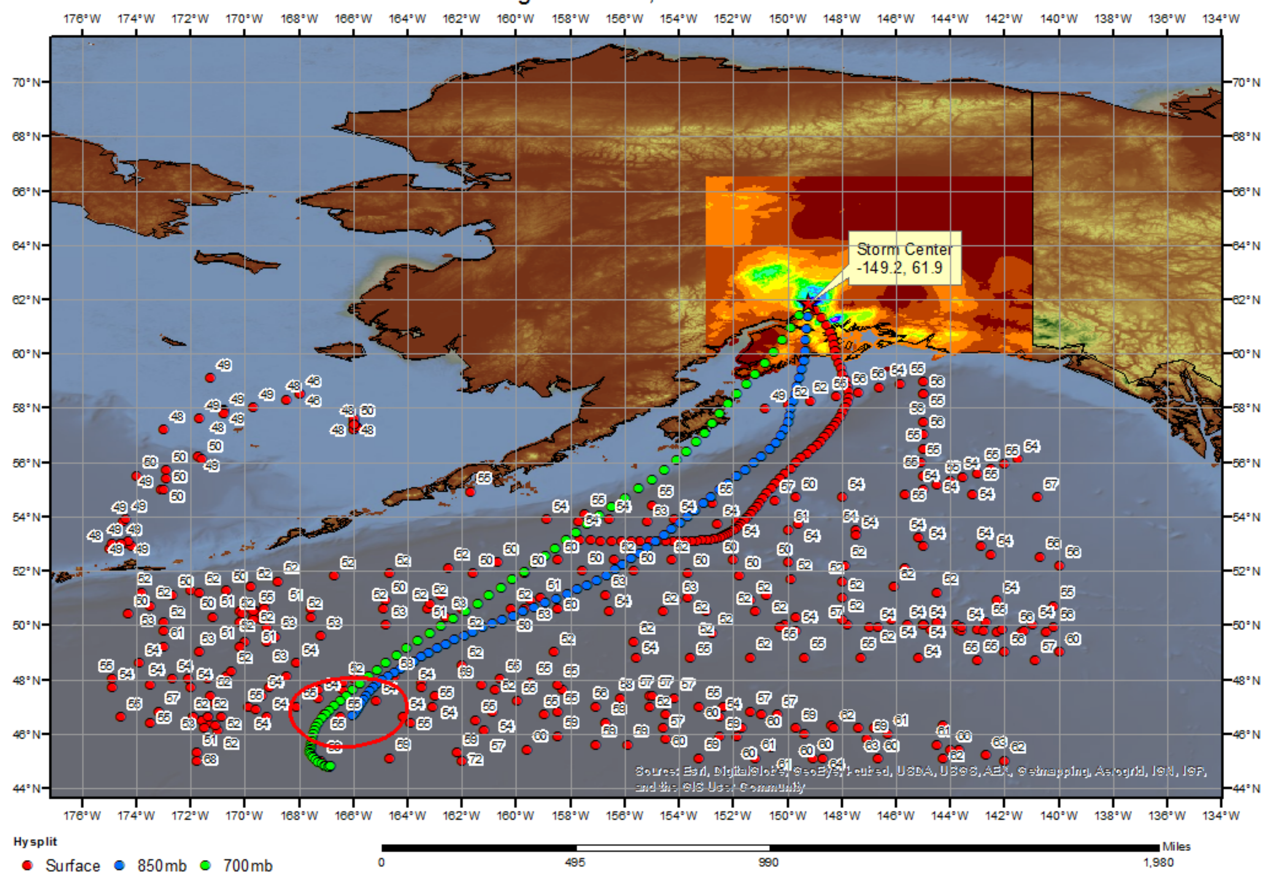
	6 Hours	12 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours	168 Hours	192 Hours
10 sq miles	3.8	5.2	7.2	8.8	9.6	10.3	10.5	11.3	11.5	12.7	12.7
100 sq miles	3.5	4.8	6.8	8.3	9.0	9.8	10.0	10.8	10.9	12.2	12.3
200 sq miles	3.2	4.4	6.4	7.7	8.4	9.3	9.4	10.1	10.4	11.4	11.8
500 sq miles	2.5	3.8	5.7	6.4	7.6	8.4	8.6	9.0	9.6	10.6	10.8
1000 sq miles	2.5	3.3	5.1	6.3	7.0	7.7	7.9	8.3	8.9	9.7	9.9
2000 sq miles	2.0	2.9	4.4	5.2	6.0	6.8	6.9	7.2	7.9	8.8	8.9
5000 sq miles	1.5	2.0	3.3	3.9	4.6	5.2	5.3	5.7	6.1	7.2	7.2
10000 sq miles	1.1	1.3	1.9	2.9	3.1	3.9	4.0	4.3	4.4	5.8	5.9
20000 sq miles	0.6	1.0	1.6	2.1	2.5	2.5	2.5	2.5	3.8	4.4	4.4

Adjusted Storm Depth-Area-Duration

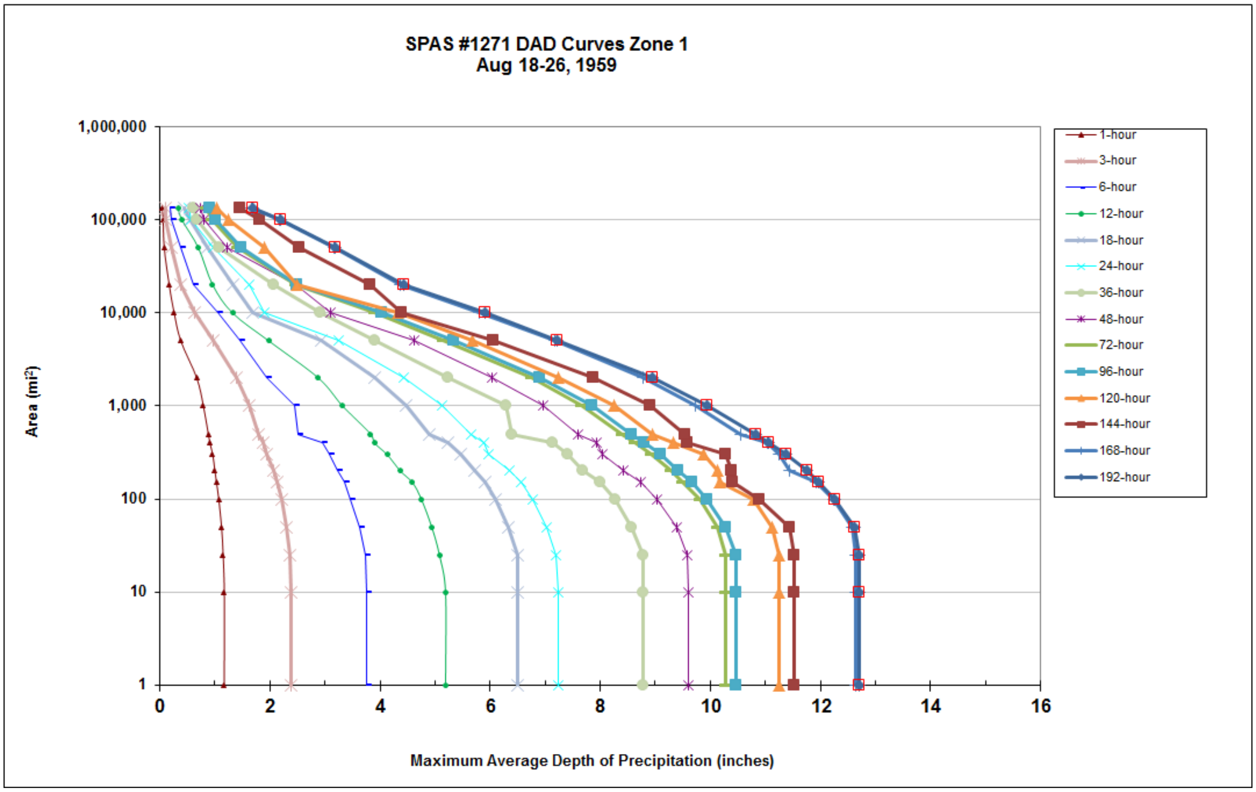
	6 Hours	12 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours	168 Hours	192 Hours
10 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
100 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
200 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
500 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
1000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
2000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
5000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
10000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
20000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!

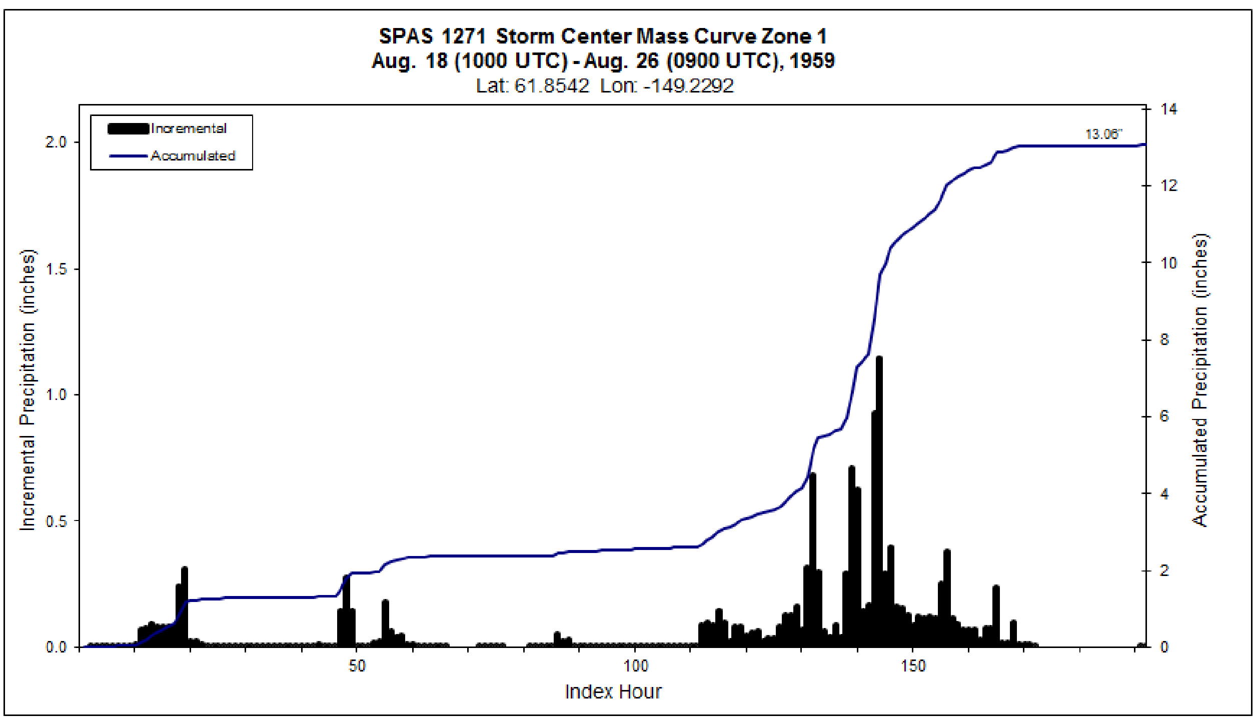
Storm or Storm Center Name	**Little Susitna-SPAS 1271 Zone 1**			
Storm Date(s)	8/18-26/1959			
Storm Type	Series of Low Pressure Systems and Associated Storms			
Storm Location	61.85 N	149.23 W		
Storm Center Elevation	5150			
Precipitation Total & Duration	13.06 inches in 192 hours			
Storm Representative SST	52.0 F		15-Aug	15-Sep
Storm Representative SST Location	52.00 N	154.00 W	56	55.5
In-place Maximum SST	56.0 F			
Moisture Inflow Vector	SSW @ 700			
In-place Maximization Factor	1.30			
Temporal Transposition (Date)	15-Aug			
Transposition SST Location	NA	NA		
Transposition Maximum SST	NA			
Transposition Adjustment Factor	#VALUE!			
Average Basin Elevation	NA			
Highest Elevation in Basin	NA			
Inflow Barrier Height	NA			
Elevation Adjustment Factor	#VALUE!			
Total Adjustment Factor	#VALUE!			

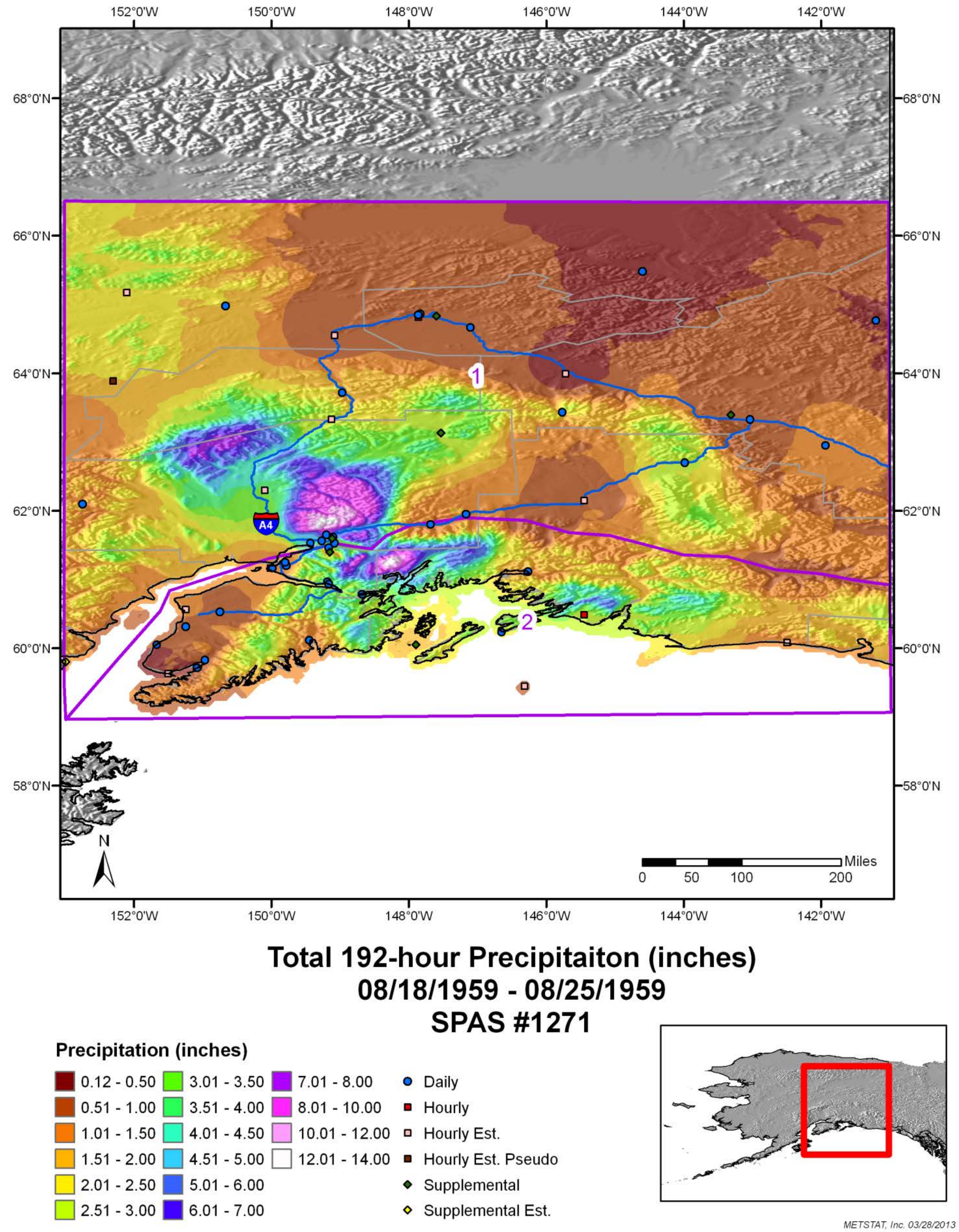
SPAS 1271 Gateway, AK Storm Analysis
August 18 - 26, 1955



Storm 1271 - Aug. 18 (1000 UTC) - Aug. 26 (0900 UTC), 1959															
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)															
	Duration (hours)														
Area (mi^2)	1	3	6	12	18	24	36	48	72	96	120	144	168	192	Total
0.2	1.19	2.44	3.84	5.33	6.7	7.41	9.04	9.86	10.59	10.74	11.58	11.86	13.03	13.06	13.06
1	1.17	2.38	3.76	5.19	6.51	7.23	8.78	9.61	10.29	10.47	11.25	11.53	12.65	12.71	12.71
10	1.17	2.38	3.76	5.19	6.51	7.23	8.78	9.61	10.29	10.47	11.25	11.53	12.65	12.71	12.71
25	1.15	2.37	3.73	5.08	6.51	7.2	8.78	9.59	10.29	10.47	11.25	11.53	12.65	12.71	12.71
50	1.12	2.31	3.63	4.94	6.34	7.03	8.57	9.4	10.14	10.28	11.13	11.44	12.59	12.62	12.62
100	1.07	2.21	3.47	4.75	6.11	6.78	8.27	9.03	9.81	9.95	10.79	10.9	12.24	12.27	12.27
150	1.03	2.13	3.35	4.59	5.92	6.56	7.99	8.74	9.5	9.67	10.17	10.4	11.92	11.96	11.96
200	1	2.06	3.23	4.37	5.73	6.35	7.69	8.42	9.29	9.41	10.14	10.38	11.43	11.76	11.76
300	0.96	1.95	3.08	4.13	5.46	5.98	7.4	8.04	8.93	9.1	9.88	10.27	11.26	11.38	11.38
400	0.91	1.87	2.95	3.9	5.23	5.88	7.14	7.93	8.64	8.81	9.32	9.59	11.04	11.07	11.07
500	0.88	1.8	2.51	3.83	4.9	5.65	6.4	7.6	8.4	8.56	8.95	9.55	10.55	10.82	10.82
1,000	0.79	1.63	2.45	3.32	4.48	5.13	6.29	6.97	7.66	7.85	8.26	8.91	9.73	9.94	9.94
2,000	0.67	1.39	1.95	2.88	3.9	4.44	5.23	6.04	6.75	6.91	7.24	7.87	8.79	8.94	8.94
5,000	0.38	0.97	1.46	1.98	2.93	3.26	3.9	4.62	5.15	5.34	5.68	6.06	7.18	7.21	7.21
10,000	0.26	0.64	1.05	1.32	1.69	1.89	2.91	3.1	3.9	4.03	4.32	4.39	5.8	5.9	5.90
20,000	0.17	0.37	0.62	0.96	1.32	1.62	2.06	2.47	2.47	2.48	2.48	3.83	4.37	4.44	4.44
50,000	0.08	0.22	0.38	0.7	0.87	0.97	1.08	1.22	1.42	1.48	1.89	2.54	3.17	3.18	3.18
100,000	0.06	0.11	0.22	0.4	0.54	0.57	0.68	0.81	0.94	1.01	1.24	1.81	2.17	2.19	2.19
132,207	0.04	0.1	0.19	0.33	0.44	0.52	0.61	0.74	0.85	0.91	1.04	1.45	1.67	1.69	1.69


SPAS #1271 DAD Curves Zone 1
Aug 18-26, 1959
Area (mi²)
Maximum Average Depth of Precipitation (inches)
1-hour
3-hour
6-hour
12-hour
18-hour
24-hour
36-hour
48-hour
72-hour
96-hour
120-hour
144-hour
168-hour
192-hour


SPAS 1271 Storm Center Mass Curve Zone 1
Aug. 18 (1000 UTC) - Aug. 26 (0900 UTC), 1959
Lat: 61.8542 Lon: -149.2292
Incremental
Accumulated
13.06"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour


152°0'W
150°0'W
148°0'W
146°0'W
144°0'W
142°0'W
68°0'N
66°0'N
64°0'N
62°0'N
60°0'N
58°0'N
1
2
A4
N
Miles
0 50 100 200
Total 192-hour Precipitaiton (inches)
08/18/1959 - 08/25/1959
SPAS #1271
Precipitation (inches)
0.12 - 0.50
0.51 - 1.00
1.01 - 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.00
3.01 - 3.50
3.51 - 4.00
4.01 - 4.50
4.51 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 10.00
10.01 - 12.00
12.01 - 14.00
Daily
Hourly
Hourly Est.
Hourly Est. Pseudo
Supplemental
Supplemental Est.
METSTAT, Inc. 03/28/2013

Denali NP, AK, SPAS 1270 Zone 2
August 2, 1967

Storm Name:	SPAS 1270-Fairbanks-DAD Zone	Storm Adjustment for Susitna-Watana
Storm Date:	8/2-17/1967	
AWA Analysis Date:	2/4/2013	

Temporal Transposition Date	15-Aug	
	Lat	Long
Storm center location	62.84 N	150.51 W
Storm Rep SST location	45.00 N	149.00 W
Transposition SST location	NA	NA
Basin location	62.84 N	147.37 W

Moisture Inflow Direction:	SSE @ 910	miles
Basin Elevation	3,650	feet
Storm Elevation	5,080	feet
Storm Duration	24	hours
Effective Barrier Height	1,483	feet

The storm representative SST is	61.0 F	with total precipitable water above sea level of			1.45	inches.
The in-place maximum SST is	62.5 F	with total precipitable water above sea level of			1.56	inches.
The transpositioned maximum SST is	NA	with total precipitable water above sea level of			4.44	inches.
The in-place storm elevation is	5,080	which subtracts	0.66	inches of precipitable water at	61.0 F	
The in-place storm elevation is	5,080	which subtracts	0.70	inches of precipitable water at	62.5 F	
The transposition storm elevation at	3,650	which subtracts	xx	inches of precipitable water at	NA	
The moisture inflow barrier height is	1,483	which subtracts	xx	inches of precipitable water at	NA	

The in-place maximization factor is	1.09
The transposition/elevation factor is	#VALUE!
The barrier adjustment factor is	#VALUE!
The total adjustment factor is	#VALUE!

Notes: Storm representative SST value was based on SST values for August 7-12, 1967 along the surface HYSPLIT trajectory data. Values were selected in region where temperature did not vary more than a 1-degree over a large area and had temperature recordings throughout the period.

Observed Storm Depth-Area-Duration

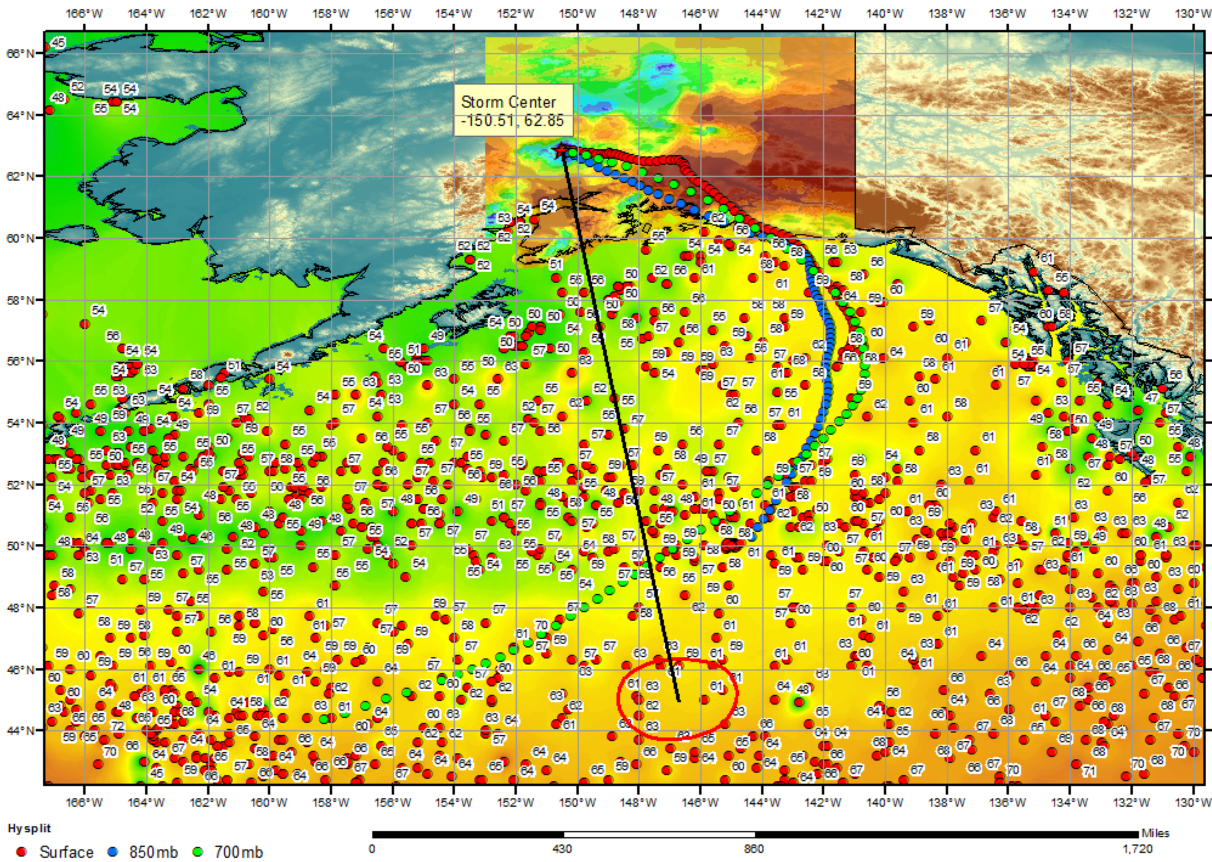
	6 Hours	12 Hours	24 Hours	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours	168 Hours	192 Hours	216 Hours	240 Hours
10 sq miles	1.6	2.2	2.9	4.5	6.4	7.6	8.5	9.5	10.6	11.4	12.0	12.1
100 sq miles	1.6	2.1	2.8	4.4	6.2	7.4	8.2	9.1	10.2	11.0	11.6	11.8
200 sq miles	1.5	2.0	2.7	4.3	6.1	7.2	8.0	8.9	10.0	10.7	11.4	11.5
500 sq miles	1.4	1.9	2.5	4.0	5.7	6.6	7.5	8.3	9.3	10.1	10.5	10.8
1000 sq miles	1.3	1.8	2.4	3.8	5.3	6.3	7.0	7.8	8.8	9.4	9.9	10.1
2000 sq miles	1.1	1.6	2.2	3.5	4.9	5.8	6.4	7.2	8.0	8.6	9.1	9.3
5000 sq miles	0.9	1.3	1.8	2.9	3.8	4.7	5.2	5.7	6.5	7.0	7.5	7.6
10000 sq miles	0.7	1.0	1.5	2.4	3.0	3.8	4.2	4.6	5.2	5.4	6.0	6.1
20000 sq miles	0.5	0.7	1.0	1.7	2.2	2.7	3.1	3.4	3.8	4.1	4.4	4.4

Adjusted Storm Depth-Area-Duration

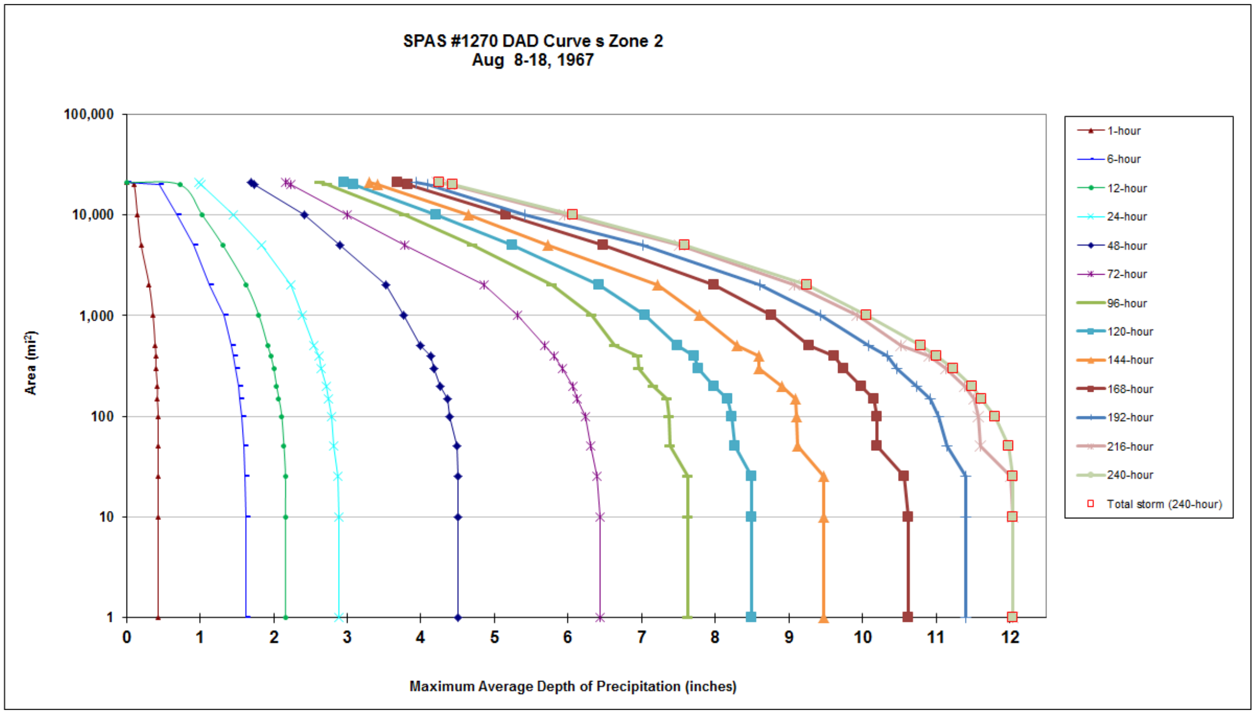
	6 Hours	12 Hours	24 Hours	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours	168 Hours	192 Hours	216 Hours	240 Hours
10 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
100 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
200 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
500 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
1000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
2000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
5000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
10000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
20000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!

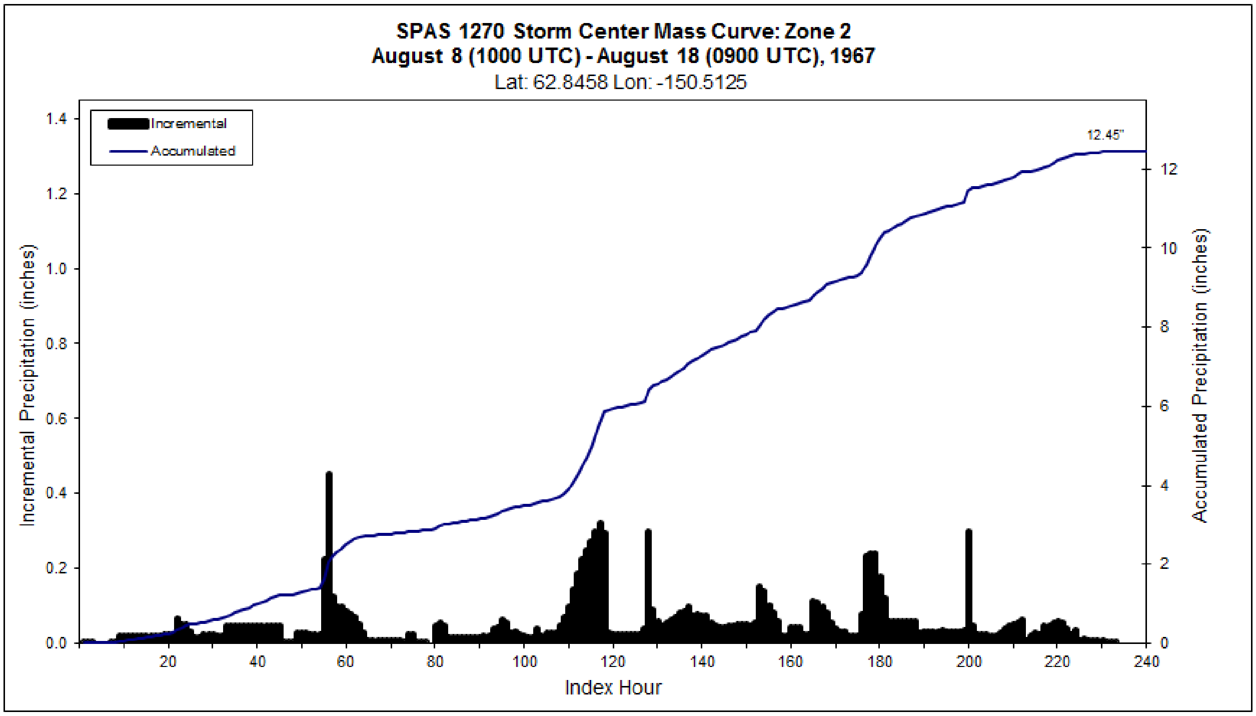
Storm or Storm Center Name	**SPAS 1270-Fairbanks-DAD Zone 2**		
Storm Date(s)	8/2-17/1967		
Storm Type	Storms and Atmospheric River Episodes		
Storm Location	62.84 N	150.51 W	
Storm Center Elevation	5080		
Precipitation Total & Duration	6.4 inches in 72 hours		
Storm Representative SST	61.0 F		
Storm Representative SST Location	45.00 N	149.00 W	15-Aug
In-place Maximum SST	62.5 F		62.5
Moisture Inflow Vector	SSE @ 910		
In-place Maximization Factor	1.09		
Temporal Transposition (Date)	15-Aug		
Transposition SST Location	NA	NA	
Transposition Maximum SST	NA		
Transposition Adjustment Factor	#VALUE!		
Average Basin Elevation	3,650		
Highest Elevation in Basin	13,131		
Inflow Barrier Height	1,483		
Elevation Adjustment Factor	#VALUE!		
Total Adjustment Factor	#VALUE!		

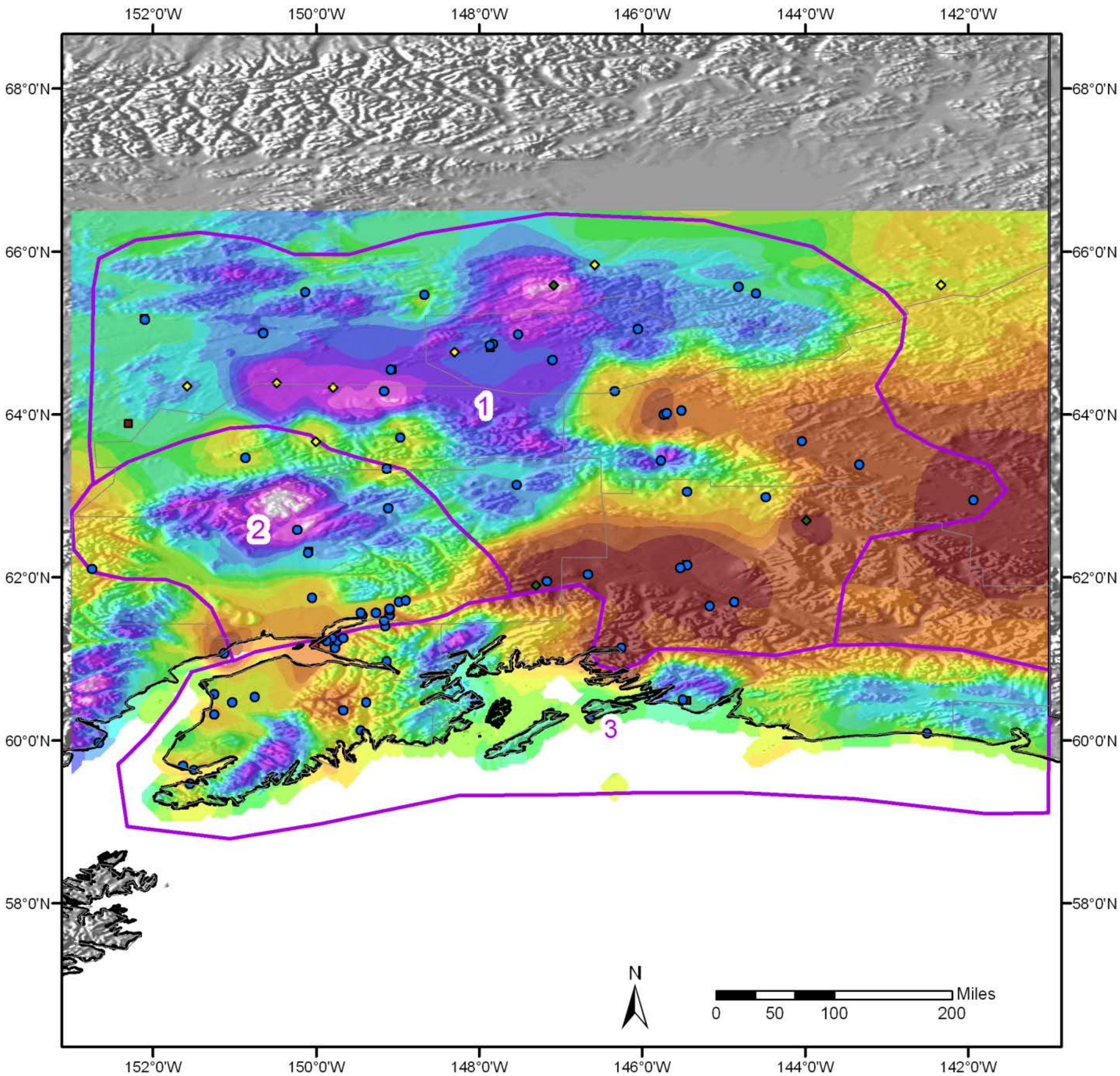
SPAS 1270 Fairbanks, AK Storm Analysis
August 11 - 16, 1967



Storm 1270 - Aug. 8 (1000 UTC) - Aug. 18 (0900 UTC), 1967														
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)														
	Duration (hours)													
Area (mi^2)	1	6	12	24	48	72	96	120	144	168	192	216	240	Total
0.2	0.45	1.66	2.24	2.95	4.67	6.59	7.91	8.78	9.74	10.91	11.75	12.36	12.45	12.45
1	0.43	1.62	2.16	2.89	4.5	6.43	7.63	8.49	9.47	10.63	11.4	12.04	12.05	12.05
10	0.43	1.62	2.16	2.89	4.5	6.43	7.63	8.49	9.47	10.63	11.4	12.04	12.05	12.05
25	0.43	1.61	2.16	2.87	4.5	6.4	7.63	8.49	9.47	10.57	11.4	12.01	12.05	12.05
50	0.43	1.6	2.14	2.82	4.49	6.31	7.39	8.27	9.12	10.2	11.15	11.61	11.98	11.98
100	0.43	1.56	2.11	2.79	4.39	6.23	7.37	8.22	9.11	10.2	11.04	11.58	11.8	11.80
150	0.42	1.54	2.07	2.75	4.37	6.13	7.35	8.17	9.09	10.15	10.92	11.52	11.62	11.62
200	0.42	1.52	2.04	2.71	4.27	6.07	7.16	7.99	8.9	9.99	10.74	11.39	11.49	11.49
300	0.4	1.48	2	2.65	4.18	5.92	6.96	7.77	8.59	9.75	10.47	11.13	11.23	11.23
400	0.4	1.45	1.96	2.61	4.13	5.81	6.94	7.72	8.59	9.61	10.34	10.91	11	11.00
500	0.39	1.43	1.92	2.54	4	5.69	6.64	7.49	8.29	9.27	10.08	10.52	10.8	10.80
1,000	0.36	1.33	1.8	2.39	3.77	5.31	6.32	7.04	7.78	8.77	9.43	9.93	10.06	10.06
2,000	0.31	1.13	1.63	2.24	3.53	4.86	5.78	6.42	7.21	7.99	8.61	9.08	9.25	9.25
5,000	0.2	0.92	1.31	1.84	2.9	3.78	4.71	5.24	5.72	6.48	7.02	7.51	7.59	7.59
10,000	0.15	0.69	1.03	1.45	2.42	3	3.78	4.2	4.64	5.16	5.42	5.95	6.07	6.07
20,000	0.1	0.45	0.73	1.01	1.74	2.23	2.73	3.08	3.41	3.83	4.09	4.39	4.43	4.43
21,152	0	0	0	0.98	1.69	2.16	2.63	2.96	3.3	3.68	3.94	4.22	4.25	4.25


SPAS #1270 DAD Curve s Zone 2
Aug 8-18, 1967
100,000
10,000
1,000
100
10
1
Area (mi²)
0
1
2
3
4
5
6
7
8
9
10
11
12
Maximum Average Depth of Precipitation (inches)
1-hour
6-hour
12-hour
24-hour
48-hour
72-hour
96-hour
120-hour
144-hour
168-hour
192-hour
216-hour
240-hour
Total storm (240-hour)


SPAS 1270 Storm Center Mass Curve: Zone 2
August 8 (1000 UTC) - August 18 (0900 UTC), 1967
Lat: 62.8458 Lon: -150.5125
Incremental
Accumulated
12.45"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0
2
4
6
8
10
12
20
40
60
80
100
120
140
160
180
200
220
240

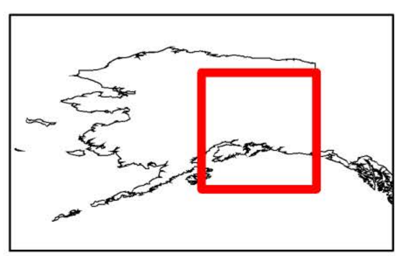


Total Storm (240-hr) Precipitation (inches)
August 8-17, 1967 - "The Great Fairbanks Flood"
SPAS #1270

Precipitation (inches)

- 0.00 - 0.50
- 0.51 - 1.00
- 1.01 - 1.50
- 1.51 - 2.00
- 2.01 - 2.50
- 2.51 - 3.00
- 3.01 - 3.50
- 3.51 - 4.00
- 4.01 - 4.50
- 4.51 - 5.00
- 5.01 - 6.00
- 6.01 - 7.00
- 7.01 - 8.00
- 8.01 - 9.00
- 9.01 - 10.00
- 10.01 - 11.00
- 11.01 - 12.00

- Daily
- Hourly
- Hourly Est. Psuedo
- Supplemental
- Supplemental Est.



