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EVALUATION OF GROUND GENERATOR CLOUD SEEDING IN SOUTHERN ALBERTA (1977-1983)

by

NACIM AKTARY

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

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IN

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Supervisor

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Date 26 September 1985

DEDICATION

NAFISSA	To my wife, Nafissa, in recognition of her love and affection during times of hardship.
MIRWAIS WALIE ZACKIE	To my son, Mirwais and my twin baby boys, Walie and Zackie, with the hope that each one some day in the future will dedicate his own thesis to his own children.

ABSTRACT

A summary of recent commercial cloud seeding operations in southern Alberta is presented. The most commonly used methods of evaluation of cloud seeding experiments are described. The conclusion of J.T. Bishop, Research Director, Alberta Weather Modification Co-operative, that average rainfall increases of 30 to 40 percent resulted from cloud seeding by release of silver iodide from ground generators in southern Alberta in 1977 and 1980-1983 is re-examined. The Bishop evaluation parameter E is directly proportional to the ratio of the control area average rainfall for the unseeded period to that of the target area for the unseeded period. This ratio, as its definition indicates, is independent of the seeded period (or of cloud seeding) and its numerical value varies with changes in the duration of the unseeded period alone. For this reason, the Bishop evaluation parameter E proves to be very sensitive to the duration of the unseeded period. The use of sets of rainfall stations different from those employed by Bishop results in different values of E. The statistical significance of differences in E-values between seeded and unseeded years is tested. No conclusive evidence of a change in target rainfall amounts could be found as a result of cloud seeding by release of silver iodide from ground generators in southern Alberta in 1977 and 1980-1983.

This conclusion is supported by alternative estimates of target rainfall derived from objective analysis of control station rainfall data.

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This study would not have been possible without the active co-operation of J. Bishop, Research Director, Alberta Weather Modification Co-operative. Mr. Bishop willingly supplied copies of his original worksheets and was always available to answer specific questions on details of the cloud seeding operations and his analysis procedure. I would like to present my sincere thanks and gratitude to Dr. K.D. Hage, my supervisor, for his advice and guidance necessary for the preparation of this work. Dr. Hage was always helpful to me when I needed him and spent many hours correcting my first draft. I wish to express my thanks and gratitude to Dr. E.R. Reinelt for his advice and counsel on objective analysis procedures and for his encouragement and moral support during my period of study at the University of Alberta. I am grateful to Dr. D. Chanasyk of Soil Science for being a member of my oral examination committee, to Dr. E.P. Lozowski, who did not hesitate to help when I needed him, and to Dr. R.B. Charlton for his friendly attitude. I am indebted to Professor Amos Eddy and his colleagues in the Oklahoma Climatological Survey for sending a special tape of Montana daily precipitation data with detailed information on data format and to Dr. Raymond Wong and his colleagues in the Atmospheric Sciences Department of the Alberta Research Council for access to tapes of Alberta daily precipitation data. My particular thanks are due to Ms. Laura Smith who kindly typed this manuscript and was always helpful during the time I spent at the University of Alberta, and to the staff of the Cartography Division for production of the figures. I wish to present my appreciation to my friend, Fred Hopper, for his help in computer programming. Financial support for this work was provided in part by the Alberta Research Council under Contract ARC-UOA 109.00.85.

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CHAPTER 1

INTRODUCTION

The object of this research work was to analyze the results of weather modification by cloud seeding in southern Alberta. The operations were carried out for the purpose of increasing rain, much needed by farmers in this dry region. Silver iodide (AgI) was dispersed as the seeding agent towards the cloud bases by ground-based generators. The details of the operations will be given in due course.

1.1. Operational Cloud Seeding

Cloud seeding is the most important aspect of weather modification and is undertaken for the purpose of stimulating precipitation, dissipating cloud or fog and suppressing hail. By definition, cloud seeding is the introduction of very small solid particles in a supercooled cloud in order to increase artificially the number of ice nuclei upon which supercooled water can freeze to form ice crystals. Once ice crystals and supercooled water droplets are both present in the seeded cloud, the Bergeron-Findeisen mechanism of rain formation is triggered. The equilibrium water vapor pressure over the surface of a supercooled water droplet is considerably higher than that over an ice crystal at the same temperature, because water molecules can escape more easily from liquid water than they can from ice. Consequently, as the ice crystal is exposed to a vapor pressure higher than the one determined by the temperature, water vapor will deposit upon it and freeze. As a result, the ice particles will grow rapidly by condensation and may reach a size of one or two millimeters during the course of an hour. Crystals of this size, on falling through the cloud and melting, may reach the ground as drizzle drops. Near the 0°C isotherm, the crystals tend to aggregate to form snowflakes which may then melt to form much larger raindrops.

The concentration of natural ice nuclei in the atmosphere is very small and occasionally it is less than that required for efficient initiation of the Bergeron-Findeisen process briefly described above. When this is the case, it should be possible in principle to induce a cloud to rain by seeding it with artificial ice nuclei that will cause ice to appear. This is the scientific basis of the rainmaking experiments that have been carried out in the past.

Scientific cloud seeding dates from the time of discoveries made by a group of American scientists in 1946 (see Section 1.2) who demonstrated that spraying some sort of solid tiny particles inside some clouds results in precipitation from the cloud. After the discoveries, some of the first cloud seeding operations performed by the public were carried out by crop dusters who experimented in cloud seeding on their own or in service to a farm group. Within several years, a more systematic cloud seeding came into being as small private firms and individuals possessing scientific knowledge in the field of meteorology and cloud physics started commercial seeding for a variety of clients.

Private cloud seeding activity in the United States has been carried on at a moderately uniform level since the early 1950's. The 30 or so annual projects during the 1950's and 1960's, excluding fog clearing, were mostly carried out by five firms, having on their staff people skilled in meteorology and cloud physics. Among these cloud seeding firms, mention should be made of the company formed in the western United States by Dr. Irving Krick, former head of the Department of Meteorology at the California Institute of Technology. After Krick left the department, his company carried out some seeding projects for ranchers in San Diego County, California, in Mexico, and for the Salt River Valley water users in Arizona in 1948 and 1949. In 1950, Krick formed the Water Resources Development Corporation in Denver and began cloud seeding over the Great Plains and elsewhere in the West, and also other countries, including Canada.[6]

The effect of cloud seeding for the purpose of increasing rain is still controversial. Although cloud seeding has spread all over the world since 1946, its acceptance as being effective is far from unanimous. The enthusiasm of the late 40's and early 50's had been eroded when some cloud seeding programs did not achieve the stated purpose of stimulating precipitation. On the other hand, there are many farmers and others who firmly believe in cloud seeding as a means of rain increase. The literature related to the practice of cloud seeding is full of articles describing cases where a rain increase has been reported as well as cases of cloud seeding with no increase at all. However, the increase in rainfall is not considered as substantial and, by some people interested in the matter, is attributed to the large variability of climate and precipitation patterns.

1.2. Schaefer's Experiments

Vincent J. Schaefer, a member of the Irving Langmuir group at the General Electric Research Laboratories in Schenectady, New York, was the first to try an actual cloud seeding experiment. On 13 November 1946, flying aboard a light aircraft, he dropped about 1.5 kg of dry ice pellets (solid CO_2) into a supercooled cloud near the Berkshire Mountains of western Massachusetts. The result was spectacular, for within five minutes or so, the super-cooled stratocumulus had turned into snowflakes. These fell down for about 600 m below the cloud base and into dry air before changing phase by sublimation.

During half a century before Schaefer's experiment, other scientists like Alfred Lother Wegener, Tor Bergeron and Walter Findeisen were involved in research in the matter of physics of clouds and precipitation (Wegener 1911; Bergeron 1933; 1935, Findeisen 1938). Through years of studies, they came to the conclusion that important atmospheric processes, including precipitation from clouds "sometimes occur or fail to occur because of the abundance or scarcity, respectively, of ice-forming nuclei in the atmosphere and that the ice nuclei might be supplied artificially" (Dennis 1980). Hence, the theoretical basis for weather modification existed prior to 1946 and Schaefer took the first step to cross the barrier separating theory and practice.

One day in July 1946, some months prior to his dramatic flight, Schaefer was conducting experiments on the behavior of supercooled water droplets in a cold box. In order to lower the temperature t desired value, he decided to add to the chamber a large piece of dry ice which has a surface temperature of about -78°C. When the dry ice pellets were dropped in the box, immediately a trail of countless small ice crystals appeared along its path. Observing the phenomenon, Schaefer was quick to realize that the freezing of the supercooled droplets was caused by the extremely low dry ice temperature. He also realized that he had discovered an effective means to nucleate supercooled clouds.

Schaefer's discovery and successful cloud seeding experiment brought to the attention of the scientific community the fact that dry ice had been used a few years earlier in attempts to modify clouds (Veraart 1931). In fact, in the summer and fall of 1930 in the Netherlands, August W. Veraart had seeded clouds using dry ice. Evidently some credit is due to Veraart for having the insight to use dry ice, but most is due to Schaefer because he discovered the use of dry ice independently and proved its effectiveness by a series of related laboratory and field measurements.

In addition to the use of dry ice, Schaefer found that an ordinary sewing needle or other objects, first cooled to a temperature of about -40°C, and then introduced into a cold box chamber containing a cloud of supercooled droplets, would have the same results as did the dry ice. Thus it was concluded that, in the first place, the dry ice lowers the temperature in the box to about -40°C and, in the second place, the snow crystals begin to form. This is because in the absence of ice nuclei, "for pure water droplets, homogeneous freezing does not occur until a temperature of about -40°C is reached" (Rogers 1979). At these temperatures, the crystals can form directly from water vapor. When a few crystals are present, they grow rapidly in size at the expense of supercooled liquid water by the Bergeron-Findeisen process.

As the experiments in the laboratory turned out to be satisfactory, the following crucial step consisted of going out into the free atmosphere to see whether or not the laboratory results could be replicated. Schaefer then laid plans to test his method in the free atmosphere on an actual supercooled cloud, and did so with the results already mentioned. While Schaefer was flying aloft, Langmuir was watching the experiment and listening on the radio from the control tower of the General Electric Laboratories. He was quite excited for he "saw the fall of crystals following the seeding and was convinced clouds could be modified" (Battan 1969). In the months which followed, the experiment was repeated many times with success.

1.3. Silver Iodide as Seeding Agent

In 1946 Bernard Vonnegut joined the team of Langmuir and Schaefer at the General Electric Research Laboratories. The team then established in short order the effectiveness of dry ice as an ice nucleant. As mentioned before, dry ice can make crystals of ice to form only by lowering the temperature to a value necessary for nucleation on the available ice nuclei or even in the absence of any nuclei. In addition to this drawback, the storage and transportation of large quantities of dry ice are difficult problems to cope with, for the amount used in cloud seeding by aircraft "runs in the vicinity of a few pounds per mile of flight of the airplane" (Battan 1962). It was then necessary to seek other substances which could serve as ice nuclei upon which the water droplets could freeze at relatively higher temperatures, i.e., a few degrees below the freezing point. Vonnegut, pressing on with the search, reasoned that a substance capable of such conversion should have crystal properties similar to those of ice and, therefore, he reviewed tables giving the structure of over a thousand crystals. At the end, he came to the conclusion that silver iodide (AgI) with its hexagonal crystal form and its atoms assuming an arrangement similar to that of oxygen atoms in ice was the most promising compound.

Continuing on with experiments in a cold box, Vonnegut found that AgI had nucleating capabilities at temperatures as high as -3°C, much above the temperature of -40°C at which pure water droplets freeze. Next came the problem of how to generate a large number of silver iodide particles from a given quantity of it. Vonnegut decided that burning the substance would solve the problem by producing a smoke of AgI particles. By burning charcoal impregnated with silver iodide or injecting acetone in which AgI is dissolved into a hot flame, a single gram of AgI produced more than 10^{12} nuclei at a temperature of about -10°C; the lower the temperature, the greater the number of nuclei.

In 1948 supercooled clouds were seeded in the free atmosphere using airborne generators of silver iodide designed by Vonnegut and installed on an airplane. The results were similar to those of Schaefer's dry ice experiments, with holes cut in the supercooled clouds and snowflakes observed falling from the cleared areas. For the experimenters, enthusiasm ran high and some of them, particularly Langmuir, spoke of the possibility offered by a small quantity of silver iodide to modify the weather over the entire United States.

The discovery of ice nucleating properties of AgI by Vonnegut made the modification of large volumes of supercooled clouds economically feasible. The fact that the AgI particles could be released from ground-based generators to seed clouds reduced the cost of the operation remarkably as compared to seeding by airborne generators. "The cost of operating a generator on the ground was only \$2.00 to \$3.00 per hour in 1948, while the cost of operating an airplane was of the order of \$25.00 per hour!" (Dennis 1980). As soon as the patents were commercialized by the General Electric Company, several individuals and corporations undertook the business of commercial cloud seeding. Their customers included mainly associations of farmers and ranchers and by 1950 almost 10% of the United States surface land was under contract to cloud seeding firms and the activities started in several foreign countries as well, including Canada.

CHAPTER 2

CLOUD SEEDING IN ALBERTA

Commercial seeding operations in Canada took place for the first time in the southwest part of Manitoba. The Water Resources Development Corporation, based in Denver, Colorado, undertook in 1953, through a Canadian affiliate, to carry out the operations and the seeding period extended from May 1 to August 6 of the same year. In 1954 the same organization undertook cloud seeding not only in Manitoba, but in southeastern Saskatchewan as well. For Manitoba the operations ran from May 22 to August 11, 1954 and for Saskatchewan from May 1 to August 7 of the same year.

Two years later, in July 1956, commercial cloud seeding operations started in the southern region of Alberta and the area's farmers had the Irving P. Krick Associates of Canada under contract for seeding activities.

2.1. Hail Damage to Alberta's Crops

Almost all of Alberta's farmlands have experienced damages due to hailfall at one time or another. But the heaviest and most consistent hailfalls occur in a region called the Alberta Hail Belt. This region consists of a strip of land some 100 to 130 km wide and about 400 km long. This strip runs from the provincial capital of Edmonton in a south-southeasterly (SSE) direction; this area includes Calgary, with Lethbridge located at the southern end of the hail belt. Breeding in the mountains and foothills of the Rockies, hail storms generally move eastwards in the direction of the hail belt, where they cause a great amount of damage to crops.

The southern one-third of the hail belt covers the area of interest for the present work. This part experienced its highest crop losses in 1945 and 1966, with damages estimated at 20 to 25% for each of these two years. The damage to crops was about 15% in 1954 and in 1960. However, the average loss for the whole belt is about 8%.

Hailfall and hail damage are common in Alberta. Hail occurs in the belt on an average of 61 days a year between May 15 and September 15, reaching its peak in July which has a hail-day probability of 66%. Then the probability falls off in the month of August and by the end of September, the hail season is effectively over. Statistics from the Alberta Hail Insurance Board show that for the eight-year period of 1961 to 1968, average annual losses to crops are estimated at 4.1%. On the other hand, statistics from Alberta Department of Agriculture (Publication Series 853, Edmonton: ADA, 1968) show that during this same period (1961-1968) the annual value of field crops grown on some sixteen million acres in the entire province averaged about $563 million. Thus, for the whole of Alberta, damage due to hail would be 4.1% of the above amount and it represents over $23 million (Petersen 1972). Now, if instead of 4.1% of the province-wide annual damage was equal to that of the hail belt, i.e., 8%, the total loss would amount to about $46 million. The above estimates do not include losses to other properties such as buildings, equipment, gardens, and lawns in both urban and rural areas.

2.2. The Inception of Alberta Weather Modification Cooperative

Farmers who have suffered hail damage tried to find ways of reducing the effects of hailfalls on their financial situation. As a first step, under the Municipal Hail Insurance Act, hail insurance boards were established as early as 1919. Then in 1938 the Alberta Hail Insurance Board was set up as a province-wide organization allowing farmers to cover their crop losses through insurance policies. As a second step, some Alberta farmers opted for the weather modification approach in the mid 1950's. This approach came to farmers' minds after the experiments conducted by Langmuir and Schaeffer and the discovery of AgI by Bernard Vonnegut. In 1952 an inquiry about the articles related to weather modification which appeared in American magazines was made by the Carbon Local of the Farmers Union of Alberta. Then in 1954 a meeting was organized by the

Drumheller Agricultural Society to discuss hail suppression. This resulted in the formation of the Kneehill Hail Suppression Association. In early 1956 another association for hail suppression was formed in the County of Mountain View. About 1000 farmers of the Kneehill and Mountain View Municipal districts gathered in May 1956 and decided to sponsor a cloud seeding program. Accordingly, with a budget of $30,000 commercial cloud seeding for the purpose of hail suppression was begun on July 20, 1956. The contractor for the operation was the Irving P. Krick Associates of Canada Ltd. Thus cloud seeding activities started in the Province of Alberta. Later on, the counties of Wheatland and Rocky View formed two associations similar to the two above. In 1964 the four associations merged under the Cooperative Societies Act in order to form the Alberta Weather Modification Cooperative Limited (AWMC).

2.3. AWMC's Cloud Seeding Program (1956-1968)

Commercial cloud seeding of the AWMC (or its founding associations before 1964) started in 1956 and continued until 1968 for a period of 13 years. In the first year the target was chosen as a strip of land some 20 km wide and 72 km long, extending eastward from Didsbury and ground generators only were used to disperse silver iodide in the clouds. In the following years ground generators were gradually supplemented by aircraft, and in the early 1960's AgI was released simultaneously both from ground and from air (Petersen 1972). The cost of the operations was carried by farmer clients alone without a grant from any government agency. That is why the AWMC was not able to seed continuously the same target area for the entire 13-year period and the target surface varied in both size and shape during the seeding years. In the beginning, funds necessary to finance the operations were raised through voluntary payments by farmers, but in later years funds were collected through a special tax in the four counties involved in weather modification. Due to the opposition of a group called the Rate Payers Protective Association the cloud seeding operations were suspended from 1969 until 1976, inclusive.

2.4. Cloud Seeding Years Covered by this Study

After a suspension which lasted eight years, a cloud seeding program for only one year was carried out in southern Alberta in 1977 financed by the farmers of the AWMC. Subsequently, the Alberta Department of Agriculture began to finance a series of cloud seeding operations with silver iodide in southern Alberta. The program started in the summer of 1980 and has been repeated each summer since its beginning.

On June 16, 1977 at the convention of Unifarm District 12 in the Town of Vulcan, farmers claimed that rainfall and crop yields have been increased and hail damage reduced in the six-year program from 1963 to 1968 (Bishop 1977). As a result, once more, funds amounting to $80,000 were raised for the purpose of cloud seeding to increase rain and the AWMC hired Irving Krick Associates of Canada to perform the operations. Consequently, cloud seeding in southern Alberta started on July 6 and ended on August 17, 1977 for a period of six weeks. Fig. 2.1 shows the irregular shape of the target area which covered an area of approximately 13,000 km² (3.2 million acres). Thirty-six

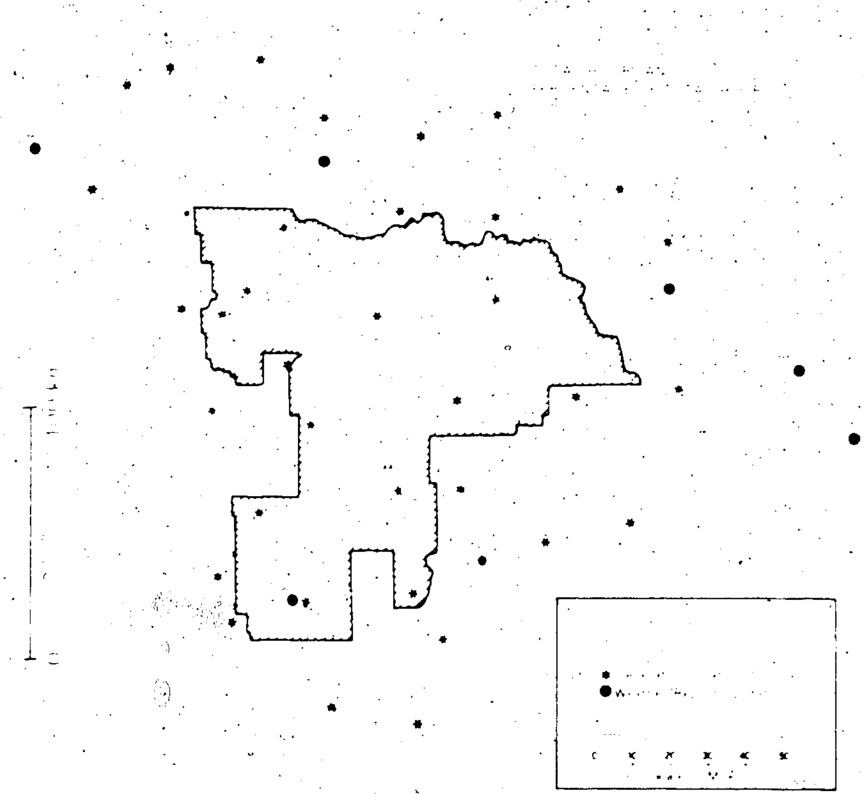


Fig. 2.1. Map of the 1977 ground generator cloud seeding target area. (Source: Bishop, J.T., 1977.)

ground generators were used, out of which 11 were located inside the target and the 25 remaining outside the target area. The generators altogether were operated a total of 1382 hours, dispersing a total mass of over 25 kg of silver iodide into the atmosphere.

After the summer of 1977, cloud seeding by ground generators was suspended for two consecutive years. Then, at the request of the farmers, a grant of $100,000 was made by the Alberta Department of Agriculture in May of 1980, enabling the Alberta Weather Modification Cooperative to carry out a cloud seeding program by ground generators (Bishop 1980). As a result the operations began on May 29 and ended, after three months, on August 29, 1980 covering an area of about 9300 km² (2.3 million acres). Fig. 2.2 shows the seeded area which is located in southern Alberta between Calgary and Lethbridge. Thirty-six generators were used in and around the target area which operated for a total of 2089 hours and dispersed some 38 kg of silver iodide.

During early 1981 the Alberta Department of Agriculture asked the Alberta Research Council to evaluate the weather modification techniques used by Irving P. Krick organization (Alberta Research Council 1981). Consequently a three-year program has been scheduled to seed clouds by ground generators in the summers of 1981, '82 and '83. The target area, located southeast of Calgary, has been

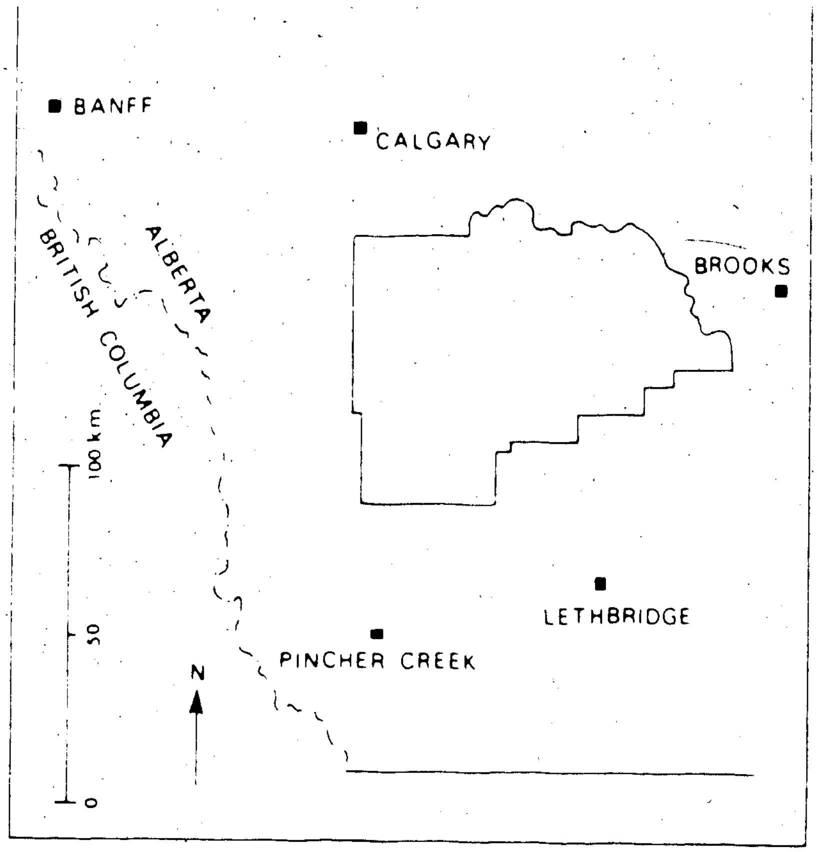


Fig. 2.2. Map of the 1980 ground generator cloud seeding target area. Source: Gray, J.M.L. and G.G. Goyer, 1983: Injection of silver iodide from cloud seeding into the atmosphere of central Alberta (Alberta Research Council, RMD 83/20).

the same for the above three years and did not change location or dimension with years. Fig. 2.3 shows the target area for the three years of 1981, '82, and '83 which covers an area of about 14,000 km^2 (3.4 million acres). Under contract with the Alberta Research Council the I.P. Krick Associates of Canada carried out all the seeding operations for the three years of the program.

The 1981 cloud seeding operations started on 20 June and ended on 21 August 1981, inclusive. A total of 85 generators of the coke and arc types were deployed to deliver silver iodide artificial nuclei to the target clouds. The generators, scattered inside and outside of the target area, operated for a total of 3612 h, averaging 42 h 30 min of operation per generator, dispersing a total mass of approximately 61 kg of AgI in the air. The operations were carried out on 45 days out of 63 days of the contract period.

In 1982, the second year of the program, the operational seeding period extended from 20 June to 19 August 1982. A network of 88 generators of coke and arc types were deployed at 66 sites in and around the target area. The generators ran for a total of 3624 h with an average of almost 41 h per unit. The total mass of AgI released by the ground generators was nearly 30 kg, on 40 days of the 61-day contract period (Alberta Research Council 1982).

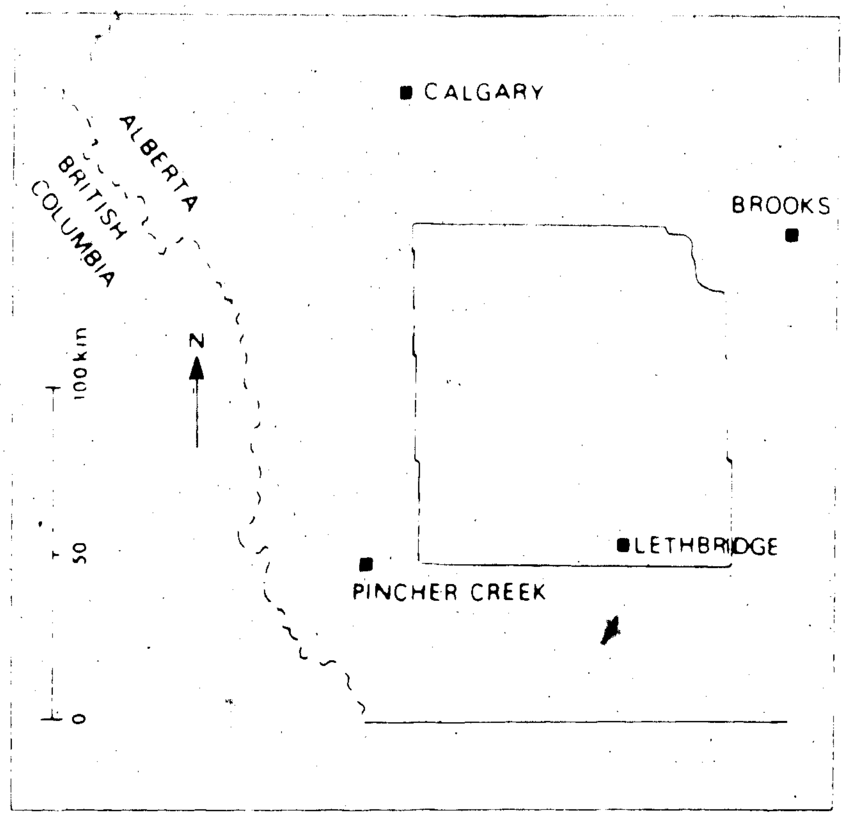


Fig. 2.3. Map of the 1981-82-83 ground generator cloud seeding target area. Source: see Fig. 2.2.

