WATERSHED HYDROMETEOROLOGICAL DATA REQUIRED FOR WEATHER MODIFICATION

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By

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Introduction

The question of what hydrometeorological data are required for adequate planning of large scale research, pilot and operational weather modification projects in five western mountain watersheds (Missouri, Snake, Bear, North Platte and Rio Grande) has been examined by the authors in connection with a study made for the Atmospheric Water Resources Management Division of the Bureau of Reclamation (North American Weather Consultants, 1971). The approach used was first to specify the types of data required for use in future planning and project design, and then to appraise the adequacy of the existing hydrometeorological network. It then became possible to identify the data gaps, and to prepare a preliminary design for an observational system that would correct the situation.

The data requirements established in the initial phase of the study indicated that high elevation data were needed. This focussed attention on snow course and other related measurements of the snow quantity and condition. It was also found that certain high elevation meteorological and cloud physics data collections would be needed. The situation with respect to high elevation streamgages was also given careful consideration. Because of the potential interest of the findings to the members of the Western Snow Conference, this paper will summarize them.

In seeding clouds over the mountainous watershed areas of the west for the purpose of increasing snowpack and runoff, the seeding would be accomplished by means of generators which produce silver iodide smoke particles, a nucleating agent which stimulates the transformation of supercooled cloud droplets to ice crystals and snowflakes. These generators would be ground based and arrayed in a network on upwind slopes. Because of the remoteness of favorable generator sites, most would have to be radio controlled. Their effect on stimulating precipitation would extend from the upwind slopes on over the crest and many miles into the downslope area. In some cases, seeding would be carried out by means of generators mounted on aircraft and flown just upwind of the target area. However, the usual operational plan includes a network of ground generators.

In the region encompassed by this study, the highest average annual precipitation estimated in the most productive part of a seeding unit was over 100 inches in western Montana. In the most southerly seeding unit in the Rio Grande watershed, maximum average annual precipitation from the most productive portion of the watershed was only about 30 inches. However, in western Montana, precipitation occurring during the October - April seeding period represented 75% of the average annual precipitation, while in the southern seeding units, seeding period precipitation may represent only 50 to 55% of the average annual precipitation. As a consequence, there is approximately a six to one ratio of the precipitation subject to weather modification activities between the northernmost and southernmost seeding units. In the less productive areas of the watersheds, differences may be even greater. Differences in the quantities of precipitation undoubtedly represent substantial differences in the number and magnitude of occurrences subject to treatment by seeding as well as possible differences in the types of storm activity and the methods of weather modification which must be employed to produce results. If storm types were suitable for seeding, extending the seeding period through May and June would substantially increase the number of storms which could be treated in the northern portion of the area studied.

It is important to be able to predict what area will be affected by the seeding, and at least roughly what the magnitude of the effect might be. This prediction is needed

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to decide what generators to run in a given situation. The area affected depends to a considerable extent upon the wind flow, the air-mass stability, and the cloud extent and temperature. The natural precipitation characteristics at the time are also important. The methods for doing this are at present being systematized into the form of computerized numerical models which use upwind meteorological balloon rawinsonde data, the terrain characteristics, and the arrangement, strength, and characteristics of the artificial nuclei sources as inputs.

Figure 1 indicates schematically the layout of the instrumentation required for an ideal mountain cloud seeding project. A base station (BS) commands a silver iodide smoke generator (G) to generate and emit nucleant which is swept by the wind up the slope and mixed eventually through a deep layer. For guiding the decision-making process, telemetered data are received at the base station from a high elevation station consisting of a shielded continuous recording gage (RG), a snow pillow (SP), and an anemometer (A). Guidance information also comes from a rawinsonde balloon sounding unit (RS). A weather radar may also be included in the instrumentation.