METSTAT, Inc. 02/04/2013

Fairbanks, AK, SPAS 1270 Zone 1
August 2, 1967

Storm Name:	SPAS 1270-Fairbanks-DAD Zone	Storm Adjustment for Alaska
Storm Date:	8/2-17/1967	
AWA Analysis Date:	2/4/2013	

Temporal Transposition Date	15-Aug	
	Lat	Long
Storm center location	65.52 N	147.33 W
Storm Rep SST location	45.00 N	149.00 W
Transposition SST location	34.45 N	71.97 W
Basin location	62.84 N	147.37 W

Moisture Inflow Direction:	S @ 1,420	miles
Basin Elevation	3,650	feet
Storm Elevation	7,600	feet
Storm Duration	24	hours
Effective Barrier Height	1,483	feet

The storm representative SST is	61.0 F	with total precipitable water above sea level of			1.45	inches.
The in-place maximum SST is	62.5 F	with total precipitable water above sea level of			1.56	inches.
The transpositioned maximum SST is	83.0 F	with total precipitable water above sea level of			4.06	inches.
The in-place storm elevation is	7,600	which subtracts	0.80	inches of precipitable water at	61.0 F	
The in-place storm elevation is	7,600	which subtracts	0.83	inches of precipitable water at	62.5 F	
The transposition storm elevation at	3,650	which subtracts	xx	inches of precipitable water at	83.0 F	
The moisture inflow barrier height is	1,483	which subtracts	xx	inches of precipitable water at	83.0 F	

The in-place maximization factor is	1.12
The transposition/elevation factor is	#VALUE!
The barrier adjustment factor is	#VALUE!
The total adjustment factor is	#VALUE!

Notes: Storm representative SST value was based on SST values for August 7-12, 1967 along the surface HYSPLIT trajectory data. Values were selected in region where temperature did not vary more than a 1-degree over a large area and had temperature recordings throughout the period.

Observed Storm Depth-Area-Duration

	6 Hours	12 Hours	24 Hours	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours	168 Hours	192 Hours	216 Hours	240 Hours
10 sq miles	2.0	3.3	5.2	7.3	8.3	8.8	9.4	9.9	10.2	10.2	10.3	10.3
100 sq miles	1.9	3.2	5.1	7.2	8.2	8.6	9.4	9.8	9.9	10.0	10.2	10.3
200 sq miles	1.9	3.1	4.9	7.0	8.0	8.5	9.1	9.6	9.8	9.9	10.1	10.1
500 sq miles	1.8	2.9	4.7	6.5	7.6	8.2	8.8	9.3	9.5	9.5	9.7	9.8
1000 sq miles	1.7	2.8	4.5	6.4	7.4	7.8	8.4	9.0	9.1	9.2	9.4	9.5
2000 sq miles	1.6	2.6	4.3	6.1	7.1	7.5	7.9	8.6	8.7	9.0	9.1	9.2
5000 sq miles	1.5	2.4	3.9	5.7	6.3	7.1	7.4	7.9	8.2	8.3	8.5	8.6
10000 sq miles	1.3	2.2	3.6	5.0	6.0	6.5	6.8	7.4	7.6	7.8	8.0	8.0
20000 sq miles	1.1	1.9	3.0	4.3	5.1	5.6	6.1	6.5	6.9	7.0	7.1	7.2

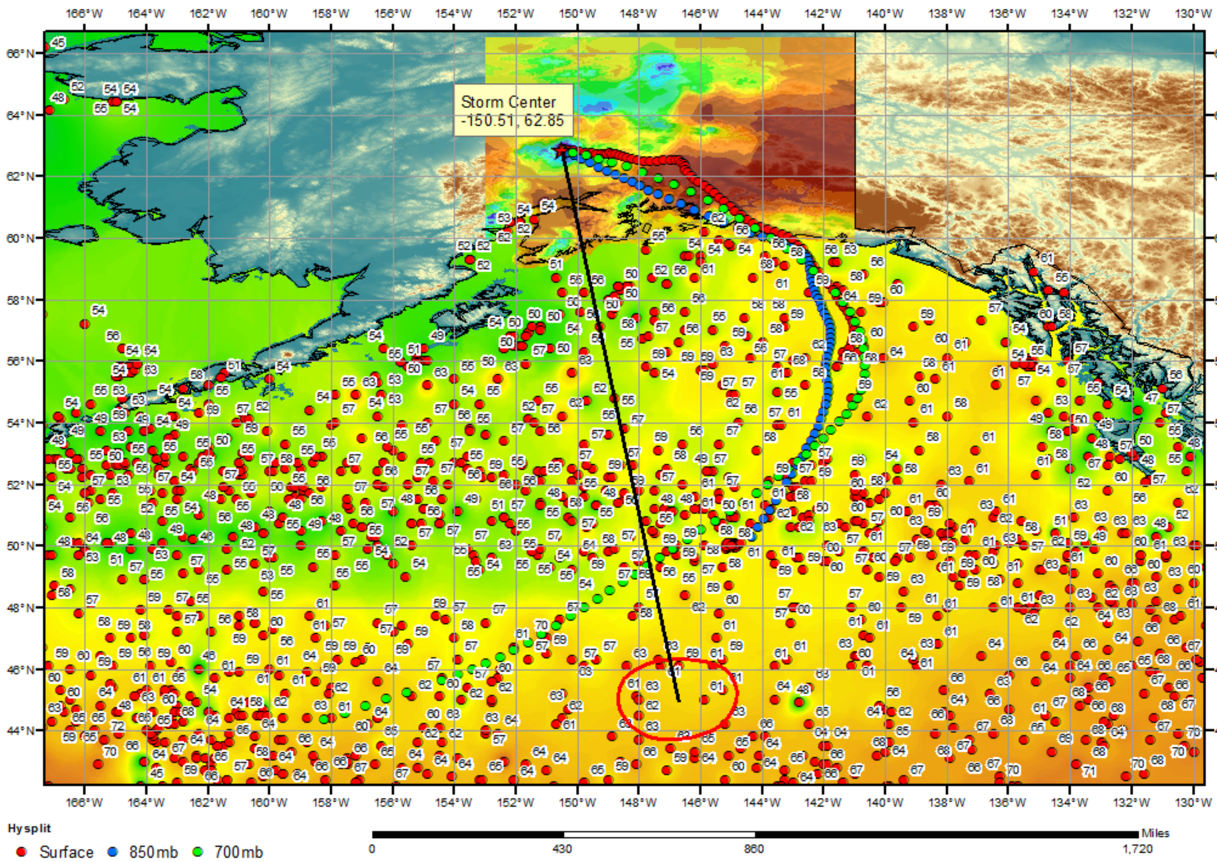
Adjusted Storm Depth-Area-Duration

	6 Hours	12 Hours	24 Hours	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours	168 Hours	192 Hours	216 Hours	240 Hours
10 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
100 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
200 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
500 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
1000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
2000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
5000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
10000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
20000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!

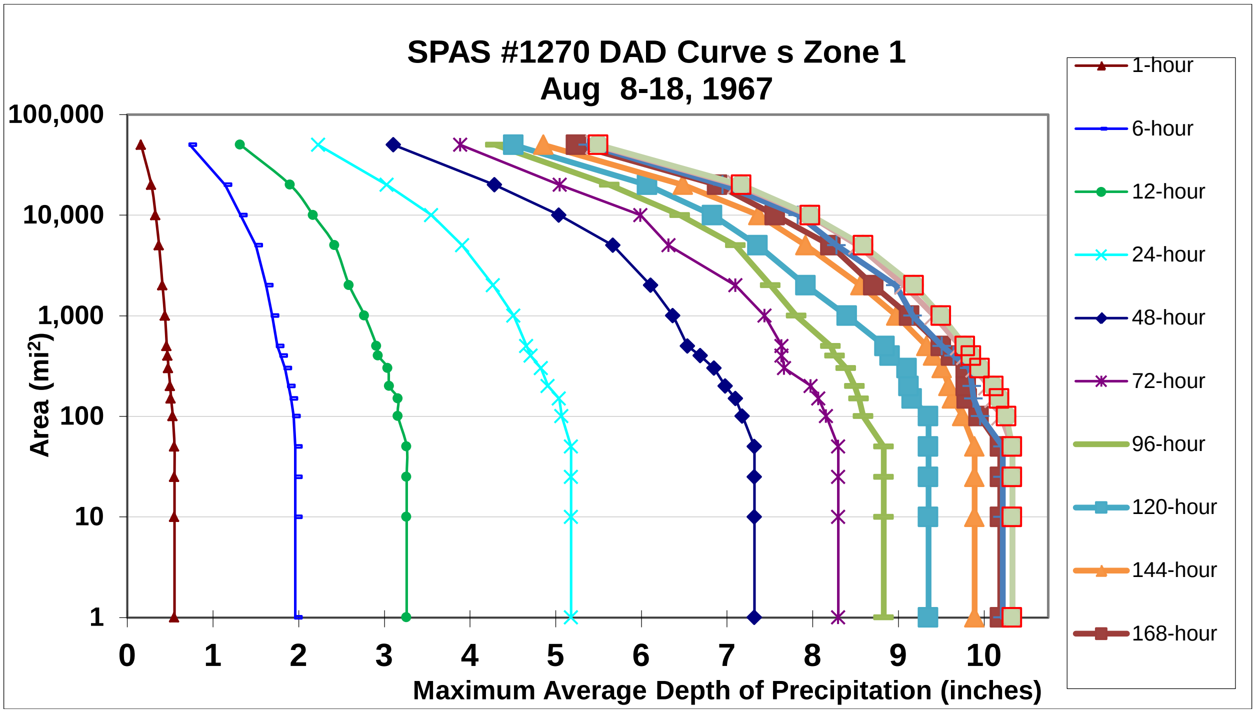
Storm or Storm Center Name	SPAS 1270-Fairbanks-DAD Zone 1		
Storm Date(s)	8/2-17/1967		
Storm Type	Storms and Atmospheric River Episodes		
Storm Location	65.52 N	147.33 W	
Storm Center Elevation	7600		
Precipitation Total & Duration	6.4 inches in 72 hours		
Storm Representative SST	61.0 F		
Storm Representative SST Location	45.00 N	149.00 W	15-Aug
In-place Maximum SST	62.5 F		62.73
Moisture Inflow Vector	SSE @ 910		
In-place Maximization Factor	1.12		
Temporal Transposition (Date)	15-Aug		
Transposition SST Location	34.45 N	71.97 W	
Transposition Maximum SST	83.0 F		
Transposition Adjustment Factor	#VALUE!		
Average Basin Elevation	3,650		
Highest Elevation in Basin	13,131		
Inflow Barrier Height	1,483		
Elevation Adjustment Factor	#VALUE!		
Total Adjustment Factor	#VALUE!		

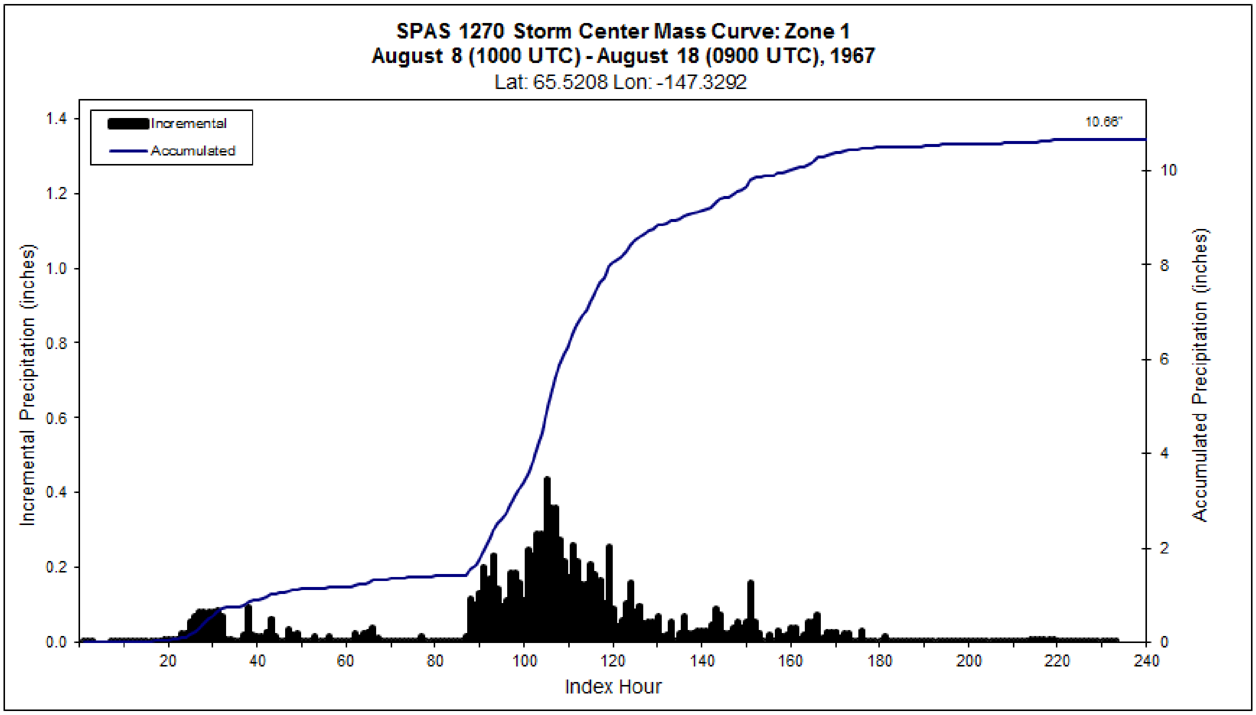
SPAS 1270 Fairbanks, AK Storm Analysis

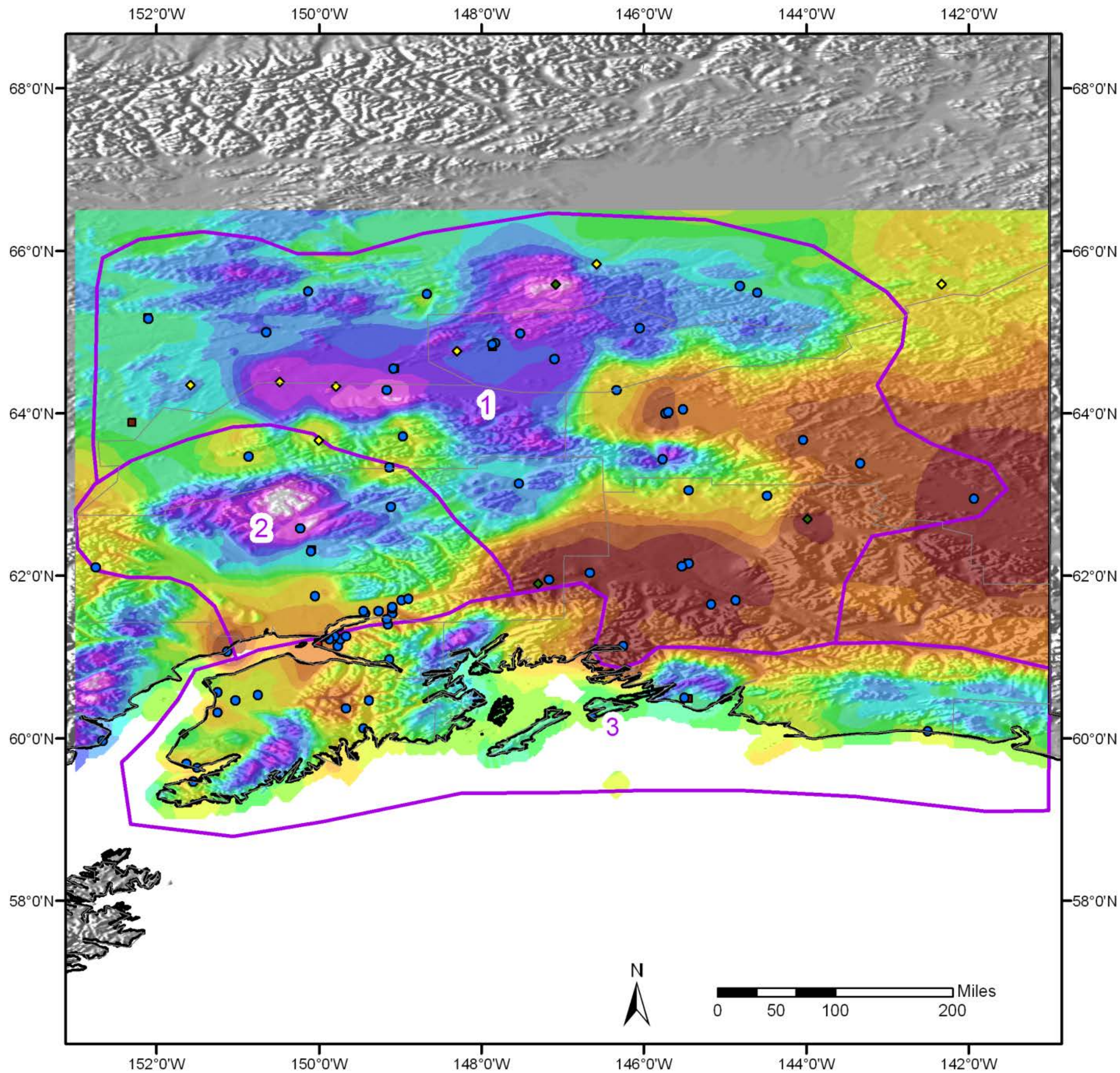
August 11 - 16, 1967



Storm 1270 - Aug. 8 (1000 UTC) - Aug. 18 (0900 UTC), 1967														
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)														
	Duration (hours)													
Area (mi^2)	1	6	12	24	48	72	96	120	144	168	192	216	240	Total
0.3	0.58	2.04	3.37	5.36	7.54	8.55	9.1	9.71	10.21	10.5	10.56	10.65	10.66	10.66
1	0.55	1.96	3.26	5.18	7.32	8.3	8.83	9.35	9.89	10.19	10.22	10.33	10.33	10.33
10	0.55	1.96	3.26	5.18	7.32	8.3	8.83	9.35	9.89	10.19	10.22	10.33	10.33	10.33
25	0.55	1.96	3.26	5.18	7.32	8.3	8.83	9.35	9.89	10.19	10.22	10.33	10.33	10.33
50	0.55	1.96	3.26	5.18	7.32	8.3	8.83	9.35	9.89	10.19	10.22	10.33	10.33	10.33
100	0.53	1.94	3.16	5.07	7.18	8.16	8.59	9.35	9.75	9.94	9.96	10.2	10.26	10.26
150	0.51	1.91	3.16	5.04	7.1	8.07	8.54	9.16	9.63	9.8	9.88	10.12	10.18	10.18
200	0.5	1.88	3.06	4.91	6.98	7.98	8.49	9.12	9.59	9.79	9.86	10.05	10.11	10.11
300	0.48	1.84	3.04	4.83	6.85	7.67	8.39	9.1	9.51	9.79	9.83	9.9	9.95	9.95
400	0.47	1.79	2.93	4.71	6.69	7.64	8.26	8.9	9.41	9.62	9.65	9.79	9.85	9.85
500	0.46	1.75	2.91	4.66	6.54	7.64	8.21	8.84	9.33	9.5	9.51	9.72	9.78	9.78
1,000	0.44	1.69	2.77	4.51	6.37	7.44	7.81	8.4	8.98	9.13	9.17	9.42	9.5	9.50
2,000	0.41	1.62	2.59	4.27	6.11	7.1	7.51	7.92	8.56	8.71	8.97	9.07	9.18	9.18
5,000	0.37	1.5	2.42	3.91	5.67	6.32	7.1	7.36	7.92	8.21	8.28	8.53	8.59	8.59
10,000	0.33	1.32	2.17	3.55	5.04	5.99	6.45	6.83	7.37	7.56	7.83	7.95	7.97	7.97
20,000	0.28	1.14	1.9	3.03	4.29	5.05	5.63	6.07	6.49	6.89	6.95	7.12	7.17	7.17
50,000	0.16	0.73	1.32	2.23	3.11	3.89	4.3	4.51	4.86	5.24	5.38	5.46	5.5	5.50


SPAS #1270 DAD Curve s Zone 1
Aug 8-18, 1967
100,000
10,000
1,000
100
10
1
Area (mi²)
0
1
2
3
4
5
6
7
8
9
10
Maximum Average Depth of Precipitation (inches)
1-hour
6-hour
12-hour
24-hour
48-hour
72-hour
96-hour
120-hour
144-hour
168-hour

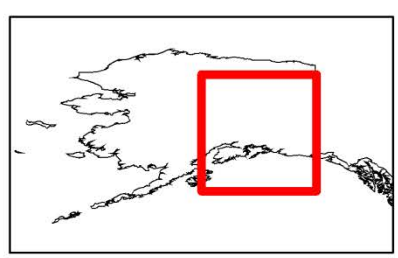

SPAS 1270 Storm Center Mass Curve: Zone 1
August 8 (1000 UTC) - August 18 (0900 UTC), 1967
Lat: 65.5208 Lon: -147.3292
Incremental
Accumulated
10.66"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour



Total Storm (240-hr) Precipitation (inches)
August 8-17, 1967 - "The Great Fairbanks Flood"
SPAS #1270

Precipitation (inches)

0.00 - 0.50	3.01 - 3.50	7.01 - 8.00	Daily
0.51 - 1.00	3.51 - 4.00	8.01 - 9.00	Hourly
1.01 - 1.50	4.01 - 4.50	9.01 - 10.00	Hourly Est. Psuedo
1.51 - 2.00	4.51 - 5.00	10.01 - 11.00	Supplemental
2.01 - 2.50	5.01 - 6.00	11.01 - 12.00	Supplemental Est.
2.51 - 3.00	6.01 - 7.00		



METSTAT, Inc. 02/04/2013

Sutton, AK, SPAS 1269 Zone 1
August 5, 1971

Storm Name:	SPAS 1269, DAD Zone 1	**Storm Adjustment for Susitna-Watana**
Storm Date:	8/5-11/1971	
AWA Analysis Date:	3/14/2014	

Temporal Transposition Date		15-Aug
	Lat	Long
Storm center location	61.90 N	148.86 W
Storm Rep SST location	38.00 N	159.70 W
Transposition SST location	NA	NA
Basin location	42.76 N	74.12 W

Moisture Inflow Direction:	SSW @ 1715	miles
Basin Elevation	3,654	feet
Storm Elevation	6,385	feet
Storm Duration	192	hours
Effective Barrier Height	1,200	feet

The storm representative SST is	71.0 F	with total precipitable water above sea level of			2.36	inches.
The in-place maximum SST is	74.0 F	with total precipitable water above sea level of			2.73	inches.
The transpositioned maximum SST is	NA	with total precipitable water above sea level of			4.44	inches.
The in-place storm elevation is	6,385	which subtracts	1.15	inches of precipitable water at	71.0 F	
The in-place storm elevation is	6,385	which subtracts	1.28	inches of precipitable water at	74.0 F	
The transposition storm elevation at	3,654	which subtracts	X.XX	inches of precipitable water at	NA	
The moisture inflow barrier height is	1,200	which subtracts	X.XX	inches of precipitable water at	NA	

The in-place maximization factor is	1.20
The transposition/elevation factor is	1.00
The barrier adjustment factor is	#VALUE!
The total adjustment factor is	#VALUE!

Notes: Storm Rep SSt taken from a region between 35-40N and 160 to 164W where temperatures remainined within a few degrees from the 4th throught the 6th.

Observed Storm Depth-Area-Duration

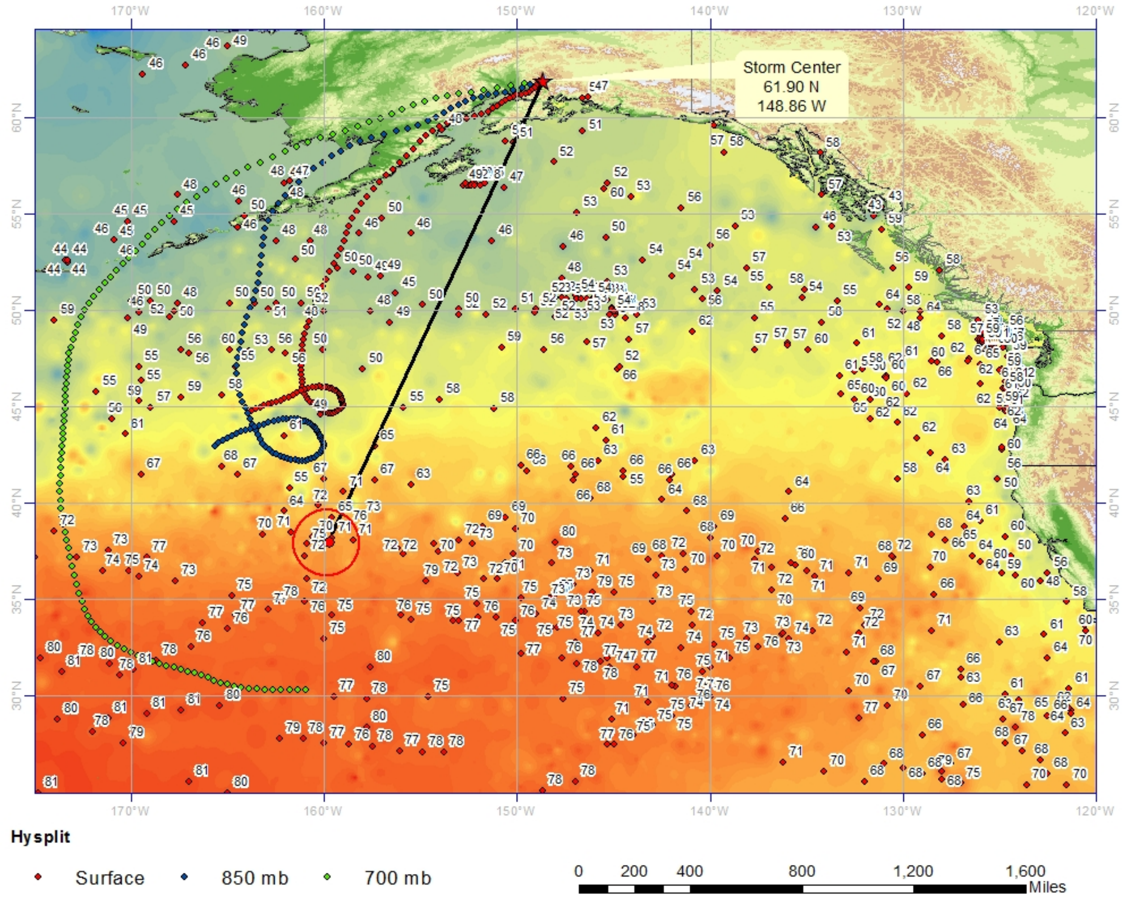
	1 Hours	6 Hours	12 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours	168 Hours	192 Hours
1 sq miles	0.6	2.7	4.1	5.3	6.1	6.7	8.8	9.5	10.7	11.0	11.1	11.1
10 sq miles	0.6	2.7	4.1	5.3	6.1	6.7	8.8	9.5	10.7	11.0	11.1	11.1
100 sq miles	0.5	2.6	3.9	5.1	5.9	6.3	8.4	9.1	10.4	10.6	10.7	10.8
200 sq miles	0.5	2.5	3.8	4.9	5.6	6.1	8.0	8.7	9.9	10.1	10.3	10.3
500 sq miles	0.5	2.3	3.5	4.5	5.1	5.6	6.9	7.8	9.0	9.2	9.3	9.4
1000 sq miles	0.4	1.9	2.9	4.0	4.3	4.7	6.2	6.7	7.5	7.7	8.4	8.5
2000 sq miles	0.4	1.7	2.6	3.2	3.7	4.1	5.0	5.6	6.9	7.0	7.4	7.5
5000 sq miles	0.2	1.2	1.9	2.4	2.9	3.4	4.1	4.9	5.7	5.8	6.0	6.1
10000 sq miles	0.2	0.9	1.4	1.8	2.3	2.7	3.6	4.0	4.7	4.8	4.9	5.0
20000 sq miles	0.1	0.4	0.6	1.0	1.6	1.9	2.5	2.9	3.4	3.4	3.6	3.7

Adjusted Storm Depth-Area-Duration

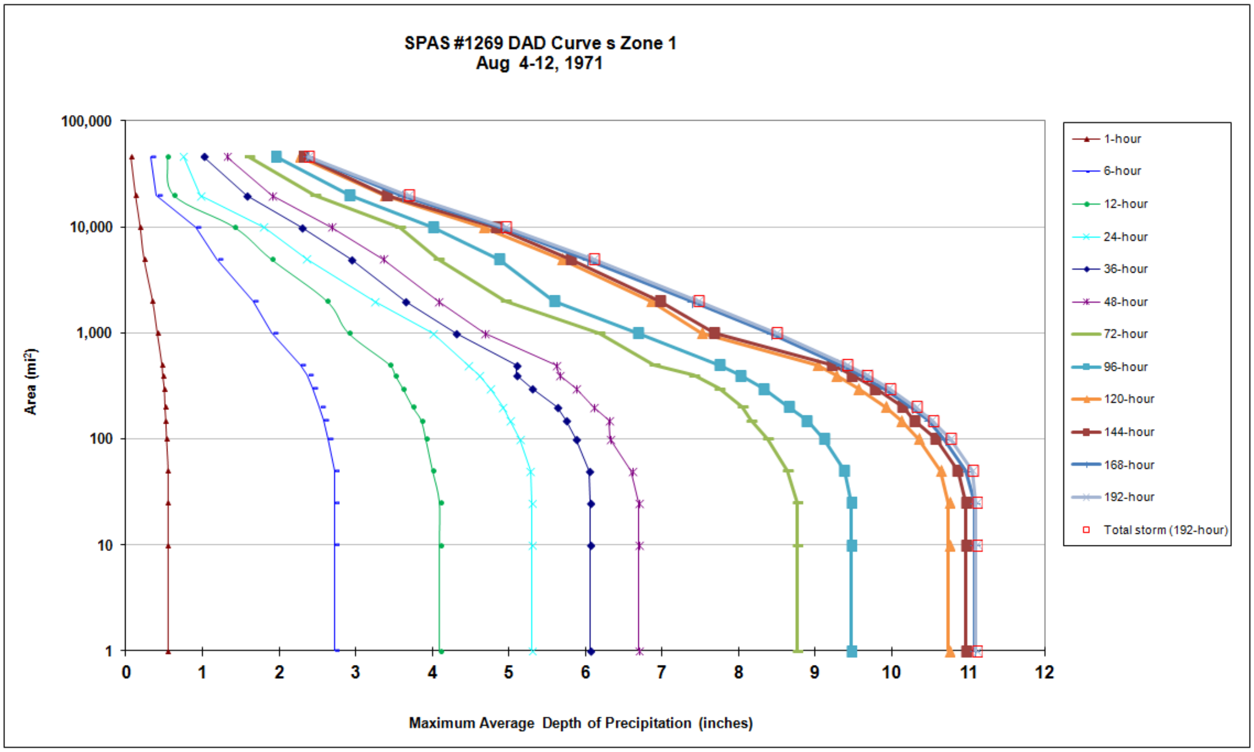
	1 Hours	6 Hours	12 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours	168 Hours	192 Hours
1 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
10 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
100 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
200 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
500 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
1000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
2000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
5000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
10000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
20000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!

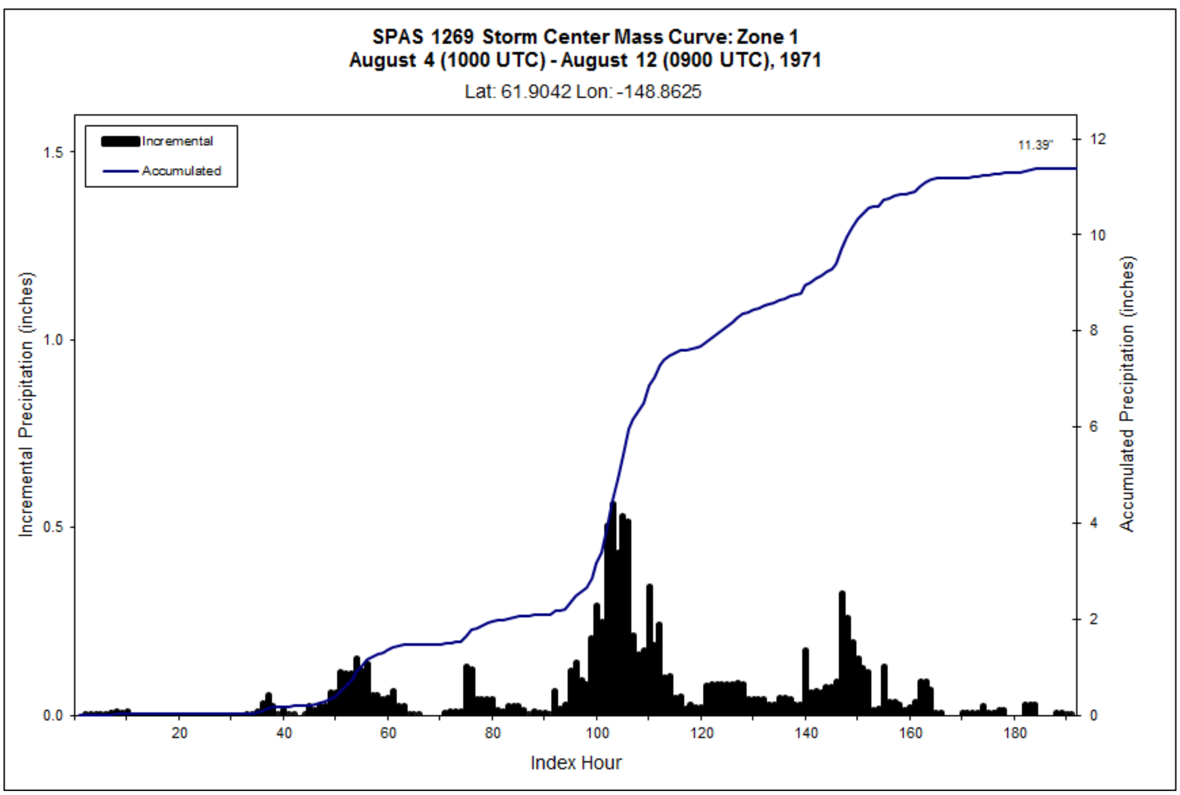
Storm or Storm Center Name	**SPAS 1269, DAD Zone 1**		
Storm Date(s)	8/5-11/1971		
Storm Type	Synoptic		
Storm Location	61.90 N	148.86 W	
Storm Center Elevation	6385		
Precipitation Total & Duration (10 sq mi)	11.1 inches in 192 hours		
Storm Representative SST	71.0 F		
Storm Representative SST Location	38.00 N	159.70 W	Aug
In-place Maximum SST	74.0 F		74
Moisture Inflow Vector	SSW @ 1715		
In-place Maximization Factor	1.20		
Temporal Transposition (Date)	15-Aug		
Transposition SST Location	NA	NA	
Transposition Maximum SST	NA		
Transposition Adjustment Factor	1.00		
Average Basin Elevation	3,654		
Highest Elevation in Basin	13,131		
Inflow Barrier Height	1,200		
Elevation Adjustment Factor	#VALUE!		
Total Adjustment Factor	#VALUE!		

