AN ANALYSIS OF THIRTEEN YEARS OF COMMERCIAL HAIL SUPPRESSION IN CENTRAL ALBERTA

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ABSTRACT

This article is a summary of a research project carried out in the Department of Agricultural Economics, University of Alberta, and financed by the Alberta Agricultural Research Trust. The commercial hail suppression project of the Alberta Weather Modification Cooperative (AWMC) and its sole contractor, Irving P. Krick Associates of Canada, is evaluated for their active cloud seeding years 1956 to 1968. An original evaluation done in 1969-70 and reported in 1971, has been supplemented by new hail loss information generated during the subsequent non seeding years 1969 to 1972 for the selected AWMC target area.

Because provisions for an effective on-going evaluation of the project were minimal, an "after the fact" post-project evaluation was required in response to controversy over the degree of success achieved by the AWMC in reducing hail losses. Several post-project evaluation models were consequently examined by the author in terms of adequacy and data availability. The decision was made to use the Target Area-Control Area model with hail insurance Loss to Risk Ratios (L/R) as a measure of hail damage. Correlation and regression analyses were utilized to draw inferences about the effectiveness of the AWMC project, and tests of statistical significance were applied.

High natural variation in hail losses between areas and years created serious statistical difficulties in attempts to isolate any positive or negative effects of the program. This was reflected in results with low levels of statistical significance. Thus strong and assertive conclusions could not be made. Comparison of pre-seeding hail losses with those experienced in the target and control areas during the active seeding program of the AWMC, suggested the possibility of hail damage reduction at low levels of reliability. However, additional "hind sight" hail damage information now available for the post seeding years negates such a conclusion, based on the method of evaluation used in this study.

This suggests that the AWMC project was either ineffective, or there was insufficient information available to provide an adequate evaluation. These conclusions are in direct contradiction to those made by Irving P. Krick and Newton C. Stone in Vol. 7, No. 1 WMA Journal of Weather Modification, April 1975, titled "Hail Suppression in Alberta 1956-1968".

BACKGROUND TO THE STUDY

Hail suppression has been an issue in Alberta for some 20 years. In 1956, a group of farm operators in south central Alberta organized into a hail suppression association and retained the services of Irving P. Krick Associates of Canada to carry out a commercial suppression program. This association eventually expanded to include four adjacent counties, resulting in formation of the Alberta Weather Modification Co-operative (AWMC).

Various forms of a commercial cloud seeding program were continued by the AWMC, with Irving P. Krick Associates as their sole contractor until 1968, when local opposition brought a halt to association financing via county tax levies. The AWMC has not carried out a cloud seeding program since that time, although in 1973 the area was included as part of a larger field experiment, financed by the Alberta government.

Concurrent with the activities of the AWMC, the Research Council of Alberta, in 1957, established a special unit on hail research called Alberta Hail Studies (ALHAS). This unit has carried out basic and widely known studies on Alberta hail storms for the past several decades but did not begin cloud seeding experiments until 1970.

Over these two decades of hail study activity in Alberta, strong but differing points of view developed between optomistic farm operators represented by the AWMC, and the more conservative research establishment represented by ALHAS. Farmers emphasized possibilities of economic benefits even though the technology of hail suppression was still in doubt, while researchers stressed the importance of further development in uncovering and understanding cause-effect relationships in hail suppression.

In 1969, responding to requests from the agricultural community, the Alberta Agricultural Research Trust provided a $3,000 grant to the author. Its purpose was to evaluate the status of hail suppression in Alberta, and particularly the 13 year commercial program of the AWMC, with the objective of making recommendations for future development in the province. The evaluation was completed in 1970, and reported as a graduate thesis in 1971. It was later published as a university publication in 1972.[1,2]

A subsequent re-examination of the original analysis has been carried out utilizing data for the years 1969 to 1972, a period when the AWMC cloud seeding program was inactive, and before the government-financed cloud seeding operation was begun in the area. Conclusions were modified accordingly, and are reported in this article.

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[1] T.A. Petersen, "Alberta Hail Suppression" Unpublished Thesis, Washington State University, 1971.

[2] T.A. Petersen, "An Analysis of Thirteen Years of Commercial Hail Suppression in Central Alberta" Applied Research Bulletin No. 13. Department of Agricultural Economics and Rural Sociology", Faculty of Agriculture, University of Alberta, March 1972.

HAIL DAMAGE TO ALBERTA CROPS

While virtually all of Alberta's agricultural croplands have experienced hail damage at one time or another, the heaviest and most consistent hailfalls are concentrated in a strip known as the Alberta Hail Belt. This is a region some 60 to 80 miles wide and about 250 miles long, running from the capital city of Edmonton, in a south south easterly direction through Calgary to Lethbridge at the southern end. This belt runs more or less parallel to the Rocky Mountains, which form the southwestern border of Alberta. Hail storms breed in the mountains and foothills, and generally move in an easterly direction into Alberta's farming areas, creating the greatest amount of damage in the hail belt described above. The location of this region is shown in Figure I.

The Alberta "hail belt" has been subject to severe hail damage virtually every year, somewhere along the 250 mile stretch. Seldom however, has the yearly hail damage been similar along the whole length of the hail prone area. It is not clear if these differences are random by nature, or whether there is a cyclical movement of hail bands in a south to north configuration.

