

# 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°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° 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°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°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°F change in either the in-place maximum SST or the transposition maximum SST.

For example, consider the following case:

Storm representative SST:	$75^{\circ}F$	Precipitable water:	2.85"
Maximum SST:	79°F	Precipitable water:	3.44"
Maximization factor = 3.44"/2.85" =	1.21		



If the storm representative SST were  $74^{\circ}$ 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  $78^{\circ}$ F with precipitable water of 3.29", Maximization factor =  $3.29^{\circ}/2.85^{\circ} = 1.15$  (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.



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	

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

The rainfall analysis results were provided on a 1/3mi<sup>2</sup> 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.



**Cumulative Precipitation** 



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



### Incremental Precipitation



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.



**Cumulative Precipitation** 



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



### Incremental Precipitation



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.



**Cumulative Precipitation** 



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



#### Incremental Precipitation



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.



### Incremental Precipitation



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 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.



### Incremental Precipitation



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 Watana drainage (Figure 12.16 - 12.18).



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



**Cumulative Precipitation** 



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



Incremental Precipitation



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.



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Table 12.2.	Station base	d and radios	onde based lar	ose rates for Sei	otember 14-30, 2012.
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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.

	Flovation	FAI
Station	(f+)	Radiosonde
	(11)	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).

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

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

\* 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.



	Flovation	FAI
Station	(f+)	Radiosonde
	(11)	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

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

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 12.22. 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).



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

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

\* -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.

		FAI	
Station	Elevation	Radiosonde	
	(11)	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).

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

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

\* 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.

	Elevation	FAI
Station	(f+)	Radiosonde
	(11)	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

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

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 12.26. 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).



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

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

\* 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).

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

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

\* 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	2, 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  $1 \text{ mm}^6 \text{ m}^{-3}$ , which is equal to  $1 \mu \text{m}^3$ . 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  $\pm 90^{\circ}$  and  $\pm 180^{\circ}$  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 moistureladen 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 sitespecific 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





2013-03-14-16:51



GraDS: COLA/IGES





2013-03-14-16:51



180. 176W 172W 168W 164W 160W 156W 152W 148W 144W 140W 136W 132W 128W 124W 120W

GRADS: COLA/IGES





2013-03-14-16:51



GRADS: COLA/IGES





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GRADS: COLA/IGES





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GRADS: COLA/IGES





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GRADS: COLA/IGES



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 Arauments: - 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:



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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 getAOlarea(): 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 \* 0.00000386102 # Converts square meters to square miles elif srunitname == "Foot" or "Foot US": aoiArea = aoiArea \* 0.0000003587 # 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: # Sets DAD area x1 for basins that are smaller than the smallest DAD area. row = rows.next() 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("\nlnitial 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":
      x^2 = 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))
                                         # If the basin area size is within the DAD table area range, the DAD depth is interpolated
    x = area
    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
                                         # The interpolated DAD depth (in inches) is returned.
    return y
  ## 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:
```



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row.setValue(pmpfield, pmpValues[i])	# Sets the PMP field value equal to the Max Adj.
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 upda return	ate complete. \n")
def outputPMP(): global outPath	
pmpPoints = outPath + "PMP.gdb\\PMP_Points" data for output	# Location of 'PMP_Points' feature class which will provide
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", arcpy.AddMessage("\nPMP Raster Creation complete.")	'w')
<pre>###### This section applies the metadata templates to the or pointMetaLoc = home + "\\Input\\Metadata_Templates\\PMP_</pre>	utput GIS files ###### Points_Metadata_FGDC.xml" # Location of
rasMetaLoc = home + "\\Input\\Metadata_Templates\\PMP_Ra	aster_Metadata_FGDC.xml" # Location
arcpv.AddMessage("\nAdding metadata to output files")	
arcpy.AddMessage("\n\tPMP_Points feature class")	
con.MetadataImporter(pointMetaLoc, pmpPoints)	# Applies metadata to
'PMP_POINTS' reature class for dur in durl ist:	# 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 cla	iss only within
## the Local, Tropical, or general feature dataset). For each du	ration,
## at each grid point within the aoi basin, the transpositionality i	S ind to the
## total adjustement factor to vield the total adjusted rainfall. The	nis line line line line line line line line
## 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.



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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(getAOlarea(),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. 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", "vqLayer") # 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)) # In no duration exists in the DAD table - move to the next storm except TypeError: 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). # get total adj. factor if duration exists try: 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) # Calls the pmpAnalysis() function to calculate the General storm PMP pmpAnalysis(basin, type) arcpy.AddMessage("\nGeneral storm analysis complete...\n\*\*\*\*\*\*