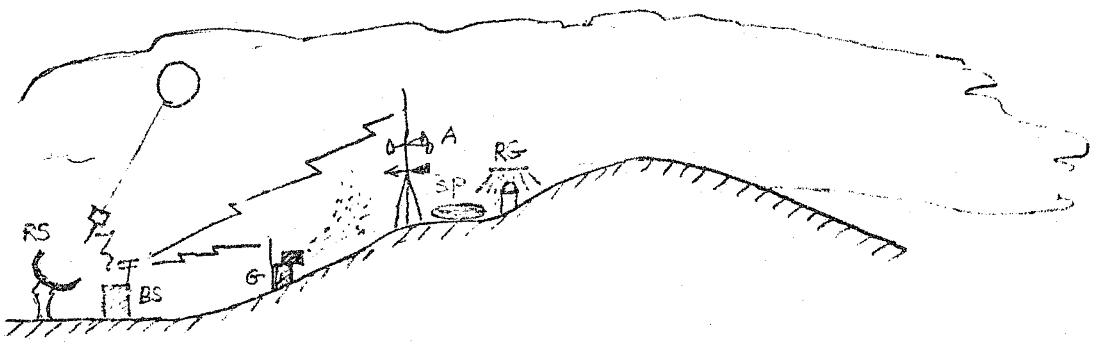

Fig. 1. Instrumentation during operational phase.

Planning and Project Design

In planning a weather modification research project or designing a pilot or operational project, a great deal of reliance will be placed upon the use of predictive models. In effect, a series of seeding experiments will be performed on paper by feeding historical hydrometeorological and rawinsonde data into a battery of seeding models. Various hypothetical arrangements of nuclei generators will be tested before an optimum network can be established. It is clear that for this procedure to be effective, a considerable collection of historical hydrometeorological and storm rawinsonde data is required from the area being examined. In addition, historical streamflow data are required to translate any seeding-produced additions in snowpack into runoff.

The existing National Weather Service rawinsonde network is considered inadequate with respect to providing historical rawinsonde data for the purposes outlined above. The stations are quite a distance from the potential seeding target areas and at most only two soundings are taken daily. What is required is sequential soundings during storms.

In examining available high elevation hydrometeorological data it was found that although there was an abundance of snow course data, there was an almost complete lack of detailed precipitation data such as that provided by continuous recording gages.

Another means for measuring precipitation is the weather radar. In planning for a seeding project it is desirable to have some historical radar films showing the precipitation patterns aloft in three dimensions in the vicinity of the planned target area. There is very limited amounts of suitable radar film of this type.

Other precipitation measurements of usefulness for background in designing projects is the incidence of various types of snow crystals. It is important to know the proportion of the snow which is rimed in contrast to the more crystaline forms. Collections of snow replicas serve well for this purpose. There are only a few such collections available from a few special locations.

A Plan for Supplementary Data

The supplementary data requirements can be met by means of two types of station installations. They are:

1. Climat station units on selected snow courses.
2. Mountain observatory units.

The climat station units would be located on a number of snow courses distributed throughout each of the five basins. There would only be one mountain observatory unit for each basin.

The instrumentation which has been proposed for each of these units will now be listed.

A. Climat Station Units on Selected Snow Courses (CSU)

1. Precipitation:

Anti-freeze charged weighing type gage equipped with a 40-day or longer recorder. The resolution must be .01 inch. A 12-inch orifice is preferable to an 8-inch, other things being equal.

or

A telemetered accumulations (storage) gage with a measurable resolution of .02 inch.

and

A snow pillow equipped with a 40-day recorder. This can be either an open or closed system. Such a unit may already be present on a SCS monitored snow course. It is also assumed that standard snow course measurements are being made.

