28 April 1978, Volume 200, Number 4340 SCIENCE

Hail Suppression and Society

Assessment of future hail suppression technology reveals its development should be sizable or ignored.

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Scientific knowledge about the effectiveness of hail suppression is incomplete and conflicting (1, 2). Limited use of this potentially beneficial technology for relieving hail losses to crops and property has continued in the face of scientific uncertainty about whether or how it works (3, pp. 10–15). Public controversy over its use has erupted in several areas and the legal implications of this uncertain technology have been under study (4–6). We performed a technology assessment to address the future of hail suppression in the nation (7). The effort required an interdisciplinary research team drawn from various physical and social sciences as well as from legal and business communities (8).

Summary. An interdisciplinary assessment of hail suppression in the past, present, and future has shown it to be currently scientifically uncertain but a potentially beneficial future technology. An established suppression technology would be widely adopted in the Great Plains, providing benefits to agriculture and secondarily to the American consumer. Development of a reliable technology will require a sizable long-term federal commitment to atmospheric and social research. Subcritical funding would be a mistake. Orderly future usage of hail suppression, with its scientific complexities and regional character, will necessitate development of governmental regulations, evaluation procedures, interstate arrangements, and means for compensating those who lose from modification.

Evaluation in depth of all past and present aspects of hail suppression became the basis from which our research group projected the technologies into an uncertain future. Initially, the national hail problem was dimensionalized, and all social and environmental questions raised by hail suppression were identified. Three models of hail suppression's future capability were extrapolated from the current uncertain status. These technological models were then coupled to social, economic, and legal variables to derive future adoption levels in the nation. The social impacts of these adoption patterns were established and evaluated. They served as the basis for identifying related policy issues, for drawing conclusions, and for making recommendations. We have drawn together the major findings of this technology assessment.

The Hail Problem

The key characteristic of hail in the United States is its enormous variability in both time and space. Most locales in the nation experience only two or three hailstorms a year (Fig. 1) and only 5 to 10 percent of these hailstorms may ever produce seriously damaging hail (9). During the warm season of the year (about April through October), crop-damaging hail falls somewhere in the eastern two-thirds of the United States on almost every day. On 20 days in an average year, crop losses from hail exceed $1 million. These infrequent but large loss events represent 5 percent of the hail loss days but 39 percent of the national loss to hail.

The most damage from hail is done to crops, averaging $773 million annually (1975 dollars); in addition, property is damaged at a cost of $75 million each year (10). The $773 million crop loss from hail represents about 1 percent of cash receipts from national marketing of farm products. Half of all hail losses occurs in the Great Plains, that is, from Texas to North Dakota, where hailstorms are intense (Fig. 1). Intensity is a function of hailstone sizes and frequencies plus attendant wind speeds. Crops most severely damaged by hail are wheat, cotton, corn, soybeans, and tobacco; about 25 percent of these crops is usually insured. The amount of food lost to the nation is equivalent to that needed to feed about 2 million Americans a normal diet for 1 year.

Insurance is the only current alternative response to the problem of hail; it serves to spread the burden of loss without reducing the losses themselves. Although hail suppression is at present a much more uncertain solution to the hail problem than insurance, the latter is not a complete solution. In areas where the loss is high, losses are sufficiently frequent and substantial so that many farmers are unable to afford insurance and the insurance industry finds it difficult to price coverage at a profitable level (11).

Hail Suppression Hypotheses and Evidence

In 1946, Schaefer discovered that Dry Ice dropped into supercooled water vapor in a laboratory cold box caused the rapid formation of ice crystals (9). The crystals that formed in the home freezer he was using for his experiments were like those of the natural atmosphere (12) and could serve to change the amounts

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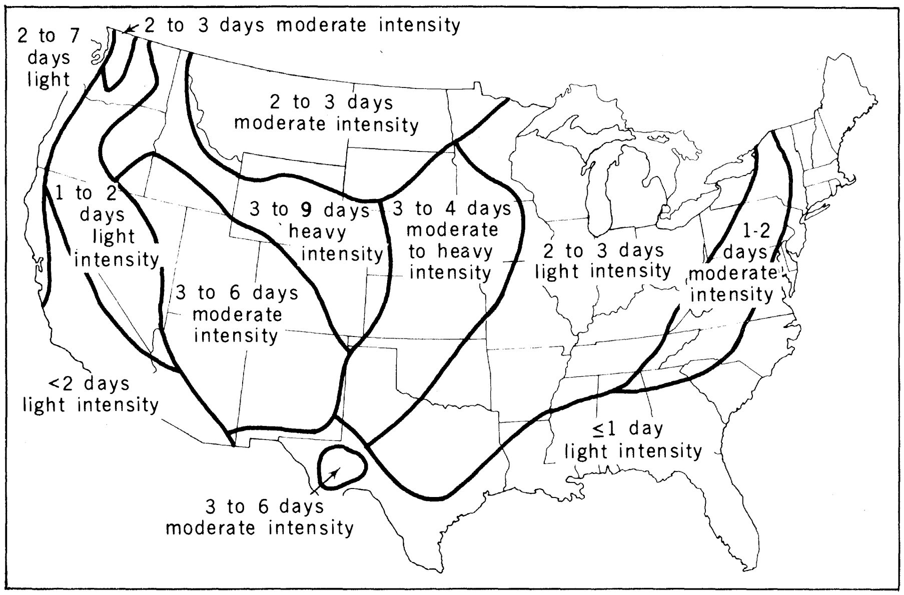

Fig. 1. Hail regions in the United States showing the average annual number of days with hail at any point in a region and the average intensity of hail.

of water and ice in the colder upper parts of clouds. The implications of the discovery were enormous. Schaefer conducted the first "cloud-seeding" flight before the end of 1946. Soon after, it was found that silver iodide could be substituted for Dry Ice with about the same effect, and this substance became the seeding agent most frequently used in contemporary weather modification efforts.

