II.6-CALB-MAP CALIBRATION SYSTEM MEAN AREAL PRECIPITATION (MAP) COMPUTATIONAL PROCEDURE

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Purpose

This Chapter describes the procedures used to compute Mean Areal Precipitation (MAP) for use in model calibration.

Recommended steps to follow in computing MAP are described in Section IV.1.2-MAP [Hyperlink].

The extraction of any hydrologic intelligence from precipitation data requires knowledge of its variation over an area. Since precipitation is normally measured as a point value, the use of the data requires an ability to estimate the value at other points. Any method of areal analysis, isohyets, Thiessen weights, etc. involves, implicitly or explicitly, inferences concerning the depth of precipitation at all points in the area of interest. The procedure described is an objective formulation that produces an estimate of the precipitation at a point as a function of that at surrounding points. The method is the result of development over many years and has been verified on both an empirical and theoretical basis.

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Estimation of Missing Precipitation Data

The following is how the estimated precipitation for point A in Figure 1 [Bookmark#1] would be determined.

North-South and East-West lines through point A divide the surrounding area into four quadrants, numbered as shown, counter clockwise from the southwest. Points B through K are points at which precipitation is known. Using the coordinates of the stations, the closest to A in each quadrant is located. These are G, D, H and J. The estimate of precipitation at A is now computed as a weighted average of that at the other four points. The weight is equal to the reciprocal of the square of the distance from point A to the reference point. As an example, let the data be as shown in Table 1 [Bookmark#1]. It can be seen that the sum of the weighted precipitation (ΣPW) is 21.88. The sum of the station weights (ΣW) is 14.23. The estimated precipitation at a given point (in this case, point A) is then taken as ΣPW/ΣW.

The estimated precipitation at A is then equal to 21.8825/14.2302 or 1.538 inches.

If one or more quadrants contain no point of known precipitation then the averaging computation involves only the remaining quadrants.

A variation of the method recognizes as a special case the situation where reference points are found in only two quadrants and those are adjacent (I and II, II and III, III and IV or IV and I). In this case the estimate is given as ΣPW rather than ΣPW/ΣW. This has the effect of reducing estimates to zero as the points move from a precipitation area toward an area of no reports.

A station which is located on a quadrant line will be placed in the nearest quadrant in a clockwise direction.

The estimating technique described can never result in a point estimate that is greater than the largest amount observed or less than the smallest. In some areas, particularly mountainous regions, precipitation patterns have known characteristics that might indicate higher or lower amounts at certain points. The 'station characteristic adjustment' modification allows this to be taken into account. The characteristic precipitation for a station is similar to its normal precipitation. The difference is that while station normals indicate the total accumulation at a station over an extended period, the station characteristics indicate the amount that might occur in one storm. In this application, the actual value of the characteristics are probably not important. What is used, in effect, is the ratio of one station characteristic to that of other stations. As defined and as used, the characteristics are probably not equal to normals and there may be a separate set of characteristics for each of a number of storm types. Using the example of Figure 1 [Bookmark#2] and Table 1 [Bookmark#2], let the characteristic precipitation for stations A, G, D, H and J be as shown in Table 2 [Bookmark#1].

Note that the characteristic for station A is considerably higher than for the estimator stations indicating an increase in the basic estimate. The estimate of precipitation for this example utilizing the characteristics from Table 2 [Bookmark#2] would be 0.0322/0.0142 or 2.27 inches.

In mountainous regions, there are often no stations in the high precipitation areas. Synthetic stations can be located at strategic points and their characteristic amounts estimated from known precipitation patterns. These stations of course will never report, but will be estimated in such a way as to define the proper pattern. A more detailed description of station characteristics and synthetic stations can be found in Section IV.1.2-MAP [Hyperlink].

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Applications of the Estimating Technique

The basic estimating method can be used in a number of ways. The precipitation at network stations that fail to report in a particular event can be estimated. Areal precipitation means can then be easily calculated using some form of station weights (i.e., predetermined, Thiessen or grid point).

Other applications of this general technique could be made. For example, if a fine grid is superimposed on the area, precipitation at each grid point could be estimated. With this information, isohyets could be plotted, depth-area studies could be made, etc.

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Grid Point Weights

The discussion so far has dealt with the analysis of an actual event in which precipitation amounts are the variables. Using the same concepts, it is possible to compute a set of station weights, similar to Thiessen weights, which can be used to compute areal averages. Consider a basin covered with a fine grid. In a particular event, the estimating procedure described could be used to compute the precipitation at each grid point that falls within the basin. The arithmetic average of all these grid point amounts would be the basin average. Station weights that will produce a basin average equal to one computed in this manner are known as 'grid point weights'. They can be determined as follows.