2. A hygrothermograph equipped with a 40-day or more recorder.

3. A cup type anemometer, equipped with a 40-day or more recorder.

4. A wind vane, feeding into a 40-day or more recorder.

5. Some type of a sunshine recorder, or a short wave radiation instrument whose output is recorded (40-day or more).

6. Some type of a long wave radiometer, whose ouptut is recorded (40-day or more).

B. Instrumentation and Manning for a Mountain Observatory Unit (MOU)

1. An expansion type ice forming nuclei counter.

2. An automatic sonic type ice forming nuclei counter.

3. A millipore filter nuclei collector.

4. Condensation nucleus counter.

5. Film strip snow crystal replicator.

6. Slide replicator devices.

7. Lapse time camera equipment.

8. A small weather radar, equipped for RHI and PPI mode, with associated camera gear.

9. Riming meter (for cloud water flux).

10. A rawinsonde installed at an upwind valley site.

11. A calibrated weather radar at an upwind valley site.

12. CSU at the MOU site and along the profile leading up to the MOU from the valley station, and down on the other side.

The observatory should be manned during precipitation situations with sufficient people, adequately trained to conduct an observing routine that will ensure continuous recorded observations where possible, and otherwise observations at hourly steps, at least.

Figure 2 summarizes the instrumentation layout for both the climat units and the mountain observatories. The latter are quite costly and a few will have to serve for a large area. The symbols are the same as in Figure 1; WR is weather radar. Note that telemetry is not required. The major requirement is for good recording of the data at the site.

The snow course choices made for the study were based upon these criteria:

Accessible enough so that they are always visited by the Soil Conservation Service in most winter months.

Represent the high yield and high level elevations in the seedable areas. A few are selected to represent a sheltered low yield low elevation portion of a seeding unit.

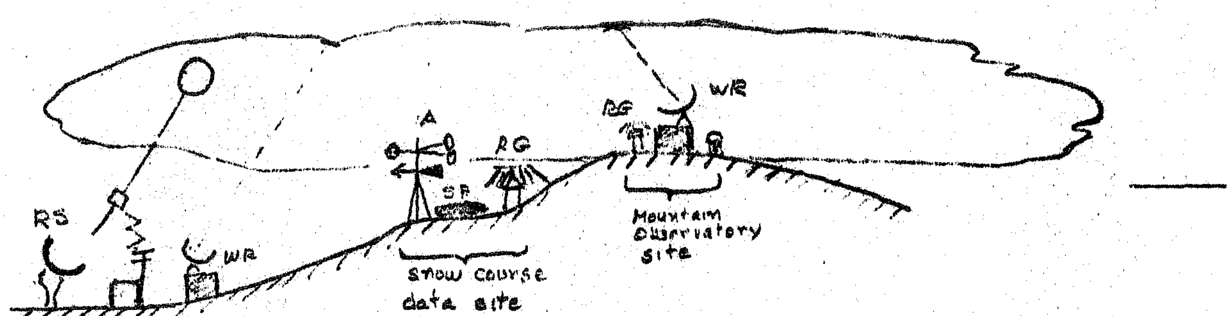

Fig. 2. Instrumentation during data collection phase.

Already have an SCS snow pillow installed.

A long record is not considered essential, although it is acceptable. The goal is to obtain continuous precipitation records and snow courses are only read monthly.

Hydrologic Implication

Area of Snowpack Accumulation

Plots were made of the average April 1st snowpack water content for all available long term snow course records. They were grouped by profiles, and when the profile extended across a range separate plots were made for the windward and leeward side. It was found that each profile had a characteristic quasi-linear increase in snowpack with elevation. The magnitude of the increase in snowpack with elevation depended upon steepness of slope, ridge orientation, and other factors. Typical values were six inches to eight inches of increase in April 1st snowpack water content for every 1000 foot increment in elevation. Increases of about twice this much occurred in several profiles where the slope was steep.

For the data analyzed, there appears to be little or no tendency for snowpack to level off or decrease at the higher elevations as has been reported in other areas.