The southern one-third of the "belt" experienced its highest crop losses in 1945 and 1966, with damage running between 20 and 25 percent for each of these two years. In 1954 and 1960, damage was about 15%.[1] The northern third of the region, centering on the town of Ponoka, experienced its heaviest losses in the years 1951, 1953, and 1957 with damage running around 20%, and 1943 and 1962 with losses around 15%. The central region, the area in which the Alberta Weather Modification Cooperative carried out its commercial hail suppression operation, experienced its heaviest losses in 1953 with damage running close to 25%. The years 1943, 1945, 1951, 1957, and 1959 were around the 15% level.

While the entire hail belt has not differed markedly in average hail losses of some 7 to 8% over the past 35-40 years, the variation between years and between areas is extremely high. Variations between years for the same area, and between areas in the same year amount to as much as 3 times the average long term hail losses. This presents a statisticians nightmare when trying to make inferences about certain phenomena such as cloud seeding. Working with averages without allowing for the probable consequences of variability on the results, would in all likelihood lead to misleading conclusions. This is where recognized procedures of statistical inference can be extremely useful.

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[1]Alberta Hail and Crop Insurance Board, Calgary, Alberta, Annual Statistics Reports. The figures given above assume that hail insurance information provides an acceptable sample for estimating original hail damage.

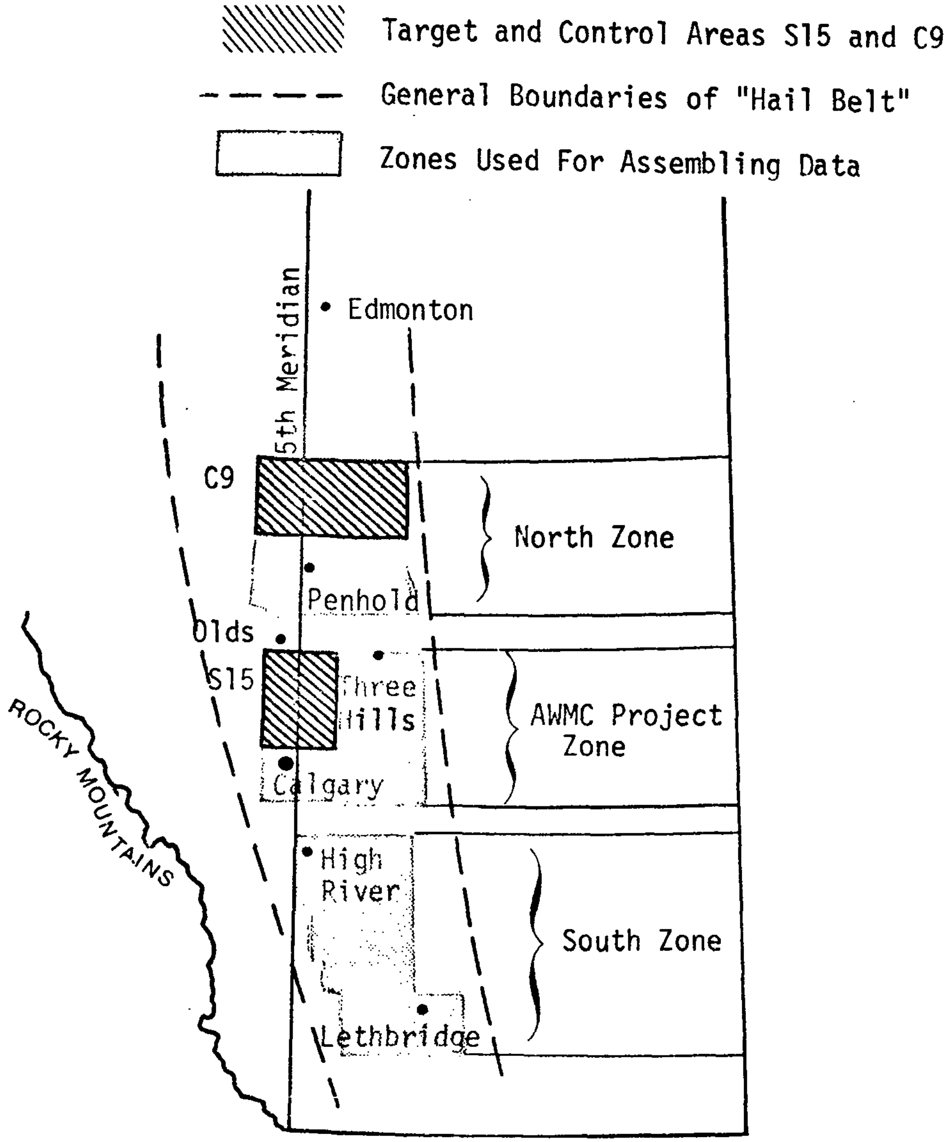

Figure 1.--Map showing location of the Alberta Hail Belt, and the three zones in the belt for which loss risk ratios were obtained, showing their location with respect to townships and the Fifth Meridian (called the North Zone; Project Zone; and South Zone, respectively).