At each grid point falling within the basin, perform the estimating procedure only as far as locating the four reference stations and computing the weights. Then normalize (adjust to total unity) the weights and assign each weight to the appropriate station. After this procedure has been repeated for each grid point, the total weight assigned to each station, after being normalized, is its grid point weight.

As an example consider the basin shown in Figure 2 [Bookmark#1]. The area is covered with a 10 by 10 grid, 47 points of which fall within the basin. The weight computations for these 47 points are shown in Table 3 [Bookmark]. The weight shown is the reciprocal of the squared distance, but the weights for each grid point have been normalized to total unity. Note that a special case exists where a station is located at the grid point.

That station is given unit weight and no other stations are used. To compute the grid point weights for the various stations, the total weight assigned to each station is determined. These totals are shown in Table 4 [Bookmark#1]. Note that the total is 47, the number of grid points. Normalizing these values results in the grid point weights.

To illustrate the application of the weights Figure 3 [Bookmark] shows the basin with a precipitation pattern superimposed on it. Point amounts at the stations are:

A=1.0 B=0.2 C=4.6 D=1.0 E=3.2 F=1.9 G=2.1 H=1.0

Using these amounts and applying the grid point weights in Table 4 [Bookmark#2] the computed basin mean is 2.764 inches.

If the computations in Table 2 [Bookmark#3] are continued to determine the precipitation at each of the 47 grid points in the basin using this precipitation pattern the computed basin mean is also 2.764.

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Thiessen Weight Computations

The determination of Thiessen weights can be done by defining a Thiessen polygon as being formed by the perpendicular bisectors of the lines connection stations. To program the equations of these lines and computations of the area bounded by them is extremely difficult. If, however, the polygon for a station is thought of as the boundary of all points which are closer to the subject station than to any other station, then the solution becomes obvious. Table 5 [Bookmark#1] shows the stations and the number of grid points closest to each from Figure 2 [Bookmark#2]. These numbers when normalized are the Thiessen weights.

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Comparison of Weighting Methods

Figure 4 [Bookmark] shows the network with conventional Thiessen polygons drawn. Weights determined from these are:

A=0.0301 C=0.3080 D=0.0323 E=0.2441 F=0.2038 G=0.1817

The agreement with the values of Table 5 [Bookmark#2] is good, considering the coarseness of the grid used. It is now possible to compute the basin mean for this event by a number of different methods. The computation has already been made using grid point weights and grid point averages and the results were, as expected, identical. The mean can also be determined by the use of Thiessen weights derived either from the polygons or the grid point count or by an isohetal analysis. The results are as follows:

Method	Basin Mean
Grid point	2.76
Thiessen weights (Polygons)	3.03
Thiessen weights (Grid point count)	3.03
Isohyetal analysis	2.62

The isohyetal analysis would probably be considered as giving the best value, one which could be used as a standard for judging those derived by other methods. The fact that the grid point method yielded a value closer to this standard than that obtained from Thiessen weights indicates superior results in this case, but this should not be the basis for generalization.

Usually, the values of grid point weights for an area are quite close to those of Thiessen weights. The most noticeable difference is that an outlying station often has a small non-zero grid point weight when its Thiessen weight would be zero. This was the case with stations B and H in the example.

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Sensitivity

The use of a finite number of grid points in the analyses shown is an approximation to the exact solution. The greater the number of grid points, the closer the approximation. Sensitivity analyses for this type of computation have indicated that adequate results will be obtained if 100 or more grid points fall within the basin. Increasing the number of points above 100 refines the results slightly but beyond 150 points there is no perceptible change.

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Mean Areal Precipitation Program

The following sections describe the MAP program is used to compute mean areal precipitation using the concepts described in the preceding sections (see Chapter III.7-MAP [Hyperlink]). Figure 5 [Bookmark] is a flow diagram of the program.

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Computation of Station Weights

The MAP program has the options of computing station weights by grid point weights, Thiessen weights (grid point count) or predetermined station weights. Predetermined station weights are used in mountainous areas where station weights are functions of elevation, aspect, etc., in addition to their two-dimension coordinate location. See Section IV.1.2-MAP [Hyperlink] for a more detailed description of station weights.

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Estimation of Missing or Accumulative Hourly Precipitation Data

MAP uses hourly and daily precipitation data. After all data are read, the program goes through the hourly precipitation stations, month by month, to estimate periods when the hourly data are missing or to distribute periods when only an accumulative value is recorded. One day from the preceding month and 2 days from the following month are also included to help estimate missing time distribution which overlaps months. Only hourly stations are used to estimate missing or accumulative hourly data.