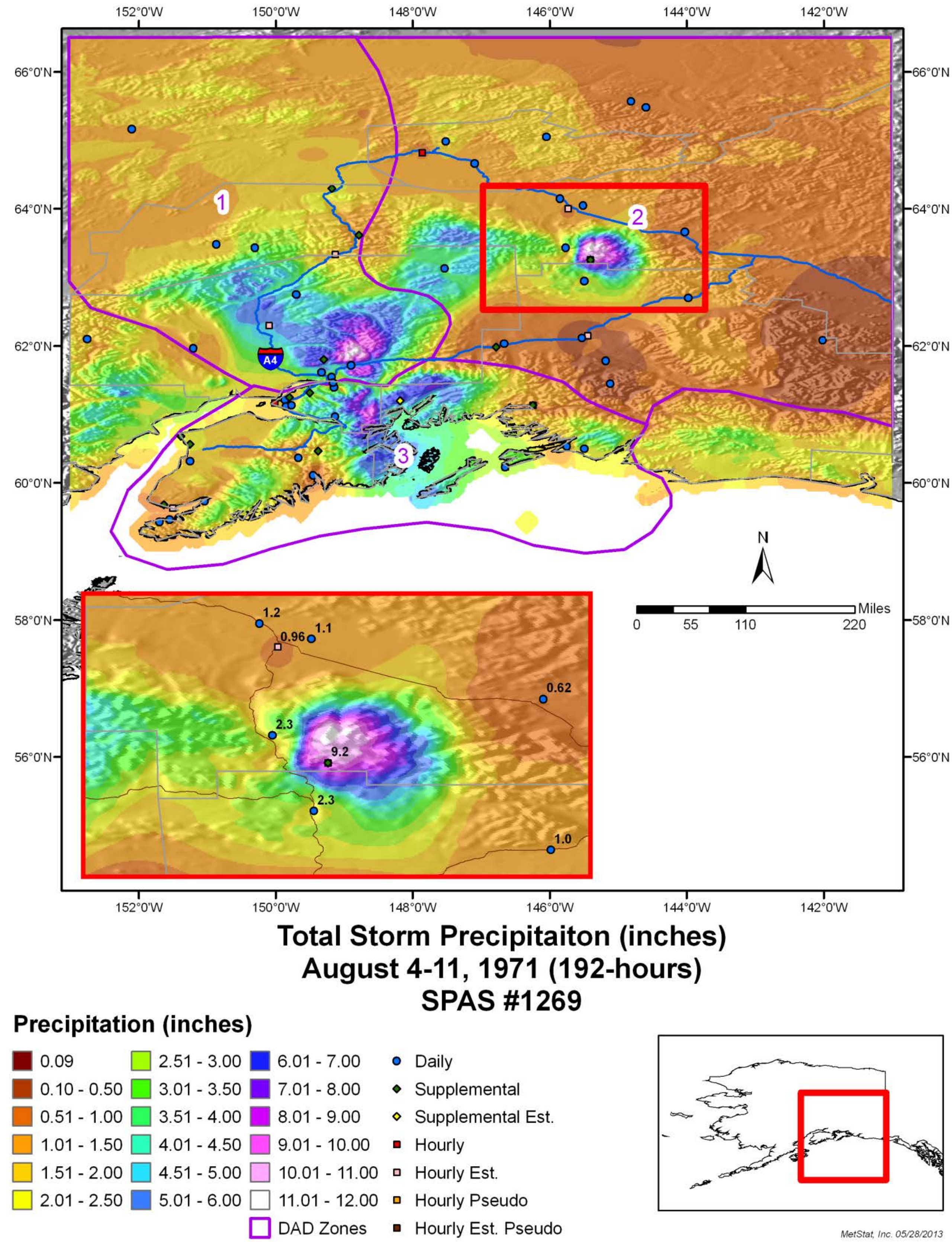
SPAS 1269
August 4, 1971



Storm 1269 - Aug. 4 (1000 UTC) - Aug. 11 (0900 UTC), 1971													
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)													
	Duration (hours)												
Area (mi²)	1	6	12	24	36	48	72	96	120	144	168	192	Total
0.2	0.56	2.8	4.19	5.44	6.23	6.87	8.99	9.7	10.97	11.24	11.35	11.39	11.39
1	0.55	2.72	4.1	5.3	6.06	6.7	8.76	9.47	10.74	10.97	11.08	11.10	11.10
10	0.55	2.72	4.1	5.3	6.06	6.7	8.76	9.47	10.74	10.97	11.08	11.10	11.10
25	0.55	2.72	4.1	5.3	6.06	6.7	8.76	9.47	10.74	10.97	11.08	11.10	11.10
50	0.55	2.72	4.01	5.28	6.04	6.6	8.63	9.38	10.63	10.86	10.97	11.05	11.05
100	0.53	2.64	3.92	5.14	5.88	6.32	8.38	9.11	10.35	10.57	10.68	10.76	10.76
150	0.52	2.58	3.86	5.01	5.75	6.31	8.16	8.89	10.11	10.29	10.47	10.52	10.52
200	0.51	2.53	3.75	4.92	5.63	6.1	8.04	8.65	9.91	10.14	10.25	10.31	10.31
300	0.5	2.44	3.62	4.75	5.3	5.87	7.74	8.32	9.56	9.78	9.89	9.96	9.96
400	0.48	2.37	3.52	4.61	5.1	5.66	7.41	8.02	9.27	9.48	9.59	9.67	9.67
500	0.47	2.28	3.45	4.47	5.1	5.62	6.9	7.75	9.02	9.22	9.32	9.41	9.41
1,000	0.41	1.91	2.91	4.01	4.3	4.68	6.18	6.68	7.51	7.68	8.41	8.49	8.49
2,000	0.35	1.66	2.63	3.24	3.65	4.08	4.96	5.59	6.85	6.97	7.38	7.47	7.47
5,000	0.24	1.19	1.9	2.36	2.94	3.36	4.07	4.87	5.69	5.8	6.01	6.10	6.10
10,000	0.19	0.91	1.42	1.8	2.29	2.68	3.57	4.01	4.66	4.83	4.9	4.95	4.95
20,000	0.13	0.4	0.63	0.97	1.58	1.9	2.46	2.92	3.37	3.4	3.59	3.68	3.68
46,397	0.07	0.32	0.54	0.75	1.02	1.32	1.61	1.96	2.27	2.32	2.36	2.38	2.38


SPAS #1269 DAD Curve s Zone 1
Aug 4-12, 1971
Area (mi²)
100,000
10,000
1,000
100
10
1
0 1 2 3 4 5 6 7 8 9 10 11 12
Maximum Average Depth of Precipitation (inches)
1-hour
6-hour
12-hour
24-hour
36-hour
48-hour
72-hour
96-hour
120-hour
144-hour
168-hour
192-hour
Total storm (192-hour)


SPAS 1269 Storm Center Mass Curve: Zone 1
August 4 (1000 UTC) - August 12 (0900 UTC), 1971
Lat: 61.9042 Lon: -148.8625
Incremental
Accumulated
11.39"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour


152°0'W
150°0'W
148°0'W
146°0'W
144°0'W
142°0'W
66°0'N
64°0'N
62°0'N
60°0'N
58°0'N
56°0'N
1
2
3
A4
N
0
55
110
220
Miles
1.2
0.96
1.1
0.62
2.3
9.2
2.3
1.0
Total Storm Precipitaiton (inches)
August 4-11, 1971 (192-hours)
SPAS #1269
Precipitation (inches)
0.09
0.10 - 0.50
0.51 - 1.00
1.01 - 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.00
3.01 - 3.50
3.51 - 4.00
4.01 - 4.50
4.51 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
11.01 - 12.00
DAD Zones
Daily
Supplemental
Supplemental Est.
Hourly
Hourly Est.
Hourly Pseudo
Hourly Est. Pseudo
MetStat, Inc. 05/28/2013

Black Rapids, AK SPAS 1269 Zone 2
August 5, 1971

Storm Name:	SPAS 1269, DAD Zone 2	**Storm Adjustment for Susitna-Watana**
Storm Date:	8/5-11/1971	
AWA Analysis Date:	3/14/2014	

Temporal Transposition Date: 15-Aug

	Lat	Long
Storm center location	63.47 N	145.48 W
Storm Rep SST location	38.00 N	159.70 W
Transposition SST location	NA	NA
Basin location	42.76 N	74.12 W

Moisture Inflow Direction:	SSW @ 1675	miles
Basin Elevation	3,654	feet
Storm Elevation	6,235	feet
Storm Duration	192	hours
Effective Barrier Height	1,200	feet

The storm representative SST is	71.0 F	with total precipitable water above sea level of			2.36	inches.
The in-place maximum SST is	74.0 F	with total precipitable water above sea level of			2.73	inches.
The transpositioned maximum SST is	NA	with total precipitable water above sea level of			4.44	inches.
The in-place storm elevation is	6,235	which subtracts	1.13	inches of precipitable water at	71.0 F	
The in-place storm elevation is	6,235	which subtracts	1.26	inches of precipitable water at	74.0 F	
The transposition storm elevation at	3,654	which subtracts	X.XX	inches of precipitable water at	NA	
The moisture inflow barrier height is	1,200	which subtracts	X.XX	inches of precipitable water at	NA	

The in-place maximization factor is	1.20
The transposition/elevation factor is	1.00
The barrier adjustment factor is	#VALUE!
The total adjustment factor is	#VALUE!

Notes: Storm Rep SSt taken from a region between 35-40N and 160 to 164W where temperatures remainined within a few degrees from the 4th throught the 6th.

Observed Storm Depth-Area-Duration

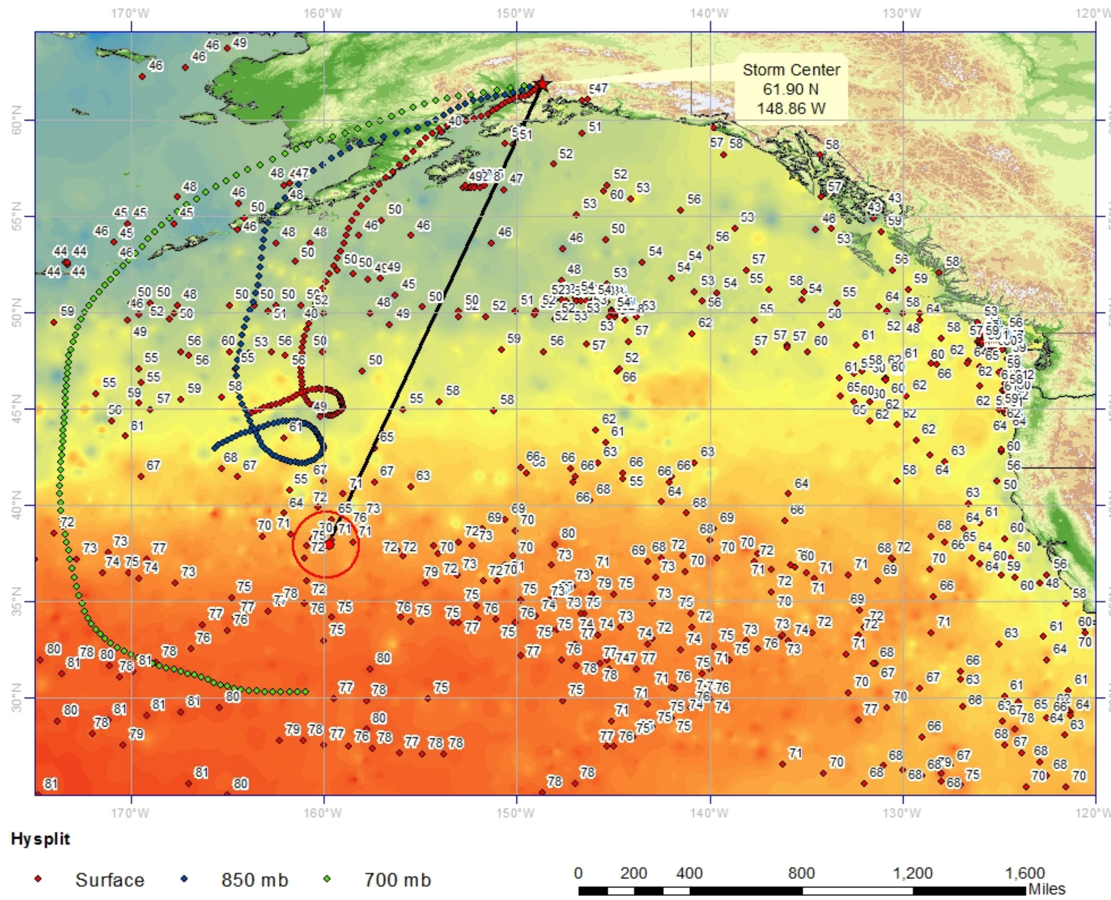
	1 Hours	6 Hours	12 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours	168 Hours	192 Hours
1 sq miles	0.4	2.1	3.1	4.6	6.0	7.5	9.0	10.0	10.7	10.9	10.9	10.9
10 sq miles	0.4	2.1	3.1	4.6	6.0	7.5	9.0	10.0	10.7	10.9	10.9	10.9
100 sq miles	0.4	2.0	3.1	4.5	5.8	7.3	8.9	9.8	10.6	10.7	10.8	10.8
200 sq miles	0.4	2.0	3.0	4.4	5.6	7.0	8.6	9.5	10.2	10.3	10.4	10.4
500 sq miles	0.4	1.7	2.6	3.8	4.9	6.1	7.5	8.3	8.8	9.1	9.1	9.1
1000 sq miles	0.3	1.3	2.0	2.8	3.9	4.8	5.9	6.5	7.2	7.3	7.6	7.7
2000 sq miles	0.2	0.8	1.5	2.2	2.8	3.5	4.6	4.7	5.8	5.9	6.2	6.2
5000 sq miles	0.2	0.7	1.1	1.6	2.2	2.8	3.4	3.7	4.5	4.6	4.7	4.7
10000 sq miles	0.1	0.5	0.7	1.0	1.4	1.6	2.0	2.3	2.6	3.4	3.7	3.8
20000 sq miles	0.1	0.4	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.4	2.5	2.6

Adjusted Storm Depth-Area-Duration

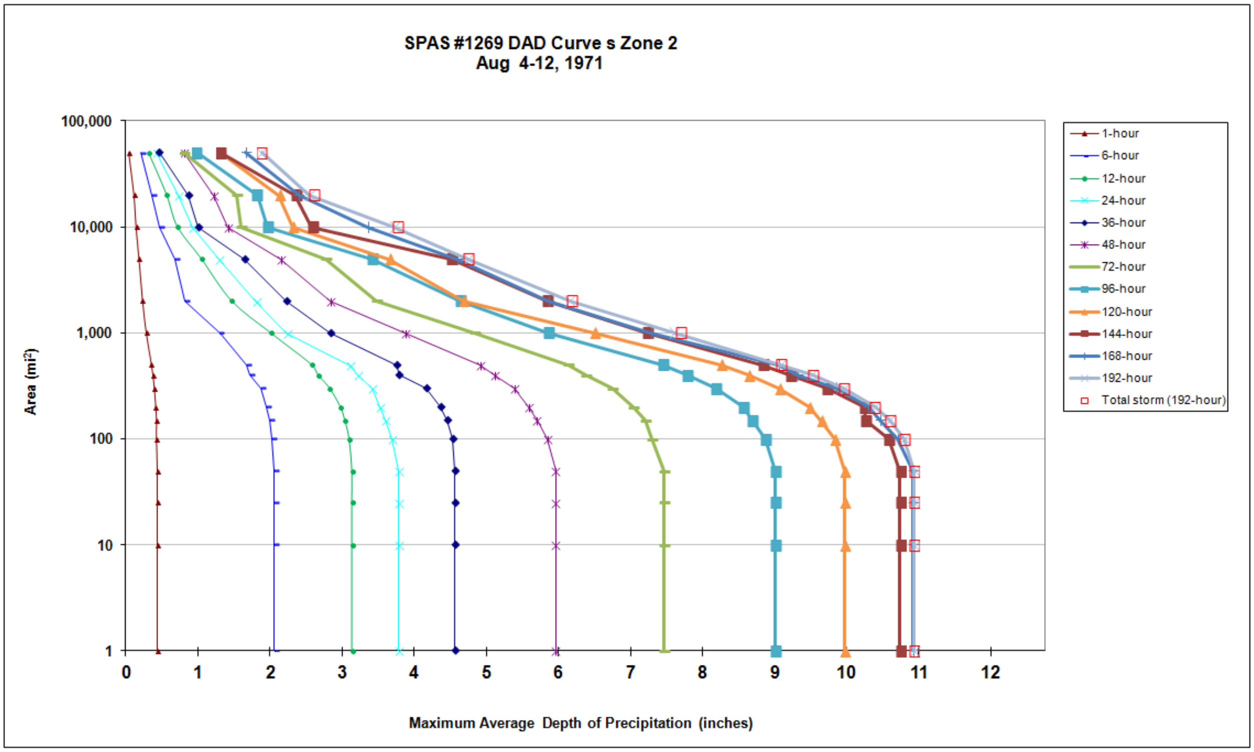
	1 Hours	6 Hours	12 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours	168 Hours	192 Hours
1 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
10 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
100 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
200 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
500 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
1000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
2000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
5000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
10000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
20000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!

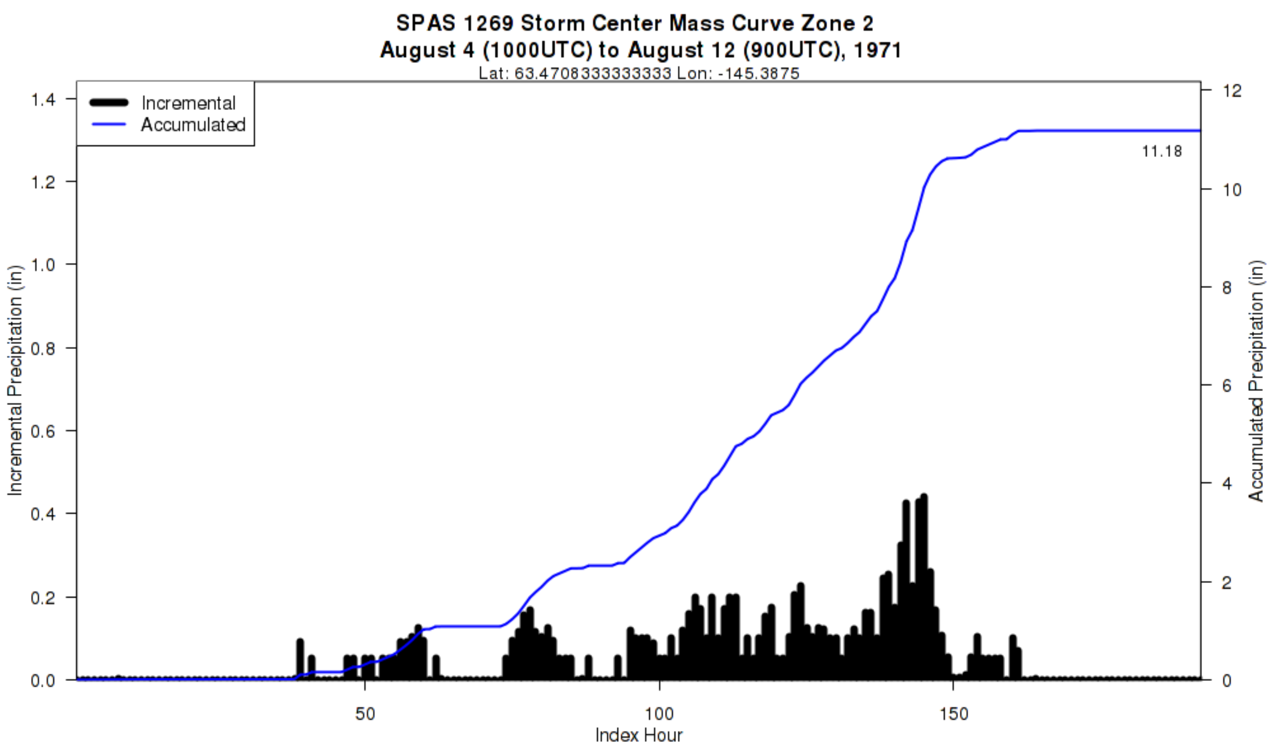
Storm or Storm Center Name	SPAS 1269, DAD Zone 2		
Storm Date(s)	8/5-11/1971		
Storm Type	Synoptic		
Storm Location	63.47 N	145.48 W	
Storm Center Elevation	6235		
Precipitation Total & Duration (10 sq mi)	11.4 inches in 192 hours		
Storm Representative SST	71.0 F		
Storm Representative SST Location	38.00 N	159.70 W	Aug
In-place Maximum SST	74.0 F		74
Moisture Inflow Vector	SSW @ 1675		
In-place Maximization Factor	1.20		
Temporal Transposition (Date)	15-Aug		
Transposition SST Location	NA	NA	
Transposition Maximum SST	NA		
Transposition Adjustment Factor	1.00		
Average Basin Elevation	3,654		
Highest Elevation in Basin	13,131		
Inflow Barrier Height	1,200		
Elevation Adjustment Factor	#VALUE!		
Total Adjustment Factor	#VALUE!		

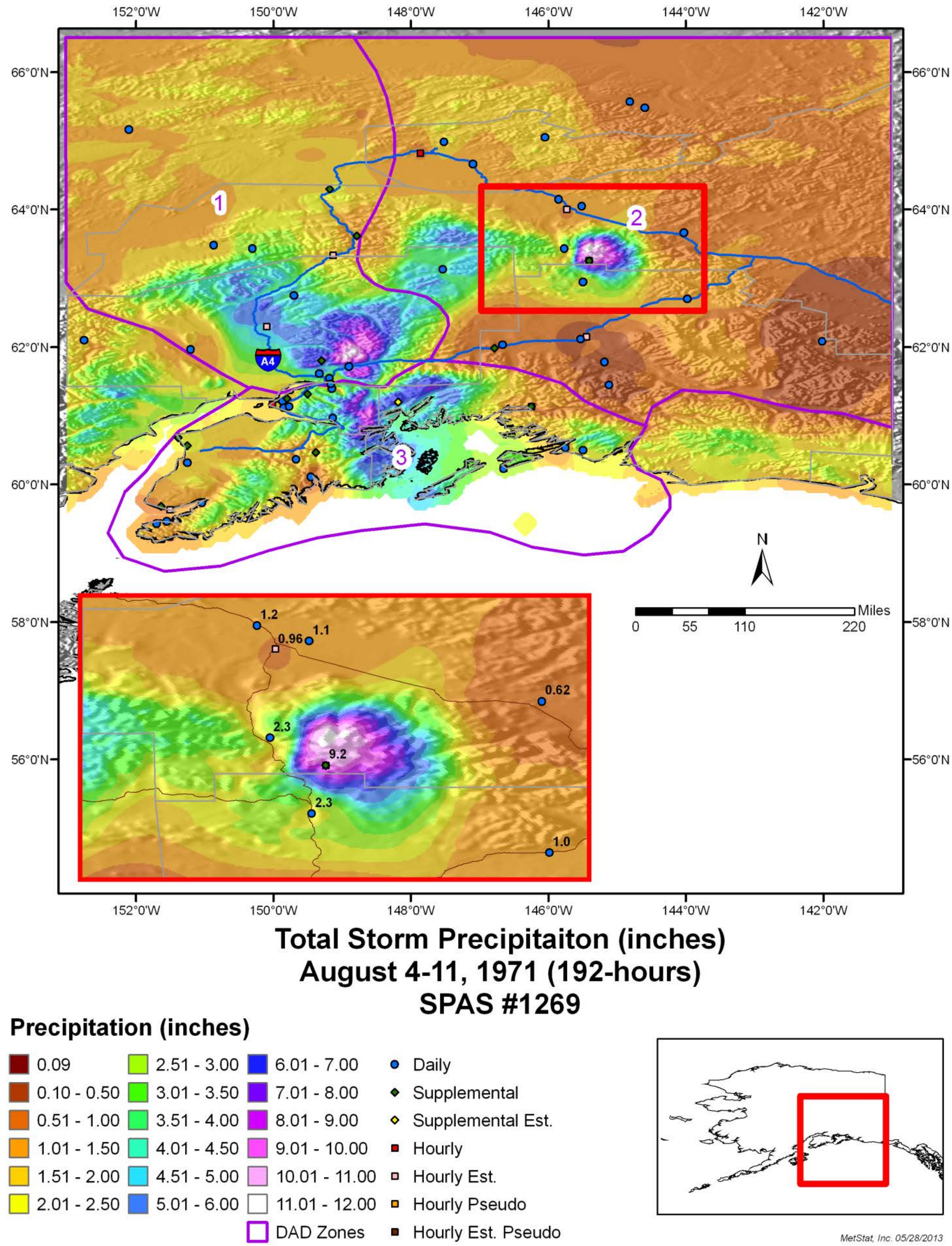
SPAS 1269
August 4, 1971



Storm 1269 - Aug. 4 (1000 UTC) - Aug. 11 (0900 UTC), 1971														
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)														
	Duration (hours)													
Area (mi^2)	1	6	12	18	24	36	48	72	96	120	144	168	192	Total
0.20	0.44	2.11	3.21	3.86	3.86	4.69	6.11	7.64	9.23	10.21	11.02	11.17	11.18	11.18
1	0.43	2.06	3.14	3.78	3.78	4.56	5.96	7.47	9.01	9.97	10.74	10.92	10.93	10.93
10	0.43	2.06	3.14	3.78	3.78	4.56	5.96	7.47	9.01	9.97	10.74	10.92	10.93	10.93
25	0.43	2.06	3.14	3.78	3.78	4.56	5.96	7.47	9.01	9.97	10.74	10.92	10.93	10.93
50	0.43	2.06	3.14	3.78	3.78	4.56	5.96	7.47	9.01	9.97	10.74	10.92	10.93	10.93
100	0.42	2.03	3.10	3.69	3.69	4.53	5.84	7.29	8.87	9.83	10.58	10.70	10.79	10.79
150	0.42	2.00	3.04	3.6	3.60	4.45	5.70	7.20	8.69	9.64	10.26	10.46	10.60	10.60
200	0.41	1.95	2.98	3.52	3.52	4.36	5.58	7.04	8.57	9.48	10.24	10.30	10.39	10.39
300	0.39	1.87	2.83	3.41	3.41	4.16	5.39	6.75	8.18	9.06	9.72	9.85	9.95	9.95
400	0.37	1.72	2.67	3.21	3.21	3.79	5.11	6.38	7.78	8.64	9.21	9.32	9.52	9.52
500	0.35	1.68	2.58	3.1	3.10	3.75	4.91	6.14	7.45	8.26	8.83	9.05	9.08	9.09
1,000	0.28	1.30	2.01	2.23	2.23	2.83	3.87	4.83	5.86	6.50	7.23	7.28	7.61	7.69
2,000	0.23	0.82	1.47	1.8	1.80	2.23	2.83	3.48	4.64	4.68	5.84	5.86	6.16	6.18
5,000	0.18	0.68	1.05	1.29	1.29	1.64	2.15	2.78	3.41	3.65	4.51	4.59	4.74	4.74
10,000	0.14	0.47	0.72	0.92	0.92	1.00	1.42	1.59	1.97	2.31	2.58	3.35	3.72	3.77
20,000	0.11	0.36	0.57	0.72	0.72	0.87	1.21	1.53	1.82	2.12	2.35	2.40	2.54	2.61
50,000	0.04	0.21	0.32	0.42	0.42	0.46	0.81	0.81	0.98	1.31	1.31	1.66	1.88	1.88


SPAS #1269 DAD Curve s Zone 2
Aug 4-12, 1971
Area (mi²)
Maximum Average Depth of Precipitation (inches)
1-hour
6-hour
12-hour
24-hour
36-hour
48-hour
72-hour
96-hour
120-hour
144-hour
168-hour
192-hour
Total storm (192-hour)


SPAS 1269 Storm Center Mass Curve Zone 2
August 4 (1000UTC) to August 12 (900UTC), 1971
Lat: 63.4708333333333 Lon: -145.3875
Incremental
Accumulated
11.18
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour



Total Storm Precipitaiton (inches)
August 4-11, 1971 (192-hours)
SPAS #1269

Mt. Geist, AK, SPAS 1268 Zone 2
July 24, 1980

Storm Name:	SPAS 1268-AK Zone 2	**Storm Adjustment for Susitna-Watana**
Storm Date:	July 24-31, 1980	
AWA Analysis Date:	3/14/2014	

Temporal Transposition Date	15-Aug	
	Lat	Long
Storm Center Location	63.64 N	146.97 W
Storm Rep SST Location	56.00 N	148.54 W
Transposition SST Location	NA	NA
Basin Location	*	*

Moisture Inflow Direction	SSW @ 530	miles
Basin Average Elevation	NA	feet
Storm Center Elevation	8,215	feet
Storm Analysis Duration	24	hours
Effective Barrier Height	NA	feet

The storm representative SST is	56.0 F	with total precipitable water above sea level of			1.13	inches.
The in-place maximum SST is	58.0 F	with total precipitable water above sea level of			1.25	inches.
The transpositioned maximum SST is	NA	with total precipitable water above sea level of			3.22	inches.
The in-place storm elevation is	8,215	feet which subtracts	0.77	inches of precipitable water at	56.0 F	
The in-place storm elevation is	8,215	feet which subtracts	0.84	inches of precipitable water at	58.0 F	
The transposition storm elevation at	NA	feet which subtracts	NA	inches of precipitable water at	NA	
The moisture inflow barrier height is	NA	feet which subtracts	NA	inches of precipitable water at	NA	

The in-place maximization factor is	1.14
The transposition factor is	#VALUE!
The elevation/barrier adjustment factor is	#VALUE!
The total adjustment factor is	#VALUE!

Notes: Storm representative SST value was based on SST values for July 25-27 along the surface HYSPLIT trajectory data. Values were selected in region where temperature did not vary more than a 1-degree over a large area and was as closest to the storm center.

Observed Storm Depth-Area-Duration

	1 Hours	6 Hours	12 Hours	18 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours	168 Hours	192 Hours
1 sq miles	0.3	0.7	1.0	1.4	1.6	2.0	2.4	3.4	3.8	4.3	4.9	5.1	5.1
10 sq miles	0.3	0.7	1.0	1.4	1.6	2.0	2.4	3.4	3.8	4.3	4.9	5.1	5.1
100 sq miles	0.3	0.7	1.0	1.4	1.6	2.0	2.3	3.3	3.8	4.3	4.8	5.0	5.0
200 sq miles	0.3	0.7	1.0	1.3	1.5	2.0	2.3	3.2	3.6	4.2	4.7	4.8	4.9
500 sq miles	0.3	0.6	0.9	1.2	1.4	1.9	2.2	3.0	3.4	3.9	4.4	4.6	4.6
1000 sq miles	0.3	0.5	0.8	1.1	1.3	1.7	2.1	2.7	3.1	3.6	3.8	4.1	4.2
2000 sq miles	0.2	0.5	0.7	0.9	1.1	1.6	1.8	2.3	2.7	3.1	3.4	3.7	3.7
5000 sq miles	0.2	0.4	0.5	0.7	0.9	1.3	1.5	1.8	2.1	2.6	2.8	2.9	3.0
10000 sq miles	0.1	0.2	0.4	0.5	0.7	1.0	1.2	1.3	1.7	2.1	2.3	2.4	2.5
20000 sq miles	0.1	0.2	0.3	0.4	0.5	0.7	0.8	1.1	1.3	1.6	1.7	1.9	1.9

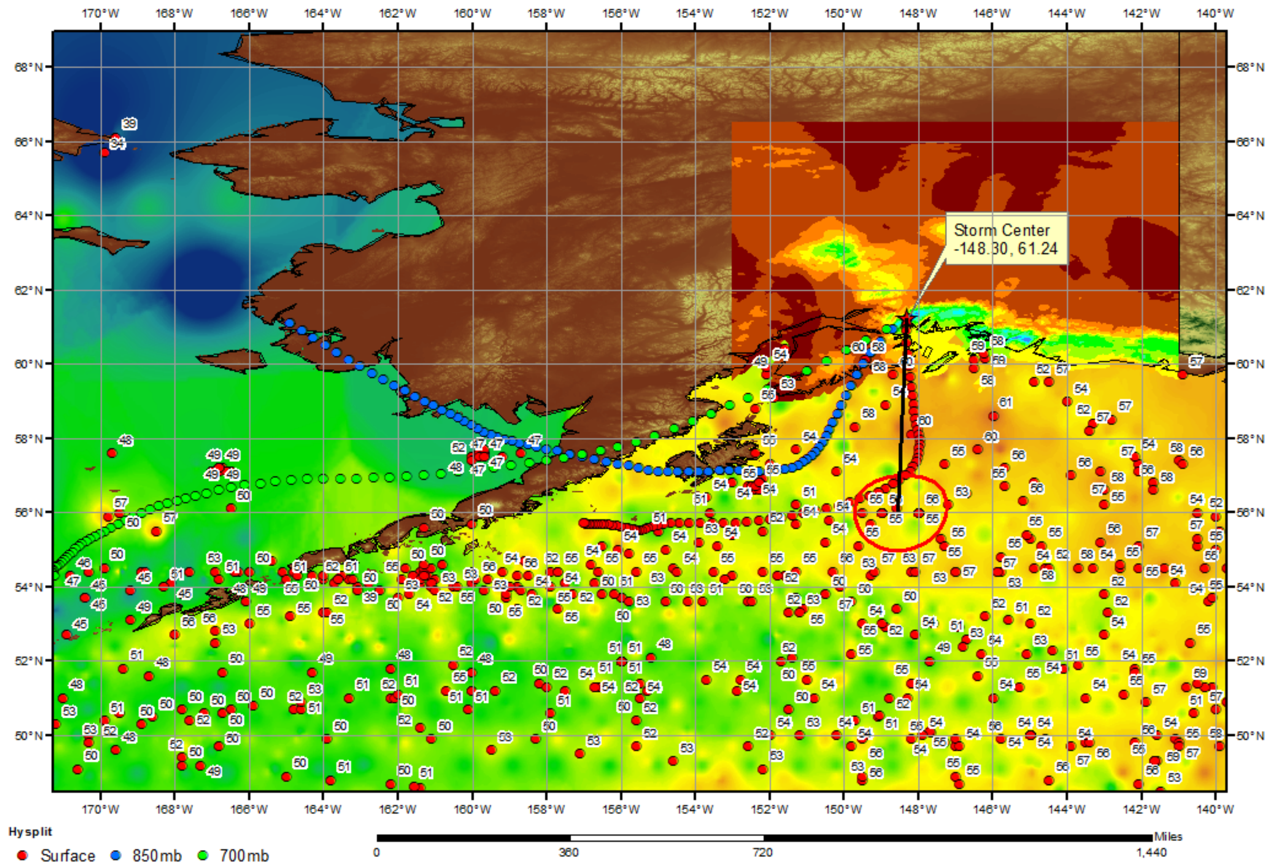
Adjusted Storm Depth-Area-Duration

	1 Hours	6 Hours	12 Hours	18 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours	168 Hours	192 Hours
1 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
10 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
100 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
200 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
500 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
1000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
2000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
5000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
10000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
20000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!

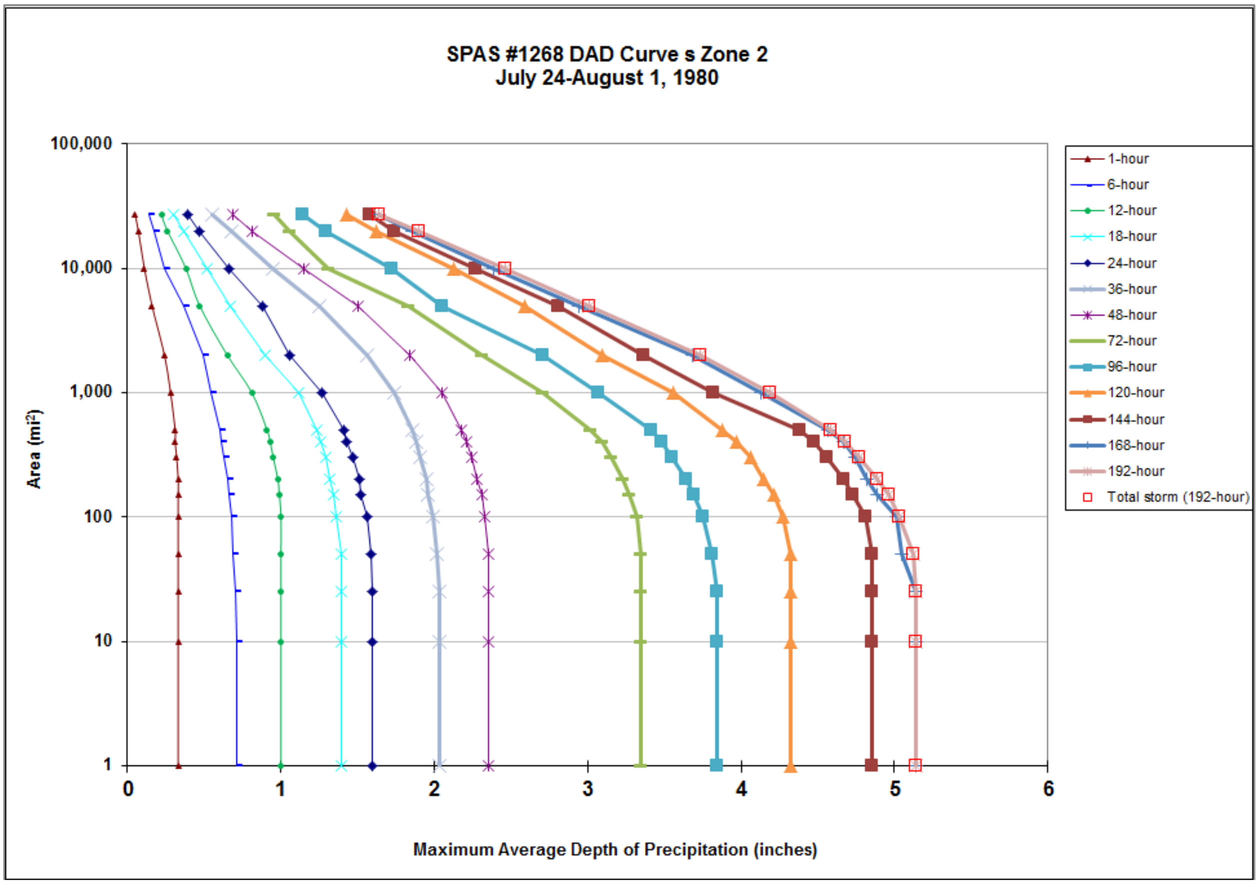
Storm or Storm Center Name	SPAS 1268-AK Zone 2			
Storm Date(s)	July 24-31, 1980			
Storm Type	Synoptic			
Storm Location	63.64 N	146.97 W		
Storm Center Elevation	8,215			
Precipitation Total & Duration (10 sq mi)	5.26 inches at 192 hours			
Storm Representative SST	56.0 F			
Storm Representative SST Location	56.00 N	148.54 W	July	Aug
Maximum SST	58.0 F		56	58
Moisture Inflow Vector	SSW @ 530			
In-place Maximization Factor	1.14			
Temporal Transposition (Date)	15-Aug			
Transposition SST Location	NA	NA		
Transposition Maximum SST	NA			
Transposition Adjustment Factor	#VALUE!			
Average Basin Elevation	NA			
Highest Elevation in Basin	NA			
Inflow Barrier Height	NA			
Elevation Adjustment Factor	#VALUE!			
Total Adjustment Factor	#VALUE!			

