Agricultural implications of weather control
by George A Pavelis

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree, of Master of Science in Agricultural Economics
Montana State University

Abstract:
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The format of the study is intended to conform to what are considered to be. logical, research procedures in professional, investigations, and rational decision-making processes at the managerial level. The chapters are independent to the extent that important information relating to particular aspects of rain increasing can be secured without perusal of the entire manuscript. However, a simultaneous recognition of potentialities and limitations of rain increasing requires perspective of technological, climatic, economic, and social factors affecting the success of operations.

In Part III, fundamental precipitation processes are described to explain why rainfall is not always adequate under apparently favorable atmospheric conditions. The results of the General Electric Company's Project Cirrus and a research program conducted by a Canadian group are then reviewed to compare the effectiveness of dry ice and silver iodide as artificial nucleating agents. A second reason for studying basic meteorological principles is to determine the natural circumstances which constitute seeding opportunities.

An effort is made in Part IV to obtain, for single localities, a rough indication of the probability of receptive weather conditions prevailing during periods when rain-increase operations would ordinarily be desired by farmers and ranchers. Probabilities are comparatively expressed as gross seeding potentials which have been based on areal rainfall variations characteristic of eight major weather types affecting Montana during the growing season.

Part V conceptually defines the relationship of rain increasing to economic decisions of farm firms and seeding firms= It further specifies how induced rainfall should be used to benefit these two producer groups, and society as well.

Secondary only to technical and climatic requirements for successful seeding programs is proper knowledge of the broad issues involved in planning operations, conducting them, and then assessing results= In Part VI, treatment is given major legal and evaluative controversies evolving from commercial seeding activities= Suggested approaches and solutions to these problems are enumerated as they might apply to Montana institutions. The final section develops an argument for postppning conclusions concerning cloud seeding effectiveness until complete and reliable evaluations are produced=

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Approved:

Head, Major Department

Chairman, Examining Committee

Dean, Graduate Division

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George A. Pavelis
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Abstract

As its title implies, this study is an attempt to isolate and analyze various socio-economic implications of weather control, with specific attention directed toward recent efforts to scientifically induce precipitation in Montana. The opening chapter contains a brief account of the extensiveness of cloud seeding operations in Montana and other western states. Local developments are analyzed in some detail to expose the kinds of organizational and operational difficulties which are likely to be encountered by agricultural producers planning rain-increase programs.

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PART I

INTRODUCTION AND THE PROBLEM SETTING

Introduction

Current interest in weather control as a new frontier in agricultural development was aroused early in 1946. While studying the problem of aircraft icing, Schaefer observed an apparent physical property of solid carbon dioxide (dry ice) which converted super-cooled water droplets to ice crystals. The transformation was thought to be associated with normal precipitation-forming processes. 1/ Schaefer's observations were checked and verified in a series of laboratory and field tests conducted by the General Electric Company, under the auspices of interested agencies in the armed services. Subsequent studies have been carried on within the United States Weather Bureau, by other research groups in the United States, and by various foreign investigators. These later studies have been concerned with finding the methods by which cloud modification can best be achieved, and the atmospheric conditions which must prevail to get beneficial and significant results.

Programs of basic research into the technicalities of weather control have revealed a number of possible applications that can prove useful to Agriculture. Apart from the prime objective of increasing precipitation, there is also promise of the ability to decrease rainfall, moderate its

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1/ For an interesting account of Schaefer's early work and General Electric Company experiments, see "Project Cirrus--The Story of Cloud Seeding", General Electric Review, November 1950.

intensity, control evaporation, suppress hail activity, and arrest the development of incipient lightning storms.

When it became evident that the crystallizing reaction of carbon dioxide might be duplicated with more stable agents, the modification of clouds over wide regions became feasible. 2/ Industry and agriculture have both recognized the potential benefits to be derived from increasing precipitation. As a result, commercial activity in weather control has become widespread. Though the extent of these operations is not definitely known, it is estimated that at least 500 million acres of western crop and range lands were under contract for cloud seeding in 1951. 3/ This acreage represents twelve times the total area of farm land included in existing irrigation projects. Over the United States, unit acre assessments to cover seeding costs have averaged one cent for grazing lands and fifteen cents for cultivated lands. 4/ While the majority of seeding programs have been designed to increase rainfall in moisture-deficient areas, some have been initiated for specific purposes of decreasing rainfall, suppressing hail, and regulating forest humidity. Utilities interested in hydroelectric power generation have conducted cloud seeding with intentions of increasing runoff and snowpack in resevoir and drainage areas. A seeding project designed to control forest fires was conducted in Tillamook County, Oregon,

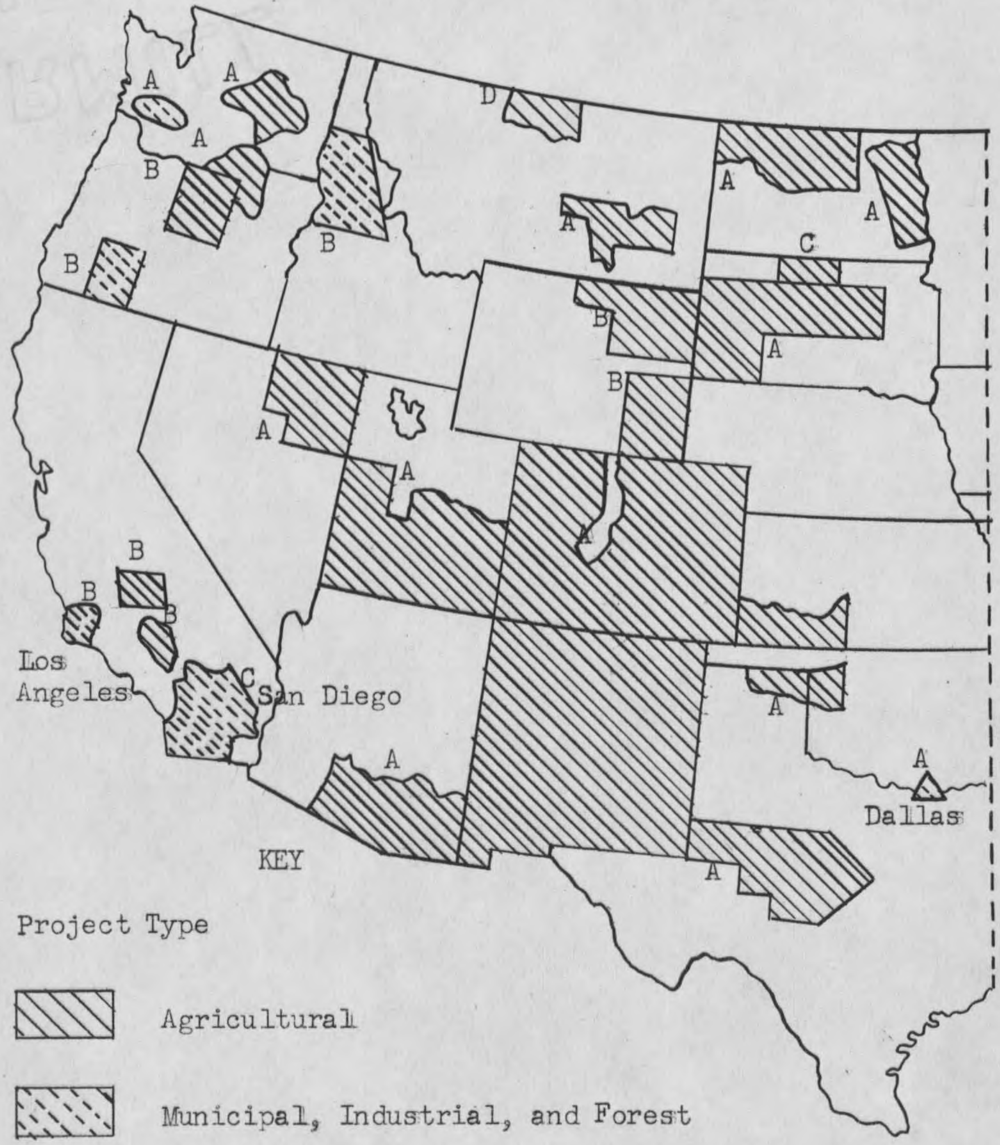
(cont. p. 4)

2/ The common agent used in large-scale seeding is silver iodide, a salt with a crystalline structure very similar to that of dry ice.

3/ Ray Mitten, "Rain Making Becomes a Science--and a Problem", Nations Business, Vol. 42, No. 3, March 1954, p. 34.

4/ Ibid., p. 35.

Figure 1. Major Cloud Seeding Operations; Western states, 1952



Seeding Firms

A- Water Resources Development Corporation

B- North American Weather Consultants, Incorporated

C- Weather Modification Company

D- Precipitation Engineers, Incorporated

Sources: Fortune, May 1953, p. 148
Survey Data, Montana operations

from August through October, 1951. Similar projects have been carried on throughout Pacific coast states, but mainly in California.

The first sizeable agricultural acreage to come under seeding was an area in south-central Washington. In 1950, an estimated 100 thousand acres of wheat land near Prosser received 190 per cent of usual summer rainfall. The large departure from normal was attributed to cloud seeding in the area. Interest in the agricultural applications of weather modification became general over the western states during 1951 and 1952. (See Figure 1).

Projects and Association Activities in Montana 5/

Though some interest in rain increasing was evident in Montana in 1950, no cloud seeding projects were underway until the following season. Agricultural programs have usually been initiated by local residents interested in securing projects for their communities. Following contact with representatives of commercial concerns, associations have been organized and legally constituted as non-profit, noncapital-stock corporations sponsoring research. In some cases, actual operations were preceded by climatic surveys of geographic areas to be included. 6/ Only one seeding firm conducted such preliminary studies. The following paragraphs summarize the activities of respective associations, noting the extent of their projects, and listing special problems encountered. 7/

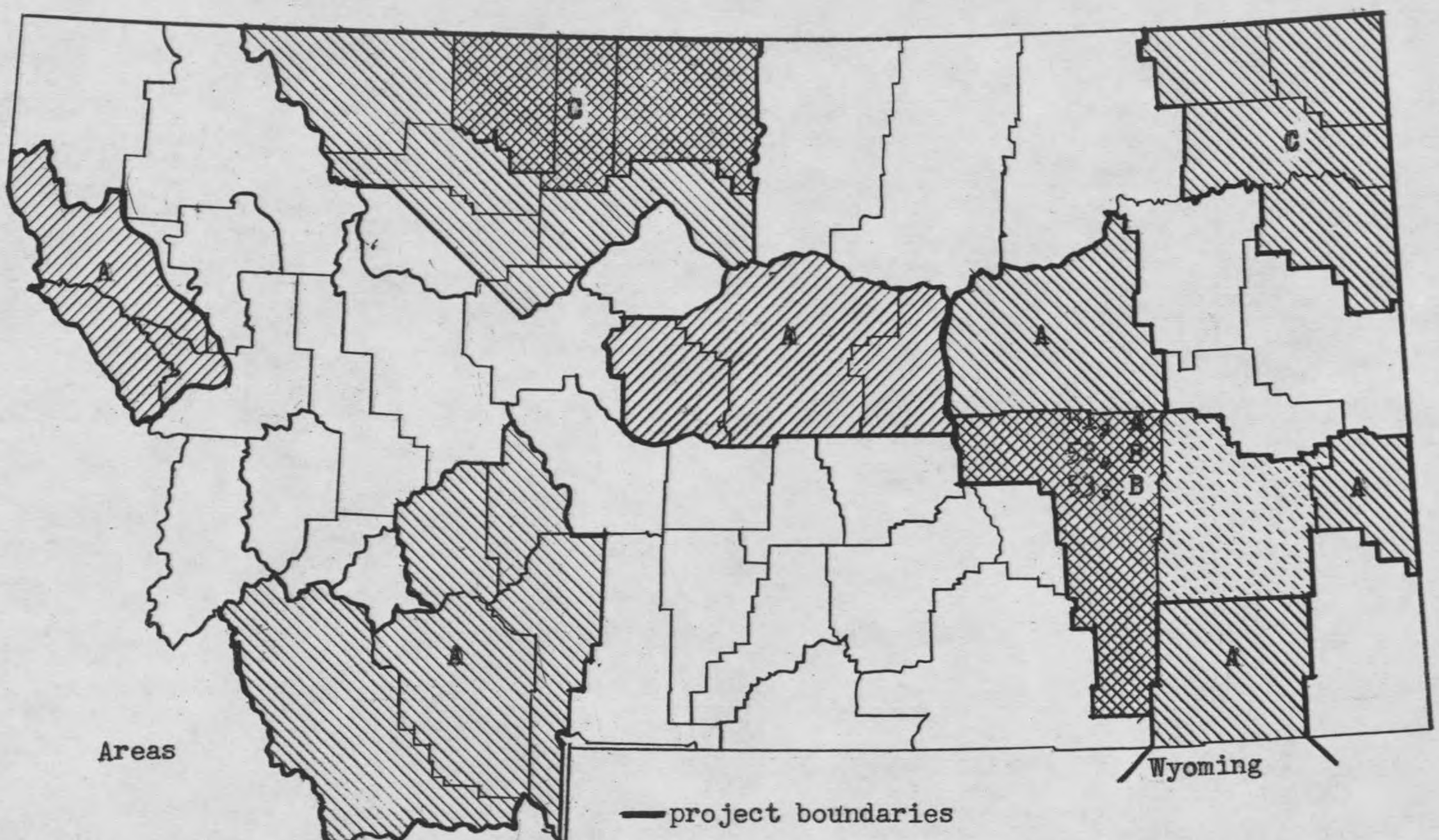
(cont. p. 8)

5/ Relevant data were secured from association officials and supplemented to some extent with information known to the writer.

6/ Surveys were to indicate whether seeding was likely to be successful, considering local features and climatic histories of the areas served.

7/ 1951-1953 operational areas are mapped in Figure 2. Accompanying data are provided in Tables I and II.

Figure 2. Major Cloud Seeding Operations; Montana, 1951-53 incl.



—project boundaries

under contract, 1951

under contract, 1951-52

under contract, 1951-52-53

A- Water Resources Development Corporation

B- North American Weather Consultants, Incorporated

C- Precipitation Engineers, Incorporated

Source: Survey Data, Montana operations

Table I. Operational Data; Montana Projects; 1951-53 incl.
Source: Survey of Montana operations, October, 1953.

ORGANIZATION 1/	SEASON	PROJECT AREA (Counties)	PERIOD
Three Rivers Weather Research Corporation*	1951	Beaverhead, Broadwater, Gallatin, Jefferson, Madison	Apr 15-Sept 30
Northeast Montana Rain Increasing Association*	1951	Daniels, Richland, Roosevelt Sheridan	May 1-Aug 30
Central Montana Weather Improvement Association*	1951	Fergus, Judith Basin, Petroleum	June 1-Aug 30
Powder River Weather Research Corporation*** (Wyoming)	1951	Powder River (Montana); other counties in Wyoming	Apr 1-Sept 30
High Line Rain Increasing Association**	1951	Hill, Liberty, Toole, (Glacier,2/ Pondera, Choteau, Cascade)	May 1-Sept 30
	1952	Hill, Liberty, Toole	May 1-Sept 30
Southeastern Montana Weather Improvement Association***	1951	Custer, Fallon, Garfield, Rosebud	May 1-Sept 30
	1952	Custer, Rosebud	May 1-Sept 30
	1953	Custer	May 1-Sept 30
Bonneville Power Company (industrial)	1951	Clark Fork, Flathead, and Pend Oreille drainages	Sept 1-Dec 30

1/ Present status indicated by: *Disbanded, **Inactive, ***Active

2/ Portions of counties enclosed in parentheses.

Table II. Relative Response and Cost Data; Montana Projects, 1951-53 incl.
Source: Survey of Montana operations, October, 1953.

ORGANIZATION	SEASON	MEMBERS 1/ No.	MEMBERS 1/ %	QUOTED COST	NET PAYMENT	ACRE ASSESSMENTS Crop	ACRE ASSESSMENTS Range
Three Rivers Weather Research Corporation	1951	300	12	$42500.00	$25100.00	$ .15	$ .03
Northeast Montana Rain Increasing Association	1951	674	25	31000.00	24800.00	.11	.05
Central Montana Weather Improvement Association	1951	400	24	42000.00	14000.00	.10	.02
High Line Rain Increasing Association	1951	540	12	40000.00	40000.00	.10	.05
	1952	380	27	40000.00	26000.00	.05	.02
Southeastern Montana Weather Improvement Association	1951	na*	-	49000.00	49000.00	.10	.02
	1952	na	-	Performance contract	2000.00	.01	.01
	1953	na	-	Performance contract	7500.00	.01	.01
Sub-totals (state)	1951	1914	-	$204500.00	$152900.00	.11	.03
	1952	380	-	40000.00	28000.00	.03	.01
	1953	na	-	-	7500.00	.01	.01
Total (state)				$244500.00	$188400.00	.05	.02

1/ Percentages of resident farm operators in project areas. Based on 1950 Census of Agriculture, Vol. 1, Part 27 (Montana), U. S. Dept. of Commerce, 1952, pp. 41-42.

*not available.

Project Histories

The first association incorporated under Montana statutes was the Three Rivers Weather Research Corporation. This group was formed in January 1951, and planned seeding operations for Jefferson, Beaverhead, Gallatin, Broadwater, and Madison counties. In negotiations with a Colorado firm, cost of seeding the area for the period April 15 through September was quoted at $42,500.00. Seeding began when $22,500.00 was paid. Two additional payments of $10,000.00 were to be paid June 1 and at the end of the contract period. The association succeeded in raising the down payment only, with contributions coming from approximately 300 farm operators in the five counties. Members were asked to contribute fifteen cents an acre for crop land and three cents for pastures. Because the summer of 1951 was abnormally dry in the region, the operation was not successful. Though seeding equipment was in place throughout the operational period, few opportunities arose for utilizing it.

The association planned no program for 1952, and disbanded in 1953, following payment of $2600.00 as a final settlement on the original contract. Association officials and members were not pleased with the results of the project. Favorable response to cloud seeding was not general; and officers attributed part of the difficulty in securing adequate funds to religious sentiment against weather control activities. Officials also concluded that contracts specifying fixed fees are not a satisfactory form of agreement.

The most extensive agricultural cloud seeding projects in Montana have been supported by the High Line Rain Increasing Association. Also incorporated in early 1951, this association sponsored seeding operations covering Hill, Liberty, and Toole counties; and parts of Glacier, Pondera, Choteau, and Cascade counties. The assessment in these areas was ten cents per acre of cultivated land, and five cents per acre of grazing land. The association was successful in raising $40,000.00 to finance operations for the period May through September. An estimated 500 ranchers participated in 1951 and in the season following. The operational area was smaller in 1952, covering only Hill, Liberty, and Toole counties. The program was curtailed because of financial difficulties, but the association paid $26,000.00 for a limited operation. Contributing members feel that programs should continue for at least several years, and that costs should be equitably distributed by county-wide mill levies. The association has attempted to secure passage of legislation authorizing counties to make such assessments.

Cited as additional obstacles to securing adequate financing were skepticism, and the withdrawal of pledges after seeding was underway. Also, ranchers in the area have been disappointed by the apparent failure of seeding to prevent hail storms. Hail suppression was an extra benefit they had hoped to derive from financing rain increasing. The association remains active, but did not conduct operations in 1953. Officials hoped new interest could be aroused if a performance contract governed payment to the contractor. However, plans for a 1953 operation failed to materialize.

The <u>Northeast Montana Rain Increase Association</u> was organized at Poplar in 1951. It was to sponsor cloud seeding operations for Roosevelt, Sheridan, Daniels, and Richland counties. A program was planned for May through August, with a harvest interruption scheduled for the early weeks in the last month. Contributions were received from nearly 700 farm operators in the area. A few townspeople also made contributions. Individual acreage assessments were eleven cents for crop land and five cents for grazing land controlled by the subscriber. The fee of the contracting concern was to be $31,000.00. The association succeeded in raising eighty per cent of this amount. Midway in the course of operations the group separately employed a contractor who practiced aircraft seeding methods, in contrast to the originally hired concern which used ground equipment. As a whole, ranchers were not satisfied with the accomplishments of their association. It was inactivated at the completion of the 1951 operation.

In June 1951, the Central Montana Weather Improvement Association was incorporated at Lewistown. This group planned June through August seeding for Fergus, Judith Basin, and Petroleum counties. Approximately one-third of the stipulated fee of $42,000.00 was raised. Operations ceased when the balance became overdue. Subscriptions were received from an estimated 400 farm operators in the three counties. The common assessment was ten cents for farm land and two cents for grazing land.