The equation used to estimate a missing hour of data is:

$$A_x = \frac{\sum_{i=1}^{i=n} \left[A_i * \frac{N_x}{N_i} * \frac{1}{(d_{i,x})^2} \right]}{\sum_{i=1}^{i=n} \frac{1}{(d_{i,x})^2}} \qquad (1)$$

where
- A_x is the hourly precipitation at the station being estimated
- i is the station being used as an estimator
- n is the number of estimators (the nearest station in each quadrant which has valid data is used as an estimator)
- A_i is the hourly precipitation at the estimator station
- N_x is the monthly characteristic precipitation at the station being estimated
- N_i is the monthly characteristic precipitation at the estimator station
- $d_{i,x}$ is the distance from the station being estimated to the estimator station

Characteristic precipitation does not need to be included in flat terrain but is necessary in mountainous areas. Monthly characteristic precipitation is used because individual storm data are not usually available and because storm types have a fairly strong correlation with season.

The equation used to estimate each hour during a period when only the accumulative value is recorded is:

$$A_x = \frac{\sum_{i=1}^{i=n} \left[A_i * \frac{T_x}{T_i} * \frac{1}{(d_{i,x})^2} \right]}{\sum_{i=1}^{i=n} \frac{1}{(d_{i,x})^2}} \qquad (2)$$

where T_x is the accumulative precipitation amount at the station being distributed

T_i is the total precipitation amount for the period of missing time distribution at the station being used to estimate the distribution

Equations 1 and 2 will handle the general case of missing data or accumulative data. The following rules apply for special cases:

- o If no valid estimator station is available the hourly precipitation for that hour is set to zero.
- o If missing time distribution extends more than 2 days into the succeeding month the entire period is set to missing data. The missing data period is again estimated using Equation 1.
- o If no station can be found to estimate a period of missing time distribution the accumulated amount is left in the last hour.

At this point in the program all hourly precipitation stations have a complete record free of missing data and accumulative amount indicators.

The following describes the estimation of missing data in program MAP [Hyperlink] by subroutines DISREC and DISNRC.

Estimation of missing hourly data (subroutine DISREC):

1. Estimate are done hour by hour using the other hourly gages.
2. Only gages with observed values are used to estimate missing data (estimated values are not used).
3. Estimated values are set to a negative value so that they are not used to estimate a value for another station (estimated zeros are set to -0.00001).
4. If the sum of the (1.0/d2) for all quadrants with a valid estimator is less than 0.00005 then the estimate is set to zero (-0.00001). This can happen when only one hourly station has observed data and it is far enough away from another hourly station that is to be estimated. This occurs when d2 is greater than 20,000 (d in units of HRAP coordinates; in the order of 400+ miles for Alaska).

Estimation of missing daily data (Subroutine DISNRC):

1. Estimated zeros (-0.00001 from subroutine DISREC) for hourly stations are set to 0.0 at the start of subroutine DISNRC thus

they are used as actual values and not estimates.

2. For the 24 hour period ending at the observation time for a given daily station with missing data the 'hourly' values from the closest station in each quadrant, either an hourly or daily station, are used to estimate the missing daily amount based on the following logic:
   a. Any station with missing values is not used
   b. The 24 hour total used in the estimation for surrounding daily stations can be computed from 'hourly' values that were either obtained by time distributing an observed daily total or were estimated for a prior daily station (estimated values are not flagged in this subroutine).
   c. A 24 hour total for a daily station will override a 24 hour total computed for an hourly station that includes estimated non-zero data (hourly non-zero estimates are stored at this point as negative values) even if the daily station is further away in a given quadrant from the station being estimated than the hourly station. However, since estimated zeros for hourly stations are not stored as negative values at this point, an hourly station with estimated zero values (no estimated non-zero values) will be used to obtain a 24 hour total whenever it is the closest station in a given quadrant.
3. The estimated 24 hour totals for each daily station are time distributed based on the closest hourly station in each quadrant.

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Distribution of Daily Precipitation Observations

Daily precipitation is converted into hourly, month by month, by using the hourly precipitation stations to determine distribution of the daily values. Converting daily precipitation into hourly is a two-pass operation. On the first pass, daily precipitation observations are distributed but missing data are ignored. Equation 2 is used to distribute the daily observations, where T_x is now the daily precipitation observation and T_i is the total precipitation since the last daily observation at the hourly station being used to estimate the distribution. A_i is the hourly precipitation at the estimator station, while A_x is the estimated hourly precipitation at a particular daily station for a particular hour. On pass two, missing daily precipitation is estimated using Equation 1. Once the daily amount is estimated, it is distributed as in pass one. The reason for a second pass is so that not only can hourly precipitation stations be used to estimate the missing daily amount, but so that the amount from a daily station will be used if it is the closest station in a particular quadrant to the station being estimated. In this case A_x in Equation 1 is now the daily precipitation at the station which is being estimated and A_1 is the total precipitation since the last daily observation at the hourly or daily station used as an estimator. For special cases the following rules apply:

- If no station can be found to distribute a daily observation the total amount is left in the hour of the time of observation.

