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PROGRESS REPORT

ON

CLOUD SEEDING IN CENTRAL COLORADO

Presented At The

SIXTEENTH ANNUAL MEETING

COLORADO RIVER WATER FORECAST COMMITTEE

Senate Chambers
State Capitol Building
Salt Lake City, Utah

10 April 1961

by

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CER61LOG25

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INTRODUCTION

It has been estimated by Wollman (9), 1960, in a report published by the Senate Select Committee on National Water Resources that sustained yield for the Colorado River by 1980 will be only 58% of project demands. It is clear that increasing water shortages can be expected. Improved water utilization, including conversion of salt water, can be expected to help alleviate growing shortages to only a limited extent. Actual increases in water supplies are needed and these can be obtained from only one source--the atmosphere. There appears to be reasonable possibility that increased water resources might be obtained from this source.

The greatest potential for obtaining additional precipitation by artificial means is in the mountainous areas where atmospheric water vapor is lifted to condensation for extended periods of time. This is fortunate since it is in these areas that the greatest percentage of precipitation goes into useable water supplies. In addition, in the cases of the Continental Divide, the lift provided by the mountains is the final opportunity for utilization of atmospheric water that has been transported inland from the Pacific Ocean. On descent east of the mountains, the potential for precipitation of any remaining atmospheric water during continued movement eastward across the U. S. is limited . While complete utilization of available water may not have been made for a lift of 12,000, 8,000, or even 5,000 ft in crossing the western U. S.,

significant orographic lift does not occur again short of the Appalachians. The moisture source for the eastern U. S. is almost entirely the Gulf of Mexico and the Atlantic Ocean. It behooves western water users to make maximum utilization of moisture passing over the Colorado River Basin.

REVIEW OF PREVIOUS INVESTIGATIONS WHICH CONSIDER ARTIFICIAL NUCLEATION OF OROGRAPHIC CLOUDS

Bergeron (2), 1949, reviewed the various types of clouds which exist in the atmosphere and considered each type with respect to its potential for producing increased precipitation from artificial seeding. He concluded that orographic clouds provide the best potential.

Ludlam (5), 1955, considered the composition and characteristics of orographic clouds and considered, with certain simplifying assumptions, the actual effects on these clouds of seeding using silver iodide released from a ground source. He concluded that substantial increases should be possible under certain moisture and temperature conditions.

Numerous commercial weather modification operations have been carried out in the Colorado River Basin. Evaluation of these have been handicapped by the lack of precipitation observations from the higher elevations. The Advisory Committee on Weather Control (8), 1958, did not attempt the evaluation of any of these particular projects for this reason.

The Advisory Committee concluded from a study of other commercial seeding operations that precipitation had apparently been increased in orographic areas as a result of the seeding.

The Advisory Committee evaluations were based on target-control relationships established from historical data. This was the only evaluation approach possible for seeding projects that had not been designed as research investigations.

The Santa Barbara Project (6), 1960, was carried out to seed orographic clouds along the Pacific Coast on a random basis. Problems with storm frequency, seeding in adjacent areas, inaccessibility of the area affected, and the complexity of both "warm" and "cold" rain processes were encountered so that findings have not been conclusive.

Battan (1), 1960, is investigating the effect of artificial nucleation of summertime orographic clouds with high freezing levels at the Institute of Atmospheric Physics of the University of Arizona.

THE COLORADO STATE UNIVERSITY ARTIFICIAL SNOW RESEARCH PROGRAM

The objective of the program at Colorado State University is to study the orographic cloud processes as described by Bergeron and Ludlam, in the higher ranges of the Colorado Rockies and to attempt to determine the potential and means for obtaining additional water supplies for these areas from weather modification.

A feasibility study was initiated in the vicinity of Climax, Colorado from 19 February to 12 May 1960. During this period procedures and equipment were tested and developed. This pilot study has been continued and expanded somewhat during the current winter season.

A. Area

The Climax area where the study is being carried out is located in Central Colorado in a section of the Rockies where the Continental Divide is oriented east-west for a short distance.

Three passes, Tennessee (10,424' msl), Fremont (11,318' msl) and Hoosier (11,542' msl) traverse this section of the Continental Divide separated by distances of around eight miles. These passes are all kept open throughout the winter so that the area is readily accessible for observations at various elevations despite snow accumulations of 6-8 feet by late winter. Roads over these passes are oriented generally north-south. An additional pass in the study area, Vail (10,603' msl), is oriented generally east-west. Elevations in the study area vary from around 8,000 feet to near 12,000 feet msl with peaks going to over 14,000 feet. The area is covered by coniferous forests. There are numerous clearings in the forested area.

Lodging and laboratory facilities are available at the top of Fremont Pass at the Climax Molybdenum Company and at the High Altitude Observatory of the University of Colorado.

B. Climatology

Climatological data for Climax is given in Table 1.

Table 1. Climatological data for Climax, Colorado, for the period November through April, based on records from November 1953 to April 1960

Average number of days with precipitation	85
Median number of days with precipitation	88
Maximum observed daily precipitation	0.81 inch
Range of precipitation amounts for 80 percent of all cases	0.04 to 0.51 inch

Free air velocity:

10,000 ft msl:	85 percent of time less than	25 mph
20,000 ft msl:	75 percent of time less than	40 mph

The large number of days with the range of precipitation within one order of magnitude is very desirable for statistical analyses.