Modern weather modification has a history of almost 30 years of parallel thrusts in experimentation and usage without clear proof of effectiveness. Cloud seeding has been conducted to seek increases in rainfall and snowfall, to suppress lightning and dissipate fog, and to mitigate hurricanes and hailstorms.

Conceivably, there are many ways to modify hailstorms, but the extensive attempts, either in field experiments or in commercial operational (nonexperimental) projects, have been based on the use of silver iodide to alter microphysical processes inside the cold upper parts of thunderstorms. Two basic approaches involving conceptual hypotheses are followed: the introduction of silver iodide either for "competition" or for "glaciation." The glaciation hypothesis involves relatively heavy seeding in an attempt to convert all the supercooled cloud water above the freezing level into ice crystals so that no hail can form. However, if only part of the supercooled water is transformed into ice, the storm could actually be worsened because growth by accretion is especially rapid in an environment composed of a mixture of supercooled drops and ice crystals. To be successful, this approach requires the massive seeding to take place well in advance of the first hailstone formation. It is the approach that has been used in a Canadian experiment and in a South African operational project (*2*).

The competition hypothesis involves the development of fewer, but still many, hail embryos (ice nuclei) that compete for the available water and thus minimize hailstone growth in the zone of maximum liquid water content. This approach has been used in major field experiments in North Dakota and Colorado and in commercial projects in Texas, South Dakota, and North Dakota. A major uncertainty with each approach is whether the desired amount of silver iodide is delivered and distributed at the right time and in the proper volume within a storm.

Results from the Canadian experiment suggest (i) success in suppression of hail in the smaller, less complex storms, but (ii) no success in the more organized, larger, multicellular hailstorms. Results of a 4-year experimental project in North Dakota indicate a 60 percent reduction in crop hail loss that is marginally significant at the .92 confidence level. The National Hail Research Experiment in Colorado, ended after 3 years of experimentation, showed that seeding neither decreased nor increased hail. The operational hail suppression projects in the Dakotas and Texas that are based on the competition hypothesis have yielded results suggesting moderate success, although scientifically suitable proof cannot be derived (*2*).

As a result, hail suppression in the United States since the 1950's has been marked by confusion, by scientific uncertainty, and sometimes by public controversy (*3*). Agriculturists utilized the services of commercial weather modification firms for operational projects before experimental results on the effectiveness of the technology were available. The three North American field experiments involving statistical controls and the collection of data on relevant atmospheric properties adequate to allow scientific evaluation that have been conducted in recent years have yielded mixed and inconclusive results. In the typical private or state-supported operational project little or no data to allow an in-depth scientific evaluation of its effects have been collected. Over the 15-year period from 1958 to 1975, 357 cloud-seeding field operational projects and experiments were conducted. Of these, approximately 17 percent (or 61) involved hail suppression, and many of them were located in the Great Plains area of the United States. The public's experience with hail suppression remains limited (*13*).

Evaluation of all available information regarding the current status of hail suppression revealed that three different positions appear in describing the current status (*2*). One view is based on the results of evaluations of six hail suppression projects. Five of the projects suggested the existence of a hail suppression capability with decreases in hail loss ranging from 20 to 48 percent, but the results were not statistically significant at the 5 percent level. In general, these results would be classed by atmospheric scientists as "optimistic." Another view of hail suppression is that afforded by the various recent scientific reviews of weather modification (*14*). These generally suggest a position that may be characterized as guarded optimism, but with no indication of definitive proof of hail suppression. The third view might best be labeled as the average scientific belief. The results of two surveys of scientific opinion show a wide range of opinion on the readiness of hail suppression for operational application. A majority of experts on weather modification indicated no belief in a hail suppression capability, but a sizable minority indicated that a moderate (more than 20 percent) reduction in hail damage was a current capability. At best, average scientific belief must be labeled "we don't know" (*15, 16*). These three views of the current status of hail suppression—optimistic, slightly optimistic, and pessimistic—reflect the wide range of opinions and results, and clearly the current status of hail suppression may be described as one of uncertainty (*1*).

Use of Hail Suppression: Past and Present

Case history material and public survey data taken in areas with weather modification projects reveal several factors associated with public acceptance or rejection of hail suppression in the past (*3, 17*).

1) The first such factor is the area's heterogeneity of weather needs. That is, within a weather modification project area differing requirements for beneficial weather may exist. For example, some crops at certain time periods benefit from additional rainfall, whereas others suffer damage if rainfall occurs at that time. Heterogeneity of weather needs is the basis for potential conflict at the community or regional level with regard to planned intervention in weather processes.

2) If a drought develops or deepens while hail suppression is being conducted, grass roots opposition groups may develop because it is perceived that the seeding to suppress hail is also accidentally suppressing rainfall.

3) The lack of scientific consensus about the readiness of hail suppression technology for operational application impedes its social acceptance.

The decision to adopt hail suppression has necessarily been reached in a context of uncertainty about its effectiveness and possible side effects. The uncertainty implies that a degree of risk is involved, and, in general, risk-takers prefer to take their own risks, rather than to have such decisions made for them. Thus, the degree of public participation in the decision to implement a hail suppression project may have an influence on whether or not the project finds ultimate acceptance in the community.

