HAIL SUPPRESSION IN ALBERTA

1956 - 1968

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ABSTRACT

A brief review of the evolution of weather modification has been traced with main emphasis on hail suppression and rain increase as progressed by our group.

Hail suppression techniques employed in Alberta have been discussed and the present status of our own capabilities for carrying out commercial operations are reviewed. Specific benefit to cost ratios for hail suppression and rain increase are included.

HISTORICAL BACKGROUND

By the outset of WWII the long range forecasting of the California Institute of Technology (CIT) group had won sufficient recognition to justify its adaptation by the allied military establishment in the conduct of the war, since no other group had demonstrated a capability for developing reliable forecasts for more than 24 hours in advance. Our basic method was reviewed in detail in a lecture series at the United States Weather Bureau, Washington, D. C., September 29 to October 4, 1941. Unfortunately all wartime research reports and publications were classified including the Krick-Elliott report on the Weather Bureau lectures. Subsequent to WWII several million dollars were spent on research by our group and by 1957 we had the capability of preparing useful long range forecasts for several months to years in advance. This method (Krick 1972) of data processing now has yielded commercially useful predictions up to five years in advance.

This capability has been a real plus in permitting us to deliver to the client in advance of a potential cloud-seeding project an estimate of the natural weather conditions that they should anticipate. On some occasions, we have recommended against a cloudseeding program because of sufficient natural precipitation or because of insufficient natural moisture to work with.

When General Electric (G.E.) announced its first experiments in this field, the authors were still identified with the Department of Meteorology at the California Institute of Technology. Over a period of many years, the meteorological group at CIT had concerned itself not only with the study of basic meteorological phenomena, but also with the application of this knowledge to related problems (Krick 1952) of agriculture, industry, commerce, and the military. After exploring the potentialities of weather modification first in a technical sense, then by actually duplicating the experiments announced by General Electric, we initiated research by seeding cumulus clouds in Arizona with aircraft to determine the engineering practicality of carrying out an economically feasible commercial rain increase operation.

We were fortunate during the research interval of the late 40's and early 50's to be able to confer periodically with Langmuir and his associates Vincent Schaefer and Bernard Vonnegut at G.E. When that company decided not to pursue any commercial work in weather modification, Langmuir recommended that our group prepare to enter this field. We did.

Based on our fingings to that date and especially the G.E. decision in early 1950 to refrain from commercial operations, it was determined to accelerate our work in this field as well as in the field of private weather forecasting, a profession originating at the CIT Meteorology Department in the early 30's. The CIT Meteorology staff joined Irving Krick in forming a non-profit research organization in the summer of 1948 with the objectives to 1) determine the feasibility of developing an operating company to implement commercial weather modification operations; and 2) to adapt the long range weather forecast technique (that had been researched intensely from the middle thirties) to a numerical process.

RESEARCH INTO ALL PHASES OF WEATHER MODIFICATION

Research was an absolute necessity prior to commercial application. Based on our theoretical and laboratory work at CIT prior to forming our objectives which were 1) commercial operations, which force a company to produce a substantial benefit to cost ratio for the consumer, 2) field research on specific problems that were considered the key to commercial operations, 3) not only a concentration on the delivery of solutions in the shortest period of time but to create a domestic pool of skill and experience that could become an exportable commodity -- we initiated field research in southeast Arizona for the Salt River Valley Water Users. Seeding and meteorological measurements were carried out with aircraft. Detailed investigations of the dynamics of the clouds were initiated prior to, and after, seeding with dry ice and AgI. The thunderstorm circulation was studied. Precipitation measurements were made. By 1949, it was found that an economical way to carry out commercial precipitation increase programs was with ground generators. It was not only found to be more economical than our aircraft work but more efficient. Then we went on and evolved many different types of generating equipment, both aircraft and ground. We eventually found that the dry type of AgI nuclei production was best. Seeding equipment took the form of coke impregnated with AgI and later solid electrodes of AgI used in an electric arc type generator. In the early 1950's we started a number of field research and operation projects. Research on the development of pyrotechnics for aircraft use started in the early 50's. Two field research projects were carried out in Colorado and northeast New Mexico in the early 50's to determine AgI rates of rise for airmasses with differing stability characteristics for each hour of the day. AgI and zinc sulphide were released at the ground and the downwind areas were traversed with an instrumented aircraft to determine width of plumes with varying instability and wind speeds. Cloud-seeding indices were developed. Evaluation procedures were worked out, first subjectively, then as experience accumulated, objective statistical and physical procedures were developed.

