The local merchants also are in a position to receive values from water supply forecast data. If they know that a short supply is probable, they may then decide to stock less fertilizer, grass and legume seed, and possibly less farm machinery. They thus are able to lower their inventory and carrying charges.

In summary, I have attempted to show briefly that the water supply forecasts do have very real money values to whomsoever may use them. I have also indicated that monetary terms may be placed on these values by recognized techniques of evaluation. Does it not then follow that you, as surveyors and forecasters, can capitalize on these facts? Documentation of the uses and physical results will give a basis for placing economic terms or money values on these uses. We know that whenever we can reduce physical facts or narrative terms to dollar and cents terms the users can visualize and comprehend them. How better can you gain wider use, give greater service for each dollar of public money spent, and increased public support for this most worthwhile program than putting its benefits in terms its users can readily understand?

EVALUATION OF CLOUD-SEEDING EFFORTS IN THE SOUTHERN OREGON CASCADES, 1952-1957[1/]

By

Manes Barton and Lyle D. Calvin[2/]

SUMMARY AND CONCLUSIONS

Cloud-seeding operations for The California Oregon Power Company have been conducted by North American Weather Consultants for the past seven years in the Southern Oregon Cascades. The purpose was to increase the mountain snowfall and consequently, the summer streamflow for the production of hydroelectric power.

Based upon regression and isopercentile analyses of the data for the first six years of seeding, the following conclusions were reached:

1. The average April 1 snow water content for 1952-57 showed a 3 percent increase over expected, a non-significant increase.

2. The average November-March precipitation for the six seeded years showed a 2 percent increase over expected, a non-significant increase.

3. The average April-July streamflow for 1952-57 showed a 4 percent increase over expected, a non-significant increase.

4. For four of the six seeded years the highest percent of normal precipitation in the state has occurred in the Fremont-Paisley area, lending strong support to the thesis that a downwind effect exists beyond the target area.

INTRODUCTION

Cloud-seeding operations have been conducted for the past seven years (1952-1958) in the Southern Oregon Cascades during the November-March period. These operations have been conducted for The California Oregon Power Company of Medford, Oregon, by North American Weather Consultants of Goleta, California. The purpose of the project was to increase mountain snowfall and consequently, the summer streamflow of several southern Oregon streams upon which The California Oregon Power Company has hydro-power plants.

1/ Technical Paper No. 1118, Oregon Agricultural Experiment Station.

2/ Assistant Water Forecaster and Statistician, respectively, Agricultural Experiment Station, Oregon State College, Corvallis, Oregon - M. Barton now Assistant Snow Survey Supervisor for Oregon, Soil Conservation Service.

The target area comprises a mountainous area of approximately 1200 square miles in the Oregon Cascades and includes portions of Jackson, Douglas and Klamath Counties. Elevation ranges from 1900 to 9510 feet. Of the target area 96 percent is above 3000 feet, 43 percent above 5000 feet and 1 percent above 7000 feet. Mean elevation is 4500 feet. Figure 1 shows the target area.

At the request of and through the financial assistance of The California Oregon Power Company, an evaluation of these cloud-seeding efforts has been made by the Oregon Agricultural Research Foundation in close affiliation with the Oregon Agricultural Experiment Station. To date six progress reports have been made. (1) (2) The seventh report covering the 1958 water year is in process. This paper of necessity will cover only the first six years of operation.

The history of cloud-seeding in the southern Oregon area predates the project covered in this paper. During the winters of 1950 and 1951 cloud-seeding was performed on part of the present target area. This earlier project was reported upon at the 20th annual meeting of this conference in Sacramento, California, in 1952. (3)

Concurrent with the present winter project there have been attempts, during several years in the Medford, Oregon, area, to disperse fog, suppress hail, and increase spring precipitation. These projects have been separate endeavors from The California Oregon Power Company's winter project, but have presented certain problems, principally in selection of control stations.

SEEDING METHODS

North American Weather Consultants performed the cloud-seeding in all its aspects. North American Weather Consultants provided a project meteorologist who directed the operation of the generator network, based on local information, instruction from his headquarters and his own experience. Table 1 shows the number of days seeded per month during the project.