Association officials report that voluntary subscription is not a satisfactory method of raising necessary funds for rain-increase programs, though response to cloud seeding was generally favorable. Among ranchers welcoming establishment of the project there were many not inclined to offer their financial support. They hoped to capitalize on the inability of contractors to 'target' rainfall with precision. The assumption was that all operators in the general area would be recipients of rainfall increases. The association remains active, but since 1951 has not engaged in any seeding.

In May 1951, Custer, Rosebud, Garfield, and Fallon counties were included in a seeding project organized by the Southeastern Montana Weather Improvement Association. Aside from minor harvesting interruptions, seeding was carried on from May through September at a cost of $49,000.00. Payment from ranchers was based on assessments of ten cents an acre for cropland holdings, and two cents for range.

In 1952, operations were limited to Rosebud and Custer counties. Because the association obtained a contract based on performance conditions, cost for seeding the two counties came to only $2,000.00. Finances were raised on the basis of a general one cent per acre rate, with relatively few ranchers contributing.

Operations were further curtailed in terms of area in 1953, with a program planned for Custer county only. The association paid $7,500.00 to a California concern for an operation running from May through September. Terms of the contract provided that lump sums of $250.00 would be paid whenever precipitation in the county averaged .25 inch in a twenty-four hour period. Required readings were taken at four official Weather Bureau recording stations. The association has been pleased with the service rendered under performance contracts, but nevertheless, expresses concern over difficulty in raising funds.

Powder River county has been included in a seeding project which extended into Montana from Wyoming. In April 1951, the Powder River Weather

Research Corporation was organized under Wyoming laws. The primary membership was drawn from Sheridan, Johnson, and Campbell counties in Wyoming. Portions of Converse, Crook, Weston, and Niobrara counties were also in the project area, which totaled over 16 million acres. Cloud seeding was conducted from April through September, at a cost of $93,500.00. The entire amount was raised, with Powder River county in Montana contributing an unknown proportion. Subsequent operations have not included Powder River county.

An industrial cloud seeding operation indirectly involving agricultural groups in Montana was announced in September 1951 by the Bonneville Power Administration, a government hydroelectric utility administering federal power plants in the Pacific Northwest.

The immediate problem was an acute shortage of available power for industries and metropolitan centers in Washington and Oregon. During the summer of 1951, pre-operational surveys of Columbia River tributaries indicated that maintenance of winter flow in the Columbia would provide a 360,000 kw. addition to the federal power pool in the Northwest. 8/ Cloud seeding was considered as a means of achieving increased runoff in the watershed areas of Idaho and Montana; particularly in the Flathead, Pend Oreille, and Clark Fork drainages.

The project was officially approved in mid-September and operations were conducted primarily in the Pend Oreille region. Operations were suspended in October. Farmers in the Flathead valley of Montana had

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8/ Great Falls (Montana) Tribune, July 30, 1951.

raised objections to the operation, expressing the fear that cloud seeding would prolong a period of late and heavy summer rains delaying harvesting in western Montana. The extent to which operational decisions were influenced by farmer opposition is not known; however, seeding originally planned to continue through December was not resumed.

Description of General Problems

In surveying rain increasing programs conducted to date in Montana, two important facts stand out as possibly comprising a problem situation. (1) Financing of projects has been very difficult, and (2) operations have almost entirely ceased. However, financial reverses and decline in interest are not problems in themselves, but merely represent a current condition. Economic motives have led to establishment of individual seeding projects. Technological and psychological factors have then determined the success of and relative response to each respective program. The importance of these underlying factors should be understood before attempting to explain current difficulties.

The present status of rain increasing as an effective means of weather control is one of doubt and uncertainty. Doubt persists because of traditional skepticism in regard to human efforts to control weather, and the supposed inability of commercial operators to produce tangible results. Uncertainty prevails because some operations have apparently been very successful, but no exact means have been discovered for segregating induced rainfall from that which might have fallen if the weather were left undisturbed. Until precise evaluation methods are developed, precipitation increases can be only dubiously attributed to cloud seeding.

Should the efficacy of cloud seeding be eventually disproved, no problem will exist for agricultural producers other than the formality of eliminating commercial activity entirely. On the other hand, if cloud seeding is definitely demonstrated to be effective, a whole series of economic and social implications will arise. Economic problems will be concerned with production effects of rainfall increases, reorganization of enterprises, and revision of production plans. Sociological problems will range from those related to organized supervision of operations to suggested measures for maximizing social benefits.

Associations surviving disappointing operations have come to recognize the limitations of weather control; and are mindful of controversies that have affected the success of past operations, both in Montana and other states. Limitations and controversies are examined in later sections. Meanwhile, attention can be given to the major factors which have limited producer response, and those which might account for the abandonment of most programs in Montana. It is difficult to attach special significance to all factors that might conceivably have affected the success of rain increasing programs. No doubt, several sources of difficulty are purely physical, with technical deficiencies underlying the failure of contractors to produce results equivalent to the expectations of subscribers. Many supporters have been lost because original programs were thought to be operational failures. Analysis of operations is beyond the scope of this study, however. The major points to be considered in reference to the present situation can be grouped in three classes: (1) Psychological attitudes, (2) Costs of participitation, and (3) Fear of legal involvement.

Psychological Attitudes

Mental 'sets' associated with distrust of novel and untried innovations in technology are influencing the response of farm people to programs aimed at increasing rainfall. Inhabitants of the Great Plains have, at times in the past, been moved through desperation to put faith in any suggested means for overcoming weather problems. Among various suggestions have been pseudo-scientific techniques ostensibly capable of increasing rainfall. 9/ Failure of previous attempts to exercise control over weather phenomena has led many people to conclude that all such activity is futile. In defining a concept of regionalism based on 'fiats' of nature, Gillette remarks that the economic endeavors and cultures of social groups are largely dictated by the natural environment. 10/ Gillette assents to what he terms partial controls over nature; i.e., irrigation, conservation practices, etc., but regrets that man will never be capable of directly controlling weather. Substantial numbers of farm operators in the Plains region (and elsewhere) have similarly accepted periodic rainfall deficiency or other weather adversities as ungovernable laws of nature or God. So long as the efficacy of cloud seeding remains unproved beyond reasonable doubt, deeply entrenched skepticism will present a serious obstacle to securing general support of cloud seeding programs. Religious disapproval would persist regardless of scientific proof; and must be regarded as unlikely to be completely overcome.

9/ N. F. Thomas, "Rainmaking Sixty Years Ago", Dakota Farmer, Oct. 7, 1951.

10/ J. M. Gillette, North Dakota Weather and the Rural Economy, Bulletin No. 11, Department of Sociology and Anthropology, University of North Dakota, p. 8, May 1948.

Costs of Participation

Individual Contributions

The specific level of acreage assessments has not been critical in securing adequate operating funds. By comparison with various insurance premiums (crop, hail, fire, etc.), farmers have considered cloud seeding costs to be almost negligible. Operators have been disposed to either accept the charges without compromise, or refuse to participate. The cost decision almost invariably has reflected individual opinion as to the probable success of seeding.

The non-profit legal status of associations permits members to write off seeding fees as contributions to research. The speculative nature of weather control might encourage the belief that exclusion of such costs from production schedules would be reasonable. Economically speaking, however, there is no distinction between direct costs of production and voluntary support of research, since both are borne with rational intentions, i. e., increased production, efficient production, improvement of competitive position.

Seeding costs to farmers are fixed and joint where equal assessment rates prevail for all classes of land and fixed-fee contracts are in effect. Where seeding firms must fulfill certain performance conditions to qualify for incentive payments or "bonuses", excesses over minimum payments would represent variable costs, because output levels would presumably vary with increments of increased rainfall. Minimum or retainer fees would constitute fixed cost in any case.

Rate differentials for crop and range lands assist somewhat in separating costs and benefits for the single farm firm and areas. However, the allocations cannot be completely determinate if not all farm operators subscribe to programs. Where non-participants receive collateral benefits by reason of location within a project, association members are bearing an unnecessary portion of social costs.

Should cloud seeding programs extend over long periods, individual farm operators should weigh requests for funds against the probability of their area receiving any benefit. The climatic character of some sections can preclude receipt of significant rainfall increases. Operators in such areas should realize that costly seeding projects would then be unwarranted. In view of high improbability of benefit, any contributions, however trivial, could not be justified economically.

Part IV includes a climatic survey of the state which might assist individuals somewhat in estimating whether cloud seeding holds promise for all areas. The information given is merely suggested as a tentative basis for determining comparative success of seeding operations in particular sections.

Aggregate Payments

While individual contributions toward rain increasing do not appear to be more than nominal, aggregate payments represent substantial sums, and have made collection difficult where response is lacking. The level of aggregate payments is important in relating costs to expected benefits on an areal basis. It also assists when attempts are made to perceive the pricing policies of practitioners.

In Montana, cloud seeding firms have often quoted fees with an emphasis on establishing projects and securing contracts, rather than limiting operations to the most promising areas. To further this policy, associations have been encouraged to distribute costs among as large a membership as possible. On some occasions, contractors have agreed to greatly enlarge target areas at no additional cost to associations. Such inducements have done little to overcome reluctance of uninterested potential subscribers. Conclusions drawn might be that an unusually large proportion of costs incurred by seeding concerns are fixed, or that some seeding charges include returns to the seeder greater than the estimated value of the services would indicate.

The fact that many producers do not wish to participate, regardless of cost, can be attributed to the factors listed under attitudes, or to dislike of promotional practices employed by some concerns and adopted by overenthusiastic association officials.

Alternative explanations of policies of contractors involve other aspects of pricing. Sizeable reductions in fees have been made from those quoted in preliminary negotiations or from costs of similar operations. It might be concluded that contractors have been willing to operate below average total cost temporarily, with intentions of establishing their position in the field, and/or increasing the demand for their services. Initial demand for the services of cloud seeding concerns presumably was created when potentialities of weather modification were publicized.

Several seeding concerns have been active in Montana, all entering simultaneously. The competitive relationship of these firms has acquired characteristics of a partial oligopoly. Each firm has recognized that changes in their pricing policies would cause reactions on the part of competitors. Complete oligopoly is ruled out on the assumptions that collusion is legally prohibited, and that no desire exists for maximization of joint profits. Demand for cloud seeding services is not inelastic enough to permit manipulation of fees in respect to the sales schedule.

Initially, (1951 season), seeding firms may have set their fees within a range--the lower limit covering estimated total costs of 'operating' a project, and the maximum representing an approximation of the average revenue schedule. If all firms followed this procedure, the level of fees should have become somewhat uniform and customary, with the kink peculiar to oligopoly average revenue curves established at this level. In the 1952 season, individual reductions from 1951 fees resulted in general rate reductions, but no increased demand for seeding services was noted. If fees for all seeding concerns planning to operate in 1952 had increased or remained at 1951 levels, quite likely no seeding projects would have been organized. As the situation developed in 1952 and 1953, it became apparent that associations were not willing to negotiate solely on the basis of a stated fee for a firm's services.

Contractual Conditions

Had first operations been considered successful, associations would probably have remained satisfied with fixed-fee contracts. When expected rainfall increases failed to materialize, however, associations realized they were bearing almost all risk of failures. Contractors were affected because successful operations are necessary for retaining and acquiring clients. The majority of associations planning 1952 operations would not agree to pay fixed fees; either in advance, or by installment, and most seeding firms were not prepared to offer their services with guarantees of specific results. The outcome was that only two projects were organized.

Operating agreements now in effect in Montana and other states require that certain performance conditions be met by seeding firms. Under this type of contract, rainfall received in target areas must equal or exceed specified amounts or averages; otherwise no payment--or minimum payment, is made. The minimum presumably helps defray operating costs. Compensation is allowed if precipitation is in excess of the base figure. In the event rainfall is greater than the base by a relatively wide margin, maximum or "bonus" payments are called for. Many variations of performance contracts have been suggested, with all of them adjusting fees to rainfall actually received.

Performance contracts take into account the real possibility of rainfall not being sufficient to produce an abundant, or even a normal crop, regardless of rain increasing efforts. However, cloud seeding should not be evaluated solely in terms of contract fulfillment because the inability of contractors to qualify for payment does not necessarily imply failure of the operation. From a technical standpoint, the project might be considered quite successful if the season was abnormally dry. 11/ The assumption is

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11/ To illustrate: Precipitation for the contract period may have been only 80 per cent of normal, with cloud seeding in progress. The seeding firm would not be entitled to payment if the base were set at normal (or median). It would be incorrect to assume, however, that modification had failed to affect rainfall to any appreciable extent. Without cloud seeding, precipitation might have fallen below normal by more than 20 per cent.

made that modification attempts must be coincident with natural storm activity; in which case, the potential for substantially increasing rainfall is dependent upon the frequency of seeding opportunities.

There is reason for believing that either form of operating contract could be made applicable to varying climatic conditions in this state. On the basis of long term records, fixed fees could reflect the probability of favorable seeding conditions occurring in the area concerned. Efficiency of seeding would be assumed, given desirable weather circumstances. Performance contracts are indirectly based on similar climatic limitations, though seeding efficiency is not taken for granted.

A suggested method for determining seeding potentials in various sections of Montana is developed in Part IV. The study is applicable to group decisions as well as those that are the responsibility of individual farm operators. Also, a relative indication of the extent to which rainfall could be affected in various localities is necessary for preliminary economic and social studies. Total cost of possible state-wide programs might be apportioned on the basis of climatic differences between various geographical regions.

Fear of Legal Involvement

Actions of associations and producer response have undoubtedly been influenced by legal factors. Popular impressions of weather control largely revolve about spectacular results, complete failures, and various legal controversies. In 1951 the Associated Press reported an impending controversy between wheat and irrigation farmers in central Washington. Press accounts of such disputes have led many Montana ranchers to conclude that their support of rain increasing projects might lead to similar complications here.

The incident referred to was reported in March, 1951. 12/ The story announced the intention of 6500 soft-fruit, hay, and bean farmers to organize with the purpose of preventing adjacent wheat areas from receiving any precipitation whatever. 13/ The contentions were that cherry crops would be damaged by untimely rains, and that both fruit and bean harvesting would be handicapped if seeding operations were successful. The cherry growers employed a seeding firm that was to prevent rain from April 1 through October 15. 14/ Incidents of this nature have led to misinformed public thinking in regard to rain increasing. More often than not, conflicts have resulted from lack of consideration for problems of other groups in organizing stages, rather than irresponsible operations. Resolution of differences should be possible without resort to preventative operations or litigation.

Conflicting interest has not been acute among agricultural groups sponsoring seeding activities in Montana. Previous mention was made of the objections ranchers in the Flathead valley raised to the proposed Bonneville project in western Montana and Idaho. Though complete agreement was not reached, Bonneville administrators and representatives of the contractor met with the ranchers, and corrected many misconceptions concerning objectives and operational plans.

12/ AP, Pasco (Washington), March 26, 1951.

13/ Sunshine Unlimited was the official name of the organization.

14/ The techniques for increasing and decreasing rainfall are identical. To prevent rain, an attempt is made to 'overseed' clouds, rather than furnish optimum concentrations of silver iodide nuclei.

From the viewpoint of individuals and associations, two types of grievances could result from sponsoring rain-increase programs. First, there is the oft-quoted possibility of depriving others of precipitation they would receive if weather were allowed to take its own course. The second type includes allegations of property damage or other harmful effects which might result from tampering with weather processes. In Montana, many farm operators see promise in rain increasing, but have withheld their support because of these unresolved legal issues.

In regard to grievances of the first type, contractors deny that downwind areas are 'robbed' of moisture because of cloud seeding. 15/ They contend that under natural conditions, approximately one per cent of precipitable water reaches the earth. Seeding might release an additional one per cent; thus leaving 98 per cent of the total, which (through mixing) should be sufficient for generating further activity. Such statements may be correct, but the issue still remains, even among professional meteorologists. The question should accordingly be examined for legal implications.

If the supply of atmospheric moisture is limited (in a practical sense), individuals or associations may be required to justify their attempts to secure additional rainfall. Where increases could be obtained only at the expense of adjacent or distant regions, special operating restrictions may be in order. Ranchers would then be facing old water problems in a new form. It appears that there are few authoritative precedents for determining entitlement to atmospheric moisture. The doctrines of riparianism and

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15/ "Can We Make It Rain?", Farm Quarterly, Summer, 1952, p. 37.

appropriation, while conoting some reference, cannot be applied to unconfined water. Oddly enough, concepts supporting claims to sub-surface water may be somewhat relevant. As in the case of underground water, however, information regarding definite sources is very inadequate.

Professional dissent is apparent in respect to the second category of grievances also. The majority of contractors deny that modification can result in damages to clients and third persons, although many seeding firms carry insurance which covers costs of possible legal actions arising from their activities.

Damage may be in the form of unwanted rainfall in other areas, or excesses for the target area. Farmers paying for the seeding could themselves suffer if operations were too successful. Usual agreements which commit ranchers to finance association activities do not state which party may be liable for damages. One association in Montana, however, has specifically refused to assume any liability for excess amounts of rainfall. 16/ Seeding firms cannot be held liable unless there is evidence of nonprofessional or negligent supervision. Such proof would be extremely difficult to establish; and meanwhile, injured outsiders might bring action against associations or members.

Various legal implications have been described in this section to illustrate their importance for individual ranchers, sponsoring groups, and others concerned with the operation of weather control programs. Legalities have certainly affected present thinking in respect to many questions, and

16/ See Section 4 of Agreement in Appendix B.

have given rise to several disputes. The major implications brought out here are discussed further in Part VI, along with other controversial aspects. The later section reviews some suggested approaches to legal problems, with emphasis on those relating to rights and liabilities of farm operators.

PART II

METHODOLOGY

Broadly speaking, agricultural implications of weather control are separable into two principal categories. First, there are those amenable to economic interpretation; and second, those requiring sociological examination and criticism. Economic implications arise directly from prospective additional moisture available for crop and forage production. Sociological aspects relate to the anticipated degree of social progress permitted by increased efficiency in economic endeavors. Perhaps also involved is a political mandate for concerted action to bring about the realization of both economic and social benefits.

Part I was concerned with introducing several economic and social problems as they have been encountered by farm operators seeking to appropriate rain increasing to the dual objectives of raising the level of farm income and reducing income variation caused by climatic uncertainty. Actual cloud seeding operations were reviewed to illustrate the potential scope of rain increasing and the kinds of difficulties likely to be encountered in its general application to weather problems in semi-arid areas. The psychological, cost, and legal factors described in Part I largely account for the current status of rain increasing and its attendant controversies.

The Problem Situation

The Problem Setting

The present rain increasing situation in Montana and other western states is characterized by doubt, confusion, and uncertainty--both in the minds of farm operators and those who deal with agricultural problems.

Because many projects have been termed unsuccessful, many participating ranchers and professional agriculturists doubt that cloud seeding is as effective as its proponents have claimed it to be. This doubt is added to that already in evidence with the large proportion of farm operators who never supported projects from the beginning.

The situation is confused for several reasons. Programs have not always been well planned; with the consequence that organization, financing, and actual operations have been haphazard. Undue haste in getting programs underway has not encouraged the proper consideration of basic technical and climatic limitations to the probable success of operations. The possibility of inopportune weather conditions persisting has not always been presented to associations and their members. Failure to realize expected benefits has then led to the blanket assumption that cloud seeding is totally unproductive.

Confusion exists also with respect to apparently successful programs. Where significant departures above normal rainfall have occurred, critics contend that the increase would ordinarily have been received in the absence of cloud seeding. In situations of this kind the individual farm operator is faced with a paradox. If rainfall has exceeded normally received amounts, he is inclined to accept as substantiated the claims of contractors that the increase can be attributed to cloud seeding activity. On the other hand, he cannot be certain that the statements of critics are incorrect because he cannot quantitatively assess results for himself.

A farm operator has two alternatives if he is doubtful of the success of a completed operation. First, he can decline to offer further support pending proof of the effectiveness of cloud seeding; or he can continue his support. There may be two reasons for doing the latter. The action might be knowingly taken as a contribution to an experiment, or with the hope that successive attempts will yield more results, (assuming operations suffered from unavoidable climatic conditions). The provision of evaluative data would not modify these alternatives but would certainly make choices easier and more deliberate. Most disappointed ranchers in Montana have selected the first alternative as the easiest way out of the dilemma, though they still concede that rain increasing has interesting possibilities. Ranchers continuing their support of operations have of course accepted the second alternative, but have relieved themselves of some risk by securing agreements based on performance conditions.