As a result of favorable field research results with cumulus and cumulonimbus clouds, we started our first hail suppression field research in 1951 in Colorado over Logan and Washington Counties, (Crow 1951) a high hail incidence area ... 40 miles wide (west to east) and 95 miles long (north to south), about 85 miles northeast of Denver. One aircraft and 24 ground generators were used. Only light hail occurred in the target whereas heavy hail was observed upwind during these experiments. Hail suppression field research and operations work were then expanded to California and Oregon.

FIELD RESEARCH AND OPERATIONS FOR HAIL SUPPRESSION EXPANDED TO ALBERTA IN 1956

In May 1956, about 1,000 farmers in Kneehill and Mountain View Municipal Districts in the province of Alberta decided to sponsor a program on their own.

Accordingly, the first hail suppression research and operations to take place in Canada started on July 20, 1956. Only ground generators were used the first season. Many problems were encountered in trying to install ground generators in the cloud-breeding areas over the mountains to the west because of lack of communications. This was partially overcome the second season.

The project area experienced damage in only a few small sections, but hail was generally severe in the Carstairs-Cremona area and in the Wimborne area, both lying outside the target. Basically, as a result of the apparent success or from chance the first season, the project was expanded in 1957.

By August 1960, we had modified our hail suppression principles and techniques to fit the specific synoptic weather patterns for Alberta targets, had developed a technique for making a hail forecast with confidence, and added new remote automatic generators. In 1960 we added more aircraft, using four Harvards to augment the ground generator network. The aircraft seeding hours increased from 115 hours in 1959 to 330 hours in 1960.

PRINCIPLES OF HAIL SUPPRESSION AND BASIC THEORY UNDERLYING COMMERCIAL OPERATION TECHNIQUES

The most commonly accepted method of hail formation in a thunderstorm is based upon two fundamental premises -- strong vertical air currents and a region of supercooling in the clouds. The theory maintains that a nucleus of frozen water is subject to a series of updrafts, which transport the initial stone or hail embryo from the warmer portion of the cloud to colder areas; there an additonal layer of ice is acquired. Then the stone may be carried higher, remain at the same altitude or drop to a lower altitude again picking up a layer of water. If the updraft becomes sufficiently strong the stone will be carried to colder levels again and again with additional layers of ice forming. When the stone grows to a size that cannot be supported by the updrafts, it falls to earth.

It has been found that weather situations which constitute a serious hail threat require the presence of water supercooled in the clouds. The degree of supercooling is very important in relation to the degree of hail threat. In these situations it has also been found that there is a substantial deficit of ice nuclei, permitting a high degree of supercooling. If artificial ice nuclei (silver iodide) are introduced, supercooling can be minimized and thus the chance of hail formation reduced.

A supercooled cloud is one in which liquid water exists at temperatures below freezing. Such a cloud becomes very favorable for hail formation as a result of airstreams carrying this unfrozen water upward to regions of sufficiently low temperatures so that the liquid water freezes.

In Alberta, the energy required to transport the liquid water upward may result from either the heating of the land, the cooling of the air aloft, lifting of the air in the cloud-breeding area due to the air flowing from the southeast, east, or northeast up the sides of the mountains or foothills, lifting of the air due to local storms, or squall lines forming over the east slopes of the mountains and becoming sufficiently intense to start an eastward movement, cold fronts, or a combination of one or more of these methods. This results in increased instability within local areas of the airmass, tending to trigger a vigorous and rapid intensification of a potential hailstorm.

If one can control the release of this energy as to place and time by the introduction of silver iodide in the proper amounts, the energy transformation will be more gradual and widespread. The physical change from the supercooled state to the ice crystal stage, releases heat energy. If there are ample ice nuclei present, the energy is released slowly and dispersed gradually, laterally as well as vertically. This effect minimizes vertical cloud development and cuts down the threat of hail. We operate in such a way that this effect takes place simultaneously over wide areas.

BASIC CONCEPTS UNDERLYING OUR COMMERCIAL HAIL SUPPRESSION OPERATIONAL TECHNIQUES INCLUDE:

1. Increasing the number of ice nuclei present by introducing silver iodide. Assuming the amount of moisture in the cloud or airmass remains the same, this requires that the individual drops or ice crystals forming on nuclei be small. The small sizes are less likely to grow into hailstones and if they should fall would be more likely to melt before reaching the ground. If an entire cloud system can be glaciated continuously *no* hail forms.