The summer of 1983 was the last season of the ground generator assessment project undertaken by the Alberta Research Council. For 1983 the operational period began on 20 June and ended on 19 August 1983 for a contract period of 61 days. Ninety-two ground generators were deployed at 69 different sites in and out of the target area. The generators of coke and arc types were operated for a total of 4390 h, averaging 47 h 40 min per generator. During the 37 days of the 61-day contract period a total mass of approximately 39 kg of silver iodide was emitted to seed the clouds (Alberta Research Council 1983).

CHAPTER 3

EVALUATION OF THE RESULTS OF CLOUD SEEDING

Shortly after Schaefer's successful experiments on cloud seeding, it appeared that a technique for increasing precipitation from clouds was within the grasp of mankind. By the early 1950's, a number of commercial cloud seeding companies had been formed. They were able to convince farmers and other people in need of water that they could bring more rain or snow by means of cloud seeding. Some cloud seeding experiments, as in Project Cirrus in April 1947 (Langmuir 1961), and in Project Skyfire in November 1956 (Final Report of the Advisory Committee on Weather Control 1957, Vol. II, pp. 199), have produced very striking visual results, leaving little doubt that precipitation was produced artificially. For instance, trails of snow have been seen after supercooled stratus cloud decks were seeded from above and this observation seemed to prove that cloud seeding had an effect. However, the precipitation produced from such clouds after seeding is normally light and often does not reach the ground to contribute significantly to the annual precipitation. Therefore, operational cloud seeding excludes thin clouds and it nearly always involves the seeding of deeper or more extensive cloud systems where the observation of visual effects is not a sufficiently accurate measure of the results. Clearly, alternative reliable evaluation methods were needed.

3.1. Physical Evaluation of Cloud Seeding

As the early wave of optimism concerning the cloud seeding results began to peak, the American Meteorological Society (AMS) formed a committee on cloud physics and weather modification (Byers 1974). The committee, decrying the claims of spectacular results, advocated cautious optimism by pointing out the need for more knowledge of cloud behavior, a better understanding of cloud physics and the physical processes involved in precipitation, and a more careful statistical evaluation. In short, the AMS, backed by a number of concerned scientists, leaned more towards a scientific physical evaluation of cloud seeding rather than to analyses of the amount of precipitation reaching the ground.

Meanwhile, a number of investigators have sought to determine the effects of cloud seeding by making use of more objective sensors than their own eyes. Devices which have been used for the purpose of physical evaluation include the cloud condensation nuclei (CCN) counter, the ice nuclei (IN) counter, devices for sampling cloud droplets and replicating the forms of ice crystals, radar sets to track precipitation packets released by seeding, and special devices to collect precipitation samples (Ruskin and Scott 1974, Hess 1974).

An active research program on the physics and chemistry of cloud systems for the purpose of intensifying and improving cloud seeding effects has been going on for many years in Alberta. The Alberta Hail Project (AHP) is a weather modification program of the Government of Alberta, funded mainly by the Alberta Department of Agriculture. The AHP cloud seeding experiments began in 1974 under the direction of the Alberta Weather Modification Board which was formed in November 1972. In April 1980, full responsibility of AHP was transferred to the Alberta Research Council (ARC 1980). The project's main target area extends over 48,000 km² and is centered on the radar site located at the Red Deer Industrial Airport, almost halfway between Edmonton and Calgary.

3.2. Precipitation Reaching the Ground

When a cloud system is treated with silver iodide or other seeding agents (dry ice or salt or water drops) for the purpose of precipitation enhancement, the seeding company and its customers expect rain or snow to fall. In the case of no precipitation, the conclusion is quickly reached: seeding had no effect. When precipitation is observed reaching the ground, the problem of assessment arises. Physical evaluation deals with the processes which take place aloft, inside the cloud itself, and do not answer the question that usually concerns people the most; i.e., did the seeding increase the total amount of precipitation reaching the ground shortly after the seeding? Has the attempt to alter the weather process produced any result different from what would have occurred naturally in the absence of the modification effort? After all, the precipitation that reached the ground as a raindrop or snowflake formed around an AgI particle might otherwise have come down in a raindrop or snowflake formed around a natural clay particle! The question could be answered beyond doubt if an accurate method of precipitation prediction for a given time and a given place were available. Then one would be able to compare the observed precipitation following the seeding with the prediction of what would have happened if nature had taken its normal course without any human intervention. Unfortunately, meteorological theory and knowledge of weather processes and cloud physics do not permit us to make a sufficiently accurate prediction for a meaningful comparison.

The main difficulty in evaluating the seeding effects stems from the tremendous variability of weather phenomena, especially precipitation. Usually a typical cloud seeding program could produce effects which are smaller than the natural background variations of the precipitation; "the search for seeding effects is a search for a weak signal in the presence of random noise, and the effects can only be estimated." (Dennis 1980).

The variable nature of rainfall is familiar to everyone. Rainfall changes from one place to another and this is particularly true in the case of thunderstorms and showers. Such storms may be only a few kilometers in diameter with the result that a torrential downpour can occur in one part of a town, while some other part of it nearby enjoys a clear sky with sunshine. This behavior of storms makes the work of a weather forecaster very difficult and terms such as "scattered showers" or "scattered thunderstorms" are often used in predictions. By these terms the weatherperson does not mean that different parts of the forecast area will receive rain at different hours of the day so that when the day is over, each part of the ground has its share of precipitation. He/she means only that thunderstorms will be distributed over the forecast area, one here, one there, and in most places, no rainfall at all. In addition to the spatial variations of precipitation, there are variations in the duration and time of occurrence of rain and snow which are most striking in thunderstorms. Sometimes they begin and end in a matter of minutes. On some days a shower brings barely a sprinkle and on other days, 3 to 5 cm of rain may fall in an hour. The amount of precipitation reaching the ground varies from week to week, month to month, year to year, even century to century. That is why the evaluation of cloud seeding experiments is not an easy task and one should always bear in mind these background variations of precipitation while assessing the results. Since we are not able to use forecasts and are faced with difficult problems of rainfall variability, we resort to the techniques of statistics which allow us to tackle the evaluation of rainmaking experiments in a quantitative way.

3.3. Evaluation of Operational Cloud Seeding

Considering the problem of precipitation variability mentioned in the previous section, it is inevitable that the evaluators of a cloud seeding program should turn to statistics. Through comparisons of seeded and unseeded clouds, one can try to show that the behavior of treated clouds is clearly outside the range of natural occurrences. There are several plans or designs for evaluation of the amount of rain falling on a predetermined land surface area called the target.

3.3.1. Target-Only Design

This design involves a single area in which the expected rain is to fall. The area is designated as the "target" which is assumed to be adequately sampled by rain gauges to measure precipitation. When the seeding period is over, the average rainfall in the target is computed and the result is compared with the long-term normal precipitation in the target area for the seeding period. The existence of any positive or negative departure from the normal would signify an increase or decrease in precipitation, respectively (McDonald 1967). This method was in use for a few years around 1950, but soon critics pointed out that even in the absence of all seeding, one must expect positive departures from normal about half the time.

Another way of evaluating the results in the case of Target-Only Design is to seed clouds at random. Randomization is a process which allows the experimenter to decide objectively and without bias whether or not to treat an experimental unit. In the case of cloud seeding, a procedure must be set up whereby the decision to seed or not to seed is made, like the tossing of an unbiased coin (or equivalent procedure). If a cloud system unit above the target is regarded as fit for seeding, the coin is flipped; when it comes up heads, the unit is seeded, while if it comes up tails, the unit is not seeded. Randomization allows one to select for the same time period (one summer, for instance) and for the same target area one set of seeded clouds systems and one set of unseeded cloud systems. By comparing the amount of rainfall from the seeded units to that of the unseeded ones, the effects of the cloud seeding experiments can be evaluated. However, this method of evaluation fails to detect small and moderate effects of seeding "since the signal may be masked by the noise of large natural variability in precipitation..." (Brier 1974).

3.3.2. Target-Control Design

This design involves a single target area and one (or more) nearby area designated as the "control." The target area is the one over which clouds are seeded and in which the rain due to seeding is expected to fall. Rain gauges must be sufficient in number in the target so that the recorded rainfalls indicate the real distribution of the precipitation in the target. The control area is the one which is not seeded and in which precipitation falls naturally. The control area is chosen close to the target so that both areas have similar types of weather. When natural rainfall is high in the target, it should be high in the control area too, and when low in the target, it should be low in the control. In other words, it is highly desirable that in both areas the natural rainfall be well correlated. In choosing the control, care should be taken to avoid all contamination so that the seeding agent particles do not influence the clouds over the control area. This could be done by selecting the control area upwind or even across the wind from the target. It is also important that the two areas have similar elevations and exposures to prevailing winds to maximize the correlation coefficient. Once the target and control areas are determined by comparing their respective precipitation, one can attempt to show that the rainfall in the target is higher (or lower) than in the control area.

3.3.2.1. Method of Percent-of-Normal

The average rainfall in the target area for a specified seeding period is computed on the basis of observations at the rain gauges and compared to that of the control area. This method of evaluation makes use of the normal rainfall of each area, corresponding to the seeding period. The normal rainfall is understood to mean the average rainfall of a historical period which usually is 30 years.

Suppose that, during an operational seeding period, the target area received R_T (Target Rain)% of its normal for that period and the control area received R_C (Control Rain)% of its own normal for the same period. In the absence of seeding, the target is expected to receive as many percent of its normal as the control did, i.e., R_C%.

Thus the change in target rainfall following the seeding is expressed by the value of the ratio $(R_T - R_C)/R_C$, where a positive or negative sign indicates an increase or decrease, respectively. This ratio, in terms of percentage, is equal to

$$100 \quad \frac{R_T - R_C}{R_C}.$$

Using numerical values, if $R_T = 75\%$, $R_C = 70\%$, then

$$\frac{R_T - R_C}{R_C} = \frac{5}{70} \text{ or } 7\%.$$

The evaluator concludes that the rainfall has been increased by about 7% over that which would have fallen without seeding.

The use of ratios in assessing weather modification effects is risky and can be misleading. "A target-control ratio cannot be less than zero, but has no upper limit" (Dennis 1980). When the computed rainfalls in target and control areas are equal, then the ratio is equal to zero, which means seeding had no effects. But consider the case where the control receives very little or no rain at all and the target receives some measurable amount of it. Then the ratio $(R_T - R_C)/R_C = R_T/R_C - 1$ will tend to infinity. Thus, an infinity percent rain increase or decrease is not realistic.

As the target and control areas are assumed to have similar weather patterns, the expected value of R_T/R_C is generally greater than one, and its exact value depends on the underlying distributions of precipitation in both areas.

3.3.2.2. Method of Historical Regression

The historical regression method has been in wide use in commercial seeding projects since about 1952-53 (McDonald 1967). This method of comparing target rainfall to control rainfall is considerably more sophisticated than a ratio comparison as in the previous case. It allows the estimation of the rainfall in the target for a specified period of time when the control rainfall value for the same period is known and the computed value can be used as a "prediction" of the target precipitation. In addition, the method permits an estimate of the probability that a departure of the target rainfall from the "prediction" is only the play of chance (Thom 1957).

In order to perform these calculations the historical regression line must be established first by means of the following steps:

- After selecting the target and control areas in compliance with the conditions already mentioned, and choosing a seeding period, compute the average rainfall for the target and for the control area for the seeding period for n years.(preferably 30 years or more). This results in a set of n pairs of values.

- On a scatter diagram, find a point for each pair by plotting the control values along the abscissa and the target values along the ordinate.

- Draw the regression line through the scattered points. The equation of the line is of the form

$$Y_E = a + bx$$

where Y_E is the estimate of rainfall in the target, x is the observed rain in the control corresponding to y, the observed rainfall in the target; x and y are the two elements of a pair. The parameters a and b are estimated by the method of least squares, using the set of paired values above.

$$b = \frac{n \sum_{i=1}^{n} x_i y_i - \left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} y_i\right)}{n \sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2}$$

$$a = \bar{y} - b\bar{x}$$

where bars denote average value (Walpole and Myers 1978).

The regression line is illustrated in Fig. 3.1 where historical control rainfall is represented on the x-axis and that of the target on the y-axis.

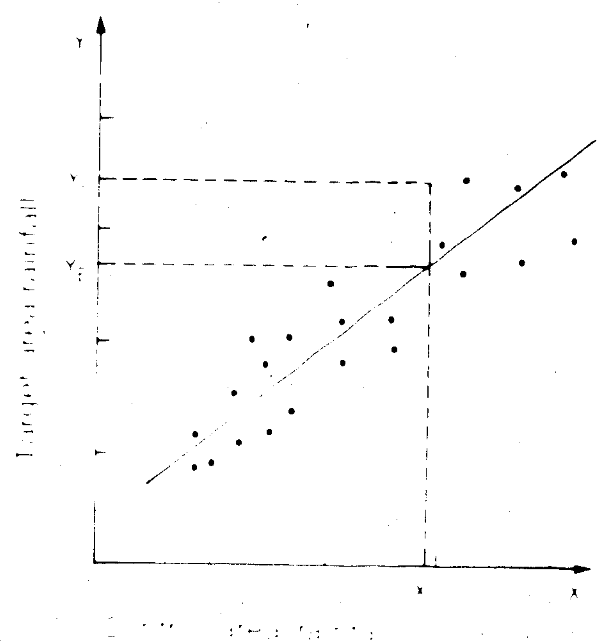


Fig. 3.1. Regression line through a plot of the rainfall over a target and a control area.

Once the historical regression line is established, it allows the evaluator to estimate the success of cloud seeding experiments performed over the selected target. Suppose that for the seeding period the control and target areas yield an average rainfall of x_C and y_T, respectively. Using x_C and the regression line, one finds a value y_E which is the "prediction" of the rain the target would have in the absence of seeding. In other words, y_E is an estimated value of y_T. Then the success of the experiment is estimated by computing the difference $(y_T - y_E)$. Evidence of success is also expressed in terms of percent of the predicted value y_E as

$$100 \frac{y_T - y_E}{y_E} .$$

In order to see if seedings have really affected the precipitation in the target, it is necessary to test statistically the significance of the departure of target rainfall from the "prediction." When the number of seeded years, n, is large (n 40), the departures $(y_T - y_E)$ are assumed to be normally distributed and for small n, the student-t distribution is used (Thom 1957).

Although the historical regression method seems reasonable, it is open to criticism on the ground that a shift in the pattern of major storms and general circulation occurring at or near the time separating the seeding period from the historical period, would result in a shift in the position of the regression line.

Furthermore, the classical linear regression model assumes that the variable x (control precipitation) is known exactly, i.e., the error in x is much less than the error in y (target precipitation). In practice both x and y have errors of comparable magnitude. In this case little can be said about confidence levels for the slope and intercept of the regression equation between true values of target and control precipitation without additional information about their probability distributions (Keeping 1962).

3.4. Method Recommended by the Review Board of the Journal of Weather Modification

This method was proposed by the scientists of the Review Board of the Journal of Weather Modification (Bishop 1980) and has been used by J.T. Bishop, Research Director of the AWMC in his evaluations of the ground generator cloud seeding experiments of 1977 and 1980-1983.

This method also utilizes a target area and a control area and, in addition, a seeded period and an unseeded period. The seeded period splits the unseeded period into pre-seeding and post-seeding periods. However, in the computations the unseeded period rainfall is taken to be the sum of pre-seeding and post-seeding precipitation. For instance, let us consider a period of seven months, from 1 April to 31 October, in which seeding experiments were conducted during the three summer months (June, July and August). Then the two months prior to summer (April and May) and the two months after the summer (September and October) would be the pre-seeding and post-seeding periods, respectively. Thus the unseeded period is composed of the four months of April, May, September, and October.

In addition to years with cloud seeding, the method considers also a number of years without any cloud seeding for the purpose of comparison. The "seeded" period in such years is taken to be the same as that in truly seeded years.

The method is based on the assumption that in the presence of seeding, real or fictitious, the ratio of the target average precipitation "estimate" for a seeded period to the control observed average precipitation for the same seeded period is equal to the ratio of the target observed average precipitation for an unseeded period to the control observed average precipitation for the same unseeded period. The assumed equality of the ratios enables one to compute an estimated value or "prediction" for the target for the seeded period.

The success of a cloud seeding program is calculated by subtracting the predicted value from the observed target rainfall for the seeded period. The increase is often expressed in terms of percentage. For more detail, the reader is referred to Chapter 4.

3.5. Method of Objective Analysis

The process of transforming the data observed and plotted on a map at irregularly spaced observation stations into data at the points of a regularly arranged grid, superimposed on the map and having a constant grid length is referred to as "objective analysis." The purpose of the objective analysis is to replace the classical geog- ical map on which rainfall (or any other meteoro- logical variable) data are plotted at the location of each observing station with a grid on which each grid point represents a computed rainfall value. For a higher degree of objectivity and accuracy, the grid point values are computed by running a computer program.

The method of objective analysis to evaluate the results of a cloud seeding experiment involves the target area and a control area, preferably surrounding the target, and it focusses on the seeded period only. Fig. 3.2 shows a schematic map of the target and control area over which a grid is superposed.

The computer program is run the first time with input data consisting of the control area rainfall data and those of some stations located outside but in the vicinity of the control area limit. The inclusion of these latter stations data allow interpolation at the grid points which are near the control area limit. These first run input data do not include the target rainfall data. From the grid which is the output of the run, a "prediction" of the average target precipitation for the seeded period is calculated by averaging grid point values within the target area. Then the program is run a second time with

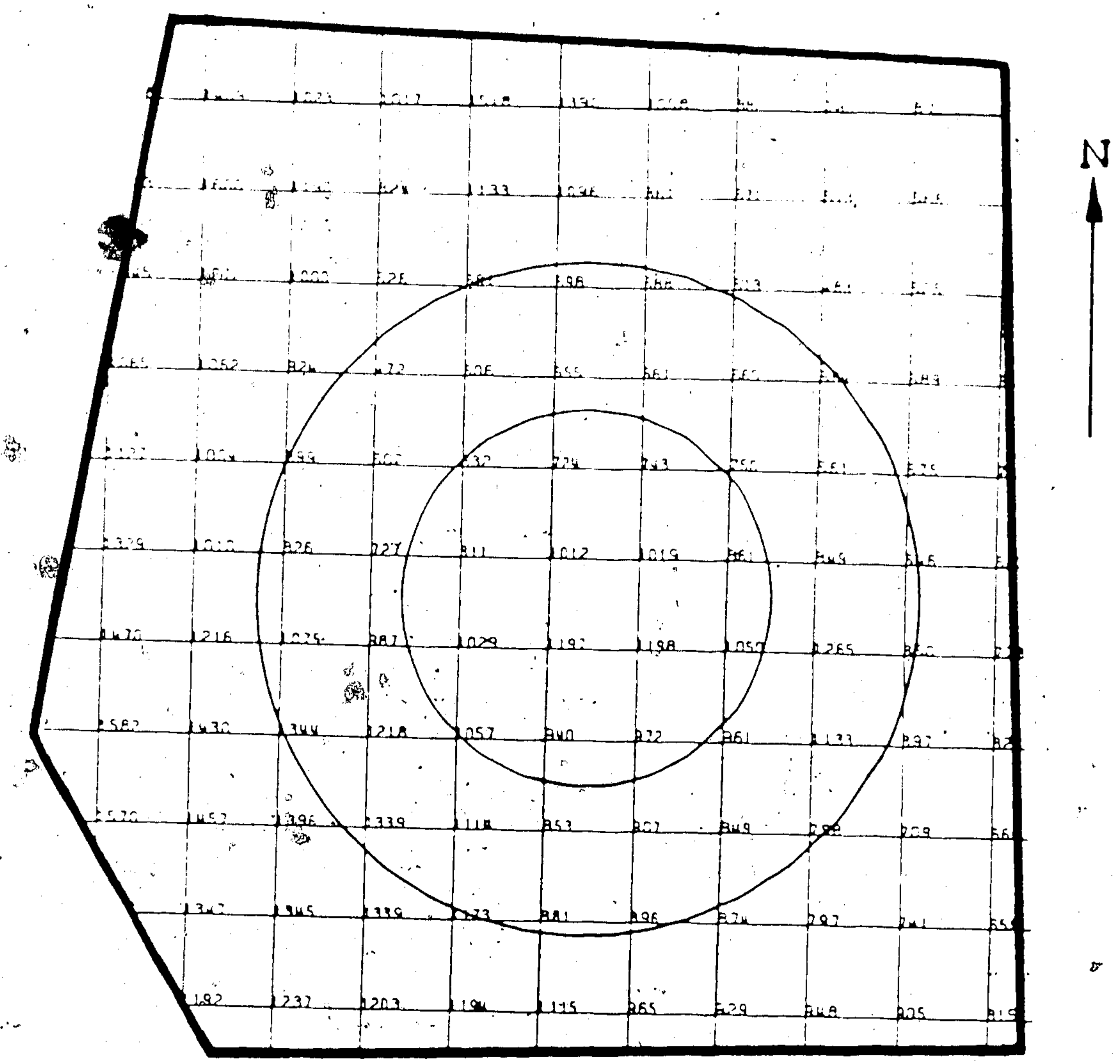


Fig. 3.2. Schematic representation of the target and control areas and a grid superimposed on the regional map. The area inside the inner circle shows the target and the area between the two circles the control area. The outer thick lines show the limits of the regional map. The observation stations are not shown.

the same input data as above to which the target data are added. From the resulting grid of this second run an "observed" averaged target precipitation for the seeded period is easily computed. The effect of cloud seeding operations on the target is then estimated by subtracting the "predicted" value from the "observed" value. For more detail the reader is referred to Chapter 4.

3.6. Statistical Tests Used for Evaluations

The imprecision of rainfall forecasts for the target area and the large natural variability of precipitation prevents one from making an accurate assessment of cloud seeding experiments and it is necessary to resort to statistical tests.

A common problem for statistical inference is to determine in terms of probability whether or not observed differences between two samples signify that the populations sampled are themselves really different. Statistical tests enable us to find out whether the observed differences are within the range which could easily occur by chance or whether they are so large that they indicate that the two samples are likely from two different populations. The choice of a test to be applied to a sample depends on the assumptions one can make about the population; i.e., assumptions about the shape of distribution of the population as well as its mean and variance which are the population parameters. However, there are populations, such as rainfall, which, as we shall see, have no known distribution and we have no information about their parameters. Nevertheless, the techniques of statistics allow us to apply some special tests to samples drawn from such populations.

3.6.1. The Distribution of Rainfall

Rainfall amounts fit no common distribution functions, for when plotted on a frequency diagram, they tend to show a skewed curve with an irregular shape. To support this point, some precipitation data for High River, Alberta, which is located in the target area was used. The selection of High River to illustrate the point is based on the fact that it has been used by Bishop in each year of the 13-year period covered by his calculations and because the data for this station are continuous. Had we chosen another station meeting the same criteria, we would have reached the same conclusion.

Table 3.1 shows the frequency distribution of the July 1982 daily rainfall data which are listed in the July 1982 issue of the Monthly Record published by Atmospheric Environment Service.

Table 3.1. Frequency of observations of daily precipitation for different ranges of rainfall, in millimeters, for the month of July 1982 at High River, Alberta.

Rainfall range (mm)	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	>8	Total
Days observed out of 31	25	1	2	1	0	0	1	1	0	31
Frequency (f%)	81	3	7	3	0	0	3	3	0	100

The frequency values listed in Table 3.1 indicate that the skewness of the frequency distribution is particularly acute in the case of daily precipitation amounts at a given point or recording station. In a case like this, most observations are clustered near zero (no precipitation) while the remaining observations form a long tail extending to larger amounts. Fig. 3.3 which is a plot of the data listed in Table 3.1, shows the skewness of the frequency distribution graphically.

Table 3.2 shows the recomputed total rainfall for the seeded period of each year as selected by Bishop and corresponding to High River alone, i.e., not for the entire target. The time period is, of course, from 1971 to 1983.

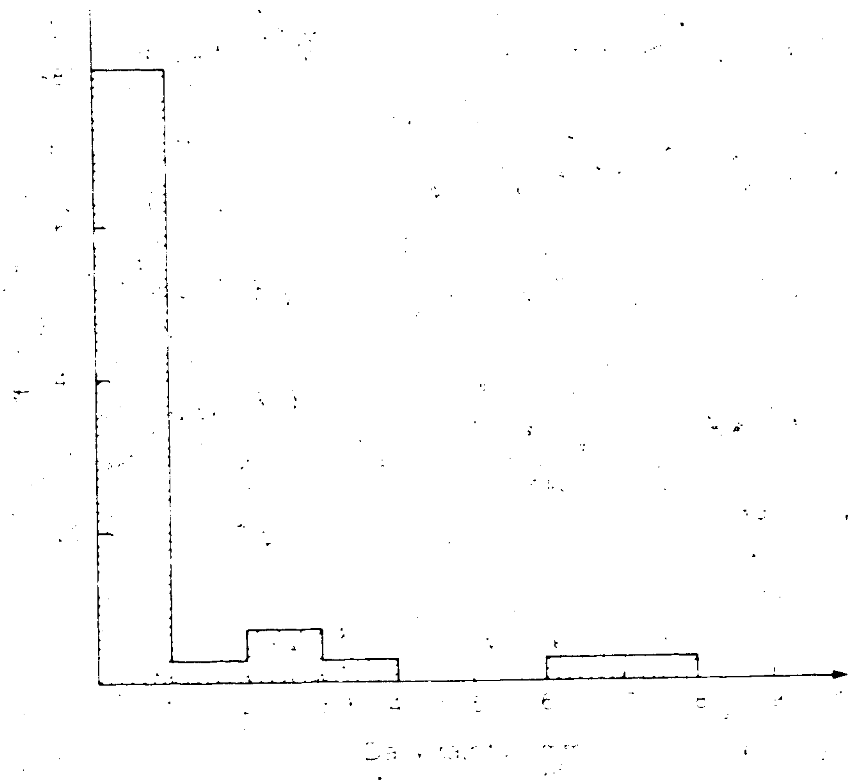


Fig. 3.3. Frequency distribution of the daily rainfall (mm) at High River, Alberta, for the month of July, 1982.

Table 3.2. Total rainfall for the seeded period of each year from 1971 to 1983, in millimeters, at High River, Alberta.

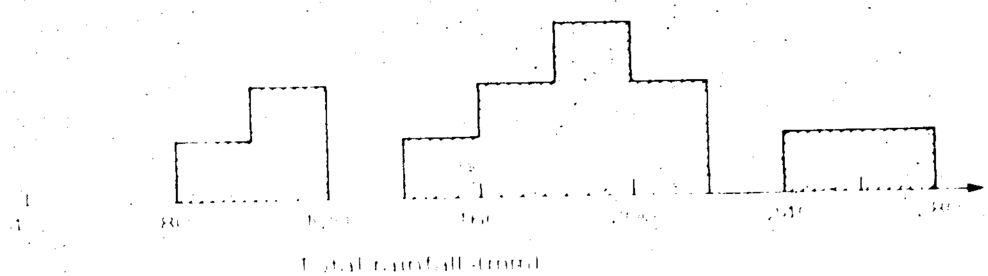
Year	Total Rainfall (mm)
1971	161.0
1972	157.9
1973	213.3
1974	176.2
1975	181.3
1976	274.5
1977	113.5
1978	210.9
1979	181.8
1980	257.0
1981	189.8
1982	84.8
1983	102.2

Table 3.3 lists the frequency distribution of the data given in Table 3.2 over the 13-year time period.

Table 3.3. Frequency distribution of total rainfall amounts for the seeded period at High River, Alberta, as listed in Table 3.2.