Doubt and confusion surrounding the weather control issue make the position of the farm operator uncertain in two respects. First, it has not yet been determined whether his financial support of past programs has been profitable. At best, his estimates of programs success can only be qualitative and very subjective. The absence of impartial evaluations of past programs is also cause for the second and more important element of uncertainty. Where evaluations are lacking, the farmer has no guide for making decisions relevant to the continuance of seeding programs. Here again he must rely entirely on his own judgement plus whatever information is supplied by commercial concerns. Actually, sponsors of projects are in the same position now as they were when the possibilities of cloud seeding were first made known to them. At that time they supported programs with the expectation that evaluations upon which to base future decisions would soon be forthcoming. However, after several years of cloud seeding activity in

Montana and other areas of the country, no generally accepted conclusions regarding effects have been reached.

If induced and naturally occurring precipitation could be segregated, the problem of evaluating rain-increase operations would be comparatively simple. The fact that both are produced under essentially similar atmospheric conditions prohibits absolute judgements of the effectiveness of various seeding agents and the success claims of contractors. Evaluations conducted to date have attempted to isolate rainfall increments statistically, usually by comparing target area precipitation to that received at selected control stations. Though some of these studies are quite impressive, none has been generally accepted. Disputes concern operational methods, statistical procedures, and the assumptions that weather phenomena are or are not the resultants of chance conditions. Such wide disagreement in the scientific area has created complex problems for economic groups interested in the application of weather control. Several methods of evaluation are described in Part VI to illustrate these points.

The Problem Statement

The outstanding problem in regard to rain increasing in Montana is the same problem currently confronting agricultural producers elsewhere, and can be summed very briefly in the form of two questions. The first is closely related to project evaluations and the second implies a decision-making process.

1.) With respect to completed operations, have supporters of rain increasing programs received any return on their investment?

2.) In regard to question 1 and in view of the contentious nature of weather control, is continued support of programs justified? If so, on what basis?

The necessity for considering alternative organizational forms for implementing programs is important also but is presently less controversial than the two questions listed and depends to a great extent on the answers to them.

Problem Analysis

An affirmative answer to the first major question necessarily requires rather complete knowledge of the efficacy of weather modification techniques. Such knowledge would make it possible to determine whether rainfall increases were actually received or not. It would also assist in measuring the economic worth of rainfall increments in terms of higher income levels or reduced variability in income over long periods. In the absence of increases it has sometimes been argued that seeding firms are entitled to compensation for attempting to increase precipitation. There are probably a few farm operators who agree with this contention. Unfortunately, however, any satisfaction derived from knowing that someone was working with the problem of rainfall deficiency represents a psychic return impossible to measure in economic terms.

A negative reply to question 1 would either imply that projects have been complete failures, or that any increases received have been inconsequential. Apparently, this is the view taken by ranchers discontinuing programs and disbanding associations. For them it is not a matter of being correct in assuming operational failure, but rather of basing decisions on available information. Where information is incomplete, questionable, or controversial, no decision can accurately reflect well-considered judgements.

The conclusion drawn here in regard to the first question is that attempts to answer it on the basis of available evidence would be ill-advised. Even though hypotheses could be formulated and tested by analyzing past operations, there are not sufficient data available to support irrefutable conclusions. With disagreement so evident among those intimately associated with the scientific aspects of the problem, and with evaluations so limited in application, critical examination of single projects is almost impossible. Consequently, no answer to question 1 will be sought in this study. There will, however, be an attempt to set up certain criteria for determining when rainfall increases would be economically significant.

Answers to the second major question are also difficult to defend, although they are less debatable in some respects. A positive attitude, probably not much more than a value judgement, would conditionally justify rain-increase programs for farm operators if there was an awareness of critical limitations and the possibility that cloud seeding could eventually be proved ineffective. This is probably the conclusion reached by ranchers currently supporting active projects. Along with other participants, they no doubt have been keenly disappointed with rain increasing programs, and yet have known that logically consistent judgements cannot be based on single cases or a very limited number of cases. Perhaps they feel that the awaiting of inviolate proof and early abandonment of projects will not serve their interests any more than will premature and unqualified acceptance of weather modification. Ranchers taking these views likely favor the continuance of programs for at least several seasons with the hope that complete information will become available. Also, there may be intentions of benefiting from continuing progress in seeding technology, or the possible onset of a series of climatic conditions uniquely favorable for increasing rainfall.

The above considerations lend some weight to arguments for continued producer support of rain increasing, but they should not be construed as warranting the indefinite extension of unsuccessful operations. Least of all are they cogent reasons for expecting that economic benefits should immediately accrue from cloud seeding activity.

As with question 1, there will be no attempt in this study to form and defend an opinion as to whether farm operators should avail themselves of the services of cloud seeding firms. This particular decision is the prerogative and responsibility of managers themselves. However, farmers and ranchers undoubtedly would welcome any information that would assist in future deliberations or in judging whether decisions to discontinue past programs were wise. The extension of information relevant to the problem situation described in previous paragraphs (why it exists and how it might be improved) is one objective of this study. A second objective is the development of methods for estimating economic potentialities of sustained cloud seeding and the setting up of criteria for an optimal distribution of economic benefits.

The Research Problem

With respect to the objective of mitigating the doubt and uncertainty characterizing the 'present day' problem in weather control, the research problem is essentially an educational one. It involves the selection and dissemination of information that will serve best in removing (or at least explaining) the underlying causes of indecision plaguing farm operators. The fact that the problem situation is composed of social as well as economic factors requires exploration into evaluating techniques and policy aspects of weather control, both of which are highly controversial. Fortunately, these major controversies are grounded in the same causes of disagreement as to economic feasibility. (Is rain increasing really effective? Who will benefit and who might be harmed?) Reliable physical data would throw light on both sets of factors.

The development of methods for analyzing the economic consequences of induced rainfall involves much more than the mere collection and distribution of data. The research problem in this case is the construction of a suitable theoretical framework within which maximizing or minimizing principles can be applied to economic questions facing farm firms, seeding firms, or society. In regard to research in agricultural economics, such a model should be adaptable to three types of studies: 1.) determining the optimum use of rainfall increases as a production factor in various agricultural enterprises, 2.) outlining the extent to which existing resource use, i.e., land utilization, might be changed because of new alternative factor combinations, and 3.) comparing the inter-area differences in 1 and readjustments in 2.

Research Hypotheses

Hypotheses relating to the first research problem have been formulated and tested in the initial phase of this study. Given the problem of why interest in rain increasing waned so quickly in Montana, the tentative solution was that farm operators and associations were concerned about apparent inefficiencies in operational techniques, means of financing, or various psychological and legal factors. This belief was substantiated by the replies of survey subjects to appropriate questions and by additive comments. The educational problem is essentially mechanical and its attempted solution can be combined with the procedure for constructing economic models.

The major hypotheses formulated in regard to the analytical problem are that no economic indicators would prove reliable unless derived directly from technical and climatic relationships; and that where usable data are lacking, it is necessary to delve into the subject matter of other disciplines, viz., meteorology and climatology. These physical sciences already have an important relationship to agriculture. Heady admits that agricultural economics, particularly its production phases, would have little content if it were not able to draw data for input-output relations, production possibilities, substitution ratios, and scale or size relationships from technical sciences. 1/ These are the kinds of data not at the disposal of economists desiring to work with weather control problems.

A secondary hypothesis, concerning the best procedure for getting needed physical data, concerns the weather-type approach to climatic and

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1/ Earl O. Heady, Economics of Agricultural Production and Resource Use, Prentice-Hall Inc., New York, 1952, p. 13.

economic problems in rain increasing. This hypothesis is elaborated upon in the section on Climatology (Part IV.)

The Research Method

The simultaneous achievement of the two objectives of this study represents a problem in applied agricultural economics and rural sociology that requires excursions into other social sciences and some physical sciences. The survey (a case study) of recent rain-increase programs in Montana revealed that the process of producer decision-making was psychological as well as economic, and probably more so. The motives of farm operators in supporting programs can be explained as well in terms of securing a more pleasant sociological environment as in realizing the financial returns of increased or stabilized production. Where a single producer is concerned, the achievement of economic 'means' to sociological 'ends' greatly depends on whether he prefers to remain a so-called 'individualist' and have complete freedom in conducting programs (even down to running his own cloud seeding generator), or allow his objectives to be reconciled with those of neighboring farmers and other societal groups. Inter-farm problems in weather control for the most part are problems in community cooperation; consequently, the acceptance of rain increasing as a new production technique involves both economic and sociological considerations. If legal aspects are as important to decisions as they appear to be, elements of political science must also be injected into problem solutions.

Described as concisely as possible, the plan of this study is as follows: The technology of weather modification and climatological principles are combined to determine what rain increasing programs can achieve with present techniques and resources. An economic section specifies how rainfall increments should be utilized to benefit farm firms and society. The final chapter, on social issues, first describes how producer choices could be limited by existing institutional factors or newer expressions of group values in the form of regulatory legislation. The study concludes with an argument for postponing any judgements of the actual effectiveness of cloud seeding until complete and reliable evaluations are produced.

PART III

TECHNOLOGY

Introduction

To see the economic potentialities of rain increasing in their proper perspective requires at least cursory knowledge of the physical processes involved and the scientific techniques employed in commercial operations. Groups interested in the application of weather modification to their particular problems are little concerned with mechanisms underlying the formation of precipitation or in the specific techniques designed to control these processes. However, participants too often have been familiarized with promising possibilities of rain increasing without being aware of the practicable limits to the use of cloud seeding techniques. The originally prevalent assumption that rain increase programs could not be anything but successful has led to dissatisfaction with the accomplishments of associations and contractors alike. If ranchers could plan programs with reference to technical limitations as well as possibilities, considerably less disappointment would follow.

A detailed knowledge of Meteorology as it is applied in scientific rain induction is not essential to the recognition of critical limits to successful weather control. The information presented here is not intended to completely cover technical aspects, though it should suffice in overcoming misconceptions of the manner in which cloud seeding techniques are being applied. In this and the follwoing section, technology and climatology are integrated in arriving at some general conclusions regarding expectancy of economic benefits in Montana.

The Meteorological Background of Weather Modification

Precipitation Theories

Before listing important research findings which relate directly to the local problem it may be helpful to briefly recount basic theories of the causes of precipitation and why it does not always occur under conditions thought to be favorable. Three major theories thus far advanced have been designated the ice crystal process, the vapor-pressure differential process, and the salt nuclei process.

The most widely accepted theory of precipitation formation was proposed in 1933 by Bergeron, who suggested that rain resulted from the inital formation of snow in the upper parts of clouds. 1/ According to Bergeron, if ice crystals, water vapor, and water droplets co-exist in a cloud, an equilibrium can be maintained only be a preferential growth of ice crystals at the expense of water droplets in its vicinity. Given sufficient moisture, snow particles eventually form from ice crystals and proceed to fall. If reaching the freezing level, they melt and leave the cloud as rain. Whether the precipitation reaches the earth or is evaporated depends primarily on the size of the raindrops or snowflakes, relative humidity, and the air temperature between the cloud base and the ground.

A second credible theory, similar to Bergeron's, has been advanced by Petterssen, who does not assume that rain must necessarily be preceded by

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1/ Berry, Bollay, and Beers, Handbook of Meteorology, McGraw-Hill Book Company, New York, 1945, p. 260.

the formation of snow. 2/ Petterssen attributes the development of raindrops to differential vapor pressures between water droplets of varying temperatures. As in the Bergeron process, differences in vapor pressure lead to preferential growth, though of cold droplets at the expense of relatively warmer ones. The presence of ice crystals is not considered essential for the reaction to continue.

The salt nuclei theory explains the formation of natural rainfall in warmer latitudes. Though Bergeron's process is considered operative even in tropical regions, the salt nuclei theory refers specifically to rain formation in warm clouds. According to this explanation, certain forms of hygroscopic nuclei present in the atmosphere attract water vapor and then enlarge by coalescence with smaller droplets encountered while falling through the cloud. 3/

The three theories are over-simplified here, but they do suggest (particularly Bergeron's) possibilities of intiating or accelerating precipitation. The major factors contributing to supercooling of air-borne moisture are thought to be lack of turbulence and a shortage of agents which ordinarily serve as necessary nuclei for ice crystals and water droplets. The object of weather modification is the provision of optimum concentrations of effective nuclei. Natural and artificial nuclei are classified into three groups corresponding to modes and temperature ranges of reaction. Included are condensation, sublimation, and freezing nuclei. Each

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2/ Sverre Petterssen, Weather Analysis and Forecasting, McGraw-Hill Book Company, New York, 1940, p. 46.

3/ Berry, et. al., p. 261.

have special functions in natural or induced precipitation processes. 4/

Condensation Nuclei

Condensation nuclei become active when atmospheric air is cooled below the dew point. 5/ The number of water droplets forming depends on the concentration of the nuclei previous to cooling. Sources of condensation nuclei are industrial and forest fire smokes as well as some kinds of salt particles coming from the oceans. These nuclei are generally abundant, though at times the atmosphere may be deficient in them at high elevations. It should be emphasized that condensation nuclei serve only as centers of water droplets that can remain liquid at temperatures warmer than -38.5° C. because 39° C. is the lower limit of supercooling.

Sublimation Nuclei and the Use of Silver Iodide

Certain kinds of submicroscopic dust particles and chemical salts can act as sublimation nuclei. They possess properties of inducing the direct conversion of water vapor to ice crystals without the intermediate formation of liquid droplets. Natural sublimation nuclei begin to be effective at -12° C. Below this point there is wide variation in the effectiveness of different soil particles. Schaefer has found the most effective types of

4/ As early as 1949, Schaefer emphasized the importance of distinguishing the relationships of various kinds of nuclei to weather control. See Vincent J. Schaefer, "Economic Aspects of Experimental Meteorology," Proceedings of the United Nations Scientific Conference on the Conservation and Utilization of Resources, Vol. IV, Water Resources, U. N. Department of Economic Affairs, New York, 1951, p. 4.

5/ Dew point is defined as the minimum temperature at which water contained in the air can exist as a vapor.

soil nuclei to be clays and volcanic residues. The results of these soil studies are shown in abbreviated form in Figure 3. Samples from this area are compared with artificial seeding agents.

A question generally raised in reference to soil nuclei is the reason for drought persisting when wind eroision presumably carries large quantities of effective dust into the atmosphere. Schaefer explains this puzzling phenomenon by stating that prevailing air and cloud temperatures in drought regions are often too high to permit deposition of ice on dust particles. 6/ Even with the presence of effective nuclei and extremely low temperatures, the absolute humidity under drought conditions may be such that sufficient mositure for precipitation is lacking. Schaefer indicates, however, that dust nuclei are responsible for creating cirrus (high altitude) clouds. 7/ Subsequent weather effects are felt because cirrus formations enlarge and settle into lower layers of the atmosphere where their ice crystals 'seed' other clouds. Many local thunderstorms are thought to be generated in this manner.

The Great Plains region and areas adjacent to the continental Divide are prolific sources of sublimation nuclei. Wind erosion and strong vertical movements of air characteristic of prairie regions account for the transportation of dust nuclei to distant areas. Schaefer illustrates this by pointing to 'dust bowl' days when soil from the western states was deposited

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6/ Schaefer, "The Occurrence of Ice-Crystal Nuclei in the Free Atmosphere," Final Report No. RL-566, Project Cirrus, General Electric Research Laboratory, Schenectady, New York, July, 1951, p. 180.

7/ Ibid., p. 196.

in noticeable quantities with rain and snow on the Eastern seaboard. Because of the random nature of erosion and convection on the Great Plains, the concentration of sublimation nuclei in the eastern United States varies considerably. Schaefer atrributes exceedingly low counts over the eastern states in the winter of 1949 to heavy snow depths in western areas which held wind erosion to a minimum.

Because dust nuclei are effective only at comparatively low temperatures, they do not influence weather as much as their abundancy would indicate. Schaefer emphasizes the importance of this limitation by concluding: "It is obvious that if sublimation nuclei active at 0° C. were common in the atmosphere at high concentration, the form of many cloud systems would be profoundly modified. Supercooled clouds would become virtually non-existent." 8/

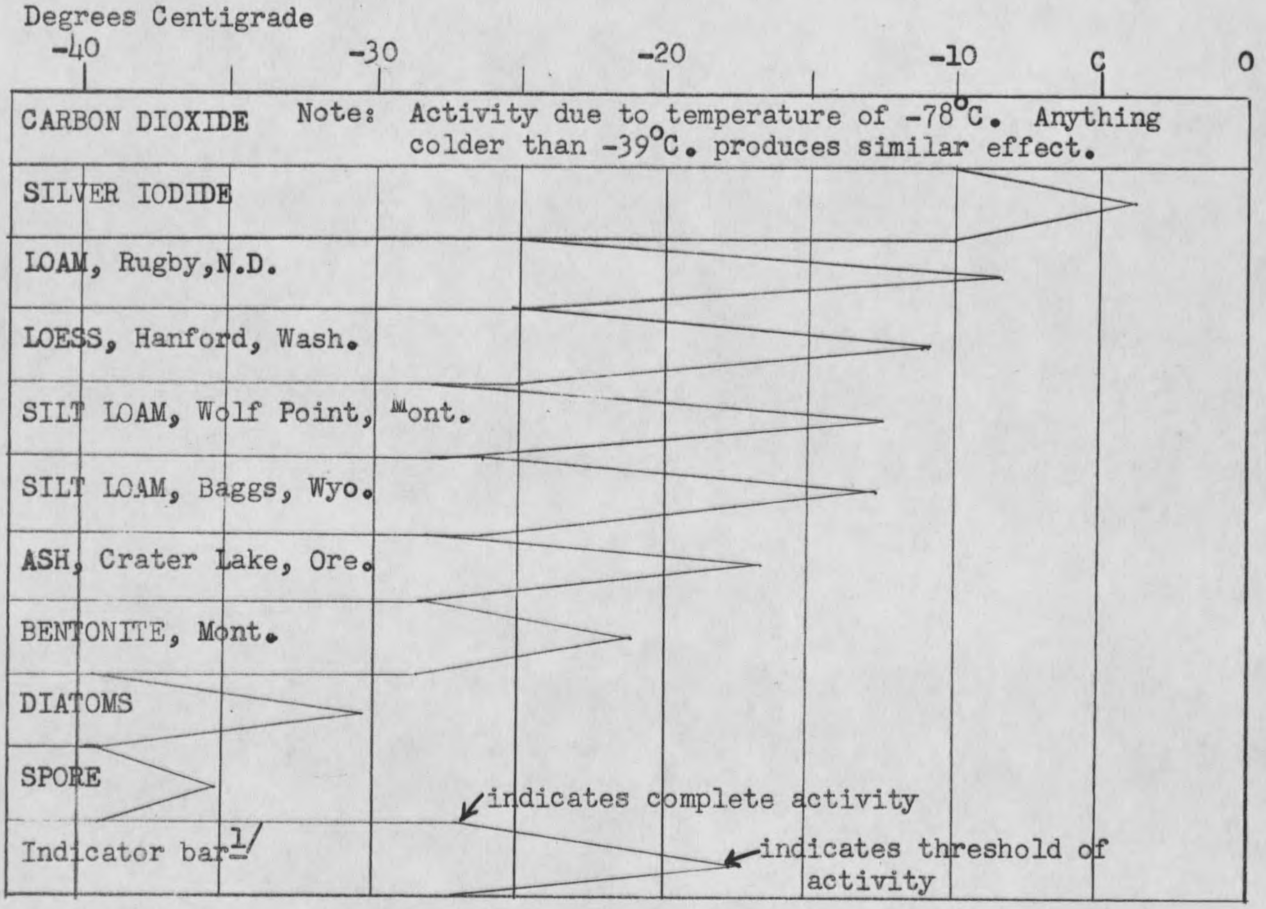
Chemical agents intended to supplement naturally occurring sublimation nuclei become active at temperatures a few degrees below freezing. Most chemical salts capable of producing the necessary reactions are metallic iodides. Vonnegut in 1946 pointed out the unique suitability of silver iodide for cloud seeding because its crystalline structure is very similar to that of ice crystals. 9/ Another advantage of the salt is that nuclei formed from it do not melt or evaporate; consequently they can remain in the atmosphere for relatively long periods. This makes it possible for them

(cont. p. 44)

8/ Ibid., p. 202.

9/ Irving Langmuir, First Quarterly Progress Report, Project Cirrus, General Electric Research Laboratory, Schenectady, New York, July 1947, p. 11.

Figure 3. Temperature-Activity Relationships of Natural and Artificial Sublimation Nuclei (after Schaefer)



Source: Vincent J. Schaefer, Final Report No. RL-785, Project Cirrus, Part I. Laboratory, Field, and Flight Experiments, General Electric Research Laboratory, Schenectady, New York, March, 1953.

