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Economic Implications of Weather Modification

South Dakota Agricultural Experiment Station

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ECONOMIC IMPLICATIONS OF WEATHER MODIFICATION

Report by Consultants to
National Advisory Committee
on Weather Control

Agricultural Economics Department
Agricultural Experiment Station
South Dakota State College
College Station, South Dakota
ECONOMIC IMPLICATIONS OF WEATHER MODIFICATION

Report on Project Two of Work Program
of Advisory Committee on Weather Control

December 1954

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The Advisory Committee on Weather Control was established by the Act of August 13, 1953 (67 Stat. 559), to make a study of all public and private experiments in weather control and report its findings to the President for submission to the Congress from time to time, making a final report no later than June 30, 1956.

The Committee set up a "Proposed Work Program Commencing July 1, 1954", dated May 28, 1954, which outlined seven projects. The portion of the program outlining Project Two is reproduced below in the section "Scope of Study and Report".

Dean A. M. Eberle, a member of the Committee, arranged a meeting of the consulting group at Brookings, South Dakota, from August 16 through August 21, 1954. This preliminary report includes material prepared at the session at Brookings, plus additional documentation and studies subsequently prepared by the several consultants.

**Scope of Project Study and Report**

The following is quoted from the "Proposed Work Program Commencing July 1, 1954":

"**Project Two. Determining Economic Value of Increased Precipitation.**

This study should be undertaken by: (a) examining material dealing with the subject; (b) considering impact of increased precipitation in representative local areas in the U. S. by means of theoretical projections or analyses of economic data obtained from years of above-average precipitation; (c) generalizing as to impact of increased precipitation amount, arbitrarily selected, throughout the U. S., considering increased crop production, hydroelectric production and other benefits.

"Part (a) should be undertaken immediately, and parts (b) and (c) as indicated. Conclusions arising from this study should be constantly reviewed, in the light of information subsequently obtained by the Committee, and made as firm as possible. The Committee may desire to extend or renew the study."
"Time assigned for project: 2 months. Personnel: Dean Eberle, member in charge of project. Estimated Cost: $2240."

The consultants believe that the scope of Project Two should be broadened as indicated by the following proposed title, "Economic Implications of Weather Modification". This change is suggested to the Committee, because it will permit inclusion of economic implications not directly related to "value", and of evaluations of weather control aimed at weather modifications other than precipitation increases. The material and suggestions which follow reflect to some degree this wider scope.

The consultants agree that in the limited time allotted it was impossible to complete any comprehensive study of the subject. It was believed that the optimum use of the time involved:

1. A review of the relatively small amount of literature on this subject.

2. A listing and brief description of the economic aspects and implications of weather modification.

3. Selection of major subject areas of evaluation, followed by more comprehensive study of these subjects. From these studies the present knowledge and need for further study could be established and proposals for research developed.

Preliminary results of the project study are presented in this report in the eight ensuing chapters. Chapter II, "Related Investigations and Reports", lists and presents a short digest of the several previous reports containing information pertinent to the economic implications of weather modification, which were reviewed in connection with the current study. Chapter III, "The Possible Extent of Economic Implications", contains a discussion of the several types of weather
modification, indicates groups and activities which could be affected, and briefly studies some varying effects of these programs. Chapter IV, "Economic Effect of Increased Precipitation for Agriculture", presents the results of project studies of the effect of one phase of weather modification, increasing the rainfall, upon irrigated areas and upon dry-farmed areas. Chapter V, "Economic Effect of Increased Precipitation Upon Hydroelectric Power Production", presents the results of project studies which were made to determine the effect of increased precipitation upon the production of hydroelectric power. Chapters VI and VII, "Economic Effect of Increased Precipitation on the Colorado River Basin", and "Economic Effect of Increased Precipitation on the Missouri River Basin", present the results of project studies for these two major and important river basins. Chapter VIII, "Proposals for Future Studies", describes some important studies which should be made to determine further the economic implications of weather modification. Chapter IX, "Conclusions", comprises a summary statement of the conclusions resulting from the project study.
CHAPTER II. RELATED INVESTIGATIONS AND REPORTS

Although a considerable amount of literature exists regarding weather modification, there are very few reports of studies of economic implications or economic evaluations. The only references known to the consultants, and which were reviewed in connection with the current study, are the following:


This is one of a number of similar reports of this institute. References to economic potentialities are incidental and in general terms. (See also Reports #45, 104, 109).


By the use of a hypothetical example based on 20 per cent rainfall increase, the author arrives at an estimate of $50 to $100 benefits for each $1 spent on seeding.


This contains some estimates of monetary value of estimated yield increases in various regions.


This thesis contains useful material on agricultural uses of rain-increasing methods and on various problems encountered or
likely to be encountered. The chapter on economic costs presents textbook concepts in terms of firms buying or selling rain-increasing services, but does not provide empirical evidence or detailed studies.


The authors assumed 10 per cent precipitation increase for two hypothetical examples, one a dry-farm area, the other an irrigated area. A very favorable ratio of benefits to costs seemed indicated. Although certain of the economic relations are over-simplified, the method is one which could be used in future studies.
CHAPTER III. THE POSSIBLE EXTENT OF ECONOMIC IMPLICATIONS

The Nation's economy is a gigantic complex of interrelated and interdependent human activities built on the framework of natural resources. No segment of the economy escapes this essential interdependence. Agriculture, commerce, industry, and the thousands of services by which we live all affect and are affected by each other. Among the natural resources which form the basis of this activity, none is more important than precipitation. Rain provides the moisture to grow our food. Rain provides the water which flows in our rivers and streams. Rain provides the water necessary to life, and the raw material for our industrial processes, and finally carries off the waste products of our civilization.

This interdependence has recently been brought to our attention again -- forcibly -- by drought conditions in the southwestern United States. Continued drought has reduced the production of farms and ranges in this area, and with it a reduction in the demand for goods and services, which has been felt in far distant areas. There are, however, recent scientific developments which give the hope that man may be approaching the time when he can exercise a degree of control over his natural environment by modifying or controlling the occurrence of precipitation.

It is easy to make the sweeping generalization that modification of weather can have tremendous economic effects upon our society. Certain applications of weather modification now being tried, as, for example, increasing precipitation for agriculture, would, if successful, offer quickly realizable returns far above costs, and would greatly affect all agriculture.
It should be also realized that the subject is larger and more complex than is at first apparent. It is probable that for some potential applications the benefit-cost ratios will be much narrower, and more careful calculation will be required. It is already certain that there are and will be conflicts of interests between groups and areas over weather control.