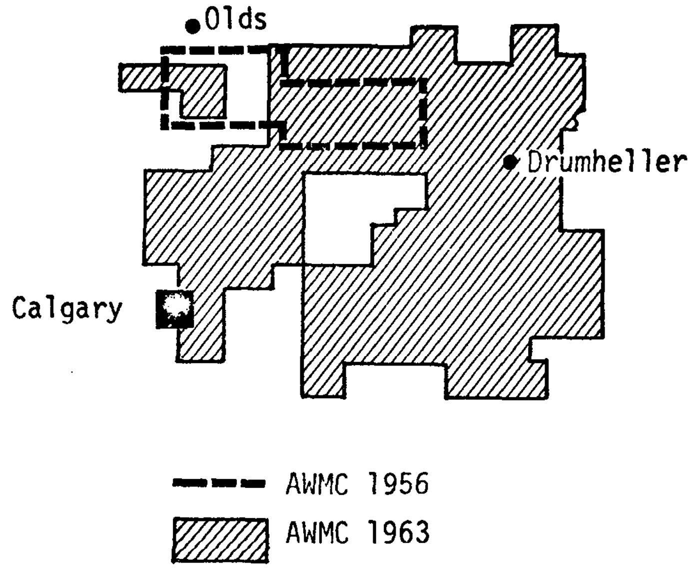

Figure 2.--Map showing the AWMC target area for the years 1956 when it was the smallest, and 1963 when it was the largest. In all of the seeding years 1956 to 1968, the specific target areas were located within the zone in Figure 1, designated as "AWMC project zone." The irregular shapes are a result of the location of those farmers who were willing to financially support the AWMC project.

THE ALBERTA WEATHER MODIFICATION COOPERATIVE

The commercial hail suppression project of the farmers association which later became the AWMC, began in 1956 in a test strip some 12 miles wide and 45 miles long, extending east from Didsbury. Irving P. Krick Associates of Canada Ltd. was the contractor with a budget of $30,000.

While ground generators only, were utilized in the first year of operation these were gradually supplemented by aircraft, until in 1960 flying became a major component in the project. This is substantiated in Table I below.

TABLE I

SILVER IODIDE OUTPUT IN GRAMS BY YEAR ON THE AWMC PROGRAM

Year	Aircraft generators	Ground generators	Number of days seeded*	Major hail days seeded	Grams per hail day or per day seeded: by air	by ground
1956	0	50,280	24		0	2,095
1957	320	257,904	90		3	2,865
1958	16,500	233,145	75		220	3,108
1959	15,125	275,640	49		309	5,625
1960	45,375	353,268		23	1,973	15,360
1961	26,950	150,194		8	3,369	18,774
1962	23,100	110,722		19	1,216	5,827
1963	44,275	283,658		19	2,330	14,929
1964	36,080	199,920		17	2,122	11,760
1965	47,080	305,007		34	1,385	8,971
1966	46,420	286,932		33	1,406	8,695
1967	35,475	160,680		21	1,690	7,651
1968	43,725	222,522		15	2,915	14,384

* A modified approach to cloud seeding was undertaken in 1960 in the light of new information concerning forecasting of hail; consequently, the information is segregated into two columns.

Source: Irving P. Krick Associates of Canada Ltd., Palm Springs, California.

Being a commercial operation fully dependent on financing by farmer clients alone, the AWMC was not able to maintain a uniform target area for the total 13 year period of its operation from 1956 to 1968. Their designated yearly target areas varied not only in size, but also in shape. The smallest target area was in 1956 and the largest in 1963, when almost 100 townships in an irregular pattern based on paying farmers were designated as "target". The other years in their active seeding program varied between these two extremes. (See Figure 2).

Restricted funds were also likely at least partly responsible for only a minimum of advance preparation of a program evaluation design, and for generation of the types of data during the on-going project, which would be required for an effective analysis of cloud seeding effects. The objective of the AWMC was to utilize the maximum amount of funds possible for cloud seeding purposes, because this was the prime selling point of the program in obtaining operating funds from farm operators.

During the latter years of the AWMC project, a major portion of the funding came from tax role checkoffs on a county by county basis, for the four counties involved in the cloud seeding program. There was however, continuous local opposition to the AWMC, its contractor, and the checkoff method of financing. In 1968, a local opposition group called the Rate Payers Protective Association took their case to the courts, effectively preventing the AWMC from carrying out seeding operations in 1969 and subsequent years.

SELECTION OF AN EVALUATION PROCEDURE

Methods of analysis in evaluating hail suppression projects are directly dependent on the original design of the cloud seeding program or experiment. Some evaluators suggest that 25% of the cost of a seeding program might profitably be spent in evaluation.[1] This would include exploration and selection of experimental designs which appear best suited to a valid verification of cloud seeding effects, as well as provision for collection of sufficient data as the program progresses. Much of the activity and cost of evaluation thus needs to be undertaken before the seeding project begins.

For obvious reasons, this is seldom undertaken in commercial seeding programs, because farmer clients are reluctant to expend funds which will not be directly used in applying silver iodide to storm clouds. This was the case for the AWMC project. Limited funding made it difficult for the directors and the contractor to provide seeding services, let alone a comprehensive evaluative system. Thus any analysis would by necessity, have to be a post project evaluative design, using whatever secondary sources of data which might be available as proxy estimators of actual hail damage.

With these restrictions in mind, several approaches to hail suppression evaluation were examined. Four of these were as follows:

1. Seeding a Designated Target and Noting Changes in Hail Damage Over Time--This is frequently called a simple time-series analysis approach. Although this method is easy to understand and use, it is considered very weak because little is known about long run hail trends. Historical hail records for specified areas have shown tendencies for damage to increase or decrease substantially over a period of years.[2] It is not well established whether this is a random or cyclical

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[1] Richard A. Schleusener, Director, Institute of Atmospheric Sciences, South Dakota School of Mines and Technology, Rapid City, South Dakota. Interview, April 1973.