1/ Bars indicate temperatures at which particles actively induce the formation of ice crystals from water vapor. Apexes represent maximum temperatures at which crystallization can occur.

to be carried long distances from their point of origin, and later to become active when encountering supercooled water droplets. Delayed reactions form the basis for fearing harmful effects of weather control.

Two important doubts have been raised in connection with the actual effectiveness of silver iodide. The first of these is that the crystal is susceptible to photoloysis, or deterioration upon exposure to sunlight. The second is uncertainty as to whether the nuclei infect the proper regions of clouds. 10/ Some studies of the first problem have been made, with most evidence indicating that deterioration is not acute under conditions when silver idoide is usually released. Humidity is apparently a controlling factor in the degree of photolysis. Schaefer suggests that if the deactivating problem does exist, it can be overcome by supplying excess quantities of crystals. 11/ The likelihood of nuclei reaching the proper regions of clouds is largely dependent on weather conditions and methods of dispersing seeding agents. The question underlies the standing argument of aircraft versus ground seeding.

Because of its chemical stability and ease of dispersion, silver iodide is particularly adapted to large-scale cloud seeding from ground levels. Generators have been constructed which are extremely efficient in producing prodigous quantities of crystals. The equipment is designed to vaporize silver iodide dissolved or impregnated in various fuels. Common fuels are foundry coke, butane, and propane.

10/ These doubts are expressed in a statement issued by the American Meteorological Society; released May 1, 1953, Boston, Massachusetts.

11/ Schaefer, Final Report No. RL-785 Project Cirrus, General Electric Research Laboratory, Schenectady, New York, March 1953, p. 34.

Two general operational procedures involve the use of silver iodide. The first might be termed 'frontal' seeding, and the second is commonly known as 'advance air mass seeding'. The frontal method involves the use of generating equipment located at ground levels so that ascending nuclei encounter cloud systems covering or likely to pass over operating zones. 12/ The equipment is positioned at various locations surrounding seeded or 'target' areas. Operations are conducted in reference to synoptic conditions prevailing or shortly expected to prevail.

Air mass seeding itself can take two forms. In the first instance, ground equipment is operated with intentions of saturating the general area with nuclei. Convective activity is relied on to bring about the assimilation of silver iodide into cloud forms present or developing in the course of the day. Companies employing aircraft seeding methods practice the second form of air mass seeding. 13/ Silver iodide is dispersed from planes in such a manner that all clouds developing early in the day are provided sufficient quantities of nuclei. The expectation is that clouds thus seeded will be ready to precipitate immediately upon reaching critical temperatures. Advocates contend that aircraft seeding allows a degree of precision unobtainable with ground equipment. Principal objections to aircraft seeding are that operations must be restricted to local areas and

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12/ Irving P. Krick, "Snow Pack Increases in the Colorado Rockies by Artificial Nucleation," 19th Proceedings of Western Snow Conference, Victoria, B.C., April 1951, p. 108.

13/ C. S. Barnes, "Precipitation Control," 18th Proceedings of Western Snow Conference, Boulder City, Nev., April 1950, p. 71.

daylight hours; and that flying is usually hazardous under conditions most favorable for seeding. Granted that aircraft operations are successful, there remains the doubt of whether the increases in precipitation obtained are significant. Some work on these questions has been done in Canada. It is reviewed later.

Freezing Nuclei and the Use of Dry Ice

Freezing and condensation nuclei are similar in that both can react directly with water droplets. The difference is that freezing nuclei go a step farther than condensation by inducing the crystallization of droplets they encounter. As with sublimation forms, they become active at temperatures slightly below freezing. Special kinds of sublimation nuclei can also act as freezing nuclei. 14/

Strictly speaking, carbon dioxide (dry ice) does not yield freezing nuclei. It is described here because its reaction is one of crystallizing any supercooled water suspended in the atmosphere. Its extremely low temperature (-78° C.) is responsible for immediate chilling of water vapor encountered, by an effect similar to that produced with sublimation nuclei. The crystals thus produced multiply by a sort of chain reaction and can often modify an entire supercooled cloud in a matter of minutes. 15/ Under certain temperature conditions, silver iodide can also intiate chain reactions. Commercial operators often ascribe their release of precipitation to 'triggering' effects of cloud seeding agents.

14/ op. cit., Schaefer, Report No. RL-785, p. 72.

15/ Ibid., p. 73.

Various methods have been devised for injecting dry ice into clouds. Experiments have been conducted using aircraft, ballons and flares. Where dry ice is used in commercial operations, however, it is always dispersed from aircraft flying above or through the clouds to be inoculated.

Research Conclusions

Many investigations have sought to determine the technical feasibility of weather control. Though a large part of the work has been carried on in the United States, numerous foreign countries have also conducted research programs. Canada, Australia, South Africa, Spain, and Israel are particularly interested in rain increasing as it might be applied to their particular problems.

The remainder of this section is a summarization of research conclusions. Those selected relate directly to prospective rain-increase programs in Montana. Findings in regard to the effectiveness of silver iodide and dry ice are combined to assist in estimating potential benefits to be derived from both methods. However, the ensuing climatic study is predicated on the seeding of major weather systems with silver iodide. Though favorable conditions for dry ice seeding are somewhat similar to those required for large scale operations, it is felt that a climatic study can be more useful if related to an operating method in general use.

Project Cirrus

Following Schaefer's original observation of the crystallizing property of dry ice (page 1), the U. S. Army Signal Corps and the Office of Naval Research under took the extended series of laboratory, field, and flight experiments which later took the code name Project Cirrus. The program continued from February 1947 to October 1952, with technical supervision and assistance provided by the General Electric Company.

Project Cirrus is important to Agriculture for two reasons. First, all currently-practiced rain increasing techniques were initially developed and tested under the program. A second contribution was that in the course of field experiments, special attention was given to the applications that would prove useful to agricultural producers. Also, experimenters soon recognized and were impressed by apparent limitations to successful rain increasing. These limitations will follow the listing of promising conclusions reached.

On the basis of numerous laboratory and field studies conducted during the five-year period of active research under the Project Cirrus program, the following conclusions were felt to be justified. 16/

1. Super cooled clouds can be modified by dry ice and/or silver iodide seeding.

2. Nuclei are of primary importance in the initial stages of the development of precipitation. The concentration of effective condensation and/or ice nuclei, together with the liquid-water content, the altitude of the base of the cloud, the height of the freezing level, the turbulence within the cloud, and the vertical thickness of the cloud, are all interrelated and must be considered if a proper understanding of cloud reactions is to be expected.

3. Since it has been demonstrated that localized effects due to seeding operations in areas up to 500 square miles are easily produced in unstable cloud systems, it seems reasonable to expect that widespread effects could be initiated with equal effectiveness.

16/ Vincent J. Schaefer, Final Report No. RL-785, Project Cirrus, Part I. Laboratory, Field and Flight Experiments, General Electric Research Laboratory, Schenectady, New York, March 1953, p. 153.

4. Experimental flights under a carefully controlled operational procedure have been accomplished with all cloud types and at altitudes ranging from a few thousand feet to more than 30,000 feet. Dry ice and silver iodide seedings in clear air and in cumulus and stratus cloud types have shown that, under conditions that occur frequently, positive reactions may be expected with each specific situation.

5. The effects of seeding operations in the atmosphere range from the formation of snow areas in previously cloud-free air to the removal or further stabilization of stratus clouds and the initiation of the precipitation cycle in cumulus clouds.

6. Since our results indicate that an effective precipitation cycle may be induced in cumulus clouds having tops below 25,000 feet, it follows that hail and lightning storms might be prevented by the judicious seeding of cumulus clouds in cloud breeding regions.

7. The complexity of the mechanisms for the development of an effective precipitation cycle is obvious. New Mexico studies have shown that under some conditions, too many ice crystals develop following the inoculation of small cumulus clouds with foreign-particle ice nuclei from dust storms. The resulting precipitation elements evaporate in the dry air before reaching the ground.

At other times, the lack of a sufficient concentration of ice nuclei permits the clouds to grow so high that the upper layers form ice crystals spontaneously. These crystals are so small that their falling velocity is negligible. As a result, they rarely reach the lower levels of the cloud to produce a seeding effect. Plumes of ice crystals, often hundreds of miles long, stream from the tops of such clouds and give visual evidence of the relative inefficiency of the precipitation process. This latter condition is the dominant one in many regions which receive marginal amounts of rain.

8. Information is now available so that seeding techniques could be designed as follows:

a. To clear a solid overcast of supercooled clouds.
b. To produce a snow area in air supersaturated with respect to ice.
c. To initiate or prevent precipitation from orographic cumulus clouds.

Economic implications of the foregoing conclusions are not difficult to foresee. If effects of cloud seeding include formation of snow areas, stabilization of clouds, hail suppression, and precipitation control, both individual and aggregate agricultural production could be affected significantly. Most weather modification programs conducted thus far have had as objectives the increasing of rainfall or suppression of hail. From the conclusions above it can be seen that there are other beneficial applications that have received too little attention. The possibility of snow areas (cirrus clouds) forming was previously listed by Schaefer as a factor in the indirect seeding of thunderstorms. The stabilization of cloud decks holds promise for reducing evaporation losses.

The third conclusion listed above implicitly refers to large-scale seeding with silver iodide. Langmuir has intensively studied seeding effects felt in areas far from the point of generation. When silver iodide was released in New Mexico according to a fixed schedule (Tuesdays), periodicities in weather were noted (Saturdays) in the Eastern states. Langmuir has concluded that relatively small amounts of silver iodide released at strategic locations can exert powerful influences over very large regions. His elaborations were published in a separate report. The comments are indicative of the potential magnitude of weather control possibilities, for Agriculture and other segments of the economy as well.

> 1. The existence of widespread effects of seeding proves that it shoudl be possible at low cost to modify, and within limits, to control the general synoptic weather patterns over whole continents.
>
> 2. A perhaps more important conclusion is that weather is not definitely determinate. It depends in large part and essentially upon meteorological events that originate from small and unpredictable beginnings, such as the location and concentration of freezing nuclei that may set off chain reactions.
>
> 3. Therefore, it is now and in the future will continue to be inherently impossible to make exact forecasts of weather. It will be easier to make the weather than to forecast it. It should, however, be possible to increase the accuracy of estimates of probable weather for limited forecast periods.

4. If seeding schedules are not well planned, floods or droughts may be produced. The harmful effects in both cases come from too long a continuation of rainy or dry weather. A simple remedy lies in planned diversification of seeding schedules, so that any given type of weather does not continue for more than a few weeks at a time.

5. Although widespread modification of weather by seeding has been proved, its mechanism is not yet understood. The situation is much like that in the germ theory of disease. We know that diseases may be produced by single bacteria, but we do not yet understand essential elements in the mechanisms such as the actions of toxins, antibodies, etc. 17/

Langmuir's correlation study was climactic in that the implications of according it scientific credence are very great. Until the results were published, weather control was a comparatively passive issue among meteorologists. Criticisms of Langmuir's interpretations of the observed periodicities in weather are the basis of the opposition's arguments. Critics contend that the noticeable effects on Eastern weather produced by cloud seeding in New Mexico have historical duplicates in natural weather sequences. 18/ Langmuir's findings can be seen in better perspective if the limits noted in his first conclusion are described in reference to Montana conditions. Professional agreement on three major barriers to complete precipitation control is universal enough to permit their listing as boundaries to expectancy of economic benefit in this area.

17/ Irving Langmuir, Final Report No. RL-785, Project Cirrus, Part II. Analysis of the Effects of Periodic Seeding of the Atmosphere with Silver Iodide, General Electric Research Laboratory, Schenectady, New York, May 1953, pp. 339-340.

18/ The Landsberg Committee, "Precipitation Control," Science, Vol. 113, February 16, 1951, p. 189.

1. The basic physical determinants of weather and climate are unchangeable. Such global features as atmospheric circulation, temperature zones, and moisture sources are fixed over the earth. Langmuir agrees that large scale seeding effects could be operative only within these existing meteorological constants.

2. Although it may be possible to lessen the severity of drought by taking advantage of local storm activity, re-orientation of stable and complex drought patterns is not forseeable. Schaefer describes drought as a condition where a stable and complex weather pattern persists for relatively long periods. Drought is usually accompanied by cloudless skies or by clouds of small vertical and horizontal dimensions. Thick layers of dry air and strong inversions impede cloud development. 19/

3. Certain timely weather conditions can render infeasible most forms of weather control. It has been demonstrated that some types of clouds are not suitable for modification, either because of their size or internal characteristics. Seeding likely results in dissipation rather than further development. This limitation is represented by fair weather clouds developing under normal weather circumstances and is relatively frequent during summer months.

Canadian Experiments with Dry Ice

A second major research program concerned with rain increasing was established in Canada in 1948. This study extended into 1949 and was

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19/ Schaefer, "Economic Aspects of Experimental Meteorology," Proceedings of the United Nations Scientific Conference on the Conservation and Utilization of Resources, Vol. IV. Water Resources, U.N. Department of Economic Affairs, New York, 1951. p. 22.

sponsored by the Canadian National Research Council and other governmental departments. 20/ The Canadians tested theories and techniques that had thus far been developed under Project Cirrus. The purpose of the project was to determine the feasibility of applying rain induction to Canadian agricultural, water power, and forestry problems. Tests were conducted over various regions of Canada, using exclusively the dry ice seeding techniques of Schaefer.

The Canadian experiments are interesting in that they indicate the possible benefits to be expected from localized seeding operations utilizing dry ice. One important limitation to the tests admittedly was lack of suitable means for measuring induced rainfall. It was thought that seeded clouds responded quite favorably, however.

The Canadians made fifty-nine seeding flights in the course of their program and worked with both supercooled and non-supercooled clouds. Although over half the tests were non-selective (clouds randomly chosen), modification or precipitation occured 76 per cent of the time, with precipitation reaching the ground in 24 per cent of the cases. Three cases of heavy rates of rainfall occurred (over .6 inches per hour). The overall results of the Canadian experiments are summarized and explained in Table III.

The Canadian experiments verify Schaefer's statement that success in cloud seeding is a function of cloud size and relative humidity. In the

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20/ John L. Orr, et. al., "Canadian Experiments on Induced Precipitation," Proceedings of the United Nations Scientific Conference on the Conservation and Utilization of Resources, Vol. IV, Water Resources, U. N. Department of Economic Affairs, New York, 1951. p. 24.

tests described above, the percentage of success was found to increase directly with: (a) increases in supercooled depth of clouds, (b) increases in relative humidity of the surrounding atmosphere, (c) decreases in the altitude of cloud bases, and (d) decreases in cloud-top temperature. Modification success reached 100 per cent if the depth of supercooling exceeded 4,000 feet or if the cloud-top temperature fell below -12° C. 21/ Cloud depth also determined whether precipitation reached the ground, once released. A cloud depth-altitude of base ratio greater than .75 was considered necessary for precipitation to reach the earth.

Final appraisal of test results indicated to this group that the dry ice technique is useful but subject to several limitations:

1. Induced precipitation can only supplement natural rainfall in any particular locality.

2. It is extremely difficult to direct induced rainfall to any particular small area because of the random nature of clouds. 22/

3. There is no control over the rate of release of precipitation with the dry ice method.

4. Since induced rainfall is strictly local it cannot be expected to affect the general character of any air mass and therefore its effectiveness may be offset by subsequent evaporation. Precipitation in the form of snow may be more efficient because of reduced evaporation loss.

(cont. p.56)

21/ It will be remembered that this is the temperature at which natural sublimation nuclei become effective as crystallizing agents. See p. .

22/ This factor was cause for disappointment with rain increasing operations in northeastern Montana. Participants were dismayed when seeded clouds were observed to release precipitation over the lands of non-members.

Table III. Results of Canadian Field Tests of Dry Ice Techniques

Observed Conditions	Random Trials - Total 59		Selective Trials-Total 21	
	Positive Results	Per Cent Success	Positive Results	Per Cent Success
Modification or Precipitation 1/	45	76	17	81
Precipitation leaving cloud	30	51	14	67
Unique precipitation leaving cloud 2/	12	20	4	20
Precipitation reaching ground	14	24	9	43
Unique precipitation reaching ground	5	9	4	19

1/ Modification is alteration of appearance only, where seeding usually initiates dissipation.

2/ Unique results are defined as those not occurring naturally within a radius of twenty-five miles.

3/ Clouds selected were developing cumulus types thought likely to produce some precipitation.

Source: Orr, Pettit, and Fraser, "Canadian Experiments on Induced Precipitation," Proceedings of the United Nations Scientific Conference on the Conservation and Utilization of Resources. Vol. IV, Water Resources, U. N. Department of Economic Affairs, New York, 1951.

5. There has been no evidence that self-sustaining storms could result from dry ice seeding.

According to the Canadian study, the usefulness of supplementary induced moisture is critically dependent on its timing with respect to the growth cycle of particular crops. The qualification would surely apply to increases obtained with the silver iodide method also. For induced rainfall to be of benefit to an individual rancher, it would be necessary to direct a minimum useful amount to his property, and if possible, to avoid excessive rates of rainfall. Under these conditions, localized operations with dry ice would be beneficial.

The climatic feasibility of conducting cloud seeding operations(dry ice or silver iodide) is apparently contingent upon a supply of suitable clouds. A major difference in the two seeding methods is that while dry ice can be effective locally, silver iodide dispersed at distant locations can assist in bring moisture-laden clouds into a project area. Silver iodide has been used to 'overseed' clouds developing on the windward sides of mountains. Instead of precipitating at normal elevations they pass ridges and act as holding resevoirs that subsequently can release their precipitation elsewhere. Because of the widespread effects of silver iodide, self-sustaining storms might be initiated. At any particular time, the general prevailing weather pattern evidently determines whether cloud seeding operations would be feasible in a general region as the state of Montana. Then there is the question of variations in the weather pattern at different locations within such an area. A suggested approach to these problems is described in the following section.

PART IV

CLIMATOLOGY

Langmuir has stated that two separate conditions must be fulfilled for heavy natural rain to occur in supercooled clouds. First, effective nuclei must be present in adequate quantities; and second, surrounding weather circumstances must be favorable. 1/ The conditions are also applicable to artificially induced precipitation, since weather modification strives to duplicate optimum natural circumstances which favor the release of precipitation.

Though sufficient nuclei can be provided quite efficiently with existing seeding techniques, the requirement for a suitable atmospheric environment cannot be met so easily. However efficient the technology of rain increasing might be, its successful application remains subject to the natural course of weather events. It might be possible through consistently successful weather control to modify weather patterns to some extent and in a sense create the conditions for further improvement; but as it was stated in the last section, basic determinants of climate are uncontrollable. Climate then is the area in which the most critical limitations of rain increasing reside. Furthermore, if it can be assumed that the usefulness of supplementary rainfall is specific to particular applications, crops, and areas, then climatic factors now influencing production must enter into any economic analysis of weather control.

1/ Irving Langmuir, "Progress in Cloud Modification by Project Cirrus," Occasional Report No. 21, Project Cirrus, General Electric Research Laboratory, Schenectady, New York, January 1950. p. 12.

A climatic critique of weather control serves two useful purposes. First, it forces re-appraisal of the potentialities of rain increasing with respect to climatic barriers precluding or limiting chances of success. A second and positive purpose is that climatic characteristics are useful keys to long run economic benefits which might accrue from successful rain increasing. These dual objectives are consistent with the interests of Montana agriculture because weather risks and uncertainties perenially confront agricultural producers, and are the major determinants of crop yields. Even with proper soil, proper tillage, and proper seed, weather conditions largely determine the crops that will or will not grow, mature, and ripen in a given locality. The climatic elements comprising these conditions are numerous, of which precipitation amount and variability are probably the most important. To see how Langmuir's second condition applies to rain increasing activities in Montana, it is necessary to define a favorable synoptic situation in realistic terms, and then determine for individual areas the probability of such situations occurring during the calendar periods when seeding operations would ordinarily be planned.

Seeding Opportunities and Seeding Potentials

In lay terminology, the synoptic situation can be described as the general view of weather prevailing at a given time over a specified area. To meteorologists however, the synoptic situation is represented by a complex of meteorological elements and atmospheric conditions existing simultaneously over an extended region. Synoptic weather maps exhibit the mean values of one or more elements (air temperature, dew-point temperature, cloud forms, humidity, wind direction, etc.) at a number of points during a selected time interval.

A synoptic situation conducive to rain increasing would exist where atmospheric conditions favored precipitation, but where sufficient concentrations of sublimation or freezing nuclei were lacking. The time interval during which the provision of additional nuclei might initiate or intensify precipitation cycles would pose a seeding opportunity.