What follows is an attempt to array and classify some of the economic considerations which are relevant. In this discussion it is assumed that the Nation, the various segments, and the individuals are trying to maximize economic well-being.

There are several types of weather modification which could be tried individually or in combination. These include:

1. Increase or decrease of precipitation, with possible effects on location or timing of it.

2. Increase or decrease of cloud cover, fog, smog, or haze.

3. Increase or decrease of storms — including hail, lightning, and winds.

4. Increase or decrease of temperatures.

It is realized that these phenomena are interrelated and that various attempts at control may conflict. Each type of control, if physically feasible, could have economic effects which should be studied from various viewpoints, including the effect upon the Nation or society as a whole, upon various firms and groups within the society and economy, and upon individuals.

Additional more detailed studies should be made to determine the effect upon industries and activities, such as agriculture, forestry, electric power, mining, recreation, military, public water supplies, health and sanitation, flood control, and navigation.
Whichever grouping is used, it is apparent that the economic effects of weather modification upon different groups will be variable and sometimes conflicting. For example: A successful rain-increasing program to assist corn growers might injure certain recreational enterprises such as fairs and carnivals; or increased precipitation and consequent increased wheat yields may help the wheat farmer, but aggravate the national crop surplus situation.

Consideration must be given to varying effects by geographic areas. For example: A control program to increase precipitation in one area may overlap on another which does not need it; a storm dispersal to save an urban area may result in excessive rains for certain agricultural crops elsewhere; or modification permitting an area to introduce a new crop or industry may have economic effects on another area already utilizing the crop or industry.

Effects over time must be considered. Short-term and long-term economic effects may be different and, possibly, conflicting. For example: Precipitation increases on certain Great Plain soils might bring profitable short-term crop yield increases, but longer-term erosion, leaching and depletion which, unless offset, would mean eventual lower yields and lower dollar returns.

A study of the economic implications of weather control must take all of the foregoing aspects into account, in order that the proper choices between alternatives can be made. Quantitative, or in some instances qualitative, evaluations can be made. The relative economic importance of the interest groupings, the conflicting interests, and the net effects of alternative courses of action can be described. If this is done well and promptly, those who must make decisions can do so on an informed basis.
CHAPTER IV. ECONOMIC EFFECT OF INCREASED PRECIPITATION FOR AGRICULTURE

There is at the present time no general agreement regarding the possibility of modifying the weather so as to increase or decrease the natural precipitation. When experience or analysis finally gives an answer to this question, describing or delimiting the favorable conditions and the range of controllable effects, it will be possible to determine in an unequivocal manner the potential economic value of weather modification programs. The final determination of the economic value must wait until this time.

However, since the possibility that the weather can be modified has been presented, and since there is in fact physical evidence which suggests this possibility, it would be useful and interesting to speculate about the possible economic results.

Lacking knowledge of the extent to which weather can be modified, it is necessary to make certain arbitrary assumptions in order to set up hypothetical or actual problems which will demonstrate economic values. At this point it is possible to anticipate what the general answer is going to be, since a simple computation based on existing data will indicate that the break-even point is unbelievably low. Assuming that a precipitation-increasing program costs five cents per acre; the selling price of spring wheat is $2 per bushel; and one inch of rainfall above eight inches if properly timed will yield two bushels of wheat; it is seen that about 0.01 inch of additional precipitation will pay for the cost of the program. Such a modest increase could not be measured if distributed among several storms, and could not be detected by statistical tests, yet might pay for a rain-increasing program. From this hypothetical illustration it can be seen that in general any assumption
of increase in precipitation is likely to show a net benefit in favor of the operation.

For the various investigations of the economic value of precipitation-increasing operations which are described subsequently, and which will require the selection of an arbitrary amount of precipitation increase, it is recommended that the assumption be made that precipitation might be increased by 20 per cent in mountain areas, and 10 per cent in other areas, for a 10 per cent increase over-all for the Nation. These figures, which are selected for use in these particular studies, represent conservative but reasonable estimates of the positive effects as determined in the several competent evaluation reports which are available at the present time.

The studies of benefits to agriculture have been divided into two broad categories: studies of the effect of precipitation-increasing programs in dry-farm areas; and studies of the effect of precipitation-increasing programs in irrigated areas. The effect of a precipitation-increasing program would probably be different under a dry-farm economy than under an irrigation economy. Dry farming makes use only of precipitation falling on the area farmed, and is directly subject to the vicissitudes of that precipitation. Dry farming is essentially a method of conserving capricious precipitation as soil moisture from season to season and from year to year. This involves the selection of crops suitable to widely varying moisture conditions, and the number of crops adaptable to this type of culture is limited. Under irrigation, however, which is based upon artificial regulation of water supplies, a wide variety of crops can be grown. It is therefore conceivable that variations in rainfall will have a different range of benefit and damage in an irrigated area than in a dry-farmed region.
Economic Value of Precipitation-Increasing Program to Irrigated Area

The only known study which has been made on this subject is described in a paper, which was prepared by personnel of the California Division of Water Resources. In this paper a study of the effect of a 10 per cent increase in precipitation on an irrigated area in California is described. It considers the effects of the increase upon the runoff of the main streams, upon the yield of the conservation and hydroelectric facilities, and upon the economy of the irrigated area, and of the higher foothill and mountain tributary watershed lands. The findings included the following:

Effect on Irrigation and Upon District Lands

1. Average annual stream flow increased by 15 per cent.
2. Stream flow in minimum year of record increased 28 per cent.
3. Average potential yield of stream increased by 15 per cent.
4. Firm yield of existing facilities increased by 10 per cent.
5. Irrigated area increased by 10 per cent with resulting total annual benefit of about $1,125,000.
6. Increase in firm power production with annual value of $50,000.
7. Additional rain on district lands during irrigation season would disturb operational plans.
8. Value of additional rain directly on district lands during winter season would probably be offset by increased maintenance difficulties.

Effect on Tributary Foothill Area Above District

1. Increase of dry-land grain production of about $48,000 annually.
2. Increase in rangeland yield of about $100,000 annually.

Effect on Tributary Mountain Area Above District

1. Greatest benefit to this area would be the providing of preventive or protective measures to forest areas, including fire protection and decreasing soil erosion.
2. Resort areas would benefit.
3. Caution should be exercised to prevent floods.

