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Precipitation Gage Placement in Mountainous Areas Based on Gage Site Characteristics

by

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INTRODUCTION

Many of the precipitation gages in the mountainous areas of the world are situated for convenience of servicing. This results in large areas of no data. As data networks are expanded, some method or combinations of methods must be used to locate these gages so that mean precipitation over a basin can be adequatly determined.

The state of Idaho has a law which states that the withdrawal of water from a basin cannot be greater than the rate of recharge. To have some measure of exchange requires estimates of mean annual precipitation. This in turn requires that the few storage gages which can be placed in large basins must be properly located.

The objective of this study was to determine which, if any, physical parameters might be useful in gage placement and network design. The area chosen for initial study was the Reynolds Creek watershed in southwestern Idaho. This watershed has a dense gage network and is operated by the Northwest Watershed Research Center, Agricultural Research Service, USDA at Boise. The drainage area is 233 sq km and the elevation ranges from 1097 m to 2252 m. About 75 percent of the mean annual precipitation occurs from October to April and is mainly in the form of snow.

ANALYTICAL APPROACH

A network of 45 shielded gages (about 1 gage every 5 sq km) was chosen as the base network for the study. The data used were for the years 1969, 1970 and 1971. The Thiessen -weighted mean annual precipitation computed for these years was considered the "true" value and is the basis for all comparisons which follow.

First, it was necessary to determine which of the physical parameters of the gage site were significantly related to the gage catch at the site. The independent parameters used were gage site elevation, slope, aspect, cover class, and the SCS hydrologic soil classification. These are quite self-explanatory except perhaps for aspect and cover class. Aspect was the azimuth of the slope in the surrounding area. Cover class was rated on a scale of one to four corresponding to vegetation densities of 0-25 percent, 25-50 percent and so forth. The dependent variable was the three year average of annual shielded-gage precipitation catch.

These data were subjected to a correlation analysis and the resulting matrix is shown in Table 1. The only significant correlation between the independent variables was found between elevation and cover class. Also noted is the highly significant correlation between precipitation and elevation and precipitation and cover class.

From a simple correlation analysis such as this, statements cannot be made about the actual relationship between precipitation and the various independent parameters so a regression analysis was also performed. A regression of precipitation and elevation yielded a R^2 of 0.49 and the addition of cover class yielded a R^2 of 0.64, an improvement of 0.15. An equation using all 5 independent variables had a R^2 of 0.66. It was also noted that the t values associated with the regression coefficients for elevation and cover class were the only t values that were significant at the 95% level. Thus, it was concluded that for this 45 gage network on Reynolds Creek only elevation and cover class would be used in the further analysis.

In order to determine a rational scheme for placing of new gages in a basin, it was decided to explore some sort of stratification scheme, and stratify Reynolds Creek first according to elevation and then according to cover class. Four zones were to be populated with gages chosen in various fashions. Four methods of divising the zones were tried. These were 4 elevation bands with approximately equal numbers of gages, (which would not work in a design situation) equal area, and equal elevation difference. The fourth method used the four cover classes as a means of stratification. The following analysis shows only the results from the equal elevation band and the cover class stratification.

When stratified sampling is used, the number of samples from each strata is proportional to $N_i s_i/C_i$ where N_i is the total population, s_i is the standard deviation, and C_i is the cost of sampling each unit in the i^{th} strata. If it is assumed that the cost is the same all over the basin (not a very good assumption in a mountainous basin) then the number of samples to be drawn from each strata is proportional to $N_i s_i$. Thus, if a strata has a high standard deviation, more samples would be taken than from a strata with a low standard deviation given the same population. Table 2 presents the results of this reasoning.

Using the 45 gages as a population, 10 different groupings of 30, 20, 10, and 5 gages were constructed for a total of 40 different possible configurations. It was not always possible to obtain the ideal number of gages in each zone since there were not always enough gages available. Also, each zone was always assigned at least one gage.

This then gave enough information to determine the standard deviation of the mean for each grouping. For example, there were 20 different groupings of 30 gages, 10 stratified by elevation and 10 by cover class with a standard deviation of the Theissen-weighted precipitation mean of the basin of 1.65 and 1.83 respectively. This information enables the plotting of Figures 1 and 2 which show confidence bands about the basin mean. Thus, for example, we see that the 95% confidence band for 20 gages ranges from 465 to 479 mm. When all 45 gages are used, the confidence band decreases to zero since the mean determined from the 45 gages is considered to be the "true" basin mean.

It is interesting to note that in all eight sets of reduced networks, the mean was higher than that for the 45 gages network and significantly so for the 30 and 20 gage networks based on the cover class. This may be attributed to the fact that in the reduced networks, the gages with relatively high annual precipitation averages are less crowded and the areas weighted with their depth of precipitation are considerably larger.

CONCLUSION

For Reynolds Creek and similar basins, gage placement based on an elevation stratification seems desirable. For the 233 sq km watershed, it would seem that 20 gages would be the minimum desirable for a determination of the Theissen-weighted mean annual precipiation.