A general requirement for success in cloud seeding is that operations must be conducted when natural storms are in progress or impending. Though the requirement is valid for determining the feasibility of operations, it must be abandoned when approximations are made of the rainfall increases that might be obtained. This is because success in cloud seeding is not proportionately related to rainfall that can occur where no seeding takes place. Where adequate quantities of nuclei are present and synoptic conditions right, it is reasonable to expect that maximum precipitation should result. If there is real danger in overseeding, attempts to increase rainfall under such circumstances might get the opposite result. At the other extreme is the case where natural storm activity might be so weak (given adequate nuclei) that effects of seeding would be negligible.

In reality, the relationship between natural storm activity and induced precipitation is probably disporportionately direct up to an optimum set of circumstances, beyond which negative or possibly deleterious results would be expected. An <u>ideal</u> seeding opportunity would be presented where atmospheric conditions for precipitation were uniquely favorable--with critical nuclei concentrations. Limited injections of artificial nuclei could then initiate and intensify the precipitation cycle so that miximum rainfall would result. If ideal opportunities were identifiable, cloud seeding could be much more deliberate, and the evaluation of operations would be greatly simplified. Because knowledge of precise atmospheric conditions existing or likely to exist is lacking, commerical cloud seeding operations cannot be completely controlled and selective. This does not imply that cloud seeding must be indiscriminate, but that operating procedures cannot be specialized to achieve best results with the various synoptic situations considered favorable for modification.

If comparable rainfall increases are not to be expected from every seeding operation, climatological and economic analyses are rendered more complicated. Estimated returns from induced precipitation are not solely dependent on the relative frequency of seeding opportunities, but are also contingent on the existing climate and the amenability of different weather situations to modification. Analyses can be somewhat simplified if a distinction is drawn between what has been labeled a seeding 'opportunity', and what would constitute seeding 'potential'. The former can be expressed in meteorological terms and the latter in climatological terms. Economic connotations are even more divergent.

Seeding 'opportunities' arise whenever receptive synoptic situations develop, and exist as long as the situations prevail. Contractors view them as opportunities to perform, and train their organizations to quickly recognize or forecast such conditions and conduct seeding operations accordingly. A similar approach to meteorological variables is taken by crop spraying firms, particularly those employing aircraft in their operations. To apply spray materials effectively, they must consider such elements as visibility, humidity, temperature, and drift. These firms do not attach much importance to the persistence of unfavorable conditions, since their operations are usually subject to only short postponements. Cloud seeding firms are in less advantageous positions, however, in that the relative frequency of seeding opportunities indirectly determines their qualification for performance payments.

Seeding 'potential', on the other hand, refers to the probable effects (qualitative or quantitative) of cloud seeding on the seasonal amount and distribution of rainfall in particular areas. For single localities, seeding potential is dictated by such variables as the existing climatic environment, the frequency of seeding opportunities, their timing, their sequence, and the expected success of cloud seeding under each favorable set of weather circumstances. The immediate use of such indexes is in predicting the influence of sustained cloud seeding on the normal precipitation regimes' in various climatic sections of Montana. Ultimately, they would serve as predictors of socio-economic adjustments and transitions.

Simultaneous consideration of the many variables associated with seeding potentials is virtually impossible with the use of readily available climatological information. Conventional sources of data list mean values of precipitation, temperature, and evaporation. Valuable as this information may be in describing the climatic status quo, it is not descriptive of the evolutionary or dynamic aspects of weather. These aspects have singular importance in weather control operations, and should therefore be considered primary factors in climatic analyses of related problems. If the association between common elements (precipitation, temperature) and others (pressure, air-mass characteristics) comprising the synoptic situation were known, frequency distributions of seeding opportunities could be determined from usual records with relative ease. Where these relationships are not known, however, an alternative analytical technique must be substituted. The procedure adopted here in the derivation of comparative seeding potentials is admittedly very imperfect, and is suggested only as a tentative approach to the problem of determining the economic worth of prospective rainfall increases.

Seeding Potentials and Problem Requirements

An application of climatological principles to rain-increase problems is not unusually involved. One complication is the reciprocal relationship of weather and weather control technology. That is, weather conditions dictate whether seeding can be practiced; and operations in turn might affect weather conditions in other areas. However, this feature does not restrict the use of climatic data if the technology of cloud seeding is assumed to be unchanging, and continued dependence on natural weather circumstances is recognized. The main difficulty is in selecting data that accurately portray the influence of single variables as well as the influence of combinations of variables. In its operational aspect, weather control primarily concerns farm operators and cloud seeding firms. Related research, therefore, should be oriented toward serving the interests of both these groups.

In outlining climatological analyses, Landsberg sets up four classes of problems in applied climatology. These include (1) designs and specifications, (2) location and operation of a facility or equipment, (farms and industrial plants), (3) planning of an operation, and (4) relations between climate and biological processes. 2/ Problems peculiar to rain increasing are likely to fall in any of these groups, though ranchers are immediately concerned with those in the third and fourth categories. Problems confronting seeding firms are concentrated in the first three groups.

Though decisions to sponsor rain increasing programs are based on estimated production increases (category 4), ranchers face the management decisions of 'if' and 'when' to engage seeding firms. If, in cooperative organizations, interested groups preferred to seed clouds themselves, their decisions would be influenced by a third question of 'how' to perform the operation. Organizational and planning decisions come under the third problem heading. After assessing the consequences of their participation (category 4), participants might then desire to make economic adjustments. Planning then reverts to the third category, but the emphasis is on farm operations rather than cloud seeding operations. If rain-increase programs were consistently successful, problems involving the location of economic activity (category 2) might become important. This kind of problem is illustrated by changed land-use patterns.

2/ Helmut E. Landsberg, "Applied Climatology", Compendium of Meteorology American Meteorological Society, Boston, Massachusetts, 1951. p. 979.

For seeding firms, problems in the first category mainly concern the maintenance of stationary ground equipment. Because of prolonged exposure to the elements, the design of nuclei generators must be weather-resistant and functional. The climate of seeding locations is undoubtedly a factor in the deterioration and depreciation of cloud seeding equipment.

With respect to the second class of problems, seeding firms utilize climatic data to determine the areas in which demand for their services should be greatest. A similar use is in determining the feasibility of initiating operations in particular areas, i.e., whether seeding opportunities are likely to be frequent.

Most problems confronting contractors probably fall in Landsberg's third class. The planning and supervision of seeding operations requires an extensive knowledge of climatology, meteorology and rain induction principles. This knowledge is indispensable in deciding 'where', 'how', and 'when' to attempt modification. Reliable seeding firms recognize the importance of this information by maintaining research and forecast centers.

Because most current problems in rain increasing involve operational planning, seeding potentials should compositely represent the many weather elements that influence the activities of ranchers and seeding contractors. The variability of weather further requires that these potentials consider the range of variation in climatic data. An allowance for variation also recognizes that ranchers do not view rain increasing attempts with equal sympathy or hope. Overly-optimistic producers may prematurely institute major adjustments, while those viewing cloud seeding with relative pessimism are likely to be unprepared for necessary adjustments.

The technique for deriving tentative and adjustable estimates of the long run effects of cloud seeding must sort out the variables to be considered, and then re-combine them in a form that suggests answers to pertinent problems. Principal factors are the normal variations in climate among dissimilar climatic areas, and variations in the probable improvement resulting from rainfall increases. Where many variables are known to be operative, Landsberg suggests that they be placed in three major paramenters. 3/ He lists these parameters as (1) Climate, composed of weather elements or combinations of weather elements, (2) Space, consisting of the surface of the earth or layers of the atmosphere, and (3) Time, comprising the series and chronological sequence of weather observations. These parameters can appear as simple or complex elements, depending on the nature of the problem. In other words, the climatic factor may involve average precipitation only, or it may require including average precipitation, evaporation, and wind velocities. Space can mean a single point, several points, or an entire area. Time may enter only in the restricted sense that a specific time interval is covered by the data, or if more complex, that the weather elements described are changing secularly.

Referring to Landsberg's problem classification, it can be seen that weather control planning problems are not as complicated as related biological problems. Agronomic studies of climate usually attempt to establish correlations between various weather factors and crop yields. New correlations

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3/ Ibid. p. 981.

based on calculated or observed rainfall increases would only be a first step in estimating the effects of sustained cloud seeding on crop yields. Thorough and systematic analyses would require the inclusion of secondary influences of controlled weather on plant growth, i.e., lowered temperatures, decreased evaporation, redistributed or attenuated rainfall.

In estimating prospective rainfall increases, the factor of climate must be an orderly conglomeration of the weather elements and physical processes involved in the formation of precipitation. Such a parameter is described in the next section. In this study, the parameter of space conforms to the state of Montana, the geographic problem area. The relation of time is not complex because cumulative effects of weather are not considered for the moment. The time factor is simplified further by limiting observations to periodic intervals (usual contract periods).

The Weather-Type Approach to Rain-Increase Problems

A useful device for solving economic problems where the climatic parameter must compositely represent many weather variables is the classification of general weather conditions into series of weather types. Weather types are synoptic composites of observations describing pressure, temperature, precipitation, or other weather elements. Catalogues of types have for some years had an application in the field of extended (2-7 days) forecasting. More recently they have been suggested as a means of dealing with problems related to weather control.

'Objective' forecasting attempts to 'type' impending weather and then predict subsequent conditions over the area in question. The procedure essentially involves initial forecasting of a specific type, followed by a prediction of rainfall and temperature variations based on the past performance of the pattern. Prediction of types entails an assumption that current weather conditions are likely to have historical replicas or 'analogues'. Where the system is rigidly practiced, analogues of prevailing patterns are selected from indexed map files and used as guides. Weather conditions usually following replicas constitute the present forecast.

An admitted shortcoming of the file method of forecasting is the de-emphasis of weather dynamics. This difficulty is corrected by supplementing analogues with separate pattern classifications based on relative conformity to ideal types. Ideal types are theoretical models constructed around semi-permanent (moving or developing in predictable manner) circulation or pressure features. Though they can be classified with respect to any number of features, they usually denote a period of time characterized by certain locations and orientations of the Pacific anticyclone (a persistent high-pressure region), the Aleutian cyclone (the Aleutian Low), or the trajectories of storm centers and outbreaks of polar air.

The extensive use of weather types in forecasting has encouraged their adoption in studies of climate. In climatology, however, their application has usually been confined to classification of single climatic elements. Landsberg has catalogued types solely with reference to air-mass characteristics, and calculated their seasonal frequencies for central Pennsylvania. 4/ His system is nearly synonymous with recognized classifications based on

4/ Helmut E. Landsberg, Physical Climatology, Pennsylvania State College, School of Mineral Industries, 1944, p. 172.

the origin of particular air-masses. The classes are not genuine types in the usual sense because they contain only a single variable. Conversely, types that represent more than one variable are sometimes too generalized to allow detailed treatment and description of single climatic elements.

In climatological studies, the best use of weather types might be in representing variations. Where predictable variations are associated with types it seems that large seasonal or annual variations in precipitation (or temperature) could be attributed to variations in the frequency of deviating types. Areal variations in precipitation might possibly be as well represented with weather type frequencies as with comparative precipitation data. Because most systems of weather typing consider rainfall variations under changing sets of weather conditions, the method is appropriate for determining the possibilities of weather modification.

Where weather types are used to evaluate the effectiveness of rain increasing attempts, natural variations peculiar to individual types are compared with variations occurring when the type is subjected to modification, or cloud seeding. Woodbridge and Decker have classified frontal systems originating off the Pacific coast with respect to the location of a specific pressure contour and resulting precipitation throughout Oregon. 5/ Thirteen of these types were further divided according to the percentage of the fronts observed to be 'wet' or 'dry'. The criterion for labeling a

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5/ D. D. Woodbridge, and F. W. Decker, "Weather-Typing Applied to Summer Frontal Rains in Oregon", Bulletin of the American Meteorological Society, Vol. 34, No. 3, January 1953, p. 28.

front wet or dry was the percentage of weather stations receiving precipitation within three climatological areas.

Woodbridge and Decker concluded that under weather conditions of certain types, no precipitation is to be expected at some stations. A few types left practically all Oregon stations without any precipitation. Others apparently set the circumstances for large deviations above normal rainfall. They further conclude that such classifications should assist in evaluating claims of success in cloud seeding. It was implied that if frontal passages usually surrendering little precipitation are observed to yield (with cloud seeding) abnormally heavy amounts, the effectiveness of rain increasing may be verified.

The technique employed in Oregon is not considered adaptable to this study because the types correspond only to that area. However, certain weather-type frequency data that describe nationwide weather movements will be utilized. Since seeding potentials are partially dependent on the probability of favorable types occurring, these data will be particularly useful. A more comprehensive system of typing that underlies the derivation of Montana seeding potentials is described in the following paragraphs.

Weather Types and Seeding Potential

A system of weather-typing embodying several semi-permanent circulation features was developed at the California Institute of Technology immediately prior to World War II. Krick, Ruch, and associates classified a number of general weather types according to the location and orientation of the Pacific anticyclone, and from these types predicted subsequent weather conditions across the United States. 6/ Although the Pacific High is the principal identifying feature (reference cell), the position and extent of the Aleutian low is another indicator of major frontal developments. The classification also delineates types on the basis of characteristic storm trajectories and polar outbreaks.

In the California system, weather conditions typical of North America and adjacent Pacific areas are catalogued into eight composite types. The composites are sub-classified into thirty-six ideal types that reflect seasonal insolation variations and resultant changes in the general circulation. Ideal types have a lifetime in any given region of approximately six days, although they may require about ten days to cross the entire continent. With the passage of respective types, individual areas of the country can expect normal precipitation or temperatures, or specified departures from six-day norms. Single types are further broken into patterns of synoptic conditions expected to prevail during each phase. Phases are approximately one day in length, and show the most probable location of frontal systems and storm centers as pressure contours move across the country. Large-scale seeding with silver iodide would presumably be practiced within storm areas, or applied to promising fronts expected to penetrate projects.

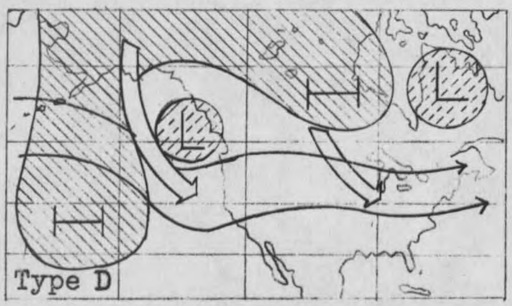
Eight of the ideal California types are subjects of this study. Those selected predominantly occur from June through September. This period

(cont. p. 72)

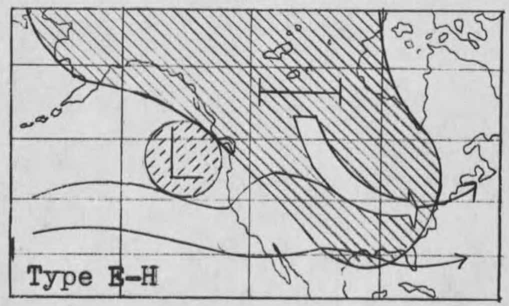
6/ The method hereafter will be referred to as "the California system". Although a revised classification more adapted to forecasting was later developed, the original is considered adequate for this study. Source: Synoptic Weather Types of North America, Meteorology Department, California Institute of Technology, December 1943.

Figure 4. Examples of Extreme Meridional and Zonal Weather Types
(after Elliott)

Meridional



Zonal



Explanation of Diagrams

Lines with arrows indicate average direction of upper winds. Hatched areas represent persistent high pressure at the surface. Stippled areas are semi-permanent low-pressure centers. Polar outbreaks are represented by the open arrows.

Explanation of Types

Meridional types are characterized by an upper-air pressure pattern that deflects Pacific storm centers North or South of their usual routes. Polar outbreaks are relatively frequent and often penetrate to southern states. In Type D, a strong outbreak comes into the north Pacific Coast from over the Gulf of Alaska. It is generally accompanied by a second outbreak in the Great Lakes region.

Zonal types are distinguished by a zonal (West-East) flow of air at upper levels. Variations in the category are caused by movement of the prevailing westerlies North or South. In Type E-H, fronts do not get over the Continental Divide because of the large mass of polar air covering the rest of the country.

Sources: op. cit., Elliott, p.836.
op. cit., CIT, Synoptic Weather Types of North America

roughly corresponds to usual contract periods of rain increasing operations in Montana. Frequency data borrowed from the Oregon study cover the same interval, but extend from 1917 to 1949. Table IV contains duration data and comparative average warm-season frequencies of the eight selected types. Sample representations of the ideal types are mapped in Appendix C with brief descriptions of associated weather conditions in Montana.

An assignment of Oregon frequencies to California types cannot be precise because of non-conformities in the two classifications. The 571 fronts of Pacific origin have been arbitrarily distributed equally among seven types. The remaining 47 are definitely associated with Type D, which shows all northern states influenced by Canadian fronts.

Elliott has separated the California types into meridional and zonal categories and applies the distinction to all systems of pressure typing. 7/ Extremes in each group are diagrammed and explained in Figure 4. Those represented are models of winter conditions. The summer counterpart of Type D is illustrated in Appendix C.

A frequency study of Pacific and Canadian cyclones (lows) crossing Montana was performed by Reitz in 1937. 8/ For the period 1923-1929, it was found that the north Pacific Coast was the source region of 28 per cent of the major storms moving across the state in the course of one year. Forty-two per cent originated in Canada, and the remainder followed unusual

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7/ R. D. Elliott, "Extended-Range Forecasting by Weather Types," Compendium of Meteorology, American Meteorological Society, 1951, p. 835.

8/ L. H. Reitz, Crop Regions in Montana as Related to Environmental Factors, Bulletin No. 340, Montana Agricultural Experiment Station, Bozeman, 1937, p. 37.

paths. The percentages are not associated with individual synoptic types, but do indicate a seasonal variation in the relative importance of the meridional group. 9/

(cont. p. 74)

Table IV. North American Weather Types Affecting Seeding Potentials in Montana, June-September incl.

Types	Precipitation Phases Montana 1/	Average Duration-U.S. 2/	Comparative Seasonal Frequency 3/
Group I - Meridional			
D	6	10	47
A	7	10	82
A-B	7	10	82
Bn-slow	5	10	82
Bn-fast	6	9	82
Group II - Zonal			
Bs	3	10	82
B-A	7	9	82
B	6	10	82

1/ Number of days on which precipitation occurs somewhere in Montana. In general, the number of precipitation phases corresponds to the period for which the type prevails in the state.

2/ Days required for the series of fronts associated with a type to cross the continent.

3/ Woodbridge and Decker found that in the twenty years covered by their study, 571 major fronts entered the United States from the Pacific. There were 47 polar oubreaks intense enough to affect Oregon weather. Outbreaks are likely to occur with all types, but those directed toward all western states are usually associated with Type D, an extreme case of meridional flow.

Sources: California Institute of Technology, Synoptic Weather Types of North America. R. D. Elliott, "Extended - Range Forecasting by Weather Types", Compendium of Meteorology, American Meteorological Society, p. 834. op. cit. Decker and Woodbridge, p. 29.

9/ The frequency of Canadian cyclones falls from a yearly percentage (as determined by Reitz) of forty-two, to a warm-season average of about eight per cent (Woodbridge and Decker).

Derivation of Seeding Potentials

In this study, the method for deriving gross seeding potentials has followed six procedural steps. They are outlined and summarized below.

1. A preliminary climatic classification based on general dissimilarities.

2. Consideration of warm-season variations in the areal distribution of non-induced precipitation.

3. The relating of natural variability to the probable success of cloud seeding.

4. The relating of probable success to the comparative frequency of respective synoptic types.

5. Calculation of seeding potentials.

6. A climatic reclassification based on seeding potentials.

The original classification separated the state into four areas corresponding to recognized climatic differences. The geographic division was not accompanied by an hypothesis that seeding potentials would be greater in any one region, although it was presumed that the potentials would vary considerably among the areas. It was thought that potentials might be a function of elevation.

Area I included that portion of the state lying west of the continental Divide, which is known to be under the modifying influence of the Pacific Ocean. Area II includes those sections east of the Divide with a general elevation of 5000 feet above sea level. This area encompasses most of the mountainous southwest portion and higher levels on the eastern slope of the main range of the Rockies. Placed in the same class was an isolated sector in southern Montana forming an extension of the Big Horn range of northern Wyoming. The remainder of the state (general elevation under 5000 feet) was divided at the forty-seventh parallel. Areas III and IV lie north and south of the parallel, respectively. The principal reason for making this separation was that southeastern Montana is rather frequently influenced by air masses of Gulf origin.