2. Introducing silver iodide into supercooled clouds or into an

airmass continually and at a time of day which reduces a hail threat. For example, the silver iodide would be released on a broad scale in the early forenoon prior to the average hail threat times (before intense surface heating during the afternoon). The resultant effect on atmospheric energy transformations might be compared to a full reservoir from which water can be released gradually in contrast to the rupturing of a dam which would suddenly release all the stored water (energy) producing great damage.

3. Introducing silver iodide into the supercooled clouds or into an airmass well back into the foothills so that any release of energy will occur well west of the Blue Hill Lookout or Mockingbird Hill Lookout (about 40 miles west of targetarea) before reaching the hail suppression target.

4. Seeding with silver iodide causes some heat to form in the airmass orsupercooled cloud when it is carried to high levels where the temperature is minus 5°C. (plus 23°F.) or colder. When this action occurs simultaneously over a wide area it causes the airmass to become more stable. Other weather parameters being equal, the vertical currents that are responsible for carrying liquid (unfrozen) moisture to higher levels are decreased.

5. Intense heating of the air in contact with the ground resulting from the sun's heating has been found to be very important in the formation of hailstorms. It has been observed that cumulus-type clouds will spread laterally (that is, cover a larger area) as they are seeded and crystallization takes place resulting in the effect described in 4. Through concentrated cloudseeding over a target area and its upwind approaches, this lateral spread of the cloud system greatly reduces the amount of insolation which reaches the ground, further reducing the chance of rapid and intense vertical cloud development.

6. When silver iodide is released into a supercooled cloud, the moisture changes to ice crystals (or snow). When and if hail should form from the ice crystals, the hail will be opaque (milky in color), soft, and will generally melt before reaching the ground. If hail forms from supercooled water, it will appear clear, will be relatively hard and hailstones will more likely reach the ground and cause crop damage in comparison to soft opaque stones.

One very important phase of a commercial hail suppression project is the requirement that it must be carried out 24 hours per day, seven days per week for the entire funded area. Randomization, which leaves some storms unseeded, is not practiced in commercial hail suppression because farmers could lose their entire crop in a few minutes (the length of time required for the hail cell to traverse a farm) should a single unseeded storm produce severe hail. Round the clock operations are also important when considering the fringe benefits from rain increase. It must be noted that 30 to 40% of the summer rainfall in Alberta occurs between 9:00 P.M. and 6:00 A.M. Cloudseeding during severe storms with aircraft generally is confined to the daylight hours and VFR conditions; therefore, only a network of ground generators achieves optimum efficiency for rain increase.