If more detail is desired on the effects of increased precipitation on irrigated areas it is recommended that this study be reviewed and certain additional and more detailed studies be made. In the first place, annual yield studies were made, and it is possible that monthly studies through a critical period would give results differing somewhat in detail, but the relative difference would probably be small. More detail could be given to the effect on nonagricultural interests, and on tributary watershed lands. A summary of the effects on all lands studied would be desirable and would better support and might temper the conclusions.

Since the irrigation district which was studied has an abundant supply of water, it might be desirable to conduct a similar study of an irrigated area with a marginal or deficient water supply. Such areas exist along the eastern Rocky Mountains and in southern California. Such a study would be complicated, however, since the conservation facilities, which sometimes include an underlying ground water basin, are operated if possible on a long-time carryover basis to effect the maximum yield.
of water.

Economic Value of Precipitation-Increasing Program to Dry-Farm Area

Although other studies have been made on this subject, it is probably the one which will require and may deserve the greatest amount of attention. Several reports, one of which was listed previously¹, of the American Institute of Aerological Research of Denver, Colorado, are available which contain estimates of increased crop yields which might result from increased precipitation. The data which are presented cite values of increase in yield for each additional inch of precipitation for several different crops. The findings were apparently based upon linear extensions of data from county crop yield reports. The reports are not evaluation reports but were prepared to assess cloud seeding potentialities in areas where operations were proposed, and therefore they only point out the increased harvests which would result from an assumed precipitation increase, which was taken as 50 per cent in the reports reviewed. Substantial benefits are of course shown.

Another study is described in the previously-mentioned paper prepared by the California Division of Water Resources. In this paper a study is presented of the economic effect of 10 per cent additional rainfall in the northern Great Plains states of North Dakota, South Dakota, and Nebraska. The effects of the increase in rainfall were explored by considering the relationships existing between average annual precipitation and per acre farm value and average size of farms, as given

in the 1950 Census. For the three northern Great Plains states of North Dakota, South Dakota, and Nebraska the study indicated that there apparently would be an increase of 35, 70, and 46 per cent, respectively, in the per acre farm values in the three states, and increases of 20, 54, and 18 per cent in the number of farms. It was therefore indicated that an increase of 10 per cent in the average annual precipitation would enable dry-farm lands in these states to support about 56,000 more families.

As stated previously, no attempt is made in the current study to evaluate the extent to which precipitation-increasing is physically possible. Moreover, the only type of economic evaluation possible under the scope of this exercise is to work out some rough approximations on the basis of several assumptions. On the basis of existing experience and literature, the assumption has been made that natural precipitation can be increased by 10 per cent by cloud seeding operations. Application of the percentage figure is that the possible effect of artificial increase of rainfall is lower in periods of little natural precipitation than in periods of greater natural precipitation, that is, the possible increase is much greater in wet years than in dry years.

A further assumption is needed regarding the probable relationship between increased rainfall and increased crop yields. In the Great Plains a considerable number of studies have indicated that, in the case of spring wheat, one inch of precipitation, above 5 to 10 inches, is associated with a yield increase of 1.5 to 3.5 bushels per acre. For the purpose of this preliminary report it is assumed that the ratio of increase in yield to increase in precipitation is 2 to 1 over a base of a minimum of 8 inches, or, in other words, one inch of rainfall will yield two bushels of wheat.

Over most of the Great Plains the annual average precipitation
is so close to the amount required for growing grain crops that the
sizeable natural fluctuations in precipitation are of extreme signifi-
cance. The benefits to be expected from an increase in rainfall would
come from two effects. The one is the effect upon the income level,
whereby increased long-run average precipitation would increase long-run
average yields and incomes. The other is the effect upon the natural
variability of precipitation, since an increase or decrease in variability
of annual precipitation, yields, and incomes, is closely related to
long-run farm success and capital accumulation. Both the effect upon the
income level and the effect upon the variability have important ramifi-
cations in the general economy.

The Effect Upon the Income Level. By using the foregoing
assumptions of a 10 per cent increase in precipitation and a yield re-
sponse of 2 bushels per acre for each additional inch of precipitation
over 8 inches, several examples will be presented representing northern
Great Plains conditions.

Example (a). Assuming an average long-run yield of spring
wheat of 15 bushels per acre and a long-run average precipitation of 15
inches, a 10 per cent increase in rainfall would give an average increased
yield of 3 bushels per acre. For South Dakota, for example, with approx-
imately 4 million acres of wheat and assuming wheat at $2 per bushel,
with no marketing problem, this represents an annual total increase in
gross income from wheat of $24 million. Since a marginal increase in
yield of 3 bushels costs practically no more to harvest, the main deduc-
tion would be the rain-increase fee. At five cents per acre this would
amount to $200,000, leaving a net increase in income of $23,800,000.
Divided among 50,000 farmers, this would bring an average increase of
nearly $500 net to each.

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If we assume equivalent responses with other crops and with range operations, average annual farm income might be raised by $1,500, for a total of $75,000,000 for the state as a whole.

Example (b). Compared with the assumed response above, the cost of the increased precipitation appeared almost negligible. How low could the response get and still pay for the program? As stated previously, with wheat at $2 and rainmaking at five cents per acre, a response of 1/40 bushel per acre would pay for itself. Assuming 2 extra bushels for an extra inch of rain, the precipitation response need only be 1/80-inch to pay for the operations.

The Effect Upon the Natural Variability of Precipitation. Because many farm expenses are relatively inflexible, farmers face the problem of having to match expenses with a highly variable income. Any technique or practice which promises to add stability to farm incomes from year to year deserves to be examined. Even with no change in long-run average level of income, a reduction in the variability is desirable. What would be the effect of artificial rain increases on income variability?

If the assumed 10 per cent increase in precipitation is applied each and every year, the program could conceivably cause an increase in the absolute variability of income. However, since the mean precipitation and income would both be raised, the relative variability might not be changed. Moreover, it is generally not the years of high yield that cause the farmers trouble, but the years of low yield. If the low yields were prevented from going so low, this would be a help to farmers even if the absolute variability were increased.