Variability in the areal distribution of natural rainfall was determined by tabulating for single stations average precipitation anomalies (deviations) experienced with the passage of each weather type listed in Table IV. For Montana, average deviations range from +.6 inch to -.3 inch. Data were secured by accurately retracing type anomaly maps (examples in Appendix C) and then tabulating values (in some cases mid-values) of isodeviates as the departures from six-day norms. No quantities were listed if rainfall was normal for the type period.

To relate variability to cloud seeding success required the assumption that rain-increase attempts must be coincident with at least mild storm activity; and that generally speaking, the chances of obtaining significant increases should become greater with intense natural activity. The relationship was established by arbitrarily converting type anomalies to seeding factors. Negative departures were assigned a factor of 0, since it was presumed that few or no seeding opportunities would arise while the type prevailed. Normals were considered to present some opportunities for modification and were assigned a factor of 1. Positive anomalies were translated into higher factors (2 for .15 inch, 3 for .45 inch).

In addition to judging whether the prevalence of a specific weather type presented opportunities for cloud seeding, it was also necessary to consider, in terms of probabilities, the relative frequency of the type during usual operational periods. This was accomplished by combining seeding factors and assumed frequencies (Column 3, Table IV) to obtain weighted factors.

The final calculation resulting in gross seeding potentials involved the addition of weighted seeding factors, and their division by the total number of fronts invading Montana during the period covered by the frequency study of Woodbridge and Decker.

Expressed as a simple formula:

$$\frac{\text{Sum (Seeding factors X Comparative seasonal frequency)}_{n(8)}}{\text{Total fronts (618)}} = \text{Potential}$$

Interpretation and Evaluation of Potentials

Mathematically, gross seeding potentials are merely averages of seeding factors. They can be thought of as indexes in the sense that a value of 100 would either indicate that all weather types presented seeding opportunities, or that those unreceptive to seeding would be offset by more frequent favorable ones. Since the eight types studied represent almost all sets of synoptic circumstances likely to develop during the growing season, their total effects should account for natural rainfall. Those types characterized by positive deviations contribute more to seasonal averages than those resulting in norms or negative departures. Indexes greater than 100 indicate that most types are 'contributory'. Potentials under 100 reflect the seasonal incidence of fewer seeding opportunities, but do not necessarily preclude the feasibility of conducting seeding operations, i.e., several types might be highly conducive to modification. 10/

The greatest weakness in the foregoing method of deriving potentials is that yearly variations in type frequencies have not been considered. While deviations characteristic of each type have been noted, comparative frequencies are in terms of a long-time average (1917-1949). If types were used in evaluation studies, their actual frequencies during operating periods would be vitally important factors.

Another major weakness is in the assumption that contributory types would be most conducive to rain increasing operations. Whether such patterns actually are meteorologically susceptible to modification might be a subject of professional debate. A third shortcoming is the omission of type sequences. Where contributory types were successive, rain increasing in a relatively short period might be highly effective and set the conditions for additional increases and more natural rainfall. 11/ With these faults undermining the validity of calculations, potentials should not be considered more than qualitative approximations of cloud seeding success.

10/ Alzada, the station with the lowest potential (39), was found to have a seeding factor of 2 under conditions of Type A. Rain increasing success in such areas would critically hinge upon efficient operations, accurate forecasting, and yearly variations in type frequencies that favored local contributory types.

11/ Type D has a marked tendency to occur in pairs, and for some stations is a contributory type. Extended precipitation periods can have a conditioning effect on the atmosphere that tends to prolong activity. See Langmuir, p. 49, conclusion 4.

Tests of Classifications

The belief that potentials would vary between climatic areas originally delineated was justified. A variance analysis showed the variance among areas to be thirty-nine times as large as the variance between stations within each area. An F test indicated that the difference is significant at the .001 level of probability, meaning there is less than one chance in a thousand the difference can be attributed to random variations. Area means, dispersions, and results of the analysis are summarized in Table V.

Gross seeding potentials for the 143 stations have been plotted in Figure 5. The map should be self-explanatory, although actual potentials for individual localities are listed in Appendix D. A test of the mapping procedure was called for to measure the effect of allowing the potentials of some stations to be masked by including them in areas with a different range of values. A second variance analysis set up as groups (a climatic reclassification) the seven color ranges of Figure 5. It was found that the variation among these groups was also greater than the variation between stations within each group, the difference again being significant at the .001 level. The results of the second analysis are also shown in Table V. Statistical validity of the mapping procudure enables the approximation of unlisted potentials directly from the map without danger of great error.

Figure 5. Cloud Seeding Potentials in Montana

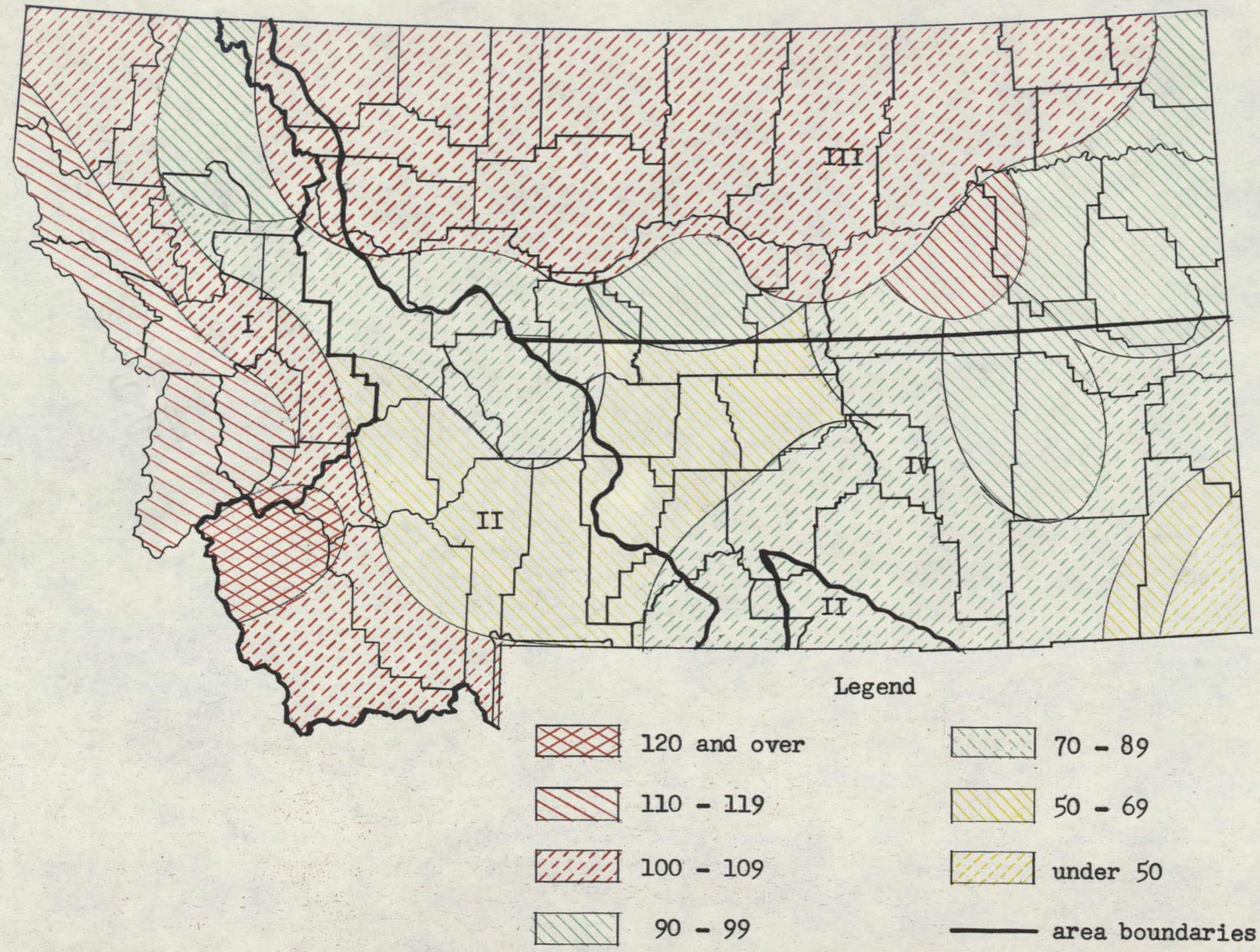


Table V. Average Seeding Potentials, Dispersions, and Tests of Classifications.

Area	Means	Standard Deviations	Variation Coefficients
Area I	103.85	10.14	9.7%
Area II	85.52	6.05	7.0%
Area III	103.29	8.75	8.7%
Area IV	73.51	13.60	18.5%

Source of Variation	Variation	Degrees of Freedom	Variance
Classification I			
Within Areas	270.720	139	1.947
Between Areas	229.559	3	76.519
Total	500.279	142	3.523
			F=39.300
Classification II			
Within Areas	345.045	136	2.537
Between Areas	155.234	6	25.872
Total	500.279	142	3.523
			F=10.197

PART V

ECONOMIC ANALYSIS

Introduction

Before proceeding with a discussion of economic questions, it might be well to briefly restate the second purpose of this study. This was described in Part II as the application of theoretical principles to production problems facing farm firms, and to a lesser extent those problems confronting seeding firms. From a welfare standpoint, a third group might be included, viz., society in general, whose task is essentially one of ensuring that some social progress is derived from weather control.

Economic analysis can contribute to the solution of rain-increase problems in three ways. With regard to utilizing available data for input-output decisions, it establishes the theoretical framework for making pre-operational choices; i.e., should farmers support programs or not? Secondly, economic evaluations of completed operations can guide future participating decisions and operations. Thirdly, it assists in economic forecasting. For instance, if empirical evidence indicated that output and net income had been measurably increased because of the receipt of induced rainfall, producers would feel justified to inaugurate or continue seeding programs. Theory could then point out new alternative factor combinations. Knowledge of additional alternatives in turn would help explain and possibly predict both short and long run transitions. Shifts could occur in land use or the employment of other factors, depending of course on the usual conditions governing input replacement and substitution.

In the following discussion, farm and seeding firms are presumed to act rationally in weighing economic decisions. Principal non-economic factors controlling their behavior have been treated in Parts I and VI. Farmers and contractors are in analagous positions in that both must make three basic choices common to all enterpreneurs. These are given as which productive enterprise to select, what level of production to sustain, and which techniques or factors to employ. Both are presumed to be adhering to the profit maxim by equating marginal cost and marginal revenue with minimum resource outlays. However, farm and seeding firms do occupy disparate institutional settings. For analytical expediency, agricultural units are generally considered to function in a purely competitive environment, and will be so considered here. Consistent with the judgement arrived at in Part I, seeding firms are assumed to operate in an economic atmosphere of imperfect competition, i.e., oligopoly. For this reason, the actions of each will be analyzed separately.

Economics of the Farm Firm

Rainfall as a Factor of Production

In brief, the management decision of whether to support rain increasing activities is the result of an estimate of prospective rainfall increases, followed by a comparison of money returns with the cost of realizing them. Applying the profit maximization principle, the farm operator, or for that matter any other interested entrepreneur, would presumably purchase rainfall increments if costs did not exceed the additions to revenue allowed by greater output. The theoretical basis of this decision can be seen in clearer perspective if rainfall, among other inputs, is considered a variable factor in the production function.

Hypothetical production curves are graphed in Figure 6-1, next page; where the total physical product (TPP_1) curve simulates a regression line between output, in this case yield, and amount of received rainfall; whether whether it be the gift of nature or induced. Average and marginal quantities are shown in the diagram as APP_1 and MPP_1. At the point where TPP_1 begins to descend, total product is at a maximum, indicating that unneeded units of precipitation will detract from yield. In a practical sense, such a level of output is achieved in bumper harvests, where an optimum quantity of ideally-distributed rainfall has been received. Crop failure attributable to drought can be similarly represented, with yields failing to rise much above the X axis. It is assumed that a minimum useful quantity of precipitation is necessary for any amount of product; consequently, the regression line extends from this minimum (q_m) rather than from the origin.

A unique characteristic of rainfall inputs is that they are variable, but not subject to deliberate variation by producers (at least before the advent of cloud seeding). Figure 6-1 shows specific output levels attainable with given quantities of precipitation. There is no question in the minds of farmers as to the quantity of rainfall desired, yet there is strong doubt if whether climatic conditions will allow it to be received. Taken as a single input with an unchanging price, a demand curve could be constructed for rainfall, the lower limit signified by the point where average and marginal product coincide, and the upper limit set at zero marginal product (q_a and q_o on graph).

The motive of ranchers in supporting projects is to gain assurance that adequate moisture will be received. If the assumption that rain increasing attempts must be coincident with natural storminess is valid, the functional effect of controlled cloud seeding on production would simply be a more frequent attainment of optimum output. Because Figure 6-1 merely expresses a physical input-output relationship, no movements or changes in slope of product lines would result.

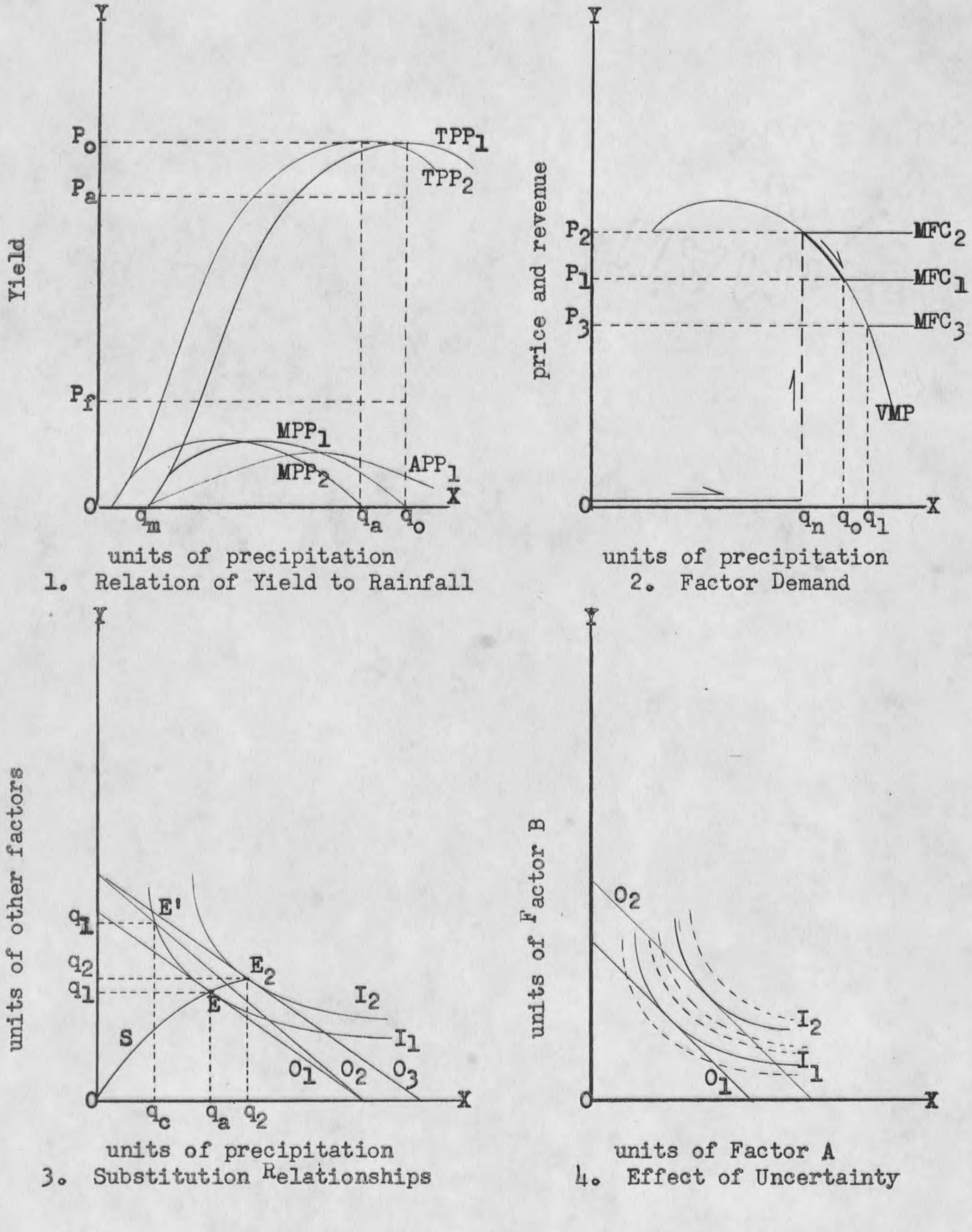
There is an incidental benefit of rain increasing, however, that might actually re-position product curves. This is the so-called 'spreading' or attenuating effect of cloud seeding. Where TPP_1 expresses an historical relationship between observed rainfall and yields, erosional and evaporation losses are reflected in the regression. Should the moderation of precipitation be demonstrated, the relationship would be better represented as TPP_2. The benefit to producers of improved precipitation effectiveness would be an easier achievement of optimum output. The demand range would be slightly altered in that average and marginal product could be equated with fewer rainfall increments.

With respect to the producer problem of enterprise selection, a series of curves similar to those of Figure 6-1 could be constructed for each crop worthy of consideration. Hydrophylic products, i.e. corn, are known to require greater minimums that q_m. Transitions would ultimately pivot on the opportunity costs of not engaging in newly-profitable enterprises.

Another use of product or regression curves is for measuring cloud seeding benefits. Correlations are the vehicle for translating rainfall increases into output units that can be given a quantitative market value.

(cont. p. 86)

Figure 6. Hypothetical Input-Output Relationships for Farm Firms



1. Relation of Yield to Rainfall

2. Factor Demand

3. Substitution Relationships

4. Effect of Uncertainty

If it were shown that rainfall in target areas had been increased from q_a to q_o, the value of the seeding would be the monetary difference between P_a and P_o. In economic as in meteorological investigations, however, it is essential to know what quantities of rainfall had been actually induced.

The third producer decision likely to be influenced by rain increasing relates to factor demand and alternative ways of combining inputs. If farmers can competitively purchase cloud seeding services in any amount, the equilibrium position in terms of factor purchasing is at the point where input price (whether it be for inches of rainfall, acres, or stated contract periods) is covered by the value of the marginal product (q_o in Figure 6-2). Stated more practically, the farmer should be interested in purchasing rainfall as long as acreage assessments did not exceed the market value of per-acre yield increases. Should alloted fees rise above this level (P_2), seeding services would be prices out of his market, since the demand schedule does not include climatically-probable rainfall. Assured quantities are represented by q_n, with the relevant demand curve extending from this point up to its intersection with VMP and thence downward to the intersection with MFC_1. Fee reductions would project the demand curve downward to MFC_3, outwardly evidencing program extensions or enlargement of target areas.

In the long run, producers have an added problem of achieving the least-cost combination of all factors, considering relative prices and output contributions. This optimum is achieved when marginal product-marginal cost ratios are equal for all inputs used. Figure 6-3 illustrates such an ideal equilibrium, with values along the X axis designating rainfall, and ordinate vlaues representing some sort of integral unit for all other factors. The volume of output sustained with varied proportions of the compared inputs is represented by the indifference curve I_1. As drawn here, the curve implies two properties of precipitation in arid agricultural production. The relatively steep portion of the line above point E denotes a very narrow substitution range of other factors for rainfall. Q_1 gives the practicable limit to the replacement of rainfall, with q_c specifying a critical amount about which yields vary considerably. In the Great Plains, q_c would roughly correspond to long-term average annual precipitation. Pronounced concavity of I_1 above E shows a very rapid decline in the marginal rate of substitution as other factors, i.e., fertilizer, are given preference. With limited expenditures and known price ratios (diagonal O_1 cutting both axes), the least-cost combination for output I_1 is reached at point E.

Additional evidence of the requisite nature of rainfall is provided by anticipating the reactions of producers to input price changes. In Figure 6-3, a price decline for factors other than rainfall could have two results. The saving could be utilized by increasing consumption of the cheapened factors (equilibrium at E'), or would allow increasing the scale of operations to reach a new output level, I_2. In the first case, comparatively few (q_a-q_c) rainfall inputs could be replaced. If the saving were devoted to expanding operations, the least-cost combination along I_2 occurs at point E_2, increasing rainfall use from q_a to q_2. A rightward deviation of the scale line (S) from point E demonstrates that rainfall has high price elasticity as well as outlay elasticity. From this analysis it can be concluded that most agricultural inputs are 'inferior' when compared with precipitation.