Adoption of hail suppression has tended to occur in areas of high loss where hail destroys up to 20 percent of the crop. Those interested in using hail suppression have included irrigating barley and lettuce growers; cotton, grain, and wheat farmers; and fruit growers. Where adoption did not occur even though hail losses were significant (mostly in the tobacco areas of the mid-Atlantic region), growers were generally unaware of the technology and did not perceive hail as a serious problem. Most of them relied on insurance to cope with crop loss to hail (*18*). As the technical performance of cloud seeding improved, as it began to depend more on public funding, and as it was used over more extensive land areas, awareness increased that the activity had implications for entire communities and regions. Adoption of weather modification thus became a collective decision, requiring action on the part of a community or larger social aggregate in order for it to be adopted. A slow rate of adoption of innovations may be considered quite normal (*19*). Thus, widespread adoption of hail suppression technology can be expected to require at least the remainder of this century, provided that an effective technology is developed (*20*).

Table 1. Preferred decision-making regarding cloud seeding. The question: Who do you think should decide whether or not a hail or rain experiment will be started (or continued)?*

Response	Percentage of number of respondents: Illinois 1974 (N = 274)	Colorado 1974 (N = 221)	South Dakota 1974 (N = 293)	South Dakota 1976 (N = 430)
Local	54	56	59	50
Nonlocal	46	44	41	50

*Questions were phrased slightly differently in each state.

Results of surveys in agricultural areas on citizen attitudes, knowledge, and belief concerning weather modification have shown that belief in the technology's effectiveness in increasing rainfall and decreasing hail is a key predictor of favorability to having a cloud-seeding project (*4, 21*). About 40 percent of those sampled have consistently expressed concern about the unknown risks involved in human intervention in weather processes. However, many respondents have favored trying to control the weather for the benefit of man. In general, environmental concern does not appear to be a basis of opposition to cloud seeding in agricultural areas of the country.

Survey findings have been notable for their marked consistency and comparability. Public response to cloud-seeding projects is far more dependent on citizen observation of actual project effects than on their initial favorability or unfavorability toward a project (*4*). If community members attribute beneficial weather events to cloud seeding, acceptance is likely. If they think weather modification causes detrimental events (as in the relatively frequent argument that hail suppression causes drought), then social rejection of the project is likely.

The majority of citizens interviewed in various parts of the nation have expressed a preference for local decision control over implementation of weather modification (Table 1). In one recent survey, the majority of respondents called for a vote to decide the matter. Widespread citizen preference for local control over cloud seeding is often in direct conflict with scientific and governmental agency desires to retain decision control over weather modification. This issue between officials and citizens has played a role in more than one community dispute over weather modification (*22*).

Nevertheless, given the popularity of participative mechanisms and their increasingly extensive use, it seems unlikely that public participation in weather modification decision-making will decline. The active and forceful participation of representatives of groups, such as attentive minorities, having a direct stake in the outcomes of public decision processes can be expected (*23*).

Up until now, weather modification projects have been implemented with a minimum of public involvement in the decision process. Since scientists and agency officials generally wish to retain control of the decisions concerning when, where, how, and for what purposes to conduct weather modification projects, and since citizens in the areas wish to have a voice in these decisions, the conflict between them requires resolution by means of an adequate decision mechanism—an institutionalized procedure that is socially acceptable. Extensive public participation should minimize the potential for community polarization (*24*).

Weather modification, and thus hail suppression, is now regulated primarily at the state level, with 60 percent of the states having enacted a relevant statute (*25, 26*). The federal government requires only that all weather modification activity in the nation be reported to the National Oceanic and Atmospheric Administration (NOAA).

States vary with respect to the complexity and degree of regulation that they impose on weather modification activity. Several states require weather modifiers to show competence and obtain a license; they may also require a permit for the conduct of each field project. In general, the federal government considers itself not answerable to state law; therefore, some federal weather modification projects have operated without any external regulatory control whatsoever.

Statutes in six states make it manda-

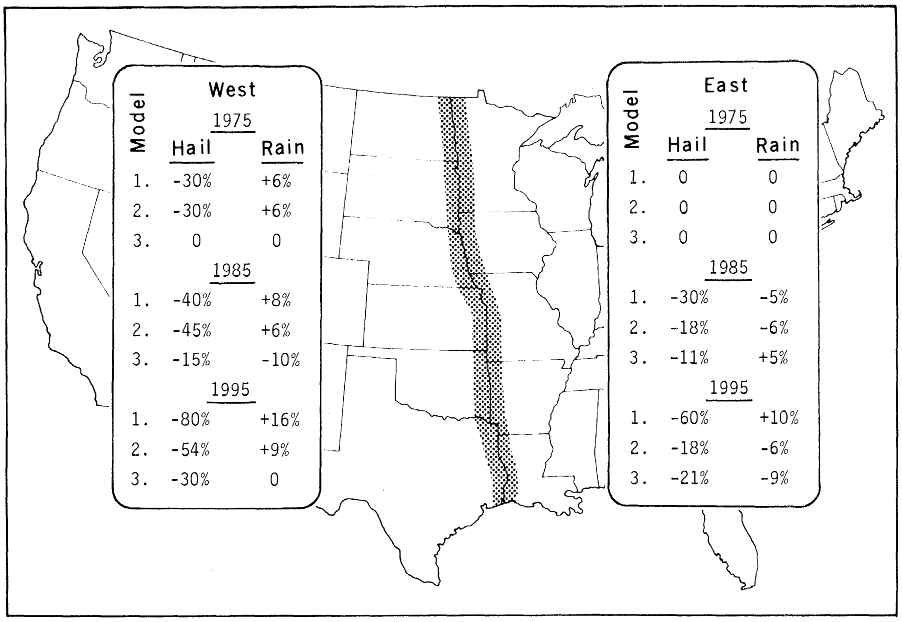

Fig. 2. Areas projected to adopt hail suppression as a result of varying hail and rain modification capabilities (technological models).

tory that public hearings be held prior to the granting of a permit to conduct field operations, while in several other states hearings are optional. Three states provide for funding of state-sponsored cloud seeding through general fund appropriations; however, most states provide minimal budgets for administration of weather modification statutes. Thus, proper evaluation of operational projects, including the required reports, is unlikely to occur.

