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Functions to Predict Optimal Irrigation Programs, by J. Ian Stewart, Robert M. Hagan, and William O. Pruitt (June, 1974. Prior Discussion: Mar., 1975).
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Discussion by Leonard J. Lane[4] and Herbert B. Osborn,[5] M. ASCE

Decisions for using weather modification for agriculture in the High Plains are of utmost importance. The authors correctly state that the users' decisions are not the same as those of scientists and engineers involved in a scientific experiment. However, the writers' major differences with the authors are in their assessment of the technology for cumulus cloud modification, which is a vital part of decision making at all levels. Moreover, we feel that their inferences concerning the state-of-the-art in cumulus cloud modification are misleading.

Under what circumstances does a farmer have "adequate justification for supporting the use of weather modification technology?" The authors seem to imply that the users perceived expected return is the basis for using or not using weather modification. The writers' major thesis is that this perception is based upon the technology assessment of the user which is in turn potentially influenced by the assessments of scientists and engineers. Thus, it is our duty to present our best assessments of the efficacy of cumulus cloud modification techniques.

The writers take greatest exception to the authors' technology assessment represented by conclusion No. 3 on p. 349:

> Research results on seeding for rain increase give statistically significant rainfall increases for individual clouds less than 30,000 ft (9,000 m) in depth, suggest rainfall increases for areas of about 1,000 sq mi (2,600 km^2), and are nonexistent for areas in the Plains larger than 10,000 sq miles (26,000 km^2).

In contrast, the National Academy of Science panel on Weather and Climate Modification (19) concluded that

> . . . demonstration of both positive and negative treatment effects from seeding convective clouds emphasizes the complexities of the processes involved. The effects indicate that a more careful search must be made to determine the seedability criteria that applies to convective clouds over various climatic regions.

In regard to cumulus cloud modification, Simpson and Dennis (20) stated that

> Paradoxically, large and expensive area seeding programs for operational purposes continue, while sound scientific foundations for them are not only incomplete, but are advancing at a snail's pace. Why? One reason for the dichotomy is that decision makers, under pressure from the public, act overoptimistically regarding what is known to be achievable with modification . . .

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The writers agree that there is a "rather general acceptance" (p. 341) of man's ability to modify single clouds and that there is no "general consensus" as to the ability to affect "weather events from multiple clouds over larger areas." On p. 343, the authors refer to a summary of research information on cloud seeding in the Northern Plains as of 1971 (8). In Ref. 8, the authors cite a paper by Dennis and Koscielski (14) as a reference for the Rapid Project that resulted in ". . . statistically significant increases in rainfall from smaller clouds and suggested a decrease from the larger storms over target areas of approximately 700 sq. miles (1,810 km^2)." Continuing with larger areas, the authors stated

> For larger areas, observations of individual events are not adequate for determining the effects of seeding, as it is not possible to calculate the interaction between clouds within such a large target area. This requires that inferences be drawn from experiments carried out over broad areas.

Following the authors' suggested procedure, the writers examined six experiments in seeding cumulus clouds over large areas. These experiments were: (1) The two Arizona experiments (13); (2) Project Whitetop (15); (3) The North Dakota experiments (18); and (4) The Colorado experiments (17).

For a summary of the results of statistical analyses of rainfall data from these experiments, see Table II in Ref. 17. Briefly, none of these six experiments showed statistically significant results. All showed decreases in rainfall that were not statistically significant. The most significant result of considering these experiments is that the effects of area-wide modification of cumulus clouds remain uncertain. Evidence is not sufficient to conclude either that seeding decreased or increased rainfall.

An alternate procedure for estimating seeding effects over large areas involves using cloud models, such as the Weinstein-Davis model. As previously noted, experimental data suggest that silver iodide may increase rainfall from smaller cumulus clouds and decrease rainfall from the larger ones. Simulation results using the preceding mathematical model tended to support this observation. Assuming that the model simulation is true, how then is precipitation over an area affected by seeding? By weighting such clouds by their frequency and area and by assuming results as previously hypothesized, Grant (16) has shown that by seeding only under favorable conditions, the change in areal rainfall is on the order of +0.1%. Many assumptions are made in such calculations (16); however, they gain empirical import by substantial agreement with observations such as the six experiments discussed previously. In these experiments, seeding was done at random and not only during the most favorable conditions as assumed by Grant.