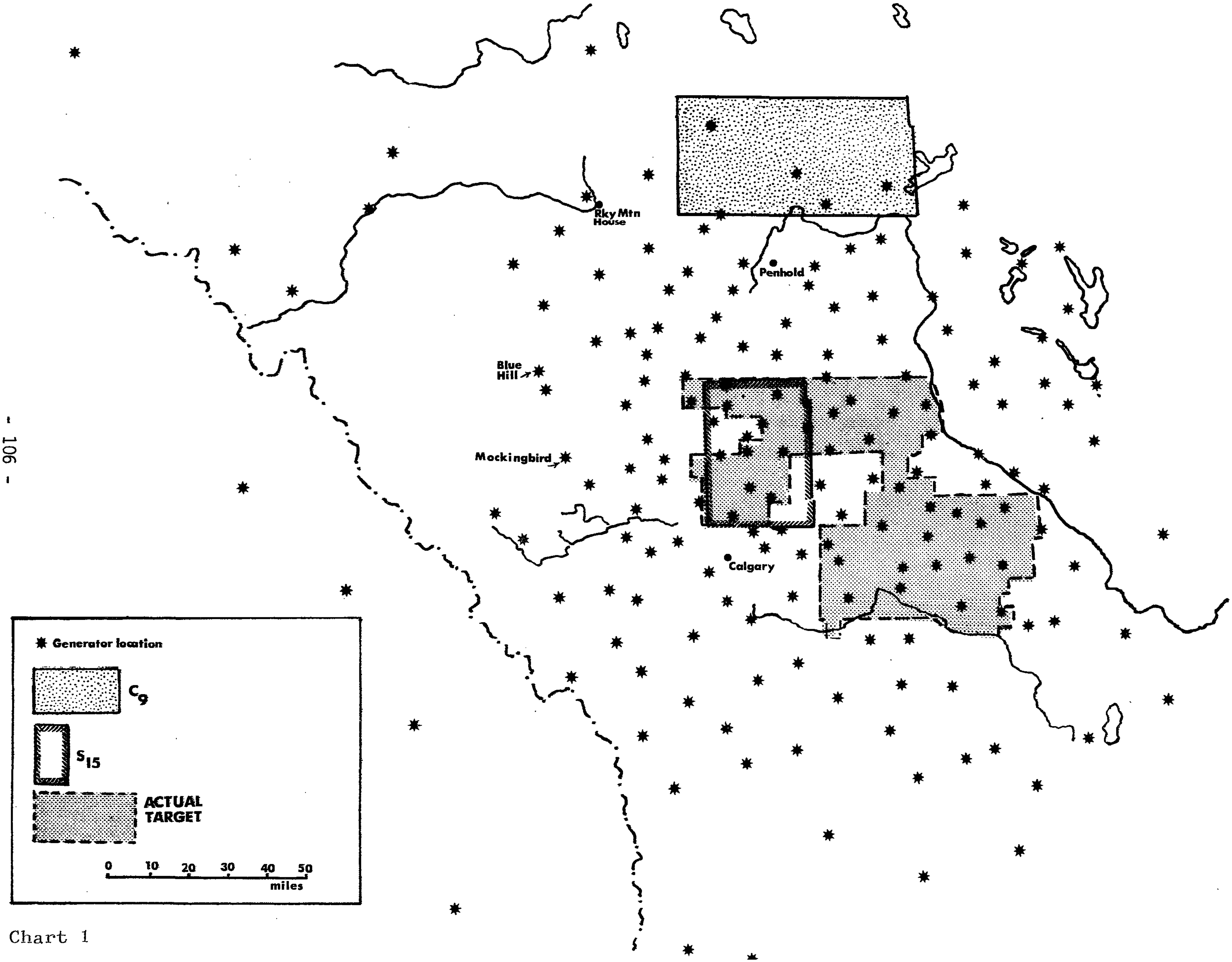
Rky Mtn House
Penhold
Blue Hill
Mockingbird
Calgary
Generator location
C_9
S_{15}
ACTUAL TARGET
0
10
20
30
40
50
miles

Chart 1

This phase of the program has become a vital adjunct to hail suppression in connection with our work in Alberta.

OUR COMMERCIAL OPERATIONAL CAPABILITY COMPLETE BY 1961

After five years of field research and operations in hail suppression specifically for Alberta, we had been able to accomplish the following:

1. Development of realistic hail model which considered the approaching airmass, the cloud-breeding area, and the life cycle of a series of developing, then dissipating cells followed by the redevelopment of new cells. No two cells develop identically and the life cycle of moving cells across the target is found to be dependent on a proper assessment of the meteorological situation, from the ground to above 40,000 feet.

2. Because of the extreme variation in the wind flow associated with cumulonimbus cells from the ground to 40,000 feet, specific aircraft seeding patterns were developed to supplement continuous ground generator operations. These patterns were coded for rapid communication to all pilots. One code number could define the approximate positions for up to three aircraft on one cell.

   Finer adjustments and changes are made during operations depending on weather reports received continually from the pilots, the Atmospheric Environmental Services special teletype circuit, our special weather observing network, and from single station analyses for interpreting any change in wind direction for the entire target area.

3. Refined hail forecast technique that permitted us to estimate timing, first threat areas (cloud-breeding zones), severity of threat, likely tops of hail cells, and the steering winds. Timing is the key concern so as to activate all cloudseeding systems <u>before</u> hail is imminent.

4. Determine equipment requirements to do the job including aircraft, aircraft generators for pyrotechnics, ground generators, atmospheric static electricity discharge meter, AgI output, suitable data records, evaluation procedures, and use of experienced personnel which was found to be the critical element in achieving real success.

5. Excellent communications had been established for both air and ground operations.

It was in 1961 that all phases of the above accomplishments were initiated at the beginning of the hail season. Our basic seeding techniques have been the same from that date, although valuable experience and skill continue to accumulate.

EVALUATION

The <u>actual</u> approximate hail suppression target is identified on CHART 1.

This area has been variable in size and shape from year to year and has averaged about two million acres. For evaluation purposes, Petersen and Apedaile, 1970, selected an area defined as S_{15} (shown on CHART 1) as the study target. This area was selected because the townships making up this area were in the actual target most frequently. The study target (S_{15}) was located in the main "hail alley" of Alberta where the most severe hail storms cause the maximum hail damage to crops with the greatest frequnecy. Many townships in the study target area show average annual hail insurance premiums as high as 20 percent. Petersen and Apedaile selected as one control area (C_9) shown on CHART 1.