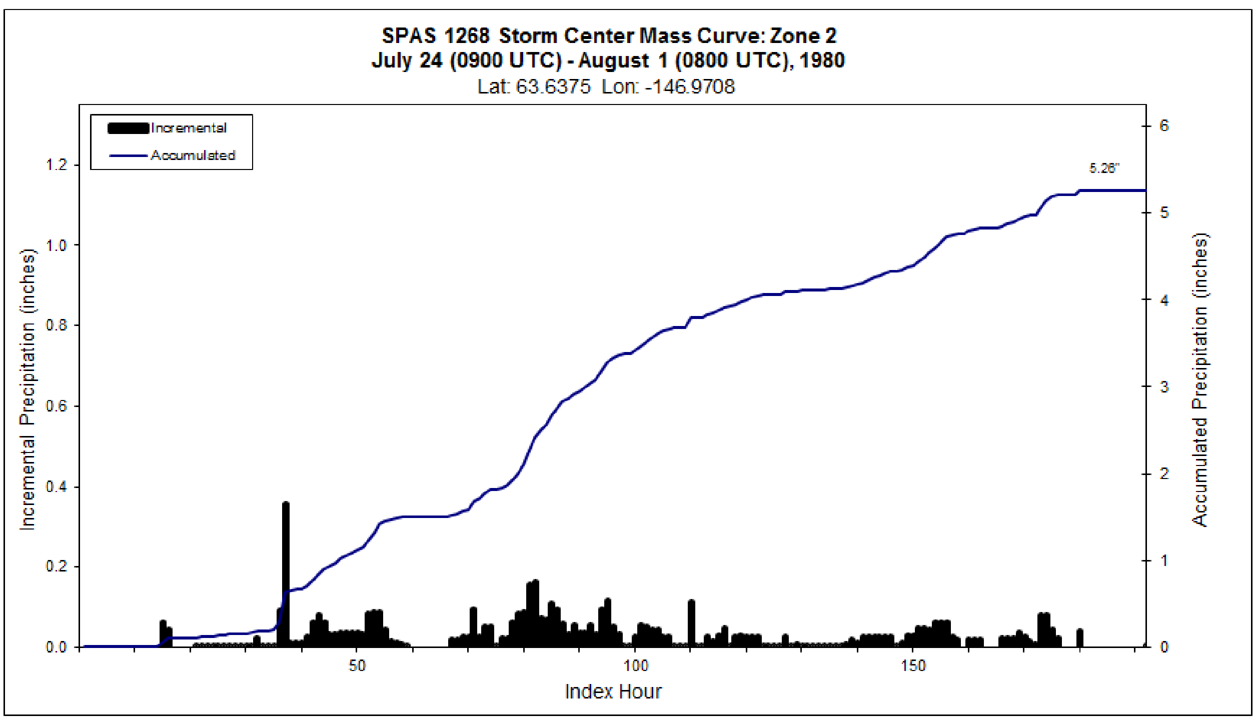
SPAS 1268 Gate AK Storm Analysis

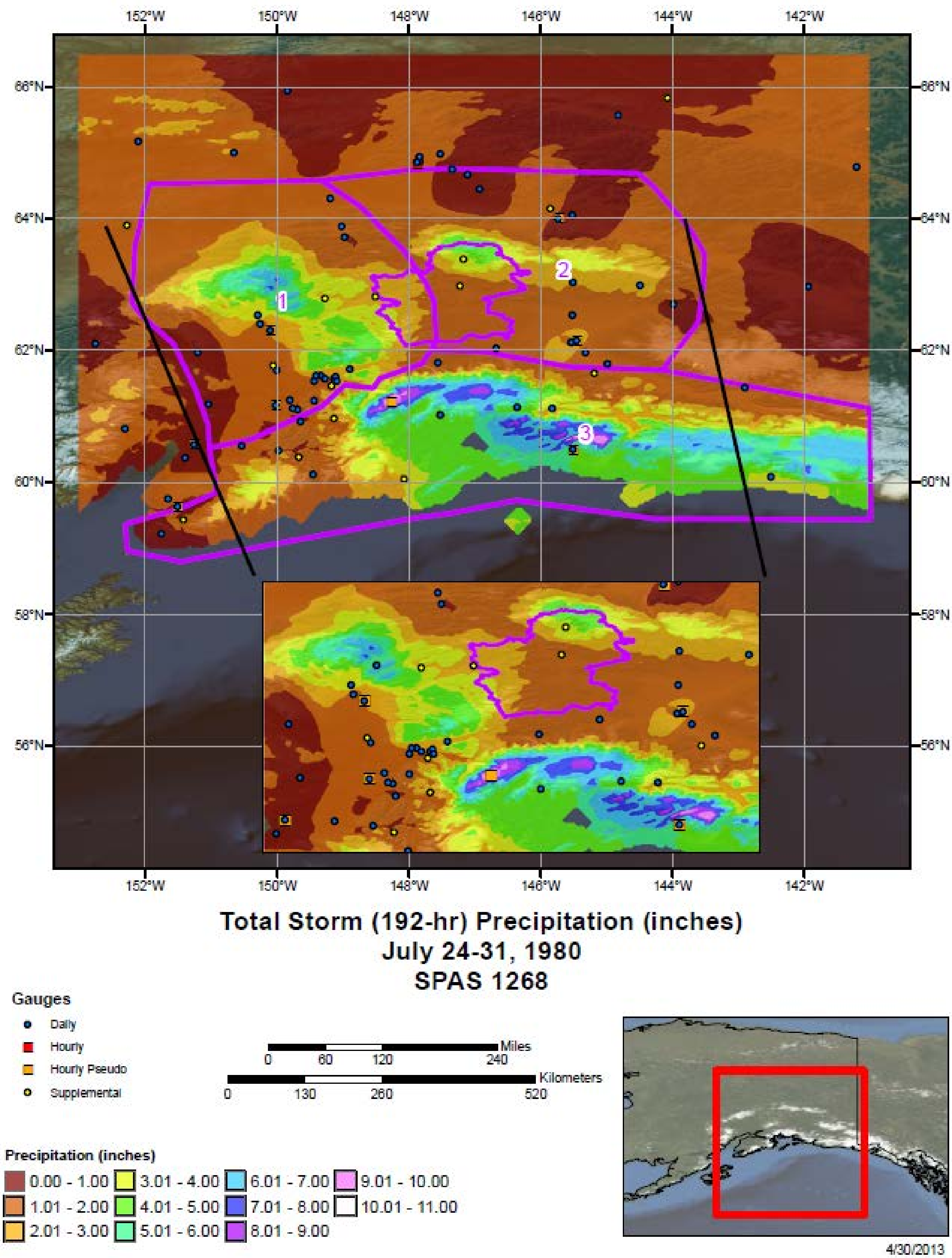
July 25 - 27, 1980



Storm 1268 - Jul. 24 (0900 UTC) - Aug. 1 (0800 UTC), 1980														
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)														
	Duration (hours)													
Area (mi^2)	1	6	12	18	24	36	48	72	96	120	144	168	192	Total
0.2	0.36	0.71	1.05	1.42	1.63	2.08	2.41	3.48	3.92	4.47	5.02	5.25	5.26	5.26
1	0.33	0.71	1	1.39	1.6	2.03	2.35	3.35	3.84	4.32	4.85	5.14	5.14	5.14
10	0.33	0.71	1	1.39	1.6	2.03	2.35	3.35	3.84	4.32	4.85	5.14	5.14	5.14
25	0.33	0.7	1	1.39	1.6	2.03	2.35	3.35	3.84	4.32	4.85	5.14	5.14	5.14
50	0.33	0.69	1	1.39	1.59	2.02	2.35	3.35	3.81	4.32	4.85	5.05	5.12	5.12
100	0.33	0.68	1	1.36	1.56	1.99	2.33	3.32	3.75	4.27	4.81	5.01	5.03	5.03
150	0.33	0.66	0.99	1.34	1.52	1.96	2.31	3.27	3.69	4.21	4.73	4.89	4.96	4.96
200	0.33	0.65	0.98	1.32	1.51	1.95	2.28	3.23	3.64	4.15	4.67	4.82	4.89	4.89
300	0.32	0.63	0.95	1.29	1.47	1.91	2.24	3.15	3.55	4.06	4.56	4.74	4.77	4.77
400	0.31	0.61	0.93	1.26	1.43	1.88	2.21	3.09	3.48	3.97	4.47	4.67	4.68	4.68
500	0.31	0.6	0.91	1.23	1.41	1.86	2.18	3.02	3.41	3.88	4.38	4.57	4.58	4.58
1,000	0.28	0.54	0.81	1.12	1.27	1.74	2.05	2.71	3.07	3.56	3.82	4.13	4.19	4.19
2,000	0.24	0.49	0.65	0.9	1.06	1.56	1.84	2.31	2.71	3.09	3.36	3.68	3.73	3.73
5,000	0.16	0.37	0.47	0.67	0.88	1.25	1.5	1.83	2.05	2.59	2.81	2.94	3.01	3.01
10,000	0.11	0.24	0.38	0.52	0.66	0.95	1.15	1.31	1.72	2.13	2.27	2.39	2.46	2.46
20,000	0.07	0.17	0.26	0.37	0.47	0.68	0.81	1.06	1.29	1.62	1.74	1.86	1.9	1.90
26,863	0.05	0.14	0.22	0.3	0.39	0.55	0.69	0.96	1.14	1.43	1.58	1.64	1.64	1.64


SPAS #1268 DAD Curve s Zone 2
July 24-August 1, 1980
Area (mi²)
100,000
10,000
1,000
100
10
1
0
1
2
3
4
5
6
Maximum Average Depth of Precipitation (inches)
1-hour
6-hour
12-hour
18-hour
24-hour
36-hour
48-hour
72-hour
96-hour
120-hour
144-hour
168-hour
192-hour
Total storm (192-hour)


SPAS 1268 Storm Center Mass Curve: Zone 2
July 24 (0900 UTC) - August 1 (0800 UTC), 1980
Lat: 63.6375 Lon: -146.9708
Incremental
Accumulated
5.26"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
50
100
150


152°W
150°W
148°W
146°W
144°W
142°W
66°N
64°N
62°N
60°N
58°N
56°N
1
2
3
Total Storm (192-hr) Precipitation (inches)
July 24-31, 1980
SPAS 1268
Gauges
Daily
Hourly
Hourly Pseudo
Supplemental
Miles
0 60 120 240
Kilometers
0 130 260 520
Precipitation (inches)
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
4/30/2013

Denali NP, SPAS 1268 Zone 1
July 24, 1980

Storm Name:	SPAS 1268-AK Zone 1	Storm Adjustment for Susitna-Watana	
Storm Date:	July 24-31, 1980		
AWA Analysis Date:	3/14/2014		

Temporal Transposition Date	15-Aug	
	Lat	Long
Storm Center Location	62.95 N	150.08 W
Storm Rep SST Location	56.00 N	148.54 W
Transposition SST Location	NA	NA
Basin Location	*	*

Moisture Inflow Direction	SSE @ 485	miles
Basin Average Elevation	NA	feet
Storm Center Elevation	4,750	feet
Storm Analysis Duration	24	hours
Effective Barrier Height	NA	feet

The storm representative SST is	56.0 F	with total precipitable water above sea level of			1.13	inches.
The in-place maximum SST is	58.0 F	with total precipitable water above sea level of			1.25	inches.
The transpositioned maximum SST is	NA	with total precipitable water above sea level of			3.22	inches.
The in-place storm elevation is	4,750	feet which subtracts	0.52	inches of precipitable water at	56.0 F	
The in-place storm elevation is	4,750	feet which subtracts	0.56	inches of precipitable water at	58.0 F	
The transposition storm elevation at	NA	feet which subtracts	NA	inches of precipitable water at	NA	
The moisture inflow barrier height is	NA	feet which subtracts	NA	inches of precipitable water at	NA	

The in-place maximization factor is	1.13
The transposition factor is	#VALUE!
The elevation/barrier adjustment factor is	#VALUE!
The total adjustment factor is	#VALUE!

Notes: Storm representative SST value was based on SST values for July 25-27 along the surface HYSPLIT trajectory data. Values were selected in region where temperature did not vary more than a 1-degree over a large area and was as closest to the storm center.

Observed Storm Depth-Area-Duration

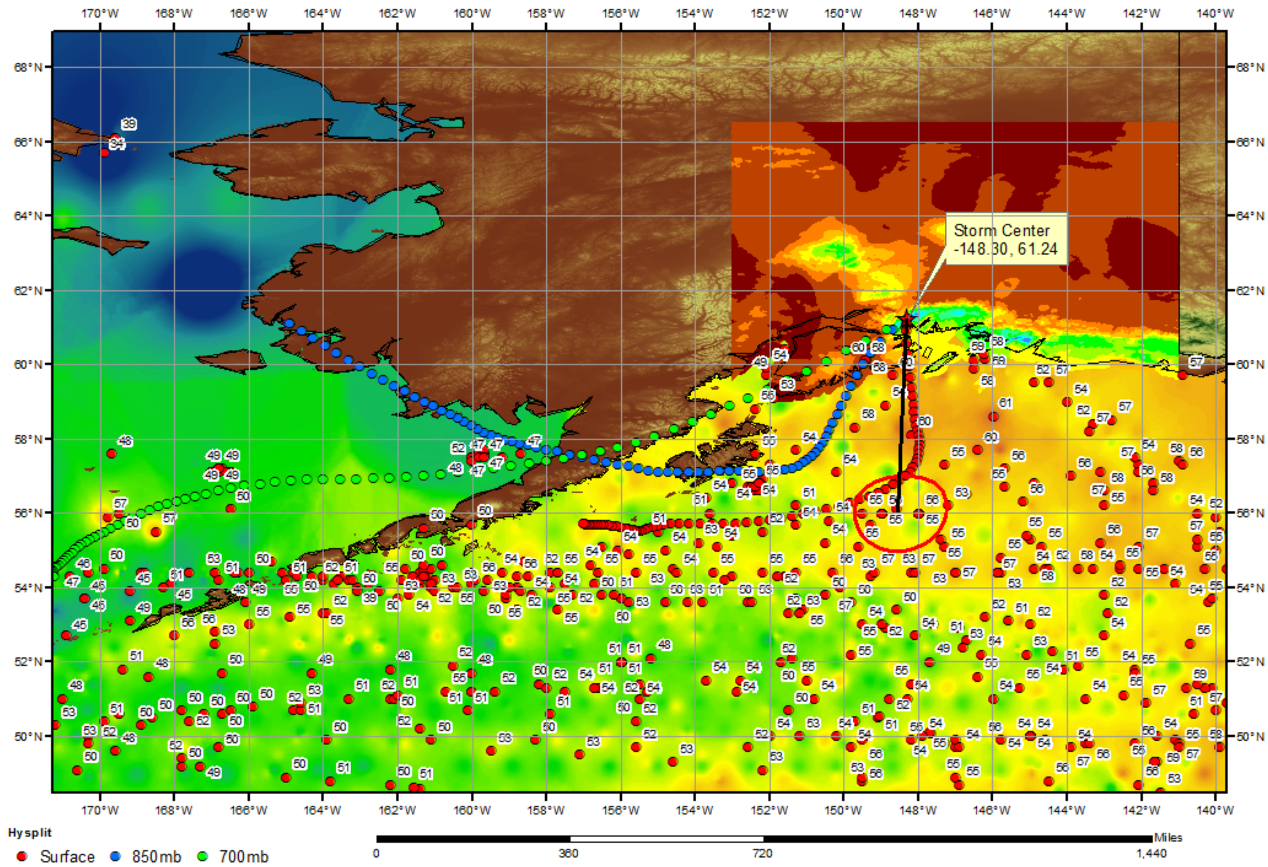
	1 Hours	6 Hours	12 Hours	18 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours	168 Hours	192 Hours
1 sq miles	0.5	1.8	2.7	3.3	3.7	4.0	5.0	6.2	6.5	6.8	6.9	7.1	7.1
10 sq miles	0.5	1.8	2.7	3.3	3.7	4.0	5.0	6.2	6.5	6.8	6.9	7.1	7.1
100 sq miles	0.4	1.8	2.6	3.3	3.6	3.9	4.8	6.0	6.2	6.5	6.6	6.6	6.8
200 sq miles	0.4	1.7	2.6	3.2	3.5	3.9	4.6	5.8	6.0	6.2	6.4	6.5	6.6
500 sq miles	0.3	1.6	2.5	3.0	3.3	3.7	4.4	5.5	5.6	5.9	6.1	6.1	6.3
1000 sq miles	0.3	1.6	2.3	2.8	3.2	3.5	4.2	5.1	5.3	5.6	5.7	5.9	5.9
2000 sq miles	0.3	1.4	2.1	2.5	2.8	3.2	3.5	4.4	4.5	4.8	5.0	5.4	5.4
5000 sq miles	0.2	1.1	1.7	2.0	2.3	2.4	2.9	3.7	3.9	4.2	4.3	4.5	4.6
10000 sq miles	0.2	0.8	1.4	1.6	1.8	2.1	2.2	2.8	2.9	3.3	3.5	3.7	3.8
20000 sq miles	0.1	0.6	1.0	1.2	1.3	1.4	1.6	2.0	2.3	2.5	2.7	2.8	2.8

Adjusted Storm Depth-Area-Duration

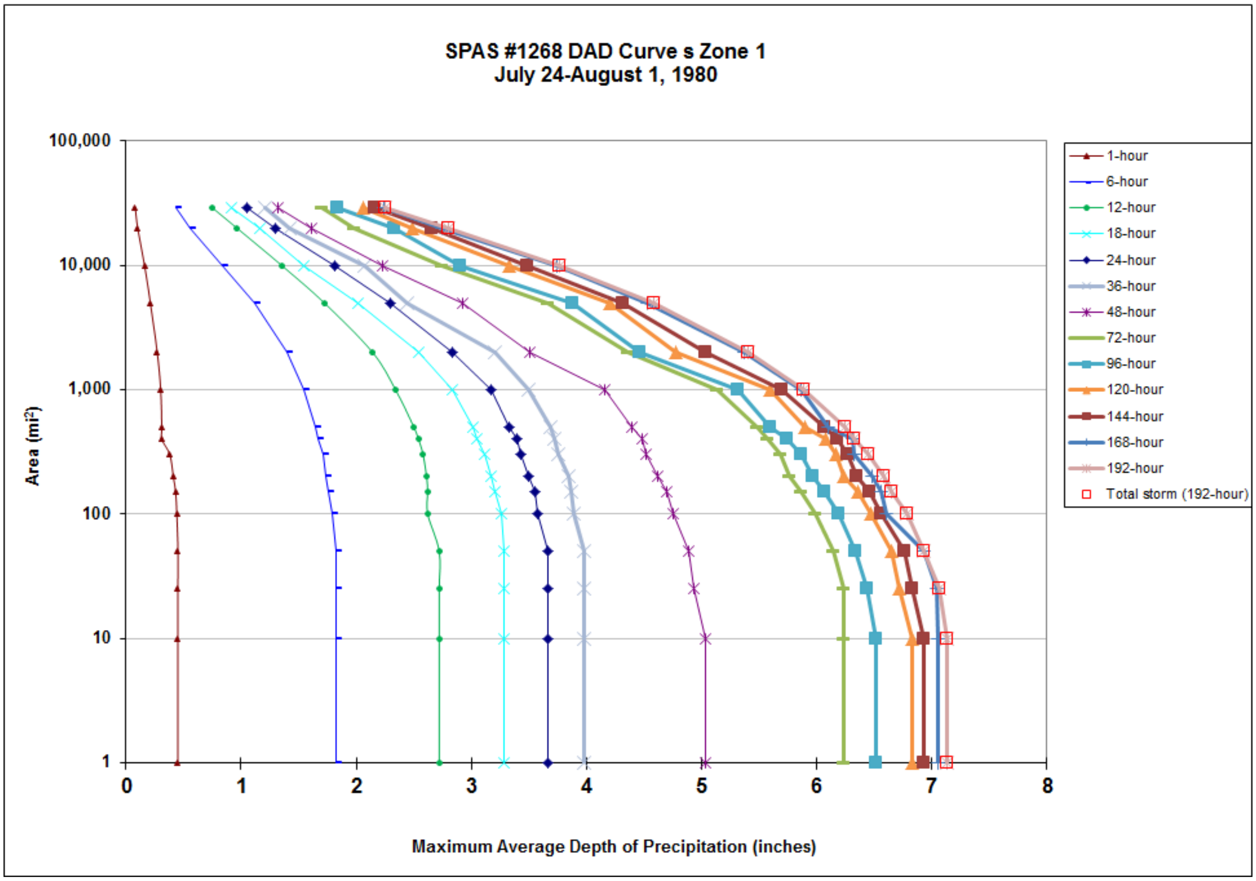
	1 Hours	6 Hours	12 Hours	18 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours	168 Hours	192 Hours
1 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
10 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
100 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
200 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
500 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
1000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
2000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
5000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
10000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
20000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!

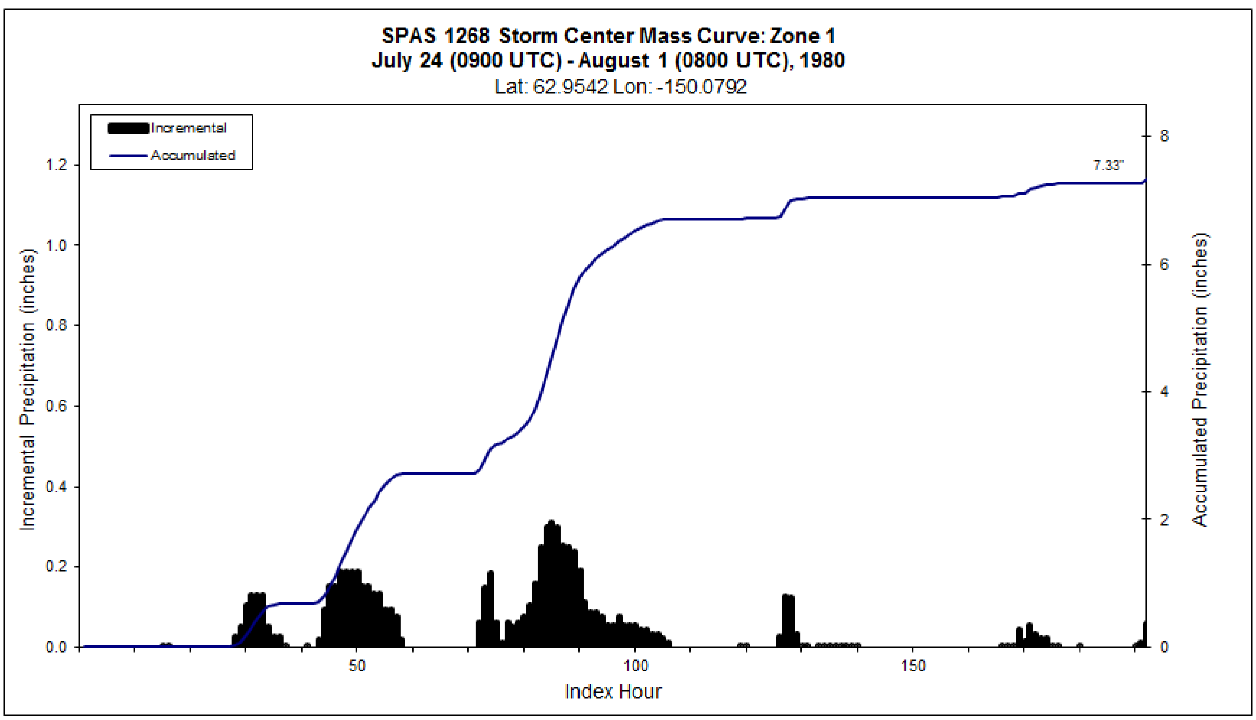
Storm or Storm Center Name	SPAS 1268-AK Zone 1			
Storm Date(s)	July 24-31, 1980			
Storm Type	Synoptic			
Storm Location	62.95 N	150.08 W		
Storm Center Elevation	4,750			
Precipitation Total & Duration (10 sq mi)	7.33 inches at 192 hours			
Storm Representative SST	56.0 F			
Storm Representative SST Location	56.00 N	148.54 W	July	Aug
Maximum SST	58.0 F		56	58
Moisture Inflow Vector	SSE @ 485			
In-place Maximization Factor	1.13			
Temporal Transposition (Date)	15-Aug			
Transposition SST Location	NA	NA		
Transposition Maximum SST	NA			
Transposition Adjustment Factor	#VALUE!			
Average Basin Elevation	NA			
Highest Elevation in Basin	NA			
Inflow Barrier Height	NA			
Elevation Adjustment Factor	#VALUE!			
Total Adjustment Factor	#VALUE!			

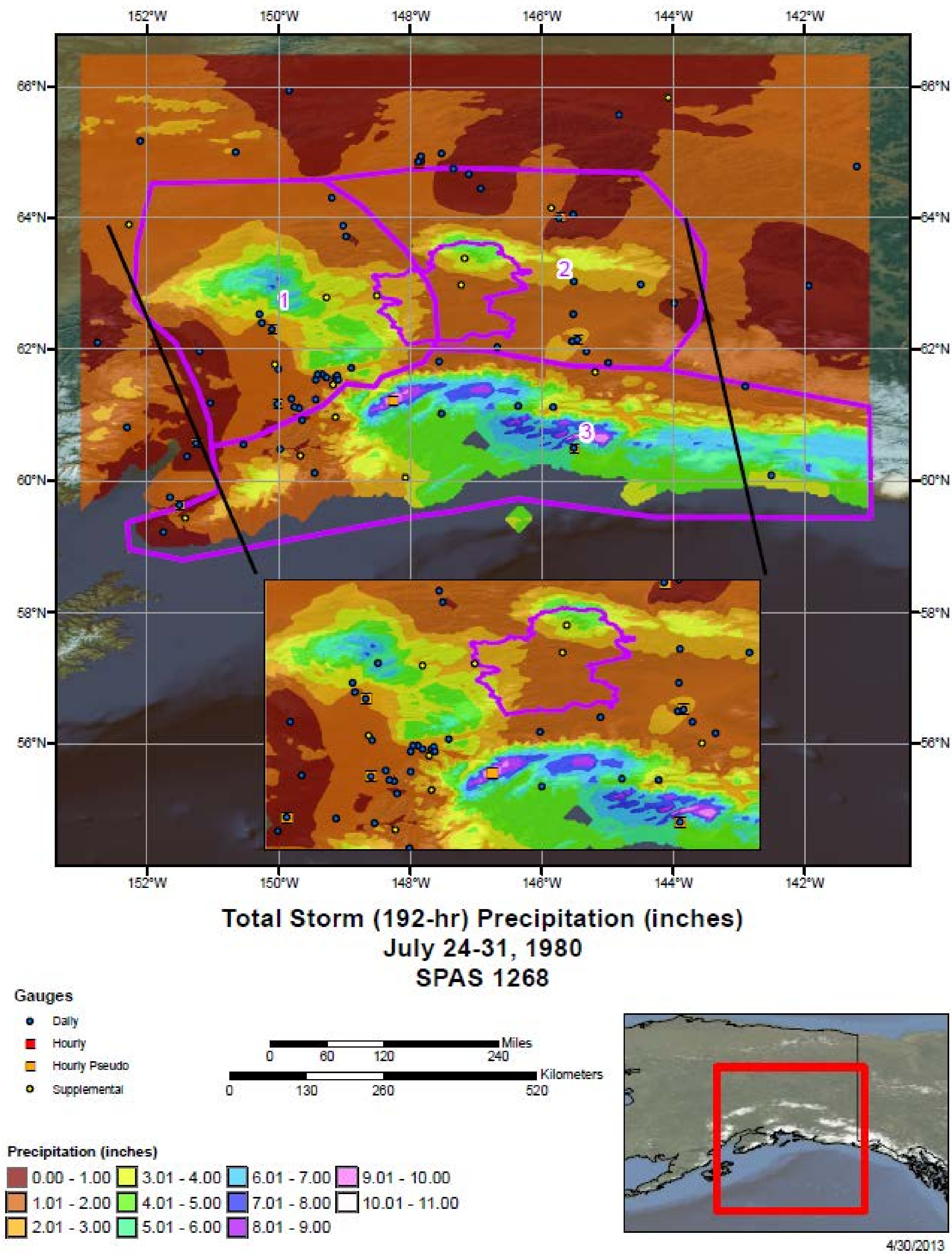
SPAS 1268 Gate AK Storm Analysis
July 25 - 27, 1980



Storm 1268 - Jul. 24 (0900 UTC) - Aug. 1 (0800 UTC), 1980 MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)														
	Duration (hours)													
Area (mi^2)	1	6	12	18	24	36	48	72	96	120	144	168	192	Total
0.2	0.49	1.85	2.8	3.37	3.74	4.08	5.2	6.49	6.71	7.04	7.17	7.33	7.33	7.33
1	0.45	1.82	2.72	3.28	3.66	3.98	5.03	6.23	6.51	6.83	6.93	7.05	7.13	7.13
10	0.45	1.82	2.72	3.28	3.66	3.98	5.03	6.23	6.51	6.83	6.93	7.05	7.13	7.13
25	0.45	1.82	2.72	3.28	3.66	3.98	4.93	6.23	6.44	6.72	6.83	7.04	7.06	7.06
50	0.45	1.82	2.72	3.28	3.66	3.98	4.89	6.14	6.34	6.65	6.76	6.93	6.93	6.93
100	0.44	1.79	2.62	3.26	3.58	3.89	4.75	5.99	6.19	6.47	6.56	6.61	6.78	6.78
150	0.43	1.76	2.62	3.21	3.55	3.87	4.7	5.87	6.07	6.36	6.46	6.56	6.65	6.65
200	0.41	1.74	2.61	3.17	3.5	3.85	4.62	5.76	5.97	6.24	6.35	6.48	6.58	6.58
300	0.38	1.71	2.58	3.11	3.43	3.75	4.52	5.68	5.86	6.17	6.27	6.33	6.45	6.45
400	0.31	1.67	2.54	3.05	3.4	3.72	4.48	5.57	5.74	6.08	6.18	6.31	6.33	6.33
500	0.31	1.64	2.5	3.01	3.33	3.69	4.39	5.48	5.6	5.9	6.07	6.1	6.25	6.25
1,000	0.3	1.55	2.34	2.83	3.17	3.5	4.16	5.14	5.31	5.6	5.7	5.86	5.89	5.89
2,000	0.27	1.4	2.14	2.54	2.83	3.2	3.51	4.36	4.46	4.78	5.03	5.37	5.4	5.40
5,000	0.21	1.12	1.72	2.02	2.3	2.44	2.93	3.67	3.88	4.2	4.32	4.53	4.58	4.58
10,000	0.16	0.84	1.35	1.55	1.81	2.07	2.23	2.75	2.9	3.33	3.49	3.74	3.77	3.77
20,000	0.1	0.56	0.96	1.16	1.3	1.42	1.61	1.98	2.33	2.49	2.66	2.75	2.8	2.80
28,940	0.08	0.43	0.75	0.92	1.05	1.21	1.32	1.7	1.84	2.06	2.16	2.24	2.25	2.25


SPAS #1268 DAD Curve s Zone 1
July 24-August 1, 1980
Area (mi²)
100,000
10,000
1,000
100
10
1
0
1
2
3
4
5
6
7
8
Maximum Average Depth of Precipitation (inches)
1-hour
6-hour
12-hour
18-hour
24-hour
36-hour
48-hour
72-hour
96-hour
120-hour
144-hour
168-hour
192-hour
Total storm (192-hour)


SPAS 1268 Storm Center Mass Curve: Zone 1
July 24 (0900 UTC) - August 1 (0800 UTC), 1980
Lat: 62.9542 Lon: -150.0792
Incremental
Accumulated
7.33"
Incremental Precipitation (inches)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Accumulated Precipitation (inches)
8
6
4
2
0
50
100
150
Index Hour


152°W
150°W
148°W
146°W
144°W
142°W
66°N
64°N
62°N
60°N
58°N
56°N
1
2
3
Total Storm (192-hr) Precipitation (inches)
July 24-31, 1980
SPAS 1268
Gauges
Daily
Hourly
Hourly Pseudo
Supplemental
0 60 120 240 Miles
0 130 260 520 Kilometers
Precipitation (inches)
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
4/30/2013

Denali NP, AWA, SPAS 1267 Zone 1
October 8, 1986

Storm Name:	Seward, AK SPAS 1267-DAD Zone 1
Storm Date:	10/8-12/1986
AWA Analysis Date:	3/4/2014

Storm Adjustment for Susitna-Watana

	Lat	Long
Temporal Transposition Date	25-Sep	
Storm center location	62.93 N	151.14 W
Storm Rep SST location	40.80 N	137.70 W
Transposition SST location	NA	NA
Basin location	62.84 N	147.37 W

Moisture Inflow Direction:	SSE @ 1620	miles
Basin Elevation	3,650	feet
Storm Elevation	5,850	feet
Storm Duration	24hr	feet

The storm representative SST is	66.0 F	with total precipitable water above sea level of			1.86	inches.
The in-place maximum SST is	68.5 F	with total precipitable water above sea level of			2.10	inches.
The transpositioned maximum SST is	NA	with total precipitable water above sea level of			4.08	inches.
The in-place storm elevation is	5,850	which subtracts	0.725	inches of precipitable water at	66.0 F	
The in-place storm elevation is	5,850	which subtracts	0.795	inches of precipitable water at	68.5 F	
The transposition basin elevation at	3,650	which subtracts	xx	inches of precipitable water at	NA	
The inflow barrier/basin elevation height is	1,483	which subtracts	xx	inches of precipitable water at	NA	

The in-place storm maximization factor is	1.15
The transposition/elevation to basin factor is	#VALUE!
The barrier adjustment factor is	#VALUE!
The total adjustment factor is	#VALUE!

Notes: DAD values taken from SPAS 1267 Zone 2. Used SST values on October 8-9 along with HYSLIT backward trajectory. Values were selected in region where temperature did not vary more than a degree over a large area.

Observed Storm Depth-Area-Duration

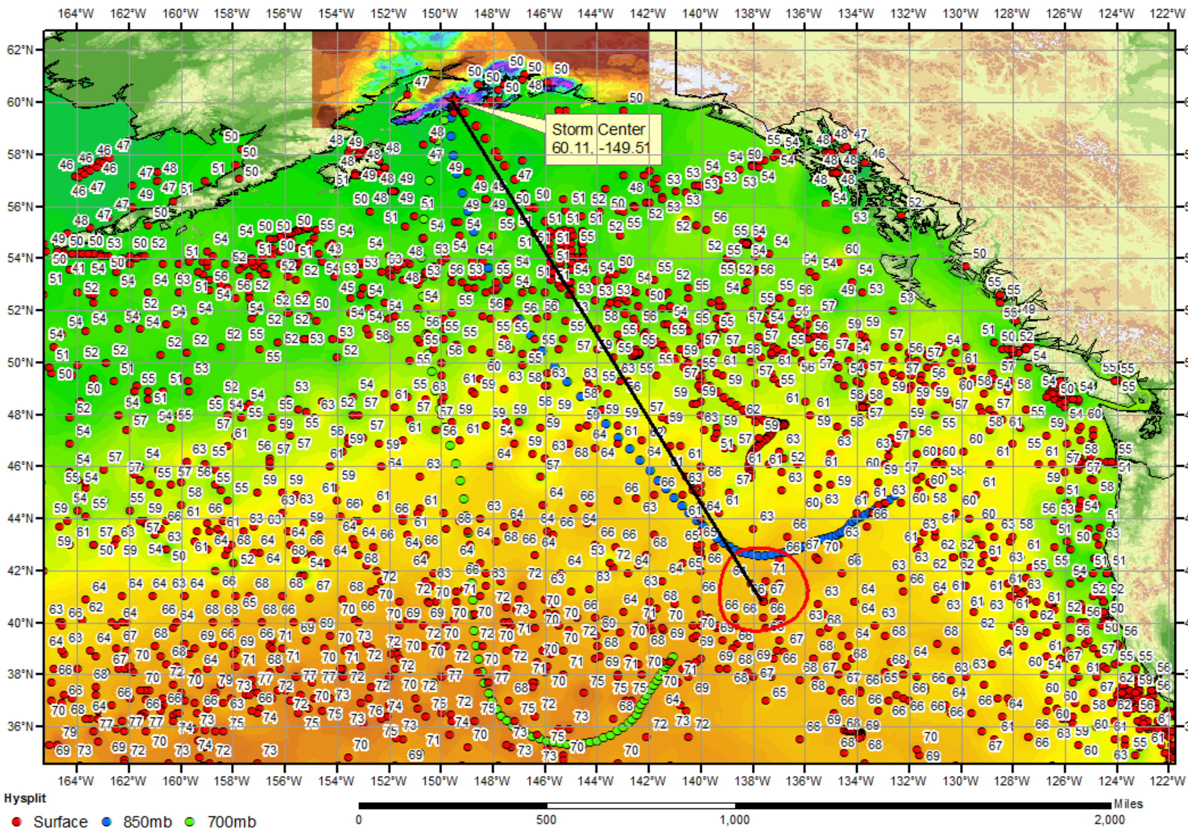
	1 Hours	6 Hours	12 Hours	18 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours
1 sq miles	0.5	2.6	4.9	6.6	7.5	9.1	10.2	10.7	10.7
10 sq miles	0.5	2.5	4.8	6.4	7.4	9.1	10.2	10.7	10.7
100 sq miles	0.4	2.3	4.2	5.8	7.0	9.1	10.2	10.7	10.7
200 sq miles	0.4	2.1	4.1	5.6	6.9	8.9	10.0	10.5	10.5
500 sq miles	0.4	2.1	4.0	5.4	6.6	8.5	9.8	9.8	10.2
1000 sq miles	0.4	2.0	3.8	5.2	6.4	8.4	9.5	9.8	9.9
2000 sq miles	0.3	1.9	3.5	4.9	6.1	8.0	9.1	9.5	9.5
5000 sq miles	0.3	1.7	3.3	4.5	5.6	7.3	8.2	8.4	8.7
10000 sq miles	0.3	1.6	2.9	4.1	5.1	6.6	7.3	7.4	7.8
20000 sq miles	0.2	1.3	2.4	3.3	4.2	5.5	6.1	6.2	6.5

Adjusted Storm Depth-Area-Duration

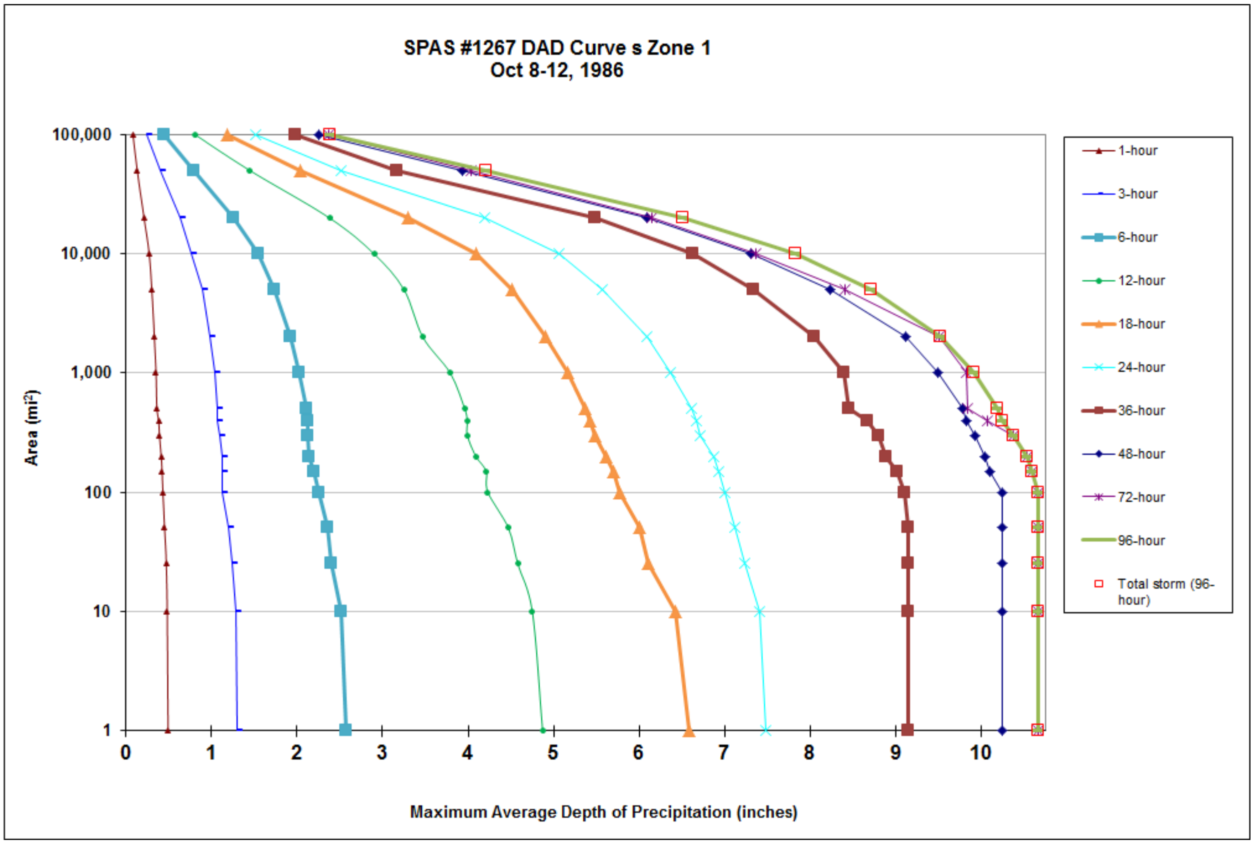
	1 Hours	6 Hours	12 Hours	18 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours
1 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
10 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
100 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
200 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
500 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
1000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
2000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
5000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
10000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
20000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!

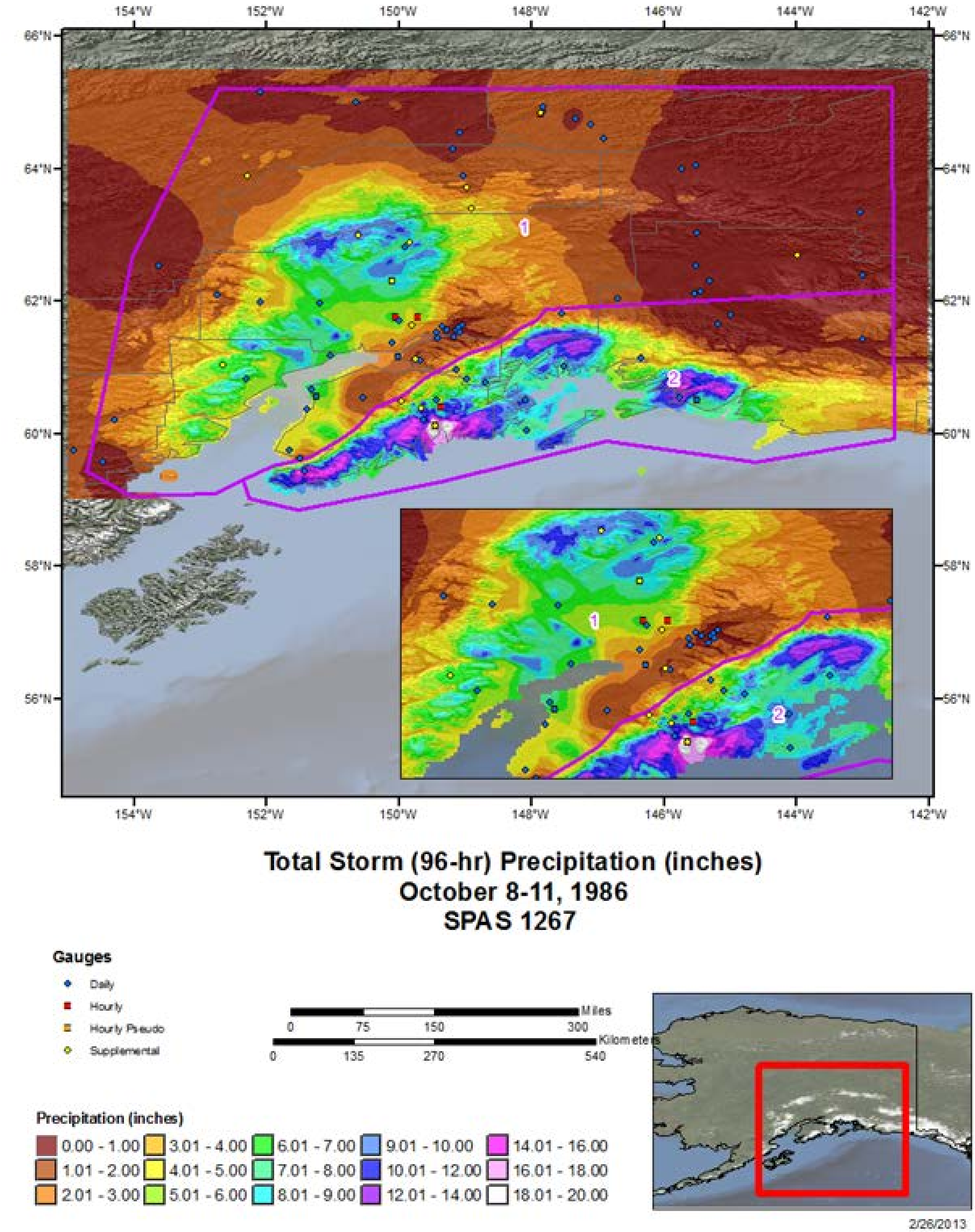
Storm or Storm Center Name	Seward, AK SPAS 1267-DAD Zone 1			
Storm Date(s)	10/8-12/1986			
Storm Type	Atmospheric River			
Storm Location	62.93 N	151.14 W		
Storm Center Elevation	5,850			
Precipitation Total & Duration	11.01 Inches 96-hours			
Storm Representative SST	66.0 F	24hr		
Storm Representative SST Location	40.80 N	137.70 W	Sep	Oct
Maximum SST	68.5 F		69.0	67.0
Moisture Inflow Vector	SSE @ 1620	Miles		
In-place Maximization Factor	1.15			
Temporal Transposition (Date)	25-Sep			
Transposition Dewpoint Location	NA	NA		
Transposition Maximum SST	NA			
Transposition Adjustment Factor	#VALUE!			
Average Basin Elevation	3,650			
Highest Elevation in Basin	13,131			
Inflow Barrier Height	1,483			
Elevation Adjustment Factor	#VALUE!			
Total Adjustment Factor	#VALUE!			

