

# HAIL SUPPRESSION IMPACTS AND ISSUES

STANLEY A. CHANGINON, Jr., RAY JAY DAVIS, BARBARA C. FARHAR,  
J. EUGENE HAAS, **J. LOREENA** IVENS, MARTIN V. JONES, DONALD A. KLEIN,  
DEAN MANN, GRIFFITH M. MORGAN, Jr., STEVEN T. SONKA,  
EARL R. SWANSON, C. ROBERT TAYLOR, JON VAN BLOKLAND

Final Report  
Technology Assessment of the Suppression of Hail

ERP75-09980  
Office of Exploratory Research and Problem Assessment  
Research Applied to National Needs Program  
National Science Foundation

**ILLINOIS STATE WATER SURVEY  
URBANA, ILLINOIS  
APRIL 1977**

Cover photograph of an approaching July  
hailstorm in South Dakota, taken  
by Stanley A. Changnon, Jr.

This report was prepared with the support of National Science Foundation Grant  
No. ERP 75-09980. The opinions, findings, conclusions and recommendations  
expressed in such a publication are those of the author(s) and do not necessarily  
reflect the views of the National Science Foundation.

# Preface



In early fall of 1974 the Research Applied to National Needs Program of the National Science Foundation issued an announcement soliciting bids on several research topics. One of these called for the performance of an extensive technology assessment of hail suppression in the United States.

*Background  
of TASH  
project*

This announcement triggered interest in four persons — each from a different discipline — but all with an interest and experience in weather modification and a base of having worked together on previous projects. The interdisciplinary character of a technology assessment required both a diversified research team and a compatible one.

Discussions were pursued among the four — *Stanley A. Changnon, Jr.*, Head of the Atmospheric Sciences Section of the Illinois State Water Survey, *Professor Ray Jay Davis*, a lawyer at the University of Arizona, *Dr. J. Eugene Haas*, a sociologist at the University of Colorado and President of Human Ecology Research Services, Incorporated, and *Dr. Earl R. Swanson*, Professor of Agricultural Economics at the University of Illinois. The discussions led to preparation of a proposal that involved these four persons and their professional groups, plus *Dr. Martin V. Jones*, a technology assessment specialist of the Impact Assessment Institute.

The proposal was prepared under the auspices of the University of Illinois as the grantee institution and was submitted to the National Science Foundation in November 1974. The two co-located Illinois scientists — *Changnon and Swanson* — were established as the co-principal investigators of the grant, with the grant to be administered and handled at the University of Illinois, Urbana Campus. The other team members were connected to the project through subcontracts or consulting agreements.

After further negotiations with NSF during the spring of 1975, the project was funded in mid-August 1975 and work began immediately. This grant for a Technology Assessment of the Suppression of Hail (TASH) was from the Office

of Exploratory Research and Problem Assessment of RANN, grant number ERP 75-09980 under the direction of *Dr. Pat Johnson*, Program Manager. Portions of the funding came from the Weather Modification Program of NSF/RANN, under the direction of *Currie Downie*.

An interesting and essential aspect of the project was the requirement for widely divergent expertise among the team. Gathering of the divergent expertise required involvement of team members and consultants from institutions widely scattered through the United States including Arizona, California, Colorado, Connecticut, Illinois, Oklahoma, Washington, D. C. and others. This dispersion in space and in interests necessitated a strong interactive research plan involving frequent use of conference calls and long-duration team meetings. Major project meetings occurred as follows:

Urbana, Illinois	August 1975
Boulder, Colorado	November 1975
Urbana, Illinois	January 1976
Tucson, Arizona	April 1976
Boulder, Colorado	June 1976
San Diego, California	September 1976
Chicago, Illinois	December 1976

In addition, there have been numerous team meetings at various scientific conferences where two or more TASH team members were present to give papers. Needless to say, there has also been extensive letter and memorandum preparation in an effort to keep everyone interested and involved at all times. When we consider the areal spread and intrinsic discipline-related differences of those involved (physical scientists, social scientists, business executives, weather modifiers, lawyers), the high degree of cooperation and attention to scheduling has been amazing. The basic responsibilities of the five groups involved in TASH were as follows:

*The five  
TASH  
teams*

- *Illinois State Water Survey (ISWS)* — project administration, meteorology and climatology, and impacted industries
- *University of Illinois* — all economic aspects
- *Human Ecology Research Services (HERS)* — all social and institutional studies
- *Ray Jay Davis* — all legal issues
- *Impact Assessment Institute (IAI)* — project guidance, environmental concerns, and special investigations

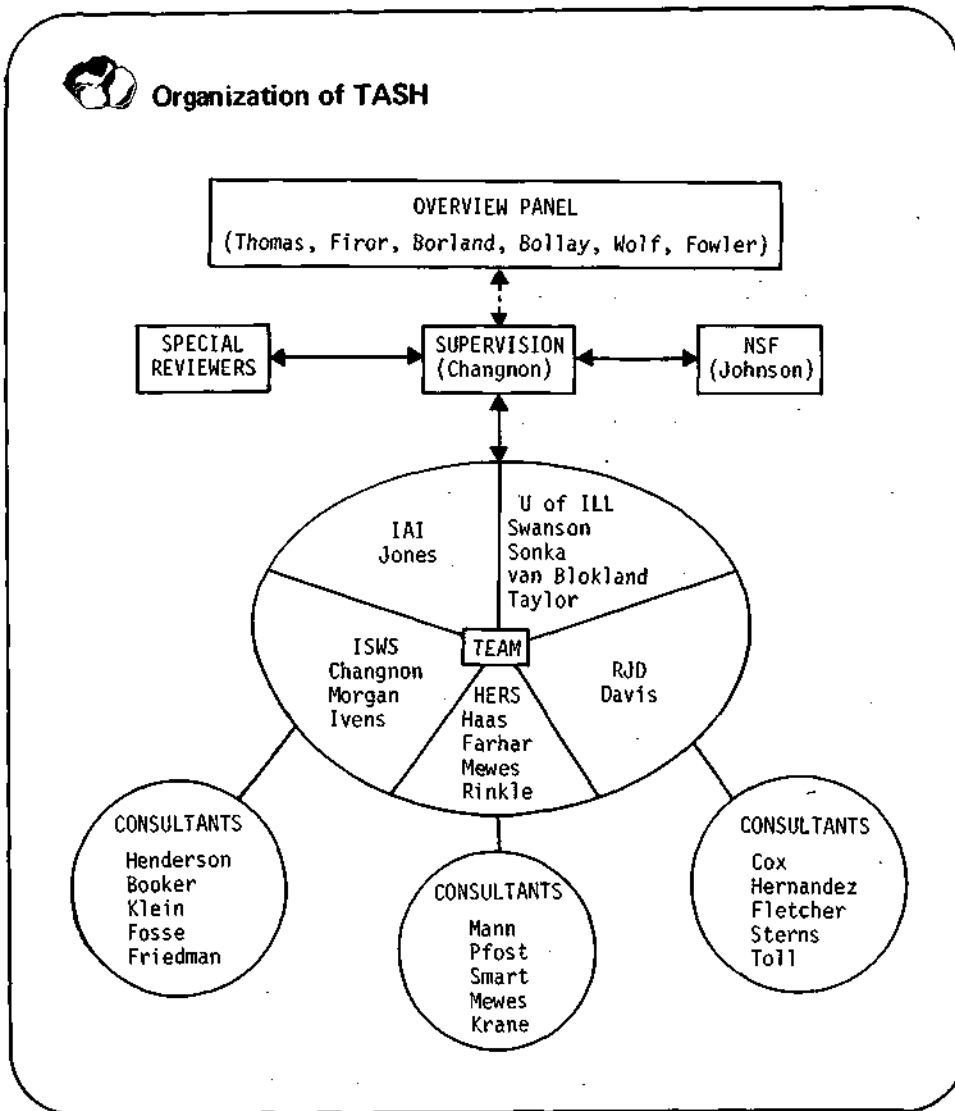
All but IAI were also scheduled to be heavily involved in the final project activity — transferring the results to users. The user interaction effort has involved not only the preparation of this final report, but also two user workshops and a summary publication, *Hail Suppression and Society*, to provide the most prominent TASH findings for general readers and policy planners.

Total funding for the 18-month project included \$290,500 from NSF/RANN

and \$60,000 from the State of Illinois. The project funds were allocated such that the Illinois State Water Survey received about \$140,000, University of Illinois \$70,000, Human Ecology Research Services \$93,000, Ray J. Davis \$25,000, and IAI \$23,500.

The organization of TASH (Technology Assessment of the Suppression of Hail) is shown in the diagram below. Project supervision, largely in a management-organizational sense, was provided by *Stanley A. Changnon, Jr.*, of the Illinois State Water Survey. The project overview panel consisted of *William A. Thomas* of the American Bar Foundation, *Dr. John W. Firor* of the National Center for Atmospheric Research, *Dr. Stewart W. Borland* of Agriculture Canada, *Wayne L. Fowler* of DeKalb AgResearch Incorporated, *Dr. Charles P. Wolf* of the Office of Technology Assessment, and *Dr. Eugene Bollay*, a meteorologist and ex-owner of a weather modification company. These panelists

Overview  
panel



reviewed and guided the early planning of TASH, and have subsequently reviewed and commented on the third and fourth versions of the final report. Their interests and contributions have been invaluable to the project.

The major TASH team was composed of the five entities shown in the center of the diagram.

*Uof I  
team*

The University of Illinois portion of the team included four agricultural economists under the leadership of Dr. *Swanson*, who directed the endeavors. Dr. *Steven T. Sonka* conducted the individual farmer analyses and the study of the value of future experimentation. Dr. *Jon van Blokland* modified the national economic model and analyzed the results therefrom, and Dr. *C. Robert Taylor* collaborated in the design and construction of the national economic model. Three graduate students assisted, including *Craig W. Potter*, who worked on the individual farm analyses, and *Emmett W. Elam* and *Klaus K. Frohberg*, who worked in the computer modeling and analysis of the national economic model. The research effort of Dr. *van Blokland* also became his doctoral dissertation and that of Mr. *Potter* was his masters thesis.

*Authors  
identified  
by section*

*It should be noted that the authors of the various sections and subsections of this report are identified throughout according to the sections they contributed. Obviously, the economists contributed to information on the costs due to hail, and all other farm, regional, and national aspects of hail loss and its modification including benefit-cost studies. All team members participated in the review of all sections.*

*Impact  
Assessment  
Institute*

The activities of the Impact Assessment Institute were under the direction of Dr. *Martin V. Jones*, an economist and specialist in technology assessment. He gave guidance in the methodology of technology assessment to the team, reviewed the products and commented on them, and helped in writing certain portions of the text. He was invaluable in guiding the team into technology assessment. He was assisted in a research and supporting role by *Richard M. Jones*.

*Davis  
team*

*Professor Ray Jay Davis*, of the College of Law at the University of Arizona, provided the legal analyses, interpretation, and related text. Much background research in various areas of law was required, and series of working papers were prepared by graduate students including *Steve Cox*, *Steven Hernandez*, *Guy Fletcher*, *Patricia Sterns*, and *Jim Toll*.

*The activities of the consultants for the other major teams of TASH were comparable to those for Davis. A basic approach used in TASH was to obtain background or "position papers" written by consultants. These were in turn used in building the final text.*

*HERS  
group*

The Human Ecology Research Services group was under the general direction of Dr. *J. Eugene Haas*, sociologist at the University of Colorado. Dr. *Haas* took on

the responsibility of integrating the results of the various components of TASH and thus the analysis of the impacts, the public policy options, and the recommendations. *Dr. Barbara C. Farhar*, also at the University of Colorado and HERS, coordinated the HERS work on TASH, prepared historical and case study material, the adoption analysis, and was a leader of the user workshops. *Julia Mewes*, Research Associate, prepared historical and case study materials, and *Ronald Rinkle*, also a Research Associate, prepared major data documents on societal parameters. *Sigmund Krane* contributed to the early development of the project, and *Charlotte Purvis* and *Dee Nervig* assisted with manuscript preparation.

*Dr. Dean Mann*, professor at the University of California at Santa Barbara, was a major consultant to HERS and the entire TASH team. He brought expertise in political institutions and institutional arrangements and wrote several valuable position papers. Other consultants for HERS were *Dr. Horst Mewes*, consultant in political science, *Dr. Donald Pfost*, consultant in sociology, who conducted the study in nonadopting eastern tobacco areas, and *Dr. George Smart*, who was a consultant in sociology and prepared the case history on North Dakota.

*HERS  
consultants*

The Illinois State Water Survey effort was threefold. *Changnon* gave scientific guidance to the meteorological-climatological efforts of the Survey as well as providing project direction and working heavily on user interactions. *J. Loreena Ivens* prepared the sections on insurance, designed the format of the final report, and made a major contribution in the difficult and tedious task of reviewing, editing, and writing so as to give the contributions of 13 authors a flavor of single authorship. *Griffith M. Morgan, Jr.*, as a meteorologist performed the major analyses of hailstorm days and wrote portions of the text relating to the theories and techniques of weather modification. *Suzi L. O'Connor* did the type composition and makeup of the text and illustrations, *John W. Brother, Jr.* prepared the art work, and *William Schmidt* and *Patti Welch* worked in the editing and reference area. Other contributing Survey staff members included *Thomas J. Ealy*, who handled much of the complicated project business affairs and assisted in the management. *Kim Young* and *Mary Owens* did the extensive data and map plotting and proofreading of the report.

*ISWS  
team  
efforts*

Consultants to the Water Survey were centered in three areas. First, to give guidance in the industrial sector of weather modification, *Thomas J. Henderson*, President of Atmospherics Incorporated, and *Dr. Ray Booker*, President of Aerometric Environment, served by reviewing documents and attending certain team meetings. *Dr. Donald A. Klein* of Colorado State University became involved through the preparation of the section on environmental impacts and was extremely helpful in this difficult area.

*ISWS  
consultants*

Major thanks go to *E. Ray Fosse*, Executive Secretary of the Crop-Hail Insurance Actuarial Association, for his considerable advice, attendance at team meetings,

preparation of an extremely valuable working paper on the crop-hail insurance industry, and provision at no cost to the project of extensive amounts of crop-hail loss data used by the University of Illinois economists. *Dr. Donald Friedman*, of Travelers Incorporated, also made a major new contribution by working in the area of property hail insurance, deriving the first good estimates of the amount of property loss from hail throughout the United States.

*We would be remiss by not mentioning that the entire Water Survey TASH effort was done under the general direction of Dr. William C. Ackermann, Chief of the Illinois State Water Survey. Without his enthusiastic backing and willingness to invest state funds in this project, it could not have been brought to a successful conclusion.*

*Special  
reviewers*

An early preparation of the final report was a major management strategy that guided the team's total efforts on this project. The full report was rewritten three times before the final draft was completed and submitted for sponsor review. This strategy, strongly urged by *Dr. Jones*, initially seemed infeasible to other team members. However, subsequent experience showed it to have at least two major advantages. First, it revealed important missing elements in the initial research plan and created a better appreciation for the project's dimensions and scope. Second, by having draft chapters available early in the life of the project, there was adequate time to obtain, and respond to, expert outside reviews. A box in the project organization chart (*page iii*) identifies this Special Review function, and the next paragraph lists the names of these reviewers.

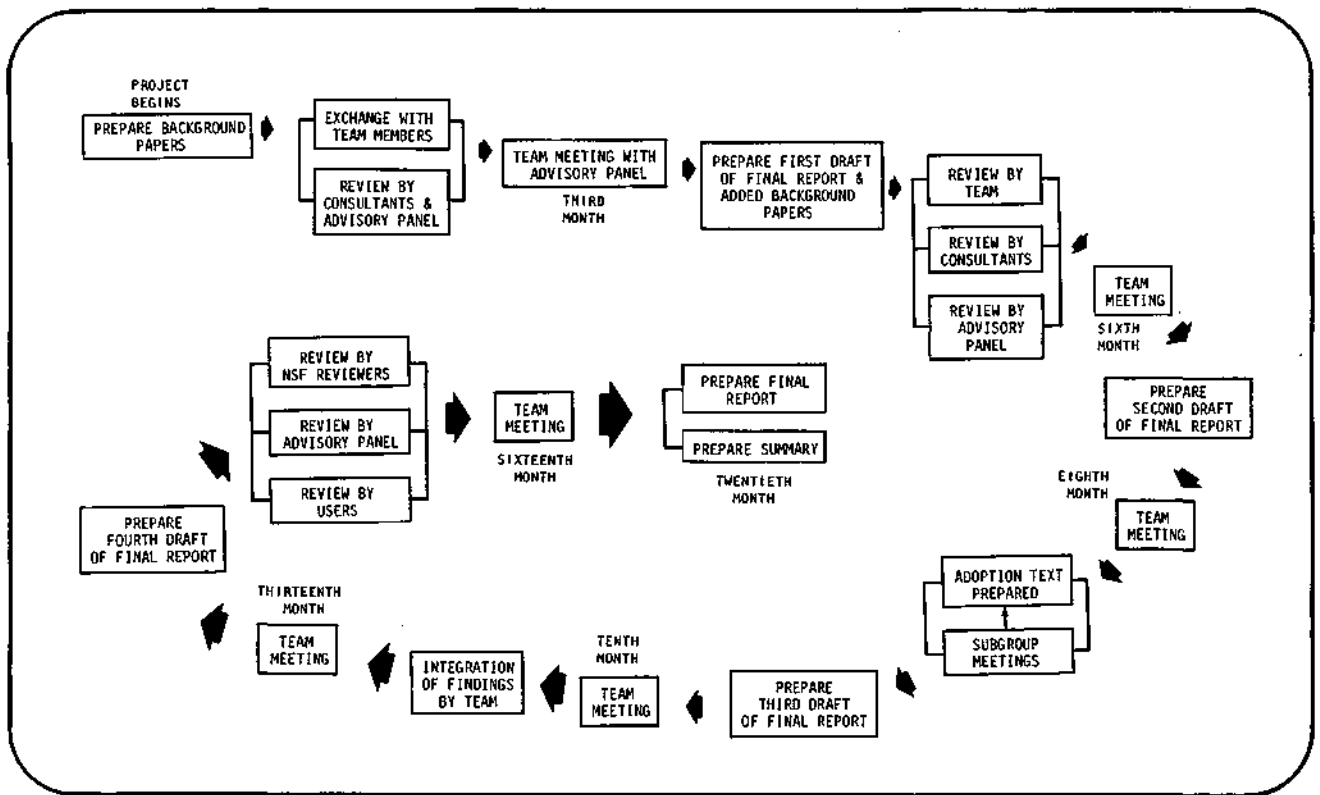
Among those who have given reviews of portions of these TASH texts are *Philip S. Brown*, President of the Hail Information Service, who critically reviewed the sections on the insurance industry. *Bryce A. Sides*, Director of Corporate Communications, and *Louis Rediger*, Head of Hail Insurance, both of the Country Companies, reviewed and commented on these insurance sections also. Material on the present and future status of hail suppression and the related technologies were reviewed and commented on by *Professor Louis J. Battan* of the University of Arizona and *Professor Roscoe Braham* of the University of Chicago. *Dr. Charles P. Cooper* of San Diego State College and *Dr. Harold Steinhoff* of Colorado State University both graciously reviewed and commented on the environmental text. Others were asked to give reviews of the entire text of the third version of the final report, including *Dorothy M. Wetzel*, an Editor at the University of Illinois, *Marc Changnon*, a County Extension Specialist in Illinois, and *Professor Howard Taubensfeld*, Professor of Law at Southern Methodist University. Advice from *Dr. Larry Davis*, President of Colorado International Corporation, on seeding technologies was very helpful. All of these reviewers gave their comments and their time at no expense to the TASH project and in all possible instances their thoughtful comments were incorporated to both correct and improve the TASH material. The critical reviews of the 34



persons who attended the TASH workshops to help us develop the summary document were extremely useful in revising and improving this final report. Our deepest gratitude goes to these people and to our special reviewers.

Two workshops were conducted in November 1976 to inform representatives from all groups interested in hail and its suppression about TASH results. Representatives came from diverse geographical areas and included people from state and federal government agencies, farmers and farm groups, the insurance industry, the weather modification industry, weather research groups, agribusiness, and environmental concerns. During these workshops, the participants provided their views as to key findings to guide us in the preparation of a separate summary document for TASH, *Hail Suppression and Society*. This short publication will be widely available.

A major issue in successful multidisciplinary research involving scientists with widely diverse backgrounds is the development of working interactions. This interaction was particularly critical for TASH since team members were distributed across the nation (Washington, D.C., Illinois, Colorado, Arizona, and California). The sequence of events involving the writing of informational (background) papers from each discipline, the writing and revision of five versions of the final report, the internal and external reviews of these documents, and team meetings is illustrated below, showing the truly multidisciplinary effort reflected in this report.



# Contents




## Part 1. The problem and solutions

### Chapter 1. Introduction —1

- What is technology assessment? —1
- Our objective and rationale —2
- The TASH approach -5
- References —8

### Chapter 2. The hail problem -9

- Characteristics of hail —9
  - The nature of hail —9
  - Hail regions in the United States —14
  - Critical storm features —16
- Economic losses from hail —24
  - Crop losses —25
  - Property losses —26
- Alternatives to hail suppression —28
  - Modifying the environment —28
  - Modifying human behavior —29
  - Summary of alternatives —30
- References —31
- Summary of chapter 2 —33
  - The hail problem and alternative solutions —33

 Part 2. The past and present

Chapter 3. Background	—37
Historical overview for hail suppression	—37
Early activities	—37
Summary	—40
Hail suppression efforts in the United States	—40
Cloud seeding records	—40
Social, economic, and political settings	—43
Project in San Luis Valley, Colorado	—46
Hail suppression in South Dakota	—50
Hail suppression in Texas Panhandle	—54
Hail suppression in other areas	—57
Nonadopting areas	—61
Hail suppression in other countries	—63
Foreign projects	—63
Exportation issues	—65
Current levels of hail suppression	—66
Project evaluations	—66
Published assessments	—69
Scientific opinion surveys	—71
References	—72
Summary of chapter 3	—77
Historical overview and current status of hail suppression	—77
Chapter 4. Hail suppression technology	—79
How it is done —the physics involved	—79
Ice nucleation	—79
Ice nucleants and how they work	—80
Delivery of seeding materials	—81
Inadvertent side effects	—83
The components of hail suppression	—87
Organizational elements	—87
Functional elements	—88
References	—92
Summary of chapter 4	—93
How hail suppression works	—93
Chapter 5. The stakeholders	—95
Agriculture as a major stakeholder	—95
Dimensions of the hail insurance industry	—97
Crop-hail insurance	—98
Government crop insurance	—101
Property insurance for hail	—104
The present hail suppression industry	—107

Firms in weather modification	—107
Size of hail suppression companies	—107
Hail suppression research —its dimensions	—109
The hail research story	—109
Major funding of research	—112
References	—115
Summary of chapter 5	—118
The major stakeholders	—118

## Chapter 6. Societal influences —119

Societal aspects of weather modification	—119
Adopting innovations	—120
Peoples' attitudes and concerns	—123
Socio-demographic variables	—129
Effect of scientific consensus	—131
Participation in modification decision making	—132
Organized opposition	—136
The law and hail suppression	—138
Our legal regime	—138
Administrative structure	—139
Direct suppression controls	—142
Indirect controls of suppression	—144
Government financing as controls	—146
Receptivity of legal controls to suppression	—148
Liability theories and actions	—150
Altered rainfall and water rights	—158
Hail suppression and the environment	—160
Alteration in species population	—161
Direct effects of nucleant	—161
Indirect effects of nucleant	—165
Changes in precipitation	—169
Legal considerations	—170
References	—173
Summary of chapter 6	—184
Societal influences	—184



## Part 3. The future of hail suppression

### Chapter 7. Generating forces —189

Food, climate, and economic interactive forces	—189
World food supply	—189
Changes in world climate	—191
Weather extremes	—192
Technology itself	—194
Potential farmer benefits from hail suppression	—195
Hail loss analysis	—195

Estimation results for six areas	—198
Comparison among regions	—205
References	—209
Summary of chapter 7	—210
Forces stimulating interest in hail suppression	—210
Chapter 8. Future suppression	—211
The future status of hail suppression	—211
Scientific assessment of future capabilities	—211
Features of future models	—214
Eastern Model 1	—215
Eastern Model 2	—219
Eastern Model 3	—219
Western Model 1	—220
Western Model 2	—220
Western Model 3	—221
Related technologies in the future	—221
Program design	—221
Operational components	—223
Costs of suppression projects	—226
Monitoring, evaluating suppression	—229
Information system	—231
Summary look at future capability	—232
References	—233
Summary of chapter 8	—236
The future of the technology	—236
Chapter 9. Future adoption patterns	—239
Methods used to estimate future adoption of hail suppression	—239
Economic incentive index values	—240
Receptivity of legal regime	—243
Socio-political factors	—244
Resulting predictions of adoption	—251
Integration of the variables	—251
Predicted adopting areas	—253
References	—255
Summary of chapter 9	—256
Future adoption of hail suppression	—256
Chapter 10. Effects of adoption	—259
National and regional economic impact	—259
The national economic model	—260
Crop production variables	—261
Demand for crops used in model	—264
Analytical approach	—265

Effect of suppression — national scale	—265
Returns to landowners — regional considerations	—266
Effects on regional production patterns	—269
Impact on commodity prices	—272
Secondary economic impacts in target communities	—274
Income, employment multipliers	—274
Size of secondary impacts	—274
Benefit-cost analysis for future suppression	—275
Basis for benefit-cost analysis	—275
Costs for operation activities	—277
Expenditures for future research	—277
DEI costs in large projects	—279
Benefits of hail suppression	—281
Benefit-cost values	—283
The research industry and future hail suppression	—287
Factors affecting future research	—287
Governmental support of research	—288
The future performers of research	—290
Value of future suppression research	—291
Effects on hail suppression industry	—303
Industry opinions about future	—303
Future outlook	—304
Effects of future suppression on hail insurance	—305
Impacts on crop-hail insurance	—305
Liability coverage problems	—312
Crop insurers' viewpoints on future suppression	—313
Effects on government insurance	—316
Impacts on property insurance	—317
Will insurance support suppression?	—322
References	—325
Summary of chapter 10	—328
Effects of adoption	—328

## Chapter 11. Future constraints — 331

Institutional arrangements for hail suppression	—331
Multijurisdictional controls of hail suppression	—333
Interstate problems, solutions	—333
International problems, solutions	—336
The environment — secondary impacts and needs	—339
Secondary impacts	—339
General conclusions	—341
Suggested actions	—342
Research needs for environment	—343
References	—344
Summary of chapter 11	—346
Future constraints	—346

Chapter 12. Future impacts	—347
Introduction —and basic assumptions	—347
Identifying and rating impacts	—349
Impacts with a significant modification capability —Model 1	—351
Major impacts —Model 1	—353
Impacts to individual —Model 1	—354
Impacts to community —Model 1	—355
Impacts to states —Model 1	—358
National impacts —general —Model 1	—360
National impacts —government —Model 1	—362
National impacts —research —Model 1	—364
National impacts —agribusiness —Model 1	—365
National impacts —suppression industry —Model 1	—366
National impacts —insurance —Model 1	—368
National impacts —international —Model 1	—370
Impacts with a limited modification capability —Model 3	—370
Major impacts —Model 3	—371
Impacts to individual —Model 3	—372
Impacts to community —Model 3	—373
Impacts to states —Model 3	—374
Impacts at national level —Model 3	—376
Scenario — Story of hail suppression at work	—378
Model 1 during 1976-1980	—379
Model 1 progress 1980-1985	—380
Model 1 advances 1986-1990	—383
Model 1 during 1991-1995	—385
Scenario — Story of hail suppression at work	—388
Model 3 during 1976-1995	—388
Model 3 impacts	—389
Summary of chapter 12	—391
Future impacts	—391



#### Part 4. What can and should be done

Chapter 13. Public policy options	—395
Public policy options —and the first issue	—395
First — what extent of support?	—396
Second —the other issues	—398
What shall be the sources of funding?	—399
Funding for research	—399
Funding for operations	—400
Should compensation be provided the losers? If so, how?	—401
The damage dilemma	—401
Workable solutions	—402
How shall regulation responsibility be divided?	—403
Present regulations	—403

Future regulation possibilities	—404
What federal involvement in multistate operations?	—405
Multistate voluntary cooperation	—406
Interstate compacts	—406
Federal corporations	—407
How involve stakeholders in policy decisions?	—407
Problems in sharing decision making	—407
Available options	—408
What administrative arrangements for operational programs?	—409
Administrative unit options	—409
Likely problems	—410
What extent of monitoring, record keeping, and evaluation?	—411
What is needed	—411
Options for handling	—412
Summary of chapter 13	—414
Public policy options	—414

## Chapter 14. Conclusions and recommendations —417

Conclusions	—417
General recommendations	—420
Public policy recommendations — federal government	—421
Public policy recommendations — states	—423
Research recommendations — interdisciplinary	—424
Research recommendations — scientific and technical	—425
Research recommendations — socio—political—economic	—426
Research recommendations — legal	—426
Research recommendations — environmental	—427

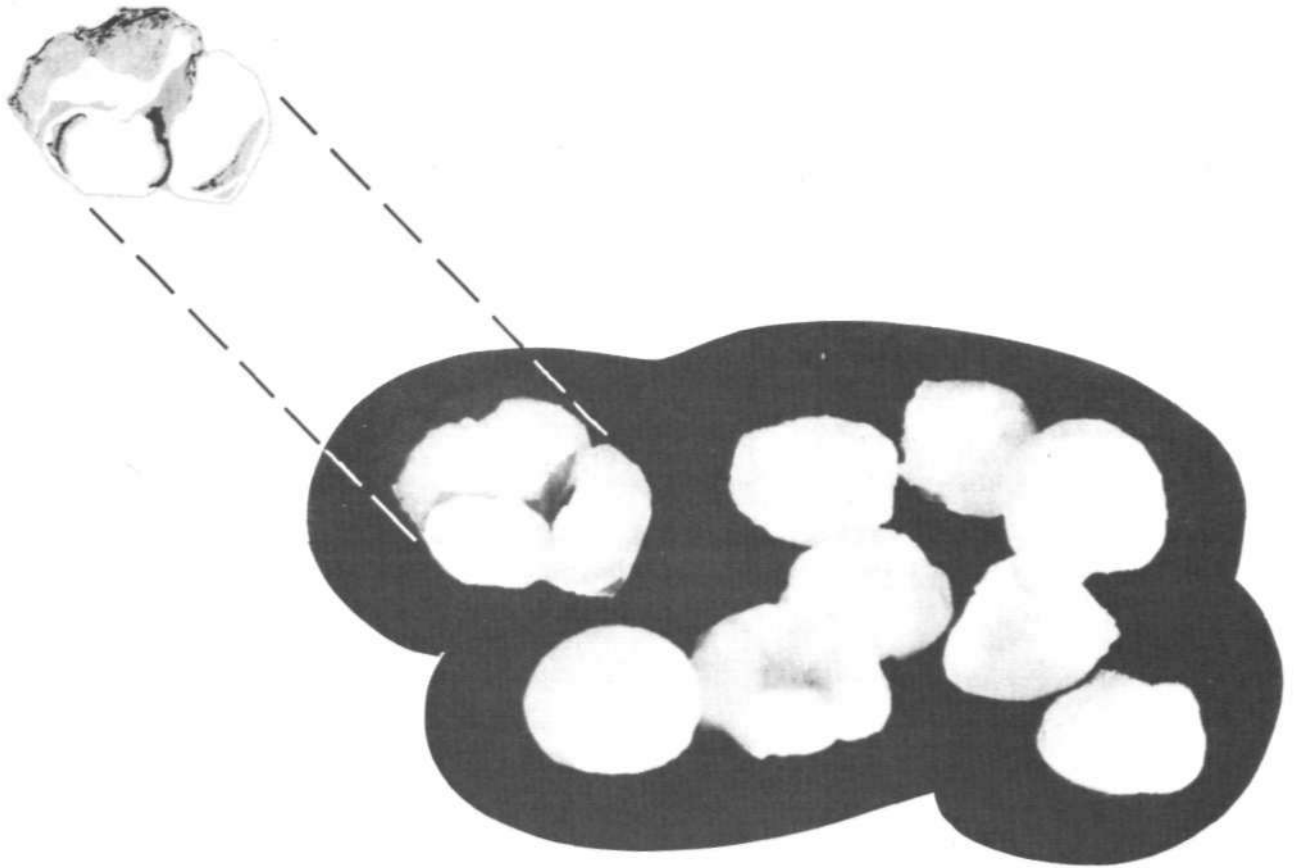
Subject index

Glossary of acronyms



# Part 1

## The problem and solutions



# 1

## Introduction



For many years — and in diverse ways — farmers have tried to protect their growing crops from the damages of hail.

A new possibility emerged shortly after World War II. With the discovery of the artificial formation of ice crystals and the subsequent development of cloud-seeding techniques, attempts to adapt cloud seeding to the suppression of hail began. A number of operational projects were tried, and a few scientific experiments later were carried out.

Thus far the results have been varied and indecisive. Some believe 20 to 30% reductions in hail have been achieved. Others believe cloud seeding efforts have increased hail, or caused droughts, or accomplished nothing. For the most part, hail suppression attempts in the United States have been accompanied by local controversies and scientific quandaries. The answer, as yet, is uncertain — but the use of hail suppression continues, as does research to further develop it.

Interested scientists and concerned national leaders therefore believed that a comprehensive technology assessment study of hail suppression would be valuable at this time. This effort was undertaken by our multidisciplinary team under the project title of TASH, Technology Assessment of the Suppression of Hail.

### WHAT IS TECHNOLOGY ASSESSMENT?\*



Technology assessment is a systematic attempt to anticipate the future effects that might result from a new or expanding technology — as an aid to planning and decision making. Its intent is not so much to explain how the technology works — although an extensive technological description is provided —

*A look  
at the future*

This chapter contributed by J. Loreena Ivens, Stanley A. Changnon, Jr., and Barbara C. Farhar.

as to explore how the technology might affect and be affected by the many facets of society it might touch.

The technology assessment study draws upon and integrates the knowledge and insights regarding the new technology from a variety of disciplines. A technology assessment may be characterized as a comprehensive, interdisciplinary, and futuristic study of a technology in relation to society.

*A look for unintended effects*

A pioneer in the field calls technology assessment a "*class of policy studies which systematically examines the effects on society that may occur when a technology is introduced, extended, or modified, with special emphasis on those consequences that are unintended, indirect, or delayed*" (Coates, 1974). The Technology Assessment Act of 1972 refers to it as a method of ascertaining "*early indications of the probable beneficial and adverse impacts of the applications of technology.*"

Approximately 50 comprehensive technology assessment studies, plus a number of limited studies, have been funded during the last five years, primarily by the National Science Foundation but also by the Congressional Office of Technology assessment, several other federal agencies, and a few private organizations.

Topics addressed in the numerous federal studies have included such diverse interests as coastal zone oil and gas development, solar energy, earthquake prediction, integrated hog farming, and the cashless-checkless society.

## OUR OBJECTIVE AND RATIONALE



The TASH study of the technology of hail suppression is intended to bring together all of the considerations involved in its application —now and in the future —to ascertain its net value to society. The study's goals are:

- To describe the current knowledge of hail suppression
- To identify long-range expectations for such a technology
- To estimate the societal impacts that might be generated by its wide use
- To examine public policy actions that would most equitably direct its beneficial use

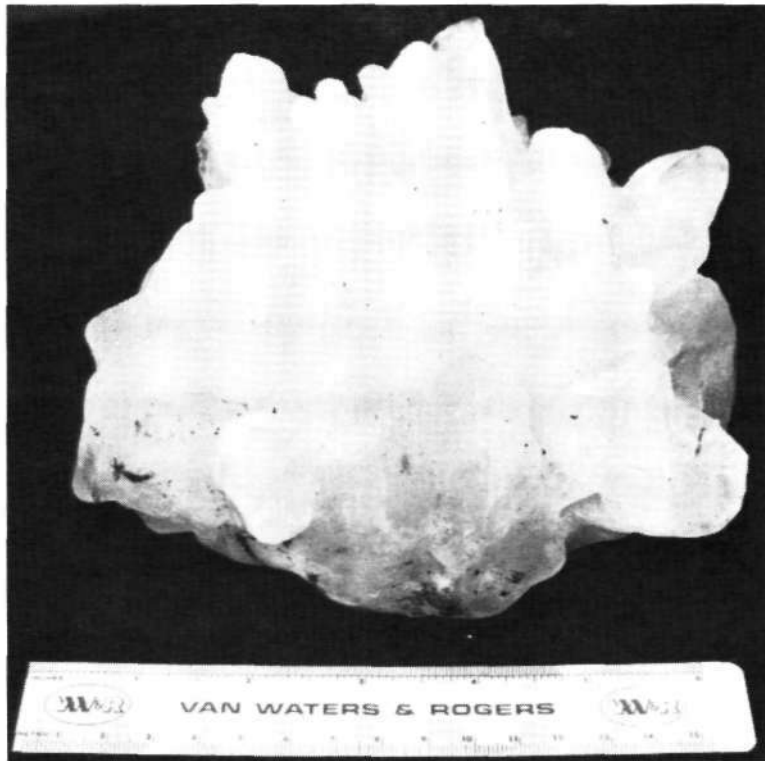
*Reasons for assessing hail suppression*

In brief, through technology assessment we are attempting to identify for the emerging technology of hail suppression a comprehensive range of potential impacts —direct and indirect, immediate and delayed, unfavorable and favorable. In its program solicitation for this assessment effort, the National Science Foundation (1974) stated that, although weather modification has the potential for a major impact, "*political, legal, economic, social issues, and constraints on the technology will become more important as large field experiments are conducted which may lead to routine practice. Hail suppression has been chosen for assessment as a specific technology having great potential benefits and as a subject of an on-going federal research program.*"



FIGURE 1

Six-inch hailstone



(Photo: NCAR)

The stage for the assessment of this technology had in part been set in 1973 by Dr. H. Guyford Stever, then Director of the National Science Foundation, when he noted that weather modification was an extremely important subject for assessment (Stever, 1973). Dr. Stever said:

"The fact that we are beginning to know enough to develop the means to suppress local hailstorms, cause rainfall, increase snowfall, and someday perhaps divert or prevent major storms such as hurricanes has enormous implications.

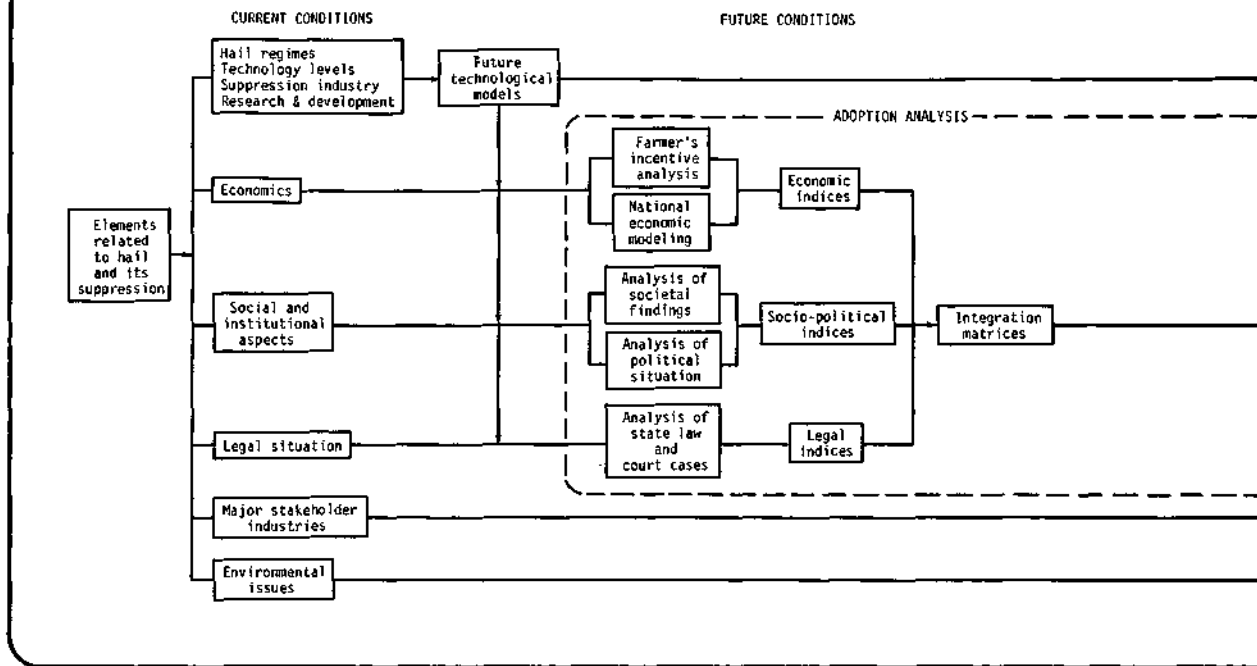
"The positive aspects are more or less obvious — vast savings of crops and property losses, more water where and when we need it and of course, a reduction of the human misery associated with the whims of weather. But we can see why a most thorough assessment is necessary when we start asking questions like: Who will control the weather? For what benefit and at whose expense? What will be the effects of improper control? Who will pay the consequences? What will be the international implications?"

Hail suppression is an appropriate subject for an assessment study because it has a substantial potential for generating a whole series of second-level impacts *over and beyond its direct mission* of reducing the financial losses from hailstorms.



**FIGURE 2**

**Key elements of hail suppression technology assessment and their temporal interactions**



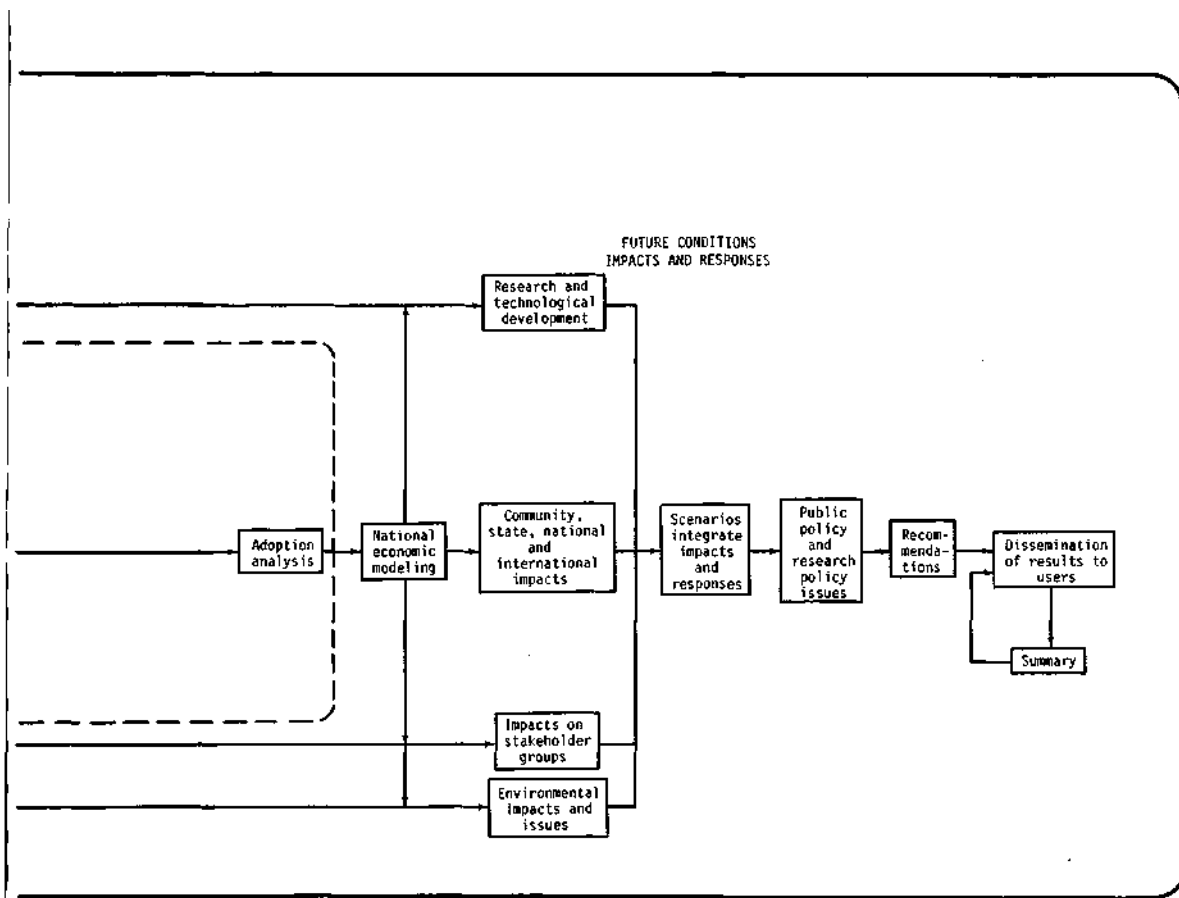
As our text will indicate, some of these second-level or delayed impacts would probably be favorable, others unfavorable. Assessment is needed because the case for either the favorable or the unfavorable has been essentially undocumented.

We realize that the present study will not, of course, completely resolve these issues one way or the other. We hope, however, it will bring the issues into sharper focus, assigning likelihood ratings to some, anticipated magnitudes to others, and finally suggesting how public policy can foster the favorable potentialities and minimize the unfavorable ones.

*Still time  
to change  
future course*

Technology assessment for hail suppression is propitious at this time for two other reasons. First, from a policy point of view, development and application of hail suppression technologies have not yet proceeded so far that efforts to redirect present trends would be institutionally impractical. There is *still time to decide* whether or not and in what manner future hail suppression efforts should proceed.

Second, we have a respectable conceptual and empirical base for conducting this study. For instance, a considerable body of field research — both physical and social science — on individual facets of this issue has been completed. We have considered it the task of this study to integrate the work completed to date and to lay a foundation for future considerations.



## THE TASH APPROACH



The assessment of hail suppression as a future technology for the United States was complicated for two reasons. First, hail as a weather element not only affects a large portion of the American populace but also has been approached by a wide variety of scientific disciplines. Second, the current technology is so uncertain that assessing the future technology itself required a more extensive effort than needed in many other technology assessments. A literature review on all relevant facets of hail suppression had never before been completed. Thus, a significant proportion of the TASH final report is concerned with defining the current state of knowledge with regard to the technology itself and its related studies. The first major effort of TASH was to collect and inventory existing data and information bases in a range of disciplines. This effort is symbolized as "CURRENT CONDITIONS" in *Figure 2*.

*Technology definition — a major effort*

Background explanatory papers, called working papers, were prepared in each discipline and distributed to inform other team members of basic results. These papers served as the first step in the integrative process of TASH. The major topical areas addressed in this early work are listed in *Figure 2* and included descriptions of the hail problem in the United States, hail suppression science and technology, social and institutional aspects, economics of hail, legal considerations,

*Current conditions dimensionalized*

environmental issues, and the identification of major stakeholder groups — those whose interests would be affected in some way by effective hail suppression.

The first draft of the final report was then prepared. This exercise enabled the study team to identify gaps in existing data bases necessary to fill during the course of the TASH study, and to define the interactions necessary among disciplines to achieve integration of disciplinary findings and the subsequent analysis of future adoption, its societal impacts, and the policy issues and recommendations following therefrom.

*Time and  
space  
frameworks*

The team decided to consider all conditions at three points in time:

- The now or 1975 conditions
- Those projected for 1985
- Those projected for 1995

Findings were treated on various space scales depending on the discipline involved. That is, states were used for legal and some societal studies, crop-producing areas for economics, and so on. Ultimately, however, all regions used in the different analyses were defined by state lines so that the findings of different disciplines could be most easily combined. These, then, were the time and space frameworks for integrating the research results.

Because none of the existing data on hail and hail suppression had been organized previously in one volume, a sizable proportion of this final report is given over to a description of the background and current conditions as a *foundation for the future analyses*.

*Models of the  
future  
technology*

The next essential step in the research process was the definition of future hail suppression capabilities. Three different levels of effective hail modification, accompanied in some cases by effects on precipitation, were projected to be attained by 1985 and by 1995. (These are labeled "Future Technological Models" under "FUTURE CONDITIONS" in *Figure 2*.) These future models of hail suppression technology were the basis for the future analyses of all facets of TASH — societal, legal, institutional, and economic — and for impact analyses and definitions of policy issues.

*Integration  
and future  
adoption estimates*

The first major integration of disciplinary findings was begun in the TASH adoption analysis. Economic findings from both individual and nationwide analyses and findings from legal studies and socio-political data were combined to yield estimates of the probable future adoption of the three future hail suppression models in the nation. This effort is shown on *Figure 2*.

Results flowing from the adoption analysis were then utilized by TASH economists to produce a nationwide evaluation of the economic impact on agriculture for each of the three future hail suppression capabilities. Other team members subsequently analyzed the probable impacts of hail suppression on direct stakeholder groups such as the hail insurance industry and the weather modification research community. Environmental impacts were evaluated during this phase of the study.

Results of these separate impact analyses were systematically combined in the TASH impact analysis utilizing a matrix of class of impact (economic, political, social, and so forth) and the system level impacted (individual, community, state, and so on). Illustrative of the impacts are two alternative scenarios of the possible future development of hail suppression and the societal consequences emanating from them.

*Predicted  
impacts*

Policy issues were identified throughout the course of the study. These issues were combined with results of the impact analyses and estimated responses, coupled with the analysis of current conditions, to produce a set of study conclusions and recommendations for public policy action and for research.

*Policy  
issues and  
recommendations*

The final step for TASH was dissemination of results to users. This final report and its supporting volumes of disciplinary working papers are two media of information exchange. Two user workshops were held in November 1976 — one with a local focus and the other with a national focus — as a basis for developing the TASH summary, a short document designed for widespread distribution. Users reviewed the next-to-final draft of the final report and made recommendations as to the key points that the summary, entitled *Hail Suppression and Society*, should contain.

*Information  
to users*

Integration of effort and thinking to produce a truly interdisciplinary treatment of hail suppression was accomplished in four ways. First was the exchange of disciplinary working papers, next the sequential preparation of four versions of the final report, then the active integration of products in the adoption analyses followed by the impact analyses, and finally frequent meetings of TASH team members.

This final report is divided into four parts. *Part 1* presents the problem. Here Chapters 1 and 2 introduce the study and the problem of hail, how and where it occurs, the damage it causes, and the alternative solutions to the problem — leading to further consideration of hail suppression as a technological alternative.

*Part 1 -  
The hail  
problem*

*Part 2* provides background — a review of the past and a look at the present. Within *Part 2*, Chapter 3 gives an historical overview, then a synopsis of detailed case histories of hail suppression projects in the United States, a glance at projects abroad, and an evaluation of the current status of the technology of hail suppression. Chapter 4 briefly describes the technology — its scientific principles and mechanisms, plus its functional components. Chapter 5 identifies the direct, major stakeholders — those who now deal with the hail problem including agriculture, insurance, commercial modifying firms, and research groups — and describes the present dimensions of their interests. Chapter 6 concludes *Part 2* with examination of the socio-political, legal, and environmental factors that now influence and may constrain the use of the technology of hail suppression.

*Part 2 -  
Background*

*Part 3* contemplates the future of hail suppression. It opens in Chapter 7 with a consideration of the generating forces — the overriding national concerns and propensities that could motivate use of a technology that would alleviate hail damage — combined with an individual farmer's economic motive.

*Part 3 -  
Future*



Chapter 8 presents the scientific models that were developed in the TASH study for the possible future technological capabilities of hail suppression at three levels, depending on levels of support and attendant developments. The three models of capability ranged from optimistic to pessimistic and were developed for both the western and eastern portions of the United States. Costs of future suppression activities and related technologies are also considered.

Chapter 9 then patterns the adoption of hail suppression in the United States for the various scientific models, based on an integrative analysis of the economic incentives, legal receptivity, and socio-political factors influencing adoption.

Chapter 10 looks to the future effects for stakeholders if the three models of scientific capability came about and were used according to the predicted adoption patterns. Considered first are the economic impacts for agriculture as depicted by the national economic model, including a full analysis of cost and benefits. Considerations of other stakeholders include impacts on the research, commercial hail suppression, and insurance industries. A method of estimating the economic value of future hail suppression research, illustrated by hypothetical data, is also presented.

Chapter 11 looks at likely developments in institutional arrangements and law for hail suppression activities of the future —and considers the possible secondary impacts and future research needs concerning the environment.

The look at the future closes in Chapter 12 with the identification of the range of secondary and tertiary impacts from adoption of hail suppression programs over the next two decades. Finally, the impacts are described in scenario form to depict time sequences and processes for the impacts flowing from the different potential hail suppression capabilities and adoption patterns.

*Part 4 —  
Options,  
conclusions and  
recommendations*

*Part 4* completes the TASH study with presentation of the team's conclusions on what can and should be done. Chapter 13 considers options for public policy as to what might be done to maximize the net public benefit and minimize disbenefit from hail suppression. Chapter 14 then presents our conclusions and recommendations for public policy actions and for research.

## REFERENCES

- Coates, J. F.  
1974 *Some methods and techniques for comprehensive impact assessment.* American Elsevier Publishing Company, Inc., Technology Forecasting and Social Change, 6, 341-357.
- National Science Foundation  
1974 *Technology assessments in selected areas.* Program Solicitation, Office of Exploratory Research and Problem Assessment, Washington, D.C., 11 pp.
- Stever, H. G.  
1973 *The growing responsibilities of science and technology.* Phi Beta Kappa Lecture, National Science Foundation, Washington, D.C., 28 pp.

# 2

## The hail problem



At the moment of its happening, a hailstorm can seem a most disastrous event. Crashing stones, often deluged in rain and hurled to the surface by wind, can create instant destruction. Picture windows may be broken, cars dented, or a whole field of corn shredded before our eyes.

Then quite quickly, the storm is over. Now the damage is before us, we perceive it to be great, and we vow to do something to prevent its happening again.

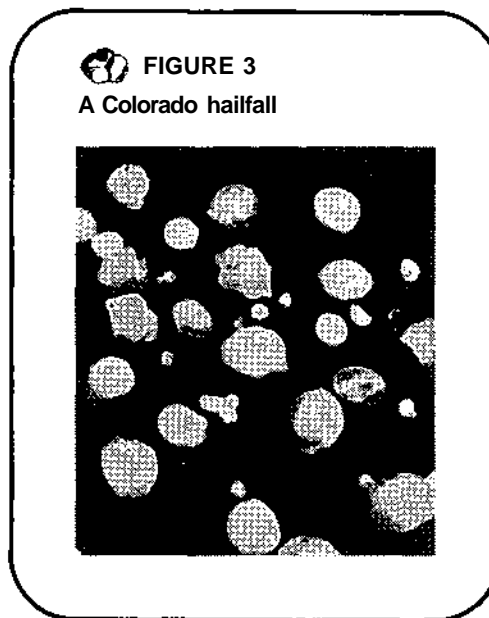
But what we have experienced is "our" storm. Hail did not happen perhaps a mile away. We may see another the same day, or never again. Thus, the concept of hail suppression is founded in a real or perceived need, but the assessment of this solution must be considered in terms of the nature of hail. This chapter provides a national overview of the dimensions of the hail problem, its economic consequences, and the various alternatives for solving the problem. It attempts to answer: Where, when, and in what manner does hail occur? What are the damages? What can we do about it?

### CHARACTERISTICS OF HAIL



The key characteristic of hail is its enormous variability—in size, in time, and in space. This variability starts with the hailstones, as we show in *Figure 3* where a dozen different sizes are found from one storm and on a surface no larger than the average kitchen floor.

*Figure 4* shows the great variabilities across the country. This is the average pattern of days with hail, based on point frequencies, and these averages range from 10 days per year to less than 1 day a year. Further, the variations occur within very short distances, though clearly high averages concentrate through the central United States.



**FIGURE 3**  
A Colorado hailfall

### THE NATURE OF HAIL\*

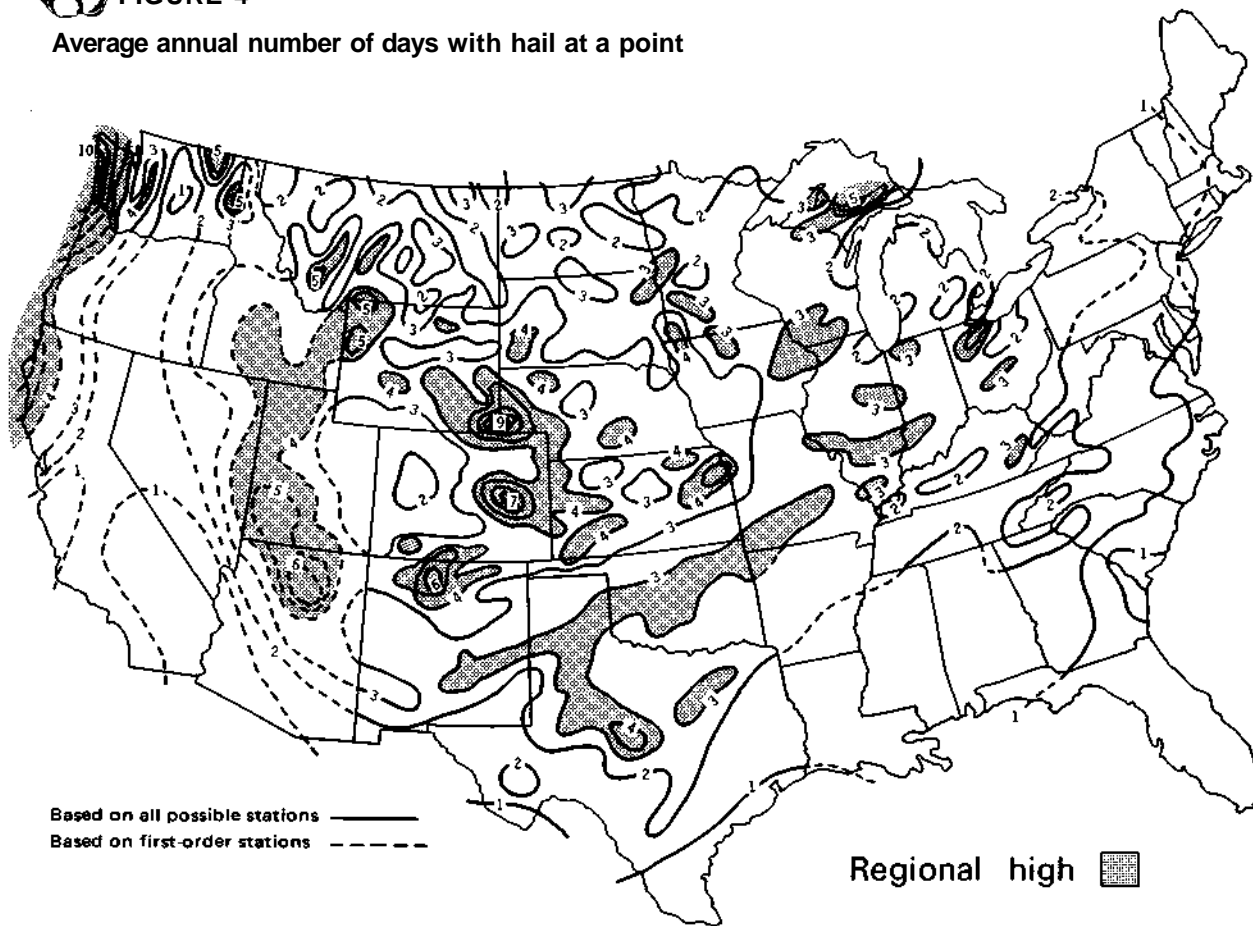
*How often does hail occur?*

\*This section contributed by Stanley A. Changnon, Jr.



FIGURE 4

Average annual number of days with hail at a point



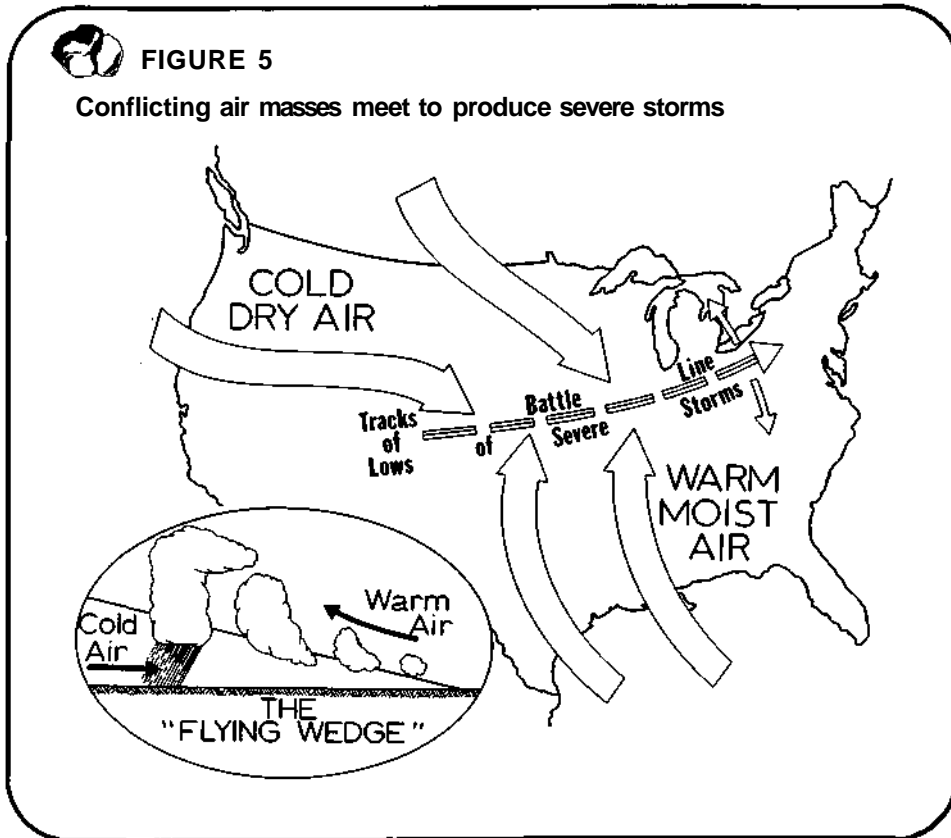
Note: The lines enclose points (stations) that have equal frequency of hail days

Thus we see hail as a very small-scale phenomenon and a relatively infrequent event at any one point.

Most of what we know of the time and space dimensions of hail in this country comes from studies made in either the 1940s or 1960s. Agricultural interests in the '40s motivated hail studies that were based on data from the 200 or so national weather service stations. A second wave of interest from aviation, insurance, and weather modification industries in the '60s brought about more intensive studies. These used not only the weather service data but also insurance data and data from special meteorological networks where hail had been measured in detail across small areas from 100 to 5000 square miles. Descriptions of hail in the United States have been brought together by Changnon (1975).

*How hail occurs*

Most hail is produced by thunderstorms in which strong vertical motions are in-



duced usually by weather fronts or the mountains. However, the Great Lakes, because of their size, also affect the frequency of hail-producing storms.

Except for the often isolated hailfalls in and near the mountains, most hailstorms in the United States are produced along a line (a front) where rapidly advancing cold air battles warm moist air, wedging under it and lifting it to produce clouds and storms. We have depicted this conflict of air masses in *Figure 5*. The locale of the battle line varies seasonally and depends on the track of the low-pressure centers which drag fronts with them. High incidences of hail occur where the fronts most frequently develop or stagnate. Study of the national pattern in *Figure 4* identified 28 major highs of hail incidence — 10 in the western states, 5 affected by the Great Lakes, and 13 in the Midwest.

*Great Plains  
 hail more  
 intense*

The "intensity" of hail is what produces damage, and intensity is a function of the number of stones, their sizes, and the wind. Intensity also varies on a national scale. Changnon and Stout (1967), through studies of crop damages, found that hailstorms during the peak of the loss season in eastern Colorado produce hail that is 18 times more intense than the typical crop season storms in the Midwest. Intensity decreased very rapidly away from the Great Plains. However, intensity differences from west to east are partially influenced by differences in the way a given crop is planted. Wheat, for instance, is put in narrow rows in the Midwest,

*"Intensity"  
 does the  
 damage*

and this higher density tends to protect it from hail, whereas the thinner wheat stands in the Great Plains are more open to damage.

*Stone sizes differ by region*

Since hailstone sizes as well as the number of stones are important to intensity, size distributions help account for regional differences. Hailstone sizes have not been systematically measured throughout the United States, but small-area studies provide some information. Clearly, the greatest frequency of large stones is found in the lee-of-the-mountain locales like Colorado. Small hailstones dominate in Illinois, New England, and the mountain-top areas of Arizona.

Look at these variations. An Illinois hailfall averages 24 stones in a square foot and only about 2% of these are over a half-inch in diameter. In northeast Colorado, a hailfall averages 202 stones per square foot and more than half of these (51%) are *larger* than a half-inch.

*Time of year makes a difference*

The season of high hail activity varies across the country, also. Season is important because of the stage of growing plants that might be damaged by hail. East of the Great Plains, maximum hail activity is in the spring months, starting in March in the far south and moving to May in the northern states. In the lee-of-the-mountain states, maximum hail activity happens in the summer months. The Great Lakes area is the only place in North America where maximum hail occurs in fall months. Along the West Coast, certain areas have their high hail in late winter or spring.

*Long-term shifts*

What about long-term changes in hail activity? We show in *Figure 6* some 10-year frequencies of days with hail for a few states in different regions. This shows that states in the Great Plains like Texas and Montana which have a high incidence of hail also can have rather long up or down trends, 20 years or more. Eastern and midwestern states show shorter fluctuations. Also, the shifts toward high or low hail incidence do not occur in the same decades in the different regions. Such changes are reflections of large multi-year shifts in atmospheric circulation patterns that greatly change the hail activity over a state or a large region. Studies show that years with big hail losses in a state or smaller area are often isolated events, but they sometimes occur in pairs.

*Peak hours for hail*

The time of day that hail occurs has some interesting regional differences — and one unusual similarity. The similarity: hail very seldom happens between 5 and 10 a.m. in areas as diverse as Illinois, Colorado, Nebraska, and Kansas. But, the hours hail most often happens run like this (local time in each case):

Close to the mountains (Denver) — noon to 3 p.m.

About 100 to 200 miles east — 3 to 6 p.m.

Farther east (Kansas City) — 6 to 9 p.m.

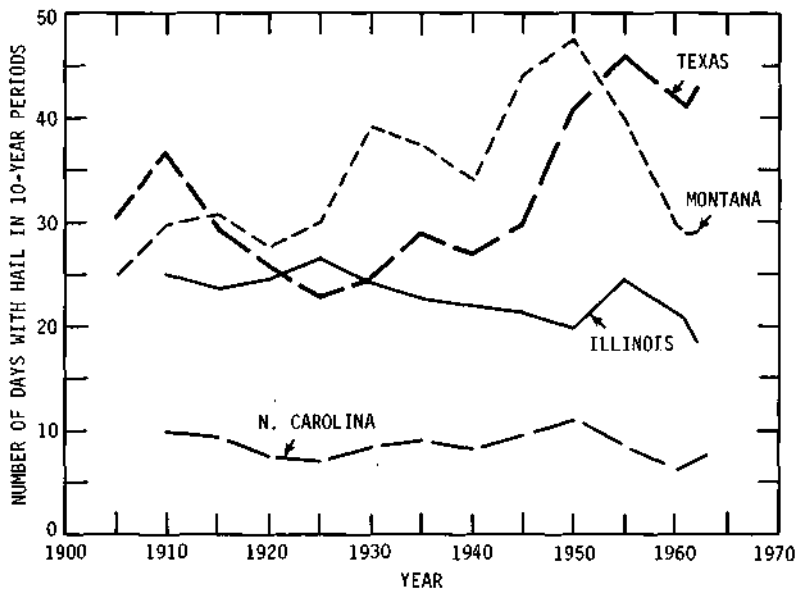
Illinois and Midwest region — 2 to 5 p.m. and midnight to 3 a.m.

The pattern of time from Denver to Kansas City suggests a west-to-east sequence of storm activity. The Midwest's secondary peak at night would be important in hail suppression because of the *difficulty of seeding clouds by aircraft at night*.



**FIGURE 6**

**Long-term fluctuations in hail days**



*Note: These are statewide mean frequencies of hail days at a point calculated for 10-year periods (1900-1910, 1911-1920, etc.)*

How long does a hailstorm last? This varies, also. The average duration of hail near the mountains is 10 to 15 minutes and in the Midwest, 3 to 6 minutes. Hailstreaks, which have a median size of 8 square miles, last an average of 10 minutes. (A hailstreak is an area hit by a single volume of hail produced in a storm. A single storm may produce one or many hailstreaks.)

*Duration  
of hail*

What types of weather are connected with hail?

In large areas like Iowa, Illinois, or Colorado, hail occurs on about 70% of all days with thunderstorms. In the Midwest, 50% of all thunderstorms connected with warm fronts and low pressure centers produce hail, but 75% of the thunder days associated with cold fronts or stationary fronts are hail days.

*Weather  
associated  
with hail*

Hail may be accompanied by moderate to heavy rainfall, tornadoes, or wind. Crop-damaging hailstorms in Nebraska, Colorado, and Kansas are generally associated with moderate rains of 0.2 to 1.0 inch, and 25% of the rain through the whole crop season falls with damaging hail. Hail days in Illinois typically have rainfall so heavy it averages nearly half (48%) of the monthly average. Studies of tornadoes in Illinois (*Changnon and Wilson, 1971*) show that major large tornadoes — those having tracks longer than 25 miles — always have hail-

falls somewhere near their tracks. Nearly 96% of 103 tornado days in Illinois during 1951-1960 were hail days and 12% of all hail days in Illinois were tornado days. Wind with hail is a critical factor to crop loss, and the Illinois studies show that windblown stones occurred in 60% of all hailfalls. And, when this happened, an average of 66% of the stones at any one point would be windblown. (Also see page 320.)

*Most loss  
in a few  
bad storms*

Much of the annual hail loss in a state is concentrated in a few storm days. For example, the five worst loss days for the year in Illinois produce between 55 and 84% of the year's total. These major loss events are usually multiple hailstorms that occur repeatedly over a large area during a period of 6 to 18 hours.

The many findings about hail in the United States clearly demonstrate the extreme variability of hail in all scales, whether for one point or the continent, for 1 minute or 50 years. The climatology of hail in the United States is more thoroughly defined than that for any other nation. Key points are:

The principal hail area of North America exists along and to the lee of the eastern Rocky Mountains, stretching from New Mexico up to Montana. This area averages more hail days, more hailstorms, more and bigger hailstones, and thus a greater hail intensity than any other area in the continent (see *Figure 4*).

Hail is a problem also in the Northwest, primarily because of specialty crops such as tree fruits that are easily hurt by hail, in the Midwest grain belt, and in the central section of the East Coast, again because of specialty crops.

Primary high occurrence spots in the Midwest hail pattern are found where hail-producing macroscale weather conditions are most prevalent, or where the Great Lakes affect and induce hailstorm development.

## **HAIL REGIONS IN THE UNITED STATES\***



An extensive study of the nation's hail climatology (*Changnon, 1975*) was performed as part of this technology assessment of hail suppression. The information indicated there were 13 very different hail climatic regions. These regions have been used throughout this assessment as a basis for the investigations of the social, legal, and economic impacts of hail suppression.

We show the outlines of the 13 hail regions on *Figure 7*, and indicate the four factors that we used to define them.

*Basic  
weather  
cause*

Which basic weather condition caused most of the hail was the first factor used to identify a hail region. The three basic causes used were marine effects, macroscale weather systems, and orographic effects.

*Frequency  
and peak  
season*

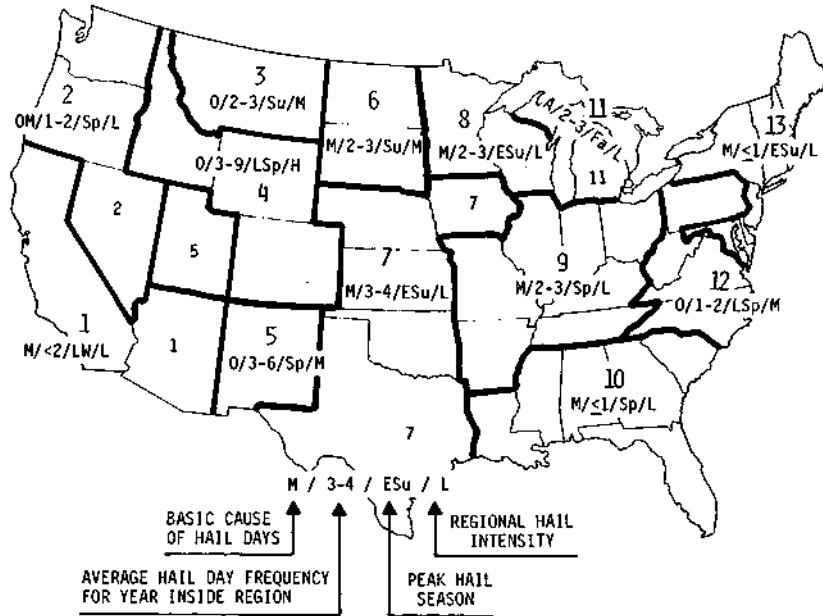
The second factor was hail frequency — the average number of days with hail in a year, taken from *Figure 4*. In general, these values were separated when the frequency doubled. The peak season of hail frequency was a closely intertwined

\*This section contributed by Stanley A. Changnon, Jr.



FIGURE 7

Hail regions of the United States



third factor since this peak season reflects the hail climate, that is, the basic causes, and also indicates the potential for crop damage.

The final factor was hail intensity. As noted earlier, hail intensity varies considerably from area to area. It is, of course, directly related to crop and property losses. The striking intensity differences in the Great Plains and upper Midwest were major reasons for certain region divisions.

*Hail intensity*

The actual climatic hailregions defined by these factors did not follow state lines exactly, but were smoothed to do so in order to use related state statistics. The states in the 13 regions are as follows:

- Region 1 — Arizona, California
- Region 2 — Washington, Oregon, Nevada
- Region 3 — Montana
- Region 4 — Idaho, Wyoming, Colorado
- Region 5 — Utah, New Mexico
- Region 6 — North Dakota, South Dakota
- Region 7 — Nebraska, Kansas, Oklahoma, Texas, Iowa
- Region 8 — Minnesota, Wisconsin



- Region 9 — Arkansas, Missouri, Tennessee, Kentucky, Illinois, Indiana, Ohio
- Region 10 — Louisiana, Alabama, Mississippi, Georgia, Florida, South Carolina
- Region 11 — Michigan
- Region 12 — Pennsylvania, West Virginia, Virginia, North Carolina
- Region 13 — Maine, New Hampshire, Vermont, Massachusetts, Connecticut, New York, Maryland, Delaware, New Jersey, Rhode Island

**CRITICAL  
STORM  
FEATURES\***



For hail suppression, time and space dimensions of hail events and the factors that cause hail must be defined. As we have seen, available studies provide some essential design information on hail frequencies at a point. However, climatic studies have not dwelt adequately on regional differences in storm activity. We show in *Figure 8* the average number of crop-damaging hail days in each state for each crop. Though there is some seasonal overlap of crops — that is, part of the Texas wheat days may overlap the cotton days — clearly, statewide hail suppression systems would require a large number of operational days.

*Hail days  
over an  
area*

An important operational-design need is for information on the frequency of hail days over different sized areas. Prior research that developed point-area relations in different areas (*Changnon, 1971*) is useful because one can employ the widely available point hail-day data to develop this estimate. *Figure 9* provides the point-area relationship showing that for a 10,000-square-mile area the area-point ratio is 20. This means that if the average point value in the area were 4 hail days per year, the area would have 80 hail days in a year.

*Daily  
hail  
activity*

Another aspect of hail critical to the design of seeding systems and operations over broad areas concerns the spatial and temporal array of *daily* hail activity across the nation. One earlier study investigated daily hail outbreak statistics across the Illinois-Iowa-Missouri area (*Changnon, 1960; 1962*), but information for other areas was very limited. Hence, a national storm-day climatology had to be developed as part of this technology assessment to provide key information for considering wisely the type of future operations, the forecasting requirements, and the future seeding systems.

Crop-hail loss data available for each county in the United States for the 1961-1965 period were obtained from the Crop-Hail Insurance Actuarial Association (CHIAA). These statistics represent only about 15% of the crops but, on a county basis of loss versus no loss, are probably not great underestimates of the areal extent of damaging hail activity.

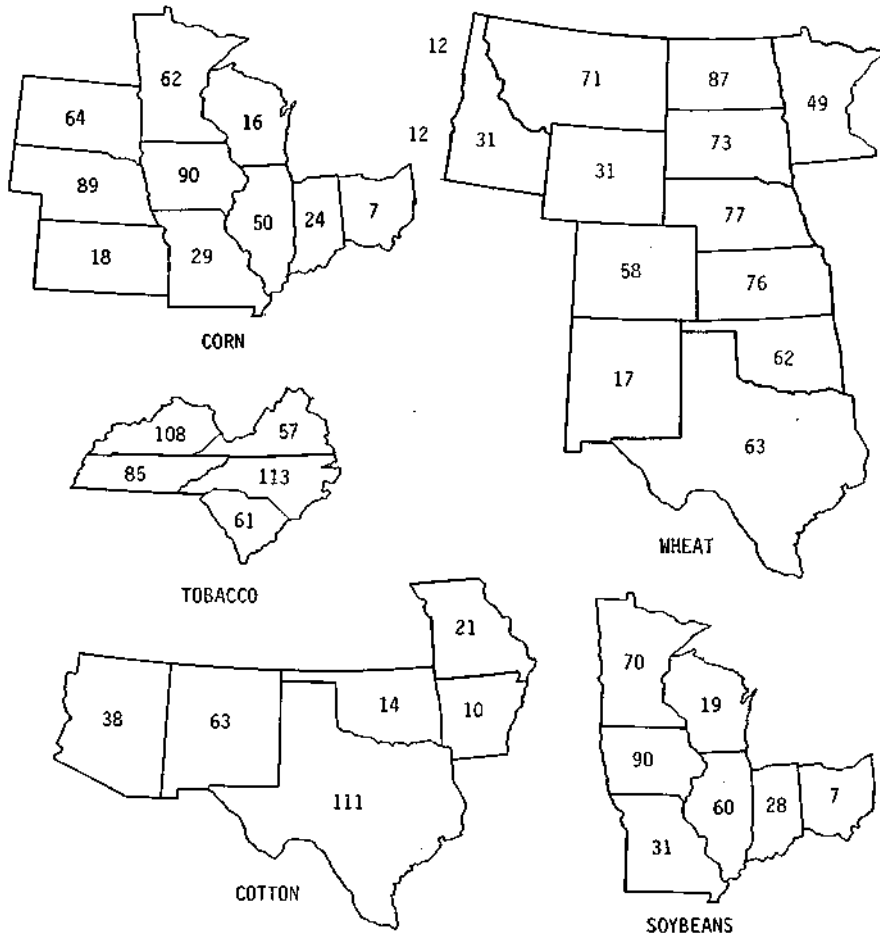
*Hail loss  
every day  
in season*

On virtually every day from April through October there is some degree of hail loss occurring in the United States. Hail loss occurred on 1201 days in the 1826 days of the 1961-1965 period. We show the loss-day totals and averages by month and season in *Table 1*. May through September were grouped because all but two days were hail-loss days.

\*This section contributed by Griffith M. Morgan, Jr.

 **FIGURE 8**

Average number of crop-damaging days

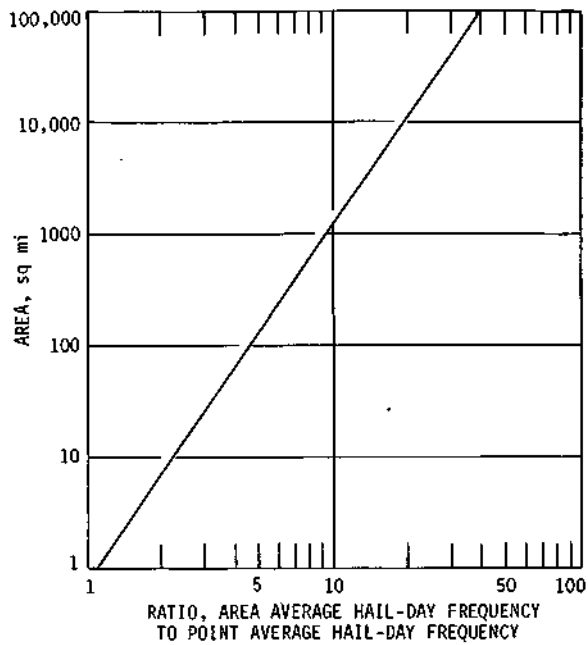


How extensive is the damaging hail on a loss day? Some appreciation for this can be gained from the distribution of the number of counties in the nation reporting loss per damage day (*Figure 10*). On most loss days (80%), fewer than 100 counties report loss, but hail loss has occurred in over 300 counties on a single day. We also show on *Figure 10* the distribution of the number of counties with loss days when the national (insured) loss total was \$1 million or more. The big hail loss days tend to be days of great areal extent of hail — more than 100 counties experience loss on 92% of the "million dollar days."

*Most loss days cover small areas*

The areal distribution of hail across the nation on a state basis for loss days is shown in *Table 2*. On two-thirds of the loss days 15 states or fewer experience loss, but days with loss occurring in 15 to 20 states are frequent, and over 25

*Million-dollar loss days widespread*

**FIGURE 9****The point-area relationship****TABLE 1****Monthly distribution of days with hail loss in the United States**

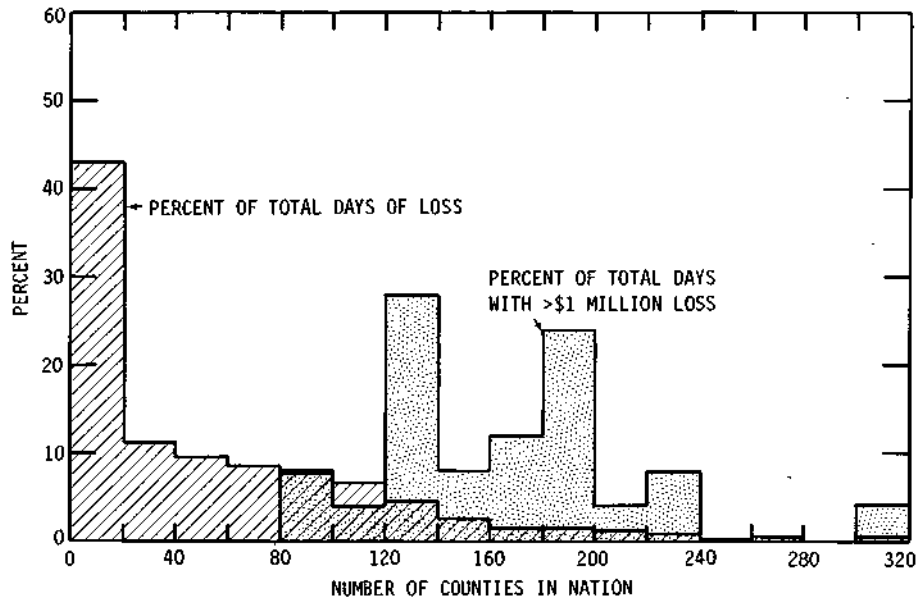
	1961	1962	1963	1964	1965	<i>Annual average</i>
January	9	17	13	22	29	18
February	0	0	0	0	4	1
March	12	0	7	6	8	6
April	26	24	26	23	28	25
May-September	153	153	153	152	151	153
October	24	26	22	26	12	22
November	8	12	9	8	22	12
December	1	2	2	3	10	3
Total	233	234	232	239	263	240

states can have hail losses on a single day. The distribution for the million-dollar loss days shows that the important loss days are those on which the loss is widespread, with 16 to 25 states involved typically.



**FIGURE 10**

**Counties reporting loss on hail-loss days**



The frequency distribution of days with loss as a function of dollars of loss is a very important characteristic of the national hail loss picture and one that affects the design for hail suppression. Relatively few high loss days contribute overwhelmingly to the total loss. On about 60% of the loss days, the national losses are less than \$100,000. The true impact of the higher loss days can be seen here:

- Days of losses over \$100,000 - 39% of days - 97% of total \$ losses
- Days of losses over \$1,000,000 - 5% of days - 39% of total \$ losses

The properties of the million-dollar days are of considerable interest. We show in *Table 3* the numbers of counties, states, and hail regions involved in these days.



**TABLE 2**

**Distribution of number of states with loss on hail-loss days (five-year totals)**

<i>Number of states with hail</i>	<i>Percent of all hail-loss days</i>	<i>Percent of hail days with loss &gt; \$1 million</i>
1-5	39	0
6-10	14	4
11-15	15	4
16-20	22	40
21-25	9	48
26-30	1	4

*Most loss in a few days*

**TABLE 3****Regional distributions of million-dollar loss days***Number of big-loss days for various state areas*

<i>1-5 states</i>	<i>6-10 states</i>	<i>11-15 states</i>	<i>16-20 states</i>	<i>21-25 states</i>	<i>26-30 states</i>
0	2	4	26	30	2

*Number of big-loss days for various county areas*

<i>0-100 counties</i>	<i>100-120 counties</i>	<i>120-140 counties</i>	<i>140-160 counties</i>	<i>160-180 counties</i>	<i>180-200 counties</i>	<i>&gt; 200 counties</i>
2	6	15	6	9	12	14

*Number of big-loss days for given hail regions*

<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>	<i>7</i>	<i>8</i>	<i>9</i>	<i>10</i>	<i>11</i>	<i>12</i>
2	0	0	2	4	10	26	16	1	3

These nationally important hail loss days point to extensive operations and large seeding systems since to suppress these events means operations in at least 6 states, more than 100 counties, and 3 or more hail regions on many days.

*Daily losses in major regions*

We tabulated the daily loss totals —in days, dollars, and counties —for the four adjacent hail regions (6, 7, 8, and 9) that have most of the crop losses from hail. These totals reflect on the operational requirements for local or regional adoption of hail suppression and for potential centralization of larger scale operations. We show the total number of days with loss in decadic dollar categories for the four regions in *Table 4*. The values in these distributions reflect, to some extent, the differences in sizes of the four regions.

**TABLE 4****The number of hail-loss days during 1961-1965 in four major hail regions, sorted by amount of loss**

<i>Region</i>	<i>\$100 to \$1000</i>	<i>\$1001 to \$10,000</i>	<i>\$10,001 to \$100,000</i>	<i>\$100,001 to \$1,000,000</i>	<i>&gt; \$1,000,000</i>	<i>Total days</i>
6	93	91	80	35	3	302
7	98	130	149	98	8	483
8	126	90	45	17	1	279
9	100	103	63	21	2	289

**TABLE 5****The synoptic-weather causes of hail-loss events (> \$100,000) in four areas**

Area	Total cases	Number of storm days		
		Fronts	Lows	Squall lines
North and South Carolina	22	17	15	4
Kansas-Nebraska	25	15	14	5
Montana-North Dakota	23	15	14	4
Texas-Oklahoma	22	20	4	5

If an effective suppression operation existed in Region 7, it would require operations on 483 days (97 per year) to cover all days with loss. However, if days with loss in excess of \$100,000 were defined as the only days for hail suppression, there would have been 106 such days in Region 7, 18 in Region 8, 38 in Region 6, and 23 in Region 9. The critical role of weather forecasting is emphasized in this example. Forecasting ability will weigh heavily on the efficiency of the operations, particularly when the "major" loss days are such a small part of the total loss days, as in Regions 8 and 9.

We also analyzed weather conditions for the days with national total losses of \$1 million or more to determine the major synoptic weather systems associated with the major centers of loss. *Table 5* shows the weather conditions for four selected 2-state areas for those days when one or both states in each area experienced loss greater than \$100,000. There are three synoptic categories and these are not mutually exclusive, that is, two or three could exist on the same storm day. Major hail outbreaks tended to occur in conjunction with fronts, and the majority of these were cold fronts. A large percentage of major hail-loss events are generated by near-to-surface low pressure centers, except in Texas. Here the few low condition events occurred in the western part of the state. The major hail events in Texas mostly occurred with cold fronts trailing from lows centered in Colorado, Kansas, and Oklahoma. In North Carolina, we observed a tendency for the lee cyclogenesis (formation of a lee low) phenomenon to accompany the hail outbreaks. The high frequency of occurrence of this mountain-caused cyclogenesis is undoubtedly a key element in the hail problem of that general area.