The basic loss to risk (L/R)* data used in this evaluation were furnished by the Alberta Hail Insurance Board. The historical data starts with 1919, but due to missing data for 1937 and other changes in the early records, it was decided to use the continuous historical period starting with 1938. One potentially serious limitation in using L/R data is the variations in risk written from season to season. Petersen and Apedaile, 1970, concluded that "for these two areas (S_{15} and C_9), variations in risk written from year to year and trends over longer periods do not seriously affect reliability of loss risk ratios for evaluation of total area losses."

Based on the L/R data of S_{15} and C_9 we find:

1. For selected study target S_{15} -

    a. L/R for historical period (1938-1960) prior to full hail suppression) = 12.4

    b. L/R for full hail suppression period (1961-1968) = 3.5

2. For selected control area C_9 -

    a. L/R for historical period (1938-1960) prior to full hail suppression) = 6.8

    b. L/R for the 1961-1968 interval (during full hail suppression for S_{15}) = 5.6

This change for C_9 from 6.8 to 5.6 is insignificant due undoubtedly to occasional effects from seeding when airstreams being treated were moving from south to north. It is very important to note that no other 8 successive year period out of a total of 16 intervals for S_{15} (historical record prior to full hail suppression) averaged less than 10.2. This compares with 3.5 for the 8 successive years for the hail suppression period (1961-1968).

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*(Estimated loss) divided by the (risk insured) x (100) expressed as a percentage. The L/R in any givenseason refers to both the areal extent and the intensity of damage within a specified region.

Based on the average L/R for the study target area (S_{15}) of 12.4 (prior to complete commercial operations) and only 3.5 for the hail suppression period, the amount of hail damage was 71% less during hail suppression. This compares with little change in the control area (C_9).

Figure 1 reviews L/R data in the selected target S_{15}, 1) before operations, 2) during research and testing period, and 3) during operational interval (see Figure 1). The period from 1956 through 1960 was defined as a developmental interval in our effort to achieve maximum efficiency. Various combinations of personnel, equipment, and procedures were tried to find the best arrangement within funding available. By 1961, these objectives had been achieved and from that year onward L/R was held well below the historical average. Thus the conclusion was finally reached placing the reduction in L/R by 71%.

Referring to Figure 1, the average L/R before operations (1938-1955) is 12.3. During the operational period (1961-1968), the L/R is 3.5. This, too, gives 71% less hail during the hail suppression interval. Since the eight successive year L/R average for the study target of 3.5 is smaller than any other such interval, it is considered highly significant. In fact, the 3.5 L/R is about one-third as large (1/3 of 10.2) as any other eight successive year period out of a total of 16 such intervals (before complete hail suppression 1938-1960).

Now, the original objective was to determine a benefit to cost ratio from a full commercial hail suppression operation. A rough average of the size of the hail suppression target, although it varied some from year to year, was 2,000,000 acres (rain increase benefits extended over an area exceeding 6,000,000 acres* -- approaching 100% of the time during operations). According to Petersen-Apedaile, the average annual value for field crops in Alberta during the 1961-1968 period was $563,000,000.00 and grown on about 16,000,000 acres. The actual hail suppression target of 2,000,000 acres is 1/8 of the total annual value (assuming that crop value is equally as valuable in all areas). 1/8 of $563,000,000.00 = about $70,000,000.00 value of crops in target. Since the long term L/R average is about 9.6 (this refers to Actual Target shown on CHART 1), this means that over a period of several years the amount of hail damage to crops as a result of hail would average about 9.6%.

The 9.6% of $70,000,000.00 = $6,700,000.00 average loss in hail suppression target because of hail. The 71% decrease in hail damage from hail suppression operations suggested from an examination of historical L/R data indicates a benefit to the farmers of $4,700,000.00, or 71% of $6,700,000.00.

