NOTES AND CORRESPONDENCE

Estimate of the Hydrologic Results of Rainfall Augmentation

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21 October 1962

Much has been written on the meteorological evaluation of cloud seeding but little, if any, work has been done to determine the hydrologic effects of a possible rainfall increase, i.e., to determine what fraction of any increase would actually be useful. Such a determination is essential in evaluating the economic return from a seeding operation. Research in hydrology at Stanford has led to the development of a digital computer model of the hydrologic cycle which will reproduce the details of streamflow hydrographs given hourly rainfall intensities as an input.¹ The model is adapted to a particular watershed by determining certain watershed parameters from historic data.

As an illustration of the possible hydrologic effect of rainfall augmentation comparative computations with actual rainfall and rainfall increased by 15 per cent have been made with the model for the water-years 1950 and 1951 for Cottonwood Creek near Friant, California. The 15 per cent increase is in the order of magnitude suggested by the President's Advisory Committee on Weather Control.² Cottonwood Creek was selected as a fairly typical arid-region watershed in the foothills of the southern Sierra Nevada. It is a watershed on which the computer model was tested and has not been subject to seeding operations.

Table 1 summarizes the results of the trial and Fig. 1 shows the flow duration curve for the two years. Cottonwood Creek drains 38 sq mi. It has a mean annual rainfall of about 18 inches and a mean annual potential evapotranspiration of about 60 inches. The 15 per cent increase was distributed uniformly over all hours of rainfall.

A comparison for two years on one stream is a very limited study and no general conclusions are possible. The sample shows that 29 and 56 per cent of the hypo-

thetical additional rainfall would have become runoff. If adequate facilities for storage and diversion had been available this added water could have been put to beneficial use. In addition the soil moisture is increased by a maximum of 1.07 inches and 0.98 inches, respectively, (end of March). If the entire watershed were in agriculture or pasture this water would also have been beneficial. Thus the *maximum* gain of beneficial water

FIG. 1. Flow duration curve for Cottonwood Creek near Friant, Calif., showing frequency of actual and synthetic daily flows for water years 1950 and 1951.

¹ Crawford, N. H., and R. K. Linsley, 1962: *The Synthesis of Continuous Streamflow Hydrographs on a Digital Computer*. Tech. Rep. No. 12, Dept. of Civil Engr. Stanford University, 123 pp.

² Advisory Committee on Weather Control, 1957: *Final Report of the Advisory Committee on Weather Control*. Washington, D. C., Vol. 1, 32 pp.

TABLE 1. The effects of rainfall adjustment on estimated Cottonwood Creek streamflow for water years 1950 and 1951. (All values in inches.)

	Recorded	1950 Computer estimates		Recorded	1951 Computer estimates	
		Actual rainfall	Rainfall increased by 15%		Actual rainfall	Rainfall increased by 15%
Rainfall	13.8	13.8	15.8	18.4	18.4	21.1
Runoff	0.36	0.27	0.86	2.22	2.24	3.76
Soil moisture (end of month)						
Oct.		0.09	0.09		1.06	1.27
Nov.		0.57	0.66		5.97	6.85
Dec.		1.66	1.99		8.17	9.11
Jan.		5.09	5.98		9.20	10.10
Feb.		5.91	6.92		9.30	10.20
Mar.		5.59	6.66		7.47	8.45
Apr.		4.12	5.04		5.26	6.16
<i>Effects of "Augmentation"</i>						
Additional rainfall			2.0			2.7
Additional runoff			0.59			1.52
Additional soil moisture (end of March)			1.07			0.98
Additional rainfall which becomes runoff (per cent)			29%			56%

would have been 83 per cent and 92 per cent respectively. The actual gain would have been less than the maximum because of area in roads, buildings, streams and non-beneficial vegetation and because efficiency of use of runoff is rarely 100 per cent.

In 1950-51 there were no water storage facilities in the Cottonwood Creek watershed and, hence, any additional runoff would have been lost. It is estimated that approximately three-fourths of the area was in pasture or cropland. Hence, the actual beneficial gain which would have resulted from the assumed rainfall increases would have amounted to about 0.80 and 0.73 inches or 40 and 27 per cent of the rainfall respectively.

Inspection of detailed hydrographs indicated that 1950 flood peaks would have been increased by the same ratio as the total yield—a factor of three. In 1957

the average peak flow would have been doubled although the yield would have increased by a factor of only 1.7. Thus, under the assumption of uniform increase in all hourly increments of rainfall, substantial increases in flood flow are indicated. In many situations the increased flood flows would be difficult to store and use.

Naturally, the results would have been different for other watersheds under different hydrologic conditions or with differing assumptions concerning the possible effects of seeding on the rainfall. However, the possibility of hydrologic evaluation of cloud seeding is demonstrated. Similar computations could easily be made for any of the basins which the model parameters have been defined, using any systematic assumption regarding the rainfall increase which seem appropriate.