Major lawsuits involving weather modification have numbered 15. Of the 13 that have been decided, the defendants (weather modifiers) have won 11. The two that they lost included a Texas case in which a temporary injunction against cloud seeding was issued, and a Pennsylvania case of criminal prosecution for hail suppression seeding (*6*). Generally, plaintiffs in court have been unable to prove the causal relation between the harm alleged by them and the cloud seeding on a given day (*25*).

Studies of the effects of cloud seeding on the environment, both in terms of silver iodide (the seeding agent most commonly employed) and of weather effects themselves (for example, the effect of increased precipitation on natural ecological processes) suggest a general finding of minimal measurable short-term environmental effects (*27*). However, environmental researchers hesitate to make definitive statements because they perceive that serious environmental effects of silver iodide and precipitation changes might occur and too little research has been accomplished. Although it is unlikely that serious adverse environmental impacts would result from widespread adoption of hail suppression, the possibility of adverse effects cannot yet be discounted.

Future Technological Models

Since an established hail suppression technology does not currently exist, we projected future capabilities. Three such projections, called technological models, were developed. Each was based on one of the three different scientific views about current capabilities in hail suppression: optimistic, slightly optimistic, and pessimistic (*15*).

The three numbered models are presented in Fig. 2. A capability was estimated for each of three levels for the eastern and western United States, a distinction made necessary because of the great differences in hailstorms and because more experimentation has occurred in the western part of the country. Estimates for future hail in the models are based on season-long averages over a seeded area (typically more than 2000 square kilometers), and they are expressions of average seasonal changes achieved in property and crop hail damages. Since a capability to suppress hail will probably affect the amount of rainfall an area receives, the estimated rainfall effects presented in the models are those anticipated as a result of the hail suppression activity itself. The lack of any information on the possible effects of hail suppression on hail or rain beyond the area of suppression activities (called the "downwind" area by atmospheric scientists) led us to exclude such effects from the models. Each model reflects a series of reasonable and probable technical developments and could best be described as scientific estimates.

Model 1 starts from a slightly optimistic assessment of the current capability in the West, and from no capability in the East (Fig. 2). Its future is characterized by relatively extensive concurrent usage and experimentation, with a major scientific breakthrough by 1995. Such a breakthrough might occur in the understanding of cloud behavior, in improved storm forecasting, and in better approaches to nocturnal storm seeding, and is expected to make possible the high level of effectiveness predicted for 1995 (with as much as 80 percent reduction of hail damage in the West).

Model 2 involves intermittent applications and experimentation with moderate advances. This model also begins with a slightly optimistic view of the current state-of-the-art in the West. Moderate advances in technical skill would occur, but no major scientific breakthrough would be achieved. By 1995, these activities would lead to a capability of reducing hail damage by about 50 percent in the West, and by about 20 percent in the East (Fig. 2).

Model 3 involves little usage anywhere in the nation and has instead an experimental focus. It is based on a pessimistic view of current capabilities for both West and East. Decreases in rainfall associated with hail suppression in the western half of the country would minimize usage, but moderate research would ultimately lead to a very modest capability (30 percent reduction of hail damage in the West) by 1995.

In the Great Plains where usage of hail suppression exists and is projected to continue, a 50 percent decrease in hail loss results in an 11 percent increase in average net income per harvest acre. If this shift in hail loss were accompanied by a 10 percent decrease in rainfall, the net effect would be a 1 percent income decrease, whereas a rain increase of 10 percent with a 50 percent hail decrease would bring an income increase of 22 percent. The relatively greater importance of rainfall modification is shown by the fact that a 10 percent rain increase alone is equivalent to a 50 percent decrease in hail loss.

Future growth of hail suppression activities will require management systems with several key program elements including design, field operations, evaluation of effects, and public information systems (*20, 28*). The probable regional nature of future programs (in response to the broad spatial distribution of hail-producing weather systems) will necessitate sophisticated program designs. Areas of effective future operations, from a technological standpoint, would be from 10,000 to 40,000 square kilometers in extent. Operational efforts will potentially involve three types of seeding systems (aircraft dispensing material at cloud base or inside storms, and a less likely use of surface rockets). Highly skilled storm-forecasting and storm-monitoring facilities will be necessary, and all components of the system will require specially trained staff. Costs for all aspects of a well-conducted future hail suppression program will reach $1 per planted acre (in 1975 dollars).

Future Adoption of Hail Suppression

Given the three alternative models of hail suppression's potential development, the research group projected future adoption patterns on the basis of several important economic, legal, and sociopolitical variables. Adoption referred to the commercial use of hail suppression technology in an area. Data on the social variables were integrated by crop-producing regions of the United States for each technological model at 1985 and 1995 (*20*). This analysis was a key integrative effort in the assessment project, making possible the ensuing evaluation of economic and other social impacts.

Seven variables were developed and utilized in the adoption analysis. First was an economic incentive index based on an analysis of individual farm operators and regional weather-crop relations. The second variable was a legal receptivity index based on data concerning the extent of legal regulation of hail suppression and of state governmental support of weather modification through appropriations, the extent and direction of trends in administrative law, and the occurrences of litigation and their outcomes. Indices on the social incentive to adopt hail suppression, based on each region's severity of hail losses and drought and on the importance of agriculture in the area's economy, were employed. Another index included heterogeneity of weather needs in each region, with respect to rain and hail, to represent an area's conflict potential. Other variables included (i) the political stance of each region as represented by statute wording, (ii) an estimate of the level of scientific consensus associated with each technological model, and (iii) an estimate of the social acceptability of each model's effects. Values for these variables were defined for each crop-producing region and for each model for the years 1985 and 1995. If the summarized value exceeded a predetermined threshold value, adoption was predicted. Threshold values were determined by examining the data in relation to the actual adoption of hail suppression.