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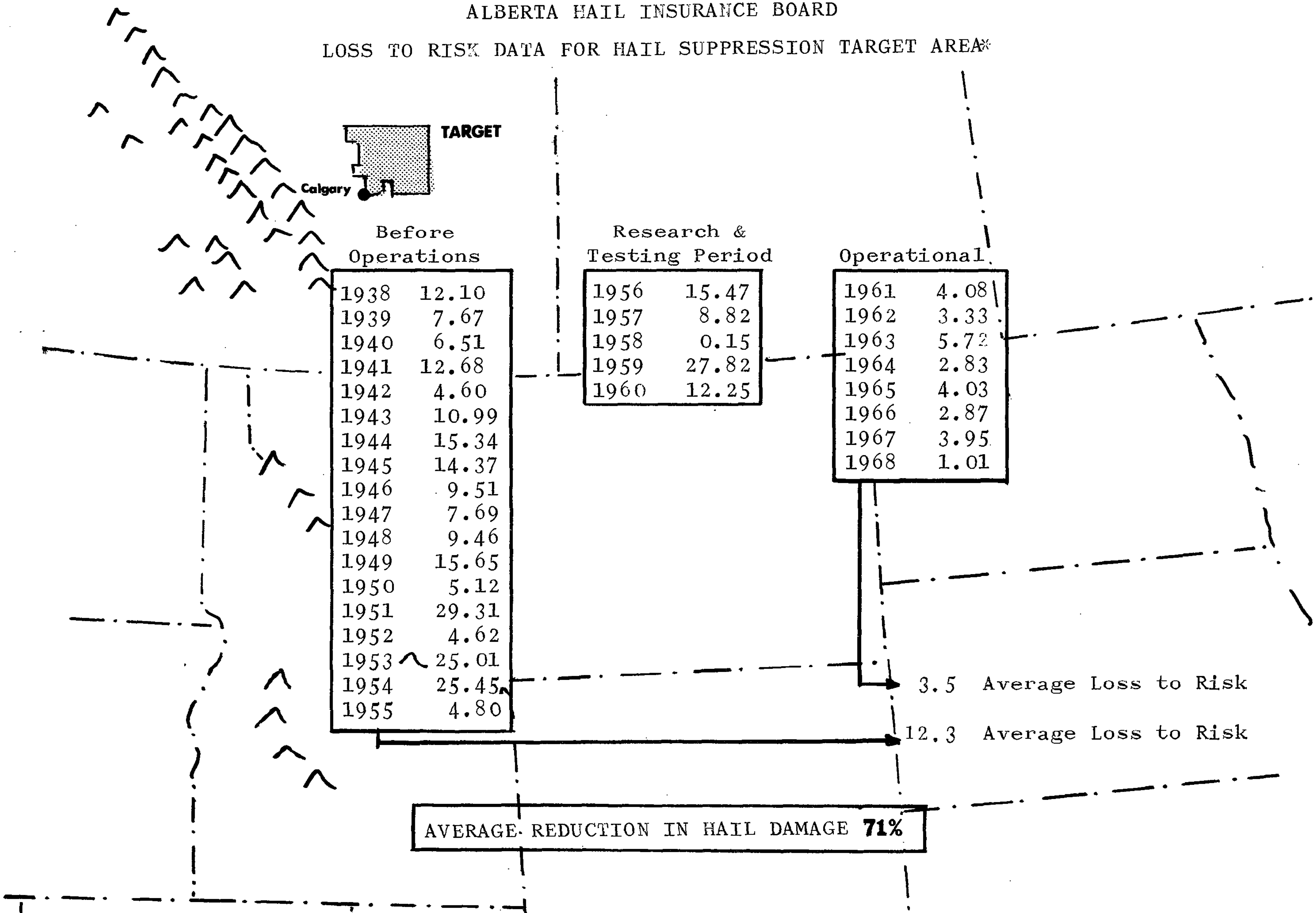
*See CHART 1 for location of silver iodide ground generator network for 1963 (which was typical). Each generator site is identified with a star and note several were over 50 miles distance from target.

ALBERTA HAIL INSURANCE BOARD

LOSS TO RISK DATA FOR HAIL SUPPRESSION TARGET AREA*



Before Operations

1938	12.10
1939	7.67
1940	6.51
1941	12.68
1942	4.60
1943	10.99
1944	15.34
1945	14.37
1946	9.51
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

Research & Testing Period

1956	15.47
1957	8.82
1958	0.15
1959	27.82
1960	12.25

Operational

1961	4.08
1962	3.33
1963	5.72
1964	2.83
1965	4.03
1966	2.87
1967	3.95
1968	1.01

3.5 Average Loss to Risk

12.3 Average Loss to Risk

AVERAGE REDUCTION IN HAIL DAMAGE **71%**

Hail suppression operations performed by Irving P. Krick Associates of Canada, Ltd.