Rainfall range (mm)	Times observed out of 13	Frequency (f%)
80	0	0
80 - 100	1	8
100 - 120	2	15
120 - 140	0	0
140 - 160	1	8
160 - 180	2	15
180 - 200	3	23
200 - 220	2	15
220 - 240	0	0
240 - 260	1	8
260 - 280	1	8
280 - 300	0	0
300	0	0
Total	13	100

The data of Table 3.3 indicate that the irregularity of the shape of the frequency distribution is particularly noticeable when one considers total rainfall amounts for a given period (such as seeded period) at a given point during a number of years. Fig. 3.4 is the



3.4. Frequency distribution of the total rainfall (mm) for the seeded period at High River, Alberta, from 1971 to 1983.

graphical representation of the data listed in Table 3.2 and shows the irregular shape of the distribution of the total rainfall of the seeded period with which we are concerned in this work at High River for the time period of 1971-1983. The frequency value of zero for total rainfall amounts smaller than 80 mm should not be interpreted as an indication of extensive rain in the seeded period. The reader is reminded that values on the abscissa axis of Fig. 3.4 represent total rainfall amounts for a period of more or less 60 days (i.e., seeded period).

A look at the histograms of Fig. 3.3 and Fig. 3.4 allows one to conclude that no common distribution function such as the normal distribution can be applied to rainfall data. As we are unable to make assumptions about the distribution of the population, we can not have information about its parameters, such as the mean and the variance. Consequently, the use of parametric tests for rainfall data could be misleading and we must necessarily have recourse to nonparametric tests.

3.6.2. Nonparametric Statistical Tests

The statistical test procedures that assume no knowledge whatsoever about the distribution of the underlying population are called nonparametric tests. These tests are often called "distribution-free tests" for they do not assume that the samples under analysis were drawn from population distributed in some specified way, e.g., from normally distributed populations. Alternatively, nonparametric tests are called "ranking tests" for the obvious reason that they do not deal with the numerical values of the sample elements but rather consider the rank of each element within the sample. Additional advantages of these tests are their usefulness with small samples and their computational simplicity.

The application of nonparametric tests to the results of cloud seeding experiments, conducted for the purpose of increasing rain in the target, enables one to infer whether or not the target precipitation population is significantly different from that of the control without specifying the magnitude of their difference. The most commonly used tests for this purpose are 1) the Wilcoxon Two-Sample or Rank-Sum Test (Dennis 1980), 2) the Sign Test (Brier 1974), and 3) the Wilcoxon Matched-Pairs Signed-Ranks Test (Brier 1974). The selection of these tests is based on their power and simplicity. In fact these nonparametric tests can be performed easily by anyone interested in the matter of weather modification.

In the next three sections we shall explain how to use each of these tests in practice without elaborating on their theoretical basis for which the reader is referred to a textbook on statistics (e.g., Siegel 1956, Walpole and Myers 1978).

3.6.2.1. The Wilcoxon Two-Sample or Rank-Sum Test

This test was proposed by Frank Wilcoxon in 1945 (Walpole and Myers 1978). It is used to test the null hypothesis H_0 against an alternative hypothesis H_1. The null hypothesis H_0 is the statement that the two populations are not significantly different. If the test rejects H_0, then we favor the alternative hypothesis H_1. At this point, we assume that the reader is already familiar with statistical hypotheses and further elaboration would be out of the scope of this work.

The Wilcoxon Two-Sample Test considers two samples, drawn from two different populations. The test allows us to determine whether H_0 is true, i.e., the two populations are not significantly different from each other. The test is performed as described below (Walpole and Myers 1978).

1. Let n_1 and n_2 be the number of observations in smaller and the larger samples, respectively. (n_1 and n_2 may be equal).
2. Combine both samples to get a set of N observations, where $N = n_1 + n_2$.

3. Arrange the N observations of the combined samples in ascending order of numerical values.

4. Assign a rank of 1,2,3.....,N-1,N to the ordered set of N observation. In the case of ties (identical observations) between two or more elements, we assign to each element of the tie a rank which is the mean of the ranks that these elements would have if they were distinguishable.

5. Sum up the ranks corresponding to the n_1 observations of the smaller sample and let this sum be w_1.

6. Sum up the ranks corresponding to the n_2 observations of the larger sample and let this sum be w_2.

7. For each of the samples compute u_i $(i = 1,2)$ with the following formula:

$$u_i = w_i - n_i \frac{(n_i + 1)}{2}$$

Thus we find u_1 and u_2 corresponding to n_1 and n_2, respectively.

8. Let u be the smaller of u_1 and u_2; i.e., $u = u_1$, if $u_1 < u_2$ and $u = u_2$ if $u_1 > u_2$.

9. Choose a level of significance . Usually is taken as 5% or 0.05 for a one-tailed test and 2.5%

or 0.025 for a two-tailed test. It is useful to remind the reader that the level of significance is defined as the probability (in %) of wrongly rejecting the hypothesis H_0 when this latter is actually true. In the language of statisticians, the level of significance α is the probability of committing a type I error.

10. Knowing u, n_1, n_2 and α, look at the statistical tables designed for use with the Wilcoxon Two-Sample (or Wilcoxon Rank-Sum) Test. These tables are given in textbooks on statistics.

11. There are two cases to consider (Walpole and Myers 1978):

A: if $n_2 \le 8$ for the value of u, computed above, and for n_1 and n_2, the table gives a probability value which we call P. Now if $P > \alpha$, the null hypothesis H_0 is accepted and the two populations are not significantly different. On the contrary, if $P \le \alpha$, H_0 is rejected in favor of the alternative hypothesis H_1.

B: if $n_2 \ge 9$, for the selected level of significance α and n_1 and n_2, the table gives a value which we call U. Now we compare the value of u as computed above with the value of U given by the table. If $U < u$, the null hypothesis H_0 is accepted. On the contrary, if $U \leq u$, H_0 is rejected in favor of the alternative H_1.

3.6.2.2. The Sign Test

The Sign Test, as its name indicates, uses plus and minus signs as its data rather than numerical values. The test is applicable to the case of two related samples drawn from two populations which are assumed to be continuous over the sample space. The Sign Test does not make any assumptions about the distributions of the two populations. The only requirement is that each element of one of the samples makes a pair with one element of the other sample. The difference between the two elements of each pair is then computed and the signs of these differences constitute the data for the Sign Test which is applied as described below (Siegle 1956, Walpole and Myers 1978).

1. Consider a first sample of n elements and write down the numerical value of each element.
2. Consider a second sample, also of size n, and [illegible] down the numerical value of each element u[illegible] the corresponding element of the first sample so that one element of each pair is placed on top of the other.

3. Subtract each element of the second sample from the corresponding element of the first sample. These differences are either positive or negative or simply equal to zero. If N pairs show no difference (= 0), they are to be dropped and the number of differences is reduced to $(n - N)$.

4. Affix the proper (+) or (−) sign to each difference according to whether it is positive or negative.

5. Let r_+ and r_- be the number of plus signs and that of the minus signs, respectively, observed in the set of differences.

6. Let the statistic r be the smaller of r_+ and r_-; i.e., $r = r_+$, if $r_+ < r_-$ and $r = r_-$, if $r_+ > r_-$.

7. Choose the level of significance, say $\alpha = 0.05$ for One-Tailed Test and $\alpha = 0.025$ for Two-Tailed Test. (For more detail about α, see the Wilcoxon Two-Sample Test.)

8. Knowing r and n (supposing $N = 0$), look at the statistical table designed for use with Sign Test. The table gives for r and n a probability value (%) which we call p.

9. If $p \leq \alpha$, the null hypothesis H_0 is rejected in favor of the alternative hypothesis H_1. On the

contrary, if $p > \alpha$, then H_0 is accepted and it is concluded that the two populations are not significantly different.

.6.2.3. The Wilcoxon Matched-Pairs Signed-Ranks Test

This test, like the Sign Test, considers two samples drawn from two different populations which do not fit a known probability function. Both samples are of the same size n and the steps to use the Wilcoxon Matched-Pairs Signed-Ranks Test are exactly the same as in Sign Test up to Step 4. The remaining steps, beginning with Step 5 are described below (Siegel 1956).

5. Once the differences between the two elements of each pair are obtained, arrange these differences in order of ascending absolute value from left to right and to each element of the set so arranged affix the same sign it had before being arranged. Thus, for instance, a difference of (-2) is located to the left of either (-4) or (+4).

6. Assign a rank of 1,2,3,.....n, to the elements of the arranged set of differences, from left to the right. In the case of ties (differences of equal value) between two or more elements, we assign to each element of the tie a rank which is the mean of the ranks that these elements would have if there were no tie.

7. Affix to each rank the sign of the corresponding element of the arranged set. The reader is reminded that differences equal to zero have been dropped from the analysis.

8. Let T_+ and T_- be the sum of the ranks with plus sign and sum of the ranks with minus sign, respectively.

9. Let the statistic T be the smaller of T_+ and T_-; $T = T_+$, if T_+ [illegible] T_- and $T = T_-$, if T_+ [illegible] T_-.

10. Choose the level of significance, say [illegible] $= 0.05$ for a One-Tailed Test and [illegible] $= 0.025$ for a Two-Tailed Test.

11. Knowing [illegible] and the number of pairs n (assuming no ties occurred), look at the statistical table designed for use with the Wilcoxon Matched-Pairs Signed-Ranks Test and find the corresponding value which we call t.

12. If T [illegible] t the null hypothesis H_0 is rejected in favor of the alternative hypothesis H_1. On the contrary, if T [illegible] t, the null hypothesis H_0 is accepted and the two populations are not significantly different.

CHAPTER 4

REANALYSIS OF CLOUD SEEDING IN SOUTHERN ALBERTA

4.1. Introduction

In recent years several deductions and conclusions about the effectiveness of cloud seeding with silver iodide (AgI) released by ground generators for the purpose of rainfall enhancement in southern Alberta have been published by J.T. Bishop, Research Director of the Alberta Weather Modification Co-operative (Bishop, 1977, 1980, 1981). The analysis technique used by Bishop for evaluation of possible rainfall changes in the target area is the method attributed to the members of the Review Board of the Journal of Weather Modification described in Section 3.4 of Chapter 3. For convenience, we will call this method the "Bishop Method."

The object of this chapter is to carry out a re-analysis of rainfall data using the same target and control area stations and the same seeded and unseeded periods as Bishop did. The rainfall data used were compiled from the daily and monthly values listed in the Monthly Weather Records, published by the Atmospheric Environment Service (AES) of the Canadian Government. The technique of evaluation is the Bishop method and the period over which the analysis is performed begins in 1971 and ends in 1983. During this 13-year period, as explained in Chapter 2, cloud seeding experiments by ground-based generators were conducted in the summers of five years only (1977 and 1980-1983). In the remaining eight years (1971-1976 and 1978-1979) no seeding was carried out and for the purpose of comparison we suppose that during these years a "fictitious" cloud seeding was performed. In Bishop's evaluation, the seeding period varied from year to year or from group of years to group of years. In this chapter we shall also carry out a reanalysis of the rainfall data using a constant seeding period throughout the 13-year period. This constant seeding period was selected to be 20 June to 19 August, inclusive, which corresponds to the interval of cloud seeding experiments conducted by the Alberta Research Council in southern Alberta (1981-1983). The unseeded period in Bishop's evaluations changed over the years and no criteria were defined as to how the unseeded period should be selected or when it should start and end. We shall also examine how this lack of selection criteria for the unseeded periods affects the validity of the Bishop method. Appropriate statistical tests will be applied to the results of the evaluations as soon as they appear to see if the possible changes in target area rainfall are statistically significant. Finally, the results of objective analysis of rainfall data will be at the end of this chapter.

4.2. The Bishop Method

This method involves the target area and a control area and a seeded period and an unseeded period. The cloud seeding experiments with ground generators were performed over the target and during the seeded period. The unseeded period was split into pre- and post-seeding periods and the sum of the rainfalls of these two components was taken to be the unseeded period precipitation.

In any year, with actual or "fictitious" seeding, let:

$\bar{R}_{TU}$ = average rainfall for all available AES stations in the target area during the unseeded period.

$\bar{R}_{CU}$ = average rainfall for all available AES stations in the control area during the unseeded period.

$\bar{R}_{CS}$ = average rainfall in the control area during the seeded period for all AES stations used to compute $\bar{R}_{CU}$.

$\bar{R}_{TSE}$ = average rainfall "expected" in the target area during the seeded period. $\bar{R}_{TSE}$ was calculated by Bishop's method.

$\bar{R}_{TSO}$ = average rainfall "actually observed" in the target area during the seeded period for all AES stations used to compute $\bar{R}_{TU}$.

Then, as mentioned in Section 3.4, Chapter 3, the Bishop method assumes:

$$\frac{\bar{R}_{TSE}}{\bar{R}_{CS}} = \frac{\bar{R}_{TU}}{\bar{R}_{CU}}$$

or

$$\bar{R}_{TSE} = \frac{\bar{R}_{TU}}{\bar{R}_{CU}} \cdot \bar{R}_{CS}$$

Now, the expected value $\bar{R}_{TSE}$ was the "prediction" of the target rainfall during the seeded period as if cloud seeding had no effect at all. But for the experimenters and farmers, cloud seeding experiments are supposed to increase precipitation in the target and the value of $\bar{R}_{TSO}$, defined above, was expected to be larger than $\bar{R}_{TSE}$ because seeding was assumed to be effective. The possible increase (or decrease) in target rainfall due to seeding, I_{TS}, is readily calculated,

$$I_{TS} = \bar{R}_{TSO} - \bar{R}_{TSE}$$

Then the increase I_{TS} was evaluated as a percentage of $\bar{R}_{TSE}$ and the evaluation parameter $E(\%)$ is given by:

$$E = 100 \cdot \frac{I_{TS}}{\bar{R}_{TSE}} = 100 \cdot \frac{\bar{R}_{TSO} - \bar{R}_{TSE}}{\bar{R}_{TSE}}$$

$$E = 100 \left(\frac{\bar{R}_{TSO}}{\bar{R}_{TSE}} - 1 \right)$$

If cloud seeding was effective in the target area (assuming that the control area was unaffected), then one expects significant positive average values of E in years with "actual seeding" and values of E that are not significantly different from zero in years with "fictitious seeding," i.e., years during which no cloud seeding experiments were conducted. After a set of E-values is calculated for a corresponding set of years with either real or "fictitious" seeding, appropriate statistical tests should be used to give an account of the significance of E-values of the years in which cloud seeding actually took place. We have used some of these tests in this chapter.

4.3. Re-computation of E-values by the Bishop Method

The analysis covers a time period of 13 years, from 1971 to 1983, inclusive; seeded years are 1977 and 1980-1983 and unseeded years are 1971-1976, 1978, and 1979. The seeded period, as well as the pre-seeding and post-seeding periods were the same for all of the 8 unseeded years where "fictitious" seeding took place from 1 June to 31 August of each year; the pre-seeding period was chosen from 1 April to 31 May and the post-seeding from 1 September to 31 October. As far as the seeded years were concerned, these periods were somewhat variable. Table 4.1 lists the beginning and the end of these time periods for each seeded year for both the target and control area, as given by Bishop, as well as the numbers of days of their durations.

Table 4.1. The starting and ending dates, inclusive, for all periods involved in the computation of E(%) for each seeded year as used by Bishop, as well as the duration of each period in days.

Seeded year:			1977	1980	1981	1982	1983
Seeded Period:		Start	6 Jul	29 May	22 Jun*	20 Jun	20 Jun
		End	17 Aug	29 Aug	21 Aug	19 Aug	19 Aug
		# of days	43	93	61**	61	61
Unseeded Period:	Pre-seeding period	Start	1 May	1 May	1 Apr	1 Apr	1 May
		End	5 Jul	28 May	21 Jun	19 Jun	19 Jun
		# of days	66	28	82	80	50
	Post-seeding period	Start	18 Aug	30 Aug	22 Aug	20 Aug	20 Aug
		End	30 Sep	31 Oct	31 Oct	31 Oct	31 Oct
		# of days	44	63	71	72	72

*Listed as 20 June by the Alberta Research Council (ARC 1981)

**63 days according to the Alberta Research Council (ARC 1981)

4.3.1. Stations Used in Computations

The AES stations used for average rainfall calculations, as well as their total number were not the same for each year either for the target area or for the control area. Table 4.2 and Table 4.3 show the rain reporting stations used in each year and their number for the target area and the control area, respectively.

The numbers of rain reporting stations used in the control area have a larger variability with years than those of the target. There were 39 stations involved in the control area but never were all 39 stations used in any particular year. Table 4.4 shows the numbers of stations used in each year in the target area and in the control area.

4.3.2. Results of Computations

For every target area station and every control station involved in the computations, the total rainfall amount for the seeded period, as well as for the unseeded period of each year from 1971 to 1983 is listed in appropriate tables in the appendix. Making use of the data just mentioned, for each of the target and control areas, the average rainfall for seeded and for unseeded periods was recalculated for every year of the 13-year time period covered by this study. The results of recalculations are shown in Table 4.5.

Table 4.2. List of stations which were used at least once in the target area by I. Bishop to compute E values. U and N indicate that the particular station was or was not used in the particular year, respectively.

*: Station with one or more missing days of precipitation data within computation period used by Bishop.

T: Station actually located within Bishop's target area for that year and a U without the superscript T shows a station used in the target while located in the control area.

AES stations used in the target area	Years With Seeding					Years Without Seeding							
	77	80	81	82	83	71	72	73	74	75	76	78	79
1. Arrowwood	N^T_*	N^T_*	N^T_*	N^T	N^T_*	U^T	U^T	U^T_*	U^T_*	N^T_*	N^T_*	N^T_*	N^T_*
2. Big Coulee	N^T_*	N^T_*	N^T	N^T_*	U^T	N^T_*	N^T_*	U^T_*	N^T_*	N^T_*	N^T_*	N^T_*	N^T_*
3. Blackie North	N^T_*	N^T_*	N^T	N^T_*	N^T_*	N^T_*	U^T	U^T	U^T	U^T	U^T	N^T_*	N^T_*
4. Blackie 2W	U^T	U^T_*	N^T	N^T_*	N^T_*	U^T	N^T	U^T	U^T	U^T	U^T	U^T	U^T
5. Brant	N^T_*	N^T	U^T	N^T_*	U^T	N^T_*	N^T_*	U^T_*	N^T_*	N^T	N^T_*	N^T_*	N^T_*
6. Carmangay Village	U^T	U^T	U^T	U^T	U^T	U^T	U^T	N^T	U^T	U^T	U^T	U^T	U^T
7. Claresholm A	N^T_*	N^T_*	N^T_*	N^T	N^T_*	N^T_*	N^T	U^T_*	U^T_*	U^T_*	N^T_*	U^T_*	N^T_*
8. Claresholm MC	U^T_*	U^T	U^T	U^T	U^T	N^T_*	N^T_*	N^T_*	N^T_*	U^T_*	N^T_*	U^T_*	N^T_*
9. Claresholm WW	U^T	U^T	U^T	U^T	U^T	U^T	U^T	U^T_*	U^T	U^T	U^T	U^T	U^T

cont'd...

Table 4.2 cont'd:

AES stations used in the target area	Years With Seeding					Years Without Seeding							
	[illegible]7	80	81	82	83	71	72	73	74	75	76	78	79
10. Fort MacLeod	F^{T}	N	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}
11. Fort MacLeod North	F^{T}	N	F^{T}_{*}	F^{T}_{*}	F^{T}	F^{T}	F^{T}	N^{T}	F^{T}	F^{T}_{*}	F^{T}_{*}	F^{T}	F^{T}
12. Fort MacLeod Stand Off	N^{T}_{*}	N_{*}	N^{T}_{*}	N^{T}_{*}	N^{T}_{*}	F^{T}	F^{T}	F^{T}	F^{T}	N^{T}_{*}	N^{T}_{*}	N^{T}_{*}	N^{T}_{*}
13. Herronton	N^{T}_{*}	N^{T}	N^{T}_{*}	N^{T}_{*}	N^{T}_{*}	F^{T}	F^{T}	F^{T}_{*}	F^{T}	N^{T}_{*}	N^{T}_{*}	N^{T}_{*}	N^{T}_{*}
14. Herronton East	F^{T}_{*}	F^{T}_{*}	F^{T}_{*}	F^{T}_{*}	F^{T}_{*}	F^{T}	F^{T}	F^{T}_{*}	F^{T}_{*}	F^{T}_{*}	F^{T}	F^{T}	F^{T}
15. High River	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}
16. High River Town	F^{T}	F^{T}	F^{T}	F^{T}_{*}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}
17. Lethbridge A	F^{T}	N	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F	F	F^{T}
18. Lethbridge CDA	F	N	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F	F	F^{T}
19. Monarch	N_{*}	N_{*}	F^{T}	F^{T}	F^{T}	N^{T}_{*}	N^{T}	N^{T}_{*}	N^{T}_{*}	N^{T}_{*}	N_{*}	N_{*}	N^{T}_{*}
20. Mossleigh	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}
21. Mossleigh Burnay	F^{T}	N^{T}	N^{T}	N^{T}	N^{T}_{*}	N^{T}	N^{T}	F^{T}	F^{T}_{*}	F^{T}	F^{T}	F^{T}_{*}	F^{T}
22. Picture Butte	F	N_{*}	N^{T}	N^{T}_{*}	N^{T}_{*}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F	N_{*}	N^{T}
23. Pincher Creek	F^{T}	N	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}	F^{T}

cont'd...

Table 4.8 cont'd:

AES stations used in the target area	Years With Seeding					Years Without Seeding							
	77	80	81	82	83	71	72	73	74	75	76	78	79
24. Queenstown	U^T	U^T	U_*^T	U^T	U^T	U^T	U^T	U^T	U^T	U^T	U^T	U^T	U^T
25. Raymond	N_*	N_*	N_*^T	N_*^T	N_*^T	U^T	N_*^T	N_*^T	U_*^T	N_*^T	N_*	N_*	N_*^T
26. Taber	U	N	U^T	U^T	U_*^T	U^T	U^T	N^T	U^T	U^T	U	U	U^T
27. Vauxhall CDA	U	N	U^T	U^T	U^T	U_*^T	U_*^T	N_*^T	U_*^T	U_*^T	U	U	U^T
28. Vauxhall North	N_*	N_*	N_*^T	U_*^T	U^T	N_*^T	N_*^T	N_*^T	N_*^T	N_*^T	N_*	N_*	N_*^T
29. Vulcan	U^T	U^T	U_*^T	U^T	U^T	N_*^T	N_*^T	N_*^T	N_*^T	U^T	U^T	U_*^T	N_*^T
Number of stations used	19	10	17	18	20	20	19	18	23	20	19	18	17

End

Table 4.3. List of stations which were used at least once in the control area by J. Bishop to compute E-values. U and N indicate that the particular station was or was not used in the particular year, respectively.

*: Station with one or more missing days of precipitation data within computation period used by Bishop.

c: Station actually located in the control area selected by Bishop for that year and a U without the superscript shows a station used in the control, while located in the target area.

AES stations used in the control area	Years With Seeding					Years Without Seeding							
	77	80	81	82	83	71	72	73	74	75	76	78	79
1. Aden	U^{c}_{*}	N^{c}_{*}	N^{c}_{*}	N^{c}_{*}	N^{c}_{*}	U^{c}	U^{c}	U^{c}	U^{c}	U^{c}	U^{c}	N^{c}_{*}	N^{c}_{*}
2. Altawan	N^{c}	N^{c}_{*}	U^{c}_{*}	U^{c}_{*}	N^{c}_{*}	N^{c}_{*}	U^{c}_{*}	U^{c}_{*}	N^{c}_{*}	U^{c}_{*}	N^{c}_{*}	N^{c}_{*}	U^{c}
3. Big Coulee	N_{*}	N^{c}_{*}	N_{*}	U_{*}	N_{*}	N_{*}	N_{*}	N_{*}	N_{*}	N_{*}	N_{*}	N_{*}	N_{*}
4. Bonnie View	U^{c}	N^{c}_{*}	N^{c}_{*}	N^{c}_{*}	N^{c}_{*}	N^{c}_{*}	N^{c}_{*}	N^{c}_{*}	N^{c}_{*}	N^{c}_{*}	N^{c}_{*}	U^{c}	N^{c}_{*}
5. Bow Island Riv-Dev	N^{c}_{*}	N^{c}_{*}	N^{c}_{*}	N^{c}_{*}	N^{c}_{*}	U^{c}	U^{c}	U^{c}	U^{c}	U^{c}_{*}	N^{c}_{*}	N^{c}_{*}	N^{c}_{*}
6. Brooks	N^{c}_{*}	N^{c}_{*}	N^{c}_{*}	N^{c}_{*}	N^{c}_{*}	U^{c}	U^{c}	U^{c}	U^{c}	U^{c}	U^{c}	N^{c}_{*}	U^{c}
7. Brooks CDA	U^{c}	U^{c}	U^{c}	U^{c}	U^{c}	U^{c}	U^{c}	U^{c}	U^{c}	U^{c}	U^{c}	U^{c}	U^{c}
8. Brooks North	U^{c}	N^{c}	N^{c}	N^{c}	U^{c}	N^{c}	N^{c}	U^{c}	U^{c}	U^{c}	U^{c}	U^{c}	U^{c}
9. Caldwell	U^{c}	U^{c}	U^{c}	U^{c}	N^{c}	[illegible]	U^{c}	U^{c}	U^{c}	U^{c}	U^{c}	U^{c}	U^{c}

cont'd...

Table 4.3, cont'd:

AES stations used in the control area	Years With Seeding					Years Without Seeding							
	77	80	81	82	83	71	72	73	74	75	76	78	79
10. Calgary Elbow	U^c	N^c	N^c	N^c	N^c	N^c	N^c	U^c	U^c	U^c	U^c	U^c	N_*
11. Calgary Glenmore	N^c_*	N^c_*	N_*	N^c_*	N^c	N^c_*	N^c_*	U^c	N^c_*	U^c_*	N^c_*	N^c_*	N^c_*
12. Calgary Int'l	U^c	N^c	N^c	N^c	N^c	N^c	N^c	U^c	U^c	U^c	U^c	U^c	U^c
13. Cardston	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c
14. Carway	U^c	U^c	U^c	U^c_*	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c_*
15. Chestermere Lake S.	U^c	N^c	N^c	N^c_*	N^c_*	N^c_*	N^c_*	N^c_*	N^c_*	U^c	U^c	U^c	U^c
16. Cochrane	U^c	N^c	N^c	N^c	N^c	N^c	N^c	U^c	U^c	U^c	U^c	U^c	U^c
17. Foremost	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c
18. Fort MacLeod	N	U^c	N	N	N	N	N	N	N	N	N	N	N
19. Fort MacLeod N	N	U^c_*	N	N	N	N	N	N	N	N	N	N	N
20. Gleichen	U^c	N^c	N^c	N^c	N^c	N^c	N^c	U^c_*	U^c	U^c	U^c	U^c	U^c
21. Lethbridge A	N^c	U^c	N	N	N	N	N	N	N	N	N^c	N^c	N
22. Lethbridge CDA	N^c	U^c	N	N	N	N	N	N	N	N	N^c	N^c	N

cont'd...