When designing networks for basins for this type, more importance should be attached to the elevation of the proposed gage location than to cover class. Aspect, slope and soil type should not be ignored but are relatively unimportant. Once the factors that contribute to mean annual precipitation variability, it will be possible to distribute a given number of gages in proportion to $N_i s_i$.

Table 1. Correlation matrix for gage site characteristics and gage catch.

CORRELATION MATRIX

	ELEVATION	SLOPE	ASPECT	COVER CLASS	SOIL TYPE	PRECIPITATION
ELEVATION	1.0					
SLOPE	0.44	1.0				
ASPECT	0.03	0.06	1.0			
COVER CLASS	0.58*	0.18	-0.11	1.0		
SOIL TYPE	0.28	0.22	0.25	-0.02	1.0	
PRECIPITATION	0.71*	0.35	-0.14	0.71*	0.09	1.0

Table 2.

STRATIFICATION BY EQUAL ELEVATION BANDS

ZONE	NUMBER	STD DEV	% OF TOTAL NS	IDEAL NUMBER OF GAGES			
1097-1372	14	62.5	13.2	4(5)	3	1	1
1372-1646	12	94.0	17.1	5(6)	3	2	1
1646-1920	12	240	43.6	13*(12)	9	4	2
1920-2195	7	247	26.1	8*(7)	5	3	1