SPAS 1267 Alaska Storm Analysis
October 7-11, 1986



Storm 1267 - Oct. 8 (1000 UTC) - Oct. 12 (0900 UTC), 1986											
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)											
	Duration (hours)										
Area (mi^2)	1	3	6	12	18	24	36	48	72	96	Total
0.2	0.5	1.33	2.63	5	6.74	7.72	9.47	10.59	11.01	11.01	11.01
1	0.49	1.3	2.58	4.87	6.59	7.48	9.14	10.24	10.66	10.66	10.66
10	0.48	1.28	2.51	4.75	6.43	7.41	9.14	10.24	10.66	10.66	10.66
25	0.47	1.24	2.4	4.58	6.1	7.23	9.14	10.24	10.66	10.66	10.66
50	0.45	1.2	2.35	4.47	6.01	7.12	9.14	10.24	10.66	10.66	10.66
100	0.43	1.13	2.26	4.23	5.78	7	9.11	10.24	10.66	10.66	10.66
150	0.42	1.12	2.2	4.21	5.7	6.93	9.01	10.1	10.6	10.6	10.60
200	0.41	1.12	2.14	4.09	5.61	6.87	8.89	10.04	10.53	10.53	10.53
300	0.39	1.09	2.13	3.99	5.48	6.72	8.8	9.93	10.38	10.38	10.38
400	0.38	1.07	2.12	3.99	5.42	6.67	8.67	9.83	10.07	10.25	10.25
500	0.36	1.06	2.11	3.96	5.37	6.61	8.45	9.78	9.84	10.19	10.19
1,000	0.35	1.04	2.02	3.79	5.16	6.36	8.39	9.5	9.83	9.92	9.92
2,000	0.33	0.98	1.92	3.47	4.91	6.09	8.04	9.12	9.51	9.52	9.52
5,000	0.3	0.9	1.73	3.25	4.51	5.57	7.34	8.23	8.41	8.71	8.71
10,000	0.27	0.76	1.55	2.9	4.09	5.06	6.62	7.31	7.37	7.83	7.83
20,000	0.21	0.64	1.26	2.38	3.29	4.19	5.49	6.09	6.15	6.51	6.51
50,000	0.13	0.4	0.79	1.45	2.04	2.52	3.16	3.93	4.03	4.21	4.21
100,000	0.08	0.24	0.45	0.81	1.18	1.51	1.98	2.25	2.37	2.39	2.39
100,631	0.08	0.24	0.45	0.81	1.18	1.5	1.97	2.24	2.37	2.38	2.38


SPAS #1267 DAD Curve s Zone 1
Oct 8-12, 1986
Area (mi²)
100,000
10,000
1,000
100
10
1
0
1
2
3
4
5
6
7
8
9
10
Maximum Average Depth of Precipitation (inches)
1-hour
3-hour
6-hour
12-hour
18-hour
24-hour
36-hour
48-hour
72-hour
96-hour
Total storm (96-hour)


154°W
152°W
150°W
148°W
146°W
144°W
142°W
66°N
64°N
62°N
60°N
58°N
56°N
1
2
Total Storm (96-hr) Precipitation (inches)
October 8-11, 1986
SPAS 1267
Gauges
Daily
Hourly
Hourly Pseudo
Supplemental
Miles
0 75 150 300
Kilometers
0 135 270 540
Precipitation (inches)
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 12.00
12.01 - 14.00
14.01 - 16.00
16.01 - 18.00
18.01 - 20.00
2/26/2013

Black Rapids, AK, SPAS 1303 Zone 1
August 17, 2006

Storm Name:	SPAS 1303 Zone 1	Storm Adjustment for Susitna-Watana
Storm Date:	8/17-22/2006	
AWA Analysis Date:	3/4/2014	

Temporal Transposition Date	15-Aug	
	Lat	Long
Storm center location	63.47 N	145.69 W
Storm Rep SST location	50.00 N	145.00 W
Transposition SST location	NA	NA
Basin location	NA	NA

Moisture Inflow Direction:	S @ 930	miles
Basin Elevation	3,650	feet
Storm Elevation	5,400	feet
Storm Duration	132	hours
Effective Barrier Height	1,483	feet

The storm representative SST is	55.0 F	with total precipitable water above sea level of			1.07	inches.
The in-place maximum SST is	59.0 F	with total precipitable water above sea level of			1.31	inches.
The transpositioned maximum SST is	NA	with total precipitable water above sea level of			4.44	inches.
The in-place storm elevation is	5,400	which subtracts	0.56	inches of precipitable water at	55.0 F	
The in-place storm elevation is	5,400	which subtracts	0.67	inches of precipitable water at	59.0 F	
The transposition storm elevation at	3,650	which subtracts	xx	inches of precipitable water at	NA	
The moisture inflow barrier height is	3,650	which subtracts	xx	inches of precipitable water at	NA	

The in-place maximization factor is	1.25
The transposition/elevation factor is	1.00
The barrier adjustment factor is	#VALUE!
The total adjustment factor is	#VALUE!

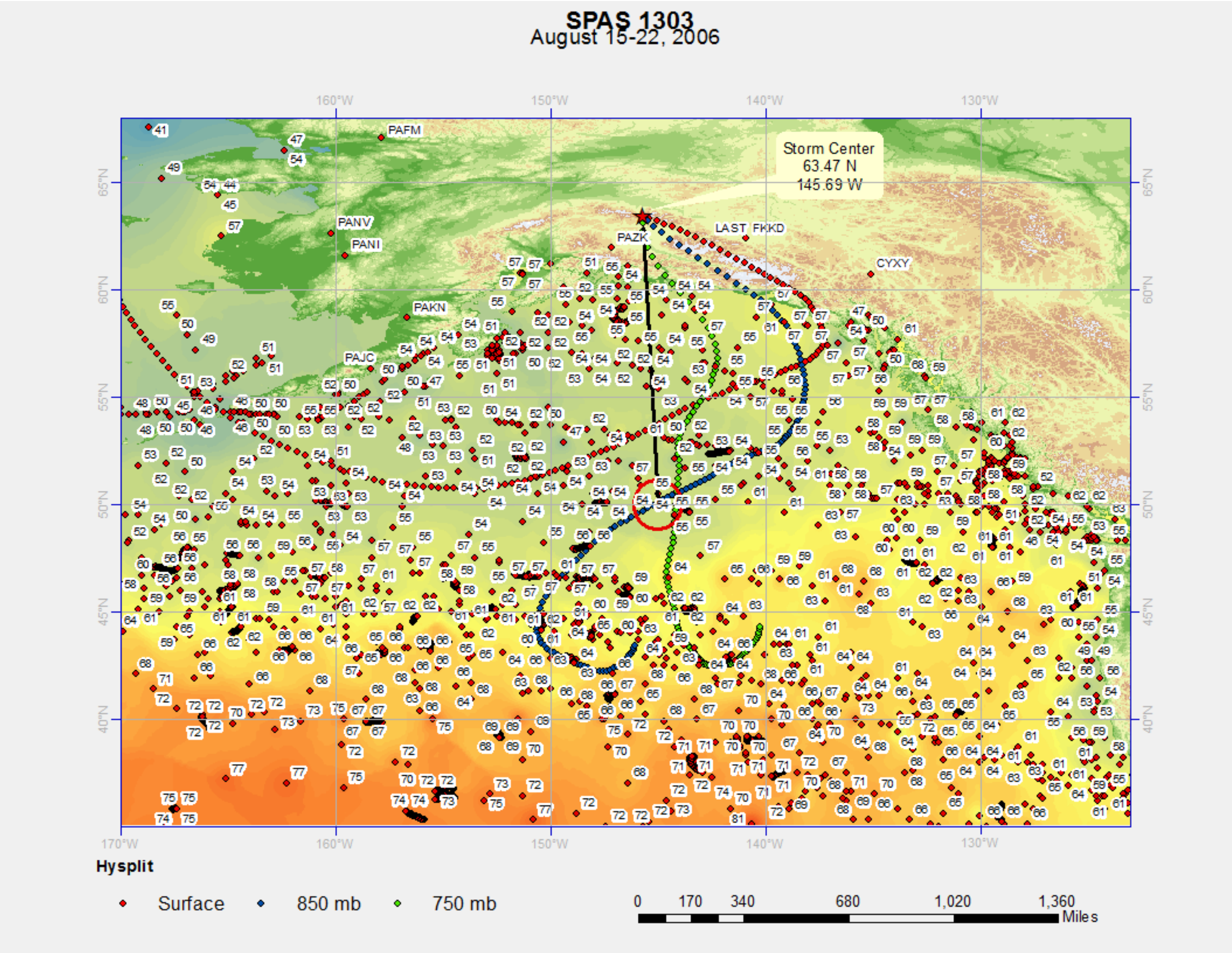
Observed Storm Depth-Area-Duration

	1 Hour	6 Hours	12 Hours	18 Hours	24 Hours	48 Hours	72 Hours	96 Hours	120 Hours	132 Hours
1 sq miles	0.7	2.9	5.1	6.0	7.7	10.4	14.2	15.1	15.7	15.7
10 sq miles	0.7	2.9	5.1	6.0	7.7	10.4	14.2	15.1	15.7	15.7
100 sq miles	0.6	2.8	4.7	5.8	7.6	10.2	13.4	14.2	14.9	15.0
200 sq miles	0.6	2.6	4.4	5.8	7.5	10.2	12.6	13.2	13.8	14.3
500 sq miles	0.5	2.3	3.7	5.5	7.1	9.6	11.5	12.3	12.7	13.0
1000 sq miles	0.4	2.1	3.4	5.1	6.5	8.7	10.4	11.3	11.7	12.0
2000 sq miles	0.4	1.8	3.0	4.5	5.6	7.2	9.1	9.9	10.4	10.6
5000 sq miles	0.3	1.4	2.4	3.6	4.2	5.3	7.0	7.6	8.2	8.4
10000 sq miles	0.2	1.1	1.8	2.7	3.1	4.1	5.5	5.9	6.7	6.9
20000 sq miles	0.2	0.7	1.4	1.6	2.0	2.5	3.4	4.4	5.06	5.2
50000 sq miles	0.1	0.5	0.6	0.7	0.9	1.6	2.4	3.1	3.25	3.5
100000 sq miles	0.1	0.3	0.4	0.6	0.8	1.2	1.7	2.0	2.3	2.4

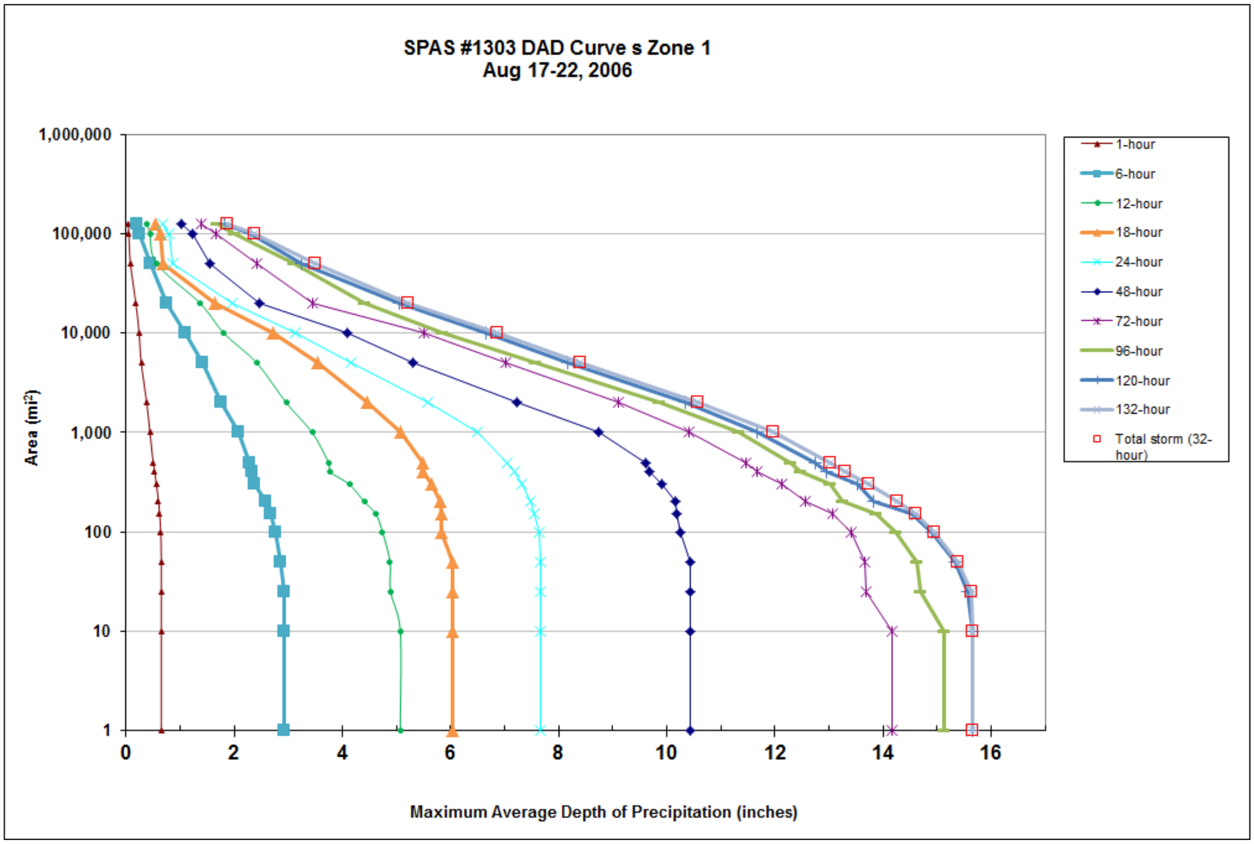
Adjusted Storm Depth-Area-Duration

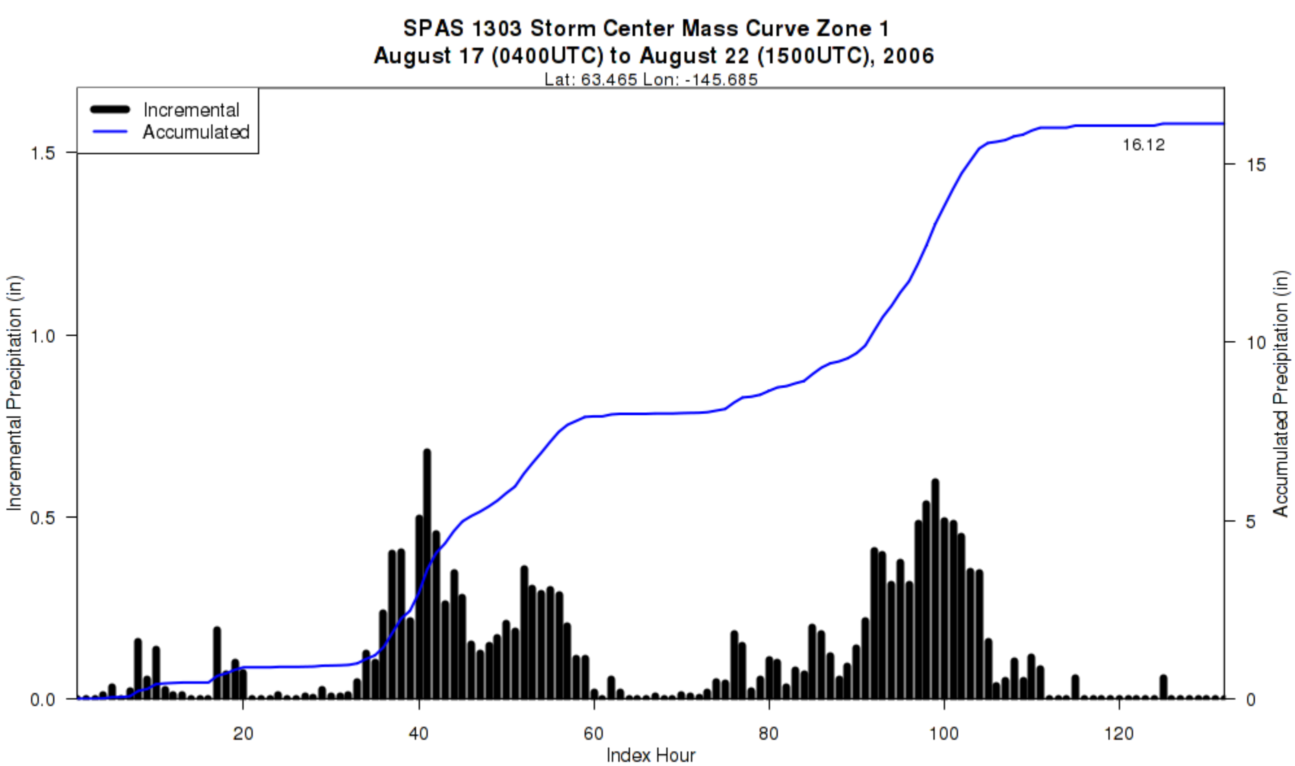
	1 Hour	6 Hours	12 Hours	18 Hours	24 Hours	48 Hours	72 Hours	96 Hours	120 Hours	132 Hours
1 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
10 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
100 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
200 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
500 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
1000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
2000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
5000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
10000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
20000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
50000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
100000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!

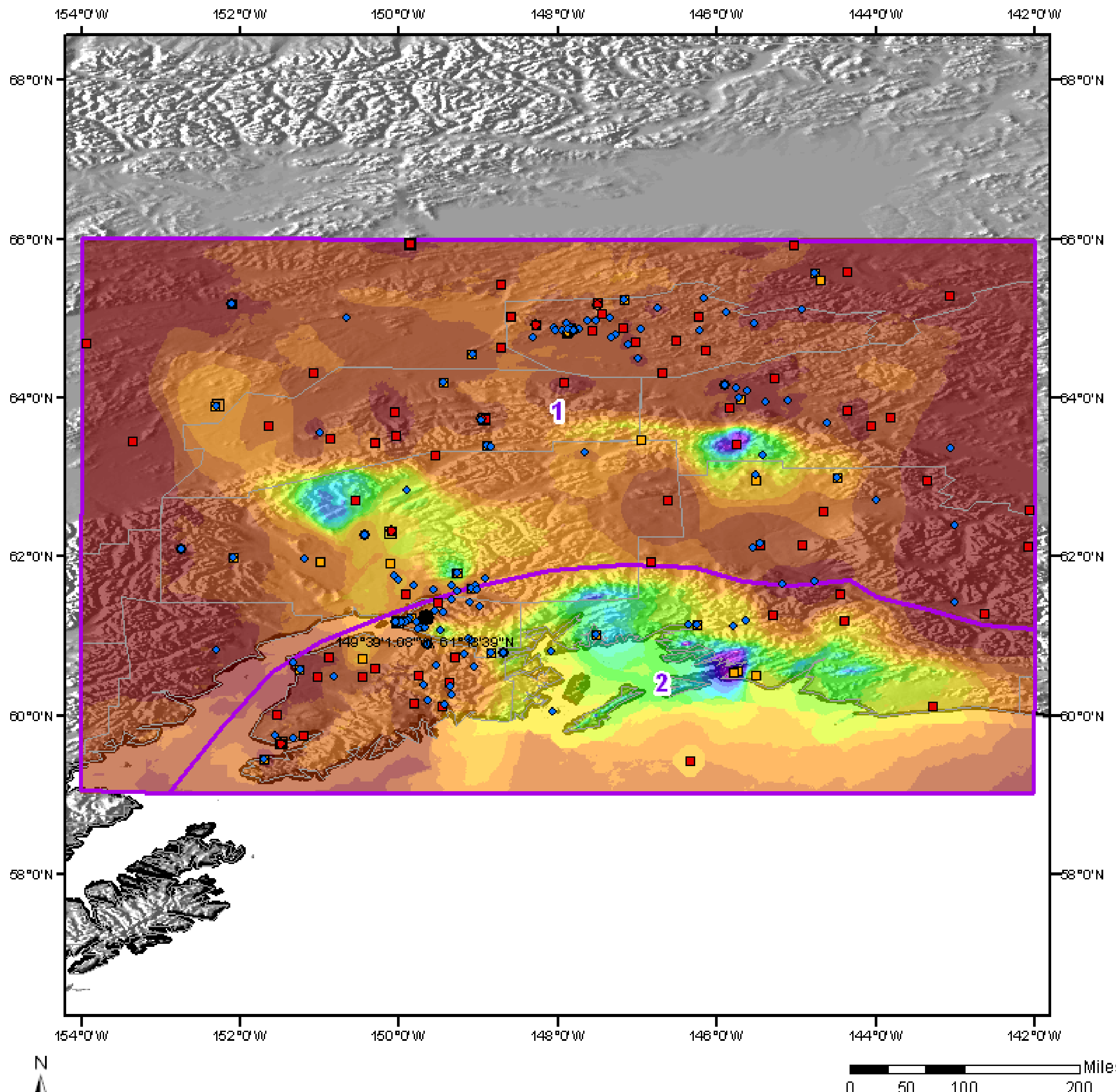
Storm or Storm Center Name	SPAS 1303 Zone 1		
Storm Date(s)	8/17-22/2006		
Storm Type	Synoptic		
Storm Location	63.47 N	145.69 W	
Storm Center Elevation	5400		
Precipitation Total & Duration (10 sq mi)	16.12 inches in 132 hours		
Storm Representative SST	55.0 F		
Storm Representative SST Location	50.00 N	145.00 W	Aug
In-place Maximum SST	59.0 F		59
Moisture Inflow Vector	S @ 930		
In-place Maximization Factor	1.25		
Temporal Transposition (Date)	15-Aug		
Transposition SST Location	NA	NA	Jul
Transposition Maximum SST	NA		
Transposition Adjustment Factor	1.00		
Average Basin Elevation	3,650		
Highest Elevation in Basin	13,131		
Inflow Barrier Height	1,483		
Elevation Adjustment Factor	#VALUE!		
Total Adjustment Factor	#VALUE!		



Storm 1303 - Aug. 17 (0400 UTC) - Aug. 22 (1500 UTC), 2006											
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)											
	Duration (hours)										
Area (mi^2)	1	6	12	18	24	48	72	96	120	132	Total
0.2	0.69	3.03	5.18	6.18	7.93	10.75	14.59	15.56	16.08	16.12	16.12
1	0.65	2.93	5.07	6.04	7.67	10.44	14.16	15.13	15.66	15.66	15.66
10	0.65	2.93	5.07	6.04	7.67	10.44	14.16	15.13	15.66	15.66	15.66
25	0.65	2.92	4.89	6.04	7.67	10.44	13.69	14.7	15.56	15.63	15.63
50	0.65	2.86	4.88	6.03	7.67	10.44	13.66	14.63	15.33	15.39	15.39
100	0.64	2.76	4.74	5.84	7.64	10.24	13.42	14.23	14.89	14.95	14.95
150	0.62	2.68	4.62	5.84	7.56	10.19	13.07	13.87	14.54	14.59	14.59
200	0.6	2.59	4.41	5.8	7.48	10.15	12.57	13.24	13.82	14.25	14.25
300	0.56	2.38	4.13	5.66	7.33	9.9	12.12	13.02	13.52	13.73	13.73
400	0.53	2.33	3.78	5.5	7.19	9.67	11.67	12.47	12.95	13.29	13.29
500	0.5	2.28	3.74	5.48	7.05	9.6	11.46	12.29	12.74	13.02	13.02
1,000	0.44	2.07	3.44	5.08	6.5	8.74	10.42	11.32	11.68	11.96	11.96
2,000	0.38	1.75	2.96	4.45	5.57	7.24	9.1	9.87	10.35	10.57	10.57
5,000	0.28	1.41	2.42	3.55	4.17	5.31	7.03	7.58	8.17	8.4	8.40
10,000	0.24	1.1	1.81	2.71	3.12	4.09	5.51	5.86	6.66	6.86	6.86
20,000	0.18	0.74	1.37	1.64	1.97	2.47	3.44	4.42	5.06	5.22	5.22
50,000	0.08	0.45	0.57	0.67	0.87	1.55	2.42	3.1	3.25	3.49	3.49
100,000	0.05	0.25	0.44	0.64	0.79	1.22	1.67	2.01	2.3	2.37	2.37
126,338	0.04	0.2	0.39	0.55	0.67	1.03	1.38	1.68	1.83	1.88	1.88


SPAS #1303 DAD Curve s Zone 1
Aug 17-22, 2006
Area (mi²)
Maximum Average Depth of Precipitation (inches)
1-hour
6-hour
12-hour
18-hour
24-hour
48-hour
72-hour
96-hour
120-hour
132-hour
Total storm (32-hour)
1,000,000
100,000
10,000
1,000
100
10
1
0
2
4
6
8
10
12
14
16


SPAS 1303 Storm Center Mass Curve Zone 1
August 17 (0400UTC) to August 22 (1500UTC), 2006
Lat: 63.465 Lon: -145.685
Incremental
Accumulated
16.12
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
0
5
10
15
20
40
60
80
100
120



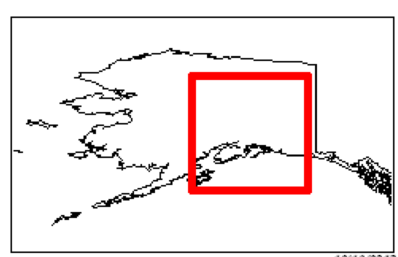
Total 132-hour Precipitation (inches)
August 17 0400 UTC - August 22 1500 UTC, 2006
SPAS #1303

Precipitation (inches)

0.00 - 1.00	7.01 - 8.00	14.01 - 15.00
1.01 - 2.00	8.01 - 9.00	15.01 - 16.00
2.01 - 3.00	9.01 - 10.00	16.01 - 17.00
3.01 - 4.00	10.01 - 11.00	17.01 - 18.00
4.01 - 5.00	11.01 - 12.00	18.01 - 19.00
5.01 - 6.00	12.01 - 13.00	19.01 - 20.00
6.01 - 7.00	13.01 - 14.00	

Stations

- Daily
- Daily omitted
- Hourly
- Hourly omitted
- Hourly pseudo
- Supplemental
- Supplemental omitted



Old Tyonek, AK, SPAS 1256 Zone 1
September 15, 2012

Storm Name:	SPAS 1256 Old Tyonek, AK DAI	Storm Adjustment for Susitna-Watana
Storm Date:	9/15-22/2012	
AWA Analysis Date:	1/22/2013	

Temporal Transposition Date	15-Sep	
	Lat	Long
Storm center location	61.26 N	151.86 W
Storm Rep SST location	49.00 N	157.00 W
Transposition SST location	NA	NA
Basin location	42.76 N	74.12 W

Moisture Inflow Direction:	SSW @ 870	miles
Basin Elevation	1,100	feet
Storm Elevation	2,730	feet
Storm Duration	24	hours
Effective Barrier Height	1,200	feet

The storm representative SST is	54.0 F	with total precipitable water above sea level of			1.02	inches.
The in-place maximum SST is	57.0 F	with total precipitable water above sea level of			1.19	inches.
The transpositioned maximum SST is	NA	with total precipitable water above sea level of			4.44	inches.
The in-place storm elevation is	2,730	which subtracts	0.18	inches of precipitable water at	54.0 F	
The in-place storm elevation is	2,730	which subtracts	0.20	inches of precipitable water at	57.0 F	
The transposition storm elevation at	1,100	which subtracts	xx	inches of precipitable water at	NA	
The moisture inflow barrier height is	1,200	which subtracts	xx	inches of precipitable water at	NA	

The in-place maximization factor is	1.18
The transposition/elevation factor is	#VALUE!
The barrier adjustment factor is	#VALUE!
The total adjustment factor is	#VALUE!

Notes: Storm representative SST value was based on SST values for September 13-14, 2012 along the surface HYSPLIT trajectory data. The HYSPLIT trajectory also represents the second period of precipitation well. Values were selected in region where temperature did not vary more than a 1-degree over a large area and had temperature recordings throughout the period.

Observed Storm Depth-Area-Duration

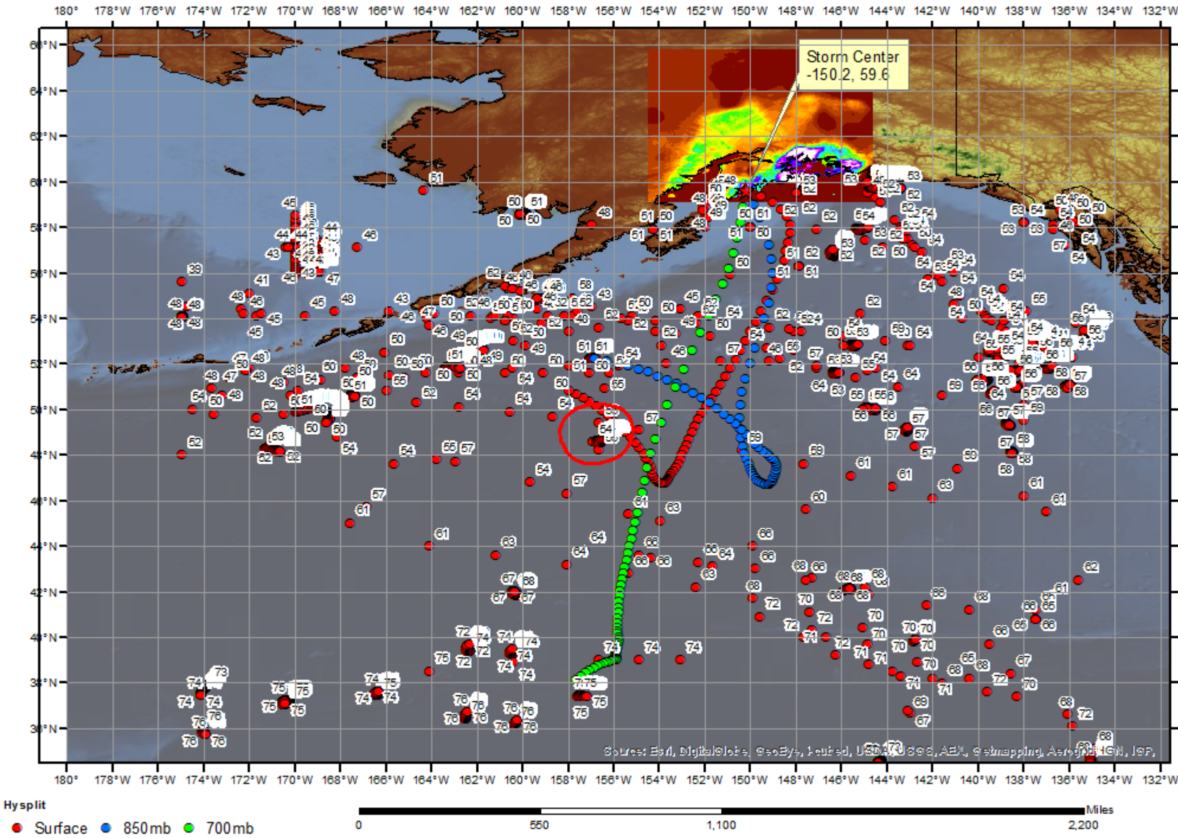
	1 Hour	6 Hours	12 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours	168 Hours
10 sq miles	0.9	3.2	3.9	6.1	8.3	8.6	9.0	10.0	11.9	15.3
100 sq miles	0.9	2.6	3.6	5.1	7.3	7.4	7.9	9.7	11.5	15.3
200 sq miles	0.8	2.4	3.5	4.5	6.4	6.6	7.5	9.7	11.3	15.0
500 sq miles	0.8	2.3	3.4	4.0	5.2	6.0	7.3	9.4	10.8	14.3
1000 sq miles	0.8	2.1	3.1	3.8	4.8	5.9	7.1	9.1	10.4	13.6
2000 sq miles	0.7	1.8	2.7	3.6	4.6	5.5	6.8	8.6	10.0	12.9
5000 sq miles	0.6	1.6	2.5	3.3	4.0	5.0	6.3	7.7	9.1	11.8
10000 sq miles	0.5	1.4	2.3	3.0	3.7	4.5	5.9	6.8	8.2	10.7
20000 sq miles	0.3	1.1	1.9	2.6	3.2	3.9	5.1	5.8	7.1	9.2

Adjusted Storm Depth-Area-Duration

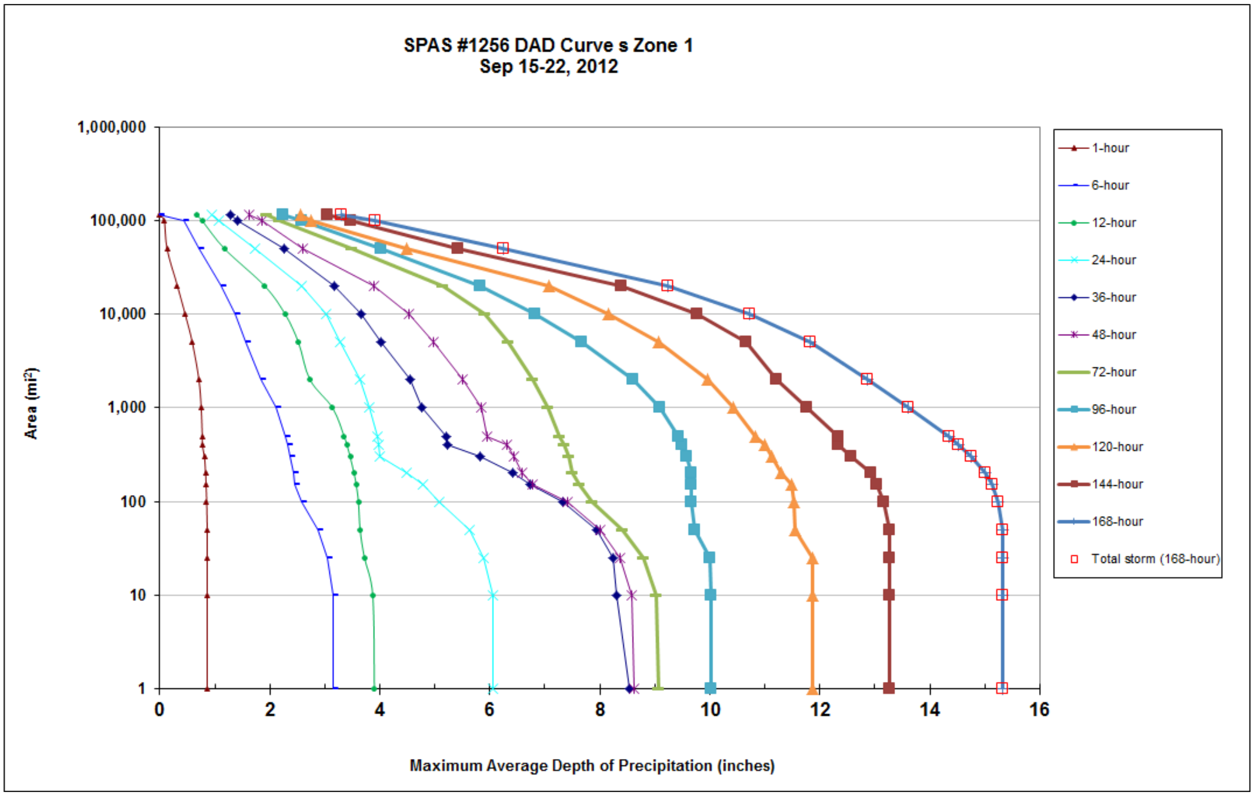
	1 Hour	6 Hours	12 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours	168 Hours
10 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
100 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
200 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
500 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
1000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
2000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
5000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
10000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
20000 sq miles	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!

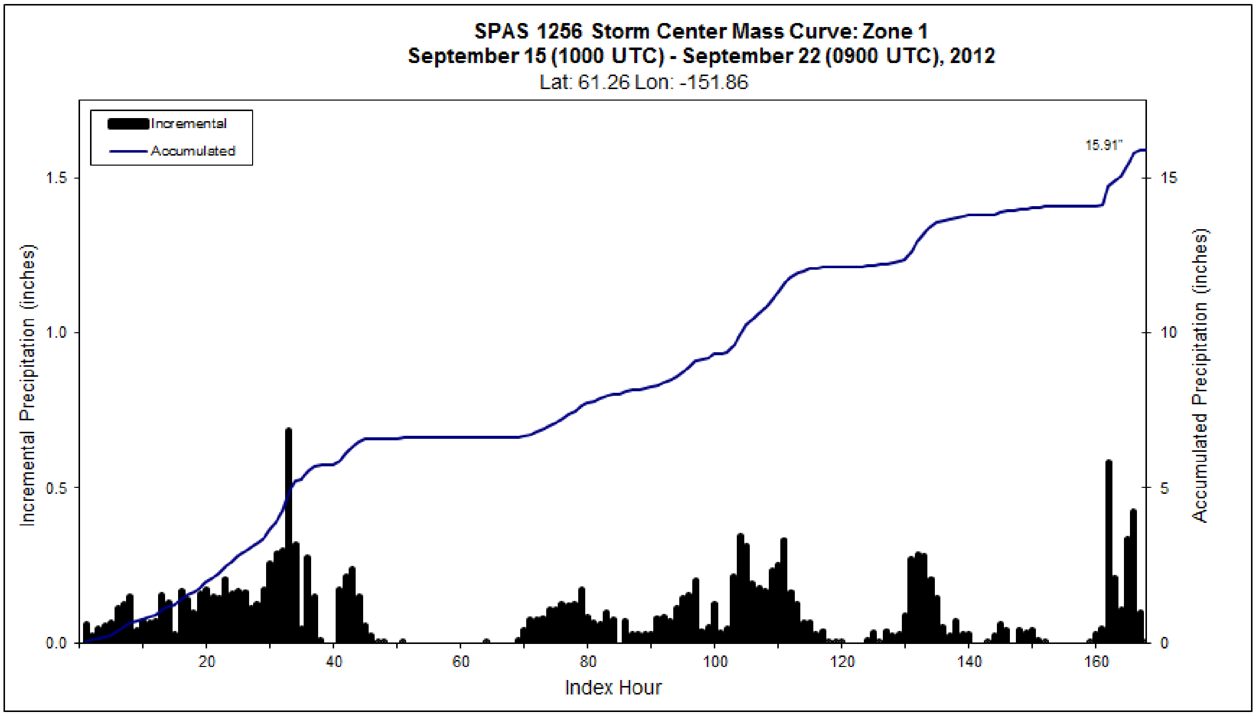
Storm or Storm Center Name	SPAS 1256 Old Tyonek, AK DAD Zone 1			
Storm Date(s)	9/15-22/2012			
Storm Type	Atmospheric River			
Storm Location	61.26 N	151.86 W		
Storm Center Elevation	2,730			
Precipitation Total & Duration	15.91 inches in 168 hours			
Storm Representative SST	54.0 F		15-Aug	15-Sep
Storm Representative SST Location	49.00 N	157.00 W	56.5	57.0
In-place Maximum SST	57.0 F			
Moisture Inflow Vector	SSW @ 870			
In-place Maximization Factor	1.18			
Temporal Transposition (Date)	15-Sep			
Transposition SST Location	NA	NA		
Transposition Maximum SST	NA			
Transposition Adjustment Factor	#VALUE!			
Average Basin Elevation	1,100			
Highest Elevation in Basin	5,333			
Inflow Barrier Height	1,200			
Elevation Adjustment Factor	#VALUE!			
Total Adjustment Factor	#VALUE!			