Results should be viewed as projections or forecasts of adoption by crop-producing regions. These results are conditional on the occurrence of the capabilities in the technological models. As can be seen on the maps of projected adopting areas (Fig. 3), the most extensive adoption predicted was for the highest level of technology (model 1, 80 percent reduction in hail damage accompanied by a 16 percent enhancement of rainfall) in 1995. The Great Plains area of the nation would be the area most heavily involved in hail suppression, with a few scattered projects in California and the Pacific Northwest.

Hail suppression was not projected to occur in the Midwest or in East Coast areas. A low-level technology (model 3) would result in virtually no adoption in the nation in 1995.

Impacts on Agriculture

Our study of impacts resulting from future use of hail suppresion established agriculture as the main impacted activity. Given the adoption patterns projected for the nation with the three technological models, a prime question was "What will be the savings in resources required to meet projected domestic and foreign demand for crops in future years?" Resource savings were defined as reductions from hail suppression in the costs of production and transportation for eight principal crops.

In conducting the analyses of the national economic impact of hail suppression, a national linear programming computer model was used (*29*). National modeling calculations included the cost for operations, expenditures for future research and evaluation, the extent of adoption, and the future demands for food.

As is shown in Table 2, the high-level hail suppression capability (model 1) would result in a resource savings of 1 percent in 1985 and 3 percent in 1995. The low-level capability (model 3) has such minimal adoption that no resource saving would occur on a national scale. In fact, the costs of attaining model 3 (including $1 per acre for operations) outweigh the benefits of hail suppression in 1995, leading to a $2 million increase in costs. The annual benefit (resource savings) derived from the high-level technology (model 1) by 1995 was calculated to be $493 million. This value is nearly twice the benefit obtained with the moderate technology (model 2 at $263 million).

In a sense, hail suppression technology can be viewed as a substitute for land. Because yields per acre increase, less farmland is required to meet projected demands. Therefore, land rents and land values tend to decline slightly in nonadopting areas, but they increase in adopting areas. The overall effect at the national level is estimated to be a slight reduction in land rents.

The adoption of hail suppression would also affect the comparative market advantage of the crops in various regions. The resulting changes in location of crop production would not appear substantial when compared to recent year-to-year changes in crop acreages by state.

Another agricultural impact question concerned which of the three alternative routes of technological development (models) promises to be the best investment for public funds. In the benefit-cost analysis performed, the benefits were based on the resource savings accomplished by the predicted adoption. The costs included the requisite research, development, and information system expenses estimated to be associated with each model. Using an 8 percent discount rate, the high-level technology (model 1) was found to have an estimated benefit-cost ratio of 14.6 : 1 (Table 3); the moderate technology (model 2) had a ratio of 16.6:1; and the low-level technology (model 3) had a ratio of −0.4:1. Use of substantially higher discount rates did not affect the relative ranking of the models, although it did reduce the benefit-cost ratios.

Although the benefit-cost ratio is highest for model 2 (because of lower predicted expenses for research and development than in model 1), the total benefits produced by model 1 are much greater. Comparison of model 1 and 2 values in Table 2 shows the difference between the benefits of models 1 and 2 is $1124 million and their difference in costs is $91 million. Thus, the benefit-cost ratio of going from model 2 to model 1 is 12.3:1, indicating that model 1 would be the best choice.

The benefit-cost ratios for models 1 and 2 appear high for two reasons. First, previous expenditures for research have provided a knowledge base for the expected future development, and second, there was no risk discounting to reflect the uncertainty of obtaining the specified technology level, given the funding level.

As we have noted, agriculture is the primary stakeholder in an effective hail suppression capability. If high-level technology (model 1) is developed, one major effect will be on the income of crop producers in adopting areas. These producers would receive immediate economic benefits from increased farm output. After an adjustment period, however, the national prices for these commodities would reflect the increased production, and some of the income advantage of producers in the first regions to adopt would be lost, but these producers would still benefit from increased stability of production. In contrast, producers of the same crops in nonadopting regions would receive neither output increases nor greater production stability and therefore would be economically disadvantaged relative to the adopters. In adopting areas, to the extent that farm income stability is increased, farmers should have less need for emergency loans, less need to default on loans, and be able to obtain new loans more easily and on better terms. There would probably be some alteration of cropping patterns caused by readjustments in the market prices of farm products.

Four social impacts of a high capability in hail suppression (model 1) were judged significant by the research team. As noted, agriculture would experience the most significant national effects of an advanced hail suppression capability. Producers in early adopting areas would receive immediate benefits from increased farm output. After a period of adjustment, the economic advantage would be decreased somewhat, but increased stability of income would remain.

Probable effects of successful hail suppression on the hail insurance industry would include benefits caused by increased purchases of insurance (as risk is reduced in high-loss areas) and increased profits because premium reductions would be slower than actual loss reductions. Problems would include shifts in methods of recording losses and the emergence of hail suppression liability insurance. On balance, there would be a slight benefit to the hail insurance industry from an effective suppression capability.

Consumers of agricultural products would benefit through slightly lowered prices. Although the economic benefit to any one individual would be small, the number of individuals benefited would be very large.

Government agencies involved in regulating hail suppression activity, in supporting research and development, and in working out interstate arrangements would experience pressure for implementing these changes. New government entities would develop in these functional areas and in response to the design, operational, and evaluation activities.

Finally, an increased stature for weather modification in general would result from favorable experience with hail suppression in adopting areas. All other impacts of an advanced hail suppression capability were judged minor.

Table 2. Future changes in national agricultural production costs due to hail suppression having different capabilities.