*As used by Prof. Petersen in a restricted report 25 September 1970

Figure 1

The cost for hail suppression and rain increase for the full hail suppression target per season averaged about $100,000.00. This gives a benefit-to-cost ratio of about 47 to 1. Thus, for every $1.00 spent there would be a return of about $47.00 as a result of hail suppression alone. Note that this does not include benefits from rain increase. The benefit-to-cost ratio for rain increase, which extended over a total area of about 6,000,000 acres, far exceeds that for hail suppression.

RAIN INCREASE AND OTHER BENEFITS ACCOMPANY HAIL SUPPRESSION

Based on our own experience, as well as that of many others in the field of weather modification, an estimate of precipitation increases achieved from cloudseeding in summer storms is a minimum of 15 to 20%. In connection with the operations in Alberta, we have found these values to be very conservative indeed.

The normal rainfall for the target during June, July and August is about 8 inches. If we take the lower value of 15% increase, this would equal 1.2 inches. It has been estimated by agricultural experts that one additional inch of rainfall will produce an added 3 bushels of Alberta wheat per acre. This would equal an added benefit of at least $3.00 per acre at that time. We are assuming the value of other crops to be in this range also. Crop values are higher now. The original cost per acre for hail suppression was $100,000.00 divided by 2,000,000. If we assume that the farmers paid the $100,000.00 for rain increase only, this would still give a benefit-to-cost ratio of 30 to 1, assuming half of the land lay fallow. This means that $30.00 is added to each farmer's income for every $1.00 spent. Now, if we take the entire area in Alberta affected by fringe benefits from rain increase as 6,000,000 acres (see ground generator network on Chart 1) and that one half lay fallow, this equals $9,000,000.00 added benefits to the Alberta farmers and ranchers. Again, assume that the entire cost of the operation is for rain increase, at an average of $100,000.00 per crop season. This alone gives a benefit-to-cost ratio of 90 to 1 excluding the benefit-to-cost of 47 to 1 for hail suppression (only within the study target).

The Institute of Atmospheric Sciences, 1970, made the following published statements which tend to substantiate some of our findings. They are:

1. "From what is known at this time the cloud seeding techniques and technology for hail suppression and rain increase operations are sufficiently similar for the programs to be emerged."

2. "Benefits obtained from hail suppression would be in addition to those received from rain increase operations."

3. Quotes spring wheat yield studies that indicate for "each additional inch of annual rainfall over 8 inches increased yields in the Great Plains by an average of 2.19 bushels per acre. However, South Dakota wheat yield is highly dependent on growing season precipi-

tation. Therefore, an additional inch of rainfall during the growing season should increase wheat yield even more than 2.19 bushels per acre. The increased yield might be as much or more than that found for southern Saskatchewan, Canada, where the yield increased by approximately 6.5 bushels per acre for each additional inch of water used above 10.5 inches".

4. Each additional inch of annual precipitation increases the average annual-unit-months per acre by 15 to 20% (under moderate use in the growing season). This applies to grass production for grazing in northern Plains and southern Canada.

5. Each additional inch of mean annual precipitation increases the value of land and buildings at an average of about $8.00 to $27.00 per acre (based mostly on 2 areas, West River grazing lands and East River crop lands in South Dakota).

6. "A program of cloud seeding which substantially reduces hail would bring large economic benefits to property owners." Savings on insurance premiums to insure farm buildings, etc. against hail damage could be substantial.

The above benefits listed in items 4, 5, and 6 are considered important but have not been included in the benefit to cost ratios cited above.

The AWMC* prepared an evaluation of crop yields based on the relationship of wheat yields in cloudseeding projects and in the Province in comparison to the historical record prior to cloudseeding. GRAPH 1 shows these comparisons. GRAPH 1 indicates that the increase in wheat yields in the seeded area is more than 6 bushels per acre (twice the value we have used in this report) greater than in the non-seeded area. It must be emphasized again that several million acres outside the target area receives fringe benefits from rain increase.

A brief explanation of GRAPH 1 -- note the following:

1. Close relationship of all areas prior to cloudseeding for period 1942-1956.

2. Close relationship between Province and Wheatland County, both not cloudseeded, is maintained for 1957-1962 period. Project yields up sharply.