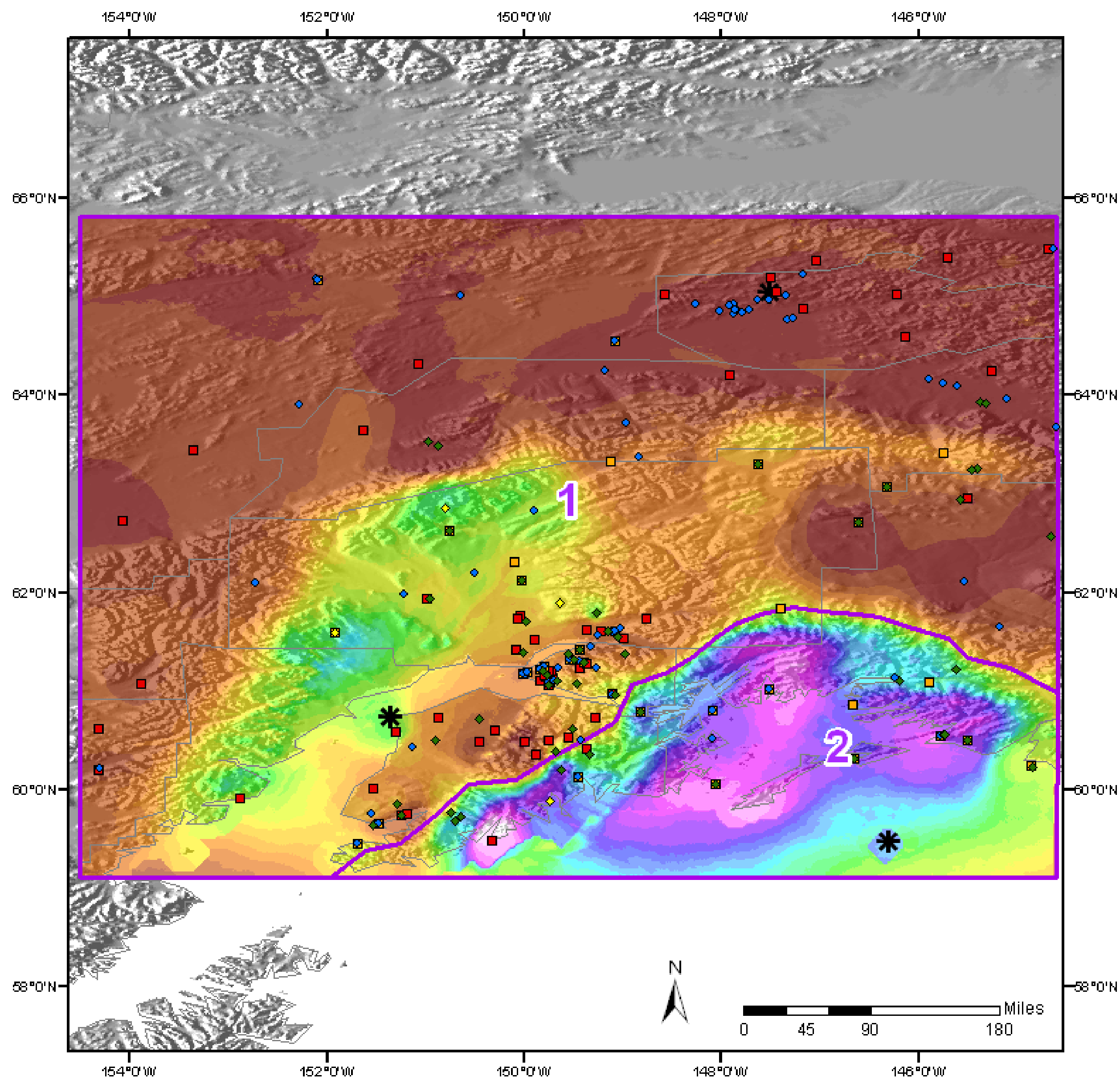
SPAS 1256 Denai, AK Storm Analysis
September 15-21, 2012



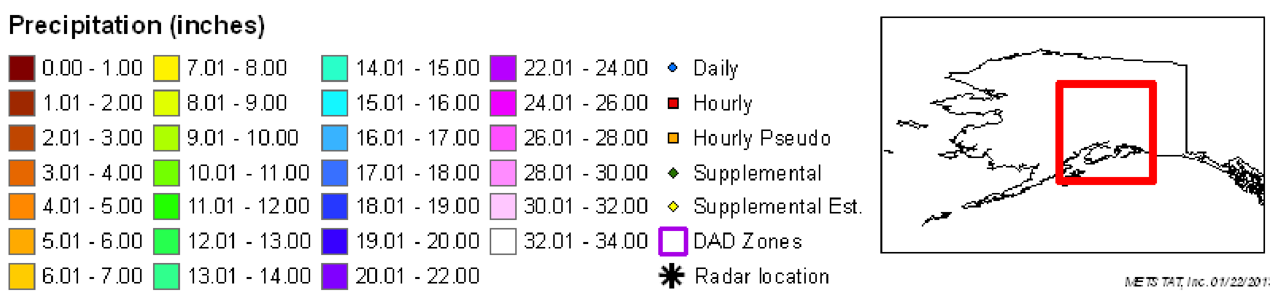
Storm 1256 - Sep. 15 (1000 UTC) - Sep. 22 (0900 UTC), 2013												
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)												
	Duration (hours)											
Area (mi^2)	1	6	12	24	36	48	72	96	120	144	168	Total
0.2	0.88	3.26	3.98	6.23	8.76	8.86	9.3	10.52	12.34	13.83	15.91	15.91
1	0.86	3.16	3.9	6.06	8.53	8.63	9.06	10.03	11.87	13.27	15.32	15.32
10	0.86	3.16	3.87	6.06	8.31	8.59	9.03	10.03	11.87	13.27	15.32	15.32
25	0.86	3.04	3.72	5.88	8.25	8.36	8.79	10.01	11.86	13.27	15.32	15.32
50	0.86	2.88	3.64	5.63	7.94	8.01	8.42	9.73	11.55	13.27	15.32	15.32
100	0.85	2.58	3.61	5.09	7.34	7.41	7.86	9.66	11.52	13.16	15.25	15.25
150	0.84	2.45	3.57	4.79	6.74	6.78	7.63	9.66	11.49	13.04	15.13	15.13
200	0.83	2.42	3.53	4.49	6.41	6.58	7.5	9.66	11.29	12.92	15	15.00
300	0.81	2.37	3.46	4	5.83	6.44	7.43	9.58	11.13	12.57	14.76	14.76
400	0.77	2.32	3.4	3.98	5.23	6.31	7.36	9.5	10.99	12.33	14.52	14.52
500	0.77	2.29	3.35	3.96	5.21	5.95	7.27	9.43	10.83	12.33	14.34	14.34
1,000	0.75	2.12	3.14	3.8	4.76	5.85	7.05	9.08	10.43	11.77	13.61	13.61
2,000	0.71	1.83	2.73	3.64	4.55	5.5	6.78	8.61	9.95	11.22	12.86	12.86
5,000	0.59	1.57	2.52	3.28	4.03	4.98	6.34	7.66	9.07	10.66	11.83	11.83
10,000	0.46	1.38	2.28	3.03	3.66	4.52	5.91	6.82	8.16	9.77	10.72	10.72
20,000	0.32	1.12	1.91	2.58	3.18	3.9	5.14	5.82	7.07	8.38	9.24	9.24
50,000	0.13	0.72	1.18	1.73	2.27	2.6	3.49	4.02	4.49	5.42	6.24	6.24
100,000	0.08	0.43	0.77	1.08	1.42	1.86	2.17	2.58	2.74	3.47	3.92	3.92
116,206	0	0	0.67	0.94	1.29	1.63	1.94	2.24	2.55	3.04	3.29	3.29


SPAS #1256 DAD Curve s Zone 1
Sep 15-22, 2012
Area (mi²)
Maximum Average Depth of Precipitation (inches)
1-hour
6-hour
12-hour
24-hour
36-hour
48-hour
72-hour
96-hour
120-hour
144-hour
168-hour
Total storm (168-hour)


SPAS 1256 Storm Center Mass Curve: Zone 1
September 15 (1000 UTC) - September 22 (0900 UTC), 2012
Lat: 61.26 Lon: -151.86
Incremental
Accumulated
15.91"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour



Total 168-hour Storm Precipitation (inches)
Sept. 15, 2012 1000 Z - Sept. 22, 2012 0900 Z
SPAS #1256



Appendix D

Storm Precipitation Analysis System (SPAS) Program Description

INTRODUCTION

The Storm Precipitation Analysis System (SPAS) is grounded on years of scientific research with a demonstrated reliability in hundreds of post-storm precipitation analyses. It has evolved into a trusted hydrometeorological tool that provides accurate precipitation data at a high spatial and temporal resolution for use in a variety of sensitive hydrologic applications (Faulkner et al. 2004, Tomlinson et al. 2003-2012). Applied Weather Associates, LLC and METSTAT, Inc. initially developed SPAS in 2002 for use in producing Depth-Area-Duration values for Probable Maximum Precipitation (PMP) analyses. SPAS utilizes precipitation gauge data, "basemaps" and radar data (when available) to produce gridded precipitation at time intervals as short as 5-minutes, at spatial scales as fine as 1 km^2 and in a variety of customizable formats. To date (February 2014) SPAS has been used to analyze over 330 storm centers across all types of terrain, among highly varied meteorological settings and some occurring over 100-years ago.

SPAS output has many applications including, but not limited to: hydrologic model calibration/validation, flood event reconstruction, storm water runoff analysis, forensic cases and PMP studies. Detailed SPAS-computed precipitation data allow hydrologists to accurately model runoff from basins, particularly when the precipitation is unevenly distributed over the drainage basin or when rain gauge data are limited or not available. The increased spatial and temporal accuracy of precipitation estimates has eliminated the need for commonly made assumptions about precipitation characteristics (such as uniform precipitation over a watershed), thereby greatly improving the precision and reliability of hydrologic analyses.

To instill consistency in SPAS analyses, many of the core methods have remained consistent from the beginning. However, SPAS is constantly evolving and improving through new scientific advancements and as new data and improvements are incorporated. This write-up describes the current inter-workings of SPAS, but the reader should realize SPAS can be customized on a case-by-case basis to account for special circumstances; these adaptations are documented and included in the deliverables. The overarching goal of SPAS is to combine the strengths of rain gauge data and radar data (when available) to provide sound, reliable and accurate spatial precipitation data.

Hourly precipitation observations are generally limited to a small number of locations, with many basins lacking observational precipitation data entirely. However, Next Generation Radar (NEXRAD) data provide valuable spatial and temporal information over data-sparse basins, which have historically lacked reliability for determining precipitation rates and reliable quantitative precipitation estimates (QPE). The improved reliability in SPAS is made possible by hourly calibration of the NEXRAD radar-precipitation relationship, combined with local hourly bias adjustments to force consistency between the final result and "ground truth" precipitation measurements. If NEXRAD radar data are available (generally for storm events since the mid-1990's), precipitation accumulation at temporal scales as frequent as 5-minutes can be analyzed. If no NEXRAD data are available, then precipitation data are analyzed in hourly increments. A summary of the general SPAS processes are shown in flow chart in Figure D.1.

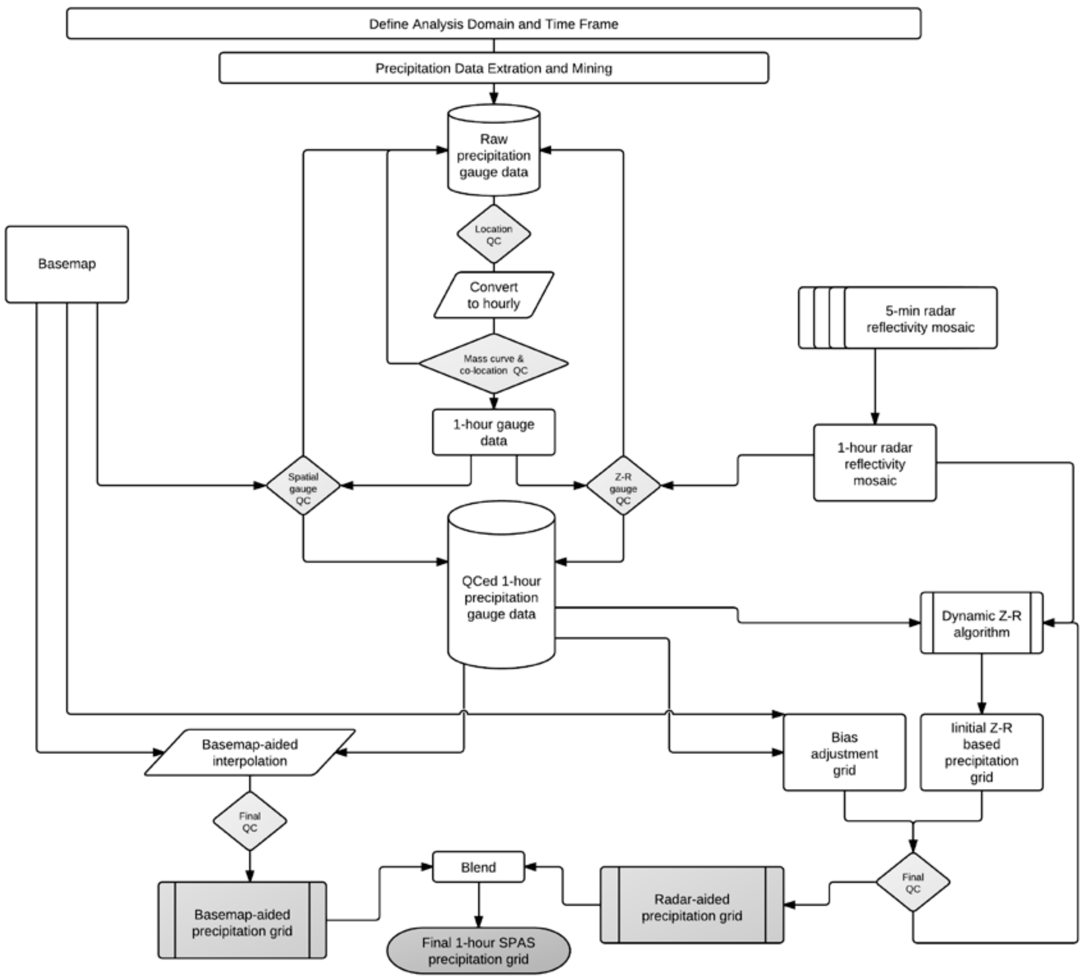


Figure D.1. SPAS flow chart.

SETUP

Prior to a SPAS analysis, careful definition of the storm analysis domain and time frame to be analyzed is established. Several considerations are made to ensure the domain (longitude-latitude box) and time frame are sufficient for the given application.

SPAS Analysis Domain

For PMP applications it is important to establish an analysis domain that completely encompasses a storm center, meanwhile hydrologic modeling applications are more concerned about a specific basin, watershed or catchment. If radar data are available, then it is also important to establish an area large enough to encompass enough stations (minimum of ~30) to adequately derive reliable radar-precipitation intensity relationships (discussed later). The domain is defined by evaluating existing documentation on the storm as well as plotting and evaluating initial precipitation gauge data on a map. The analysis domain is defined to include as many hourly recording gauges as possible given their importance in timing. The domain must include enough of a buffer to accurately model the nested domain of interest. The domain is defined as a longitude-latitude (upper left and lower right corner) rectangular region.

SPAS Analysis Time Frame

Ideally, the analysis time frame, also referred to as the Storm Precipitation Period (SPP), will extend from a dry period through the target wet period then back into another dry period. This is to ensure that total storm precipitation amounts can be confidently associated with the storm in question and not contaminated by adjacent wet periods. If this is not possible, a reasonable time period is selected that is bounded by relatively lighter precipitation. The time frame of the hourly data must be sufficient to capture the full range of daily gauge observational periods for the daily observations to be disaggregated into estimated incremental hourly values (discussed later). For example, if a daily gauge takes observations at 8:00 AM, then the hourly data must be available from 8:00 AM the day prior. Given the configuration of SPAS, the minimum SPP is 72 hours and aligns midnight to midnight.

The core precipitation period (CPP) is a sub-set of the SPP and represents the time period with the most precipitation and the greatest number of reporting gauges. The CPP represents the time period of interest and where our confidence in the results is highest.

DATA

The foundation of a SPAS analysis is the "ground truth" precipitation measurements. In fact, the level of effort involved in "data mining" and quality control represent over half of the total level of effort needed to conduct a complete storm analysis. SPAS operates with three primary data sets: precipitation gauge data, a "basemap" and, if available, radar data. Table D.1 conveys the variety of precipitation gauges usable by SPAS. For each gauge, the following elements are gathered, entered and archived into SPAS database:

- Station ID
- Station name
- Station type (H=hourly, D=Daily, S=Supplemental, etc.)
- Longitude in decimal degrees
- Latitude in decimal degrees
- Elevation in feet above MSL
- Observed precipitation

- Observation times
- Source
- If unofficial, the measurement equipment and/or method is also noted.

Based on the SPP and analysis domain, hourly and daily precipitation gauge data are extracted from our in-house database as well as the Meteorological Assimilation Data Ingest System (MADIS). Our in-house database contains data dating back to the late 1800s, while the MADIS system (described below) contains archived data back to 2002.

Hourly Precipitation Data

Our hourly precipitation database is largely comprised of data from NCDC TD-3240, but also precipitation data from other mesnonets and meteorological networks (e.g. ALERT, Flood Control Districts, etc.) that we have collected and archived as part of previous studies. Meanwhile, MADIS provides data from a large number of networks across the U.S., including NOAA's HADS (Hydrometeorological Automated Data System), numerous mesonets, the Citizen Weather Observers Program (CWOP), departments of transportation, etc. (see http://madis.noaa.gov/mesonet_providers.html for a list of providers). Although our automatic data extraction is fast, cost-effective and efficient, it never captures all of the available precipitation data for a storm event. For this reason, a thorough "data mining" effort is undertaken to acquire all available data from sources such as U.S. Geological Survey (USGS), Remote Automated Weather Stations (RAWS), Community Collaborative Rain, Hail & Snow Network (CoCoRaHS), National Atmospheric Deposition Program (NADP), Clean Air Status and Trends Network (CASTNET), local observer networks, Climate Reference Network (CRN), Global Summary of the Day (GSD) and Soil Climate Analysis Network (SCAN). Unofficial hourly precipitation are gathered to give guidance on either timing or magnitude in areas otherwise void of precipitation data. The WeatherUnderground and MesoWest, two of the largest weather databases on the Internet, contain a good deal of official data, but also includes data from unofficial gauges.

Table D.1 Different precipitation gauge types used by SPAS.

Precipitation Gauge Type	Description
Hourly	Hourly gauges with complete, or nearly complete, incremental hourly precipitation data.
Hourly estimated	Hourly gauges with some estimated hourly values, but otherwise reliable.
Hourly pseudo	Hourly gauges with reliable temporal precipitation data, but the magnitude is questionable in relation to co-located daily or supplemental gauge.
Daily	Daily gauge with complete data and known observation times.
Daily estimated	Daily gauges with some or all estimated data.
Supplemental	Gauges with unknown or irregular observation times, but reliable total storm precipitation data. (E.g. public reports, storms reports, "Bucket surveys", etc.)
Supplemental estimated	Gauges with estimated total storm precipitation values based on other information (e.g. newspaper articles, stream flow discharge, inferences from nearby gauges, pre-existing total storm isohyetal maps, etc.)

Daily Precipitation Data

Our daily database is largely based on NCDC's TD-3206 (pre-1948) and TD-3200 (1948 through present) as well as SNOTEL data from NRCS. Since the late 1990s, the CoCoRaHS network of more than 15,000 observers in the U.S. has become a very important daily precipitation source. Other daily data are gathered from similar, but smaller gauge networks, for instance the High Spatial Density Precipitation Network in Minnesota.

As part of the daily data extraction process, the time of observation accompanies each measured precipitation value. Accurate observation times are necessary for SPAS to disaggregate the daily precipitation into estimated incremental values (discussed later). Knowing the observation time also allows SPAS to maintain precipitation amounts within given time bounds, thereby retaining known precipitation intensities. Given the importance of observation times, efforts are taken to insure the observation times are accurate. Hardcopy reports of "Climatological Data," scanned observational forms (available on-line from the NCDC) and/or gauge metadata forms have proven to be valuable and accurate resources for validating observation times. Furthermore, erroneous observation times are identified in the mass-curve quality-control procedure (discussed later) and can be corrected at that point in the process.

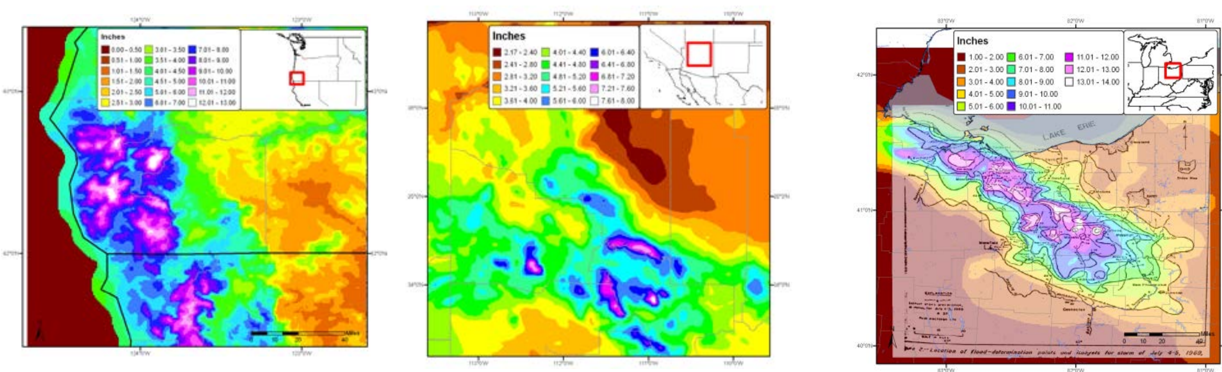
Supplemental Precipitation Gauge Data

For gauges with unknown or irregular observation times, the gauge is considered a "supplemental" gauge. A supplemental gauge can either be added to the storm database with a storm total and the associated SPP as the temporal bounds or as a gauge with the known, but irregular observation times and associated precipitation amounts. For instance, if all that is known is 3 inches fell between 0800-0900, then that information can be entered. Gauges or reports with nothing more than a storm total are often abundant, but to use them, it is important the precipitation is only from the storm period in question. Therefore, it is ideal to have the analysis time frame bounded by dry periods.

Perhaps the most important source of data, if available, is from "bucket surveys," which provide comprehensive lists of precipitation measurements collected during a post-storm field exercise. Although some bucket survey amounts are not from conventional precipitation gauges, they provide important information, especially in areas lacking data. Particularly for PMP-storm analysis applications, it is customary to accept extreme, but valid non-standard precipitation values (such a bottles and other open containers that catch rainfall) in order to capture the highest precipitation values.

Basemap

"Basemaps" are independent grids of spatially distributed weather or climate variables that are used to govern the spatial patterns of the hourly precipitation. The basemap also governs the spatial resolution of the final SPAS grids, unless radar data are available/used to govern the spatial resolution. Note that a base map is not required as the hourly precipitation patterns can be based on station characteristics and an inverse distance weighting technique (discussed later). Basemaps in complex terrain are often based on the PRISM mean monthly precipitation (Figure D.2a) or Hydrometeorological Design Studies Center precipitation frequency grids (Figure D.2b) given they resolve orographic enhancement areas and micro-climates at a spatial resolution of 30-seconds (about 800 m). Basemaps of this nature in flat terrain are not as effective given the small terrain forced precipitation gradients. Therefore, basemaps for SPAS analyses in flat terrain are often developed from pre-existing (hand-drawn) isohyetal patterns (Figure D.2c), composite radar imagery or a blend of both.



a) b) c)

Figure D.2 Sample SPAS "basemaps:" (a) A pre-existing (USGS) isohyetal pattern across flat terrain (SPAS #1209), (b) PRISM mean monthly (October) precipitation (SPAS #1192) and (c) A 100-year 24-hour precipitation grid from NOAA Atlas 14 (SPAS #1138).

Radar Data

For storms occurring since approximately the mid-1990s, weather radar data are available to supplement the SPAS analysis. A fundamental requirement for high quality radar-estimated precipitation is a high quality radar mosaic, which is a seamless collection of concurrent weather radar data from individual radar sites, however in some cases a single radar is sufficient (i.e. for a small area size storm event such as a thunderstorm). Weather radar data have been in use by meteorologists since the 1960s to estimate precipitation depths, but it was not until the early 1990s that new, more accurate NEXRAD Doppler radar (WSR88D) was placed into service across the United States. Currently, efforts are underway to convert the WSR88D radars to dual polarization (DualPol) radar. Today, NEXRAD radar coverage of the contiguous United States is comprised of 159 operational sites and there are 30 in Canada. Each U.S. radar covers an approximate 285 mile

(460 km) radial extent and while Canadian radars have approximately 256 km (138 nautical miles) radial extent over which their radar can detect precipitation. (see Figure E.3) The primary vendor of NEXRAD weather radar data for SPAS is Weather Decision Technologies, Inc. (WDT), who accesses, mosaics, archives and quality-controls NEXRAD radar data from NOAA and Environment Canada. SPAS utilizes Level II NEXRAD radar reflectivity data in units of dBZ, available every 5-minutes in the U.S. and 10-minutes in Canada.

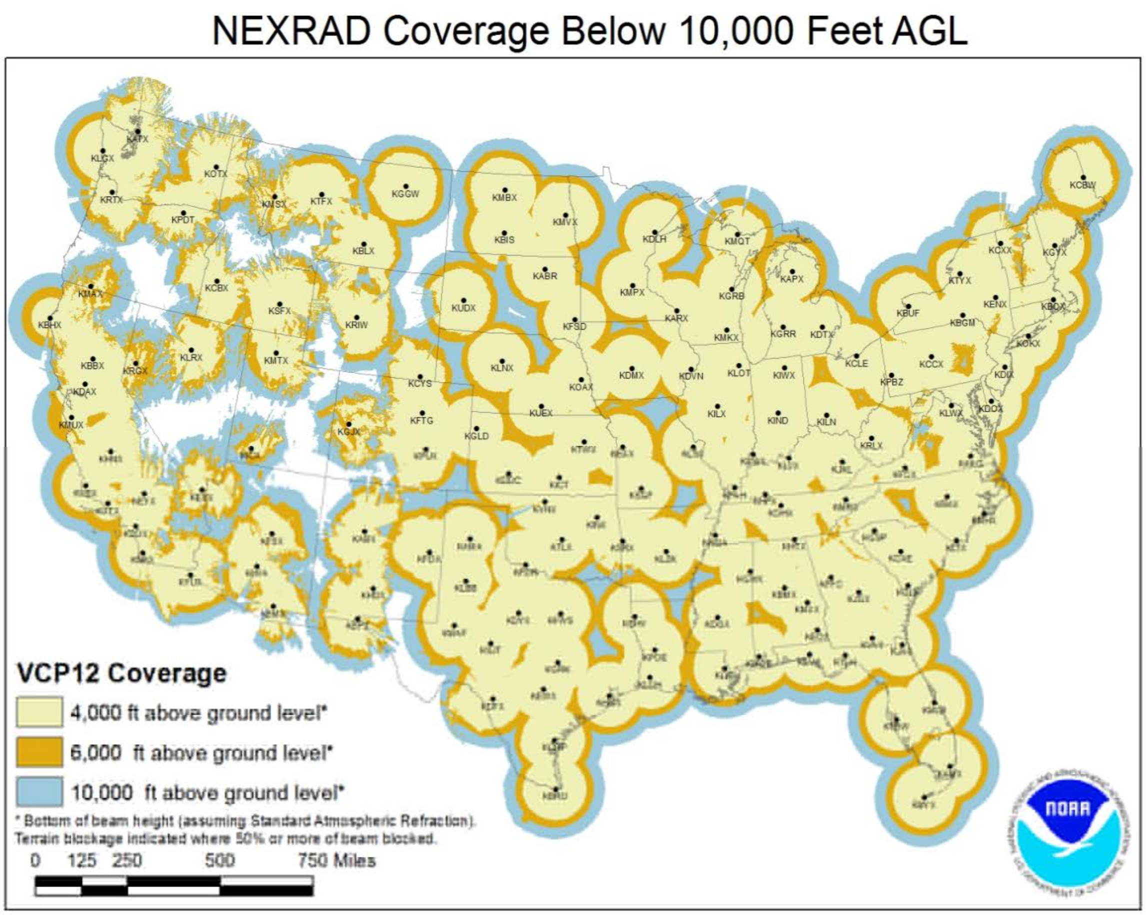
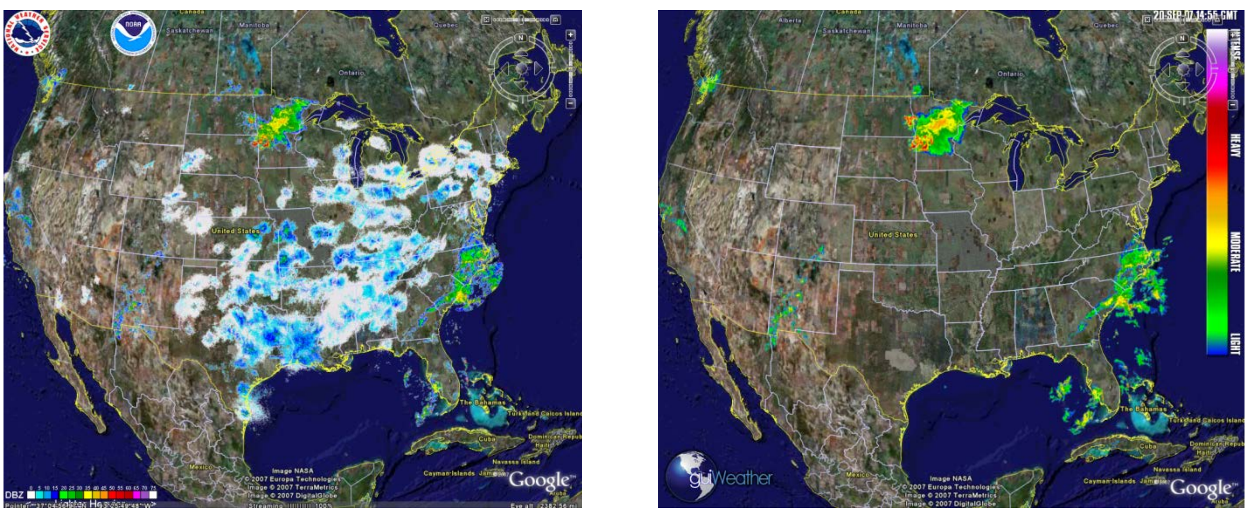


Figure D.3. U.S. radar locations and their radial extents of coverage below 10,000 feet above ground level (AGL). Each U.S. radar covers an approximate 285 mile radial extent over which the radar can detect precipitation.

The WDT and National Severe Storms Lab (NSSL) Radar Data Quality Control Algorithm (RDQC) removes non-precipitation artifacts from base Level–II radar data and remaps the data from polar coordinates to a Cartesian (latitude/longitude) grid. Non-precipitation artifacts include ground clutter, bright banding, sea clutter, anomalous propagation, sun strobes, clear air returns, chaff, biological targets, electronic interference and hardware test patterns. The RDQC algorithm uses sophisticated data processing and a Quality Control Neural Network (QCNN) to delineate the precipitation echoes caused by radar artifacts (Lakshmanan and Valente 2004). Beam blockages due to terrain are mitigated by using 30 meter DEM data to compute and then discard data from a radar beam that clears the ground by less than 50 meters and incurs more than 50% power blockage. A clear-air echo removal scheme is applied to radars in clear-air mode when there is no precipitation reported from observation gauges within the vicinity of the radar. In areas of radar coverage overlap, a distance weighting scheme is applied to assign reflectivity to each grid cell, for multiple vertical levels. This scheme is applied to data from the nearest radar that is unblocked by terrain.

Once the data from individual radars have passed through the RDQC, they are merged to create a seamless mosaic for the United States and southern Canada as shown in Figure D.4. A multi-sensor quality control can be applied by post-processing the mosaic to remove any remaining "false echoes". This technique uses observations of infra-red cloud top temperatures by GOES satellite and surface temperature to create a precipitation/no-precipitation mask. Figure 4 shows the impact of WDT's quality control measures. Upon completing all QC, WDT converts the radar data from its native polar coordinate projection (1 degree x 1.0 km) into a longitude-latitude Cartesian grid (based on the WGS84 datum), at a spatial resolution of ~1/3rd mi^2 for processing in SPAS.



a) **b)**

Figure D.4. (a) Level-II radar mosaic of CONUS radar with no quality control, (b) WDT quality controlled Level-II radar mosaic.

SPAS conducts further QC on the radar mosaic by infilling areas contaminated by beam blockages. Beam blocked areas are objectively determined by evaluating total storm reflectivity grid which naturally amplifies areas of the SPAS analysis domain suffering from beam blockage as shown in Figure D.5.

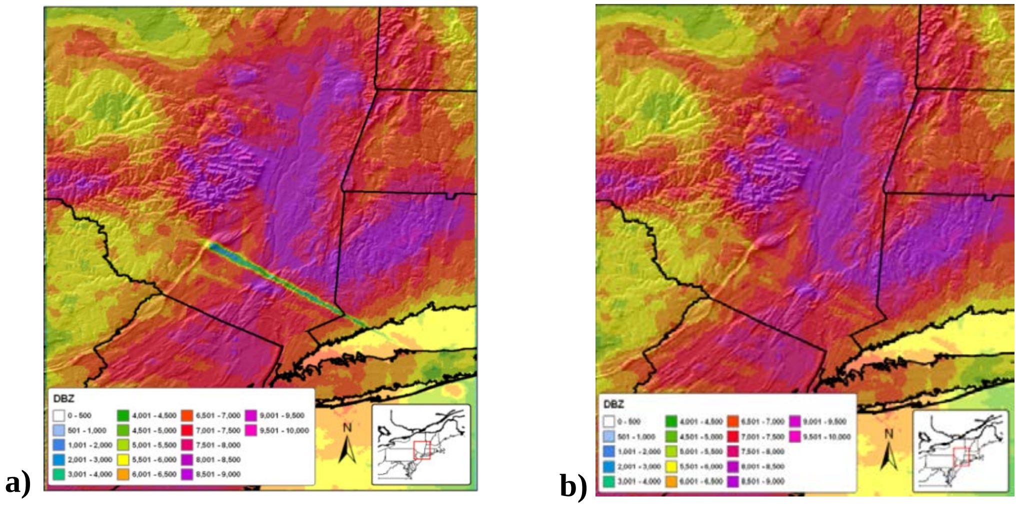


Figure D.5. Illustration of SPAS-beam blockage infilling where (a) is raw, blocked radar and (b) is filled for a 42-hour storm event.

METHODOLOGY

Daily and Supplemental Precipitation to Hourly

To obtain one hour temporal resolutions and utilize all gauge data, it is necessary to disaggregate the daily and supplemental precipitation observations into estimated hourly amounts. This process has traditionally been accomplished by distributing (temporally) the precipitation at each daily/supplemental gauge in accordance to a single nearby hourly gauge (Thiessen polygon approach). However, this may introduce biases and not correctly represent hourly precipitation at daily/supplemental gauges situated in-between hourly gauges. Instead, SPAS uses a spatial approach by which the estimated hourly precipitation at each daily and supplemental gauge is governed by a distance weighted algorithm of all nearby true hourly gauges.

To disaggregate (i.e. distribute) daily/supplemental gauge data into estimate hourly values, the true hourly gauge data are first evaluated and quality controlled using synoptic maps, nearby gauges, orographic effects, gauge history and other documentation on the storm. Any problems with the hourly data are resolved, and when possible/necessary accumulated hourly values are distributed. If an hourly value is missing, the analyst can choose to either estimate it or leave it missing for SPAS to estimate later based on nearby hourly gauges. At this point in the process, pseudo (hourly) gauges can be added to represent precipitation timing in topographically complex locations, areas with limited/no hourly data or to capture localized convention. To adequately capture the temporal variations of the precipitation, a pseudo hourly gauge is sometimes necessary. A pseudo gauge is created by distributing the precipitation at a co-located daily gauge or by creating a completely new pseudo gauge from other information such as inferences from COOP observation forms, METAR visibility data (if hourly precipitation are not already available), lightning data, satellite data, or radar data. Often radar data are the best/only choice for creating pseudo hourly gauges, but this is done cautiously given the potential differences (over-shooting of the radar beam equating to erroneous precipitation) between radar data and precipitation. In any case, the pseudo hourly gauge is flagged so SPAS only uses it for timing and not magnitude. Care is taken to ensure hourly pseudo gauges represent justifiably important physical and meteorological characteristics before being incorporated into the SPAS database. Although pseudo gauges provide a very important role, their use is kept to a minimum. The importance of insuring the reliability of every hourly gauge cannot be over emphasized. All of the final hourly gauge data, including pseudos, are included in the hourly SPAS precipitation database.

Using the hourly SPAS precipitation database, each hourly precipitation value is converted into a percentage that represents the incremental hourly precipitation divided by the total SPP precipitation. The GIS-ready x-y-z file is constructed for each hour and it includes the latitude (x), longitude(y) and the percent of precipitation (z) for a particular hour. Using the GRASS GIS, an inverse-distance-weighting squared (IDW) interpolation technique is applied to each of the hourly files. The result is a continuous grid with percentage values for the entire analysis domain, keeping the grid cells on which the hourly gauge resides faithful to the observed/actual percentage. Since the percentages typically have a high degree of spatial autocorrelation, the spatial interpolation has skill in determining the percentages between gauges, especially since the percentages are somewhat independent of the precipitation magnitude. The end result is a GIS grid for each hour that represents the percentage of the SPP precipitation that fell during that hour.

After the hourly percentage grids are generated and QCed for the entire SPP, a program is executed that converts the daily/supplemental gauge data into incremental hourly data. The timing at each of the daily/supplemental gauges is based on (1) the daily/supplemental gauge observation time, (2) daily/supplemental precipitation amount and (3) the series of interpolated hourly percentages extracted from grids (described above).

This procedure is detailed in Figure D.6 below. In this example, a supplemental gauge reported 1.40” of precipitation during the storm event and is located equal distance from the three surrounding hourly recording gauges. The procedure steps are:

Step 1. For each hour, extract the percent of SPP from the hourly gauge-based percentage at the location of the daily/supplemental gauge. In this example, assume these values are the average of all the hourly gauges.

Step 2. Multiply the individual hourly percentages by the total storm precipitation at the daily/supplemental gauge to arrive at estimated hourly precipitation at the daily/supplemental gauge. To make the daily/supplemental accumulated precipitation data faithful to the daily/supplemental observations, it is sometimes necessary to adjust the hourly percentages so they add up to 100% and account for 100% of the daily observed precipitation.

	Hour						
Precipitation	1	2	3	4	5	6	Total
Hourly station 1	0.02	0.12	0.42	0.50	0.10	0.00	1.16
Hourly station 2	0.01	0.15	0.48	0.62	0.05	0.01	1.32
Hourly station 3	0.00	0.18	0.38	0.55	0.20	0.05	1.36
	Hour						
Percent of total storm precip.	1	2	3	4	5	6	Total
Hourly station 1	2%	10%	36%	43%	9%	0%	100%
Hourly station 2	1%	11%	36%	47%	4%	1%	100%
Hourly station 3	0%	13%	28%	40%	15%	4%	100%
Average	*1%*	*12%*	*34%*	*44%*	*9%*	*1%*	*100%*
Storm total precipitation at daily gauge				1.40			
	Hour						
Precipitation (estimated)	1	2	3	4	5	6	Total
Daily station	0.01	0.16	0.47	0.61	0.13	0.02	1.40

Figure D.6 Example of disaggregation of daily precipitation into estimated hourly precipitation based on three (3) surrounding hourly recording gauges.

In cases where the hourly grids do not indicate any precipitation falling during the daily/supplemental gauge observational period, yet the daily/supplemental gauge reported precipitation, the daily/supplemental total precipitation is evenly distributed throughout the hours that make up the observational period; although this does not happen very often, this solution is consistent with NWS procedures. However, the SPAS analyst is notified of these cases in a comprehensive log file, and in most cases they are resolvable, sometimes with a pseudo hourly gauge.

GAUGE QUALITY CONTROL

Exhaustive quality control measures are taken throughout the SPAS analysis. Below are a few of the most significant QC measures taken.

Mass Curve Check

A mass curve-based QC-methodology is used to ensure the timing of precipitation at all gauges is consistent with nearby gauges. SPAS groups each gauge with the nearest four gauges (regardless of type) into a single file. These files are subsequently used in software for graphing and evaluation. Unusual characteristics in the mass curve are investigated and the gauge data corrected, if possible and warranted. See Figure E.7 for an example.