TABLE 1

NUMBER OF DAYS SEEDED PER MONTH, 1951 - 1957

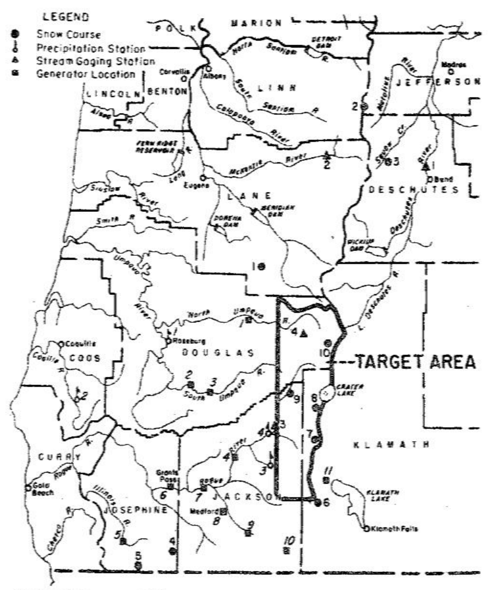
	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Total
1951-52	9	15	12	15	18	2	71
1952-53	2	21	13	11	22	0	69
1953-54	8	10	17	10	11	0	56
1954-55	7	18	15	9	15	1	65
1955-56	10	14	15	14	11	0	64
1956-57	0	9	16	8	16	0	49
TOTAL	36	87	88	67	93	3	374

North American Weather Consultants used propane fueled, silver iodide generators. (4) A generator consisted of a propane burner into which a solution of silver iodide was sprayed and thus vaporized. The generators were instrumented so that the "smoke" output could be varied by pulsing. Thus the quantity and size of the silver iodide nuclei were varied.

Meteorological conditions were selected during the seeding period when the addition of silver-iodide nuclei to the storms passing through seemed both possible and practical. A fixed network of generators was established in order that most storms could be seeded regardless of their direction of approach or wind condition on the ground. Figure 1 shows these locations. One mobile generator mounted on a pickup truck was also used.

WEATHER

Climate of the area is typical west coast marine as modified by mountainous terrain. Mean annual temperature ranges from 39°F at Crater Lake Park Headquarters to 50°F at Prospect, Oregon. Mean annual precipitation above 2000 feet ranges from 27 inches at Lake Creek, Oregon, to 60 inches at Crater Lake, Oregon. Most precipitation falls as snow during December, January, February and March.



SNOW COURSES

1. Champion
2. Hogg Pass
3. 3 Creek Meadows
4. Grayback Peak
5. Althouse
6. Lake of the Woods
7. 7 Lakes #2
8. Annie Springs
9. Silver Burn
10. Diamond Lake

PRECIPITATION STATIONS

1. Roseburg
2. Powers
3. Big Butte Springs
4. Prospect

STREAM GAGING STATIONS

1. Tumalo Creek and Columbia Southern Canal
2. McKenzie River at McKenzie Bridge
3. Rogue above Prospect
4. Clearwater above Trap Creek

GENERATOR LOCATIONS

1. Steamboat
2. Days Creek
3. Tiller
4. Trail
5. Cave Junction
6. Grants Pass
7. Gold Hill
8. Medford
9. Ashland
10. Pinehurst
11. Rocky Point

FIGURE 1.