*Type of weather on big-loss days*

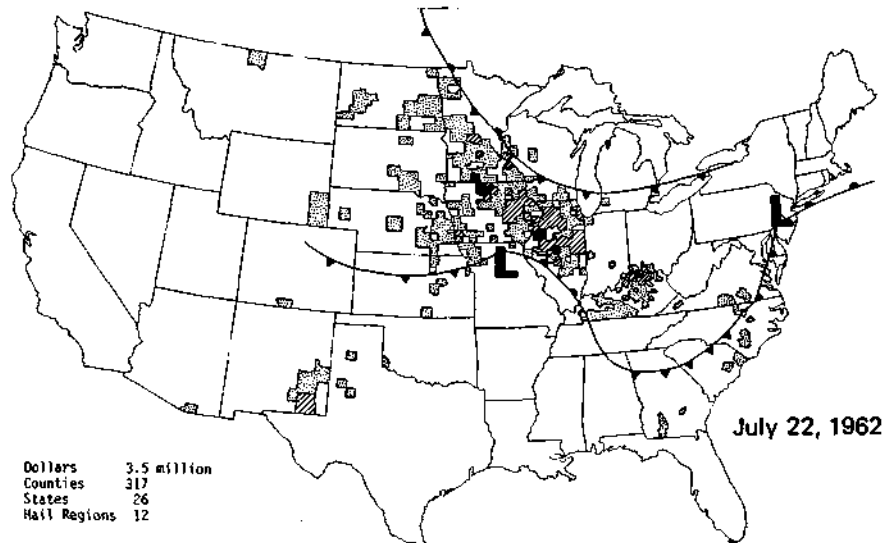
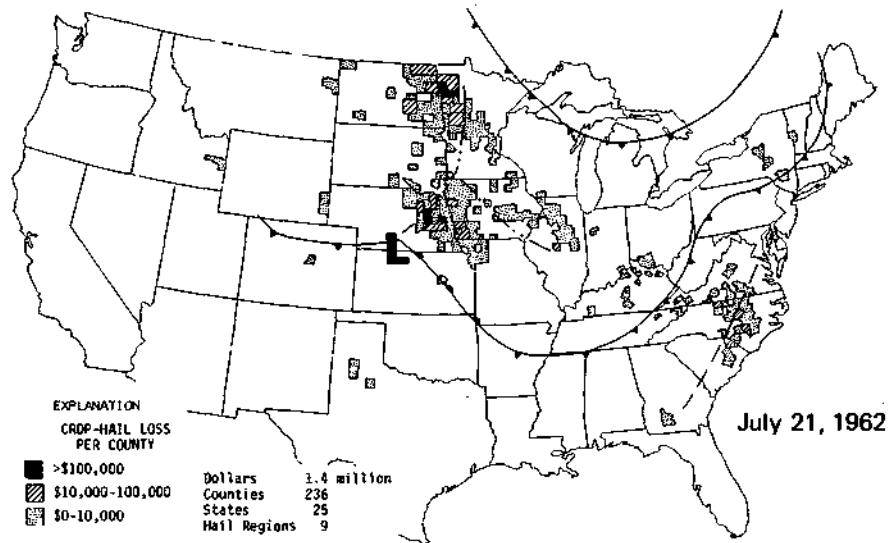
We can usefully illustrate the areal distribution of hail losses and the weather conditions helping to cause them by an actual example. We chose a widespread hail outbreak on July 21-24, 1962, as an example of a very severe period of hail. Their story is depicted through the maps in *Figure 11*. Over \$1 million in losses occurred on each day (totals were \$1.45, \$3.53, \$1.39, and \$1.21 million for a 4-day total > \$7 million).

*Severe hailstorms in July 1962*



FIGURE 11

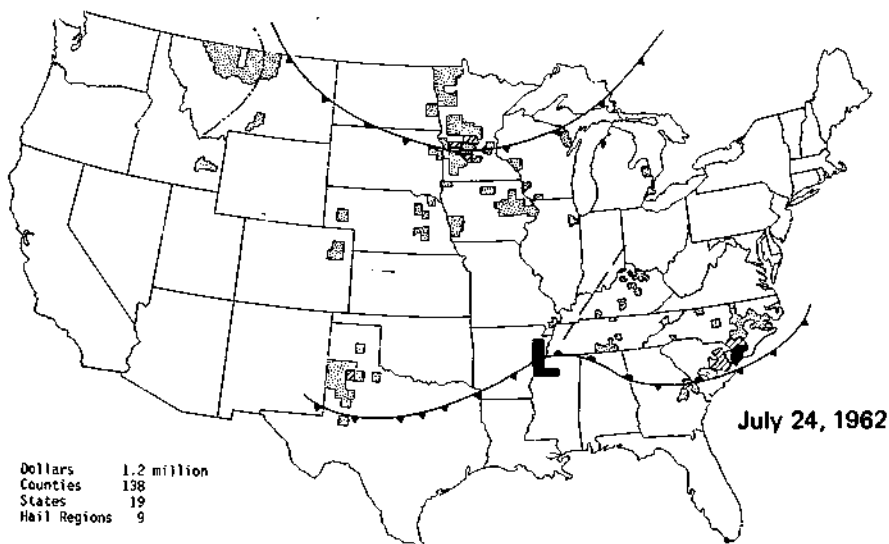
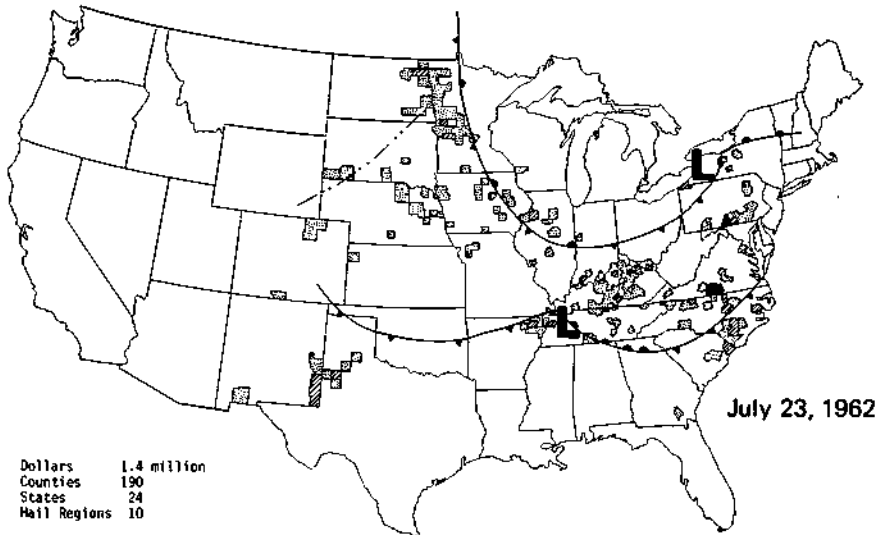
Crop-hail losses and weather conditions causing them during severe hailstorms



July 21 —  
cold front  
moves in

On July 21, hail loss occurred in an area through North Dakota and Minnesota during the late morning to early evening. It was due to the combined action of a cold front approaching from the northeast and at least one squall line south (ahead) of the front. Hailstones 2 and 3 inches in diameter were reported in northwestern Minnesota. Another hail loss area occurred in eastern Nebraska

on July 21-24, 1962



and western Iowa (> \$780,000 loss) during the afternoon and evening. These storms, including one accompanied by a tornado in southwestern Iowa, were associated with the passage of a low pressure center and frontal wave just south of the hail area. Hailstones 4½ inches in diameter were reported in Nebraska. Lesser loss areas occurred in eastern Iowa, northern Illinois, and Kentucky, and



a third major loss area occurred in North Carolina during the afternoon. This last area occurred in a lee trough (an area of reduced surface pressure caused by wind flow over the mountains upwind or west of the area).

*July 22 —  
approaching  
fronts  
cause  
colossal  
damage*

On July 22 (*Figure 11*), the cold front had moved slowly into Minnesota and Wisconsin and the frontal low had moved from southern Nebraska across northern Missouri. The combined influence of the approach of these two systems produced a colossal band of hail losses through Minnesota, Iowa, and the northern half of Illinois (> \$2.7 million). Another major loss area occurred in Kentucky (> \$0.5 million) ahead of the warm front associated with the low center in northern Missouri. The cold front which was in the western Alleghenys on the previous day had crossed the mountains and was relatively inactive. A third, lesser hail area occurred in eastern Nebraska and western Iowa. Tornadoes and funnel clouds occurred in Illinois, Wisconsin, and Minnesota.

*July 23 —  
major  
losses  
to the east*

On July 23, the cold front had become nearly stationary in the Minnesota-Iowa-Illinois area resulting in continued but lesser losses there. It continued to move through Ohio and Pennsylvania causing major losses in the latter state. Winds in excess of 60 miles per hour (mph) accompanied the hailstorms in southern Pennsylvania and neighboring areas of the surrounding states and hailstones up to 4 inches in diameter occurred in Pennsylvania. Major losses also occurred in Kentucky (as the low which had been in northern Missouri moved into western Kentucky and Tennessee) and in Virginia and North Carolina (due to thunderstorms in and behind the cold front which had crossed the mountains the previous day). Surface winds over 90 mph were reported in North Carolina.

*July 24 -  
new system  
causes  
damage*

On July 24, the cold front which had entered from Canada on July 21 and passed through Pennsylvania on July 23 was not distinguishable. However, a new weather system had crossed the Canadian border and was responsible for minor hail losses in Montana, new losses in Minnesota, and a tornado in northern Wisconsin. The major hail losses of this day occurred in the Carolinas where the cold front still lay semistationary. About \$1 million in losses occurred in the 3-state area of the Carolinas and Georgia, and two tornadoes occurred in South Carolina.

On these four days few states were untouched as 31 states experienced damaging hail and the overall area of hail damage was very great.

## **ECONOMIC LOSSES FROM HAIL\***



Damaging hailstorms are a measles-like plague of occasionally intensive losses that are distributed by thunderstorms across the United States during each year. They can be disasters that wipe out crops at ten farms leaving a thou-

\*These sections contributed by Stanley A. Changnon, Jr., and Earl R. Swanson.

sand farms lying unharmed between them. An individual, particularly a farmer, is either faced with a sizeable loss or he totally escapes his turn, which may come in a week, a year, twenty years, or never in his lifetime.

Estimates of the magnitude and distribution of economic losses from hail provide a particular type of perspective in terms of evaluating the seriousness of the hail "problem." In terms of public and private decision making regarding remedial action, economic losses from hail, in and of themselves, have virtually no meaning. The crucial elements appear when the *reduction* in economic losses is compared with the *costs* of such a reduction.

*Interpreting  
hail losses*

For example, whether we estimate hail losses to be \$1 billion a year or \$2 billion a year may or may not affect whether the cost — of the research, development, and operations — of a given technology will be less than, equal to, or greater than the expected *reduction* in economic losses. Thus in interpreting the following estimates of economic losses from hail we should keep in mind that the "losses" result from a comparison between the present situation and one with no hail.



Hail damages most crops grown in this country. The crops most easily damaged are fruits which lose their value, their quality, from even slight bruising by small hail. Tobacco is ranked second. Then in order of susceptibility to hail damage are certain vegetables, soybeans, barley, rye, wheat, corn, cotton, sugar beets, potatoes, and sorghum.

**CROP  
LOSSES**

However, the major crop losses from hail — and their loss as a percentage of the 1963-1967 national total of crop losses from hail — are wheat 51%, cotton 11%, corn 10%, soybeans 9%, and tobacco 7% (*Changnon, 1972*). On the average about 30% of the national tobacco crop, 25% of the wheat crop, 20% of the corn crop, and 20% of the soybean crop are insured.

*Major  
crops  
lost*

There have been two moderately extensive studies of crop-hail losses in the country. Changnon (*1972*) focused on the losses shown by insurance data for 1960-1969, and Boone (*1974*) developed total loss estimates from insurance data for 1966-1970. In *Table 6* we summarize some of the crop loss and insurance values for the ten top loss states in the nation. Certain interesting findings can be pointed out. Texas, for instance, leads in losses but is only 7th ranked in total liability, or coverage. Illinois and North Carolina lead in liability assumed and North Carolina and Kentucky lead in the number of losses per year. Idaho, New York, and Oregon — which have losses to high value specialty crops — rank high in the magnitude of the average per-farm paid loss.

*Where  
losses  
occur*

Locations of these ten leading loss states are also of interest. Six are in the Great Plains, three in the Midwest, and one on the East Coast. Comparison of the loss estimates with the value of the annual crop production in these states reveals

**TABLE 6****How top states rank in crop-hail liability and losses**

Rank	Average annual liability (\$ million)*	Average annual number of paid losses (1000's)*	Average individual paid losses (\$1000's)*	Average annual loss, estimated (\$ million)**
1	IL (315.1)	NC (10.8)	ID (1.8)	TX(51.0)
2	NC (190.8)	KY(9.8)	NY (1.7)	IA(39.6)
3	IA (161.5)	ND( 9.3)	OR (1.6)	NE (35.8)
4	ND (112.6)	IA ( 8.2)	FL(1.5)	MN(28.5)
5	NE ( 91.5)	KS ( 7.8)	CA(1.4)	KS (27.1)
6	KS ( 86.0)	NE ( 7.7)	AZ(1.4)	ND (26.2)
7	TX ( 84.4)	SD ( 5.4)	PA (1.3)	NC (16.6)
8	MN( 73.7)	IL ( 5.0)	WA(1.2)	IL (16.3)
9	WA( 64.2)	TX ( 4.5)	MT(1.1)	SD (16.2)
10	KY ( 59.9)	MN( 4.4)	CO (1.0)	CO (15.9)

\*Changnon (1972, Table 2), based on 1960-1969 data from crop-hail insurance companies insuring about 10% of the national crop value.

\*\*Boone (1974) in 1968 dollars, for 1966-1970.

that losses in midwestern states represent about 1% of the annual crop value. This percentage increases westward, to 2½% in Iowa and 5% in the Great Plains states.

*Boone data underestimates hail losses*

We show the crop-hail loss estimates made by Boone (1974) for the 13 hail regions in Table 7. His figures were updated by the use of an estimated 1975 crop price index. Boone points out that the loss estimation procedures he used are apt to result in a net underestimation of losses. In addition, if there were no hail, some areas would shift to crops more economically optimal (pasture to wheat, for example) and this would be another source of underestimation. For all crops, Boone's estimate of loss was \$685 million in 1973 prices.

In spite of their limitations, the Boone estimates are presently the most comprehensive set available. They provide us an adequate view of the spatial profile of losses by hail regions, as we see in Table 7. Clearly, the two important hail regions in terms of crop losses are Region 7 (Iowa, Kansas, Nebraska, Oklahoma, and Texas) and Region 9 (Arkansas, Illinois, Indiana, Kentucky, Missouri, Ohio, and Tennessee).

## PROPERTY LOSSES



What about hail damage to property, urban as well as rural? What kinds of damage occur and what is the size of the loss? Primarily, property loss due to hail involves structures, livestock, trees, and vehicles.

Some examples: Collins and Howe (1964) measured in detail the property damages produced by a very severe hailstorm in St. Louis and found that losses to roofs were 72% of the total property loss, to awnings 13%, exterior paint 7%, glass 5%, and to siding 3%. A 1934 hailstorm that hit a 15,000 population community in Illinois caused a \$2.6 million loss to property, and NCAR surveys of damaged smaller cities showed a \$40,000 loss at Kimball, Nebraska, in 1974, and a \$31,000 loss at Grover, Colorado, population 100. We picture a common type of property loss in *Figure 12*.

The property loss due to hail is considerably smaller than the crop loss. Changnon's 1972 studies of property loss in Illinois showed that average Illinois property loss was about 10% of the crop-hail losses. An economic analysis of hail loss in Alberta by Summers and Wojtiw (1971) indicated property losses in this mountain-hail region likewise involved 10% of the crop loss value.

Friedman (1976) provided for this assessment estimates of 1975 property losses by hail regions, as we have shown in *Table 7*. The previous estimates of property losses at 10% of crop losses appear to be consistent with these data, with \$773,511,000 in crop losses and \$75,000,000 in property losses for a total of \$848,511,000.

*Property losses 10% of crop losses*



**TABLE 7**

**Annual losses to crops and property due to hail, by hail regions**

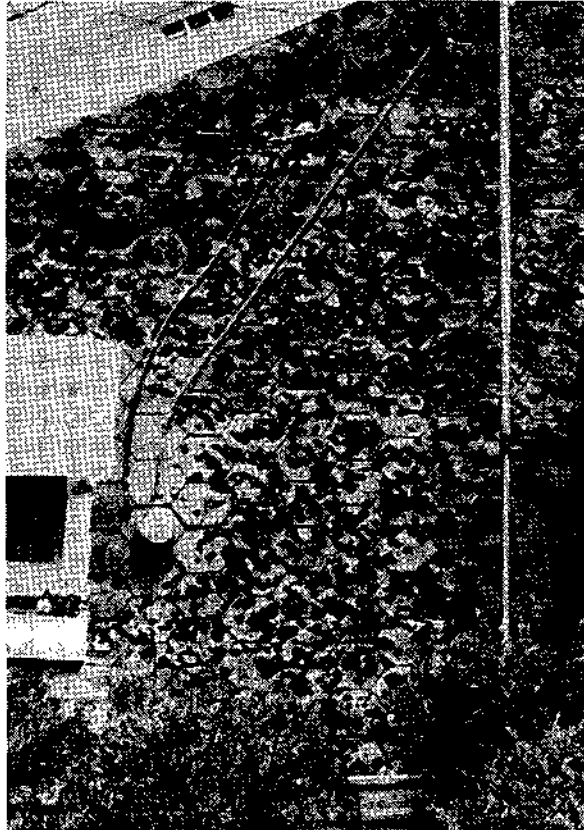
<i>Hail region</i>	<i>1975 values * in \$1000's</i>		
	<i>Crops</i>	<i>Property</i>	<i>Total</i>
1	18,520		18,520
2	8,906		8,906
3	27,204	520	27,724
4	47,273	690	47,963
5	8,771	80	8,851
6	81,552	130	81,682
7	319,881	15,140	335,021
8	61,960	1,640	63,600
9	104,436	14,140	118,576
10	32,979	5,270	38,249
11	4,066	1,470	5,536
12	44,317	670	44,987
13	13,646	250	13,896
Unallocated		35,000	35,000
United States	773,511	75,000	848,511

\*Crop losses are estimated from Boone (1974) by applying an estimated 1975 crop price index of 194 (1967 = 100). Property losses are from Friedman (1976), Table 17 in 1975 dollars. The property losses allocated to hail regions represent those associated with catastrophes (storms in which losses total over \$1 million). The unallocated property losses are those from weather events causing less than \$1 million damages, for which the geographical distribution is unknown (Friedman, 1976, p. 29).



FIGURE 12

Hail damage to house siding



## ALTERNATIVES TO HAIL SUPPRESSION\*



Our consideration of hail suppression as an adjustment to the hail hazard for property and crops in the United States must be coupled with consideration of other means of adjusting to this hazard. Other potential means for minimizing or adjusting to hail loss — whether on an individual or national scale — include either modifications to the environment or modifications to human behavior (*Brinkmann, 1975*).

### MODIFYING THE ENVIRONMENT



For one thing, farmers could alter crops grown in high hail regions to grow those less subject to hail damage. However, prevailing cropping patterns indicate that increased net returns from reduced hail damage would more than be offset by accompanying lower receipts — and/or higher input costs — associated with

These sections contributed by Stanley A. Changnon, Jr., and J. Loreena Ivens.

cultivating more hail resistant crops. Usually in any region two or more crops can be grown successfully, and the one more resistant to hail could be selected — for example, in Washington state, wheat could be grown instead of fruit crops which are highly susceptible to hail. There is little evidence that this shift in cropping due to hail loss is a valid one to consider, partly because hail loss is not often extremely severe and partly because other limiting physical factors (soil, rainfall, and temperature) dictate the type of crops. Investigation of this alternative does not appear to promise a substantial payoff (*Brinkmann, 1975*).

*Shift to  
hail  
resistant  
crops*

Only minor attention has been given to a related potential adjustment — making crop strains such as wheat more hail resistant through genetic breeding. However, when we consider the extreme impact energy of hail, the improved breeding answer does not appear promising. Another alternative, based on the prevailing direction of hailstorms in an area, would concern the direction of planting of row crops. Rows of crops, if parallel to the prevailing direction of hailstone fall, protect each other and allow some hail to fall on bare ground, thus reducing loss. This is an adjustment that could be easily applied — and at no cost — where physical environment allows planting in any direction.

*Genetic  
breeding  
for hail  
resistance*

*Planting  
parallel  
to hailfall  
direction*



Four other means of adjustment to hail loss concern modification of human behavior. The first concerns the savings through improvement in hailstorm forecasting. Continued emphasis on hailstorm and thunderstorm research expected in the next ten years will improve the accuracy for hailstorm forecasts for small areas. However, even with good forecasts and warning systems, the range of protective actions available to the individual is quite limited. There is practically nothing that can be done about crops, although movable property such as aircraft and automobiles could be sheltered for some savings. However, improved hail forecasting and warning systems would not be a very effective means of reducing hail property damages.

**MODIFYING  
HUMAN  
BEHAVIOR**

*Better storm  
forecasting*

Another approach to reducing the impact of hail loss, particularly to the individual, is through noncontiguous land holdings. Since the average hailstreaks are quite small, about two-thirds of a mile wide and six miles long (*Changnon, 1970*), a scattering of land holdings over an area diffuses the target for a given individual. This approach to noncontiguous land is a growing trend throughout much of the wheat and corn regions of the United States. Farmers now receive a discount on their hail insurance if their property is scattered.

*Scattering  
land  
holdings*

It is important to realize that although this adjustment serves to reduce the loss to the individual, it cannot be expected to reduce the total area loss due to hail. However, it does appear to be an adjustment that is desirable, if economically feasible for other reasons, by farmers in high crop-hail loss areas.

*Crop-hail  
insurance  
protection*

The third means for reducing hail loss to the individual is through insurance. Insurance is the most widely used adjustment to crop and property damages due to hail. About one of every six farms in the United States has crop-hail insurance and \$300 million was spent on crop insurance in 1975. Various levels of coverage and types of policies are available to farmers (as we show in Chapter 5) and can be purchased at any time during the season to allow for varying values of crops and available resources to purchase coverage. In certain high hail loss areas insurance rates are so high (25 to 30% of the crop value) that many farmers do not purchase it (*Brinkmann, 1975*). The federal government also offers crop insurance through the Federal Crop Insurance Corporation (FCIC), which protects against crop losses from all natural causes (all risk). FCIC coverage against losses is fixed to the production expenses and must be purchased before specific closing dates such as at seeding time. It has tended to encourage and support crop production in marginal growing areas, such as corn in colder northern areas. A further evaluation of the advantages and disadvantages of FCIC is contained in *Brinkmann (1975)*. Hail damage to property is largely covered by homeowners' policies which insure against damage from a variety of adverse weather conditions. Such extended coverage is frequently required for dwellings financed by mortgage agencies.

*Federal  
disaster  
relief*

A fourth means for adjusting to the hail hazard is through relief and rehabilitation. Federal emergency assistance to farmers for damaged crops is available in low interest loans which are available when a disaster is declared. Unfortunately, damages from hailstorms alone often are not sufficiently severe over an area to evoke a disaster declaration. However, a farmer can also seek assistance from severe hail losses through the Agricultural Stabilization and Conservation Service (ASCS) as low interest loans.

SUMMARY  
OF  
ALTERNATIVES



The various adjustments to the hail hazard can be considered as one of two types, those adjustments which can be expected to reduce the average losses, and those adjustments which spread the burden of loss but do not reduce them. Hail suppression, hail warning systems (as they relate to protectable property), and resistant crop strains (or planting practices) fall into the first category. Noncontiguous land holdings, insurance, and disaster relief fall into the second, unrecoverable category.

There are several reasons why hail insurance is not a complete or satisfactory solution (to either sellers or buyers) for the hail problem in areas where there is a high frequency of years with high losses.

First, the farmer perceives the frequent losses and saves by insuring himself because he sees no advantage of insurance which is based on the perception of irregular, unpredictable losses.

Second, the losses are so great that the cost of insurance, in relation to the total farm costs of wheat production, is high (10 to 15% of the production cost) creating a cash flow problem for many farmers. Insurance companies also find it difficult to price the insurance at a level that is both *marketable* and *profitable*.

Third, the companies realize that they can experience great losses, within the rate constraints they have to charge in high loss areas, and they tend to restrict the liability they will assume in a given area (*Hail Insurance Services, 1970*).

Until recently it has been debated whether agriculture suffered sufficiently from hail to invest in research aimed at reducing losses. This debate is understandable when we consider that, up until 1971, the nation had large farm surpluses and farmers were paid for *not planting* certain crops. Now the situation is different. The current lack of substantial food surpluses in the United States and the world, and the growing concern with the world food crisis, have led to increased emphasis on research to enhance crop production (*Ford, 1976*).

*The changing  
world food  
situation*

The 94th Congress will be considering changes in farm price and income policy and will be taking into account the fact that grain supplies have increased as a result of the 1976 harvests. Because of the size of the current grain supplies there will be some pressure to increase crop price support levels. However, our focus in this technology assessment is on the longer-term period of twenty years. The projections for demand and the rates of crop yield increase from technology, which underlie our economic analysis, are presented in Chapter 10, pp. 263-265.

It would appear that the need for increased food production, coupled with economic benefits including stability of income, could cause greater emphasis on the adjustments to hail loss which can be expected to reduce, not spread, the loss — given hail is recognized as a problem worthy of tackling. Certainly, research to make crops more resistant to hail loss and incorporation of protective planting practices seem valid. However, they do not seem to hold the potential for reducing hail losses that hail suppression, if successful, can provide.

*The need is  
to reduce  
the hail loss*

Boone, L. M.

1974 *Estimating crop losses due to hail.* U.S. Department of Agriculture, ERS, Washington, D.C., Agricultural economic report 267, 40 pp.

Brinkmann, W. A. R.

1975 *Severe local storm hazard in the United States: A research assessment.* Institute of Behavioral Science, University of Colorado, Boulder, 154 pp.

Changnon, S. A.

1960 *Severe summer hailstorms in Illinois during 1915-1950.* Transactions Illinois Academy of Sciences, 53, 146-156.

1962 *Regional characteristics of severe summer hailstorms in Illinois.* CHIAA, Chicago, Research report 14, 19 pp.


1970 *Hailstreaks.* Journal Atmospheric Sciences, 27, 109-125.

## REFERENCES



- 1971 *Means for estimating areal hail-day frequencies.* Journal Weather Modification, 3, 154-159.
- 1972 *Examples of economic losses from hail in the United States.* Journal Applied Meteorology, 11(7),1128-1137.
- 1975 *Scales of hail.* NHRE Symposium/Workshop on Hail: Preprint Vol. 1. NCAR, Boulder 52 pp.
- Changnon, S. A., and G. E. Stout  
 1967 *Crop-hail intensities in central and northwest United States.* Journal Applied Meteorology, 6, 542-548.
- Changnon, S. A., and J. W. Wilson  
 1971 *Record severe storms in a dense meteorological network.* Weatherwise, 24, 152-163.
- Collins, G. F., and G. M. Howe  
 1964 *Weather and extended coverage.* TRC Service Corporation, Hartford, Connecticut, Final report, 42 pp.
- Ford, G.  
 1976 *Agricultural research priorities.* News release, April, White House, Washington, D.C., 1 p.
- Friedman, D. G.,  
 1976 *Hail suppression impact upon property insurance.* Illinois State Water Survey, Urbana, Illinois, TASH working paper 11, 69 pp.
- Hail Insurance Services, Inc.  
 1970 *Sample crop hail study, Big Stone County, Minnesota.* Ormond Beach, Florida, 8 pp.
- Summers, P. W., and L. Wojtiw  
 1971 *The economic impact of hail damage in Alberta, Canada and its dependence on various hailfall parameters.* Preprints, 7th Conference Severe Local Storms, American Meteorological Society, Boston, pp. 158-163.

## SUMMARY OF CHAPTER 2- THE HAIL PROBLEM AND ALTERNATIVE SOLUTIONS

 The key characteristic of hail is its enormous variability in both time and space. Except for a few Great Plains locales in the lee of the Rocky Mountains where it hails on 5 to 10 days per year, most places in the United States have only two or three hailstorms per year, and only one in 10 or 20 of these may ever produce seriously damaging hail.

*Problems  
with hail*

However, during the warm season (April-October), crop-damaging hail is falling somewhere in the eastern two-thirds of the United States on almost every day; in fact, major loss (>\$1 million) days occur 20 times a year in the nation. These infrequent but large loss events typically result from losses covering 15 or more states, and although these events represent only 5% of the hail loss days, they account for 39% of the national loss.

Losses from hail are concentrated in crops, averaging \$773 million annually (1975 dollars) with \$75 million in property losses. Fifty percent of all losses occur in the Great Plains (Texas to North Dakota). The intensity of hailfalls (hail and wind combined) is from 5 to 15 times greater in this area than elsewhere in the United States. This coupled with the area's greater number of hail days where wheat is the major crop results in heavy wheat losses. Wheat losses are 51% of the national loss total, cotton is 11%, corn 10%, soybeans 9%, and tobacco 7%. About 25% of these crops are usually insured.

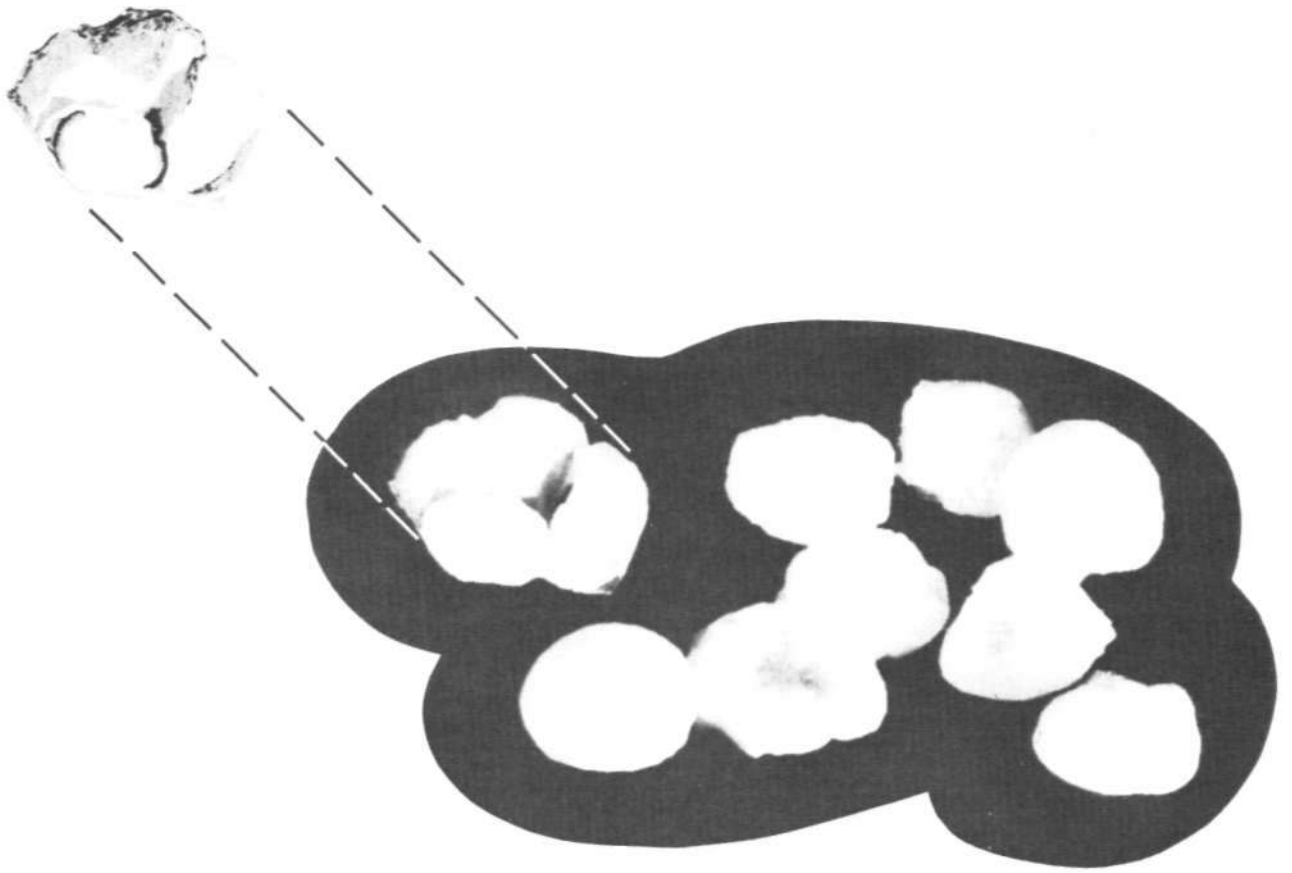
*Losses  
from hail*

Insurance is the only major alternative to hail suppression, but insurance spreads the burden of loss without reducing the losses as effective hail suppression could. Although hail suppression is a much more uncertain alternative than insurance, insurance is not a complete solution. In the bad loss areas of the Great Plains, losses are so great and frequent that farmers tend to self-insure, or to be unable to afford insurance. Also in these areas, the insurance industry finds it difficult to price coverage at a profitable level, and they tend to restrict liability they will assume in any given area. Other alternatives to hail loss include more resistant crop strains (yet to be developed), noncontiguous land holdings, and disaster relief.

*Alternative  
solutions*

# Part 2

## The past and present



# 3

## Background



Hail suppression, as a solution to the hail problem, is not new. It has been thought about for many years, and practiced for at least a quarter of a century. Our assessment of the technology of hail suppression rests, first of all, on a clear view of what has happened in the past, of the social-economic-political climate in which hail suppression has been "born and raised," and of the current status of the technology that can be determined at this time. These background factors are addressed in this chapter to form a base for future considerations.

### HISTORICAL OVERVIEW FOR HAIL SUPPRESSION\*



The field of planned weather modification has a modern history of almost 30 years of application and experimentation throughout many parts of the United States. These activities have tended to be intermittent and have concerned rain and snow enhancement, hail suppression, and very local fog dissipation at airports. Each of these areas of modification is in various stages of development as a technology to alleviate weather-related stresses over areas of varying size, generally ranging from counties up to large portions of certain states.

EARLY  
ACTIVITIES

Efforts to suppress hail began in the United States in the 1950s. Privately supported projects over small areas took place in high crop-hail loss areas in Nebraska and West Virginia well before scientific experimentation had established either a scientific approach to hail suppression or proof of its effectiveness. However, the efforts then, as now, were conceptually based largely on the hypothesis that additional ice nuclei in the hail formation zone of a thunderstorm will increase competition for the available super-cooled moisture, producing many small hailstones that will either melt by the time they reach the surface or be sufficiently small to be harmless. In these early years, there was no way to directly inject the materials for modification into the hailstone formation zones at high levels in storms, so the materials were released either from the ground or from airplanes circling below the storm clouds. (Note typical clouds in *Figure 13*.) The theories and methods of cloud seeding for hail suppression are discussed in detail in Chapter 4. The first major experimentation with hail suppression occurred in northeastern Colorado in 1959 (*Schleuseuer, 1962*), but results were inconclusive.

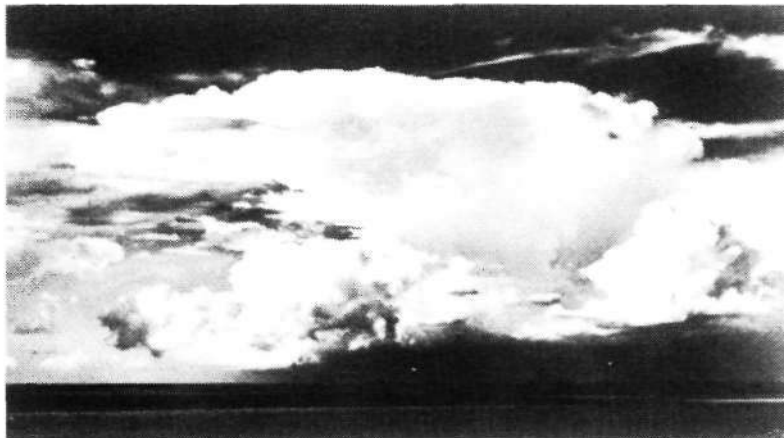
*Projects  
precede  
experiments*

\*This section contributed by Stanley A. Changnon, Jr.



FIGURE 13

Typical hail-producing thundercloud



Operational programs of hail suppression, without any proof of success or any foundation of sound scientific experimentation, continued into the 1960s and 1970s in Colorado, Kansas, Texas, North Dakota, and South Dakota where weather modification companies have been employed to suppress hail. About 70,000 square miles of the United States were seeded in 14 different projects for hail suppression in 1974 (Charak, 1975).

*Reaction  
to Soviet  
claims*

In this same general time period, a series of events in the Soviet Union had a considerable bearing on the eventual hail research and suppression activities in the United States.

The Soviet Union has several major crop areas along its southern boundary where wheat and high value crops suffer greatly from hail. The Soviets first experimented, using a systematic engineering and empirical type of approach, with hail suppression and then began operational (nonexperimental) hail suppression projects in their high hail-loss regions during the late 1950s and early 1960s. Their published claims indicated a 50 to 80% reduction in crop-hail losses (Sulakvelidze, 1967). Their claims had a considerable impact on both the American scientific community and our federal agencies concerned with weather and its modification, and helped promote a national hail effort in the United States (Hosier, 1974).

The Interdepartmental Committee on Atmospheric Sciences (ICAS), made up of atmospheric scientists from each federal agency, reacted to the 1964-1965 Soviet claims of successful hail suppression (Cbangnon, 1975a). A National Science Foundation (NSF, 1968) report stated that the United States needed to test the

Soviet method of hail suppression, and yet this report contained a section which shows that the Soviet verification efforts were unrealistic and their claims of suppression could not be substantiated. ICAS proceeded to recommend that NSF and other agencies develop a comprehensive plan for hail suppression research. The proposed plan of the Hail Suppression Research Steering Committee (NSF, 1968) stated, "We must determine if hailstorms can indeed be modified, and then learn if it is worth the effort."

Some atmospheric scientists accepted the difficult challenge of hail suppression. Presumably, many saw in this new "national goal" the promise for substantial increases in research funding, and many also believed a major modification breakthrough could be achieved with hailstorms of the Great Plains (NCAR, 1969). The launching of a multimillion dollar national program of hail suppression research, which eventually led to this assessment ten years after the hail program began and after at least \$25 million had been spent on it, was not preceded by nor founded on results of any social or economic investigations.

*Challenge  
accepted  
by scientists*

Taubenfeld (1973) urged that study of societal implications begin early and be a key input to the decision to start any major research project. This approach was not used in the case of the national hail suppression research effort, or most other weather modification projects, in the United States. It appears, although not all would agree, that a national hail suppression effort was launched largely on the basis of scientific hypothesis and opportunistic reasons.

*Societal  
studies  
omitted*

Suppression experimentation, in conjunction with rain enhancement experimentation, was conducted in parts of North and South Dakota during 1966-1972. Although the experimental results were not considered conclusive by the scientific community, widespread adoption of operational hail suppression coupled with intentional rain-making took place in these two high hail-loss states. More than half of each state was being routinely seeded with a goal to suppress hail and make rain in 1975. Public controversy ended the state program in South Dakota in 1976 after four years of operations.

Hail research that focused on suppression began in 1959 in northeastern Colorado and was pursued in the 1960s where a high hail frequency area exists (see Figure 4, Chapter 2). This circumstance, coupled with the presence and interest of several major weather research groups in Colorado, made that the site eventually chosen for a major national hail research experiment on suppression (NCAR, 1969). Thus, the reaction to the Soviets' claims led to a national commitment to execute a major research experiment to establish whether hail could be suppressed and, if so, to develop the physical explanations for it (NSF, 1968). After delays in planning, this National Hail Research Experiment (NHRE) was initiated in 1972. After three years of randomized daily seeding experimentation (1972-1974) and one year of analysis (1975), results indicated increases in hail

*National hail  
experiment  
launched*

and in rain, but these increases were not found to be statistically significant. These results are considered by many scientists to be inconclusive because of a variety of questionable experimental procedures and technical problems; nevertheless very useful findings about the structure of hailstorms are being produced.

The third part of the national commitment to hail research and suppression led to a third hail research program in Illinois. A series of projects culminating in the design of a hail suppression experiment applicable to the storms of the Midwest have been completed in Illinois (*Changnon and Morgan, 1976a*). However, no operational projects nor experiments have been pursued yet in the Midwest.

## SUMMARY



The 20-year history of hail suppression in the United States is a story of considerable confusion and scientific uncertainty. The history shows that operational projects have been adopted and experimentation has followed. Private weather modification companies have provided a service involving an uncertain technology when farmers were suffering from hail losses, and all this occurred well before scientific experimentation occurred or any definitive understanding of processes could be developed. In fact, it has yet to be developed.

Recent experimentation in North Dakota has provided encouraging statistical evidence. Evaluation of longer-term operational projects without the benefit of randomization is difficult, but several evaluations have been performed to get information on the current status of hail suppression (*Changnon and Morgan, 1976b; Simpson, 1975*). These have tended to indicate a suppression of crop losses due to hail on the order of 20 to 40%, but this has not been established. The statistical evidence is much stronger than the physical explanatory evidence. The National Hail Research Experiment has not provided any indication of suppression of hail, either from a statistical or physical standpoint.

## HAIL SUPPRESSION EFFORTS IN THE UNITED STATES\*



An important part of the task set out for this technology assessment of hail suppression was to investigate the societal factors involved with the technology — a feature neglected in its early development. The record of past and present hail suppression projects and descriptions of some of their social, economic, and political settings are important background clues to assessing future development.

## CLOUD SEEDING RECORDS



No complete record of cloud seeding activity in the United States exists. Weather modification has been characterized by partial and fragmentary record-keeping; therefore, we had to use a variety of sources of data.

\*These sections contributed by Barbara C. Farhar.

The first and major sources were the ten annual reports on weather modification published by the National Science Foundation (*NSF, 1959 through 1968*). In 1958 Congress passed P. L. 85-510 giving NSF responsibility to initiate a national program of research and development in weather modification. In 1966, NSF utilized its authority to require reporting of all commercial activities in the United States, but in 1968, NSF's role in weather modification was curtailed and its authority to require reporting was lost. It is unclear, however, whether all federally sponsored projects (such as classified projects of the Department of Defense) were reported during this period. Reporting was then continued on a voluntary basis until 1971. Between 1971 and November 1972, no records were kept at all on the federal level, but compilations of weather modification were reported by Haas (*1973*) and Farhar (*1975*).

On November 1, 1972, under the authority of P. L. 92-205, the National Oceanic and Atmospheric Administration (NOAA) required reporting of all commercial cloud seeding. Subsequently, NOAA worked out protocol reporting agreements with the other federal agencies conducting or sponsoring weather modification field projects. Thus, January 1, 1974, marked the start of the first year in which complete records of all such activity were kept (*U.S. Department of Commerce, 1974a, 1975*).

*Intermittent reporting programs*

The findings reported here cover the period July 1, 1958, to February 28, 1975, or approximately 15 years. The figures reported undoubtedly underestimate weather modification activity because:

*Limitation of the data*

- 1) Reporting was not compulsory for most of this period
- 2) Records were not kept at all for part of the period

However, the figures have been drawn from all the possible data sources, making this the most accurate summary currently available.

The NSF activity reports did not contain detailed descriptions of reported projects, but only a breakdown by state and by whether the project was experimental or operational. It was possible to fill in some of the missing data through other sources (*National Academy of Sciences, 1973; U.S. Department of Commerce, 1973a, 1973b, 1974b; Comparative Study data, 1975*), but for about 40% of the known activities, the project's purpose is not known. In sum, the figures reported here are approximate and conservative.

Over the 15-year period Farhar, Haas, and colleagues located 357 weather modification projects.\* As we show in *Table 8* each of the 13 hail regions of the country experienced weather modification field activity during this period. However, eight states (17% of the continental United States) had *no* cloud seeding activity; these are: Delaware, Georgia, Kentucky, Mississippi, North Carolina, Ohio, South Carolina, and Tennessee. Most activity has been carried out in the western United States. More than 70% of the projects were operational rather than experimental.

*Findings on cloud seeding*

\*A project was counted only once even if it occurred for several consecutive years; projects range from 1 month to 15 years.



**TABLE 8****History of cloud seeding, 1958-1975**

Hail region	States	Number of projects			Involving hail
		Experimental	Operational	Total	
1	Arizona, California	19	29	48	0
2	Nevada, Oregon, Washington	11	39	50	1
3	Montana	5	9	14	0
4	Colorado, Idaho, Wyoming	13	33	46	7
5	New Mexico, Utah	5	9	14	0
6	North Dakota, South Dakota	14	31	45	19
7	Iowa, Kansas, Nebraska, Oklahoma, Texas	12	36	48	6
8	Minnesota, Wisconsin	2	8	10	0
9	Arkansas, Illinois, Indiana, Kentucky, Missouri, Ohio, Tennessee	5	12	17	0
10	Alabama, Florida, Georgia, Louisiana, Mississippi, South Carolina	4	12	16	0
11	Michigan	0	17	17	0
12	North Carolina, Pennsylvania, Virginia, West Virginia	4	5	9	1
13	Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, Vermont	11	12	23	1
	Totals	105	252	357	35
		29%	71%	100%	9%

About  
17% involve  
hail  
suppression

About 9% of the projects (or 35 of the 357 projects located) definitely involved hail suppression, either alone or in combination with precipitation augmentation. As noted earlier, however, a large proportion of project purposes are not known; it is likely that some of the unidentified projects were, indeed, hail suppression projects. Of the 357 projects, 207 were identified as to purpose; 17% of these involved hail suppression. A simple extrapolation to the unknown projects suggests that the number of hail suppression projects over the last 15 years in the United States is about 61 (17% of the total).

Table 8 indicates that seven hail regions did *not* experience hail suppression, while six did. Actually, 12 states (25% of the continental states) are known to have experienced a project involving hail suppression during the 15 years. These states are: Colorado, Idaho, Kansas, Nebraska, North Dakota, Oregon, South Dakota, and Texas. During this period, there were projects in portions of Pennsylvania, Maryland, Virginia, and West Virginia.

We present in Table 9 the data on projects by region and project purpose. The most frequently occurring type of project was precipitation augmentation, fol-

**TABLE 9****Recent history of cloud seeding by hail region and type of project**

Type of project	Hail regions													Total N	Percent
	1	2	3	4	5	6	7	8	9	10	11	12	13		
Hail suppression		1		5		1	4					1	1	13	3
Precipitation augmentation and hail suppression				2		18	2							22	6
Precipitation augmentation	16			1	4	2	23	9	6	4	9	1		75	21
Snowpack augmentation	22	6	2	9	3	2		1						45	13
Drought relief	1						3				1			5	1
Fog dispersal	6	9	1	2		1	1	3	1			3	8	35	10
Lightning suppression	1		2	1	1					1				6	2
Snow or rain redistribution		1											1	2	1
Cloud electrification				2					1					3	1
Hurricane modification											1			1	0*
Not known	2	33	9	24	5	21	13		9	9	8	4	13	150	42
Total	48	50	14	46	14	45	48	10	17	16	17	9	23	357	100

\*.0028011

lowed by snowpack augmentation, fog dispersal, precipitation augmentation in combination with hail suppression, and hail suppression.\*

The western United States has experienced far more weather modification activity than the eastern part of the country, a finding which holds for hail suppression as well. About half of the hail regions, but a quarter of the states, have experienced a project involving hail suppression since 1958.

*Most activity  
in the west*

The public's experience with hail suppression is indeed limited (*Farhar, 1975*).



The sociological aspects of weather modification have been studied since the late 1960s. Two longitudinal surveys of populations experiencing hail suppression were taken in northeastern Colorado (*Haas and Pfof, 1972; Haas and Krane, 1973a, 1973b; Krane, 1975*) and in South Dakota (*Farhar and Krane, 1973; Farhar and Mewes, 1974, 1976*). Other projects have been monitored by social scientists studying acceptance/rejection processes. Hail suppression has been accepted in northeastern Colorado, Kansas, and North Dakota; it has been the focus of controversy and organized opposition in the San Luis Valley of Colorado, the Texas Panhandle, South Dakota, and the Blue Ridge area. Opponents in these rural areas have felt that hail suppression "dissipates" clouds and results in reduced rainfall. Some opponents believe cloud seeding did not effectively decrease hail (*Farhar, 1976a; Mewes, 1976*).

**SOCIAL,  
ECONOMIC, AND  
POLITICAL  
SETTINGS**

*Some projects  
accepted, others  
opposed*

In order to give the reader a better understanding of the types of events that may surround a hail suppression effort, three case histories, representing areas

\*Detailed summaries of projects by purpose and state, as well as the raw data, are available from Human Ecology Research Services, Boulder, Colorado.



FIGURE 14

Locations of hail suppression projects



where hail suppression has become a controversial issue, are presented. Specifically, we describe the events and processes surrounding hail suppression efforts in Colorado (San Luis Valley), South Dakota (South Dakota Weather Modification Program), and Texas (Littlefield/Plainview) from their inception until 1976. We show the locations of these projects in *Figure 14* along with the sites of the hail suppression experiments. The three cases involved *operational* (not experimental) cloud seeding.

*Local weather needs differed*

Several important factors concerning social response to hail suppression are highlighted by these cases. First, each case involved heterogeneity of weather needs. That is, within the project area, differing requirements for beneficial weather existed. Some crops at certain periods of time benefit from additional rainfall while others would suffer damage from rainfall at that time. Range or pasture may benefit from moisture deposited by hail, while crops are damaged by hail. Irrigated crops are less dependent upon natural precipitation than dryland crops or range. Heterogeneity of weather needs is the basis for system-level conflicts of interest with regard to planned intervention in weather processes.

*Droughts occurred at the time of projects*

Second, in each case a drought developed while cloud seeding was being implemented. Opponents were inclined to attribute dry conditions to cloud seeding for hail suppression. The opponent theory of hail suppression is that all clouds approaching the target or protected area are seeded to cause their dissipation so that they cannot build up to hailstorm size. In the process, opponents say,

clouds that would have produced beneficial moisture are being destroyed. Those conducting the cloud seeding deny these allegations, stating that, if anything, seeding for hail suppression should increase rainfall in the target area.

Third, each project was carried out in a context of scientific dissensus about the readiness of hail suppression for operational application. All three of the cases to be discussed occurred concurrently with the National Hail Research Experiment (NHRE) in Colorado, whose purpose was to discover whether and by what means hail could be suppressed. Since no definitive answer has yet emerged from the NHRE effort, operational hail suppression remains a matter of scientific controversy.

*Scientists  
disagreed*

Findings from a survey of weather modification experts showed that experts varied in their opinions about how ready for operational application various technologies are (Farhar, 1976b). The survey, conducted by mail in April 1975 with 551 respondents, showed that among 12 technologies studied, there was general agreement on seven that they were or were not ready for operational application, and general disagreement on five. The five technologies on which there was disagreement included summertime precipitation augmentation and hail suppression. Disagreement on these technologies occurred on the basis of:

- Organizational affiliation (with respondents affiliated with weather modification firms more likely to state that the technology was ready for operational application than respondents from research institutes or federal agencies)
- Organizational responsibility (with those responsible for or interested in applications more likely to assess technologies ready for operations than those engaged in physical research and development)
- Academic background (with those trained in agriculture, engineering, and social science more likely to assess technologies as operationally ready than those trained in meteorology, atmospheric science, physics, and statistics)

In general, the higher the education level of the respondent, the less likely he was to assess these five technologies as ready for applications.

One implication of these differences in expert opinion is that in some areas the adoption decision to be made is a decision with regard to a scientifically uncertain technology. The uncertainty implies that a degree of risk is involved (the degree may be quite limited, but may be said to exist); in general, risk-takers prefer to adopt their own risks, rather than have such decisions made for them.

Fourth, the degree of public participation in the adoption decision varied in the three cases. In Colorado and Texas, voluntary associations of agriculturists (irrigating farmers in both cases) raised funds and contracted for hail suppression with a weather modification firm. In South Dakota, the adoption decision was made at the county level by county commissioners. It is probable that the degree of participation in the adoption decision in all three areas was not high.

*Participants  
in adoption  
limited*

*High hail  
loss affected  
adoption*

Fifth, it is noteworthy that in all cases adoption occurred in high hail-loss areas — where hail destroys up to 20% of the crop. Willingness to adopt an uncertain technology — one perceived as potentially ameliorative and possessing a low probability of causing damage — is clearly enhanced in areas where hail is a serious problem.

*Operators'  
credibility  
questioned*

Finally, in all three cases, the credibility of those supporting and running the programs was called into question by opponents. A polarized situation developed in communities where hail suppression was adopted. Arguments raged over both the technology's effectiveness and how decisions were made to adopt it. Organized opposition emerged in the three cases; in two, the opposition groups were successful in halting the projects; in one, a decision is pending on the program's continuance.

**PROJECT IN  
SAN LUIS VALLEY,  
COLORADO**



In a normal climate of scanty rainfall (6.5 inches per year) and relatively frequent occurrence of damaging hail, cloud seeding was introduced in 1951 into the San Luis Valley. This early effort resulted in local opposition on the grounds that "abnormal weather" was occurring, primarily drought (*Kaplan, 1973*). Subsequently, four major lettuce growers in the Valley financed a program for hail suppression from 1963 to 1965. One of the sponsors felt that the program suppressed hail but was too expensive to maintain (*Kaplan, 1973*).

In 1967, an ex-Navy man with some experience in weather modification projects persuaded Coors Industries of Golden, Colorado, that a weather modification program could aid the brewing barley crop grown in the hail-prone San Luis Valley. Since hail (or moisture in any form) is particularly damaging to barley during its ripening stages, the brewery was interested in what could be done to protect the crop. For the summer of 1967, Coors hired a commercial firm to seed San Luis Valley clouds for hail suppression (*Garcia, 1973*). At that time, the Colorado statute provided minimal regulation of cloud seeding, with no provisions for public hearings (151-1-1 *et seq.* C. R. S. 1963). The modification firm implemented a project in 1969 with three purposes:

- 1) To increase precipitation during the growing season
- 2) To decrease precipitation at harvest time when moisture could damage the ripening barley
- 3) To suppress hail throughout the growing season

These three project purposes were themselves a source of controversy in an area where 75% of the local economy was dependent on ranching, and pasture stood to benefit from almost any type of precipitation. The rain suppression (or "rain diversion") aspect of the project was especially controversial in this setting. The firm apparently claimed that it was within its technical ability to control a variety of severe storm situations, including tornadoes, hail, high winds, and heavy rains (*Flavin, 1971; Pickering, 1970*).

In 1970, an independent insurance company, Western Inter-Insurance Exchange, was formed to support the weather modification projects and to insure against hail damage. The Valley Growers, a group of about 300 producers of Moravian barley under allotment to Coors, were the supporters of the Exchange. At the end of the 1971 season, the insurance company became defunct. Over a million dollars in hail damages had been paid out that year. Subsequently, Coors informed the Valley Growers that they were to be responsible for the support of continuing a hail suppression program, a prerequisite for Coors' continued purchasing of Valley barley (*Valley Courier*, 1972a).

*Insurance  
company  
short-lived*

During the period the weather modification operations were under way, the entire Southwest was experiencing dry weather conditions which became more severe during 1971. The underground water table dropped, resulting in a critical effect on range plants whose roots could reach the water table under normal conditions and which were now beginning to die. During this time, ranchers experienced severe problems in pasturing cattle.

*Drought  
develops  
in Southwest*

The economy of the Valley was far more dependent on ranching than it was on the barley or lettuce crops grown there. Ranchers were more dependent on natural precipitation than were the irrigating barley growers, and this heterogeneity of weather needs was basic to the entire course of events in the Valley. In addition, there were many Valley residents who were either skeptical about the efficacy of cloud seeding to produce beneficial results or who were opposed to any intervention whatsoever in natural weather processes.

Ranchers and timber interests in the Valley and on its periphery had not been included in the weather modification decision process. These important local interest groups felt they were being economically damaged by the cloud seeding operations, and that they had had no means of making their position effectively felt in connection with the cloud seeding project.

An opponent group, the San Luis Valley Citizens Concerned About Weather Modification, organized in October of 1970. The group's president stated that the organization was not against hail suppression per se, but was attempting to stop what they saw as an incompetent operator. Another weather modifier made several trips to the Valley and met with the Concerned Citizens and the Valley Growers. He was subsequently awarded the cloud seeding contract in March 1972. At this point, the leadership of the organized opposition group felt they could support the new operator, and they discontinued opposition activity. However, many other members of the original Concerned Citizens group remained adamant, and in July 1972 a new opposition group, Citizens for the Preservation of Natural Resources, was formed. Its president was a rancher from a prominent Valley family.

*Opposition  
group  
organizes*

There had been debate among the weather modifiers involved in the cloud seeding program over the years about the project's purposes and the technical capability to carry them out. One meteorologist resigned from the firm's staff, charging that

they were decreasing rainfall in the Valley. The controversy was reported in the local news media and citizens of the area became aware that meteorologists were not necessarily in agreement about the state of the art. We show a variety of headlines regarding opposition activities in *Figure 15*.

*New law  
requires  
permit*

In 1972, Valley opponents were influential in aiding the passage of legislation regulating weather modification in Colorado (Colorado H. B. 1019, 1972). The law provided for public hearings in the project area prior to the granting of project permits. The first such hearing was held in the Valley on July 31, 1972, with about 600 persons attending (*Valley Courier, 1972b*). Subsequently, a permit was approved by the Department of Natural Resources and the project finished the season.

*Trailer  
dynamited*

Two weeks following the granting of the permit, a trailer containing project equipment was dynamited, causing about \$50,000 damage. Although state and local authorities investigated the incident, no one was ever arrested for the bombing.

The following March, a second public hearing on the permit for the 1973 season was attended by about 300 persons. The strongest ammunition the opponents had was the result of a straw vote taken the previous November during the general election. Ballots from a five-county straw vote resulted in an overwhelming negative response: citizens voted against weather modification four to one. In addition to testimony by local agriculturists who claimed that clouds were being dissipated, a number of defenders of cloud seeding, primarily weather modification scientists, testified. The collective effect of the proponent testimonies, which demonstrated a lack of professional cohesiveness, was to challenge the reputability of cloud seeding for hail suppression as an operationally viable technique.

*Public vote  
considered  
in litigation*

Even though the straw vote had no legally binding power, it was cited by the Advisory Committee to the Department of Natural Resources as the major reason for their recommendation that the permit not be granted for the 1973 season. The Department followed the Advisory Committee's recommendation, and the Valley Growers appealed to District Court. However, the judge affirmed denial of the permit, the first time in litigation that a public vote was considered in reaching a weather modification decision (*Davis, 1974*).

No further summertime weather modification has been conducted in the Valley despite threats by the Coors Company to decrease the amount of barley purchased there by 10% each season that weather modification is not conducted (*Mewes, 1976; Farhar, 1976b*).

There is little doubt that the announced intent of the early cloud seeders to decrease rainfall, followed by subsequent denials of that intent accompanied by dry weather conditions, led to severe credibility problems for hail modifiers in the San Luis Valley. An adversary situation was promoted by the exclusion of major Valley interests in most cloud seeding decisions and the failure to negotiate conditions that might have made the hail suppression efforts tolerable to those opposed.



FIGURE 15

Headlines revealing various opposition activities

IN STRAW BALLOTING

Hail Suppression Project Trowned

By HARRY WELSH... WHILE a amendment decisions were creati... modification straw... printed here...

Hail Suppression Program Foes Express Confidence

With some days into activities... the hail suppression program... the Farmers and Ranchers... Association for Hail Supp...

Cloud seeding: Threat or blessing?

Hail Suppression Plan Oppos

By FRANK PATRICK Staff Writer... PLAINVIEW—Supporters of hail suppression look... farmers from throughout the... area made an impressive... show of strength in opposition... to weather control programs...

Farmers Oppose Group To Fight Hail Program

The High Plains Round... A number of local and area... farmers have formed... a group to fight the... hail suppression program...

Battle Rages Over Hail Supp

This opposition group, in turn, formed... their own weather committee... Atmospherics, Inc., a California based... firm, became involved in this area after a... feasibility study on a hail suppression... research program was conducted on the... High Plains in October, 1966, for the Texas... Management Board.

Key Issue Remains In Focus At Hail Suppression Trial

...program unprecedented in Texas... Judge Pat Boone Jr.'s... Court has clouds... Court has made... the trial... the trial... the trial...

NOTICE
A meeting of High Plains Rainfall Association has been called for 7:30 p.m. Friday, March 19, at Kress School Cafeterium. ALL PERSONS INTERESTED IN OPPOSING THE HAIL SUPPRESSION PROGRAM INVITED TO ATTEND.

PROTESTS REGISTERED

Hail Suppression Blasted

By KAREN HERRI... some damage in Hale County last year in suppress... hail... about 30 area residents... areas last year in suppress... hail... about 30 area residents... areas last year in suppress... hail... about 30 area residents...

Bombing blamed on weather dispute

Successful, but many farmers... especially west and... Littlefield, have blamed... the hail... directly on the hail... activities. Those who believe that... hail... directly on the hail... activities. Those who believe that... hail... directly on the hail... activities. Those who believe that...

Support and contributions urged to continue the fight

Man made drought. Most of you are aw... down by Ju...



*Valley Growers  
still interested  
in weather  
modification*

An interesting sequel to these events developed in 1975. The Valley Growers, still interested in possible benefits from applied weather modification, decided to sponsor an operational snowpack augmentation project in the mountains west of the Valley to increase runoff, and thus the Valley's water supply. Former opponents of cloud seeding expressed opposition to this new project, but agreed to convene with the project's operator and sponsors to discuss the situation. The weather modifier described the project's purposes and methods and asked the opponents about the nature of their concerns.

The outcome of the meeting was an agreement between project supporters and opponents — an agreement that became a condition of the project's operation. This condition called for:

- A citizen committee to monitor the project's operations
- Veto authority by a majority of the committee to suspend operations at any time during the operational season

*Opponents  
tolerate  
snow project  
with 'veto'*

The citizen committee's membership was selected by both proponents and opponents to represent different geographical regions affected by the project. A committee member was contacted prior to each seeding decision to obtain clearance for operations; no difficulties were experienced in utilizing this approach. The operator, toward the end of the first operational season under these conditions, thought the committee was functioning very well. This is the only known instance of an organized opposition agreeing to tolerate a weather modification project subsequent to their success in halting prior operations. Although hail suppression and snowpack enhancement are different goals, and less public skepticism concerning the latter may have existed, these developments were unique in the history of public response to weather modification. The trade-off negotiated between project proponents and opponents — citizen committee monitoring and veto authority in exchange for opponent tolerance of the project — made it possible for the project to function.

## **HAIL SUPPRESSION IN SOUTH DAKOTA**



Citizen interest in cloud seeding to ameliorate weather conditions has a history in South Dakota dating back to the late 1940s. By 1951, weather modification was being carried out in a third of the state's counties. Since 1961, the Institute of Atmospheric Science of the South Dakota School of Mines and Technology in Rapid City has received several million dollars in grants for the study of rain stimulation and hail suppression. There is no record of any active opposition to the research projects which spanned more than a decade, culminating in the initiation of a statewide cloud seeding program in the spring of 1972.

In 1971, the state's earlier weather modification statute was amended to allow for the implementation of cloud seeding by the state. The legislature appropriated \$100,000 for the development of the state cloud seeding program, called the



**TABLE 10**

**Development of the SDWMP\***

Year	Number of participating counties	Number of acres affected	Proportion of land area of state affected, %	State funding, \$	County funding, \$	Total funding, \$
1972	26	17,181,000	35	250,000	90,000	340,000
1973	42	26,612,000	54	643,818	190,000	833,818
1974	46	29,547,000	60	870,000	200,000	1,070,000
1975	45	28,464,000	58	776,500	258,800	1,076,800

\*Sources include Division of Weather Modification (1974), Comparative Study Data, (1975), Leonard (1974), and Donnan *et al.* (1976).

South Dakota Weather Modification Program (SDWMP). Between 1972 and 1975, funding increased from a quarter of a million dollars to about a million dollars. The number of counties involved increased from 26 to 46 during that interval. We show the development of the South Dakota program in *Table 10*.

*State program starts*

The conviction that county government should be involved in weather modification decision making originated at the state level from the inception of the program. The most important decision to be made by the counties, specifically the county commissioners, was whether or not to participate in the program. Their additional responsibilities were certain other policy matters, such as suspension of seeding during the season and whether or not seeding should continue during tornado watches. The purpose of the SDWMP was to suppress hail and increase rainfall, with hail suppression having operational priority. The county provided 25% of the cost of operation through mill levy taxes and the state contributed 75% from the general fund.

Actual operations were performed under contract to the State's Division of Weather Modification by weather modification firms supplying personnel, planes, and equipment. An effort was made to "target" seeding effects in participating counties, although scientific uncertainties remain concerning "extra-area" effects. Contiguous nonparticipating areas might have experienced seeding effects, but the extent and nature of such effects remains largely unidentified.

*Commercial firms perform operations*

Based on earlier research, estimates of the SDWMP's benefits were that rain could be increased an average of 10% over a growing season (May 1 to September 1) and hail reduced by 40 to 60%, resulting in a benefit:cost ratio of at least 10:1 (*Division of Weather Modification, 1974*).

Public response to the SDWMP has been monitored since before the program's initial operations. A longitudinal survey of a random citizen sample in 20 par-

ticipating counties was conducted over four time periods between 1972 and 1974. In summary, the survey and monitoring of events indicated the following responses (*Farhar and Mewes, 1976*):

- 1) Prior to the beginning of the South Dakota Weather Modification Program, the survey showed majority favorability in participating counties to the idea of modifying the weather for the benefit of agriculture.
- 2) Between the first and second waves of survey interviewing, the Rapid City flood occurred in the presence of cloud seeding on June 9, 1972. An official report on the flood stated that cloud seeding did not contribute materially to the flood occurrence. Most respondents, when interviewed in the fall of 1972, did not attribute the flood to cloud seeding.
- 3) By the second wave of interviewing, respondents were more convinced than they had been earlier that cloud seeding could actually increase rainfall and decrease hail.
- 4) At the September 1973 interview, basically favorable attitudes remained the majority perspective with little change having occurred. A sizeable minority had consistently expressed reservations about cloud seeding on the grounds that there might be undesirable consequences from it, or that modifying the weather was an activity best left to nature or God. This minority decreased slightly by the fall of 1973, but still remained near the 40% level.
- 5) At the September 1974 interview, belief that cloud seeding could actually increase rainfall had fallen off somewhat to 64%. During 1972-1974, dry conditions had deepened in the state. Evaluation of programs was somewhat less favorable than it had been at the earlier interviews with the majority of respondents in the neutral-to-favorable range. There is some evidence to suggest that weather modification was not an issue of great significance for nearly half of the sample.
- 6) Concerns about side effects and the religio-natural orientation were the most important factors in determining respondent evaluation of programs prior to the SDWMP's inception. Over time, however, these concerns were replaced in importance by perception of project effects themselves. Perceptions of cloud seeding's effectiveness and economic consequences became the most relevant factors in how projects were evaluated.
- 7) Throughout the survey, the majority of respondents indicated their preference that the decision to participate in a cloud seeding program be made by or shared with the local level —the people to be affected by the program.
- 8) A policy of active information dissemination had been adopted by the Division of Weather Modification. But, levels of awareness about program activity in South Dakota remained low throughout the course of the study. For example, 45% of respondents were aware that their county had a cloud seeding program after three operational seasons. The relationship between increased knowledge about weather modification and favorable evaluation appears to be one of no direct correlation. Those becoming more knowledgeable become more strongly opposed or more strongly favorable than they were previously. Thus, public education programs, while imperative to keeping the citizenry informed, should not be assumed to produce more favorable public opinion to weather modification.
- 9) In fact, after three operational seasons, organized opposition to weather modification developed in South Dakota with the formation in December of 1974 of a group called Citizens Against Cloud Seeding. The opposition formed in a context of overall public favorability (in the 20 participating counties) to the idea of modifying the weather, but it was initiated and supported at the grassroots level by farmers and ranchers in different locales who felt the program was damaging them economically. The major damage attributed to cloud seeding was drought. The opposition's stated purpose was to bring the South Dakota Weather Modification Program to a halt.

Opposition activity continued through the 1975 operational season with public meetings, letters to the editor, television appearances, circulation of petitions, and so forth, throughout many counties of the state. While the opposition did not emphasize the hail suppression component of the SDWMP, there were occasional contentions that the cloud seeding either increased hail or failed to reduce it. There have also been opponent allegations to the effect that small clouds were seeded to prevent hail, and subsequently dissipated, failing to produce rainfall.

*Opposition grows and organizes*

The eyewitness accounts of "disintegrating clouds" were reminiscent of weather modification controversies in Texas and Colorado, where similar observations were reported by opponents to hail suppression programs there. There was no reason to believe that opponents in South Dakota had been in contact with either the Texas or Colorado opponents prior to their own opposition effort. However, subsequent to their organization, the South Dakota group, Citizens Against Cloud Seeding, did get in contact with two other opposition groups in different parts of the country and exchanged information with them. Citizens Against Cloud Seeding was successful in halting operations in some counties during the 1975 season and, more importantly, in preventing county commissioners from signing contracts with the Division for operations during the 1976 season.

Since the Division of Weather Modification was funded primarily to carry out operational cloud seeding, it had few resources available for evaluation of program effects in a scientifically acceptable manner. The Division was, therefore, extremely hampered when legislators and others raised questions about proving the effects accomplished by the million dollar investment of taxpayer funds.

*No money for program evaluation*

During the state legislative session of 1975, some attempts were made to scuttle the SDWMP, but these were unsuccessful. However, by the 1976 legislative session, the opponents had made progress with members of the state legislature, and were more successful in reaching their goals. The appropriation for the South Dakota Weather Modification Program had been made part of the Governor's general appropriations bill in 1973, but that move was now reversed by the Joint Appropriations Committee. A special appropriations bill was introduced by a legislative supporter of the program, but the bill required a two-thirds majority of both the Senate and the House for passage. The night of its debate on the Senate floor, the bill achieved a simple majority but failed to pass by the two-thirds majority.

Thus, the SDWMP was not funded for the 1976 season. The Division of Weather Modification ceased to exist on July 30, 1976, after four operational seasons. Some members of the legislature felt that cloud seeding had become institutionalized somewhat too rapidly in South Dakota without adequate evaluation of the effect of seeding on precipitation and on downwind areas such as Minnesota.

*Program not funded in 1976*

The power of a grassroots organized opposition in terms of halting projects has never been more convincingly demonstrated than it is in the South Dakota case. The outcome is of particular interest since local government participated in.

decision making relative to the cloud seeding project and, at least theoretically, the interest groups of the community should have been represented in the decision process. However, when the economic viability of farmers is threatened through drought, and vestiges of doubt remain about the efficacy of a weather modification program, the impetus for an organized opposition is startlingly high.

*Local areas  
continue  
cloud seeding*

Some 19 counties in the state had signed contracts with the Division for the 1976 season; some of these counties have formed weather modification districts utilizing remaining state funds and county tax monies to finance local cloud seeding for the 1976 season. Thus, hail suppression and precipitation enhancement continued to be practiced in two local areas of the state during 1976.

#### HAIL SUPPRESSION IN TEXAS PANHANDLE



The semi-arid land surrounding Plainview and Littlefield, Texas, receives an average of 18 inches of rainfall and relatively frequent damaging hail each year. Beneath part of this agricultural area lies an isolated segment of the Ogallala aquifer, providing irrigation for those farmers fortunate enough to have purchased land lying above it. Farmers in both the irrigated and dryland sections of the area raise cotton, grain sorghum, and some wheat and row crops. Cattle graze in the brush of a rough infertile area to the east.

After a two-season attempt to reduce hail through cloud seeding in the early '50s, the area experienced no further weather modification until 1970. Opponents to the early effort feared that it was causing drought in the area.

*Private  
group hires  
firm to  
suppress hail*

In 1970, the Plains Weather Improvement Association (PWIA), a voluntary organization of local agriculturists, contracted with a weather modification firm to suppress hail during the growing season. Funds were contributed by subscribers to the service as well as by crop insurance agencies, businesses, and homeowners. The "target area" included Hale, Lamb, and portions of Floyd Counties. Opponents to this new project were alienated at the outset by the refusal of the PWIA leadership to confer with them regarding their concerns about the project.

Little public opposition to the proposed project was voiced, however, and the Texas Water Development Board (TWDB), the state agency responsible for administering the 1971 weather modification statute, granted the project a permit to conduct weather modification. Although opponents were not vocal at this time, expressions of concern were made to the TWDB by at least two local citizens.

*Opponents  
protest  
unsuccessfully  
to state  
board*

These citizens called a meeting of farmers to protest cloud seeding operations in October following an unusually dry first season of operations. The opponents, calling themselves the Farmers and Ranchers for Natural Weather (FRNW), contracted with a meteorologist to prepare a report on the effects of the 1970 seeding on rainfall in the area. His conclusion stated:

On the basis of this investigation, it is not possible to reject the hypothesis that cloud seeding for hail suppression has reduced the rainfall in certain areas. (*Atmospherics, Inc., 1975*)

Opponents appeared before the TWDB to present these results in opposition to the granting of the permit for the 1971 season. The permit was granted, however, and FRNW began circulating petitions against the project. In May, a straw vote was conducted in the operations area, resulting in majority disapproval of cloud seeding. The vote itself became a focus of controversy, with charges and counter-charges concerning its validity being made. After reviewing the situation, the TWDB stood by its decision to grant the 1971 permit in spite of the vote (*Plainview Daily Herald, 1971*).

Subsequent to these events, opponent activity declined in intensity during 1972 when the area experienced relatively plentiful rainfall and adequate soil moisture conditions for crops. The hail suppression projects in Plainview and Littlefield continued during this period, with two separate sponsoring entities: the PWIA in Plainview and Better Weather, Inc, (BWI) in Littlefield. For the 1973 season and subsequently, PWIA operated its own program, and BWI contracted with a commercial firm.

*Rainfall  
lessens  
opposition*

However, in July 1973, FRNW called a public meeting to discuss possible legal action to halt the hail suppression project (*Lamb County Leader News, 1973*). Although a good crop for 1973 was anticipated, FRNW feared that cloud seeding might harm its chances. Nearly \$5000 was pledged by opponents for legal fees in initiating an action against the project's continuance. The primary focus of opposition was the BWI project in Littlefield.

When opponents met with the Governor in late summer 1973, he referred them to the TWDB. An FRNW attorney then submitted a formal protest to the TWDB on the grounds that rainfall was being reduced by hail suppression. The TWDB refused to revoke the permit, contending that there was insufficient evidence to take such action. Although presented with opposition testimony regarding the 1974 permit applications, the TWDB granted permits to both PWIA and BWI for the 1974 season.

*Permits  
granted  
despite  
opposition*

In May, FRNW filed an equity action against the BWI program, and in June five days of testimony were heard by a local judge on a possible preliminary injunction against the project. Among the expert witnesses testifying in defense of the project were atmospheric scientists reporting studies on the area's rainfall. The research findings indicated no change in rainfall, and estimated a 40% reduction in hail damage as a result of the hail suppression program (*Changnon, 1975b*).

Most of the opposition testimony was offered by local residents and was based on their personal observations of the weather, crops, and cloud seeding activities. They repeatedly reported that clouds which would have rained were dissipated by cloud seeding aircraft. The judge ruled in favor of the defendants, however,

*Legal action  
unsuccessful*

and the opposition became financially pressed and possibly disenchanted with court proceedings as a method to stop the project. Although it would have been possible for them to pursue judicial action at that time, they did not choose to do so. Financial difficulty may have prevented their further pursuit of court action.

In November 1974, the TWDB met with opponents in nearby Lubbock to listen to their grievances against the two hail suppression projects. The Board reminded opponents that the Texas statute compelled them to issue permits for weather modifiers complying with stipulated requirements. The Board recommended to opponents that, if the statute were unsatisfactory in their view, they could contact their legislative representatives with regard to it.

*Statute  
modified*

Opponents were influential in obtaining legislative action on the weather modification statute early in 1975, although they were unsuccessful in obtaining a legal requirement for a county-wide vote — a provision they intensely desired, and which proponents did not want. A revision of the statute was passed into law, becoming effective January 1, 1976. New provisions were:

- 1) Wording that the TWDB "may" (rather than "shall") issue a permit to conduct operations to those complying with requirements
- 2) A lengthened permit period of up to four years with annual review
- 3) A required public hearing in the operational area if requested by at least 25 persons

*Permits  
accompanied  
by monitoring*

In the meantime, the TWDB granted a permit to BWI and PWIA for the 1975 season, specifying that operations should be limited to within 15 miles of the target areas of both projects. They also provided an on-site monitor to observe Littlefield operations for the season and report back to the Board on a weekly basis. Opponents by and large refused to observe project operations at the airport, although BWI invited them to do so.

Opponents believed that irrigating farmers (project subscribers) were less concerned about receiving rainfall than they, the dryland farmers, were. Proponents contended that pumping was costly and that they, too, required rainfall to "make a profit." Some residual resentment between the more fortunate irrigating and less fortunate dryland portions of Lamb County probably contributed to the project's credibility problems. Though the weather modifier consistently claimed not to be reducing precipitation, and to be operating within permit stipulations, opponents refused to believe that this was the case.

*New law  
brings  
public  
hearings*

BWI and their contractor submitted an application for a permit for the 1976 through 1979 operational seasons, under provisions of the new statute. Opponents quickly obtained the number of signatures requisite for public hearings, and quasi-judicial proceedings occurred in both Plainview and Littlefield in compliance with the law.

*Permit  
again  
granted*

On May 18, 1976, a permit to conduct hail suppression for one year was granted. The hearing officer responsible for findings of fact indicated that the proposed operation would not (and probably could not) dissipate clouds, that the natural course of rainfall would not be prevented by the project, that the project

would probably increase rainfall in the area, that there would be no material detriment to the people and property in the operational area, and that there might be a benefit from the elimination of hail.

Project supporters have begun to consider initiating a wintertime precipitation augmentation program in the area to aid the problem of insufficient moisture for crops. They hope that the opposition might be more willing to tolerate a hail program if such positive action were taken with regard to precipitation.

The Texas Panhandle projects are the only known examples of hail suppression projects continuing to be permitted in the face of extensive and long-lived organized grassroots opposition. The degree of community polarization in the Littlefield area is quite high; interactions between opponents and proponents are often characterized by threats and counter-threats of lawsuits. Two factors appear to be important in accounting for the project's continuance:

- The existence of "hard data" about hail and rainfall effect in the project's target area (*Farhar, 1975*), coupled with
- The proponent position of Texas weather modification officials toward the implementation of the technology (*Comparative Study Data, 1975*)

We show in *Figure 16* various newspaper and advertisement headlines that reflect proponent views.



In addition to the detailed discussions of three projects, brief reviews of several other projects in various parts of the country are presented. Both the scope and outcome of these efforts have varied.

1 — Crops in western Kansas — primarily corn, milo, and wheat — are threatened by both dry weather and hail. About a third of the cultivated land is irrigated through pumping underground water from the Ogallala aquifer. In 1973, the Western Kansas Water Management District No. 1 was established under a new state law following a favorable five-county vote, to work on the conservation of groundwater resources. Cloud seeding was one of the conservation approaches the District was interested in implementing.

Following three seasons of precipitation enhancement programs in western Kansas carried out by different organizations, the District organized a combined precipitation and hail project for the 1975 season. With funding and cooperation from 11 counties in the area and a local advisory committee, the project was run by the District for the 1975 and 1976 seasons. No organized protest to the cloud seeding operations developed (*Mewes, 1976*).

2 — A grassroots organization in northeastern Colorado sponsored hail suppression in 1958, but the project died in 1959, in part because of opposition sentiment. Concerns about drought and about the effectiveness of the technology were pri-

\*This section contributed by Barbara C. Farhar and J. Eugene Haas.

## **HAIL SUPPRESSION IN OTHER AREAS\***

1 — *Western  
Kansas*

2 — *Northeastern  
Colorado*





FIGURE 16

Newspaper and advertisement headings reflect proponent views

### Weather Modification Reaches

Cloud seeding to boost rainfall or reduce hail way of life for farmers in western parts of the turning a South Dakota weather political issue

By Daryl Mazz

### HAIL SUPPRESSION PROGRAM Directors Claim Success

... hail was reported in the ...  
... hail was reported in the ...  
... hail was reported in the ...



## CAN YOU AFFORD THIS IN

### Now Is The Time To Get Your Money In To Protect Your Investment

\*According To Reliable Statistics From Illinois Water Survey The Past Five Years Hail Has Been Reduced From 50 TO 60% In Seeded Areas.  
The Illinois Weather Survey Statistics Have Found No Change In Rainfall In Unseeded Areas.

**WORLD WAR ON HAIL**

... that this program also suppresses moisture ...  
... that this program also suppresses moisture ...  
... that this program also suppresses moisture ...

### Hail Suppression Action Is Urged

... that this program also suppresses moisture ...  
... that this program also suppresses moisture ...  
... that this program also suppresses moisture ...

# SUPPRESSION PROGRAM

... WE MUST ACT NOW!

## Efforts Underway To Continue Hail Suppression Through

... hail was reported in the ...  
... hail was reported in the ...  
... hail was reported in the ...

### Judge Denies Cloud Seeding Injunction

... hail was reported in the ...  
... hail was reported in the ...  
... hail was reported in the ...

### Hail Suppression Headway Claimed

... hail was reported in the ...  
... hail was reported in the ...  
... hail was reported in the ...

### Support Of Airplane Pilots, Crops

... hail was reported in the ...  
... hail was reported in the ...  
... hail was reported in the ...

### Weather Modification Reaches

... hail was reported in the ...  
... hail was reported in the ...  
... hail was reported in the ...

### Support - WE MUST ACT NOW!

... hail was reported in the ...  
... hail was reported in the ...  
... hail was reported in the ...

operations may have produced a net increase in hail apparently never reached potentially interested citizens or organizations; no organized opposition to NHRE emerged from 1971 to 1975 (*Farhar, 1976a; Krane, 1975*).

3 — A grassroots collection of dryland wheat and barley farmers in Idaho funded cloud seeding in 1974 and 1975. Hail suppression was seen as incidental to the primary desire for increased rainfall. There has been widespread, enthusiastic support. Neither damaging hail nor drought have been perceived to have occurred during these two years (*Mewes, 1976*). During the summer of 1976 a hail seeding project was carried out in southern Idaho and northern Utah under the sponsorship of an interstate nonprofit corporation (Note *page 316*).

3 — *Southern Idaho*

4 — Apple growers organized to support a hail suppression effort in 1956. After a cloudburst damaged his orchard, the owner filed suit and was successful in getting a court to grant a temporary restraining order which halted operations for the remainder of the season. The injunction was not made permanent but the program died nevertheless for lack of support (*Mewes, 1976*).

4 — *Eastern Washington*

5 — In the late 1940s and early 1950s pear growers and shippers in the Medford area assessed themselves to support a hail suppression program. In the mid-50s, the effort was discontinued largely because of doubts about its effectiveness. Some efforts by opponents, who feared undesirable changes in the weather, probably hastened the demise of the program (*Mewes, 1976*).

5 — *Medford, Oregon, area*

6 — In the North Platte River Valley of the Nebraska panhandle, sugar beets, beans, potatoes, and corn are grown under irrigation. From 1951 to 1957 the farmers in the area banded together and contributed funds to operate a hail suppression effort. In 1958, under the provisions of a new state law, the program was funded by county taxes. A successful court suit forced the county to refund tax monies spent for the hail suppression effort.

6 — *Western Nebraska*

No hail suppression has been carried out in the area since the court suit. There were no complaints of drought, and during the last three years of the effort, hail damage was minimal (*Mewes, 1976*).

7 — Fruit growers in the mountain foothills of El Dorado and Placer Counties of California sponsored an operational hail suppression project for several years prior to 1958. After a damaging hailstorm occurred, the orchardists decided that the project was costing more than the degree of protection it afforded, and they ceased supporting it (*Farhar and Rinkle, 1976*).

7 — *Northern Sierra Nevada Mountains*

8 — The Blue Ridge area includes parts of Maryland, Virginia, West Virginia, and Pennsylvania. In the summer of 1956, there was severe hail damage to orchard crops in the area. A local organization was formed and a commercial operator was hired to suppress hail for 1957. Efforts to get the "approval" of the county extension agents and meteorologists at Pennsylvania State University were unsuccessful.

8 - *Blue Ridge area*

The northeastern drought continued into 1957. Opponents, disturbed by drought conditions, arose in large numbers. During the next five years, there was adequate rainfall and no serious opposition to the hail suppression effort.

Opposition re-emerged and organized during 1962 when conditions became extremely dry. Acts of vandalism broke out. Opposition leaders were very committed to the cause and were successful in convincing many others to join in the crusade.

In 1964, several townships in south-central Pennsylvania passed ordinances prohibiting cloud seeding. One arrest and conviction of a weather modifier followed.

An attempt to get a court injunction against cloud seeding activity failed in 1968, but by then the orchardist sponsors of the hail suppression effort had decided on a one-year moratorium (1965). Maryland had passed a two-year prohibition against weather modification which was later renewed through 1971. In 1969, West Virginia and Pennsylvania passed weather modification laws so restrictive as to forbid cloud seeding for all practical purposes (*see Table 29, Chapter 6*).

Nevertheless, some very vocal opponents continued to insist that illegal cloud seeding was continuing in secret. Conspiracy theories of several types are not only discussed but believed, especially by opponents in south-central Pennsylvania. The Pennsylvania state weather modification law provides for surveillance by the State Patrol and that organization has been called upon to catch the culprits, but such efforts have been unsuccessful.

The opponents in the Blue Ridge area, called the Tri-State Natural Weather Association, have been in contact with opponents in other parts of the country to aid in bringing cloud seeding projects to a halt in those areas (*Mewes, 1976*).

## 9 — North Dakota

9 — Interest in weather modification in North Dakota was initiated in the Bowman Slope area in the southwestern part of the state. A local agriculturist who had experienced severely damaging hail availed himself of a "crash" course in cloud seeding during the late fall of 1960. Neighbors became interested in his operations, begun in 1961, and contributed funds in order to share in the service. Gradually the hail project expanded to four counties in the area, and in 1969, the Institute of Atmospheric Sciences, South Dakota School of Mines and Technology, under sponsorship from the Bureau of Reclamation, established an experimental cloud seeding program in McKenzie, Mountrail, and Ward Counties to the north. This project, studying precipitation augmentation and hail suppression, terminated at the end of the 1973 growing season.

North Dakota's weather modification statute provides for the formation of weather modification authorities at the county level by petition. By the spring of 1974, 17 counties had formed such authorities and were conducting cloud seeding operations. At about this time, the North Dakota legislature amended the statute to provide for a North Dakota Weather Modification Program (NDWMP), funded

by state and county taxes, and modeled after SDWMP. In fact, South Dakota's director was hired to head the new NDWMP, which commenced operations for the 1976 season. North Dakota strove to learn from South Dakota's experiences in designing its program, and one of the provisions it made was funding for continuing study of project effects (*Smart, 1976*).

Although the first hint of organized opposition to the NDWMP developed in the spring of 1976, overall public response to the newly initiated program has paralleled that of South Dakota in 1972 — majority neutral-to-favorable attitudes toward weather modification (*Johnson and Falk, 1974*).

Further discussion of variables illustrated in these cases occurs in Chapters 6 and 9 of this report.



As pointed out earlier, hail suppression has not been utilized in most states to cope with hail damages to crops. But in certain areas of the country, crop loss to hail appears to be of enough significance to warrant consideration of hail suppression. Where the economic payoff would seem to be so great, why has hail suppression never been tried?

NONADOPTING  
AREAS\*

It was not possible, of course, to collect new data on this question from all of the potentially relevant areas, but a special effort was made to secure information from selected locations. Fifteen counties in the mid-Atlantic region were selected for special investigation; these counties produce high value crops and have relatively severe hail losses.† County agricultural agents and growers were interviewed using a standard set of questions which covered the following topics:

*Interviews  
in high value  
crop areas*

- Methods used to cope with the hail threat
- Awareness of any past or present efforts to use hail suppression
- Probable response of agriculturists in the county if a hail suppression effort were proposed in the future (*Pfost, 1975*)

Tobacco and apples are the principal crops in the Virginia counties — tobacco, fruit, and corn in the North Carolina counties. In the South Carolina counties the prime hail-relevant crops are peaches in the north and cotton, tobacco, and soybeans farther south.

But despite the variation in crops and weather patterns, the findings were strikingly similar for all 15 counties. Basically, the conclusions were:

- 1) Insurance constitutes the only significant method of coping with the problem of crop loss to hail.
- 2) No weather modification effort of any kind has been considered or carried out in any of the counties or states contacted.
- 3) Hail suppression has not been tried because residents are generally unaware of the technology and hail is not perceived as a serious problem by growers.

\*This section contributed by Barbara C. Farhar and J. Eugene Haas.

† The counties studied were: 1) Virginia: Grayson, Carroll, Patrick, Henry, Pittsylvania; 2) North Carolina: Avery, Stokes, Surry, Yadkin, Forsyth; and 3) South Carolina: York, Chester, Kershaw, Lee, Sumter, Calhoun.

- 4) There is little interest in the possibility of hail suppression efforts in the future because: insurance is considered to be a satisfactory means for dealing with hail, and hail is not considered to be a serious problem especially when compared with excessive or insufficient moisture and high wind.
- 5) If hail suppression were to be considered in the future, growers would be concerned about: the costs and methods of financing such a program, the efficacy of such hail suppression efforts, and the possible side effects of cloud seeding.

*Hail loss  
not viewed  
as problem*

While there are some slight variations from these general findings, they are minimal. Some fruit growers in Virginia claim that insurance is not available. Some growers in South Carolina disperse their crops geographically to avoid catastrophic loss to hail, and a few growers intentionally diversify their investment in agricultural production. But the general conclusion had remarkably wide support among those persons who have intimate knowledge of crops and hail loss in these 15 counties in three states. *They do not see hail loss as a serious problem within the context of available options.* They have not considered hail suppression in the past and are unlikely to view it favorably in the future.

These findings suggest that considerable caution should be used in estimating how rapidly adoption will come for various regions of the country. Even a demonstrably effective and efficient hail suppression technology may be viewed as unnecessary by growers if they see the hail threat as relatively minor.