Year	Basic cost of production	Reduction in annual cost					
		Model 1		Model 2		Model 3	
		Dollars*	Percent	Dollars*	Percent	Dollars*	Percent
1985	$15,840	206	1	152	1	0	0
1995	15,850	493	3	263	2	−2	0

*Dollar cost in millions

Table 3. Present values of benefits and costs with various hail suppression capabilities.

Item	Model 1	Model 2	Model 3
Present value of benefits (million dollars)	+2,840.235	+1,715.870	−7.555
Present value of costs (million dollars)	+194.186	+102.758	20.839
Benefit-cost ratio	14.6:1	16.6:1	−0.4:1

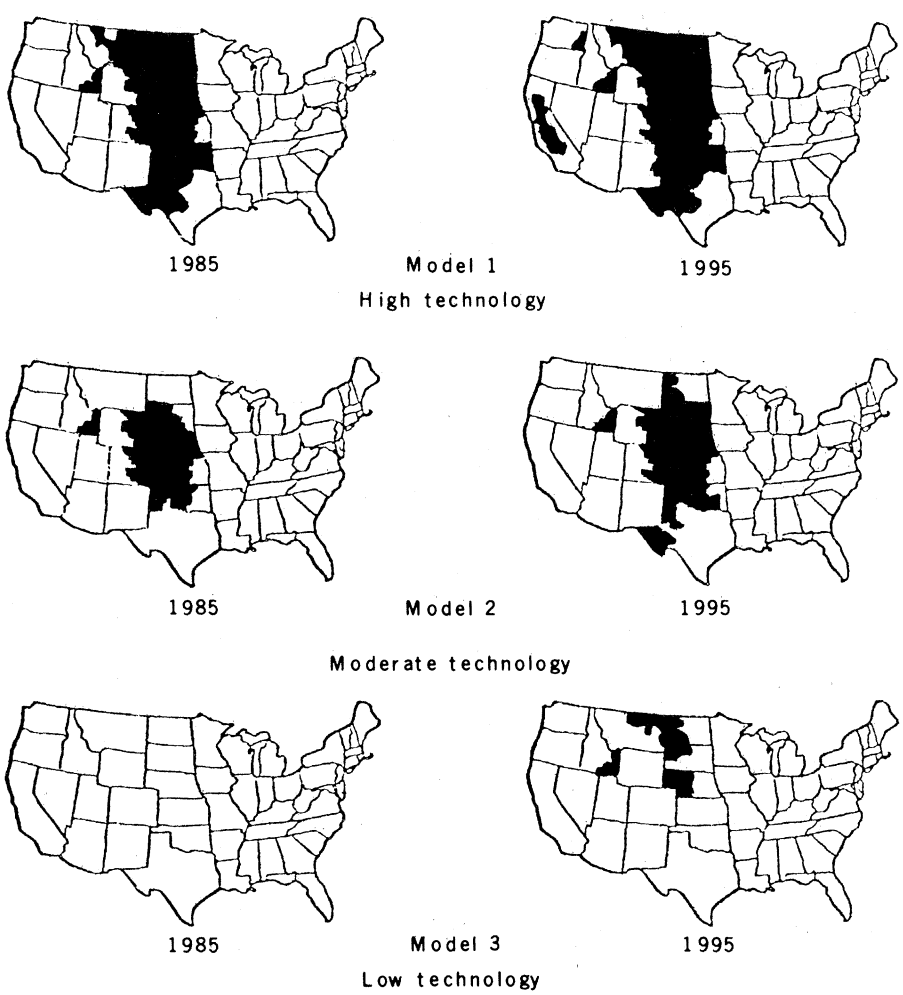

Fig. 3. Three future technological models (1, 2, and 3) with capabilities for hail suppression and modification of rainfall resulting from hail suppression in the western and eastern United States.

Policy Issues

With regard to hail suppression, the most significant policy question at all levels of government is the extent of financial and institutional support for the development of hail suppression technology. Assuming that national goals of ensuring adequate food supplies for the entire population while maintaining environmental quality and other social values are served by (or at least not violated by) an effective hail suppression technology, then the removal of the scientific and technical uncertainties is the major policy action addressed (*20*).

Removing these uncertainties will require (i) orderly federal management and adequate long-range funding with a lead agency addressing the modification of severe convective storms, and (ii) a scientific research group dedicated to a well-designed program of basic and applied research. The utilization of hail suppression technology will probably not await the final resolution of all scientific uncertainties. Application, discouragement, encouraging research results, scientific argument, and fairly prolonged debate will probably characterize the technology's scientific and technical development.

Four important policy questions were identified in the assessment study.

The first of these concerned the sources of funding. In general, federal funding of research and user funding of operations have been prevailing patterns. However, policy options can involve federal funding of the evaluation of operational projects and taxpayer funding of operations.

A second policy question is whether compensation should be provided for the losers and if so, how. The question of causation has been a substantial barrier to the development of a compensation mechanism, but this difficulty will be overcome with technological and scientific improvements. Several policy options with regard to this question may be considered, but no workable arrangement for compensation has yet been institutionalized.

The third issue concerns the appropriate division of responsibility, between the states and the federal government, in regulating hail suppression. Throughout our study, the atmosphere was considered a common property resource, and thus public regulation of intentional weather modification has been viewed as inevitable. Heretofore, regulation has resided with the state governments; however, regulation might also arise in conjunction with financial regulation in support of hail suppression design, operation, and evaluation.

The fourth issue deals with monitoring, record keeping, and evaluation. Where operational programs are conducted, a contribution to scientific knowledge can be achieved by adequate data collection, analysis, and evaluation. Policy decisions are needed on who should fund and conduct these evaluations.

In general, policy decisions on hail suppression revolve around two basic issues (i) whether or not to stimulate the further development of hail suppression technology, and (ii) how to handle the implications concomitant with its development and application.