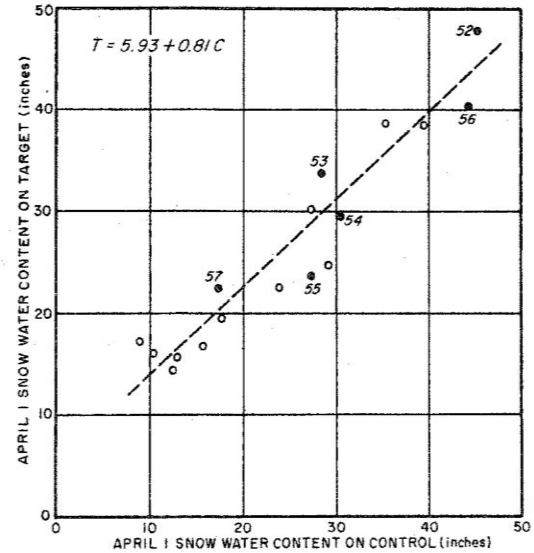


FIGURE 2. RELATIONSHIP BETWEEN TARGET AND CONTROL SNOW WATER CONTENT

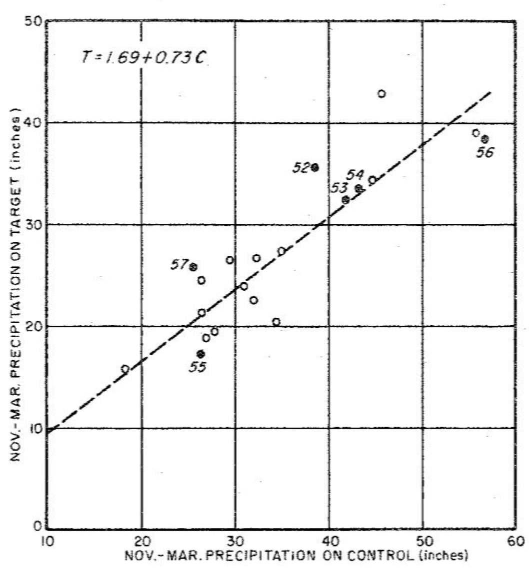


FIGURE 3. RELATIONSHIP BETWEEN TARGET AND CONTROL PRECIPITATION

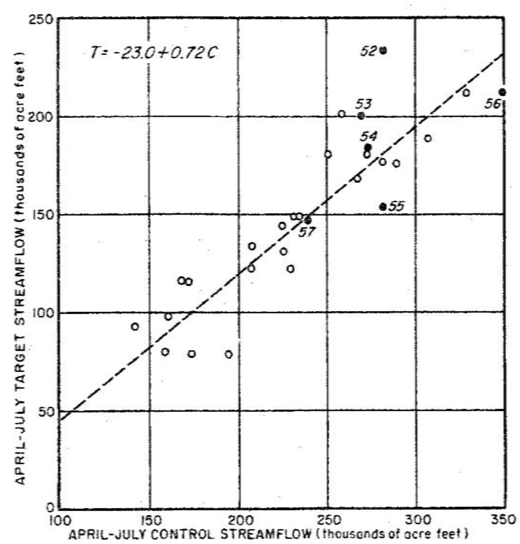


FIGURE 4. RELATIONSHIP BETWEEN TARGET AND CONTROL STREAMFLOW

According to studies made by North American Weather Consultants under storm conditions suitable for seeding there usually exists a strong southwest to westerly flow aloft near the -5°C level, while at or near the surface in the Medford basin area, winds are light and variable or southeasterly in direction. (4)

METHODS OF ANALYSIS

Before attempting to make the first evaluation in 1952 preliminary studies were made to select stations outside the target area to be used as controls. A large number of precipitation stations, snow courses, and stream gaging stations were considered. All stations which were not directly affected by the generated locations and were within a reasonable distance (300 miles) were included in these preliminary studies.

Comparisons were made between individual stations outside the target area and the individual stations within the target area. Using historical data for all years of record prior to 1950, scatter diagrams were made to illustrate relationship of the April 1 snow water content, November-March precipitation and April-July streamflow for individual stations. Any comparisons showing a poor relationship were eliminated from further consideration. For the remainder, correlation coefficients were calculated and only those comparisons with correlation coefficients of .85 and above were used in subsequent analyses.

This reduced the comparisons on April 1 snow water content from 319 to 61 comparisons (14 control and 10 target stations) which met this criterion. The precipitation comparisons were reduced from 90 to 9 (5 control and 3 target stations) and the streamflow from 16 to 5 comparisons (2 control and 2 target stations).

In subsequent evaluations it was necessary to change some stations because of insufficient data, changes of locations, etc. Linear regression equations were fitted to each of these comparisons using the data from the target stations as the dependent variable. These equations were then used in subsequent analyses to predict the result which would have been obtained had no seeding taken place. The observed value of snow water content, precipitation, or streamflow was then compared to the predicted or expected value and a Student's t test made to determine whether the difference was statistically significant.