If, because of flood hazard or erosion, it was not deemed desirable to increase the rainfall in years of natural excess, the
arrangement might be made to discontinue cloud seeding operations whenever the weekly cumulative precipitation total was running more than, say, 25 per cent above normal. Under this program, variability of yields would be reduced because low yields would be slightly raised, but the highest yields would not.
CHAPTER V. ECONOMIC EFFECT OF INCREASED PRECIPITATION UPON HYDROELECTRIC POWER PRODUCTION

Additional precipitation, either as rain or snow, will increase the rates of flow in streams and rivers. To the extent that such additional stream flows can be utilized, it is possible to generate additional hydroelectric power. Usually, this power can replace steam-generated power, so there is a direct saving in fuel cost. In addition, the use of water to generate power is a nonconsumptive use, since the water is delivered back into the rivers and is available for other use downstream. Consequently, there would be two general benefits from increased precipitation upon watershed lands above a hydroelectric plant; fuel would be saved to the extent that increased runoff could be utilized, and additional water would be available for downstream diversion and use.

It is not possible to make any other generalizations with regard to the value of additional precipitation for the generation of hydroelectric power. Each watershed and each hydroelectric plant or series of plants present a unique problem which must be analyzed, giving consideration to all factors. Differences in rates of runoff of precipitation and snowpack and in the variability of precipitation, differences in the sizes of reservoirs and conduit with relation to the magnitude and occurrence of runoff, and differences in the types, capacities, and operational requirements of power plants, all affect the extent to which additional runoff could be utilized. However, as an example of the type of study necessary to determine the value of increased runoff, and to give an indication of the benefits which might be realized from increased runoff, the following study is presented:
Given these data:

1. Three hydro plants in sequence on a given river.
2. One upstream storage reservoir, capacity 130,000 acre-feet.
3. Average annual runoff as follows, in acre-feet.

<table>
<thead>
<tr>
<th>Month</th>
<th>Inflow</th>
<th>Discharge to power</th>
<th>Reservoir houses</th>
<th>Reservoir change</th>
<th>Reservoir level</th>
<th>Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>57,000</td>
<td>30,000 + 27,000</td>
<td>47,000</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>May</td>
<td>69,000</td>
<td>30,000 + 39,000</td>
<td>86,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>June</td>
<td>110,000</td>
<td>30,000 + 44,000</td>
<td>130,000</td>
<td>36,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>July</td>
<td>10,000</td>
<td>30,000 - 20,000</td>
<td>110,000</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>August</td>
<td>1,000</td>
<td>30,000 - 29,000</td>
<td>81,000</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remainder</td>
<td>3,000</td>
<td>64,000 - 61,000</td>
<td>20,000</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td>250,000</td>
<td>214,000</td>
<td></td>
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</tbody>
</table>

4. Maximum capacity of conduits to power house, 30,000 acre-feet per month.
5. Minimum lake level at start of filling, 20,000 acre-feet.
6. Generating capacity, 1,200 kilowatt-hours per acre-foot of water used.
7. Value of power, $0.003 per kilowatt-hour.
8. An irrigation project downstream with need for additional water.

The operation during an average year is indicated in the following tabulation:
Assuming that a 20 per cent increase in precipitation will result in an average 25 per cent increase in runoff, the operation is indicated in the following tabulation:

<table>
<thead>
<tr>
<th>Month</th>
<th>Inflow</th>
<th>Discharge</th>
<th>Inflow</th>
<th>Discharge</th>
<th>Inflow</th>
<th>Discharge</th>
<th>Inflow</th>
<th>Discharge</th>
<th>Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>60,000</td>
<td>30,000</td>
<td>+ 30,000</td>
<td>50,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>May</td>
<td>72,500</td>
<td>30,000</td>
<td>+ 42,500</td>
<td>92,500</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>June</td>
<td>115,500</td>
<td>30,000</td>
<td>+ 37,500</td>
<td>130,000</td>
<td>48,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>July</td>
<td>51,000</td>
<td>30,000</td>
<td>0</td>
<td>130,000</td>
<td>21,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>August</td>
<td>10,000</td>
<td>30,000</td>
<td>- 20,000</td>
<td>110,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remainder</td>
<td>5,000</td>
<td>95,000</td>
<td>- 90,000</td>
<td>20,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td>314,000</td>
<td>245,000</td>
<td></td>
<td>69,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increases</td>
<td>64,000</td>
<td>31,000</td>
<td></td>
<td>33,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It is therefore seen that in the case of this example, a 20 per cent increase in precipitation would result in an annual increase in runoff of 64,000 acre-feet, of which 31,000 or 48 per cent could be utilized to produce hydroelectric power, and the remainder, 33,000 acre-feet or 52 per cent, would be spilled.

The value of this additional water would be determined as follows:

\[
31,000 \text{ a.f.} \times 1,200 \text{ kwh/a.f.} \times \$0.003 = \$112,000
\]

Estimated cost to perform the seeding = $20,000

Gain (to power-generating agency) = $92,000

Gain (to downstream irrigation users, @ $2.50/a.f.), assuming 70% marketable, 70 \times 64,000 \times 2.50 = $112,000

Total gain to downstream water users = $204,000

Cost/a.f. of water gained = $0.32

Cost/a.f. of water used = $0.66
The Colorado River Basin includes portions of seven states, Wyoming, Utah, Colorado, New Mexico, Arizona, Nevada and California, and has its delta area in Mexico, flowing into the Gulf of California. The total area of this great basin is about 259,000 square miles, of which about 2,000 square miles is in Mexico. Although the annual precipitation is in excess of 40 inches in scattered higher mountain regions of Colorado, the Colorado River Basin is generally arid, a large portion of the Basin receiving less than 10 inches of precipitation annually. This great river is the source of water and the economic life-blood of the entire southwestern part of the Nation.

Most of the water originates in the upper water-shed above Lees Ferry, Arizona, which includes a water-shed area of approximately 110,000 square miles. The remainder of the water-shed is principally desert, from which, in a normal or dry year, the runoff into the Colorado River is negligible.

During the last 20 years the main stream and its tributaries have furnished slightly less than 12,000,000 acre-feet average seasonal runoff at Lees Ferry; however, the annual water crop has varied from about 4,400,000 to nearly 20,000,000 acre-feet under dry and wet year conditions respectively. There are indications that substantially higher rates of flow occurred during the 19th Century based on flood marks.