*Citizen  
response  
in Illinois*

A 1974 survey in Illinois also provides relevant findings. As in the mid-Atlantic states, hail crop loss is occasionally high but hail suppression efforts are yet to be conducted. Anticipating that possibility, however, the Illinois State Water Survey and Human Ecology Research Services conducted a survey among rural, small town, and city residents (N = 274) in a five-county area of central Illinois in April 1974 (Krane and Haas, 1974). Among the relevant findings were the following:

- 1) More than half of the respondents agreed that instead of trying to change the weather, man should find other ways of dealing with it, such as cheaper insurance and improved weather forecasting.
- 2) Only one in five persons believed that current hail suppression technology can actually reduce hail damage; most are uncertain regarding its effectiveness.
- 3) A clear majority (60%), when asked to assume the effectiveness of hail suppression, believed that it would be of personal economic benefit.
- 4) Rural, more than town or city residents, perceived personal economic benefit from an effective hail suppression program.
- 5) But, all of the above must be interpreted in light of the finding that *82% of the respondents said that they had never even heard of any weather modification programs that attempted to decrease hail!*
- 6) Almost two-thirds felt that "we should try to solve other problems before spending more tax money on weather modification programs." The lower the socio-economic status of the respondent, the more likely he was to agree with this statement.
- 7) While only one-third favored a future operational hail suppression program, 54% favored such an effort if it were to be experimental. The majority preferred to have the state government as the financial sponsor for a hail program.
- 8) The views of farmers who regularly carry crop hail insurance did not differ significantly from those who seldom or never purchase such insurance.
- 9) Those who had recent uninsured hail crop losses did not hold essentially different views from those who had not.

As with the findings from the mid-Atlantic states, the Illinois citizen responses suggest that they were not particularly concerned about the current hail situation. That view should be put in perspective, however. The majority had little knowledge about hail suppression technologies and were uncertain or skeptical about the effectiveness of hail suppression efforts. Despite these views, 50% of the farmers questioned indicated a willingness to contribute money directly toward the cost of an *experimental* hail suppression project. In general, then, the social climate toward hail suppression in Illinois was clearly not hostile, but there was not great eagerness, either.

*Not hostile,  
not eager  
in Illinois*

These two areas, the mid-Atlantic states and Illinois, are the only nonadopting areas for which direct data are available on the knowledge of and attitudes toward hail suppression on the part of potential users of the technology. It is not possible to say with confidence whether the findings can be generalized to other regions.

## HAIL SUPPRESSION IN OTHER COUNTRIES\*



Our background for assessing hail suppression would not be complete without at least a brief look at the extent of the use of this technology in other countries, and the interaction between weather modification technologies in this country and others.

Hail suppression has been practiced on all continents save Antarctica. In fact, United States companies have played an important role, through exportation of hail suppression, in the global spread of its use (*Changnon, 1973; 1975c*). American firms have been heavily involved in projects in Canada, Kenya, Italy, and South Africa. Most foreign projects have been ended by a lack of continued financial support because the evidence of hail suppression was not strong.



In 1973 there were 14 foreign nations operating hail suppression projects (*WMO, 1973*). The 15 foreign nations which have employed hail suppression in the past 20 years include:

FOREIGN  
PROJECTS

Australia	Hungary	South Africa
Argentina	Rumania	Switzerland
Bulgaria	Japan	Soviet Union
Canada	Kenya	West Germany
France	Italy	Yugoslavia

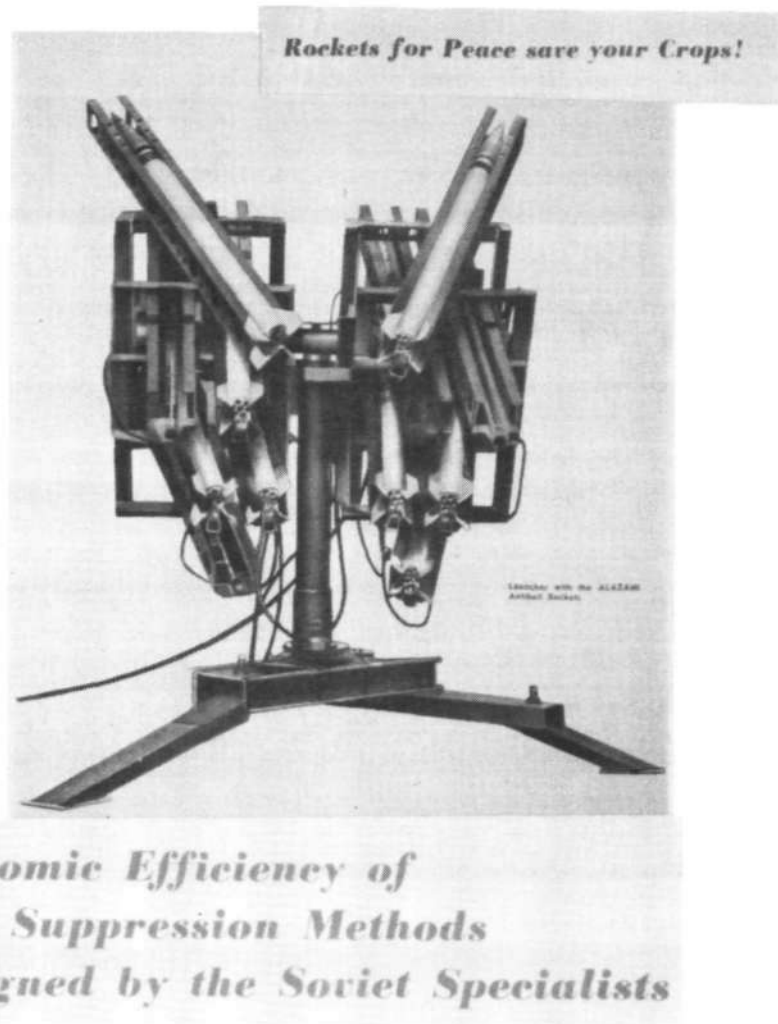
Hail suppression has been attempted in those areas which have 1) valuable crops susceptible to hail damage, and 2) considerable hail. Except for Kenya, these are all mid-latitude regions where mountain-induced hailstorms are the prime problem.

\*This section contributed by Stanley A. Changnon, Jr.



FIGURE 17

Soviet equipment being marketed



Interestingly, hail suppression, which the Soviet Union ambitiously developed, has since been fostered in several of its satellite countries, and Soviet hail seeding equipment and supplies are marketed for sale around the world (*Mashpriborintorg, 1973*). We show examples of features advertised in the 1973 Soviet catalog in *Figure 17*. American businessmen and Soviet bureaucrats both are selling an empirically based technology to the nations of the world, either for profit and/or for political gain. The delivery technologies offered differ, with the American approach using aircraft for seeding below or above storm clouds, sometimes combined with surface seeding devices, and the Soviet approach using ground-based rockets (or artillery) to shoot the material inside of storms.

In Canada, as in the United States, there has been a mixture of operational applications of hail suppression prior to and then during research and experimentation with hail suppression. A large privately sponsored hail suppression project conducted by a United States firm in the lee of the Canadian Rockies began in the late 1950s and lasted about 10 years (*Krick and Stone, 1975*). Hail research efforts appeared in Canada in the 1960s, culminating in hail suppression experimentation in the 1970s (*Renick, 1975*). However, pressure from the research and operational groups led to a program involving a mixture of operations and experimentation using cloud-base and cloud-top seeding techniques (*Renick, 1975*), and farmer pressure in 1976 ended the randomized experimentation two years (1977, 1978) before it was to be completed.

*Canada's  
program*

Three nations vitally interested in hail loss and its suppression have joined in an experiment beginning in 1976 to use and test the Soviet rocket suppression system. Italy, France, and Switzerland have pooled funds, facilities, and manpower to conduct this experiment in Switzerland (*Federer, 1975*).

*Tri-nation  
experiment*

South Africa's hail suppression program was started in 1971 by an American firm which is under contract to continue for another eight years. The project is funded at about \$1 million annually, making it one of the most expensive hail suppression projects in the world. High performance jet aircraft, employing a "cloud-top seeding approach" (also being used and tested in Canada) are used over a protected area of 3000 square miles. A significant 40% reduction in hail severity has been recorded, but other hail characteristics (areal extent and amount of losses) do not appear statistically significant (*Changnon and Morgan, 1976a*).

*South Africa's  
extended  
program*

The program in South Africa is financed by a farmers' tobacco cooperative which has levied an 8% fee on production costs. This covers the costs of both insurance and hail suppression, including a Lloyd's of London catastrophe provision. Some citizens have complained that the seeding has reduced precipitation, and there has been a threat to use violence to stop the seeding. Government Weather Bureau records show an inconclusive, minor (4%) reduction in precipitation (*Katsiambrias, et al., 1975*).



Exportation is an issue of concern for the American firms which sell the technology of hail suppression and for the federal government, which sets foreign policy, adopts foreign-related regulations, and attempts to resolve foreign conflicts. Foreign support of commercial weather modification firms from the United States is sizeable, being 45% of the income of the firms in 1972 (*Changnon, 1973*). [The weather modification industry, as a stakeholder in hail suppression progression, is discussed in more detail in Chapter 5.] It also appears plausible, from experiences in the United States (*Farhar and Mewes, 1975*), that conflicts over the use of hail suppression in a foreign nation could be blamed on the United States and the American firm because of its conduct of the effort.

EXPORTATION  
ISSUES



It also appears that American firms and the Soviet Union are in a loose competition in world markets over the sale of their hail suppression systems and staff. Hence, the federal government or an international body may have to consider an "international policy" for the exportation of weather modification. Such a policy would provide a means to monitor modification activity (*Evans, 1975*), to evaluate the results, possibly to ensure its quality, and to encourage its use in less well-developed countries which have major hail and agricultural problems (*Borland, 1975*).

## CURRENT LEVELS OF HAIL SUPPRESSION\*



So, where does hail suppression stand? As we have seen, the technology has been practiced in areas that suffer from hail losses in this country and abroad — regardless of the lack of full scientific experimentation and understanding. We attempt now to evaluate the current understanding — to establish the capabilities of the hail suppression technology as they exist today.

Information on the current levels of hail suppression was sought from three sources. These were to be anchor points, or an empirical base, from which the future hail suppression levels could be estimated through scientific-technical models in Chapter 8.

*Information sources*

First, we drew upon the various evaluations of existing hail suppression projects. All available evidence was gathered and analyzed. The second source of information was the recent reviews of weather modification by scientific groups. Third, two recent opinion surveys furnished information. One survey was done as a part of this TASH project to get estimates of future suppression levels, but it also included questions relating to the current capabilities. Detailed information about this evaluation effort is presented elsewhere (*Changnon and Morgan, 1976b*)

PROJECT  
EVALUATIONS



Results from several recent or ongoing hail suppression projects that had lasted for three or more years were sought.

*Evaluation of Texas program*

One set of information was obtained from a recent evaluation (*Changnon, 1975d*) of the first four years of the ongoing six-year-old commercial hail suppression project in Texas that was technologically based on cloud-base seeding and use of the competition hypothesis (*Henderson, 1975*). [The various hypotheses and seeding methods are discussed in detail in Chapter 4.] This project, in basically a two-county area, was investigated with the use of historical Weather Bureau

These sections contributed by Stanley A. Changnon, Jr.

**TABLE 11**

**Comparison of differences in insurance rates between counties seeded for hail suppression and unseeded adjacent counties in southwestern North Dakota**

	Actual values		Actual rate difference expressed as percent of the control counties mean rate	
	A-C <sup>1,2</sup>	B-C <sup>1,2</sup>	A-C	B-C
Average difference before seeding began	6.3	1.6	53	12
Average difference after seeding began	6.0	1.0	40	6
Difference in before-after seeding values	0.3	0.6	13	6
Before-after difference as a percent of before value	5	37	25	50

<sup>1</sup> A=Bowman and Slope counties where seeding began in 1961; before-seed period was 1954-1960.

B=Adams and Hettinger counties where seeding began in 1968; before-seed period was 1954-1967.

C=Stark and Grant counties are the control (no-seed) adjacent counties.

<sup>2</sup> Rates per \$100 coverage.

hail-day data and crop-hail insurance data. Ten time-space comparisons showed hail reductions ranging from 5 to 94%.

The value considered the *single best estimate* of a meaningful reduction was a 48% reduction in the insurance loss cost (loss/liability). Schickedanz (1975) found the differences between actual and predicted (based on preproject relations) losses to be statistically significant at the 5% level, indicating strong evidence of hail suppression after four years. Study of the rainfall in and around the seeded area revealed there was no detectable alteration (Schickedanz, 1974).

In southwestern North Dakota, insurance rates in an area operationally seeded for 15 years with silver iodide at cloud base (and with the competition hypothesis) were compared with those for adjacent nonseeded counties (Butchbaker, 1973). Their differences are summarized in Table 11. Here the before-seeding values were compared with those after the seeding began for the target (seeded) counties and for the control counties. Four values were determined and a relative decrease for the seeded counties was shown by each, ranging from 5 to 50%. The median of these four values was a 31% reduction. Time did not permit an extensive testing of these values for statistical significance.

*North Dakota  
insurance  
comparison*

An experimental hail suppression and rain modification project carried out for four years in North Dakota (Miller et al., 1975a) offers another useful set of

*North Dakota  
experiment  
evaluation*

information on the current status of hail suppression in the mountain-High Plains climatic area. The competition hypothesis of hail suppression was employed involving updraft seeding, with silver iodide released at cloud base. The project also attempted to increase rainfall.

Four sets of hail change values are published for this experiment, each with varying degrees of significance. These values included a 4% reduction in hail depth, a 21% reduction in hailfall energy, a 40% reduction in radar reflectivity, and a 60% reduction in crop-hail damage. Collectively, they indicate an overall reduction of about 30%. This project also indicated a 23% increase in rainfall. Simpson (1975) evaluated this project and largely supports their results stating "This project provides substantial, but not conclusive, evidence of a cause-effect relationship between seeding and hailfall in the intended direction."

*South Africa  
project  
results*

Schickedanz (1975) investigated the tobacco loss data from the first three years of the ongoing hail suppression project in South Africa. The project involves cloud top seeding with silver iodide to reduce hail on the basis of the glaciation hypothesis. [Again, see Chapter 4 for details.] Various comparisons of surface data show a variety of alterations, most of which are not highly significant. In general, the seeded data results show a diminution of large damage values but an increase in small damage values, indicating less heavy hail but more light hailstorms. However, the crop severity ratio (amount of loss ÷ area of loss) showed a reduction of 40% that is significant at the 5% level (Changnon and Morgan, 1976a).

Davis and Mielke (1974) evaluated this South African project and reported comparable results. Simpson (1975) also investigated the project and states, "The data for the three seasons so far (as of May 1975) would show, if the control cases were randomly selected (they were not), a near-conclusive demonstration of hail damage reduction on the order of 50 percent." An analysis of the rainfall from seeded days indicated little change, -4% (Katsiambrias et al., 1975).

*South Dakota  
statewide  
program*

A fifth set of information was the results from the South Dakota statewide seeding program. Here, cloud base seeding with silver iodide was used to suppress hail (by the competition approach) and to increase summer rainfall. Between 50 and 70% of the state was seeded from 1972 through 1975. The results (*South Dakota Division of Weather Modification, 1976; Miller et al., 1975b*) show 1) a consistent increase in rainfall in each year with values from 3.9 to 11.5%, and 2) decreases in hail losses of -50% in 1972 and -20% in 1973, and a 6% increase in hail loss in 1974. The four-year medians are +7% for rainfall and -20% for hail loss.

*Results  
of NHRE*

A sixth set of potential information was the 1972-1974 hail suppression experimentation in northeast Colorado (the National Hail Research Experiment). Cloud-base updraft seeding was used in all years and it was coupled to rocket seeding from the cloud base aircraft in 1974 to achieve a hail embryo competition approach. Although all results from the randomized experimental period (27 days

were seeded and 30 days were not seeded as control data) are not yet available, the NHRE Project Plan (NCAR, 1976) presents surface rain and hail results.

These three-year results indicate a 14% increase in hail mass on seeded days when hail fell and this is not statistically significant. The rain change was +19%, also not significant. Another analysis that included data when hail did not occur on some seeded days showed a nonsignificant increase in hail of +19% and a rain increase of 37%. Neither value was statistically significant. The medians are +17% for hail and +27% for rain. A variety of operational problems and alterations in the activities make the results highly questionable (RANN-UCAR Panel, 1974; Flueck and Mielke, 1975). Some of the serious problems included the shift in seeding technique in 1974 from that used in 1972 and 1973; between-year changes in the study areas size, shape, and locale; changes in type and distribution of surface hail sensors; and errors on the calibration of the radar signal level which was the key criterion for choosing clouds to be seeded.

The results from these projects were examined to select the best estimates of alteration in hail and rain. These are shown in Table 12. The six hail modification project values —listed in the order presented in Table 12 — are -48%, -31%, -30%, -40%, -20%, and +17%. Although most are not statistically significant at the 5% level, an important feature is that all but one (NHRE) are reductions. The general level of reduction of 20 to 40% is in agreement with NCAR expectations for a future NHRE, indicating a 30% reduction is a more realistic possibility (ESIG, 1975). The best estimates of rain modification, listed in order on Table 12, are  $\pm 0$ , no information, +23%, -4%, +7%, and +27%. None is statistically significant but they indicate a tendency to modify rain increases (3 out of 5 values available). This is in general agreement with earlier findings from Switzerland which showed 60 to 110% rain increases 0 to 125 miles downwind of a seven-year hail suppression experiment (Neyman et al., 1968).

*Best estimates  
of project  
values*



A second set of information was that available in recent published assessments by scientific groups and scientists.

## **PUBLISHED ASSESSMENTS**

The American Meteorological Society (AMS, 1973) in its statement on weather modification labels the status of hail suppression as "positive but unsubstantiated claims and growing optimism." The National Academy of Sciences (NAS, 1973) reports on 30 to 50% reductions in hail in the Soviet Union and a 15% reduction in France, but their report stresses that neither of these has been established through experimentation. The Academy report also addresses apparently successful hail suppression in Kenya, both with rockets and silver iodide seeding, but no reductions are listed.

*AMS,  
NAS  
reports*

Hitschfeld (1975) in a review of hail suppression status pointed to the great evaluation problems. He offered a scientist's response to those who wished to

*Scientist's  
response*



**TABLE 12**

**Information sources for the status of hail suppression and related rainfall modification in 1975**

*Best estimates from project evaluations*

1. Texas: hail = -48% (crop loss), with no change in rainfall
2. Southwestern North Dakota: hail = -31% (crop-hail insurance rates), with no rain change information available
3. North Dakota Pilot Project: hail = -30% (a composite of 4 hail characteristics), with +23% change in rainfall
4. South Africa: hail = -40% (crop-loss severity), with -4% change in rainfall
5. South Dakota Statewide Project: -20% in crop losses, +7% increase in rainfall
6. NHRE: +17 in hail mass, with +27% increase in rain

*Published assessments*

1. AMS = Positive but unsubstantiated claims and growing optimism
2. NAS = 30 to 50% reductions in USSR, and 15% decreases in France, but neither proven by experimentation
3. CSU Workshop = -30% hail (Nationwide - USA)  
-30% hail (High Plains), with  $\pm 10\%$  rain  
hail unknown (Midwest), with unknown rain

*Opinion surveys (median values)*

1. Farhar questionnaire (214 answers) = -25% crop-hail damage (Nationwide), although majority (59%) indicate they do not know
2. ISWS questionnaire (63 answers) = -30% hail loss with +15% in rain (Great Plains)  
= -20% hail loss with +10% in rain (Midwest)

employ hail suppression, and indicated the proper scientific position is "there is a technology of suppression but it is of unknown power."

CSU  
Workshop

The fourth recent assessment-oriented report is that from a 1975 workshop held at Colorado State University where 60 scientists with agricultural and weather modification expertise were convened (*Grant and Reid, 1975*). Two sets of assessments of hail suppression were made from evaluations by two separate subgroups. One assessment indicated the capability of a 30% reduction in hail with a 70% confidence over areas from 100 to 60,000 square miles. This value is the reduction of 30% shown in *Table 12*. The other subgroup assessment indicated the current hail suppression capabilities include a reduction of 30% for hail loss in the Great Plains with a possible  $\pm 10\%$  change in rainfall (*Table 12*). It also identified the status of hail suppression in the Midwest as unknown.

Hence, the assessments from this workshop, both for the Great Plains and the nation, indicate belief in an existing 30% reduction capability. This agrees favorably with the best estimate values from the project evaluations shown in *Table 12*.



The final sets of current values of hail suppression were determined from two surveys.

SCIENTIFIC  
OPINION  
SURVEYS

An extensive questionnaire developed by Dr. Barbara Farhar of the University of Colorado and later with the TASH team was distributed in 1975 to weather scientists. It asked the question: "On the average, about how much hail damage to crops (in percentages) can be reliably decreased during a year given current technology?" A total of 318 (59%) of the 534 responses listed "don't know" to the question. Of the 214 who answered the question with a specific value, percentage decreases ranged from 0 to 82%. The median value was a reduction of 25%, the best estimate shown in *Table 12*.

A questionnaire developed for TASH got responses from 63 hail scientists. The median values of the "current" or 1975 suppression capabilities indicated by these answers were 30% reductions in the Great Plains and 20% reductions in the Midwest; both values appear in *Table 12*. Of considerable interest is the fact that the median values from the questionnaires (-30%, -25%, and -20%) and those from the CSU workshop report (-30%) are in reasonably good agreement with the other values shown in *Table 12* which were results obtained from a variety of independent projects. The scientific consensus about hail suppression — don't know — and the evaluations of current projects — values of +17 to -48% with most in the -20 to -40% range — do not agree.

Thus, the current status of hail suppression in the United States can be characterized by:

- 1) Lack of physical measurements and understanding of in-cloud processes during hail suppression efforts
- 2) Scientific uncertainty and disagreement as to levels of alterations related to inconclusive experimentation
- 3) Continued growth of the operational use of hail suppression in the United States with the total area being 130,000 square miles in 1975
- 4) Evaluation of most ongoing operational hail suppression programs revealing 20 to 40% reductions that are mostly not statistically significant, though without randomization it is difficult to get conclusive tests and wide scientific acceptance

The current situation surrounding hail suppression reflects a similar one for rainfall modification 5 to 15 years ago. The users (agriculturists) and applicators (industry) have joined forces to apply an uncertain technology, while the scientific community does not agree and wants more proof of the preciseness of the technology. Various relevant groups tend to argue, each contending for prominence in establishing its definition of the situation for the status (or state of the art) of hail suppression. In this situation, the groups tend to argue, each attempting to set its own rules for establishing the status of hail suppression.

## REFERENCES

- American Meteorological Society  
1973 *Policy statement of the AMS on purposeful and inadvertent modification of weather and climate.* Bulletin American Meteorological Society, 54, 694-695.
- Atmospherics, Inc.  
1975 *Final report: The BWI weather modification program.* Fresno, California, p. 42.
- Borland, S.G.  
1975 *Hail suppression: Progress in assessing its benefits and costs.* In NHRE Symposium/Workshop on Hail: Preprint vol. 1, NCAR, Boulder, 50 pp.
- Butchbaker, A. F.  
1973 *Results of Bowman-Slope hail suppression program.* Journal Weather Modification, 5,133-145.
- Changnon, S. A.  
1973 *Weather modification in 1972: Up or down?* Bulletin American Meteorological Society, 54, 642-646.  
1975a *The paradox of planned weather modification.* Bulletin American Meteorological Society, 56, 27-37.  
1975b *Evaluation of an operational hail suppression project in Texas.* Journal Weather Modification, 7(1), 88-100.  
1975c *Present and future of weather modification: Regional issues.* Journal Weather Modification, 7, 154-176.  
1975d *Scales of hail.* In NHRE Symposium/Workshop on Hail: Preprint vol. 1, NCAR, Boulder, 52 pp.
- Changnon, S. A., and G. M. Morgan  
1976a *Design of a hail suppression experiment for Illinois.* Illinois State Water Survey, Urbana, Illinois, Bulletin 61, 194 pp.  
1976b *The present status and future potential of hail suppression.* Journal Weather Modification, 8(2), 164-189.
- Charak, M.  
1975 " *Preliminary information on U.S. weather modification activities in CY 1974.* Journal Weather Modification, 7, 200-204.
- Comparative Study Data  
1975 *Comparative study of public support of and resistance to weather modification projects.* J. E. Haas and B. C. Farhar, Co-principal investigators, Institute of Behavioral Science, University of Colorado, Boulder, and Human Ecology Research Services, Inc., Boulder.
- Davis, R.J.  
1974 *Weather modification law developments.* Oklahoma Law Review, 27, 409-439.
- Davis, R. J., and P. W. Mielke  
1974 *Statistical analysis of crop damage and hail day rainfall — weather modification season, 1973/74.* Submitted to Laeveldse Tabakkooperasie Beperk, Colorado International Corporation, Boulder, Annual report, Volume 2.
- Division of Weather Modification  
1974 *The South Dakota weather modification program.* Department of Natural Resource Development, Pierre, South Dakota, Report DWM R-74-2.
- Donnan, J. A., J. L. Pellett, R. S. Leblang, and L. F. Ritter  
1976 *The rise and fall of the South Dakota weather modification program.* Journal Weather Modification, 8(1), 14.

Environmental and Societal Impacts Group

- 1975 *Environmental impact statement, national hail research experiment.* NCAR, Boulder, Draft of 3 November, 65 pp.
- Evans, F. E.  
1975 *A bill to provide for research and development in weather modification, to establish a comprehensive system and means for the orderly, safe, and scientific development of weather modification activities, and for other purposes.* H. R. 10039, 94th Congress, 1st Session, Washington, D.C., October 6.
- Farhar, B. C.  
1975 *Weather modification in the United States-. A socio-political analysis.* Unpublished doctoral dissertation, Department of Sociology, University of Colorado, Boulder, 387 pp.  
1976a *Working papers: Technology assessment for hail suppression.* Human Ecology Research Services, Inc., Boulder.  
1976b *Weather modification goes public.* Paper presented at the Annual Meeting of the Weather Modification Association, Los Angeles, California, April 1.
- Farhar, B. C. and S. Krane  
1973 *Weather modification and public opinion: South Dakota, 1972.* Institute of Behavioral Science, University of Colorado, Boulder, Interim report.
- Farhar, B. C. and J. Mewes  
1974 *Weather modification and public opinion: South Dakota, 1973.* Institute of Behavioral Science, University of Colorado, Boulder, Second interim report.  
1975 *Weather modification decision making: State law and public response.* Journal Applied Meteorology, 14, 694-701.  
1976 *Social acceptance of weather modification: The emergent South Dakota controversy.* Institute of Behavioral Science, University of Colorado, Boulder, Monograph 23.
- Farhar, B. C. and Ron Rinkle  
1977 *A societal assessment of the proposed Sierra snowpack augmentation project.* Human Ecology Research Services, Inc., Boulder, January.
- Federer, B.  
1975 *Methods and results of hail suppression in the European area and in the USSR.* In NHRE Symposium/Workshop on Hail: Preprint vol. 1, NCAR, Boulder, 17 pp.
- Flavin, J.  
1971 Letter to Tom Ten Eyck, Department of Natural Resources, State of Colorado, February 15th.
- Flueck, J. A., and P. W. Mielke  
1975 *Evaluation of hail suppression experiments.* In NHRE Symposium/Workshop on Hail: Preprint vol. 1, NCAR, Boulder, 26 pp.
- Garcia, B.  
1973 *Background is given on weather modification flying in Valley.* Valley Courier, February 5, p. 1.
- Grant, L. O., and J. D. Reid  
1975 *Workshop for an assessment of the present and potential role of weather modification in agricultural production.* Colorado State University Ft. Collins, Atmospheric science paper 236, 236 pp.
- Haas, J. E.  
1973 *Social aspects of weather modification.* Bulletin American Meteorological Society, 54(7), 647-657.



- Haas, J. E., and S. Krane  
 1973a *Social implications of the national hail research experiment: 1972 final report.* Human Ecology Research Services, Inc., Boulder.
- 1973b *Social implications of the national hail research experiment: 1973 final report.* Human Ecology Research Services, Inc., Boulder.
- Haas, J. E., and D. Pfof  
 1972 *Social implications of the national hail research experiment: 1971 final report.* Human Ecology Research Services, Inc., Boulder.
- Henderson, T. J.  
 1975 *Status of a hail suppression program in Texas.* Journal Weather Modification 7(2), 84-92.
- Hitschfeld, W. F.  
 1975 *Hail suppression: Evaluation and other problems.* Journal Applied Meteorology, 14, 655-658.
- Hosier, C. L.  
 1974 *Overt weather modification.* Reviews Geophysics Space Physics, 12, 523-527.
- Johnson, J. E., and L. Falk  
 1974 *Social attitudes toward weather modification. In The Effects of Added Rainfall During the Growing Season in North Dakota, Submitted to the Division of Atmospheric Water Resources Management, Bureau of Reclamation, North Dakota State University, Fargo, Final report, 147-163.*
- Kaplan, H. M.  
 1973 *Should we try to change our weather?* Empire Magazine, Denver Post, Sunday, May 6, 22-27.
- Katsiambras, E., J. Barnett, and W. Beaver  
 1975 *Comments on the rainfall analysis for hail days in Nelspruit area.* South African Weather Bureau, Pretoria, Report, 12 pp.
- Krane, S.  
 1975 *Social implications of the national hail research experiment: A longitudinal study.* Human Ecology Research Services, Inc., Boulder.
- Krane, S., and J. E. Haas  
 1974 *The public view toward weather modification in Illinois-. A social assessment.* Human Ecology Research Services, Inc., Boulder, 90 pp.
- Krick, I. P., and N. C. Stone  
 1975 *Hail suppression in Alberta 1956-1968.* Journal Weather Modification, 7(2), 13-27.
- Lamb County Leader News  
 1973 *Cloud seeding opponents set Tuesday night meet.* Texas, July 22, p. 1.
- Leonard, J.  
 1974 *South Dakota leads the nation in the cloud seeding business.* Winner Advocate, South Dakota, July 24, p. 28.
- Mashpriborintorg, V. O.  
 1973 *Hail suppression means and methods used in Soviet Union.* Moscow, 23 pp.
- Mewes, J.  
 1976 *Working papers: Technology assessment for hail suppression,* Human Ecology Research Services, Inc., Boulder.
- Miller, J. R., E. I. Boyd, R. A. Schleusener, and A. S. Dennis  
 1975a *Hail suppression data from western North Dakota 1969-1972.* Journal Applied Meteorology, 14, 755-762.

- Miller, J. R., A. S. Dennis, S. L. Wang, and R. L. Schwaller  
 1975b *A preliminary examination of South Dakotas hail suppression efforts as revealed by crop-insurance data.* Institute of Atmospheric Sciences, South Dakota School of Mines and Technology, Rapid City, Report 75-20, 25 pp.
- National Academy of Sciences  
 1973 *Weather and climate modification: Problems and progress.* Washington, D.C.
- National Center for Atmospheric Research  
 1969 *Plan for northeast Colorado hail experiment.* Boulder, 44 pp.  
 1976 *Revised plan for the national hail research experiment, February 1976.* Boulder, 186 pp.
- National Science Foundation  
 1968 *Proposed plan for a national hail suppression research program.* Washington, D.C., 201 pp.  
 1959-1968 *Weather modification: First [through Tenth] annual report.* Washington, D.C., p. 7.
- Neyman, J., E. L. Scott, and M. A. Wells  
 1968 *Influence of atmospheric stability layers on the effect of ground-based cloud seeding: I. Empirical results.* Proceedings National Academy of Science, 60, 416-423.
- Pickering, D.  
 1970 *Co-op scans the skies.* Corpus Christi Times, Corpus Christi, Texas, May 15.
- Plainview Daily Herald  
 1971 *Anti-hail permit okay.* Plainview, Texas, May 25, p. 7.
- Pfost, D. R.  
 1975 *The response to hail in selected southeastern states.* Human Ecology Research Services, Inc., Boulder, December, TASH working paper 13.
- RANN-UCAR Panel  
 1974 *Report of the national hail research experiment review panel.* National Science Foundation, Washington, D.C., 31 pp.
- Renick, J.  
 1975 *The Alberta hail project.* Journal Weather Modification, 8(2), 1-6.
- Schickedanz, P. T.  
 1974 *Evaluation of the rainfall data in the vicinity of the Texas hail suppression program.* Atmospheric, Inc., Fresno, California, 27 pp.  
 1975 *Evaluation of hail suppression.* In NHRE Symposium/Workshop on Hail: Preprint vol. 1, NCAR, Boulder, 24 pp.
- Schleuseuer, R. A.  
 1962 *The 1959 hail suppression effect in Colorado and evidence of its effectiveness.* Nubila, 5, 31-59.
- Simpson, J.  
 1973 *Bayesian statistics applied to Florida cumulus modification experiments.* Preprints, 3rd Conference on Probability and Statistics, American Meteorological Society, Boston, 73-80.  
 1975 *Assessment of results of hail suppression experiments around the world.* In NHRE Symposium/Workshop on hail: Preprint vol. 1, NCAR, Boulder, 9 pp.

- Smart, George R.  
 1976 *Weather modification in North Dakota.* Human Ecology Research Services, Inc., working paper 24, August.
- South Dakota Division of Weather Modification  
 1976 *Recent rain and hail analyses of the South Dakota weather modification program.* Pierre, South Dakota, 10 pp.
- Sulakvelidze, G. M.  
 1967 *Results of the Caucasus anti-hail expedition of 1965.* NCAR library translation 182, Boulder.
- Taubenfeld, R. F.  
 1973 *Weather modification, technology assessment and the social control of "progress."* Paper presented at Conference on Legal-Political-Social-Economic Aspects of Climate and Weather Modification, Center for the Future, Santa Barbara, California, 36 pp.
- U.S. Department of Commerce  
 1973a *Summary report of weather modification: Fiscal year 1972.* National Oceanic and Atmospheric Administration, Rockville, Maryland.  
 1973b *Summary report of weather modification: Fiscal years 1969, 1970, 1971.* National Oceanic and Atmospheric Administration, Rockville, Maryland.  
 1974a *Weather modification activity reports, November 1, 1972 to December 31, 1973,* M. T. Charak and M. T. DiGiulian, National Oceanic and Atmospheric Administration, Rockville, Maryland.  
 1974b *Summary report of weather modification: Fiscal year 1973.* National Oceanic and Atmospheric Administration, Rockville, Maryland.  
 1975 *Weather modification activity reports, calendar year 1974.* National Oceanic and Atmospheric Administration, Rockville, Maryland.
- Valley Courier  
 1972a *Valley growers intend to conduct hail suppression program.* Colorado, December 27.  
 1972b *600 attend weather meeting.* Colorado, August 1.
- World Meteorological Organization  
 1973 *Cloud physics and weather modification.* Commission for Atmospheric Services, 6th Session, Versailles, France, CAS-VI/document 26.

## SUMMARY OF CHAPTER 3- HISTORICAL OVERVIEW AND CURRENT STATUS OF HAIL SUPPRESSION



The 20-year history of hail suppression in the United States has been marked by considerable confusion, scientific uncertainty, and sometimes public controversy. Agriculturalists used the services of commercial weather modification firms before experimental results on the effectiveness of the technology were developed. Although some field experiments seem to have resulted in hail decreases (such as in North Dakota); others (e.g., NHRE) have not. Thus the current situation is one of scientific dissensus about the state of the art.

*A history  
of confusion*

Over the 18-year period from 1958 to 1975, existing records reveal that 357 cloud-seeding field operations and experiments were conducted. Of these, approximately 17% (or 61) were estimated to have involved hail suppression, much of it in the Great Plains area of the United States. The public's experience with hail suppression remains limited.

Case history material on public controversies in hail suppression project areas reveals several factors associated with the emergence of opposition. Among these were local heterogeneity of weather needs, occurrence of drought periods during cloud seeding efforts, lack of scientific consensus about the readiness of the technology for operational application, and general lack of public participation in decisions to adopt hail suppression.

*Reasons for  
controversies*

Adoption tended to occur in high hail loss areas where hail destroys up to 20% of the crop. Those interested in adopting have included barley and lettuce growers who practice irrigation; cotton, grain, and wheat farmers; and fruit growers. Where adoption did not occur, even though hail losses were significantly high in an objective sense (mostly in 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 as a solution to crop loss from hail.

*Adoption and  
nonadoption*

Three different types of information regarding the current status of hail suppression were evaluated — and three different positions appear in describing the current status.

*Different  
views of  
current  
status*

One view is that based on the results of evaluations of six hail suppression projects. Five of these projects indicate the existence of a hail suppression capability ranging from 20 to 48%, but most results are not statistically significant at the 5% level. In general, these results would be classed by most atmospheric scientists as optimistic.

Another view of hail suppression is that afforded by the various recent scientific reviews of weather modification. These basically reveal a position that suggests 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 opinion surveys show wide-ranging but basically bipolar attitudes.

A majority of the scientists indicate no belief in a hail suppression capability, but a sizeable minority indicates that a moderate (greater than 20%) capability for suppressing hail now exists. At best, the average belief must be labeled "don't know."

These three views of the current status of hail suppression —which we label as optimistic, slightly optimistic, and pessimistic —reflect a wide range of opinions and results. Clearly, the current status of hail suppression is in a state of uncertainty.

Most of what is currently known about the status, either the success or failure, of hail suppression has been through examination of surface hail (and rain) data in a project area during seeded periods. Very little has yet been shown through study of the physical behavior of the atmosphere and the interior of storms from the suppression efforts. Hence, most of what is known is largely empirical.

There are major meteorological unknowns facing hail suppression at this time. The major unknowns include:

- 1) The in-cloud processes involved in hail suppression and how varying amounts of seeding material affect these under different storm types and stages of storm lifetime (see pages 79-80)
- 2) The distribution (diffusion) of seeding material (silver iodide) in and around a storm seeded by different techniques (see pages 82-83)
- 3) The effects of the seeding design for hail suppression, using either the competition or glaciation approach, on storm rainfall rates and total yield, surface winds, lightning, and other closely interconnected convective storm phenomena (see pages 83-86)
- 4) The effect of hail suppression and hence storm modification, over varying sized areas, on the weather in areas beyond the area of desired modification (see pages 214 and 230)
- 5) Methods, involving both physical and statistical techniques, to adequately evaluate hail suppression (see pages 229-231)
- 6) The lack of comparable in-cloud and thunderstorm studies around the nation and in apparently different storm areas for translation of modification results (see page 302)

# 4

## Hail suppression technology



In classical Greece farmers attempted to prevent hail by burying laurel leaves moistened with menstrual blood in their fields, and by other magical or religious practices. Hail suppression efforts in the past 2000 years have included prayers, magical rites, protective nets, hail cannons, and rockets (*Morgan, 1973*). Now we are devising a modern technology based on scientific principles by which to deal with the hail problem.

How does it work? What are the scientific principles behind the efforts used to prevent or inhibit the growth of hail in a storm? What are the mechanisms required? What organizational and functional elements are involved? Answers to these questions are outlined briefly in this chapter, as a further base for our assessment of hail suppression and its potential as a useful technology for the nation.

### HOW IT IS DONE-THE PHYSICS INVOLVED\*



Freezing of water to form ice is a complex phenomenon in clouds and, interestingly, often does not take place at 0° C. In fact, pure water without the action of any foreign surface must be cooled to somewhere near -40° C before it will freeze (homogeneous nucleation). Water in a liquid state at temperatures below 0° C is referred to as *super-cooled water*.

At temperatures between 0 and -40° C, small particles known as *ice nuclei* can act as catalysts and cause — trigger — freezing. These particles are microscopic but they are invariably present in water and in the atmosphere, though their concentration is usually quite low. For example, particles capable of causing ice formation at -20° C would have a typical concentration in the atmosphere in

### ICE NUCLEATION

*Ice nuclei  
trigger  
freezing*

\*These sections contributed by Griffith M. Morgan, Jr.

the range of 0.1 to 1.0 per liter of air. In contrast, concentrations of condensation nuclei, the particles on which cloud or rain droplets form, might range from 100 to more than 1000 per cubic centimeter of air (up to a million per liter). Thus, we can appreciate the natural rarity of ice nuclei.

*Cloud seeding can do the triggering*

Most cloud seeding involves intentional triggering (nucleation) of the ice phase in clouds. This triggering aims either to stop the production of hailstones or to make many small stones that will fall harmlessly on the ground, instead of a few large ones. A few other methods of cloud modification exist (such as seeding by hygroscopic nuclei for rain enhancement in the warmer layers of clouds), but ice nuclei seeding remains the most promising for hail suppression.

## **ICE NUCLEANTS AND HOW THEY WORK**



There is no fully acceptable theory of ice nucleation at present. This is not surprising in light of the incomplete understanding regarding the physics of water in its condensed phases. Natural ice nuclei are thought to be soil particles — in particular certain clays — and locally may be organic particles produced by plants and fungi. Numerous particles which are active in ice nucleation are dispensed into the air by industries and other activities of man. Freezing occurs in the upper portions of all summer thunderstorms, which usually extend 4 to 6 miles above the freezing level in the air, located 2 to 3 miles above the ground.

An early theory on ice nucleation (and one which may be correct) predicted that active nuclei were crystalline substances which had a crystal structure closely resembling that of ice. Such substances would act as surrogate ice crystals and allow ice to form on them. This theory successfully predicted that silver iodide (AgI) should be an excellent ice nucleant — and AgI is still the most widely used artificial nucleant. However, other substances not resembling ice have been found to be very active ice nucleants.

The action of artificial ice nuclei in cloud seeding rests on the following:

*Ice crystal steals from water drop*

Over a wide range of subfreezing temperatures, the equilibrium vapor pressure over ice is lower than that over water. This means that an ice crystal in the presence of a cloud of water drops will grow at the expense of the drops. We illustrate this growth in *Figure 18*. The ice crystal will, in fact, grow large enough to begin to fall at a higher speed than the drops, and will begin collecting and freezing those with which it collides. This is the essence of the famous Bergeron-Findeisen theory of precipitation formation, a powerful and elegant concept in cloud physics. The large particles formed in this way are precipitation embryos or hailstone embryos.

*Hail embryo collects smaller drops as it falls*

Hailstone embryos grow by collecting and freezing smaller (cloud and rain) drops which they sweep up as they fall. Normally very few of these hail embryos exist (low concentration) because of the paucity of ice nuclei that we noted earlier, and so the embryos grow freely until they fall out of the cloud. Two processes can alter this situation:

One would be this: The number of embryos increases to such a point that they *compete* for the available super-cooled water —and though greater in number, they individually reach smaller sizes. Then either they fall to the ground as smaller, less damaging stones, or they melt and reach the ground as rain. Several studies have shown that in summertime hailstones which do not reach a size of approximately 1 centimeter in diameter (about the width of a piece of chalk) will melt completely before reaching the ground. This is called the "increased competition" approach to hail prevention.

Or this can happen: Most of the liquid water can be frozen. Since ice crystals can collide with the growing hailstone without sticking to it, the hailstone is deprived of the material for its growth. This is called the "total glaciation" approach to hail prevention.

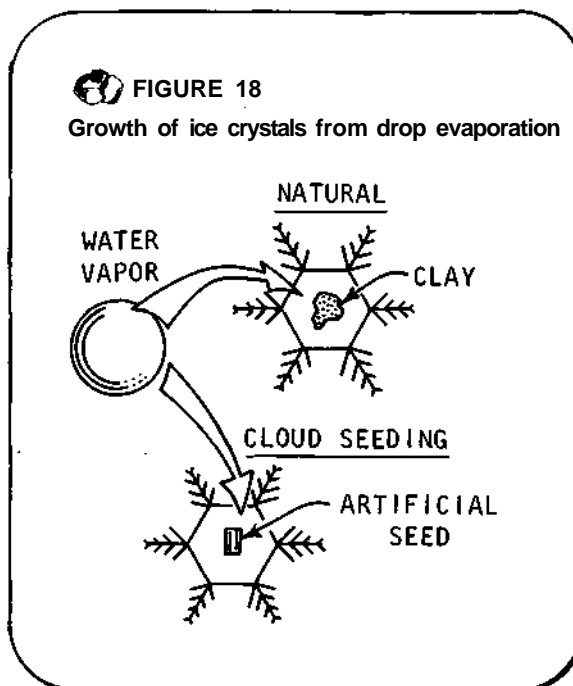
The latent heat of freezing, amounting to roughly 80 calories per gram of water, is released during the freezing of water under either approach. This heat is transferred to the surrounding air, raising its temperature. This increases the buoyancy of the air, which will be accelerated upward. The entire storm, as a result, may increase in size and intensity. We have illustrated this effect of added heat in *Figure 19*. Such an effect could also make the storm capable of supporting larger hailstones or cause other side effects of questionable value. Purposeful efforts to seed clouds in a manner to promote this rapid heat release and increase in rainfall is called "dynamic seeding," which appears to be accomplished in a certain class of storms.

The total glaciation approach to hail prevention is logistically and economically impractical. Enormous quantities of silver iodide would be required to glaciare even a moderate-sized storm cloud.

The most reasonable and feasible approach to hail suppression is through the mechanism of increased competition. In theory, it requires acceptably low quantities of silver iodide and reasonable numbers of aircraft for its delivery. It is at least not intended to promote an increase in storm size or intensity.



Ideally, one would like to alter the ice nuclei content of all of the air which is processed by the storm so that the storm would not produce hail. In practice,



*Too many embryos — not enough 'water' to grow*

*'Water' freezes, can't stick to embryo*

*Subsequent results*

*Competition mechanism feasible*

**DELIVERY OF SEEDING MATERIALS**





FIGURE 19

Effect of added heat from seeding

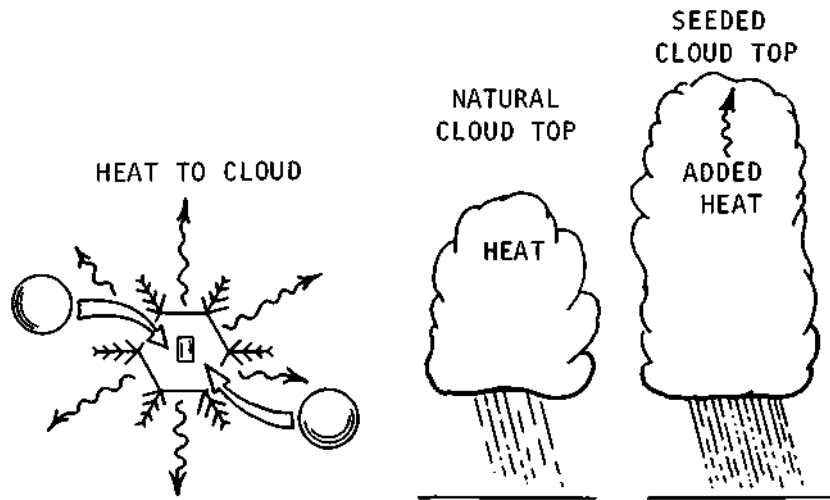
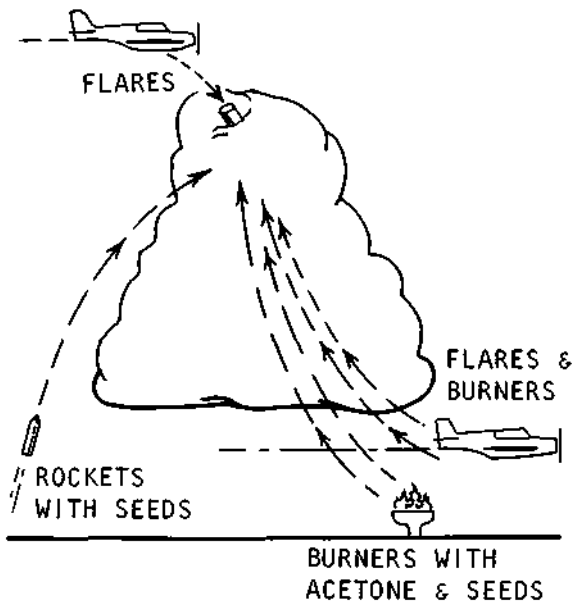


FIGURE 20

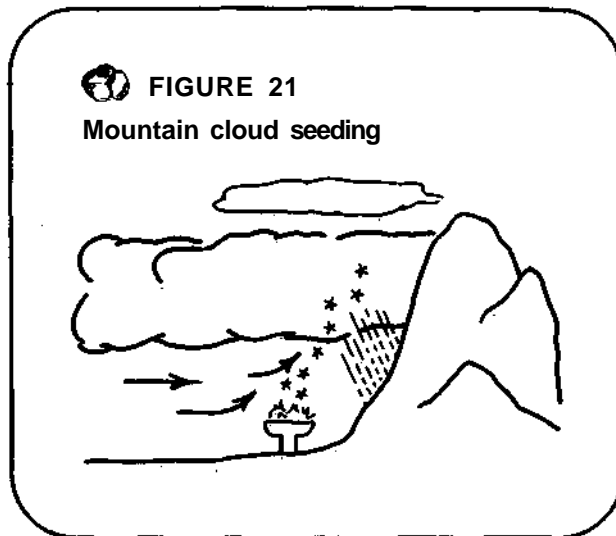
Some methods of cloud seeding



seeding is accomplished in a more or less discontinuous fashion by flying under the cloud where the air is flowing into it — as we illustrate in *Figure 20* — or by flying through the cloud while burning mixtures whose smoke contains large numbers of ice nuclei (usually AgI). These applications are highly localized in time and space, and, for the mixing of the silver iodide in the cloud, one relies on the naturally present turbulence to diffuse the material through large volumes of space.

Some foreign suppression programs have used rockets or artillery to place the nucleant in specified regions of the cloud where hail was expected to form and grow, as we also show in *Figure 20*. The greatest controversy has surrounded another seeding method shown in that figure — the emission of nucleants by burning AgI mixtures from burners on the ground. Attempts to document the mixing and transport of the AgI

from the ground to the bases of the clouds have produced conflicting results, even in situations involving large numbers, in the hundreds, of burners. However, these ground burners have been found to work well in mountainous terrain where the forced upward air flows help the seeding material into the clouds, as sketched in *Figure 21*.



Over most of the United States, one can rule out for the foreseeable future the use of surface rockets or artillery for hail prevention because of the obvious conflicts with aviation and general public concern for safety. Until further research is done on the problems associated with the ground-burner mode of operation, the airborne approach to cloud seeding is left as the most feasible method of delivery.

Various means have been employed for generating the finely divided AgI aerosols employed in weather modification. In the early years of cloud seeding, such techniques included mixing iodine vapors with air drawn past an electric arc between silver electrodes, burning charcoal bricks impregnated with AgI solutions, burning rope or string impregnated with such solutions, or burning the same solution in a hydrogen flame. Today, the aerosols are produced very efficiently by two methods and a variety of devices, as the pictures illustrate:

*Generating  
the AgI  
aerosols*

- 1) By burning complexed mixtures of AgI,  $\text{NH}_4\text{I}$ , and acetone or other solvents in specially designed wing-mounted burners on airplanes (*Figure 22*)
- 2) By burning pyrotechnic flares or fusees mounted on wings (top pictures in *Figure 23*) or by burning pyrotechnic fusees dropped from special fixtures mounted on the fuselage or a wing of the aircraft (bottom pictures in *Figure 23*) which burn while falling in the cloud.



It is unthinkable to expect that a single aspect of a storm, such as production of hail, can be altered without some effect on many other aspects. There is a considerable concern and even greater lack of knowledge about the effects of hail suppression done in one area on the weather in surrounding areas (see *page 214*).

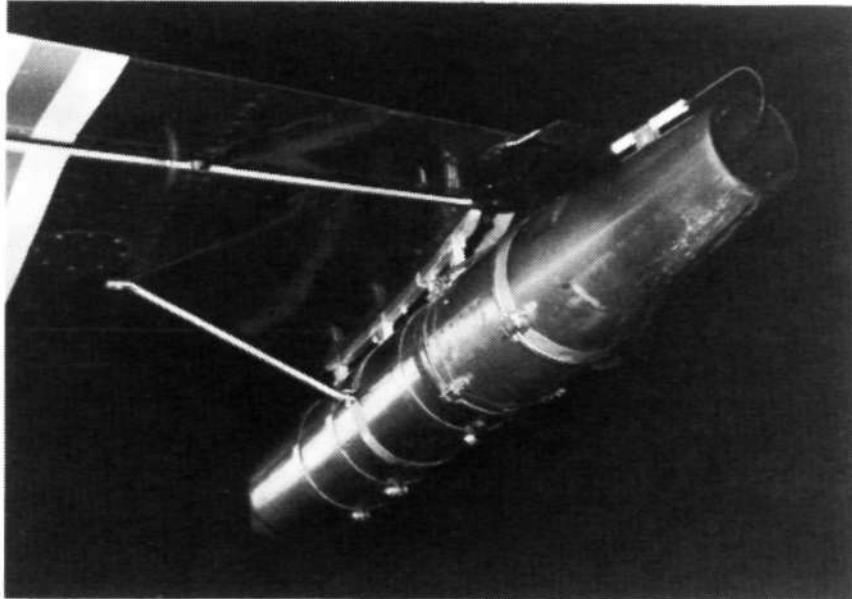
**INADVERTENT  
SIDE EFFECTS**

A cloud system is a complex array of interdependent processes; changing one will change most if not all. The problem of the degree to which hail prevention by chosen techniques will change the rest of the cloud and the surrounding atmosphere is complex to a nearly intractable degree. Negative impacts, if there are any, must be avoided. All other effects must be determined empirically, and only the barest beginnings have been made to date.



FIGURE 22

Acetone AgI generator on wing tip of seeding aircraft



*Rainfall —  
increase or  
decrease?*

It is possible to rationally develop arguments which predict quite opposite effects on rainfall as a result of hail prevention cloud seeding.

Under the competing embryo hypothesis, the simplest reasoning leads to a prediction of an increase in rainfall. So many hail embryos are created by the seeding that they take up all, or nearly all, of the cloud water (*Figure 18*). This amounts to a very efficient conversion of cloud water to precipitation in a system that is not naturally so efficient — and hence leads to a net increase in rainfall.

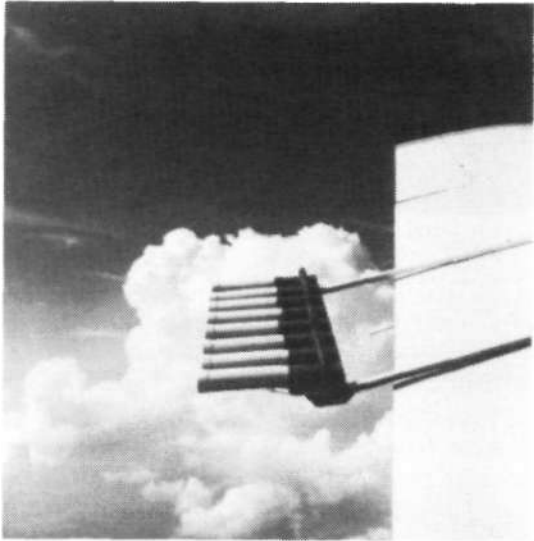
Under the hypothesis based on more massive applications of seeding material (glaciation) the effect on precipitation is much more difficult to predict — because of opposite and competing effects. On the one hand the dynamic (heating) effect of freezing water becomes significant, potentially intensifying the inflow of water vapor into the storm. If the precipitation efficiency remains the same, this should produce more rainfall. On the other hand, after heavy glaciation of the cloud, many of the small ice crystals that are created may be swept away, as cirrus clouds in an anvil, by strong horizontal winds at the top of the storm — hence, less rainfall.

Importantly, at temperatures below  $-10^{\circ}\text{C}$ , ice crystals do not aggregate — that is, stick together — very efficiently so that few large particles can form (*Braham, 1968*) to help the rain process.

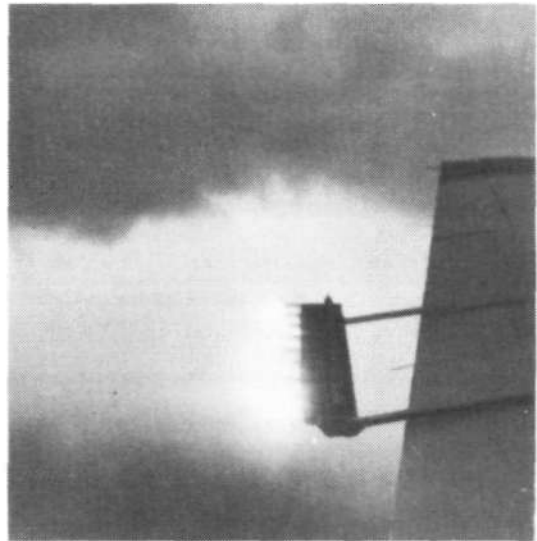


FIGURE 23

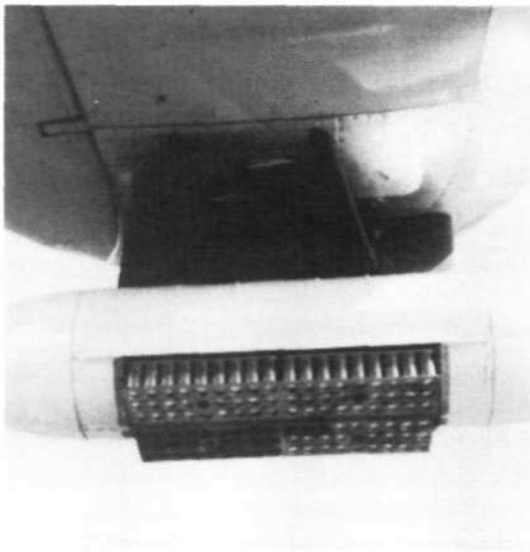
Pyrotechnic devices, either mounted or droppable, to release AgI



Mounted pyrotechnic flares



Same flares burning in flight



Container to drop fuses mounted on wing of NOAA aircraft used in Florida experiment



Flare container built in bottom of modified Lear jet used to drop flares for hail suppression in South Africa

There are, in addition, secondary and higher-order effects which might influence rainfall both locally and outside the area of attempted hail suppression. It is almost impossible to predict with confidence even the net sign of these effects. Some candidate mechanisms that are discussed in detail by Morgan (1976) are:

*Secondary effects on rainfall*

- Stabilization by return settling (a complex looping mechanism by which the strong convective updrafts in storms are opposed by downdrafts that warm and stabilize the surrounding air)
- Gravity waves (sometimes generated in a stratified atmosphere to affect storms in other areas)
- Lifting of potentially unstable air by gravity flows of cold air (which can create violent convection or squall fronts at great distances from the source)
- Effects of anvil outflows (where the upper plume of the anvil spreads out and shadows large areas, reducing solar heating and thus convective activity)
- Effects due to wetting of the ground by rainfall (which vary, but often tend to bring subsequent clouds and rain)
- Effects of uncontrolled transport of the artificial cloud seeding substance (which are uncertain, since the substance may be washed out of the atmosphere or be swept downwind to other clouds)

Some of these mechanisms have now been observed by weather satellites and many are the subject of research.

*Altered surface winds*

The strong damaging winds produced by severe thunderstorms and hailstorms are a manifestation of the downdraft phenomenon. The strong organized downdraft of such storms is caused by the evaporation of rain into very dry air encountered at some distance (6000 to 16,000 feet) above the ground. The evaporation chills the air — the same process that is exploited in the evaporational air conditioners used in arid regions. This process lowers the density of the air to the point that it becomes negatively buoyant. The melting of hail also influences this process. During its descent, the chilled air acquires considerable kinetic energy which is diverted horizontally near the ground. Winds approaching 100 mph due to this cause are not unheard of.

Any process which alters the production of rain and hail in a storm will alter the rate of production of cold air in the downdraft and hence, to some unknown degree, the strength of winds and gustiness at the ground. Results from preliminary studies of wind data from two field experiments, one on hail prevention and the other concerning inadvertent urban weather modification, are given in the section on the future status of hail suppression in Chapter 8.

*Influence on tornadoes*

Tornado production and the way it might be influenced by cloud seeding is even more complex to discuss. Strong updrafts and downdrafts are characteristic features of tornadic storms, and processes producing changes in updrafts and downdrafts could have some (unknown) effect on the occurrence of tornadoes.

*Lightning relations*

Lightning is a serious source of damage associated with thunderstorms. The relationships between lightning — its strength and frequency — and other parameters of convective storms are poorly, or not at all, understood. There is some weak evidence for a negative correlation between hailfall and lightning — that is, storms with hail produce less lightning. Cloud seeding has been under test as a means of reducing lightning-caused forest fires, suggesting a decrease in cloud-to-ground lightning and an increase in cloud-to-cloud lightning.

## THE COMPONENTS OF HAIL SUPPRESSION\*



A technological process does not exist in a vacuum but rather within the confines of certain societal structures. Farhar (1975) identified five basic organizations involved in weather modification, including hail suppression. These are:

### ORGANIZATIONAL ELEMENTS

- 1) Research organizations
- 2) Commercial firms
- 3) Support groups
- 4) Opposition groups
- 5) Regulatory and policy entities

The first three are briefly discussed here because they are the immediate components, directly involved in carrying out the modification processes and the various functions that constitute a hail suppression project. The opposition groups and the myriad regulatory and policy-making entities are the constraining organizations, and are discussed in detail in Chapter 6 (Societal Influences).

The research organizations involved in hail suppression are basically of two types, either government agencies and their laboratories, such as the National Center for Atmospheric Research (NCAR), or various university groups. Among the research endeavors involving hail, the largest has been the National Hail Research Experiment (NHRE), which has been the responsibility of NCAR. Most of the support for the hail research activities comes from the federal government, specifically from the National Science Foundation. Smaller amounts of research support have come from certain state governments, such as Illinois.

*Research  
organizations*

Some of the university research groups, especially in South Dakota and Illinois, have worked on specific local-area projects, but others have been subcontracted by NCAR to be involved in NHRE. In some cases, commercial firms also have been contracted to provide facets of the research effort for hail suppression. Because research organizations will have a direct stake in the future development of hail suppression, their dimensions as a stakeholder industry are described in Chapter 5. Research groups have been attacked as promoting research (and their survival) without solving problems.

Commercial weather modification firms, the second major organizational component, likewise will be stakeholders in the future of hail suppression, as we describe in Chapter 5. These firms basically serve three groups — private sponsors, public sponsors for operational programs, and public sponsors for research and evaluation. The firms typically have specially trained staffs and facilities to serve their customers. Farhar (1975) provides an interesting description of the commercial weather modifiers as follows:

*Commercial  
firms*

The role of a weather modifier is somewhat ambiguous. Weather modifiers are pleased to call themselves scientists; most often, however, they are considered businessmen by others. Many of them are pilots, some have advanced degrees, and many are officers of their own firms. Their primary stance towards the technology is that it is ready for operation; they

\*These sections contributed by Stanley A. Changnon, Jr.

conduct weather modification as a service for clients and for profit. However, they also subcontract for research through the federal government and carry out field studies, data collection, and data analyses. Thus most weather modifiers wear two hats: the entrepreneur and the scientist. They are dissimilar to academic scientists, however; the question about their vested interest in providing the scientific basis of the technology, their evident resistance to regulation, their resentment at totally research-oriented projects and organizations, and their enthusiastic support of commercial operational program projects underscores the idea that their basic motivation is success in the business world.

### *Support groups*

The third organizational component in weather modification is labeled the "support groups." The organizations and levels of support involved in the research and development phase of hail suppression are discussed in Chapter 5 and some of the private support groups are described in the project case studies of Chapter 3.

Operationally, weather modification is supported for two basic reasons: first, to avoid losses and second, to gain additional benefits or profits (*Farhar, 1975*). An important concept in the private and public support of operational (non-experimental) weather modification efforts is a basic belief that it works, since scientific proof of hail suppression remains ambiguous. Weather modification has been supported by six basically different groups:

- Hydropower companies
- Federal sponsors such as the Bureau of Reclamation (these first two groups have been interested solely in precipitation enhancement)
- Airports and airlines (interested only in fog suppression)
- Agricultural groups
- State and local governments (such as South Dakota)
- Private industry

The last three types of sponsoring groups have all been involved in research and operational sponsorship of hail suppression. The agricultural groups have typically developed in small regions such as in Colorado, Kansas, and Texas to employ local hail suppression operational programs. A beer manufacturer in Colorado sponsored a local program in hail suppression. Finally, state and local governments such as in South Dakota (1972-1976) and now in North Dakota (1976), as described in Chapter 3, have provided funds for hail suppression projects, in both cases with simultaneous efforts to increase rainfall.

## **FUNCTIONAL ELEMENTS**



Past and current efforts to carry out hail suppression fall into two distinct categories — operational projects and research experiments.

Although the two types of activities differ greatly in many respects, they can consist in varying dimensions of five functional elements:

- 1) A design or plan
- 2) Field operations including equipment and personnel
- 3) An evaluation of the results
- 4) An assessment of the socioeconomic effects
- 5) An information-communication effort

Because of the great differences in the amount of attention, support, and effort that is given to these functions for most operational projects in contrast to research projects, we shall look at the elements for the two categories separately.

Operational hail suppression projects, as can be noted from Chapter 3, come in a variety of sizes and styles. They have ranged from a few farmers "hiring a cloud-seeder" to the tax-supported, nearly statewide operation in South Dakota that lasted four years. However, most of the functional elements are exemplified by the moderate-area commercial operational projects.

*First —  
operational  
projects*

The design or plan — which includes the area, the time and amount of seeding, and all other facets of the program — is essentially determined by the funds provided by sponsors and the type of technology that the commercial modifying firm specializes in. For example, if funds are raised by 25% of the farmers over a 2-county area at a rate of 15 cents per planted acre, that sum fairly well determines the amount of effort, staffing, and equipment that can be brought to bear. The duration of the operations is also determined by the sponsors, who know when and how long the crops must be protected.

*Operational  
designs*

Typical field-operation functions — provided by the commercial firm — start with a "forecast" of weather to guide the daily operations. The forecast is usually done by a meteorologist of the firm who dictates operations locally, but it is sometimes done remotely by the firms from their central headquarters many miles away.

*Commercial  
field  
operations*

In the field operation, the type of seeding determines the equipment and staff involved:

- One calls for ground generators (*Figure 20*) and their operators, who are often local citizens hired to run the generators "on call" from the forecast headquarters.
- The other requires one or more aircraft carrying various seeding devices, as described earlier in this chapter (*Figures 22-23*). Frequently the aircraft will use a weather radar system both to help forecast the operation and to direct the pilot to potential storms for seeding. In a few projects, the radar is also tied to a mini-computer which records selected data that assist in the operations and in some later evaluation.

The staff of a commercial firm typically includes meteorologists for directing the field operations and forecasting, pilots for the aircraft used, technicians for equipment maintenance, and generator operators if that method is used. Supervision generally rests with the company leadership.

Evaluation *per se* is typically a minor function in privately supported projects. Basically, the local sponsors make their evaluation through an annual decision of whether the job was "worth it." Continued payment is the ultimate evaluation of success or failure.

*Minimal  
evaluation*

However, in certain instances, such as the South Dakota program, the routinely collected crop-hail insurance data and National Weather Service rainfall data have been evaluated with respect to the suppression operations. Simplistically, good or



poor results are spelled by the value of crop-loss insurance claims and advantageous rainfall.

It is important to realize that evaluation of ongoing nonrandomized operational programs is an extremely difficult task that requires a variety of data and sophisticated techniques. Private sponsors or local supporting groups are generally not willing to pay for this type of effort and extra cost. On the other hand, there is clear evidence from the review of suppression projects in Chapter 3 that the lack of good evaluation of benefits (or losses) is a frequent problem in sustaining privately supported projects.

*Impacts generally disregarded*

The fourth function, measurement of various socioeconomic impacts of the hail suppression operation, is typically not a focus for privately supported hail suppression operations. Research groups with some federal sponsorship, such as the University of Colorado and the Illinois State Water Survey, have attempted to make social and economic impact analyses of operational projects but not without local funding.

*Irregular information efforts*

The fifth, the information-communication function, is generally an ad hoc effort in the privately sponsored operational projects. The effort rests largely on local dissemination of information by the sponsors, coupled with materials supplied by the commercial firm, generally on request.

*Actual costs of operations*

A final note on the operational projects concerns the costs and support, which have varied considerably depending largely on the extent of the seeded area and the type of seeding devices employed. For the most inexpensive approach — which has been wide-area seeding involving only ground generators — costs are typically only a few cents per planted acre of the region. Even the costs in the widespread South Dakota program that involved radars and aircraft seeding were on the order of 3 to 5 cents per acre (*ESIG, 1974*). However, a hail suppression project with several aircraft and radars in a small area can be much more expensive, up to 60 cents per planted acre. In general, most past projects that included forecasting, aircraft, and radars have ranged from 10 to 20 cents per planted acre (*ESIG, 1974*).

*Second — research experiments*

Achieving the five key functions of weather modification in experimental research projects has brought forth much larger — more extensive and more expensive — efforts than those involved in the privately supported operational projects. Although there are records of 105 experiments dealing with weather modification (*Table 8* in Chapter 3), there have been only two significant hail suppression research experiments in the United States — the National Hail Research Experiment (NHRE) and the North Dakota Pilot Project (NDPP).

*Experimental designs*

Both of these hail suppression research projects have labored extensively over the experimental design to fit goals and effort within the funding levels available to them. Typically, the design of the experiment has involved both statisticians and atmospheric scientists and has often depended on input from outside advisory panels and subcontractors.

For example, NHRE managers employed a university group to look at the effects of randomization and various alterations in hail on the length of their experiment (*Schickedanz and Changnon, 1971*). Since the evaluation in these experiments was to rest on comparisons (seeding some days and not on others), it was important to include randomization of selection in the design. Although much more attention has been given to design in these obviously broader-based and more complex research experiments than in the private projects, the design effort has not always insured a well-rounded experiment, as shown by NHRE (*RANN-UCAR Panel, 1974*).

The operational functions in the hail suppression research projects have also been more extensive than in the private programs. For example, the forecasting has included several local soundings of the atmosphere (radiosondes) with the results going into computer cloud models to specify the likelihood of hailstorms.

*Experimental  
operations*

The experiments have employed aircraft as the major seeding device with cloud-base updraft seeding, although in one year (1974) NHRE also used small rockets containing silver iodide fired vertically from aircraft beneath the cloud in combination with regular cloud-base updraft seeding. Operations have also included several weather radars tied to computers to serve various functions including tracing movement of storms into the project area, directing the project aircraft, and collecting data for evaluation.

The experimental programs typically have had sophisticated surface data collection networks not existent in the private programs which are unwilling to invest in such expensive endeavors. Both hail suppression experiments have employed dense networks of raingages and hail sensing devices. NHRE also employed research aircraft to puncture clouds and surface devices to measure atmospheric electricity and surface winds, in an effort to better describe the behavior of the entire atmosphere.

The evaluation phase of the research experiments has represented an exceptional effort to integrate the results from the randomized seeding. Various comparisons involving the surface rain and hail data (including insurance data), radar echo information, and cloud models have been used to develop a more comprehensive understanding of what has taken place. Thus, any differences found are based on physical theory as well as statistical principles.

*Evaluation  
extensive*

NHRE has also had a sizeable and important effort in the fourth functional area, study of the impacts. This has included research into the economic impacts of hail suppression, both present and future, the social aspects and public attitudes involved, and the environmental questions relating to possible effects of silver iodide on the biosphere and weather alterations well beyond the experiment. The final activity, the information function, has been done quite aggressively in the experimental research projects. For instance, NHRE developed a citizens' committee in the experimental region and also had a formal information program.


*Social,  
information  
aspects*

The staffs of research projects obviously have been much larger and more diverse in talents than those employed in the operational programs. Typically, scientists trained in cloud physics, cloud dynamics, and statistics have been employed. The actual cloud seeding activities of NHRE were subcontracted to a commercial firm. The greater design, evaluation, and impact analyses have required sizeable groups of analysts and sophisticated electronic equipment including weather radars and computers and thus have included electrical engineers and physicists on the staff. At the height of the NHRE experiment (1972-1974) approximately 200 scientists and technicians were employed full time on the project. Costs of the research efforts in hail suppression are described in Chapter 5.

## REFERENCES

- Braham, R. R.  
1968 *Meteorological bases for precipitation development.* Bulletin American Meteorological Society, 49(4), 343-353.
- Environmental Societal Impacts Group  
1974 *Organizational and operational characteristics of hail suppression programs in the Great Plains.* NCAR, Boulder, 167 pp.
- Farhar, B. C.  
1975 *Weather modification in the United States: A socio-political analysis.* Unpublished doctoral dissertation, Department of Sociology, University of Colorado, Boulder, 387 pp.
- Morgan, G. M.  
1973 *A general description of the hail problem in the Po Valley of northern Italy.* Journal Applied Meteorology, 12, 338-353.  
1976 *Hail prevention principles.* Illinois State Water Survey, Urbana, TASH working paper 3, 7 pp.
- RANN-UCAR Panel  
1974 *Report of the national hail research experiment review panel.* National Science Foundation, Washington, D.C., 31 pp.
- Schickedanz, P. T., and S. A. Changnon  
1971 *Design and evaluation of the national hail research experiment in northeast Colorado.* Journal Weather Modification, 3, 160-176.

## SUMMARY OF CHAPTER 4 HOW HAIL SUPPRESSION WORKS

 Hail suppression, as currently practiced, seeks to intervene in a very complex process inside a thunderstorm by use of very small amounts of a chemical — silver iodide (AgI) — to alter the normal growth of hailstones.

*Intervention  
in thunderstorm  
processes*

In the vast volumes comprising the upper cold parts of all thunderstorms (where temperatures are below freezing) there is usually an immense quantity of still unfrozen water, and the ice nuclei (microscopic ice particles usually from dust) cause the freezing of this water, to eventually grow and become either raindrops or hailstones. The concentration of these nuclei is critical to hailstone growth — the presence of too much water and the typically few nuclei aloft can lead to sustained stone growth by their recirculation in this water-moist air.

Thus, man seeks, in adding AgI (which serves as ice nuclei), to alter the water-to-ice process, hoping to increase the competition for water and thus produce more but mostly small hailstones that eventually melt in falling to the earth.

Some of the uncertainty about hail suppression to date has related to the delivery of the amount of AgI inside the cloud where and when desired. Man has generally delivered AgI with aircraft, releasing it at the cloud's base where air is going in and up to the cold zones inside the cloud, in an intermittent fashion, hoping that the turbulent air currents will diffuse the AgI nuclei inside the cloud.

*'Delivery'  
brings on  
uncertainty*

It is unthinkable to expect that a single aspect of a storm, such as hail production, can be altered without some effect on many other interdependent processes like rainfall, subsequent downdrafts (that lead to surface gusts), and lightning. Careful tuning is essential or the rain quantity and other phenomena could be increased or decreased. The uncertainties also could promote weather changes beyond the area where hail suppression is intended.

Organizationally, hail suppression has been performed by either of two groups: *research organizations* (universities and national laboratories) doing experimental projects, or *commercial firms* which attempt to suppress hail using existing knowledge and methods to serve a group providing financial support. Such operational support has typically been from agricultural interests and/or state governments, whereas government (largely federal agencies) has supported the research experiments.

*Organized in  
two different  
ways*

The operational (commercial) projects and research experiments differ in many aspects but they both consist of a project plan (design effort), field operations (equipment and personnel to seed clouds), and an information effort. Operations in commercial projects attempt, in an area, the modification efforts under all hail situations, whereas the typical experiment chooses, on a random basis, to not seed certain storms (or days) so as to get a control sample for comparison with the seeded cases.

Experimental efforts generally have much greater investments in measuring equipment (radars, surface instruments, field and analytical staff), and hence are much more expensive than operational projects (which often charge 10 to 20¢ per planted acre). The experimental projects also have to include elements generally

not found in commercial operational projects: major evaluations of the effects of seeding on both hail and rain, and of the social, economic, legal, and environmental impacts of the potential changes.

# 5

## The stakeholders



If we extend the technological capabilities and the use of hail suppression, it will affect those who are now dealing with the hail problem in one way or another.

Who are these direct stakeholders? What are the size — the dimensions — of the stakes they hold? Before we can assess the future impacts of the technology on these interests, we must look at them as they are now, at their present magnitude and scope. Stakeholders are those whose economic interests are affected and those whose organizational domains are affected.

The TASH team has identified major stakeholders for hail suppression — agriculture in its many facets, the hail insurance industry, the hail suppression industry, and hail suppression research — and these are dimensionalized in this chapter. The future impacts on these groups and on the less direct stakeholders, those of second- or third-order, including the U.S. consumer, are considered in later chapters.

### AGRICULTURE AS A MAJOR STAKEHOLDER\*



Without doubt, the largest stakeholder — the national segment with the most to lose and the most to gain from hail and its suppression — is agriculture. Many facets of agriculture are and will be affected — in particular the farmer but also certain agribusinesses and selected governmental agricultural agencies.

We see the major stake of agriculture in hail from the loss values presented in *Table 7* (Chapter 2) — \$770 million in crop losses annually due to hail. Hail not only reduces the quantity of crop yields, it also affects the quality of crop yields. And, it can damage property and kill farm animals. Crop-hail damage occurs over many of the agricultural regions of the United States, but as detailed in Chapter 2, losses from hail are greatest in the Great Plains and the Midwest. (Note hail damage to wheat in *Figure 24*). Certainly, a reduction in crop-hail losses will affect farm incomes, production, and overall purchasing power.

\*This section contributed by Stanley A. Changnon, Jr.



**FIGURE 24**

**Badly damaged winter wheat with hail still on the ground**



*Where  
to look  
for specific  
details*

The importance of hail to the various elements of agriculture is sufficient to lead to specific treatment of individual agricultural components in various sections of this report. For example, the economic considerations of hail suppression for the individual farmer are so relevant that they are described in detail in Chapter 7. The potential regional and national economic values of hail suppression, which are relevant for agribusiness as well as for state and federal governmental policies, are treated individually in Chapter 10. The obvious importance of hail suppression to crop-hail insurance is revealed in the next section of this chapter.

Selected agribusinesses also can be affected, depending on the areal extent and success of hail suppression programs. In an adopting region, successful hail suppression leads to increased profits to most commercial and transportation elements related to agriculture. The general magnitude of such effects is discussed in Chapter 10. If hail suppression leads to shifts in cropping patterns, the related shifts in agricultural equipment, use of fertilizers, pesticides, and herbicides could also have effects on the manufacturing industry as well as on the regional elements that sell and provide services in these areas of agriculture. Added production also affects needs for crop storage facilities, handling facilities, and transportation in the adopting regions.

*Business  
related to  
agriculture*

The effects of hail suppression on research and development in agriculture is currently minimal. The U.S. Department of Agriculture has not been involved in supporting the research relating to hail suppression. However, small amounts of National Science Foundation (NSF) research support have been directed into agricultural economic analyses performed by the economic research services (Boone, 1974) and in studies of the relationships between hail parameters and crop losses being done at two state universities.

*Research in  
agriculture*

## **DIMENSIONS OF THE HAIL INSURANCE INDUSTRY\***



Because today's financial protection from damage by hail rests in insurance, the insurance industry becomes a major stakeholder to be considered in hail suppression progression. In this section we describe the dimensions of the insurance industry involved, both private and federal.

Insurance is a mechanism whereby — for a consideration or premium — one party (the insurer) agrees by contract (the policy) to indemnify or guarantee another (the insured) against loss from specified contingencies (risks). It is a means by which an individual can substitute small, certain payments for large, uncertain, and unpredictable losses.

*Insurance  
and how  
it works*

Private industry provides insurance services through chartered and regulated organizations variously structured as corporations, reciprocal exchanges, and mutual benefit associations. Although these vary in the amount of capital involved, all depend solely upon the premiums paid by policy holders to meet:

- Costs of losses that occur
- Operating costs
- Return on capital

In the main, insurance companies are chartered only for the purpose of insurance, but they may be held by corporations engaged in other pursuits. Most hail insurance companies also sell other types of insurance.

\*This section contributed by J. Loreena Ivens, based partially on Fosse (1976) and Friedman (1976).



Insurance services are also provided by governmental agencies. Usually, the cost of operation and administration is subsidized, as in the case of the Federal Crop Insurance Corporation (FCIC) established by legislation in 1938 to provide "all risk" crop insurance. Also, government agencies may provide insurance to private insurance companies as "reinsurance" for all or part of a risk they have assumed.

*Buying is a personal choice*

Except in a few states that have legislated mandatory automobile insurance usage, insurance protection of all kinds is elective as to use and amount. Insurance is obtained not so much because of anticipation of an inevitable calamity, but because of the *possibility* of a calamitous occurrence and the financial impact thereof in each circumstance (*Fosse, 1976*). Insurance may be used to provide a relatively uninterrupted continuation of a business, or an orderly family life.

General application of effective hail suppression in the future would primarily affect the segment of the insurance industry that provides coverage for growing crops against loss from hail. The property insurance segment could also be affected, but to a lesser degree since about 90% of all hail loss is to crops (*see Table 7*).

**CROP-HAIL INSURANCE**



In 1975, the premiums written by all companies for crop-hail insurance totaled about \$311 million, representing insured crop values approaching \$8.2 billion. However, Changnon (*1972*) indicated that less than 20% of the total crop value in the United States is insured, and Brinkmann (*1975*) noted that about one in six farms in the nation is covered by commercial crop-hail insurance. The 1975 premiums and liability were up nearly threefold from 1972 due mostly to higher commodity prices but also to an estimated 10 to 12% increase in number of policies.

*Losses average 60% of premiums*

For the 1975 season, losses amounted to about 58% of premiums and since 1948 have averaged nearly 60%. The 1948-1974 statistics by hail region are given in *Table 13*. These are from the Crop Hail Insurance Actuarial Association (CHIAA) for companies representing about 75% of the hail insurance industry in the United States. (The hail regions were outlined on *Figure 7* in Chapter 2.)

Since 1948 CHIAA has collected insurance statistics on more than 125 crops, but 95% of the annual liability is on 5 major crops as follows:

	<i>Total liability, 1948-1974</i>
Cereal grain crops	\$12.3 billion
Corn and maize	\$ 3.8 billion
Tobacco	\$ 8.6 billion
Soybeans	\$ 4.7 billion
Cotton	\$ 3.8 billion

 **TABLE 13**

**Crop-hail insurance statistics, 1948-1974**

Hail region	Liability (x\$1000)	Premiums (x\$1000)	Losses (x\$1000)	Range of loss ratio,* %	Range of average rate, \$	Range of loss cost,* \$
1	1,333,100	33,199	16,862	49-51	2.42-3.22	1.24-1.58
2	2,234,568	40,408	14,998	18-41	1.74-2.74	0.51-0.82
3	1,136,965	96,015	57,610	60	8.44	5.07
4	1,227,700	64,001	40,917	57-71	3.23-10.80	1.83-7.67
5	386,831	25,939	18,907	61-73	3.37-6.85	2.05-5.01
6	3,913,138	269,146	165,223	59-63	6.69-7.28	4.19-4.30
7	11,848,759	657,232	414,031	55-73	3.24-7.19	2.36-4.90
8	2,482,247	121,669	70,803	56-58	2.19-5.29	1.22-3.09
9	12,268,554	264,859	151,144	43-66	1.57-5.57	0.72-3.28
10	2,112,203	92,115	61,044	24-72	1.77-4.68	0.43-3.35
11	135,694	2,864	1,322	46	2.11	0.97
12	5,486,344	257,542	144,269	39-76	4.61-6.71	2.59-4.05
13	387,188	16,070	9,490	29-100	2.39-5.58	0.98-5.39
Totals	44,953,291	1,941,059	1,116,620	Averages 60	4.32	2.60

Note: CHIAA statistics for all forms of crop-hail insurance except multiple peril lines

\*Loss ratio = Loss ÷ Premiums

Loss cost = (Loss ÷ Liability) x 100

Some business is written in each of the 48 continental states, but 80% of the 1970-1974 business was concentrated in 14 states and about 90% in 20 states. Currently, the leading states in liability are Illinois, Iowa, Kansas, North Dakota, and North Carolina. (The details were shown in *Table 6* of Chapter 2.) High rates occur in Colorado, Wyoming, Kansas, New Mexico, Montana, and South Dakota, among others, and low rates in Washington, Oregon, Indiana, Illinois, and Wisconsin.

The average production cost of an acre of winter wheat in northeastern Colorado (*Borland, 1975*) is \$63.86 — exclusive of any hail insurance premium. The current average level of hail insurance rates for wheat in Colorado is \$13 per \$100 of insurance. To insure only the production cost of \$63.86 would cost \$9.34 per acre for a total cost of \$73.20 per acre, of which hail insurance would be 12.8%. Such costs are regarded as too high by some Great Plains wheat farmers. In Illinois, the corn production costs are nearly \$150 per acre and insurance costs are about 1% of this total.

Although more than 200 companies are engaged in writing crop-hail insurance, about 80% of the business is conducted by 50 companies or groups of companies under common ownership and/or management. For most of these, crop-hail insurance does not exceed 3 to 5% of their total activity. The largest single writer does not exceed 10% of the total industry crop-hail business. Of the total property and casualty business, crop-hail insurance premium income is less than

*High rates  
in some  
states*

*Crop-hail  
business  
only small  
portion*

**TABLE 14****Comparative frequency of hail loss years, 1957-1971**

*In percent of years that loss occurs*

	<i>State</i>	<i>County</i>	<i>Selected township</i>	<i>Average of all sections *</i>	<i>Highest frequency section</i>	<i>Percent of sections with no loss in period</i>
Kansas (wheat)	100					
Cheyenne		94	80	18	40	14
Kearney		90	67	20	53	25
Sumner		98	58	21	40	3
Minnesota (corn)	100					
Lyon		98	81	29	67	6
Fairbault		96	62	33	60	0
Blue Earth		100	54	10	27	25
Illinois (corn)	100					
LaSalle		100	71	20	40	0
DeWitt		100	61	14	47	14
Knox		100	50	9	27	25

\*The township is made up of 36 sections of 1 square mile each

1%. (The 1974 property-liability writings were \$43.5 billion.) A very few companies, accounting for less than 15% of the crop-hail business, write little or no other insurance lines.

*Single state companies*

Certain crop-hail insurance companies are chartered to operate in only one state. Some of these companies are diversified to sell other types of insurance and some are not. These companies, with less areal diversification than the national multistate coverage companies, can be greatly affected by catastrophic hail losses. Their threat lies in the nature of hail loss which tends to concentrate in a state for two to five consecutive years and not be high in other states, as was shown on *Figure 6* in Chapter 2. Their access to reinsurance is of great importance.

*Frequency of claims*

Nationwide, an average of 20 to 25% of the hail insurance policies annually incur a paid claim. However, the policyholders being paid are not the same each year. Analyses of relative frequency at county, township, and section levels (*Fosse, 1976*) suggest that the need for hail insurance at any given farm is not from substantial annual or frequent loss experience. There is great variability in frequency, as we indicate in *Table 14*. The frequency experience of the farmer (as shown by the section data) will be different from that of township, county, or state officials, and these different experiences will affect their view of hail suppression.

*Frequent losses for regions, not for farms*

Although the three states listed in *Table 14* — Kansas, Minnesota, Illinois — represent relatively high, moderate, and low loss cost areas, all three states and most of the counties have some hail loss each year, or 100% frequency. (We

show some comparisons of loss cost values in *Table 15*.) However, at the section or farm level, the frequency drops dramatically. In Cheyenne County, Kansas, with its very high loss cost (*Table 15*), even the section with the highest frequency has hail loss in only 40% of the years and 14% of the sections had no hail in 1957-1971. Similar section frequencies occur in the Illinois counties where the loss costs are much lower, reflecting the fairly frequent but less severe Illinois hailstorm regime.

Average loss costs for 1948-1967 by crop districts in the major hail regions are shown in *Figure 25*. Loss costs are a ratio that "normalize" loss to the liability, allowing regional and temporal comparisons, and as shown the district loss costs in Illinois are about \$0.5 compared with values of \$1.0 to \$8.5 in Kansas. High values (around \$6.5) exist in the central and northern Great Plains.

The areal variations of loss cost for areas smaller than crop districts are illustrated in *Table 15*. These are quite large in both high and low loss states.

The total annual loss accumulates from frequent minor damages to crops rather than major or total losses of crops. *Figure 26* illustrates, for example, that 53% of the dollars paid for corn damages are for losses of less than 30% of a crop's value; only 4% of all dollars paid was for "total" corn crop losses. The regional differences are striking in that 18% of the dollars paid for wheat was for "total loss" claims. It should be noted that the "total crop loss" percentage stems from the catastrophe type storms that occur only two or three times a year, as discussed in Chapter 2.



**TABLE 15**

**Comparative mean annual loss costs**

	Mean annual loss cost (dollars)		
	State	County	Selected township
Kansas (wheat)	4.06		
Cheyenne		11.45	11.69
Kearney		8.68	8.29
Sumner		2.69	4.05
Minnesota (corn)	2.40		
Lyon		3.60	2.93
Fairbault		2.06	2.78
Blue Earth		1.23	1.80
Illinois (corn)	0.68		
LaSalle		1.62	3.78
DeWitt		0.46	0.57
Knox		1.13	2.63

*More minor losses than catastrophes*



The FCIC, under the U.S. Department of Agriculture, was created in 1938 to promote the national welfare by providing crop insurance to improve the economic stability of agriculture. The original program was limited to wheat and to counties subject to economic disaster as a result of a crop failure. Although the structure and operation of FCIC have changed several times, its purpose of economic stabilization is still the same.