[2] P.W. Summers, Note on the Use of Hail Insurance Data for the Evaluation of Hail Suppression Techniques (Edmonton: Research Council of Alberta, 1966).

phenomenan. Should a suppression program be undertaken during a general upswing or downswing in hailfall activity, any suppressive effects would be dampened so that erroneous conclusions could easily occur. Reliable evidence could only be obtained over an extremely long period of years, if at all, making the experiment prohibitively expensive and impractical. Because of these obvious inadequacies, this method of assessment is almost completely discounted by neutral evaluators of field programs in hail suppression. Thus this method was not considered as a sufficient approach in evaluation of the AWMC project.

2. Predictive Model Method--In this method, a great deal of basic research must be done on cloud physics so that a simulated hailstorm can be programmed for computer use, thus providing the possibility for hail damage prediction from weather conditions existing on a given day for a particular storm. If this can be done, hail damage from potential storms can be predicted. They can then be seeded and the deviation from predicted damage measured and attributed to seeding. This has been suggested as a method of evaluating precipitation increases. However, the method is still in the early development stages for hail. Although it is not a practical approach to evaluation at the present time, it should be kept in mind as a future possibility. The method involves expensive equipment and great meteorological expertise. Considerable work is in progress to develop hail simulation models for computer use.[1]

3. Randomized Experimental Design--There is wide agreement among meteorologists and statisticians on the value of randomized experimental design for the evaluation of cloud seeding effects. There are a number of different ways in which the seeding process can be effectively randomized. The concept of randomization involves selection of storms to be seeded on the basis of chance. The potential storms for a day, week, month, or season are assigned numbers. The storms to be seeded are then selected randomly.

Specific types of experimental design involving randomization are:

1. randomized no control,
2. randomized target-control,
3. randomized crossover experiments.

In each case, the randomization is introduced to reduce experimental error created by natural trends and variability of hail damage over time and among areas, which masks any seeding effect which might have occurred.

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[1] Myron Tribus, "Physical View of Cloud Seeding," Science, (April 10, 1970). Dr. Tribus was Assistant Secretary for Science and Technology of the U.S. Department of Commerce, and Chairman of the Interdepartmental Committee for Amospheric Sciences of the Federal Council for Science and Technology.

The last method, called "randomized cross-over," is considered the most effective design for detecting changes in hail damage from cloud seeding. In this method, two similar test areas are selected. During each test period (day, week, or month), either one or the other test area (but not both) is seeded, based on random selection. Thus the unseeded area becomes the control or check area when the other area is seeded, and vice versa. This considerably reduces the error that might enter an evaluation from potential natural hailfall trend divergences between years as well as regions, given fixed target and control areas. It also reduces the length of the experiment needed for statistical verification.[1]

4. Target Versus Control Area--In this method, a control or nonseeded area is selected with which the target or seeded area can be compared to ascertain the probable change in hail damage. This method requires judicious selection of a control area. It should be quite similar to the target area with respect to the type of farming, crops grown, and methods of measuring hail damage. It must also have a similar hailfall history prior to the beginning of the seeding experiment. This requires that it be affected by a set of natural weather conditions similar to those of the selected target area.[2]

Because two separate areas will never be completely identical in all these respects, there is considerable room for experimental error in this method of evaluation. There is some chance that natural hailfall relationships between the two areas might change over time and that this divergence will mistakenly be attributed to cloud seeding. This could erroneously make the suppressive effects appear either more or less favorable than was actually the case.

Inasmuch as the AWMC project required post project evaluation the Target Area - Control Area model was selected for the reasons described. The simple time series approach was considered too error prone. The predictive model procedure obviously was not perfected for the AWMC project; and the randomized cross-over method required pre project planning and randomized seeding, which was not done. Thus by elimination, the Target-Control method utilizing secondary sources of data, was considered the most feasible evaluation method. This decision was further justified by the modest budget allocated to the author for post project evaluation purposes.

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[1]A.J. Dennis, Outline of Design Principles and Data Requirements for Field Programs in Weather Modification. (Rapid City: Institute of Atmospheric Sciences, South Dakota School of Mines and Technology, 1967).

[2]H.C.S. Thom, A Method for the Evaluation of Hail Suppression, Final Report of the Advisory Committee on Weather Control, Vol. II, Technical Report No. 4 (Washington, D.C.: Government Printing Office, 1957), pp. 55-69.

SELECTION OF DATA AND TARGET-CONTROL AREAS

(a) The Data--Hail causes extensive damage to buildings and equipment as well as farm crops.[1] However for crops, proxies are available to estimate the relative extent of damage. Therefore, most evaluations including this one, use crop loss data for analysis.

For this evaluation, one of the more available indicators of hail damage to crops, was hail insurance information. The Alberta Hail Insurance Board underwrites a major portion of Alberta's hail insurance. Percentage losses experienced by insured farmers are aggregated at the township level (a six square mile block), and accumulated as a set of time series data.[2] These statistics are available since 1938 for all of Alberta, including particularly the hail belt. For each township, hail loss is calculated as a percentage of the total insurance written. The resulting figure is called the Loss-Risk Ratio (L/R). By utilizing these data as building blocks, it is possible to arrive at an estimate of actual hail damage inside and outside the AWMC target area, as well as before, during and after the active seeding period from 1956 to 1968.