Bureau of Reclamation estimates indicate a long-term mean seasonal runoff of about 16,970,000 acre-feet at the international boundary, assuming no upstream diversions. Bureau estimates also indicate an ultimate potential seasonal net use of the order of
The Bureau's estimate of available water seems optimistic in the present situation since there has apparently been a substantial decline in the average runoff from this river which started about 20 years ago. For example, the average flow measured below Needles, California in the 17 years, 1917 to 1933, was about 20,260 CFS whereas the average flow in the 17 years, 1934 to 1951, was 14,080 CFS. Only about 1/2 of this decline can be accounted for by the filling of Lake Mead and by evaporation losses from the Lake. During these same periods, the average annual runoff measured at Lee's Ferry has declined from 14,800,000 to 11,800,000 acre-feet; a reduction of 3,000,000 acre-feet per year. This would indicate that if the present weather regime continues, the potential deficit could reach as much as nine or ten million acre-feet including the million and one-half acre-feet which is required to be furnished to Mexico under the Mexican Treaty. It can be seen, therefore, that there is not enough water in the Colorado River to meet present plus future expected demands and that additional water will have to be secured in some manner if these potential demands are to be met.

In the following section of this report there are presented studies which were made to determine the effect of increasing precipitation of the Upper Colorado River Basin by means of weather modification operations. These studies have been set up on a basis of an assumed 10 per cent increase and an assumed 20 per cent increase in precipitation from which the effects upon runoff, hydroelectric power potential, and agriculture have been estimated. In addition, findings of the studies have been summarized and compared with the estimated costs of the weather modification program.
Effect Upon Runoff

Studies were made of the effect of precipitation increases upon the runoff at Lees Ferry in a dry season, an average season, and a wet season. For each of the seasons studied the runoff resulting from the increased precipitation was estimated by utilizing rainfall-runoff relationships for the watershed, as determined by the Hydrologic Division of the United States Weather Bureau. The Hydrologic Division has developed a river-flow forecast procedure based upon the inter-relationships between various subdivisions of the watershed. The contribution from each of the principal tributary streams is determined by considering its past rainfall-runoff performance as determined by a system of weighting applied to the monthly rainfall measured at 83 stations. Consideration is given the carry-over of runoff from one season to the next. Figure 1 shows the relation between the runoff of the Colorado River at Lees Ferry and the weighted precipitation index.

The following seasons were selected for study:

Average Season. The average of the seasonal stream flows measured at Lees Ferry from 1934 through 1953 is 11,836,000 acre-feet. Ignoring the effect of upstream diversions to other drainage basins, which as yet have not reached significant levels, this amount is considered to represent the average runoff of the river at this point. The flow during 1944-45 was 11,530,000 acre-feet, closely approximating the average season. The precipitation index for 1944-45, including 25 percent of the previous season's index for carry-over effect, was 1.73, which falls exactly on the regression line of Figure 1.

Dry Season. The minimum runoff in any season during the period of record occurred in 1933-34; some 4,377,000 acre-feet. This plots very close to the regression line. Using the 1933-34 precipitation
index, the indicated stream flow as read from the chart would be 4,000,000 acre-feet, which quantity will be used hereafter to represent the dry-season runoff.

Wet Season. The maximum runoff in the past 20 years occurred in 1951-52; some 17,960,000 acre-feet. This also plots close to the regression line. While higher seasonal runoffs have undoubtedly occurred in the past, the precipitation data are not adequate to permit their consideration in this study. Furthermore, it is likely that any effort to increase the rainfall would be suspended under such extreme conditions, because of flood potential. Using the 1951-52 precipitation index, and reading the value of the runoff from Figure 1, a probable runoff of 17,300,000 acre-feet in wet-seasons on conditions is indicated, which quantity will be used hereafter to represent the wet-season runoff. It should be noted that there were cloud seeding projects in operation in portions of the Upper Colorado River Basin during 1951-52.

By use of the rainfall-runoff relationship, the seasonal runoff of the Colorado River may be computed for any assumed percentage increase in precipitation simply by increasing the precipitation index by the assumed percentage, since all weightings are linear. In the cases of 10 and 20 per cent increases, this computation gives the following results:

<table>
<thead>
<tr>
<th>Season</th>
<th>Indicated runoff at Lees Ferry in acre-feet</th>
<th>Per cent of natural precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry season, approximately 1933-34</td>
<td>4,000,000</td>
<td>5,600,000</td>
</tr>
<tr>
<td>Average season, 1944-45</td>
<td>11,530,000</td>
<td>13,800,000</td>
</tr>
<tr>
<td>Wet season, approximately 1951-52</td>
<td>17,300,000</td>
<td>20,200,000</td>
</tr>
</tbody>
</table>
Therefore, the indicated increases in runoff of the Colorado River at Lees Ferry under the assumed 10 per cent and 20 per cent increases in precipitation are:

<table>
<thead>
<tr>
<th>Season</th>
<th>10 per cent increase</th>
<th>20 per cent increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry season, approximately 1933-34</td>
<td>1,600,000</td>
<td>40</td>
</tr>
<tr>
<td>Average season, 1944-45</td>
<td>2,270,000</td>
<td>20</td>
</tr>
<tr>
<td>Wet season, approximately 1951-52</td>
<td>2,900,000</td>
<td>17</td>
</tr>
</tbody>
</table>

The above tabulation indicates that in an average season, 10 and 20 per cent increases in precipitation would apparently result in increases in seasonal runoff of the Colorado River of 20 and 40 per cent, respectively. In a dry season the apparent increases in seasonal runoff would be 40 and 78 per cent, respectively, and in a wet season, 17 and 33 per cent, respectively. It will be noted that the percentage increase in runoff is greatest in the dry season. This is because nearly all of the additional precipitation in any year above the requirements of water-shed vegetation and other irrecoverable losses appears as runoff.

Effect Upon Hydroelectric Power Production

For the purpose of this study the additional runoff was valued at $0.50 per acre-foot; which is approximately the value of water used through the hydroelectric generating plants at Hoover, Parker and Davis Dams. This yields the following dollar values on an average year basis:

<table>
<thead>
<tr>
<th>Precipitation Increase</th>
<th>Power value</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>$1,135,000</td>
</tr>
<tr>
<td>20%</td>
<td>$2,285,000</td>
</tr>
</tbody>
</table>
Use of the water for hydro generation is non consumptive, since the water is returned to the rivers, and is available for downstream agricultural and other users.