Risk-Uncertainty Aspects of Weather Control

In varying degree, risk and uncertainty characterize all forms of economic activity, being especially apparent in unregulated systems. They are primary factors underlying a perennial problem of western agricultural producers; that of achieving income stability. Risk and uncertainty are rooted in consumption patterns as well as production peculiarities. For individual industries, many price and cost variations are associated with unforseen changes in consumer preferences or disposable income. Production variations arise from the very nature of processes themselves, or from external factors as weather which control the processes.

Knight differentiates risk and uncertainty by drawing analogies with degrees of knowledge. 1/ These are termed certainty, risk, and uncertainty. If an event is certain as to time of incidence and magnitude, entrepreneurs having knowledge of it can prepare and act accordingly. If complete knowledge is lacking, but the likelihood of occurrence can be stated in terms of probabilities, the situation is described as risky. On the other hand, uncertainty is immeasurable and results from knowing little about even the probabilities of an event occurring. Knight further remarks that while the practical connotation of risk is the prospect of a loss, uncertainty refers to a possible failure of management to realize gains, given otherwise favorable conditions. Although there are crude attempts to place some weather adversities in the category of risks (calculable on the basis of

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1/ F. H. Knight, Risk, Uncertainty and Profit. (Seventh Edition; New York: Houghton Mifflin Company, 1921) p. 233.

empirical data), weather in general is a variable of uncertainty, because risk can apply only to completely insurable losses. In uncertain situations, producers are left to their own discretionary actions, usually achieving protection by flexible organization (a form of hedging) or other internal cushions.

Johnson notes that five factors create uncertainty for farm operators. These are listed as: (1) imperfect knowledge about production methods, (2) changes in production methods, (3) incomplete information pertaining to prices and price fluctuations, (4) unpredictable actions of personalities associated with the farm business, and (5) imperfect knowledge of institutions and institutional changes affecting agriculture. 2/ Where so many variables influence production decisions, it is evident why producers cannot easily gauge the consequences of alternative courses of action. In semi-arid regions, a sixth factor can easily be added to Johnson's classification; that pertaining to the unpredictable character of weather.

Even if it were possible to remove such economic variables as price and cost fluctuations from the uncertainty problem, income instability would persist because of random yield variations traced to weather elements, particularly the element of rainfall. The significance of the moisture factor in farming was portrayed in the first three diagrams of Figure 6. An impression of rainfall criticality in dry-land areas can be had by

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2/ Glenn L. Johnson, "Handling problems of Risk and Uncertainty in Farm Management Analysis", Journal of Farm Economics, Vol. XXXIV, No. 5, (Dec. 1952) p. 816.

referring to Figure 6-4. Production curves here are drawn to show a functional relationship between two inputs other than rainfall. Assuming known factor prices, the proportionate outlay line O_1 is tangent to I_1 at point E. I_1 is the level of output that could be achieved if the two factors were concertedly allowed to exert their maximum effect on production. However, a singular feature of agriculture is that only rarely does output actually coincide with I_1. Rainfall variability itself implies that I_1 and I_2 would more accurately be represented by a range of output, shown between the dotted production contours. Ascension from one production contour to another is probably even more difficult because of the magnified influence of weather. Below-average rainfall accompanied by heavy investment or indebtedness has been known to disastrously affect the liquidity positions of many farm firms.

Superficially, it appears that rain increasing should be an ideal medium for coping with uncertainty by dampening yearly variations in rainfall. It is even hoped that weather control will remove chance of complete crop failure. Unfortunately, the present state of rain increasing technology suggests that this is not the case. Adherence to the postulate that cloud seeding success is directly, though disproportionately, related to natural storm activity (see p. 59) leads to the conclusion that rain increasing in regions of variable climate might actually intensify the amplitude of variations about long-term averages. Cloud seeding would be most successful in peak years, with troughs of cycles little affected (assuming that precipitation in wet seasons is not already at a maximum). Under these conditions, weather control could not be expected to significantly contract the range of uncertainty shown in Figure 6-4.

If rain increasing can do little toward removing climatic 'causes' of uncertainty, it can nevertheless simplify the application of remedial measures to mitigate the 'problem'. The factor that makes the advantages of asset storing and flexible organization so difficult to propagate is that wet and dry years exhibit a tendency to follow in sequence rather than alternate. In series of favorable years, many producers are disposed to let down their guard and devote income surpluses to securing returns to scale, even at the danger of not discharging outstanding indebtedness. The consequence is that a series of relatively dry (not necessarily drought) years easily bankrupts over-extended operators, making them subjects of costly public assistance programs.

Perhaps one of the greatest benefits to be derived from successful weather control programs is that more reserves could be laid aside in high rainfall years for stabilizing income during periods of low rainfall. Producers inclined to provide for lean years might then rely more heavily on such devices as rotated storage or cash saving, and depend less on the problematic receipt of credit aid. Few organizations would then become immediate casualties of low yields.

Economics of Seeding Firms

The principal reason for analyzing seeding concerns separately is not that their economic objectives are greatly different from those of agricultural units (both are motivated by profit expectations), but that they proceed differently in adjusting output and mobilizing resources. Where ranchers cannot manipulate product prices, seeding firms apparently can and have. Where farmers need not be concerned with the immediate reactions of their neighbors to management decisions, seeding firms must seriously reckon with the actions and reactions of their competitors, especially those involving the pricing of services. The present oligopolistic relationship of rain increasing contractors evolved quite rapidly from a near-monopoly situation in which one or two firms were reaping the benefits of a previously unexploited market, and enjoying abnormal profits. Such conditions characteristically encourage the entrance of profit-seeking, market-sharing competitors into the field, with the consequence that all firms must then approach normal equilibrium, or operate closer to minimum average cost.

This analysis is not concerned with the eventual outcome of intense rivalry between contractors except to note that weather control appears to be a line of endeavor in which there are significant economies in scale. A relatively large proportion of fixed costs in the form of skilled labor, generating equipment, requirements for research and forecasting facilities, etc., suggests an extensive yet specialized organization capable of profitably functioning within a widely dispersed market. The scale of optimum efficiency is probably large enough in comparison with potential clientele and technical operating requirements to permit the survival of only a few efficient firms. These factors alone indicate that elements of imperfect competition will pervade the industry for some time to come.

In the analysis of farm firms, rainfall was considered to be a variable input entering into agricultural productive processes. It can similarly be an appropriate focal point for discussions of seeding firms; though it should then be considered an intermediate product made available to farming enterprises for their subsequent use in further production. As a product it represents an important variable for contractors, who must decide how much should be marketed and what techniques most efficiently induce rainfall. In view of the probabilities currently attached to cloud seeding, the first decision might be defined more accurately as how much could be profitably be placed on the market.

Rainfall as a Product

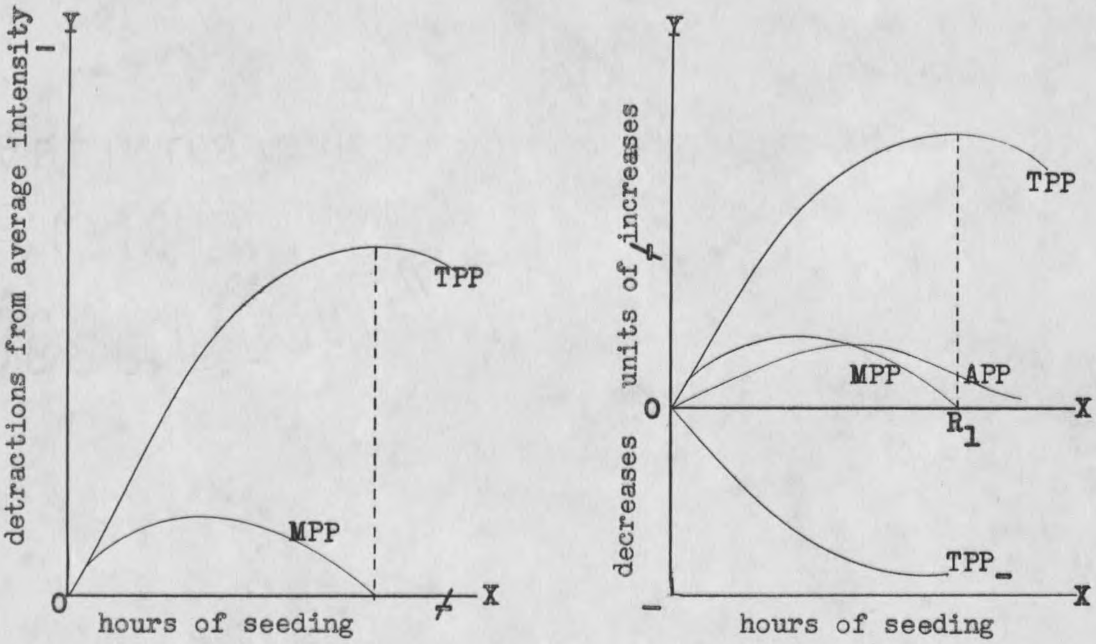
The production of rainfall from cloud seeding is graphically represented in Figure 7-2, page 95. A convenient standard of comparison is taken to be a hypothetical, functional relationship between accumulated units of rainfall received over project areas and hours of cloud seeding practiced within a specified time interval. The unknown importance of other meteorological variables functioning makes impossible the exact derivation of respective product curves. However, almost universal applicability of the law of diminishing physical productivity suggests that beyond a certain point (R_1), cloud seeding will decrease rainfall. TPP is drawn with the assumption that optimum nuclei concentrations are generated in each synoptic situation affording opportunities for seeding. The effect of consistent 'overseeding' during operational periods might be that TPP would pass through the origin, then indicating rainfall decreases rather than increases

(TPP-). Depicting the simultaneous attenuation of rainfall is more difficult. In this case, hours of seeding should be compared with some measure of rainfall dispersion. Possible standards are decreases in average precipitation intensity (inches per hour from single storm types), or seasonal increases in observations of below-usual intensity. Figure 7-1 relates hours of seeding to detractions from average precipitation received per stormy day. The TPP curve takes a form similar to that in Figure 7-2, but zero magnitude on the Y axis now denotes an historical average of rainy-day precipitation. It will be noted that ordinate values are negative. Getting efficiency gains into product terms is another distinct problem, likely requiring reversion to a type of correlation measure as TPP_2 in Figure 6-1.

To maximize profits, seeding firms as well as farmers must produce in quantities sufficient to equate marginal costs and marginal revenue. Theoretically, price should be set at a level where the necessary volume of output coincides with the needs and capabilities of clients. Figure 8 defines the equilibrium position (E) of a typical seeding firm. Curve D signifies quantities of rainfall farmers would buy at different prices per unit, and corresponds to the relevant segment of the factor demand curve of Figure 6-2. The presence of the kink in D was explained in the opening chapter (pp. 18-19). Concepts illustrated in the diagram (Figure 8) apply to relations with individual farmers, single weather improvement associations, or all associations, since cost and revenue schedules can be selected with reference to the particular clients served and the necessary scope of operations.

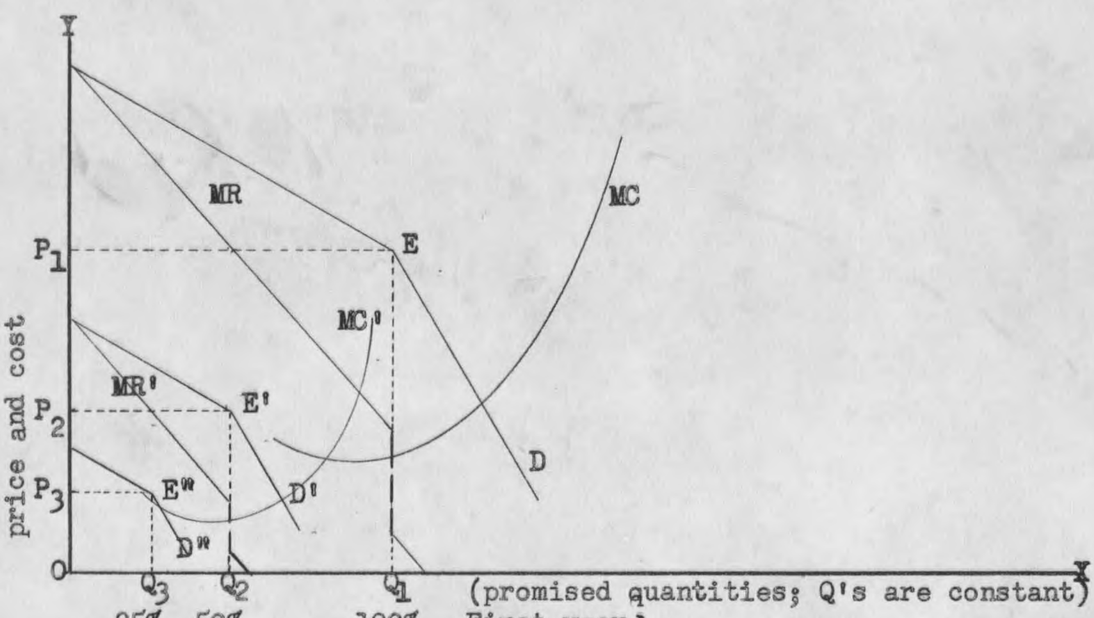
(cont. p. 96)

Figure 7. Functional Effect of Seeding, Overseeding, and Attenuation



1. Effect of Rainfall Attenuation 2. Effect of Seeding and Overseeding

Figure 8. Successive Equilibrium Positions of a Seeding Firm in Oligopoly



The managerial process of selecting the most productive inputs and seeding techniques is basically the same for seeding firms as with ranchers. The least-cost or optimum combination of labor, materials, etc., is achieved when the ratios of marginal productivity to marginal factor cost are equal for all inputs used. One consequence of the kink in D is a possible failure of contractors to adjust prices in response to cost variations. Those firms who might succeed in lowering average and marginal costs could also profitably lower prices and increase profits, but are afraid to do so because they fear similar price reductions by competitors. Conversely, an industry-wide rise in the cost of inputs, or new expense items, i.e., license fees imposed by several states, may result in a movement of the kink (or current general price) up the schedule to the extent that prices to clients would be increased at the same time contractors moved out of relatively unprofitable areas.

Risk-Uncertainty Problems of Seeding Firms

When interpreting the reactions of agricultural producers to rain-increase programs, many observers are prone to conclude that all risk and uncertainty involved in the economic promulgation of weather control has devolved upon or been unethically transferred to participants. However, if a risk-uncertainty frame of reference is fitted to problems of seeding firms, it becomes evident that these concerns operate under as great or greater uncertainty stress than do the economic units interested in their product. Cloud seeding operations are no less subject to weather and climate variables than farming enterprises, for just as minimum useful amounts of precipitation are necessary for successful agricultural production, certain favorable weather conditions must seasonally develop for contractors to be of service to their clients. Also, it is erroneous to assume that agriculture is much more affected by periodic fluctuations in the general level of business activity.

Uncertainty manifests itself to contractors in two forms which do not usually concern farm operators. The first of these is doubt on the part of one firm in regard to the reactions of competitors to their policies, a characteristic feature of oligopoly. The second is imperfect knowledge of where to set price, an uncertainty problem common to all firms engaged in monopolistic competition. It appears that seeding firms are also susceptible to a special risk factor not affecting agriculture. While farmers can ordinarily market their output at the current price and simultaneously complete transactions, seeding firms must establish selling relationships and gain assurance of payment through the medium of contracts. As in other businesses, contracts can often be in default. It should be relatively simple to determine whether failure to pay was the result of assumed non-performance or deficits, but adjustments to the conditions might be very difficult.

It has been argued that participants are not obligated to pay for unreceived increases. This contention is relevant only to performance contracts unfulfilled by contractors. The argument is not valid in the case of fixed-fee contracts because there is too much danger that results are subjectively measured by association members. If subscribers are not dramatically impressed with an operation (even assuming they are not led to expect dramatic results), they are apt to unjustly discount the value of more subtle benefits. Incidentally, a policy of willfully misrepresenting possibilities of weather control can only be explained in terms of a contractor sacrificing the objective of firm maintenance to maximize abnormal and short-run profits.

Figure 8 also illustrates a seeding firm's retrogression from an initially profitable equilibrium to a situation in which it is no longer feasible to attempt operations. The diagram explains the evolution of the current rain increasing situation in many western states. Two magnitudes are measured on the X axis; quantity refers to promised increases, and percentages refer to the proportion of contributors considering programs successful. The two ranges of values on X are required to introduce a supposed relationship between estimates of program success and effective demand. Curve D is the demand schedule originally catered to. Price and cost variables are on the Y axis. Price applies to promised units of rainfall. The first aggregate fee, or contract price, is enclosed by $OP_1 \times OQ_1$. Unit price is OP_1.

If operations prove to be 100 per cent successful (in the minds of subscribers), the firm can expect a contract renewal and continued equilibrium at point E (assuming no changes in costs). On the other hand, if a significant group of subscribers, say 50 per cent of the membership, does not believe results were significant, collection of final contract installments becomes a problem. The firm may secure payment of only one-half the fee, represented by the area $OP_2 \times OQ_1$. When discussing new contracts, associations may want to bargain on the basis of what was collected the previous season (P_2) because their members' demand schedules only comprise an effective demand of D'. In order to achieve a new equilibrium (E'), the firm must strive to lower its operating costs to MC'.

If a second operation is also considered a failure by some subscribers, the firm will again encounter collection difficulties, and in the following season, demand will accordingly have fallen to D". The net effect of successive failures, be they assumed or proved, is that seeding firms are forced to achieve 'retrenching' equilibria. Continuation of the process eventually drives firms out of the industry entirely, or at least out of some areas. This tendency toward extinction can be arrested or reversed only by operations being successful beyond the expectations of remaining subscribers and the public. Attraction or re-attraction of clients would then raise demand curves to former levels and allow contractors to regain the advantages of scale.

Welfare Implications

As in technological investigations, a social criticism of weather control must proceed on the basis of qualifying assumptions. This brief review of welfare aspects of rain increasing rests upon its general acceptance as an effective production technique. Acceptance implies diversions of labor and capital to a weather modification industry in addition to the horizontal transference of resources within agriculture. In view of existing circumstances, the assumption may reflect unwarranted positivism. However, the relating of economics to concepts of social progress suggests that social science be applied in assessing consequences of rain increasing rather than deliberating on the question of technical effectiveness. If rain increasing is demonstrated to have but minor economic importance, then no significant social problems will be presented. This reservation facilitates an impersonal economic analysis of forseeable welfare problems.

In its broad sense, welfare economics concerns the attainment of such goals as optimum consumption and production patterns, or ideal income distribution--through institutional manipulations. An institutional interpretation of allocation problems, particularly those involving product allocations, is described in the final chapter (Part VI). The problem of resource allocation, involving elements of distribution theory, can be defined conceptually with equations representing a so-called normative equilibrium. In asserting the interests of society, these equations apply equally to farm and seeding firms.

Where resources are commanded by contractors, it would be desirable that they be bought and sold in purely competitive markets. In this case, the supply of an input is represented by average cost, and firm demand schedules are synonomous with the market value of marginal products. Contractors would then be purchasing inputs in much the same manner as ranchers. The specific quantity of an input desired would be determined by a contractor equating industry marginal factor cost with this individual value of marginal product. Under these conditions, firms would be wanting just enough of a resource for its revenue contribution to cover average purchasing costs. Farmers would gain because the cost to them of induced rainfall would not exceed the marginal costs of firms producing it.

If these are criteria for social equilibrium, it becomes clear that the present oligopolistic relationship of weather modification concerns precludes optimum resource use. Though contractors may competitively buy many needed inputs, non-competitive output policies of the industry at large make it inexpedient for them to buy in quantities that would equalize average factor cost with value of marginal product. This is because their output is geared to less than infinitely elastic demand, while schedules of agricultural units do not imply price concessions. Monopsonistic elements in factor markets would be even more disturbing, since steeper marginal cost curves would tend to directly restrict production.

In the more realistic case of multiple resource use, an ideal combination would be where (still assuming oligopoly) marginal value products of all factors were proportionate to what their average cost would be in a competitive market. In other words, marginal productivities of resources used in cloud seeding should be no less than what they were in previous uses. If all contractors maximized resource efficiency (assuming a given resource supply), total benefits of rain increasing would simultaneously be maximized. Furthermore, the scale of seeding firms would be comparable, indicating optimum operating efficiency as well.

For the interests of farmers, contractors, and the public to coincide, desired commodities (wheat or rainfall) should be produced in correct proportions. This would occur only if marginal revenues (simply price for farmers) of both producing groups corresponded with an increment of social gain, and marginal costs reflected a social expense (resource depletion). This does not imply that the interests of farmers and contractors should be subverted to those of the public on all occasions. In some instances, discrepancies between private profit and social gain can be attributed to public apathy or outright unwillingness to share social costs.