For practical purposes all clouds occur at temperatures below freezing and are consequently in the temperature range where the "ice process" can be expected to be the primary process for the formation of precipitation.

C. Procedure

The procedure being followed in carrying out the study involves snowfall and atmospheric observations and ground-based seeding operations.

1. Snowfall Observations

Daily snowfall observations were made at 33 sites spaced at about one mile intervals along Highway 91 from Leadville over Fremont Pass to Frisco during the spring of 1960. Daily observations are being made

at 65 sites over Fremont, Hoosier and Vail passes during the current winter season. Observation of snowfall and water content are made at each site daily and a sample of new snow is collected for laboratory analysis to determine the freezing point depression of the snow water.

2. Ice Nuclei Observations

Since weather modification operations are based on the assumption that there is a deficiency of natural ice nuclei in the atmosphere, observations of atmospheric ice nuclei from the upper part of the mountain range is an essential part of the project. Ice nuclei observations (3, 4)* have been made daily at the High Altitude Observatory at Climax since the fall of 1954 and are being continued. Several observations are made daily.

3. Local Weather Observations

Local weather observations are obtained a number of times each day at the High Altitude Observatory and at each of several silver iodide generator sites. These observations include information of wind, temperature, and clouds.

4. Special Observations

Special observations are taken periodically when Colorado State University personnel are in the area. These include observations, both visual and photographic, of the cloud forms, structure and

*Numbers refer to appended references.

movement, snow crystal structure, and snowfall characteristics. In future phases of the program these observations will be made on a routine basis. It is planned that observations will include stereo-cloud photographs obtained with K-24 stereo-camera pairs, that have been developed at Colorado State University, crystal structure, mass and fall velocities obtained from different mountain elevations.

5. Free-Air Observations

Limited observations have been made of wind, temperature and humidity from nearby Quandary Peak (14,252' msl) which is an isolated peak in the project area. Plans are being made to obtain routine observations from this mountain peak in future years.

6. Artificial Cloud Seeding

Seeding is carried out on a random basis using hypodermic needle type silver iodide generators. Determination of suitable experimental days for seeding is currently being made independently by the U. S. Weather Bureau in Denver. Investigations are underway which are designed to make this determination completely objective in the future. A system of "straight randomization" (as opposed to "random pairs") is used for obtaining the random decision to "seed" or "not seed" on days which have precipitation potential. Clear days are of course not considered. Snowfall and atmospheric observations for the "seed" and "noseed" days are being compared.

PRELIMINARY FINDINGS

A. Instrumentation and Procedures for Daily Snow Observations.

1. The reliability of catch using gages shielded from the wind and those not shielded have been considered. The deficiency of catch in an unshielded gage, at Climax, Colorado during the spring, 1960, project period, was 30 percent with respect to an adjacent shielded gage. It is apparent that gage shielding should be considered in any treatment of precipitation data from the Upper Colorado River Basin during winter.

2. The reliability of catch obtained with snowbands from which observations are taken daily has been investigated. Accumulated snow catch during the spring of 1960 was 5 percent in excess of the catch of an adjacent shielded gage. This is considered to represent good agreement. Snowboard data has been evaluated by additional techniques which have included comparison between boards, testing for representativeness of catch for surrounding areas for a large number of cases, tests of radiational heating effects on snowboard of different colors, and investigations of the patterns of snowfall resulting from snowboard observations. Additional studies have considered the sites at which snowboards are located.

All evidence indicates that reliable observations of daily snowfall can be obtained with the use of snowboards if care is taken in the selection of observing sites.

B. Snow Observations.

1. Patterns of snowfall with respect to elevation and exposure have been obtained for a number of storms which are suitable for analysis of snowfall patterns for the respective weather situations.

2. Accumulated snowfall during the spring of 1960 increased rather uniformly with elevation up to the maximum elevations where measurements were made at 11,300' msl.

3. For corresponding elevations actual snowfall was considerable greater, elevation for elevation, on the north slope of Fremont Pass.

C. Ice Nuclei Observations.

1. Concentrations of ice nuclei during unseeded periods have usually been of the order of 1-2 per liter, in close agreement with observations during unseeded periods since 1954.

2. Concentration on a number of seeded days have been 10 to over 100 times greater than observed on unseeded days. Increases in ice nuclei have clearly resulted from the release of silver iodide at upwind sites.

D. Random Cloud Seeding.

Twenty eight test days, 12 seeded and 16 unseeded, were observed during the spring of 1960. This sample is too small for reaching conclusions as to the effect of seeding on snowfall. Snowfall was considerably greater, however, on the seeded days. This trend of considerable greater snowfall

on seeded days has continued at about the same level at the Climax Observatory for 23 additional days, (11 seeded and 12 unseeded) during the current season. Data from most snowboard sites have not been analyzed for the current season. As of 5 April 1961, 60 test days (28 seeded and 32 unseeded) have been accumulated. About 10 additional days can be expected during the remainder of April so that a total sample of around 70 should be available at the end of the season.

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