**Effect Upon Agriculture**

The effect of increased precipitation upon irrigated agriculture would depend upon the extent to which the resultant increased runoff could be conserved and applied to beneficial use. The yields of all existing and proposed water conservation works would be increased as a result of increased runoff. The amount of the increased yield of these facilities would depend upon the quantity and occurrence of the additional runoff and upon the relation of the size of the conservation facility to runoff. No quantitative estimates are made of possible increased yields of works above Lake Mead. However, in the case of Lake Mead, with a useable storage capacity of over 29 million acre-feet, some 240 per cent of the average seasonal runoff at this point, the additional firm seasonal yield of water due to 10 and 20 per cent increases in precipitation is assumed to be equal to the increase in runoff at Lees Ferry, or 2,270,000 acre-foot and 4,570,000 acre-foot, respectively. In addition to producing hydroelectric power at Boulder, Davis and Parker Dams, this water is available for diversion to agricultural, urban, or industrial uses, and for purposes of illustration is assumed to have a value of $0.50 per acre-foot, for total annual revenues of about $1,135,000 and $2,285,000.

There is little dry-land farming in the Upper Colorado River Basin; however, livestock and livestock products accounted for about 50 per cent of the total value of agricultural production in the Basin in 1940, indicating the importance of the vast areas of grazing land.
Census figures for the Upper Basin indicate that in 1940 there were approximately 2,000,000 head of livestock. There are also approximately 50,000,000 acres of grazing land in the Upper Basin. If, as a highly simplified assumption it can be assumed that, during a six-month grazing season, this grazing land therefore has an annual carrying capacity of one-quarter animal unit per month, the total increase in grazing land yield due to increase in precipitation can be estimated. One animal unit month is equivalent to about four-tenths ton of alfalfa hay, and if hay is valued at $25 per ton, then one-quarter animal unit month is equivalent to $2.50 per acre in food value. It is believed that the carrying capacity of this grazing land would be increased proportionately to an increase in rainfall. Therefore, the total annual increase in grazing land yield would amount to $12,500,000 and $25,000,000 per year for increases in precipitation of 10 and 20 percent, respectively.

Effect Upon General Economy of Basin

It has not been possible at this stage in our studies to develop an appraisal of the total effect on the regional economy of the additional precipitation. The direct beneficiaries would, of course, be the agriculturalists whose crop or range land yields would be increased, and the revenue to the Federal Government from the sale of the additional power and water.

The indirect benefits would be, of course, far reaching, as the additional farm incomes are translated into demands for goods and services which extend into all parts of the Nation.

Certainly the additional water, if realized, would help to offset part of the potential water deficit in the Basin. The ultimate
The economic value is not calculable at this time, since we have no means of determining when the demand will reach the present limiting values.

**Summary of Benefits and Estimates of Costs**

Benefits to the Colorado River Basin as determined in the foregoing sections are set forth in the following tabulation:

<table>
<thead>
<tr>
<th>Assumed increase in precipitation, in per cent</th>
<th>10</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average increase in seasonal runoff in acre-feet</td>
<td>2,270,000</td>
<td>4,570,000</td>
</tr>
<tr>
<td>Value of increased hydroelectric production, in dollars</td>
<td>$1,135,000</td>
<td>$2,285,000</td>
</tr>
<tr>
<td>Value of increased runoff for agricultural uses in dollars</td>
<td>$1,135,000</td>
<td>$2,285,000</td>
</tr>
<tr>
<td>Value of increased grazing land yield, in dollars</td>
<td>$12,500,000</td>
<td>$25,000,000</td>
</tr>
<tr>
<td>Total dollar value of increase</td>
<td>$14,770,000</td>
<td>$29,570,000</td>
</tr>
</tbody>
</table>

Total annual costs of a weather modification program to increase precipitation upon the Colorado River Basin above Lees Ferry, Arizona are estimated to be approximately $1,000,000 per year, which is slightly less than the value of the additional water for power generation alone, if 10 per cent increase in precipitation results.
Note: Runoff for years before 1934 was adjusted by a 74% "Time Trend" factor. Years after 1933 plotted as observed.

Total Precipitation Index
(Current Year + 0.15 x Prev. Yr.)
The Missouri Basin is a wide country where "you kin look further than you kin see". It has a formidable climate and open terrain where "our only windbreak is the North Star". Early settlers who left to us remarks such as those quoted above, found it a difficult land, extremely variable, long on distance and a little short on rain.

This area is unusually subject to the effects of its climate.

"The climate of the region is continental. It is characterized by extremes and great irregularity throughout the four seasons. Winters are relatively long and cold over much of the basin while summers are sunny and hot. Spring is cool, moist and windy, and autumn is cool, dry, and sunny. In the Great Plains part of the basin, farmers must contend with low humidity, much wind, intense local storms with tornado and hail damage, high evaporation in relation to precipitation, and the possibility of early frost."

If the climate were uniformly arid, semiarid, or humid, farms could more readily select suitable types of farming, crops, and practices and they could calculate with some accuracy their chances of success. But in most of the basin, years with better-than-average weather — sometimes several in succession — encourage farmers to grow crops and use practices suited to more humid regions. Then when unfavorable weather comes crop and livestock losses are heavy.

The great drought of the 1930's and the tremendous floods in 1951 and 1952 attracted national attention, but each year some part of the basin suffers on a smaller scale, often when the basin as a whole is producing a bumper crop."

The Basin contains all or parts of ten states and a little of Canada. The states are Montana, Wyoming, Colorado, North Dakota, South Dakota, Nebraska, Kansas, Minnesota, Iowa and Missouri. Almost

1. Northern Great Plains Tenure Committee, "Facts About Agriculture In the Missouri River Basin" Great Plains Council Publication #2, Nebraska Experiment Station Bulletin 422, November 1953, Lincoln, Nebraska. (Subsequent references to agricultural data are from this source unless otherwise indicated.)
one-fifth of the land area of the nation lies within this Basin.

Agriculture is the dominant industry. About one-fourth of the nation's land in farms is here but only 9 percent of the nation's farm population. The principal products are cattle, hogs, sheep, corn, wheat and oats. It is a region of commercial farming and ranching. The operators know that their's are relatively high risk businesses. Therefore, there have been numerous attempts at various forms of weather control intended to aid agriculture in this area, and much popular interest in the efforts.

In addition to agriculture, the region has some processing and distributive business, some mining and lumbering. The tourist and recreation industry is second only to agriculture in some areas. Hydro-electric power production along Missouri becomes increasingly important as the generators start turning at the large, federally constructed dams such as Garrison and Fort Randall.

The Upper Missouri Basin is of importance to communities farther downriver because of the effects of runoff on flood control and navigation.