In addition to the regression analyses, isopercentile maps of precipitation were also made. All stations in Oregon and northern California with ten or more years of record were included. Monthly percentages of normal from November to March and the November to March totals were calculated for each station. These values were then plotted and isopercentile lines drawn to indicate areas of high or low precipitation. No tests of significance were calculated on these data. They were used primarily to give a visual picture of any change which might have occurred in the precipitation pattern.

Beginning with the 1953 evaluation several additional tests of the data were made. These included tests for curvilinearity, for common regression in both historical and seeded periods, and to determine if deviations about the regression lines increased with increasing values. These tests indicated that the regression lines were linear and that common regression lines could be used in both the historical and seeded periods. Deviations about the regression lines appeared constant throughout their length.

After the first year, the control stations and the target stations were grouped and the average values used rather than separate values for each station. Because of changes in some of the stations it was necessary to change the regression equations slightly from one year to another.

In 1953 and 1954 stations downwind of the target area had higher than usual amounts of precipitation. To further examine this phenomenon the stations with the high and low percent of normal for the state were determined for each year in the historical and seeded periods. The number of highs in the seeded years were compared with the highs in the historical years in an attempt to ascertain if these downwind highs were abnormal. Although this procedure gives an unbiased comparison of highs (and lows) from the historical to those of the seeded period, the frequency of such extremes in any area will be influenced by the seasonal variation in precipitation at each station. If the relative variation is greater at low precipitation stations than at high precipitation stations, then more high (and low) years should occur at low precipitation stations. A study of the relative variation revealed that this was actually the case, although the effect was not pronounced. To correct for the situation, the standardized deviation from the average, rather than percent of average, was used to determine high and low years. The frequency of extremes was changed among areas; however, the comparison of historical with seeded years remained approximately the same for each area.

RESULTS

April 1 Snow Water Content

Because the location of generators used by North American Weather Consultants has undergone several changes during the six years of operation, it was necessary to use only control snow courses with complete records. The five control snow courses used in the analysis were Champion, Hogg Pass, Three Creek Meadows, Gray-back Peak, and Althouse.

Data from several of the snow courses in the target area were not always available, and therefore these stations were omitted from the analysis. Target snow courses used were Diamond Lake, Silver Burn, Lake of the Woods, Annie Springs, and Seven Lakes #2. The locations of the control and target stations are shown in Figure 1 and the data in Table 5.

TABLE 2. APRIL 1 SNOW WATER CONTENT ON TARGET DURING SEEDED PERIOD

WATER CONTENT (IN.)

Year	Observed	Predicted	Increase	Increase (%)	P(t)[1/]
1952	47.96	42.59	5.37	13	0.07
1953	33.92	29.15	4.77	16	0.04
1954	29.70	30.84	-1.14	- 4	0.67
1955	23.64	28.12	-4.48	- 16	0.95
1956	40.06	41.96	-1.90	- 5	0.72
1957	22.34	19.94	2.40	12	0.18
Avg. 1952-57	32.94	32.10	0.84	3	0.33

1/ P(t) is the probability that the indicated increase could have been due to chance variation if seeding had no effect.

In Figure 2 are shown the regression line and observed data over both the historical and seeded years. In Table 2 are given the observed and expected values of April 1 snow water content for each of the six seeded years and for the entire seeded period. The percent increase for observed over expected is included with the probability that the observed increase could have been due to chance if the seeding program had no real effect. If the probability is sufficiently low, the conclusion would ordinarily be that the increase was not due to chance but to some outside influence, say the seeding program. The level of probability that must be reached before drawing such a conclusion is dependent upon the value of any real increase and upon the cost of making an incorrect conclusion. Although no significance level can definitely be given as establishing "proof", any probability higher than 0.10 can scarcely be considered as very adequate evidence that any factor other than chance is operating.

November-March Precipitation

The control stations used in precipitation analyses were Roseburg and Powers. The target stations were Big Butte Springs and Prospect. The locations of the control and target stations are shown in Figure 1 and the data in Table 5.