- If missing time distribution extends more than 2 days into the succeeding month the entire period is set to missing data.

- If no valid estimator station is available for a missing daily amount the daily amount is set to zero.

Now all the hourly precipitation stations are complete and all daily stations have been converted into an hourly record which has no missing data and accumulated amount indicators.

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Computation and Output of Mean Areal Precipitation

Computation of mean areal precipitation is now accomplished by going through the entire period for each area, multiplying the hourly precipitation by the station weight for all stations within the area and summing these results to create a mean areal hourly precipitation sequence. The MAP program has the option to output the results in 1 hour, 3 hour or 6 hour increments.

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Consistency Checks

Before using the results of the MAP program, some check on the consistency of the individual station records is needed. The MAP program uses the station records just prior to the computation of mean areal precipitation (i.e., hourly precipitation stations are complete and all daily stations have been converted into an hourly record) to produce the following table and plots:

- A table which lists for each station and month the accumulated precipitation at the station, the double mass value from the group to which the station is assigned and double mass value from a group containing all other stations. Group assignments are made so that stations can be compared against other stations with the same geographical characteristics. If a station is not assigned to a group then it will be compared to the group-one double mass. In this case group one would be composed of stations judged to have the highest quality records.

- A plot of the accumulative values for each station against the double mass of all other stations and against the double mass of the group to which the individual station is assigned.

If the double mass plots indicate a change in consistency for some station, it is possible to correct for this by assigning adjustment factors beginning and/or ending any time in the precipitation record for each precipitation station. Thus adjustments can be made for such factors as changes in exposure, location, equipment or procedures which may cause a definite break in a double mass analysis for a particular station.

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Precipitation Estimation Comparison

An option is available in the MAP program to compare observed and estimated precipitation data at an individual station for the purpose of checking the accuracy of the estimating technique.

A 'synthetic' precipitation station is positioned at exactly the same coordinate location as an actual station for which the comparison is to be made. MAP estimates precipitation data for the synthetic station utilizing surrounding stations but excluding the actual station which has the same coordinates as the synthetic station. Thus, a comparison can be made between a generated precipitation record and an actual precipitation record for a given location and period of record.

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References

Staff, Hydrologic Research Lab, 'National Weather Service River Forecast System, Forecast Procedures', NOAA Tech Memo NWS HYDRO-14, U.S. Department of Commerce, Silver Spring, Maryland, 1972.

Table 1. Estimating the amount of precipitation at station A from surrounding station amounts

Point	X	Y	Precip	ΔX	ΔY	D^2	$Wx10^3$	$PWx10^3$
A	75	50	----	--	--	---	------	------
G	92	59	2.61	17	9	370 1/	2.7027 2/	7.0540 3/
D	67	62	1.78	8	12	208	4.8077	8.5577
H	63	43	0.56	12	7	193	5.1813	2.9015
J	94	33	2.19	19	17	650	1.5385	3.3693
Sum	--	--	----	--	--	---	14.2302	21.8825

Notes:
1/ 17**2 + 9**2 = 370
2/ 1/370 * 10**3 = 2.7027
3/ 2.61 * 2.7027 = 7.0540

Table 2. Adjusting the amount of precipitation at station A by the 'station characteristic adjustment' method

Point	Characteristic	N_x/N_i	$P_i(N_x/N_i)[1/(d_{i,x})^2]$
A	4.2	--	--
G	3.4	1.235	0.0087
D	2.9	1.448	O.0123
H	3.0	1.400	O.0041
J	2.0	2.100	O.0071
Sum			0.0322