Table 4.3, cont'd:

AES stations used in the control area	Years With Seeding					Years Without Seeding							
	77	80	81	82	83	71	[illegible]	73	74	75	76	78	79
23. Manyberries CDA	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c
24. Masinasin	N^c_*	N^c_*	U^c	U^c	U^c_*	N^c_*	N^c_*	N^c_*	N^c_*	N^c_*	N^c_*	N^c_*	N^c_*
25. Medicine Hat A	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c
26. Milk River	U^c	N^c_*	N^c_*	N^c_*	N^c_*	U^c	N^c	N^c	U^c	U^c	N^c_*	U^c	N^c_*
27. Mountain View	N^c_*	U^c_*	U^c	U^c	U^c	U^c	U^c	N^c_*	N^c	N^c_*	N^c_*	N^c_*	U^c
28. Pincher Creek	N	U^c	N	N	N	N	N	N	N	N	N	N	N
29. Pothole McIntyre	N^c_*	N^c	N^c_*	N^c	U^c_*	N^c_*	N^c_*	N^c_*	N^c_*	N^c_*	N^c_*	N^c_*	N^c_*
30. Rainier	U^c_*	N^c_*	N^c_*	N^c_*	N^c_*	U^c	U^c_*	U^c	U^c	U^c	U^c	U^c	U^c
31. Ralston	N^c_*	N^c_*	N^c_*	N^c_*	N^c_*	U^c	U^c	U^c	U^c	U^c	N^c_*	N^c_*	N^c_*
32. Redcliff	U^c	N^c	N^c_*	N^c_*	U^c_*	N^c_*	N^c_*	N^c_*	N^c_*	N^c_*	N^c_*	U^c	U^c
33. Standard	N^c_*	N^c_*	N_*	N_*	N^c_*	N^c_*	N^c_*	U^c	U^c	N^c_*	N^c_*	N^c_*	N^c_*
34. Strathmore East	U^c_*	N^c	N_*	N_*	N^c	N^c_*	N^c_*	U^c	U^c	U^c	U^c	U^c	U^c
35. Suffield A	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c	U^c

cont'd...

Table 4.3, cont'd:

AES stations used in the control area	Years With Seeding					Years Without Seeding							
	77	80	81	82	83	71	72	73	74	75	76	78	79
36. Suffield Hamlet	N^c_*	N^c_*	U^c	U^c	U^c	N^c	N^c_*	N^c_*	N^c_*	N^c_*	N^c_*	N^c_*	N^c_*
37. Taber	N^c	U^c	N	N	N_*	N	N	U	N	N	N^c	N^c	N^c
38. University of Calgary	U^c	N^c	N^c	N^c	N^c	N^c	N^c	U^c_*	U^c	U^c	U^c	U^c	U^c
39. Vauxhall CDA	N^c	U^c	N	N	N	N_*	N_*	U_*	N_*	N_*	N^c	N^c	N^c
40. Warner West	N^c_*	N^c_*	N^c_*	N^c_*	U^c_*	N^c_*	N^c_*	N^c_*	N^c_*	N^c_*	N^c_*	N^c_*	U^c
41. Whiskey Gap	U^c	U^c	U^c	U^c	U^c	U^c	U^c	N^c	U^c	U^c	U^c	U^c	U^c
42. Writing on Stone	N^c_*	N^c_*	U^c	U^c	U^c_*	N^c_*	N^c_*	N^c_*	N^c_*	N^c_*	N^c_*	N^c_*	N^c_*
Number of stations used	22	17	14	15	16	16	16	25	23	25	20	21	22

End

Table 4.4. Numbers of rainfall stations used in the calculation of the evaluation parameter E as selected by J. Bishop for each year.

	Year	Treatment	Number of rainfall stations	
			Target	Control
1.	1977	Seeding	19	22
2.	1980	"	10	17
3.	1981	"	17	14
4.	1982	"	18	15
5.	1983		20	16
	Mean	"	17	17
6.	1971	No Seeding	20	16
7.	1972		19	16
8.	1973		18	25
9.	1974		23	23
10.	1975	"	20	25
11.	1976	"	19	20
12.	1978	"	18	21
13.	1979	"	17	22
	Mean	"	19	21

Table 4.5. Target and control area average rainfalls (mm) for seeded and unseeded periods of each year.

	Year	Treatment	Target area		Control area	
			$\bar{R}_{TSO}$	$\bar{R}_{TU}$	$\bar{R}_{CS}$	$\bar{R}_{CU}$
			Seeded period	Un-seeded period	Seeded period	Un-seeded period
1.	1977	Seeding	64.4	163.2	63.9	187.5
2.	1980	"	152.0	161.5	156.9	187.4
3.	1981	"	[illegible]	242.1	76.2	242.1
4.	1982	"	[illegible]	[illegible]	78.0	217.7
5.	1983	"	[illegible]	[illegible]	98.7	87.3
	Mean	"	[illegible]	[illegible]	94.7	184.4
6.	1971	No Seeding	144.8	124.2	116.4	125.8
7.	1972	"	138.7	144.2	149.5	167.6
8.	1973	"	156.1	93.3	156.7	84.6
9.	1974	"	119.6	164.2	110.6	135.5
10.	1975	"	162.9	202.2	167.8	207.9
11.	1976	"	205.2	105.5	196.9	91.4
12.	1978	"	204.4	256.7	215.4	254.8
13.	1979	"	108.8	103.8	108.1	120.6
	Mean	"	155.1	151.8	152.7	148.5

The average rainfall "expected" in the target area during the seeded period, i.e., $\bar{R}_{TSE}$ is then easily recomputed, making use of the data entered in Table 4.4 by the equation

$$\bar{R}_{TSE} = \bar{R}_{CS} (\bar{R}_{TU}/\bar{R}_{CU}) .$$

The possible increase in the target average precipitation in the seeded period I_{TS} due to seeding is computed using $\bar{R}_{TSO}$ from Table 4.4 and the above $\bar{R}_{TSE}$ value by the equation

$$I_{TS} = \bar{R}_{TSO} - \bar{R}_{TSE} .$$

Then the evaluation parameter E(%) is found for each year using the formula

$$E = 100\left(\frac{\bar{R}_{TSO}}{\bar{R}_{TSE}} - 1\right)$$

The results of the recalculations are listed in Table 4.6.

Table 4.6. Values of $\bar{R}_{TSO}$ (mm), $\bar{R}_{TSE}$ (mm), I_{TS} (mm), and the evaluation parameter E(%) for each seeded and unseeded year.

	Year	Treatment	$\bar{R}_{TSO}$ (Table 4.4)	$\bar{R}_{TSE}$	I_{TS}	E(%) (Rounded)
1.	1977	Seeding	64.4	55.6	+ 8.8	+16
2.	1980	"	152.0	134.9	+17.1	+13
3.	1981	"	93.7	76.2	+17.5	+23
4.	1982	"	94.3	68.6	+25.7	+38
5.	1983	"	118.0	75.0	+43.0	+57
	Mean	"	104.5	82.1	22.4	+29
6.	1971	No Seeding	144.8	115.2	+29.6	+26
7.	1972	"	138.7	128.6	+10.1	+ 8
8.	1973	"	156.1	172.4	-16.3	-10
9.	1974	"	119.6	150.4	-30.8	-20
10.	1975	"	162.9	162.8	+ 0.1	0(+)
11.	1976	"	205.2	226.4	-21.2	- 9
12.	1978	"	204.4	217.6	-13.2	- 6
13.	1979	"	108.8	93.0	+15.8	+17
	Mean	"	155.1	158.3	- 3.2	+ 1

Values of E as computed by Bishop for each year of the period covered by this study have been published (Bishop 1984). Our calculations have produced somewhat different E values as listed in the last column of Table 4.7. For purposes of comparison, the results of both calculations are shown in Table 4.7.

Table 4.7. Evaluation parameter E, as published by Bishop and as recomputed in this work.

	Year	Treatment	Evaluation Parameter E(%)	
			Published by Bishop	Recomputed
1.	1977	Seeding	+62	+16
2.	1980	"	+17	+13
3.	1981	"	+22	+23
4.	1982	"	+26	+38
5.	1983		+55	+57
	Mean	"	+37	+29
6.	1971	No Seeding	+20	+26
7.	1972	"	+10	+ 8
8.	1973	"	+ 4	-10
9.	1974	"	-14	-20
10.	1975	"	-13	0
11.	1976	"	-17	- 9
12.	1978	"	-10	- 6
13.	1979	"	+14	+17
	Mean	"	- 1	+ 1

4.3.3. Statistical Significance of the Recomputed E's

In Section 4.2 the evaluation parameter E (%) is given as

$$E = 100\left(\frac{\bar{R}_{TSO}}{\bar{R}_{TSE}} - 1\right).$$

Because of the presence of the ratio $(\bar{R}_{TSO}/\bar{R}_{TSE})$ the statistic E tends to have a skewed distribution; its minimum possible value is -100%, when $\bar{R}_{TSO} = 0$, and its maximum value approaches infinity as $\bar{R}_{TSE}$ goes to zero. This fact implies that for this analysis the average value of E will not necessarily be close to zero and, therefore, the median of the set of E-values is a better measure of central tendency than the mean value of the sample. This fact suggests that in a situation like this, the significance, if any, of the E values corresponding to seeded years should be tested with an appropriate nonparametric or rank test (Smith 1964).

The recomputed E's are listed in the last column of Table 4.6. We can consider the E-values for the five seeded years as a sample drawn from a population of seeded E's and the remaining E-values for eight unseeded years as a sample from a population of unseeded E's. As the two samples are of different size, the Wilcoxon Two-Sample Test can be used to test whether or not their populations are significantly different, i.e., whether the null hypothesis H_o should be rejected in favor of H_1 or accepted.

In order to perform this test, we followed the steps given in Section 3.6.2.1

1. $n_1 = 5$ elements of the smaller sample are (see Table 4.6): 16, 13, 23, 38, 57.

   $n_2 = 8$ elements of the larger sample are (see Table 4.6): 26, 8, -10, -20, 0, -9, -6, 17.

2. Both samples are combined in one set of N elements ($N = n_1 + n_2 = 5 + 8 = 13$), where the elements of the smaller sample are underlined 16, 13, 23, 38, 57, 26, 8, -10, -20, 0, -9, -6, 17.

3. The ascending numerical values are: -20, -10, -9, -6, 0, 8, 13, 16, 17, 23, 26, 38, 57.

4. The assigned ranks are shown under each element: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13.

5. The sum of the ranks for the smaller sample $w_1 = 50$.

6. The sum of the ranks for the large sample $w_2 = 41$.

7. $u_1 = w_1 - n_1 (n_1 + 1)/2 = 35$

   $u_2 = w_2 - n_2 (n_2 + 1)/2 = 5$.

8. Let the statistic u be equal to the smaller of u_1 and u_2, i.e., $u = u_2 = 5$.

9. The level of significance $\alpha = 0.05$ for one-tailed and $\alpha = 0.025$ for two-tailed test. The E values in Table 4.6 are either positive (seeded E larger) or negative (seeded E smaller), depending on years. This fact suggests that a two-tailed test should be used with $\alpha = 0.025$. However, "the importance of

the one-tailed test in cloud seeding evaluation arises from the fact that one usually knows by his interest or the meteorological situation whether he is looking for increases or decreases. Since, as to be expected, the one-tailed test is somewhat more powerful than the two-tailed test, it seems best to use the one-tailed test in most instances" (Thom 1957). Consequently, this test and also those of the coming sections will be performed as both one-tailed and two-tailed cases.

10. For $u = 5$, $n_1 = 5$, and $n_2 = 6$, the statistical tables give a value for $\alpha = 0.015$ or 1.5%.

11. For a two-tailed test, as $\alpha = 0.015$ [illegible] $= 0.025$, the null hypothesis H_0 is rejected in favor of the alternative hypothesis H_1. For a one-tailed test, as $\alpha = 0.015$ [illegible] $= 0.05$, H_0 is rejected and one can conclude that the E-values in seeded years were significantly different than those in unseeded years.

4.4. Recomputation of E by the Bishop Method Using Constant Sets of Stations with Continuous Data

In Section 4.3.1 it was pointed out that the stations selected by Bishop as well as their number varied from year to year in the target and in the control areas.

It is possible that a better way of selecting stations would be to use for all years a constant set of stations in the target and another constant set of stations in the control area. Therefore, in this section, E-values were computed for a constant number of stations with continuous data for the months involved in calculations throughout the 12-year time interval.

4.4.1. Results

The seeded periods and unseeded periods were taken to be the same as those selected by Bishop for his calculations and listed in Section 4.3. The target area which here did not vary with years was assumed to be that of 1981-1982 in which the Alberta Research Council carried out its cloud seeding experiments. The control area stations were scattered east and south of the target in accordance with Bishop's selected control. Only 6 stations in the target fulfilled the requirement (data continuity) while 12 stations did so in the control area. Stations like High River Town or Carmangay Village which had missing data for even one month only during the entire 12-year period, were not considered. The 6 target stations are listed below: Claresholm W.W., Fort Macleod, High River, Lethbridge A, Lethbridge CDA, and Mossleigh. Although in 1977 and 1981 Lethbridge Airport, Lethbridge CDA and Fort Macleod were not located in the target as defined by Bishop, they were chosen because they are located in the target selected in this section. The 12 control stations are listed below: Beaver Mines, Brooks CDA, Brooks North, Caldwell, Cardston, Coleman, Foremost, Gleichen, Manyberries, Medicine Hat A, Suffield A, and Whiskey Gap. Not all of these were used by Bishop in all years as control stations and Beaver Mines and Coleman were never considered.

Making use of official rainfall data published by AES in the Monthly Record, values for $\bar{R}_{TS}$, $\bar{R}_{TE}$, $\bar{R}_{CS}$ and $\bar{R}_{CE}$ as defined in Section 4.2 were calculated for different years. These values are listed in Table 4.8.

Making use of data entered in Table 4.8, the average rainfall "expected" in the target area during the seeded period, $\bar{R}_{TSE}$ as well as I_{TS} and E values, as defined in Section 4.2 were calculated. The results obtained are shown in Table 4.9.

4.4.2. Statistical Significance of E-values Listed in Table 4.9

The E-values listed in Table 4.9 are different from those shown in Table 4.6, although they are supposed to measure the effectiveness of the same cloud seeding experiments. The difference may result from the fact that the target and control stations, used in Section 4.4.1, were not all selected from the sets used in each year by

Table 4.8. Target and control area average rainfalls (mm) for seeded and unseeded periods of each year, using a constant set of 6 stations in the target area and a constant set of 12 stations in the control area.

	Year	Treatment	Target Area		Control Area	
			$\bar{R}_{TSO}$	$\bar{R}_{TU}$	$\bar{R}_{CS}$	$\bar{R}_{CU}$
			Seeded period	Un-seeded period	Seeded period	Un-seeded period
1.	1977	Seeding	68.6	165.4	64.9	166.5
2.	1980	"	155.4	170.2	149.6	163.2
3.	1981	"	103.4	256.1	89.0	244.9
4.	1982	"	90.6	191.5	88.8	211.4
5.	1983	"	117.2	73.4	104.5	83.2
	Mean	"	107.0	171.3	99.4	173.8
6.	1971	No seeding	149.1	130.8	122.1	140.0
7.	1972	"	126.9	158.6	136.8	179.0
8.	1973	"	139.9	103.0	130.9	81.6
9.	1974	"	132.3	189.2	127.1	15[illegible].1
10.	1975	"	159.2	167.2	215.4	244.5
11.	1976	"	229.3	111.9	208.3	90.5
12.	1978	"	238.8	295.0	201.4	250.1
13.	1979	"	126.5	118.6	110.5	115.7
	Mean	"	162.8	159.3	156.6	156.8

Table 4.9. $\bar{R}_{TSE}$ (mm), I_{TS} (mm) and E (%) based on a constant set of 6 stations in the target and a constant set of 12 stations in the control area.

	Year	Treatment	$\bar{R}_{TSO}$ (Table 4.8)	$\bar{R}_{TSE}$	I_{TS}	E(%) (Rounded)
1.	1977	Seeding	68.6	64.3	+ 4.3	+ 7
2.	1980	"	155.4	155.6	- 0.2	0(-)
3.	1981	"	103.4	93.4	+10.0	+11
4.	1982	"	90.6	80.8	+ 9.8	+12
5.	1983	"	117.2	92.0	+25.2	+27
	Mean	"	107.0	97.2	9.8	11
6.	1971	No seeding	149.1	113.6	+35.5	+31
7.	1972	"	126.9	119.0	+ 7.9	+ 7
8.	1973	"	139.9	164.9	-25.0	-15
9.	1974	"	132.3	157.6	-25.3	-16
10.	1975	"	159.2	146.5	+12.7	+ 9
11.	1976	"	229.3	258.3	-29.0	-11
12.	1978	"	238.8	237.7	+ 1.1	+ 1
13.	1979	"	126.5	113.8	+12.7	+11
	Mean	"	162.8	163.9	- 1.2	+ 2

Bishop. Therefore, the significance of the seeded E-values of Table 4.9 was statistically tested. As in Section 4.3.3 in this case, there are two samples of different size which suggest the use of the Wilcoxon Two-Sample Test. In the previous case, the test was described in detail to aid the reader. Here, however, a condensed summary is presented. The seeded E-values are underlined so that they can be distinguished from the unseeded ones.

$n_1 = 5$ elements of seeded E's are: 7, 0, 11, 12, 27.

$n_2 = 8$ elements of unseeded E's are: 31, 7, -15, -16, 9, -11, 1, 11.

Combined sample: 7, 0, 11, 12, 27, 31, 7, -15, -16, 9, -11, 1, 11.

Increasing E's: -16, -15, -11, <u>0</u>, 1, 7, <u>7</u>, 9, <u>11</u>, 11, <u>12</u>, <u>27</u>, 31.

Ranks: 1, 2, 3, <u>4</u>, 5, 6.5, <u>6.5</u>, 8, <u>9.5</u>, 9.5, <u>11</u>, <u>12</u>, 13.

$w_1 = 4 + 6.5 + 9.5 + 11 + 12 = 43$

$w_2 = 1 + 2 + 3 + 5 + 6.5 + 8 + 9.5 + 13 = 48$

$u_1 = w_1 - n_1 (n_1 + 1)/2 = 28$

$u_2 = w_2 - n_2 (n_2 + 1)/2 = 12$

$u = u_2 = 12$, (the smaller of u_1 and u_2)

The level of significance, $\alpha = 0.05$ for one-tailed test and $\alpha = 0.025$ for two-tailed test.

For $u = 12$, $n_1 = 5$, $n_2 = 8$, the tables give, $\beta = 0.142$.

As $\beta = 0.142 > \alpha = 0.05$ and $\beta = 0.142 > \alpha = 0.025$, the null hypothesis H_o is accepted and the populations of the two samples are not significantly different from each other.

Consequently, for a constant set of stations in the target area and a constant set of stations in the control area, no statistically significant difference was found in the evaluation parameter E between seeded and unseeded years.

4.5. Calculation of E-values for a Constant Seeded Period and a Constant Unseeded Period Using Bishop's Stations

During the re-computation of E-values in Section 4.3, the seeded period varied from year to year, except for years with "fictitious" seedings. The starting and ending dates of the seeding operations as listed by Bishop were shown in Table 4.1. Based on Table 4.1, the number of days comprising the seeded period involved in Bishop's calculations for each year is given in Table 4.10. However, the duration of the seeded period of years with "fictitious" seeding was 92 days.

Table 4.10. Length (days) of seeded periods in each year for which seeding operations were conducted.

Seeded years	77	80	81	82	83
Seeding period in days	43	93	61*	61	61

*63 according to the Alberta Research Council (ARC 1981).

The large difference in number of days making up the seeding periods in the first two seeded years arose from the fact that in 1977 the cost of the operations was paid by interested farmers (Bishop 1977), while in 1980, the AWMC financed the operations through a grant from the Alberta

Department of Agriculture (Bishop 1980). However, from 1981 to 1983 the length of the seeded period was kept constant because of the involvement of the Alberta Research Council as the organizing and supervising body.

For a proper evaluation of cloud seeding experiments, carried out for the purpose of increasing rain in the target, it would be highly desirable to perform the operations during the same period of each seeded year.

The computations for this section are based on a seeded period which is constant in number of days and the seeding operations are supposedly performed in the same period of the year throughout the 13-year interval covered, in both seeded and unseeded years. This constant seeding period began on 20 June, lasted 61 days, and ended on 19 August, inclusive. The dates and the period of the year were so selected because the Alberta Research Council carried out its cloud seeding operations for 3 out of 5 seeded years under analysis during the same time interval in southern Alberta.

Table 4.1 shows that the duration of the unseeded period which comprises the number of days of the preseeding and that of the post-seeding periods was not constant and varied from year to year in Bishop's calculations. In this section, an unseeded period which is constant for all 13 years and made up of the month of May as preseeding period and the month of September as post-seeding period is considered. The only exception is 1980, where the preseeding period, beginning 1 May, ended on 28 May, inclusive, for the remaining 3 days were seeded. The selection of May and September allows an unseeded period which, in matter of duration, is equal to the selected seeded period. The months of June and August were not selected for they were seeded almost entirely in 1980 and partly in some other seeded years.

In the present computations the target area and the control area, as well as the rain reporting stations used in each area and their numbers, are exactly the same as used by Bishop and detailed in Section 4.3. The method of evaluation is, of course, the Bishop Method and the symbols $\overline{R}_{TU}$, $\overline{R}_{CU}$, $\overline{R}_{CS}$, $\overline{R}_{TSE}$, $\overline{R}_{TSO}$, I_{TS}, and E(%) stand for the same quantities as defined in Section 4.2.

4.5.1. Results of Computations

Using the AES data, the average rainfall for seeded and for unseeded periods in the target and in the control areas were calculated for each year and the results of computations are listed in Table 4.11.

The data of Table 4.11 were used to compute $\overline{R}_{TSE}$, the average rainfall "expected" in the target area during the seeded period and I_{TS}, the increase (or decrease) in rainfall in the target for the seeded period as well as the evaluation parameter E(%) with formulas given in

Table 4.11. Target and control area average rainfalls (mm) for seeded and unseeded periods. The seeded period has a constant length of 61 days for each year.

Year	Treatment	Target Area		Control Area	
		$\bar{R}_{TS0}$	$\bar{R}_{TU}$	$\bar{R}_{CS}$	$\bar{R}_{CU}$
		Seeded period	Un-seeded period	Seeded period	Un-seeded period
1. 1977	Seeding	88.7	91.9	88.3	121.0
2. 1980	"	95.3	134.8	94.2	148.2
3. 1981	"	93.8	147.8	74.9	148.7
4. 1982	"	94.3	102.4	78.0	139.9
5. 1983	"	118.0	37.0	98.7	30.1
Mean	"	98.0	102.8	86.8	121.6
6. 1971	No seeding	49.2	73.6	48.5	83.8
7. 1972	"	105.2	90.0	109.7	111.4
8. 1973	"	65.9	54.9	45.7	40.7
9. 1974	"	114.1	73.8	84.7	72.9
10. 1975	"	91.0	135.6	84.5	123.4
11. 1976	"	158.9	74.3	148.8	55.3
12. 1978	"	148.2	176.8	140.4	167.7
13. 1979	"	49.1	46.0	63.6	56.0
Mean	"	97.7	90.6	90.7	88.9

Section 4.2. The results of such calculations are shown in Table 4.12.

4.5.2. Statistical Significance of E-values listed in Table 4.12

The E-values involved in this case are those entered in the last column of Table 4.12. Once more there

Table 4.12 Rainfall amounts (mm) and evaluation parameter E(%) for a constant assumed seeding period of 20 June to 19 August.

	Year	Treatment	$\bar{R}_{TSO}$ (Table 4.11)	$\bar{R}_{TSE}$	I_{TS}	E(%) (Rounded)
1.	1977	Seeding	88.7	67.1	+21.6	+32
2.	1980	"	95.3	88.0	+ 7.3	+ 8
3.	1981	"	93.8	74.4	+19.4	+26
4.	1982	"	94.3	57.1	+37.2	+65
5.	1983	"	118.0	72.9	+45.1	+62
	Mean	"	98.0	71.9	+26.1	+39
6.	1971	No seeding	49.2	42.6	+ 6.6	+15
7.	1972	"	105.2	88.6	+16.6	+19
8.	1973	"	65.9	61.6	+ 4.3	+ 7
9.	1974	"	114.1	85.7	+28.4	+33
10.	1975	"	91.0	92.9	- 1.9	- 2
11.	1976	"	158.9	199.9	-41.0	-21
12.	1978	"	148.2	148.0	+ 0.2	+ 1
13.	1979	"	49.1	52.2	- 3.1	- 6
	Mean	"	97.7	96.4	-1.3	+ 6

are samples of size 5 and size 8 drawn from the seeded and unseeded E populations, respectively. As the samples are of different size, the Wilcoxon Two-Sample Test was applied to test the statistical significance of the seeded E-values. The different steps for application of the Wilcoxon Two-Sample Test are given in Section 3.6.2.1. In the lists of data to follow, the elements belonging to the seeded sample (which is the smaller sample) are underlined.

n_1 = 5 elements of seeded E's are: 32, 8, 26, 65, 62.

n_2 = 8 elements of unseeded E's are: 15, 19, 7, 33, -2, -21, 1, -6.

Combined sample: 32, 8, 26, 65, 62, 15, 19, 7, 33, -2, -21, 1, -6.

Increasing E's: -21, -6, -2, 1, 7, 8, 15, 19, 26, 32, 33, 62, 65.

Ranks: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13.

$w_1 = 6 + 9 + 10 + 12 + 13 = 50$

$w_2 = 1 + 2 + 3 + 4 + 5 + 7 + 8 + 11 = 41$

$u_1 = w_1 - n_1 (n_1 + 1)/2 = 35$

$u_2 = w_2 - n_2 (n_2 + 1)/ = 5$

$u = u_2 = 5$ (the smaller of u_1 and u_2)

The level of significance, $\alpha = 0.05$ for one-tailed test. and $\alpha = 0.025$ for two-tailed test.

For $u = 5$, $n_1 = 5$, $n_2 = 8$, the statistical tables give $P = 0.015$.

As $P = 0.015 < \alpha = 0.05$ and $P = 0.015 < \alpha = 0.025$, the null hypothesis H_o is rejected in favor of the alternative hypothesis H_1 and the populations of the seeded E's and unseeded E's samples are statistically different.

4.6. E-values for Constant Sets of Stations with Continuous Data and Constant Seeded Period and a Constant Unseeded Period

In Section 4.3 it was pointed out that the seeded as well as the unseeded periods varied from year to year and that the same was true for the rain reporting stations used and their total numbers. For consistency, it seems reasonable to consider elements which do not change with time. When this condition is fulfilled, a comparison of E-values obtained for different years should be more meaningful. In this section, a constant set of 6 stations and a constant set of 12 stations were used in the target and control areas, respectively. All the stations involved had continuous data for the period of years under analysis and the details regarding their selection are given in Section 4.4.1. The selected constant seeded period is composed of the months of June, July, and August, while the pre-seeding period is April and May and the post-seeding period September and October. This partition of time periods is the same as that of Bishop for all years without seeding.

Although the selected seeded period (June, July and August) is different from that of any seeded year, it, nonetheless, contains the seeded period of each year within it. The only exception is 1980 where only 3 seeded days

(29, 30 and 31 May) are left out in the pre-seeding period. To compensate for this shortcoming, it was assumed that the rainfall during these 3 days was due to seeding alone and the average rainfall for the 3 days in question was computed for the target and the control area and was found to amount to 8.1 mm and 5.5 mm respectively. Then these amounts were subtracted from the average rainfall of May for both areas. In other words, the average precipitation for May, 1980 was taken to be that fallen between 1 May and 28 May, inclusive and amounted to 96.0 mm for the target area and 85.0 mm for the control area. In this manner, no seeded days were included in any unseeded period. However, the amounts of 8.1 mm and 5.5 mm were not added to the $\bar{R}_{TS}$ and $\bar{R}_{CS}$, respectively, for they correspond to days prior to 1 June 1980 where the selected seeded period started.

4.6.1. Results of Computations

Making use of the rainfall data, published by AES in the Monthly Record, the amounts of $\bar{R}_{TSC}$, $\bar{R}_{TU}$, $\bar{R}_{CS}$, and $\bar{R}_{CU}$, as defined previously, were computed. These quantities, expressed in mm of rain, are shown in Table 4.13.

The data entered in Table 4.13 allow the computations of the "expected" rainfall in the target $\bar{R}_{TSE}$ and the change in the target average rainfall I_{TS} and the

Table 4.13. Average rainfall in the target and in the control areas for seeded and for unseeded periods. Six stations with continuous data were used in the target, and 12 stations with continuous data in the control area. The seeded and unseeded periods were kept constant with years.

