Reply

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We appreciate the interest in optimum rain gage densities. However, the title is justified since our objectives were clearly stated. The problem (as presented at the National Fall Meeting of AGU in 1969) was not posed in the decision theory framework attributed to *Davis et al.* [1972]. But, since the discussion seems to preclude any framework other than the decision theory framework, the objectives, criteria, constraints, and algorithm are listed in that way:

1. The objectives are to determine volumes and maximum rates of precipitation from individual thunderstorms, to predict runoff from selected watersheds, and to determine the mean annual and seasonal rainfall.
2. The criteria are to preserve a prespecified level of correlation between adjacent gages for specific rainfall variables and between estimated rainfall from various gaging densities and measured runoff rates and amounts.
3. The constraints are to preserve the natural runoff process and to maintain reasonable costs.
4. The algorithm is to maintain the minimum level of correlation in terms of the objectives and to satisfy the constraints.

With regard to point 4 concerning the algorithm a more careful reading of *Gunnerson* [1966, p. 107] will reveal a description of his algorithm and a definition of the optimum sampling interval.

> The basic approach is straightforward. The entire record of data is examined in detail by one or more statistical methods until the maximum understanding or insight is developed. Next, either the amount of data or the statistical effort is reduced in a series of successive steps. Sooner or later, this reduction results in a loss of detail necessary to understand the behavior of the estuary during the particular study period. This marks the point at which the data collection or sampling interval is at the optimum.

This approach is precisely the one used in the study under discussion.

The word optimum has different meanings to different people. In the classical sense [e.g., *Hillier and Lieberman*, 1967, Appendix 2] we did not solve an equation for an extremum, but we did maximize the distance between sampling points and maintained the minimum acceptable level of correlation. This is a perfectly acceptable method of arriving at an optimum in the less classical sense.

Advocating that total cost minimization be the only objective of a data collection network is being quite restrictive. *Hillier and Lieberman* [1967, p. 13], in discussing the use of long-run profit maximization as the only objective, said the following:

> In particular, the objective of long-run profit maximization is specific enough to be used conveniently, and yet it seems to be broad enough to encompass the basic goal of most organizations. In fact, some people tend to feel that all other legitimate objectives can be translated into this one. However, this is such an oversimplification that considerable caution is required!

We feel that this comment is also appropriate for total cost.

We are familiar with the paper on optimum density of rainfall networks by *Eagleson* [1967]. Without entering into a lengthy discussion of Eagleson's paper, we suggest that the discussers should note the many restrictive assumptions in Eagleson's paper that limit its application for predicting thunderstorm rainfall–runoff relationships for small (100 mi² and less) arid land watersheds in the Southwest.

The discussers point out that, if the form of

the spatial distribution of rainfall $R(s)$ is known, then the required spacing of rain gages can be determined. In reality, the form of $R(s)$ is not known but must be assumed. Much of the current research in thunderstorm rainfall is pointed toward better estimates of the spatial distribution of rainfall. In other words the discussers would put the cart before the horse. The results are only as good as the assumptions or simplifications used. The choice of assumptions or simplifications is, of course, the biggest problem in all methods.

Finally, we must take exception to the word invalid. Although we do not want to discuss research philosophy, we believe that calling this method invalid is dogmatic. We feel that spectral analysis is only one tool of many available in determining the required density of rain gage networks.

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