In this setting, an economic evaluation of weather modification becomes principally an estimate of net benefits of possible precipitation increases to agriculture. However, effects on power production (municipal water supplies), flood control and navigation cannot be ignored. Likewise, the implications of other possible weather modifications such as control of temperatures should be considered.

The estimates which follow are based upon comparisons of known past data, with an assumed 10 percent increase in precipitation. This would mean increases of from 1.5 inches to 3.0 inches in various parts of the Basin. The further assumption is made that the increases
of large, moisture bearing air masses are not considered in the making of these estimates.

**Effects Upon Agriculture in the Basin**

The agriculture in the Basin is principally dryland farming and ranching. However, 37,300 of the 548,956 farms and 4,429,000 of the 285,000,000 acres in farms are irrigated. This means that about 93 per cent of the farms are dryland farms.

In Chapter IV, pages 15-19 of this report some estimates are presented of the probable yield increases to be obtained under Great Plains conditions from a 10 per cent precipitation increase. For much of the farming area in the Basin this is estimated to be about 3 bushels additional wheat or 9 bushels additional corn per acre, approximately 20 per cent increases on a wheat equivalent basis. At current price levels this could mean at least $5 increase in production per crop acre, with relatively little increase in production costs.

Five dollars increase per acre per year on the 90,000,000 acres of cropland harvested in the Basin would represent an increase of over $450,000,000 in gross returns, or almost $1,000 per farm. In addition some value must be placed on increased carrying capacity of pasture lands if precipitation is increased. It is reasonable to assume that a 15 to 20 per cent increase in forage production could be obtained with the precipitation increase. The increase in value of production per acre would be much less than for crops.

It is estimated that a 10 per cent increase in sales of cattle and sheep could result. Based on 1949 sales, this could mean
about $150,000,000 additional for the Basin. The total possible gross increase for crops and livestock would be about $600,000,000, subject to the considerations which follow:

(1) The foregoing estimates do not allow for several considerations which might further increase the possible benefits:

(a) A substantial cropland acreage is left unharvested in many years. Increased precipitation might increase the 90 million acres harvested to more than 100,000,000 with a consequent increase in gross sales of crops.

(b) Precipitation increase in less favorable years might tend to reduce the variation in farm incomes and further strengthen the situation of agriculture in the region.

(c) A 10 per cent increase in precipitation might cause changes in the type of farming. These would probably be in the direction of more intensive farming on the midwestern model. Such changes could increase the gross product as well as the population and related economic activities of the Basin. This consideration would be very important but cannot be evaluated in dollar terms at this time.

(2) The foregoing estimates do not allow for several considerations which might decrease the possible benefits:

(a) Further increases in production of crops now in surplus such as wheat, and corn might weaken the marketing situation so as to either reduce prices considerably or increase costs of agricultural price support programs.

(b) Changes take time. Allowance would have to be made for time lags in application of precipitation increasing techniques and in consequent farming developments.
(c) Precipitation increasing might be needed only about one-half of the years. Therefore, estimates of income changes should be discounted.

(d) Costs of rain increasing programs would have to be subtracted from the increased gross farm returns. Current estimates of costs of operating rain increasing programs run from two to five cents per acre. At two cents per acre for the entire Basin the total would be $6,750,000 annually. However, some experts feel the cost of future programs may run considerably higher, particularly if more elaborate control techniques become necessary.

Because of the uncertainties and conflicting considerations indicated, it seems best to estimate the probable short-run benefits to agriculture in the Basin at 250 million to 300 million dollars annually. This would represent about an 8 per cent increase above 1949 levels.

Effects on Power, Flood Control and Navigation

Estimates of runoff from the Missouri Basin range from 21.5 million to 105 million acre-feet for various years. The average has been about 58.9 million acre-feet over 50 years. A 10 per cent increase in precipitation over the Basin area probably would increase the average runoff at least 3 to 5 per cent or two to three million acre-feet.¹

The hydroelectric power production on the Missouri has been increasing but the full production potential has not been reached. Neither have the demands of the region for power been reached. Therefore it is somewhat difficult to estimate the value of the increased runoff for power production.

It appears that the total potential production of power of the Basin under normal runoff would be about 45 billion kilowatt-hours annually. A 3 per cent increase in runoff would provide about 1.4 billion kilowatt-hours of additional power worth about \$7,000,000.

The effects the additional runoff would have on flood control and navigation would need investigation.

Effects on Industrial Development and Service Industries

Increases in agricultural production and power production as shown above would have definite effects on other groups. Based on the added volume of gross farm income it can be estimated that there would be an increase in volume of other business by at least 60-70 per cent of the primary increase. This would mean that if farm incomes were increased 300 million dollars, other businesses in the Basin would gain about 200 million in volume. However, evidence and opinions on these secondary effects are varied and conflicting.¹

¹ Estimates on multiplier effects are based on two reports: Thompson, John Eldon, "Estimating Commercial Expansion From Irrigation Development in the Cahs Unit" (thesis); Harmston, F. K., "The Multiplier As a Measure of the Indirect Benefit of Natural Resources Development" (paper) College of Commerce and Industry, University of Wyoming, Cheyenne, Wyoming, undated.
Summary

It would seem that a 10 per cent increase in precipitation would be worth at least $300,000,000 to the Missouri Basin in terms of agriculture and power. The value of greater increases in precipitation and of other weather modifications which would temper the harsh climate to permit more certain production, would be even greater.

People, who most summers watch every cloud with hope, can afford to watch meteorological advances with the knowledge that the potential economic gains are large.
CHAPTER VIII. PROPOSALS FOR FUTURE STUDY

This report is only a start toward a more definitive set of economic evaluations. Additional study is needed along several lines.

More complete and definite physical data must be gathered to serve as a foundation for economic evaluations. The physical results to be obtained from applications of various weather modification techniques are not yet definitely established or measured. For example: what percentages of precipitation increases can be obtained under various conditions? What are the effects of cloud seeding upon areas downwind of the targets? Problems of this nature are being studied by others. The answers will be important to economists. Meanwhile, economic evaluations must rest on a temporary platform of assumptions and estimates.

In the realm of economic evaluation there should be:

1. In addition to the evaluation of economic implications on Agriculture and Hydropower, included herein, there should be evaluations concerning effects on such vital industries as public water supply, and health and sanitation.

2. In addition to the two river basins considered in this report, there should be study of the effects on all other major river basins.