**GOVERNMENT CROP INSURANCE**

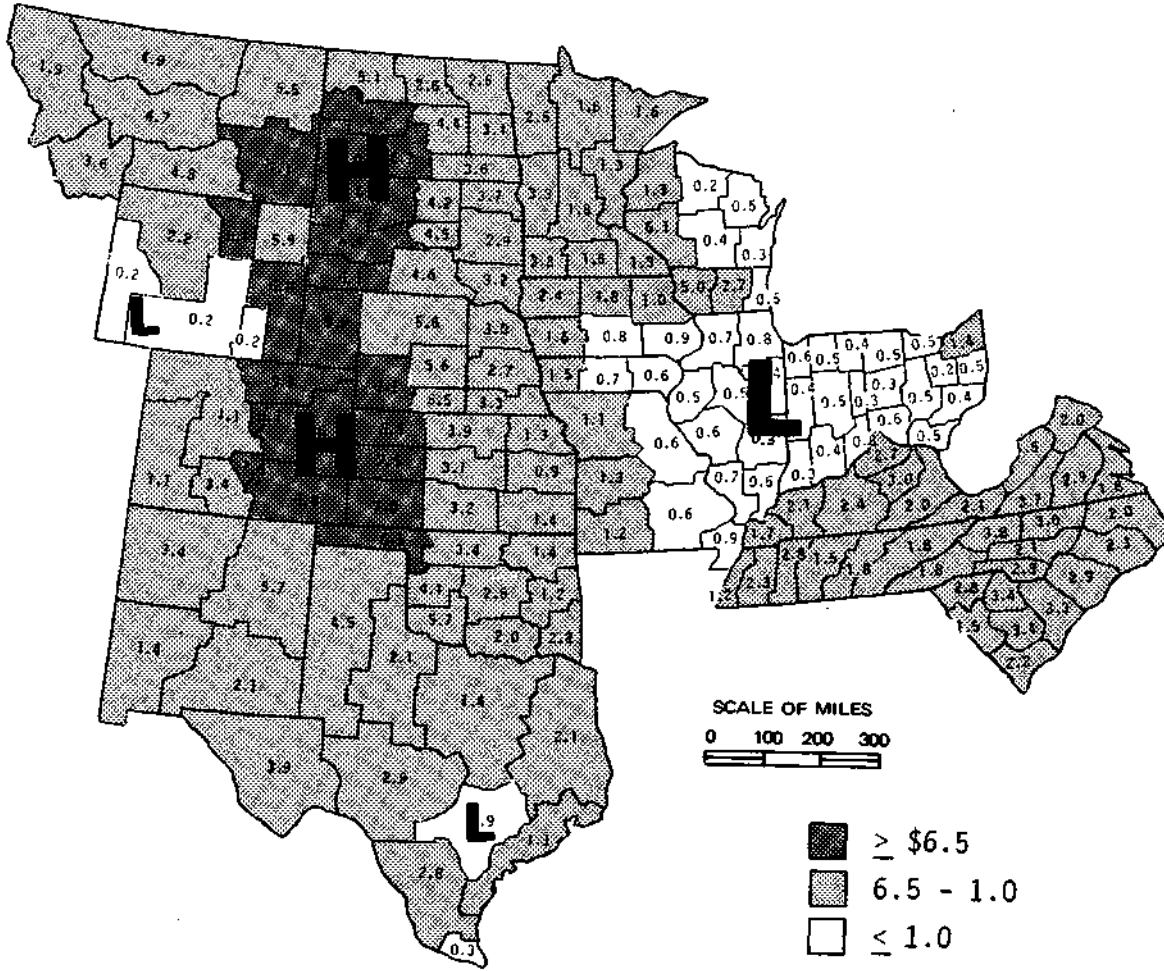
FCIC's insurance program now allows purchase of coverage for more than 20 crops. Coverage includes practically all causes of loss, including hail and all forms of adverse weather, insect infestation, and plant diseases. The insurance is not available in all counties nor on all crops in any county. It does cover major crops in most counties where these are important to the local economy. In 1975, 22 crops under 3657 county programs in 39 states were insured (*USDA, 1975*).

*All risk, limited coverage*



FIGURE 25

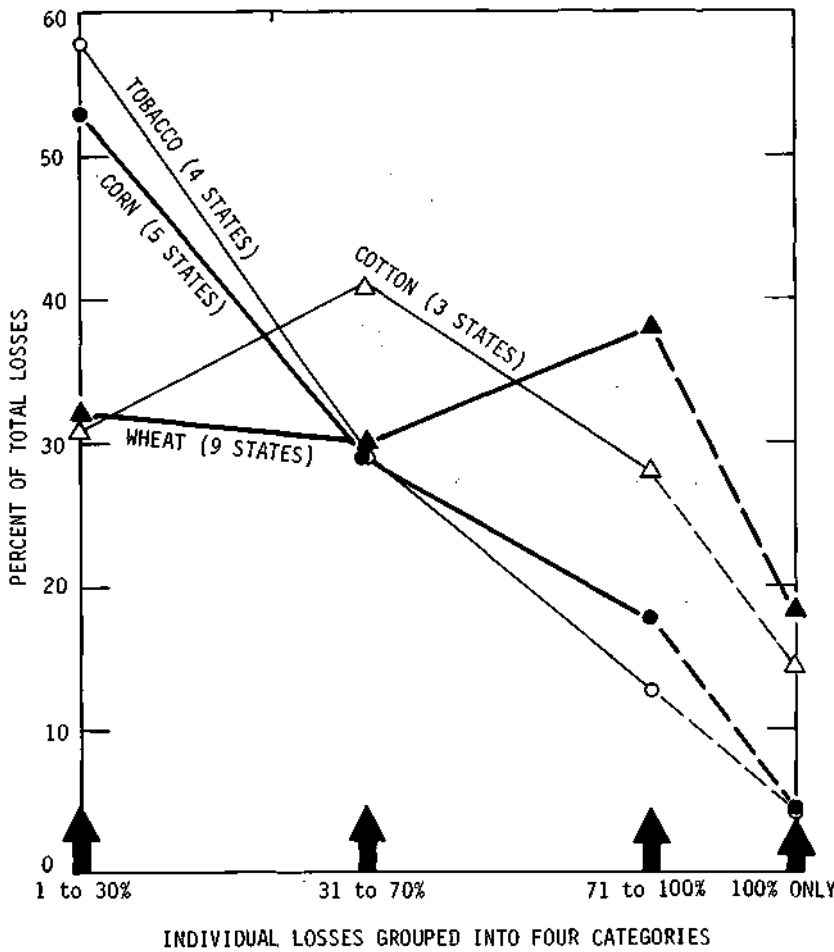
Loss costs by crop districts



FCIC covers 'producing' the crop

FCIC insurance is voluntary, and crop producers pay premiums for the protection which cannot exceed 75% of the farm's average yield or generally be more than the cost of producing the crop. The premiums may vary widely depending on the crop insured, the risks of the area, and the amount of insurance protection for each acre. The premium is a tax-deductible business expense, and premium discounts of up to 25% may be attained after several years of favorable insurance experience accompanied by good farming practices. Application for the insurance must be made *preceding* the usual planting period.

Liability protection has been over \$1 billion each year since 1973, but it increased dramatically in 1975 as more farmers sought greater protection for more acres. A major part of the increase was from corn producers who had had much below normal crops in 1974 as a result of bad weather (wetness, dryness, and early frost). These losses reduced cash reserves and credit resources, which, coupled with increasing production costs, influenced farmers to insure those costs in 1975 with FCIC. We show some recent FCIC figures in *Table 16*.

**FIGURE 26****How individual losses vary between crops**

FCIC also shows an expense ratio (cost of conducting program in relation to premiums) averaging 36.4 for 1948-1973. The 1975 values in *Table 16* are preliminary.

Major commodities insured by FCIC are wheat, corn, tobacco, cotton, and soybeans. For 1948-1972, the five leading states for FCIC premiums were North Dakota, Minnesota, Kansas, Montana, and Iowa; the five states with highest indemnities were Minnesota, North Dakota, Texas, Kansas, and Colorado.

**TABLE 16****Summary of recent FCIC statistics**

Period	Total liability (billion \$)	Total premiums (million \$)	Total indemnities (million \$)	Loss ratio
1948-1973	12.774	744.742	673.714	0.90
1974	1.154	54.204	63.752	1.18
1975	1.573	73.599*	60.670	0.82

\*Unofficial estimate for 1976 premiums is \$90+ million

The FCIC records for 1949-1974 indicate that hail ranks third among causes of loss, generally well behind drought and excess moisture (*USDA, 1975*). The FCIC basic dimension as "crop production" protection suggests that the magnitude of loss due to hail would be very small, in light of the preponderance of small hail losses (<25%) shown in *Figure 26*, that would *not* lead to payments under the FCIC 75% maximum level of coverage.

*Free, but  
limited  
'disaster'  
program*

The Department of Agriculture has a second program offering some protection to agricultural producers — the Commodity Credit Corporation's (CCC) disaster payment program. This is a free, direct-payment program that is limited to producers with acreage allotments for upland cotton, wheat, and three feed grains — corn, grain sorghum, and barley. These crops are also covered by FCIC in major production areas. The disaster program is intended to alleviate losses when natural disasters or other uncontrollable conditions prevent specified crops from being planted or result in abnormally low production. This program was authorized in 1973 for the 1974-1977 crop years.

As a result of the extremely adverse weather in 1974, CCC paid \$557 million on 321,500 farms, primarily in Texas, Nebraska, Iowa, South Dakota, Illinois, and Missouri. Payments for 1975 were estimated to be \$275 million. Payments in 1974 were:

- 58% for drought
- 19% for excess rain
- 15% for frost or freeze
- 4% for hail
- 2% for flood
- 1% for disease
- 1% for other

Legislative proposals in 1976 (*USGAO, 1976*) would eliminate the disaster payments, extend to other areas the coverage of FCIC for the five crops, and provide improved reinsurance to private companies to provide greater capacity for making multiple peril crop insurance available to farmers.

## **PROPERTY INSURANCE FOR HAIL**



The size of the property insurance segment affected by hail is more difficult to quantify than that of the crop-hail segment. Very little is known about average annual property damages by hail because of the present insurance practice of grouping various perils into "package" coverages. Weather perils are in the categories of *fire and lightning* and *wind and hail*, and reports of damage are for the combined perils. Because the wind-and-hail grouping covers diverse storms from hurricanes and tornadoes to straight line winds in thunderstorms (often with hail), losses in this category are of little value in determining the effect of hail as an individual peril.



FIGURE 27

Automobile top damaged by hail



The property hail insurance industry is sizeable. More than 2900 companies sell insurance that includes coverage for hail loss to houses, automobiles, commercial structures, plants, and animals. We show a common type of property damage in *Figure 27*.

*Industry is large*

The property liability coverage in 1974 was \$43.5 billion and the income from premiums that included hail was \$7.6 billion. The insurance that included hail as a peril covered 80% of the homes, 85% of the automobiles, and 60% of all commercial structures in the United States.

We summarize in *Table 17* the total losses in 1974 covered by the major types of package policies that include hail as a peril. The Allied Lines, which is the smallest loss line in *Table 17*, refers to extended coverage that focuses primarily on weather hazards for all types of property. Therefore, hail is



TABLE 17

Property losses in 1974 for major types of package policies that include hail

<i>Type of coverage</i>	<i>1974 losses, \$</i>
Homeowners Multiple Peril	2,173,000,000
Commercial Multiple Peril	1,475,000,000
Allied Lines (extended coverage)	481,000,000
Automobile Physical Damage	<u>4,526,000,000</u>
Total	8,655,000,000



 **TABLE 18**

**Estimated distribution of U.S. property losses  
in weather catastrophes, 1948-1975**

<i>Cause of loss</i>	<i>Amount of loss, \$</i>	<i>Average annual loss, \$</i>	<i>Percent of total</i>
Winds associated with hurricanes or tropical storms	3,749,300,000	138,900,000	41
Windstorms not associated with thunderstorm activity	1,179,700,000	43,700,000	13
Thunderstorm (straight line) winds	777,500,000	28,800,000	~8
Tornadoes	2,396,100,000	88,700,000	26
Hail	1,080,300,000	40,000,000	12
Total	9,182,900,000	340,100,000	100

most important in the Allied Lines package (*Friedman, 1976*). Hail is moderately important in the Homeowners and Commercial Multiple Peril lines, but is only a small contributor to the Automobile package.

*Hail damage estimates for big storms*

The best estimate of the importance of hail as a damage producer was obtained from extensive analyses (*Friedman, 1976*) of property insurance records kept since 1949 on "catastrophes" caused by weather hazards. The property insurance industry defines a catastrophe as a single event that causes aggregate insured losses of \$1 million or more. Information on each event includes the principal cause of loss, among other data. Characteristics of the storm involved in each event from monthly *Storm Data* issues of the Environmental Data Service were studied to aid in allocating losses to the various weather hazards.

Of the 411 weather catastrophes in the 27-year period, 335 were caused by one or a combination of the three thunderstorm hazards — hail, wind, and tornadoes. The estimated distribution of the insured property losses from a total of \$9.2 billion caused by the 411 events is shown in *Table 18*. These values are in 1975 dollars.

As indicated, the average annual loss attributable to hail is \$40 million, or 12% of the total.

*Hail losses in small storms*

There are, of course, additional property losses caused by lesser storms in which damages total less than \$1 million. Although very little information is available, recent loss experience in Homeowners and Commercial Multiple Peril lines suggest that these noncatastrophe losses equal or exceed the catastrophe losses on an average annual basis (*Friedman, 1976*). However, the hail contribution would be somewhat less from the smaller storms than in the catastrophe situation. Consequently, a reasonable estimate of the total annual average insured property loss due to the hail hazard is about \$75 million.

Although no meaningful hail loss estimate can be made for each year, the yearly totals of the three thunderstorm hazards give some idea of property loss variations with time (*Friedman, 1976*). The total losses from these hazards were \$4.3 billion during the 27-year record of catastrophes. The annual average loss is \$157 million with extremes of \$680 million in 1974 and \$24 million in 1952. The second highest total was \$365 million in 1975 and only three other years had losses above \$200 million.

*Yearly losses vary*

## THE PRESENT HAIL SUPPRESSION INDUSTRY\*



As we noted also in Chapter 4, the commercial firms that conduct hail suppression activities will have a direct stake in the progress of the technology. According to federal records there were 15 commercial weather modification companies operating in the United States during 1975, performing various weather-related activities (*Charak, 1976*). However, only four of these — about 20% — conducted hail suppression projects.

### FIRMS IN WEATHER MODIFICATION

There were 14 geographically separate hail suppression projects active in the United States in 1975. This represents 19% of the 73 precipitation (nonfog) related operational weather modification projects that year. On the basis of company involvement and number of projects, hail suppression is not a major portion of the modification business. It should be noted, however, that hail suppression — unlike many other modification efforts such as orographic snow enhancement and fog dissipation — generally requires a considerable commitment and a volume of expensive equipment and related staff.

*Hail projects not large portion of business*

Three of the four companies have conducted hail suppression projects in other countries, as has one other company which has not conducted a hail project in the U.S. Thus, there is an industry concern with foreign projects as well as U.S. projects.

Operational projects of the 1971-1975 period generally were in one of two modes. One mode has been to provide specified seeding services — usually the radars plus aircraft and support personnel — as part of projects run by state-county groups. Such projects cover large portions of a state. The state or other subcontractors usually furnish the design, forecasting, monitoring, and evaluation (if any) functions. The other mode is for small projects — from one to two counties, or 500 to 5000 square miles — locally supported with all functions conducted by the company hired to perform the seeding. Additional information on the major functions of weather modification companies appears on pages 88-90.

*Operate for others, or alone*



The four companies which provided the hail suppression services employed in the U.S. during 1975 were sampled to dimensionalize the industry further. As we show in *Table 19*, their gross income for hail suppression was \$1.45 mil-

### SIZE OF HAIL SUPPRESSION COMPANIES

\*This section contributed by Stanley A. Changnon, Jr.

 TABLE 19

Dimensions of hail suppression industry

*Based on four companies conducting hail suppression in the United States during 1975*

	<i>Total or average</i>	<i>Lowest</i>	<i>Highest</i>
Income for hail suppression projects, million \$	\$1.45 (total)	\$0.1	\$0.9
Total income, million \$	\$6.0 (total)	\$0.8	\$2.0
Profit margin	11% (average)	9%	15%
Percent of income from hail suppression	26% (average)	5%	50%
Number of service activities provided (hail suppression, forecasting, etc.)	4 (average)	2	5
Full-time staff, number	67 (total)	5	25
Part-time staff, number	191 (total)	6	125
Aircraft owned, number	24 (total)	0	12
Weather radars owned, number	14 (total)	0	7
Meteorological systems owned, number	21 (total)	0	15
Seeding systems, number	269 (total)	12	125
Value of all equipment, million \$	\$2.1 (total)	\$0.13	\$1.0

lion, and single company incomes ranged from a low of \$0.1 million to a high of \$0.9 million. All of this income came from operational, nonexperimental projects with funds from local groups or combinations of local and state entities. One firm in 1974 had received federal funding for furnishing aircraft and related staff for seeding as a part of the National Hail Research Experiment (NHRE). The total 1975 income of these companies was about \$6.0 million, with hail efforts being about 25% of the total. Their profit margins were all comparable, about 11%.

*Firms do  
other  
weather  
services*

The four companies were involved in several other weather service activities — all four of them with rain modification, two with snow modification, two in air pollution studies, one in weather forecasting, two with weather design information, and one in research. None was involved in fog modification or in the selling of weather equipment.

The incomes from the hail suppression activities of the four companies — expressed as a percent of their total 1975 income — were 5, 10, 40, and 50%. The company with 50% of its income from hail suppression was also quite diversified, having four other service areas for income. All should appropriately be classed as weather modification companies, not as hail suppression companies, since diversification is a key feature.

*Typical  
company  
staff*

The owners of these companies have varied backgrounds including military weather training, advanced degrees in meteorology, and/or practical weather experience from aviation training. The typical company staff includes 11 full-time professionals, 3

pilots, 2 administrative personnel, and 48 part-time assistants. A typical modification project has three full-time meteorologists and three technicians (*Brown et al., 1975*). The typical hail industry operation is modest, as we show by the picture in *Figure 28*.

The total field equipment possessed by these four companies in 1975 included 24 aircraft (single and twin engine) worth \$1.1 million, and the companies leased 20 additional aircraft. Leasing provides year-to-year flexibility to handle fluctuations in projects obtained. One company did not own any seeding aircraft and the largest number owned by one firm was 12. Three of the companies owned weather radar systems for a total of 14 systems worth \$0.9 million. Three companies possess two meteorological systems (weather stations) having a total worth of \$10,000. Their collective ownership of seeding systems — surface

generators and aircraft mounted systems — was 269 worth \$158,000. The total worth of their weather modification equipment was \$2.1 million. Each has capital invested in buildings and other support facilities.

Three companies purchase seeding supplies from three different manufacturing companies, none of which is highly dependent on income from weather modification companies. One company manufactures its seeding material. Aircraft were purchased and leased from major national corporations and their regional offices, and weather radars were obtained from two different companies which manufacture radars and antennas for many other purposes. Thus, there are no major subsidiary industries heavily dependent on hail suppression activities.

*No major dependent subsidiaries*



FIGURE 28

Typical industry operation showing the building where operations are located; the radar antenna is located on the tower



#### HAIL SUPPRESSION RESEARCH-ITS DIMENSIONS\*



The dimensions of recent research on hail suppression have been such that this "industry" — scientists, technicians, laboratories, equipment — must be considered to have a sizeable stake in the future of the technology. In this section

This section contributed by Stanley A. Changnon, Jr.

THE HAIL  
RESEARCH  
STORY

we review the size of the major research programs related to hail suppression and look at the total funding for hail research.

*Early  
program  
in Colorado*

The U.S. history of research focusing on hail suppression began with a program at Colorado State University in 1959 initially using state funds and later NSF funds. This research was conducted in northeast Colorado, a high hail-loss area, and was supported at less than \$100,000 annually until the late 1960s when it essentially became an integral part of the preparations for the national experiment.

Useful complementary hail research was in progress elsewhere in the nation during the 1950s and 1960s to satisfy needs of the hail insurance and aviation industries (*Changnon, 1975*).

*Studies  
elsewhere*

Hail suppression research developed at several other universities and related institutions (in South Dakota, Wyoming, Nevada, Illinois), at the weather service laboratories in Colorado, and at the National Center for Atmospheric Research (NCAR) in the late 1960s. Experiments involving hail suppression and rain increase were conducted in the Dakotas in 1966-1972 (*Miller et al., 1975a, b*). Ultimately most of these research groups and their related hail research support from NSF were rerouted into direct involvement with NHRE.

*Size and  
scope of  
NHRE*

NHRE had two complex goals — one to verify whether hail could be suppressed experimentally (with overtones of testing the Soviet hail suppression hypotheses) -- the other to study all facets of hailstorms so as to understand storms and explain the modification results. As noted previously in Chapter 4, this major national research effort was funded largely by NSF with small inputs of state funds. Facility installations and testing in northeast Colorado began in 1971. The experimental area is shown in *Figure 29*. Throughout this area there were numerous sites with surface instruments to measure rain and hail, like the one shown in *Figure 30*.

*Extensive  
equipment  
involved*

Large sophisticated weather radars designed to detect hail also were developed and employed in NHRE. One of these — a dual wavelength radar called CHILL for its developers, the University of Chicago and the *ILL*inois State Water Survey — is pictured in *Figure 31*. The basic program dimensions of NHRE appear in *Figure 32*. The full seeding experiment and research program began in the summer of 1972 and was also conducted in 1973 and 1974.

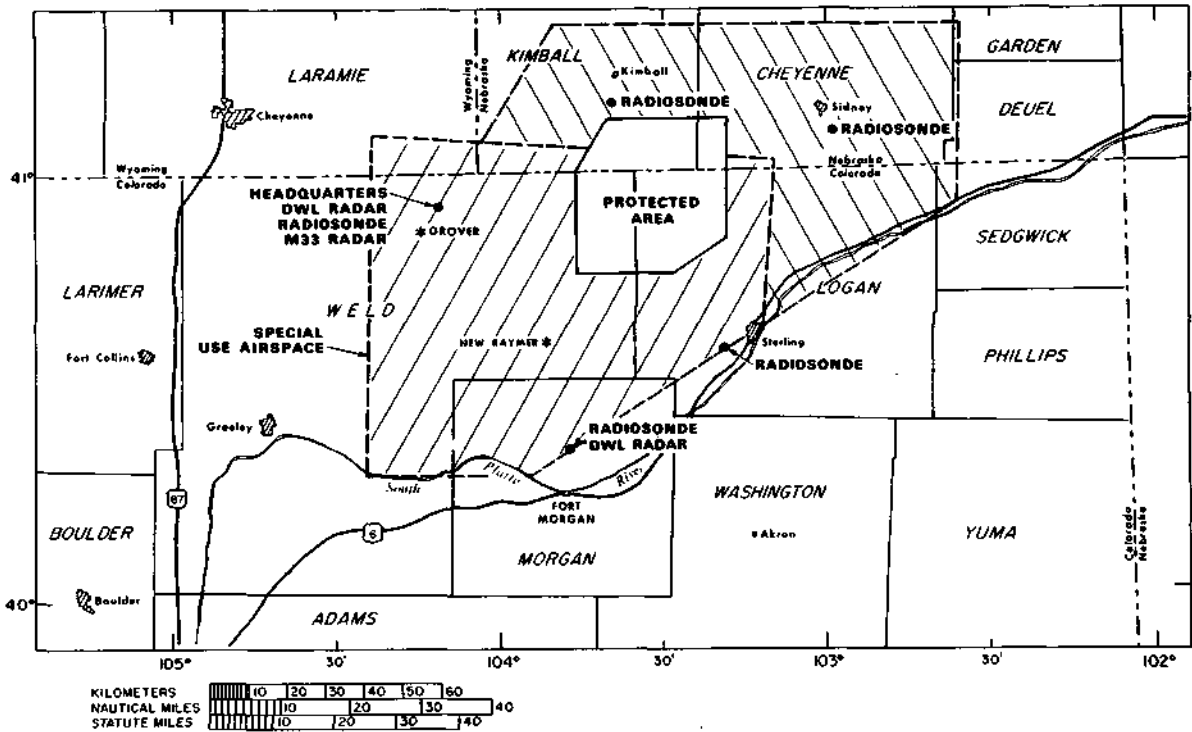
*Problems  
develop*

A series of problems (*RANN-UCAR Panel, 1974*) related to "poorly stated" and hard to achieve goals, governmental (NSF) shifts in project policies, and lack of analysis caused the seeding experiment to stop after 1974. The studies of the hailstones and the studies in the clouds suggested that the frozen drop embryo assumption, on which the seeding strategy was based, was not valid in the NHRE area; and the statistics assembled so far, even if added to a postulated very high "success" rate for two more years, would not show a high rate of suppression. Research and key field measurements were pursued in 1975-1976.



FIGURE 29

Experimental area for the National Hail Research Experiment



The annual funding to the University Corporation of Atmospheric Research (UCAR) and then on to NCAR and the various subcontractors (see Figure 32) has approximated \$4 million annually in the 1970s (Fleagle et al., 1974). Approximately \$23.5 million total has been spent by NSF on NHRE. State support through participating groups is estimated at \$500,000. The results of the evaluation of the 1972-1974 surface hail and rain data were discussed in Chapter 3 and shown in Table 12. Current plans (NCAR, 1976) call for continued intensive analyses of the 1972-1975 data to develop a more definitive design of a new suppression experiment for launching in 1977 or 1978, and more storm information.

*Funding of NHRE*

Another federal and state sponsored research program concerning hail suppression is labeled by NSF as "Societal Impacts Studies." About ten NSF-RANN (Research Applied to National Needs) projects representing \$700,000 in annual funding were being conducted in 1973-1976 and have addressed subjects such as public attitudes toward hail suppression endeavors, environmental consequences of silver from seeding, economic impacts, legal consequences, and effects on rain and hail in areas downwind of seeded areas (Mordy and Mordy, 1974).

*Related societal research*



**FIGURE 30**

**A field site in the NHRE network**

*Left to right, recording raingage, recording hailgauge, and hailpad*



A third current research area, based on continued NSF-RANN and state (Illinois) funding at a rate of about \$150,000 annually since 1967 has concerned basic hail research and the subsequent development of a design of a hail suppression experiment for the Midwest. This research was sustained by NSF, in addition to NHRE, to provide the experimental background in an area with a hailstorm climatology quite different from that in Colorado.

The complex field research in this eight-year research program carried out by the Illinois State Water Survey led to a variety of hail sensing instruments. One example is the recording hailgauge shown in the front center on *Figure 33*. Another is the five-sided hail cube in *Figure 34* that was designed to study windblown hailstones (size and number of stones, and angles). This research was completed in 1976 with a final Design of an Experiment to Suppress Hail (DESH), as described by *Changnon and Morgan (1976)*. A future experiment for 1977 or later awaits definitive results from NHRE.

The fourth current hail suppression research effort is this technology assessment of hail suppression.

Hopefully, its results will give useful guidance for future hail suppression research. It too is funded by NSF-RANN and Illinois at a level of \$350,000 for an 18-month effort.

**MAJOR FUNDING OF RESEARCH**



As has been mentioned, most federal funding of hail suppression research has come from the National Science Foundation. Support originated in the Basic Sciences Division of the Foundation, but in 1973 was switched to RANN. Sizeable funds (\$9.5 million) from the Foundation to NCAR have also been redirected by NCAR into support of staff and facilities of NHRE.

*Annual funding on research \$4.7 million*

The total annual federal (largely NSF) funding for hail suppression research, as averaged over the 1971-1975 period, is about \$4.5 million (*Fleagle et al., 1974*), plus an estimated \$200,000 from state funds, or about 5% of the total. This annual expenditure (\$4.7 million), and the 1975 private funding for hail suppression operational projects (\$1.45 million) represents a total expenditure of \$6.15 million for hail suppression. Research spending represents 74% of the total.

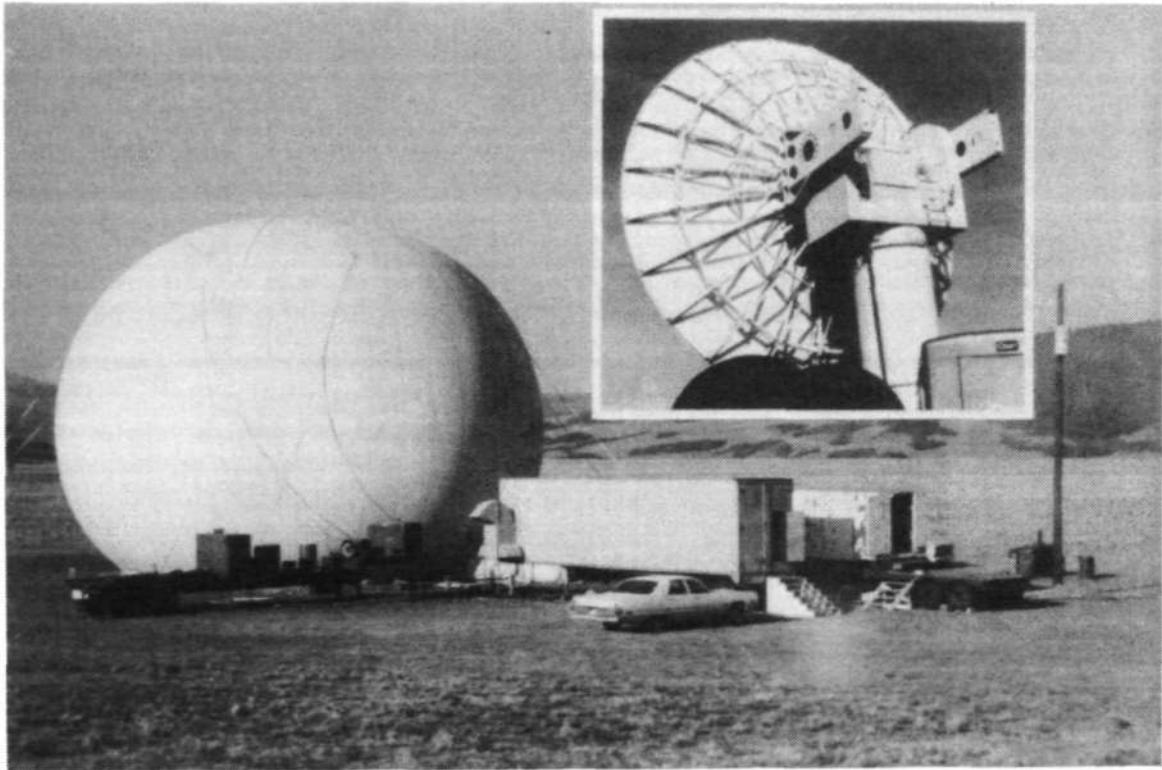
*About one-third to hail suppression*

The federal research expenditures for all of weather modification are shown in *Table 20*. Hail suppression expenditures, at about \$4 million per year, have represented 20 to 33% of the annual totals shown in the table.



**FIGURE 31**

**Radome and installation for CHILL radar (insert shows antenna)**



**TABLE 20**

**Federal funding for planned weather modification research**

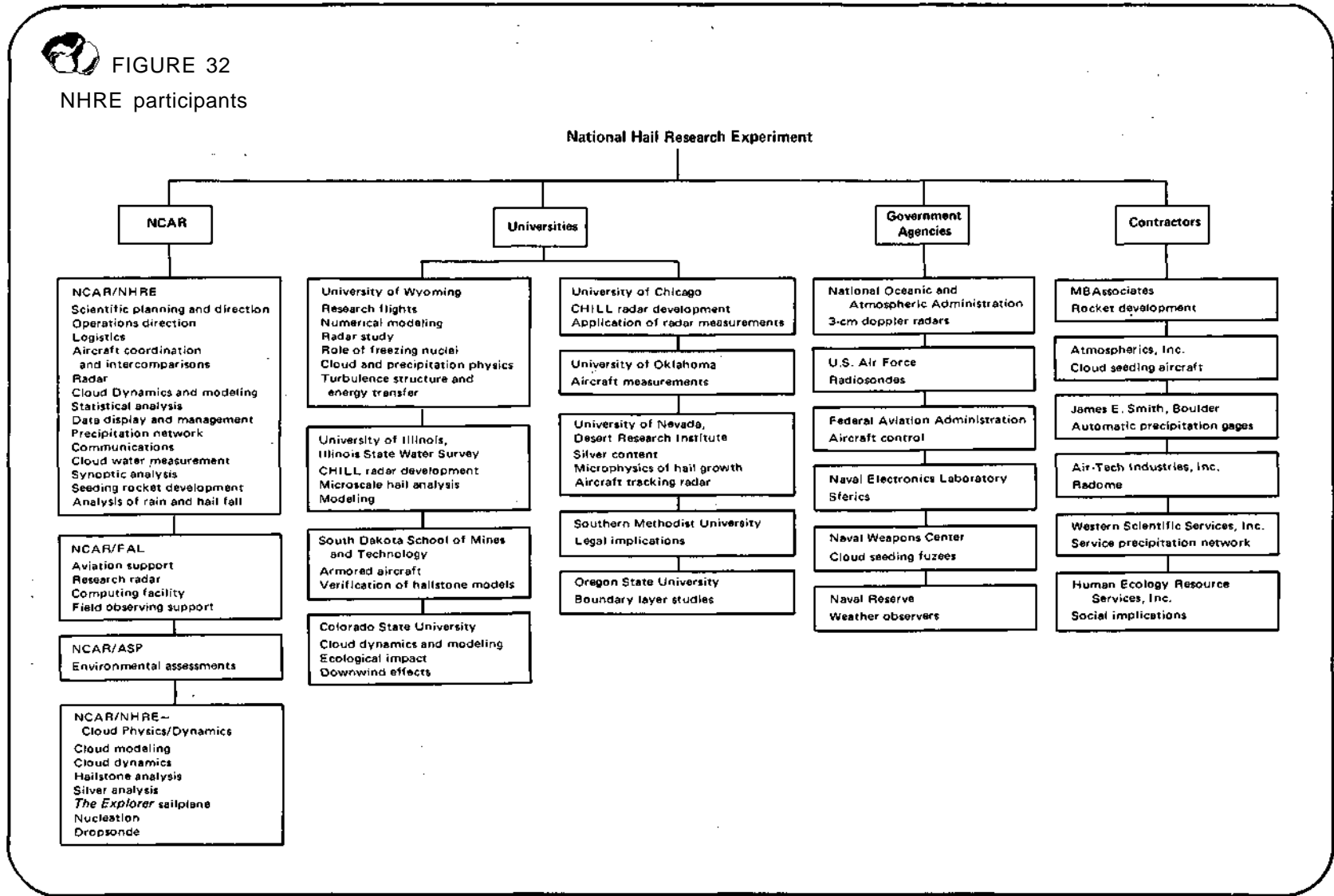
<i>Agency</i>	<i>FY 72</i>	<i>FY 73</i>	<i>million \$</i>		
			<i>FY 74</i>	<i>FY 75</i>	<i>FY 76</i>
Department of Agriculture	0.4	0.3	0.3	0.1	0.1
Department of Commerce	3.9	3.8	3.3	2.7	3.3
Department of Defense	1.8	1.2	1.2	1.3	0.5
Department of Interior	6.7	6.4	3.9	3.5	4.6
Department of Transportation	0.4	0.4	0.1	0.1	0.0
National Science Foundation	5.5	6.2	4.7	4.7	5.6
Totals	18.7	18.3	13.5	12.4	14.1





FIGURE 32

NHRE participants





**FIGURE 33**

**A weather station site in an Illinois hail-rain network**

*Left to right, recording raingage, recording hailgage, hailpad, and rainwater collector basket; on tripod, recording wind system*



Boone, L. M.

1974 *Estimating crop losses due to hail.* U.S. Department of Agriculture, ERS, Washington, D.C., Agricultural economic report 267, 40 pp.

Borland, S.

1975 *Hail suppression: Progress in assessing its benefits and costs.* In NHRE Symposium/ Workshop on Hail: Preprint vol. 1, NCAR, Boulder, 61 pp.

Brinkmann, W. A. R.

1975 *Severe local storm hazard in the United States: A research assessment.* Institute of Behavioral Science, University of Colorado, Boulder, 154 pp.

Brown, K. J., A. Dennis, and R. L. Lininger

1975 *Survey of industry practices in weather modification.* Journal Weather Modification, 7, 177-183.

**REFERENCES**



**FIGURE 34**

**A ISWS-developed five-sided "hail cube"**



Changnon, S. A.

1972 *Examples of economic losses from hail in the United States.* Journal Applied Meteorology, 11(7), 1128-1137.

1975 *Scales of hail.* In NHRE Symposium/Workshop on Hail: Preprint vol. 1, NCAR, Boulder, 52 pp.

Changnon, S. A., and G. M. Morgan

1976 *Design of a hail suppression experiment for Illinois.* Illinois State Water Survey, Urbana, Bulletin 61, 194 pp.

Charak, M.

1976 *Weather modification activities for calendar year 1975.* National Oceanic and Atmospheric Administration, Rockville, Maryland, 27 pp.

Fleagle, R. G., J. A. Crutchfield, R. W. Johnson, and M. F. Abdo

1974 *Weather modification in the public interest.* University of Washington Press, Seattle, Washington.

Fosse, E. R.

1976 *Impacts of effective hail suppression on crop insurance industry and probable policy actions responses.* Illinois State Water Survey, Urbana, TASH working paper 8.

Friedman, D. G.

1976 *Hail suppression impact upon property insurance.* Illinois State Water Survey, Urbana, TASH working paper 11.

- Miller, J. R., E. I. Boyd, R. A. Schleusener, and A. S. Dennis  
1975a *Hail suppression data from western North Dakota 1969-1972.* Journal Applied Meteorology, 14, 755-762.
- Miller, J. R., A. S. Dennis, S. I. Wang, and R. L. Schwaller  
1975b *A preliminary examination of South Dakota's hail suppression efforts as revealed by crop-insurance data.* Institute of Atmospheric Sciences, South Dakota School of Mines and Technology, Rapid City, Report 75-20, 25 pp.
- Mordy, W. A., and B. D. Mordy  
1974 *Weather modification in service of society.* The Center for the Future, Santa Barbara, California, 61 pp.
- National Center for Atmospheric Research  
1976 *Revised plan for the national hail research experiment.* Boulder, 186 pp.
- RANN-UCAR Panel  
1974 *Report of the national hail research experiment review panel.* National Science Foundation, Washington, D.C., 31 pp.
- U.S. Department of Agriculture  
1975 *Annual report to Congress 1975.* Federal Crop Insurance Corporation, Washington, D.C., 26 pp.
- U.S. General Accounting Office  
1976 *Alleviating agricultural producers' crop losses: What should the federal role be?* Department of Agriculture, report to the Congress by the Comptroller General of the United States, Washington, D.C., 58 pp.

## SUMMARY OF CHAPTER 5 THE MAJOR STAKEHOLDERS

*Agriculture  
is prime  
stakeholder*

There are five major stakeholders for effective hail suppression: agriculture in its many facets, the hail insurance industry, the hail suppression industry, hail suppression research, and consumers. Agriculture is the prime stakeholder with the most to lose and gain from hail suppression — successful suppression activities over wide areas will directly affect and eventually will impact on farmers and agribusiness leading to more sales, food storage, and transportation facilities.

*Crop-hail  
insurance  
industry*

The crop-hail insurance industry insures about \$8 billion of the national crop value, about 20% of the total. Eighty percent of all insurance is sold in the Great Plains, Midwest, and in the eastern tobacco states — and losses typically represent 60% of the premiums. Crop-hail insurance is handled by 200 companies, but for most the hail insurance is only 3 to 5% of their total insurance activity. Many companies sell coverage in several states, but some companies operate in only one state.

The frequency of loss varies regionally; counties in states like Kansas and Illinois have a loss somewhere in almost every year, but any given square mile has loss in only 10 to 20% of the years.

Startling regional differences do exist in the magnitude of individual farm losses; i. e., more than 50% of all losses to corn (Midwest) and tobacco (East) are in the 1 to 30% range with less than 5% being total (100%) losses. In the wheat and cotton areas (Great Plains), 30% of the farm losses are in the 1 to 30% class with nearly 20% being total losses. The federal crop insurance (under FCIC) in 1975 had \$1.5 billion in liability, largely in the Great Plains, compared with \$45 billion in private industry. However, only 4% of the FCIC payments were for hail losses (most were for drought).

Property loss data due to hail is difficult to assess because insurance companies package it with all weather hazards. Property hail loss is estimated at 12% of the total.

*Commercial  
and research  
industries*

The current hail suppression industry (only four companies with a gross of \$1.4 million in 1975) is not large. The hail suppression research industry is larger with annual expenditures of \$4.5 million from NSF in recent years. The National Hail Research Experiment (NHRE), focusing on suppression experimentation and hail research in Colorado since 1972, has been the major effort with other related socio-economic studies and an experimental design project in Illinois. NHRE has been conducted by NCAR and has involved staff and facilities from NCAR and several universities. Uncertain experimental results due to a variety of problems (conflicting goals, lagging analysis, etc.) has resulted in a recent focus in NHRE on more basic research.

# 6

## Societal influences



The technology of hail suppression indirectly affects — and more importantly, is directly affected by — those elements of our society that influence and constrain human endeavors, including technological development.

Because our objectives in this technology assessment for the future give emphasis to the second and higher order impacts of hail suppression, the societal influences that affect it now are important as a base for that evaluation.

In this chapter we examine these societal elements — the socio-political, legal, and environmental influences and constraints — as they apply to hail suppression.

### SOCIETAL ASPECTS OF WEATHER MODIFICATION\*



Societal elements may be favorable or nonfavorable to hail suppression — some may boost its progress, others may hold back or prevent its progress. In this section we present some of the factors that cause social movement in either direction.

We discuss here some key characteristics of hail suppression as an innovation that affect its rate of adoption by communities. Since in general rates of adoption of individual innovations (those based on private rather than public decisions) tend to follow an S-shaped curve, it is important to understand whether the adoption of a collective innovation such as cloud seeding follows the same pattern. Evidence to date suggests that it may not, with sporadic fluctuations in usage in response to the vagaries of the weather. For example, rushes of projects have tended to occur during drought or high hail conditions followed by periods of relative quiescence during more beneficial weather.

The views of individuals where weather modification has been proposed or adopted as expressed by survey interviews are described here, as is the relationship between

\*This section contributed by Barbara C. Farhar.

socio-demographic characteristics (such as sex, education, and income) and favorability toward technological development. We also consider the problems brought about by the lack of scientific consensus regarding hail suppression and by the present techniques for decision making. A final discussion concerns how organized opposition develops.

An important point to be kept in mind is that *social systemic* in combination with individual factors play the decisive role in whether a collective innovation technology such as hail suppression will be adopted or not.

## ADOPTING INNOVATIONS



This century has produced incredible numbers of technological innovations — innovations that have been implemented and have had profound consequences for our individual lives and our society, some of them totally unanticipated.

### *Private decisions*

Many of these innovations, once they were developed and introduced to the public, have been adopted by individuals. An individual can decide to plant hybrid seed corn or to use the birth control pill — adoption of these innovations is a personal matter requiring no particular decision on the part of the community, once the technology is available.

### *Public decisions*

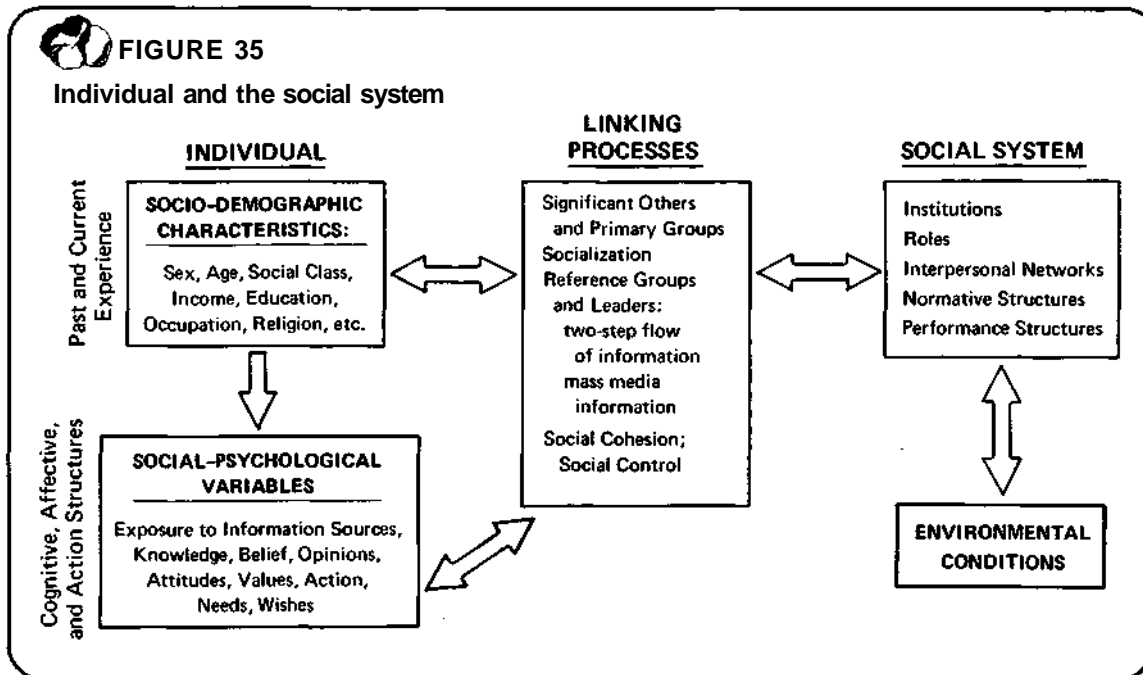
Other new technologies, such as nuclear power plants and fluoridation, require decision making at the community level for adoption to occur. We must recognize weather modification as an innovation which was used early in its history by *individuals* — by a farmer or small group of farmers, for example. As its application became more sophisticated, as it began to depend more on public funding, and as it was used over more extensive land areas, there was a general increase in awareness that the activity had implications for entire communities rather than for the individual user alone.

Weather modification thus became a *collective* innovation decision, or a public decision, requiring action on the part of a community or larger social aggregate in order for it to be adopted.

### *What affects rate of adoption*

It is important, then, to study the social aspects of weather modification at both the individual and systemic levels, since individual (social-psychological) and social systemic variables are interrelated, forming the complex whole of social life. The diagram presented in Figure 3 5 presents a simplified model of how individual and systemic variables relate in an iterative fashion, with continuous feedback, each component affecting the other. Five characteristics of innovations (assuming their established effectiveness) have been found to contribute to their rate of adoption (*Rogers and Shoemaker, 1971*). These are:

- Relative advantage
- Compatibility
- Complexity
- Trialability
- Observability



*Relative advantage* is the degree to which an innovation is perceived as better than the idea it supersedes. In the case of weather modification, the idea it supersedes is "Mother Nature," or for some, God, or passive acceptance of the vagaries of the weather. As one opponent put it:

*How much advantage?*

"Before we had only God and the Devil to blame for the weather, but now we have God, the Devil and the weather modifiers."

It matters less whether the innovation has a great deal of "objective" advantage; what matters more is whether individuals *perceive* the innovation as being advantageous, including consideration of the risks involved. The greater the perceived relative advantage of an innovation, the more rapidly it will be adopted.

A sense of high relative advantage is expressed by the farmer who says (especially after experiencing severe crop damage), "If I can possibly protect my crop from damaging hail at taxpayer expense with little or no risk, it is well worth a try." A high benefit-to-cost ratio will affect perceptions of relative advantage.

*Compatibility* is the degree to which an innovation is perceived as being consistent with existing values, past experiences, and the needs of potential adopters. A compatible idea will be adopted more rapidly than one outside the usual experience and needs.

*Is it compatible?*

With regard to compatibility, hail suppression is in an ambivalent position. Where its application is carried out in the regular free-enterprise fashion, it is consistent with the norms governing private enterprise. To the extent that these norms are acceptable, this mode of the technology's application is acceptable.



The idea of mastery over nature has a long tradition in Western civilization; yet the rise of the environmentalist social movement is at odds with that ancient desire. Environmentalists are not in sympathy with this value, and may raise questions concerning interference with natural weather processes, as well as with its scientific feasibility and predictability.

The concept of "weather needs" is highly sophisticated. Most people would require an explanation of the idea. Yet incentive for weather modification is evident in such social facts as crop damage from hail and drought. Where the expression of concern about weather needs arises spontaneously in the population, acceptance of the technology will proceed fairly rapidly.

*How complex is it?*

*Complexity* is the degree to which an innovation is perceived as difficult to understand and use. Some innovations are readily understood — others are not.

With regard to this variable, hail suppression is destined to a long time-lag in adoption, since it is highly complex. Understanding the physical mechanisms of meteorological conditions is no simple matter, yet such understanding is basic to a grasp of cloud seeding techniques that require the use of sophisticated equipment and chemicals. Even the terminologies of meteorology and weather modification are not widely used.

In addition to the complexities of the physical science aspects, the application of hail suppression is uniquely bound up in legal, economic, social, agricultural, and political ramifications which are difficult to sort out. Past experience in diffusion of innovations indicates the rate of adoption for hail suppression will be slowed by its complexity.

*Can it be tried easily?*

*Trialability* is the degree to which an innovation may be experimented with on a limited basis. An innovation that can be tried represents less risk to the individual or community considering it — and will be adopted more quickly.

Here again, hail suppression may experience slow diffusion because of the difficulty of trial runs. At best, an experimental field project may be held in an area in order that the local population can observe its results (in addition, of course, to its scientific purposes). But many local citizens will not have the opportunity to observe the operations directly and will remain unaware of project effects. These difficulties relate to the next characteristic.

*Can it be readily observed?*

*Observability* is the degree to which the results of an innovation are visible to people. The easier it is for an individual to see the results of an innovation, the more likely he is to adopt it.

The remarkable difficulty with hail suppression (with less than total elimination of hail) is that it is virtually impossible for an individual to discern its effects "at the ground." The problem with observability revolves around the great natural variability of hail (Chapter 2) over a small area, making it extremely difficult for the casual observer to distinguish accurately which weather effects are the result

of cloud seeding and which are not. Hail suppression's rate of adoption will be slowed by the difficulty in observing its effects.

Of these five characteristics affecting rate of adoption, three suggest a very slow adoption rate for weather modification (complexity, trialability, and observability), one is unclear (compatibility) and one may tend toward a faster adoption rate (relative advantage). It should be noted, however, that a rather slow and measured rate of adoption can be considered quite normal. Also, collective adoption decisions require more time to take place than individual adoption decisions.

*Rather slow  
adoption  
normal*

The adoption process covers three phases

- Planning/decision
- Implementation
- Continuation

*The adoption  
process*

The first phase includes the initial stimulus for a weather modification project from whatever sources, project planning and design, funding arrangements, and the decision process itself (*Farhar, 1975*). The outcome is either implementation, delay, or an abandonment of the planning effort. A project may be planned for one or more subsequent growing seasons.

The second phase, implementation, refers to the conduct of the effort for the first time period, usually one hail or crop season. Either the project continues forward much as planned, or there is an unplanned termination at some point during the season.

Continuation refers to the period following the first season but before a second season. During this phase a decision may be made to continue hail suppression in the second season much as in the first, to continue the effort but with changes, or to discontinue it (*Farhar, 1975*). Beyond that point the implementation and continuation phases may be repeated indefinitely.



Surveys of citizen views toward hail suppression have been carried out in Illinois, Colorado and South Dakota. Each survey was based on a scientifically drawn random sample of the population in the study area. The Illinois interviews in 1974 were conducted as part of a baseline study for a proposed hail experiment in central Illinois (*Krane and Haas, 1974; Changnon and Morgan, 1976*). The Colorado respondents were interviewed in connection with the National Hail Research Experiment (NHRE) in northeastern Colorado at four time periods beginning in 1971 and ending in 1974 (*Krane, 1976*). Four surveys (a longitudinal panel study) in South Dakota counties experiencing attempted hail suppression and precipitation augmentation were conducted beginning in early 1972 and ending in 1974 (*Farhar and Mewes, 1974b; 1976*).

A new sample — first reported in this publication — of citizens from both participating and nonparticipating counties was interviewed in 1976 just after the

**PEOPLES'  
ATTITUDES  
AND CONCERNS\***

This section contributed by Barbara C. Farhar.

legislature had voted to end the South Dakota Weather Modification Program (SDWMP).

Selected findings from among the key items duplicated in these surveys are presented here. In all cases, data from the most recently conducted surveys, representing a total of 1217 respondents from different parts of the Great Plains, are presented.

*Favorability  
to the idea*

Three interview items have factored together in several data analyses indicating a consistent cluster of items measuring favorability to the idea of intervening in weather processes for human benefit. We present these three items in *Table 21* with the findings from four surveys.

Favorable attitudes have been found to correlate with favorable evaluation of projects. The pattern of response is remarkably consistent between Illinois, Colorado, and South Dakota, with at least two-thirds of the respondents indicating favorable attitudes toward the development and use of cloud seeding technology, especially for the benefit of agriculture. After four seasons of operational weather modification in South Dakota, about 63% still expressed favorable sentiment, although the proportion opposed increased from 15% to 25%.

It should be noted that these items are addressed to the *concept* of human intervention in weather processes, not to the *evaluation* of any specific project.

*Religio-natural  
orientation*

*Table 22* presents data on three items forming a cluster related to negative evaluation of projects. The "religio-natural orientation" has been characterized as an attitude or belief that man should not intervene in weather processes — that these processes rightfully fall within the domain of the Supreme Being or of nature. It should be pointed out that the religio-natural orientation items together comprise a measure of concern regarding the risks involved in human intervention in weather processes. If the effects of cloud seeding are not fully understood, some degree of uncertainty about outcomes is bound to exist in the population prior to and during the cloud seeding project. These uncertainties may be vague, but can include concerns about effects on the environment and ecological systems, about economic impacts resulting from weather changes, about socio-political problems arising from the projects, about arousing the displeasure of the Almighty, and about other things. Thus, to interpret the findings on religio-natural items as a consequence of either environmentalist or religious concern is to miss their primary meaning. Sentiment on these items may best be understood, where attitudes negative toward cloud seeding are expressed, as a degree of concern among citizens about risk-taking. There could be a decline in religio-natural concern over time as projects are experienced *if no undesirable effects* accompany its implementation.

Concern about risk-taking is posited to be associated with the strong citizen preference for local control of weather modification and for public participation in decision processes, discussed later in this chapter. Social scientific

evidence is beginning to accumulate showing that voluntary risks are more easily accepted, even with greater potential consequences, than imposed risks (*Otway et al., 1975; Velimirovic, 1975*).

In most surveys, the proportions of respondents expressing a religio-natural orientation, and those rejecting it, each comprise approximately 40% of the samples. Illinois respondents exhibited a majority religio-natural orientation, an even higher proportion than in South Dakota prior to its experience with weather modification. The results of surveys over time show that the proportion expressing religio-natural concerns tends to decline somewhat with time as programs are experienced. However, the 1976 South Dakota results show an increase in those expressing religio-natural concerns to about half of the sample, reversing the earlier trend.

Our data in *Table 23* show that a large difference exists between the Illinois sample and the other three samples on whether or not cloud seeding actually works to prevent hail. The Illinois results, with 62% indicating that they are uncertain, parallel those in South Dakota prior to the inception of the cloud seeding program there. (Illinois has not yet experienced a hail program.)

The proportion of South Dakota respondents believing hail suppression to be effective rose from 19% at the first interview to 53% at the fourth. However, results from the South Dakota survey showed that belief in the effectiveness of hail suppression dropped to 31%, while the proportion unsure of its effectiveness had nearly doubled. These results indicate that respondents in areas having experienced hail suppression are significantly more likely to believe in its effectiveness than those which have not. But after four years, belief in South Dakota turned dramatically downward.



**TABLE 21**

**Favorability toward the idea of modifying weather**

*In percent of number of respondents*

<i>Response</i>	<i>Illinois 1974 (N = 274)</i>	<i>Colorado 1974 (N = 221)</i>	<i>South Dakota 1974 (N = 293)</i>	<i>South Dakota 1976 (N = 430)</i>
It is a good idea for scientists to experiment with cloud seeding so that we can find out if it really does work.				
Strongly agree	7	10	13	15
Agree	56	71	65	55
Unsure	17	6	11	7
Disagree	16	11	9	17
Strongly disagree	4	2	2	6
State or county officials should feel free to use such things as cloud seeding if it might help farmers avoid crop losses.				
Strongly agree	11	6	12	9
Agree	60	67	62	50
Unsure	11	9	9	11
Disagree	15	16	14	21
Strongly disagree	3	2	3	9
If weather is a problem to farmers, it is appropriate to try to directly control extreme weather conditions by using the most effective techniques known—for example, cloud seeding to increase rain if moisture is needed.				
Strongly agree	4	5	9	9
Agree	62	73	64	57
Unsure	14	8	11	13
Disagree	18	12	13	18
Strongly disagree	2	2	3	3

'Belief that it works' is the key

Results from several multiple regression analyses show that *belief in the technology's effectiveness is the single most important social-psychological variable in determining favorable social evaluation* of experienced cloud-seeding projects (in both South Dakota and Colorado).

Ecological concern

Great Plains agriculturists are not notably likely to join or support environmentalist organizations, and complaints against such organizations are frequently heard. As data presented in *Table 24* show, the majority of respondents in South Dakota and Colorado did not feel that cloud seeding would result in environmental

harm, or that it would damage plant or animal life, soil or water in any way. Illinois respondents had a tendency to be more uncertain about this question, and about a quarter indicated that cloud seeding might prove ecologically damaging. In general, environmental concern does not appear to be a basis of opposition to cloud seeding in agricultural areas.

Respondents in Illinois and South Dakota were asked to anticipate whether an effective hail suppression program would result in *economic benefit or harm to them*. Data presented in *Table 25* show that most citizens felt such a program would be economically beneficial (up to 85% in South Dakota). A tiny fraction — 2% in Illinois — anticipated that suppressing hail would be harmful to them.

Respondents in Colorado and South Dakota later were asked to assess whether the cloud-seeding program, experienced for several seasons, had *resulted* in economic benefit or

harm to them. Results, presented in *Table 26*, show that 7% of Colorado respondents felt they had benefited from the National Hail Research Experiment (NHRE) 2% felt they had been harmed and 91% indicated that they didn't know, or that it had made no difference to them.

In South Dakota, where cloud seeding was carried out for both hail suppression and precipitation augmentation, the results show a different pattern. Although



**TABLE 22**

**Religio-natural orientation toward the weather**

*In percent of number of respondents*

Response	Illinois 1974 (N = 274)	Colorado 1974 (N = 221)	South Dakota 1974 (N = 293)	South Dakota 1976 (N = 430)
Cloud seeding probably violates God's plans for man and the weather.				
Strongly agree	12	5	7.5	16
Agree	36	35	32	33
Unsure	15	15	11	11
Disagree	33	38	42	32
Strongly disagree	4	7	7.5	8
Even when carefully controlled, cloud seeding programs are very likely to upset the balance of nature.				
Strongly agree	9	6	4	13
Agree	41	33	40	37
Unsure	29	26	18	24
Disagree	20	32	34	23
Strongly disagree	1	3	4	3
Man should take the weather as it comes and not try to alter it to suit his needs or wishes.				
Strongly agree	18	2	5	10
Agree	46	28	25	33
Unsure	13	16	11	13
Disagree	22	50	51	37
Strongly disagree	1	4	8	7

85% indicated that they anticipated economic benefit from an effective hail program, 31% of those aware of their local programs in 1974 said they had benefited from it, 12% indicated they had been harmed by it, and 57% said they didn't know or that it made no difference to them.

In 1976, 17% of respondents in counties that had participated in the program for several years felt they had benefited from it, 8% thought they had been harmed, and 75% said either that the program made no difference to them or they did not know how it had affected them.

A possible explanation for the finding of relatively few subjectively defined beneficiaries is that although *the idea* of effective hail suppression is economically appealing, *the experience* of an actual program did not bear out the anticipation. There was disappointment when damaging hail occurred in target counties, and when dry weather conditions persisted in spite of the cloud-seeding effort. Suppression is, indeed, *hard to perceive*.

The majority of respondents in surveys on weather modification have expressed a preference for *local decision* control over implementation of the technology. *Table 27* presents data showing that respondents in Illinois, Colorado, and South Dakota felt that decisions on whether to have a cloud seeding project should be locally made, although the results do not specify in what manner.

In 1976, South Dakota respondents were asked how such a decision should be made: 50% indicated a preference for local decision making, and 54% thought the decision ought to be made by a vote of county or state residents, or of county agriculturists. Widespread citizen preference for local control over cloud seeding is a pattern found wherever surveys have been conducted, although there is much opposition to such mechanisms as voting among weather modification experts — scientists and decision makers. As noted earlier, concern about risk-



**TABLE 23**

**Belief in efficacy of hail suppression**

*In percent of number of respondents*

<i>Response</i>	<i>Illinois 1974 (N = 274)</i>	<i>Colorado 1974 (N = 221)</i>	<i>South Dakota 1974 (N = 293)</i>	<i>South Dakota 1976 (N = 430)</i>
Do you think that cloud seeding can actually suppress hail?				
No	18	19	19	15
Uncertain	62	27	28	54
Yes	20	54	53	31



**TABLE 24**

**Ecological concern**

*In percent of number of respondents*

<i>Response</i>	<i>Illinois 1974 (N = 274)</i>	<i>Colorado 1974 (N = 221)</i>	<i>South Dakota 1974 (N = 293)</i>
Do you think that a cloud seeding program might damage the ecology of an area —that it might prove harmful to plant or animal life, soil or water in any way?			
No	31	57	59
Uncertain	41	26	26
Yes	28	17	15

Among the South Dakota sample, 54% of those indicating an ecological concern (N = 43) thought cloud seeding might cause flooding. In Colorado, 17% of those indicating such concern (N = 77) mentioned possible flooding.

**TABLE 25****Anticipated benefit/harm from hail suppression***In percent of number of respondents*

Response	Illinois	South
	1974 (N = 274)	Dakota 1974 (N = 293)
If a cloud seeding program were able to suppress hail (reduce damage from hail) would you say it would probably be of economic benefit to you, harmful to you, or make no difference to you?		
Harmful	2	1
No difference/don't know	38	14
Beneficial	60	85

**TABLE 26****Assessment of benefit/harm from cloud seeding program***In percent of number of respondents*

Response	Colorado	South	South
	1974 (N = 221)	Dakota 1974 (N = 293)	Dakota 1976 (N = 430)
Did the cloud seeding program benefit you, harm you, or make no difference to you?			
Harm	2	12	8
No difference/don't know	91	57	75
Benefit	7	31	17

**TABLE 27****Preferred decision making regarding cloud seeding***In percent of number of respondents*

Response	Illinois	Colorado	South	South
	1974 (N = 274)	1974 (N = 221)	Dakota 1974 (N = 293)	Dakota 1976 (N = 430)
Who do you think should decide whether or not a hail or rain experiment will be started (or continued)?*				
Local	54	56	59	50
Nonlocal	46	44	41	50

\*Questions phrased slightly differently in each state

taking in connection with hail suppression projects is very likely related to citizen preference for local control over what is to be done to their weather. Scientists and officials, on the other hand, feel they have the expertise to make decisions to employ the technology more "rationally" than the public, and they also have organizational domain interests at stake.

*Evaluation  
of cloud  
seeding*

Table 28 presents data on the favorability of the samples toward anticipated or experienced cloud seeding projects. In all cases except South Dakota in 1976, the majority of the samples expressed favorability to the weather modification program.

In South Dakota after the program had ceased to function, 46% favored it, 33% opposed it, and 21% were neutral or undecided. These results showed an increase

in the proportion of those opposed on the order of 20% (and a decrease among those favorable of 12%) after the formation of the organized opposition in South Dakota. Note that the 1974 South Dakota sample was drawn only from the counties participating in cloud seeding during 1972, while the 1976 sample was drawn from both the participating and nonparticipating counties.

The analysis of these survey results showed that knowledge about weather modification was not correlated with favorability toward programs, providing no support for the hypoth-

esis that if citizens were educated about cloud seeding they would be more favorable toward it. Instead, citizens may be favorably inclined toward cloud-seeding programs that hold promise of benefiting agriculture, but their evaluation of such programs will depend more on their experiences with it, in terms of the weather, of economic well-being, and of social acceptance, than on their preexisting attitudes.

*Observation of project effects counts far more in whether a program will continue to be accepted over a period of many years than favorability to the idea of giving it a trial in the first place.*



A number of investigators have tested the relationship between favorability to weather modification and such variables as age, sex, education, occupation, income, social status, urban/rural residence, political activism, and religious affiliation. Some of these analyses were conducted in order to discover whether certain widely held ideas (e.g., opponents tend to be older or more religious than the population at large) had any basis in social scientific fact. The results of these analyses are summarized here.

Findings on the relationship between age and "favorability" to weather modification (variously defined, but generally an expression of sentiment in response to a questionnaire or interview situation) are mixed. The preponderance of findings was that older respondents tended to be less favorable, but half of these analyses may not have been of the highest quality. In analyses by two authors, age was not related to favorability (*Krueger, n.d.; Haas, 1971; Farhar, 1973; Lanham, 1974; Bohland, 1974; Krane et al., 1975*).

Three studies examined the relationship between respondent's sex and favorability to weather modification. These analyses resulted in significant differences

\*This section contributed by Barbara C. Farhar.

**TABLE 28**

**Position toward cloud seeding**

*In percent of number of respondents*

<i>Response</i>	<i>Illinois 1974 (N = 274)</i>	<i>Colorado 1974 (N = 221)</i>	<i>South Dakota 1974 (N = 293)</i>	<i>South Dakota 1976 (N = 430)</i>
<i>As a resident of this area, how do you feel about the project (or proposed project)?</i>				
Strongly favor	6	15	17	10
Favor	48	52	41	36
Neutral/undecided	25	18	29	21
Oppose	16	7	8	20
Strongly oppose	5	8	5	13

**SOCIO-  
DEMOGRAPHIC  
VARIABLES\***

*Age*

*Sex*



in attitudes toward weather modification by sex: women are more cautious and skeptical about cloud seeding than are men (*Farhar, 1973; Krane et al., 1975; Falk, 1976*). Sex has also been found to be a consistently differentiating variable in favorability and opposition to nuclear power installations, with women more likely to be opposed than men (*Passino and Lounsbury, 1976*).

- Education* Five analyses reported the relationship between education and favorability to be positive —that is, the higher the educational attainment of the respondent, the more likely he or she is to be favorable (*Strodbeck, 1967; Krane and Haas, 1974; Krueger, n.d.; Haas, 1971; Farhar, 1973*). One direction of these findings on educational levels of citizen respondents is the opposite of those for weather modification experts reported on page 47. Among scientific respondents, higher levels of education are associated with more skepticism concerning the readiness of some cloud seeding technologies for operational application.
- Occupation* Relating occupation to favorability, Haas (*1971*) found that managerial and professional workers were more favorable; Farhar (*1973*) and Falk (*1976*) found no significant difference by occupation.
- Income* In one analysis reporting on the relationship between income and favorability, Farhar (*1973*) found a very slight tendency for higher income groups to be more favorable. Krane and Haas (*1974*) reported lower income groups to be less favorable than other income groups.
- Social class* Two investigations combined the previous three variables (education, occupation, and income) to measure social class. They reported that the higher the social class of the respondent, the more likely he or she was to be favorable to the technology (*Pfost, 1972; Krane et al., 1975*).
- Voluntary association membership* One author investigated the relationship between a high rate of membership in voluntary associations (such as Elks, Rotary, Lions) and favorability. He reported that a low rate of membership was more likely to be associated with opposition (*Pfost, 1972*).
- Political activity* In regard to personal political activity Haas (*1971*) found that politically active respondents (voting citizens) were more favorable.
- Urban/rural residence* Three investigators reported that place of residence made no difference in attitudes toward weather modification (*Lanham, 1974; Farhar and Meives, 1974a; Bohland, 1974*).
- Range/crop agriculturists* Two investigators reported little difference between farmers and ranchers in their assessment of cloud seeding (*Larson, 1973; Farhar, 1975*). Larson found that respondents from crop counties were slightly more favorable toward precipitation augmentation than those from range counties.

Some analyses have examined respondent location vis-á-vis the project target area in relation to other variables. Haas and Krane (1973a, b) found, for example, that residents of the NHRE target area were more knowledgeable about the project than were residents of a control area several hundred miles away. Farhar and Mewes (1974b) found differences in concerns about direct and indirect impacts of a proposed snowpack augmentation project by location of residence. Johnson and Falk (1974) found little difference in the attitudes of residents of seeded and nonseeded counties in North Dakota.

*Residence  
in relation  
to target area*

Two investigators reported no differences in attitudes toward weather modification on the basis of religious denomination or lack of religious affiliation (Krueger, n. d.; Farhar, 1973). One investigator did report that firmness of religious conviction was associated with opposing views. The analysis, however, was not well explained (Krueger, n. d.).

*Religious  
considerations*

Of the socio-demographic characteristics examined, sex, education, and social class appear to be the most consistently verified differentiating variables salient to attitudes toward weather modification. Thus, some of the commonly held views about the nature of the supporters and opponents of weather modification received little support from social scientific evidence.

*Discussion  
of variables*

In all probability, the more determinative variables with regard to community adoption or rejection of cloud seeding technologies are not individual characteristics or even individual preexisting attitudes about weather modification. Rather, system-level variables, such as those described on pages 43-46 and page 136 and in Chapter 9 of this report, appear to be factors causally related to the formation of organized opposition and to outcomes for projects (termination or continuance). Research on the sociological aspects of weather modification began with a focus on individual variables and evolved over time to a position of more emphasis on systemic factors as causal variables.



To the present, claims by scientists and practitioners concerning their ability to modify the weather have not received unanimous support. Official reports by highly prestigious bodies such as the Committee on Atmospheric Sciences of the National Academy of Sciences have nevertheless revealed a progressive evolution toward consensus that the weather can be modified deliberately (NAS, 1966, 1971, 1973). With respect to hail, the 1973 NAS report calls for substantial enlargement of research on the nature of hailstorms and hailstorm modification. Specific emphasis was placed on "physically and statistically sound experimental procedures . . . ."

**EFFECT OF  
SCIENTIFIC  
CONSENSUS\***

Scientific consensus concerning hail suppression will probably remain relatively low for the period covered by this technology assessment. It is highly likely that respected scientists and statisticians will continue to quarrel with the

*Scientific  
quarrels  
to continue*

\*This section contributed by Dean Mann

scientific evidence adduced to demonstrate the effectiveness of hail suppression technology. Such scientists will continue to have forums for their views in scientific journals, in legislative hearings, and in courts of law. Those who oppose hail suppression will make use of such expert testimony as suits their purposes.

*Quarrels on  
all aspects  
still fuel  
for opposition*

The scope of the argument may become increasingly narrow, but this in itself may not preclude serious disagreements. For example:

- There may develop substantial consensus that hail suppression technology "works " but disagreement over the extent to which hailstone size or hail frequency is reduced.
- There may be general consensus on the above but dissensus on the extent to which hail suppression affects precipitation within the target area.
- Or there may be consensus on all the above but little on the question of downwind effects.
- Or there may be consensus on all the foregoing but disagreement on the general environmental effects.

To the extent that these disagreements persist, they will provide ammunition for those who oppose the adoption of hail suppression technology on grounds that their self interest or the public interest is endangered by the practice.

These uncertainties and risks impose burdens on those who espouse and design hail suppression programs. They must insure against excessive and differential assumptions of risk by the contracting parties and risks imposed on those who are not contracting parties. The tactics used to avoid these problems may vary from obtaining of waivers of claims to damage to schemes for indemnification for those whose interests are threatened.

*Debate  
does not  
preclude  
adoption*

The fact that there is disagreement on hail suppression among the informed community has not precluded the adoption of the technology in several locations. The virtue of a decentralized system of decision making provided by the federal system is that local and state communities can decide about the adoption of an uncertain technology in accordance with their estimate of social benefits and costs to themselves (*Kilpatrick, 1963*). Thus, assuming that weather modification (and hail suppression) will not be completely "federalized," states will be able to make these independent estimates and proceed as they wish. Moreover, the evidence and satisfaction (or dissatisfaction) resulting from experimentation may provide more conclusive evidence of the effectiveness of the technology.

## **PARTICIPATION IN MODIFICATION DECISION MAKING\***



During the 1960s and early 1970s there has been a manifest increase in the demands by various groups to participate actively in decisions that affect their welfare. Recognizing that administrative agencies have decidedly real power to affect their interests, these groups are not content to rely on representation that may come through elected representatives. Their influence is lost in a welter of communication that bombards the representative and is diffused in the bargaining process that takes place with respect to a broad range of public policies.

\*This section contributed by Dean Mann.

Given the popularity of participative mechanisms today and their increasingly extensive use, it seems unlikely that such devices will decline in use. One cannot expect the participation of large numbers of people, but one can expect the active and forceful participation of the representatives of groups —attentive minorities —having a direct stake in the outcome of public decision-making agencies.

*Participation  
can be expected  
to continue*

Farhar (1975) has classified levels and quality of participation in weather modification decision making in three models:

- The free enterprise model
- The government model
- The civic model

The differences in these models are found in the relationships among those involved in the weather modification enterprise itself, the opportunities for parties not directly involved in the enterprise to express themselves, and the extent of public requirements for participation. Farhar found that in 96 weather modification projects studied in 1974, 20% were implemented using the government model, which allowed the least participation; 54% used the free enterprise model, which allowed or required more participation; and 26% used the civic model, which allowed greater participation through elected representatives.

*Civic model  
gives more  
participation*

If we assume that substantial participation by interested parties in public decision making will retain its appeal and even increase in the future, it is useful to explore the various points in the decision-making process at which individuals, groups, and communities can participate and the form of participation that will provide maximum benefit. To a considerable extent, the participation arrangements will reflect decisions made with respect to weather modification operations and management itself:

- Will it become an activity of the federal or state agencies?
- Will operations be carried out through private contractors?
- Will those who engage the weather modification agents be voluntary associations, public districts, or state or federal agencies?

*Operations  
dictate form  
of participation*

State legislatures authorize weather modification and thus provide public legitimacy and impose public responsibilities on weather modification personnel and companies. But the licensing of operators and the permits to undertake projects are discretionary acts that depend on satisfaction of criteria that are themselves often vague and subject to varying interpretations. State legislatures may choose to "encourage" weather modification; they may require that weather modifiers be competent in given disciplines and have certain experience; they may specify certain conditions under which weather modification takes place.

It is this enormous discretionary authority that invites public participation because the state has not stamped legitimacy on every operator or project and that may invite serious questions about the qualifications and plans of operators because of the need for adequate protection of the public interest.

*An invitation  
to public  
questioning*

In Farhar's free enterprise model, the distinction is drawn between the situation in which a utility engages a weather modifier under state law and that in which a

*Public views  
encouraged*

voluntary association does so. Except as state law may require public approval, the first case allows no public participation. In the second case, the voluntary association seeks as many subscribers as possible and in so doing encourages broad public consideration of the matter. There is, however, except as state law may require it, no formal means of testing public sentiment except in terms of the number of subscribers.

*Formal approval required*

In contrast, use of the civic model requires formal approval by representatives of the affected public with respect to a given project. The County Board of Supervisors might be asked to give its approval. Or possibly the voters of the affected communities might be asked to approve a given project.

*Projects do not fit political boundaries*

The complexities of requiring or even permitting such broad participation in weather modification decision making are great because the boundaries of projects do not neatly correspond with political boundaries. At the present time, it is difficult to speak with much confidence about the area that is actually affected by any cloud-seeding operation. As these meteorological definitions become clearer, it may be possible to speak with greater certainty about the appropriate political boundaries for given projects.

The utilization of weather modification districts — if properly defined in meteorological terms — might provide appropriate decision-making parameters. Such districts might be authorized by public vote or by approval of elected officials in areas covered by the district. To expect the public to pass on every project would seem unduly burdensome, but the availability of a referendum device might provide the means by which those who are opposed to a given project can provide an assessment of public sentiment.

Warner (1971) has classified three public participatory mechanisms:

- Education/information — includes efforts on the part of the public agency to inform and educate the public through newspaper articles, radio and television programs, speeches, field trips, newsletters, and conferences
- Review/reaction — includes public hearings, survey questionnaires, and public meetings
- Interaction/dialogue — includes workshops, special task forces, interviews, advisory boards, and seminars

*The first stimulates interest*

The quality of participation obviously varies in the three categories. In the first, the agency communicates to a community or a series of groups that are themselves relatively passive and have restricted opportunities to talk back. While this device *may* help to stimulate interest and willingness to express views on the desirability of the project, it does not *guarantee* meaningful public participation nor even a stimulation of interest if none existed previously.

*The second provides public input*

In the second category, one finds more formal devices for providing public input. Representatives of various groups, as well as the public agency involved, can express themselves and open up issues of concern to both. These are particularly useful when there are specific proposals to be considered and debated.

The final category emphasizes two-way communication through more or less informal consultative proceedings. These devices are particularly effective in defining problems, in exploring alternatives, in assessing community goals, and in creating a sense of confidence between the agency personnel and members of the community or representatives of various groups.

*The third  
gives two-way  
interchange*

There are, of course, difficulties in using these techniques (Meade, 1971). First there will remain the problem of defining the various interests in the community and obtaining their viewpoints. Community participation generally is skewed strongly toward its upper and middle class members, and group activity to a considerable extent excludes members of the disadvantaged classes (Nie and Verba, 1972). Agency representatives are, therefore, compelled to encourage the broadest participation and at the same time recognize their own responsibilities to represent all citizens, not just those who attend meetings and claim to represent others.

*Problem of  
defining all  
interests*

Second, under law, the agency representatives are obligated to make decisions in accordance with the purposes and constraints laid down in the statutes and regulations of their agency. Advisory boards, planning committees, and the like do not in fact share in the decision-making authority although they may powerfully influence the decisions that are made. The experience with such advisory boards is again mixed. Where they are extensively used and have real influence, they are often accused of dominating the agencies. If they are seldom used and have little use, they are considered rubber stamps. Their membership is again crucial in that many interests with more diffuse concerns and less salient perspectives are often ignored when opinions are sought.

*Agencies  
versus  
advisors*

Third, there is the temptation on the part of the agency officials to use participative devices for purposes of manipulation or cooptation. They may provide the "facade" of participation, but their commitment to a given project may be such that no amount of community opposition will sway them. Or they may pose the issues in such a way that there are, seemingly, no realistic alternatives but those presented by the agency.

*Manipulated  
'participation'*

Timing is a very important factor in all of these matters. There is understandable resentment when agencies bring fully developed proposals before local groups and present them as all-or-nothing propositions. Citizen involvement, if it is to be realistic and effective, must occur throughout the process of project formulation and adoption.

Public participation has obvious relevance to weather modification generally and to hail suppression projects in particular. Those proposing projects would do well to consider these techniques both to avoid opposition and to ensure that projects, in fact, serve community purposes and are acceptable at least to those who are sufficiently articulate to express an opinion. This is as true of federal agencies as it is of state weather modification agencies or of interstate compact agencies if they come into being.

*Better  
participation  
helpful*

**ORGANIZED  
OPPOSITION\***



As our presentation of cases in Chapter 3 was intended to illustrate, adoption (or nonadoption) of hail suppression technology is a complex societal process.

Cases undoubtedly exist in which hail suppression was proposed in or for a local area, and the idea encountered such skepticism that it was quietly dropped. Such instances are known to have occurred with regard to snowpack augmentation projects (*Comparative Study Data, 1975*). In these situations, no need for an active, organized opposition to arise is apparent — opponents' wishes are obtained, and they need not bring resources to bear until such time as a new project is proposed.

*Project starts,  
then opposition  
follows*

Proponents, on the other hand, might desire to press for project implementation, but there is no known case in which proponents organized to implement a project that had been prevented by public opposition.

The usual course of events in the organization of an opposition is that proponents are successful in achieving project implementation, and opponents organize in response to actual cloud seeding in their local areas. However, opponents have sometimes been successful in terminating project proposals before they are actually implemented.

*Both sides  
minority*

Both proponents and opponents are local minority interest groups contending for ascendancy in a situation perceived to be affecting their interests. Even in locales where agriculture is the mainstay of the economy, the attentive publics (those interested in weather modification issues) are in a minority of the population. In cases where votes have occurred, these minorities have attempted to persuade the population at large of the Tightness of their respective positions.

*No partisan  
politics, yet*

Although a few allegations have been made that cloud seeding became a political issue, there is little evidence that political parties have adopted a stand toward cloud seeding, or that candidates have risen or fallen due to their position on the issue. However, in the future, partisan politics could easily become part of the picture, with local party platforms containing planks on cloud seeding projects of local concern.

We have presented the diagram in *Figure 36* in order to summarize some of the more important variables involved in the development of organized opposition to hail suppression projects. These variables are described on pages 43-61 and in Chapter 9 of this report.

*Secondary  
impacts*

The social consequences of hail, beyond direct economic loss, are not well understood at present. Secondary impacts of hail loss involve such matters as solvency of families, possible out-migration, foreclosures, and less business for grain elevators, transportation industries, and the like.

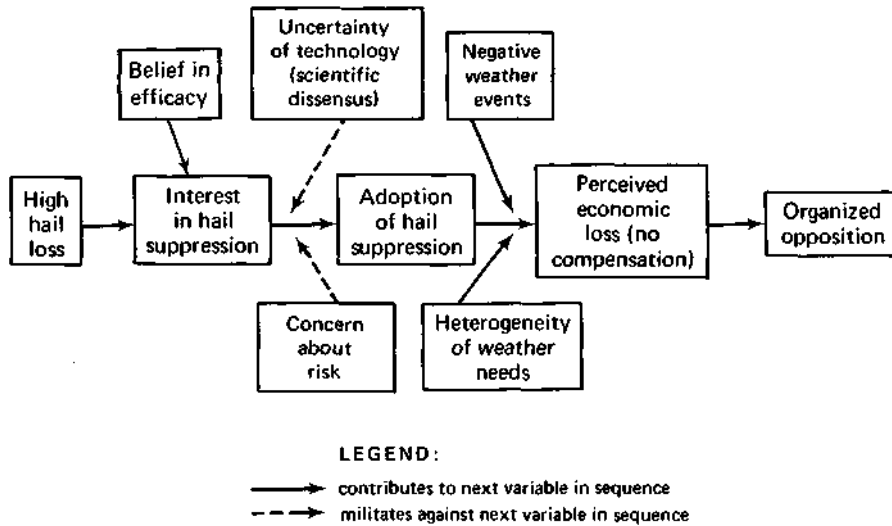
The attempt to reduce damaging hail through cloud seeding appears to have social consequences of its own, however. The intentional intervention in potentially

\*This section contributed by Barbara C. Farhar.



FIGURE 36

Principal variables leading to organized opposition



damaging weather processes shifts the responsibility for weather effects from events out of human control (acts of God, acts of nature) to being at least somewhat within human control. The boundaries of partial atmosphere control are not known, either scientifically or legally.

Application of an uncertain technology implies that a relatively unknown level of risk is experienced by recipients. Added to the technological uncertainty is the normal uncertainty about weather and climatic fluctuations. Normal climatic variation might be attributed to technological intervention. If the economic effects of the weather are not beneficial during the period of application, recipients have come to feel that the risks involved are too great in comparison with the possibility of advantages that could accrue. Recipients are not limited to the sponsoring organization, but are members of the community at large. Adequate decision processes relative to the application of weather modification have not yet been developed.

*Uncertain technology — unknown risk*

The nation as a whole stands to benefit economically if crops and property could be protected from damaging hail. Farmers in high hail-loss areas have already evidenced interest in adopting hail suppression if it could be accomplished without undesirable side effects.


But the adoption of hail suppression in its uncertain scientific status carries the potential for socially disruptive consequences, and the costs of the research and development necessary to achieve a reliable technology are high. Even with a reliable technology, the normative complexities involved in human responsibility for weather effects will present special societal problems. In the end, the promise of hail suppres-

*Suppression decision difficult*



sion as an adjustment to the hail hazard is a value decision —a difficult decision given the complexities involved.


## THE LAW AND HAIL SUPPRESSION\*

 And what of the law? What are the influences of our legal regime on the technology of hail suppression? What are the legal structures, the statutes, and the indirect controls involved? With what legal favor is hail suppression received in the federal structure and by the various states? What of the problems of legal liability and rights?

The legal considerations —both federal and state —are addressed in this section. They form an important part of the foundation for assessing the future of hail suppression.

### OUR LEGAL REGIME

*Suppression legal — 'unless...'*

 In the United States conduct is lawful and cannot be penalized, enjoined, or otherwise controlled unless some statute, administrative action, or court decision has so ruled. Our tongue-in-cheek comparison in *Figure 37* helps to illustrate this principle. Consequently, hail suppression activities are lawful unless some applicable legal norm declares otherwise. Our legal regime, as described by Breitel (1965), is:

"... pervasive and universal; it blankets all conduct in an organized society. There is no non-law; what the law does not forbid, it allows."

\*These sections contributed by Ray Jay Davis.



#### FIGURE 37

##### A look at the law

*A tongue-in-cheek comparison of the common law legal system of the English-speaking world with other legal systems*

**The common law regards everything as legal,  
Unless statute or case law makes it illegal;  
Under German law everything is illegal,  
Unless the law specifically declares it legal;  
According to Russian law everything is illegal,  
Even though the law says it is legal;  
But in France everything is legal,  
Even though the law says it is illegal.**



Creation of legal norms happens when interested persons, usually those directly affected by some activity, induce legislators, administrators, or judges to pass a law, promulgate an administrative rule or decision, or create a judicial precedent during the course of litigation. Norms which can be used as hail suppression legal controls can be classified as follows:

- Law dealing specifically with hail suppression activities
- Law dealing with weather modification in general or with cloud seeding activities intended for purposes other than hail suppression
- General legal principles concerning administration, procedures, regulation liability, and rights

Other than some principles developed from litigation, there is very little law which deals specifically with suppression of hail. A fair number of legal norms relating to cloud seeding generally or to precipitation enhancement specifically can be applied to control hail suppression. But most of the legal regime under which hail suppressors operate stems from general legal principles which are or can be applied to their activities.

The aspects of the legal regime which relate most pointedly to hail suppression and which will be examined in this chapter break down into administrative and legal considerations including:

- The administrative structure for legal control of hail suppression
- Direct regulation of hail suppression
- Indirect regulation of hail suppression
- Receptivity of legal controls to hail suppression
- Legal liability for harm caused by hail suppression
- Legal rights associated with hail suppression consequences



In order to have effective legal regulation of hail suppression activities, a jurisdiction should have a weather control statute. Sixty percent of the states have enacted such laws, but in many cases the legislation is inadequate. According to the managers of the South Dakota program, the original statewide seeding operation in the United States (*Donnan, et al., 1976*):

## **ADMINISTRATIVE STRUCTURE**

The first step must be to obtain a law. Generally, without a law, there is no state agency with the authority or time to organize any activity. But not just any law. Insist upon a comprehensive regulatory piece of legislation which, the first time, addresses every conceivable problem area.

The administrative structure established by such a comprehensive law should include (*Davis, 1974a*):

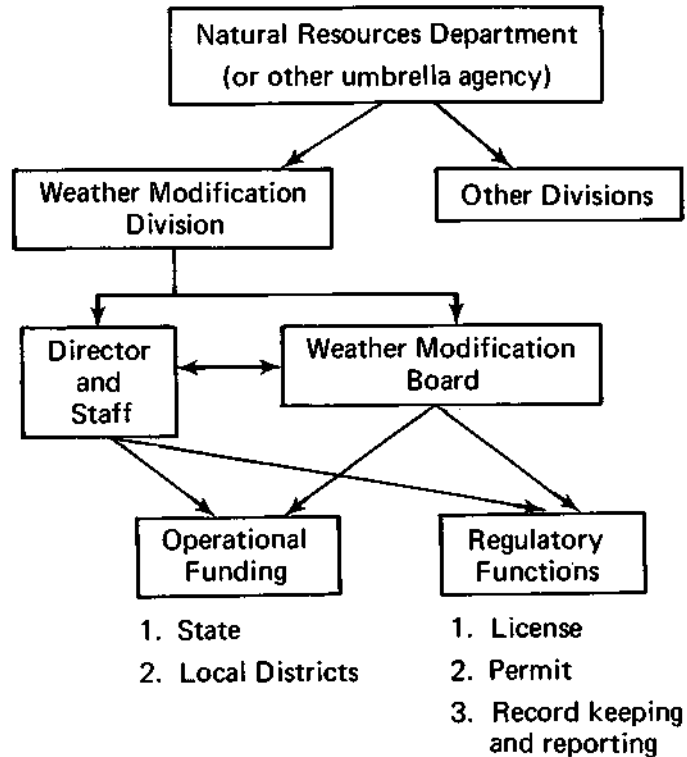
- An umbrella agency within the governmental framework
- A weather modification division of that agency
- Delegation of adequate administrative functions to the agency and its division
- Provision for meaningful public participation in significant decisions about weather control.

Our diagram in *Figure 38* shows the design of a comprehensive state administrative structure established by a weather control act.



FIGURE 38

Weather control administrative structure



An *umbrella agency* is usual because, though hail suppression is important to professionals in the weather modification industry (Table 19, Chapter 5), the volume of regulatory business has not been large enough to warrant incurring the expense of setting up independent agencies to control the activities of hail suppressors and other weather modifiers. Instead, administration of weather control legislation has been added to the powers and duties of existing government commissions and departments. They can accommodate enforcement requirements with less additional manpower than could an independent weather modification regulatory body.

Lawmakers in half of the American states within the hail regions discussed in Chapter 2 have delegated to some state agency responsibility to administer weather control legislation. In 1975 there were 14 states in which the umbrella organization was a natural resources or environmental agency. The category included water commissions, natural resources departments, an ecology department, and an office of environmental affairs. Four state agricultural departments and seven other governmental entities handled such matters (Davis, 1975a; Farhar and Mewes, 1974c).

In states with comprehensive laws, weather modification divisions are lodged within the structure of the umbrella agencies. While other divisions of such bodies perform their assignments, the weather modification division carries out its responsibilities with a small full-time professional staff headed by a director and a part-time weather modification board. There were 12 states in 1975 in which legislation had created special weather modification boards. These were of three types: boards with policy and decision-making powers which reported their actions to the state umbrella agency, boards which were authorized to give advice to the state agency administering weather control legislation, and independent weather modification boards (*Davis, 1975a*).