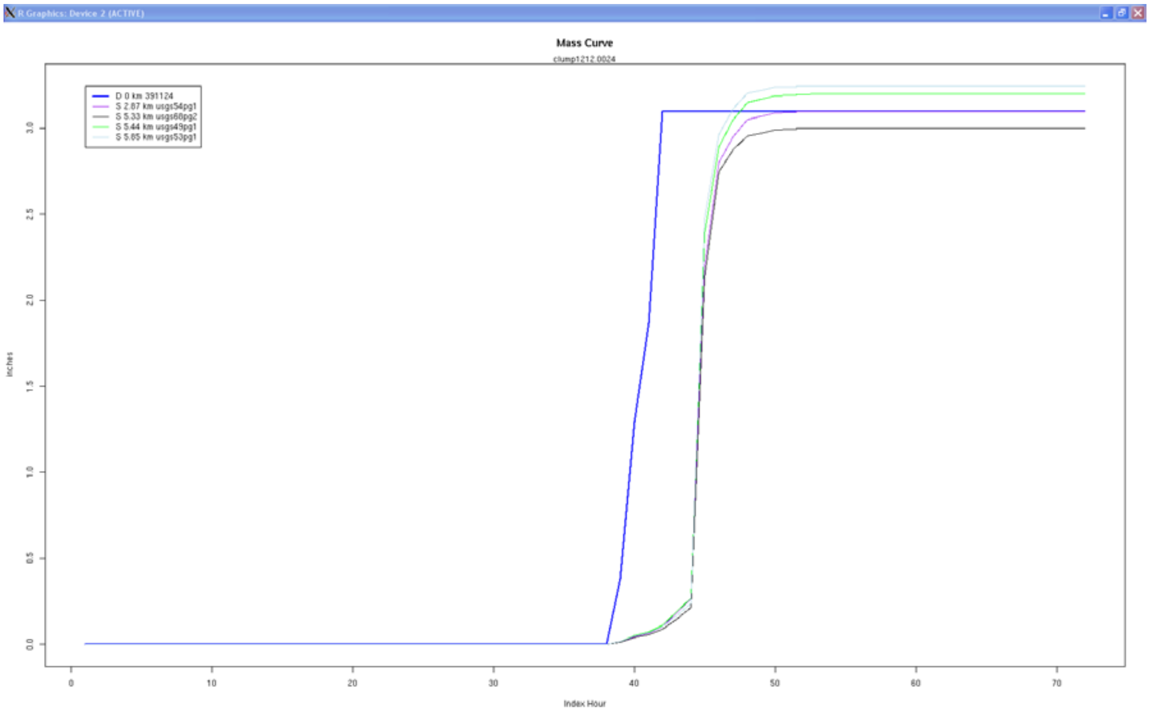


Figure D.7 Sample mass curve plot depicting a precipitation gauge with an erroneous observation time (blue line). X-axis is the SPAS index hour and the y-axis is inches. The statistics in the upper left denote gauge type, distance from target gauge (in km), and gauge ID. In this example, the center gauge (blue line) was found to have an observation error/shift of 1 day.

Gauge Mis-location Check

Although the gauge elevation is not explicitly used in SPAS, it is however used as a means of QCing gauge location. Gauge elevations are compared to a high-resolution 15-second DEM to identify gauges with large differences, which may indicate erroneous longitude and/or latitude values.

Co-located Gauge QC

Care is also taken to establish the most accurate precipitation depths at all co-located gauges. In general, where a co-located gauge pair exists, the highest precipitation is accepted (if deemed accurate). If the hourly gauge reports higher precipitation, then the co-located daily (or supplemental) is removed from the analysis since it would not add anything to the analysis. Often daily (or supplemental) gauges report greater precipitation than a co-located hourly station since hourly tipping bucket gauges tend to suffer from gauge under-catch, particularly during extreme events, due to loss of precipitation during tips. In these cases the daily/supplemental is retained for the magnitude and the hourly used as a pseudo hourly gauge for timing. Large discrepancies between any co-located gauges are investigated and resolved since SPAS can only utilize a single gauge magnitude at each co-located site.

SPATIAL INTERPOLATION

At this point the QCed observed hourly and disaggregated daily/supplemental hourly precipitation data are spatially interpolated into hourly precipitation grids. SPAS has three options for conducting the hourly precipitation interpolation, depending on the terrain and availability of radar data, thereby allowing SPAS to be optimized for any particular storm type or location. Figure D.8 depicts the results of each spatial interpolation methodology based on the same precipitation gauge data.

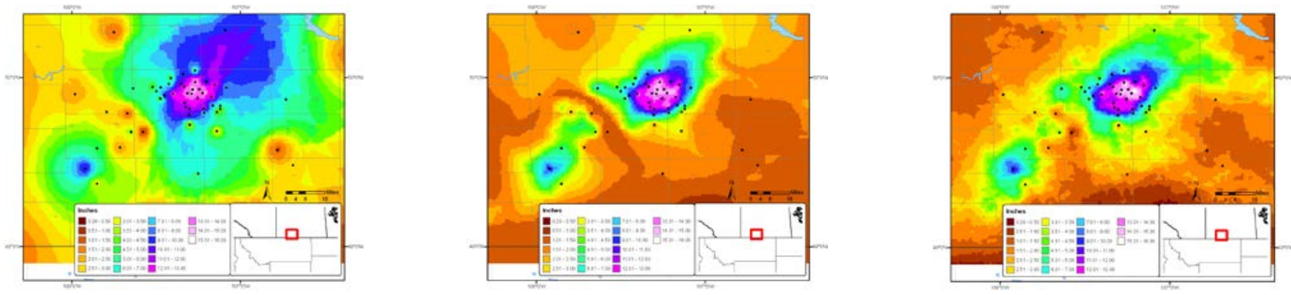


Figure D.8. Depictions of total storm precipitation based on the three SPAS interpolation methodologies for a storm (SPAS #1177, Vanguard, Canada) across flat terrain: (a) no basemap, (b) basemap-aided and (3) radar.

Basic Approach

The basic approach interpolates the hourly precipitation point values to a grid using an inverse distance weighting squared GIS algorithm. This is sometimes the best choice for convective storms over flat terrain when radar data are not available, yet high gauge density instills reliable precipitation patterns. This approach is rarely used.

Basemap Approach

Another option includes use of a "basemap", also known as a climatologically-aided interpolation (Hunter 2005). As noted before, the spatial patterns of the basemap govern the interpolation between points of hourly precipitation estimates, while the actual hourly precipitation values govern the magnitude. This approach to interpolating point data across complex terrain is widely used. In fact, it was used extensively by the NWS during their storm analysis era from the 1940s through the 1970s (USACE 1973, Hansen et al. 1988, Corrigan et al. 1999).

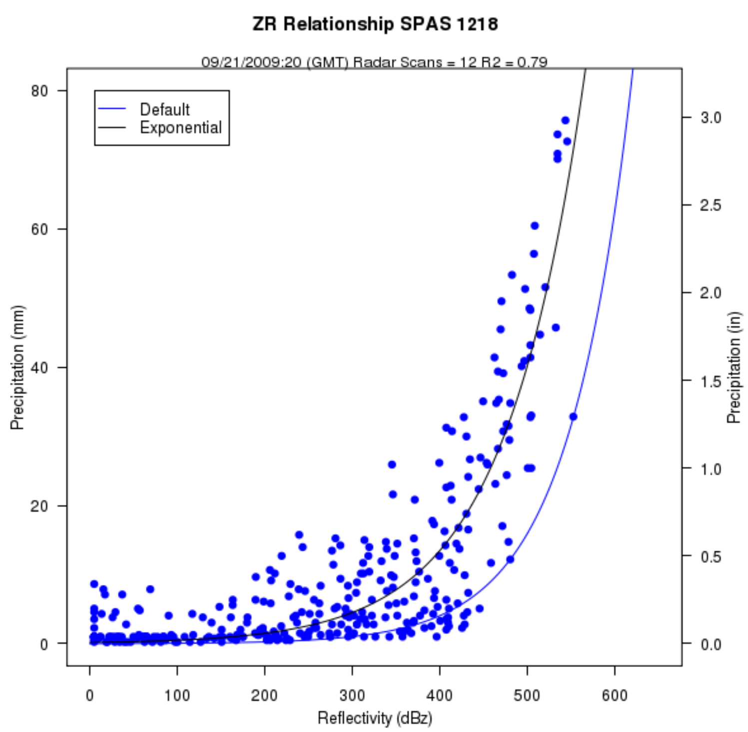
In application, the hourly precipitation gauge values are first normalized by the corresponding grid cell value of the basemap before being interpolated. The normalization allows information and knowledge from the basemap to be transferred to the spatial distribution of the hourly precipitation. Using an IDW squared algorithm, the normalized hourly precipitation values are interpolated to a grid. The resulting grid is then multiplied by the basemap grid to produce the hourly precipitation grid. This is repeated each hour of the storm.

Radar Approach

The coupling of SPAS with NEXRAD provides the most accurate method of spatially and temporally distributing precipitation. To increase the accuracy of the results however, quality-controlled precipitation observations are used for calibrating the radar reflectivity to rain rate relationship (Z-R relationship) each hour instead of assuming a default Z-R relationship. Also, spatial variability in the Z-R relationship is accounted for through local bias corrections (described later). The radar approach involves several steps, each briefly described below. The radar approach cannot operate alone – either the basic or basemap approach must be completed before radar data can be incorporated.

Z-R Relationship

SPAS derives high quality precipitation estimates by relating quality controlled level–II NEXRAD radar reflectivity radar data with quality-controlled precipitation gauge data to calibrate the Z-R (radar reflectivity, Z, and precipitation, R) relationship. Optimizing the Z-R relationship is essential for capturing temporal changes in the Z-R. Most current radar-derived precipitation techniques rely on a constant relationship between radar reflectivity and precipitation rate for a given storm type (e.g. tropical, convective), vertical structure of reflectivity and/or reflectivity magnitudes. This non-linear relationship is described by the Z-R equation below:



$$Z = A\,R^{b} \qquad (1)$$

Figure D.9. Example SPAS (denoted as "Exponential") vs. default Z-R relationship (SPAS #1218, Georgia September 2009).

Where Z is the radar reflectivity (measured in units of dBZ), R is the precipitation (precipitation) rate (millimeters per hour), A is the "multiplicative coefficient" and b is the "power coefficient". Both A and b are directly related to the rain drop size distribution (DSD) and rain drop number distribution (DND) within a cloud (Martner and Dubovskiy 2005). The variability in the results of Z versus R is a direct result of differing DSD, DND and air mass characteristics (Dickens 2003). The DSD and DND are determined by complex interactions of microphysical processes that fluctuate regionally, seasonally, daily, hourly, and even within the same cloud. For these reasons, SPAS calculates an optimized Z-R relationship across the analysis domain each hour, based on observed precipitation rates and radar reflectivity (see Figure D.9).

The National Weather Service (NWS) utilizes different default Z-R algorithms, depending on the type of precipitation event, to estimate precipitation from NEXRAD radar reflectivity data across the United States (see Figure D.10) (Baeck and Smith 1998 and Hunter 1999). A default Z-R relationship of $Z = 300R^{1.4}$ is the primary algorithm used throughout the continental U.S. However, it is widely known that this, compared to unadjusted radar-aided estimates of precipitation, suffers from deficiencies that may lead to significant over or under-estimation of precipitation.

RELATIONSHIP	Optimum for:	Also recommended for:
Marshall-Palmer ($z=200R^{1.6}$)	General stratiform precipitation	
East-Cool Stratiform ($z=130R^{2.0}$)	Winter stratiform precipitation - east of continental divide	Orographic rain - East
West-Cool Stratiform ($z=75R^{2.0}$)	Winter stratiform precipitation - west of continental divide	Orographic rain - West
WSR-88D Convective ($z=300R^{1.4}$)	Summer deep convection	Other non-tropical convection
Rosenfeld Tropical ($z=250R^{1.2}$)	Tropical convective systems	

Figure D.10. Commonly used Z-R algorithms used by the NWS.

Instead of adopting a standard Z-R, SPAS utilizes a least squares fit procedure for optimizing the Z-R relationship each hour of the SPP. The process begins by determining if sufficient (minimum 12) observed hourly precipitation and radar data pairs are available to compute a reliable Z-R. If insufficient (<12) gauge pairs are available, then SPAS adopts the previous hour Z-R relationship, if available, or applies a user-defined default Z-R algorithm from Figure 9. If sufficient data are available, the one hour sum of NEXRAD reflectivity (Z) is related to the 1-hour precipitation at each gauge. A least-squares-fit exponential function using the data points is computed. The resulting best-fit, one hour-based Z-R is subjected to several tests to determine if the Z-R relationship and its resulting precipitation rates are within a certain tolerance based on the R-squared fit measure and difference between the derived and default Z-R precipitation results.

Experience has shown the actual Z-R versus the default Z-R can be significantly different (Figure D.11). These Z-R relationships vary by storm type and location. A standard output of all SPAS analyses utilizing NEXRAD includes a file with each hour's adjusted Z-R relationship as calculated through the SPAS program.

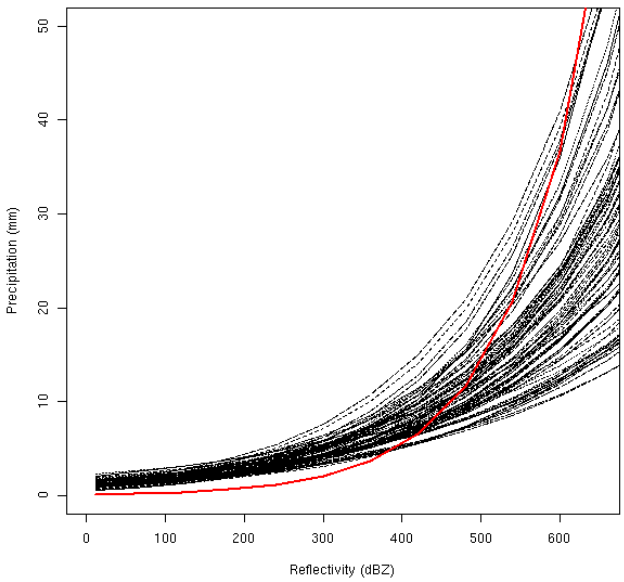


Figure D.11. Comparison of the SPAS optimized hourly Z-R relationships (black lines) versus a default Z=75R2.0 Z-R relationship (red line) for a period of 99 hours for a storm over southern California.

Radar-aided Hourly Precipitation Grids

Once a mathematically optimized hourly Z-R relationship is determined, it is applied to the total hourly Z grid to compute an initial precipitation rate (inches/hour) at each grid cell. To account for spatial differences in the Z-R relationship, SPAS computes residuals, the difference between the initial precipitation analysis (via the Z-R equation) and the actual "ground truth" precipitation (observed – initial analysis), at each gauge. The point residuals, also referred to as local biases, are normalized and interpolated to a residual grid using an inverse distance squared weighting algorithm. A radar-based hourly precipitation grid is created by adding the residual grid to the initial grid; this allows the precipitation at the grid cells for which gauges are "on" to be true and faithful to the gauge measurement. The pre-final radar-aided precipitation grid is subject to some final, visual QC checks to ensure the precipitation patterns are consistent with the terrain; these checks are particularly important in areas of complex terrain where even QCed radar data can be unreliable. The next incremental improvement with SPAS program will come as the NEXRAD radar sites are upgraded to dual-polarimetric capability.

Radar- and Basemap-Aided Hourly Precipitation Grids

At this stage of the radar approach, a radar- and basemap-aided hourly precipitation grid exists for each hour. At locations with precipitation gauges, the grids are equal, however elsewhere the grids can vary for a number of reasons. For instance, the basemap-aided hourly precipitation grid may depict heavy precipitation in an area of complex terrain, blocked by the radar, whereas the radar-aided hourly precipitation grid may suggest little, if any, precipitation fell in the same area. Similarly, the radar-aided hourly precipitation grid may depict an area of heavy precipitation in flat terrain that the basemap-approach missed since the area of heavy precipitation occurred in an area without gauges. SPAS uses an algorithm to compute the hourly precipitation at each pixel given the two results. Areas that are completely blocked from a radar signal are accounted for with the basemap-aided results (discussed earlier). Precipitation in areas with orographically effective terrain and reliable radar data are governed by a blend of the basemap- and radar-aided precipitation. Elsewhere, the radar-aided precipitation is used exclusively. This blended approach has proven effective for resolving precipitation in complex terrain, yet retaining accurate radar-aided precipitation across areas where radar data are reliable. Figure D.12 illustrates the evolution of final precipitation from radar reflectivity in an area of complex terrain in southern California.

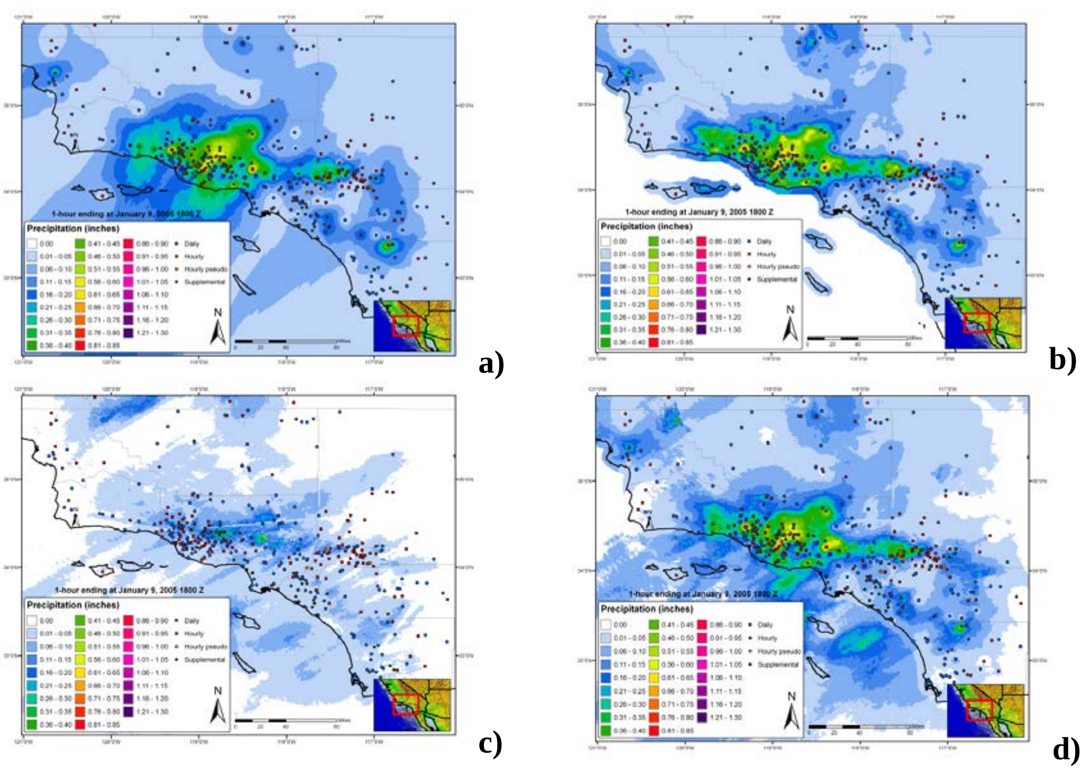


Figure D.12. A series of maps depicting 1-hour of precipitation utilizing (a) inverse distance weighting of gauge precipitation, (b) gauge data together with a climatologically-aided interpolation scheme, (c) default Z-R radar-estimated interpolation (no gauge correction) and (d) SPAS precipitation for a January 2005 storm in southern California, USA.

SPAS versus Gauge Precipitation

Performance measures are computed and evaluated each hour to detect errors and inconsistencies in the analysis. The measures include: hourly Z-R coefficients, observed hourly maximum precipitation, maximum gridded precipitation, hourly bias, hourly mean absolute error (MAE), root mean square error (RMSE), and hourly coefficient of determination (r^2).

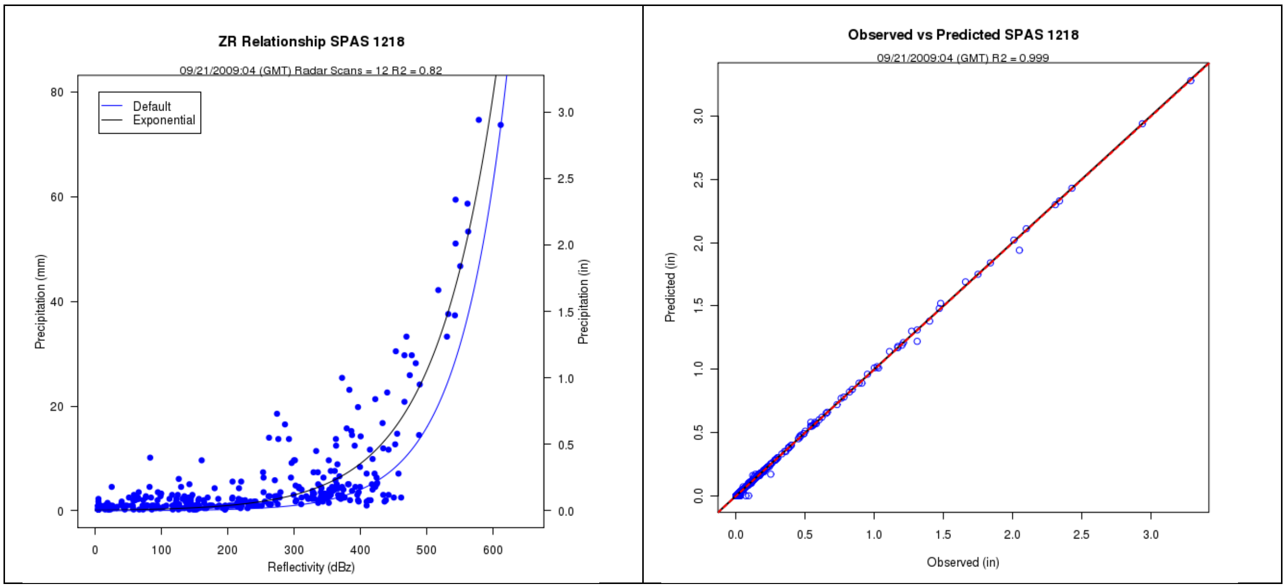


Figure D.13. Z-R plot (a), where the blue line is the SPAS derived Z-R and the black line is the default Z-R, and the (b) associated observed versus SPAS scatter plot at gauge locations.

Comparing SPAS-calculated precipitation (R_{spas}) to observed point precipitation depths at the gauge locations provides an objective measure of the consistency, accuracy and bias. Generally speaking SPAS is usually within 5% of the observed precipitation (see Figure D.13). Less-than-perfect correlations between SPAS precipitation depths and observed precipitation at gauged locations could be the result of any number of issues, including:

- **Point versus area:** A rain gauge observation represents a much smaller area than the area sampled by the radar. The area that the radar is sampling is approximately 1 km^2, whereas a standard rain gauge has an opening 8 inches in diameter, hence it only samples approximately 8.0×10^{-9} km^2. Furthermore, the radar data represents an average reflectivity (Z) over the grid cell, when in fact the reflectivity can vary across the 1 km^2 grid cell. Therefore, comparing a grid cell radar derived precipitation value to a gauge (point) precipitation depth measured may vary.

- **Precipitation gauge under-catch:** Although we consider gauge data "ground truth," we recognize gauges themselves suffer from inaccuracies. Precipitation gauges, shielded and unshielded, inherently underestimate total precipitation due to local airflow, wind under-catch, wetting, and evaporation. The wind under-catch errors are usually around 5% but can be as large as 40% in high winds (Guo et al. 2001, Duchon and Essenberg 2001, Ciach 2003, Tokay et al. 2010). Tipping buckets miss a small amount of precipitation during each tip of the bucket due to the bucket travel and tip time. As precipitation intensities increase, the volumetric loss of precipitation due to tipping tends to increase. Smaller tipping buckets can have higher volumetric losses due to higher tip frequencies, but on the other hand capture higher precision timing.

- **Radar Calibration:** NEXRAD radars calibrate reflectivity every volume scan, using an internally generated test. The test determines changes in internal variables such as beam power and path loss of the receiver signal processor since the last off-line calibration. If this value becomes large, it is likely that there is a radar calibration error that will translate into less reliable precipitation estimates. The calibration test is supposed to maintain a reflectivity precision of 1 dBZ. A 1 dBZ error can result in an error of up to 17% in R_{spas} using the default Z-R relationship $Z=300R^{1.4}$. Higher calibration errors will result in higher R_{spas} errors. However, by performing correlations each hour, the calibration issue is minimized in SPAS.

- **Attenuation:** Attenuation is the reduction in power of the radar beams' energy as it travels from the antenna to the target and back. It is caused by the absorption and the scattering of power from the beam by precipitation. Attenuation can result in errors in Z as large as 1 dBZ especially when the radar beam is sampling a large area of heavy precipitation. In some cases, storm precipitation is so intense (>12 inches/hour) that individual storm cells become "opaque" and the radar beam is totally attenuated. Armed with sufficient gauge data however, SPAS will overcome attenuation issues.

- **Range effects:** The curvature of the Earth and radar beam refraction result in the radar beam becoming more elevated above the surface with increasing range. With the increased elevation of the radar beam comes a decrease in Z values due to the radar beam not sampling the main precipitation portion of the cloud (i.e. "over topping" the precipitation and/or cloud altogether). Additionally, as the radar beam gets further from the radar, it naturally samples a larger and larger area, therefore amplifying point versus area differences (described above).

- **Radar Beam Occultation/Ground Clutter:** Radar occultation (beam blockage) results when the radar beam's energy intersects terrain features as depicted in Figure D.14. The result is an increase in radar reflectivity values that can result in higher than normal precipitation estimates. The WDT processing algorithms account for these issues, but SPAS uses GIS spatial interpolation functions to infill areas suffering from poor or no radar coverage.

- **Anomalous Propagation (AP):** AP is false reflectivity echoes produced by unusual rates of refraction in the atmosphere. WDT algorithms remove most of the AP and false echoes, however in extreme cases the air near the ground may be so cold and dense that a radar beam that starts out moving upward is bent all the way down to the ground. This produces erroneously strong echoes at large distances from the radar. Again, equipped with sufficient gauge data, the SPAS bias corrections will overcome AP issues.

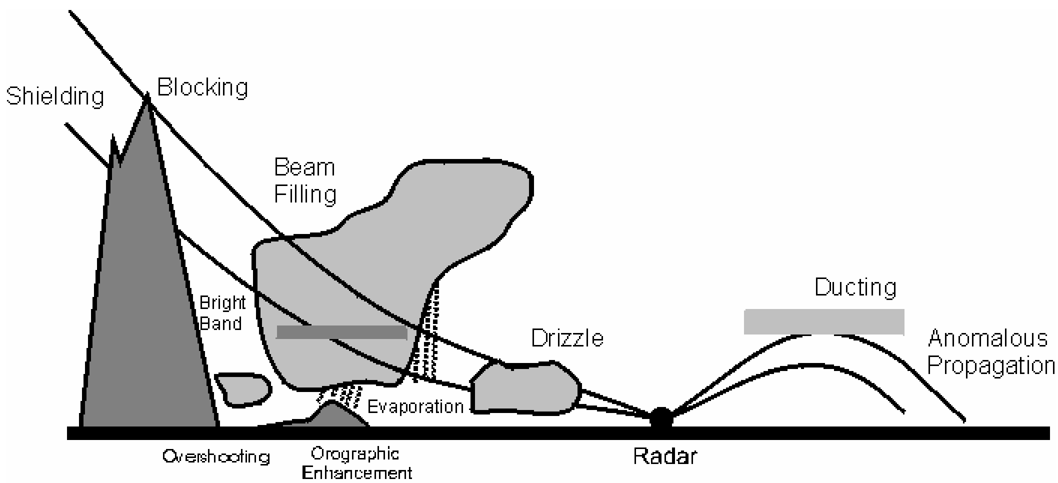


Figure D.14 Depiction of radar artifacts. (Source: Wikipedia)

SPAS is designed to overcome many of these short-comings by carefully using radar data for defining the spatial patterns and relative magnitudes of precipitation, but allowing measured precipitation values ("ground truth") at gauges to govern the magnitude. When absolutely necessary, the observed precipitation values at gauges are nudged up (or down) to force SPAS results to be consistent with observed gauge values. Nudging gauge precipitation values helps to promote better consistency between the gauge value and the gridcell value, even though these two values sometimes should not be the same since they are sampling different area sizes. For reasons discussed in the "SPAS versus Gauge Precipitation" section, the gauge value and gridcell value can vary. Plus, SPAS is designed to toss observed individual hourly values that are grossly inconsistent with radar data, hence driving a difference between the gauge and gridcell. In general, when the gauge and gridcell value differ by more than 15% and/or 0.50 inches, and the gauge data have been validated, then it is justified to artificially increase or decrease slightly the observed gauge value to "force" SPAS to derive a gridcell value equal to the observed value. Sometimes simply shifting the gauge location to an adjacent gridcell resolves the problems. Regardless, a large gauge versus gridcell difference is a "red flag" and sometimes the result of an erroneous gauge value or a mislocated gauge, but in some cases the difference can only be resolved by altering the precipitation value.

Before results are finalized, a precipitation intensity check is conducted to ensure the spatial patterns and magnitudes of the maximum storm intensities at 1-, 6-, 12-, etc. hours are consistent with surrounding gauges and published reports. Any erroneous data are corrected and SPAS re-run. Considering all of the QA/QC checks in SPAS, it typically requires 5-15 basemap SPAS runs and, if radar data are available, another 5-15 radar-aided runs, to arrive at the final output.

Test Cases

To check the accuracy of the DAD software, three test cases were evaluated.

“Pyramidville” Storm

The first test was that of a theoretical storm with a pyramid shaped isohyetal pattern. This case was called the Pyramidville storm. It contained 361 hourly stations, each occupying a single grid cell. The configuration of the Pyramidville storm (see Figure D.15) allowed for uncomplicated and accurate calculation of the analytical DA truth independent of the DAD software. The main motivation of this case was to verify that the DAD software was properly computing the area sizes and average depths.

1. Storm center: 39°N 104°W
2. Duration: 10-hours
3. Maximum grid cell precipitation: 1.00”
4. Grid cell resolution: 0.06 sq.-miles (361 total cells)
5. Total storm size: 23.11 sq-miles
6. Distribution of precipitation:

   Hour 1: Storm drops 0.10” at center (area 0.06 sq-miles)

   Hour 2: Storm drops 0.10” over center grid cell AND over one cell width around hour 1 center

   Hours 3-10:

   1. Storm drops 0.10” per hour at previously wet area, plus one cell width around previously wet area
   2. Area analyzed at every 0.10”
   3. Analysis resolution: 15-sec (~.25 square miles)

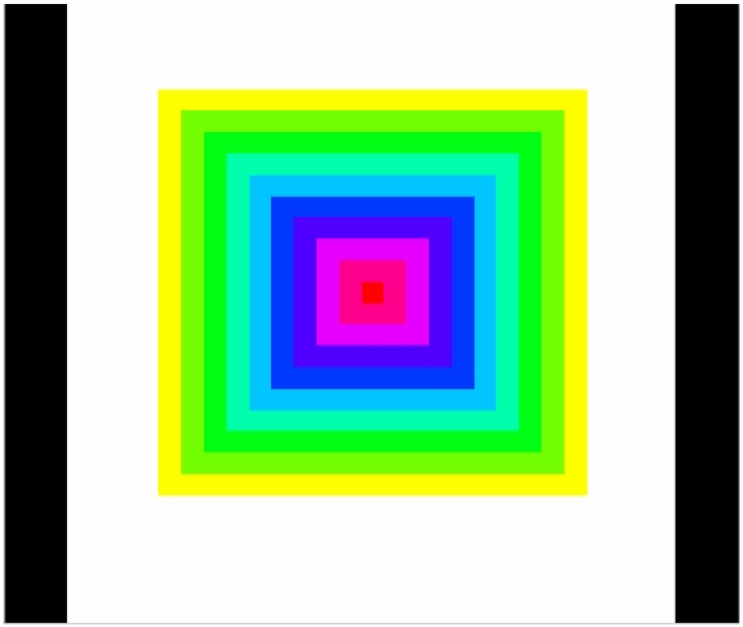


Figure D.15 "Pyramidville" Total precipitation. Center = 1.00", Outside edge = 0.10".

The analytical truth was calculated independent of the DAD software, and then compared to the DAD output. The DAD software results were equal to the truth, thus demonstrating that the DA estimates were properly calculated (Figure D.16).

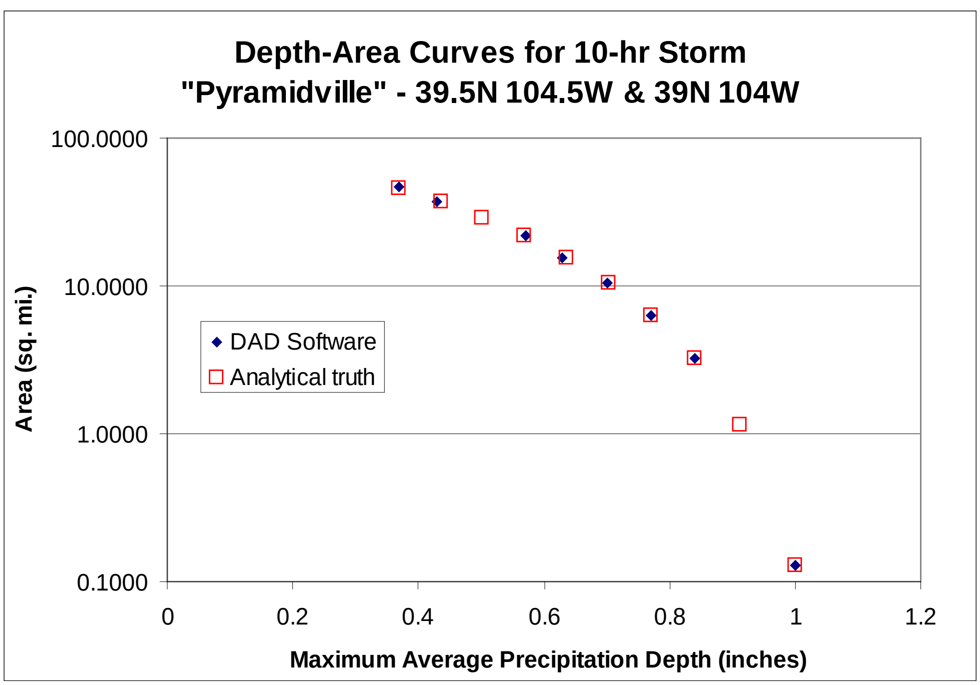


Figure D.16 10-hour DA results for "Pyramidville"; truth vs. output from DAD software.

The Pyramidville storm was then changed such that the mass curve and spatial interpolation methods would be stressed. Test cases included:

- Two-centers, each center with 361 hourly stations
- A single center with 36 hourly stations, 0 daily stations
- A single center with 3 hourly stations and 33 daily stations

As expected, results began shifting from the 'truth,' but minimally and within the expected uncertainty.

Ritter, Iowa Storm, June 7, 1953

Ritter, Iowa was chosen as a test case for a number of reasons. The NWS had completed a storm analysis, with available DAD values for comparison. The storm occurred over relatively flat terrain, so orographics were not an issue. An extensive "bucket survey" provided a great number of additional observations from this event. Of the hundreds of additional reports, about 30 of the most accurate reports were included in the DAD analysis.

The DAD software results are very similar to the NWS DAD values (Table D.2).

Table D.2. The percent difference [(AWA-NWS)/NWS] between the AWA DA results and those published by the NWS for the 1953 Ritter, Iowa storm.

% Difference

	Duration (hours)				
Area (sq.mi.)		6	12	24	total
10		-15%	-7%	2%	2%
100		-7%	-6%	1%	1%
200		2%	0%	9%	9%
1000		-6%	-7%	4%	4%
5000		-13%	-8%	2%	2%
10000		-14%	-6%	0%	0%

Westfield, Massachusetts Storm, August 8, 1955

Westfield, Massachusetts was also chosen as a test case for a number of reasons. It is a probable maximum precipitation (PMP) driver for the northeastern United States. Also, the Westfield storm was analyzed by the NWS and the DAD values are available for comparison. Although this case proved to be more challenging than any of the others, the final results are very similar to those published by the NWS (Table D.3).

Table D.3. The percent difference [(AWA-NWS)/NWS] between the AWA DA results and those published by the NWS for the 1955 Westfield, Massachusetts storm.

% Difference

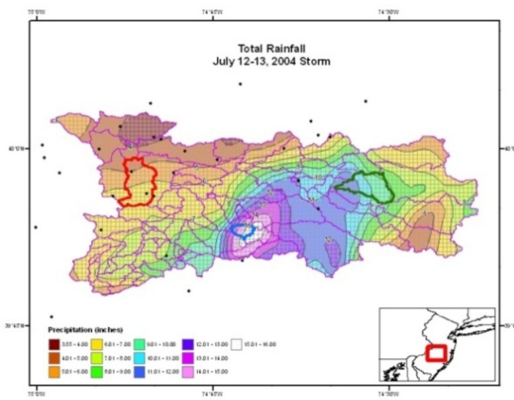
	Duration (hours)							
Area (sq. mi.)		6	12	24	36	48	60	total
10		2%	3%	0%	1%	-1%	0%	2%
100		-5%	2%	4%	-2%	-6%	-4%	-3%
200		-6%	1%	1%	-4%	-7%	-5%	-5%
1000		-4%	-2%	1%	-6%	-7%	-6%	-3%
5000		3%	2%	-3%	-3%	-5%	-5%	0%
10000		4%	9%	-5%	-4%	-7%	-5%	1%
20000		7%	12%	-6%	-3%	-4%	-3%	3%

The primary components of SPAS are: storm search, data extraction, quality control (QC), conversion of daily precipitation data into estimated hourly data, hourly and total storm precipitation grids/maps and a complete storm-centered DAD analysis.

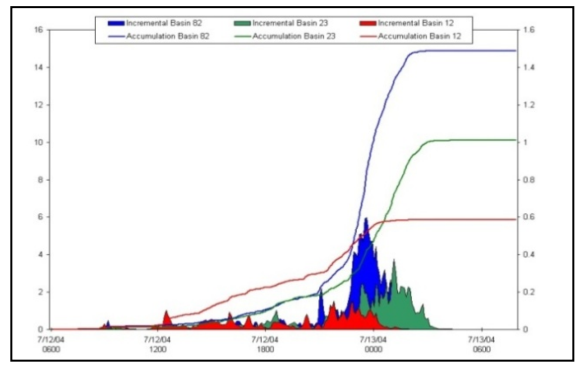
OUTPUT

Armed with accurate, high-resolution precipitation grids, a variety of customized output can be created (see Figures D.17A-D). Among the most useful outputs are sub-hourly precipitation grids for input into hydrologic models. Sub-hourly (i.e. 5-minute) precipitation grids are created by applying the appropriate optimized hourly Z-R (scaled down to be applicable for instantaneous Z) to each of the individual 5-minute radar scans; 5-minutes is often the native scan rate of the radar in the US. Once the scaled Z-R is applied to each radar scan, the resulting precipitation is summed up. The proportion of each 5-minute precipitation to the total 1-hour radar-aided precipitation is calculated. Each 5-minute proportion (%) is then applied to the quality controlled, bias corrected 1-hour total precipitation (created above) to arrive at the final 5-minute precipitation for each scan. This technique ensures the sum of 5-minute precipitation equals that of the quality controlled, bias corrected 1-hour total precipitation derived initially.

