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VOL.98 NO.IR2, JUNE 1972

JOURNAL OF THE IRRIGATION AND DRAINAGE DIVISION

PROCEEDINGS OF
THE AMERICAN SOCIETY
OF CIVIL ENGINEERS

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of Civil Engineers
1972

analysis. In a calculation for a pumped pipe-line system (1) the optimum diameter turned out to be 41 in. Changing the diameter within the range 36 in. to 46 in. raised the cost by less than 5 % indicating that the cost of the design is not particularly sensitive to the value chosen for the overall size parameter. It would be interesting to have Professor Christensen's opinion in view of his experience in designing a wider range of systems.

In many cases of water transport schemes the mean annual flow increases with time to meet a growth in demand. It is therefore worthwhile considering the possibility of developing the scheme in stages to save the cost of unused capacity in the early years of operation of the scheme. The writer has considered this problem in relation to the design of pumped pipe lines (1) using similar methods to those of Professor Christensen and has come to the conclusion that staging is not worthwhile unless the growth of demand is greater than 4 %. For growth rates greater than 4 %, however, staging is worthwhile, although care must be taken in the choice of staging times as nonoptimum stages can lead to increases of up to 13 % in the cost of the design.

Appendix.—Reference.

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STATUS OF WEATHER MODIFICATION IN WATERSHED MANAGEMENT[a]

Discussion by Herbert B. Osborn and Kenneth G. Renard

HERBERT B. OSBORN[2] AND KENNETH G. RENARD,[3] MEMBERS, ASCE.—The author presents an interesting review of California cloud seeding experiments and programs and makes reasonable estimates of the value of added precipitation if the reported results of these programs are accepted at face value. However, as he points out, most results in California experiments are based on "radar observation, photographic observation, and visual effects," and quantitative determinations are generally not possible from these techniques. This statement leads the reader to wonder about the validity of these experiments, yet the author goes on to state favorable percentages for all projects he reports.

[a] December, 1971, by Merlin C. Williams (Proc. Paper 8608).

[2] Research Hydraulic Engr., Southwest Watershed Research Ctr., Agricultural Research Service, USDA, SWC, Tucson, Ariz.

[3] Research Hydraulic Engr., Southwest Watershed Research Ctr., Agricultural Research Service, USDA, SWC, Tucson, Ariz.

Furthermore, the author fails to mention numerous weather modification programs in other states and countries, and particularly important comprehensive 5-yr and 7-yr experiments in Missouri and Arizona that should be of interest in California even though carried out elsewhere. The two experiments involved seeding cumulus clouds with silver iodide the White Top experiment conducted in Missouri by the Univ. of Chicago and the Santa Catalina Experiment conducted in southern Arizona by the Univ. of Arizona (17,18). The results of the Missouri and Arizona experiments were based on intense rain gage networks, rather than radar, and the results strongly suggest that the overall effect of seeding cumulus clouds with silver iodide is to decrease precipitation in the target area and downwind of the target area possibly as far as 65 miles (17,19,22,23,24). In the Arizona experiment, rainfall in the target area on seeded experimental days was 30 % less than on nonseeded days, although the differences were not statistically significant. On seeded days, when the winds were generally from the northwest, precipitation as measured by a dense network of rain gages 65 miles southeast of the target area was 70 % less than on nonseeded days. This was highly significant statistically. In the White Top project, precipitation on seeded air-mass thunderstorm days was significantly less than on nonseeded air-mass thunderstorm days in and immediately downwind from the target area both during seeding and for some hours after the seeding had ended. It is possible that cumulus clouds over Missouri and Arizona differ in some way from those over the Sierras, but it is important that results from the only two relatively long-duration, comprehensive and reasonably well-instrumented thunderstorm cloud seeding programs in this county which were based on quantitative measurements of precipitation at ground level strongly indicated overall negative effects of cloud seeding.

Part of the problem lies in the use of radar. Most meteorologists agree that introducing silver iodide to a cumulus cloud can cause marked changes in the cloud. However, what happens to ground level precipitation both immediately below the cloud and in the surrounding area as a result of the seeding is not known. Furthermore, at the recent 14th Annual Radar Meteorology Conference (Tucson, Arizona, 1970), there were few meteorologists that would claim better than a plus or minus 25 % accuracy in predicting rainfall from radar, and most suggested accuracies in precipitation based on radar must be suspect (20).