*Weather  
modification  
division*

Government involvement with weather modification can include either funding operations or the performance of regulatory functions, or the exercise of both kinds of powers. Legislation determines the type and extent of such involvement. Funding laws can authorize expenditures by the states, by local districts, or by both. Among the included water commissions, natural resources departments, an ecology department, and an office of environmental affairs. Four state agricultural departments and seven other governmental entities handled such matters (*Davis, 1975a; Farhar and Mewes, 1974c*).

*Administrative  
functions*

Our legal system affords means for public participation in official decision making. Among techniques for citizen inputs are public hearings, public opinion polls, workshops (*Heberlein, 1976*), and litigation (*Sax, 1970*). Although hail suppression permits are issued or denied by weather modification boards or other governmental agencies, there are avenues established by law through which their official actions can be influenced by the general public. The two most frequently used means are:

*Public  
participation*

- Public notification
- Public hearings

Statutes from 18 of the permit-granting states require advance public notification by applicants who must publish legal notices in the areas to be affected by proposed hail suppression projects. One other jurisdiction lets the agency determine the need for notice (*Davis, 1975a*). Although such legal notices cannot always be equated with actually informing the citizenry (*Davis, 1976a*), publication does increase the possibility of public awareness of proposed activities.

*18 states  
require public  
notification*

Findings that people prefer local decision making support the use of public hearings as another technique for citizen influence on issuance of hail suppression permits (*Farhar and Mewes, 1974c*). Statutes in six states make it mandatory for the agency to hold hearings at which those persons interested in the project can present their views. In Texas the board must hold a public hearing if requested by at least 25 persons in the operational area. Moreover, under a new state administrative procedure act, there must additionally be adjudicatory hearings conducted whenever there are contested cases concerning issuance of permits by state agencies (*Hamilton and Jewett, 1976*).

*Some states  
hold hearings  
for permits*

In several states the agency has the option to hold hearings as part of the administrative process. These laws are premised upon the proposition that the agency should be free to act without incurring the expense of hearings when the potential impact of the operation is relatively minor (*Ackermann, et al., 1974*).

Local decision-making was built into the South Dakota program not by statute but by administrative practice through giving authority to county officials to call for cessation of seeding (*South Dakota Department of Natural Resource Development, 1974*). And in the San Luis Valley case discussed in Chapter 3, an administrative hearing examiner admitted into evidence, as an indication of public sentiment, the results of a vote on approval or disapproval of cloud seeding. Although this admitting was done without any statutory basis, in *Atmospherics, Inc. v. Ten Eyck*, a reviewing court found that the evidence was properly admitted (*Davis, 1974b*).

## **DIRECT SUPPRESSION CONTROLS**



Direct regulation of hail suppression is accomplished through laws which provide for licensing professionals, issuing permits, keeping records, and making reports. Appropriations for administration and enforcement of these statutes are not uniformly sufficient to make them as meaningful as would be the case with adequate funding.

### *Licensing to practice suppression*

The licensing component for hail suppression concerns issuance of state certification of the right to practice weather modification to an individual. It does *not* relate to provisions under which the power to conduct precipitation enhancement operations in a specified area for a specified time period is granted. Thirteen states now require persons who would suppress hail to obtain professional licenses before practicing their trade (*Davis, 1975a*).

Both criteria and procedures for getting licenses vary widely among the states. Competency in meteorology is the most frequently mentioned qualification, but states generally have not set up any system for determining competency. Both statutes and administrative regulations tend to give the licensing authorities a wide range of discretion both as to what constitutes competency and as to how the decision to grant a license shall be made (*Davis, 1968a*). The Colorado statute has the most detailed listing of qualifications of any of the state laws.

### *Regulation welcomed*

Most occupations, trades, and professions which have been subjected to licensing by state laws have not been unwillingly limited by governmental requirements. On the contrary, professional licensing has generally been sought by practitioners in regulated occupations (*Gellhorn, 1956*). Weather modifiers have taken leading roles in bringing about their own professional regulation. Persons with established competency and solid reputations have the most to gain by barring hail suppression seeding by the fly-by-night operators.

There are 23 states which now either require registration of projects or mandate

obtaining operational permits (Davis, 1975a). Permits are of critical importance in the regulation of hail suppression. Properly drafted legislation or administrative rules require applicants to supply sufficient information for a competent agency staff to judge whether the project is soundly conceived (Davis, 1976a). Appropriate conditions and limitations of seeding timing and methodology can be written into project permits.

*Permits  
to operate  
projects*

The scope of permits can be adjusted to encourage or discourage use of the technology. Also there are sanctions which give: governmental supervision of hail suppression real teeth. Permits can be modified, suspended, and revoked in appropriate situations, and operators with poor records can be denied renewal of permits in future seasons.

The permit mechanism can be used as a means of banning hail suppression. Although there now is some scientific suspicion that seeding supercell storms may sometimes cause negative precipitation consequences (Browning and Foote, 1975), some persons in the Pennsylvania-West Virginia-Maryland tri-state area have long believed that clandestine and illegal hail suppression efforts have exacerbated drought conditions. The current Pennsylvania statute, which has been copied in West Virginia, was enacted in response to anti-hail-suppression public sentiment. The permit system which it sets up, along with other features of the law, makes it so difficult to get permission to seed that hail suppression has ceased in those two states (Davis, 1974b).

*Permit laws  
can ban  
suppression*

Earlier a Pennsylvania township had overtly banned seeding, and Maryland for several years barred all weather modification. The township ordinance was held valid in a criminal case brought against the operator of a ground-based generator (Davis, 1968b).

Information is essential for effective legal controls on hail suppression. Laws permit regulatory agencies to get information by inspection of projects and by requiring seeders to keep records and make reports. There now are 22 states which mandate keeping weather modification records and making periodic reports of the data recorded (Davis, 1976b). The kind and amount of information which must be supplied varies from state to state. Unfortunately data evaluation funding for most state regulatory agencies is very limited.

*Records  
and reports*

The only direct federal regulation of hail suppression is carried out by NOAA under the authority of Public Law 92-205, which authorizes the Department of Commerce to make regulations for reporting nonfederal weather modification activities. Federal agencies have agreed to report their activities also (Charak and DiGiulian, 1974). Although NOAA compiles the information received by it into an annual report, it does not have the funding to make a complete analysis and evaluation of the information.

Some states have avoided the potential duplication of effort inherent in the dual federal-state reporting system by providing that receipt of copies of reports to NOAA will satisfy the state requirement (Texas Water Development Board, 1976; Utah Division of Water Resources, 1974). At the present time, hail suppression reports are *not required to contain evaluation of data*.

 TABLE 29

State regulation of weather modification and receptivity to hail suppression technology

Hail region number	State	Extent of regulation*	Adoption receptivity**	Hail region number	State	Extent of regulation*	Adoption receptivity**	Hail region number	State	Extent of regulation*	Adoption receptivity**
1	Arizona	+2	+1	7	Oklahoma	+3	+3	11	Michigan	+1	+1
	California	+2	+2		Texas	+3	+3	12	Pennsylvania	-1	-1
2	Nevada	+3	+2	8	Minnesota	0	+1		North Carolina	0	+1
	Oregon	+2	+2		Wisconsin	+2	+1		Virginia	0	+1
	Washington	+3	+2	9	Arkansas	0	+1		West Virginia	-1	-1
3	Montana	+3	+2		Illinois	+3	+2	13	Connecticut	0	+1
4	Colorado	+3	0		Indiana	0	+1		Delaware	0	+1
	Idaho	+2	+3		Kentucky	0	+1		Maine	0	+1
	Wyoming	+2	+2		Missouri	0	+1		Maryland	0	+1
5	New Mexico	+2	0		Ohio	0	+1		Massachusetts	+1	+1
	Utah	+3	+3		Tennessee	0	+1		New Hampshire	0	+1
6	North Dakota	+3	+3	10	Alabama	0	+1		New Jersey	0	+1
	South Dakota	+3	+3		Florida	+2	+2		New York	+1	+2
7	Iowa	0	+2		Georgia	0	+1		Rhode Island	0	+1
	Kansas	+3	+3		Louisiana	+3	+2		Vermont	0	+1
	Nebraska	+1	+2		Mississippi	0	+1				
					South Carolina	0	+1				

\*State regulation of hail suppression is expressed in the following numerical values:

- 1 *Ban*. The jurisdiction, in its administration of the law, had so extensively regulated weather modification as to bar use of the technology.
- 0 *No regulation*. The jurisdiction had no case precedent on weather modification by 1975 that was relevant to hail suppression and had no weather modification regulatory statute or administrative rule.
- +1 *Minimal regulation*. There was case precedent in the jurisdiction on weather modification that was relevant to regulation of hail suppression, or by statute or administrative rule, the jurisdiction had adopted at least one of the three following key elements of weather modification regulation:
  - Professional licensing
  - Operational permits
  - Recording and reporting
- +2 *Partial regulation*. The state had adopted two of the above listed three key elements of weather modification regulation.
- +3 *Extensive regulation*. The state had adopted all three of the key regulatory elements.

\*\*State receptivity to adoption of hail suppression technology is expressed in the following numerical values:

- 1 *Ban*. The law, as administered, effectively bans hail suppression.
- 0 *Antipathy*. The legal regime, although its utilization does not ban hail suppression, manifests antipathy in its regulation of the technology.
- +1 *No position*. Either there is no express legal regime dealing with weather modification, or its administration demonstrates an indifference to the technology—neither antipathy nor encouragement.
- +2 *Encouragement*. The regulation of hail suppression is designed to encourage its practice, but there is no recent history of funding of hail suppression by the state government or local governmental entities acting under state weather modification laws.
- +3 *Encouragement and funding*. The regulation of hail suppression is designed to encourage its practice, and there has been a history of governmental funding during the preceding year.

*Numerical summary*

The extent to which the states regulated hail suppression during 1975 is summarized in *Table 29* and expressed in numerical values which were chosen to represent the regulatory positions of the states.

**INDIRECT CONTROLS OF SUPPRESSION**



Among the types of legal norms which apply to control of hail suppression are aviation law and agricultural law. Environmental law, which also applies, is discussed with other environmental considerations in the last section of this chapter.

*Aviation controls*

As indicated in Chapter 4, hail suppression technology extensively uses aircraft as a delivery system for seeding materials. The Federal Aviation Administration (FAA) has rather wide regulatory power over aircraft operations. The Federal Aviation Regulations, which are set forth in Title 14, Chapter 1, of the Code of Federal Regulations, specifically mention weather modification in section

21.25 (b) (5). Cloud seeding is a "special purpose operation" for which an applicant must obtain a "restricted category" certificate. Special purpose equipment would include burners, tanks for carrying seeding material, flares, and racks for carrying flares.

Hail suppression operators currently conduct their operations under Part 91 of the regulations, which deals with general operating and flight rules. The FAA has been cooperative with users of cloud-seeding aircraft. For example, it has given over control of the air space to some weather modifiers in the area of modification operations, except during periods of high priority traffic (*Davis, 1968b*).

*Cooperation  
with seeders*

An argument can be advanced, however, that Part 137 of the Federal Aviation Regulations should apply. It includes operation of an airplane for the purpose of "engaging in dispensing activities directly affecting agriculture." Part 137 on agricultural aircraft operations requires prior approval of the governing body of a "congested area," and prohibits dispensing "any material or substance in a manner that creates a hazard to persons or property on the surface."

Regulation 103 on the transportation of dangerous materials does not apply to hail suppression. Section 103.1 (c) (2) excludes from the restrictions of that regulation "material carried in hoppers or tanks of aircraft certificated for use in aerial seeding, dusting, spraying, fertilizing, crop improvement, or pest control, to be dispensed during such an operation." Aerial seeding resulting in crop improvement is, of course, the purpose of most hail suppression activities.

*Seeding material  
not restricted*

Aviation rules, although their impact on the weather modification industry in the United States is quite similar to their effect upon other industries using aircraft, can be used as a major method of legal control on hail suppression. For example, the Australian Department of Civil Aviation is the single most important regulator of weather modification in that commonwealth (*Davis, 1972*).

There are various federal programs designed for aid, insurance, and relief of agriculturalists which have been created by laws that would interrelate with hail suppression activities.

*Agricultural  
controls*

Federal aid programs are tied to federal regulation of agriculture. The main tools of such regulation are:

- Quotas on production and marketing
- Allocation of acreages and marketing shares
- Parity prices
- Import restrictions and taxes
- Price supports

All of these could be affected by a successful crop-hail suppression program. To the extent such a program increased farm yields and hence supply in excess of demand, all of these tools could be used to protect the producer (*Fletcher, 1975a*).



*Indirect impacts*

Although hail suppression would not be regulated directly, there could be indirect impacts upon it. For example, farm programs might limit acreage planted and consequently reduce the area in need of hail protection. It would be important to determine anticipated production of lands proposed for hail suppression projects when considering acreage allotments.

*Federal 'crop' insurance*

Federal crop insurance legislation sets up a governmental crop-insurance system parallel to that of private industry, as discussed in Chapter 5. Although there are limitations upon coverage, congressional appropriations for operating and administrative costs of FCIC affect premiums and keep this form of insurance an alternative to commercial crop-hail insurance and to hail suppression (Fletcher, 1975b). Should rates be reduced to the point that federal insurance is an attractive alternative to hail suppression protection, this federal program also would indirectly regulate suppression by reducing the demand for it.

*Disaster relief*

In the unlikely event hail suppression activities result in some disaster, such as flooding, federal law makes disaster relief available for state and local governments, other public bodies, businesses, and individual families (Fletcher, 1975c). There also is a federal flood insurance program which can be used in communities which have adopted land use planning for flood-prone areas (Fletcher, 1975d). These assistance programs reduce risks for governments, groups, and individuals who might be adversely affected by hail suppression programs. *They indirectly encourage the use of the technology.*

## **GOVERNMENT FINANCING AS CONTROLS**



Governmental financial support for hail suppression has been an important method for effecting legal control of it. The U.S. Supreme Court has noted that people who do business with the government must "turn square corners." That is to say, they must do business within the terms set by the government.

*Government contracts 'control'*

Through its grants and contracts, a governmental agency can completely control hail suppression it supports. Governmental influence over contractors can extend beyond operations they perform for government agencies. For example, during the time that NSF lost its authority to require reporting (as we noted in Chapter 3), modifiers were requested to continue reporting activities on a voluntary basis so there would be continuity in the records. Most modifiers who voluntarily reported to NSF were holders of federal weather modification contracts (Davis, 1970a).

*Legislation controls money*

To a large extent weather modification research and development has been funded by various federal agencies, and operational programs in several states have been supported by state and local monies. Such governmental expenditures for hail suppression must be based upon legislation. Congress and state legislatures have the power of the purse which they exercise by collecting monies under their taxing powers and dictating expenditures by use of their spending powers. Two kinds of legislation are involved in expending government monies:

- Authorization statutes
- Appropriation laws

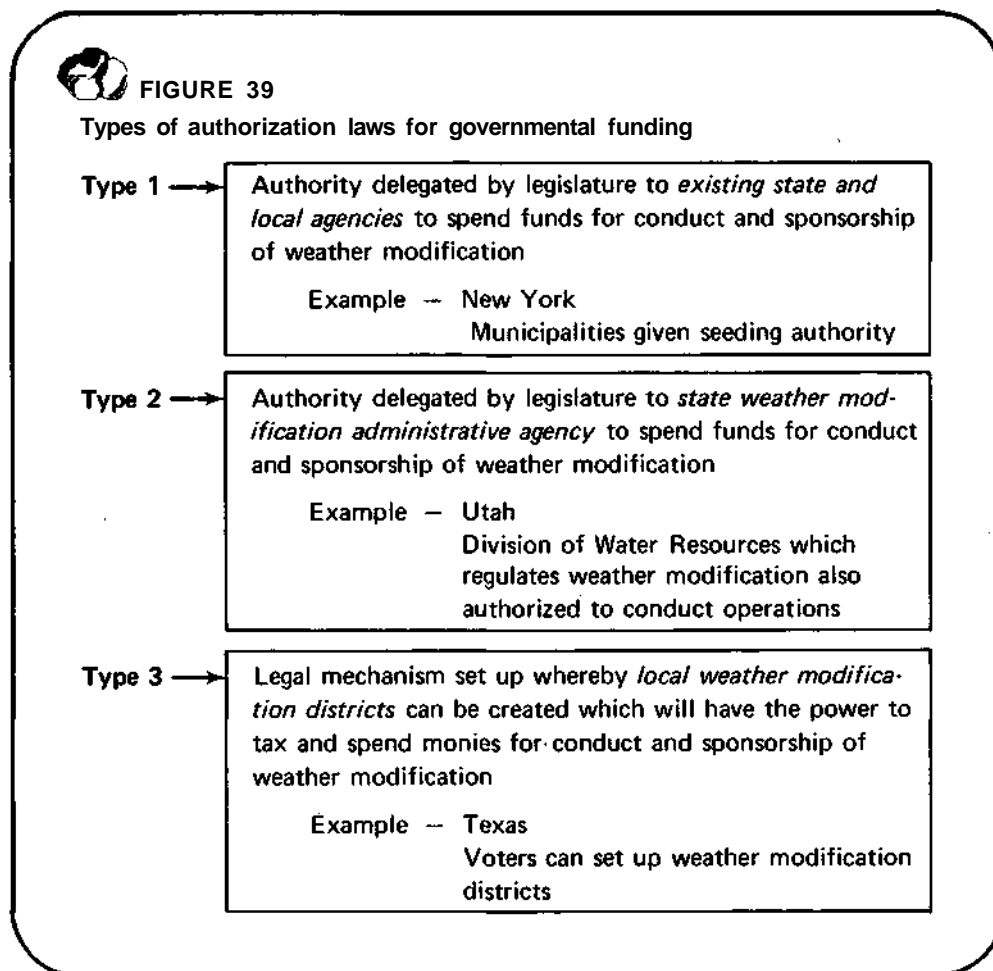
There are 21 states with special legal provisions authorizing use of public funds for weather modification (Davis, 1976b). These funding laws are of three types, as we show in Figure 39.

*Authorization  
statutes*

The first type, giving authority to existing governmental bodies to spend for weather modification, can classify those agencies with respect to the kind of functions they exercise. Thus, in California there is a grant of power to governmental bodies with water resources missions to carry out precipitation enhancement projects (Sato, 1970).

*To various  
existing  
agencies*

Authorization can be given to certain types of bodies, such as the New York grant of weather modification power to municipalities. Or it might expressly limit the delegation of power to named governmental units. In Minnesota only a few counties which are named in the law can act. The enabling grant also can place limits on what might be appropriated and spent. The Minnesota legislation has a \$5000 yearly ceiling (Davis, 1974b).



To the  
modification  
agency

The second type of authorization law gives power to the state agency administering weather modification legislation to spend public funds for conduct or support of weather modification activities. This is narrower in a sense than the first type of law because only one agency is given power, but it is broader in that there is statewide power and normally the authorization law does not limit either the type of weather modification or the amount that may be appropriated for spending.

To special  
modification  
district

The third type, which creates a legal mechanism for setting up special weather modification districts with power to tax and spend, has been used by the tier of states in the High Plains. In most of these states districts have been set up and have carried out hail suppression projects. Nebraska's original law was struck down by the courts in *Summerville v. North Platte Valley Weather Control District* on the grounds that property owners who lived outside the district could not vote on its creation along with those who lived in the district. Nebraska's rewritten law has not been used (*Davis, 1968b*).

Combined  
types

The statewide programs of North and South Dakota involve both the second and third types of authorization laws. The state weather modification divisions have authority to conduct hail suppression operations, and there also is provision for setting up county districts or authorities which can tax and raise money for payment of the county share of the cost of seeding (*South Dakota Department of Natural Resource Development, 1974*).

Appropriation  
laws

Authorization does not carry with it the power to spend money that has not been appropriated. Legal control of legislators over hail suppression is most dramatically manifested by the amount of money either appropriated for that specific purpose or appropriated without restrictions that would bar spending it for hail suppression seeding.

Operation  
not funded

Although the South Dakota authorization laws were not repealed by the 1976 legislative session, failure by the state senate to pass the appropriations bill by the necessary margin killed the operational program (*Donnan et al., 1976*).

The extent to which state laws financially supported hail suppression in 1975 is summarized in *Table 30*, expressed in numerical values which represent the extent of support. These values were utilized in the derivation in Chapter 9 of the legal climate affecting adoption of hail suppression.

## RECEPTIVITY OF LEGAL CONTROLS TO SUPPRESSION



The extent to which the legal regime of each state may be regarded as receptive to adoption of hail suppression technology in 1975 is included in *Table 29*. These numerical values were partly derived from the extent of regulation column of that table. Although these numerical values have not been produced by statistical analysis techniques, neither are they the consequence of omphaloskepsis. They are in part derived from the extent of regulation column of that table. Also the numerical values are partly the product of cogitation, based upon familiarity with

 **TABLE 30**

**State financing provisions for hail suppression**

<i>Extent of support</i>	<i>Number of</i>	<i>states</i>	<i>States</i>
-1 <i>Ban.</i> The state not only failed during 1975 to support hail suppression, but in its administration of the law so extensively regulated weather modification as to bar use of the technology.	2		Pennsylvania, West Virginia
0 <i>No legislation.</i> During 1975, the state had neither a law authorizing use of government funds for support of hail suppression nor an appropriation law was in force.	25		All continental states not named in other categories
+1 <i>State authorization of existing agencies.</i> The law authorized hail suppression activities by existing state or local entities.	10		California, Nevada, Washington, Montana, Colorado, Wyoming, Minnesota, Florida, New Hampshire, New York
+2 <i>State authorization of special agencies.</i> The law provided a means for creation of special weather modification agencies and authorized them to engage in hail suppression, or authorized a state weather modification board to undertake hail operations or research and development.	5		Oregon, Idaho, Iowa, Nebraska, Connecticut
+3 <i>State authorization and funding.</i> The statutes of the state both authorized governmental weather modification and appropriated monies either to carry it out or to prepare for operations during 1976.	6		Utah, North Dakota, South Dakota, Kansas, Oklahoma, Texas

the actual administration of state laws in 1975 (*Davis, 1975a, 1976b*) and represent an informed judgment.

*Tables 29 and 30* deal exclusively with the legal regime in the states, and do not consider either federal recording and reporting requirements in force during 1975, or federal funding of weather modification in 1975. The present direct federal regulation of weather modification, which has only one of the three key regulatory elements, would be coded as 0 if included in *Table 29*. The present federal funding and adoption receptivity would be coded as +3.

Since the advent of scientific weather modification, there has been a flood of proposed federal regulatory and operational legislation (*Johnson, 1970; MacDonald, 1969*). Through failure by Congress to do more than pass the reporting law and appropriations (mostly for research and development), the states have assumed the primary regulatory role (*Davis, 1968a, 1970b, 1975b, 1976b*). Some legislatures have purported to regulate federal weather modification activities in spite of serious question about the constitutionality of efforts by states to regulate the federal government (*Cox, 1975a*).

During the 94th Congress several bills have been introduced which would support weather modification operations, regulate cloud seeding, seek means of

*Federal regulation*

*New bills being considered*

**TABLE 31****Bills related to weather modification (94th Congress)**

<i>Bill number</i>	<i>Date</i>	<i>Sponsor</i>	<i>Purpose</i>
H.R. 2742	February 4, 1975	Sisk	Allow weather modification and data collection in wilderness areas
H.R. 4325	March 5, 1975	Rhodes	Authorize demonstration precipitation management projects under national program
H.R. 10013	October 3, 1975	Hayes	Authorize Secretary of Commerce to establish coordinated national climate program
H.R. 10039	October 6, 1975	Evans	Establish federal regulation over weather modification projects
H.R. 12083	February 25, 1976	English	Authorize Secretary of Agriculture to use federal funds for drought relief seeding
H.R. 13736	May 1976	Mosher	Establish a coordinated national climate program
S. 2705	November 18, 1975	Bellmon	Establish commission to study need for weather modification coordination and regulation
S. 2706	November 18, 1975	Bellmon	Authorize Secretary of Commerce to conduct drought relief experiments
S. 2707	November 18, 1975	Bellmon	Authorize Secretary of Commerce to assist states in drought emergencies
S. 3383	May 5, 1976	Pearson	Authorize Secretary of Commerce to study need for weather modification coordination and regulation
H.R. 14544	June 30, 1976	Brown	Extend for three years authority of Secretary of Commerce to require reporting

reaching a consensus over weather modification goals, and establish a national program related to climate (*Davis, 1976b*). We have listed these proposals in *Table 31*. Three sets of congressional hearings have been held, and S. 3383, which would have the Secretary of Commerce recommend national weather modification goals after appropriate study, has been amended by H. R. 14544, passed, and signed into law on October 13, 1976. It is PL 94-490. Nevertheless, past history indicates that for the present and the immediate future there is not likely to be significant federal regulatory or operational legislation enacted.

**LIABILITY  
THEORIES  
AND ACTIONS**



Litigation before judicial or administrative tribunals is one method in which an aggrieved person or group can play a role in legal control of hail suppression. About half of the lawsuits over weather modification relate to hail suppression.

Several of the hail suppression programs outlined in Chapter 3 have become entangled in litigation. The most frequent charge made in these cases by complainants is that their right to natural precipitation has been interfered with by reduction in rainfall which they believe has been associated with the hail suppression seeding. Cases in which such allegations are made thus involve both an effort to fix liability and a claim of invasion of rights to precipitation.

Some weather modification lawsuits have involved assertions that the seeding increased storm damage, either directly by intensifying hailfall or indirectly by adding to runoff. Liability claims in those situations were premised upon alleged interference with property rights other than the right to the use of water. Liability and rights are different sides of the same coin.

*Basis for liability*

The basis for legal liability in the typical hail suppression lawsuit is diagrammed in *Figure 40*. The plaintiff who seeks to recover damages from the cloud seeder or obtain a court order to require the project to shut down must claim and then prove:

- An act by the defendant which will give rise to responsibility under some legal liability theory
- Harm to some legal right of the plaintiff
- A causal relationship between the act of the defendant and the harm done the plaintiff

Weather modification lawsuits have been brought against both the cloud seeders whose activities were alleged to have caused the harm and the sponsors of the seeding projects. Sponsor liability has been asserted on two alternate theories: either the sponsor exercised control over the seeding activities and hence should be responsible for the harm, or the sponsor did not effectively control cloud seeding that was so dangerous that responsibility for control could not legally be delegated to the seeder (*Prosser, 1971*).

*Act of defendant*

As we show in *Figure 40*, four theories have been advanced by plaintiffs in liability lawsuits. Some cases have involved claims based on all four theories; others have not considered all of them. The liability theories are:

- Trespass
- Negligence
- Abnormally dangerous activity
- Nuisance

In order to win their lawsuits, plaintiffs must prove at least one of these theories. Defendants attempt to rebut plaintiffs' proofs of liability and also may advance some defense for their actions.

The American Law Institute, an organization of judges and lawyers who are experts in their particular fields of law, has undertaken various "restatements" of the principles of the common law. The Institute examines the cases which have established precedents relating to particular principles, and then determines and restates a consensus view of positions taken by American courts. These restatements have been very influential in guiding judges called upon to decide cases in which no precedents from their own jurisdictions bind them. The *Restatement of the Law* deals with trespass and the other legal liability theories (*American Law Institute, 1964*).

*'Trespass' examined*

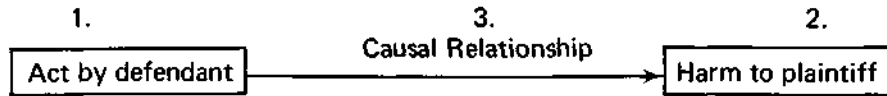
According to section 158 of the *Restatement*, trespass has two elements:

- Entry on land in possession of another
- An intended act



FIGURE 40

Basis for legal liability



Liability Theories

Trespass – intentional harm

1. Physical invasion of real property – entry by aircraft, seeding agent, precipitation, runoff
2. Intent to do act which constitutes the invasion

Negligence – careless harm

1. Defendant's duty to act carefully
2. Breach of duty by defendant – failure to conform to standard of care

Abnormally Dangerous Activity – liability without fault

1. High degree of risk of harm
2. Gravity of harm likely to be great
3. Cannot eliminate risk by reasonable care
4. Activity not a common usage
5. Activity inappropriate to place where carried on
6. Relative value of activity to community

Nuisance

1. Substantial invasion of right to use real property
2. Intentional conduct, negligence, or abnormally dangerous
3. Balance utility of conduct against gravity of harm –
  - a. Social value of purpose of conduct
  - b. Suitability of conduct to community
  - c. Impracticability of preventing or avoiding harm

*Land* includes the atmosphere above the surface (section 159), and *intent* includes conduct which the defendant knows will result in such an entry (section 163, comment c).

Arguments have been made in hail suppression cases that entry of aircraft above the plaintiff's land, dispersal of seeding agents into the atmosphere over the land, and changes in precipitation and runoff (particularly if increases are involved) all constitute trespasses.

Defendants respond that airplane flights carried out in a reasonable fashion in accord with aviation regulations no longer are regarded as trespasses (section 159 b), and that the law of trespass has typically dealt with particles large enough to be seen. Trespass has not been a successful liability theory in hail suppression cases (*Davis, 1968b*).

People have a duty to act carefully with respect to other persons and their property. According to section 282 of the *Restatement*, "negligence is conduct which falls below the standard established by law for the protection of others against unreasonable risk of harm." A professional is under a duty to perform with such care, skill, and diligence as persons in that profession ordinarily exercise (section 299A). Failure to conform to that standard of care is negligence.

*Negligent  
opposite  
of 'careful'*

Claims of negligence have been made in hail suppression litigation, but they have not been proved (*Davis, 1968b*). In order to decide whether professionals have acted with less care than professional standards would require, expert witnesses are called to testify in court (*Sullivan and Roberts, 1975*).

*Claims of  
negligence  
not proved*

Although lay witnesses may be used to establish matters of common knowledge, it usually is appropriate to use expert witnesses to establish standard of care matters in weather modification litigation (*Toll, 1975a*). In the past plaintiffs have been hampered by their inability to muster sufficiently impressive expert witnesses (*Mann, 1968; Morris, 1968*). However weather modifiers and sponsors who have defended lawsuits have generally been able to get persuasive expert witnesses, at least in part because weather modifiers are accepted as expert witnesses. In the future there is the likelihood that plaintiffs will be able to draw from a larger pool of experts, and will be able to prove deviation from professional standards.

It is not necessary to prove fault (either trespass or negligence) in situations involving an abnormally dangerous activity. Section 522 of the *Restatement* lists those factors which are considered in deciding whether an activity is abnormally dangerous, as we have shown in *Figure 40*. These factors concern the nature of the risk, and the kind of locality in which the activity takes place.

*Abnormally  
dangerous  
activity*

Plaintiffs argue that hail suppression involves a high degree of risk of harm, that the gravity of the harm is likely to be great, and that, even with exercise of reasonable care, seeders cannot eliminate the risk.

Seeders answer that neither the risk nor the potential harm from it are great, and that with careful selection of the storm cells to seed and use of appropriate seeding techniques they can reduce (if not completely eliminate) the risk.

Plaintiffs also assert that hail suppression is uncommon, inappropriate to the place where carried on, and of relatively little value as compared with the alleged loss in precipitation. In hail-prone areas the appropriateness of seeding



is obvious, it can be a matter of common usage, and its value to the community can be established by techniques applied to the project area such as those used in Chapter 10 of this volume for national economic analysis (*Cox, 1975b*).

*State laws vary*

In the absence of case precedent which authoritatively determines whether weather modification is an abnormally dangerous activity, several state legislatures have passed laws which answer the issue. In Pennsylvania and West Virginia, it is not necessary to prove fault in order to recover for harm done by weather modification activities. In Illinois, Texas, and North Dakota, statutes declare that weather modification is not an ultrahazardous activity [a term from the first *Restatement* of Torts which is parallel to "abnormally dangerous" in the second *Restatement*] (*Davis, 1974b*).

*Private nuisance*

An alternative method of evading the fault requirement is to establish that the suppression constituted a private nuisance. The law of nuisance involves balancing the harm likely to be caused against the good likely to result, and then determining whether on the balance there has been an unreasonable interference with the plaintiff's right to the use and enjoyment of his property (*Prosser, 1971*).

*Suppression not proved a nuisance*

No court has struck the balance against hail suppression. In *Slutsky v. City of New York*, a precipitation enhancement case, language from the court tends to support the proposition that development of atmospheric water resources on behalf of a municipality does not constitute a nuisance to property owners who might suffer from additional precipitation (*Davis, 1968b*). That, of course, leaves considerable doubt about what some court in some jurisdiction other than New York would do in a hail suppression case when balancing an alleged decrease in precipitation against the diminution of damaging hailfall.

*Defenses to liability*

In the event a plaintiff should be able to establish a liability theory, harm, and a causal linkage, defendants would still be able to escape liability by establishing a defense. In negligence cases the most common defense is contributory negligence by the plaintiff.

*Contributory negligence*

Contributory negligence consists of conduct by the plaintiff that falls below that which a reasonable person would exercise in care of his or her own welfare (*American Law Institute, 1964*). In spite of negligence by the seeder, a lawsuit against him would not prevail — or the recovery of damages would be reduced — if the plaintiff's carelessness was a cause of the harm (*Prosser, 1971*). Contributory negligence is not a very likely defense in most hail suppression cases.

*Consent to the risk*

Consent to the risk involved would constitute a defense. The concept of consent denotes willingness that an invasion of an interest take place (*American Law Institute, 1964*). Farmers who agree to hail suppression activities have consented to them, but they may not be barred from recovery for harm caused by the consequences of those activities. Consent only binds the plaintiff within the scope of the consent given.

A person has a legal privilege to protect his property by appropriate means in particular situations. One privilege is the right of a farmer in some jurisdictions to fend off surface waters as he sees fit without being required to take into account consequences to others who have a right to protect themselves as best they can (*Hernandez, 1975a*). Perhaps there is an analogy between this "common enemy" doctrine and a privilege to use weather modification to stop hail damage to lands and crops.

*Protecting  
property*

Sovereign immunity is another defense. Although many states have abolished the doctrine, there still are those American jurisdictions in which the state and its agencies are immune from liability for losses they negligently cause (*Prosser, 1971*).

*Sovereign  
immunity*

The federal government has, by virtue of the Federal Tort Claims Act, partially waived its sovereign immunity. An important exception to the waiver is any so-called "discretionary function" of the federal government (*Reynolds, 1968*). Case law has held that weather forecasting is within the exception, because it involves daily decisions which include policy and judgment as well as discretion in predicting and disseminating reports about the weather (*Cox, 1975c*). Hail suppression might be treated in a similar vein.

*Forecasting  
still  
immune*

It also has been held that activities at the planning level, as contrasted with the operational level, are within the exception (*Cox, 1975d*). Thus, even if operational activities connected with federal hail suppression are not immune from liability, planning will not give rise to federal liability.

To recover damages for harm or to get a court order banning further cloud seeding, the plaintiff must allege and prove specific injuries which he has suffered. Courts have been reluctant to allow recovery when the only showing is that the plaintiff suffered emotional strain, anxiety, and fear. One of the problems in entering judgments for such intangible injuries is that they are so differently perceived by each individual (*Toll, 1975b*).

*Harm  
must be  
proved*

Courts, however, do enter judgments on behalf of claimants whose persons or property has suffered physical harm. Consequently, if property loss from hail suppression is increased by a suppression effort, the harm is the sort which can be compensated. If rain is adversely increased or decreased by seeding for hail, compensation or issuance of an injunction stopping the project will be ordered if, but only if, the plaintiff is regarded as having a property right in natural weather.

*Property  
loss can be  
compensated*

Even though a landowner might be injured, the expense of litigation might make it impractical to sue. The so-called "class action" is a legal mechanism to join together persons who have been harmed so that they can pool their financial resources. There are, however, numerous technical legal requirements that must be met by persons who seek to institute such a lawsuit. Since World War II the trend generally has been toward reduction of the difficulties with class

*"Class  
action"  
suits*

actions, but in recent years the federal courts seem to have changed their trend, and have rendered decisions which decrease the vitality of the class action concept (*Hernandez, 1975b*).

*Proving  
causation*

Failure to demonstrate the linkage between the conduct of the defendant and the harm to the plaintiff's property has been the major stumbling block in litigation involving hail suppression and other types of cloud seeding.

Only in one case has the plaintiff succeeded in establishing the required causal link. The *Southwest Weather Research* litigation arose in Texas during the 1950s. Because there was conflict in the expert testimony, the judge relied upon evidence by the landowners themselves in order to find the necessary connection between the loss to the complainants and the seeding (*Davis, 1968b*).

In spite of the one Texas case, the usual way to prove causation is through expert testimony (*Toll, 1975c*). Proof that hail suppression can reduce hail and proof that seeding over a season has in fact reduced hail or rain, do not establish legal cause. There must be proof that a particular series of events formed necessary antecedents of the harm — that without the seeding the loss would not have taken place.

Courts have been reluctant to rely upon statistical proof, but in recent years there has been adequate showing that judges will be more receptive in the future to statistical demonstration of cloud seeding effects (*Serra, 1975*).

*Preliminary  
decision  
by board*

A section of the present Colorado weather modification law was added to it to facilitate proof of causation. If a person files a claim for harm caused by weather modification activities, the weather modification advisory board makes a preliminary decision about causation which then can be used as evidence in any court action. Presumably the board is in a better position to make an expert judgment about causation than would a judge or a jury.

*Summary  
of liability  
actions*

There have been 15 major weather modification lawsuits filed. Of the 13 which have been decided, the defendants have won 11. The two they lost included the *Southwest Weather Research* case and the *Fulk* case from Pennsylvania — both of them hail suppression cases. *Fulk* was a criminal prosecution for hail suppression seeding.

There have been five other hail suppression cases. The *Auvil Orchard* case claimed flash flooding from hail suppression, two Colorado cases involved hail suppression permit applications, and in a recent Texas case and a ten-year-old Pennsylvania case unsuccessful claims were made that hail suppression should be enjoined on the grounds it reduced rain.

*Litigation  
control  
ineffective*

It is risky to generalize from so few cases, but thus far liability litigation has not proved to be an effective means of legal control of hail suppression. *Table 32* shows the names, citations, dates, and outcomes of weather modification cases. Given persuasive evidence of injury and causation, it is likely that a court will find liability in future litigation and will employ whatever theory it deems most appropriate under the facts to sustain its decision.

In both Colorado and Texas opponents of hail suppression have been successful in inducing legislators to tighten weather control laws. In Pennsylvania and West Virginia the opposition induced passage of legislation which has had the effect of stopping all weather modification in those states. In Maryland, for a while, there was a statutory ban on weather modification (*Davis, 1976c*).

*Legislative process better than judicial for opposers*



**TABLE 32**

**Weather modification cases**

<i>Case</i>	<i>Outcome</i>
<i>Adams v. California</i> [Yuba City flood case], Civil No. 10112 (Superior Court Sutter County, CA, 1964)	No liability for snowpack enhancement because it did not cause flooding
<i>Auvil Orchard Co. v. Weather Modification, Inc.</i> , Civil No. 19268 (Superior Court Chelan County, WA, 1956)	Temporary restraining order not made permanent because no proof hail prevention caused flash flooding
<i>Atmospherics, Inc. v. Ten Eyck</i> [San Luis Valley permit case], Civil A (District Court Alamosa County, CO, 1973)	Administrative hearing examiner can rely on vote against weather modification in denying hail suppression permit
<i>Lumsden v. Atmospherics, Inc.</i> , No. 7594 (District Court Lamb County, TX, 1974)	Injunction against hail suppression denied because of failure to prove it caused precipitation loss
<i>Lunsford v. U.S.</i> [Rapid City flood case], Civil No. 5031 (U.S. Dist. Court, SD, filed 1975)	Claim alleging flooding caused by seeding with salt — case not yet litigated
<i>Montana Wilderness Association v. Hodel</i> , Civil No. 74-5-GF (U.S. Dist. Court, MT, filed 1974)	Case claiming violation of environmental statutes by grant of permit for snowpack enhancement — not tried because it became moot
<i>Pennsylvania ex rel. Township of Ayr v. Fulk</i> , No. 53 (Common Pleas, Fulton County, PA, 1968)	Upheld constitutionality of ban on cloud seeding in township in case involving criminal conviction
<i>Pennsylvania Natural Weather Association v. Blue Ridge Weather Modification Association</i> , 44 Pennsylvania D. & C. 2d 749 (Common Pleas, Fulton County, PA, 1968)	Court denied injunction against hail suppression because of failure to prove harm
<i>Reinbold v. Summer Farmers, Inc.</i> , No. 2734-C (Circuit Court, Tuscola County, MI, 1974)	Plaintiff failed to prove precipitation enhancement project caused hailstorm losses
<i>Samples v. Irving P. Krick, Inc.</i> , Civil Nos. 6212, 6223, and 6224 (U.S. Dist. Court, OK, 1954)	Plaintiff failed to prove precipitation enhancement project caused flooding
<i>Shawcroft v. Department Natural Resources</i> , Civil A (Dist. Court Alamosa County, CO, 1972)	Unlitigated claim that hail suppression permit applicant would cause decrease in precipitation
<i>Slutsky v. City of New York</i> , 197 Misc. 730, 97 N.Y.S.2d 238 (Supreme Court, 1950)	Failure to prove claim that precipitation enhancement would cause flooding
<i>Southwest Weather Research, Inc. v. Duncan</i> , 319 S.W.2d 940 (Texas Civil Appeals Court, 1958)	Hail suppression enjoined on ground that it caused decrease in precipitation
<i>Summerville v. North Platte Valley Weather Control District</i> , 170 Nebraska 46, 101 N.W.2d 748 (1960)	Formation of weather-control district voided on grounds statute establishing procedure unconstitutional
<i>Weather Engineering Corporation of America v. U.S.</i> No. 343-72 (U.S. Court of Claims, filed 1972)	Weather modification device patent infringement case — not yet decided

The legislative route has been more fruitful for the opposition of hail suppression than the judicial. Costs of lobbying are not inconsequential, but opponents have found it cheaper than suing.

## ALTERED RAINFALL AND WATER RIGHTS



There are two principal legal theories upon which persons asserting a right to the use of surface and underground waters base their claims:

- Riparian rights, followed in eastern states
- The doctrine of prior appropriation, followed in various forms in western states

Atmospheric water rights, which can come in question when allegations are made that seeding for hail suppression has reduced precipitation, have not been subjected to the long statutory, administrative, and judicial interpretations that surface and groundwater rights have. It is quite natural that, in their search for analogies on which to base rules on use of atmospheric water, legal commentators, judges, legislators, and lawyers have looked at the rules on other waters.

### *Riparian rights*

The doctrine of riparian rights bases the legal right to use of water upon ownership of land abutting the stream from which the water is taken. The riparian owner holds the right to use the water along with all other riparians along the watercourse. We have illustrated this in *Figure 41*.

The riparian rights concept would be useful to a landowner asserting a claim against a cloud seeder for atmospheric waters flowing above his lands. The analogy, however, is incomplete in that atmospheric waters do not flow within recognized watercourses. Removal of liquid water through seeding is not equivalent to taking a bucket of water from a stream. There are many factors other than the liquid water content of the atmosphere that influence precipitation (*Davis, 1967*).

### *Prior appropriation*

The doctrine of prior appropriation is a minority view adopted in western states where in pioneer times no one had registered ownership of lands upon which they could base a riparian water rights claim. The first person to divert water and apply it to beneficial use has priority to the water, even though he may not be a riparian and may be downstream of some later diverter. This also is shown on *Figure 41*.

Prior appropriation would be beneficial to the claim of a cloud seeder or sponsor of a project. Under that doctrine their "diversion" of atmospheric waters would give them a prior right. Of course, law designed for the Gold Rush days, when an argument could be made that development depended more upon one user getting all his needs than upon sharing water, could be considered as inappropriate when conservation rather than consumptive use is considered an important factor.

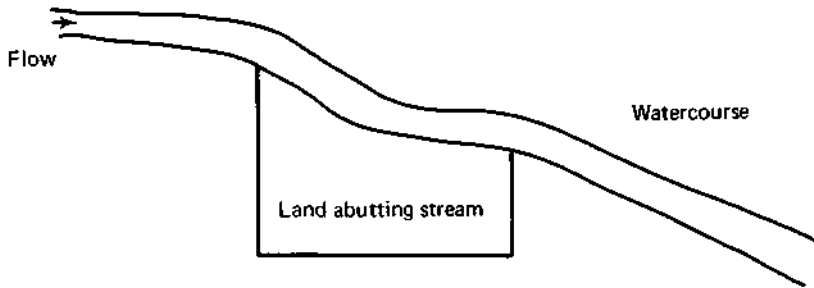
Appropriation states developed a system of registration of water rights which has been taken up in some riparian jurisdictions. Issuance of permits to appropriate water bears a strong parallel with issuance of weather modification operational permits (*Davis, 1967*).



FIGURE 41

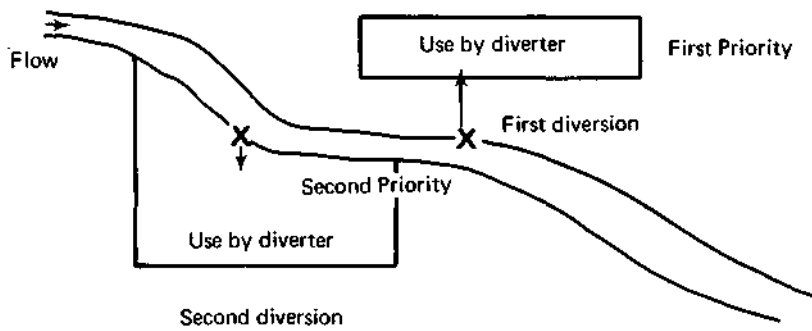
Water rights doctrine

RIPARIAN RIGHTS DOCTRINE



Common rights to use by all riparians

APPROPRIATION DOCTRINE



Priority based on first use — even though downstream

There have been three states in which weather modification cases contain language by the judges indicating the position they adopted with respect to atmospheric water rights. Also there are three states which have statutory provisions concerning water rights. These states, as indicated in *Table 33*, have taken inconsistent positions with each other. To the extent that hail suppression alters precipitation, the issue of water rights is unresolved in most states.

*Water 'rights' unresolved*



**TABLE 33**

**Weather modification and water rights**

<i>Source</i>	<i>Decision</i>
New York <i>Slutsky v. City of New York</i>	Property owners "clearly have no vested property rights in the clouds or the moisture therein"
Texas <i>Southwest Weather Research, Inc. v. Duncan</i>	Landowner has a right to "such precipitation as Nature deigns to bestow . . . to such rainfall as may come from clouds over his own property"
Pennsylvania <i>Pennsylvania Natural Weather Association v. Blue Ridge Weather Modification Association</i>	Although "every landowner has a property right to the clouds and the water in them," that right is subject to "weather modification activities undertaken . . . under . . . governmental authority"
Colorado <i>Colorado Statutes section 151-1-3</i>	"All moisture suspended in the atmosphere which falls or is artificially induced to fall" is "dedicated" to the use of the people in accordance with the prior appropriation principles of the state constitution ( <i>Colorado Legislative Council, 1971</i> )
Utah <i>Utah Code section 73-15-4</i>	Water from cloud seeding "part of Utah's basic water supply" — interpreted as giving rights to senior appropriators to the extent they have filed on the water, and then to junior appropriators ( <i>Fischer, 1976</i> )
North Dakota <i>North Dakota Code section 2-07-01</i>	The law applicable to "natural precipitation shall also apply to precipitation resulting from cloud seeding"

## HAIL SUPPRESSION AND THE ENVIRONMENT



Any effects on the environment are, and will be, a consideration and a constraint for hail suppression. Information about some of the possible ecological problems is limited at this time because such matters have not been monitored in most past hail suppression projects and are expected to be indirect and of long-term evolution. We have obtained relevant information, however, in an attempt to provide insight to future impacts and problems.

In this section we discuss not only the possible impacts but also the legal constraints regarding the environment as they affect hail suppression.

Hail suppression programs could potentially affect the environment in at least three ways. First, a reduction in the amount of hail could directly alter the numbers and vitality of certain species. Second, the nucleating agent used to suppress hail could either directly —or indirectly through chemical changes in soil or water —affect animal and plant growth and populations. Third, to the extent that hail suppression alters the precipitation level in a region, the growth and survival of certain species could be altered.

*Possible  
suppression  
effects \**



Hail suppression, in addition to reducing direct hail damage to agricultural crops and property, would probably reduce damage to some wildlife and perhaps plants. For instance, it has been reported that song-birds and pheasants have sometimes been "decimated" by hailstorms (*Steinhoff, 1975a*).

**ALTERATION  
IN SPECIES  
POPULATION\***

Speaking more generally, Cooper (*1975*) has hypothesized that hail suppression might alter what he terms "ecological succession." His reasoning is as follows:

. . . there may be a possibility that frequent hail acts to hold back ecological succession (in the same sense that periodic fire does). If so, the early successional (or hail tolerant) plants and animals might be replaced by others more strongly competitive but unable to tolerate frequent hail.

The direct effects of the suppression of hail on plant succession could, however, be considered minimal in the crop-growing areas where hail suppression might be used because the crops of economic interest will not be a part of a particular succession.

*Little effect  
on succession  
for crops,  
grasses*

With grass communities, usually predominant in the nation's intensive hail regions, fully established, or climax, communities are only achieved in 20 to 40 years (*Odum, 1971*). Within this time scale, the presence or absence of hail events should have a minimal effect on the final establishment of a community. Also, as grassland ecosystems approach a climax community, a greater portion of plant biomass will be in the below-ground zone, approaching 85 to 90% (*Sims and Singh, 1971*), so that a hailstorm might have a minimum effect —particularly in comparison with herbivore grazing and extended droughts.



The most common nucleating agent used in this country for hail suppression has been silver iodide (AgI). In evaluating the possible ecological effects of use of this type of agent, it is necessary to consider the different delivery methods which can be used, the possible spatial and temporal distribution of this material, the direct effects which imposition might have on ecosystems, and possible longer-term ancillary effects.

**DIRECT  
EFFECTS  
OF NUCLEANT**

For hail suppression, the methods and rate of delivery of the nucleating agent are somewhat different from those used in other weather modification efforts such as winter snowpack augmentation. In seeding of orographic or winter clouds, ground-based seeding generators are usually used, with burn rates of 25

\*These sections contributed by Donald A. Klein.



grams per minute of AgI in acetone (*Dennis and Kriege, 1966*) usually complexed with excess halide (in the forms of sodium iodide, or ammonium iodide). The materials released accumulate in the snowpack, usually in mountainous regions, where the nucleant is trapped in the snowpack until the beginning of snowmelt in spring. When the plants utilize this water which might contain the nucleating agent, it is usually through plant root absorption processes.

*Delivery methods differ*

In contrast, for hail suppression, the usual method for delivering the nucleating agent is through pyrotechnic devices where the AgI is mixed directly with a rocket propellant or explosive composition, without preparation as a halide complex.

*Delivery rate high, area smaller*

Under these conditions, the seeding agent is delivered to selected clouds at shorter-term, much higher rates. Also, the localized nature of convective storms tends to place the nucleating agent on smaller areas leading possibly to higher potential silver concentrations. In addition, most hail suppression work is done during the growing season, so that when the AgI nucleating agent returns to the ground, hopefully in the form of rain instead of hail, it is in contact with plants that are approaching maturity and have larger leaf surfaces for accumulation of the agent.

Thus, the season of use and the nucleant delivery rate will differ markedly between weather modification in winter snowpack augmentation and in hail suppression. Of special interest is the use of a complexing halide, such as iodide, in ground-based generators which might influence the subsequent ecological effects of the silver iodide. There is a body of knowledge available concerning the silver amounts which may be present in seeded versus unseeded precipitation (*Teller and Cameron, 1972; Douglas, 1968*), where up to tenfold higher levels of silver have been observed in seeded storms, in comparison with unseeded storms. This increase in silver count is not as large as it may appear because the background silver count naturally present is minimal.

*Various forms of silver*

Before making predictions of the possible ecological effects of silver iodide-derived nucleating agents on ecosystems, it is necessary to consider some of the physical characteristics of silver in various forms, in relation to the history of silver use in biology and sanitation.

Silver —unlike mercury, lead, and cadmium — is not found consistently in lists of toxic metals, or among the metals which are monitored in ecological studies on metals (*VanLoon et al., 1972; Duce et al., 1972*). However, Wood (*1974*) has placed silver in the group of metals which are considered toxic and relatively accessible, without providing specific documentation.

*Silver most toxic in ionic form*

In addition, silver is usually considered most toxic in the ionic form, a characteristic which has led to the widespread use of silver ion in hygiene and sanitation. The term silver is often used when silver ion is really meant (*Fitzgerald et al., 1952*).

As a secondary impact, this has led nonspecialists to consider and use the known and valuable "toxicity" of silver ion as a point condemning its use as a nucleating agent.

Occasional misinterpretation and quotation out of context have led to many difficulties in explaining and predicting the effects of nucleating agents on impact ecosystems, especially in relation to legal cases (*Chambers et al., 1962, Just and Szniolis, 1936; Fleagle et al., 1974*). The need for information has outstripped the ability of investigators to generate and interpret these data, leading to an information gap that can generate still more misunderstanding by the public.

*Need for  
information  
a problem*

There are a series of general concepts on ecological effects of silver as related to weather modification in general which have become well established in the literature (*Cooper and Jolly, 1970*). These are:

- Silver ion will be the most toxic silver form which may play a part in ecological impact studies
- Silver iodide, due to its low solubility, will have negligible biological effects
- Iodide will have essentially no effects on experimental (test) ecosystems

Much of the interpretation of these statements depends on the time scale within which potential effects are being considered, the ecosystem to which these materials are added, and the secondary ramifications which might be considered.

Although the previous literature indicates that the free silver ion is very toxic for microorganisms, the effects of silver ion, even as massive doses, are not serious for animals, including humans (*Hill and Pillsbury, 1939*). This is due to the ability of the liver to remove much of the added silver from the body, while any remaining will be held by the skin. Humans can tolerate a single ingested dose of 3.0 grams of silver nitrate, while 10.0 grams is reported to be lethal (*Standler and Vonnegut, 1972*).

*Biological  
effects on  
higher  
organisms*

This general lack of lethality is also due to the instability of the methylated form of silver (in comparison with mercury) which tends to hold silver in forms which will not pass the blood-brain barrier. For humans, the general conclusion is that seeding agents will have minimal effects (*Cooper and Jolly, 1970*), although at least one legal suit on weather modification has centered on this point. In reviewing information available, AgI has been used to inhibit microbial growth on the mucous membranes (*Stecher, 1973*). The only effect of long-term AgI use has been argyria (a skin discoloration), which has involved use of 2 to 50 grams of AgI.

*Ingestion  
not serious  
for humans*

However, other studies indicate that there may be points of concern with silver, even when used as silver ion for microbiological control in domestic water supplies. Russian researchers (*Barkhov and El'piner, 1968*) have noted that

*Limited in drinking water*

the silver content of drinking water should be limited, especially electrolytic or ionic silver. Mice and rats were used in these studies, and only with medium-term experiments (30 days) using 15 to 16 milligrams per kilogram (mg/kg) silver treatments were pathohistological changes observed. Silver doses of 0.25 to 0.025 mg/kg could produce changes in immunological capacity, whereas a dose of 0.00025 mg/kg could not. This dose is within the level of 0.05 milligram per liter, the U.S. Public Health Service (USPHS) standard for silver in drinking water (*USPHS, 1962*).

As with most metals, silver has been found to cause stimulation of cellular processes at low levels (*Chappell and Greville, 1954*), and has also been used as a control for parasitic intestinal worms of the aspicularis group (*Dwanczuk and Wichrowska, 1973*). Thus, the toxic properties of silver ion have generally been beneficial.

*Direct inhalation possible*

Another possible route by which the silver-containing compounds can be imposed upon humans is through direct inhalation. The possibility of mobilization of silver from cloud seeding (especially summer hail suppression activities) and subsequent adsorption on dust and power plant particulates could lead to a greater burden of respirable silver. Recent work (*Natusch et al., 1974*) has shown that the content of toxic trace elements (not including silver, which was not studied) is highest in the smallest respirable particles emitted by a power plant. Even the size of silver particles emitted in the process of nucleant production (*Mossop and Tuck-Lee, 1968*) is well within the 1 micrometer size of particles which are adsorbed with 50 to 80% efficiency by the lungs (*Phalen and Morrow, 1973*).

*Does not impair rumen, caecum functions*

Work with animals also has been concerned with the possible effects of nucleating agents on rumen and caecum functions (*Jones and Bailey, 1973*). These studies have shown that the rumen can rapidly detoxify silver ion, and that vitamin production in the rabbit caecum is *not* decreased in the presence of high silver levels. The even lesser activity of silver iodide burn complexes, together with the short residence times of these materials in the rumen, led these researchers to conclude that accumulation of these agents in or on plant materials should not lead to impairment of rumen or caecum functions, or to silver bioconcentration in the animals. Other workers (*Martz et al., 1974*) have confirmed this view and found that greater than 50% of silver ingested with forage is precipitated and physically attached to food particles, where it will not influence digestion processes.

These studies would indicate that oral ingestion may be considered to have a minimal effect on humans or animals. The possible inhalation of these particles should be given greater consideration, especially with the possibility of silver adsorption on dust and power plant emission materials (*Natusch et al., 1974*).

Related studies of possible silver ion and nucleating agent effects on birds, reptiles, and fish are much less complete and subject to many interpretive prob-

lems. Regarding the possible effects of silver on fish, both as adults and as eggs, the available literature does not show any clear-cut danger to fish life in lakes where seeding has taken place. In the laboratory, it is possible to show deleterious effects of silver ion and silver iodide to fish (Goettl *et al.*, 1974). Yet, in natural environments, where similar silver levels have been observed, no effects have been detected (Freeman, 1975).

*No clear-cut danger to fish life*

Generally, with higher organisms, the lesser effects of silver have been due to the relatively transient contact of the imposed metal on the organisms. However, when considering the potential effects of the metal on the soil-plant-micro-organism system, the longer-term presence of the nucleant and its particular chemical characteristics become more important.

*Biological effects on plants, microbes*

The most important point about silver, together with many other metals, is its ability to form complexes with excess halides. Iodide produces a silver compound with an extremely low solubility,  $8.5 \times 10^{-17}$  moles per liter, implying that if excess iodide is present, it will gradually displace chloride and other anions as the major ion binding silver. In addition, the presence of excess iodide in a soil system can lead to increased AgI solubility, especially in nonaqueous solvents (Specker and Pappert, 1965). This can also occur in the presence of other alkali metals and ammonia (St. Amand *et al.*, 1971).

*Thus, the presence or absence of excess halide may be important in predicting the potential localization and effects of silver in the plant-soil system. The final disposition of silver iodide, when it might be added to an ecosystem, would again depend on the type of seeding activity and the season when the agent was being imposed on the ecosystem. For hail suppression work, silver is added at the peak of the crop-growing season, when corn, wheat, or other crops are at the maturing stage. At this point the agent would have the possibility of accumulating on the surfaces of above-ground plant parts.*

*Excess halide a guide*

However, one should always bear in mind that the concentrations of silver iodide are extremely low so that the amounts found in drinking water, inhaled by humans, coming in contact with fish, birds, and reptiles, and entering the plant-soil system are not likely to affect life or health.



When the nucleating agent reaches ground level through precipitation, it may fall on plant, soil, or water surfaces. The interactions that then occur through chemical processes must also be considered and these are labeled as "indirect effects." Note our *Figure 42*.

## **INDIRECT EFFECTS OF NUCLEANT**

Since most hail suppression is carried out in agricultural areas, it is probable that most of the precipitation which does not land on plants will tend to fall on surface soils. Unless sheeting erosion and direct water movement occurs, evidence available to the present time indicates that silver will tend to be held in the surface soil zone (Sokol and Klein, 1975; Swanson *et al.*, 1966). This would be due to the extreme ability of humic materials to retain metals and to the ability of plants to take up silver through the root system, with the subsequent return of these above-ground plant parts to the surface soil during decomposition (Knight, 1975).

*Plant interactions*



FIGURE 42

Deposition of AgI



*Effects on plant growth, flowering*

Various studies have been carried out to evaluate the possible effects of silver compounds on pollen-tube germination and on flowering of plants (*Takimoto and Tanaka, 1973*). In that study the presence of silver ion in soil was noted to promote long-day flowering. In spite of such isolated results, the general indication is that the presence of nucleating agents on the surfaces of plants, at the levels which would be expected under field conditions, should have minimal effect on growth or maturation processes.

As an additional viewpoint on possible ecological effects of nucleating agent accumulation on above-ground plant parts, it has been noted that nucleating agents which are adsorbed to pine needles can be released again, causing secondary nucleation phenomena (*Fish, 1972*). Thus, a longer-term nucleating effect may result from use of these agents and their accumulation at any specific time.

*Soil interactions*

The accumulation of silver from weather modification activities in surface soils, where it will be held predominantly under aerobic conditions, appears to lead to effects upon plant-microorganism relationships, although this does not appear to be entirely negative, if it might occur.

Based on the earlier literature it has been postulated (*Cooper and Jolly, 1970*).

Perhaps the most likely possibility is that adsorbed silver will inhibit the growth of algae, fungi, and bacteria in fresh water. If such an effect does occur, it is most likely to be selective reduction in growth rates of certain organisms than a dramatic lethal response.

In addition, silver will have seasonal variations in its movement in the plant, with 5- to 50-fold lower amounts found in plants in September, by comparison with May (*Horowitz et al., 1974*). This seasonal trend had also been observed in field-soil plants from northeastern Colorado (*Teller and Klein, 1974*).

Although increased silver in soils will result in increased silver uptake by plants, a decreasing relative movement into plants will occur. In laboratory culture, a 10-fold increase in soil silver levels resulted in only a 4.6-fold increase in the plant silver concentration (*Wallace, 1971*). This has also been observed in Colorado field treatment plots where AgI-I complexes were transported to even a lesser extent than silver originally added as silver ions, although the AgI-derived silver was more tightly bound to plant root surfaces (*Klein and Sokol, 1974*).

In general, the field research which has been carried out to the present time where plant growth occurs has supported this postulation. With imposition of AgI on a grassland ecosystem for 2½ years, a gradual trend toward increased soil organic matter in direct relation to the AgI added has been observed (*Klein and Molise, 1975*). This can occur if the organic matter breakdown processes are being slightly inhibited, resulting in more organisms growing at a slower rate. This effect has been observed only with silver imposed at 10 to 100 times the normal soil silver levels. However, with the possibility of plants accumulating silver in the root zone it may be possible for this to occur under field conditions (*Klein and Sokol, 1974*).

*Increased  
soil organic  
matter*

If this type of change were to occur, it could have predominantly beneficial effects upon plant growth processes. If soil organic matter breakdown can be retarded, it can lead to increased soil tilth and water-holding capacity, both vital for continuance of the fertility and plant-growing capability of soils. The loss of soil nutrients for plant use would not seem to be a major factor with the minor amounts of organic matter which might accumulate.

*Benefit  
to plant  
growth*

It is important to note that similar imposition of silver as the free silver ion has not led to equivalent responses of the soil-plant ecosystem. This may be due to the ability of plants (*Jensen and Kavaljian, 1956; Weier, 1938*) and microorganisms (*Summers and Sugarman, 1974*) to reduce ionic silver to metallic silver. A similar reduction of AgI has been described through chemical means (*Gmelin, 1972*) and has been observed by microorganisms in laboratory culture (*Klein and Sokol, 1974*). This has not been detected under field conditions, due to the insensitivity of silver assays which are available.

*Silver ion  
response  
different*

In summary, the current state of knowledge would indicate that on a longer-term basis silver iodide may be able to cause more distinct changes in the function of the soil-plant ecosystem than free silver ion, a result which is essentially the opposite of that which has been postulated from shorter-term laboratory experiments where plant growth processes could not contribute organic matter to the soil compartment (*Weaver and Klarich, 1973*). This again emphasizes the possible role of excess halides in controlling or potentiating silver effects in soil.

If silver enters aquatic ecosystems, either directly in precipitation or indirectly through movement of plant materials or soils, an additional set of possible effects might need to be considered. The literature indicates that silver, along with other metals, will tend to be concentrated in bottom muds (*Freeman, 1975; Cowgill, 1973*). In this anaerobic zone, silver will tend to be trapped in the lake bottom organic matter. Only with aeration, as with turnover of a lake in the spring and fall, would silver tend to be released to the water column (*Segar et al., 1973*).

*Aquatic  
interactions*

Under these conditions, the major process which might be influenced would

*Loss effect  
on anaerobic  
processes*

be that of methanogenesis. Klein and Giangiordano (1976) suggest that silver in various forms may have lesser effects on these anaerobic processes than anaerobic processes in soils and plants, in contrast to earlier postulations. The prior literature (Hosenfeld, 1938a, b) also suggests that metallic silver would have lesser effects than the silver ion under anaerobic conditions. This may be due to formation of metal sulfides which are markedly less soluble than silver iodide which can lead to detoxification of silver.

In this context Cooper and Jolly (1970) also suggested that methanogenesis in sewage treatment would not be adversely affected, due to the short-term contact of the metal with microorganisms in this open system.

Generally, muds in aquatic systems will have 1000 times more silver than the water above these areas (Freeman, 1975; Cowgill, 1973). The anaerobic zone is the area where mercury has been found to be transformed microbially to methyl mercury which can be bioconcentrated leading to major toxicological problems (Saha, 1972). However, the instability of the corresponding methyl silver compounds precludes a similar fate for silver.

*Effects from  
combined  
metals  
possible*

Of perhaps greater interest in aquatic ecosystems is the possibility of synergistic relationships which might occur between silver and other metals. In both freshwater and saltwater systems (Skei et al., 1972) strong correlations have been observed between silver and copper levels, which could indicate a potential for ecological effects of these metals in combination, which has been observed with algae (Young and Lisk, 1972).

Although a great amount of work has been completed on the possible effects of silver ion on aquatic and marine organisms, where median lethal levels of 0.019 to 0.025 milligram per liter typically have been observed (Nelson, 1970; Coleman and Cearley, 1974), these do not provide information on the effects of silver complexed halides, metallic silver, or combinations of metals which would more likely be present in these ecosystems.

*Problems in  
monitoring*

Research to date (Klein et al., 1975) has not shown significant increases in silver concentrations in soils on weather modification target areas, in spite of known increased silver precipitation from seeded versus unseeded storms. The major cause of this problem is the difficulty of sampling of a soil-plant-water system on a representative basis with seasonal silver movement in plants, soil, and water occurring. Even if sampling would be carried out at similar chronological periods, the climatological variations in any community would make it difficult to compare results on a year-to-year basis.

The plant root zone may be the point where most effective monitoring of silver imposed on terrestrial ecosystems may be possible.

Another problem is that the analytical techniques presently available do not allow determination of different silver forms at the level of resolution (in the order of parts per billion) required in these types of investigations.



Weather modification, including hail suppression, has been criticized by some groups as running the risk of causing additional, unwanted precipitation — and by others as contributing to drought (*Farhar, 1975*). To the extent that hail suppression significantly either increased or decreased a region's precipitation level, it could have major impacts on the volume of farm production and, therefore, on the prices of agricultural production and the level of farmers' incomes. See Chapter 10 for discussion of the economics of hail suppression.

**CHANGES IN  
PRECIPITATION\***

At this time it is unknown whether hail suppression would normally increase or decrease the amount of rainfall. This uncertainty exists because many factors, including the wide annual variation in precipitation amounts (as much as 50% in some localities) (*Cooper, 1973*), make it difficult to draw conclusive judgments on the basis of scientific evidence. See Chapter 8 for discussion of precipitation changes in the context of various hail suppression models.

The potential environmental effects of changes in the volume of precipitation can be attributed to a general ecological principle. Steinhoff (*1975a*) has expressed this principle as follows:

"Organisms are adapted to their environment and are affected by it. Any change in the environment will result in some corresponding change in the organisms, though the change may (sometimes) be too small to measure and may be unimportant to man."

For this reason, if hail suppression were either to increase or decrease the amount of rainfall significantly, certain ecological-environmental consequences would occur. Some changes would occur because plants and animals, although they can adapt to seasonal variations, are affected by changes in annual mean rainfall (*Steinhoff, 1975a*).

*Plants, animals  
affected by  
rain changes*

Precipitation-sensitive plants would experience moderate shifts in migration, numbers, reproduction rates, growth, and mortality, as would some animals (*Teller, 1972*). Large mammals could change in number, but none would likely become extinct. There would be little effect on most insects. Changes that would occur would be neither sudden nor catastrophic and would probably go unnoticed by the general public for a period of years. However, population shifts in only a few, or even just one, insect species, could be of great consequence.

One certain, and perhaps important, consideration might be complex ecological interactions among pesticide applications, air pollution, and weather modification, especially the accumulation of nucleating agents in ecosystems which are under stress from other factors.

The effects of sizeable shifts in average growing season precipitation on impact ecosystems were estimated from available information and are summarized in *Table 34*. Most biological effects are classed as "none or marginal." Double entries in *Table 34* are used to denote different effects related to major geographical variations in soil and climate.

*Little or no  
biological  
effects*

\*This section contributed by Donald A. Klein and Martin V. Jones.





**TABLE 34**

**Estimated effects of changed precipitation on ecosystems**

	<i>None or marginal</i>	<i>Slight effect</i>	<i>Clear effect</i>
<i>Plant growth processes</i>			
Planting			x
Initial growth			x
Preharvest			x
Harvest			x
Pasture production		x	x
<i>Water cycles</i>			
Runoff			x
Evaporation			x
Water storage		x	
Flood control		x	
Soil erosion		x	
Nutrient leaching	x	x	
<i>Secondary biological effects</i>			
Plant diseases	x	x	
Insect population	x		
Mammals	x		
Birds	x		
Decomposers	x		

A detailed analysis of the potential impacts of additional precipitation which might result from weather modification was prepared for the South Dakota area (*Study Team, 1973*). This study provides an excellent summary of the wide range of potential effects which changed precipitation patterns could potentially have on an impact area.

**LEGAL CONSIDERATIONS\***



The environmental movement in 1975 appears to have lost some of its earlier thrust, but it has produced a legacy of environmental law which, among other things, has left its mark on the legal control of hail suppression. Two types of environmental legal norms are of particular importance:

- Rules and laws requiring disclosure of environmental information
- Legal provisions which have been used to ban cloud seeding or associated weather modification activities on environmental grounds

*Required disclosure*

There are legal provisions which require disclosure of environmental information both prior to hail suppression projects and after performance of cloud seeding activities. Often permit application forms call for preassessment by the applicant of anticipated environmental consequences of the proposed project. This provides state officials with estimated environmental effects which they can consider in deciding whether or not to grant permits (*Davis, 1975c*).

*Environmental impact statement*

The National Environmental Policy Act (NEPA) is the most frequently litigated statute requiring advance disclosure of environmental information (*Anderson, 1973*). NEPA section 102(C) requires federal agencies to file "detailed statements" providing the information set forth in *Figure 43* whenever they propose any "major Federal actions significantly affecting the quality of the human environment." The act does not cover projects funded solely by states, local agencies, or nongovernmental groups. It does, however, cover a federal project like NHRE for which an impact statement has been filed. It also would require filing by a federal agency doing business in a corporate form which might undertake an operational hail suppression project.

There are three steps in preparation of an environmental impact statement. First, a draft statement is prepared which covers those items in *Figure 43*. The data

\*This section contributed by Ray Jay Davis.



**FIGURE 43**

**Contents of federal environmental impact statement**

1. The *environmental impact* of the proposed action
2. Any *adverse environmental effects* which cannot be avoided should the proposal be implemented
3. *Alternatives* to the proposed action
4. The relationship between *local short-term uses* of man's environment and the maintenance and enhancement of *long-term productivity*
5. Any irreversible and irretrievable *commitments of resources* which would be involved in the proposed action should it be implemented

upon which the draft is based may come from prior environmental literature such as that just noted in this chapter, from studies prepared for the particular project (*Steinhoff, 1975b*), and from other environmental reviews and assessments (*Weisbecker, 1974*).

*Preparing  
impact  
statement*

Second, the draft impact statement is circulated among interested state and federal agencies, and to concerned groups and persons. Public hearings may be held, and indeed should be conducted whenever a project is likely to be controversial (*Black, 1975*). The third step involves preparation of a final statement, incorporating information from the draft statement and the comments and hearings, which is filed with the Council on Environmental Quality.

The states have followed the lead of Congress in passage of environmental impact reporting legislation (*Hagman, 1974*). About a third of them, many of which also control weather modification, have passed such statutes (*Davis, 1974c*).

*States  
'follow'  
Congress*

Disclosure of environmental information subsequent to hail suppression activities is now required by the reporting rules of the Department of Commerce. They request cloud seeders to disclose whether they have filed impact statements and, if so, to supply copies to NOAA. Other questions asked in the report form are:

- Have provisions been made to acquire the latest forecasts, advisories, and warnings? If so, they should be specified.
- Have any safety procedures and environmental guidelines been included in operational plans? If so, descriptions of them should be furnished (*Charak, 1975*).

*Regulation  
by adverse  
publicity*

If a report to NOAA indicates potentially harmful environmental consequences, the operator and responsible state officials will be notified and appropriate recommendations will be made when deemed necessary (*Charak, 1975*). Such regulation by adverse publicity can be most effective (*Galhorn, 1973*).

A few of the state laws also require reporting environmental information (*Davis, 1974d*).

*Some laws  
'ban'  
seeding*

The Wilderness Act of 1964 and subsequent laws setting up specific wilderness areas have created a system in which lands have been legislatively designated to be preserved and protected in their natural condition. Questions have arisen whether weather modification and collection of hydrometeorological data in wilderness areas result in unnatural conditions incompatible with the intent of Congress.

Most of the controversy has been over artificial augmentation of snowfall. The plaintiffs in *Montana Wilderness Association v. Hodel* argued that cloud seeding which was intended to increase the snowpack in a wilderness area violated the act. Also some units of the National Park Service (NPS) and the National Forest Service (NFS) have asserted that artificial snowpack efforts result in unnatural conditions incompatible with congressional intent, and they restrict installation and monitoring of hydrometeorological data collection equipment in wilderness areas.

*Outcome  
uncertain*

The Bureau of Reclamation has taken the position that the effects of cloud seeding "are not manifested as an observable artificiality in wilderness character and that the Wilderness Act was not intended to, and does not, prohibit weather modification" (*Division of Atmospheric Water Resources Management, 1974*). The case filed in Montana never came to trial, and proposed legislation which would permit collection of hydrometeorological data, under certain conditions, in wilderness areas has not been passed (*Davis, 1974b*). Which interpretation of the Wilderness Act will prevail remains uncertain.

In view of the wide discretion given agencies having jurisdiction over the wilderness system, it appears that they could ban such seeding activities (*Sterns, 1975a*).

Unlike artificial augmentation of snowfall, most hail suppression seeding and monitoring does not take place in or near wilderness areas. However, with the gradual expansion of the wilderness system by congressional action and potential increases in the areas serviced by hail suppression projects, the conflict could involve suppression activities.

Another area of conflict concerning snowpack augmentation has been the insistence of some forest service officials that weather modification activities in national forest lands cannot be carried on without issuance by the NFS of special use permits. Since national forest lands encompass many times the acreage of wilderness areas and include land which would likely be involved in hail suppression activities, this dispute could well result in forest service officials banning hail suppression by refusing a special use permit.

*Forest  
service  
permits*

On the basis of various federal laws and regulations concerning the national forest lands, they may well be entitled to deny such permits (*Sterns, 1975b*). It has been argued, however, that weather modification is not the sort of nonconforming use of forest lands that requires issuance of a special use permit.

*Issue  
undecided*

Several versions of a Toxic Substances Control Bill were introduced in Congress during 1975 and 1976. S. 3149, the bill which became the vehicle for passage in 1976 of control legislation, delegated authority to the Environmental Protection Agency (EPA) to test new chemicals coming on the market, make premarket notification in the *Federal Register*, and by rule regulate their manufacture, processing, or distribution. The original Senate bill and earlier House versions would have provided for regulatory action, which could include banning the chemical, when a substance could "cause or contribute to" an unreasonable risk. The statutory language which was enacted changes this to "cause or significantly contribute to" an unreasonable risk.

*Toxic  
substance  
proposals*

Although the environmental risk of AgI, as noted earlier in this chapter, is small enough that new compounds of it coming on the market might not come within the scope of any of the versions of the Toxic Substances Control Bill, EPA regulation is less likely when it must be found that the substance would "significantly contribute to" an unreasonable risk than should a law be passed that merely requires a contribution to such a risk. Passage of the bill in any of the likely forms would, however, create an additional hurdle for use of any new seeding substance for hail suppression purposes.

*AgI may  
not be  
affected*

Ackermann, W. C., S. A. Changnon, and R. J. Davis

1974 *The new weather modification law for Illinois.* Bulletin American Meteorological Society, 55,745-750.

American Law Institute

1964 *Restatement of the law, torts: Second.* American Law Institute Publishers, St. Paul, Minnesota.

Anderson, F. R.

1973 *NEPA in the courts: A legal analysis of the national environmental policy act.* Johns Hopkins University Press, Baltimore, Maryland.

Barkov, G. D., and L. I. El'piner

1968 *The need for limiting the silver content of drinking water.* Hygiene and Sanitation, 33,16-21.

## REFERENCES

- Black, P.  
1975 *Environmental impact statements in planning water and related land resources.* Water Resources Bulletin, 11, 881-886.
- Bohland, J.  
1974 *Social attitudes and perceptions.* Unpublished manuscript, Department of Geography, University of Oklahoma, Norman, June.
- Breitel, C.  
1965 *The lawmakers.* Association of the Bar of the City of New York, New York.
- Browning, K. A., and G. B. Foote  
1975 *Airflow and hail growth in supercell storms and some implications for weather modification.* NCAR, Boulder, NHRE technical report 75/1.
- Chambers, C. W., C. M. Proctor, and P. W. Kabler  
1962 *Bactericidal effect of low concentrations of silver.* Journal American Water Works Association, 54, 208-216.
- Changnon, S. A., and G. M. Morgan  
1976 *Design of an experiment to suppress hail in Illinois.* Illinois State Water Survey, Urbana, Bulletin 61.
- Chappell, J. B., and G. D. Greville  
1954 *Effect of silver ions on mitochondrial adenosine triphosphatase.* Nature, 174, 930.
- Charak, M. T.  
1975 *Weather modification activity reports: Calendar year 1974.* National Oceanic and Atmospheric Administration, Office of Environmental Monitoring and Prediction, Rockville, Maryland.
- Charak, M. T., and M. DiGiulian  
1974 *Weather modification activity reports: November 1, 1972, to December 31, 1973.* National Oceanic and Atmospheric Administration, Office of Environmental Monitoring and Prediction, Rockville, Maryland.
- Coleman, R. L., and J. E. Cearley  
1974 *Silver toxicity and accumulation in largemouth bass and bluegill.* Bulletin Environmental Contamination Toxicology, 12, 53.
- Colorado Legislative Council  
1971 *Controlling weather modification activities.* Denver, Colorado, Research publication 174.
- Comparative Study Data  
1975 *Comparative study of public support of and resistance to weather modification projects.* J. E. Haas and B. C. Farhar, Co-principal investigators, Institute of Behavioral Science, University of Colorado, Boulder, and Human Ecology Research Services, Inc., Boulder.
- Cooper, C. F.  
1973 *Ecological opportunities and problems of weather and climate modification.* In *Modifying the Weather, a Social Assessment*, edited by W. R. D. Sewell, University of Victoria, British Columbia, Canada.  
1975 *Personal communication.* San Diego State University, San Diego, California.
- Cooper, C. F., and W. C. Jolly  
1970 *Ecological effects of silver iodide and other weather modification agents: A review.* Water Resources Research, 6(1), 88-98.
- Cowgill, U. M.  
1973 *Biogeochemical cycles for the chemical elements in Nymphaea odorata ait. and the aphid Rhopalosiphum nymphaeae (L.) living in Linsley Pond.* Science of the Total Environment, 2, 259-303.

- Cox, S.
- 1975a *State power over federal activities.* Illinois State Water Survey, Urbana, TASH working paper.
  - 1975b *Application of strict liability to suppression of hail.* Illinois State Water Survey, Urbana, TASH working paper.
  - 1975c *Weather forecasting as a discretionary function.* Illinois State Water Survey, Urbana, TASH working paper.
  - 1975d *The planning vs. operational level test of federal liability.* Illinois State Water Survey, Urbana, TASH working paper.
- Davis, R.J.
- 1967 *New wine in old bottles: Weather modification legal analogies.* In *Man and the Quality of His Environment: Western Resources Conference*, University of Colorado Press, Boulder.
  - 1968a *Legal guidelines for atmospheric water resources management.* Submitted to Bureau of Reclamation, Weather Modification Law Project Staff, College of Law, University of Arizona, Tucson, Report.
  - 1968b *The legal implications of atmospheric water resources development and management.* Submitted to Bureau of Reclamation, Weather Modification Law Project Staff, College of Law, University of Arizona, Tucson, Final report.
  - 1970a *State regulation of weather modification.* *Arizona Law Review*, 12, 35-69.
  - 1970b *The legislative process and assessment of technological developments in weather modification.* Paper presented at Second National Conference on Weather Modification, April Meeting, Santa Barbara, California, Preprint, p. 303.
  - 1972 *The law of precipitation enhancement in Victoria.* *Land & Water Law Review*, 7, 1-30.
  - 1974a *Legal background and problems.* Conference on weather modification in the United States: Potential and Problems for Interstate Action, Sioux Falls, South Dakota, June.
  - 1974b *Weather modification law developments.* *Oklahoma Law Review*, 27, 409-439.
  - 1974c *Report on environmental impact statements.* Conference on Weather Modification in the United States: Potential and Problems for Interstate Action, Sioux Falls, South Dakota, June.
  - 1974d *Trends in weather modification legislation.* *Journal Weather Modification*, 6, 17-27.
  - 1975a *Description of components of hail suppression legal regime.* Illinois State Water Survey, Urbana, TASH working paper.
  - 1975b *Uniformity among weather modification laws.* ASCE National Convention, November Meeting, Denver, Colorado, Preprint 2548.
  - 1975c *Legal response to environmental concerns about weather modification.* *Journal Applied Meteorology*, 14, 681.
  - 1976a *Text and commentary for weather modification law.* Submitted to Office of Water Resources and Technology, Tucson, Arizona, Report A-064-ARIZ.
  - 1976b *The role of the states in control of weather modification.* In *Hydrology and Water Resources in Arizona and the Southwest: Proceedings of the 1975 meetings of the Arizona Section, American Water Works Association and the Hydrology Section, Arizona Academy of Science*, volume 6, Tucson.
  - 1976c *Legal uncertainties of weather modification.* In *Legal and Scientific Uncertainties of Weather Modification*, edited by W. A. Thomas, Duke University Press (In press).

- Dennis, A. S., and D. F. Kriege  
 1966 *Results of ten years of cloud seeding in Santa Clara County, CA.* Journal Applied Meteorology, 5, 684-691.
- Division of Atmospheric Water Resources Management  
 1974 *Position paper on weather modification over wilderness areas and other conservation areas.* Denver, Colorado.
- Donnan, J. A., J. L. Pellet, R. S. Lebland, and L. F. Ritter  
 1976 *The rise and fall of the South Dakota weather modification program.* Journal Weather Modification, 8, 2.
- Douglas, W.J.  
 1968 *Toxic properties of materials used in weather modification.* In Proceedings of the First National Conference on Weather Modification, American Meteorological Society, Boston, 351-360.
- Duce, R. A., J. G. Quinn, C. E. Olney, S. R. Piotrowicz, B. J. Ray, and T. L. Wade  
 1972 *Enrichment of heavy metals and organic compounds in the surface microlayer of Narragansett Bay, Rhode Island.* Science, 176, 161-163.
- Dwanczuk, I., and B. Wichrowska  
 1973 *Effect of silver on the variability of ora of the human intestinal worms ascaris lumbricoides and enterobius vermicularis in swimming pools.* Chemical Abstracts, 80, 128.
- Falk, L. L.  
 1976 *They are changing the weather: Attitudes toward weather modification in North Dakota.* Paper presented to the Annual Meeting of the Midwest Sociological Society, St. Louis, Missouri, April.
- Farhar, B.C.  
 1973 *The relationship of socio-demographic characteristics and attitudes toward weather modification: The South Dakota study 1972.* Journal Weather Modification, 5(1), 261-276.  
 1975 *Weather modification in the United States: A socio-political analysis.* Unpublished doctoral dissertation, University of Colorado, Boulder, 387 pp.
- Farhar, B. C. and J. Mewes  
 1974a *Public response to proposed snowpack augmentation in the Sierra Nevada.* In A Summary of the Initial Public Involvement Meetings, Correspondence and Public Response to a Proposed Research Program for Snow Augmentation in the Sierra Nevada California, Bureau of Reclamation, U.S. Department of the Interior, Washington, D.C.,  
 1974b *Weather modification and public opinion: South Dakota, 1973.* Institute of Behavioral Science, University of Colorado, Boulder, Second interim report.  
 1974c *Weather modification decision-making: State law and public response.* Fourth National Conference on Weather Modification, November Meeting, Ft. Lauderdale, Florida, Preprint, 563 pp.  
 1976 *Social acceptance of weather modification: The emergent South Dakota controversy.* Institute of Behavioral Science, University of Colorado, Boulder, Monograph 23.
- Fischer, W.  
 1976 *Weather modification and the right of capture.* Natural Resources Journal, 8, 639-657.
- Fish, B. R.  
 1972 *Electrical generation of natural aerosols from vegetation.* Science, 175, 1239-1240.

- Fitzgerald, G. N., G. C. Gerloff, and F. Skogy  
 1952 *Studies on chemicals with selective toxicity to blue-green algae.* Sewage and Industrial Wastes, 24, 888-896.
- Fleagle, R. G., J. A. Crutchfield, R. W. Johnson, and M. F. Abdo  
 1974 *Weather modification in the public interest.* University of Washington Press, 88 pp.
- Fletcher, G.  
 1975a *Aid to agriculture.* Illinois State Water Survey, Urbana, TASH working paper.  
 1975b *Disaster relief.* Illinois State Water Survey, Urbana, TASH working paper.  
 1975c *Federal crop insurance.* Illinois State Water Survey, Urbana, TASH working paper.  
 1975d *Flood insurance.* Illinois State Water Survey, Urbana, TASH working paper.
- Freeman, R. A.  
 1975 *Study of the effects of weather modification on Alpine lakes.* Colorado Division of Wildlife, Denver, Project report F-33-R-10, 87 pp.
- Galhorn, E.  
 1973 *Adverse publicity by administrative agencies.* Harvard Law Review, 86, 1380.
- Gellhorn, W.  
 1956 *Individual freedom and governmental restraint.* Louisiana State University Press, Baton Rouge.
- Gmelin, L.  
 1972 *Gmelins Handbuch der Anorganischen Chemie: Silber.* Teil B2; System 61, 8 Auflage, Verlage Chemie, GmbH, Weinheim, Germany.
- Goettl, J. R., Jr., J. R. Sinley, and P. H. Davies  
 1974 *Water pollution studies.* Colorado Division of Wildlife, Denver, Job progress report F-33R-9.
- Haas, J. E.  
 1971 *Applied technology without representation: Some social consequences of planned weather modification.* Paper presented to the Joint Meeting of the American Meteorological Society and the American Institute of Biological Sciences, San Francisco, California.
- Haas, J. E., and S. Krane  
 1973a *Social implications of the national hail research experiment: 1972 final report.* Human Ecology Research Services, Inc., Loveland, Colorado.  
 1973b *Social implications of the national hail research experiment: 1973 final report.* Human Ecology Research Services, Inc., Loveland, Colorado.
- Hagman, D.  
 1974 *NEPA's progeny inhabit the states: Were the genes defective?* Urban Law Journal, 7,3-17.
- Hamilton, R., and J. J. Jewett, III  
 1976 *The administrative procedure and Texas register act: Contested cases and judicial review.* Texas Law Review, 54, 285.
- Heberlein, T. A.  
 1976 *Some observations on alternative mechanisms for public involvement: The hearing, public opinion pool, the workshop and the quasi-experiment.* Natural Resources Journal, 16, 197-212.
- Hernandez, S.  
 1975a *Hail suppression and the common enemy doctrine.* Illinois State Water Survey, Urbana, TASH working paper.