The regression line and the observed precipitation of both the historical and seeded years are shown in Figure 3. In Table 3 are given the observed and expected values of November-March precipitation for each of the seeded years and for the entire seeded period. The percent increase for observed over expected is included with the probability that the observed increase could have been due to chance if the seeding program had no real effect.

TABLE 3. NOVEMBER-MARCH PRECIPITATION ON TARGET DURING SEEDED PERIOD

TOTAL PRECIPITATION (IN.)

Year	Observed	Predicted	Increase	(%)	P(t)1/
1952	35.53	29.89	5.64	19	0.07
1953	32.47	32.27	0.20	1	0.48
1954	33.49	33.18	0.31	1	0.47
1955	17.04	20.71	- 3.67	- 18	0.84
1956	38.32	43.20	- 4.88	- 11	0.86
1957	25.63	20.42	5.21	26	0.09
Avg. 1952-57	30.41	29.94	0.47	2	0.40

1/ P(t) is the probability that the indicated increase could have been due to chance variation if seeding had no effect.

April-July Streamflow

The control stations used were Tumalo Creek and Columbia Southern Canal and McKenzie River at McKenzie Bridge and the target stations Rogue above Prospect and Clearwater above Trap Creek. The locations of the control and target stations are shown in Figure 1 and the data in Table 5.

The regression line for the observed streamflow data for both historical and seeded years is shown in Figure 4. The observed and expected values of April-July streamflow for each of the seeded years and for the entire seeded period are given in Table 4. The percent increase for observed over expected is included with the probability that the observed increase could have been due to chance if the seeding program had no real effect.

TABLE 4. APRIL-JULY STREAMFLOW ON TARGET DURING SEEDED PERIOD

STREAMFLOW (1000 ACRE FEET)

Year	Observed	Predicted	Increase	(%)	P(t)1/
1952	234.5	180.8	53.7	30	0.005
1953	201.4	171.9	29.5	17	0.06
1954	184.3	174.2	10.1	6	0.29
1955	153.9	181.0	-27.1	-15	0.93
1956	212.0	229.8	-17.8	- 8	0.81
1957	147.2	149.9	- 2.7	- 2	0.54
Avg. 1952-57	188.9	181.3	7.6	4	0.22

1/ P(t) is the probability that the indicated increase could have been due to chance variation if seeding had no effect.

November-March Precipitation "Highs" and "Lows"

The "highs" and "lows" of percent of normal precipitation were recorded for six areas of the state. These are listed for both the historical and seeded periods in Table 6. During four of the six seeded years the precipitation "high" has occurred at Fremont or Paisley. This area is downwind from the target area and may be considered as evidence of a downwind effect beyond the target area. No statistical test of this effect is made because of the limited data available and the inability of any such test to detect real differences even if they do exist.

Percent of Normal Precipitation

The precipitation data used in the computation of percent of normal precipitation were obtained from the U. S. Weather Bureau's Climatological Bulletins. (5) All stations having at

TABLE 5

DATA USED IN REGRESSION ANALYSES a/

Year b/	April 1 Water Content of Snow (in.)		November-March Precipitation (in.)		April-July Streamflow (1000's of acre-feet)	
	Control Average	Target Average	Control Average	Target Average	Control Average	Target Average
1928					225.4	131.0
1929					229.7	122.7
1930					158.0	80.0
1931					194.6	78.9
1932					288.4	175.6
1933					328.4	211.7
1934					173.4	79.0
1935					233.4	149.6
1936			32.37	26.85	234.6	149.6
1937			27.64	19.38	282.0	176.1
1938			55.79	38.99	257.8	200.8
1939	29.18	24.72	26.34	24.76	207.7	133.7
1940	8.90	17.28	34.94	27.36	161.2	98.7
1941	10.26	16.08	26.95	18.84	143.2	93.4
1942	15.76	16.70	34.22	20.21	171.5	115.7
1943	27.04	30.28	45.67	42.82	273.2	182.5
1944	12.48	14.38	18.35	15.78	167.8	116.5
1945	17.54	19.54	30.92	23.80	224.9	144.2
1946	35.36	38.96	44.75	34.36	251.4	180.9
1947	12.98	15.56	26.59	21.24	207.7	121.8
1948	23.98	22.84	31.94	22.42	267.4	169.6
1949	39.52	38.46	29.64	26.30	307.5	189.0
1952	45.06	47.96	38.71	35.53	281.9	234.5
1953	28.54	33.92	41.99	32.47	269.6	201.4
1954	30.62	29.70	43.23	33.49	272.8	184.3
1955	27.28	23.64	26.12	17.04	282.2	153.9
1956	44.28	40.06	56.99	38.32	349.7	212.0
1957	17.22	22.34	25.72	25.63	239.2	147.2

a/ Specific stations used in development of averages are shown in Figure 1.

b/ 1950 and 1951 omitted due to an earlier cloud-seeding project.