	Year	Treatment	Target Area		Control Area	
			$\bar{R}_{TS}$	$\bar{R}_{TU}$	$\bar{R}_{CS}$	$\bar{R}_{CU}$
			Seeded period	Un-seeded period	Seeded period	Un-seeded period
1.	1977	Seeding	144.5	97.3	124.3	124.7
2.	1980	"	151.6	195.2	144.8	187.4
3.	1981	"	184.9	173.0	154.4	179.5
4.	1982	"	157.3	126.5	125.3	175.1
5.	1983	"	142.3	99.9	141.2	84.8
	Mean	"	156.1	138.4	138.0	150.3
6.	1971	No seeding	149.1	130.8	122.1	140.0
7.	1972	"	126.9	158.6	130.8	179.0
8.	1973	"	139.9	103.0	130.9	81.6
9.	1974	"	132.3	189.2	127.1	153.1
10.	1975	"	159.2	167.2	215.4	244.5
11.	1976	"	229.3	111.9	208.3	90.5
12.	1978	"	238.8	295.0	201.4	250.1
13.	1979	"	126.5	118.6	110.5	117.7
	Mean	"	162.8	159.3	156.6	156.8

evaluation parameter E(i). These quantities were computed by Bishop Method and the results obtained are shown in Table 4.14.

Table 4.14. E-values, rounded to the closest percentage point, and $\bar{R}_{TSP}$ expressed in mm are calculated by Bishop Method using the data of Table 4.13.

	Year	Treatment	$\bar{R}_{TSO}$ (Table 4.13)	$\bar{R}_{TSL}$	d_{TS}	E (%) (Rounded)
1.	19[illegible]	Seeding	144.5	97.0	+47.5	+4[illegible]
2.	1980	"	151.6	150.8	+ 0.6	0 (+)
3.	1981	"	184.9	148.2	+36.7	+2[illegible]
4.	1982	"	157.3	90.2	+67.1	+74
5.	1983	"	142.3	166.6	-24.3	-15
	Mean	"	156.1	130.6	25.5	2[illegible]
6.	1971	No seeding	149.1	113.6	+35.5	+31
7.	1972	"	126.9	119.0	+ 7.9	+ 7
8.	1973	"	139.9	164.9	-25.0	-15
9.	1974	"	132.3	157.6	-25.3	-16
10.	1975	"	159.2	146.5	+12.7	+ 9
11.	1976	"	229.3	258.3	-29.0	-11
12.	1978	"	238.8	237.7	+ 1.1	+ 1
13.	1979	"	126.[illegible]	113.6	+12.7	+11
	Mean	"	162.8	163.9	- 1.2	+ [illegible]

4.6.2. Statistical Significance of E-values Listed in Table 4.14

The E-values to be statistically tested are entered in the last column of Table 4.14. The sample drawn from a population of seeded E's is of size $n_1 = 5$, and that from a population of unseeded E's is of size $n_2 = 8$. As the samples are of different size, the Wilcoxon Two-Sample Test will be applied to them. The different steps of this test are explained in Section 3.6.2.1. The seeded E-values are underlined.

n_1 = 5 elements of seeded E's are: $\underline{49}$, $\underline{7}$, $\underline{25}$, $\underline{74}$, $-\underline{15}$.

n_2 = 8 elements of unseeded E's are: 31, 7, -15, -16, 9, -11, 1, 11.

Combined sample: $\underline{49}$, $\underline{7}$, $\underline{25}$, $\underline{74}$, $-\underline{15}$, 31, 7, -15, -16, 9, -11, 1, 11.

Increasing E's: -16, -15, $-\underline{15}$, -11, $\underline{0}$, 1, 7, 9, 11, $\underline{25}$, 31, $\underline{49}$, $\underline{74}$.

Ranks: 1, 2.5, $\underline{2.5}$, 4, $\underline{5}$, 6, 7, 8, 9, $\underline{10}$, 11, $\underline{12}$, $\underline{13}$.

$w_1 = 2.5 + 5 + 10 + 12 + 13 = 42.5$

$w_2 = 1 + 2.5 + 4 + 6 + 7 + 8 + 9 + 11 = 48.5$

$u_1 = w_1 - n_1 \ (n_1 + 1)/2 = 27.5$

$u_2 = w_2 - n_2 \ (n_2 + 1)/2 = 12.5$

$u = u_2 = 12.5$ (the smaller of u_1 and u_2)

The level of significance, $\alpha = 0.05$ for one-tailed test and $\alpha = 0.025$ for two-tailed test.

For $u = 11$, $n_1 = 5$, $n_2 = 8$, the statistical tables give $p = 0.16$.

As $p = 0.16$ $= 0.05$ and $p = 0.16 > \alpha = 0.025$, the null hypothesis H_o is accepted and the two populations are not significantly different from one another.

Consequently, when the seeded and unseeded periods were not changing with years and a constant set of stations with continuous data was used in the target area and another one in the control area, the test showed that E-values were not significantly different.

4.7. The Selection of the Unseeded Period Affects the E-values

It was pointed out previously that for the years in which cloud seeding experiments were carried out, the seeded and unseeded periods as selected by Bishop for his computations varied from year to year. The variability of the seeded period is, of course, explained by the fact that in a particular seeded year, seeding experiments were physically started and terminated on fixed dates and the time interval between them constitutes, undoubtedly, the seeded period. The number of days making up the seeded period were listed in Table 4.10. However, the variability of the unseeded period from year to year remains unexplained and the Bishop Method does not define criteria according to which the unseeded period is selected. Table 4.15, which is based on Table 4.1 of Section 4.3 and produced here for convenience, shows the number of days involved in preseeding and in post-seeding periods as well as their totals which represent the unseeded period in each seeded year as used by Bishop in his evaluations.

Table 4.15. Durations of pre-seeding, seeding, and post-seeding periods in seeded years according to Bishop (1977, 1980-83).

Seeded year	1977	1980	1981	1982	1983
Number of days of pre-seeding period	66	28	82	80	50
Number of days of post-seeding period	44	63	71	72	72
Total days of the unseeded period	110	91	153	152	152
Number of days of the seeded period (from Table 4.10)	43	93	61	61	61

Table 4.15 shows that the pre-seeding and post-seeding periods were never of the same duration. However, except for 1980, the ratio of the unseeded period expressed in days to the seeded period in days was approximately the same and almost equal to 2.5. Since the Bishop Method does not specify the length of the pre-seeding period or that of the post-seeding period, one is tempted to feel free to start and end the unseeded period on the dates of one's choice. Because of the large variability of precipitation, especially in the case of thunderstorms, increasing or decreasing the length of the unseeded period by a few days or a few weeks would change the amount of $\overline{R}_{CU}$ or that of $\overline{R}_{TU}$ or eventually both values. As $\overline{R}_{CU}$ and $\overline{R}_{TU}$ are involved in the computation of the evaluation

parameter E(%), the results so obtained would be different from those reached if the duration of the unseeded period did not change.

To illustrate this point, in this section, an unseeded period which begins and ends on the same dates for all 13 years was selected. These two dates are the same as chosen by Bishop in his evaluation of the 1977 cloud seeding experiments. For each year, the pre-seeding period started on 1 May and ended on the date listed in Table 4.1 and similarly the post-seeding period began on the date listed in Table 4.1 and ended on 30 September. In this illustration, however, the seeded period of each year with actual or "fictitious" seedings was taken as used by Bishop and listed in Table 4.1.

4.7.1. Results of Computations

The stations used as well as the seeded period are the same as in Section 4.3. The only change affects the unseeded period, as explained above. New values of $\overline{R}_{TU}$ and $\overline{R}_{CU}$ were computed. The amounts of $\overline{R}_{TSO}$ and $\overline{R}_{CS}$ do not change, for the seeded period did not change (see Table 4.5, Section 4.3.2). The results are shown in Table 4.16.

Making use of the data entered in Table 4.16, the "expected" average rainfall in the target for the seeded period, $\overline{R}_{TSE}$, the precipitation increase in the

Table 4.16. The amounts of $\bar{R}_{TU}$ and $\bar{R}_{CU}$ were computed for an unseeded period beginning 1 May and ending 30 September for all 13 years. $\bar{R}_{TSO}$ and $\bar{R}_{CS}$ are the same as listed in Table 4.5.

	Year	Treatment	Target Area		Control Area	
			$\bar{R}_{TSO}$	$\bar{R}_{TU}$	$\bar{R}_{CS}$	$\bar{R}_{CU}$
			Seeded period	Un-seeded period	Seeded period	Un-seeded period
1.	1977	Seeding	64.4	163.2	63.9	187.5
2.	1980	"	152.0	137.3	156.9	150.5
3.	1981	"	93.7	216.6	76.2	208.7
4.	1982	"	94.3	165.4	78.0	180.6
5.	1983	"	118.0	62.9	98.7	81.7
	Mean	"	104.5	149.1	94.7	161.8
6.	1971	No seeding	144.8	73.6	116.4	83.8
7.	1972	"	138.7	90.0	149.5	111.4
8.	1973	"	156.1	54.9	156.7	40.7
9.	1974	"	119.6	73.9	110.6	72.9
10.	1975	"	162.9	135.6	167.8	123.4
11.	1976	"	205.2	74.4	196.9	55.3
12.	1978	"	204.4	176.8	215.4	167.7
13.	1979	"	108.8	46.0	108.1	56.0
	Mean	"	155.1	90.7	152.7	88.9

target, I_{TS}, and the evaluation parameter E(%) were calculated by Bishop Method and the results are shown in Table 4.17.

Table 4.17. $\overline{R}_{TSE}$, I_{TS} and E-values are computed using an unseeded period starting on 1 May and ending 30 September of all years.

	Year	Treatment	$\overline{R}_{TSO}$ (Table 4.16)	$\overline{R}_{TSE}$	I_{TS}	E(%) (Rounded)
1.	1977	Seeding	64.4	55.6	+ 8.8	+16
2.	1980	"	152.0	143.1	+ 8.9	+ 6
3.	1981	"	93.7	79.1	+14.6	+18
4.	1982	"	94.3	71.4	+22.9	+32
5.	1983	"	118.0	76.0	+42.0	+55
	Mean	"	104.5	85.0	-19.4	+25.4
6.	1971	No seeding	144.8	102.2	+42.6	+42
7.	1972	"	138.7	120.8	+17.9	+15
8.	1973	"	156.1	211.4	-55.3	-26
9.	1974	"	119.6	112.1	+ 7.5	+ 7
10.	1975	"	162.9	184.4	-21.5	-12
11.	1976	"	205.2	264.9	-59.7	-23
12.	1978	"	204.4	227.1	-22.7	-10
13.	1979	"	108.8	88.8	+20.0	+23
	Mean	"	155.1	164.0	- 8.9	+ 2

4.7.2. Statistical Significance of E-values Listed in Table 4.17

In Section 4.3.3 it was statistically shown that the recomputed E-values corresponding to seeded years are significantly different from those of the years with "fictitious" seeding. It is useful to remind the reader that the time and space conditions which gave rise to E-values of Section 4.3 are the same as those for E-values of Section 4.7 except that in Section 4.7 the unseeded period starts and ends on dates which are the same for all years, while in Section 4.3 these dates varied from year to year. The E-values of Section 4.7 will be tested to see whether or not the E-values of the seeded years are significantly different from those of the unseeded years. Like the cases already studied, there are two samples of different size and again the Wilcoxon Two-sample Test will be performed and the seeded E's are underlined.

n_1 = 5 elements of seeded E's are: 16, 6, 18, 32, 55.

n_2 = 8 elements of unseeded E's are: 42, 15, -26, 7, -12, -23, -10, 23.

Combined sample: 16, 6, 18, 32, 55, 42, 15, -26, 7, -12, -23, -10, 23.

Increasing E's: -26, -23, -12, -10, 6, 7, 15, 16, 18, 23, 32, 42, 55.

Ranks: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13.

$w_1 = 5 + 8 + 9 + 11 + 13 = 46$

$w_2 = w_1 - n_1 \ (n_1 + 1)/2 = 31$

$u_2 = w_2 - n_2 \ (n_2 + 1)/2 = 9$

$u = u_2 = 9$ (the smaller of u_1 and u_2)

The level of significance, $\alpha = 0.05$ for one-tailed test and $\alpha = 0.025$ for two-tailed test.

For $u = 9$, $n_1 = 5$, $n_2 = 8$, the tables give $P = 0.064$.

As $P = 0.064 > \alpha = 0.05$ and $P = 0.064 > \alpha = 0.025$, the null hypothesis H_o is accepted and the two E populations are not significantly different.

Consequently, when the unseeded period started on a given day and ended on another given day in every year of the 13-year time interval, the resulting E-values for seeded years were not significantly different from those for unseeded years.

4.8. Comments Regarding the Selection of the Unseeded Period

The difference between the set of E-values of Section 4.3.2 and that of Section 4.7.1 indicates the importance of the length of the unseeded period and the amount of precipitation reaching the target and the control areas during this period, i.e., $\bar{R}_{TU}$ and $\bar{R}_{CU}$. There is no need to say that, in most cases, the longer the unseeded period is, the larger $\bar{R}_{TU}$ and $\bar{R}_{CU}$ are. It should be mentioned in the first place that these quantities do not increase proportionally with time.

In Section 4.2 the evaluation parameter E resulting from Bishop's Method was given by

$$E = 100\left(\frac{\bar{R}_{TSO}}{\bar{R}_{TSE}} - 1\right) ,$$

where

$$\bar{R}_{TSE} = \frac{\bar{R}_{TU}}{\bar{R}_{CU}} \cdot \bar{R}_{CS} ,$$

Substituting for $\overline{R}_{TSE}$ in the expression of E, one gets:

$$E = 100\left(\frac{\overline{R}_{TSO}}{\overline{R}_{CS}} \cdot \frac{\overline{R}_{CU}}{\overline{R}_{TU}} - 1\right)$$

For a particular year, the seeded period which is determined by the duration of the cloud seeding experiments is constant. The quantities $\overline{R}_{TSO}$ and $\overline{R}_{CS}$ are also constant for the year under consideration for the reason that they represent average precipitation fallen during a constant time period (seeded period) over two predetermined land surfaces, i.e., target area and control area, respectively. Thus, one can deduce that the ratio $\overline{R}_{TSO}/\overline{R}_{CS}$ is constant for the year in question and let this constant be K. Then:

$$E = 100\left(K\,\frac{\overline{R}_{CU}}{\overline{R}_{TU}} - 1\right)$$

and, as it turns out, the E-value in a given year is directly proportional to the ratio $\overline{R}_{CU}/\overline{R}_{TU}$. It is obvious that $\overline{R}_{TU}$ and $\overline{R}_{CU}$ do not vary with the space element because the target area and also the control area are fixed in advance and therefore $\overline{R}_{TU}$ and $\overline{R}_{CU}$ change only with the time element, i.e., the duration of the unseeded period. Rainfall amounts over the target or control area do not vary proportionally with time and, consequently, the ratio $\overline{R}_{CU}/\overline{R}_{TU}$ can not be kept constant when the duration of the unseeded period changes. As a result, the ratio $\bar{R}_{CU}/\bar{R}_{TU}$ on which the E-value is depending, will take on different values according to whether the duration of the unseeded period is one month, 2 months, or 3 months. However, for the same year, with different unseeded periods, different E-values are obtained and each E-value is supposed to be an indication of the rainfall change in the target due to the one and unique series of cloud seeding experiments. That is where the Bishop Method breaks down unless it puts forth some specific criteria for the selection of the unseeded period. It should be pointed out that if ultimately the Review Board of the Journal of Weather Modification to which the Bishop Method is attributed, did propose such criteria, Bishop did not mention them, nor did he use them in his calculations. Because of the sensitivity of E to the choice of unseeded period we are forced to conclude that unseeded periods should be identical in seeded and unseeded years. Otherwise statistically significant differences may be found between seeded and unseeded years entirely as a result of rainfall differences in unseeded time periods.

4.9. Evaluation by the Method of Objective Analysis

The method of objective analysis for evaluation of the cloud seeding experiments was described in Section 3.5. The method considers a target area and a control area surrounding the target. In addition, it uses the seeded periods alone in contrast to the Bishop Method which require unseeded periods. The method of objective analysis requires a grid with a constant gridlength in both x and y directions which is superimposed on the portion of the map which includes both the target and the control areas. If rainfall data of the seeded periods are plotted on the map at the location of each rain reporting station, one is able to compute a precipitation value at any gridpoint using simply a method of interpolation. Once the values for all gridpoints covering the target and control areas are computed, an average rainfall can be calculated for the target by computing the mean value of all gridpoints which happen to be located within the target area. The value computed in this manner is an estimate of the average rainfall observed in the target area during the seeded period and to be consistent with Bishop Method, let this value be $\bar{R}_{TSC}$.

Assuming that the target rainfall observations are not available, and, for this reason, not plotted on the map, it seems reasonable to think that in the absence of seeding, rainfall patterns in the target are similar to those of the control area. Thus, by means of interpolation and using rainfall values plotted in the control area only, a value for each target gridpoint can be calculated. These gridpoint values are, of course, the expected rainfall values that the endpoints in question would have if the target rainfall observations were not missing and their mean represents the average rainfall "expected" in the target area during the seeded period, i.e., $\bar{R}_{TSE}$, as defined for the Bishop Method.

Finally, making use of $\bar{R}_{TSO}$ and $\bar{R}_{TSE}$ as computed above, the possible rainfall changes in the target area I_{TS} as well as the evaluation parameter E can be calculated.

The advantage of the method of objective analysis is that it is not concerned with the unseeded period which proved to be an important weakness of the Bishop Method. In addition, it allows the use of a large number of rain reporting stations in the target and in the control area and this latter is not confined to some selected area but, on the contrary, surrounds the target so that $\bar{R}_{TSO}$ and $\bar{R}_{TSE}$ result from contributions from all directions. The use of a computer program for more accurate and objective interpolations which result in more reliable values of $\bar{R}_{TSO}$ and $\bar{R}_{TSE}$ is an asset for the method of objective analysis.

In this work, the method of objective analysis was applied to rainfall data in a search for a possible effect of the cloud seeding experiments carried out in southern Alberta. The time interval covered is 1971 through 1983 and the years with actual and "fictitious" seeding are the same as those described for the Bishop Method.

4.9.1. The Area of Analysis and the Grid

The target area described by Bishop is located approximately in the center of the analysis area. This latter includes southern Alberta, south of Red Deer, the northern region of Montana limited by the 47° 40'N latitude circle, part of southwestern Saskatchewan west of 109°W longitude, and the southeastern part of British Columbia east of 117°W longitude. The map used was a polar stereographic projection, true at 60°N latitude with a scale of 1:3,666,000. The use of a polar stereographic map is required by a computer program which, using the longitude and latitude of each station as input, computes the x and y coordinates of the station with respect to the grid.

The grid which was superimposed on the map is a large square with the side measuring 550 km. Each side was then divided in 15 equal parts. Each part had a length of 36.66 km which corresponds to the typical spacing between the target area stations. Thus, the grid was made up of 15 x 15 = 225 small squares of 36.66 km side. The side of each of these small squares is called the gridlength and their corners are the gridpoints for which rainfalls are calculated. Since on each side of the large grid there were 16 gridpoints, including end-points, the total number of gridpoints involved in the grid was 16 x 16 = 256.

The grid was superimposed on the area of analysis described previously, in a manner allowing the target area to be located almost at the center of the large square. If two consecutive sides of the square are considered as x and y axes of a coordinate system, the y-axis was set parallel to the 113°W longitude line (longitude circles are straight lines on a polar stereographic map) and this latter corresponded to the equation $x = 7$. The selection of the 113°W longitude line was made because it crosses the target area almost in the middle. The x-axis which is perpendicular to the y-axis and, therefore, perpendicular to the 113°W longitude line, was placed as a line tangent to the 47° 40'N latitude circle at the point it crosses the 113°W longitude in order to include northern Montana. Thus, the coordinates of this latter intersection point were $x = 7$, $y = 0$. The grid being positioned in this manner, its north edge passed near Red Deer Industrial Airport while its east edge was at a small angle to the 109°W longitude line. Given the dimensions of the large square, the entire grid covered an area of about 3×10^5 km^2. Figure 4.1 shows the grid positioned on the map of the region described.

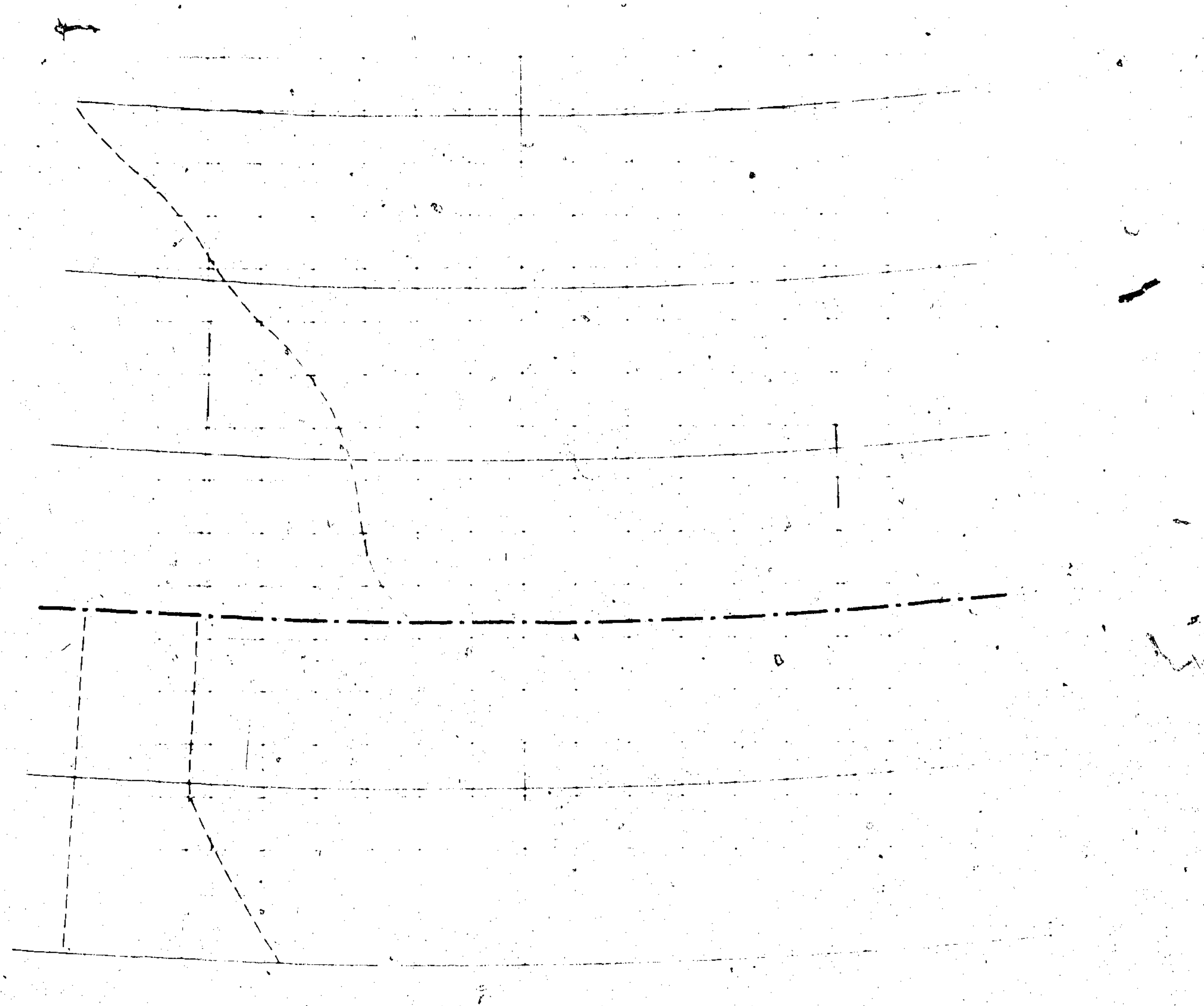


Fig. 4.1. The objective analysis grid positioned on a map showing southern Alberta, western Saskatchewan, northern Montana and south-eastern British Columbia.

4.9.2. Rainfall Stations and Data

It was pointed out earlier that the method of objective analysis is concerned only with the seeded period. Therefore, a seeded period beginning on 20 June and ending on 19 August was selected. The reason for its selection is that it is contained in the actual seeded period of all 13 years under analysis, except 1977, where the seeding experiments started on 6 July and ended 17 August. In addition, this was the time interval selected by the Alberta Research Council to carry out its cloud seeding operations in southern Alberta from 1981 through 1983. Thus, for each rain reporting station used in the analysis, the total rainfall amount between 20 June and 19 August was calculated for each year from 1971 through 1983. Because of some missing data, the total number of stations used varied from year to year, although the density of the stations used in any particular year was thought to be large enough to obtain accurate gridpoint values by the program. A complete list of the stations used in each year, together with the rainfall amounts for the seeded period is given in Table A.5 in the Appendix. The total number of stations used in each year is listed in Table 4.18 for each province involved as well as for northern Montana.

Table 4.18. Number of rain reporting stations used in the objective analysis for each year, listed for different areas covered by the grid.

	Year	Number of Rainfall Stations Used in Objective Analysis				
		Alberta	British Columbia	Montana	Saskatchewan	Total
1.	1971	98	42	42	30	212
2.	1972	95	43	43	32	213
3.	1973	98	43	41	30	212
4.	1974	102	42	40	32	216
5.	1975	98	41	41	32	212
6.	1976	90	34	42	28	194
7.	1977	87	37	43	33	200
8.	1978	83	38	42	31	194
9.	1979	81	36	34	31	182
10.	1980	74	27	35	31	167
11.	1981	71	32	38	26	167
12.	1982	80	31	36	29	176
13.	1983	80	31	36	28	175
	Mean	87	37	40	30	194

The selected seeded period precipitation data for all stations located in southern Alberta were read by computer from magnetic tapes kindly supplied by the Alberta Research Council. These data could also have been obtained from the Monthly Record, published by the Atmospheric Environment Service, but the task would have been extremely time consuming. Data which were used for the re-analysis of Bishop calculations of years, such as 1983, where the seeded period was 20 June through 19 August, were then compared to data read from the magnetic tapes and it was found, that for a given station, both values were equal. Similarly, the data for northern Montana stations were read by computer from magnetic tapes, kindly supplied by the Oklahoma Climatological Survey, Norman, Oklahoma. For stations located in British Columbia and Saskatchewan and involved in calculations, however, the data for the seeded period were hand-calculated, using precipitation data published in the Monthly Record, for the 13 years under analysis.

4.9.3. Objective Analysis Computer Program

The computer program used to calculate rainfall data at gridpoints was developed and described by Glahn and Hollenbaugh (1969). The original purpose of the program was to perform analyses of the 500-mb heights over Canada and the United States. This method of analysis by computer is based on that of Bergthórsson and Döös (1955) and Cressman (1959). The use of the program and the system of analysis is not restricted, however, to the heights of isobaric surfaces for it "has been used to analyze many different types of variables" (Cressman 1959) and can also be used for averaged precipitation data. In addition to the actual data of a given meteorological variable, reported by the observation stations, the program requires a "first guess field" which consists of some initial value of the variable at each gridpoint, thus the total number of these different values is equal to the number of gridpoints. The values of the first guess field are arranged in the form of an array which is then entered in the computer as an input file. "The choice of a first guess is in some cases arbitrary, but can easily be changed if a better guess can be obtained by some other means" (Cressman 1959). However, the use of a first guess field, derived by interpolation from climatological normals or from a forecast valid for the same time, as the objectively analyzed chart is, seems appropriate (Bergthórsson and Döös 1955). In order to obtain a final objectively analyzed field of greatest accuracy, it is essential that the first guess field be as accurate an approximation to the final field as possible.

The objective analysis scheme is essentially a method of applying corrections to the gridpoint values of the first guess field. The corrections are determined from a comparison of the data at the location of the station with gridpoint values of the first guess field.