Table 3. Normalized weights for each grid point

		Quadrant I			Quadrant II			Quadrant III			Quadrant IV		
X	Y	Sta	D^2	W	Sta	D^2	W	Sta	D^2	W	Sta	D^2	W
1	2	-	-	-	F	1	.944	D	17	.056	-	-	-
1	3	-	-	-	F	2	.833	D	10	.167	-	-	-
2	1	-	-	-	-	-	-	F	1	.980	B	50	.020
2	2	-	-	-	-	-	-	F	0	1.000	-	-	-
2	3	F	1	.828	G	17	.048	D	9	.092	B	26	.032
2	4	F	4	.411	G	20	.082	D	4	.411	B	17	.096
3	1	-	-	-	H	36	.044	G	10	.159	F	2	.797
3	2	-	-	-	G	9	.093	E	13	.065	F	1	.842
3	3	F	1	.755	G	10	.075	E	8	.094	D	10	.076
3	4	F	5	.295	G	13	.115	E	5	.295	D	5	.295
3	5	F	10	.071	E	4	.179	C	20	.036	D	1	.714
4	2	-	-	-	G	4	.417	E	10	.166	F	4	.417
4	3	F	5	.295	G	5	.295	E	5	.295	D	13	.115
4	4	F	8	.091	G	8	.091	E	1	.727	D	8	.091
4	5	F	13	.057	E	1	.738	C	13	.057	D	5	.148
4	6	F	20	.056	E	2	.555	C	10	.111	D	4	.278
5	2	-	-	-	G	1	.818	E	9	.091	F	9	.091
5	3	F	10	.111	G	2	.552	E	4	.276	D	18	.061
5	4	F	13	.057	G	5	.148	E	1	.738	D	13	.057
5	5	-	-	-	-	-	-	E	0	1.000	-	-	-
5	6	E	1	.731	G	17	.042	C	5	.146	D	9	.081
5	7	E	4	.429	C	4	.428	A	41	.042	B	17	.101
5	8	E	9	.269	C	5	.485	A	26	.094	B	16	.152
6	2	-	-	-	-	-	-	G	0	1.000	-	-	-
6	3	G	1	.749	H	13	.057	C	17	.044	E	5	.150
6	4	G	4	.276	H	18	.062	C	10	.110	E	2	.552
6	5	G	9	.082	H	25	.030	C	5	.148	E	1	.740
6	6	E	2	.458	H	34	.027	C	2	.458	D	16	.057
6	7	E	5	.155	C	1	.776	A	20	.039	B	26	.030
6	8	E	10	.143	C	2	.716	A	17	.084	B	25	.057
7	2	-	-	-	H	5	.162	C	25	.032	G	1	.806
7	3	G	2	.615	H	8	.154	C	16	.077	E	8	.154
7	4	G	5	.340	H	13	.131	C	9	.189	E	5	.340
7	5	G	10	.154	H	20	.076	C	4	.385	E	4	.385
7	6	E	5	.157	H	29	.027	C	1	.785	D	25	.031
7	7	-	-	-	-	-	-	C	0	1.000	-	-	-
7	8	C	1	.872	H	53	.016	A	10	.088	B	36	.024
7	9	C	4	.692	A	9	.308	-	-	-	-	-	-
8	4	G	8	.348	H	10	.278	A	29	.096	C	10	.278
8	5	G	13	.199	H	17	.152	A	20	.130	C	5	.519
8	6	E	10	.140	H	26	.054	A	13	.107	C	2	.699
8	7	E	13	.062	H	37	.022	A	8	.102	C	1	.814
8	8	C	2	.675	H	50	.027	A	5	.270	B	49	.028
8	9	C	5	.444	A	4	.556	-	-	-	-	-	-
9	6	E	17	.164	-	-	-	A	10	.279	C	5	.557
9	7	E	20	.100	-	-	-	A	5	.400	C	4	.500
9	8	C	5	.279	-	-	-	A	2	.699	B	64	.022

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Table 4. Grid point weights for the various stations

Station	Sum of Weights	Grid Point Weight
A	3.294	0.0701
B	0.562	0.0119
C	12.312	0.2619
D	2.730	0.0581
E	10.348	0.2202
F	8.931	0.1900
G	7.504	0.1597
H	1.319	0.0281
Sum	47.000	1.0000

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Table 5. Grid points used to compute Thiessen weights

Station	Number of Points	Thiessen Weight
A	2	$\frac{2}{47}$ = 0.0426
B	O	0.0
C	16	$\frac{16}{47}$ = 0.3404
D	3	0.0638
E	10	0.2128
F	9	0.1915
G	7	0.1489
H	0	0.0
Sum	47	1.0000

Figure 1. The 4 quadrants surrounding precipitation station A

Figure 2. Grid superimposed on an area for estimating grid point weights (Thiessen polygons shown with dashed lines)

Figure 3. Precipitation pattern superimposed on an area

Figure 4. Thiessen polygon network by the conventional method

Figure 5. Flow diagram of Mean Areal Precipitation program

Figure 5. Flow diagram of Mean Areal Precipitation program (continued)