An example of social inconsistency has cropped up in Montana, where some ranchers have hoped to get rainfall increases without sharing in program costs. Such attitudes make seeding costs of participants unnecessarily burdensome, and greater than real costs to the agricultural community. Benefits are correspondingly less than those accruing to the public. The equitable correction of such situations would suggest compulsory cost sharing. Conversely, public disapproval of programs can be traced to a fear that social costs would exceed apparent benefits. Claims to direct and incidental benefits of rain increasing pose special problems for society to resolve through its judiciary. They are examined in the following chapter.

PART VI

CONTROVERSIAL ASPECTS

Legalities

In striving to reach higher output levels or increase efficiency, the entrepreneur is often confronted with problems outside the management area and beyond his personal control. Many of these external factors are social in character, generally presenting issues which demand mature negotiation and eventual compromise. An outstanding example of such a factor in agricultural development has been the rapid extension of irrigation farming into almost every area in the West. When it became evident that climatic moisture deficiencies could be offset by irrigating, the employment of water resources quickly reached the point where supplies were inadequate for all intended uses. In consequency, a special body of law has evolved to define procedures for allocating scarce water resources among diverse interests. A similar problem faces agricultural producers interested in weather control, and it is not entirely associated with the water supply as such.

It was noted in Part I that fear of legal involvement has conditioned the attitudes of many Montana ranchers toward rain-increase programs. Also noted was the absence of evaluative information--contributing to the uncertainty surrounding past programs and a general reluctance to continue them. The discussion in this section does not offer concrete solutions to these difficulties, but attempts to enumerate some interpretations and approaches to legal problems, as well as describe the factors which make evaluation of rain increasing so complex.

The relationship of the two kinds of problems is indicated by an apparent hesitancy to resolve legal issues without sufficient proof of man's ability to harness natural weather processes. Most preliminary legal analyses have concluded with the recommendation that experimentation be allowed to proceed until sufficient technical data are available to permit the formulation of specific policies. The urgency of the immediate situation is witnessed by the fact that farmers needing additional water have not waited for legal authorization to embark on seeding programs.

To explore legal ramifications without restraint, it is advisable to temporarily ignore the contentions of commerical interests that cloud seeding does not deprive anyone of rightful rainfall, and has no adverse effects. The veracity of these statements is undoubtedly a question of fact, but as yet the facts have not been determined. Consequently, it should be assumed that atmospheric moisture might be a depletable resource, and that apprehensions of undesirable features of weather control may be justified.

The objection of Flathead Valley ranchers to the proposed Bonneville project has been the only instance of inter-group conflict in Montana. Nonetheless, if the effectiveness of cloud seeding is eventually conceded, a host of legal controversies could complicate agricultural programs.

In this discussion, anticipated legal problems are classed in three broad groups. They concern (1) entitlement to atmospheric moisture and increased surface water, (2) liability of associations and contractors for possible harmful effects, and (3) governmental intervention. The applicability of existing Montana statutes to these problemes is emphasized.

Atmospheric and Increased Surface Waters

General Considerations

A question that should be raised immediately in reference to water rights in weather is this: "Does ownership refer to air-borne moisture or to that deposited on the earth as a result of weather modification?" The question is exceedingly important because the two forms of occurrence are clearly not the same, each representing water in separate stages of its hydrologic cycle. The intended effect of cloud seeding is the transformation of atmospheric moisture from the vapor phase to the solid (snow) and liquid (rain) phases so that the supply of water available for economic pursuits is increased. Successful rain increasing can add to water supplies in streams, underground reservoirs, and directly on crop lands, although much of the additional rainfall on crops and ranges would be evaporated or transpired long before becoming incorporated in watercourses or underground storage. In the case of water retained and utilized by crops, the question of entitlement is largely one of ownership of atmospheric moisture and rights to practice weather modification. Entitlement to increases in stream flow is different matter.

Wiel legally distinguishes terrestrial waters as having definite or indefinite form. 1/ Definite waters are those confined to surface or underground watercourses. Examples are lakes, rivers, man-made reservoirs, and subterranean streams. The indefinite class includes unconfined or

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1/ Samuel C. Wiel, Water Rights in the Western States, Bancroft-Whitney Co., San Francisco, 1911, p. 1.

diffused surface and underground waters. Wiel's distinction would place atmospheric moisture in the indefinite class. However, the separation of received increases cannot be as specific because induced precipitation mingles with both definite and indefinite waters. It is the lack of knowledge about weather processes and the difficulty of tracing rainfall increases that make weather control legalities appear so complex. Until such time as the effects of modification are proven, legal problems will continue to arise. Meanwhile, interim approaches to adjudication must follow the same lines of reasoning for apportioning naturally-occurring water supplies. Claims for personal injury or property damage can be argued under present statutes once proof can be established.

In the succeeding paragraphs, concepts historically developed for establishing rights to water will be individually reviewed, with their relevancy to rain increasing noted. The appropriation doctrine is systematically re-interpreted because it prevails in Montana water law.

The Riparian Doctrine

The classic riparian doctrine accords to each owner of land contiguous to a stream the right to make whatever use of the water he requires for domestic purposes and the watering of livestock. The riparian owner can extend his use to irrigation or other economic purposes provided the application is reasonably consistent with similar uses by all other owners adjacent to the same stream.

In its primitive form, the riparian doctrine equally entitled all adjoining owners to an undiminished and unpolluted water supply. Strict compliance would have forbidden all uses. Brooks applies the primitive riparian law to weather control because of uncertainty. 2/ In place of the natural flow of streams is visualized an endless flow of atmospheric moisture contained in clouds. If the flow is disturbed by weather modification, some property holders will presumably suffer because all land is riparian to the atmosphere. As with surface streams, primitive riparian law applied to weather would prohibit diversions and controls, including experimentation.

Brooks extends the riparian principle of reasonable use to rain increasing by presuming no need for fulfilling natural uses unless water is generally scarce. Where restrictions are in force, the right of a farmer to take rainfall increases for crops should take precedence over the desire to raise the level of a lake for amusement purposes. Requirements of population centers are not mentioned. It would seem that municipal needs constitute a natural use that should hold priority over agricultural uses, particularly since Brooks cites as a controlling principle promotion of the use which fulfills the most critical needs, or provides the greatest general benefit to the community.

Although the riparian doctrine was early repudiated in Montana (Bannack Statutes, 1865), vague support for an atmospheric counterpart can be found in the Uniform State Law for Aeronautics. 3/ Section 601 of Title 15 asserts state sovereignty in the space above lands and waters, subject

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2/ E. P. Brooks, "Legal Aspects of Rainmaking", California Law Review, 37-114 (1949) p. 116.

3/ Revised Codes of Montana, Annotated, Vol. 1 (1947) (1-601), p. 347.

only to the exercise of federal police power or rights of eminent domain. Section 602 supports the 'ad coelum' doctrine of individual ownership of air objects by reading: "The ownership of the space above the lands and waters of this state is declared to be vested in the several owners of the surface beneath, subject to the right of flight." 4/

Principal flaws in the practical application of riparianism to weather control appear to relate to concepts of private property. One group contends that riparian theories of rights in clouds are wholly inconsistent with traditional principles defining property. 5/ Under the civil law, property is segregated into two classes; private and common. Common property includes the air, oceans, running water, and wild animals. Necessary conditions for private property are occupancy, proximity, and control. This group does not conceive the occupancy of clouds, and contends that even if it were possible, its scope would be narrow, because clouds continually move and dissipate.

Neither is the proximity of clouds to land considered a basis for riparan ownership because the water contained in them is common property that can be owned by the first person taking possession. It is admitted that while farmers are entitled to naturally-occurring precipitation, this right does not extend to moisture that has not yet fallen. In other words, farmers use rain, but only after they have it.

4/ The 'ad coelum' principle dates from early common law and implies that "he who owns the surface owns all air above it".

5/ Stanford Law Review, Vol. 1, (November 1948), p. 225.

With respect to the third qualification, it is argued that the element of legal control is lacking until clouds are directly over the lands in question. According to this view, farmers or other economic groups could assert no property rights in weather beyond the boundaries of surface holdings. If this were the case, landowners might find themselves in a curious situation where their efforts to secure additional rainfall by seeding in outlying areas were forbidden by their own riparian rights. Under these circumstances, cloud seeding operations would be confined to very local areas and probably limited to aircraft techniques.

In summary, the riparian doctrine is inadequate for solving legal problems in weather control because of three faults. First, the analogy of atmospheric flow and streams is false because clouds are not confined to regular channels. A second shortcoming is the inherent prohibition against seeding over areas other than those to be benefited. Thirdly, the riparian doctrine does not provide for the equitable distribution of rainfall increases that might find their way into natural watercourses. Where upland watersheds were seeded to supplement irrigation supplies, sponsoring farmers would surely and vigorously oppose exclusive claims of riparian landowners to the increases. It was the need for diversion of water to non-riparian lands that helped cause the rejection of riparianism in semi-arid states. Considering its many inconsistencies with presently accepted rules for water allocation in the West, the riparian doctrine will probably not be applied to weather control problems.

The Appropriation Doctrine

A second doctrine governing rights to the use of water in watercourses gives to the first user the right to continue his use so long as it is beneficial. Furthermore, the prior appropriator can use the entire supply if it is necessary for his beneficial purposes. Surpluses are available to later appropriators in the order of their priorities in time.

With certain revisions, appropriative principles might be applied to rain-increase problems. Provisions for non-riparian diversions, diminution, time priority, and beneficial use all have some relevancy to weather control, particularly in regard to expected changes in surface water supplies. Rights to atmospheric moisture and legal authorization to practice weather modification would be more difficult to determine.

One approach, suggested by Ball, would modify the appropriation doctrine so that the entire atmosphere would constitute a body of diffused (suspended) water. 6/ By compliance with statutes, an appropriator could abtain a "right to the use of the atmosphere" superior to that of later applicants. The right would be conclusive against all but the police power and eminent domain. This interpretation is in accord with the contention that clouds are common property that can become private when appropriated. There have been several attempts to lay claim to clouds under this reasoning. Huffman cites the appropriation claim of a Nevada rancher to 1000 cubic feet per second of water from all clouds passing over his (the rancher's) property. 7/ The claim was made under statute providing that "The water of all sources of

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6/ Ball, "Shaping the Law of Weather Control", Yale Law Journal, Vol. 58 (1949) p. 224.

7/ Roy E. Huffman, Irrigation Development and Public Water Policy, Ronald Press Co., New York, (1953), p. 33.

water supply within the boundaries of this state (Nevada), whether above or below the surface of the ground, belongs to the public and can be appropriated by them." 8/

Ball does not discuss provisions for diversion of atmospheric moisture, nor does he define what uses of such moisture should be considered most beneficial. In these respects his atmospheric doctrine is reminiscent of the original surface doctrine. In Montana's territorial days, the only condition for a valid appropriation was a completed ditch for some useful or beneficial purpose. Since 1885, however, there have been two methods for appropriating water: first, by complying with the customs of early settlers (completed ditch and a useful purpose); and second, by complying with the terms of statutes (posting of notices, filing, construction, etc.). More recent regulations concern procedures for adjudicating individual rights to water, and plicies adopted with regard to interstate and federal water resource programs. Though these statutes were framed in reference to natural water problems, they nevertheless have some bearing on the kinds of difficulties currently posed by widespread weather control operations. For this reason principal provisions of the Montana water code will be listed, with brief comments on their possible relationship to agricultural cloud seeding programs. 9/

8/ Nevada Compiled Laws, (7890).

9/ Provisions are excerpted from the Revised Codes of Montana, Annotated, Vol. 7. References preceding the items identify specific sections and clauses.

89-801. What waters may be appropriated The right to the use of the unappropriated water of any stream, river, ravine, coulee, spring, lake, or other natural source of water may be acquired by appropriation, and an appropriator may impound flood, seepage, and waste waters in a reservoir and thereby appropriate the same.

This provision is very similar to the Nevada statute under which an appropriation claim to atmospheric moisture was made. In Montana, however, title to natural sources of water rests in the State, and not with the public. A citizen can own only a right to the use of water to the extent of his legitimate needs. It could be supposed that landowners do not own clouds, but might acquire a right to seed them in any area for their subsequent benefit. Whether an appropriative right to the airspace overlying property would forbid others to seed in the immediate area is a ponderable question.

89-802. Appropriation must be for a useful purpose

No statutes apply here. The general rule has been for courts to determine beneficial purposes by questioning the appropriator's intentions and the circumstances surrounding his diversion. The use of water for irrigation has never been questioned, but other economic and recreational uses have at times been considered useful also. In addition, contemplated use is as acceptable as actual use, provided that diversionary facilities are completed.

Similar reasoning could apply to weather modification, since the purpose of cloud seeding is nothing more than an increased water supply available for existing uses. In regard to contemplated use, farmers would be authorized to conduct winter seeding projects over relatively distant drainage areas even though the water contained in heavier snowpacks could not be utilized until the following growing season.

89-803. Change of point of diversion The person entitled to the use of water may change the point of diversion if others are not thereby injured.

This would permit seeding operations in the most desirable areas, i.e., high elevations and cloud-breeding regions. It could also legalize the taking of proven increases out of streams, if the diversions could be effected with the approval of those controlling property through which new or enlarged ditches and flumes must need pass. Additional support could be implied in the succeeding provision.

89-804. Reclaiming of diverted water The water appropriated may be turned into the channel of another stream and mingled with its waters and then reclaimed.

If the atmosphere is considered a reservoir (Ball), rainfall increases could be directed toward efficient catchment basins and later reclaimed. Where runoff was extraordinarily excessive in target areas, the desire for reclaiming could be quite strong.

89-807. Priority As between appropriators, the one first in time is first in right.

This notable feature of the appropriation doctrine could be enforced, albeit with some difficulty. However, undue emphasis on time priority in weather rights could prevent the realization of many desirable benefits. For society to realize maximum returns from weather control, priority should perhaps be allocated in a somewhat different fashion. Rainfall increases used to supplement irrigation supplies would no doubt contribute more to the social product than increases accumulated in lakes. Also, some regulation might be needed where controversies were simply a matter of weather control versus no weather control. Here it would be a question of prospective additions to the social product on one hand, and possible detractions on the other.

To properly exploit weather control, a dual system of priority might devised. As between similar uses time priority would still hold. As between diverse interests, however, priority would be granted to whichever use was considered to be the more socially valuable. Under such an arrangement, the more beneficial uses could legally usurp time priorities of those less desirable.

89-808. Appropriation by the United States The government of the United States may, by and through the Secretary of Interior, appropriate the waters of streams or lakes in the same manner as individual appropriators.

This type of provision could authorize federal participation (without eminent domain proceedings) in rain increasing activities within state boundaries, and allow federal appropriation of stream flow increases.

89-810. Notice of appropriation Any person hereafter desiring to appropriate the waters of a river, stream, etc., or other natural source of supply concerning which there has not been an adjudication of the right to use the waters must post a notice in writing . . . ., stating therein: The quantity of water claimed, the purpose for which it is claimed and the place of intended use, means of diversion and date.

Most criticisms of the appropriation doctrine do not concern its basic concepts, but are leveled at statutory procedures for completing claims. In nearly all states supporting the doctrine, a valid appropriation requires intent to apply to a beneficial use, the diversion from a natural channel, and an actual appropriation to a useful industry. By describing techniques and operating plans for increasing rainfall, farmers might feel or contend that the requirement for stating the means of diversion had been met. It is argued, however, that while ranchers could lay claim to a specific amount of atmospheric moisture, and state its intended use, they have no means of channelling or controlling its fall. 10/ A similar attitude toward appropriation is taken by Brooks, who conceives a cloud to be an object floating by instead of an integral part of the airstream. 11/ The only practical way for a farmer to gain legal control (appropriate) of clouds is by causing them to precipitate when immediately overhead. (Brooks seriously compares cloud seeding to shooting ducks.)

89-815. Adjudication of claims In any action hereafter commenced for the protection of rights acquired to water under the laws of the state. . . ., the court may in one judgement settle the relative priorities and rights of all parties to such action.

Eventual proof of the effectivenss of weather control and corresponding influences on areal moisture balances will almost certainly require determination of the relative rights of economic groups to engage in rain increasing activities.

89-846. Appropriation of waters for use out of state None of the waters of the state of Montana shall ever be appropriated, diverted, impounded, or otherwise restrained or controlled while within the state for use outside the boundaries thereof, except pursuant to a petition to and an act of the legislative assembly of Montana permitting such action.

The potential importance of this provision is illustrated in recent legislation concerning the promotion and regulation of rain increasing in other states. Wyoming was first to specifically assert its sovereignty in atmospheric moisture. In Section 1 of the Wyoming act: "It is hereby declared that the state of Wyoming claims its sovereign right to the use for its residents and best interests the moisture contained in the clouds

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10/ op. cit. Stanford Law Review, p. 50.

11/ op. cit. Brooks, p. 116.

and atmosphere within its sovereign state boundaries." 12/ The Colorado Weather Control Act declares "that the State of Colorado claims the right to all moisture suspended in the atmosphere which would fall so as to become part of the natural streams of Colorado, for use in accordance with its laws; and also the prior right to increase precipitation by artificial means for use in Colorado without material damage to others." 13/

Enforced laws of this nature would prohibt the location of seeding equipment outside the state to be benefited. Since weather (like surface streams) is notoriously disrespectful of political boundaries, such prohibitions would severly limit the extensiveness of commercial operations, and in some instances render them impracticable. Colorado foresaw the implications of undue restraint and implies a willingness to reciprocate by providing in a subsequent section: "Weather control operations may not be carried on in Colorado for the purpose of affecting weather in any other state which prohibits such operations to be carried on in that state for the benefit of Colorado or its inhabitants." 14/

Conciliation of the issues arising between states would probably take the form of regulating atmospheric water supplies in the public interest. Such control would be indispensable if the economic feasibility of rain increasing were demonstrated, with their stringency dependent on the relative success of cloud seeding among areas. A desirable policy would provide for

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12/ Session Laws of Wyoming, Enrolled Act No. 53. (1951).

13/ House Bill No. 251, State of Colorado (1951).

14/ Ibid. Section 13.

the fulfillment of essential needs and the balancing of reasonable uses. In interstate compacts relating to irrigation and municipal development of water supplies, the federal government has invoked a rule of 'equitable apportionment' and urged cooperation. A similar attitude would likely be taken toward regional weather control problems.

The foregoing review of Montana appropriation statutes was not meant to propose their adoption for dealing with weather control. At the time of their enactment there was not the slightest expectation they should ration water rights in weather. However, there is one principle in Montana water law (not statutory) which has an especially interesting relationship to rain increasing. This rule states that "a person who, by his own exertions, creates a new and independent source of water supply which would not otherwise have flowed into a stream, the waters of which have been appropriated, has the prior right to use the water to the extent of the increase." 15/

Indefinite Waters and Correlative Rights

Water right concepts most comparable to atmospheric moisture are those relating to so-called diffuse surface and percolating subsurface waters. The principal similarity is that relatively little is known about the origins of ground water and rainfall. A failure to recognize the interdependence of sources has historically resulted in disputes over underground waters. A similar lack of knowledge currently complicates rain increasing controversies. To complete the parallelism, it could be assumed that

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15/ George Y. Patten, "Water Rights in Montana", Rocky Mountain Law Review, Vol. 23-2, (December 1950) p. 165.

atmospheric water supplies are as exhaustible as surface or underground supplies, though the methods of gaining access and diverting are very different.

Rights to the use of percolating waters in various western states are subject to several principles of law. These alternatives will be outlined with brief comparisons to rain increasing problems.

The earliest principle recognized was the English rule of absolute ownership, under which a landowner is privileged to extract water from his land in any quantity that suits his convenience, regardless of the effect upon the water supply on his neighbor's land. Landowners in Montana can appropriate any water under their property, provided there is no malicious intent. If the English rule extended to the atmosphere, all landowners could practice weather modification. A damaging effect of the concept has been the over-development of ground water to the point where recharges cannot maintain the supply. Indiscriminate and widespread attempts to increase rainfall are similarly feared because they might upset natural processes to the extent that deficient areas would receive less precipitation than if weather were left alone.

Another ground water principle is called the American rule of reasonable use. This allows the landowner to withdraw water from his land, but requires his use to bear a reasonable relationship to the use of overlying land. The rule has been invoked in some areas to restrict the sale of large quantities of water for use at other points. Applied to weather control, the principle would entitle a landowner to increases he could get to his property, but would forbid the sale of increases retained in watercourses.