Depth-area-duration (DAD) tables/plots, shown in Figure D.17d, are computed using a highly-computational extension to SPAS. DADs provide an objective three dimensional (magnitude, area size, and duration) perspective of a storms' precipitation. SPAS DADs are computed using the procedures outlined by the NWS Technical Paper 1 (1946).



a)



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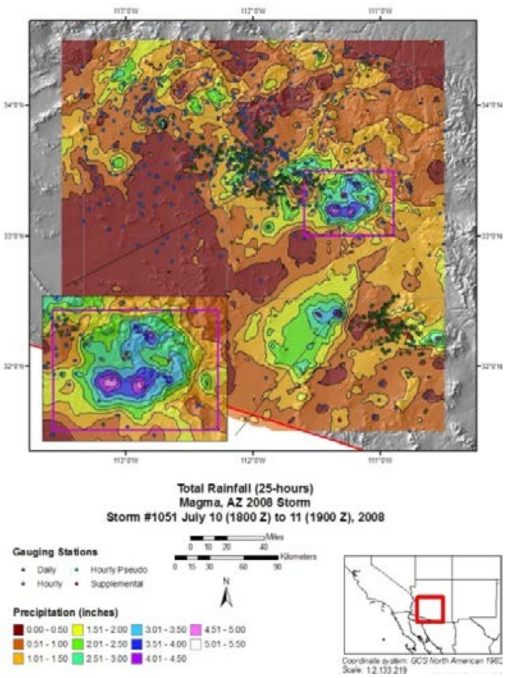
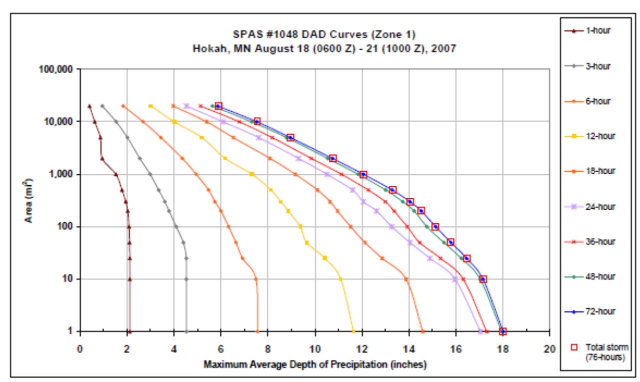


c)

Storm 1048 - Hokah, MN August 18 - August 21, 2007

MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)

Area (mi^2)	Duration (hours)									
	1	3	6	12	18	24	36	48	72	Total
0.24	2.45	4.77	7.85	11.89	14.88	17.31	17.55	18.19	18.26	18.26
1	2.12	4.53	7.56	11.64	14.59	17.05	17.31	17.95	18.02	18.02
10	2.12	4.53	7.49	11.10	13.88	15.96	16.31	17.03	17.15	17.17
25	2.12	4.53	6.92	10.42	12.86	14.89	15.34	16.23	16.45	16.46
50	2.11	4.40	6.64	9.65	12.13	14.05	14.46	15.49	15.79	15.79
100	2.09	4.10	6.33	9.37	11.52	13.27	13.93	14.76	15.14	15.14
200	2.03	3.79	6.00	8.87	10.96	12.62	13.37	14.22	14.52	14.52
300	1.95	3.61	5.74	8.55	10.64	12.06	12.99	13.74	14.04	14.04
500	1.79	3.35	5.47	8.13	10.11	11.60	12.27	13.01	13.29	13.30
1,000	1.53	2.99	4.95	7.33	9.17	10.51	11.13	11.84	12.07	12.07
2,000	0.95	2.55	4.36	6.18	8.09	9.30	9.85	10.54	10.75	10.76
5,000	0.87	2.02	3.45	5.19	6.53	7.61	8.18	8.79	8.96	8.98
10,000	0.63	1.54	2.69	4.02	5.39	6.09	6.78	7.31	7.53	7.55
20,000	0.41	0.95	1.84	3.02	3.97	4.53	5.13	5.63	5.87	5.90



d)

Figure D.17. Various examples of SPAS output, including (a) total storm map and its associated (b) basin average precipitation time series, (c) total storm precipitation map, (d) depth-area-duration (DAD) table and plot.

SUMMARY

Grounded on years of scientific research with a demonstrated reliability in post-storm analyses, SPAS is a hydro-meteorological tool that provides accurate precipitation analyses for a variety of applications. SPAS has the ability to compute precise and accurate results by using sophisticated timing algorithms, "basemaps", a variety of precipitation data and most importantly NEXRAD weather radar data (if available). The approach taken by SPAS relies on hourly, daily and supplemental precipitation gauge observations to provide quantification of the precipitation amounts while relying on basemaps and NEXRAD data (if available) to provide the spatial distribution of precipitation between precipitation gauge sites. By determining the most appropriate coefficients for the Z-R equation on an hourly basis, the approach anchors the precipitation amounts to accepted precipitation gauge data while using the NEXRAD data to distribute precipitation between precipitation gauges for each hour of the storm. Hourly Z-R coefficient computations address changes in the cloud microphysics and storm characteristics as the storm evolves. Areas suffering from limited or no radar coverage are estimated using the spatial patterns and magnitudes of the independently created basemap precipitation grids. Although largely automated, SPAS is flexible enough to allow hydro-meteorologists to make important adjustments and adapt to any storm situation.

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Appendix B

Intermediate Flood Routing Technical Memorandum

14-08-TM

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Technical Memorandum
14-08-TM
v1.0

Susitna-Watana Hydroelectric Project

Intermediate Flood Routing

FINAL DRAFT

AEA11-022

Prepared for:
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May 2014

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TABLE OF CONTENTS

List of Tables

List of Figures

List of Exhibits

1. INTRODUCTION

The primary purpose of this Technical Memorandum (TM) is to determine a range of potential operating scenarios for the 50-year flood (i.e. the 2% annual exceedance probability flood) from which a selected Project operation plan can be made with consideration of the tradeoffs in related factors. Factors that may be considered in the tradeoff evaluation include the low-level outlet works (LLOW) capacity versus the amount of reservoir storage used to attenuate the peak outflow during large flood events. Greater LLOW capacity would result in a smaller reservoir pool allocated to flood control storage and therefore a lower dam crest elevation. Increased LLOW capacity would result in a slight reduction in generation as less flood surcharge storage would be routed through the powerhouse. Downstream fluvial geomorphology and other environmental considerations may also factor into the flood surcharge operation. Also, the capability to pass a given discharge, such as the 2-year flood peak flow of 38,500 cfs indicated in Table 3 below, may be a factor in the selection of LLOW valve capacity.

A Probable Maximum Flood (PMF) study is being performed for the Susitna-Watana Hydroelectric Project (Project) by MWH under NTP 13. The PMF is the spillway design flood for Watana Dam, and as such the inflow PMF routed through the reservoir will ultimately determine the required capacity of the spillway, the total outflow capability at Watana Dam, the reservoir surcharge storage between the maximum normal pool level and the maximum flood pool level, and the final dam crest level that assures the flood safety of the dam.

To limit the frequency of spillway operation, which may result in undesirable downstream gas supersaturation, an operating criterion is being adopted such that the Project should be able to pass floods up to the 50-year 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 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.

The 50-year construction diversion flood was also routed with a limiting maximum reservoir level at El 1553, which is planned to be the top elevation of the impervious core of the upstream cofferdam.

Results of the 50-year construction diversion flood routing provided herein will show whether there is any significant attenuation of the flood due to storage behind the cofferdam.

2. PEAK FLOW FREQUENCY

2.1 Peak Annual Flows

The most frequently referenced parameter for a rare flow event such as the 50-year flood is the peak flow. Peak annual flows in the Susitna River near the Project site have been recorded by the USGS at Gold Creek, as summarized in Table 1. 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 annual flows for the Susitna River at Gold Creek are presented in Table 2.

Table 1 Peak Annual Instantaneous Flows for 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	90,500

Table 2 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

2.2 50-Year Annual Flood Peak

Peak flows were estimated for return periods up to 1,000 years at the Watana Dam site by transposing peak flow analysis results at Gold Creek to Watana according to the following equation:

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

where 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 annual flood frequency values for Watana Dam presented in Table 3 can also be used to develop the construction diversion floods. The resulting 50-year annual instantaneous flood peak is 80,800 cfs.

Table 3 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

2.3 50-Year Seasonal Flood Peak

The initial reservoir elevation at the beginning of a flood is an important parameter for flood routing modeling. If the reservoir elevation was below El 2050 at the start of the 50-year flood, much or all of the 50-year flood water would fill the reservoir up to El 2050, the point at which surcharge storage operations would begin and results would indicate a reduced need for fixed-cone outlet valve discharge capacity. The months when the reservoir elevation is very unlikely to be at El 2050 are therefore eliminated from the analysis so that the assumed initial reservoir elevation can be set at El 2050.

As is standard procedure at the feasibility level of studies, a number of preliminary reservoir operation cases have been tested. Figure 1 is a reservoir elevation frequency diagram, derived from the current power operation modeling preliminary Run 11C. Only the months of May through September need to be considered for the 50-year annual flood because these are the only months of occurrence of the peak annual flood in 134 station-years of record at the Susitna River USGS gaging stations at or above Gold Creek where the Project is located. For the 50-year seasonal flood, May is eliminated because the reservoir is never full (i.e. at El 2050) during May. June can also be eliminated because the reservoir is full less than 1% of the time in June, which means that the maximum June reservoir levels are the end result of a sequence of high inflows, not the initial level, so large floods after that month are very unlikely. For routing of a 50-year flood, a June full reservoir (El 2050) starting elevation would be an excessively conservative assumption.

The remaining months when historical annual peak flows have been observed to occur and when the reservoir is more likely to be full are July, August, and September. Therefore, a seasonal flood frequency analysis was performed for the months of July through September to develop the seasonal 50-year flood for detailed flood routing through the surcharge storage pool above El 2050. This same seasonal duration was used in the 1985 Susitna study.

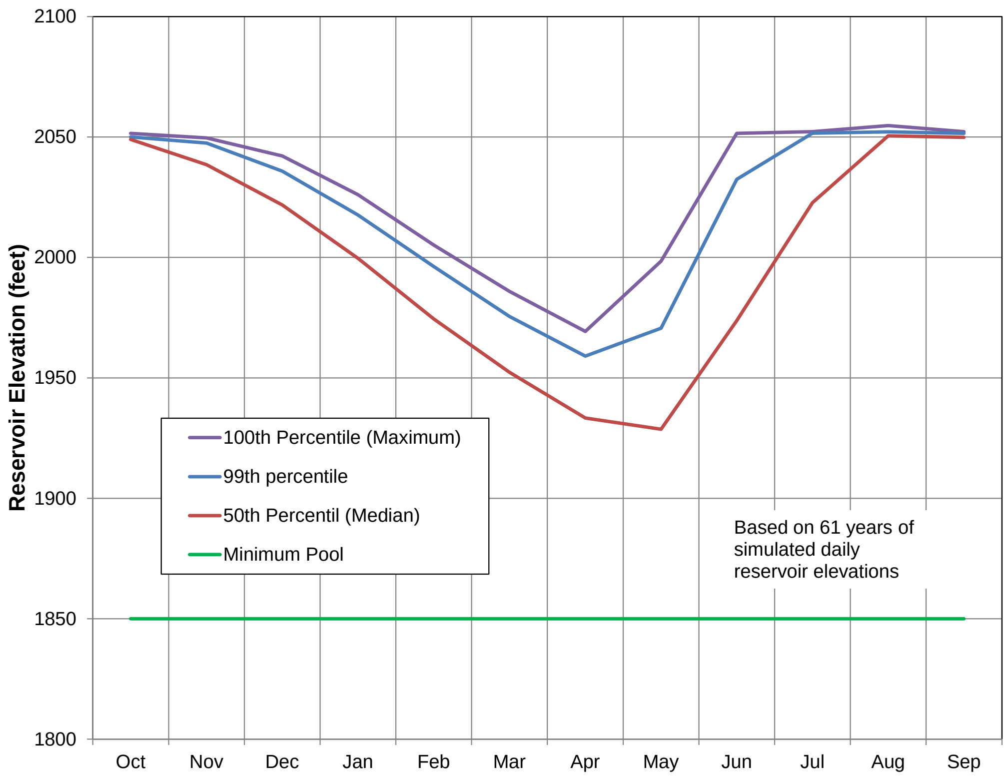

Figure 1 Reservoir Elevation Frequency

The basic source of seasonal flow data was the 61 years of daily Watana Reservoir inflows as developed from the USGS record extension study for the Susitna River basin (Curran 2012). For reference, the 61 years of daily inflows to Watana Reservoir are plotted on the attached Exhibit 1. A frequency analysis of the annual 1-day maximum Watana Reservoir inflow in the July through September period is shown on Figure 2. The 50-year 1-day inflow from the frequency analysis is 57,900 cfs. The largest 1-day inflow as developed from the historic record was 66,800 cfs in August 1971, which was also the largest month of August inflow. The second largest 1-day inflow was 60,800 cfs in August 1967, which was also the third highest month of August inflow to the reservoir.

An analysis of the five largest August through September recorded peak flows at the USGS gage at Gold Creek showed that peak instantaneous flows were 5% to 12% larger than the average daily flows, with the average value being 8% larger. The calculated 50-year 1-day average flow of 57,900 cfs would equate to an instantaneous peak flow of 62,500 cfs with the average 8% increase.

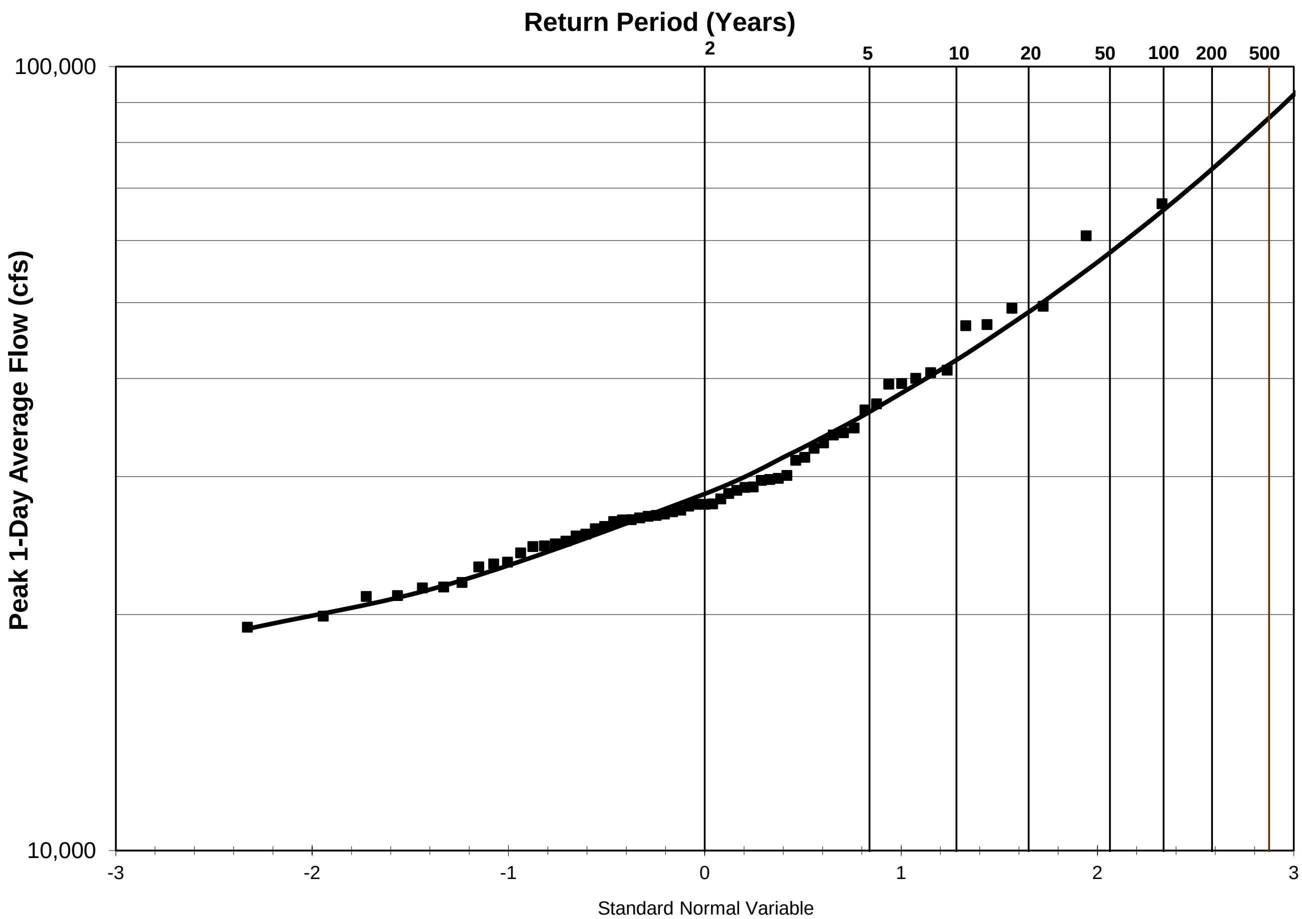

Figure 2 Watana Reservoir July – September Peak 1-Day Average Inflows

For reference, the September 2012 flood had a peak daily flow of 58,700 cfs and an instantaneous peak of 60,700 cfs at the USGS gaging station at Tsusena Creek, which has a drainage area essentially the same as Watana Dam. The September 2012 flood was by far the largest September flood of record at the USGS gaging station at Gold Creek.

3. FLOOD VOLUME FREQUENCY

The 50-year floods were routed through the reservoir to determine the peak water levels and peak outflows. During construction, the diversion flood would start at about El 1465, near the bottom of an unfilled reservoir wherein the area is relatively small. The storage space available for inflow flood attenuation would be small, about 29,000 acre-feet up to the elevation 1553, the top of the impervious core of the diversion cofferdam. During operation, the 50-year July–September flood would begin at El 2050, the maximum normal pool level, which means that storage space available for inflow flood attenuation is much greater.

As a conservative design parameter, the 50-year flood hydrographs to be routed through the reservoir were developed to contain not only the 50-year peak inflow, but also the 50-year total hydrograph volume. A review of historic hydrographs indicates that the high flows of maximum floods tend to occur over a period of about 20 days. Therefore, the 50-year flood should embody the 50-year, 20-day volume as well as the 50-year flood peak. In a manner similar to the determination of the 50-year 1-day average floods at Watana Dam, the 50-year 20-day average flood flow was determined.

3.1 50-Year Annual Flood Volume

A statistical analysis of the 61-year Watana Dam inflow record indicates that the all-season 50-year 20-day average inflow volume would be 39,900 cfs (1,583,000 acre-feet total over 20 days). In the developed 61-year period of Watana inflow record, the maximum 20-day average volume was 50,210 cfs (1,992,000 acre-feet total over 20 days) in June 1964. The second maximum 20-day average in the 61-year period of record was 40,670 cfs (1,613,000 acre-feet total over 20 days) in June 1962 and the third largest in 61 years was an average of 33,800 cfs (1,341,000 acre-feet total over 20 days) in August 1981. By comparison to those three historical maximum values, the calculated volume of 1,583,000 acre-ft over 20 days was confirmed for the 50-year annual flood volume.

3.2 50-Year July – September Flood Volume

For the July through September season, the calculated 50-year 20-day average Watana inflow volume was 34,100 cfs (1,353,000 acre-feet total over 20 days). The two largest 20-day average flows in the

61-year period of estimated inflow record were 33,800 cfs (August 1981), and 32,900 cfs (September 1959). Because of the clustering of maximum values, the 50-year 20-day volume of 1,353,000 acre-feet was considered to be acceptable.

4. 50-YEAR FLOOD INFLOW HYDROGRAPHS

The shape of the 50-year inflow hydrographs was based on historic floods for the appropriate season as taken from the calculated 61-year period of Watana Reservoir daily inflows. Historic floods that had a single peak and a classic hydrograph shape were favored. The historic hydrographs were scaled to provide the desired peak flow and volume with some rearranging of flows to give ascending flows before the peak and descending flows after the peak of the hydrograph.

4.1 50-Year Annual Flood Hydrograph

The 50-year annual flood hydrograph shape was based on the June 1971 flood for which the historic inflow at Watana was estimated to be 66,800 cfs with a 20-day volume of 1,285,000 acre-feet. The rescaled 50-year annual peak flow was 80,800 cfs and the 20-day volume was 1,581,000 acre-feet. The 50-year annual flood is plotted on Figure 3.

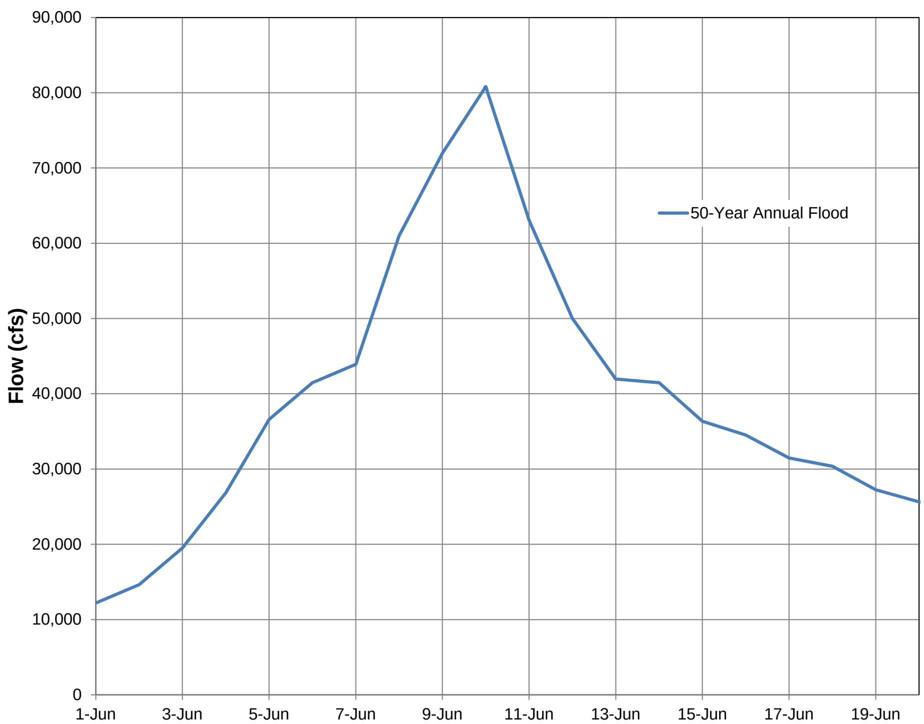

Figure 3 50-Year Annual Flood Hydrograph

4.2 50-Year Seasonal Flood Hydrograph

The 50-year July-September seasonal flood was based on the August 1971 historical flood for which the peak daily flow at Watana was 66,800 cfs and the 20-day volume was 1,265,000 acre-feet. The peak flow for the 50-year seasonal flood, as shown on Figure 4, is 62,500 cfs and the 20-day volume is 1,352,000 acre-feet.

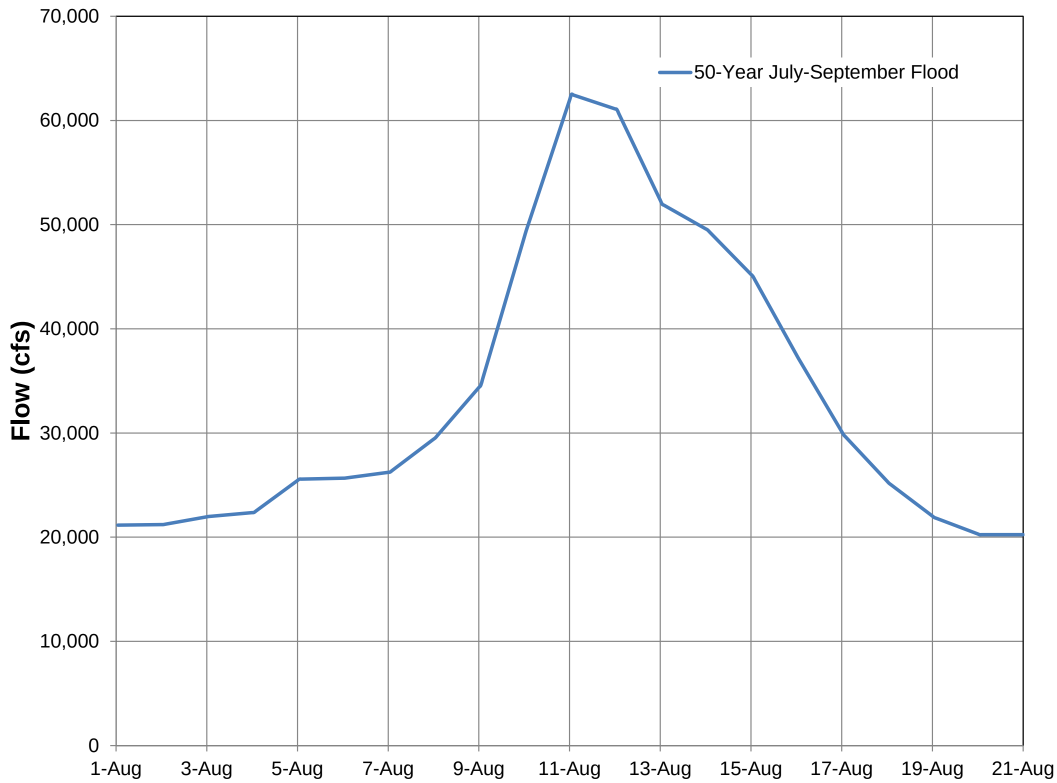

Figure 4 50-Year July - September Flood Hydrograph

5. RESULTS OF ALTERNATIVE ROUTINGS OF THE 50-YEAR FLOOD

The HEC-1 Flood Hydrograph Package was used for routing the floods through the available reservoir storage. Daily inflows were input to the model, which disaggregated the daily data to hourly data, as plotted on Figure 3 and Figure 4.

5.1 Diversion Flood Routing (During Construction)

5.1.1 Diversion Facilities Description

The construction diversion facilities would consist of the following main components:

- An upstream cofferdam with crest at El 1560 and an impervious core at El 1553. The upstream cofferdam would have a 120-ft wide overflow spillway on each abutment with a crest level at El 1530.

- A 36-ft diameter, vertical sided, horseshoe-shaped, lined diversion tunnel. The enlarged tunnel entrance would have two 22-ft wide by 36-ft high gated intakes. The design criterion is that the tunnel alone should pass the 5-year flood assuming no hydraulic capacity reductions due to ice or debris.

- A 44-ft wide (50-ft wide at the entrance) by 44-ft high sluice through the RCC main dam. The design criterion is that the sluice alone should pass the 50-year flood under the conservative assumption that the tunnel is completely plugged.

- A downstream cofferdam designed to wash away in the event that the sluice operates.

5.1.2 Diversion Flood Routing Results

Results of the diversion flood routings indicate that the available storage upstream of the cofferdam is insufficient to attenuate the 80,800 cfs peak of the 50-year annual inflow flood shown in Figure 3 in any meaningful way such that the diversion facilities essentially must pass the entire peak of the inflow flood. The storage impounded by the cofferdam up to the top of the impervious core at El 1553 is only about 29,000 acre-feet. An inflow of 50,000 cfs, which occurs for several days during the 50-year flood, would have a daily inflow volume of about 100,000 acre-feet.

Because the potential for at least partial plugging of the diversion tunnel with ice floes cannot be dismissed, the following two cases were run:

- The first case assumes no hydraulic capacity reductions of the diversion tunnel and includes usage of the sluice. The calculated peak outflow was 80,050 cfs at a peak reservoir level at elevation 1540.4.
- The second case assumes the most extreme case of complete plugging of the diversion tunnel. The calculated peak outflow was 80,090 cfs at a peak reservoir level at elevation 1552.6.

5.2 50-Year Surcharge Storage Flood Routings (During Operation)

As used herein, 50-year surcharge storage means the reservoir storage between the maximum normal pool level at El 2050 and the maximum water level of the 50-year routed seasonal flood. An additional increment of reservoir storage may be used for routing of the Probable Maximum Flood (PMF). The objective of the surcharge storage flood routings is to provide enough information so that an informed choice of fixed-cone outlet valve capacity and surcharge storage can be made.

Assumptions and analysis parameters that are constant or are can vary between runs include the following:

- The initial reservoir level is at El 2050 in all runs.
- The 50-year seasonal (July – September) flood is the inflow flood.
- The gated spillway is not to be used because spillway flows could potentially cause gas supersaturation downstream from Watana Dam.
- The emergency (diversion tunnel) outlet is not to be used.
- Flood forecasting is not used to improve the surcharge storage operation.

- The number and total capacity of the fixed-cone outlet valves is a variable. Each fixed-cone valve is assumed to have a capacity of 4,000 cfs.

- The fixed-cone valves begin to open as soon as the reservoir level rises above El 2050.

- The reservoir level at which the fixed-cone valves are fully open is a variable.

- The amount of turbine flow up to the 15,000 cfs capacity is a variable. The turbine flows are assumed to be constant during the flood routing.

The primary results of the analysis are peak reservoir level and peak total outflow.

Both pluses and minuses can be assigned to the variables. Increased fixed-cone valve capacity and a faster rate of opening of the valves would reduce the amount of necessary surcharge storage and thus reduce the height and cost of the dam. But flow through the fixed-cone valves is essentially “spill”, released water that is not available for generation, so there is a resulting power loss which is a dis-incentive to use them. Fluvial geomorphology considerations tend to favor releasing higher flows that are capable of moving sediment and maintaining natural channel characteristics.

Assuming an operating rule for the fixed-cone valves where the valves would hold the reservoir level at exactly El 2050 could result in a very abrupt opening of the valves. The reservoir could store the early part of the flood hydrograph but El 2050 could be reached at a high flow, say 50,000 cfs, that could require immediate maximum valve flows. Forecasting of inflows could be done to improve the operation, such as beginning to open the valves more gradually before El 2050 is reached, but no prior knowledge of inflow rates is assumed herein for the present analysis.

For routing of the PMF, the normal assumption is that the turbines are not operating due to extremely stormy conditions and associated power outages or transmission line drops. This is not necessarily the case for routing of a much smaller flood such as the 50-year flood, so the turbines are assumed to be operable for that case. The areas of greatest energy consumption are far from Watana Dam and may not be experiencing unusually stormy conditions. The July through September time period is not the period of peak power demand, so maximum power output at Watana may not be usable and energy production may be limited. Therefore, it may not be reasonable to assume the powerhouse could discharge at maximum output, which would correspond to a maximum flow of about 15,000 cfs. Releases above those made through the powerhouse would need to be made through the LLOW.

The expected PMF operation will be for the turbines to operate until the maximum 50-year flood reservoir elevation is achieved and then the turbines will shut down and the spillway gates will begin to open. Because the fixed-cone valves are assumed to be operational for both the 50-year flood and the PMF, incorporation of additional fixed-cone valves could result in a corresponding reduction in required spillway capacity. This is a tradeoff that is being evaluated as part of the ongoing engineering feasibility studies.

The 1980s Susitna feasibility study allocated 14 feet of reservoir flood storage space above the maximum normal pool level before the spillway gates began to open. In the current feasibility studies it was anticipated that the current design would use at least a few feet of reservoir storage to attenuate the inflow flood, rather than passing the entire peak of the inflow flood without an increase in reservoir level. Table 4 provides the reservoir elevation-volume table for the elevation range of potential flood surcharge storage.

Table 4 Reservoir Elevation – Capacity Data

Elevation (feet)	Reservoir Volume (acre-feet)
2050	5,170,000
2055	5,289,300
2060	5,407,900
2065	5,530,900
2070	5,654,500
2075	5,780,400

A range of flood routings were performed using the HEC-1 model; results are summarized in Table 5. The range of possible fixed-cone valve capacity covered was from 24,000 cfs (6 valves operating) to 40,000 cfs (10 valves operating) in combination with the turbines discharging at about full or half capacity. Also tested in the modeling was a slower opening of the valves that would be done to save some additional water for generation, which showed that raising the full-open level of the valves by 1-foot results in a corresponding 1-foot increase in the peak reservoir level. The results of the model runs shown in Table 5 are available for evaluation and selection of the preferred configuration by AEA.

Table 5 Flood Routing Results

Run	All Turbines Maximum Total Outflow (cfs)	Valves Maximum Total Outflow (cfs)	All Valves Fully Open Elevation (feet)	Peak Outflow (cfs)	Peak Reservoir Elevation (feet)	Comments
1	15,000	24,000	2051	39,000	2057.9	Similar in concept to 1980s design
2	7,500	24,000	2051	31,500	2062.4	Reduces turbine output due to lower load
3	15,000	28,000	2051	43,000	2055.8	Like Run 1, but adds 1 valve
4	7,500	28,000	2051	35,500	2059.9	Like Run 2, but adds 1 valve
5	15,000	32,000	2051	47,000	2054.1	Like Run 1, but adds 2 valves
6	7,500	32,000	2051	39,500	2057.6	Like Run 2, but adds 2 valves
7	15,000	36,000	2051	51,000	2052.8	Like Run 1, but adds 3 valves
8	7,500	36,000	2051	43,500	2055.6	Like Run 2, but adds 3 valves
9	15,000	40,000	2051	55,000	2051.9	Like Run 1, but adds 4 valves
10	7,500	40,000	2051	47,500	2053.9	Like Run 2, but adds 4 valves
11	15,000	36,000	2052	51,000	2053.8	Like Run 7, but opens valves more slowly
12	7,500	36,000	2052	43,500	2056.6	Like Run 8, but opens valves more slowly

Figure 5 is an example plot of the flood routing for Run 6. The reservoir level is output by HEC-1 in 0.1 ft increments that results in a slightly jagged plot of reservoir elevation. As shown, the peak elevation rise for the reservoir is 7.6 feet (El 2050.0 to El 2057.6), and that peak occurs about 15 days after the flood begins.

AEA has evaluated the results presented in Table 5, and Run 6 was the selected alternative. Therefore, the proposed Watana Dam configuration will include 8 fixed-cone valves, each capable of discharging 4,000 cfs with the reservoir level at El 2050 for a maximum fixed-cone valve outlet capability of 32,000 cfs. For routing of the PMF, the following conditions will be incorporated:

- The 8 fixed-cone valves will begin to open when the reservoir level rises above El 2050.0 and will become fully open when the reservoir level reaches El 2051.0.
- Turbine flow will be 7,500 cfs until the reservoir reaches El 2057.6, at which point the turbines will be completely shut down for the remainder of the PMF routing.

- The spillway gates will not begin to open until the reservoir level has reached El 2057.6.

- The size of the spillway gates and the total outflow capability of the spillway will be as determined in the PMF Study.

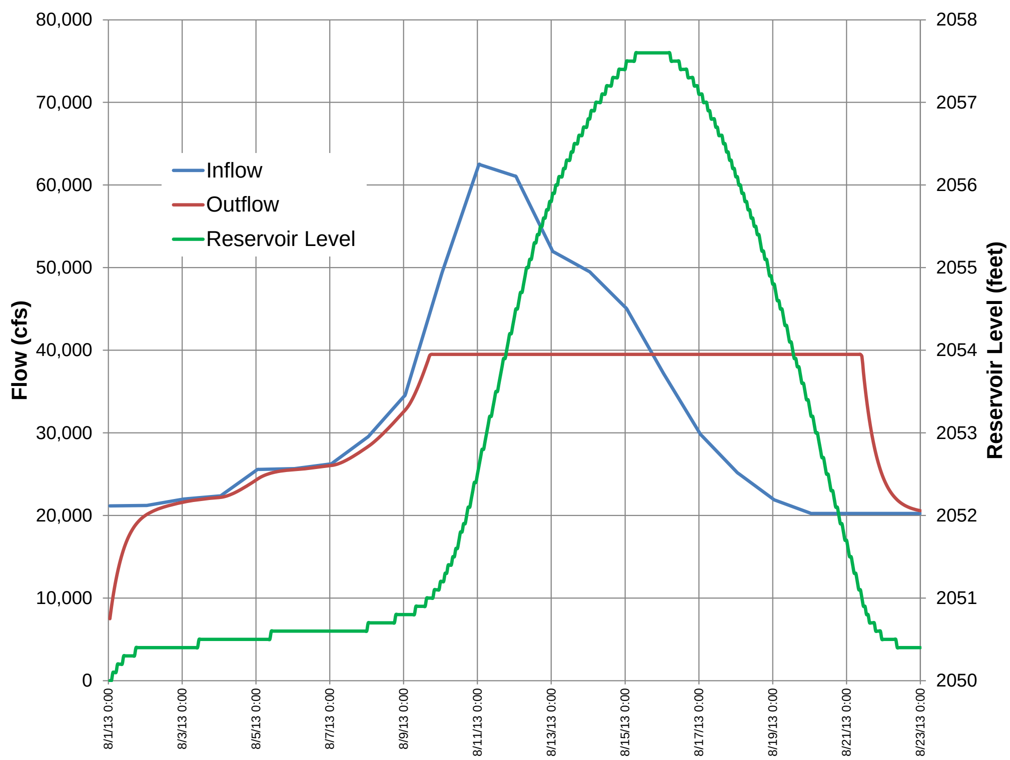

Figure 5 Run 6 Inflow, Outflow, and Reservoir Level

5.3 Comparison with 1980's Results

For comparison, results from the 1985 FERC License Application for the Susitna Project are shown in Table 6. Based on plots of the study results, it appears that the spillway gates began to open at a level higher than the peak of the 50-year July – September flood. The reasons for this difference have not been evaluated to date.

Table 6 Summary of 1985 Flood Routing Study Results

Parameter	1985 Watana Stage I	1985 Watana Stage III
Maximum normal pool level (feet)	2000.0	2185.0
Fixed-cone valves total capacity (cfs)	24,000	30,000
50-year flood peak reservoir level (feet)	2011.0	2191.5
50-year flood peak outflow (cfs)	34,000	33,900
Elevation that spillway begins to operate (feet)	2014.0	2193.0
PMF peak reservoir level (feet)	2017.1	2199.3
PMF peak outflow (cfs)	302,000	284,000

6. BIBLIOGRAPHY

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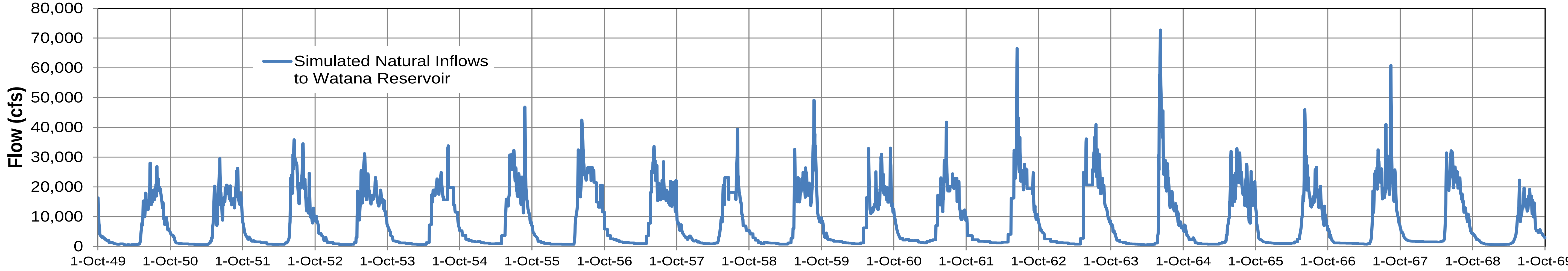
2. Curran, J.H., 2012. *Streamflow Record Extension for Selected Streams in the Susitna River Basin*, Alaska, U.S. Geological Survey Scientific Investigations Report 2012-5210, 36 p.

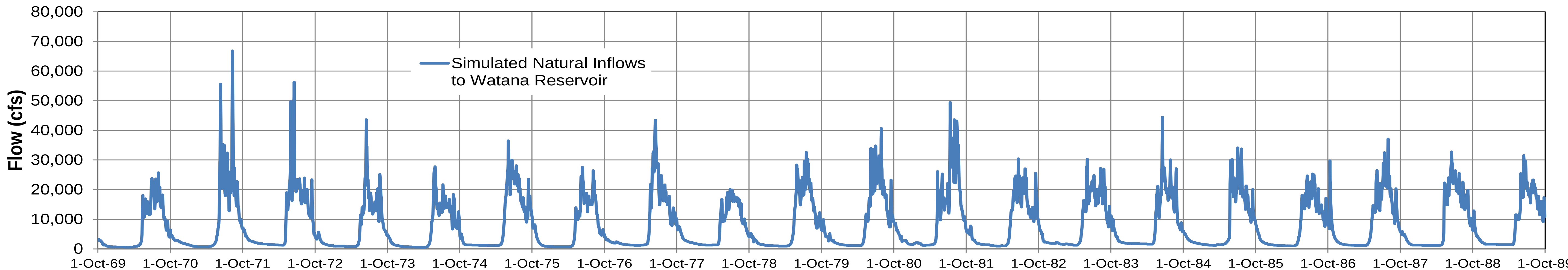
3. MWH, 2014. *Interim Feasibility Report*, Susitna-Watana Hydroelectric Project.

4. MWH, 2014. *Probable Maximum Flood Study*, Susitna-Watana Hydroelectric Project.

Exhibit 1

Watana Reservoir Daily Inflows





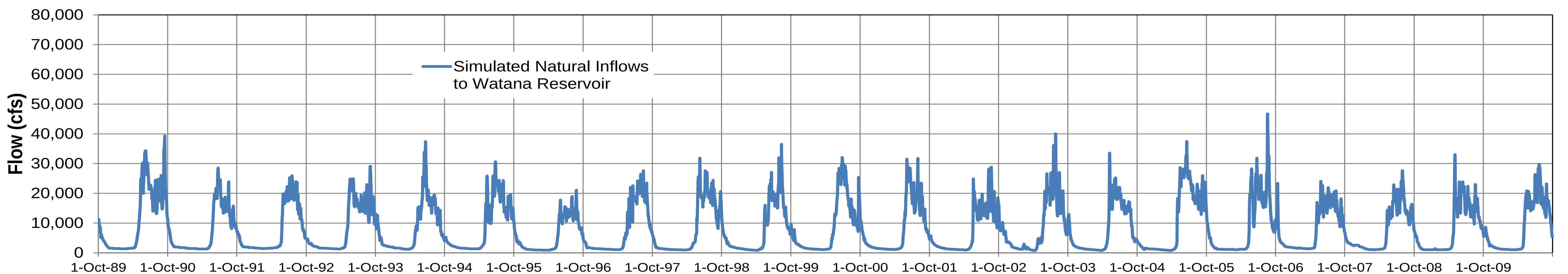


Exhibit 1: Watana Reservoir Daily Inflows