Public Policy Recommendations

The federal government should attempt to develop hail suppression with an approach that will lead to a technology having a high level of effectiveness. Most of the research and development should be the responsibility of a single federal agency having broad control over the whole federal program on planned weather modification. Support of hail suppression research should be at a level of at least $3 million annually and should be sustained for at least 20 years or until it is clear that a highly useful technology is developed or cannot be developed. Low-level support is not warranted.

Operational hail suppression programs should be permitted only under conditions of full disclosure to a governmental agency. Full disclosure includes revelation of all advertising, contract, and promotional material, as well as reports on project effects. Operational projects should be required by law to provide sufficient data to independent government agencies (on a cost-reimbursement basis) so that monitoring and evaluation of project effects will be expedited.

For the present, regulation of hail suppression projects should continue to be a state responsibility. However, federal standards for monitoring and evaluation should be developed and incorporated into state regulations. States should appropriate more funds for the administration of weather modification statutes, especially to allow a more extensive analysis of current records.

The decisions to authorize, interrupt, or discontinue any hail suppression effort should be made at the local and state levels. Such decisions should involve active participation of potentially affected groups and, if tax funds are to be used, it is possible that all of the citizens within the potentially affected areas should vote on a referendum.

Some type of compensation mechanism is needed to provide for payment to those with legitimate damage claims. Discretion to develop such compensation mechanisms should be left to the states.

Research Recommendations

Advancement of the capability to suppress hail can be wisely accomplished through a two-pronged scientific effort. First, a well-defined experimental analytic research program must be conducted, with strong continuity and a focus on all the atmospheric science issues. It should include efforts to monitor closely and to evaluate operational hail suppression projects, and should also include a continuing program to integrate the findings from both efforts. Second, the storm modification hypotheses of the future must consider the whole convective storm process, to attempt to suppress hail and to reduce associated strong surface winds. These hypotheses should include a simultaneous goal and study of producing no change or an increase in rainfall and to address downwind effects.

Within this recommendation, certain specific basic and applied research activities should be followed including (i) in-cloud measurements throughout the lifetime of storms, (ii) sufficient regional and climatic sampling to ensure transferability of results, and (iii) a study of weather forecasting issues, to improve design and operation of future programs.

The technical aspects of integrating the advanced understanding of atmospheric processes achieved through the studies recommended above should be developed. Aspects such as seeding technologies and delivery systems need further development. A technology assessment of the modification of precipitation should be conducted, since rainfall effects were found to be more important than hail effects in economic and sociopolitical impacts.

Along with research, a comprehensive study of potential compensatory mechanisms that would be economically feasible as well as socially and legally acceptable is needed, to refine further the parameters of feasible and socially acceptable decision-making mechanisms. Work should be continued on the development of a model weather modification law for interested states, and research into possible federal standards for program monitoring and evaluation should be launched.

The specific environmental studies recommended include (i) the effects of altered precipitation on ecosystems; (ii) basic studies on plant and microorganism adaptation to seeding agents; (iii) the potential for combination of seeding agent silver with other metals, pesticides, power plant emission products, and other pollution sources; (iv) tracer studies of nucleants in seeded storm cells to locate their deposition in the environment; and (v) long-term monitoring of silver levels and dynamics in the soil-plant-aquatic environment before and after cloud-seeding activities.

Several of our findings indicate that scientific research and policy research efforts should be continued as well as monitoring and reevaluation of effects. A continuing assessment of the nation's hail suppression capability should occur in the years ahead.