- Hernandez, S. (*continued*)
- 1975b *Hail suppression and federal class action suits*. Illinois State Water Survey, Urbana, TASH working paper.
- Hill, W. R., and D. M. Pillsbury
- 1939 *Agyria, the pharmacology of silver*. Williams and Wilkins Co., Baltimore, 421 pp.
- Horowitz, C. T., H. H. Schock, and L. A. Horovitz-Kisimova
- 1974 *The content of scandium thorium, silver and other trace elements in different plant species*. *Plant and Soil*, 40, 397-403.
- Hosenfeld, M.
- 1938a *Die Oligodynamie in Theorie und Praxis: I*. *Chemiker Zeitung*, 62, 3-5.
- 1938b *Die Oligodynamie in Theorie und Praxis: II*. *Chemiker Zeitung*, 62, 20-22.
- Jensen, W. A., and L. G. Kavaljian
- 1956 *The cytochemical localization of ascobic acid in root tip cells*. *Journal Biophysical Biochemical Cytology*, 2, 87-92.
- Johnson, J. E., and L. Falk
- 1974 *Social attitudes toward weather modification*. In *The Effects of Added Rainfall During the Growing Season in North Dakota*, submitted to the Division of Atmospheric Water Resources Management, Bureau of Reclamation, North Dakota State University, Fargo, Final report, 147-163.
- Johnson, R.
- 1970 *Federal organization for control of weather modification*. *Natural Resources Journal*, 10, 222.
- Jones, A. M., and J. A. Bailey
- 1973 *Effect of silver from cloud seeding on cecal flora of rabbits*. *Water, Air, Soil Pollution*, 3, 353-363.
- Just, J., and A. Szniolis
- 1936 *Germicidal properties of silver in water*. *Journal American Water Works Association*, 28, 492-506.
- Kilpatrick, J. J.
- 1963 *The case for "states' rights."* In *A Nation of States: Essays on the American Federal System*, edited by R. A. Goldwin, Rand McNally and Company, Chicago, 88-105.
- Klein, D. A., and R. A. Giangiardano
- 1976 *Evaluation of potential impacts of silver iodide nucleating agents on aerobic and anaerobic aquatic microbial processes*. Paper presented at International Conference on Weather Modification, August, Boulder.
- Klein, D. A., and E. M. Molise
- 1975 *Ecological ramifications of silver iodide nucleating agent accumulation in a semi-arid grassland environment*. *Journal Applied Meteorology*, 14, 673-680.
- Klein, D. A., and R. A. Sokol
- 1974 *Silver toxicity*. In *The San Juan Ecology Project*, edited by H. L. Teller *et al.*, Colorado State University, Fort Collins, Interim progress report, Sept. 1973-Oct. 1974.
- Klein, D. A., W. D. Striffler, and H. L. Teller
- 1975 *Disposition and environmental impact of silver iodide in the national hail research experiment*. Colorado State University, Fort Collins, Operations report 4, 63 pp.
- Knight, D. H.
- 1975 *The Medicine Bow ecology project*. University of Wyoming, Laramie, USBR contract 14-06-N-7198, p. 337.

- Krane, S.  
1976 *Social implications of the national hail research experiment: A longitudinal study.* Human Ecology Research Services, Inc., Boulder, January.
- Krane, S., and J. E. Haas  
1974 *The public view toward weather modification in Illinois.* Human Ecology Research Services, Inc., Boulder.
- Krane, S., J. E. Haas, and S. A. Changnon  
1975 *The desirability of an experimental weather modification program for central Illinois: A social and political assessment.* Paper presented to the Annual Meeting of the American Meteorological Society, Denver, Colorado.
- Krueger, D. A.  
n. d. *Measurement of attitudes toward weather modification.* Fresno State College Foundation, Fresno, California.
- Lanham, O. B.  
1974 *Attitudes of north central South Dakota residents toward weather modification.* South Dakota State University, Brookings, Pamphlet 127.
- Larson, W. L.  
1973 *Impacts of induced rainfall on the Great Plains of Montana.* Montana Agricultural Experiment Station, Montana State University, Bozeman, Section 6, Research report 42.
- MacDonald, G.  
1969 *Federal weather modification programs.* In *Weather Modification: Science and public policy*, edited by Robert Fleagle, University of Washington, Seattle.
- Mann, D.  
1968 *The Yuba City flood: A case study of weather modification litigation.* Bulletin American Meteorological Society, 49, 690.
- Martz, F. A., P. J. VanSoest, J. R. Vogt, and E. S. Hildebrand  
1974 *Use of elemental tracers and activity analyses of digestion, rate of ingesta flow and food particle tracking studies in cattle.* European Association Animal Production Proceedings 14, 111-114.
- Meade, M.  
1971 *Participative administration: Emerging reality or wishful thinking?* In *Public Administration in a Time of Turbulence*, edited by D. Waldo, Chandler Publishing Company, Scranton, Pennsylvania, 169-187.
- Morris, E. A.  
1968 *Preparation and trial of weather modification litigation.* In *Weather Modification and the Law*, edited by H. Taubenfeld, Oceana Publication, Dobbs Ferry, New York.
- Mossop, S. C., and C. Tuck-Lee  
1968 *The composition and size distribution of aerosols produced by burning solutions of AgI and NaI in acetone.* Journal Applied Meteorology, 7, 234-240.
- National Academy of Sciences  
1966 *Weather and climate modification: Problems and prospects, I.* Committee on Atmospheric Sciences, National Research Council, Washington, D.C.  
1971 *The atmospheric sciences and man's needs: Priorities for the future.* Committee on Atmospheric Sciences, National Research Council, Washington, D.C.  
1973 *Weather and climate modification: Problems and progress.* Committee on Atmospheric Sciences, National Research Council, Washington, D.C.

- Natusch, D. F. S., J. R. Wallace, and C. A. Evans, Jr.  
 1974 *Toxic trace elements: Preferential concentration in respirable particles.* Science, 183,202-204.
- Nelson, D. A.  
 1970 *Inhibition of embryonic development of the hard clam Mercenaria mercenaria by heavy metals.* Bulletin Environmental Contamination Toxicology, 7611(1), 92-97.
- Nie, N. H., and S. Verba  
 1972 *Participation in America: Political democracy and social equality.* Harper and Row, Publishers, New York.
- Odum, E. D.  
 1971 *Fundamentals of ecology.* Third edition, W. B. Saunders, Co., Philadelphia, Pennsylvania, 574 pp.
- Otway, Harry J., Philip D. Pahner, and Joanne Linnerooth  
 1975 *Social values in risk acceptance.* International Institute for Applied Systems Analysis, Vienna, November.
- Passino, Emily M., and John W. Lounsbury  
 1976 *Sex differences in opposition and support for construction of a proposed nuclear power plant.* In *The Behavioral Basis of Design — Book 1: Selected Papers*, edited by Peter Suedfeld and James A. Russell, Stroudsburg, Pa.
- Pfost, D. R.  
 1972 *Alienation, social position, and the response to planned weather modification.* Unpublished doctoral dissertation, Department of Sociology, University of Colorado, Boulder.
- Phalen, R. F., and P. E. Morrow  
 1973 *Experimental inhalation of metallic silver.* Health Physics, 24, 509.
- Prosser, W. L.  
 1971 *The law of torts.* Fourth edition, West Publishing Co., St. Paul, Minnesota.
- Reynolds, O.  
 1968 *The discretionary function exception of the Federal Tort Claims Act.* Georgetown Law Journal, 57, 81.
- Rogers, E. M., and F. F. Shoemaker  
 1971 *Communication of innovations.* Second edition, The Free Press, New York.
- St. Amand, P., W. G. Finnegan, and L. Burkhardt  
 1971 *Understanding of the use of simple and complex ice generated from pyrotechnics and acetone burners.* Journal Weather Modification, 3(1), 31-48.
- Saha, J.G.  
 1972 *Significance of mercury in the environment.* Residue Reviews, 42, 103.
- Sato, S.  
 1970 *The role of local governmental units in weather modification: California.* In *Controlling the Weather: A Study of Law and Regulatory Processes*, edited by H. Taubefeld, Dunellen Co., Inc., New York.
- Sax, J.  
 1970 *The public trust doctrine in natural resource law: Effective judicial intervention.* Michigan Law Review, 68, 471.
- Segar, D. A., J. L. Gilio, and R. E. Pellenberg  
 1973 *Some aspects of the biogeochemical cycles of trace metals in a sub-tropical estuary including ecosystem compartment models.* Symposium Environmental Biogeochemistry, Utah State University, Logan.

- Serra, L.  
 1975 *Potential uses of statistical demonstration of cloud seeding effects in the judicial process.* Paper on file in the College of Law, University of Arizona, Tucson.
- Sims, P. L., and J. S. Singh  
 1971 *Herbage dynamics and net primary production in certain ungrazed and grazed grasslands in North America.* In Preliminary Analysis of Structure and Function in Grasslands, edited by N. R. French, Range Science Department, Colorado State University, Fort Collins, Science series 10.
- Skei, J. M., N. B. Price, and S. E. Calvert  
 1972 *The distribution of heavy metals in sediments of Sorfjord, West Norway.* Water, Air, Soil Pollution, 1,452-461.
- Sokol, R. A., and D. A. Klein  
 1975 *Responses of soils and soil microorganisms to silver iodide weather modification agents.* Journal Environmental Quality, 4(2), 211-214.
- South Dakota Department of Natural Resource Development  
 1974 *The South Dakota weather modification program: Administration, operations, and technology.* Division of Weather Modification, Pierre, South Dakota, Report R-74-2.
- Specker, H., and W. Pappert  
 1965 *Extrahierte Halogenverbindungen von Kupfer, Silber, Gold und Thallium.* Zeitschrift Anorganische Allgemeine Chemie, 341, 287-292.
- Standler, R. B., and B. Vonnegut  
 1972 *Estimated possible toxic effects of AgI cloud seeding.* Manuscript, Department of Physics, New Mexico Institute of Mining and Technology, Socorro.  
 1972 *Estimated possible effects of AgI cloud seeding on human health.* Journal Applied Meteorology, 11(8):1388-1391.
- Stecher, P. G.  
 1973 *Merck index.* 8th Edition, Merck and Company, Rahway, New Jersey, 1713 pp.
- Steinhoff, H. W.  
 1975a *Personal communication.* Cooperative Extension Service, Experiment Station Forest Service, Ft. Collins, Colorado.  
 1975b *Conclusions from the San Juan ecology project.* Special Regional Weather Modification Conference, Augmentation of Winter Orographic Precipitation in the Western United States, Abstracts, San Francisco, California.
- Sterns, P.  
 1975a *Weather modification and the collection of hydrometeorological data in wilderness areas.* Illinois State Water Survey, Urbana, TASH working paper.  
 1975b *Weather modification activities and national forest land use permits.* Illinois State Water Survey, Urbana, TASH working paper.
- Strodtbeck, F. L.  
 1967 *Weather modification as an uncertain innovation.* In Social Science and the Environment, edited by Morris E. Garnsey and James R. Hibbs, University of Colorado Press, Boulder, 103-114.
- Study Team  
 1973 *Effects of additional precipitation on agricultural production, the environment, the economy and human society in South Dakota.* Submitted to U.S. Bureau of Reclamation, Denver, Colorado, by Agriculture Experiment Station, South Dakota State University, Brookings, Final report, 177 pp.


- Sullivan, J. L., and R. J. Roberts  
 1975 *Expert witnesses and environmental litigation.* Journal Air Pollution Control Association, 25, 353.
- Summers, A. O., and L. I. Sugarman  
 1974 *Cell-free mercury (II): Reducing activity in a plasmid-bearing strain of E. coli.* Journal Bacteriology, 119(1), 242-249.
- Swanson, V. E., I. C. Frost, L. F. Rader, Jr., and C. Huffman, Jr.  
 1966 *Metal sorption by northwest Florida bumate.* Geological Survey Research 1966, Chapter 6, U.S. Geological Survey, Reston, Virginia, Professional paper 550, 174-177.
- Takimoto, A., and O. Tanaka  
 1973 *Effects of some SH-inibitors and EDTA on flowering in Lemna perpusilla 6746.* Plant and Cell Physiology, 14, 113-1141.
- Teller, H. L.  
 1972 *Current studies in the ecological effects of weather modification in Colorado.* In American Meteorological Society, Third Conference on Weather Modification, American Meteorological Society, Boston.
- Teller, H. L., and D. R. Cameron  
 1972 *Preliminary studies in the terrestrial disposition of silver from cloud seeding.* Water Resources Bulletin, 8, 715-723.
- Teller, H. L., and D. A. Klein  
 1974 *Disposition and environmental impact of silver iodide in the national hail research experiment.* Colorado State University, Fort Collins, Operations report 3, 128 pp.
- Texas Water Development Board  
 1976 *Rules, regulations and modes of procedure relating to the Texas weather modification act.* Austin.
- Toll, T.  
 1975a *Standard of care and the necessity of expert witnesses.* Illinois State Water Survey, Urbana, TASH working paper.  
 1975b *Harm and recoverability.* Illinois State Water Survey, Urbana, TASH working paper.  
 1975c *Expert testimony: Proving causation.* Illinois State Water Survey, Urbana, TASH working paper.
- U.S. Public Health Service  
 1962 *Drinking water standards.* Title 42, Chapter 1, Part 27, Federal Register, 27, 2152.
- Utah Division of Water Resources  
 1975 *Rules and regulations.* Cloud Seeding Seminar, Salt Lake City.
- VanLoon, J. C., J. Lichwa, D. Rultan, and L. J. Kinrade  
 1972 *The determination of heavy metals in domestic sewage treatment plant wastes.* Water, Air, Soil Pollution, 2, 473-482.
- Velimirovic, Helga  
 1975 *An anthropological view of risk phenomena.* International Institute for Applied Systems Analysis, Vienna, November.
- Wallace, A.  
 1971 *Regulating of the micronutrient status of plants by chelating agents and other factors.* Edward Bros., Inc., Ann Arbor, Michigan, 36-40.

- Warner, K. P.  
1971 *A state of the arts study of public participation in the water resources planning process.* Prepared for the National Water Commission, Washington, D. C.
- Weaver, T. W., III, and D. Klarich  
1973 *Ecological effects of silver iodide in terrestrial ecosystems: A preliminary study.* Montana Agriculture Experimental Station, Bozeman, Research report 42.
- Weier, E.  
1938 *Factors affecting the reduction of silver nitrate by chloroplasts.* American Journal Botany, 25,501-507.
- Weisbecker, L.  
1974 *Impacts of snow enhancement: Technology assessment of winter orographic snowpack augmentation in the upper Colorado River basin.* Compiled for Stanford Research Institute, University of Oklahoma Press, Norman.
- Wood, J. M.  
1974 *Biological cycles for toxic elements in the environment.* Science, 183, 1049-1052.
- Young, R. G., and D. J. Lisk  
1972 *Effect of copper and silver ions on algae.* Journal Water Pollution Control Federation, 44, 1643, 1647.

## SUMMARY OF CHAPTER 6

### SOCIETAL INFLUENCES

*Adoption of hail suppression a collective decision*

 This chapter has examined the socio-political, legal, and environmental settings for hail suppression and the constraints they might offer to the development and adoption of the technology. We observed that the adoption of hail suppression as an innovation is a collective decision, a public decision, requiring a longer time period to reach than individual adoption decisions. Hail suppression was characterized as offering high relative advantages in an economic sense, but its adoption will be slowed by its complexity and the difficulty of observing its effects.

*Citizens concerned about risk of unknown consequences*

From surveys of citizen attitudes toward weather modification technology, we learned that *belief in* the effectiveness of cloud seeding technology is highly associated with favorability toward projects. A significant proportion of respondents in various surveys have expressed concern about the degree of risk of unknown consequences involved in employing an uncertain technology. Researchers believe that this uncertainty about risk is associated with the widespread citizen preference for some form of local decision control over cloud seeding *projects*. Risk-takers prefer to take risks voluntarily, rather than to have them imposed from above or by powerful organizations. We noted that weather modification scientists and officials have indicated a preference to retain decision control over cloud seeding, resulting in a situation of disagreement between public and scientific opinion on who should decide.

*Mechanism for public participation must be developed*

Nevertheless, the trend toward public participation in public decisions of all types is unlikely to reverse itself, and weather modification technology will not be exempt from its influence. Thus, mechanisms for qualitatively sound public participation in reaching decisions about where and when to use hail suppression need to be developed.

*Increased legislative control of hail suppression*

In recent years, increased legislative and administrative activity to regulate weather modification has occurred, and 60% of the states now have weather modification statutes. Under the more complex state laws, hail suppression may not be practiced lawfully unless operators obtain professional licenses and operational permits to conduct projects. The Federal government and some states require reporting of all weather modification activity. A few states provide for public funding of operational projects and their evaluation.

*Judicial control not as effective*

Public control through the judiciary has proven less effective than control through legislation. Plaintiffs in court have generally been unable to establish the causal relationship between harm alleged by them and specific cloud-seeding activity.

*More research on possible environmental impact needed*

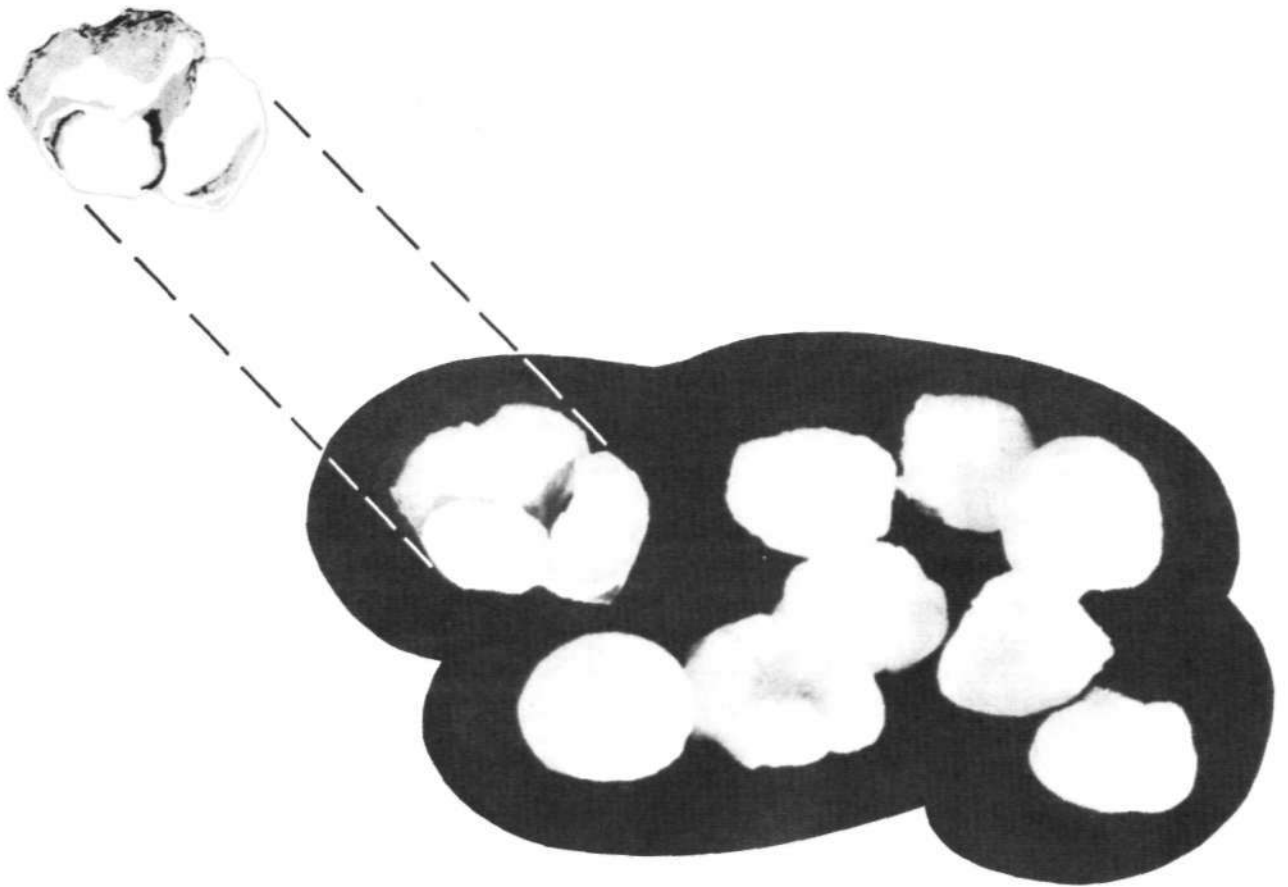
With regard to environmental aspects of hail suppression, our present level of knowledge suggests that serious adverse environmental impacts are unlikely to occur. Concern about ecosystem effects have been expressed in two main areas: 1) the effects of silver iodide on humans, animals, and the ecosystem and 2) the

effects of altered precipitation patterns on ecosystems. While no short-term adverse impacts of cloud seeding have been discovered, more research on the environmental impacts of hail suppression must be conducted, especially concerning long-range impacts, before the possibility of adverse impacts can be ruled out. Downwind effects of projects, both in terms of weather and environmental effects, also require extensive and careful investigation.



# Part 3

## The future of hail suppression



# 7

## Generating forces



The future of hail suppression will be influenced in part by its past — by all of the technological and societal factors that we have reviewed in Part 2. Numerous variables will enter into adoption of the technology of hail suppression in the future — and many of these have been quantified and analyzed by the TASH team in later chapters.

In this chapter we pause to consider what might be the activators in the future for continued or expanded hail suppression — the generating forces superposing adoption variables. We have identified certain national and world concerns — and some peculiarities of our technological nation — that can generate use of hail suppression. While one or all of these large forces might be at work, one other force could be operating — the belief by the individual farmer that suppression of hail is economically beneficial to him.

### FOOD, CLIMATE, AND ECONOMIC INTERACTIVE FORCES\*



There are numerous uncertainties at the local, regional, national, and international levels of economic and political decision making. Economic forces and national policy issues that impinge on those for whom hail suppression is a practical possibility will provide the constraints within which hail suppression must be chosen and evaluated as a suitable technology. Four large "generating forces" exist — or will occur — to affect use of hail suppression — the world food demand, changes in climate, weather extremes, and technology itself.



One key factor influencing the future adoption of production-increasing technologies such as hail suppression will be the worldwide demand for food.

**WORLD  
FOOD  
SUPPLY**

\*These sections contributed by Stanley A. Changnon, Jr., and Dean Mann.

*Famine or  
inadequate  
diet?*

Worldwide food shortages are frequently predicted, but they are highly controversial and refutations are almost as numerous as the predictions (*Meadows et al., 1972; Committee on Resources and Man, 1969; Poleman, 1975*).

The incidence of food shortages and famines depends largely on the variations in climate, although some foresee severe shortages even under the most favorable climatic conditions. Moreover, a severe food shortage presently exists if one looks at the availability of food supplies with reference to an adequate level of consumption and diet. If world opinion were to shift in the direction of establishing a minimum level of nutrition throughout the world, there would already exist a severe food shortage (*Ehrlich and Pirages, 1974*).

The general United States policy toward food is as follows:

- The United States has long had a commitment to be self-sufficient in food; that is, the country has a commitment to feed its people.
- The United States has a traditional commitment to help the rest of the world feed itself by helping to develop the agricultural resources of other countries. This is not a commitment to feed the world, but to help the rest of the world feed itself.
- The United States has an historical commitment to relieve the act of famine here and elsewhere around the world.
- The United States has had occasion to use agricultural exports to improve its *financial* and *political positions* in the world and will continue to do so.

Successful suppression of hail would substantially increase the U.S. supply of food with which to meet both domestic and foreign demand. For example, the crops most severely damaged by hail in the U.S. are wheat, cotton, corn, soybeans, and tobacco. Although about 25% of these crops are usually insured, the amount of food lost to the nation is equivalent to that needed to feed about two million Americans a normal diet for one year. Thus with food shortages a growing problem because of population increases, the nation can ill afford to lose such a large amount of food to hail damage. Also, the profit the farmer could make on an increase in crop yield might make hail suppression a wise investment because, although his loss may be covered by insurance, his premium inevitably reflects the cost to the insurance company. Moreover, increased demand for food produced in the United States, whether expressed through the present market structure or through policies of governments to ensure adequate diets (which would also be expressed in price), might have several ramifications with respect to hail suppression. With higher market prices for farm products, farmers might have a greater inducement to invest in hail suppression technology because of a desire to protect an investment in crops likely to provide substantial dividends, and the cost of hail suppression is low.

*A reason  
to invest*

Simply said, crops having higher value would justify greater and/or extra protection.

One would also have to assume that the increases in prices for farm products would be substantially higher than increases in the costs of hail suppression applications that result from general inflationary trends.

Moreover, farmers are likely — assuming the market price remains high over a considerable period of time — to have disposable income to invest in a practice that may not seem worth the risk when times are more difficult.

*An income  
to invest*

Government policy to increase food supplies might take the form of support for risk insurance or of subsidies for use of hail suppression techniques. Support for risk insurance in the form of reinsurance would reduce the perceived need for hail suppression programs, but the two might well be combined in such a way that reduced insurance rates for protection of crop production against hail might be made dependent on the adoption of hail suppression programs. Costs of current hail suppression (see p. 90) are much less than for hail insurance (see p. 99).

*Support  
for risk  
insurance*

Also, since no major future breakthroughs for food production are seen by agricultural experts, as described in the *New York Times* (McElheny, 1976), hail suppression may rate equally with other potential agricultural technologies capable of small increment production increases. Moreover, in our economic analysis of hail suppression at the national level we projected crop yield increases for 1995 to range from 6 to 37%, depending on the crop (Table 46, p. 263). For example, wheat yields are expected to increase 31% and corn yields by 18%. A comparison of these yield increases with the yield impact of a hail suppression effectiveness, for example, of 50% for wheat in the west north central states, provides a perspective. Hail losses for wheat in this area have been estimated at 4.8% (Boone, 1974), and a 50% effective hail suppression technology would reduce this loss to 2.4%. This represents an increase of approximately 3% over the present yield levels as compared with a projected yield increase of 31% from other technologies. On the other hand, hail losses from corn in this same region are 2.2 %, and a 50% reduction in these losses would represent approximately a 1% increase over present yields as compared to an estimated 18% increase in yield from other technologies.

Associated with food shortages are convulsions of a military and political sort. Such events interrupt the flow of those resources contributing to agricultural productivity (especially petroleum to produce fertilizers) and their occurrence might increase food prices very substantially. There are many who predict such convulsions as the result of conflicts between the "haves" and "have-nots" in the present and future world (Heilbroner, 1975).

*Military  
convulsions  
and food*



The future climate of North America and the world is a subject of considerable speculation, but significant climatic changes may have impacts on agricultural production and thus on related technologies.

**CHANGES  
IN WORLD  
CLIMATE**

Some observers have foreseen a gradual cooling of the earth's climate with increased rainfall (MacDonald, 1975). Increases in precipitation may bring increases in hail and greater hail losses to crops. Very slight reductions in mean temperatures can also have a disastrous effect on areas where agriculture is already marginal because of the short growing season and drought (Newman and Pickett, 1974).

*Gradual  
cooling?*

*Greenhouse effect?*

On the other hand, there are those who perceive a gradual warming effect — a greenhouse effect — resulting from various activities of man, including burning of fossil fuels (*MacDonald, 1975*). Such a general trend would presumably lead to less rainfall in the United States.

*Hail loss 'hurts' in droughts*

In the absence of significant amounts of precipitation, hail suppression might appear a relatively unprofitable enterprise for farmers and government agencies alike, but Lemons (*1942*) showed how hail losses during the droughts of the 1930s were particularly critical from an economic standpoint. Thus, it appears likely that precipitation enhancement for major droughts could include efforts to concurrently suppress hail. There is no evidence of a secular change in precipitation or hail.

*Variability of weather important*

There are those who place more emphasis on *variability* of weather as a factor in grain production than on gradual changes in temperature and rainfall (*Thompson, 1975*). Increased variability of weather since 1971 has been demonstrated (*Changnon, 1975*) — that is, extremes (droughts, floods, heat waves) have been more frequent than in the 1956-1971 period. Such a future increase will affect agricultural production making it less certain from year to year as we apparently return to a variable climate more like that of the 1890-1950 period, even though modern technology has brought more stability.

## **WEATHER EXTREMES**



Short-term variations and extremes of weather without any secular climatic changes can greatly affect possible utilization of hail suppression and insurance. These extremes can be one of two types and they have direct economic impact. This can be labeled the "loss factor," which, from the personal, community, or national standpoint, can be expressed as:

*I (we) turn to hail suppression in stress, largely financial, because I (we) cannot stand the loss.*

*Social incentive to adopt*

The first of the two possible "climatic extreme" factors that affect consideration of hail suppression is the local and/or regional frequencies of hail loss that are sufficient — in magnitude and persistence — to entice local or state groups to consider hail suppression.

*Figures 44 and 45* show how the bad loss years are isolated events in Illinois counties and for that state, conditions typical of the Midwest. However, in the western, higher hail loss states, sequences of two or three (or more) bad-loss years are common, on both the county and state scales. Nationally, the sequences of good and bad years are more evenly distributed.

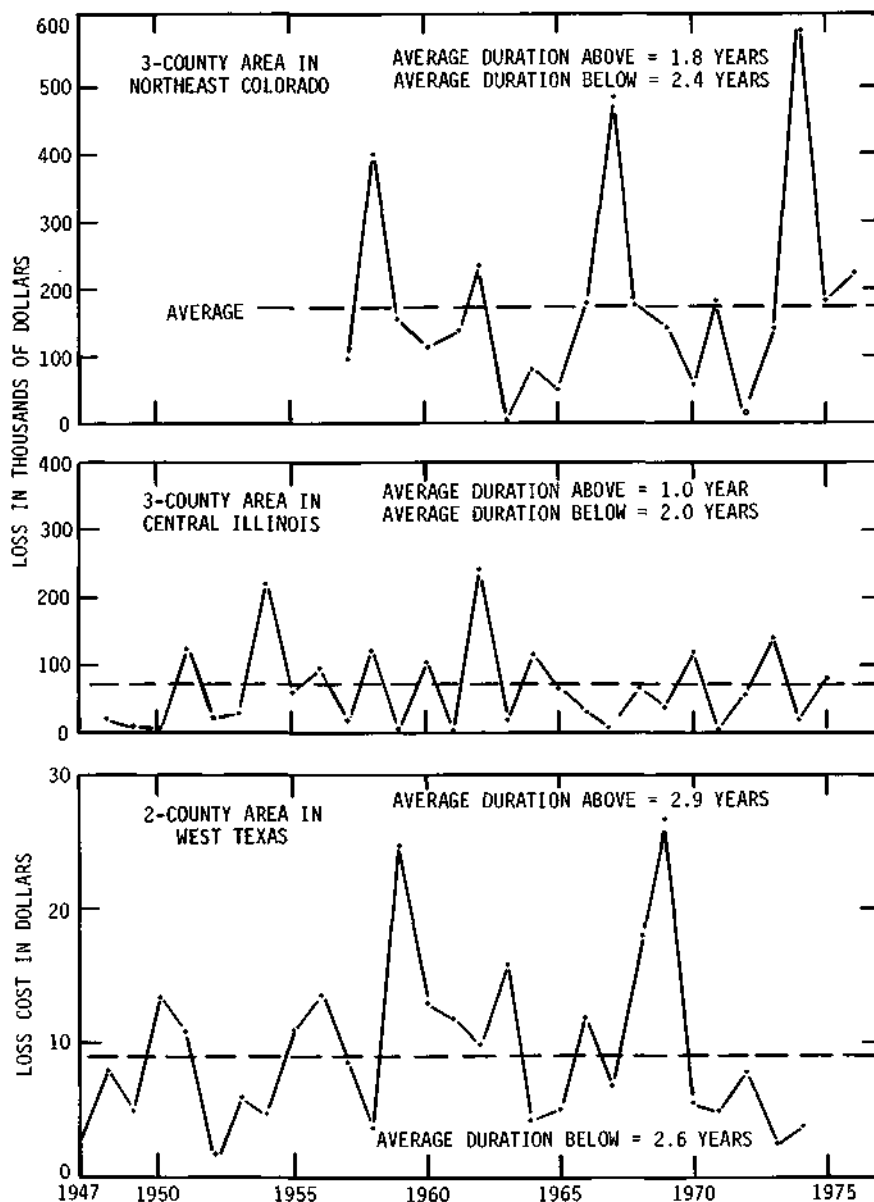
*Similar needs spread use 'nearby'*

If state-scale adoption of hail suppression occurs, another factor involving climatic stress is the "near neighbor" use of the technology which can affect use of hail suppression in an adjacent state or area. The similar stresses and consequent similar needs — plus the ease of acceptance of a technology employed nearby — occur essentially through "geographical conditioning." The widespread adoption of hail suppression in North Dakota following its wide use in South Dakota is an example (see Chapter 3).



FIGURE 44

Persistence of high-loss and low-loss years in small areas



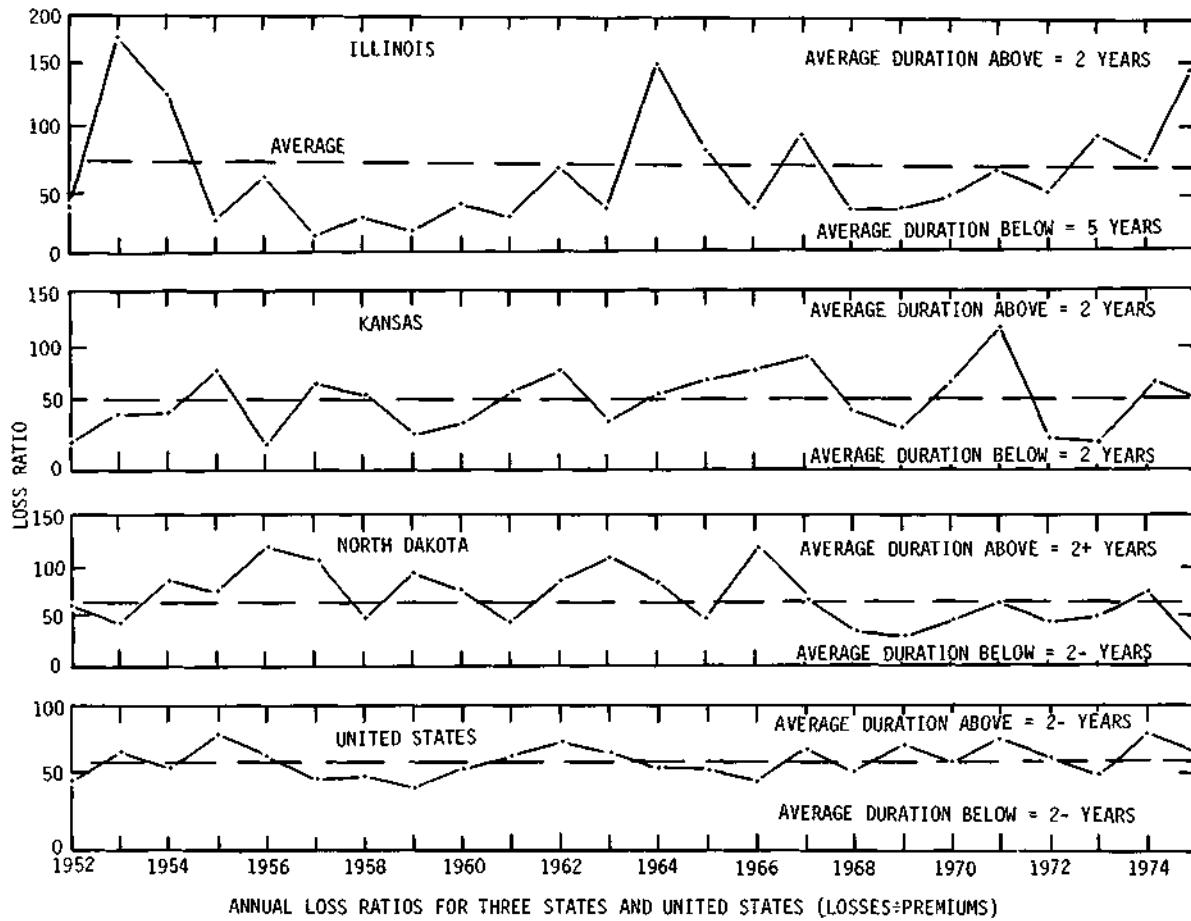
The other climatic extreme involves larger-scale severe stress on agricultural production, such as the national-scale droughts in 1933-1936 or 1952-1955. Such agricultural stress in the future would likely result in sufficient national concern about weather to bring great pressure to use weather modification — as in the severe local droughts in Florida, Texas, and Oklahoma in 1971 (Changnon, 1973). Any national decision to use weather modification would be likely to

*Extreme national droughts*



FIGURE 45

Comparison of persistence of high-loss and low-loss years for various states and the nation



simultaneously include widespread use of hail suppression as part of rainfall modification to minimize large-area losses.

TECHNOLOGY ITSELF



A fourth generating force is not related to the "loss focus" on food demand, weather extremes, or climatic change. This force is rooted in the governmental tendency to continue to develop a technology once that effort has begun. This is best labeled "improving the technology for its own sake."

*Technology improves — then is used*

Such bureaucratic-oriented development generally leads to an improved technology capable of attracting its use for protecting against bad losses or more profits. This "profit motive" is the option by an individual, state, or nation to use the technology for advantage when the technology manages to reach a definable, cost-beneficial level.

Basically, this fourth factor exists because the governmental development of the technology of hail suppression has been happening for ten years and is quite likely to continue with or without "loss" pressures. Such a development of a technology continues because of the great numbers of national priorities, the lack of coherent planning, our national wealth sufficient to allow investment in many technological developments, and the scientific disciplines which progress because of their own advocates. New thrusts into agricultural research along a multitude of avenues will likely help sustain hail suppression research to develop this technology along with a host of others.

*Suppression grows along with other technologies*

Development of a definitive capability in hail suppression will lead to its use by farmers, state-only insurance companies (see p. 96), and others because hail suppression would represent a means to increase and/or to stabilize income, as long as the consequential effects are not greater than its potential for good.

### POTENTIAL FARMER BENEFITS FROM HAIL SUPPRESSION\*



The value of hail suppression to the individual farmer could be a powerful generating force for hail suppression. Because the farmer's incentive seems crucial, a special economic analysis was made to determine the extent to which a farmer might benefit, if at all, from suppression of hail and the regional differences in such economic incentives.



At first glance it might seem that an accurate perception of the individual farmer's concern for hail loss could be gained by estimating the average annual hail loss to crops in a region. But calculation of the annual average effect does not completely depict an individual farmer's concern for hail *as a production risk*. This potential inaccuracy arises because the individual farm operator must be concerned about the distribution of hail losses among years as well as the average loss.

HAIL LOSS ANALYSIS

For example, a 3 or 4% annual average hail loss may be of less concern if those losses occur every year rather than as a 40% loss one year with no loss in other years. (Note the totally destroyed corn field in *Figure 46*.) A large crop loss in one year is particularly damaging for the undercapitalized farming operation which may be forced into partial or total liquidation if cash receipts are insufficient to cover cash expenses in a particular year.

*Average loss versus one big loss*

Because of the year-to-year variability of hail loss for a particular location, hail losses are a type of risk for which insurance may be useful. By taking out insurance, a farmer hopes to substitute a smaller known loss (the premium) for a larger but uncertain loss. Presence of insurance programs for hail losses is a second reason that calculation of average hail loss by itself would not adequately describe the farmer's incentive — or disincentive — to participate in hail suppression programs.

*Insurance useful or not?*

\*These sections contributed by Steven T. Sonka.





FIGURE 46

The farmer's concern — a totally destroyed corn field



To more accurately depict the farmer's economic incentive to favor adoption of hail suppression, a detailed analysis of hail loss as it affects the individual farmer was conducted for specific areas of the nation. Six areas were selected for this analysis. The areas and the type of farming in each are:

*Six farm areas selected*

Northwestern Kansas	Wheat
Southwestern North Dakota	Wheat
North-central Iowa	Corn and Soybeans
East-central Illinois	Corn and Soybeans
West-central Texas	Cotton
Central North Carolina	Tobacco

The crops represented in these six areas are crops for which hail losses are significantly large — either because the crop is particularly susceptible to hail or because very large quantities of the crop are grown.

The particular areas chosen are representative of larger regions which produce major portions of the national production of these crops. In addition, these are representative of most areas having histories of significant hail loss levels. The higher frequencies of hail days in these areas are shown in *Figure 4*, Chapter 2.

*Represent large regions*

To account for the year-to-year variability of hailstorms, this individual farmer analysis considered both the *average income* and the *variability of income* for various strategies the farmer can adopt. Three major types of hail-related strategies were considered, though several specific actions may be associated with each type.

*Types of strategies*

- *Self Insurance.* The farmer chooses not to purchase any insurance against fluctuations in crop production levels. In addition, no hail suppression programs are in operation.
- *Insurance.* Both commercial hail insurance and federal all-risk crop insurance are available in most, but not all, areas.

Commercial hail insurance strategies include options to insure the total value of the crop or to insure only the cost of production. Also, 30, 40, and 50% deductible policies are considered in the Kansas and North Dakota regions. Hail insurance strategies result in payments to the farmer only if crop losses are due to hail damage.

Federal all-risk insurance results in payments to the farmer for crop losses due to a range of natural hazards. Hail loss is one of these hazards but certainly not the only eligible hazard. Commercial hail insurance and federal all-risk insurance can be taken out simultaneously and this possibility is also considered.

- *Hail Suppression.* The hail suppression effectiveness levels presented here bracket the levels that are set in the scientific models of Chapter 8, but all relate to a 1975 situation. Three levels of reduction in crop damage due to hail are considered — 20, 50, and 80%. In addition, three levels of rainfall variation are associated with each level of crop damage reduction — a 10% reduction, no change, and a 10% increase in rainfall during the hail season.

*Consider rain variations at each hail level*

For all the strategies considered, disaster provisions of the 1973 Agricultural and Consumer Protection Act providing for the Commodity Credit Corporation's direct-payment program (see page 100) are assumed to be in effect. There are no direct costs to the farmer for participating in this program.

*Net income estimates for strategies*

Historic yield variability coefficients and present-day agricultural technology were used to create net income estimates for each strategy from the perspective of a farmer contemplating his next season production decision. Each potential strategy has a specific net income (NI) equation associated with it. For each area, the most general of these yearly income statements would be that shown in *Figure 47*.

## ESTIMATION RESULTS FOR SIX AREAS



For each of the several strategies considered, the previously described process generated a net income estimate for each year of the simulation series. These estimates were then averaged, as we show in *Table 35*, and an estimate of yearly income variability was determined for each strategy. *Table 36* presents the coefficient of variation for the six areas considered. For each area only the more attractive strategies are presented.

*Kansas — wheat*

We discuss first the estimation results for the northwestern Kansas area. To obtain the most accurate view of the impact of hail on yearly income fluctuation, township hail-loss data were used. The specific township chosen in this area of Kansas was township 135 south, 29 west in Gove County. For the entire 49-year simulation period, yearly hail loss averaged 12% of the wheat crop in this township.

The average net income for this area is \$25.58 per acre for Strategy A (*Table 35*). This situation assumes that the farmer does not insure the wheat crop and no hail suppression program is in effect. The standard deviation of this net income series, a measure of the pure variability of income, was \$29.92 per acre. To compare strategies where both the average income and the standard deviation of income change, the coefficient of variation was used. The coefficient of variation is defined as the standard deviation of income divided by the average income multiplied by 100 (a lower value for the coefficient of variation implies greater income certainty than does a higher value). For strategy A, the coefficient of variation is 117 (*Table 36*).

One would not expect the purchase of hail insurance to increase average income. Thus, the very slight increases noted for Strategies C and E should not be given a great deal of emphasis. Hail insurance rates for each township are a function of both that township's loss experience and the loss experience of a nine-township area including the specific area (*Fosse, 1975*). Because the township selected for each area was chosen to be susceptible to hail loss relative to the rest of its county, inclusion of the nine-township factor in the rate formula may explain the slightly increased net incomes in Strategies C and E. Use of township data, therefore, may slightly overstate the attractiveness of hail insurance.

**FIGURE 47****General net income equation**

$$NI_i^t = (AP \cdot Y_i^t \cdot TS) + P_{HI}^t + P_{AR}^t + P_{DP}^t - PC - C_{HI} - C_{AR} - C_{HS}$$

where

$t$  = year of the simulation series

[Because of data limitations in some states, the time series used in this study ranged from 20 to 49 years; the data base used was 1925 to 1972 in North Carolina, 1954 to 1973 in Iowa, 1953 to 1974 in Texas, 1926 to 1974 in North Dakota and Kansas, and 1948 to 1974 in Illinois.]

$NI_i^t$  = net income to a crop-share tenant in the  $t$ th year for the  $i$ th strategy

$AP$  = 1972-1974 average price for the commodity produced at a major market appropriate for each area, i.e., Kansas City for the northwestern Kansas area (*U.S. Department of Agriculture, 1974*)

$Y_i^t$  = estimated yield for the  $t$ th year given 1973 technology and the  $i$ th strategy (this estimate varies by nonhail related yield fluctuations and the hail suppression and rainfall modification levels assumed)  
 [This estimated yield is created by first regressing yields for the simulation time period on simple trend variables representing technology. The percentage error between the predicted and actual yields are then combined with the yield estimate fixed at the 1973 technology level to give a base series of yields. This base series is further adjusted to account for reduced crop damage due to a specific hail suppression effectiveness level. Essentially this procedure recreates the period of time for which there are data in each area and estimates the net-income outcome if present day technology and assumed levels of hail suppression effectiveness had been available in each year of that period. A detailed presentation of this process is given by Potter (1976).]

$TS$  = crop-share tenant's portion of the crop (*Commodity Economics Division, 1975*)

$P_{HI}^t$  = payment for each hail insurance strategy given the  $t$ th year hail loss (*Fosse, 1975*)

$P_{AR}^t$  = payment from all-risk crop insurance given the  $t$ th year yield (*Sharp, 1975*)

$P_{DP}^t$  = amount of the federal disaster payment given the  $t$ th year yield (*Agricultural Stabilization and Conservation Service, 1974*)

$PC$  = tenant's share of production costs in 1973 dollars, not including hail or all-risk crop insurance and hail suppression costs (*Commodity Economics Division, 1975*)

$C_{HI}$  = premium for each hail insurance strategy (*Fosse, 1975*)

$C_{AR}$  = premium for all-risk insurance (*Sharp, 1975*)

$C_{HS}$  = cost of hail suppression, set at \$1 per harvested acre (based on costs in Chapter 8 and ratio of harvested acres to total acres)

For the hail insurance options, Strategies B through E, the coefficient of variation is reduced 7 to 10%. This reduction in variability of income results even though hail insurance was assumed to be purchased in each year of the simulation period in this analysis. But after a dry winter, for example, farmers in this area may choose not to participate in hail insurance if crop prospects are significantly reduced. The inability to model this behavior probably causes an understatement of the attractiveness of hail insurance.

**TABLE 35****Estimated results for crop production in terms of average net income (dollars per acre)**

Strategy		Northeast Kansas: wheat	Southwest N. Dakota: wheat	N-central Iowa: corn/soybeans	E-central Illinois: corn/soybeans	W-central Texas: cotton	Central N. Carolina: tobacco	
A	No hail insurance, no hail suppression	25.58	7.52	53.93	49.55	1.89	361.06	
<i>Hail insurance strategies</i>								
B	Value of production	25.25	7.08	60.05	50.05	3.12	330.13	
C	40% deductible on value of production	25.91	7.42					
D	Cost of production	25.44	7.18	57.04	49.82	3.99	331.21	
E	40% deductible on cost of production	25.78	7.44					
F	All-risk crop insurance	24.86	7.13	53.29				
G	All-risk and cost of production hail insurance combined	24.52	6.69	59.42				
<i>Hail suppression possibilities</i>								
	Reduction in crop damage		Change in rainfall					
H	20%	10% decrease	22.60	7.42	52.40	47.46	1.70	343.83
I		no change	25.74	7.62	55.50	49.63	3.57	364.21
J		10% increase	28.47	7.83	58.62	51.80	5.43	385.54
K	50%	10% decrease	22.34	9.18	56.35	48.33	9.01	350.32
L		no change	27.35	9.40	59.45	50.50	9.86	370.71
M		10% increase	30.11	9.62	62.58	52.67	11.75	392.03
N	80%	10% decrease	25.98	11.35	60.30	49.20	14.72	356.82
O		no change	29.12	11.56	63.40	51.37	15.64	377.20
P		10% increase	31.88	11.67	66.53	53.54	17.60	398.53

*Insurance 'expensive' in Kansas area*

A major disadvantage of hail insurance in this area is that hail insurance premiums are expensive in relation to other production costs. The hail insurance premium on the full value of production in this area is more than \$8 per acre (Fosse, 1975). This cost compares with the tenant's noninsurance production costs of about \$40 per acre (Commodity Economics Division, 1975). Although in large part offset by the hail losses of this area, this relatively large insurance cost would tend to reduce participation in hail insurance programs.

All-risk crop insurance is another option available to the farmer to reduce income fluctuations caused by variations in crop yields. Both Strategies F and G reduce variability of income and average income. The combination of all-risk insurance and hail insurance on the cost of production results in the lower coefficient of variation for these two strategies.

Although the estimates for the all-risk insurance option were calculated on the basis of total yield variability, the measures presented here do not capture one important attribute of an all-risk insurance program — a guaranteed lower income limit with respect to production variability. This guarantee is operative regardless of the yield-reducing phenomenon (except poor farmer management, of course), whereas hail insurance or hail suppression principally relate to one production hazard. Neither of these latter

**TABLE 36**

**Estimated results for crop production in terms of coefficient of variation**

Strategy	Northeast Kansas: wheat	Southwest N. Dakota: wheat	N-central Iowa: corn/soybeans	E-central Illinois: com/soybeans	W-central Texas: cotton	Central N. Carolina: tobacco		
A No hail insurance, no hail suppression	117	273	34	24	2715	100		
<i>Hail insurance strategies</i>								
B Value of production	106	264	15	20	1592	108		
C 40% deductible on value of production	105	256						
D Cost of production	106	257	18	21	1276	108		
E 40% deductible on cost of production	109	253						
F All-risk crop insurance	116	269	30					
G All-risk and cost of production hail insurance combined	110	278	19					
<i>Hail suppression possibilities</i>								
	<i>Reduction in crop damage</i>	<i>Change in rainfall</i>						
H		10% decrease	130	265	31	24	3047	104
I	20%	no change	115	258	29	23	1461	99
J		10% increase	106	252	27	22	963	93
K		10% decrease	119	205	20	22	598	102
L	50%	no change	107	201	19	21	551	97
M		10% increase	99	197	18	21	464	91
N		10% decrease	111	168	14	21	390	100
O	80%	no change	100	166	13	20	370	95
P		10% increase	93	166	12	20	330	90

options is of value if a drought, for example, reduces crop production. Therefore, farmers who are averse to risk, because of either a vulnerable financial position or personal preferences, may be interested in all-risk insurance programs even though the estimates presented here might indicate otherwise. This study's estimates do indicate the income penalty this risk-averse behavior entails.

The data of *Table 35* clearly show that the benefit of a hail suppression program to the individual farmer is directly related to the effectiveness of that program. Without rainfall effects, a 20% reduction in crop damage due to hail only slightly increases average income and does not improve certainty of income relative to options presently available.

Two factors reduce the positive effects of hail suppression. One, of course, is the \$1 per harvested acre suppression cost. The second factor is the federal disaster payment program. The tenant is estimated to receive an average of \$1.80 per harvested acre for each year of the simulation period for Strategies A through G. But 20% hail suppression effectiveness with a 10% increase in hail season rainfall reduces this payment to \$1.27 per harvested acre.

The 50 and 80% effectiveness levels (Strategies L and O) result in higher average incomes and more certain incomes than do presently available options, even with

*Suppression value directly related to effectiveness*

*Suppression value depends on rainfall change*

the \$1 cost and lowered disaster payments. But any change in rainfall in this area can very much alter the benefits from hail reduction. *A 10% increase in rainfall makes the 20% crop damage reduction level superior to any of Strategies A through G. Decreasing rainfall 10%, however, can overcome the income benefit of a 20 or 50% crop damage reduction to make strategies H and K inferior to Strategies A through G.*

For this analysis, weather modification activities were assumed to be undertaken primarily to suppress hail with rainfall changes as side effects. Therefore, rainfall effects in each area are accounted for only in months when hail suppression activities are likely to be undertaken in each area — April through August in northwestern Kansas.

All of the 80% reduction in crop damage situations would have greater expected incomes and less variability of income (as measured by the coefficient of variability) than Strategy A. But some of the hail insurance strategies are roughly equivalent to the 80% damage reduction level if growing season rainfall is reduced by 10%.

*North Dakota — wheat*

The southwestern North Dakota region studied is primarily a wheat-producing region as is the Kansas area. But *Tables 35 and 36* show that the average net income is much lower and the coefficient of variation is much higher in the North Dakota area. Township 131 north, 85 west of Grant County was the particular township for which hail loss data were studied.

Insurance strategies in this area are consistent with those presented for Kansas. Participating in hail insurance and/or all-risk insurance programs reduces the pure variability of the income series (its estimated standard deviation) and generally reduces the coefficient of variation (*Table 36*). Again, hail insurance is expensive in relation to other production costs in this area.

*20% hail reduction 'little help'*

As in the Kansas area, 20% reductions in crop damage are only marginally better than the nonhail suppression activities. And federal disaster payments are again a factor. Federal disaster payments to the tenant, which would average \$1.69 per harvested acre for Strategy A, are reduced to \$1.33 per harvested acre if a 20% reduction in crop damage due to hail and a 10% increase in May to August rainfall were to occur.

*50 and 80% reductions 'superior'*

But unlike the Kansas situation, *50% effectiveness is considerably superior to the nonhail suppression strategies.* This superiority occurs both in terms of average income and variability of income. For example, Strategy K, which combines 50% reductions in hail-caused crop damage and 10% less rainfall, is estimated to increase average income by \$1.66 per acre over Strategy A. On a percentage basis this is a 22% increase in income over Strategy A and contributes to a 23% decrease in the coefficient of variation. The 80% effectiveness strategies are even more attractive than the 50% level.

Township 98 north, 27 west in Kossuth County was selected as the particular township for analysis in Iowa. For purposes of this analysis the farmer is assumed to plant corn and soybeans in a 3:2 ratio, which is representative of this western corn belt region.

*Iowa —  
corn and  
soybeans*

This township suffered an annual average hail loss of 7.6% for corn and 13.6% for soybeans during the period 1954 to 1974 (*Fosse, 1975*). Lack of yearly yield data for this area before 1954 restrained the analysis to the 20-year period. Analysis of hail-loss data prior to 1954 indicates that this township suffered relatively greater hail losses in the 1954 to 1974 period. This township suffered hail losses of 5% for corn in the period 1930 to 1973 and 10.7% for soybeans in the period 1948 to 1973 (*Fosse, 1975*).

Hail insurance strategies in this region surprisingly result in sharply higher net income estimates than that estimated for Strategy A. For example, Strategy B, which involves insurance on the full value of production for the corn and soybean crops, is estimated to have an annual net income of \$60.05 per acre (*Table 35*). This estimate is \$6.12 higher than when no insurance is purchased.

*Insurance  
strategies  
'beneficial'*

As discussed previously, the nine-township factor used by insurance companies in the rate determination might explain part of this income increase. A larger factor is that the years in the simulation period were years of relatively large hail loss. This means that earlier years with good (little) hail loss experience could not be included in the simulation but do influence the insurance rate structure. Lastly, 1976 hail insurance premiums were used in this simulation. Sharply higher premium rates have recently been calculated for this area — necessitated by the outcomes presented in *Table 35* (*Fosse, 1975*).

The all-risk crop insurance program, Strategy F, results in reduced income variability at a cost of reduced average income. Again, it should be noted that an important feature of the all-risk program, a minimum income guarantee with respect to production hazards, cannot be captured in this analysis.

Hail suppression, especially at more than the 20% effectiveness level, holds considerable promise for reducing income variability in this western corn belt area (*Table 36*). Although hail suppression at the 80% effectiveness level, Strategy O, increases net income by only 18%, income variability is reduced by over 60%. This result indicates that the hail hazard is a major factor in year-to-year crop production fluctuations in this region.

*Suppression  
reduces  
variability  
of income*

The potential rainfall fluctuations in the months of June to August were also considered. These fluctuations do not greatly offset the effects of reduced hail damage. Net income estimates tend to be positively related to rainfall changes in these hail season months with a 10% fluctuation in rainfall causing a 6% change in per acre net income.

In the eastern corn belt region, with no hail insurance or hail suppression, average



*Illinois —  
corn and  
soybeans*

net income was estimated to be \$49.55 per acre based on a simulation period from 1948 to 1974 (*Table 35*). The standard deviation of that net income series was only \$11.83, resulting in a coefficient of variation of 24 (*Table 36*). These estimates are specific to township 15 north, 2 east of Macon County in east-central Illinois. Hail losses in this area are much less severe than in the western corn belt region just discussed. In this township, hail losses averaged only 1.5% for corn and 3.7% for soybeans for the simulation period.

*Insurance  
lowers  
income  
variability*

Hail insurance strategies lead to lower income variation as indicated by the reduced coefficients of variation (*Table 36*). The slightly higher net income estimates for Strategies B and D are probably the result of the modeling imperfections discussed for the Kansas area and should not be given too much significance.

It should be noted that, for the period considered here, yearly yield fluctuations in the simulation model never fell to a level where all-risk insurance or federal disaster payments became operable. If an expanded yield series, especially including the unstable weather years of the 1930s, could have been used, these two options would probably have become a factor.

*Suppression  
benefits  
minor*

Because of the slight hail losses experienced in this region, hail suppression results in relatively minor benefits either in terms of average income or variability of income. The 80% effectiveness level with no rainfall effects, Strategy O, contributes only a 4% increase in average net income. Ten percent rainfall fluctuations in the months from June through August are positively related to a 4-5% change in net income at each hail damage reduction level.

*Texas —  
cotton*

By Crop-Hail Insurance Actuarial Association (CHIAA) terminology, an area described as statistical township 9 in Castro County was selected as a Great Plains cotton-producing area (*Fosse, 1975*). This area suffers extreme yield fluctuations. For the 1953 to 1974 period, average cotton yields were 281 pounds of cotton lint per acre with a standard deviation of 145 pounds per acre. Hail was a major contributor to this variability with 20% average annual cotton losses due to hail.

Several of the procedures adopted for the other study areas were altered for this area. The actual county yield data for this county exhibited extreme variability but trend variables could not be found which explained any systematic change in yield over time. Therefore the percentage change from the average yield during this period was used to depict yearly yield variability. Further, when 1972-1974 average cotton prices were used, net income estimates were negative, indicating that farmers in this area could not expect to cover variable costs with these prices. Because a decision to plant given this price expectation would not agree with common sense, the output price was adjusted upward to 50 cents per pound, which resulted in positive average incomes above variable costs.

*Extreme  
variability*

An additional indication of the income variability experienced in this region is given by the results of Strategy A in *Table 35*. The average annual net income for this

no-hail-insurance, no-hail-suppression situation is \$1.89 per acre, but the standard deviation of that income was \$51.23 per acre.

Hail suppression at the 50 or 80% level would be tremendously attractive to this region's farmers. Average net income estimates for Strategies L and O are \$9.86 and \$15.64 per acre, respectively. These estimates are substantially higher than for Strategy A and contribute to greater certainty of income.

*'Good' hail  
suppression  
attractive*

At these levels of hail suppression effectiveness, the possibility of 10% reductions of April to November rainfall do not nearly offset the benefits estimated by reduced crop damage due to hail.

*Benefits  
even with  
less rain*

Federal disaster payments are a very significant factor for this area. For the no-hail-suppression situation, annual average disaster payments were estimated at \$27.28 per acre. Although these payments can be reduced if hail suppression takes place, the payments were still a major factor for the hail suppression activities. Even for Strategy P where 80% hail suppression and 10% increased growing season rainfall are assumed, disaster payments were estimated at \$17.25 per acre annually.

*Insurance  
"helps"  
slightly*

Tables 35 and 36 also present estimates for tobacco production in Pitt County in central North Carolina. County loss data were used because of the lack of adequate hail-loss data at the subcounty level. This limitation should lead to an understatement of yield variability for this area.

*North Carolina —  
tobacco*

Hail loss for tobacco for this county averaged 1.7% per year for the period 1925 to 1972. With no hail suppression or hail insurance, average annual income was estimated at \$361.06 per acre with a standard deviation of \$362.53 per acre.

*Income  
related  
to rainfall*

Results for the two hail insurance strategies indicated a slight decrease in the standard deviation of net income. But this decreased variability was at a cost of approximately \$30 per acre in average income.

From the data of Table 35 it would appear that reducing hail damage to tobacco production would not be economically exciting in this area. Even the 80% effectiveness level only translates into a 4% increase in net income. But the data of Table 35 indicate a greater sensitivity to rainfall in the months from May to September. These data suggest a \$20 to \$22 per acre variation in net income being directly related to 10% change in rainfall.



The discussion of this section has so far concentrated on results between different strategies within one farming area. Another goal of this analysis, however, was to identify those regions where hail suppression holds greater potential benefits.

**COMPARISON  
AMONG  
REGIONS**

 TABLE 37

Comparison of average incomes and coefficients with strategy A

Strategy		KS	ND	IA	IL	TX	NC	
A No hail suppression		100	100	100	100	100	100	
<i>Percent average net income is of Strategy A net income</i>								
	<i>Reduction in crop damage</i>	<i>Change in rainfall</i>						
H		10% decrease	88	99	97	96	90	95
I	20%	no change	101	101	103	100	189	101
J		10% increase	111	104	109	105	287	107
K		10% decrease	87	122	104	98	477	97
L	50%	no change	107	125	110	102	521	103
M		10% increase	118	128	116	106	622	109
N		10% decrease	102	151	112	99	779	99
O	80%	no change	114	154	118	104	828	104
P		10% increase	125	155	123	108	931	110
<i>Percent coefficient of variation is of Strategy A coefficient of variation</i>								
H		10% decrease	111	97	91	100	112	104
I	20%	no change	93	95	85	96	54	99
J		10% increase	91	92	79	92	35	93
K		10% decrease	102	75	59	92	22	102
L	50%	no change	91	74	56	88	20	97
M		10% increase	83	72	53	88	17	91
N		10% decrease	95	62	41	88	14	100
O	80%	no change	85	61	38	82	14	95
P		10% increase	79	61	35	83	12	90

Table 37 was prepared to compare Strategy A (the no-hail-insurance, no-hail-suppression situation) with the nine hail suppression situations, Strategies H through P. In Table 37 the average income and coefficient of variation estimates have been normalized so that the outcomes for Strategy A are equal to 100 for both variables, and outcomes for the other strategies are expressed as percentages of the Strategy A results.

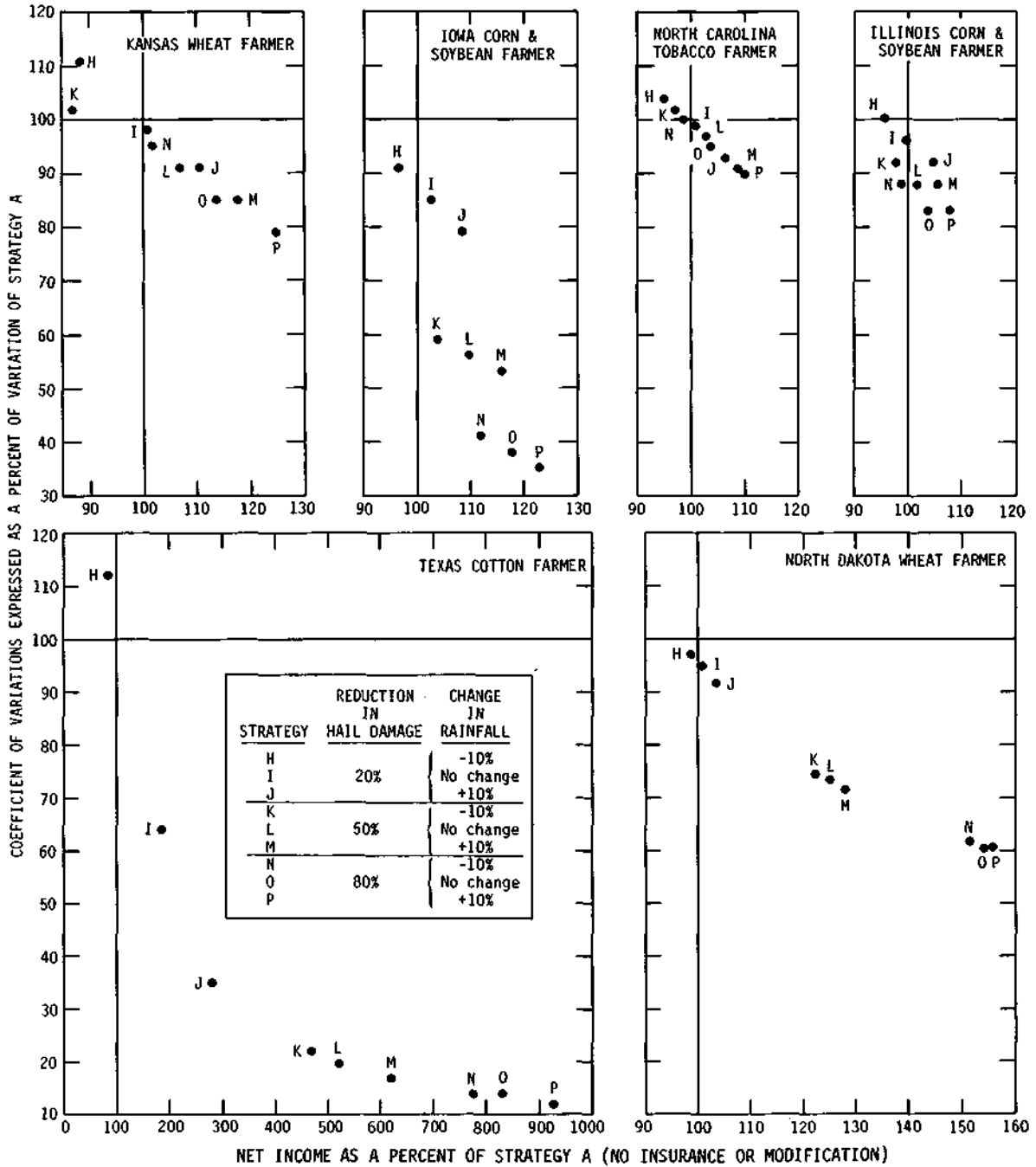
To further highlight the differential hail suppression potentials between regions, we have graphed these data in Figure 48. The scale of the Texas data is of a different magnitude from that of the other states because the percentages are very large — and indicate that hail suppression potentially has large benefits in this portion of the Great Plains.

The net income percentage is graphed on the horizontal axis and the coefficient of variation percentage is shown on the vertical axis of Figure 48. Therefore, movements to the right indicate increasing income, and movements downward



**FIGURE 48**

How net incomes change by strategies and regions



indicate decreasing income variability (relative to Strategy A). The most advantageous strategies would be in the lower righthand corner of each graph.

*Little benefit in East*

As we view the six graphs as a group, the differences in hail suppression potential are readily apparent. The data for the two easternmost regions — North Carolina (tobacco) and Illinois (corn/soybeans) — show little potential for hail suppression benefits. The hail-rain modification results for both of these regions are grouped very closely to the intersection (no benefit) of the two axes.

*Potential economic gains in West*

In contrast, the graphs for the other four areas — Iowa (corn/soybeans), Kansas (wheat), Texas (cotton), and North Dakota (wheat) — all indicate that economic potential for hail suppression may be present. In these four areas, hail suppression with no rainfall effect is indicated to have potential gains. Although Iowa and Texas show advantage at the 20% level, all four areas show significant potential benefits at the 50 and 80% levels.

*Benefits related to rainfall*

The pattern displayed in each of these areas is also informative. For Kansas, relatively large benefits are indicated for only five of the nine suppression strategies. These five, strategies L, O, J, M and P, represent (respectively) 50 and 80% effectiveness with no change in rainfall and all three hail suppression levels with 10% increases in rainfall.

For North Dakota, the larger benefits occur for the 50 and 80% levels, and for all three rainfall assumptions. In this region potential gains are indicated for both average income and certainty of income.

For Iowa, the most pronounced benefits relate to the certainty of income variable. Even the 20% effectiveness level indicates surprisingly pronounced gains in certainty of income for this area.

In Texas, all strategies except H (20% hail decrease and 10% rain decrease) show great gains.

*Sensitivity to rainfall varies*

Another interesting feature depicted is the areally varying sensitivity to rainfall fluctuations. Of course, changes in rainfall are shown to affect average income and variability of income in all areas. But in Texas, North Carolina, and Kansas, the 10% fluctuations in hail season rainfall are shown to have quite pronounced effects relative to reduction of hail damage.


In North Carolina all three negative rainfall fluctuations result in poorer outcomes than Strategy A. And for the Kansas example, Strategies H and K (which combine 10% reductions in hail season rainfall with 20 and 50% hail suppression effectiveness, respectively) result in reduced certainty of income and greater than 10% reductions in net income. Conversely 10% increases in hail season rainfall are related to relatively large benefits in these two areas.

- Agricultural Stabilization and Conservation Service  
 1974 *Emergency and disaster assistance available through ASCS*. U.S. Department of Agriculture, Washington, D.C., BI 13.
- Boone, L. M.  
 1974 *Estimating crop losses due to hail*. U.S. Department of Agriculture, ERS, Washington, D.C., Agricultural economic report 267, 40 pp.
- Changnon, S. A.  
 1973 *Weather modification in 1972: Up or down?* Bulletin American Meteorological Society, 54, 7, 642-646.  
 1975 *Climate, is it changing? What will change mean to agriculture?* Crops and Soils Magazine, October, 9-12.
- Committee on Resources and Man  
 1969 *Resources and man*, W. H. Freeman and Company, San Francisco, Chapters 4, 5.
- Commodity Economics Division  
 1975 *Firm enterprise data system*. Submitted to Economic Research Service, U.S. Department of Agriculture, by Department of Agricultural Economics, Oklahoma State University, Stillwater.
- Ehrlich, P. R., and D. C. Pirages  
 1974 *Ark II: Social response to environmental imperatives*. W. H. Freeman and Company, San Francisco, 18-25.
- Fosse, E. R.  
 1975 *Personal communication*. Crop-Hail Insurance Actuarial Association, Chicago.
- Heilbroner, R. L.  
 1975 *An inquiry into the human prospect*. W. W. Norton & Co., New York.
- Lemons, H.  
 1942 *Hail in American agriculture*. Economic Geography, 18, 363-378.
- MacDonald, G. J. F.  
 1975 *Man, weather and climate*. In Environment: Resources, Pollution and Society, 2nd edition, edited by W. W. Murdoch Sinauer Associates, Inc., Sunderland, Mass., 381-397.
- McElheny, V. K.  
 1976 *Scientific deadend faces U.S. in its agricultural technology*. New York Times, New York, Monday, May 31.
- Meadows, D. H., D. L. Meadows, J. Randers, and W. Behrens, III  
 1972 *The limits to growth*. Universe Books, New York.
- Newman, J. E., and R. C. Pickett  
 1974 *World climates and food supply variations*. Science, 186(4167), 877-881.
- Poleman, T. T.  
 1975 *World food: A perspective*. Science, 188(4188), 510-518.
- Potter, C. W.  
 1976 *Economic aspects of hail suppression to the individual farmer*. Unpublished masters thesis, Department of Agricultural Economics, University of Illinois at Urbana-Champaign.
- Sharp, E. S.  
 1975 *Personal communication*. Actuarial Division, Federal Crop Insurance Corporation, U.S. Department of Agriculture, Washington, D.C.
- Thompson, L. M.  
 1975 *Weather variability, climatic change, and grain production*. Science, 188(4188), 535-541.
- U.S. Department of Agriculture  
 1974 *Agricultural statistics, 1974*. Washington, D.C.

## SUMMARY OF CHAPTER 7

### FORCES STIMULATING INTEREST IN HAIL SUPPRESSION

*World food demand and supply*

 In this chapter we identify the general forces which provide the stimulus for continued consideration of hail suppression. Because agriculture is the principal industry which would be affected by hail suppression, the long-term outlook for the demand-supply situation for food on both a national and worldwide basis is an important general factor conditioning the interest in the development of the technology. Research and development on other output-increasing agricultural technologies will affect the impact of this force on development of hail suppression.

*Future climate changes*

The increased attention given to the future of the climate of North America is another background factor influencing the interest in hail suppression. Some scientists are predicting a gradual cooling, while others note a gradual warming effect. There is, however, no evidence of a secular change in precipitation or hail.

*Variations over time in hail damage*

The pattern of variation over time in hail damage is also a general force that generates an interest in hail suppression. Bad loss years are, for example, isolated events in Illinois counties and also at the state level, but in the western, higher-loss states, sequences of two or three (or more) bad-loss years are common. We would expect interest in hail suppression to be higher in these areas.

*Tendency of 'technologies' to continue*

Finally, and perhaps most important among the general forces determining the continued development of hail suppression, there is the inertia of publicly funded programs to continue. In a sense the developing technology has a life of its own, independent of potential uses, with the implicit rationale being to improve technology for its own sake even though arguments for continued government support are couched in utilitarian terms.

*Farmers' economic incentive*

The general demand-supply situation mentioned above will reflect itself in the economic incentives for adoption of hail suppression. An analysis was made of representative farm situations in Kansas, North Dakota, Iowa, Illinois, Texas, and North Carolina. Three major types of hail-related strategies were considered: self-insurance, commercial and federal all-risk crop insurance, and various hail suppression technologies involving reductions in hail loss of 20%, 50%, and 80% combined with three levels of rainfall variation: reduction of 10%, no change, and an increase of 10%, all during the hail season. The analysis took into account the effect of the choice of strategy on average net income over a period of years and also the year-to-year variability of net income. In general, the average net incomes are increased very slightly in North Carolina (tobacco) and Illinois (corn and soybeans), and there appears to be little incentive for adoption of hail suppression in these situations. Hail suppression with no rainfall effects has potential gains in the other four farming situations — Iowa (corn and soybeans), Kansas (wheat), Texas (cotton), and North Dakota (wheat). Rainfall effects are important components of the potential gain, especially in Kansas and Texas.

# 8

## Future suppression



The future use of hail suppression will rest in great part on the capabilities of the technology that will exist in the future. What can we expect of hail suppression? In what direction — under given circumstances — will the techniques of suppressing hail develop?

This chapter presents the scientific models that were developed for TASH by which we can look at the future status of the technology of hail suppression. It also presents the likely developments of related technologies.

### THE FUTURE STATUS OF HAIL SUPPRESSION\*



This technology assessment was rooted in the premise that there would be improved and more specific hail suppression capabilities in 1985 and 1995. Estimates of these capabilities were to be used in the socio-economic modeling to derive estimates of future adoption.

Consideration of the wide-ranging values and beliefs about the current status called for the use of three levels, or "starting points," which can be labeled as *optimistic*, *neutral*, and *pessimistic*. The actual calculation of the future capabilities was performed from a scientific modeling approach. The models were anchored to the current level (*Table 12* in Chapter 3) and were bounded by two considerations:

- The potential future experimentation and resulting scientific developments relevant to hail suppression
- The potential future operational use of hail suppression

\*This chapter contributed by Stanley A. Changnon, Jr., and Griffith M. Morgan, Jr.

### SCIENTIFIC ASSESSMENT OF FUTURE CAPABILITIES

*Assumptions  
for models*



*Alternative routes for future*

The amount of future activity in these two limiting areas will depend on the future demand of society (need to increase food production, excessive local or regional hail losses, interstate compacts, legal conflicts, and many others). With three different levels of suppression as starting points, and these limiting influences, three alternative routes were developed according to three premises about the future. The alternative routes are:

- 1) Moderate-to-heavy usage of operational hail suppression will occur with only meager experimental support initially, followed by increased experimentation due to a major scientific breakthrough.
- 2) Moderate but intermittent usage of operational projects will be coupled with moderate attention to experimentation.
- 3) Moderate-to-heavy attention (governmental support) will be given to field experimentation with only meager operational activities occurring.

The individual models were then framed around the question, "*Given current hail suppression status X and circumstance 1 above, how will the hail suppression capability change?*" Each model is an evolving temporal description of the development of a technical capability to suppress hail.

*Empirical base*

Such progress can only be accepted by those willing to believe in the essentially empirical evidence available now. These future interactive activities are considered realistic in that they are fashioned after recent experimentation and the adoption of hail suppression in the Dakotas following development of some proof of suppression success by experimentation there during 1966-1972 (*Division of Weather Modification, 1974*).

It is quite possible that physical explanations and theoretical analyses of hail formation convincing to all of the scientific community will not occur within the next 10 to 20 years. Certainly to many groups who now support and conduct hail suppression, convincing explanations exist now. However, future application of suppression will be based more on statistical empirical information than on well-explained physical results.

*Western, eastern differences*

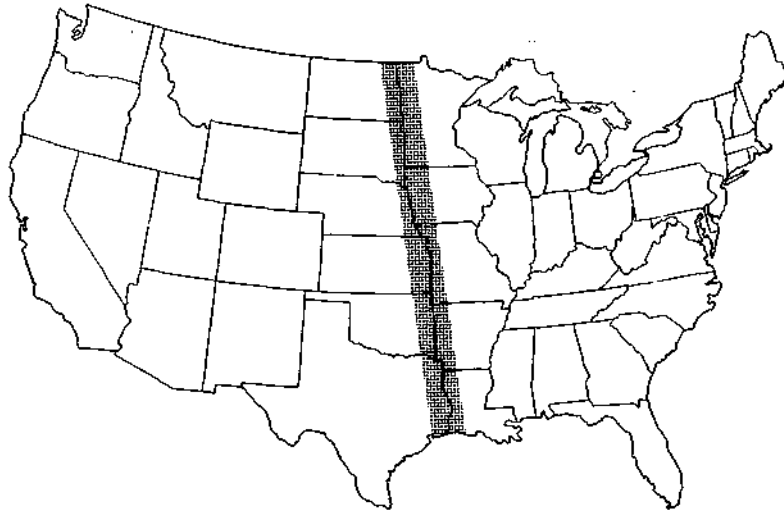
The great apparent difference in hailstorms of the western mountains and those of the eastern U.S., plus greater past application and experimentation in the West, furnished the rationale for developing three models for the western U.S. and three models for the eastern U.S. We show the rough division of the country in *Figure 49*. The ragged division indicates that storm types may overlap in those areas.

The varied history of the scientific and technological development of hail suppression in the past 20 years, plus consideration of the problems yet to be resolved to advance the science and technology, provided the basis for each of the six models. Consequently, they cover a wide range of technological outcomes in the western and eastern United States.



**FIGURE 49**

**West-east division for scientific assessment**



Any marked improvements in the specification of the technological capabilities and scientific acceptance of hail suppression will require many activities including sound scientific experimentation and careful evaluation of ongoing projects. Experimentation and evaluation will not occur unless they are coupled to a host of other factors including social adjustments, economic incentives for adoption, and institutional arrangements reflected in public, commercial, and governmental concern and interest in hail suppression.

Each model reflects reasonable and likely scientific and technical developments and not just fanciful imagination. In preparing these models, a critical interest in the various past and present hail prevention projects was temporarily suspended, and for the purposes at hand, we accept as valid those results which cannot be underwritten as certain. These six models are "educated scientific estimates," and are not the results of in-depth scientific research.

*Models are  
reasonable  
and likely*

Certain intangibles are difficult to deal with in such a scientific modeling approach. Improvements or discoveries in some scientific-technical areas would greatly affect the level of modification technology, although socio-political factors would be quite important in the rate of their application. Among these discoveries would be the development of a truly satisfactory theory of ice nucleation, although this does not seem imminent. There are foreseeable improvements in the understanding of measurements of concentrations of natural and artificial ice nuclei.

*Intangibles  
difficult  
to predict*

Other more mundane developments expected relate to the logistical and cost aspects of weather modification. Included are more refined techniques in air-

*Refined techniques expected*

craft control and greater confidence in rockets for nucleant delivery. Improvements in the means of prediction of hailstorms would reduce the number of occasions on which it will be necessary to intervene, with an obvious effect on costs and skill in evaluation. This can be demonstrated by the North Dakota results (*Miller et al., 1975*) showing that in 27% of the storms in a four-year period hail either was not altered or was increased. The final result would have been more impressive if these cases had not been seeded.

Continuing scientific study of severe nocturnal hailstorms plus continued nocturnal seeding operations and experimentation will upgrade the knowledge and skills for modification of nocturnal storms.

*Opportunity for discoveries*

In summary, the important point here is that there are *many opportunities for scientific and technical discoveries and/or improvements* during the next 20 years which will affect and improve the technology of hail prevention and may favorably affect (reduce) its cost.

## **FEATURES OF FUTURE MODELS**



The six models developed (three for the West and three for the East) outline the future levels that hail suppression can achieve. Each covers a 20-year period (1976-1995) of activities, and each addresses changes in hail and in the rainfall (including altered hail) directly affected by the purposeful modification of hailstorms.

*Downwind effects considered 'not large'*

For widespread regional adoption of hail suppression, possible downwind effects on hail and rain were considered. A realistic specification of this effect would contain the range (distance) and the quantitative effect — the increase or decrease in hail, rain, severe weather, or cloudiness. However, the lack of specific information or evidence on downwind effects from hail suppression activities leads to the conclusion that for the sake of this study no large-scale alterations in the downwind precipitation and other weather could be defined.

This is not to imply that the effects on the weather and environment in the region beyond a hail suppression area could not occur nor be important. Conceptually, effective large-area seeding could measurably alter convective activity and rainfall around —and particularly east of —the seeded area. The possibility of this potentially serious and yet totally uncertain issue makes it one of the major unknowns that should be resolved before large-scale hail suppression is launched (*Borland, 1975*).

*Hail-change values*

Since most of the hail reductions evident in 1975 (*Table 12*) are measured in crop-hail loss values, the future values of hail change in the models are considered to be expressions of *changes achieved in property and crop-hail damages*. Thus, they imply a change in all the hailstorm factors — the hailstone size, hailstone frequency, and wind associated with hail — that collectively interact to produce crop and property damage attributed to hail.

*Rain-change values*

The rainfall changes listed are in the amount of the total rainfall that would occur during the season when suppression is used. This season could be April

to July, or May through November, depending on the hail season of an area. However, the changes in rainfall shown are only those produced as a result of changes in the rain quantity *on days when hail occurs*. The rest of the season's rainfall in an area is presumed to remain intact, but could be seeded with the same equipment.

Future hail and rainfall values in the models are also season-long averages over a seeded area, whether it is 500 or 50,000 square miles. However, alteration on most hail days or with individual hailstorms will not attain this modeled average value. A variety of factors including failures in the seeding system, forecasting errors, and storm complexity will lead to different outcomes on a day-to-day and storm-to-storm basis.

*Future values  
are season  
averages  
for the area*

For instance, Simpson (1973) has shown a capability to increase rainfall in individual storms by 300%, but the overall area increase is much less, about 10%. Similar results were obtained in the St. Louis Metropolitan Meteorological Experiment (METROMEX) where urban-industrial effects produce 100 to 200% increases of rainfall in a few storms, but the area-seasonal average increase is only 25% (Changnon, 1974a).

The first model is described in detail to demonstrate the approach used, but the other five are condensed and details about each can be found elsewhere (Changnon and Morgan, 1976a).



Model 1 for the East follows the first alternative route: *application and experimentation with major scientific breakthroughs*.

## **EASTERN MODEL 1**

The *sense* of the rain and hail changes noted in the studies of inadvertent weather modification at St. Louis and LaPorte (Changnon, 1968; 1972; Semonin and Changnon, 1974) was assumed to be reversed under planned hail prevention in the eastern United States (Semonin and Changnon, 1975).

*Inadvertent  
changes  
reversed*

Seven of nine other cities studied were found (Changnon, 1974b) to have average changes in warm season precipitation ranging for rainfall from 9 to 27% increases, for thunderstorms from 10 to 42% increases, and for hailstorm days from 67 to 276% increases. None had decreases.

Results at St. Louis indicate 25% increases in warm season rainfall are associated with 80% increases in hail (in terms of frequency and intensity), with 30% increases in lightning frequencies, and with 80% increases in strong wind frequencies (Changnon, 1974a). Since all were increases, they suggest that by decreasing the hailfall all of the other phenomena might be decreased. Silverman and Nelson (1975) substantiate this possibility in their cloud model calculations.

It should be realized that the processes by which an urban area modifies a storm are somewhat different from those hypothesized for planned modification (Chang-

*Reversals used to give varied outcomes*

*non and Semonin, 1976; Semonin and Changnon, 1975*). A reversal of the urban findings has been used, although it is not considered too likely, so that the models would reflect a wide range of outcomes.

The urban results suggest that for a given reduction produced in hail in the eastern United States a relatively smaller reduction in rainfall might occur, such as found in South Africa (*Table 12*). Inverting the urban figures to infer weather modification tendencies would indicate that the percentage decrease in rain would be from 1/4 to 1/3 the percentage decrease in hail — that is, 60% in hail with 20% in rain. The inverted percentage reductions in high surface wind speeds would match that for hail, and that for lightning would be about 1/3 of the hail decrease.

*Considers only rain on hail days*

Another factor to be determined is the percent of rainfall falling on "operational seeded" days, or only on hail days. The unidentified urban inadvertent weather modification mechanism operates on *all* days. In Illinois, 47% of the warm season rainfall falls on days with hail (*Changnon, 1975a*), and the rainfall temporal variations explain 60% of the hail loss variations in Kansas (*Stout, 1965*) and 50% in Illinois (*Huff, 1960*).

*Model 1 1975 skill rated zero*

In this model, the 1975 capability for modifying hail and associated rain, winds, and lightning is rated as zero (no skill). However, since a portion of the urban alteration of hail and rain is related to microphysical processes (*Braham, 1974*), it is not unreasonable to expect that the degree of inadvertent modification shown will lead to *moderate* future utilization of hail suppression in parts of the eastern United States.

Adoption may occur because of periods of high hail losses such as those in the Midwest during 1973-1975 (*see Figure. 50*). Illinois led the nation in hail losses in 1973 and 1975 and Iowa led in 1974 (*Changnon and Morgan, 1976b*). Such high loss periods occur in midwestern and East Coast crop states about once every 8 to 12 years (*Changnon, 1975a*), as shown on Figure 45.

*1985 skill is -30% for hail*

If one couples these conditions with the reduction values suggested in the Dakotas — by considering some to be largely representative of the storms of the Midwest — a reasonable expectation would be a capability of 30% reduction in hail by 1985.

*Rain change is -5%*

The inadvertent urban results suggest that this would be accompanied by 10% (1/3 of hail value) reductions in summer rainfall. But, since only half the summer rain falls with hailstorm situations, the net rain change would be -5%.

The associated reduction in the frequencies of strong summer winds (gusts 30 mph) would be 30%, and that for lightning would be 10% (1/3 of the hail value). There would be benefits from less hail, wind, and lightning but possible disbenefits from less rain, though a 5% reduction is not often critical in the humid East.



FIGURE 50

Headlines on Midwest hailstorms

'73 Hailstorm Damage: \$80 Million In Iowa, Illinois

Clark Hainoch, Farm Editor

Hailstorms during 1973 inflicted crop damage totaling an estimated \$80 million in Iowa and Illinois...

destructive hailstorms that may affect more than 100 million...

PRIVATE insurance companies and firms insured nearly \$75 million in Illinois...

claims in Illinois where the loss to premium ratio...

"This is unusual because Illinois hail frequency and damage historically has been...

only \$22 million, or 62 per cent of premium...

Illinois farmers were paid nearly \$11 million, or 28 per cent of premium...

THESE SAID the most destructive hailstorm of the year in Illinois struck Aug. 13...

Illinois counties were hit June 26 with 1 1/2 inches of hail...

heavy damage also was reported in Champaign, Peoria, Douglas and Quincy counties...

Stanley A. Chambers Jr., state director of the Illinois State Water Survey...

anyway, soybeans, corn, garden, truck crops and fruit were wide areas...

ALSO POLLUTION in industrial areas such as Chicago and St. Louis...

overwhelmed into freeways in... 10 days during the...

Champaign said: "Our hail storm measured 2 1/2 inches in a one-foot-square area within five minutes..."

Damage to Illinois crops hit record high in '73

Illinois was hit harder by destructive hailstorms in 1973 than any state with crop losses estimated in excess of \$60 million...

Broken windows, dented automobiles, damaged roofs, telecommunications and property are generally protected by wind-storm policies...

entire crop — the crop of soybeans and collected \$250,000 from his insurer...

insurance I would have been insured financially," he said. The storm covered an area about a mile and a half wide...

Illinois Hardest Hit By Damaging Hailstorms

Illinois was hit harder by destructive hailstorms in 1973 than any state with crop losses estimated in excess of \$60 million...

of the part of Illinois escaped hail damage a major insurer reported claims from all of the state's 100 counties except three...

THESE SAID the most destructive hailstorm in 1973 hit Illinois in Champaign, Peoria, Douglas and Quincy counties...

Granite City Farmer rec'd Biggest Payment Hailstorms Singled Out Illinois in 1973; Insurance Payments Soared to \$21.7 Million

Illinois was hit harder by destructive hailstorms in 1973 than any state with crop losses estimated in excess of \$60 million...

Business I would have been insured financially," he said. The storm covered an area about a mile and a half wide...

South of DeWitt a June 23 storm ripped into a field, heavily damaged 80 acres of soybeans and corn...

Illinois was hit harder by destructive hailstorms in 1973 than any state with crop losses estimated in excess of \$60 million...

Illinois was hit harder by destructive hailstorms in 1973 than any state with crop losses estimated in excess of \$60 million...

Illinois was hit harder by destructive hailstorms in 1973 than any state with crop losses estimated in excess of \$60 million...

Illinois was hit harder by destructive hailstorms in 1973 than any state with crop losses estimated in excess of \$60 million...

Illinois was hit harder by destructive hailstorms in 1973 than any state with crop losses estimated in excess of \$60 million...

Illinois was hit harder by destructive hailstorms in 1973 than any state with crop losses estimated in excess of \$60 million...

Hailstorm damage high Illinois hardest hit of all states

Illinois was hit harder by destructive hailstorms in 1973 than any state with crop losses estimated in excess of \$60 million...

Illinois was hit harder by destructive hailstorms in 1973 than any state with crop losses estimated in excess of \$60 million...

Illinois was hit harder by destructive hailstorms in 1973 than any state with crop losses estimated in excess of \$60 million...

Illinois was hit harder by destructive hailstorms in 1973 than any state with crop losses estimated in excess of \$60 million...

Illinois was hit harder by destructive hailstorms in 1973 than any state with crop losses estimated in excess of \$60 million...

Illinois was hit harder by destructive hailstorms in 1973 than any state with crop losses estimated in excess of \$60 million...