When the program is run, the analysis is performed in a series of passes over the station's data. On each pass, an observed datum occasions a change or correction to the values of all gridpoints located within a given distance R from the station, where R is expressed in grid-length units and is called the radius of influence. The distance R varies with the pass number and usually decreases for later passes. As the process continues, corrections, resulting from the contributions of all stations located around and within the distance R of the gridpoint, are added (or subtracted) to the value of that gridpoint. Finally, when the spatial distribution of the modified gridpoint values matches the general pattern of the data of all stations, the program stops.

It was pointed out earlier that the program was originally developed to perform analyses of isobaric surfaces. That is why, in addition to the height values, the input data include the wind speed for each station. This allows the computation of a partial correction by using hydrostatic and geostrophic relationships. However, in applying the program to rainfall data of the case discussed in this section, the wind speed was input as equal to zero for all stations involved in computations. Consequently, the partial corrections due to wind speed, just mentioned, were equal to zero and had no influence on the results of the precipitation analysis. The remaining partial corrections were computed by subroutine NTRP, included in the program, which uses biquadratic interpolation with the Bessel Central Differences scheme in the inner part of the grid and a bilinear series of Taylor expansion terms along the grid edges. Since rainfall forecasts were not available, the gridpoint values of the "first guess field" array were calculated using the average value of normals of the months of June, July, and August for the period 1951-1980. This first guess field array was then entered in the computer and served as such for each analysis of the 13-year period under consideration. For more detail about the program, the reader is referred to a paper by Glahn and Hollenbaugh (1969).

4.9.4. Results of Computations

The total number of stations used in computations for each year is listed in Table 4.18. For each year, all the stations, together with their longitudes and latitudes, as well as their corresponding rainfalls for the seeded period (20 June through 19 August) were entered in the computer and stored in a file. In this manner, 13 separate files were created for the 13-year time interval. Then each file served as an input to a preliminary program which converted the longitude and latitude of every station into x and y coordinates, respectively, with respect to the grid, because the main program, developed by Glahn and Hollenbaugh, uses the coordinates of stations instead of longitudes and latitudes. Consequently, a new file was created for each year in which the coordinates and the precipitation amounts for all stations were stored. The new file served as input to the main program. It should be mentioned that the same array of "first field guess" derived from normals and described in the previous section was used as input for all 13 years. When the main program is run, using the two input files just described, it outputs an array and each element of the array is a gridpoint value.

4.9.4.1. Target Area Gridpoint

It was pointed out in Chapter 2 that the size and shape of the target area varied from year to year. The target area for 1977, that for 1980 and that for 1981-83 are shown in Figure 2.1, Figure 2.2 and Figure 2.3, respectively. The limits of these three targets were redrawn on the polar stereographic projection map involved in objective analysis and each target enclosed a number of gridpoints, i.e., a number of elements of the array output by the program.

If the elements of the array are indicated by A_{ij}, (i = 1,2.....16), (j = 1,2,.....16), where i is the number of rows, increasing from top to bottom and j is the number of columns, increasing from left to right, then the gridpoints enclosed in a target can easily be identified. For each target the gridpoints were identified and are as follows:

- 1977 target: A_{66}.

A_{76}, A_{77}, A_{78}, A_{79}.

A_{86}, A_{87}, A_{88}, A_{89}.

A_{96}, A_{97}.

A_{106}, A_{107}.

Number of gridpoints = 13

- 1980 target: A_{68}.

A_{76}, A_{77}, A_{78}, A_{79}.

A_{86}, A_{87}, A_{88}, A_{89}.

Number of gridpoints = 9

- 1981-83 plus unseeded years: A_{77}, A_{78}, A_{79}.

A_{87}, A_{88}, A_{89}.

A_{97}, A_{98}, A_{99}.

A_{107}, A_{108}, A_{109}.

Number of gridpoints = 12

It is worthy of note that the distribution of these gridpoints on the grid, roughly resembled the configuration of the target on the map. Locating the gridpoints enclosed in the target accurately is of prime importance for $\overline{R}_{TSC}$ and $\overline{R}_{TSE}$, previously defined, were calculated using the values assigned to them by computer.

4.9.4.2. Computation of $\overline{R}_{TSO}$, $\overline{R}_{TSE}$, and E

To compute $\overline{R}_{TSO}$, the average target precipitation observed during the selected seeded period, the program was run once for each year. In addition to the "first guess field" array, the input data consisted of data for all stations located both in the target and in the control areas. An array of gridpoint values was output by each run. From the array, $\overline{R}_{TSO}$ was computed for each year by adding the values of those gridpoints which are located in the target and were given in the preceding section and then dividing the sum by the number of such grid points.

For the computation of $\overline{R}_{TSE}$, the average target precipitation expected during the seeded period, the same procedure was followed. The only exception was that <u>all stations situated in the target area were excluded from the input data</u>. This can be likened to the situation where no rain reporting stations existed in the target area while a large number of them were scattered all over the control area and one was asked to estimate the amount of precipitation that had fallen in the target area during a specified length of time.

For each year, from 1971 through 1983, $\overline{R}_{TSO}$ and $\overline{R}_{TSE}$, calculated by computer, as well as the evaluation parameter E, computed by the Bishop Method are listed in Table 4.19.

Table 4.19. Values of $\overline{R}$ (mm) and $\overline{R}_{TSE}$ (mm) and their differences I_{TS} (mm) computed by objective analysis using a computer program. E(?) was calculated by the Bishop Method. The number of target gridpoints were different in 1977 and 1980 in accordance with changes in the target area.

	Year	Treatment	No. of target grid-points	$\overline{R}_{TSO}$	$\overline{R}_{TSE}$	I_{TS}	(E( ) (Rounded)
1	1977	Seeding	13	87.2	96.1	- 8.9	- 9
2	1980	"	9	92.4	99.1	- 6.7	- 7
3	1981	"	12	75.0	89.9	-14.9	-17
4	1982	"	12	91.8	71.1	+20.7	+2[illegible]
5	1983	"	12	117.0	104.3	+12.7	+12
	Mean	"	12	92.7	92.1	+ 0.6	+ 2
6	1971	No seeding	12	46.2	56.5	-10.3	-16
7	1972	"	12	77.8	84.3	- 6.5	- 8
8	1973	"	12	41.5	45.8	- 4.3	- [illegible]
9	1974	"	12	78.8	67.4	+11.4	+17
10	1975	"	12	82.6	68.0	+14.6	+21
11	1976	"	12	137.7	153.3	-15.6	-10
12	1978	"	12	112.3	124.6	-12.3	-10
13	1979	"	12	55.5	75.7	-20.2	-27
	Mean	"	12	79.1	84.5	- 5.4	- [illegible]

4.10. Statistical Significance of E-values

The E-values shown in Table 4.19 need to be tested to see whether or not the population of the E-values of the seeded years was significantly different from that of the unseeded years. The E-value samples being of different size, the Wilcoxon Two-Sample Test was applied once again (values for the seeded years are underlined).

n_1 = 5 elements of the seeded E's are: $-\underline{9}$, $-\underline{7}$, $-\underline{17}$, $\underline{29}$, $\underline{12}$.

n_1 = 8 elements of the unseeded E's are: −18, −8, −9, 17, 21, −10, −10, −27.

Combined sample: $-\underline{9}$, $-\underline{7}$, $-\underline{17}$, $\underline{29}$, $\underline{12}$, −18, −8, −9, 17, 21, −10, −10, −27.

Increasing E's: −27, −18, $-\underline{17}$, −10, −10, −9, $-\underline{9}$, −8, $-\underline{7}$, 12, 17, 21, $\underline{29}$.

Ranks: 1, 2, $\underline{3}$, 4.5, 4.5, 6.5, $\underline{6.5}$, 8, $\underline{9}$, $\underline{10}$, 11, 12, $\underline{13}$.

$w_1 = 3 + 6.5 + 9 + 10 + 13 = 41.5$

$w_2 = 1 + 2 + 4.5 + 4.5 + 6.5 + 8 + 11 + 12 = 49.5$

$u_1 = w_1 - n_1 (n_1 + 1)/2 = 26.5$

$u_2 = w_2 - n_2 (n_2 + 1)/2 = 13.5$

$u = u_2 = 13.5$ (the smaller of u_1 and u_2)

For $u = 13.5$, $n_1 = 5$ and $n_2 = 8$, the statistical tables give $p = 0.19$.

As usual, the level of significance, $\alpha = 0.05$ and

α = 0.025 for one-tailed and two-tailed tests, respectively.

Since [illegible] = 0.19 [illegible] α = 0.05 and [illegible] = 0.19 [illegible] α = 0.025, the null hypothesis H_o is accepted and the two populations are not significantly different.

Thus, it is concluded that the method of objective analysis led to the result that cloud seeding experiments carried out in southern Alberta had no significant effect on the evaluation parameter E.

4.11. Statistical Significance of the Differences Between $\bar{R}_{TSO}$ and $\bar{R}_{TSE}$ Computed by Objective Analysis

In the cases studied previously, no test was performed to give an account of the significance of the difference between $\bar{R}_{TSO}$ and $\bar{R}_{TSE}$ because of the involvement of the unseeded period in $\bar{R}_{TSE}$. It was pointed out that the unseeded period varied with years and its length was chosen somewhat arbitrarily. The method of objective analysis is not concerned with the unseeded period and consequently $\bar{R}_{TSO}$ and $\bar{R}_{TSE}$ arise from the same time interval and, for a particular year, for the same target area. These considerations enable one to apply a statistical test to the differences between $\bar{R}_{TSO}$ and $\bar{R}_{TSE}$ as listed in Table 4.20. However, the tests should be applied to the results obtained for seeded years only for trying to

Table 4.20. Values of $\overline{R}_{TSO}$ averaged from rainfall amounts at Bishop's stations and those averaged from objective analysis gridpoints. The time period for both computations was 20 June through 19 August.

	Year	Treatment	$\overline{R}_{TSO}$ (mm) Averages from Bishop's stns (Table 4.11)	$\overline{R}_{TSO}$ (mm) Gridpoint averages (Table 4.19)	Difference (d, mm)
1.	1977	Seeding	88.7	87.2	+ 1.5
2.	1980	"	95.3	92.4	+ 2.[illegible]
3.	1981	"	93.8	75.0	+18.8
4.	1982	"	94.3	91.8	+ 2.5
5.	1983	"	118.0	117.0	+ 1.[illegible]
	Mean	"	98.[illegible]	92.7	+ 5.3
6.	1971	No seeding	49.2	46.2	+ 3.[illegible]
7.	1972	"	105.2	77.8	+27.4
8.	1973	"	65.9	41.5	+24.4
9.	1974	"	114.1	76.8	+37.3
10.	1975	"	91.0	82.6	+ 8.4
11.	1976	"	158.9	137.7	+21.2
12.	1978	"	148.2	112.3	+35.9
13.	1979	"	49.1	55.5	- 6.4
	Mean	"	97.7	79.1	18.6

assess the results of cloud seeding while no actual seeding took place is not very reasonable. In previous cases, values from unseeded years were compared to values from seeded years. In the present case the observed average rainfalls were compared to the average rainfall expected in the target. Since the samples drawn from the populations of $\bar{R}_{TSO}$ and $\bar{R}_{TSE}$ are of the same size; i.e., of size $n = 5$, the Sign Test and also the Wilcoxon Matched-Pairs Signed-Ranks Test are appropriate. The different steps to perform these tests are explained in Sections 3.6.2.2 and 3.6.2.3.

4.11.1. Application of the Sign Test

For each year, the value of $\bar{R}_{TSO}$ and that of $\bar{R}_{TSE}$ form a pair and there were 5 pairs for seeded years. The test is performed as follows using rainfall amounts listed in Table 4.19.

years: 1977, 1980, 1981, 1982, 1983.

$\bar{R}_{TSO}$: 87.2, 92.4, 75.0, 91.8, 117.0.

$\bar{R}_{TSE}$: 96.1, 99.1, 89.9, 71.1, 104.3.

$d = \bar{R}_{TSO} - \bar{R}_{TSE}$: -8.9, -6.7, -14.9, 20.7, 12.7.

$r_+ = 2$ (number of positive d's)

$r_- = 3$ (number of negative d's)

$r = r_+ = 2$ (the smaller of r_+ and r_-)

The level of significance $\alpha = 0.05$ for one-tailed test and $\alpha = 0.025$ for two-tailed test.

For $n = 5$ and $r = 2$, the statistical tables give $p = 0.15$.

Since $p = 0.15 > \alpha = 0.05$ and $p > \alpha = 0.025$, the null hypothesis is accepted and the populations were not significantly different.

Consequently, the results obtained by the method of objective analysis show that cloud seeding experiments had no significant effect on rainfall amounts in the target or control areas.

4.11.2. Application of the Wilcoxon Matched-Pairs Signed-Ranks Test

The first few steps of this test are the same as in the case of the Sign Test. From the line where the differences are calculated, the two tests are performed in different ways and the steps are as follows:

$d = \bar{R}_{TSO} - \bar{R}_{TSE}$: -8.9, -6.7, -14.9, 20.7, 12.7.

Increasing absolute value of d: -6.7, -8.9, 12.7, -14.9, 20.7.

Ranks with signs: -1, -2, 3, -4, 5

$T_+ = 3 + 5 = 8$

$T_- = 1 + 2 + 4 = 7$

$T = T_- = 7$ (the smaller of T_+ and T_-).

$\alpha = 0.05$ and $\alpha = 0.025$ for one-tailed and two-tailed tests, respectively.

For $\alpha = 0.05$ and $n = 5$, the statistical tables give $t = 1$ and for $\alpha = 0.025$ and $n = 5$, $t = 0$.

Since $T = 7$ $t = 1$ and T $t = 0$, the null hypothesis H_o is accepted and the populations were not significantly different.

The test leads to the conclusion that the results computed by the method of objective analysis show that cloud seeding experiments carried out in southern Alberta had no significant effect on rainfall amounts in the target or control areas.

4.12. Comparison of $\overline{R}_{TSO}$ as Computed by Objective Analysis with $\overline{R}_{TSO}$ Computed for a Constant Seeding Period

In Section 4.5.1 a constant seeding period beginning 20 June and ending 19 August was considered and $\overline{R}_{TSO}$ was computed for each year by simply averaging all rainfall amounts for the target stations which were selected by Bishop. For the method of objective analysis the seeded period was also selected to be 20 June through 19 August and $\overline{R}_{TSO}$ was computed by averaging gridpoint values calculated by computer. These two values of $\overline{R}_{TSO}$, computed by two different methods are supposed to represent the same quantity, i.e., the depth, in mm, of the average precipitation observed over the entire target surface. While $\overline{R}_{TSO}$ of Section 4.5.1 results from the contribution of a number of selected stations, $\overline{R}_{TSO}$ given by objective analysis arises from the contribution of a large number of stations. In order to see whether or not the two methods of computation were in agreement with each other, statistical tests were applied to their results. The results are shown in Table 4.20. Since the samples are of the same size ($n = 13$), and since both values of $\overline{R}_{TSO}$ for the same year form a pair, the appropriate nonparametric tests are the Sign Test and the Wilcoxon Matched-Pair Signed-Ranks Test.

A - Application of the Sign Test

Values for each pair of $\overline{R}_{TSO}$ as well as the difference between each pair are listed in Table 4.20; the remaining steps of the Sign Test are as follows:

$r_+ = 12$

$r_- = 1$

$r = r_- = 1$ (the smaller of r_+ and r_-)

= 0.05 for one-tailed test and = 0.025 for two-tailed test.

For $n = 13$ and $r = 1$, the statistical tables give 0.001.

Since P 0.001 = 0.05 and 2 0.002 = 0.025, the null hypothesis H_o is rejected and the two populations of $\overline{R}_{TSO}$ are significantly different from each other for one-tailed and two-tailed tests.

B - Application of the Wilcoxon Matched-Pairs Signed Ranks Test

Pairs of $\overline{R}_{TSO}$ estimates and their difference are shown in Table 4.20. The column of d's shows that there is only one d with a minus sign; i.e., the d corresponding to 1979 and the rank of its absolute value is 6. The remaining steps of the test are as follows:

$T_{+} = 85$

$T_{-} = 6$

$T = T_{-} = 6$ (the smaller of T_{+} and T_{-})

$\alpha = 0.05$ for one-tailed test and $\alpha = 0.025$ for two-tailed test.

For $\alpha = 0.05$ and $n = 13$, the statistical tables give $t = 21$ and for $\alpha = 0.025$ and $n = 13$, the statistical tables give $t = 13$.

Since $T = 6 < t = 21$ and $T = 6 < t = 13$, the null hypothesis H_O is rejected for one-tailed and two-tailed tests and the two populations of $\overline{R}_{TSO}$ were significantly different from each other.

The results of the Sign Test and the Wilcoxon Matched-Pairs Signed-Ranks Test lead to the conclusion that the two methods of computing $\overline{R}_{TSO}$ yield results which differ from each other, although the magnitude of the differences shown in Table 4.20 were rather small for the seeded years. The gridpoint averages should represent more accurate estimates of the true areal target mean because they were derived from values distributed uniformly in space over the target, whereas the station averages came from a non-uniform spatial distribution of values. However, this has not been demonstrated.

CHAPTER 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1. Introduction

In recent years J. Bishop, Research Director, Alberta Weather Modification Co-operative, concluded that cloud seeding by the emission of silver iodide from ground generators had increased summer rainfall in seeded time periods by about 30 to 40 percent in a small target area centered near 50°N, 113°W in southwestern Alberta. His conclusion was based on a quantitative comparison of five seeded and eight or more unseeded years using the ratios of the differences between observed rainfall amounts and rainfall amounts expected in the absence of cloud seeding, to the expected rainfall amounts. These ratios were found to be positive and rather large in seeded years and highly variable but averaging near zero in unseeded years.

In the present study Bishop's conclusions were re-examined, and his calculations reproduced, using AES rainfall data for the target and control area stations as well as for the seeded and unseeded periods involved in his evaluations. The problem was complicated by the fact that the period of cloud seeding varied from year to year and the fact that Bishop chose to use sets of target and control rainfall stations that varied somewhat from year to year. Furthermore, because the expected target rainfall amount in the absence of cloud seeding required the use of pre-seeding and post-seeding target-to-control rainfall ratios, the variations in the actual seeded periods meant that it was impossible to match the unseeded periods in seeded and unseeded years.

In the re-evaluation of Bishop's work, the sensitivity of the results to changes in rainfall station selections, changes in the choice of seeded period, and changes in the choices of pre-seeding and post-seeding periods was investigated. A remarkable feature of the results was that the unseeded target-to-control rainfall ratios in seeded years were systematically lower than those in unseeded years.

An alternative method of estimating target rainfall in the absence of cloud seeding was tried. The method used objective spatial analysis of control rainfall amounts at stations within an area of 300,000 km^2 centered near the middle of the target area. Measured rainfall amounts were transferred by interpolation procedures to a regular array of gridpoints having a gridlength of 36.66 km. The analysis yielded estimates of actual target rainfall when target stations were included, and estimated target rainfall when target stations were omitted.

5.2. Summary of Results

The sensitivity of Bishop's evaluation parameter E to the selection of stations and to that of the seeded and unseeded periods was investigated. Appropriate statistical tests were applied to test the significance of E-values for seeded years versus those for unseeded years and the results are given in the following sections.

5.2.1. Evaluation Based on Bishop's Selection of Rainfall Stations

Bishop's original calculations were reproduced using the seeded and unseeded periods as well as the rainfall stations that he used. The mean error in predicted values, as compared with observed values was +22.4 mm with a standard deviation, s = 11.6 mm for seeded years, and -3.2 mm (s = 16.[illegible] mm) for unseeded years. The recomputed E-values were all positive and averaged +29% for seeded years and they were highly variable with an average of +1% for unseeded years. The fact that positive E-values were found in 5 out of 5 seeded years, while positive and negative values of E occurred almost equally in 8 unseeded years, seems very unlikely to have occurred by chance. The Wilcoxon Two-Sample nonparametric test was applied and confirmed that the E-values for the seeded years were significantly different from those for unseeded years.

Since in Bishop's calculations the duration of the seeded period and that of the unseeded period were not the same for all 13 years under analysis, the calculations were carried out using Bishop's stations for each year and a seeded period and an unseeded period which did not vary from year to year. The calculations yielded a mean error in predicted values as compared to observed values of +26.1 mm (s = 15.4 mm) for seeded years, and of +1.3 mm (s = 12.8 mm) for unseeded years. Similar to the case above, the E-values for all seeded years were found to be positive with an average of 39%, while those for unseeded years were positive and negative, averaging +6%. The Wilcoxon Two-Sample nonparametric test was applied to the results and once more it confirmed that E-values for seeded years were significantly different from the E-values for the unseeded years.

5.2.2. Evaluation Based on a Constant Set of Rainfall Stations

The evaluation parameter E was re-computed, using stations with continuous data for the period of time involved in calculations throughout the 13-year interval covered. The number of such stations was found to be [illegible] in the target area and 12 in the control area. The seeded and the unseeded periods chosen for the calculations were those used by Bishop. The calculations resulted in predictions of target rainfall which were more accurate than in the case where Bishop's selected stations were used and resulted in much smaller E-values for all seeded years. The mean error in predicted target rainfall, as compared to the observed values was 9.8 mm (instead of [illegible].4 and [illegible].1 above) with a standard deviation s = 8.6 mm for seeded years and -1.2 mm (instead of -3.2 and +1.3 above) with s = 21.[illegible] for unseeded years. The E-values for seeded years were all positive or zero, averaging 11[illegible], and those for unseeded years were positive or negative with an average value of +[illegible]. Thus, the choice of rainfall stations influenced the results of computations. The Wilcoxon non-parametric test was applied to E-values and no statistically significant difference was found in the evaluation parameter E between seeded and unseeded years, in contradiction to the results described before based on a variable network of rainfall stations.

[illegible].2.3. Sensitivity of E to Changes in Seeded and Unseeded Periods

As discussed earlier in this chapter, Bishop's calculations were carried out using his selection of rain-fall stations, together with seeded and unseeded periods which were kept constant for all years and thus different from those of Bishop which varied from year to year. The resulting individual E-values were quite different from those yielded by the re-calculation of Bishop's original work. Their mean values rose, from 2% to 3% for seeded years and from 1% to 6% for unseeded years. It is important to stress that the Bishop evaluation parameter E was highly sensitive to changes in the seeded and unseeded periods.

To support this point, constant sets of stations were used in the target and in the control areas and E-values were computed for variable time periods selected by Bishop and also for constant seeded and unseeded periods but different from those of Bishop. Again, the individual E-values for seeded years, resulting from each series of computations were very much different. Although large variability of the individual E-values for seeded years and also that of their means with changes in choices of seeded and unseeded period was found, it should be mentioned that no statistically significant difference was found between the newly computed E-values for seeded years and those for unseeded years.

Bishop's original calculations were reproduced using a constant unseeded period instead of variable ones that he considered. The change in unseeded period alone resulted in an individual E-value for each seeded and unseeded year different from the corresponding E-value of the original calculations. In addition, the change in the duration of the unseeded period resulted in a change in the statistical significance of the Bishop evaluation parameter, i.e., contrary to the case of the original re-calculations, the newly computed E-values for the seeded years were not significantly different from the E-values for the unseeded years.

5.2.4. Target Rainfall Estimates by Objective Analysis

The objective analysis rainfall estimation procedure performed well with a mean prediction error of +0.[illegible] mm with s = 13.7 mm for seeded years and of -5.4 mm with s = 11.6 mm for unseeded years in target rainfalls. Values of the evaluation parameter E for seeded years were found to be not significantly different from those of the unseeded years. The Sign Test and the Wilcoxon Matched-Pairs Signed-Ranks Test were applied to the differences between the observed and estimated target rainfall amounts for seeded years, derived by objective analysis and the rainfall amounts were found to be not significantly different. Furthermore, the same tests were applied to the differences between the observed target rainfall amounts (20 June - 19 August) computed by averaging station precipitation data and the estimates of observed rainfall amounts (20 June - 19 August) derived from objective analysis and it was concluded that the populations of the rainfall amounts in question were significantly different from each other. Except in 1979, the observed rainfall amount for each year, computed from station averages was larger than the corresponding value estimated from objective analysis. The mean difference was 5.3 mm with s = 6.6 mm in seeded years and 18.6 mm with s = 14.4 mm in unseeded years. It was pointed out that rainfall amounts computed by objective analysis should represent more accurate estimates of the true mean target precipitation for they were derived from values distributed uniformly over the target, whereas the station averages resulted from a non-uniform distribution of precipitation values.

5.3. Conclusions

Calculations carried out using target and control rainfall stations selected by Bishop, resulted in values of his evaluation parameter E for seeded years that were significantly different from E-values for unseeded years.

When constant sets of rainfall stations, which were not all used by Bishop and which had no missing data in seeded and unseeded periods throughout the 13-year interval (1971-1983) were selected for the target and for the control areas, the resulting E-values for seeded years were not significantly different from those for unseeded years.

The individual E-values for seeded and unseeded years, as well as their means, were found to be sensitive to changes in the duration of the seeded period and that of the unseeded period, and also to changes in the rainfall stations used.

The evaluation parameter E for seeded years computed by the Bishop Method using estimates of target observed rainfalls and target predicted rainfalls for the period 20 June - 19 August derived from objective analysis, were not significantly different from those for unseeded years.

Because of the large natural variability of precipitation, the sizes of the samples of seeded years and unseeded years were much too small to detect possible small effects due to seeding. Therefore, it is not easy to decide conclusively whether or not cloud seeding from ground generators in 1977 and 1980-83 had an effect on rainfall amounts in the target area located in southern Alberta. However, it can be concluded that if such an effect occurred, it was very much less than the 30 to 40 percent increase claimed by Bishop. The precision of the results was severely limited by lack of randomization in experimental design, the small size of the sample of seeded years, and the year-to-year variations in seeded periods and the populations of target and control rainfall stations.

5.4. Recommendations

No reason was found to reject the evaluation procedure used by Bishop but it is concluded that, in using this procedure, it is essential that the selection of seeded and unseeded periods be identical for seeded and unseeded years, and that homogeneous sets of target and control rainfall stations be used. If the purpose of evaluation is to establish the reality of a target rainfall increase, as distinct from a possible control area rainfall decrease due to cloud seeding, then the evaluation procedure should use only upwind control stations.

It was pointed out that for a given year involved in the analysis, the Bishop evaluation parameter E is directly proportional to the ratio of mean control area rainfall for the unseeded period to the mean target area rainfall for the unseeded period, i.e., $\bar{R}_{CU}/\bar{R}_{TU}$. This ratio is not constant with time and its numerical value changes with a change in the duration of the unseeded period. Thus, different E-values are obtained for different unseeded period selections in the evaluation of the cloud seeding experiments for the year under consideration. Therefore, it is important that the duration of the unseeded period be determined according to some criteria (perhaps equal to the duration of the seeded period, for instance) and kept constant for all years involved in the analysis.

Rainfall stations used to compute mean precipitation should be uniformly distributed over the target and control areas, and not clustered in a rather small area, so that the computed areal means are as accurate as possible.

In this work, no clear-cut evidence of rain increase in the target resulting from cloud seeding operations was found, and some of the doubt and uncertainty which existed prior to this study still persists, because the evaluation techniques used in this study are incapable of identifying small effects on the rainfall. People who desperately need water, may go on and seed clouds in the hope that nature will respond favorably to their wishes. Those who do not, and are interested in the scientific aspects of cloud seeding, should push on with more research until the day when a convincing solution is found to the problem. It is strongly stressed that more and more research on the physics, the chemistry, the vertical extent, the updraft velocity, the concentration of supercooled droplets of the clouds, and the optimal temperature necessary for the action of silver iodide particles is needed.

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APPENDIX

Table A-1. Total precipitation (mm) at each of the target stations for the actual seeded period in seeded years and June, July and August in unseeded years.