STRATIFICATION BY COVER CLASS

CLASS 1	14	71.6	16.4	5	3	2	1
CLASS 2	16	112	29.4	9(10)	6	3	1
CLASS 3	6	241	23.7	7*(6)	5	2	1
CLASS 4	9	207	30.5	9	6	3	2

* MORE GAGES NEEDED THAN ARE AVAILABLE

() INDICATES ACTUAL NUMBER USED IF DIFFERENT FROM IDEAL

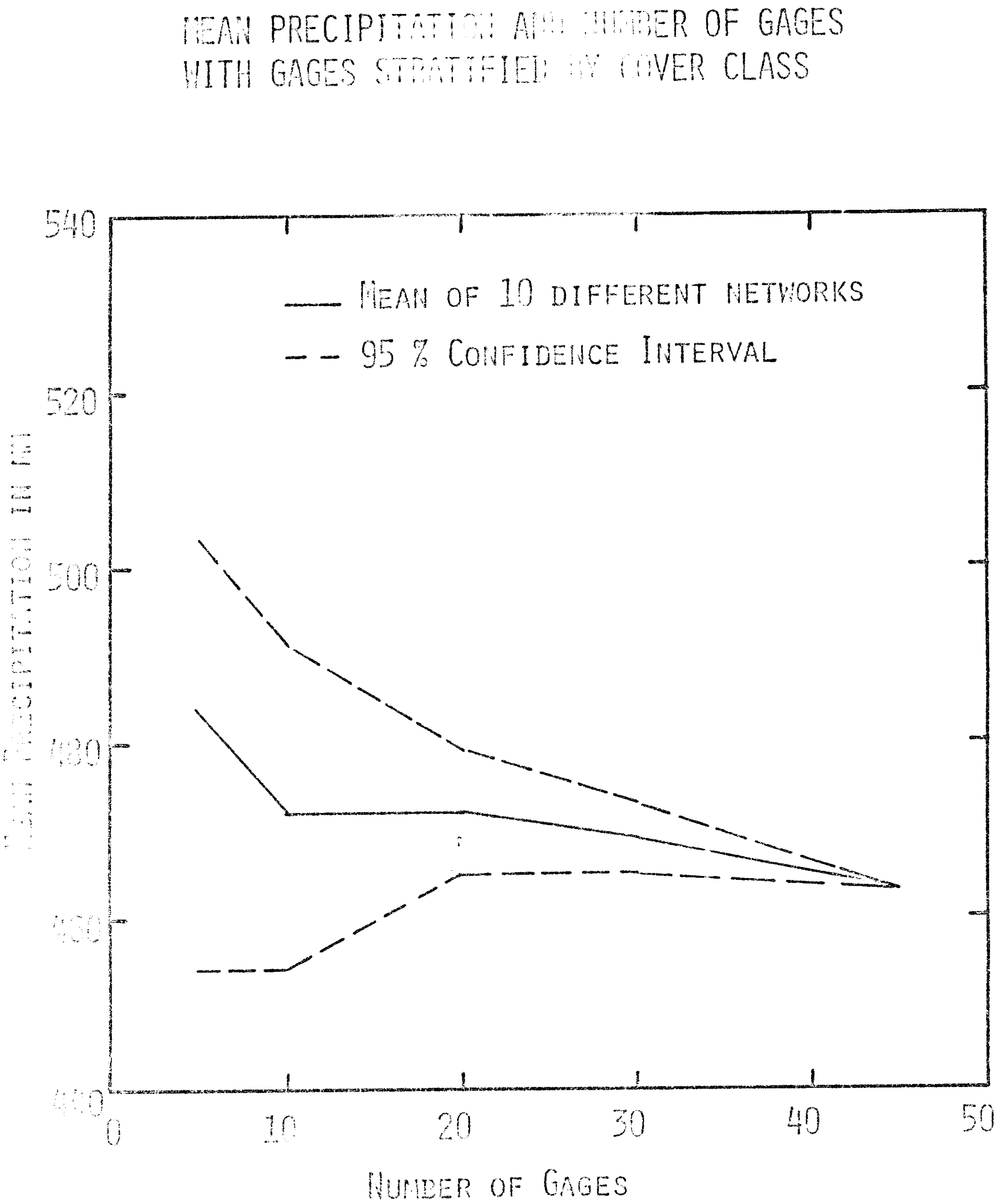

Figure 1. Confidence band for gages stratified by cover class.

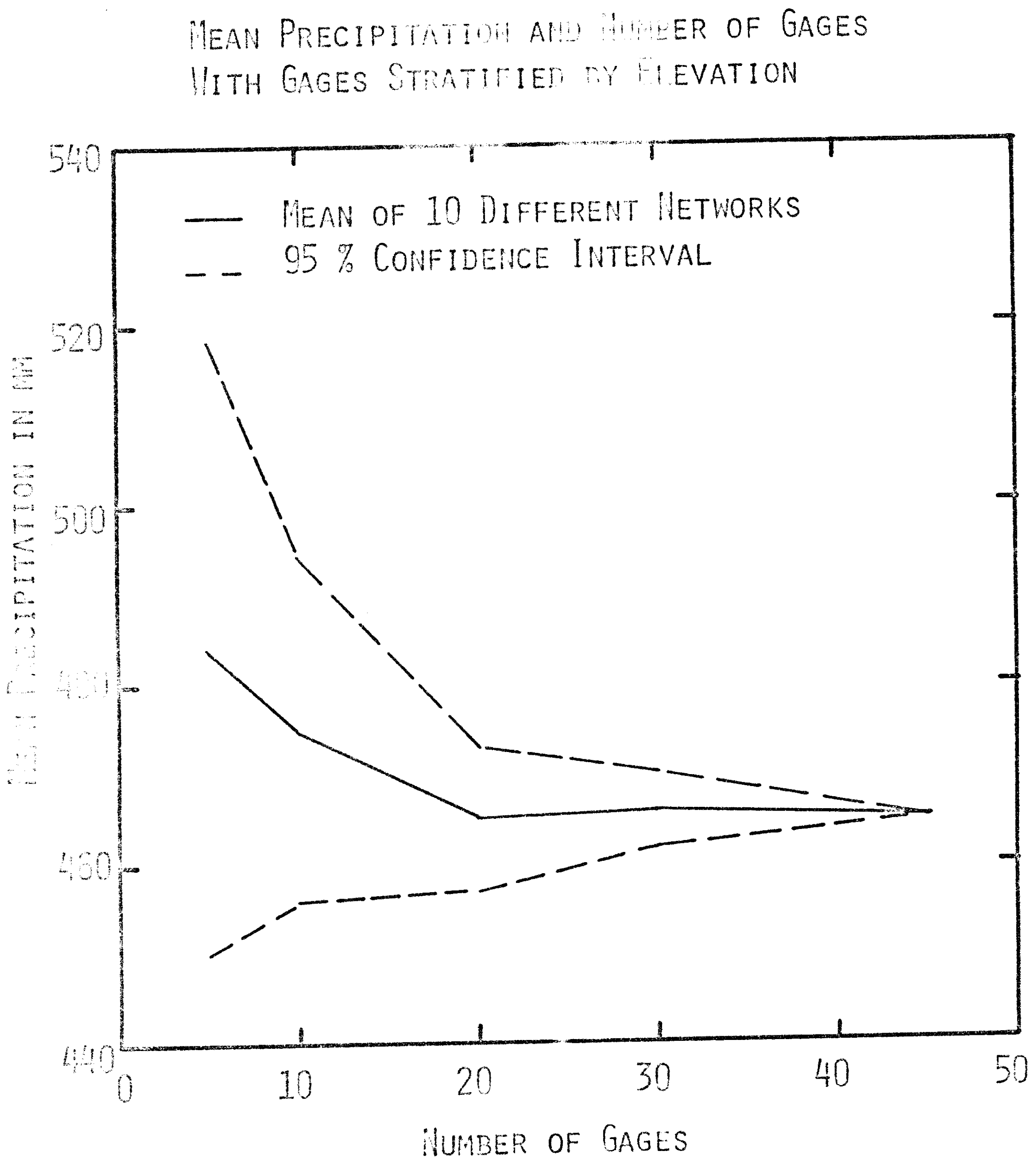

Figure 2. Confidence band for gages stratified by elevation.