Illinois was hit harder by destructive hailstorms in 1973 than any state with crop losses estimated in excess of \$60 million...

Illinois was hit harder by destructive hailstorms in 1973 than any state with crop losses estimated in excess of \$60 million...

Illinois was hit harder by destructive hailstorms in 1973 than any state with crop losses estimated in excess of \$60 million...

Demonstration of this capability by 1985 could lead to considerable field experimentation and additional research, so that by 1995 a major scientific breakthrough...

Such major developments are hypothesized to result by 1995 in a doubling of the 1985 hail suppression capability resulting in a 60% hail reduction. These major

 TABLE 38

Models of future hail suppression and related modification capabilities in the hail season

Models	Percentage changes	
	Western U.S. capabilities	Eastern U.S. capabilities
1. Applications and experimentation based on existing findings with a major scientific breakthrough	1975 Hail = -30 Rain = +6	1975 Hail = 0 Rain = 0
	1985 Hail = -40 Rain = +8	1985 Hail = -30 Rain = -5 High winds = -10 Lightning = -10
	1995 Hail = -80 Rain = +16	1995 Hail = -60 Rain = +10 High winds = -20 Lightning = -20
2. Intermittent applications and experimentation based on existing findings with moderate advances	1975 Hail = -30 Rain = +6	1975 Hail = 0 Rain = 0
	1985 Hail = -45 Rain = +6	1985 Hail = -18 Rain = -6
	1995 Hail = -54 Rain = +9	1995 Hail = -18 Rain = -6
3. Experimental focus with minimal application	1975 Hail = 0 Rain = 0	1975 Hail = 0 Rain = 0
	1985 Hail = -15 Rain = -10	1985 Hail = -11 Rain = +5
	1995 Hail = -30 Rain = 0	1995 Hail = -21 Rain = +9

advances could lead to a capability to moderately increase rainfall (+10%), and to a doubling in the wind and lightning suppression capabilities. We show the resulting values for this model of events, along with others, in *Table 38*.



Model 2 for the eastern part of the country follows the neutral route of the second alternative with *moderate applications and experimentation as well as moderate advances*.

EASTERN  
MODEL 2

This model also assumes no eastern hail suppression capability in 1975. Successful experimentation with advances in knowledge of storms and seeding techniques in the Great Plains during 1976-1985 is predicted to lead to a 45% hail suppression capability with a +6% rain change, as shown by Western Model 2 for 1985. This capability would be translatable to the East, but since only 40% of the Great Plains hailstorms are similar to those of the East (*Changnon, 1975a*) the seasonal average hail decrease would be 18% (*Table 38*). The associated rain change, as suggested in the urban results, would be -6% or 1/3 of the hail value.

*Model 2  
1985 skill  
is -18%  
for hail*

Some slight adoption and experimentation in the East would occur between 1985 and 1995 since the 1985 values are not economically exciting. This mild application and experimentation would *not* unlock the complexities of modifying the major storm systems, and the capability in 1995 would not improve over that in 1985, as we see in *Table 38*.

*1995 skill  
would not  
improve*



Model 3 for the East follows the third alternative that calls for very little operational activity and *an experimental focus*.

EASTERN  
MODEL 3

This model is the experimental scenario originally envisioned as a goal for the Midwest by the Illinois State Water Survey in its experimental design program for a hail suppression experiment in Illinois (*Changnon and Morgan, 1976b*). It is keyed to federal funding and to the National Hail Research Experiment (NHRE) in Colorado. No hail prevention experimentation would begin until moderately successful results from NHRE were announced (around 1980).

*Eastern  
experiment  
after 1980*

There would then be an experiment in the eastern United States of some three to five years duration to assess suppression capabilities and the transferability of the NHRE technology.

By 1985 the eastern technology would be in the early application stage. The expected hail reduction, based on the current western levels (*Table 12*), would be 30%, but this would apply to only 37% of the storms, indicating no eastern success with nocturnal storms and supercells. Thus the yield would be a seasonal reduction of 11% (*Changnon and Morgan, 1976a*). The hail-associated rainfall would be increased by 25%, but the seasonal total rain increase would be only 5% (the rain with modified hail).

*Model 3  
1985 skill  
is -11%*

Since neither value would be impressive, efforts to improve the technology would be minimal and would be based largely on continued experimentation, not application. Continued NHRE, SESAME (Severe Environmental Storm and Mesoscale Experiment), and Illinois severe storm research would reveal successful means to modify supercells and nocturnal storms.

*Minimal  
efforts to  
improve*



Hail skill  
of -21%  
by 1995

By 1995, there would be 30% reductions of hail in 70% of the storms (21% of total loss), and although the point rain increase capability also would not improve (+25%), its successful application to 70% of the rain yields a seasonal increase of 9%, as we show in *Table 38*. These and other modeled values are *estimates* based on possible scientific and technological developments coupled to potential adoption.

## WESTERN MODEL 1



The western models follow the same three routes as the eastern models starting with the optimistic *applications and experimentation with major scientific breakthroughs*.

Western  
1975 skill  
is -30%  
for hail

The 1975 status of hail suppression in the West used in this model is based on the results presented in *Table 11* for the three projects in the Dakotas. This represents a model with an average reduction of hail loss of 30% plus an associated rain increase of 24%. Since rain with hail is about 25% of the seasonal total (*Crow, 1969*), the net seasonal increase is 6%. Although it was not evaluated as a part of this hail assessment, at least on nonhail rain days, it is likely that purposeful efforts to increase rainfall would be conducted with the hail suppression programs.

Reaches  
-40% by  
1985

Knowledge from ongoing operational projects in the Great Plains, plus data from NHRE, would provide a gradual increase in skill (approximately 1% per year) leading to capabilities of -40% for hail in 1985 and +8% for associated rain. In particular, the capability to modify equally successfully nocturnal storms (20% of the total) could be expected and this alone would account for an overall 6% improvement in hail reduction.

Hail skill  
doubled  
by 1995

This model includes the occurrence of a major scientific-technological breakthrough, as with the Eastern Model 1, during the 1985-1995 period. This potential breakthrough (in nucleation theory, forecasting, or correct storm detection) would lead to a doubling of the research and applications, and the 1995 modification capabilities would be greatly improved over those in 1985. Hence, the 1995 hail suppression skill would be -80% and associated rain increases would lead to a 16% increase in related seasonal rain (*Table 38*).

## WESTERN MODEL 2



The second model for the West calls for *moderate applications and experimentation with moderate advances*.

Hail skill  
improves  
slowly

This model assumes that the same hail suppression capability exists in 1975 as in the previous model, -30% hail and +6% rain. Such a capability could result in intermittent application of suppression largely in the Great Plains during 1975-1985 and a general —but slow— increase in the seeding skills.

NHRE would not provide any major breakthrough to enhance the capability rapidly. Hence, a slow rate of improvement (1.5% per year) in modification appears to be a reasonable expectation, leading to a 45% reduction capability in 1985 (*Table 38*).

Continued slow improvements in the skills for forecasting and for seeding of nocturnal storms (20% of the total) would lead to a 9% overall improvement by 1995 in hail and a 3% increase in rain capability.

*Reaches  
-54%  
by 1995*



The third model for the West, with its *experimental focus*, is founded largely on NHRE. The 1975 NHRE results on hail and rain are questionable and inconclusive for a variety of reasons. Hence, the 1975 hail and rain values are zero, reflecting no capability (*Table 38*).

### **WESTERN MODEL 3**

NHRE has considered potential changes in lightning, but no data are available and alterations are considered negligible (*ESIG, 1975*). An analysis of the surface wind gust data from NHRE does not suggest any seeding-related changes.

*Hail skill  
is zero  
in 1975*

The future experimentation and analysis in the 1976-1985 period may either exclude supercells or show no capability for their suppression (*Browning and Foote, 1975*). For a reasonable capability (-30%) for hail suppression from ordinary, nonsupercell storms, which produce 50% of the total loss, the overall hail reduction capability will be -15% (*Table 38*). A modest decrease in rain with hail (-25%) could be shown (by inverting current NHRE results in *Table 12*) for 1985, yielding a potential seasonal rain decrease of 10%. Conceptually, seeding could produce increases in winds and lightning (*ESIG, 1975*), but changes in the strength of high surface winds and frequency of lightning associated with hail suppression activities are considered unlikely.

*Modest  
decreases  
in rain, hail*

The harmful side effects of the decrease in rainfall shown by the NHRE results around 1985 would minimize operational application of hail suppression (*Dennis, 1969*). However, careful evaluation of the NHRE 1985 results would be sufficiently encouraging to the scientific community to support a second NHRE focusing on supercells and nocturnal storms after 1985.

*Support for  
2nd NHRE  
after 1985*

Resolution of the proper seeding approach to these storms could be expected by 1995 along with skilled forecasts and detection in incipient hailstorms. The then well-established 30% reduction in hailstorms would apply to all storms, yielding a seasonal capability of -30% (*Table 38*). Skill in treatment and storm selection would also remove the 1985 problem of rain reductions associated with hail decreases.

*Hail skill  
is -30%  
in 1995*

## **RELATED TECHNOLOGIES IN THE FUTURE**



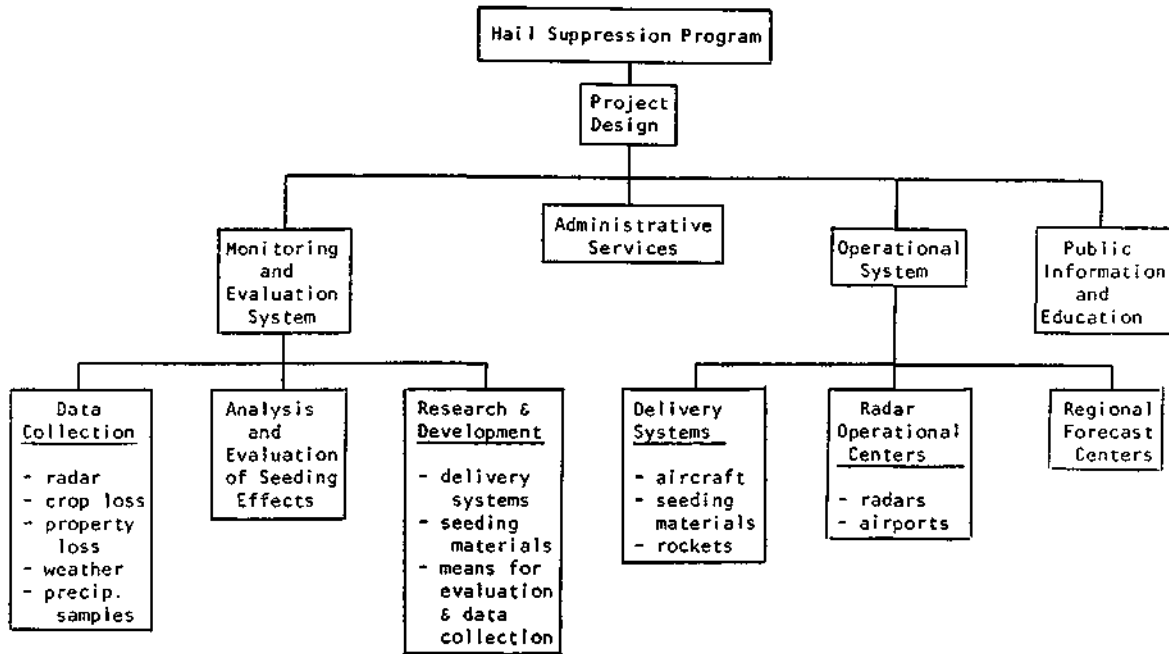
The future status of the hail suppression industry and research programs, described later in Chapter 10, points to the need for comprehensive program design activities. These designs must consider a wide range of complex activities and systems including:

### **PROGRAM DESIGN**



FIGURE 51

Key elements of a hail suppression program



- 1) Meteorological and environmental research
- 2) Operational staff, facilities, and decision processes
- 3) Monitoring and evaluation of project results
- 4) Assessment of social, environmental, and economic impacts
- 5) Dissemination of project information
- 6) Data collection and processing system
- 7) Legal and industrial arrangements

We show the functional elements of a hail suppression program, including its design activity, in *Figure 51*. Most existing large hail suppression projects have had a semblance of all the key elements, but the evaluation effort has been too meager in most operational programs, as we noted in Chapter 4. The NHRE experimental program had all the key elements but suffered from slowness in development of key equipment (radars and seeding rockets) and in data processing.

*Proper design required*

If hail suppression expands much beyond its present levels of use, great attention must be given, presumably on state and federal levels, to ensure both proper design and proper functioning of the other key elements of a program.

The dimensions of the systems, including the costs needed in such programs, are addressed in the following sections. However, project designs critical to dimen-

sionalizing future seeding, operational, monitoring, and evaluation systems must be developed in light of the phenomena (hailstorms) to be modified, available facilities, and cost considerations. Performance of the design functions is considered in a later section.

Climatic information about hail as described in Chapter 2 —without consideration of other conditions affecting adoption of hail suppression — suggest that the most efficient modification system would be based on use in large regions. The northern Great Plains, for example, would best be treated as a "suppression region" because its hail climate indicates there is homogeneity in its hail-producing weather conditions —as there is in its crops. Other potential "suppression regions" for the future include the central and southern Great Plains, the Midwest, and the central Atlantic Coast.

*Large-region  
suppression  
efficient*



Future hail suppression activities, whether or not performed in combination with rainfall modification, will incorporate operational systems involving three components:

- The seeding system, including the delivery vehicles and the seeding materials
- The support facilities and activities, generally including operational weather radars, forecasting activities, and buildings
- A trained staff for all phases of the system

The components of future projects will not be unlike those of the statewide seeding program in South Dakota (*Williams, 1973*) and the current program in North Dakota. The envisioned operational system would also be similar to that developed in South Dakota —basically, a group of aircraft operating with a given radar, then several different radar sites each with aircraft, and a statewide forecasting system (*Division of Weather Modification, 1974*).

The analysis of the operational suppression systems of the future was treated on the basis of the areal scale of effort. This was divided into "small-scale areas" — 1000 up to 5000 square miles —and "large-scale areas" — 5000 to 15,000 square miles. This was to accommodate differences in adoption by large or small areas based on operational-cost analyses. These had revealed that costs over areas of 15,000 square miles were less than those over 5000 square miles or less, a condition noted in Borland's (*1975*) analysis of cost effectiveness of ongoing hail suppression projects. Any areas larger than 15,000 square miles would be a replicate of the facility and approach recommended here for the large-scale areas.

*Areal scale  
differences  
important*

The organizational approaches to handling the operational suppression systems will vary. It seems likely that the operations over small-scale areas (5000 square miles or less) should and will be arranged and managed locally. However, large-area operations would have to be managed by a state (*Williams, 1973*), a large corporation, or a federal agency. It seems likely that very extensive

## **OPERATIONAL COMPONENTS**

suppression systems for multi-state programs will ultimately be controlled and managed by a federal agency (*Domestic Council, 1975*). The envisioned elements of the operational system are those shown in *Figure 51*.

*First —  
delivery  
systems*

First, let us look at the delivery systems expected for hail suppression use in the future — through 1985 and 1995.

The means of delivery of seeding materials into the critical portions of storms where hailstones are formed, and the diffusion of these materials within storms, have varied widely (see Chapter 4). In general, delivery systems used in the future will be of two classes:

- 1) The *indirect air transport* in which atmospheric motions transport the seeding materials to the critical area inside the storm and diffuse it within the storm
- 2) The *direct delivery approach* in which the seeding material is placed directly inside the critical storm area, often with a built-in means of diffusing the material within a volume of the cloud

*Delivery  
techniques*

The techniques envisioned for future use in hail suppression will involve either aircraft (with seeding materials dropped from cloud tops into the storms or released below storms in updraft zones), or surface-to-air rockets containing seeding material for firing into storms (see *Figure 20*). Each of these techniques has been diagnosed as to its utility, safety, cost, and future developmental needs. Also, their potential was evaluated in light of both local-area suppression projects and large-area projects, since different arrangements will be needed over different sized areas.

*Cloud-base,  
standard  
aircraft*

There are three basic potential seeding systems of the next 20 years. The first is the cloud-base approach involving standard available aircraft which release seeding material into the updrafts at the bases of thunderstorms. This technology exists and certainly is a distinct possibility for application up through 1995, and its costs for small and large areas are the lowest of the three delivery systems (as will be seen in *Table 39*). The cloud-base approach now has certain problems with major complex storms and those at night.

This technique can be modified by use of small rockets fired from the aircraft, as used in NHRE in 1974. However, there is an uncertainty about the aiming and targeting of these rockets. That could be resolved in the future by use of better "control" radars, particularly airborne radar systems.

*Cloud-top,  
high jet  
aircraft*

The second seeding system considered is also an existing technology. It consists of high-flying jet aircraft that inject seeding material downward into the tops of growing storms. This "cloud-top" delivery technique is more direct than the cloud-base approach and more capable of meeting the glaciation approach to suppression. However, it also has limitations relating to treatment of some complex storms.

*Techniques  
that are not yet  
suitable*

Seeding from the ground with inexpensive silver iodide generators may be usefully done in conjunction with aircraft seeding in mountainous areas. However, on the basis of avail-

able results and expectations for technological developments of the next 20 years, it is not considered a suitable suppression technique in the near future and in most areas.

It is conceivable that atmospheric modeling (conceptual and numerical) will eventually suggest means for massive atmospheric seeding from ground generators, but this approach likewise cannot be expected within the next 20 years. Research on this subject should be pursued.

The third approach considered consists of surface-to-air rockets, which can deliver desired amounts of seeding materials directly to hail formation zones up to levels of 25,000 feet and out to distances of 10 miles. Such rockets are currently available for purchase from the Soviet Union (see *Figure 17* in Chapter 3) and Czechoslovakia, and it seems reasonable that similar rockets could be made available by United States firms with proper developmental activity by 1985.

*Rockets from  
surface  
to clouds*

However, there are problems with the use of surface rockets, including air space safety for private and commercial aircraft, high costs, and development of a system for firing the rockets. These factors suggest that adoption of surface rocket seeding systems will represent a substantial commitment and will likely not develop across wide areas. The control of the rockets and the trade-offs for freedom of air space would be more acceptable in areas where hail is a serious problem.

*Air safety,  
costs are  
problems*

Under the first two technologies involving aircraft, all that is required basically would be an airfield and related facilities at radar centers. In the rocket approach, the radar system would be employed as a regional command post. To obtain personnel (available 24 hours a day) over large areas who would be capable of pointing and firing the rockets will require the training and employment of citizens as rocket launchers — at considerable cost.

*Training  
personnel  
a problem*

Fulfilling this activity would require finding and training personnel (three per site) scattered around the seeded area at distances of about 10 miles apart. It would involve a communication system to the radar from each launch site and training in the firing of the rockets. In this approach, the radar operational center would diagnose the needs for rocket usage and then instruct each appropriate rocket site for aiming and action. It is likely that the cloud-top and cloud-base approaches will be combined as a dual technique.

Activities relating to the two aircraft-seeding techniques would be less costly over large-scale areas than over small areas because of a lack of replication of forecast facilities at each radar center and a more efficient use and deployment of seeding aircraft. The cloud-top approach over an area of 15,000 square miles of the Great Plains or Midwest would involve six jet aircraft such as Lear types 23 or 24, with an average residence time aloft of 2.5 hours, plus one jet with longer residence time to move with the traveling storm systems and to cover refueling outages of the shorter range jets. The cloud-base approach over 15,000 square miles would need 17 twin-engine aircraft.

*Various  
aircraft  
required*

*Second —  
future  
seeding  
materials*

As a second element of the future operational suppression program, we will consider briefly the seeding materials that may be used in 1985 and 1995.

The seeding materials most often used have been silver iodide or lead iodide, each of which make ice nuclei to enhance nucleation of the supercooled water in the cold part of the storm, as discussed in Chapter 4. Hygroscopic materials that attract moisture, such as salt, have also been employed to alter the coalescence process in the warmer parts of the cloud.

Within the next 20 years it is envisioned that the primary seeding material in use will be silver iodide, although hygroscopic nuclei may be employed in certain types of clouds and certain regions. There is much greater uncertainty at this stage about the effects of hygroscopic seeding on hail development.

*Third —  
future  
support  
facilities*

Each future field operational unit, whether on a local scale or in a larger scale program, will focus its operations around a sophisticated weather radar system. This system, coupled to a computer, will be used to detect potential storms for seeding, to direct the seeding vehicles, and to store data. Current weather radars and signal processing systems are generally adequate to the needs of future hail suppression programs.

An important part of the field operation system is the forecast center. In a local-area project, this will undoubtedly exist in conjunction with the radar operational center. In large-scale area projects, modeled to cover areas from 5000 up to 50,000 square miles, there will be several radar centers but only one regional forecast center like that used in South Dakota during 1972-1975. The function of the forecast centers will be to develop, on scales of 3 to 72 hours in advance, forecasts of hailstorm activity, both in time and space. Greater study of and attention to storm forecasting will certainly lead to improved forecasting of hailstorm conditions. This will be assisted as new computer techniques and data from satellites are used more effectively in project areas.

## **COSTS OF SUPPRESSION PROJECTS**



In a 1973 analysis of costs of 11 hail suppression projects, Borland (1975) revealed a wide range of costs. These generally varied inversely with the size of the seeded area. The costs listed for all acres, not just planted acres, varied from a low of 2 cents per acre in a large North Dakota project to 4 cents in the South Dakota statewide project, up to 23 cents per acre in two small-area Texas projects.

These costs involved different facilities, project durations, seeding approaches, profit margins, and seeding rates to the extent that the number of storms seeded and the amount of seeding material per storm likely differ and their costs are hard to compare.

*Assumptions  
for costs*

Thus, to establish a common base for comparing costs of the three different seeding systems considered viable for future suppression efforts — cloud-base

seeding, cloud-top seeding, and surface-to-air rocket seeding — an analysis of each was performed on the basis of a series of assumptions. The critical assumptions included:

- Staff and facilities for treatment of 80% of the storms in an area during a six-month operational period
- An average frequency of storms of 400 in 5000 square miles and 1000 in 15,000 square miles
- A 10% profit margin
- A weather forecast center
- A sophisticated radar system with computer and data storage systems
- Use of silver iodide seeding rates aimed to deliver 100,000 nuclei per cubic meter, effective at the  $-10^{\circ}$  C level in clouds.

These are operational costs and do not include those relating to monitoring and evaluating the effectiveness of the suppression operation, discussed in the next section.

We show the costs of the three operational approaches calculated for use in both small-scale areas and large-scale areas in *Table 39*. Because of the stringent assumptions used, particularly the one calling for seeding of a large percentage of all possible storm cells, the calculated costs are greater than those of most current projects, which are in the 10 cent to 20 cent per acre range (*ESIG, 1975; Davis, 1975*).

Comparison of the costs in *Table 39* reveals the considerable expense of the envisioned surface rocket system. This indicates that emphasis should not be placed on the development of surface-to-air rockets, nor on institutional considerations about their utility, unless their modification capability can be shown to be markedly better than that of the aircraft approaches.

Hopefully, the European experiment beginning in 1976, discussed in Chapter 3, will define the rocket capability by 1980. Since their widespread use is not likely for several social reasons, it appears that either or both of the aircraft approaches will be most widely employed.

Costs become less in the aircraft approaches going from the smaller to larger areas. The aircraft approaches also offer a flexibility advantage of rapid installation and operation that the rocket approach would not have (*Borland, 1975*). Off-season nonoperational hail suppression periods will vary between five months in the southern hail zones to seven months in the northern hail zones. During these nonoperational periods, project crews can be involved

*Aircraft  
operation  
flexible*


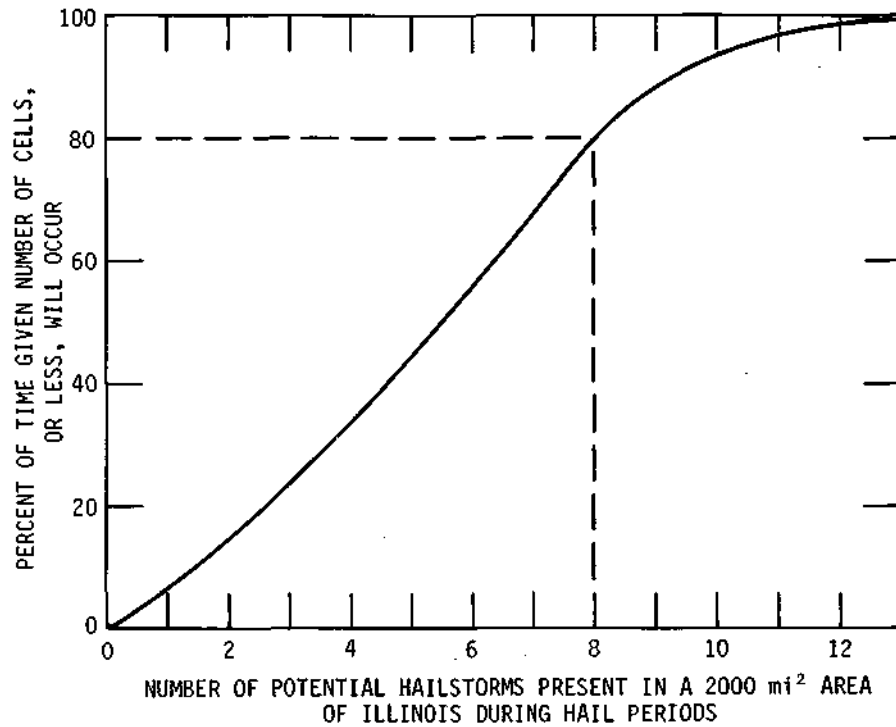
 <b>TABLE 39</b> <b>Costs of future hail suppression</b>		
	Annual costs (1975 dollars)	
	Per square mile	Per acre
<i>Small-scale areas (5000 square miles)</i>		
Cloud-base approach	100	0.16
Cloud-top approach	219	0.34
Surface-to-air rockets	272	0.43
<i>Large-scale areas (15,000 square miles)</i>		
Cloud-base approach	86	0.13
Cloud-top approach	181	0.28
Surface-to-air rockets	272	0.43





FIGURE 52

Frequency of potential hailstorms



in operations for other types of weather modification, preliminary data evaluation, equipment maintenance, and vacation. Again, the flexibility of weather modification systems is an important virtue.

*Seeding  
all storms  
impractical*

It is probably not realistic to staff and fund hail suppression projects to seed all potential hailstorms. There is a great savings in cost to be realized by having facilities only for treating 70 or 80% of all hailstorms. This is illustrated by Figure 52, which is based on Illinois hail data (Changnon and Morgan, 1976b). It shows the percent of the time during storm periods that a given number, or fewer, potential hailstorms (defined by radar echo entities whose reflectivity exceeds a certain value indicative of hail potential) were present in a 2000-square-mile area of Illinois.

*Cost of being  
able to treat  
all storms*

If, for discussion, the problem of planning is reduced to one involving only the factors derivable from this graph, several useful facts can be obtained.

First, to treat all storms, one would need enough delivery systems (say, aircraft) and staff to treat 13 storms at one time. However, with such means available to it, the project would have many facilities and staff seldom used in comparison with the means for treating only 8 storms — the maximum conditions present 80% of the time.

If one aircraft were needed for each storm, a 5/13 savings in aircraft and crews could be achieved by not seeding some of the storms during 20% of the time hail occurs.

In fact, consideration of the shape of the curve (*Figure 52*) shows the overall loss due to designing for full seeding capability 80% of the time will amount to only 10% of storms. Thinking inversely, to cover the 10% of storms which are lost at that level would require multiplying the seeding aircraft and staff costs by 13/8. We can write that the net effectiveness is:

$$E_N = ExP$$

where  $E$  is the maximum achievable effectiveness, and  $P$  is the percent of storms to be treated.

In general, cost of hail suppression is a nonlinear function of  $P$  and must be based on distributions such as that shown in *Figure 52*. Basically, low-cost (2 to 5 cents per acre) hail suppression projects inherently admit to an overall low effectiveness — that is, many hailstorms go unseeded.

Let us look again at the Texas and South Dakota projects. As was shown in *Table 12*, the small-scale Texas project attained a 48% reduction in crop-hail loss versus only 20% reduction in South Dakota. The Texas program cost 23 cents an acre compared with 4 cents an acre in South Dakota. The differences may reflect not only different seeding effectiveness, cloud type differences, areal extent economies, or a better seeding skill in Texas — but also a *greater commitment* of resources to ensure that a greater number of storms are seeded.

It will be noted that the economic impact analyses in Chapter 10 used a charge of \$1 per acre for hail suppression. This was done to account for a variety of cost uncertainties. The primary difference between the costs here and that figure rests in the fact that this analysis required costing for *all acres*, whereas the economic analysis involved only *planted acres*. Other uncertainties, such as regional differences, development costs, and possible liability increases, made the \$1 cost a reasonable figure for broad areas in the national economic analysis.



The continued application of hail suppression, especially on state and larger regional scales, requires careful monitoring and evaluation. A key signal from past efforts in weather modification has been that — without evaluation of the efforts — doubts and problems arise about the modification obtained (*Changnon, 1975b*). Thus, the means to accomplish the monitoring and evaluations needed, and the costs to meet these needs, are a part of a system to be considered in future hail suppression programs, particularly the nonexperimental operational ones (*Domestic Council, 1975*).

Means for monitoring and evaluating the suppression results are varied — but difficult in a nonrandomized project. The system envisioned will monitor and establish quantitatively the alterations of hail, rain, and other related weather phenomena being affected by future hail suppression projects. This will be done through both physical evaluations and statistical techniques. Furthermore,

*Calculating  
system's net  
effectiveness*

*'Low cost'  
equals 'less  
effective'*

*Texas —  
greater  
commitment*

*Basis for  
different  
cost figures*

## **MONITORING, EVALUATING SUPPRESSION**

*Physical,  
statistical  
evaluations*

research and development to better understand and improve the seeding technology will be a part of this system. The three elements of this system have been shown in *Figure 51*.

*First —  
collect,  
store data*

The first function will be collection and storage of essential data. This will include all possible information on crop losses from hail collected through insurance companies and by remote sensing involving aerial surveillance (*Changnon and Barron, 1971*). Information on property losses will be obtained through field investigations and remote sensing by aerial surveillance. In addition, revised methods to collect property insurance data so as to identify hail, wind, and lightning losses separately will be used.

*Remote  
sensing  
needed*

These efforts will require *developments* in the remote sensing of hail and other types of weather damages using aerial photography and satellite sensors, as well as action by the property insurance industry to identify losses due to each type of weather hazard.

*Radar echo  
model  
by 1985*

As additional information, echo data from the radars of the operational system will be collected at each operational site. Operations of these radars in a three-dimensional scanning mode will allow the study of echo behavior. Future experimentation should define by 1985 a predictive model of echo activity after seeding. Finally, all types of weather data including rainfall and upper air data will be utilized to evaluate the storm activity in line with mesoscale numerical models.

*Monitor  
downwind,  
environment*

As part of the data collection and evaluation effort, a network of precipitation samplers will be established at existing Environmental Data Service stations throughout the seeded region and within 100 miles of its borders to obtain downwind effects. These samples can be routinely analyzed for the presence of the seeding material. This activity will be useful in the evaluation of the seeding effectiveness by where it is found, and for monitoring the amount of potentially undesirable seeding material, such as silver, going into the environment. Soil and plant samples would also be routinely collected at a few sites throughout the seeded region to monitor the amount of silver or other seeding material accumulating in the region and the effect of the altered weather on the ecosystem.

*Second —  
analysis of  
data collected*

As the second major function, the analysis activities will involve comparison of radar echo results against cloud models and against predicted behavior of seeded storms under different synoptic weather conditions.

As noted, future experimentation will establish the type of echo behavior when hail is diminished so that echo behavior can be used as a control.

The hail and rainfall data for the seeded area will be compared with that from the premodification periods and with that from adjacent areas not undergoing seeding. This effort will also include the study of hail and rainfall areas downwind of the seeded region to detect changes and to quantify them.

As shown in *Figure 51*, the evaluation system will also have a third arm, a research component. The research group will perform the evaluation of results to determine better seeding techniques and delivery systems. Laboratory studies will focus on research and development of new seeding materials.

*Third —  
research  
component*

It seems likely that the monitoring and evaluation system envisioned will be operated by a governmental agency (*Domestic Council, 1975*). Included in its activities will be the collection of all historical data on hail losses plus past and current data on rain, hail occurrences, and radar echoes for areas in the seeded regions and within 100 miles of their boundaries. Evaluation will include continuing assessment of the economic aspects of the program.

*Operated by  
government  
agency*

This system would serve a 50,000 square mile region, for which a detailed cost analysis has been made (*Changnon and Morgan, 1976c*). Costs relating to data collection, data processing, analyses, evaluation, research, and all facilities would be \$1.5 million per year or 0.047 cents per acre of all land. Facilities would include a building, a computer system and related equipment, and surveillance aircraft and special equipment. These facilities are readily available and do not require any developmental costs.

*Costs of  
evaluating*

Basically, staff needs will include meteorologists and statisticians to perform these activities with a few biologists and economists. Any major development of hail suppression over two or three, or more, large regions would necessitate trained personnel currently unavailable. This will require emphasis on specialized training of atmospheric scientists and statisticians to meet the unique needs of this system.

*Staff  
needs*

It seems likely that the "program design" effort, essential for future hail suppression growth, will be an activity handled by federal agencies, either by their staffs or by contract to qualified weather modification groups or companies. These design activities will logically be housed and performed within the organization handling the monitoring and evaluation of projects. The costs of these activities are a part of the organizational costs already identified.



A small but key component of a hail suppression program is its information and educational activities. This activity is the interface of the project with the public in the project area and with nonproject interested parties.

## **INFORMATION SYSTEM**

Public attitude studies regarding weather modification (*Haas, 1973*) clearly point to the importance of thorough public education on weather modification and the maintenance of routine communications about the project results. Informed citizens groups, such as NHRE employed (*Borland, 1975*), are helpful.

*Public  
education  
needed*

A second information effort relates to the transmission of project information to nonlocal (project area) parties who have a stake in the outcome. These include other scientists, insurance interests, affected weather industries, governmental agencies, and regulatory bodies.

**TABLE 40****Estimates of future status of hail suppression**

	<i>Great Plains (West)</i>		<i>Midwest (East)</i>	
	<i>Hail</i>	<i>Rain</i>	<i>Hail</i>	<i>Rain</i>
1995 — ISWS opinion survey median values	-70%	+20%	-60%	+20%
2000 - CSU workshop values	-75%	+15%	-50%	+10%
1995 — Scientific models				
Model 1	-80%	+16%	-60%	+10%
Model 2	-54%	+9%	-18%	-6%
Model 3	-30%	0	-21%	+9%

In small-area projects, local project officials and members of weather modification firms will typically share in this low-cost, but important, function. In large-area, multistate programs, this function would need to be coordinated and handled by a single body, potentially the federal agency performing the monitoring and evaluation. The cost would be negligible, estimated at \$50,000 for a 50,000 square-mile area (\$1 per square mile).

**SUMMARY LOOK AT FUTURE CAPABILITY**

Six future weather modification models were developed on the basis of the great differences found in the current status. They reflect a wide range of possible technologies, both in 1985 and 1995. These model values are assumed to be scientifically certain, representing an average statistical change and not one occurring on any given day. They are not considered to have an equal likelihood of occurrence, on the basis of past development of weather modification.

*Estimate  
most likely*

The models of moderate scientific advance based on intermittent experimentation and applications seem second most likely, indicating a hail suppression capability in 1995 of -18% in the eastern U.S. and -54% in the western U.S. The experimental-focus model is considered the most likely outcome —and the model of application plus major scientific advances seems least likely.

We present in *Table 40* the estimates of the future status of hail suppression. The first set of values is for 1995 obtained from the opinion survey carried out for TASH, and the second set is for the year 2000 from a 1975 workshop on weather modification (*Grant and Reid, 1975*). The 1995 values for the three models in *Table 38* are shown for comparison. The values show that the scientific belief is:

- The capability to decrease hail will improve with time

- The hail suppression capability in the Great Plains will be greater than that in the Midwest and elsewhere in the nation

Of interest also is the fact that the 1995 medians from the opinion survey are in agreement with those of the workshop, both indicating hail reductions with simultaneous rain increases of a similar magnitude 20 to 25 years from now. Some of the future seeding models have values comparable to those expected by the scientists and representatives of hail suppression companies who were sampled.

*Suppression  
of hail will  
improve*

Although the future modification models are focused on hail suppression capabilities with some form of change in attendant rainfall, it seems likely to expect that most future hail suppression efforts will be combined with efforts to simultaneously increase rainfall. Present large-area projects (South Dakota and North Dakota) have this mix toward more complete modification of growing season weather.

*To combine  
hail, rain  
modification*

Borland, S. G.

- 1975 *Hail suppression: Progress in assessing its benefits and costs.* /« NHRE Symposium/ Workshop on Hail: Preprint vol. 1, NCAR, Boulder, 50 pp.

Braham, R. R.

- 1974 *Cloud physics of urban weather modification: A preliminary report.* Bulletin American Meteorological Society, 55, 100-106.

Browning, K. A., and G. B. Foote

- 1975 *Airflow and hail growth in supercell storms and some implications for hail suppression.* NCAR, Boulder, NHRE technical report 75/1, 75 pp.

Changnon, S. A.

- 1968 *The La Porte anomaly: Fact or fiction?* Bulletin American Meteorological Society, 49(1), 4-11.
- 1972 *Urban effects on thunderstorm and hailstorm frequencies.* Preprints, Conference on Urban Environment, American Meteorological Society, Boston, 177-184.
- 1974a *Interim report of METROMEX studies: 1971-1973.* Illinois State Water Survey, Urbana, Report NSF GI-38317, 181 pp.
- 1974b *A review of inadvertent mesoscale weather and climate modification and assessment of research needs.* Preprints, 4th Conference on Weather Modification, American Meteorological Society, Boston, 347-352.
- 1975a *Scales of hail.* In NHRE Symposium/Workshop on Hail: Preprint vol. 1, NCAR, Boulder, 52 pp.
- 1975b *The paradox of planned weather modification.* Bulletin American Meteorological Society, 56, 27-37.

Changnon, S. A., and N. Barron

- 1971 . *Quantification of crop-hail losses by aerial photography.* Journal Applied Meteorology, 10, 86-96.

Changnon, S. A., and G. M. Morgan

- 1976a *The present status and future potential of hail suppression.* Journal Weather Modification, 8(2), 164-189.

## REFERENCES

- Changnon, S. A., and G. M. Morgan (*continued*)
- 1976b *Design of a hail suppression experiment for Illinois.* Illinois State Water Survey, Urbana, Bulletin 61, 194 pp.
  - 1976c *Costs of future of operational hail suppression projects.* Illinois State Water Survey, Urbana, TASH working paper 6.
- Changnon, S. A., and R. G. Semonin
- 1976 *Studies of selected precipitation cases from METROMEX.* Illinois State Water Survey, Urbana, Report of investigation 81, 329 pp.
- Crow, L.
- 1969 *Relationships between hail and rain in Kansas, Nebraska, and eastern Colorado.* Loren Crow, Inc., Denver, Colorado, Final report NSF-G-522, 34 pp.
- Davis, L. G.
- 1975 *Recent advances on hail suppression operations.* Paper presented at International Association of Hail Insurers Congress, Copenhagen, Colorado International Corporation, Boulder, 6 pp.
- Dennis, A.
- 1969 *The theory and practice of hail suppression.* Institute of Atmospheric Sciences, South Dakota School of Mines and Technology, Rapid City, 8 pp.
- Division of Weather Modification
- 1974 *The South Dakota weather modification program.* Department of Natural Resource Development, Pierre, South Dakota, Report DWM R-74-2.
- Domestic Council
- 1975 *The federal role in weather modification.* Environmental Resources Committee, Subcommittee on Climate Change, Washington, D.C., 29 pp.
- Environmental Societal Impacts Group
- 1975 *Environmental impact statement national hail research experiment.* NCAR, Boulder, Draft of 3 November, 65 pp.
- Grant, L. O., and J. D. Reid
- 1975 *Workshop for an assessment of the present and potential role of weather modification in agricultural production.* Colorado State University, Ft. Collins, Atmospheric science paper 236, 236 pp.
- Haas, J. E.
- 1973 *Social aspects of weather modification.* Bulletin American Meteorological Society, 54(7), 647-657.
- Huff, F. A.
- 1960 *Relations between summer hailstorms in Illinois and associated synoptic weather.* Prepared for CHIAA, Chicago, Research report 5, by Illinois State Water Survey, Urbana.
- Miller, J. R., E. I. Boyd, R. A. Schleusener, and A. S. Dennis
- 1975 *Hail suppression data from western North Dakota 1969-1972.* Journal Applied Meteorology, 14, 755-762.
- Semonin R. G., and S. A. Changnon
- 1974 *METROMEX: Summary of 1971-1972 results.* Bulletin American Meteorological Society, 55,95-100.
  - 1975 *METROMEX: Lessons for precipitation enhancement in the Midwest.* Journal Weather Modification 7, 77-87.

Silverman, B., and L. Nelson

1975 *Some model results for natural and seeded hail-bearing clouds.* NHRE Symposium/ Workshop on Hail: Preprint vol. 1, NCAR, Boulder, 15 pp.

Simpson, J.

1973 *Bayesian statistics applied to Florida cumulus modification experiments.* Preprints, 3rd Conference on Probability and Statistics, American Meteorological Society, Boston, 73-80.

Stout, G. E.

1965 *Summary of research on hailstorms during 1964.* Crop-Hail Insurance Actuarial Association, Chicago, Research report 24, 53 pp.

Williams, M.


1973 *Progress in the South Dakota Weather Modification Program.* Proceedings of the Southern Plains Region Cloudtap Conference, Texas Water Development Board, Austin, 111-126.



## SUMMARY OF CHAPTER 8

### THE FUTURE OF THE TECHNOLOGY

*Uncertainties  
required three  
future models*

 The assessment of future hail suppression was based on three models, or levels of capability, to modify hail and associated rainfall in 1985 and 1995. These model estimates provided the basis for subsequent socio-economic modeling of impacts and estimates of adoption.

Three models were chosen because of the uncertainty about the current status of hail suppression, and they reflect a wide range of possible capabilities. Various assumptions about scientific and technical developments, both in the western and eastern United States (separated because of storm type differences) were made. Model 1, leading to substantial capabilities by 1985 and 1995, reflects both wide operational usage and a major scientific breakthrough. Model 2 was less optimistic and Model 3, based on moderate experimentation and minimal operational activities, led to a very limited capability by 1995. Opinion surveys of weather modification experts about likely future capabilities are within the range of the three models. Quantification estimates of the three models are given in *Table 38*.

*Future  
design and  
operations*

Future growth of hail suppression activities will require attention to four program elements — design, operations, evaluation, and an information system. The likely regional nature of hail suppression application, often crossing state boundaries, will necessitate sophisticated technological designs. The operational efforts will potentially involve three types of seeding systems (aircraft dispensing a nucleant at cloud base, aircraft dispensing a nucleant inside storms, and, less likely, use of surface rockets to dispense the nucleant). Such operations will necessitate forecasting and storm-monitoring systems and specially trained operational staffs. Effective operations would typically embrace a mix of staff with scientific and operational expertise, ground (radar) facilities, and aircraft operating most effectively as modification units over areas of either 5000 or 15,000 square miles.

*Future  
cost  
estimates*

Operational costs per acre (in 1975 dollars) for a 15,000-square-mile unit would be 13¢ for the cloud base aircraft approach, 28¢ for in-cloud aircraft, and 43¢ for rockets. For subsequent economic modeling, a cost of \$1 per acre was set to allow for other costs (evaluation and information activities), plus uncertainties about costs for development, liability, etc.

*Evaluation will  
be a future  
necessity*

A key aspect of future regional usage of hail suppression will be an ongoing evaluation effort to assess, both on a statistical and physical basis, the program's effectiveness and any effects on downwind weather. Techniques to perform this difficult task must be developed. The evaluation task will involve monitoring and research skills best developed and conducted in a regional laboratory serving the project.

*Information,  
education  
also required*

A fourth major element of these future regionally focused programs will concern an information-education activity to routinely inform the public of the program — its elements, activities, and results.

Most future design, operations, evaluation, and information activities will either be conducted or closely supervised by state and federal agencies because of the regional character of the programs.

# 9

## Future adoption patterns



We now come to the key integrative analysis made for TASH. Here we combine the variables for the future adoption of hail suppression — under the conditions of the six scientific models presented in Chapter 8.

In this chapter we describe the methods used to estimate the values of economic incentive, legal receptivity, and socio-political factors influencing the adoption of hail suppression. We also describe the complex integration of these factors and present the patterns of future adoption of hail suppression derived from them for each version (model) of the future development of scientific potential.

### METHODS USED TO ESTIMATE FUTURE ADOPTION OF HAIL SUPPRESSION\*



Given the three alternative routes (models) of hail suppression's potential development, future adoption patterns were assessed on the basis of a number of important economic, legal, and socio-political variables. Only regional-level variables were included, with the exception of part of the economic analysis which considered the individual farmer's economic incentives for adoption, described in Chapter 7.

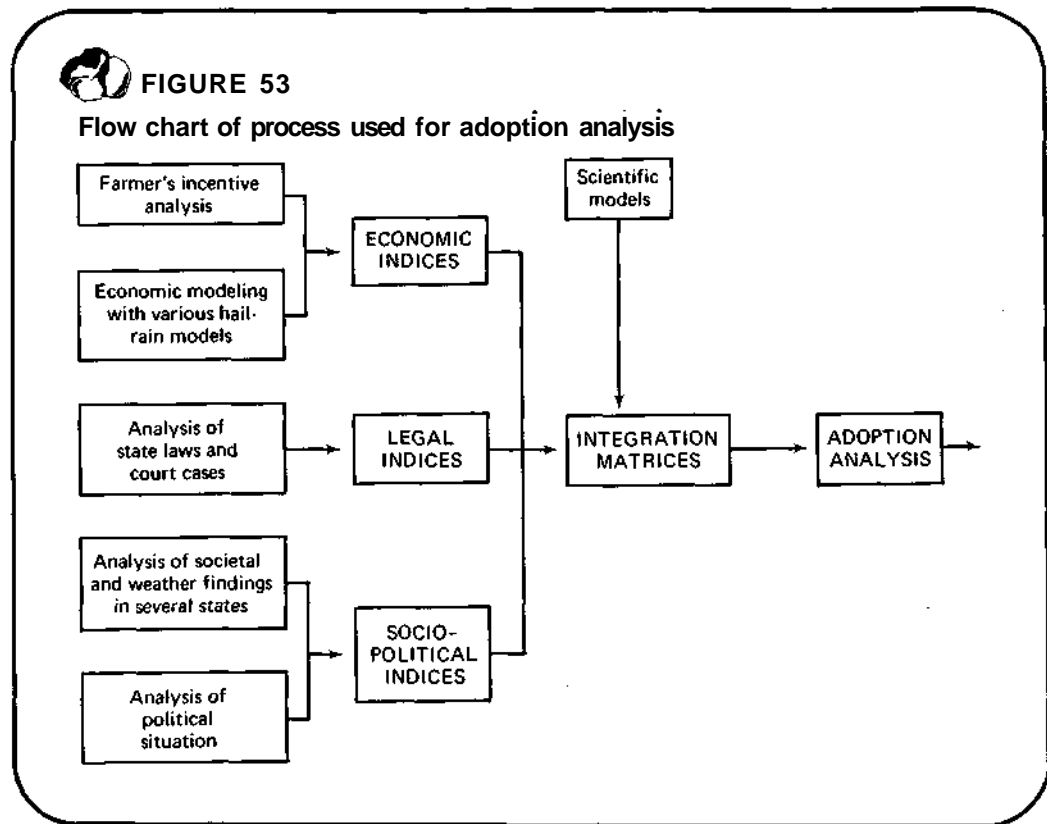
Adoption refers to the utilization of hail suppression technology either experimentally or operationally in an area.

*'Adoption'  
defined*

In the analysis described here, adoption was projected to occur or not to occur in various crop-producing areas of the United States. Generally, each state is divided by the U.S. Department of Agriculture into several relatively homogeneous crop-producing areas. These areas, 132 of which were analyzed, served as the units of analysis (see map in *Figure 57*, Chapter 10).

The three types of variables — economic, legal, and socio-political — affecting adoption and the meaning of the numerical coding assigned each are described


\*This section contributed by Barbara C. Farhar.



*Analytical process*

in this section. Complete data matrices are presented in HERS (1976), a sample of which is depicted later in Figure 55. The estimates of adopting and nonadopting areas were necessarily dichotomous in order to fulfill the requirements of the TASH national economic analysis. The variables used in analysis are interrelated in complex ways, approaching the relevant factors from different perspectives; none are simultaneously determined with adoption. Coding for the variables falls within the range of -3 to +3, but some are restricted to narrower ranges on the basis of their nature and importance. The restricted variables do not influence the adoption results as much as the others. We also describe the procedures used in analyzing the data to produce the adoption estimates for each of the models. The flow chart in Figure 53 illustrates the process used in integrating the social-economic-legal-political (SELP) constraints and incentives and in making the estimates of adoption.

**ECONOMIC INCENTIVE INDEX VALUES\***

 Values of the economic incentive index (EII) for each of the crop-producing areas are indicators of the strength of an economic incentive for adoption of each of the three models representing six assumed levels (three each for the East and West) of performance of hail suppression technology for 1985 and 1995.

"Economic incentive" in this context has a rather restricted meaning. The potential total revenue increase estimated for each of the six future technology levels may be viewed as a technical, nonbehavioral variable indicating potential financial gain to producers in each area.

\*This section contributed by Earl R. Swanson, Jon van Blokland, and Steven T. Sonka.

The scope and nature of the economic preference function indicating the strength of the economic incentive can be described as follows: We have a preference function which depends on the mean total revenue increase potential  $\langle TRIP \rangle$  and a measure of risk  $R$ , which is represented by some feature of the distribution of  $TRIP$ . Thus we have

$$EII = f(\langle TRIP \rangle, R)$$

We assume that EII is an increasing function of  $\langle TRIP \rangle$  (more revenue is preferred than less), but at a decreasing rate. We assume EII is a decreasing function of  $R$ , i.e., less risk is preferred to more risk. The values for  $TRIP$  and  $R$  are assumed to be those represented by our data and not those necessarily perceived by producers. The considerations dealing with uncertainty of the information base for decision making are dealt with by other variables in the adoption. Thus, the economic evaluation of  $R$  is a very restricted one dealing only with the naturally caused year-to-year yield variation. In the calculations underlying  $TRIP$  the performance of the various hail-suppression capabilities was viewed as fixed or deterministic.

*How increase  
is determined*

Construction of the EII values began with estimation of the crop yield effect of each of the six technology levels in the models. In addition, the effect of precipitation augmentation was taken into account in Hail Regions 4, 6, 7, 9, and 12 — the most important hail loss areas. This evaluation was based on a regression analysis of yields of each of the major crops in each state and rainfall values during the months in which the hail suppression activity would be expected to occur.

*Effect on  
crop yields*

The percentage increase in total revenue  $TR$  from crop production due to the hail suppression technology level under consideration was chosen as the *critical variable* upon which the EII was based. The total revenues for each crop within a producing area were summed to derive a total revenue for the area, assuming use of each of the six technology levels. In addition, total revenue for a no-hail-suppression-technology situation, or benchmark, was calculated as a base of comparison.

*% increase  
in total  
revenue  
critical*

In general, the total revenue for a given producing area with  $i$  crops may be expressed as follows:

$$TR = \sum_i A_i Y_i P_i$$

*Equation 1 —  
total revenue*

Where

$A_i$  - acres of the  $i$ th crop

$Y_i$  = yield of the  $i$ th crop

$P_i$  = price per unit of the  $i$ th crop (five-year national average for the  $i$ th crop, 1970-1974)

With this general representation, the expected potential impact, in terms of economic incentives, of hail suppression may be gauged by the following comparisons of total revenues for a given production area:

$$\frac{TR(\text{Model } m, \text{ Time period } t)}{TR(\text{Benchmark}, \text{ Time period } t)} \times 100 = TRIP$$

*Equation 2 —  
revenue potential*

Where:

$m$  = models 1, 2, and 3

$t$  = 1985 or 1995

**TABLE 41****Conversion of TRIP values to EII**

<i>Total revenue increase potential</i>	<i>Economic incentive index</i>
115 and above	+3 —A strong positive economic incentive
105 to 115	+2 —A moderately strong positive economic incentive
102 to 105	+1 —A weak or marginal positive economic incentive
100 to 102	0 —No interest from an economic standpoint
less than 100	-1 —A weak or marginal negative economic incentive

It should be noted that the only variables which differ in value between the numerator and denominator of equation 2 are the yields,  $Y_i$ . The acreages and prices are constant within a given time period, 1985 or 1995. The differences in yields are due to effects of hail suppression and its consequent rainfall effects.

*Determining  
the effects  
of hail*

Hail effects were determined by taking the appropriate percentage of the 100% reduction in hail losses. For example, if yield is normally 100 bushels per acre and yield with no hail loss is 101 bushels per acre, then a 30% effective hail suppression technology, without rain effects, would increase yield by 0.3 bushels per acre. The rainfall effects were calculated in a similar manner.

Thus, the value of the index represented by equation 2 would be 100 if the hail suppression technology had no effect on total revenue. But, if the hail suppression technology increased total revenue by 5%, then the index would be 105.

Note that the comparisons are always within a given time period (1985 or 1995) and that the "benchmark" situation represents no employment of hail suppression technology.

In order to develop the EII for each area under each of the six technology levels, it was necessary to relate the values from equation 2 to the EII. We show this relationship in *Table 41*.

*Relating  
TRIP to  
EH values*

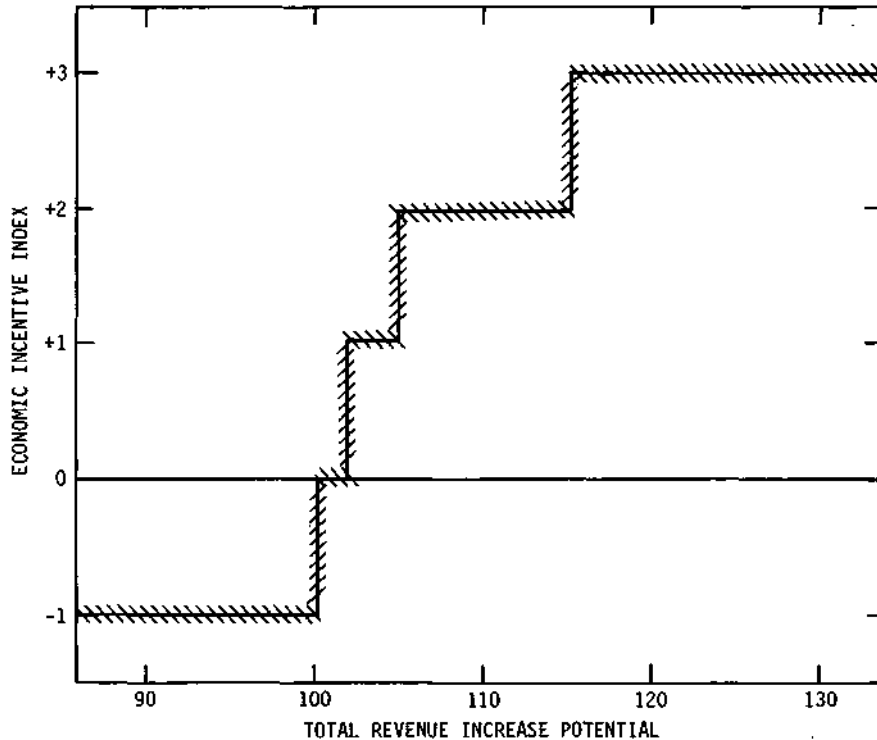
In developing this relationship, we drew partially on existing economic theory dealing with utility. In *Figure 54* we indicate the general shape of the assumed relationship. Note the incentive increases at a decreasing rate.

In addition, data from the detailed farm analysis in Chapter 7 provided information on risk considerations in terms of the impact of hail suppression technology on year-to-year income variability, as well as the impact on average returns. These results were used, in an informal and judgmental way, to assist in making the necessary judgments concerning the EII-TRIP relationship. The EII values for each crop-producing region are presented in the matrices (*HERS, 1976*).



**FIGURE 54**

**Relationship of economic incentive index to total revenue increase potential**



The 1975 receptivity of the legal regime to the adoption of hail suppression was set forth in *Table 29* of Chapter 6. These values were derived from data on two major legal variables which affect the adoption of hail suppression. These are:

- The extent of legal regulation of hail suppression
- The extent of support of governmental hail suppression through state funding and appropriation laws

The numerical values of adoption receptivity shown in *Table 29* indicated that the estimated positions of the states range from a -1, representing the least favorable legal climate for adoption of hail suppression, to a +3, the most favorable. The same numerical values, explained in full in *Table 29*, were used in stating the future receptivity in the matrices. Briefly, they are:

- 1 = Ban
- 0 = Antipathy

\*This section contributed by Ray Jay Davis.

**RECEPTIVITY  
OF LEGAL  
REGIME\***

*Receptivity  
in 1975*

- 1 = No Position
- 2 = Encouragement
- 3 = Encouragement and funding

*Future  
receptivity*

The 1975 values for adoption receptivity served as the baseline for determining the receptivity of states toward each of the three future scientific models. The figures in the integrative matrices (see *Figure 55*) represent informed intuitive projections of the adoption receptivity in 1985 and 1995.

*Legal  
trends  
determined*

The coding took into account legal trends. These trends were manifested by litigation in those states in which weather modification cases have been filed. The number of cases, the dates when they were filed and litigated, the importance of the cases, and their outcome were all considered. Also trends from earlier legislation and bills in a jurisdiction, through present legislation and bills, and prospective legislation were taken into account. Additionally, administrative rules and regulations and the direction of their trends were used. The analysis was not limited to weather modification law but included all the relevant laws.

The future legal receptivity to adoption values does not take into account non-legal factors, other than in the case of a 10% rain decrease for the western hail regions (Western Model 3 for 1985). In that instance, a rain decrease was considered sufficiently significant to lead to governmental withholding of funding for hail suppression activities in the state. Hence no western state was coded above +2 in that model.

**SOCIO-  
POLITICAL  
FACTORS\***



Many systemic variables have been posited to have a relationship with social acceptance or rejection of weather modification projects as they have been implemented in the United States (*Haas, 1973; Farhar, 1975*). A high proportion of these variables pertain to the specific circumstances of projects at the community level, and these are not suitable for inclusion in an analysis of adoption of hail suppression technology at a production-area level.

For example, it is hypothesized that the occurrence of negative weather events, particularly drought, is associated with the formation of organized opposition to projects. Since there is no meaningful way to predict the occurrence of damaging weather conditions concurrently with future projects, this variable was not included in the analysis.

*Less relevant  
variables*

Some variables are less relevant to hail suppression than they are to other weather modification technologies. For example, snowpack augmentation projects may spark social controversy on the basis of local disbenefit from a project whose purpose is to provide additional water to communities downstream. This situation is not applicable to hail suppression, which primarily affects the community expecting to receive the benefits from it.

Conflict could occur between hail suppression target-area communities and com-

\*This section contributed by Barbara C. Farhar.





FIGURE 55

Sample page of matrices of adoption variables

MATRIX 1

Scientific model 1 for 1985

Hail east = -30  
Rain east = - 5

Hail west = -40  
Rain west = + 8

Hail region	State	Crop producing region	Prior history of weather modification	Presence of prior organized opposition	Social incentive to adopt (hail effects)		Area conflict potential		Political stance index	Scientific controversy index	Receptivity of the legal regime index	Economic incentive index	Social incentive to adopt (rainfall effects)	Social acceptability index
					Severity of hail loss index	Salience index	Heterogeneity of weather needs index						Severity of drought index	
							Precipitation	Hail						
1.	California	120-122	3	0	-1	2	2	2	3	1	2	0 <sup>b</sup>	1	2
		123	0	0	-1	2	2	2	3	1	2	0 <sup>b</sup>	2	2
		131	1	0	-1	2	2	2	3	1	2	0 <sup>b</sup>	0	2
	Arizona	124	0	0	-1	3	2	1	2	1	1	0 <sup>b</sup>	0	2
		125	1	0	-1	3	2	1	2	1	1	0 <sup>b</sup>	0	2
		126	1	0	-1	3	2	1	2	1	1	0 <sup>b</sup>	0	2
2.	Nevada	None												
		Oregon	114	1	-1	0	2	2	0	3	1	3	0 <sup>b</sup>	2
	Washington	113	1	0	0	2	2	0	3	1	2	0 <sup>b</sup>	0	2
		114	1	0	0	2	2	0	3	1	2	0 <sup>b</sup>	1	2
		115	2	0	1	2	2	0	3	1	2	0 <sup>b</sup>	1	2
3.	Montana	117	1	0	3	3	2	0	3	1	3	1 <sup>b</sup>	1	2
		118	1	0	3	3	2	0	3	1	3	1 <sup>b</sup>	1	2
		136	1	0	3	3	2	0	3	1	3	0 <sup>b</sup>	0	2
4.	Colorado	107 <sup>a</sup>	2	0	3	3	1	0	3	1	2	2	2	2
		108	1	0	3	3	1	0	3	1	2	2	2	2
	Idaho	116	1	0	3	2	2	0	2	1	3	2	1	2
		119	1	0	1	2	2	0	2	1	3	0	2	2
	Wyoming	103	0	0	3	3	2	0	3	1	2	2	2	2

<sup>a</sup>Crop producing region known to have adopted hail suppression.

<sup>b</sup>Economic incentive rated for hail effects only, not rain effects.

munities downwind that feel they are being negatively affected by a hail project, but the occurrence of such events cannot reasonably be predicted, so they were excluded from this analysis.

*Variables  
selected*

Ten variables were selected for inclusion in the present analysis. The first seven of these provide a basic socio-political index that is not dependent on the different scientific models presented in Chapter 8. The coding for these variables is based on actual data; it is not changed for 1985 and 1995. The last three socio-political variables differ by scientific model.

The socio-political variables used and their coding are described below.

*Variable 1 —  
prior  
history*

*Prior history of weather modification.* \* If an area had experienced a weather modification project between 1958 and 1975, assuming that the project generated no public protest, the area would be more likely to adopt hail suppression technology. Prior experience with cloud seeding contributes to acceptance of subsequent projects if that experience produced no undesired effects.

Sources of data for this variable were National Science Foundation (*NSF, 1959-1968*), the National Oceanic and Atmospheric Administration (NOAA) reports on weather modification activity, and Rinkle (*1976*). Numerical coding for the variable is:

- 0 = No cloud seeding projects occurred
- 1 = Fewer than five projects occurred
- 2 = Five to nine projects occurred
- 3 = Ten or more projects occurred

*Variable 2 —  
prior  
opposition*

*Presence of prior organized opposition.* If two or more persons interacted to take organized action for the purpose of blocking or halting a weather modification project, then organized opposition is said to have occurred. A history of organized opposition to cloud seeding in an area will impede later adoption; former opponents may again become active if a cloud seeding project is proposed (*Comparative Study Data, 1975; Rinkle, 1976*). Numerical coding for the variable is:

- 0 = No history of organized opposition
- 1 = History of organized opposition

*Variable 3 —  
social  
incentive,  
hail loss*

*Social incentive to adopt hail suppression (hail effects).* \*\* The greater the actual loss to hail and the year-to-year variability in an area, the greater will be the incentive in the area to adopt hail suppression. Hence, one of the basic variables included is severity of hail loss in the country's crop-producing areas.

Hail severity is the product of the average loss and its extreme. Indices of hail severity were based largely on the average annual loss-cost values for the crop

\*Descriptions of variables contributed by Barbara C. Farhar, except as otherwise noted.

\*\* This subsection on Variable 3 contributed by Stanley A. Changnon, Jr.

reporting districts (*see Figure 25*). Loss cost is the ratio of losses to liability, which normalizes for any time and space differences in coverage. Loss costs were used by Changnon and Stout (1967) to define hail severity nationally.

Five severity values ranging from -1 (practically no hail losses) to +3 (heavy losses) were based on a five-class division within the range of loss-cost values, \$0.1 to \$12.1. The most likely indicator of incentive to adopt — a +3 value — was

set for all regions with a loss cost greater than \$4 because it incorporated all western regions where hail suppression has developed. Crop district loss-costs values in the East where hail suppression was employed in small fruit areas underestimate the local fruit area loss-cost values. The levels set are shown in *Table 42*.

Also, for areas with severity values of 2 or less, an adjustment upward by one level (0 to 1, -1 to 0) was performed if the coefficient of variation of the loss-cost values exceeded 50%. In this way, the impact of year-to-year variability on the incentive to adopt was incorporated as part of a hail severity index.

*Social incentive to adopt hail suppression (salience).* If weather is economically important to an area, weather modification projects have more relevance or importance than if the area were not economically dependent on the weather. The more salient the weather is, the more likely is adoption of hail suppression. For this analysis, salience was coded by using data provided by the TASH agricultural economists on the proportion of land area of each state devoted to nonforest agricultural production.

Precipitation augmentation and hail suppression are considered to have high salience for states devoting 70% or more of their land area to agricultural production. For states using 50 to 69% of their land in agricultural pursuits, moderate salience is indicated; low salience is coded for states with less than half their land in agriculture. Numerical coding for this variable is:

- 1 = Low salience
- 2 = Moderate salience
- 3 = High salience

*Area conflict potential — heterogeneity of weather needs.* This is considered two variables because the computations were done separately for rain and hail (*note Figure 55*). Various agricultural pursuits existing in the same locale may have differing requirements for beneficial weather at the same time. To the extent that agricultural activities in close proximity share common needs for precipita-

<i>Loss cost (dollars)</i>	<i>Hail severity index</i>
>4.0	3
3.1 to 4.0	2
2.1 to 3.0	1
1.1 to 2.0	0
<1.0	-1

*Hail severity indices*

*West-East differences*

*Variable 4 — social incentive, salience*

*Portion of land in agriculture*

*Variables 5,6 — conflict of weather needs*

tion, for example, at the same periods or seasons, the area may be considered homogeneous with regard to weather needs. To the extent that the opposite is the case — that different requirements exist — heterogeneity of weather needs characterizes the area.

*Mixed needs  
reduce  
adoption*

Heterogeneity of weather needs may form the basis for system-level conflicts of interest with regard to weather modification generally and hail suppression specifically. Thus high heterogeneity would not be conducive to adoption. Sources of data for this variable were:

- Data on the primary agricultural production (crops and livestock) for each state provided by TASH agricultural economists (*Rinkle, 1976*)
- Designation of the hail season months for each region of the country by TASH meteorologists
- Weather requirements for several basic crops in terms of how the weather might be altered to benefit each crop for each month during the year. Only precipitation and hail changes were included in this analysis.

The data on crops were generated by a group of agriculturists attending a workshop on weather modification and agriculture in July 1975 (*Grant and Reid, 1975*) and by interviews with agricultural specialists. Changes in precipitation were indicated by a plus for additional rainfall or the moisture deposited on range by hail, a minus for less rainfall or hail. Thus only the *direction* of the desired change, but not its extent, was indicated by the agriculturists. Only the portion of the data pertaining to the hail season months were used in this analysis.

*Economic  
values  
considered*

The economic value (in dollars) of each crop or livestock production activity identified above was taken into account by weighting the weather needs of activities with a "crop value factor." If the activity was over \$500 million, an approximation of value mid-points, a factor of 3 was used; if it was under \$500 million, a factor of 2 was used.

For each month of the hail season, the desired increments or decrements (more or less precipitation,  $+P$  or  $-P$ , and hail,  $+H$  and  $-H$ ) for each major agricultural activity for each state were counted. The totals for  $+P$  (or  $+H$ ) were then weighted by the appropriate factor, as were the totals for  $-P$  (or  $-H$ ). The resulting two yield values,  $Y_1$  and  $Y_2$ , were then converted to a ratio expression as follows:

$$\begin{aligned} N(-P) \times f &= Y_1 \\ N(+P) \times f &= Y_2 \\ [Y_1 / (Y_1 + Y_2)] &: [Y_2 / (Y_1 + Y_2)] \end{aligned}$$

Where:

$N(\pm P)$  = number of months an increase or decrease in precipitation would be beneficial for the major agricultural activities in the state  
/ = the "crop value factor" defined above

These computations were done separately for rain and hail. If the ratio is between 1:1 and 2:1, a condition of high heterogeneity of weather needs exists. If the ratio is between 2:1 and 3:1, moderate heterogeneity exists. If the ratio is between 3:1 and 1:0, homogeneity exists. Since heterogeneity is inversely re-

lated to adoption, the coding for these two variables (for precipitation and for hail) is:

- 0 = High heterogeneity of weather needs
- 1 = Moderate heterogeneity of weather needs
- 2 = Homogeneity of weather needs

The coding computed for the state as a whole was assigned to each crop-producing area within that state.

*Political stance index.* Decision makers administering state statutes regulating the application of hail suppression may have an impact on whether or not the technology is adopted. Where administrators are favorable to the technology's application, adoption is more likely to occur; where they are less favorable, adoption is less likely to occur.

*Variable 7 —  
political  
stance*

Administrators are often guided in their behavioral interpretation of statutes by statute wording. Phrases in statutes have been invoked by weather modification decision makers in support of administrative decisions, especially concerning permit granting, that they have made.

Data developed by Farhar and Mewes (1975) were used to analyze statute wording in terms of its encouragement or discouragement of weather modification research and operations. The numerical coding for this variable (comprising the sum of coding each state separately) is:

- 3 = Encouraging
- 2 = Regulating
- 1 = Minimal regulation
- 0 = Indifference
- 1 = Prohibition

*'Words' can  
encourage,  
discourage*

The code derived for the state was assigned to each crop-producing area within the state.

*Scientific controversy index.* The national level of scientific consensus concerning the readiness of a technology for operational application will affect the rate of its adoption. The higher the level of scientific consensus about the readiness of the technology for operational application, the more likely widespread adoption will be.

*Variable 8 —  
scientific  
controversy*

The three technological models were coded as to the level of scientific consensus each would probably achieve in 1985 and 1995. Model 1, involving a major scientific breakthrough, was expected to be associated with a high degree of scientific consensus in both 1985 and 1995. Model 2, with subcritical research funding and little evaluation of operational projects, was expected to be associated with scientific dissensus. Model 3, the experimental development, was expected to be accompanied by moderate levels of scientific consensus.

*Coded to  
the three  
models*

The numerical coding for this variable is:

- 3 = High levels of scientific consensus
- 1 = Moderate levels of scientific consensus
- 1 = Low levels of scientific consensus

Variable 9—  
social  
incentive,  
rainfall

*Social incentive to adopt (rainfall effects) —frequency of drought.\** The greater the crop loss from the lack of rainfall in an area, the greater is the reason to adopt or reject a hail suppression technology altering rainfall. Since most of the future hail suppression models included a change in seasonal rainfall of 5 to 15%, and since the economic impact of such changes is measurable (Chapter 10), an indication of drought frequency was checked to measure this incentive to adopt or to reject.


Classes  
of drought  
frequency

Court (1974) presented information on the frequency of severe drought months, and these frequencies, which range from 1 to 28% of the time across the nation, were divided into five classes. Each class was assigned an index number as shown in Table 43. Thus, the value of 3 indicates the highest possible incentive to adopt hail suppression that concomitantly increases rainfall.

Effect  
of rain  
changes

If a hail suppression model carries a rainfall decrease, the impact of drought frequency on adoption would be reversed. Modeling has clearly shown the dramatic economic importance of a small percentage change (5 to 15%) in rain in comparison with the large (40 to 80%) decrease in hail loss.

The areas with 0 to 4% frequency of drought months are extremely humid, often regions that are too wet (greater than 50 inches of rain annually), located along the Gulf and Atlantic Coasts. A proposed minor (1 to 10%) decrease in rainfall would have little agricultural effect and in fact might be viewed favorably in many wet months. Thus, the drought index chosen for these areas was 0, or no effect from a small rain decrease with hail suppression.

 <b>TABLE 43</b> <b>Drought indices for rainfall increases and decreases</b>	
<i>Frequency of months with severe drought (%)</i>	<i>Drought index</i>
<i>Drought index for rainfall increase</i>	
20	3
15 to 19	2
10 to 14	1
5 to 9	0
1 to 4	-1
<i>Drought index for rainfall decrease</i>	
0 to 4	0
5 to 9	-1
10 to 14	-2
15	-3

The scale of index numbers adopted for drought frequency coupled with a rain decrease is also shown in Table 43. A value of -3 indicates the strongest rejection of hail suppression and simultaneously decreased rainfall. This coding was assigned to all areas where drought occurred in 15% or more months.

\*This subsection on Variable 9 contributed by Stanley A. Changnon, Jr.

*Social acceptability index.* Another variable concerning the probable acceptability of each technological model in the eastern and western United States was coded. The variable, termed "acceptability," refers to the probable tolerance level of communities regarding the increases or decreases in rainfall and decreases in hail that the models project.

*Variable 10 —  
social  
acceptance*

For example, any hail suppression technology having the effect of decreasing rainfall in the Great Plains almost certainly would encounter grassroots opposition and would be coded not acceptable. The *idea* of decreasing rainfall in this region is anathema.

*Acceptance  
depends on  
rainfall*

The coding for acceptability is based on researchers' informed and intuitive judgment concerning the probable community acceptance of each technology assumed effective as described, and omitting other considerations. The focus is on the technological model itself, not on other factors. The coding for this variable is:

- 3 = Highly acceptable
- 2 = Acceptable
- 1 = Somewhat acceptable
- 0 = Indifferent
- 1 = Not acceptable

A sample page of data on these ten variables in matrix form is shown in *Figure 55*. The entire set of data may be reviewed in HERS (1976).

#### RESULTING PREDICTIONS OF ADOPTION\*



As noted earlier, adoption refers to the utilization of hail suppression technology either experimentally or operationally in an area. In the case of this analysis, adoption was projected to occur or not to occur in crop-producing areas of the United States.

#### INTEGRATION OF THE VARIABLES

Data described in this chapter were analyzed to produce lists of crop-producing areas projected as likely to adopt each of the three hail suppression technology models in 1985 and 1995. The analysis was carried out in the following manner:

Data on seven socio-political variables were summed to produce a base socio-political score for each crop-producing area — a score that did not vary by technological model, but instead was intended to be descriptive of the areas themselves. These variables were: prior history of weather modification activity, prior occurrence of organized opposition to weather modification, social incentive

*'Basic'  
variables*

\*These sections contributed by Barbara C. Farhar, Ray Jay Davis, and Earl R. Swanson.

to adopt (hail effects and salience), area conflict potential (heterogeneity of weather needs with respect to rainfall and hail), and political stance on weather modification.

*'Model'  
variables*

The data on five additional factors were summed to produce a variable score for each region that differed according to each technological model. These variables were: the level of scientific consensus projected to be associated with the model, the economic incentive index for the model, the receptivity of the legal regime, the frequency of drought occurrence associated with the rainfall effects of the model, and the social acceptability of the model.

Additionally, a total sum of all the data for each crop-producing area was produced. The means and standard deviations for these total scores were computed for each of the six matrices. Since a similar number of crop-producing areas would have scores equal to or greater than one standard deviation above the mean for each matrix, use of the standard deviation in and of itself as a threshold value to distinguish adopting from nonadopting regions was judged inadvisable.

Instead, the scores in Matrix 1 (Model 1 for 1985) of crop-producing areas known to have adopted hail suppression were examined to determine how they compared with the entire body of data. It was determined that:

- 1) All crop-producing areas known to have adopted hail suppression had scores equal to or greater than one standard deviation above the mean, with the exception of mid-Atlantic Coast regions. These were considered anomalous for purposes of determining threshold values.
- 2) About 40% of all crop-producing areas with scores equal to or greater than one standard deviation above the mean were known to have adopted hail suppression.
- 3) The range of the base socio-political score and of the variable score (i.e., the sums described above) for each crop-producing area was examined to determine the lowest values associated with adoption. The ranges of the scores for severity of hail loss and the economic incentive index score for these areas were examined as well. It was found that areas that had adopted hail suppression had base socio-political scores no lower than 9, and variable scores no lower than 7.

*Tests for  
adoption  
areas*

The following tests, derived from these determinations, were then applied to each of the matrices to produce a list of adopting crop-producing areas —that is, those which "passed the test" as follows:

Test 1: Was the base socio-political score greater than 8 *and* the variable score greater than 7?

Test 2: Was the base socio-political score greater than 8 *and* the severity of hail loss score 3 *and* the economic incentive index equal to or greater than 2?

Considerable discussion by team members centered around various aspects of the methodology used to produce these lists of adopting regions. The consensus was that although empirical evidence exists for the relevance of factors chosen for inclusion in the matrix, and for the general direction of the coding itself, no empirical or theoretical grounds existed on which to base a decision to either



1) weight certain variables, or 2) select certain variables as critical or key variables which, if they occurred (or did not occur), would have a decisive impact on adoption.

Team members also felt that multiple regression, factor, and sensitivity analyses for 1975 data were not within the possibility of project resources. The team concluded that the variables identified and coded should therefore be handled in the straightforward manner ultimately used in order to determine the patterns of the social-economic-legal-political (SELP) constraints they yielded.



Results of the numerical integration of all factors yielded the numbers of crop-producing areas shown in *Table 44*.

The locations of the adopting crop-producing areas are presented in *Figure 56*, illustrating that in the case of the most extensive adoption (Matrix 2 on Model 1 in 1995) the Great Plains areas would be most heavily involved, with a few scattered projects in California and the Pacific Northwest. Model 3 showed very little adoption (1995 only), and the three models (and their six matrices) display a wide range of outcomes. Notably, hail suppression is not adopted in the Midwest or East Coast areas.

It should be reiterated that the designation of "adopting" and "nonadopting" areas forced a dichotomous choice made necessary because the national economic model treats each production area as a homogeneous unit with respect to crop production capabilities. Therefore, the results should be viewed as predictions or forecasts of adoption by actual crop-producing areas conditional on the occurrence of the scientific models.

**PREDICTED  
ADOPTING  
AREAS**

*Adoption  
mostly in  
Great Plains*



**TABLE 44**

**Summary of adoption results**

Matrix	Year	Percent changes				Number of areas adopting	Passed test 1	Passed test 2 *
		East		West				
		Rain	Hail	Rain	Hail			
<i>Scientific model 1</i>								
1	1985	-5	-30	+8	-40	31	31	
2	1995	+10	-60	+16	-80	36	36	
<i>Scientific model 2</i>								
3	1985	-6	-18	+6	-45	16	12	4
4	1995	-6	-18	+9	-54	23	20	3
<i>Scientific model 3</i>								
5	1985	+5	-11	-10	-15	0		
6	1995	+9	-21	0	-30	5	5	

\*In all cases, variable score = 7



**FIGURE 56**

**Maps of projected adoption areas**



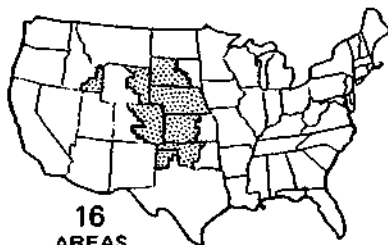
a. MODEL 1 - 1985

	E	W
Hail	-30	-40
Rain	-5	+8



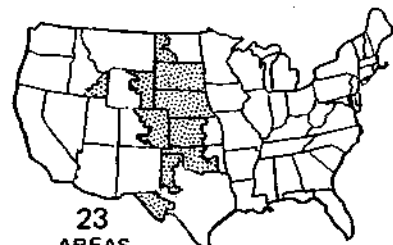
b. MODEL 1 - 1995

	E	W
Hail	-60	-80
Rain	+10	+16



c. MODEL 2 - 1985

	E	W
Hail	-18	-45
Rain	-6	+6



d. MODEL 2 - 1995

	E	W
Hail	-18	-54
Rain	-6	+9



e. MODEL 3 - 1985

No Adoption



f. MODEL 3 - 1995


	E	W
Hail	-21	-30
Rain	+9	0

The predictions are useful in what they reveal about the patterns of potential adoption and the locations of areas where hail suppression is likely to be adopted. The results also inform us as to the relative societal desirability of different modification capability levels.

- Changnon, S. A., and G. E. Stout  
 1967 *Crop-hail intensities in central and northwest United States.* Journal Applied Meteorology, 6, 542-548.
- Comparative Study Data  
 1975 *Comparative study of public support of and resistance to weather modification projects.* J. E. Haas and B. C. Farhar, Co-principal investigators, Institute of Behavioral Science, University of Colorado, Boulder, and Human Ecology Research Services, Inc., Boulder.
- Court, A.  
 1974 *The climate of the conterminous United States.* In World Survey of Climatology, Volume 11: Climates of North America, edited by R. A. Bryson and F. K. Hare, Elsevier Scientific Publishing Co., Amsterdam, 193-343.
- Farhar, B. C.  
 1975 *Weather modification in the United States: A socio-political analysis.* Unpublished doctoral dissertation, Department of Sociology, University of Colorado, Boulder, 387 pp.
- Farhar, B. C., and J. Mewes  
 1975 *Weather modification decision making: State law and public response.* Journal Applied Meteorology, 14(5), 694-701.
- Grant, L. O., and J. D. Reid  
 1975 *Workshop for an assessment of the present and potential role of weather modification in agricultural productivity.* Colorado State University, Ft. Collins, Atmospheric science paper 236, 236 pp.
- Human Ecology Research Services  
 1976 *Working papers for technology assessment of suppression of hail.* Human Ecology Research Services, Inc., Boulder, Colorado, HERS-TASH resource volume 2.
- Haas, J. E.  
 1973 *Social aspects of weather modification.* Bulletin American Meteorological Society, 54(7), 647-657.
- National Science Foundation  
 1959-1968 *Weather modification: First [through Tenth] annual report.* Washington, D. C.
- Rinkle, R.  
 1976 *Relevant societal characteristics: Descriptions for each state.* Human Ecology Research Services, Inc., Boulder, TASH working paper 14.

**SUMMARY OF CHAPTER 9**  
**FUTURE ADOPTION OF HAIL SUPPRESSION**

*Adoption patterns based on hail models*

 Given the three alternative models of hail suppression's potential development, future adoption patterns were projected on the basis of several important economic, legal, and socio-political systemic variables. Data on these variables were integrated by crop-producing areas of the United States for each scientific model at 1985 and 1995. This analysis was a key integrative effort for the TASH project, making possible an assessment of national economic and other societal impacts.

*Variables used in adoption analysis*

Variables used in the adoption analysis included: 1) an economic incentive index based on an individual farmer's incentive analysis and on national economic modeling, 2) a legal receptivity index based on data concerning the extent of legal regulation of hail suppression and of governmental support through appropriations, the extent and direction of trends in administrative law, and the occurrence of litigation and their outcomes, 3) indices on the social incentive to adopt hail suppression based on each region's severity of hail losses, severity of drought, and the importance of agriculture in the area's economy, 4) indices on each region's heterogeneity of weather needs with regard to rain and hail representing the conflict potential for that region, 5) the political stance of each region as represented by statute wording, 6) the level of scientific consensus estimated to be associated with each scientific model, and 7) an estimate of each scientific model's social acceptability by region.

These data were coded for each crop-producing area and each scientific model and analyzed to discover whether they exceeded a predetermined threshold value for adoption. The variables included and the range of coding for each are as follows:

	<i>Range of coding</i>
<b>Variables in Basic Socio-Political Index</b>	
Prior history of weather modification	0 (no projects occurred) 3 (ten or more projects occurred)
Presence of prior organized opposition	-1 (history of opposition) 0 (no prior opposition)
Social incentive to adopt hail suppression as measured by severity of hail losses	-1 (least hail loss) 3 (greatest hail loss)
Salience	1 (low salience) 3 (high salience)
Area conflict potential (heterogeneity of weather needs)	0 (high heterogeneity) 2 (low heterogeneity)
Political stance index	-1 (prohibiting) 3 (encouraging)
<b>Other Variables</b>	
Scientific controversy index	-1 (low scientific consensus) 3 (high scientific consensus)

Receptivity of the legal regime	-1 (ban) 3 (encouragement and funding)
Economic incentive index	-1 (marginal negative economic impact) 3 (strong positive impact)
Frequency of drought index	-3 (most frequently occurring drought for rainfall decrease models) 3 (most frequently occurring drought for rainfall increase models)
Social acceptability index	-1 (not acceptable) 3 (highly acceptable)

Results should be viewed as predictions or forecasts of adoption by crop-producing areas conditional on the occurrence of the scientific models. The most extensive adoption predicted was for a high-level technology (80% reduction in hail accompanied by a 16% enhancement of rainfall) in 1995. The Great Plains area of the nation would be most heavily involved, with a few scattered projects in California and the Pacific Northwest. Notably, hail suppression is not projected to occur in the Midwest nor in East Coast areas. A low-level technology in 1995 would result in virtually no adoption in the nation.

*Most adopting  
with high-level  
technology*

# 10

## Effects of adoption



Now we look to the stakeholders of the future. When the technology of hail suppression reaches the various capabilities set forth in the scientific models of Chapter 8 —and is adopted according to the patterns predicted in *Figure 56* —what will be the impacts on the major stakeholders?

We consider first in this chapter the economic impacts of hail suppression for agriculture on a broad national-regional scale —as depicted by the national economic model. Considered also are the secondary impacts on local target communities. We then look at the costs of reaching the goals of the scientific models and pit these costs against economic benefits on both the national-regional scale and the local scale.

We then turn to consideration of other major stakeholders —the research industry, the hail suppression industry, and the insurance industry.

### **NATIONAL AND REGIONAL ECONOMIC IMPACT\***



This section evaluates the national and regional economic impacts of the adoption of three hail suppression technologies, each with different performance capabilities and adoption patterns.

At the national level, the economic impacts studied focus on the effect of adoption of various hail suppression technologies on the total cost of producing and transporting the principal food and fiber crops to the point of consumption.

At the regional level, shifts in cropping patterns that are likely to occur as a

\*These sections contributed by Earl R. Swanson, C. R. Taylor, and Jon van Blokland.

result of hail suppression are examined. In addition, the impact of hail suppression on returns to landowners is examined, and the effect on commodity prices is considered. These economic impacts were estimated by the use of a national economic model of agriculture.

## THE NATIONAL ECONOMIC MODEL



A mathematical model (linear-programming spatial-equilibrium) was the framework used for estimating the regional and national economic impacts of adoption of hail suppression. The usefulness of the concept of spatial-equilibrium, as it is embodied in linear-programming models, is well described in the literature (*Dean et al., 1970*). A survey of the applications of spatial-equilibrium models in agriculture indicates a variety of uses of this type of model in the economic analysis of agricultural production and marketing (*Weinschenck et al., 1969*).

The linear-programming spatial-equilibrium model has been applied by Boone (*1975*) to the problem of estimating impacts of hail suppression activity at the state level, in this case Nebraska. The University of Illinois model used in the TASH study deals with hail suppression at national and regional levels.

### *How the model works*

In brief, the model, as used in the evaluation of hail suppression, estimates the economic impact by taking into account the changes in the comparative advantage of various crops among regions, as producers adopt the technique in an effort to *minimize the costs of producing a predetermined set of food requirements*, for both domestic and export uses. The interdependencies among markets and producing areas are an important feature of the model. A solution using the model provides:

- 1) The set of acreages
- 2) Methods of production for each crop which minimizes the costs of
  - a) Producing the crops considered in the model
  - b) Transporting them to the processing centers

### *Solutions compared with benchmark*

The solution to the model under the assumption that hail suppression technology is employed at its actual 1975 level, called "benchmark," was compared with the solutions calculated under various assumptions about differing hail modification capabilities, different adoption rates, and different years. In this manner, estimates were made concerning the expected economic impact and in particular the cost of producing the fixed crop requirements and the adjustments in cropping patterns.

The key elements relating to the detail in the model appear in the next two sections. A more complete description of the general properties of the model, as well as additional data, may be found in Taylor and Swanson (*1975*), and in Taylor et al. (*n. d.*).



The eight crops considered as variables in the model are corn, sorghum, barley, oats, wheat, rye, cotton, and soybeans. The geographic distribution of the losses by state and the proportion of losses for major crops are presented in *Table 45*. Included in the national economic model used in the TASH analysis are the crops listed in the first five columns of this table. They represent 79% of crop-hail damage in the nation.

**CROP  
PRODUCTION  
VARIABLES**

Because of differences among regions in soil productivity, climate, distance from markets, and other factors, the United States is divided into some 140 *producing* areas, as we show in *Figure 57*, and 21 *consuming* regions, as shown in *Figure 58*. Use of these producing and consuming regions permits the model to reflect the interregional nature of agricultural production and distribution in the country.

Producing areas are selected to embrace homogeneous production as accurately as possible. Each producing area has at least one crop-production activity. A crop-production activity is defined for a given producing region if that activity is agriculturally important for that region and the crop may, if appropriate, be grown

*Producing  
areas  
defined*



**TABLE 45\***

**Estimated annual average hail losses by crop for states**

State	Percentage of total losses							Total
	Wheat	Corn	Soy-beans	Cotton	Coarse grains**	To-bacco	Fruits, vegetables	
Texas	2.5		0.2	7.2	2.4		0.4	12.7
Iowa	0.01	4.6	4.6		0.5		0.04	9.8
Nebraska	2.5	4.0	0.6		0.6		1.1	8.9
Minnesota	0.3	2.6	2.8		1.1		0.3	7.1
Kansas	5.3	0.4	0.1		0.6		0.1	6.7
North Dakota	4.2	0.09	0.1		1.8		0.2	6.5
North Carolina	0.03	0.1	0.04	0.07	0.01	3.6	0.3	4.1
Illinois	0.1	1.7	1.8		0.07		0.1	4.0
South Dakota	1.3	1.4	0.2		1.1		0.01	4.0
Colorado	2.1	0.6			0.3		0.9	4.0
Montana	2.5	0.01			0.7		0.3	3.5
Oklahoma	2.3	0.03	0.01	0.4	0.5			3.2
Kentucky	0.01	0.06			0.01	2.3	0.04	2.5
Missouri	0.3	0.7	0.8	0.2	0.01	0.04	0.1	2.1
South Carolina	0.01	0.09	0.2	0.3	0.01	0.9	0.3	1.8
Idaho	0.4	0.01			0.2		1.1	1.7
California	0.03	0.01		0.07	0.3		1.3	1.7
Indiana	0.1	0.6	0.7		0.04	0.06	0.1	1.6
All other	1.2	1.2	1.1	2.7	0.9	2.6	4.4	14.1
	25.2	18.1	13.4	11.0	11.4	9.6	11.3	100.0

\*Source: Adapted from Boone, 1974; figures based on 1973 price levels, in millions of dollars.