AES stations used in the target area	Years With Seeding					Years Without Seeding							
	77	80	81	82	83	71	72	73	74	75	76	78	79
1. Arrowwood						148.3	152.2	195.5	91.2				
2. Big Coulee					136.0								
3. Blackie North							178.0	202.2	134.9	127.7	197.4		
4. Blackie 2W	71.3	205.2				157.2		209.5	162.6	114.6	215.4	188.0	108.1
5. Brant					89.8								
6. Carmangay Village	55.7	104.0	101.6	73.2	125.2	149.0	205.7		147.8	236.4	157.0	214.2	105.5
7. Claresholm A								48.3	109.7	162.9			
8. Claresholm MC	73.7	117.4	132.6	94.2	130.5							225.2	92.5
9. Claresholm WW	44.5	154.4	73.0	78.6	119.7	143.2	119.9	60.5	152.1	207.5	242.3	194.6	100.2
10. Fort MacLeod	80.5		40.6	77.4	157.0	122.2	114.6	113.6	136.7	209.7	245.6	209.9	94.0
11. Fort MacLeod N	84.2		68.4	92.3	116.4	161.8	103.7		108.0	247.1	272.1	199.6	111.2
12. Fort MacLeod Stand Off						161.4	171.8	120.2	140.2				
13. Herronton						164.6	107.7	203.3	132.6				
14. Herronton East	72.7	119.3	112.3	127.1	111.4	177.8	147.3	180.4	63.8	90.3	182.7	167.8	85.9

cont'd..

Table A-1, cont'd:

AFS stations used in the target area	Years With Seeding					Years Without Seeding							
	77	80	81	82	83	71	72	73	74	75	76	78	79
15. High River	113.5	257.0	189.8	84.8	102.2	161.0	157.9	213.3	176.2	181.3	274.5	210.9	181.8
16. High River Town	63.5	178.2	121.3	122.8	122.5	140.8	187.2	211.0	[illegible]	130.2	221.0	142.2	120.7
17. Lethbridge A	50.9		83.7	117.9	119.8	125.2	110.3	107.7	104.7	189.4	188.2	278.4	105.6
18. Lethbridge CDA	38.2		71.3	101.2	97.5	153.7	102.9	101.8	42.6	167.1	180.1	279.8	143.5
19. Monarch			91.8	43.4	74.4								
20. Mossleigh	83.6	125.8	162.2	83.3	107.0	192.8	156.0	206.7	128.5	96.5	244.9	259.3	134.1
21. Mossleigh Burnav	69.3							206.7	68.4	130.0	185.9	221.5	119.6
22. Picture Butte	55.8					120.4	140.9	98.9	107.5	183.5	135.7		
23. Pincher Creek	80.1		61.9	67.5	91.0	111.7	164.3	119.9	187.0	282.5	272.3	225.6	117.9
24. Queenstown	66.3	127.5	109.6	116.9	123.3	139.5	121.1	209.8	128.5	167.4	173.5	227.8	91.5
25. Raymond						129.8			89.1				
26. Taber	20.5		28.7	78.5	153.3	135.2	103.8		91.0	180.1	203.7	204.2	82.3
27. Vauxhall CDA	20.9		45.4	120.0	106.5	101.2	116.6		71.8	139.6	131.0	167.9	55.2

cont'd..

Table A-1, cont'd:

AES stations used in the target area	Years With Seeding					Years Without Seeding							
	77	80	81	82	83	71	72	73	74	75	76	78	79
28. Vauxhall North				98.6	111.2								
29. Vulcan	78.2	131.2	98.2	120.2	165.0					157.3	176.3	149.8	
Number of stations used	19	10	17	18	20	20	19	18	23	20	19	18	17
Total	1223.5	1520.0	1592.4	1697.8	2359.7	2896.8	2634.9	2809.3	2750.2	3257.9	3899.6	3679.1	1849.6
Average	64.4	152.0	93.7	94.3	118.0	144.8	138.7	156.1	119.6	162.9	205.2	204.4	108.8

End

Table A-2. Total precipitation (mm) at each of the target stations for the unseeded period used by Bishop in seeded years and April, May, September and October for unseeded years.

AES stations used in the target area	Years With Seeding					Years Without Seeding							
	77	80	81	82	83	71	72	73	74	75	76	78	79
1. Arrowwood						99.5	125.4	79.2	143.2				
2. Big Coulee					115.7								
3. Blackie North							110.5	104.4	187.3	176.7	131.2		
4. Blackiw 2W	180.2	165.0				87.8		113.8	184.3	172.9	122.9	160.8	98.4
5. Brant					33.4								
6. Carmangay Village	163.9	177.9	215.5	188.4	65.6	136.1	138.9		196.1	217.7	85.0	189.0	76.8
7. Claresholm A								92.8	173.2	187.5			
8. Claresholm MC	186.5	156.0	261.5	199.1	83.0							233.8	70.9
9. Claresholm WW	186.9	159.7	181.3	203.8	61.1	147.8	196.6	126.0	218.2	218.7	126.0	270.4	123.2
10. Fort MacLeod	157.2		330.4	165.0	100.0	145.3	197.6	75.5	180.3	217.2	99.9	246.8	101.9
11. Fort MacLeod S	178.8		311.8	198.3	80.4	136.3	150.7		177.1	131.8	84.3	229.8	68.3
12. Fort MacLeod Stand Off						154.8	154.5	95.6	217.2				
13. Herronton						94.7	109.8	75.4	232.1				

cont'd..

Table A-2, cont'd:

AES stations used in the target area	Years With Seeding					Years Without Seeding							
	77	80	81	82	83	71	72	73	74	75	76	78	79
14. Herronton East	130.6	186.6	225.9	195.6	42.7	100.1	115.8	54.6	195.6	163.6	112.2	270.0	92.5
15. High River	174.3	164.4	257.0	298.4	80.0	144.5	180.4	133.4	226.5	122.0	158.0	302.1	120.7
16. High River Town	181.5	153.1	239.4	235.1	62.5	97.9	128.3	113.3	206.2	160.3	141.8	256.0	86.0
17. Lethbridge A	172.8		264.4	153.1	97.0	124.2	127.0	104.6	163.4	222.0	92.7	343.1	119.2
18. Lethbridge CDA	127.7		255.7	155.3	64.1	122.2	101.5	86.0	153.1	223.4	87.5	285.0	119.7
19. Monarch			242.6	195.4	74.2								
20. Mossleigh	173.6	172.9	247.8	173.5	38.0	100.9	148.6	96.6	193.8	225.0	112.6	322.6	126.4
21. Mossleigh Burnay	157.8							57.4	144.2	196.4	110.1	259.8	87.8
22. Picture Butte	157.8					127.3	119.7	63.0	136.2	229.6	100.8		
23. Pincher Creek	179.4		336.4	184.6	96.4	183.4	232.5	132.0	258.8	235.7	116.6	261.9	[illegible]
24. Queenstown	134.2	143.5	200.2	201.6	41.7	122.4	143.7	76.6	166.3	250.2	94.5	242.9	128.9
25. Raymond						155.6			225.2				
26. Taber	135.7		180.9	162.2	52.7	93.2	128.2		124.3	253.8	71.7	271.8	94.2

cont'd...

Table A-2, cont'd:

AES stations used in the target area	Years With Seeding					Years Without Seeding							
	77	80	81	82	83	71	72	73	74	75	76	78	79
27. Vauxhall CDA	177.6		178.8	170.9	56.8	100.3	129.5		132.5	224.0	62.0	216.9	80.1
28. Vauxhall North				189.8	26.8								
29. Vulcan	153.6	136.0	177.6	168.2	50.3					217.6	99.3	258.7	
Total	3100.1	1615.1	3116.2	3338.3	1322.5	2484.3	2715.1	1680.2	4235.8	4035.0	2004.0	4621.4	1763.8
Number of stations used	19	10	17	18	20	20	19	18	23	20	19	18	17
Average	163.2	161.5	242.1	191.0	66.1	124.2	134.2	93.3	184.2	202.2	105.5	256.7	103.8

End

Table A-3. Total precipitation (mm) at each of the control stations for the actual seeded period in seeded years and June, July and August in unseeded years.

AES stations used in the control area	Years With Seeding					Years Without Seeding							
	77	80	81	82	83	71	72	73	74	75	76	78	79
1. Aden	28.4					131.4	155.7	115.1	130.5	244.6	157.8		
2. Altawan			74.3	80.6			165.6	121.3		166.9			95.2
3. Big Coulee				76.0									
4. Bonnie View	46.7											372.3	
5. Bow Island Riv Dev						110.2	135.4	144.0	101.9	14.8			
6. Brooks						103.5	167.2	214.5	127.5	175.0	203.7		158.1
7. Brooks CDA	53.8	116.7	113.1	99.6	131.9	94.6	103.9	193.5	95.5	149.4	183.1	197.1	135.2
8. Brooks North	57.9				128.6			187.7	92.0	140.9	160.6	195.4	137.7
9. Caldwell	94.3	270.8	95.3	58.9		154.6	204.4	121.1	177.0	314.7	239.5	281.8	117.1
10. Calgary Elbow	73.6							215.4	106.9	163.3	229.9	202.8	
11. Calgary Glenmore								149.8		81.8			
12. Calgary Int'l	98.8							207.8	121.2	161.6	222.6	220.1	122.3
13. Cardston	86.7	200.0	73.5	55.8	106.2	159.5	170.7	83.1	188.5	333.3	236.4	290.1	102.6

cont'd..

Table A-3, cont'd:

AES stations used in the control area	Years With Seeding					Years Without Seeding							
	77	80	81	82	83	71	72	73	74	75	76	78	79
14. Carway	99.7	167.7	47.6	57.9	102.0	127.0	150.1	66.4	105.7	310.9	183.4	270.9	72.4
15. Chestermere Lake S	78.4									103.7	187.9	189.3	104.9
16. Cochrane	100.2							191.3	120.2	109.8	214.4	235.7	125.1
17. Foremost	28.5	120.2	68.7	104.0	74.7	107.0	142.9	97.3	90.3	175.1	183.4	214.4	66.0
18. Fort MacLeod		132.4											
19. Fort MacLeod N		118.0											
20. Gleichen	76.3							166.4	128.5	82.8	186.4	186.6	95.4
21. Lethbridge A		127.4											
22. Lethbridge CDA		135.1											
23. Manyberries CDA	31.4	114.0	46.8	74.3	86.8	133.4	112.0	99.8	124.7	222.3	175.2	117.1	96.0
24. Masinasin			88.4	68.2	60.8								
25. Medicine Hat A	57.7	132.1	64.7	134.1	104.3	71.[illegible]	118.9	167.9	116.6	141.5	187.4	132.2	129.0
26. Milk River	21.8					118.4			87.7	191.5		217.5	

cont'd..

Table A-3, cont'd:

AES stations used in the control area	Years With Seeding					Years Without Seeding							
	77	80	81	82	83	71	72	73	74	75	76	78	79
27. Mountain View		249.3	121.3	62.5	98.5	147.9	217.4						115.6
28. Pincher Creek		183.2											
29. Pothole McIntyre					113.3								
30. Rainier	63.9					89.9	136.7	159.0	71.8	129.5	175.5	201.5	98.5
31. Ralston						79.8	130.2	152.5	53.7	135.6			
32. Redcliff	48.4				84.5							142.9	111.6
33. Standard								259.6	89.4				
34. Strathmore East	67.6							221.7	119.6	84.8	170.1	228.4	96.2
35. Suffield A	32.6	131.5	81.3	96.3	90.4	73.9	96.8	167.2	66.8	152.5	174.7	146.6	99.3
[illegible]ffield Hamlet			53.1	87.8	108.9								
3[illegible]r		161.2						109.5					
38. University of Calgary	103.8							188.0	109.2	99.2	240.3	216.1	109.4
39. Vauxhall CDA		155.0						117.9					

cont'd..

Table A-3, cont'd:

AES stations used in the control area	Years With Seeding					Years Without Seeding							
	77	80	81	82	8[illegible]	71	72	73	74	75	76	78	79
40. Warner West					107.4								53.9
41. Whiskey Gap	55.4	152.5	76.8	60.0	85.6	159.3	183.6	[illegible]	118.4	310.7	214.8	265.2	135.6
42. Writing On Stone			62.4	53.6	79.0								
Total	1405.9	2667.1	1067.4	1169.6	1578.9	1861.7	2391.5	3917.8	2533.6	4196.2	3937.1	4524.0	2377.1
Number of stations used	22	17	14	15	16	16	16	25	23	25	20	21	22
Average	63.9	156.9	[illegible]	78.0	98.7	116.4	149.5	156.7	110.6				108.1

End

Table A-4. Total precipitation (mm) at each of the control stations for the unseeded period used by Bishop in seeded years and April, May, September and October for unseeded years.

AES stations used in the control area	Years With Seeding					Years Without Seeding							
	77	80	81	82	83	71	72	73	74	75	76	78	79
1. Aden	168.1					84.1	137.5	95.8	128.4	296.6	81.8		
2. Altawan			204.6	187.1			149.5	48.0		207.6			127.9
3. Big Coulee				313.4									
4. Bonnie View	147.9											352.8	
5. Bow Island Riv Dev.						87.1	171.9	67.8	123.3	269.5			
6. Brooks						115.3	130.3	74.7	86.2	232.5	72.4		118.7
7. Brooks CDA	180.2	111.3	187.5	208.8	65.3	102.6	120.1	50.5	77.3	239.3	68.0	221.9	119.2
8. Brooks North	183.8				63.8			56.2	70.3	202.1	60.7	245.4	124.1
9. Caldwell	167.1	325.1	384.7	256.5		257.8	288.3	132.1	240.3	422.5	133.4	339.0	161.6
10. Calgary Elbow	276.4							1.0	156.8	122.9	137.7	291.8	
11. Calgary Glenmore								100.5		34.3			
12. Calgary Int'l	260.4							88.7	169.9	122.0	123.2	245.9	118.1
13. Cardston	184.5	285.2	385.4	233.2	107.9	229.9	238.3	88.8	217.7	291.9	128.8	307.5	102.4
14. Carway	120.1	250.2	285.6	192.0	129.3	158.0	221.2	103.5	133.9	230.6	56.4	219.5	39.7

cont'd..

Table A-4 cont'd:

AES stations used in the control area	Years With Seeding					Years Without Seeding							
	77	80	81	82	83	71	72	73	74	75	76	78	79
15. Chestermere Lakes	239.0									151.2	92.0	251.7	101.6
16. Cochrane	230.8							148.1	177.0	121.5	132.1	250.7	146.0
17. Foremost	174.2	127.6	188.2	231.2	95.8	85.5	129.4	71.3	92.3	206.5	86.3	243.5	133.3
18. Fort MacLeod		179.7											
19. Fort MacLeod North		184.9											
20. Gleichen	142.8							67.2	124.8	191.8	84.3	225.3	101.3
21. Lethbridge A		184.5											
22. Lethbridge CDA		159.9											
23. Manyberries CDA	151.8	97.0	182.2	214.4	94.0	70.1	114.0	72.6	151.8	217.2	56.6	191.3	107.8
24. Masinasin			210.2	247.0	100.9								
25. Medicine Hat A	162.5	100.4	185.8	215.4	75.5	100.3	127.8	73.6	106.2	177.8	61.5	251.8	105.3
26. Milk River	180.4					73.7			96.0	244.2		231.8	
27. Mountain View		391.1	401.4	243.6	170.0	206.0	312.4						194.1
28. Pincher Creek		241.2											

cont'd..

Table A-4, cont'd:

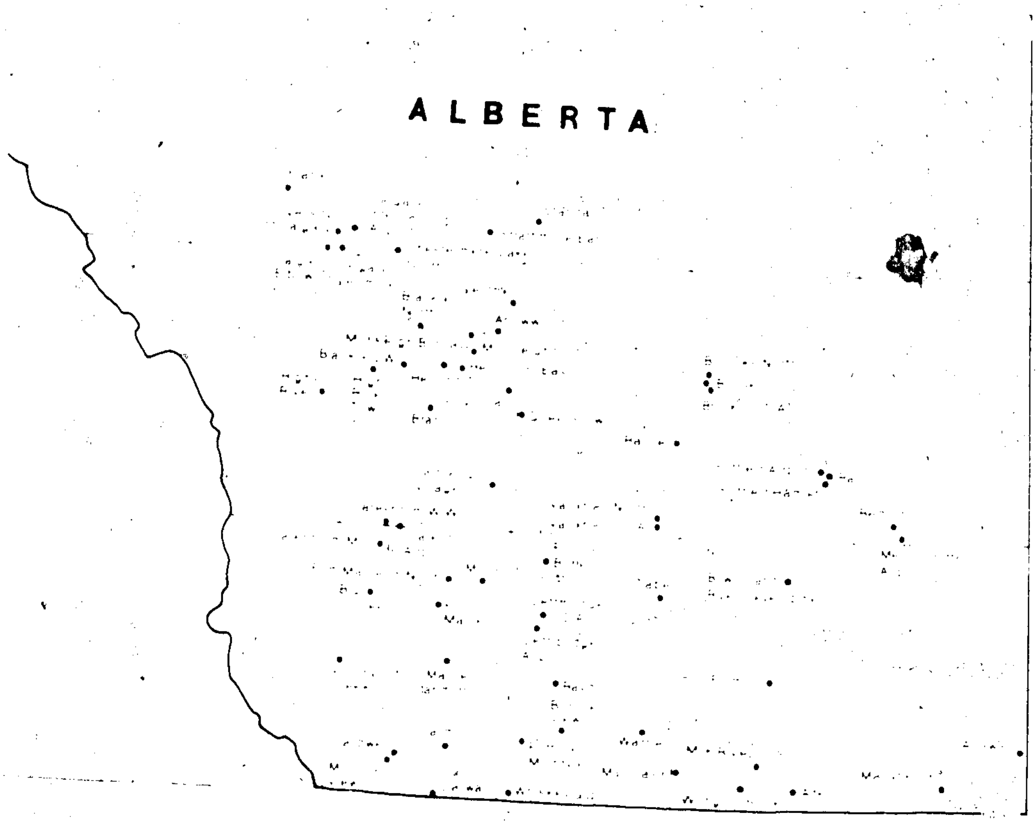
AES stations used in the control area	Years With Seeding					Years Without Seeding							
	77	80	81	82	83	71	72	73	74	75	76	78	79
29. Pothole McIntyre					98.7								
30. Rainier	224.8					98.5	128.4	53.1	93.4	251.7	62.7	272.3	136.6
31. Ralston						69.8	120.7	64.3	103.8	176.9			
32. Redcliff	140.8				69.2							236.8	124.8
33. Standard								102.3	121.2				
34. Strathmore East	206.5							102.6	145.5	202.1	96.8	243.5	131.3
35. Suffield A	197.6	112.2	170.6	186.5	59.5	70.4	138.7	59.9	108.7	210.9	66.5	226.2	101.5
36. Suffield Hamlet			173.8	183.6	49.6								
37. Taber		135.0						82.7					
38. University of Calgary	237.0							112.5	199.3	96.7	100.8	260.7	123.3
39. Vauxhall CDA		129.6						56.7					
40. Warner West					65.6								162.6

cont'd..

Table A-4, cont'd:

AES stations used in the control area	Years With Seeding					Years Without Seeding							
	77	80	81	82	83	71	72	73	74	75	76	78	79
41. Whiskey Gap	142.4	170.3	233.9	208.6	44.6	204.4	153.1		192.4	287.1	126.4	240.6	61.3
42. Writing On Stone			195.0	244.4	106.8								
Total	4124.5	3185.2	3388.9	3265.7	1396.9	2013.5	2681.3	2114.4	3116.5	5197.4	1828.4	5350.0	2652.5
Number of stations used	22	17	14	15	16	16	16	25	23	25	20	21	22
Average	187.5	187.4	242.1	217.7	87.3	125.8	167.6	84.6	135.5	207.9	91.4	254.8	120.6

End



. A-1. Map of southern Alberta showing rainfall stations used by Bishop in his calculations to evaluate the effects of cloud seeding by ground generators in the target area. Not all of the stations were used in each year.

Table A-5. Rainfall stations and precipitation data (mm) for the period 20 June - 19 August for each year used in the objective analysis. Data for southern Alberta and Montana were extracted from magnetic tapes by computer. Data for British Columbia and Saskatchewan were hand-calculated.

Stations Used	Years With Seeding					Years Without Seeding							
	77	80	81	82	83	71	72	73	74	75	76	78	79
ALBERTA													
1. Acme CDA EPF	76.7	199.7	160.9	31.4	-	74.7	129.5	121.4	78.0	73.9	121.7	92.1	134.4
2. Aden	45.7	21.5	-	0.0	64.6	32.7	95.2	21.8	122.1	103.8	107.0	-	34.4
3. Altawan	8.7	11.5	74.3	78.3	101.2	-	159.7	21.4	86.7	158.1	21.3	111.8	60.5
4. Banff	123.0	100.3	141.6	99.6	127.9	56.1	99.3	60.8	97.1	139.9	122.2	75.6	63.7
5. Baseline Lo	180.0	241.3	406.9	240.7	200.0	35.0	288.3	205.6	179.7	161.4	238.[illegible]	242.9	107.2
6. Beaver Mines	93.4	111.2	73.9	80.8	96.8	54.2	157.6	18.8	123.7	132.8	184.4	175.7	27.2
7. Big Coulee	-	-	-	76.0	136.0	-	-	-	-	-	-	-	-
8. Bowden	182.9	252.6	185.4	204.4	170.0	80.8	150.4	157.5	170.2	101.1	232.7	148.0	113.5
9. Bow Island Riv Dev	-	-	-	-	-	40.9	104.1	51.8	83.8	120.6	-	-	-
10. Bow Valley P. Pk	141.4	112.2	-	-	-	0.0	163.4	66.6	107.0	153.4	184.7	140.1	12.6
11. Brant	-	-	-	-	89.8	-	-	-	-	-	-	-	-
12. Brooks	72.5	-	-	-	-	31.5	81.8	56.1	87.6	111.8	167.9	-	113.2
13. Brooks Horticulture	70.9	91.4	114.4	99.6	131.9	24.2	73.5	42.5	59.7	82.7	146.2	85.8	95.1
14. Brooks North	-	-	-	-	128.6	-	-	52.1	66.5	71.4	127.5	86.2	116.1
15. Brooks One Tree	85.1	98.4	3.4	22.8	81.3	21.4	53.3	59.5	62.2	44.7	153.9	83.2	114.2
16. Burnstick Lo	177.5	203.9	299.9	209.7	199.7	101.9	281.6	169.1	149.3	130.9	191.4	250.9	109.0
17. Caldwell	115.0	129.5	95.3	58.9	104.6	102.3	157.1	34.9	104.3	101.7	155.5	208.4	39.2
18. Calgary Elbow View	109.4	-	-	-	-	-	-	87.1	94.0	102.9	181.9	148.1	-
19. Calgary Glenmore	77.0	-	-	-	-	47.9	140.8	67.5	74.1	89.6	216.5	123.4	21.4
20. Calgary Int. A.	150.8	-	-	-	-	-	-	82.3	98.6	121.4	177.3	156.6	101.1
21. Carbon	91.5	56.2	128.0	83.0	-	49.2	79.2	93.9	57.1	25.3	-	43.0	-
22. Cardston	111.1	111.4	72.5	55.8	106.2	100.1	139.3	38.7	139.7	66.6	200.4	215.1	33.8
23. Carmangay Village	83.1	68.8	101.6	73.2	125.2	36.5	101.3	30.5	125.5	134.6	121.8	125.1	68.8

cont'd...

Table A-5, continued:

Stations Used	Years With Seeding					Years Without Seeding							
	77	80	81	82	83	71	72	73	74	75	76	78	79
24. Carway	115.7	78.8	45.6	57.9	102.0	79.4	125.2	16.6	69.1	67.7	122.8	231.8	14.0
25. Castle R.S.	–	–	–	–	–	62.6	162.1	–	67.7	126.4	189.8	–	–
26. Chedderville R.S.	223.6	–	–	–	–	131.1	294.9	92.0	159.8	177.0	223.6	–	–
27. Chestermere L.S.	130.0	–	–	–	–	–	–	–	–	52.8	146.1	136.0	84.3
28. Claresholm	115.3	74.6	132.6	94.2	130.5	–	–	87.1	121.7	81.2	–	195.2	28.2
29. Claresholm W.W.	60.4	105.5	73.0	78.6	119.7	44.4	98.8	103.9	126.2	103.9	197.8	163.2	28.6
30. Clearwater R.S.	130.1	258.1	29.7	268.4	204.5	135.5	354.6	151.4	226.3	153.8	246.3	168.4	188.5
31. Cochrane	132.4	84.9	–	134.1	135.6	62.9	116.1	50.3	101.2	61.0	142.8	160.3	72.9
32. Coleman	103.2	77.7	86.2	85.0	116.8	66.4	112.6	31.8	89.7	161.1	254.9	156.6	27.7
33. Columbia Icefield	123.1	136.7	–	129.6	105.0	65.6	133.8	63.7	98.8	–	119.7	–	–
34. Consort CDA	–	–	–	–	–	60.3	112.2	70.4	77.2	109.4	–	–	–
35. Coronation	71.5	171.2	99.8	173.6	193.0	122.6	156.5	150.2	144.7	102.4	131.9	83.4	136.7
36. Cowley Olin Creek	96.2	165.0	86.6	41.0	112.0	110.7	160.3	33.2	109.3	115.7	258.9	241.4	35.6
37. Drumheller-Andrew	64.8	154.1	82.4	93.0	–	54.9	90.4	72.7	52.8	47.4	122.6	45.0	79.4
38. Duchess	61.0	–	–	–	–	64.8	66.6	61.7	36.6	–	135.4	79.3	–
39. Eckville South	185.2	256.7	258.3	188.4	186.0	–	–	151.8	155.3	114.8	178.8	133.0	68.3
40. Elbow R.S.	197.4	118.5	180.6	103.1	150.6	66.7	194.4	83.8	147.3	142.3	242.9	227.8	95.2
41. Empress	47.1	95.5	120.5	106.4	157.1	69.5	89.7	63.5	100.7	72.2	111.3	102.2	84.2
42. Foremost	45.8	81.4	64.9	104.0	74.7	43.0	133.3	28.2	79.5	61.9	122.4	174.4	45.5
43. Fort Macleod	104.1	71.2	40.6	77.4	157.0	41.7	98.7	70.9	83.4	120.7	194.9	153.3	14.4
44. Fort Macleod North	96.4	59.7	59.7	92.3	116.4	29.2	77.3	–	75.2	142.5	172.2	150.8	25.6
45. Fort Macleod Stand-Off	–	–	–	–	–	48.4	119.6	44.9	88.9	–	–	–	–
46. Ghost R.S.	147.9	133.2	258.1	137.4	166.3	125.9	254.4	107.1	147.8	113.4	201.5	180.9	65.8
47. Gleichen	104.3	78.1	184.2	100.4	127.4	58.8	129.9	55.9	105.5	52.6	148.9	105.0	72.4
48. Hanna	–	–	–	207.8	85.0	99.2	172.0	156.5	102.1	79.5	113.3	–	–
49. Herronton East	83.9	85.6	112.3	127.1	111.4	157.7	131.4	81.6	85.4	101.7	134.3	113.2	49.7

cont'd...