Loss-Risk Ratios are by no means a perfect measure of hail loss to farm crops. Firstly, only 15 to 20% of potential farmers took out hail insurance each year during the period under review; and yearly risk written varied considerably. Thus the size of sample as well as its representativeness must be questioned. Some farmers participating in a hail suppression project might have dropped their insurance, thus making the suppression statistics self fulfilling, even though hail may not have been reduced.

Furthermore, differing types of crops as well as the stage of maturity, will show varying degrees of damage from similar hail intensities. This can make L/R ratios poor estimators of actual hailfall. Additionally, there are several ways of weighting L/R ratios when they are aggregated. While simple averaging can be extremely misleading, there are also several recognized methods of aggregation, each one correct depending on the approach of the researcher.

Locations of insured farmers were plotted visually, and regression analysis was utilized to test for sample representativeness. The conclusion was that hail insurance data were usable as estimators of hail damage. No analysis of the crop variety and maturity problem was undertaken due to lack of information.

Other data sources were also examined. Crop yield statistics were obtained from the Alberta Wheat Pool by grain elevator point, and used to support the hail insurance data. Hail/precipitation ratios were also

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[1] S. A. Changnon, Hail Evaluation Techniques, Parts I and II (Urbana: Illinois State Water Survey, April 1969).

[2] Alberta Hail and Crop Insurance Corporation, Calgary, Alberta, Computor Storage Unit.

explored with the possibility that changes in the ratios during cloud seeding, might be a valuable statistic to use for evaluation. There were not however, sufficient precipitation data on a small area basis to provide usable information. This might well be a useful statistic to establish and record on future cloud seeding projects.

(b) The Target and Control Areas--The philosophy behind the Target-Control model for evaluation, is to reduce statistical error due to unpredictable random changes in the natural hail patterns of a target region. Incorporating these changes into the hail suppression analysis obviously introduces hail loss experience which is not attributable to cloud seeding, thus creating error of an undeterminable degree. This is why the elementary method of comparing hail losses in the target area alone, for the seeded and non-seeded years is not emphasized by serious evaluators.

While the randomized cross-over design discussed earlier largely overcomes this problem, the method could not be utilized in this evaluation because it was not built into the original A.W.M.C. project. The Target-Control model is therefore a compromise which helps to reduce the probabilities of errors arising from changes in natural hail patterns but certainly does not eliminate their possibilities.

This method utilizes as a check, a non-seeded control area with similar hail patterns to the target area, in the pre seeding period. Relative hail damage results are then compared during seeding in the target area. The validity of the Target-Control model relies heavily on natural hail trends remaining similar in the target and control areas, had the target not been seeded. Should these deviate, natural random changes will be mistaken for cloud seeding effects, which may be either positive or negative.

In order to locate a suitable control area for the AWMC project evaluation, yearly Loss-Risk ratios were assembled for three large zones in the Alberta Hail Belt. (See Figure I). These included the general zone encompassing the AWMC target areas, and also two zones lying north and south of the target area zone. The purpose was to analyze hail damage patterns and trends with the prime objective of locating a control area which was as identical as possible, to the AWMC target area for the pre-seeding years.

Although all three zones have experienced severe hail years, the degree of correspondence varies considerably. Analysis of Loss-Risk ratios over time for the three large regions, showed that the south zone was not closely related to the AWMC suppression zone in hail damage experience, with a low correlation of .44.[1] The correlation between the

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[1]Loss-Risk ratios over time were compared for all three zones, using the statistical technique of correlation analysis. A correlation of 1 would indicate a perfect correspondence between two zones in hail experience over a given time period.

north zone and the south zone was a very low .18 indicating virtually no relationship in yearly hail damage patterns. Comparison of the north zone to the AWMC project zone however, showed a correlation of .68, indicating approximately a two-thirds correspondence over the pre-seeding years examined. Consequently the north zone was chosen for location of a smaller "control" area which might perhaps have even a higher relationship to the target area in hail experience for the pre-seeding years.

The next problem was to make a decision about the "Target" area to be utilized. Due to the large yearly variations in size and shape of the AWMC project area, it was neither practical nor statistically sound to utilize yearly project boundaries (See Figure 2). The decision was thus made to utilize a more regular shaped block inside the actual AWMC project zone for all of the years being analyzed.[1]

A large number of possible Target-Control pairs from the northern zone, and the AWMC project zone were compared in all possible combinations through correlation analysis. In total, fifteen potential target, and 10 potential control areas were tested. While the majority of pairs tested showed correlations of over .50, one Target-Control pair in particular, showed a correlation of .88. These two areas were labelled Suppression 15 (S15) and Control 9 (C9), and utilized for the remainder of the analysis.

ANALYSIS OF THE DATA

Three approaches to data analysis are utilized in an attempt to evaluate changes in hail damage for the AWMC target area during their seeding program. These are: 1. The target area simple "seeded" and "unseeded" years approach. 2. The target-control area regression analysis approach, and 3. Mean barley yield analysis approach. These are discussed below.

1. Target Area Time Series Analysis--Although this approach is not considered as a viable method by serious evaluators, it has been included here because other evaluations of the AWMC project have been done by this method. Another purpose is to indicate the problems which are likely to arise through random changes in natural hailfalls which create unmanagable errors in the process of isolating cloud seeding effects.