TABLE 6

OCCURRENCE OF NOVEMBER-MARCH PRECIPITATION "HIGHS" AND "LOWS"

Historical Period (1924-49) -- Seeded Period (1952-57)

"Highs" Station	Year	"Lows" Station	Year
Area A			
Astoria	1934	Astoria	1942, 1943
Headworks	1933	Headworks	1927
Hood River	1949	Oakridge	1930
Newport	1955	Parkdale	1940
Parkdale	1935	Salem	1928, 1957
Area B			
Bend	1946	Bend	1945, 1955
Big Eddy	1948	Madras	1934, 1939
Condon	1937	Pilot Rock	1941
Durfur	1924, 1927	Wasco	1944, 1947
Hepner	1926		
Wasco	1930		
Weston	1931		
Area C			
Baker	1932	LaGrande	1938, 1952
Cove	1925	Union	1936
Joseph	1929	Wallowa	1929, 1935
LaGrande	1947		
Area D			
Adrian	1944	Adrian	1953, 1954, 1956
Vale	1938, 1945	Vale	1948
Area E			
Fremont	1952, 1957	Fremont	1931, 1932, 1937
Harney Br Exp Sta	1936	Harney Br Exp Sta	1949
Lakeview	1941, 1942	Lakeview	1924, 1946
Paisley	1940, 1953, 1956	Paisley	1926
Round Grove	1928	Valley Falls	1933
Area F			
Fish Lake	1939	Grants Pass	1925
Medford	1943		
Talent	1954		

Note: Seeded years underlined.

least ten years of record prior to 1949 and having 1951 to 1957 data available were used. A total of 107 stations were used for the 1956-57 record and 77 stations for the six-year seeded period record.

Because of the scarcity of the data in some regions of the state and because of station to station variability within a relatively small area in the state it is impossible to draw the iso-percentile lines with any great objectivity. They give only a rough qualitative measure of the precipitation pattern over the period covered and have, therefore, not been included in this report.

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GRAPHICAL METHOD FOR DETERMINATION OF AREA-ELEVATION WEIGHTING OF SNOW COURSE DATA1/

By

J. F. Hannaford, C. G. Wolfe, and R. W. Miller2/

At one time, Mark Twain stated, "History alone is a trustworthy prophet." This statement applies rather well to the science and art of water supply forecasting--science, where the forecaster can assemble history and withdraw a forecast of future conditions from this history--art, where the information leading to the forecast goes beyond the realm of history and the limits of historical data.

CALIFORNIA'S FORECAST SCHEMES

Forecasting schemes used by the California Cooperative Snow Survey to forecast runoff during the April-July snowmelt period on typical Sierra drainage basins are based upon some 28 years of historical snow survey records. The schemes in use are multiple-graphical correlations (Plate 1) incorporating data on snowpack, precipitation, and runoff. ("Multiple Graphical Correlation for Water Supply Forecasting," Proceedings of the Western Snow Conference, April, 1956) Forecasts are based upon conditions as of April 1, with appropriate adjustments made for forecast dates other than April 1. Variables used in these forecasting schemes to predict run-off during the snowmelt period are outlined in the following paragraphs.

1/ Paper presented at THE WESTERN SNOW CONFERENCE, April 16-18, 1958, Bozeman, Montana.
2/ J. F. Hannaford, C. G. Wolfe, and R. W. Miller, Assistant Hydraulic Engineer, Senior Hydraulic Engineer and Civil Engineering Associate, respectively, are employees of the California Department of Water Resources. California Cooperative Snow Surveys.