Table A-5, continued:

Stations Used	Years With Seeding					Years Without Seeding							
	77	80	81	82	83	71	72	73	74	75	76	78	79
50. High River	142.1	151.2	189.8	84.8	102.2	56.1	127.4	100.3	135.0	95.4	238.4	161.2	100.9
51. High River Town	105.1	77.3	121.3	122.8	122.5	49.8	51.3	78.5	136.5	69.1	155.7	404.9	90.4
52. Highwood R.S.	–	–	–	61.4	–	39.2	25.3	11.2	52.2	–	–	–	–
53. Horse Show Lake	77.3	194.1	143.2	134.4	–	125.9	61.8	144.1	84.5	126.3	200.0	107.1	–
54. Huxley	84.2	107.8	109.5	143.4	99.8	4.6	72.3	96.2	109.5	64.9	158.3	131.9	70.2
55. Jenner	–	–	–	51.6	56.5	–	–	–	–	–	–	–	–
56. Junction Lo	180.4	127.1	189.3	86.4	111.2	–	120.2	–	123.9	172.0	203.6	245.1	105.5
57. Kananaskis	153.0	144.3	207.2	102.3	150.2	66.2	188.4	77.0	137.0	127.2	174.6	176.5	39.6
58. Kananaskis R.S.	153.8	109.8	182.9	93.4	148.1	69.4	136.3	78.0	116.7	119.0	170.2	178.3	74.7
59. Lake Louise	116.7	103.4	190.0	119.5	137.0	63.9	127.7	59.3	88.1	88.6	129.1	112.2	85.6
60. Lethbridge A	89.3	69.7	83.2	117.9	119.8	55.7	86.2	54.9	94.5	98.6	144.7	189.5	15.1
61. Lethbridge CDA	67.2	88.4	71.3	101.2	97.5	65.4	76.5	38.4	145.8	78.6	141.3	177.3	12.5
62. Livingstone R.S.	122.5	90.2	136.4	58.5	92.4	48.7	109.6	45.9	92.4	109.7	215.8	161.7	35.9
63. Lousana	–	–	–	–	–	99.0	121.6	120.9	44.3	83.8	–	–	–
64. Majorville	–	–	–	–	–	52.3	40.6	52.2	34.5	–	–	–	–
65. Manyberries CDA	48.2	85.2	45.8	74.3	86.8	40.3	97.8	17.1	109.1	99.4	107.7	92.0	50.2
66. Masinasin	–	–	75.2	68.2	60.8	–	–	–	–	–	–	–	–
67. Medicine Hat A	62.8	96.9	64.2	134.1	104.3	29.2	81.6	22.1	97.6	98.8	158.7	67.3	67.7
68. Metiskow CDA	42.0	–	–	–	–	114.8	131.6	115.1	129.1	73.2	102.6	67.9	–
69. Milk River	47.4	–	–	–	–	42.8	80.1	30.0	61.3	83.6	61.7	148.9	39.4
70. Mockingbird Lo	185.7	148.2	272.0	127.2	226.0	104.2	210.5	107.3	165.8	184.9	202.0	196.9	110.0
71. Monarch	–	–	91.8	33.4	74.4	–	–	–	–	–	–	–	–
72. Mossleigh	102.1	87.2	166.8	83.3	107.0	56.6	139.2	63.5	117.9	49.3	170.4	168.8	78.9
73. Mossleigh Burnay	81.0	54.1	119.4	67.6	108.2	59.3	97.4	65.3	131.5	59.8	123.8	162.5	69.6
74. Mount Eisenhower	–	–	–	–	–	54.2	–	–	–	–	–	–	–
75. Mountain View	–	126.9	121.3	62.5	98.5	55.2	136.5	24.9	75.1	9.9	–	202.6	31.6
76. Mountain View Birdseye	128.5	130.0	–	–	–	53.5	174.5	53.0	76.4	115.9	132.8	262.7	65.3

cont'd...

Table A-5, continued:

Stations Used	Years With Seeding					Years Without Seeding							
	77	80	81	82	83	71	72	73	74	75	76	78	79
77. Olds	126.5	199.7	181.0	187.1	133.1	82.0	206.5	133.6	105.3	66.4	183.8	185.1	92.6
78. Oven Cappon	76.3	110.4	127.4	161.4	198.3	–	–	–	–	132.0	119.9	36.8	112.0
79. Pekisko	170.1	136.8	157.0	75.1	128.0	33.5	176.3	95.2	158.6	179.8	276.2	240.7	94.2
80. Picture Butte	85.1	–	–	–	–	36.8	101.9	26.9	86.6	68.8	96.8	–	–
81. Pincher Creek	95.4	113.8	61.5	67.4	91.0	54.3	141.8	55.7	138.2	144.8	209.2	186.5	38.6
82. Pine Lake	155.5	233.6	–	–	–	145.0	188.4	200.7	179.8	104.7	204.9	158.3	93.0
83. Pollockville	56.3	157.2	76.1	150.0	55.8	0.3	119.6	52.8	86.7	83.7	144.3	106.4	98.7
84. Pothole McIntyre	–	–	–	–	113.3	–	–	–	–	–	–	–	–
85. Prairie Creek R.S.	21.6	180.1	–	271.1	191.6	147.9	313.8	169.9	227.6	87.1	121.5	187.5	124.7
86. Queenstown	88.1	79.3	119.8	116.9	123.3	60.1	100.4	66.9	107.8	97.6	130.5	147.1	65.8
87. Rainier	–	–	–	–	–	36.6	102.9	36.8	58.9	70.9	136.6	86.6	66.2
88. Ralston	–	–	–	–	–	16.8	61.6	29.6	26.4	51.3	–	–	–
89. Raspberry Lo	6.0	122.9	169.3	36.4	90.1	3.3	134.9	83.1	11.5	125.0	234.5	132.2	83.4
90. Raymond	–	–	–	–	–	56.7	117.2	24.2	124.7	–	132.8	–	–
91. Redcliffe	56.8	–	–	–	100.5	–	–	–	–	–	–	78.9	67.1
92. Red Deer	186.5	188.7	257.4	203.4	192.4	120.0	183.1	179.8	167.6	122.5	171.3	152.1	100.2
93. Red Deer A	175.1	206.7	229.1	215.9	179.5	126.0	169.4	198.7	191.7	143.1	155.4	161.2	95.6
94. Scollard	107.3	151.5	76.2	183.2	87.4	102.2	98.7	89.8	97.8	89.5	90.7	73.9	45.5
95. Sheep R.S.	–	–	–	–	–	67.4	150.6	98.5	107.8	155.3	–	–	–
96. Sibbald	33.2	118.6	130.6	173.2	192.2	82.4	91.5	131.9	133.8	57.2	103.7	39.2	111.7
97. Standard	–	–	–	–	–	74.2	84.6	83.3	47.	11.2	–	–	–
98. Stettler	10.4	–	–	–	–	142.5	193.5	223.6	168.5	165.5	179.9	–	–
99. Strathmore East	96.9	126.8	45.8	125.6	127.4	–	179.0	86.2	97.1	32.9	123.5	127.2	72.8
100. Suffield A	45.1	97.3	81.1	96.3	90.4	16.3	68.2	46.6	51.3	87.5	156.1	58.3	61.0
101. Suffield Hamlet	–	–	58.1	87.8	108.9	–	–	–	–	–	–	–	–
102. Sullivan Lake	15.3	137.8	105.8	160.8	129.4	–	–	–	107.2	69.7	49.1	78.8	63.8
103. Sundre R.S.	208.2	158.6	237.0	213.8	169.4	83.8	275.3	128.1	119.9	92.8	170.8	217.9	122.2

cont'd...

Table A-5, continued:

Stations Used	Years With Seeding					Years Without Seeding						
	77	80	81	82	83	71	72	73	74	75	76	78
104. Swalwell	–	–	–	–	–	60.1	–	–	–	–	–	–
105. Taber	36.7	97.1	27.7	78.5	153.3	60.9	87.9	24.1	84.6	82.2	187.4	89.3
106. Three Hills	75.9	–	–	–	–	66.0	114.4	104.6	75.5	120.3	147.0	–
107. Trochu 2	–	–	–	–	–	73.7	128.6	21.6	97.1	79.9	–	–
108. Trochu Equity	98.6	171.9	112.6	211.0	185.5	77.7	163.0	107.9	101.1	119.7	155.6	73.3
109. Turner Valley	–	–	–	–	–	54.6	232.1	137.4	151.8	–	–	–
110. Univ. of Calgary	145.5	–	–	–	–	–	–	77.0	99.6	64.8	204.5	161.5
111. Vauxhall CDA	36.9	97.0	45.8	120.0	106.6	33.4	57.7	13.3	66.7	85.4	102.9	83.3
112. Vauxhall North	–	–	–	98.6	111.2	–	–	–	–	–	–	–
113. Vulcan	104.9	78.0	96.4	120.2	165.0	–	–	–	–	68.9	134.6	155.2
114. Warner	–	–	–	–	107.?	58.1	–	–	–	–	–	–
115. Wastina Hemaruka	–	–	–	–	–	96.9	118.4	120.2	81.0	22.3	136.4	–
116. Waterton P. HQ	–	–	–	–	–	164.3	–	–	–	–	–	–
117. Whiskey Gap	77.2	105.4	74.6	60.0	85.?	84.1	140.3	23.9	87.3	87.4	132.4	199.2
118. Willow Creek R.S.	–	–	–	–	–	66.2	–	–	–	–	–	–
119. Wimborne Gas Plant	–	–	–	–	–	66.3	140.6	130.3	213.2	190.6	–	–
120. Writing On Stone	–	–	60.8	53.6	7?.?	–	–	–	–	–	–	–
BRITISH COLUMBIA												
121. Aberfeldie	61.4	–	–	–	–	53.3	157.2	?.9	–	83.3	164.8	111.2
122. Brisco	87.5	105.4	104.5	110.0	13?.5	47.5	90.9	36.3	61.5	115.1	91.7	89.5
123. Canal Flat R.S.	58.7	63.8	120.8	105.3	[illegible]	30.0	85.8	–	74.7	88.6	92.2	70.3
124. Castlegar A.	50.2	115.7	114.4	174.4	15?.3	87.1	121.7	45.0	101.8	13?.?	159.5	112.4
125. Columbia Gardens	–	–	–	–	–	78.2	105.?	90.?	[illegible]	[illegible]	–	–
126. Cranbrook A.	54.8	99.8	83.1	88.1	125.3	29.2	81.6	88.8	104.1	80.5	[illegible]	75.5
127. Creston	38.8	109.2	115.6	115.0	126.?	80.1	100.?	?6.1	[illegible]	[illegible]	[illegible]	69.?
128. Deer Park	20.7	72.2	135.2	[illegible]	112.8	47.4	132.9	?0.1	90.4	94.2	112.8	146.?

cont'd

Table A-5, continued:

Stations Used	Years With Seeding					Years Without Seeding						
	77	80	81	82	83	71	72	73	74	75	76	78
129. Duncan Lake Dam	76.3	–	178.4	168.1	172.2	69.9	105.7	43.2	128.5	152.7	141.5	102.4
130. Elko	47.0	–	117.1	117.1	–	72.1	130.5	14.5	152.1	128.5	197.4	166.6
131. Fauquier	55.5	–	172.0	278.1	158.0	50.3	102.9	22.1	119.1	127.8	152.6	120.5
132. Fernie	111.7	162.9	109.4	109.4	263.0	95.5	153.2	39.9	191.5	168.7	238.8	156.4
133. Fording River Com	104.1	143.1	137.7	55.8	95.9	45.7	141.0	59.7	72.4	146.5	–	150.2
134. Glacier N.P.M. Fidelity	[illegible]	256.7	209.4	415.1	361.9	127.0	226.1	161.8	151.4	294.6	297.9	201.3
135. Glacier N.P. Rogers Pass	171.5	186.3	172.0	281.3	269.1	80.5	172.2	109.0	149.6	217.9	205.0	148.1
136. Golden	73.5	80.[illegible]	155.3	155.3	139.4	50.0	89.4	45.7	37.3	92.5	149.1	83.6
137. Grand Forks	31.1	105.0	124.8	159.6	155.8	51.8	77.0	32.3	63.2	99.3	116.1	111.4
138. Grasmere	88.2	136.0	89.8	117.7	187.6	62.5	–	17.8	33.0	126.2	158.5	147.5
139. Greenwood	–	–	–	–	–	59.2	64.3	2.0	86.1	72.1	–	–
140. Kaslo	70.2	120.6	179.2	179.2	195.0	72.4	115.1	18.0	144.5	130.0	139.2	136.0
141. Kimberley	54.4	–	92.6	73.1	106.9	30.7	118.9	16.3	90.7	80.8	88.1	58.0
142. Kootenay Nat. Pk. Ftn. Crs.	129.3	–	–	–	137.8	50.5	88.6	38.1	54.1	132.3	100.3	95.8
143. Kootenay N.P. West Gate	75.1	67.0	90.4	100.0	117.2	50.5	84.3	34.5	1.9	115.8	66.0	73.6
144. Lardeau	–	–	–	–	–	[illegible].1	96.8	27.4	130.[illegible]	144.5	46.3	84.0
145. Lumby	–	–	–	–	–	32.5	–	–	–	–	–	–
146. Lumby Sigalet Rd	53.6	112.9	191.2	266.6	150.8	70.1	119.1	88.1	102.9	70.1	190.2	80.7
147. Mable Lake	–	–	–	–	–	66.5	111.5	89.2	70.9	67.6	–	–
148. Malakwa	–	–	–	–	–	85.9	177.8	–	–	–	–	–
149. Marysville	50.8	80.4	88.6	71.4	102.8	–	–	42.4	73.7	–	–	55.9
150. Nakusp	70.5	119.1	173.0	[illegible]	215.0	91.2	118.4	57.4	114.6	142.7	186.4	76.7
151. Natal Harmer Ridge	84.4	113.6	86.0	104.0	107.3	–	137.4	64.0	118.1	[illegible]	–	133.7

Table A-5, continued:

Stations Used	Years With Seeding					Years Without Seeding							
	77	80	81	82	83	71	72	73	74	75	76	78	79
152. Natal Kaiser Resources	76.7	–	–	–	–	45.7	110.[illegible]	56.4	80.8	86.4	205.5	150.3	36.3
153. Needles Whatshan	–	–	–	–	–	–	113.5	–	–	–	–	–	–
154. Nelson 2	43.2	127.0	165.3	167.7	–	40.9	107.2	25.4	111.0	168.9	116.3	127.7	131.0
155. New Denver	77.0	118.2	223.1	206.6	208.0	70.4	139.4	33.5	140.7	151.9	124.0	156.6	86.8
156. Revelstoke A.	74.0	147.8	128.7	234.4	233.8	66.5	142.0	67.8	84.3	123.2	–	121.5	62.8
157. Richland	–	–	–	–	–	57.7	123.4	78.2	93.5	–	–	–	–
158. Robson	25.9	–	–	–	–	69.6	110.0	22.4	93.5	129.0	166.4	88.2	94.8
159. Rossland	27.3	136.8	120.3	169.5	130.8	70.9	136.1	27.7	85.9	96.0	158.5	107.4	65.7
160. Seymour Arm	72.7	159.5	165.4	255.2	231.9	–	–	111.0	67.6	187.7	303.3	120.5	59.7
161. Shuswap Falls	–	–	–	–	–	75.4	135.1	–	–	–	–	–	–
162. South Slocan	56.0	125.4	151.1	276.2	161.0	79.2	146.6	17.5	102.6	135.1	135.1	86.1	71.2
163. Spillimacheen	–	–	–	–	–	41.4	81.3	41.1	55.6	53.6	–	–	–
164. Waneta	12.9	–	–	–	–	61.2	110.2	17.8	86.4	–	–	–	–
165. Wardner Ktny Hry	–	–	–	94.4	118.6	–	98.0	16.3	103.9	86.9	111.0	106.5	34.5
166. Warfield	22.1	110.4	123.8	–	121.3	63.0	132.3	41.1	–	58.7	142.0	89.2	69.7
167. Wasa	59.0	73.6	136.2	–	152.4	38.9	108.2	19.6	88.4	108.7	127.0	143.3	35.0
168. Yoho N.P. Boulder Crs	112.8	–	253.0	197.4	175.6	–	–	81.0	74.4	154.7	181.9	142.3	59.7
SASKATCHEWAN													
169. Abbey	74.3	97.8	44.8	139.1	209.0	–	–	–	–	–	–	55.1	84.0
170. Alaska Hardene	44.3	123.0	–	132.4	205.4	–	–	–	122.7	74.2	133.1	75.9	93.6
171. Bad Lake IHD 102	67.7	152.0	67.4	122.4	124.6	–	91.9	58.9	198.9	95.3	160.3	74.4	–
172. Biggar	57.0	110.1	98.5	110.6	171.2	170.7	123.7	53.6	–	92.2	136.1	60.5	64.7
173. Bracken CDA	–	–	–	–	–	–	40.4	–	–	–	–	–	–
174. Cabri	–	–	–	–	[illegible]	76.5	48.5	56.6	177.5	–	–	–	–

cont'd...

Table A-5, continued

Stations Used	Years With Seeding					Years Without Seeding							
	77	80	81	82	83	71	72	73	74	75	76	78	79
175. Cadillac	83.8	137.4	71.8	171.2	–	–	–	–	137.2	83.3	96.0	49.9	62.3
176. Claydon	24.2	85.6	–	99.4	179.2	–	89.9	17.5	138.2	–	81.0	105.7	121.6
177. Consul CDA	38.1	71.4	35.1	56.0	–	32.3	77.7	16.8	126.7	84.6	80.0	112.8	88.1
178. Cypress Hills	–	–	–	91.3	218.7	–	–	–	–	–	–	–	–
179. Denzil	77.0	124.0	146.0	186.8	–	136.9	158.8	–	120.9	210.3	–	81.6	138.8
180. Eastend CDA S	–	–	–	–	–	–	–	–	–	103.1	–	–	–
181. Eston	59.3	112.6	–	135.5	113.5	109.2	81.3	64.5	–	94.7	174.2	103.2	155.7
182. Garden Head	–	–	–	–	–	43.4	71.6	–	–	–	–	–	–
183. Golden Prairie	60.0	102.6	62.6	129.7	118.2	–	58.4	–	–	–	94.2	115.2	126.2
184. Gull Lake CDA	94.6	198.6	86.7	183.3	153.7	29.5	63.8	26.4	148.6	84.1	121.9	60.4	130.2
185. Harris	76.9	140.2	57.4	95.9	261.2	–	–	104.6	187.7	105.7	134.1	–	130.2
186. High Point	98.2	169.0	–	173.0	179.0	85.3	63.8	58.9	185.2	134.1	–	62.6	106.2
187. Hughton	–	–	–	–	–	136.9	63.8	47.8	–	–	–	–	–
188. Ingebright Lake	54.4	166.7	70.7	112.8	66.6	32.0	52.1	32.5	121.9	63.8	146.1	74.7	117.1
189. Instow	–	–	–	–	–	61.2	45.5	40.1	134.6	39.4	–	–	–
190. Kerrobert	48.8	101.6	177.6	287.6	190.4	99.1	132.3	75.7	155.4	101.6	194.8	36.0	156.8
191. Kindersley	–	118.0	115.2	124.6	210.6	119.1	102.9	61.7	169.4	83.1	211.1	57.3	134.6
192. Klintonel	72.7	125.9	74.4	166.1	156.1	55.4	94.7	34.5	161.8	124.5	108.0	81.0	87.6
193. Leader 2	71.6	109.8	116.0	154.0	180.2	108.1	67.8	72.1	159.0	76.2	179.6	66.2	121.4
194. Leny	41.6	149.6	92.3	139.2	204.8	138.2	93.0	121.7	158.0	93.2	101.9	79.6	104.2
195. Loverna CDA	–	–	–	–	–	98.8	–	–	–	–	–	–	–
196. Macklin	65.9	–	–	–	–	230.6	143.3	135.4	133.4	125.2	243.6	101.3	141.7
197. Maple Creek	91.0	114.7	88.1	–	–	–	–	–	–	86.6	95.5	73.1	92.4
198. Maple Creek North	78.0	109.5	80.1	128.1	262.6	14.7	76.4	11.9	119.6	62.7	95.3	68.3	99.0
199. Nashlyn	29.8	–	–	–	–	21.3	91.2	24.1	146.3	130.6	74.9	95.0	–
200. Pennant	120.3	172.4	66.1	148.8	166.8	54.1	–	30.0	155.9	64.0	–	56.0	94.5
201. Roadene	91.8	109.5	112.1	145.4	204.5	46.2	60.7	46.0	189.2	64.0	137.2	45.0	92.3

cont'd....

Table A-5, continued:

Stations Used	Years With Seeding 77	80	81	82	83	Years Without Seeding 71	72	73	74	75	76	78	79
202. Rosetown CDA	97.6	136.8	-	144.4	155.6	102.4	-	73.4	173.7	85.9	132.1	76.0	78.0
203. Scotstown	[illegible]	104.0	129.6	148.2	189.6	179.6	130.6	87.1	96.0	-	183.9	55.1	141.7
204. Scott CDA	45.8	116.9	99.7	130.5	161.8	157.5	151.1	36.3	142.5	141.5	198.9	58.6	127.2
205. Senate	35.2	-	-	-	-	27.4	73.2	-	86.7	70.9	83.8	-	-
206. Shackleton CDA	92.6	121.2	48.8	171.6	164.2	102.1	70.6	49.5	177.5	83.3	178.1	-	69.4
207. Shaunavon 2	61.9	-	-	-	-	79.2	60.5	32.0	190.5	108.7	-	74.8	-
208. Swift Current A	109.7	142.8	112.3	156.1	133.9	70.1	72.9	34.8	176.5	81.3	136.9	28.2	77.7
209. Treelon	58.6	89.1	33.4	[illegible]	145.9	-	65.0	45.2	136.4	102.4	100.8	80.7	98.6
210. Val-Marie	65.6	74.0	49.0	-	51.2	59.4	42.9	27.2	108.2	89.2	-	87.5	111.2
211. Willow Creek	-	85.4	68.2	68.2	132.6	-	-	-	102.6	-	-	-	101.8
MONTANA													
212. Augusta	61.7	58.7	69.8	66.3	114.4	21.6	128.0	10.7	95.0	95.8	69.9	87.6	25.9
213. Babb 6 NE	151.4	93.2	55.2	51.3	72.6	71.9	150.6	18.6	65.5	101.1	162.6	223.0	25.2
214. Big Sandy	67.4	88.6	66.0	133.6	126.5	15.8	99.4	16.3	105.7	117.6	76.6	91.5	107.2
215. Browning	126.7	-	-	-	-	72.9	-	-	53.2	38.9	81.8	207.0	25.4
216. Cascade 5 S	95.1	86.0	32.9	44.1	173.8	-	90.6	8.7	74.3	90.2	86.2	122.9	58.0
217. Chinook	32.5	-	74.2	-	-	23.1	64.6	41.9	162.8	108.6	83.3	65.5	-
218. Choteau Airport	86.6	77.0	55.7	[illegible]	77.4	17.1	92.3	22.2	90.2	72.9	130.1	140.8	14.8
219. Conrad Airport	70.6	87.9	36.8	81.5	72.7	28.0	121.0	9.4	88.7	77.2	100.9	[illegible]	14.5
220. Cut Bank FAA AP	101.5	66.8	33.5	-	48.7	37.9	133.2	10.6	111.4	100.4	89.4	143.6	30.4
221. Darby	44.8	73.9	50.3	60.3	105.7	10.5	24.9	17.0	-	60.8	90.3	57.9	-
222. Dunkirk 15 NNE	39.9	-	-	-	-	44.7	72.2	21.0	76.4	75.8	[illegible]	-	-
223. East Anaconda	50.9	-	-	-	-	37.0	66.1	40.7	63.1	122.8	80.9	80.2	-
224. Fairfield	102.2	76.3	60.8	97.6	100.6	32.3	92.5	11.5	103.2	103.9	83.1	118.5	33.4
225. Flatwillow 4 ENE	57.8	[illegible]	28.2	91.0	40.5	36.8	154.4	31.1	95.1	104.5	44.7	101.8	39.3
226. Fort Assiniboine	24.0	[illegible]	62.5	82.7	-	20.7	79.9	20.9	113.9	115.7	76.4	72.3	44.8

cont'd...

Table A-5, continued:

Stations Used	Years With Seeding					Years Without Seeding							
	77	80	81	82	83	71	72	73	74	75	76	78	79
227. Fortine 1 N	90.3	118.3	72.2	109.8	118.7	75.6	71.0	22.5	87.2	70.7	129.7	106.9	13.3
228. Gibson Dam	83.2	66.7	80.3	80.6	147.2	38.4	114.1	12.5	111.6	81.1	77.6	77.8	42.5
229. Great Falls WSO	84.5	59.5	43.4	82.4	155.0	11.2	67.4	10.3	107.8	106.9	91.1	96.7	21.0
230. Hamilton	48.9	60.8	28.8	76.6	98.6	9.0	29.1	19.3	65.9	53.9	76.2	32.6	19.7
231. Harlem	70.2	–	53.5	83.7	125.5	27.5	50.5	–	153.9	69.9	88.7	169.5	56.5
232. Haugan 3 E	40.4	83.4	36.3	122.7	101.7	61.8	48.9	11.2	41.5	72.7	97.6	119.6	28.4
233. Havre WSO	20.9	70.1	69.0	103.0	123.3	13.8	66.5	17.3	104.5	113.9	76.9	66.1	37.0
234. Helena 6 N	38.2	–	–	–	–	12.9	50.9	26.2	–	110.3	47.9	78.9	–
235. Helena WSO	41.0	82.0	46.7	77.6	119.7	29.8	48.8	13.6	89.1	160.1	45.5	83.5	31.1
236. Heron 2 NW	33.7	101.8	55.1	88.3	158.6	82.2	87.3	11.3	62.7	82.1	155.0	161.4	33.2
237. Hotler Dam	68.7	70.9	78.3	46.1	117.7	22.3	73.2	15.5	74.2	93.6	59.7	100.7	35.2
238. Kalispell WSO	86.3	65.5	33.7	149.8	97.2	76.4	79.0	6.3	63.6	52.5	141.1	97.1	17.8
239. Lewistown FAA	104.3	73.6	38.0	74.6	105.1	63.7	169.9	28.2	139.8	146.5	81.6	234.3	41.8
240. Libby 1 NE	51.1	72.4	75.7	109.0	76.5	52.9	78.5	0.3	–	45.7	63.9	97.8	–
241. Missoula WSO	34.3	55.6	45.5	72.1	116.4	33.2	35.3	[illegible]	63.0	80.2	56.9	47.6	26.8
242. Moccasin Exp St	99.4	119.5	83.1	56.9	98.6	43.9	117.1	28.7	[illegible]	103.7	138.5	168.9	41.8
243. Philipsburg RS	54.3	94.2	20.3	117.7	131.8	48.6	61.0	32.0	69.1	120.9	99.4	78.0	34.0
244. Pleasant Valley	–	–	–	–	–	77.9	78.4	–	–	–	–	–	–
245. Polson	51.0	–	43.7	92.1	112.7	–	57.6	10.4	69.9	68.3	118.2	136.9	15.6
246. Roundup	61.0	76.2	92.8	50.7	35.4	[illegible]	80.3	32.5	60.7	85.2	37.4	110.5	–
247. Saint Ignatius	30.9	100.0	43.6	109.0	175.6	50.2	45.7	8.3	100.4	–	–	145.7	21.8
248. Silver Lake	77.2	123.6	52.3	96.9	135.0	60.5	63.8	45.0	76.2	138.3	105.2	127.0	49.9
249. Simpson 6 NW	48.5	86.0	85.3	82.0	130.2	26.0	73.3	12.0	71.5	82.2	118.7	96.1	43.3
250. Stevensville	39.7	56.4	25.9	70.7	138.3	15.6	21.0	8.5	59.5	–	63.0	29.0	–
251. Superior	26.0	57.9	9.7	81.5	97.3	76.7	32.5	5.4	39.2	75.8	86.2	103.0	48.6
252. Thompson Falls PH	43.0	59.7	32.4	112.4	117.0	67.1	67.8	6.9	29.2	62.7	98.6	122.3	21.1

cont'd...

Table A-5, continued:

Stations Used	Years With Seeding					Years Without Seeding							
	77	80	81	82	83	71	72	73	74	75	76	78	79
253. Valier	94.0	73.4	61.8	119.0	60.4	21.6	121.7	17.5	120.1	117.4	124.6	124.0	10.8
254. White Sulphur SPR	75.5	-	-	-	-	38.2	64.1	42.0	102.9	109.2	112.4	126.1	-
255. Winifred	124.0	77.7	61.2	96.5	88.6	69.9	128.0	48.0	194.1	116.6	91.2	123.2	26.9

End