Table 2 shows a simple time series for the target area selected in this evaluation, namely S15, for the years 1938 to 1972.

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[1]While certain farms and blocks inside the AWMC yearly target areas were not designated as "target" by the AWMC due to lack of financial support, it was assumed that cloud seeding with silver iodide could not be effectively stopped at fence lines. Thus the area bounded by the AWMC project area was assumed to be a solid seeded block.

Table 2

YEARLY LOSS-RISK RATIOS FOR TARGET AREA S15 FOR THE YEARS 1938 to 1972 SHOWING THE PRE SEEDING TIME PERIOD, THE AWMC "DEVELOPMENTAL" PERIOD, THE AWMC "OPERATIONAL" PERIOD, AND THE POST SEEDING PERIOD

PERIOD							
Pre Seeding		"Developmental"		"Operational"[a]		Post Seeding[b]	
Year	L/R	Year	L/R	Year	L/R	Year	L/R
1938	12.10	1956	15.47	1960	12.25	1969	0.46
1939	7.67	1957	8.82	1961	4.08	1970	5.69
1940	6.51	1958	0.15	1962	3.33	1971	0.27
1941	12.68	1959	27.82	1963	5.72	1972	2.75
1942	4.60			1964	2.88		
1943	10.99			1965	4.03		
1944	15.34			1966	2.87		
1945	14.37			1967	3.95		
1946	9.51			1968	1.01		
1947	7.69						
1948	9.46						
1949	15.65						
1950	5.12						
1951	29.31						
1952	4.62						
1953	25.01						
1954	25.45						
1955	4.80						
Mean	12.27	XXXX	13.06	XXXX	4.45	XXXX	2.31

[a]There is some question as to when the AWMC project entered the "operational" stage as defined by the contractor. Table 1 suggests that this was in 1960, when both aircraft and ground generators began to be utilized extensively. A number of farmers interviewed, thought the operational period started in 1956 when they began contributions, although the contractor now suggests 1961.

[b]The Alberta Hail Studies (ALHAS) performed some isolated seeding tests in or close to the target area S15 in 1972, which may have had some effect on 1972 hailfall.

What conclusions can be drawn from Table 2? Qualified practitioners of statistical inference in weather modification evaluation would place little significance on the results due to large yearly variations in Loss-Risk ratios, and the relatively short time series. However, some evaluators have tried to justify the approach.[1] The logic of this method would suggest, using the table, that the AWMC seeding project reduced hail damage from an average of 12.27 percent for the pre-seed years in S15, to 4.45 percent in the "operational" period, a reduction of substantial proportions.

Following the same logic, Table 2 suggests that the "developmental" period was responsible for an increase in hail damage to 13.06 percent. Carrying this logic to its ultimate conclusion, Table 2 suggests that cessation of cloud seeding in 1968 was responsible for a substantial drop in hail damage of some 48 percent to 2.31 percent. Unfortunately this type of analysis is lacking in design and statistical rigor. Consequently little or no reliability can be placed on the results.

2. Target-Control Regression Analysis--This method of evaluation has been utilized by a number of weather modification evaluators.[2] The nethod involves plotting target area L/R ratios against those in the control area for the non seeded years. These can then be compared to the results for the seeded years. The control area acts as a possible check on random changes in natural hailfalls in the target during the project.

Plots for the seeded and unseeded years are shown in Figure 3.

Figure 3 indicates some degree of correlation (correspondence) between S15 and C9 for the non seeded years under review. This is indicated by a suggestion of these plots running in a "north easterly" direction. The relationship obviously is not a strong one. This is indicated by the rather wide deviance of many of the "non seed" plots from this "north easterly" trend.[3] Were plots for the seeded years to lie in an "easterly" direction, close to the C9 axis, this would be an indication of hail suppression effects. If these on the other hand, were to fall in a "northerly" direction closer to the S15 axis, the evidence would point to hail increase from seeding. A random scattering of the seeded year plots on the other hand, would suggest no effect.