3. More detailed study of the major subjects discussed in this report.

4. Study of economic implications of all forms of weather control including precipitation increase, on segments of the economy. Storm, hail and lightning reduction, temperature control, dispersal of unwanted clouds, deliberate changes in movement or phasing of storms, all should be considered as these become physically feasible. Such
integrated studies should include consideration of factors mentioned
in this report, in particular, effects on various industries and on
major drainage basins.

5. Study of the economic effects of weather control on human
work efficiencies and recreational activities.
CHAPTER IX. CONCLUSIONS

This weather modification idea strikes all of us right where we live. Weather is noticed by us as individuals, noticed often, with varying feelings, sometimes with prayer and sometimes with profanity.

For centuries man has tried to modify weather. We believe that he has failed until recently to accomplish anything on a large scale. We know that he has succeeded for a long time on a small scale. Houses, greenhouses, heating devices, air conditioning and shelter belts all modify weather in small areas.

Now, our scientists press toward that large scale weather modification. Efforts directed at precipitation increases are becoming routine. Experimentation increases on other modifications such as hail or lightning suppression. Cut beyond this some scientists talk of diverting, guiding, phasing large air masses in order to change the climates of whole geographic regions. This is not idle talk, but rather the expression of problems for serious study. The "gleam in their eyes" seems to be controlled climates for this earth someday.

The economists can see similar new horizons for weather modification, once the physical feasibility can be firmly established. At present, these economic evaluations must be based on assumptions that certain physical results can be obtained. Therefore, few economic studies have been made. Yet it is necessary to take these assumptions and make economic estimates in order to help determine how much can be spent on experiments. It is useful, also, to look ahead to possible effects of varying degrees of successful weather control on our economy. These effects could be great and far reaching.
The Nation's economy is a gigantic complex of interrelated and interdependent human activities built on the framework of natural resources. No segment of the economy escapes this essential interdependence. Agriculture, commerce, industry, and the thousands of services by which we live all affect and are affected by each other. Among the natural resources which form the basis of this activity, none is more important than weather.

It is easy to make the sweeping generalization that modification of weather can have tremendous economic effects upon our society. Certain applications of weather modification now being tried, as, for example increasing precipitation for agriculture, would, if successful, offer quickly realizable returns far above costs, and would greatly affect all agriculture.

It should be also realized that the subject is larger and more complex than is at first apparent. It is probable that for some potential applications the benefit-cost ratios will be much narrower, and more careful calculation will be required. It is already certain that there are and will be conflicts of interests between groups and areas over weather control. Effects over time must be considered. Short-term and long-term economic effects may be different and, possibly, conflicting.

The complexity of these possible economic effects calls for studies, increasing in intensity as the advance of physical scientific progress justifies. Such studies should treat whole industries, such as agriculture, power, and public water supply. It will be necessary to study whole areas, probably by drainage basins such as the Missouri River or the Colorado River.
In general, it is possible to estimate the value of benefits of a proposed weather modification, subtract the costs of operation and arrive at a net gain or loss figure. However, estimating the benefits involves both benefits and losses or damages, to different groups, over different time periods. It involves items difficult or impossible to value in monetary terms. Although, it appears now that costs of operation might be negligible in relation to possible benefits this cannot be expected to be true in all cases or at all times.

The following summaries of preliminary studies give some indications of both the potential economic gains and the complexities of evaluation posed by weather modification.

Agriculture is very dependent upon favorable weather. Therefore, many of the rain increasing projects have been sponsored and financed by farmers and ranchers. Agriculture in the United States is a $35,000,000,000 industry in terms of value of products sold.

No study has been made of the effects of weather modification on the whole of American farming nor even on selected areas. Some attention has been devoted to effects of precipitation increases on small areas.

For an irrigation district in California it has been estimated that a 10 per cent increase in precipitation on the general area would increase stream flow and yield about 15 per cent, and increase irrigated area by 10 per cent with annual benefits of about $1,125,000. In addition, there would be increases in value of dryland grain and range production for the area of about $48,000 and $100,000 respectively.
plus some additional electric power. No cost estimates were given.\textsuperscript{1}

The same study estimated possible gains from a 10 per cent precipitation increase to the wheat growers of South Dakota at 12,000,000 bushels or $24,000,000. With rain increasing costs estimated at five cents per acre the total costs would be only $200,000. These estimates were based on numerous assumptions, and the example was deliberately oversimplified. However, it served to highlight the economic appeal of rain increasing to Great Plains farmers.

The power industry has a considerable stake in weather modification. Additional precipitation, either as rain or snow, will increase the rates of flow in streams and rivers. To the extent that such additional stream flows can be utilized, it is possible to generate additional hydroelectric power. Usually, this power can replace steam-generated power, so there is a direct saving in fuel cost. In addition, the use of water to generate power is a nonconsumptive use; the water is delivered back into the rivers and is available for other use downstream.

Each water-shed and each hydroelectric plant or series of plants present a unique problem which must be analyzed, giving consideration to all factors. For a particular western, mountain water-shed with a series of three power plants on the river, a 20 per cent precipitation increase could produce additional power worth $112,000 at a cost for rain increasing estimated at $20,000. In addition, there would be gains to downstream users for irrigation or other purposes.

Public water supplies (and sanitation) are vital to our

existence as an industrialized nation. An increasing number of areas are being bothered by water shortages or water pollution problems. The development of feasible methods of precipitation increasing will offer valuable relief to such areas.

The interrelationships between water usages of agriculture, power, and public agencies point up the need for evaluations by river basins.

The Colorado River Basin includes parts of seven states. A 20 per cent increase in precipitation would increase runoff 40 per cent. This would produce additional power worth about $2,285,000 annually. The gross benefits to agriculture were estimated to be another $2,285,000. In addition, there would be large benefits to users of upstream grazing areas. Forestry, recreation, and public water users would also gain. It was estimated that the costs of a rain increasing program would be approximately $1,000,000 per year.

The Missouri River Basin contains a land area of 338,780,000 acres which produced about $3,440,000,000 worth of farm products in 1949. A 10 per cent increase in precipitation would increase agricultural income about $450,000,000 annually, if assumed practicable each year. This would average about $1,000 per farm. Even if this is discounted 50 per cent to allow for contingencies such as possible failure to seek the increase in some years, and marketing problems, the gross gain would average $500 per farm. However, these calculations do not consider the possibility of changes in type of farming. Estimates of costs for rain increasing projects for the entire Basin were $1.00 per acre, or a total of $6,750,000. This would be about $0.50 per capita for the population of the Basin.

In addition to this there would be increased water for hydro-