Another characteristic of the snowfall-elevation plots is that the straight line relationship can be extrapolated down to an apparent zero April 1st snow accumulation at some base elevation. In the Missouri, Snake and the Bear-Wasatch basins, this base elevation was usually about that of the adjacent valley area, and it is believed that this apparent zero value reflects the true average April 1st valley condition with some fidelity. The apparent base elevations are characteristically 5,000 to 6,000 feet throughout the Missouri, Snake and Bear-Wasatch basins. In the North Platte basin, it is 7,500 to 8,500 feet and in the Rio Grande 8,000 to 9,000 feet.

The pattern of base elevation is clear-cut enough to suggest that the snowmelt yield lies entirely above this base, and seeding should be concentrated on the area above it to produce runoff controlled by the snowmelt portion of the hydrologic cycle. Hydrologic data supports this view. The design for the upper Colorado Atmospheric Water Resources program is focussed upon seeding in areas above 8,000 to 9,000 feet elevation, which fits this pattern in snow accumulation. It would appear that in the more westerly and northerly basins (Missouri, Snake and Bear-Wasatch), attention should be focussed upon the area lying above 5,000 to 6,000 feet elevation.

Although the preceding paragraphs suggest that the emphasis in weather modification and hydrometeorological data collection system should be at elevations above 8,000 to 9,000 feet in the southern basins and above 5,000 to 6,000 feet in the northern ones, a more extended area must be examined to cover any potential for downwind or extra-area effects. Future work will undoubtedly provide a means for assessing such effects on the basis of hydrometeorological data and air mass data inputs.

Hydrologic Hazard

The area and elevation range in which incremental snowpack accumulates may be used is one means of limiting potential risk resulting from high rates of runoff during the snowmelt period. In general, snowmelt peaks from the higher elevation areas rarely cause major flood damage in the area investigated. Hazard evaluation procedures could be developed to dictate project suspension before high elevation snowpack magnitude becomes critical. More often, flooding results from a combination of snowmelt runoff and intense spring or early summer precipitation.

During June 1964, major storms in Montana produced up to sixteen inches of precipitation in various mountainous areas of the state. Most of this precipitation above 9,000 feet fell as snow. Although the storm occurred during the snowmelt period, the major portion of the snow below 9,000 feet had probably already melted. This type of situation appears to generate the most critical conditions leading to flooding during the snowmelt period.

In other portions of the five-basin area, summer cloud-bursts pose a potential flood threat. An example of this problem occurred on July 11, 1965 at Ouray, Colorado. Snowmelt probably had little to do with production of flood peaks, although the watershed soils were still near saturation (Grant, 1969). The extreme peak flow was probably the result of intense summer season rainfall and there is no information to suggest that snowmelt contributed substantially to the flood.

In most areas, water users and project operators have developed criteria for project operation based upon water supply forecasts. They know from experience that if anticipated flows exceed certain established values, critical conditions may occur. As a result, hazard evaluation in terms of anticipated snowmelt runoff may provide a valuable operational tool in proposed weather modification projects in most areas of the western mountains.

Incremental Flows

Estimates were made of the effect of a ten percent increase in October-April seeding period precipitation on average annual runoff. The total anticipated increase in runoff from all seeding units within the five major watersheds would be approximately

2,175,000 acre-feet, while an additional 1,000,000 acre-feet would be realized outside of the five major watersheds from seeding units straddling major watershed boundaries. It is estimated that extending the seeding period through May and June with the same ten percent increase in precipitation could increase the runoff from the five study basins by a total of 440,000 acre-feet. Precipitation during this late season could possibly result in some undesirable flooding in some areas. Extreme caution would have to be exercised in designing a weather modification project to operate during the late season.

References

Grant, L. O., et. al., 1969: An operational adaptation program for the Colorado River Basin. Interim Report to Bureau of Reclamation, Contract No. 14-06-D-6467.

North American Weather Consultants, 1971: A hydrometeorological data appraisal and design study in certain river basins in the Western United States. Report No. 15-15, July 1971.