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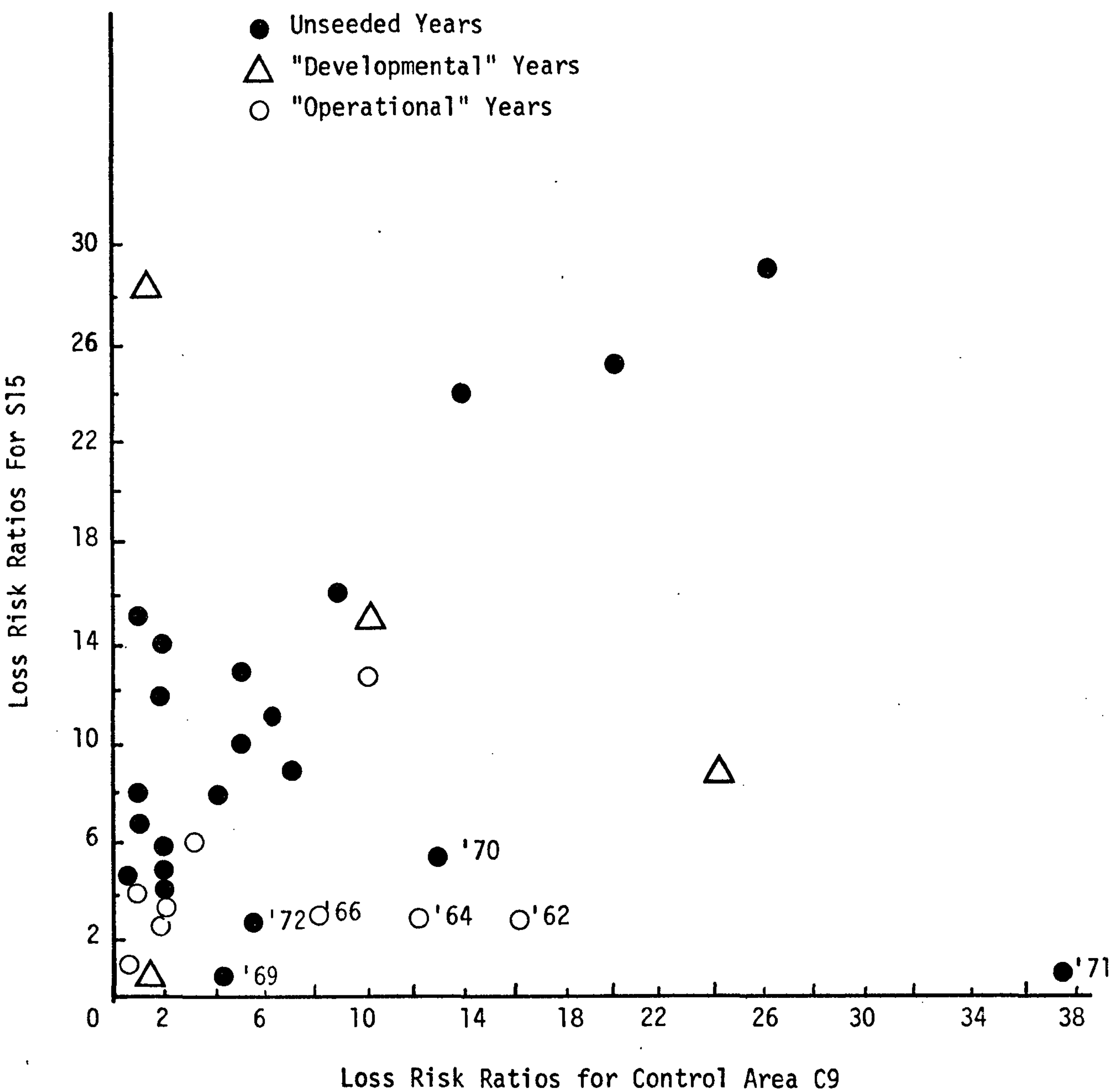
[1] Irving P. Krick and Newton C. Stone "Hail Suppression In Alberta 1956-1968". Journal of Weather Modification, Vol. 7, No. 1, April 1975, Weather Modification Association, Norman, Oklahoma.

[2] H.C.S. Thom, A Statistical Method of Evaluating Augmentation of Precipitation by Cloud Seeding, op. cit.

[3] Addition of the post project non seeded years 1969 to 1972 substantially lowered the correlations of natural hail damage between S15 and C9 suggesting that the close correspondence in natural hailfall was not maintained during the seeding period, thus weakening the evaluative power of the Target-Control method.

Figure 2

Graph Showing Relationship of Loss-Risk Ratios in Control Area C9 and Target Area S15 for the Non Seeded Years, the "Developmental" Years and the "Operational" Years of the AWMC Project[a]



[a] The graph indicates hail damage comparisons between the control and target areas under the different types of treatment in the AWMC project. Complete hail suppression through seeding, were it attained, would be represented by all of the Loss-Risk ratios for the "operational" years lying on the horizontal C9 axis. This would represent no hail damage in S15, but with varying yearly amounts in C9. No seeding effect on the other hand, would be represented by a more or less random scatter of the plots representing the "operational" years across the quadrant, while an increase in hail damage from seeding would be suggested by the plots falling in a more "northerly" direction toward the vertical axis.

A regression equation was attempted by standard statistical procedures for the non seed years, to establish a numerical relationship between S15 and C9. However, the regression line was statistically insignificant. There is visual evidence of this in Figure 3, where the graph indicates a rather random location of the plots. Furthermore, neither the "developmental" nor the "operational" plots indicate any particular visual trend which would show them to be separate and distinct in nature from the non seed ones. Thus the conclusion is that the evidence does not suggest a statistically significant change in hail damage in S15 as a result of the AWMC project.

Before leaving this evaluation approach however, there are several questions to consider. Firstly, what years should be considered "developmental" in the AWMC project? Secondly, what does the unusually low hail damage experience for the non seeded post project years of 1969 to 1972 indicate? Does it suggest a downward natural trend in hail damage experience thus invalidating the Target-Control evaluation model, or are there other inadvertant weather modification forces at work? In any event, the occurrence of these data appear to largely neutralize assertions based on Loss-Risk ratio data, that the AWMC cloud seeding project reduced hail damage in S15. On the other hand, how effective are Loss-Risk ratios as proxies for hail damage, and what assurance is there that S15 and C9 remained effective target and control areas for evaluation during the seeding period?