In view of these assessments, we conclude that the technology for rainfall enhancement from cumulus clouds over an area is at a stage where hopes for significant increases of rainfall are more wishful than factual, and, therefore, the authors' conclusion No. 3 is misleading.

The writers also feel that some other sections of the paper are unclear or could be misleading. For example, in Table 1, the authors give ratios of cloud depth for seed and no-seed days. However, the title of the table is incorrect as these radar data are not rainfall measurements. Instead, they are qualitative

figures indicative of processes in the clouds but not necessarily indicative of rainfall as measured on the ground. No estimates of the actual rainfall at ground level as a function of such radar data are given.

Seed and no-seed data for rainfall averaged over all raingages are shown in Table 2. The average R values in Cols. 3 and 7 indicate increased rainfall. Is this increase statistically significant? The ratio of average rainfall per day for seed and no-seed days for the North Dakota Pilot Project (Table 2, Cols. 3 and 7) is

$$S/NS = \frac{0.157}{0.074} = 2.12 \quad \ldots \quad (1)$$

Yet, at the bottom of p. 344, the authors state ". . . (2) the seed/no-seed ratio is 1.23." Why are these values different? Are all data used for each calculation?

Concerning the South Dakota Weather Modification Commission Project, what does the statement on p. 348 mean?

> Fig. 8 shows a comparison of seeded and nonseeded storms in the target area. A covariance analysis shows a statistically significant difference (probability greater than 99%) between these categories. This difference is attributed to skill in the selection of echoes to be treated rather than to a physical result of the seeding treatments in this analysis.

If the differences are not due to seeding, then why include the figure?

The writers feel that the paper is valuable in presenting the scope of weather modification projects and in pointing out the differences in perspective from user and research viewpoints. However, the writers' assessment of the current technology in cumulus cloud modification differ from those of the authors, especially concerning conclusion No. 3.

Appendix.—References

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Estimation of Rainfall Erosion Index[a]

Discussion by Kenneth G. Renard,[2] M. ASCE

Difficulties associated with estimating the rainfall erosion index (R) of the Universal Soil Loss Equation (USLE) in mountain and range country where orographic precipitation effects are prevalent will make erosion estimates truly educated guesses until precipitation patterns are better quantified. The author is to be commended for his contribution to this complex problem.

To assume that rainfall in all parts of the country, except the Pacific slopes of California, Oregon, and Washington, can be expressed by one dimensionless rainfall graph as was done in Fig. 2 is not realistic. Nevertheless, such an approach *might* be applicable for broad planning purposes, but it should not be expected to suffice for detailed investigation.

The rain storms of the Palouse area in Washington, Oregon, Idaho, and the air mass thunderstorm-dominated precipitation area of the Southwest are two interesting examples of why such a rainfall distribution will not suffice for computing the rainfall erosion index.

Some of the most severe erosion per unit area in the United States occurs in the Palouse area. Yet in this area, the 2-yr, 6-hr rainfall values from Fig. 5 vary between about 0.75 in. and 1.0 in. which indicates very low values of R. Work by McCool in this area indicates an adjusted R value must be developed to account for snow, rain on snow, or rain on frozen ground plus the overland flow from contributing areas upslope.

In most of the rangeland areas of the Southwest, air mass thunderstorms dominate the runoff response of a watershed to precipitation. Such storms are characteristically of limited aerial extent, high intensity, and very short duration (11). Examples of the depth-duration curves for selected air mass thunderstorms are superimposed on the two curves of Fig. 8. These data are from storms (the central gage from storms creating high runoff) at the 90-gage Walnut Gulch Experimental Watershed near Tombstone in Southeastern Arizona, and at the 66-network on the Alamogordo Creek Experimental Watershed near Santa Rosa in Eastern New Mexico.

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[a]September, 1974, by John K. H. Ateshian (Proc. Paper 10817).

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