References and Notes

1. D. Atlas, *Science* **195**, 139 (1977).
2. S. Changnon, *Bull. Am. Meteorol. Soc.* **58**, 20 (1977).
3. B. Farhar, Ed., *Hail Suppression: Society and Environment* (monograph 24, Institute of Behavioral Science, University of Colorado, Boulder, 1977).
4. ——— and J. Mewes, *Social Acceptance of Weather Modification: The Emergent South Dakota Controversy* (monograph 23, Institute of Behavioral Science, University of Colorado, Boulder, 1976), pp. 10–15.
5. J. Mewes and B. Farhar, in (*3*), pp. 35–45; M. Smith, B. Farhar, J. Mewes, R. Davis, S. Cox, in *ibid*, pp. 124–155; S. Cox and S. Hernandez, in *ibid*., pp. 156–170; S. Hernandez and T. Toll, in *ibid*., pp. 171–188; G. Fletcher, in *ibid*., pp. 189–195; R. Davis, in *Weather and Climate Modification*, W. Hess, Ed. (Wiley, New York, 1974), pp. 767–786.
6. J. Mewes, in (*3*), pp. 80–95 and 103–116.
7. G. H. Stever, Phi Beta Kappa Lecture, Washington, D.C., 18 May 1973; S. Changnon, *Bull. Am. Meteorol. Soc.* **56**, 27 (1975); *ibid.* **57**, 234 (1976).
8. The other major contributors to this assessment study, with their specialty areas in parentheses, were R. Davis (law), E. Fosse (crop insurance), D. Friedman (property insurance), J. Haas (sociology), T. Henderson (weather modification practices), J. Ivens (science writer), M. Jones (technology assessment), D. Klein (ecology), D. Mann (political science), G. Morgan (meteorology), S. Sonka (economics), C. Taylor (economics), and J. Van Blokland (economics).
9. S. Changnon, *J. Appl. Meteorol.* **16**, 837 (1977).
10. L. Boone, *Estimating Crop Losses due to Hail* (Agricultural Economics Report 267, U.S. Department of Agriculture, Washington, D.C. 1974), pp. 4–40; S. Changnon, *J. Appl. Meteorol.* **11**, 1128 (1972); E. Fosse, *Impacts of Effective Hail Suppression on Crop Insurance Industry and Probable Policy Action Response* (Report of Crop-Hail Insurance Actuarial Association, Chicago, 1976), pp. 4–41; D. Friedman, *Hail Suppression Impact Upon Property Insurance* (Report of the Travelers Insurance Company, Hartford, Conn., 1976), pp. 1–69.
11. W. Brinkmann, *Severe Local Storm Hazard in the United States: A Research Assessment* (Institute of Behavioral Science, University of Colorado, Boulder, 1975), pp. 1–154.
12. V. Schaefer, *J. Weather Mod.* **8**, 5 (1976).
13. B. Farhar, thesis, University of Colorado, Boulder (1975).
14. Committee on Atmospheric Science, *Weather and Climate Modification, Problems and Progress* (National Academy of Sciences, Washington, D.C., 1973) pp. 100–106; *Bull. Am. Meteorol. Soc.* **54**, 694 (1973); L. Grand and J. Reid, *Workshop for an Assessment of the Present and Potential Role of Weather Modification in Agricultural Production* (Atmospheric Sciences Paper 236, Colorado State University, Fort Collins, 1975), pp. 38–236.
15. S. Changnon and G. Morgan, *J. Weather Mod.* **8**, 164 (1976).
16. B. Farhar and J. Clark, in preparation. Scientific opinion could have changed since these 1975 cross-sectional surveys [see also (*15*)], as a result of maturation and developments in the field. However, it is unlikely that it would have changed sufficiently to define hail suppression as a currently feasible and certain technology.
17. J. Haas, *Bull. Am. Meteorol. Soc.* **54**, (No. 7), 647 (1973); B. Farhar, *Mass Emergencies* **1**, 313 (1976).
18. D. Pfost, in (*3*), pp. 117–123.
19. E. Rogers and F. Shoemaker, *Communication of Innovations* (Free Press, New York, 1971); B. Farhar, "Public reaction to weather modification," paper presented National Science Foundation Advisory Panel Meeting, Boulder, Colo., 14 July 1975.
20. S. Changnon *et al.*, *Hail Suppression Impacts and Issues* (Report of Illinois State Water Survey, Urbana, 1977), pp. 1–442.
21. S. Krane, *Social Implications of the National Hail Research Experiment: A Longitudinal Study* (Human Ecology Research Services, Boulder, Colo., 1976); B. Farhar and J. Mewes, *Weather Modification and Public Opinion: South Dakota, 1973, Second Interim Report* (Institute of Behavioral Science, University of Colorado, Boulder, 1974).
22. B. Farhar, "The locus of control of weather modification: scientists vs. citizens," paper presented at the Midwest Sociological Society Meeting, Minneapolis, 15 April 1977.
23. D. Mann and B. Farhar, in (*3*), pp. 196–218.
24. B. Farhar, R. Rinkle, G. Johnson, "Cloud seeding in California: risk, control and citizen response," paper presented at the Pacific Sociological Society Meetings, Sacramento, 21 April 1977.
25. R. Davis, *Hydrology and Water Resources in Arizona and Southwest* (Proceedings 1975 Meeting of AWWA and Hydrology Section of Arizona Academy of Sciences, Tucson, 1976), vol. 6, pp. 48–64.
26. R. Davis, paper presented at National Convention of American Society of Civil Engineers, Denver, 10 December 1975.
27. D. Klein, *J. Appl. Meteorol.* **14**, 673 (1975); C. Cooper, *Modifying the Weather, A Social Assessment* (University of Victoria, Victoria, British Columbia, 1973), pp. 99–134.
28. S. Changnon, paper presented at the AAAS Annual Meeting, Denver, 22 February 1977.
29. C. Taylor and E. Swanson, *The Economic Impact of Selected Nitrogen Restrictions* (AERR-133, Department of Agricultural Economics, University of Illinois, Urbana, 1975); C. Taylor, P. Van Blokland, E. Swanson, K. Frohberg, *Two National-Equilibrium Models of Crop Production*. (AERR-147, Department of Agricultural Economics, University of Illinois, Urbana, 1977).

30. We thank R. Davis, J. Haas, J. Ivens, M. Jones, D. Klein, D. Mann, G. Morgan, S. Sonka, C. Taylor, and J. Van Blokland. Many others gave support and critical reviews, including W. Ackermann and 34 attendees at a user's workshop; and the members of the advisory panel including S. Borland, E. Bollay, J. Fivor, W. Fowler, W. Thomas, and C. Wolf. Many students contributed to the background research, and two theses based on various elements of the study were awarded at the University of Illinois. This work was supported by grant ERP 75-09980 from the National Science Foundation and by the State of Illinois.

Highly Reiterated Sequences of

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Hagai Rosenberg, Maxine Singer, Martin Rosenberg

The DNA of eukaryotes characteristically contains multiple copies of certain nucleotide sequences that occur anywhere from a few to millions of times per genome. The more highly repetitive sequences typically occur in long tandem arrangements and can comprise a substantial portion of the genome (*1–3*). Certain of these sequences (termed satellites) can be isolated directly from total genomic DNA by virtue of their unique buoyant density (reflecting a difference in base composition from the bulk DNA). In other instances, the highly repeated sequences cannot be distinguished by density but can be obtained in relatively pure form by virtue of their rapid reannealing characteristics after denaturation of sheared total DNA. Some of the highly repetitive sequences can also be isolated by digestion of total DNA with restriction endonucleases which cleave at specific sites within the repeated sequence. In most cases studied, the repeating unit has been defined as a relatively short oligonucleotide segment (less than 20 residues) (*2*, *3*); however, more recently, the existence of much longer repeat units has been indicated (*4–6*). The highly repetitive sequences often appear localized within the centromeric region of metaphase

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