3. Mean Barley Yield Analysis Approach--Barley yields per acre are another source of data, which might be a useful indicator. Barley is a crop of major importance in not only the target and control areas S15 and C9, but also the southern zone, lying south of Calgary and the AWMC target area. Barley yield analysis has a further advantage of exploring the possibility of rain increase combined with hail suppression, an achievement suggested by the AWMC cloud seeding contractors.[1]

It is generally believed that years of high rainfall are associated with high hail incidence and visa versa. Thus a successful hail suppression program might be expected to provide an increase in yields through not only hail damage reduction, but also a precipitation increase.[2] Consequently barley yield analysis would appear to be a useful approach in evaluation of the AWMC project.

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[1] Irving P. Krick and Newton C. Stone "Hail Suppression in Alberta 1956-1968" Journal of Weather Modification, Vol. 7, No. 1, April 1975, Weather Modification Association, Norman, Oklahoma.

[2] Ibid.

Target area S15 and control area C9 are located in the same soil zone as defined by Alberta soils studies. Furthermore the same soil zone extends south of S15 to the Canada-United States border in a thin strip along the Calgary-High River highway.[1]

Crop yield appraisals since 1938 are available for C9, S15, and the area of similar soils south of the AWMC target area. Alberta Wheat Pool yield appraisals by grain elevator point, combined with Canadian Wheat Board acreage data provide the opportunity for weighted yield estimates of barley.[2]

Table 3 shows weighted barley yields by elevator point for control area C9, target area S15 and for an area south of Calgary on the same type of soil.

Table 3

MEAN BARLEY YIELDS PER ACRE FOR C9, S15, AND A SELECTED AREA IN THE SOUTH ZONE, INCLUDING STANDARD DEVIATIONS

Period	Area C9		Area S15		South Area	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
1938-1955 (Pre seed)	27.5	6.5	27.5	5.1	29.2	6.3
1956-1968 (Seed)	31.0	7.5	39.5	6.2	38.8	9.9

The data indicate an increase in barley yields per acre in both C9 and S15. Target area S15 shows a substantially higher increase for the 1956-68 period. Statistical tests of inference were utilized to test for significance of the yield data. Yield increases in S15 during the seeding period were found to be statistically significant.

[1]Alberta Soil Survey, University of Alberta, Edmonton, Alberta, Canada.

[2]Canadian Wheat Board, "Seeded Acreages by Elevator Point, Farmer Delivery Permits" Canadian Wheat Board, Winnipeg, Manitoba.

This at first suggests the possibility of a relationship between higher yields and cloud seeding to suppress hail and increase precipitation. However, barley yield information for the area south of the AWMC project indicates that increased yields were not restricted to target area S15. Yield increases in the south area were verified as being statistically identical to those in S15, suggesting that factors other than cloud seeding were responsible.

GENERAL CONCLUSIONS

1. It is not apparent from the evaluation approaches used in this study that the AWMC - Krick cloud seeding project was effective in reducing hail damage in Alberta for the years 1956 to 1968. This is verified by:

(a) The simple time series analysis approach, where observation of the L/R time series for the "developmental" period indicated higher hail damage than in the preceding non-seeded years in target area S15, and for the post project non-seed period 1969 to 1972, lower hail damage than during the "operational" period (Table 2).

(b) The Target-Control regression analysis approach, where attempts to derive numerical regression lines between the two areas gave statistically nonsignificant results (Figure 3).

(c) The use of barley yield analysis for the target and control areas, and also an additional area on a similar soil type, south of the target and control areas. Yield increases during the seeded period were equally large in the south area to those in the target area (Table 3).

2. The dangers of inadequate pre planning for evaluation are exemplified by the AWMC project. The result is that likely more man hours have been spent in discussing and analyzing the outcome of the project, than were used in the original cloud seeding program itself.

3. The shortcomings of especially the simple time series analysis, but also the Target-Control method in the face of unpredictable, random changes in natural hail damage between areas and between years, is demonstrated. In the former method, interpretation of the data is extremely prone to error because any seeding effects cannot be effectively separated from randomly occurring natural variations. In the latter case, a "control" area is utilized to assist in detection of changes in natural hail damage patterns in the target area. While pre-seeding hail damage correspondence between the target and control areas may appear adequate for evaluation, a deviance might well develop during the seeding project due to the vagaries of mother nature. Were such a deviance to occur, any conclusions about hail suppression by this method would be invalid. (In this study, "hind sight" analysis suggests that such a deviance occurred, even though pre-seeding correlations were high).

4. The benefits of a randomized experimental design for evaluation are made more obvious as a result of the AWMC experience. Through some type of randomization of storms to be seeded, the evaluator can much more easily cope with unforeseen natural changes and their misleading effects on his results. This is because the non-seeded check storms act as a more current indicator of these changes, should they occur.

Farm operators obviously are not overly enthusiastic about paying for a randomized cloud seeding program either through seeding fees, or crop losses, as a way to enhance public knowledge about cloud seeding effects. Thus in order to prevent continuing arguments, public assistance appears justified in financing establishment of built-in well recognized randomized evaluation designs in all cloud seeding programs, both experimental and commercial. Assistance could take the form of special subsidized crop insurance programs to offset any detrimental effects of non-seeded storms, as well as provision for design, collection and analysis of the evaluation data in the project areas. Stated conversely, public expenditure on cloud seeding projects does not appear justified unless the best available evaluation designs are employed. The need is for accumulation of reliable evaluation data which can strengthen verification of cloud seeding effects. There is in fact, some justification for legislating evaluation requirements for all cloud seeding projects, both experimental and commercial.