Contrary to what the author suggests in his paper, it is the writers' opinion that at least for modification of cumulus clouds by cloud seeding, weather modification is still in the experimental stage. Rather than a multitude of little experiments with results based on highly subjective evidence such as radar and visual observation, there is definite need for more carefully planned, fully instrumented thunderstorm modification programs that include adequate measurement of precipitation at ground level over a large enough area to determine what happens both in time and space when cumulus clouds are seeded.

Further, experimentation also is needed in seeding of frontal storms. The author has reported results claimed by professional cloud seeding organizations, without outside verification of results from cloud seeding by people not advocating the seeding. These claims may be valid, but cloud seeding is still uncertain enough to demand objective experimentation and verification by outside scientists and engineers. Also, quoting percentage increases for individual events can be misleading, particularly when small amounts are usually

involved. Annual or seasonal predictions are more meaningful, and most predictions are for increases on the order of 15 % or less. Since such predictions are too small to verify mathematically from available data, there must still be questions as to their validity. Such questions can only be answered by more comprehensive experiments than have as yet been carried out. The current experiment to increase snowfall by the Bureau of Reclamation in southwest Colorado may approach the necessary design for valid results.

The biggest question in seeding frontal storms is still whether an increase in one area will result in a decrease in some other area. (This might be the biggest question in seeding cumulus clouds as well, with the added possibility in cumulus cloud seeding of larger overall decreases than increases.) The experiment in southwestern Colorado by the Bureau of Reclamation suggests effects as much as 150 miles downwind from the target area, yet no experiment, including the Colorado experiment, has yet been formulated to look at possible changes in precipitation over so great a distance or so large an area.

Still other questions arise from weather modification proposals which require consideration by the scientific community. These questions must be explored, experimented, and reported before widespread operational programs are undertaken. (1) What are the legal responsibilities of possible off-target detrimental effects? (2) What are possible ecological effects such as widespread vegetative changes? and (3) What are possible erosional consequences of weather modification including (a) sheet erosion, (b) rill erosion, and (c) stream channel erosion.

Answers to these questions are complex and uncertain with our present knowledge in the broad water resources spectrum. The answers are undoubtedly not independent of the type of storm system being seeded; i.e., the differences to be achieved through winter storm modification and summer cumulus modification are quite different.

The legal implications of weather modification are complicated and thankfully are not being overlooked by the Bureau of Reclamation with their support of legal research grants. The ecological effects of supplemental moisture in upstream watersheds are complicated by lack of planned experiments to evaluate even such fundamental concepts as vegetation changes. Renard (25) reported dramatic increases in vegetative basal area and total forage production from only 4 inches of additional moisture in a southeastern Arizona rangeland area. This work also showed that this additional vegetal cover decreased runoff (26). Thus, long-term additions of precipitation may not produce sustained increases in downstream water. It seems conceivable as well that additional snow packs in high mountains might have deleterious effects on timber production, as well as limiting wildlife habitat.

Jones (21) recently completed a report which questioned possible effects of weather modification on the precipitation drop size spectrum. His report indicated that more questions arise than there are answers available and concluded with the statement "additional studies of the effects of weather modification on rainfall intensity and drop size distribution are needed." One can readily realize that the effect of rainfall on erosion can be direct through raindrop impact and subsequent transport or indirect through its influence on runoff characteristics.

In summary, the basis for using weather modification is well founded by the author and obviously beyond reproach. As pointed out, problems associated with the variability of water both temporally and spatially lend credence

to investigations of weather modification. Additionally, the values used to compute benefits from weather modification can hardly be argued. We feel, however, that the author has presented a far too optimistic view of weather modification. He has ignored most experiments and projects carried on outside of California (there are numerous such experiments not mentioned herein). His view may be harmful to the numerous scientists and engineers who are attempting to obtain funds and set up experiments on cloud seeding to satisfy the pressing questions still to be satisfied. Rather than consider management at this time, interested persons should try to answer the many demanding questions on weather modification that still remain.

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