3. Sharp advance in yields of both cloudseeding areas compared to Province 1963-1968.

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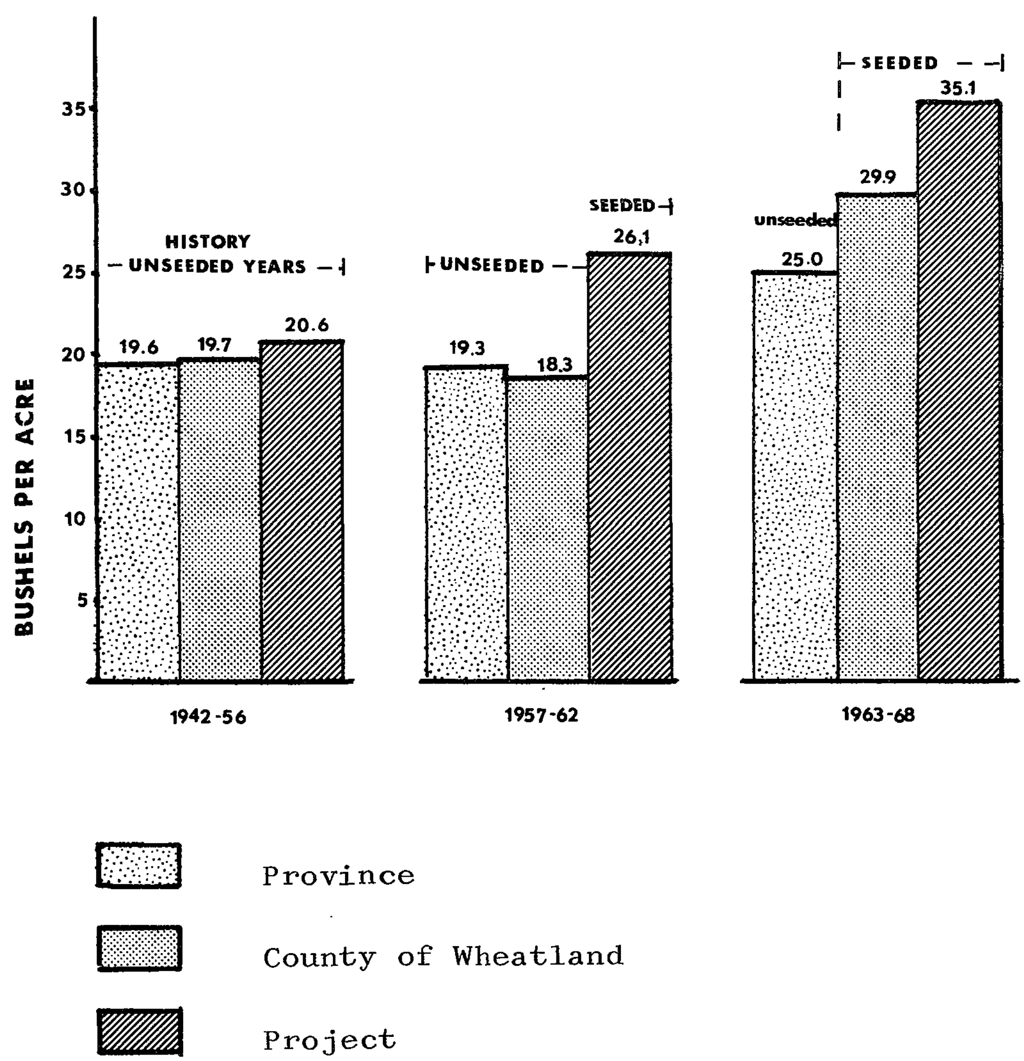
*Alberta Weather Modification Co-op (group sponsoring the hail suppression research and field operations). The Graph was prepared by J. T. Bishop, Data Compiling Division of AWMC, 1969.

RELATIONSHIP OF WHEAT YIELDS IN CLOUDSEEDING PROJECTS
AND IN THE PROVINCE IN COMPARISON TO HISTORY PRIOR TO CLOUDSEEDING

Yield records supplied by Alberta Crop Insurance Corporation



Graph 1

4. Wheatland County had a 6 year average of 2 bushels higher than the highest individual year in history.

5. Part of this increase may have been due to improved farming practices, but it may still prove significant when viewing subsequent years.

CONCLUSIONS

1. Commercial hail suppression operations (based on the Alberta project from 1961 through 1968) show a benefit-to-cost ratio of 47 to 1. Added benefits in the study target from rain increase were 30 to 1. Thus, total benefit-to-cost in the target is about 77 to 1.

2. For the 1961-1968 period of operations and based on the Petersen-Apedaile 1970 report, the hail damage in the study target was 71% less than during the historical period 1938-1960 while at the same time no significant change occurred in the control area.

3. Fringe benefits from the inevitable rain increase phase over a total of about 6,000,000 acres (3 times the size of hail suppression target) yielded a benefit-to-cost of around 90 to 1.

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