See Table 6, page 26 for total dollar values.

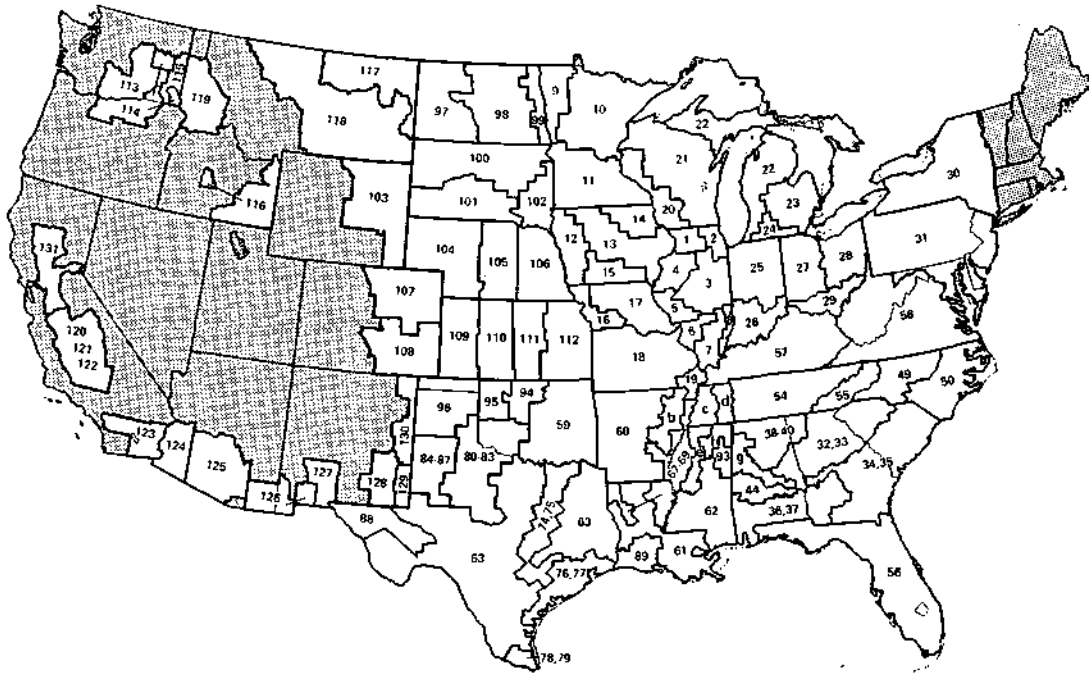
\*\*Coarse grains: barley, rye, sorghum, oats.





FIGURE 57

Crop-producing areas used in the economic analysis



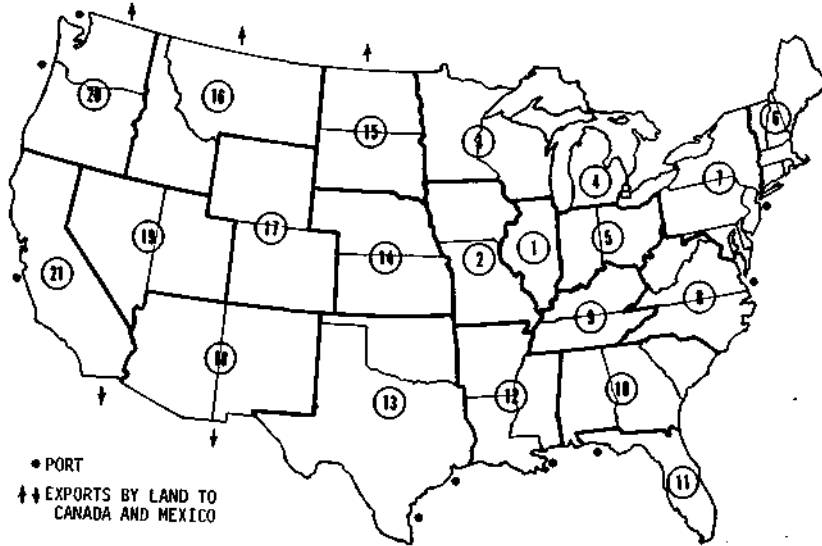
under either dryland or irrigated conditions or both, whichever is the least-cost method for each case.

Although the producing areas do not blanket the whole country, they do embrace more than 99% of the feed grain, cotton, and soybean acres and around 97% of the small grain acres. Any production of these commodities outside the producing regions is included in the model as a constant fixed at approximately 1973 production levels. Production of the eight crops is concentrated in only a few of the hail regions (see *Figure 7* in Chapter 2). For example, Regions 6, 7, 8, and 9 contain 83% of the U.S. acreage of these crops, with Regions 7 and 9 accounting for 40% and 23% respectively.

The predominant hail regions for the eight crops — grouped as food grains (wheat and rye), feed grains (corn, sorghum, barley, and oats), and oil meals or oil seeds (soybeans and cotton) — are as follows:

- Three hail regions — 7, 9, and 10 — contain 88% of the oil seed acres, with 9 and 7 having 40% and 37% respectively
- Regions 6, 7, 8, and 9 have 90% of the feed grains, while 7 and 9 contain 37% and 23% each
- Regions 2, 7, 8, and 9 constitute 75% of the food grain acres, and region 7 alone has 47%

*Hail region  
acres  
of crops*

**FIGURE 58****Consuming regions of the United States****TABLE 46****Estimated future yield increases due to technological innovations**

	1972-1974	1985	1995
Corn (bu/acre)	86.5	97.5	102.5
Barley (bu/acre)	40.4	52.0	56.0
Oats (bu/acre)	48.4	60.0	64.0
Sorghum (bu/acre)	54.7	60.0	62.5
Wheat (bu/acre)	30.6	37.0	40.0
Rye (bu/acre)	24.6	30.0	33.0
Cotton (lbs/acre)			
seed	780.0	800.0	830.0
lint	490.0	500.0	520.0
Soybeans (bu/acre)	26.3	34.0	36.0

Crop yields are expected to increase by 1985 and 1995 through the application of technologies other than hail suppression. In order to take this effect into account, yield increases were estimated (*van Blokland, 1976*) as shown in *Table 46*. The yield increases estimated for 1985 and 1995 are generally consistent with other estimates; differences are modest and, in general, the yields

*Future  
crop yield  
increases*

**TABLE 47****Future demands for crops**

	<i>Domestic demand</i>			<i>Export demand</i>		
	<i>1970</i>	<i>1985</i>	<i>1995</i>	<i>1971-1973</i>	<i>1985</i>	<i>1995</i>
Feed grains (corn, oats, barley, sorghum)	100	108	112	100	140	150
Food grains (wheat, rye)	100	110	114	100	135	145
Soybeans	100	116	122	100	120	125
Cotton	100	104	108	100	105	110

reflect somewhat less optimism regarding yield increases than the estimates from other sources. In any event, the magnitude of error is not apt to seriously affect the estimates of the economic impact of the various hail suppression technologies.

## DEMAND FOR CROPS USED IN MODEL

### *Basic demands for crops*



Total demand for each crop is estimated in the model for each of the 21 consuming regions and entered in the model as a requirement to be met (*van Blokland, 1976*). The consuming regions follow state boundaries and were created to specify regional commodity demands, and at the same time make interregional commodity transportation internal to the model. Transport costs, as well as production costs, are estimated to remain at their 1975 levels. The total demand for the eight crops in a consuming region is broken down into the following constituent parts for each crop:

- 1) Domestic demand for human consumption
- 2) Domestic seed demand
- 3) Domestic demand for specified grains for all livestock
- 4) Export demand, specified by port, or over a land route in the case of corn or soybeans moving to Mexico or Canada

### *Domestic demand estimates*

These demands or requirements appear in the model in such a way that "exports" and "imports" of crops among the various regions in the United States may occur. This interregional flow of crops permits the *tracing of the adjustments to a new technology, such as hail suppression, throughout the entire agricultural economy.*

The domestic demand estimates for 1985 and 1995 presented in *Table 47* are based, in part, on the following U.S. population estimates:

- 1975 = 212.8 million
- 1985 = 231.8 million
- 1995 = 249.4 million

The assumed increases in export demands, as shown in *Table 47*, take into account past trends and recent events but are, of course, quite conjectural. The general pattern indicates a strengthening of export demand at a substantially greater rate than domestic demand.



The economic impacts of hail suppression adoption were estimated by obtaining and comparing the following solutions to the model:

- 1) *Benchmark*. In the case of 1975, this solution characterizes the present situation (whether existing hail suppression has impact or not). It is used not only to validate the model but also as the base for comparison with other 1975 solutions. In 1985 and 1995 the benchmark solution represents one in which hail suppression occurs at the same level (no improvement) as it does in 1975.
- 2) *No-hail*. This solution assumes that hail would simply disappear at no cost. Thus the solution gives an estimate of losses from hail on the eight crops.
- 3) *Levels of hail suppression technology*. Three levels of hail suppression (and rain modification) are assumed and used (see *Table 38* in Chapter 8) for 1985 and 1995.
- 4) *Time periods*. Three dates are considered - 1975, 1985, and 1995.

Twelve solutions to the model formed the basis for evaluation of the economic impact of hail suppression insofar as it relates to agricultural production. Those computed were:

	<i>Benchmark</i>	<i>No-hail</i>	<i>Model 1</i>	<i>Model 2</i>	<i>Model 3</i>
<b>1975</b>	x	x	-	-	-
<b>1985</b>	x	x	x	x	x
<b>1995</b>	x	x	x	x	x

The six solutions for Models 1,2, and 3 were based upon the adoption rates (and areas) conditioned by the constraints imposed by social, economic, legal, and political considerations (see *Table 44* in Chapter 9).

The relevant comparisons used in evaluation of hail suppression technologies were the following solutions.

- *Benchmark vs. the various models (within years)*. Differences in these solutions give an indication of overall impact of the technology.
- *Among models (for entire period)*. These comparisons, together with levels of funding associated with each, provide an approximate measure of the desirability, in economic terms, of further funding.
- *Benchmark vs. no-hail (within years)*. These comparisons give an idea of the magnitude of the "hail problem" insofar as it relates to the production of the eight crops. It is the hypothetical upper limit of benefits.



The first general estimate of the future economic impact of hail suppression was developed on the basis of effects shown in production and transportation costs. The production costs used are the *full* cost of production in the sense

**EFFECT OF SUPPRESSION - NATIONAL SCALE**

**TABLE 48****Potential cost decreases due to hail suppression expressed by changes in production costs (including rent) and transportation costs**

<i>Year</i>	<i>Benchmark</i>	<i>No-hail</i>	<i>Model 1</i>	<i>Model 2</i>	<i>Model 3</i>
1975 (billion \$)	17.499	16.642			
Cost decrease		0.857			
Cost decrease (as % of benchmark)		5			
1985 (billion \$)	18.915	18.329	18.695	18.672	18.915
Cost decrease		0.586	0.220	0.243	0
Cost decrease (as % of benchmark)		3	1	1	0
1995 (billion \$)	18.744	18.176	17.853	18.413	18.741
Cost decrease		0.568	0.891	0.331	0.003
Cost decrease (as % of benchmark)		3	5	2	0

that they include land rents. Thus, reductions in these costs may be viewed from the standpoint of the consumer as increases in efficiency of the total production system. As discussed in later sections dealing with regional aspects of the economic effects, land values and hence the rents derived from land are reduced slightly as a result of adoption of hail suppression technology.

*Less land required*

In order to produce the quantities of crops required for domestic and export demand in 1985 and 1995, somewhat less land is required with the use of hail suppression technology. As land becomes less scarce, its capital value (and rent) falls. Of course, other factors such as inflation may actually offset the land-substituting effects of adoption of an output-increasing technology. Any reduction in the land required for agricultural purposes decreases the total pressure on our land supply, including the urban-related demand.

*Model 1 gives largest reductions*

The gains from adopting hail suppression nationally with land costs (rents) included in the production and transportation costs are shown in *Table 48*. The largest cost reductions result from use of Model 1 (the best technology).

Model 1 in 1995 is more effective in reducing costs than the costless elimination of hail (no-hail solution). This is due to the importance of the 16% increase in rainfall associated with the 80% reduction in hail. It should be realized that the no-hail value applies to the entire nation, whereas Model 1 applies to 36 adopting regions. The cost decreases presented in *Table 47* are considered in modified form in a later section of this chapter which deals with a comparison of benefits and costs of hail suppression.

**RETURNS TO LANDOWNERS - REGIONAL CONSIDERATIONS**



We now turn to an examination of the impact of hail suppression on regional patterns of rents, or returns to landowners.

Land is considered to be the only fixed resource in the model. Therefore, as production becomes more efficient with the introduction of a yield-increasing

**TABLE 49****Total annual returns to landowners by hail regions, 1985**

Hail region	Benchmark (x\$1000)	No-hail		Model 1		Model 2		Model 3	
		Total (x\$1000)	Index*	Total (x\$1000)	Index*	Total (x\$1000)	Index*	Total (x\$1000)	Index
1	20,124	19,370	96	19,516	97	19,663	98		
2	142,068	134,218	94	138,343	97	142,314	100		
3	19,448	20,602	106	17,688	91	17,561	90		SAME
4	40,889	40,714	99	47,390	116	38,095	93		
5	3,535	4,033	114	3,408	96	3,472	98		
6	117,278	118,189	101	118,707	101	104,670	89		AS
7	881,929	854,642	97	850,019	96	890,637	101		
8	141,096	172,389	122	137,089	97	131,844	93		
9	455,354	436,820	96	440,829	97	441,755	97		BENCHMARK
10	12,590	10,060	80	12,029	96	12,031	96		
11	3,393	1,131	33	1,588	47	2,058	61		
12	86,300	83,603	97	83,907	97	84,548	98		
13	<i>(Crop acreages predetermined)</i>								
Total	1,924,004	1,895,771	98	1,870,513	97	1,888,648	98		

\*Benchmark = 100

technology like hail suppression, land is less scarce and its ability to command rent declines when the U.S. is viewed as a unit.

However, the pattern of rent effects is affected by the geographical pattern of introduction of the hail suppression technology. Those regions with improved comparative advantage as a result of adopting hail suppression lose less (in some cases actually gaining) than other regions.

Results pertaining to the impact of hail suppression technology on the returns to landowners appear in *Tables 49* and *50*. These data represent total rents and *not* rent per acre. The differential impact among regions, when we consider the no-hail regime, indicates that some regions gain while others lose, with a net loss to the U.S. landowners as a group.

We would expect landowners in those hail regions adopting the new technology to gain relative to other regions — either to experience an absolute increase in returns to land or to suffer a lower loss relative to landowners in other regions.

Although not evident from the data in *Tables 49* and *50*, we would also expect those smaller adopting areas, within each of these rather large hail regions, to experience gains in the returns to landowners, even if the total returns for all landowners in the region decrease.

In 1985 (*Table 49*) note that for the "no-hail" values the landowners as groups within each of several hail regions (3, 5, 6, and 8) would gain (> 100%) as a result of the costless elimination of hail, even though the total rents in the U.S. are 98% or a decrease of 2%.

*Some regions gain — others lose*

*Small areas also could have gains*

*Other factors can affect rents*

 **TABLE 50**

**Total annual returns to landowners, by hail regions, 1995**



Hail region	Benchmark (x\$1000)	No-bail		Model 1		Model 2		Model 3	
		Total (x\$1000)	Index*	Total (x\$1000)	Index*	Total (x\$1000)	Index*	Total (x\$1000)	Index*
1	20,384	19,934	98	19,132	94	20,041	98	20,362	100
2	146,964	139,810	95	142,426	97	146,064	99	146,964	100
3	19,904	21,336	107	12,331	62	15,759	79	19,863	100
4	39,035	38,902	100	43,645	112	43,271	111	38,730	99
5	3,177	3,791	119	3,051	96	3,135	99	3,177	100
6	101,507	107,374	106	85,838	85	100,279	99	99,426	98
7	809,410	821,408	101	819,340	101	850,249	105	808,320	100
8	137,203	172,284	126	87,831	64	126,097	92	137,203	100
9	450,806	431,180	96	380,917	84	437,197	97	450,122	100
10	13,782	10,875	79	9,965	72	13,370	97	13,732	100
11	3,177	1,136	36	883	28	1,408	44	3,177	100
12	91,188	87,835	96	84,072	92	89,501	98	91,188	100
13									
Total	1,836,537	1,855,865	101	1,689,431	92	1,846,371	101	1,832,264	100

\*Benchmark =100

The differential regional impacts of hail elimination on rents cannot be linked directly to the present pattern of hail damage. Other factors, such as the change in comparative advantage of the several crops grown in each region (in part determined by the quality and quantity of the land resource), play a role. Thus, we cannot sketch a simple cause-effect relationship between rent changes and adoption patterns.

*Examples of losses, gains in 1985*

For example, under Model 1 for 1985 adoption occurs in 31 producing regions (see Table 44) which are located primarily in Hail Regions 3, 4, 6, and 7. However, Table 49 shows that landowners in Hail Region 3 (Montana) with an index of 91 suffer a loss both with respect to their pretechnology position (100%) and the U.S. average (97%).

Landowners in Regions 4 and 6 gain (indices of 116 and 101, respectively) both in terms of their pretechnology position and in relation to the U.S. average.

Landowners in Region 7 suffer a slight loss in comparison with the U.S. average (96 versus 97). However, Figure 56 (Chapter 9) indicated that only a part of the producing areas in Region 7 were assumed to be adopters of Model 1 in 1985.

Thus, the impact of hail suppression technology on land rents in individual hail regions occurs through a rather indirect route, traceable, in part, by a study of the crop acreage shifts described in detail later.

*Nonadopters may also gain*

As an example, in the case of Model 1 in 1985 Hail Region 3 also loses its comparative advantage in feed grain production and, as a result, reduces acreage by 3% (see Table 52 in the next section), even though it adopts the hail suppression technology. Producers in other hail regions such as 7, which contains some producing areas that adopt, gain. Similarly other regions such as 8 which

do not adopt the technology but which are in the same national market gain in their comparative advantage in feed grain production vis-a-vis Region 3.

The change in rent pattern for Model 1 in 1995 (*Table 50*) corresponds roughly to our expectation regarding adopting regions. Hail Regions 4 and 7 experience absolute gains in rent in terms of the benchmark situation. Of the 36 adopting producing areas, 21 are in Regions 4 and 7. Region 5, New Mexico and Utah, has a land rent decrease less than the U.S. (index - 96 vs. 92 for the U.S.). The other hail regions that contain producing areas which adopt under Model 1 (Regions 3 and 6) have decreases in rent greater than the average for the U.S. in 1995.

1995  
gains  
losses

This can be explained by the regional shifts in crop acreages that we will see from *Table 54* in the next section. Acreage declines occur in Region 3 for both food grains and feed grains (indices = 90 and 94 respectively). Because the rents reported in *Tables 49* and *50* are total rent costs (acres X rent per acre), the drop in acreage plays an important role. The national requirements for food grains and feed grains could more economically be grown in regions other than 3, in spite of the fact that Model 1 was adopted in parts of 3. Other acreage shifts may be explained in a similar manner. The acreage shifts for the eight individual crops under the three models in 1985 and 1995 are presented elsewhere (*Swanson, 1976*).



The impact of the adoption of hail suppression on the aggregate national costs of production that we have just discussed is accompanied by regional shifts in cropping patterns that result from altered relationships regarding comparative advantage. The results, in terms of shifts in crop patterns, give an indication of the scope of the adjustment which might be required of producers (farmers) within a region.

## EFFECTS ON REGIONAL PRODUCTION PATTERNS

The changes in the comparative advantage of the three classes of crops considered (food grains, feed grains, and oil seeds) that result from adoption of the various hail suppression technologies are presented in *Tables 51, 52, and 53*. Under the no-hail loss assumption (*Table 51*) there is an overall U.S. reduction in acreages in all classes. This occurs because less land is required to meet the *fixed* set of demand requirements. However, the comparative advantage of several classes of crops shifts.

'Advantages'  
of some  
crops shift

For example, complete hail suppression "helps" Hail Regions 2, 4, and 7 (important food grain production areas) to maintain their position in food grain production, whereas acreages of food grains in Regions 6 and 8 (upper Midwest) decrease.

Although complete hail elimination does not increase acreages of food grains in any hail region, the impact on comparative advantage is such that feed grain and oil seed crops actually increase in certain hail regions. Hail Regions 4 and 8 both have slight increases in feed grain acreages, whereas Regions 1 and 8 increase oil seed crop acreages.





**TABLE 51**

**Changes in regional crop acreages expected if no hail loss existed in 1975**

Hail region	No-hail*		
	Food grains	Feed grains	Oil seeds
1	92	96	112
2	100	100	100
3	80	100	100
4	100	102	100
5	99	101	100
6	90	89	94
7	100	100	98
8	86	102	110
9	89	97	94
10	100	96	97
11	95	91	100
12	100	99	100
13	100	100	100
U.S.	96	97	93

\*Benchmark is 100 for all crop classes and all regions

Of course, the above patterns result from an unrealistic no-hail assumption; nevertheless, the shifts do represent the upper limit on what might be expected under the various hail suppression technologies to be considered. Importantly, the results show that no shifts in the present cropping pattern will occur when viewed at the level of each hail region.

Before examining further the impact of hail suppression on crop acreage shifts, a perspective of historical patterns of acreage shifts is valuable. During 1946-1966 Swanson (1969) presented the acreage shifts in percentage terms for each major crop in each crop reporting district of Illinois. His results were:

- For the state as a whole, year-to-year decreases in corn acreage occurred in 12 years (average decrease 5.4%) and increases in 8 years (average increase 5.6%).
- The temporal patterns for the nine crop reporting districts indicated a greater percentage shift in some districts. For example, in the southeast crop reporting district, corn acreage increases from the preceding year averaged 8.7% (in 13 years) and decreases averaged 11.3% (in 7 years).
- In general, the acreage shifts were less pronounced for major crops in a region than for minor crops. The year-to-year wheat acreage (minor crop) for Illinois over the period 1946-1966 increased an average of 9.9% in 12 years in which an increase occurred —and decreased an average of 11.3% in 8 years of decreases in wheat acres.

A few selected recent acreage shifts on a state level may also assist in interpretation of the scope of the likely impacts suggested in *Tables 52* and *53*. The percentage changes in the wheat acreage seeded and the corn acreage planted in five states are shown in *Table 54*.


*Acreage shifts occur but are small*

The acreage shifts in 1985 and 1995 (*Tables 52* and *53*) predicted for hail suppression —when viewed in the light of these samples of historical patterns of year-to-year changes —could be easily accommodated by the social and economic systems of the regions involved. There would be some variation in this impact among localities.

It should be kept in mind that the acreage shifts shown in *Tables 52* and *53* represent movements from 1) a solution based on a 1975 level of hail suppression technology with other factors (other kinds of technology and demand) as they are expected to be in 1985 and 1995 to 2) a solution with a specified level of hail suppression technology. This change in cropping patterns would occur *over a period of years*. Thus, the crop acreage adjustments which the model predicts for hail suppression may be *less abrupt* than those occurring with present agricultural practices.

*Acreage impacts modest in 1985*

Model 1 by 1985 is adopted in 31 production areas concentrated in Hail Regions 3, 4, 6, and 7. The acreage impacts (*Table 52*) in these hail regions are generally


 TABLE 52

Crop acreage changes in 1985, expressed as a percent of benchmark\*



Hail region	No-hail			Model 1			Model 2			Model 3		
	Food grain	Feed grain	Oil seeds	Food grain	Feed grain	Oil seeds	Food grain	Feed grain	Oil seeds	Food grain	Feed grain	Oil seeds
1	100	97	102	100	97	102	100	97	102	100	100	100
2	100			100			100			100	100	100
3	101	93		100	97		100	100		100	100	100
4	96	104		100	100		97	102		100	100	100
5	100	93	123	100	100	100	100	100	100	100	100	100
6	96	103	139	89	86	109	100	94	100	100	100	100
7	95	104	100	97	103	100	97	103	100	100	100	100
8	95	87	125	84	107	97	95	103	92	100	100	100
9	93	97	86	98	95	98	95	96	95	100	100	100
10	100	100	95	100	100	95	100	100	95	100	100	100
11	100	85	99	100	100	100	100	100	100	100	100	100
12	99	100	100	100	100	100	100	100	100	100	100	100
13	100	100		100	100		100	100		100	100	100
U.S.	96	99	96	96	99	98	97	99	97	100	100	100

\*Benchmark = 100%, for 1985 with 1975 level of hail suppression technology adopted at 1975 rate of adoption

 TABLE 53

Crop acreage changes in 1995, expressed as a percent of benchmark\*

Hail region	No-hail			Model 1			Model 2			Model 3		
	Food grain	Feed grain	Oil seeds	Food grain	Feed grain	Oil seeds	Food grain	Feed grain	Oil seeds	Food grain	Feed grain	Oil seeds
1	95	102	101	95	102	101	95	98	106	100	100	100
2	100			100			100			100		
3	101	93		90	94		100	100		100	100	
4	100	112		101	110		100	112		100	100	
5	100	93	123	100	100	100	100	100	100	100	100	100
6	90	94	139	68	99	110	90	94	110	100	99	100
7	97	102	100	96	101	105	96	101	103	100	100	100
8	90	96	117	84	94	111	84	106	98	100	100	100
9	94	96	88	86	91	88	94	94	92	100	100	99
10	82	100	95	79	90	95	82	100	100	100	100	103
11	100	85	99	78	85	100	100	100	100	100	100	100
12	99	100	100	99	100	100	99	100	100	100	100	100
13	100	100		100	100		100	100		100	100	
U.S.	96	99	97	91	97	98	95	99	98	100	100	100

\*Benchmark = 100%, for 1995 with 1975 level of hail suppression technology at 1975 rate of adoption

 **TABLE 54**

**Year-to-year changes in wheat and corn acreages**

	Wheat (% change)		Corn (% change)	
	1971 to 1972	1972 to 1973	1971 to 1972	1972 to 1973
North Dakota	-19	+19	-13	+10
South Dakota	-11	+19	+15	+15
Kansas	+7	+5	-5	+21
Texas	+15	+14	-18	+29
Illinois	+21	+7	-8	+5

modest. In Region 3, feed grain acres decrease 3%; there is no change in Region 4; in Region 6 a reduction of 11% occurs in food grains, 14% in feed grains, and an increase of 9% in oil seeds; in Region 7 there is a decrease of 3% in food grain and an increase of 3% in feed grain. Because the adoption would occur over a period of years, these shifts do not appear to be disruptive.

*Long period  
for adjustment*

The 1995 results (*Table 53*) include percentages which compare crop patterns under the three hail suppression technologies with a 1995 benchmark that assumes a 1975 level of hail suppression at its actual level of adoption. Thus, an even longer period of time is available (up to 20 years) to make the adjustment.

Again, Model 1 is adopted in 1995 in production areas (36 in all) which are concentrated in Hail Regions 3, 4, 6, and 7. The largest percentage shift in these regions is a 32% decrease in food grains in Region 6. Some of this decrease (11%) would already have occurred by 1985 (*Table 52*).

*Only minor  
repercussions  
expected*

In brief, the general pattern of the shifts appears to be such that insofar as impacts related to crop acreage shifts are involved, only minor agricultural repercussions would be expected. However, these shifts are at the level of the hail region and it is unlikely that all production areas, or smaller units, will act in concert. Thus some areas will have larger acreage shifts and some smaller.

**IMPACT ON  
COMMODITY  
PRICES**



The national linear programming model produces, as a part of each solution, a set of calculated commodity prices (*Swanson, 1976*). Indices of calculated (shadow) prices for 1975, 1985, and 1995 are presented in *Table 55*. In each year the comparison is between prices from a benchmark solution and the prices from a solution with different levels of hail suppression.

*Price changes  
would be  
gradual*

It is important to recognize that the indicated changes would occur over a period of time. For example, for Model 1 in 1995, the corn and sorghum price is 94% of what it would be in 1995 with the earlier predicted 1995 crop yields and

**TABLE 55**

Calculated (shadow) prices of commodities for 1975, 1985, and 1995, as a percent of benchmark\*

Commodity	1975			1985			1995		
	No-hail	No-hail	Model 1	Model 2	Model 3	No-hail	Model 1	Model 2	Model 3
Wheat	97	99	99	99	100	99	98	99	100
Corn and sorghum	95	96	98	98	100	96	94	97	100
Oats	94	96	101	100	100	96	94	97	100
Soybeans	95	98	100	99	100	98	97	100	100
Barley	94	95	98	97	100	96	91	98	100
Rye	95	98	100	100	100	98	97	100	100
Cottonseed	94	96	100	99	100	97	91	98	100

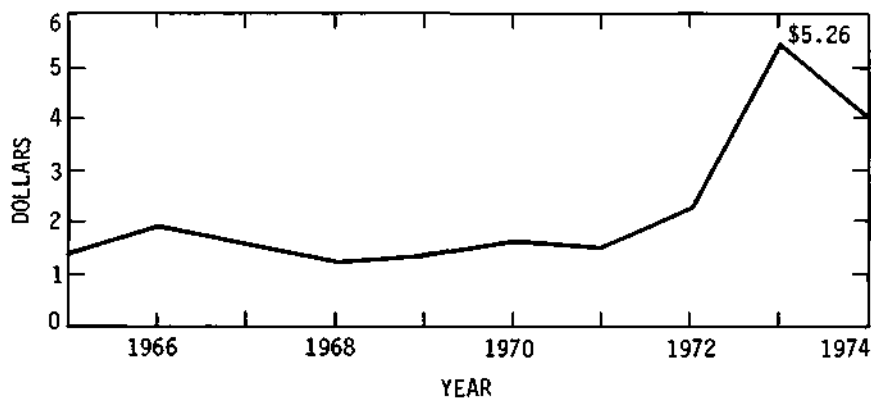
\*Benchmark is 100 in all cases

demand requirements and the 1975 level of hail suppression technology — thus, a 6% reduction. The regional adoption patterns (*Table 44* in Chapter 9) show that Model 1 is adopted by 31 crop-producing areas in 1985 and 36 producing areas in 1995, so that much of this adjustment to the new price level has already occurred.

Because these price changes would occur gradually over a period of years as adoption progresses relatively slowly, they may be difficult to observe empirically. This would be especially true when one examines the usual price fluctuations such as those for recent years shown in *Figure 59*.

**FIGURE 59**

Quarterly (January-March) prices of wheat, per bushel



## SECONDARY ECONOMIC IMPACTS IN TARGET COMMUNITIES\*



Increased economic activity in an area due to increased agricultural output resulting from effective hail suppression may provide an additional incentive for adoption of the technology. Although the TASH project does not include the analysis of such secondary benefits for specific areas or communities, it should be recognized that these secondary economic effects may play a role in adoption.

### INCOME, EMPLOYMENT MULTIPLIERS



Secondary impacts are often measured by use of two different types of multipliers — the income multiplier and the employment multiplier. The Keynesian income multiplier deals with highly aggregated variables and is based on a relationship between new investment and the propensity to consume. That relationship is:

$$K = \frac{1}{1 - b}$$

Where

$K$  = the income multiplier

$b$  = the propensity to consume

If  $b = 0.7$  — that is, persons consume, rather than save, 70% of their income —  $K = 3.3$ ; if  $b = 0.5$ ,  $K = 2.0$ .

*Modified for  
input-output  
analysis*

However this concept of the income multiplier has been modified and refined in those regional economic impact studies that have utilized input-output analysis. (Clark *et al.*, 1974; Doeksen and Schreiner, 1974; Palmimi *et al.*, 1977). In these applications, the input-output approach involves division of the local economy into sectors such as agricultural production, agricultural processing, manufacturing and mining, service, and households.

*Estimates  
made by  
sectors*

The interdependencies among the various sectors are taken into account in estimating the income and employment multipliers. The income multiplier for a given sector is the total amount of income generated in the area by the increase of one unit — for example, one dollar — of output in that sector.

In a similar fashion, the employment multiplier derived from input-output analysis represents the total increase in the number of persons employed as a result of an increase of one person employed in the sector considered. Both the income and employment multipliers take into account the direct and indirect effects of the change in output of the sector considered.

### SIZE OF SECONDARY IMPACTS



A sample of the results of a few studies which have estimated or used multipliers in assessing economic impacts in agricultural areas are presented to provide information on the magnitude of such impacts. In the case of hail suppression, the sectors most likely to be affected include, among others, farm implement and fertilizer sales and grain marketing.

These sections contributed by Earl R. Swanson.

In Canada, Peterson (1972) used a multiplier of 1.5 to represent secondary effects, but noted: "Secondary benefits must be carefully interpreted and used in assessing the merits of a public project. In this study, it is assumed that Alberta is a sub-region of Canada and will, therefore, receive regional benefits from a hail reduction program, even though Canada as a whole may not gain. This is compatible with federally stated goals of reducing regional disparities across the nation." It is apparent that the rationale for inclusion of secondary benefits was on the grounds of regional income distribution believed by the Canadian government to be desirable, and not on considerations of efficiency. These secondary benefits do not necessarily imply a net social gain for Canada as a whole.

Little and Doeksen (1968) estimated income multipliers for various sectors of the state of Oklahoma. They considered 16 sectors which included, among others, livestock and livestock products, crops, agricultural processing, and manufacturing. The income multiplier for the crops sector was estimated to be 1.52. The employment multiplier for the crops sector was not calculated because of the presence of underemployed resources and unused capacity in the basic agricultural sector.

Clark et al. (1974) used an 18-sector model for the Star Valley area of Wyoming. In the small grains sector, an income multiplier of 2.24 and an employment multiplier of 2.15 are reported.

Palmini et al. (1977) estimated the employment impact of environmental controls in two counties of Illinois. The nine-sector model included a sector "Wholesale-Farm Raw Materials" which contained all crop and livestock sales. The employment multiplier associated with this sector was 1.19 for Piatt County and 1.07 for Stark County.

Thus we note a great deal of variation in the secondary impacts of increased crop output (that would result from hail suppression) as measured by income and employment multipliers. This is due not only to differences in the area and time period studied but also to differences in methodology. Nevertheless, we may conclude that secondary impacts, although often modest, are, in principle, a part of a comprehensive evaluation of the impact of hail suppression in a local area. A prerequisite for their importance in any empirical analysis is, of course, first-order or *direct effects of an appreciable magnitude*. The following benefit-cost analysis considers only efficiency and hence does not include secondary benefits.

*Secondary  
impacts  
modest*

## **BENEFIT-COST ANALYSIS FOR FUTURE SUPPRESSION\***



A nationally focused analysis of the benefits and costs of future hail suppression was based on developing benefit-cost ratios, as calculated for the three scientific models postulated for the future.

**BASIS FOR  
BENEFIT-  
COST ANALYSIS**

These sections contributed by Earl R. Swanson and Stanley A. Changnon, Jr.

*Benefits  
are 'reduced  
costs'*

Benefits were determined with the values from shifts (reductions) in production and transportation costs derived from the national economic model. The decrease in that component of production costs represented by rent is a gain to consumers but a loss to landowners. Because these gains and losses offset each other, the benefits are based on cost reductions including only nonland costs, with rent excluded. Thus, these cost reductions, or benefits, are somewhat less than those presented earlier in *Table 48*, which included land rent.

*Costs start  
with project  
operations*

Costs in this analysis were determined for three major activities, one in the private sector and two in the public sector. The first is the cost of the operational activities diagrammed in *Figure 51* of Chapter 8. These costs were set at \$1 per planted acre, a value 3 to 5 times the expected future costs of hail suppression operations (*Table 39* in Chapter 8).

This higher value allows for differences between all-acreage costs and the planted-acre cost (about a 1:2 ratio for the nation) and for uncertain, but possibly sizeable, cost increases. Such increases may result from lawsuit outcomes that would produce much higher insurance costs for the modifier, and also from costs related to compensation payments to those in a seeded area with heterogeneous crops who experience identifiable economic losses. It is assumed that such insurance costs and compensation payments reflect actual damage to third parties and that these costs are not simply transfer payments.

*R & D costs  
and others  
included*

The second cost area relates to the public outlays for research and development costs for hail suppression. A third set of costs incorporated are the public outlays related to the design, evaluation, and information activities (DEI) that would be associated with widespread projects. As noted in Chapter 8, regional centers for performing these activities would lead to costs of \$1.5 million per 50,000 square miles, or \$30 per square mile.

*'Present  
values'  
calculated*

In order to introduce comparability of the time streams of the benefits and costs, the present values (as of January 1, 1976) of each series were calculated with the approximate current interest rate of 8%. Substantially higher discount rates were also used to determine if the results were sensitive to the choice of discount rate, and the outcome of this analysis is presented below (see page 284). Although the calculations pertaining to benefit-cost analyses may be performed in several equivalent ways (*Prest and Turvey, 1965*), we chose to use ratios of the present values of benefits to costs. The present values (*PV*) were calculated by applying the following formula:

$$PV = a_0 + a_1/(1+r) + a_2/(1+r)^2 + \dots + a_n/(1+r)^n$$

Where

$a_t$  - the cost or benefit in the designated year,  $t$

$r$  = the discount rate

The cost calculations were based on annual costs estimated for the operations,

for the research and development, and for the design-evaluation-information activities, where and when applicable. The costs were all computed on the basis of the areal extent and timing of adoption of hail suppression within the context of the three models, as described in Chapter 9.



Because our focus is on returns to public investment, the costs for operational activities — such things as forecasting, seeding, seeding materials, and related facilities — were all assessed at a value of \$1 per planted acre. These are costs that users of the technology are assumed to pay directly. This operational cost was entered, in performing the model calculations for reductions in production-transportation costs, by subtracting it directly from the model calculations of benefits (savings) related to shifts in production and transportation costs.

## **COSTS FOR OPERATION ACTIVITIES**

No adjustments were made for changing the price with time or area, as a basic assumption. In every respect, the \$1 per acre cost is considered a "high value," with most future costs (*Table 39* in Chapter 8) very apt to be lower.



Expenditures for hail research and development can be divided into two categories. The first includes those directly addressed to hail suppression research — such as current projects like NHRE, Design of Experiment to Suppress Hail (in Illinois), and the Societal Impacts research efforts. The indirect expenditures are those which are not specifically directed toward the hail suppression problem but which will yield relevant information. These include funds dedicated to research on cloud physics, cumulus dynamics, other aspects of weather modification, synoptic meteorology, and weather forecasting.

## **EXPENDITURES FOR FUTURE RESEARCH**

*Direct and  
indirect  
spending*

For the purposes of estimating future costs attributable to hail suppression, we arbitrarily assumed that the indirect research costs will amount to 20% of the total direct expenditures. Planned or ongoing field research projects which will indirectly yield information bearing on the hail suppression include SESAME, HIPLEX, CAP, and METROMEX.

The government (federal and state) research and development expenditures have been projected in the pattern of the three scientific models (*Table 38*) structured to estimate future hail suppression capabilities. These future costs, which we present in *Table 56*, are based on past costs and federal projections for the next five years. These three different forecasts involving varied research and development rates lead to estimates of expenditures that vary by roughly a factor of 3.

*R & D costs  
a fraction  
of crop loss*

At current crop-loss levels, these expenditures each amount to a fraction of 1% of the expected crop loss due to hail, which over the next 20 years would add up to something in excess of \$16 billion.



 **TABLE 56**

**Research and development costs for scientific models**

<i>Period</i>	<i>Activities</i>	<i>Annual cost (millions)</i>	<i>Totals (million \$)</i>
<i>Model 1, characterized by applications and experimentation with a major scientific breakthrough</i>			
1976-1980	Current funding levels	3.5	17.5
1981-1985	Moderate research with extensive applications together leading to a major breakthrough after 1985	3.0	15.0
1986-1995	Renewed and amplified field and laboratory research and development of new seeding facilities and instrumentation	9.0	90.0
Total			122.5
<i>Model 2, characterized by intermittent application of hail suppression and moderate scientific improvement</i>			
1976-1980	Current level of expenditure for 5 years	3.5	17.5
1981-1985	Reduced involvement in field research; heavy analysis research involvement	2.0	10.0
1986-1990	Renewed field involvement	3.0	15.0
1991-1995	Reduced field involvement; heavy analysis involvement	2.0	10.0
20-year total			52.5
<i>Model 3, characterized as the experimental approach, with an expanded research period</i>			
1976-1980	Decreased levels of support	1.5	7.5
1981-1985	Expansion of field experimentation in Colorado and Illinois	3.0	15.0
1986-1988	Intensive analysis period (few useful results)	4.0	12.0
1989-1995	Minimal research	0.2	1.4
Total			35.9

The major expenditure based on Model 1 includes potential developmental costs for seeding rockets, a field test thereof, airborne radars for hailstorm detection, and new seeding equipment and materials in the 1986-1995 period.

*Present values of R & D*

The temporal distribution of these costs (outlays) for research and development, as shown in *Table 57*, are important in determining their present values (*PV*). The discount factors used for calculating the present values for each year from 1976 through 1995 are also presented in *Table 57*.

The subtotals show that the present value of the 20-year outlays for suppression Model 1 is \$54 million, or 44% of its undiscounted sum of \$122.5 million. The same cost calculation for Model 2, given the present value, is 56% of the undiscounted sum of outlays. The effect of discounting for Model 1 is more


 **TABLE 57**

**Present values of public costs for research & development and design-evaluation-information activities**

Year	Model 1 (million \$)		Model 2 (million \$)		Model 3 (million \$)		Discount factor 8%
	R&D	DEI	R&D	DEI	R&D	DEI	
1976	3.5	0	3.5	0	1.5		1.000
1977	3.5	0	3.5	0	1.5		0.926
1978	3.5	0	3.5	0	1.5		0.857
1979	3.5	0	3.5	0	1.5		0.794
1980	3.5	9.0	3.5	0	1.5		0.735
1981	3.0	11.8	2.0	0	3.0		0.681
1982	3.0	14.6	2.0	9.0	3.0		0.630
1983	3.0	17.5	2.0	10.0	3.0		0.583
1984	3.0	20.4	2.0	11.0	3.0		0.540
1985	3.0	23.2	2.0	12.0	3.0		0.500
1986	9.0	23.2	3.0	12.8	4.0	NONE	0.463
1987	9.0	24.0	3.0	12.8	4.0		0.429
1988	9.0	24.0	3.0	13.6	4.0		0.397
1989	9.0	24.7	3.0	14.4	0.2		0.368
1990	9.0	24.7	3.0	14.4	0.2		0.340
1991	9.0	25.5	2.0	15.2	0.2		0.315
1992	9.0	25.5	2.0	15.2	0.2		0.292
1993	9.0	26.2	2.0	16.0	0.2		0.270
1994	9.0	26.2	2.0	16.4	0.2		0.250
1995	9.0	27.0	2.0	17.2	0.2		0.232
Present values (in January 1976 dollars)							
Subtotals							
	54.098	140.088	29.669	73.089	20.839	0	
Totals	194.186		102.758		20.839		

important than for Model 2 because the larger outlays for Model 1 are postponed until late in the 20-year period.

The effect of discount is less important for Model 3 where the present value of the outlays is 58% of the undiscounted sum. The large R & D outlays for Model 3 occur earlier in the 20-year period than the large outlays for Model 1.

 The third major type of cost that will develop, but which will concern only *widespread* future use of hail suppression, is that related to the project design, evaluation, and program information activities (DEI) that were described in Chapter 8. This is also assumed to be a public outlay. *Figure 51* in Chapter 8 shows all the functions of a successful hail prevention program. The \$1 per acre cost previously assigned covers only the operational facets shown in that figure. Costs (other than research and development costs for future hail suppression) for the other functions shown in *Figure 51* must be accounted for.

DEI COSTS  
IN LARGE  
PROJECTS

*DEI work essential to 'accepted' suppression*

Consideration of the reasons for public and scientific rejection of past weather modification projects (Chapter 3) and the factors deemed relevant for its adoption (Chapter 9) reveals that *large-area adoption and sustained acceptance of hail suppression will not occur without the performance of these design-evaluation-information functions* by unbiased groups. As explained in Chapter 8, the cost of these activities would be a function of area size, costing (likely in public funds) \$30 per square mile per year, once they had begun.

*Assumed area size for DEI centers*

Therefore, we postulated that once the adoption of hail suppression extends over a contiguous area exceeding 250,000 square miles — and also covers portions of at least three states — sufficient rationale and pressure would exist for use of public funds to establish, and continuously operate thereafter, regional centers where project design and revision, monitoring, evaluation, and information dissemination functions would be performed.

*Calculating support costs*

Calculations of costs for these support activities were performed for each of the scientific models. The average size of the crop areas of the western U.S. (25,000 square miles) was used along with the rate of areal adoption such that when the first ten areas adopted, the costs for design-evaluation-information (DEI) began one year later. The rates of areal adoption were calculated from linear plots for 1975-1985 and for 1985-1995, based on the crop area adoption frequencies set forth for each model in *Table 44* of Chapter 9. Costs for DEI were linearly increased thereafter in accordance with the rate of areal expansion of hail suppression.

*Based on areal rate of adoption Model 1*

*DEI costs start in 1980*

The linear rate of crop area adoption for Model 1 revealed ten crop areas adopting by 1979, and the \$30 per-square-mile costs for DEI were assigned to begin in that model in 1980. By then, because of rapid rate of adoption, 12 areas (300,000 square miles) would have adopted hail suppression, making the first year or 1980 costs \$9 million (*Table 57*). Costs would grow rapidly in each year to 1985 when 31 areas (775,000 square miles) would have hail suppression. An annual cost was computed for each year through 1995 after the initial adoption of DEI costs began.

*No DEI costs under Model 3*

Similar calculations were done for scientific Model 2 with the rate of adoption producing initiation of DEI costs in 1982. Adoption of hail suppression under Model 3 (*Table 44* in Chapter 9) never reaches an areal extent where these public-supported DEI centers and related costs would develop, as we show in *Table 57*.

*Present values of DEI*

The present values (*PV*) were calculated from the DEI with the discount factor in the same manner as for the research and development costs. *Table 57* shows that the present discounted values of costs for DEI efforts under Model 1 are \$140 million, compared with \$73 million for Model 2 and, of course, 0 for Model 3.

When both the discounted costs for R & D and DEI are summed (*Table 57*), we

 **TABLE 58**

**Potential changes in total nonland production and transportation costs to point of processing for 1975, 1985, and 1995**

<i>Year</i>	<i>Benchmark</i>	<i>No-hail</i> *	<i>Model 1</i>	<i>Model 2</i>	<i>Model 3</i>
1975 (billion \$)	15.053	14.664			
Cost change		-0.389			
Cost change (as % of benchmark)		3			
1985 (billion \$)	15.840	15.408	15.634	15.688	15.840
Cost change		-0.432	-0.206	-0.152	0
Cost change (as % of benchmark)		3	1	1	0
1995 (billion \$)	15.850	15.423	15.357	15.587	15.852
Cost change		-0.427	-0.493	-0.263	+0.002
Cost change (as % of benchmark)		3	3	2	0

\*The hypothetical elimination of all hail at no cost

find that the total is \$194 million for Model 1, \$102 million for Model 2, and \$39 million for Model 3. Thus, the cost for Model 2 is roughly 53% of the cost for Model 1, and the cost for Model 3 is roughly 39% of the Model 2 costs.



Reductions in crop production and transportation costs computed in the national model were considered as the benefits of future hail suppression. These computations were made for each of the three scientific models. Computations were based on the reductions computed in nonland production costs and transportation costs. The annual benefits are presented in *Table 58* and *Figure 60*.

The effect of hail suppression itself will be to lower rents, viewed as an aggregate for the United States (the regional pattern of the rent impact is presented in the earlier section, *Returns to Landowners*). Because rents on agricultural land are, to a large extent, determined by the value of agricultural production, the benefit-cost analyses for the overall national effects were based on the model calculations of production and transportation costs without land rent, or on "nonland production costs." These are the values presented in *Table 58*. The costless elimination of hail (no-hail) reduces costs approximately 3% in all years considered.

In interpreting the results of the benchmark values versus the model cost comparisons (*Table 58*), one should bear in mind the variation in adoption patterns among the models (*Table 44* and *Figure 56*, Chapter 9). For example, Model 1

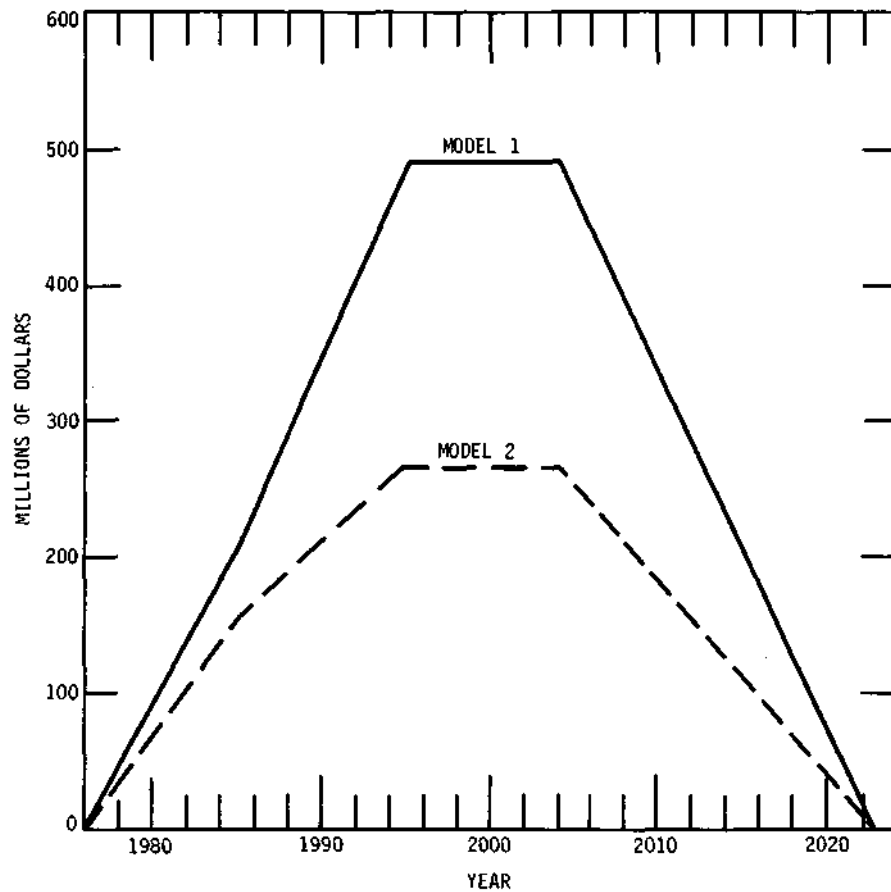
**BENEFITS  
OF HAIL  
SUPPRESSION**

*Nonland  
production  
costs used*



**FIGURE 60**

**Benefits, or reductions in nonland production costs and transport costs, for the scientific models**



in 1995 is adopted in 36 crop-producing areas whereas Model 3 is adopted in only 5 crop-producing areas in 1995. Further, the effectiveness of the models differs greatly (Table 44). These two forces are the important factors influencing the cost decreases.

In 1985, scientific Model 1 decreases costs nationally by \$206 million, whereas Model 2 reduces costs (or produces benefits) by \$152 million. These each represent about a 1% reduction. Since there is no adoption of Model 3 in 1985, the cost of production and transport for it is identical to the benchmark solution.

*Model 1  
'rainfall'  
a benefit*

In 1995, Model 1 reduces costs by approximately 3% and its monetary value is slightly larger than that for the no-hail situation. This is due to the beneficial effect of rainfall augmentation associated with Model 1 capabilities in 1995 — *these are absent in the no-hail solution.*

As shown in *Figure 60*, a straight-line interpolation was used to construct benefit values for the intervening years. The benefit (cost decrease in production and transportation) derived from Model 1 by 1995 is \$493 million (*Table 58*), and it should be remembered that this benefit has already had the \$1 per planted acre costs subtracted. This value is nearly twice the benefit obtained with Model 2 (\$263 million).

*Model 1  
benefits  
highest*

Model 3 exhibits an increase of \$2 million in cost resulting from adoption in **1995**. In the adopting regions operational costs are considered at the \$1-per-acre level, along with other production costs. For producing areas designated as having adopted hail suppression, the alternative of the more economical method of production (no-hail suppression) was assumed not to be available. A number of factors entered into the determination of adoption patterns (*Table 44* in Chapter 9), and one of these, the economic incentive index, was based on the percentage increase in total revenue that would be expected with the specified hail suppression capability. This calculation did not include the \$1-per-acre operational cost which was used in the linear programming model to derive values shown in *Table 58*.

*Model 3  
does not  
benefit*

More importantly, the selection of adopting producing regions took into account several noneconomic considerations. The economic incentive index for each of the five adopting regions in Model 3 for 1995 was +1, a weak or marginally positive economic incentive. Thus, the economic incentive index was sufficiently low to result in a net loss when \$1-per-acre operational charge was included.

One could reasonably speculate, however, that the cost per acre within the situation envisioned for 1995 and Model 3 (see *Chapter 8* description) might well be less than \$1 per acre and more nearly at the \$.20 to \$.35 level shown for 1995 in *Table 39*.

Regardless, the five production regions were considered to be adopters under Model 3 in 1995. Thus, Model 3 for 1995 shows a slightly higher cost from adoption than the benchmark solution. Basically it reflects that the cost of modification with a relatively low capability level must be very low, and that if adoption occurs with the \$1 per planted acre estimate, it will be for reasons other than economic ones.



The benefit-cost computations are based on the future outlays for research and development and for DEI (*Table 57*) — and the stream of benefits therefrom (*Figure 60*). We assumed that the R & D outlays would end in 1995 and the stream of benefits could not be maintained as a permanent technological gain. Other technologies are likely to make these obsolete, and, as shown in *Figure 60*, after a ten-year plateau of benefits (1995-2004) a linear phase-out period of 19 years was assumed.

**BENEFIT-  
COST  
VALUES**

Actually, the precise description of events after 1995 is not of much consequence for the benefit-cost analyses since we used an 8% discount rate. For example, the discount factor for 1995 (*Table 57*) is 0.232, and for the year 2022 (the last year considered for benefits) it was only 0.029.



**TABLE 59**

**Present values of benefits and costs with 8% discount rate**

	<i>Model 1</i>	<i>Model 2</i>	<i>Model 3</i>
Present value of benefits (millions)	+2,840.235	+1,715.870	-7.555
Present value of costs (from <i>Table 57</i> ) (million \$)	+194.186	+102.758	20.839
Benefit-cost ratio	14.6:1	16.6:1	-0.4:1

The present (discounted) values of the benefits and costs for the three models are presented in *Table 59*. As shown, the benefit-cost ratio for suppression Model 1 is 14.6:1 and that for Model 2 is slightly higher, 16.6:1. The benefit-cost ratio for Model 3 is a slight negative value resulting in a ratio of -0.4:1.

The benefit-cost ratio for the increment of investment required

to go from Model 2 to Model 1 (\$91,428 million) is 12.3:1. The benefit-cost ratios of going from Model 3 to Models 1 or 2 are larger, 16.4:1 and 21.0:1, respectively.

The choice between Model 1 and Model 2 should take into account the high incremental benefit-cost ratio for the added investment to accomplish Model 1 capability (12.3:1). Viewed in another way, the added benefits achieved by development of Model 1 increase by \$1,124 million while added costs increase by only \$91 million. Therefore, our benefit-cost analysis leads to the selection of Model 1.

*Comparison with other research*

These benefit-cost ratios should be compared with the results of other studies of returns for public investment in agricultural research. Griliches (1964) found that the returns for total public investment in research and extension in agriculture were in the range of \$10 to \$16 for each dollar spent.

Dealing with a more specific innovation — the tomato harvester, Schmitz and Seckler (1970) estimated a gross return of approximately \$9 per dollar spent in research and development (including the private sector). After adjustments were made to compensate for 50% of the labor displaced, the rate of return was between \$4 and \$5 per dollar spent.

*Other returns comparable*

Peterson (1967) used two different methods in calculating the returns to poultry research, and estimated that this research had yielded a return on investment of approximately 20 to 30% per year. Thus, the available studies of returns to past public investments in agricultural research indicate returns comparable with those for a well-developed, reliable hail suppression technology.

It should be recognized that in addition to the use of different methods of analysis, the above cited benefit-cost studies were based on returns that actually occurred, in

contrast to the TASH study of future benefits and costs based on *expected* research and development accomplishments. That is, there is no risk-discounting applied to the estimates of the three models. If these estimates were reduced to "certainty equivalents," their effectiveness would be reduced with a consequent lowering of the benefit-cost ratio. Another way to view the uncertainty of the output of technology from the R & D process is to estimate the R & D costs high enough to increase substantially the probability of success. The cost estimates presented in Table 57 are judgments based on past experience.

The cost of hail suppression used is partially understated because prior research and development investments (pre-1976) in hail suppression, and more generally in the fields of basic atmospheric and engineering knowledge that support the predicted levels of performance by 1985 and beyond, are not considered as costs. For the purposes of the current decision making about the future value of hail suppression, these "sunk" costs should not be considered. These investments are no longer an option, although they may increase the productivity of the future investments.

*Prior R&D  
not applicable  
to future costs*

It is of interest to note the impact of the use of a discount rate higher than 8% on the benefit-cost ratios. Substantially higher rates were used with the ranking of the models remaining the same, although the sizes of the benefit-cost ratios decreased. For example, a 30% discount rate reduced the benefit-cost ratio for Model 1 from 14.6:1 to 8.3:1.

In summary, although data are not available to make a comparison between further investments in hail suppression and other candidates for research funding, either within or outside the atmospheric science area, the benefit-cost ratios are such that hail suppression with attendant rainfall augmentation appears to warrant serious consideration.

We do know that a number of groups have indicated agricultural research priorities — some that include weather modification and others that do not. One view of the current research priorities in the area of food production is given in the interim report of the National Academy of Sciences (1975). These are the seven areas recommended for expanded U.S. support of research:

*Agricultural  
research  
priorities*

- 1) Increasing the amount of biological nitrogen fixation in major food plants and in the soil
- 2) Increasing the rate at which the major food plants synthesize carbohydrates and convert them to foodstuffs
- 3) Widening the potential for genetic or other biologic improvement in plants by development and application of new techniques of cell and tissue culture and DNA recombination
- 4) Increasing the effectiveness and lowering the costs of chemical fertilizers, particularly to widen use by the mass of poor farmers in the tropics
- 5) Reducing food losses caused by pests by strengthening the tools used to combat pests and devising better combinations of these tools to apply to the great variety of farming and post-harvest situations around the world



- 6) Increasing the production of livestock products, particularly from cattle, by improving forages for the predominant worldwide types of range land, suppressing major diseases of tropical livestock, and increasing livestock reproductive efficiency
- 7) Increasing, through genetic changes, the protein to humans and animals of the principal grains consumed worldwide

A similar benefit-cost analysis for each of these may show a higher or lower benefit-cost ratio than those for hail suppression. In addition to research investments there is, of course, the possibility of greater application of known technologies, for example, irrigation.

*'Priorities'  
exclude  
weather,  
climate*

Agriculturalists recently stated (*McElheny, 1976*) that no major crop-increasing technologies are coming along. Nevertheless, our estimates of crop yield increases for 1995 (*Table 46*) are believed to be less optimistic than most projections that have been made. Furthermore, the seven topics listed in the NAS report discussed above do not address directly any weather or climate issues, and these are now strongly before us (*Changnon, 1975a; Thompson, 1975*).

An in-depth agricultural review of the applications of weather modification to agriculture in 1968 (*USDA, 1968*) called for increased attention to weather modification because of its potential benefits to agriculture.

A report from a conference sponsored by the Agricultural Research Policy Advisory Committee (*ARPAC, 1975*) discussed problems and priorities within "research need" areas. One research-need area was Weather and Climate, which was ranked by the conferees as 31st in a list of 89 need areas. Within the Weather and Climate area, the "most important" research problem was judged to be: *Evaluate those areas where renewable resources can be optimally developed in relation to agriculture and food production.* Research on weather modification was placed in the "important" class.

Two other groups have recently drawn greater attention to the agricultural importance of weather modification research. Grant and Reid (*1975*) provided a review pointing to the various benefits of weather modification to agriculture.

*Agriculture  
studies call  
for research  
on weather  
modification*

Recently, the Board on Agriculture and Renewable Resources of the National Academy of Sciences (*NAS, 1976*) reviewed agricultural production, climatic change, and the role of weather modification. The report concludes that the potential for weather modification to help meet the food production needs of the United States and the world is sufficiently great that weather modification should be heavily investigated. Foreseeable capabilities presented in that report do not lead to major gains in food production in the United States, but are comparable

with other potential technologies. Another recent report dealing with U.S. food and climate also suggests the potential use of weather modification as one means to address shortages (*Institute of Ecology, 1976*).

## THE RESEARCH INDUSTRY AND FUTURE HAIL SUPPRESSION\*



We now look at the effects of future hail suppression on another major stakeholder group — the research "industry." There are a variety of factors that are influences on future research. The research industry will be composed basically of those who perform the research and those who support it. The level of future support was estimated for the TASH calculations of future benefits, as presented in the preceding section. Uncertainties over the future levels resulted in calculating three different levels of support, in line with the three future scientific models.

A prime question of governmental decision makers about hail suppression is its future worth. Basically, "*Is it worth supporting?*" In one sense, this entire report provides a host of answers that should be considered in discerning the value of added hail suppression research. However, a specific economic analysis, based on the potential value of hail suppression and related rain modification to a large area in northwestern Kansas, is included to help illustrate some of the knowledge needed to make decisions about support and dimensions of future hail suppression research.



The current level of knowledge concerning hail suppression is debatable, despite a number of years of research effort by the National Center for Atmospheric Research (NCAR) and other groups. Moreover, the discussion on the best scientific course of action to follow during the next several years of NCAR research on hail suppression has been marked with considerable controversy between those who favor large statistical experiments and those who favor greater emphasis on more fundamental laboratory, theoretical, and narrowly defined field research on cloud physics (*RANN-UCAR Panel, 1974*). The resolution of this controversy has not been achieved.

An assumption that the levels of knowledge will increase — or the levels of uncertainty will decline — concerning hail suppression technology is undoubtedly a reasonable one, despite the spirited debates that have taken place since 1947. It is far less likely that there will be dramatic and rapid scientific breakthroughs because of the subcritical level of funding and the nature of funding of weather modification research generally.

### FACTORS AFFECTING FUTURE RESEARCH

*No rapid  
increases in  
science or  
its support*

\*These sections contributed by Stanley A. Changnon, Jr., and Dean Mann.

Scientists bitterly complain of the sporadic, short-range, and limited funding of their work, blaming the lack of progress on the short-sightedness of Congress and the Office of Management and Budget (*Simpson and Dennis, 1972*). Others blame the lack of progress on too-early emphasis on field experiments and statistical studies and too-little emphasis on basic research (*Changnon, 1973, 1975b; National Advisory Committee on Oceans and Atmosphere, 1975*).

Nevertheless, the promise of past and current research, the existing levels of resource commitment, public expectations that progress should continue, and convictions by scientists and program managers that hail suppression will contribute to their missions will most probably lead to a reasonably steady improvement in the understanding of hail suppression technology.

*Research will continue*

Future research and development related to hail and its suppression is thus assumed to continue throughout the next 20 years. Basically, the lack of definitive information about the physics of the modification of hailstorms and severe convective storms in general is so great that it is unlikely that the complexities can be totally resolved in the next 20 years, even with sizeable support and a major scientific attack on the issue. Thus, the major issue of the future research is its rate of progress and the factors that directly affect this.

*Lack of future 'priority' for hail suppression*

The difficulty of achieving a complete consensus on the technology will continue to provide ammunition for those who seek different research or public policy directions. There is evidence that weather modification does not presently have the public, agency, or perhaps even scientific appeal to give it the sense of urgency or glamor that cancer research or space exploration enjoy (*Mann, 1975*). When the budget crunch comes — and it is coming rather consistently as administrations seek to counter inflationary pressures — research programs such as those in weather modification frequently find that they are "optional," not crucial, in the solution of major national problems.

*Levels of research and support directly linked*

The level of future research and development can vary considerably as a result of different levels of interest, support, and effort. However, hail research has an upward ceiling based largely on the availability of scientists trained to perform such complex research. The facilities needed to make advances have been largely developed. To address these potentially varying levels of future effort, three alternative routes of future research activity have been developed within the context of the scientific models as was shown in *Table 56*. Knowledge of past spending coupled with the alternate routes posed in these models were the basis for calculating the rate of funding that will be expended on hail suppression.

## **GOVERNMENTAL SUPPORT OF RESEARCH**



A significant indication of current thinking regarding weather modification generally is found in a report of the Subcommittee on Climate Change of the Domestic Council within the Executive Office of the President (*Domestic Council, 1975*). The Subcommittee concluded that weather modification had much beneficial potential and recommended that the federal government "foster a

broad-based effort of research and experimentation in weather modification designed to realize this potential during the next decade."

*Near future  
federal outlook*

The Subcommittee recommended increased funding, particularly in basic cloud physics, socio-economic and environmental impacts, and evaluation methodologies. It did not conclude, however, that the development of weather modification science and technology should constitute a national goal.

It is uncertain which federal agencies will fund future hail suppression research. The National Science Foundation (NSF) has the traditional role, having funded most of the hail suppression research performed since research began in 1959. However, recent problems in the NSF support and management of hail research, partially related to the 1973 shift of support from the basic sciences division to the Research Applied to the National Needs program (*RANN-UCAR Panel, 1974*), have produced problems for both the agency and for the NHRE research program of NCAR, the major recipient of the research support (*Science, 1976*).

*Will NSF role  
continue?*

Presumably, NSF will continue in the future to support hail research, with or without a direct focus on hail suppression, in fulfillment of its main mission of supporting basic research.

However, other mission-oriented agencies which deal with subjects where hail has its major impacts — such as the Departments of Agriculture and Housing and Urban Development — may ultimately take on a major role of the support of hail suppression research. Recent reports (*Grant and Reid, 1975; National Academy of Sciences, 1973; Changnon, 1975b*) have also pointed to the need to have a re-alignment of federal direction and support of weather modification research.

*Other potential  
federal agencies*

NACOA (1975) charged the U.S. Department of Agriculture with taking on a greater involvement in weather modification. The USDA did support a weather modification program in the 1960s dealing with the suppression of lightning in forested areas. However, in recent years their support of weather modification research has been minimal (see *Table 20* in Chapter 5) and has dwindled to less than \$100,000 per year (*Domestic Council, 1975; Changnon, 1975b*). Thus, their undertaking of hail suppression research would require a considerable shift from current agency policies although they are the most logical federal agency to deal with hail suppression.

Another federal agency that could become involved in a more substantial way in hail suppression research is the National Oceanic and Atmospheric Administration (NOAA) of Commerce. This agency is the major weather agency of the nation and has had the third largest financial commitment to weather modification (*Table 20*), now dealing largely with modification of rainfall from tropical cumulus and the modification of hurricanes.

*Will future  
reorientation  
give NOAA  
the leadership?*

Both the National Academy of Sciences (1973) and the National Advisory Committee on the Oceans and Atmosphere (1975) have made recommendations to the federal government that NOAA should assume federal leadership for weather modification. Currently

there is no one leader and the field is split among the various mission agencies with the Bureau of Reclamation focusing on rainfall and snowfall enhancement in the western half of the United States, the National Science Foundation on hail, the Air Force on fog, etc. If these recommendations are followed, NOAA would become the leader and then, with time, could become the major research support agency of the future. The 1976 enactment of P.L. 94-490 calls for a review of the national program in weather modification under the direction of the Department of Commerce.

However, the Domestic Council (1975) in its recommendations about the role of the federal government in weather modification did not strongly endorse a leadership role for NOAA and supported the status quo. Hence, major shifts in the support of hail suppression research away from NSF, if they do occur, are apt to be sometime after the 1980-1985 period when currently planned research involving the National Hail Research Experiment would be terminated. NSF has already considered future expenditures of several million for hail research in the next few years.

*Will states  
get  
involved?*

There is some argument against federal support which is in part directed toward state assumption of responsibility for programs presently funded at the federal level. The question is whether the states, in fact, would assume the responsibility for such research programs, particularly if they involve substantial expenditures and therefore taxes.

Revenue-sharing provides some incentive for states and local governments to undertake operational programs more or less of their own choosing, depending on the extent to which they are subject to federal requirements. Few states have so far undertaken financial support of weather modification *research* and it is unclear that states can or should financially support it.

## **THE FUTURE PERFORMERS OF RESEARCH**



Another involved group includes those who will perform the research. These include the scientists, the laboratories, and the commercial firms who collectively will perform the future research using their staffs and facilities. The scientific models revealed that one or more National Hail Research Experiments, or phases thereof, will continue to at least 1995. Such field and analytical efforts will continue to be controlled and partially performed by scientific groups such as NCAR and those at universities.

*Goal will be  
scientific  
consensus*

An eagerly sought goal of the future research will be to achieve scientific consensus about the experimental results, and this strongly dictates an approach involving scientific groups in nonprofit organizations as directors of programs. However, the inability of such groups to perform well the sizeable operational tasks will result in considerable involvement of the commercial weather modification firms.

The major scientific involvement will likely occur at the institutes, laboratories, and universities in the Rocky Mountain-Great Plains area where hail is a regionally recognized problem. NCAR will ultimately become uninvolved in hail suppression research, and such research direction will likely fall to an atmospheric sciences group at a university.

*Western  
scientists will  
be in control*



A problem associated with publicly sponsored research is the attempt to determine in advance what promising lines of research to support. How can rational decisions be made to allocate resources to the most potentially valuable research projects? *How can we determine the value of scientific research?*

**VALUE OF  
FUTURE  
SUPPRESSION  
RESEARCH\***

For example, the question has been raised as to what we now know which we would not have known had we not had \$23.5 million of support for the National Hail Research Experiment during 1971-1975. The national amount of loss from hail estimated for the five-year period 1971 through 1975 is \$3,865 billion. The \$23.5 million support of NHRE thus represents 0.6% of the resources lost to hail during that period, not including the cost of other adjustments such as insurance or disaster assistance. No standard exists to tell us whether that ratio of research proportional to the problem is a reasonable one or not.

The most important findings from the National Hail Research Experiment, as defined by the Director of the National Center for Atmospheric Research, are as follows:

*Key findings  
from NHRE*

- 1) On the Great Plains there are at least two distinct categories of hailstorms, each requiring a different seeding strategy. One type, the supercell hailstorm, *may* prove to be unseedable. The competition hypothesis on which seeding is based may not apply to the supercell.
- 2) The process of hail embryo growth in Great Plains storms is dominated by the riming of ice crystals and not by the freezing of large supercooled drops, which previously had been thought to be the case.
- 3) Within Great Plains thunderstorms are portions or areas having high liquid water content which are not supported by the storm's updraft. The support of hailstones in the updraft is a part of the competition hypothesis of hail formation. The thunderstorm dynamics to explain this unexpected finding are not understood.

Other NHRE results include:

- 1) Most of the damaging hail falls from a small percentage of the total number of storms. Thus, a statistical demonstration of seeding efficacy must rely on either a) a very extended field experiment in time and space in order to accumulate enough cases to obtain statistical significance or b) a demonstrated predictive capability such that if a storm that was predicted to produce hail did not in fact do so after seeding, the result would be powerful support for the effectiveness of seeding.

2) The relative value in economic terms of additional rainfall as compared to reduced hail is very high.

3) The Russian hailstorm model is not applicable in the Great Plains.

4) The methods of surface sampling of hail damage are better developed, and the expertise of the NHRE staff has been increased.

NHRE also found no reduction in damaging hail at the ground as a result of seeding. The overall result is that a great deal more needs to be known about the hail formation process and the dynamics of severe convective storms before seeding can be effectively applied.

*Monetary value  
of NHRE findings  
hard to assess*

Clearly it is not possible to assign a dollar value to these important NHRE findings because they are, in one sense, negative findings — that is, findings not resulting in decreases in damaging hail. The value of negative findings is commonly underestimated, perhaps because they seem at first less "glamorous" than positive results. However, they may in the long-term sense be extremely valuable in expanding our knowledge about atmospheric processes and how best to modify them.

Furthermore, to the best of our knowledge no empirical data exist to tell us in research, as a whole, how many blind alleys had been followed before we came upon the right path. Serendipity is an inherent part of scientific discovery: it cannot by definition be planned in advance. A high payoff in the utility of a certain line of research seems always to occur among a plethora of related inquiries being conducted in a variety of disciplines and places. It is premature, then, to judge the ultimate value of the National Hail Research Experiment or to attempt to assess the value of future research for hail suppression from these findings.

*Decisions  
on research  
investments  
difficult*

The scientific decision-making process that brought NHRE into being began in the 1960's, and was significantly influenced by Soviet claims of an effective hail suppression capability in a context of international competition. An intensive field experiment on hail suppression, patterned somewhat after the space program, was conceived as the best approach to hail research. American scientists interested in hail had to align themselves in some way with the National Hail Research Experiment where almost all of the nation's resources for studying hail were located. In a sense, all the eggs were in the NHRE basket. The problem appeared to be, in retrospect, that not enough basic research had been completed to form the requisite foundation for this "moonshot" approach to hail suppression.

To put the problem in even clearer perspective, the successful landing of a man on the moon resulted in the reduction of no particular damaging losses on earth, but the nation clearly saw it as a successful venture worth a great deal of money. The "payoffs" of the moonshot were far more in the areas of international prestige, a sense of national power and competence, and the awesome quality of the idea of man setting foot on another planet.

We have learned, then, that the suppression of hail is an extremely complex scientific problem. If we had approached the research problem in a different

way in the 1960's when the Soviet claims became known, might we have decided to expend our research monies for the study of hail suppression in a different way? We think possibly so.

The following exercise into determining the possible value of future suppression research, conducted by a TASH economist, resulted in two important insights concerning the kinds of information needed on which to base decisions allocating resources to such research. The first insight is that the best possible information on the current status of knowledge in the field, and the forecasts of the leaders in the field, are needed. The second insight is that studies on a broad geographical scale and in affiliated disciplines provide needed information on the transferability of potential research results. How widespread would their application be? If applications were more widespread, then the economic value of a research payoff would, of course, be greater. The problem of transferability leads the decision maker, then, to seek information from affiliated disciplinary areas beyond the primary disciplinary area in question.

*A method  
for examining  
value of  
future weather  
modification  
research*

In the case of hail suppression research, it is useful to have estimates of potential net benefits from a research project before the costs of the project have been incurred, and with the assumption that the research results could be negative. Methods to provide estimates of potential net economic benefits exist. In this section of the report, a method is presented and its use is illustrated in a plausible hail suppression context.

Three cautions are needed in understanding the discussion. The first is that the exercise is not an attempt to estimate net economic benefits from hail suppression; a hail suppression situation in a high-hail-loss area is used simply to illustrate the techniques employed. (Estimates of benefit-cost ratios for hail suppression are provided elsewhere in this chapter.) Second, the method discussed does not eliminate the decision maker's need for other kinds of information and for informed value judgments about the potential success of the contemplated research effort. Third, the data used to illustrate the method are hypothetical. The analysis presented was applied to one area of northwestern Kansas.

Data needed to address the value of more information (through research) of hail suppression fall into three segments:

- The relationship between expected benefits and changes in physical factors induced by the hail suppression activity
- A probability distribution of the changes in physical factors caused by a hail suppression program, before and after the proposed research
- The costs associated with the technology including both development and operational costs

A hypothetical relationship between changes in physical factors and direct benefits is depicted in *Figure 61*. For this example, we assume that only two physical factors —hail damage to crops and growing season precipitation —would be affected by hail suppression programs. Also, we restrict the direct benefits variable to net income from crop production (a simplifying assumption) and the benefits accrue only to farm operators.

*First —  
computation of  
benefits*





FIGURE 61

Relation between physical factors and benefits

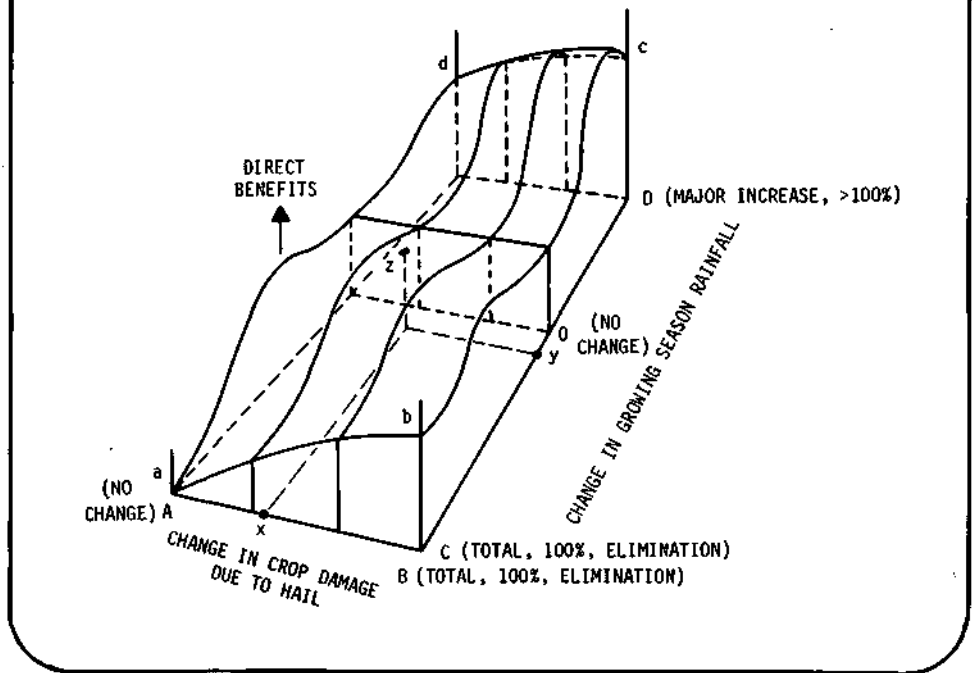


Figure 61 relates varying levels of damage reduction and changes in rainfall to the value of direct benefits associated with each level of these physical factors. If we had no prior knowledge of the physical results from hail suppression, only two of the endpoints for the hail damage and rainfall variables could be specified. That would be point B, which must be a maximum of 100% signifying no crop loss due to hail, and point C, which could be a maximum of a 100% reduction in rainfall.

*Prior knowledge can restrain endpoints*

Typically, however, prior knowledge would be available to restrain endpoints A and D as well as possibly limiting the range of endpoints B and C. If that knowledge did not exist, or simplifying assumptions could not be made, the economic evaluation would have to stop at this point.

The surface enclosed by points *abcd* completely describes the potential net income outcomes for the technology. For any particular outcome, with respect to reduced crop damage or changes in rainfall, a specific direct benefit level can be determined. For example, point *x* for a change in crop-hail damage and point *y* for a change in rainfall are uniquely associated with direct benefit level *z* in Figure 61.

The total cost of a hail suppression technology can be subdivided into two portions, developmental and operational. Because the development costs often occur as large expenditures before the flow of benefits commences, the time value of money must be considered. To account for this, the value of the flow of expected benefits was discounted, as discussed later, to have the same time dimension as the development costs.

*Second —  
cost  
calculations*

Operational costs were subtracted from the gross returns of hail suppression, and thereby captured in the net direct benefits variable — assuming the payers of those operational costs are also recipients of the benefits. If the operational costs are borne by the public sector, or in the private sector but by individuals not receiving the benefits, a more proper profitability test would involve comparison of returns from the next best use of the monies which would go to operational costs.

An additional potential cost of a new technology like hail suppression is the possible reduction in benefits for individuals for whom the technology is not intended. This is the "externality" problem of economics. An illustration: construction of a multistory apartment building might reduce property values of the existing properties in a residential area (*Henderson and Quandt, 1971*). Such costs were not incorporated in this analysis. However, these costs must be taken into account if such reductions are significant.

The benefit relationship of *Figure 61* alone cannot indicate the level of benefits to expect if a particular hail suppression program became operational. The likelihood of each physical outcome (for all physical factors) after the proposed research is completed is also needed, at least in a probabilistic sense.

*Third —  
probable  
outcome*

The derivation of an expected benefit value for any innovation like hail suppression results from combining the benefits accruing from each physical outcome which the event can cause, with the likelihood that each outcome will occur.

Derivation of an expected benefit value from *Figure 61* follows a two-step sequence. First, the endpoints for the range of physical outcomes, points *A* and *B* as well as *C* and *D*, could probably be restrained to a smaller range than previously alluded to.

*Likely future  
technology  
levels set*

For example, existing evidence (*Table 12* in Chapter 3) suggests it is very unlikely for hail suppression programs to increase hail damage to crops. Also the ability to totally reduce hail damage to crops may be considered to be impossible, restraining point *B* to some upper level (i.e., 80, 85, or 90%). Similarly, the effect of a hail suppression program on rainfall may be reasonably known to have some outer limits (i.e.,  $\pm 20$ ,  $\pm 30\%$ , or  $+20$  and  $-50\%$ , etc.).

But even when the endpoints of the benefit function are specified, the expected value of the program cannot be estimated until the *likelihood* of each physical outcome within these limits is determined. Therefore, one needs to know the

*Probability of  
future levels  
is needed*

probability that each possible reduction in crop damage due to hail would occur,  $P_D$ , and the probability that each change in growing season rainfall could occur,  $P_R$  — between endpoints  $A$  and  $B$  and  $C$  and  $D$ , respectively.

If the two physical events were independent of each other, the joint probability of any benefit value can be determined by multiplying the two separate probabilities,  $P_{NB} = P_D \times P_R$ . However, if interactions between reducing crop-hail damage and changing growing season rainfall were known to exist, a joint probability distribution,  $P'_{NB}$ , would have to be estimated.

*Fourth —  
value of  
additional  
information*

The question of the value of additional information about hail suppression appears most interesting when asked regarding the aforementioned probability functions. A plausible setting for this question arises from the likely future solicitation of public funds for research to develop more effective procedures to suppress hail. The federal agency receiving such a solicitation should ask, "What will be the payoff from this research, if it is successful?"

The proper estimation process to use in calculating the value of an additional experiment is dependent on the purpose of the experiment proposed. Basically, two procedures are available.

- One, which relates to an experiment to develop a *new technology*, compares the expected net benefits of that new technology with costs of obtaining such knowledge.
- The second procedure, pertaining to an experiment intended to develop *better estimates of a presently available technology*, evaluates the maximum benefit available if the proposed research rectifies an otherwise wrong decision.

*Kansas  
example  
selected*

Numeric examples for hail suppression are presented for both of these experimental situations. For discussion, a simplified circumstance was assumed to be meaningful. This circumstance considered the net benefits of additional research on hail suppression effectiveness to wheat producers in a 12,000-square-mile area of northwestern Kansas, a major hail-loss area.

*Twelve  
hail/rain  
levels used*

A set of expected net benefits for several assumed levels of hail suppression effectiveness were calculated — as we show in *Table 60* — and expressed as net income per acre of wheat production. The endpoints of the benefits distribution were restrained to be from no change in crop-hail damage to an 80% reduction, and to a  $\pm 10\%$  change in growing season rainfall. These extremes (endpoints) closely match those in the future scientific models (*Table 38* in Chapter 8).

The restriction of benefits to net income from wheat production is not meant to describe the entire net benefits from hail suppression, but rather to serve as an example of the estimation process in an area where one crop dominates the agriculture and where hail loss is large.

The net income estimates of *Table 60* range from a low of \$21.56 per acre to a high of \$31.88 per acre. The operational costs variable was accounted for by deducting \$1 per harvested acre as payment for the suppression program for each income estimate.

*Let us look at procedures that relate to development of a new technology.*

Given the net benefits associated with various physical outcomes (*Table 60*), the likelihood that each of the various physical outcomes will occur, both before and after the proposed experiment and research, had to be calculated. Possible sources of this information are the evaluations of previous hail suppression experiments, but no scientific consensus has formed regarding their interpretations.

Since no universally accepted probability function now exists for hail suppression, a decision maker in a support agency must develop and use a subjective likelihood function. Since this subjective likelihood function will probably be quite influential in the decision to fund or not fund future research, efforts should be made to seek out and quantify this probability function for hail suppression. A decision maker might choose to use this project's conclusions, or to seek out added advice and use those opinions to form a likelihood function.

One possible likelihood function to consider is that the present-day technology is ineffective. One can assume that no change in hail damage or in rainfall will occur with 100% probability and all other outcomes in *Table 60* would have 0% probability. Another possible assumption, and the one used in this example, was that each of the 12 possible outcomes of *Table 60* is equally likely. The resulting probabilities (8.3% each) are presented in *Table 61*.

*All outcomes are assumed equally likely*

The expected value of the uncertain present-day technology ( $E[V_{PD}]$ ) was calculated from the net benefit estimates listed in *Table 60* and the prior probabilities given in *Table 61*. This calculation is:

$$E(V_{PD}) = \sum_{i=1}^{12} (0.083 \times NB_i) = \$26.58 \text{ per harvested acre}$$

In this equation,  $NB_i$  is the  $i$ th net income estimate of *Table 60*. If the proposed research is relevant to the wheat-producing area of northwestern Kansas,



**TABLE 60**

**Net income changes for wheat production in northwestern Kansas**

Percent reduction in crop-hail damage	Percent change in growing season rainfall	Average net income, \$, per harvested acre*
0	-10	21.56
	No change	24.58
	+10	27.31
20	-10	22.60
	No change	25.74
	+10	28.47
50	-10	24.34
	No change	27.35
	+10	30.11
80	-10	25.98
	No change	29.11
	+10	31.88

\*Income estimates based on economic analysis in Chapter 7.

**TABLE 61****Hypothetical probability distributions before and after proposed research is completed**

Percent reduction in crop-bail damage	Percent change in growing season rainfall	Selected prior probability	Possible Outcome 1	post Outcome 2	probabilities Outcome 3
0	-10	0.083	0.0	0.0	0.0
	No change	0.083	0.0	0.125	0.0
	+10	0.083	0.0	0.125	0.0
20	-10	0.083	0.111	0.0	0.0
	No change	0.083	0.111	0.125	0.0
	+10	0.083	0.111	0.125	0.0
50	-10	0.083	0.111	0.0	0.0
	No change	0.083	0.111	0.125	0.250
	+10	0.083	0.111	0.125	0.250
80	-10	0.083	0.111	0.0	0.0
	No change	0.083	0.111	0.125	0.250
	+10	0.083	0.111	0.125	0.250
Relative likelihood that a particular distribution will occur if the research is completed (expressed as a probability) =			.20	.70	.10

*Net income \$45 million with uncertain technology*

the technology could apply to an area (12,000 square miles) encompassing 1,700,000 acres of wheat (*U.S. Bureau of the Census, 1972*). This value in the equation means that the expected net income from altered wheat production with the 12 equally uncertain hail suppression outcomes is \$45.2 million.

*Outcomes compared with uncertain technology*

The estimate of annual net income with this technology-probability outcome was compared with three likely modification levels to demonstrate the different income results obtainable. These other plausible modification outcomes were based partially on current results and expected improvements (see *Chapters 3 and 8*). They were arbitrarily assigned different likelihoods of occurrence (*Table 61*).

*'Poor' outcome is worth \$1.2 million a year*

The first level, labeled Outcome 1, represents only modest success derivable from the future experiment (20 to 80% reductions in hail with all three rain changes). This could be viewed as a worst outcome. The expected value is \$27.29 per harvested acre or \$46.4 million for the area. This estimate results in an annual net benefit for the area's farmers of \$1.2 million more than the *totally uncertain technology*.

A result with more substantial success is Outcome 2. Here, although the range of hail damage is not restrained, the possibility of reductions in hail season rainfall was eliminated. With this assumption and an equally likely probability

distribution for the remaining eight physical events, the per acre expected net income is \$28.07. This translates to an expected income of \$47.7 million for the area's wheat producers, a net benefit of \$2.5 million yearly.

Outcome 3 is a case that might exemplify results from a major technological breakthrough (Model 1) during the future research. The only physical events assumed to be likely are 50 and 80% crop-hail damage reductions coupled with no change or a 10% increase in hail season rainfall. The expected income value is \$29.61 per acre, \$3.03 more than the preexperiment expected value. The annual net benefit to the area's wheat growers is \$5.2 million for this outcome.

*A major  
breakthrough  
is worth  
\$5.2 million  
per year*

Three net benefit levels ranging from \$1.2 million to \$5.2 million per year were defined. However, before future research benefits can be compared with its costs, one expected benefit figure has to be chosen. For this estimate, subjective beliefs of scientists or other decision makers as to likely results probably will be used. Presumed subjective estimates (last line of *Table 61*) were converted to a probability framework to illustrate this point. If future research is conducted, Outcome 1 is expected with 20% probability, Outcome 2 at 70%, and Outcome 3 at 10%. The expected net annual benefit associated with the various outcomes of this hypothetical research project was calculated as follows:

*Single benefit  
value must  
be chosen*

$$\begin{aligned} \text{EV} &= 0.2 \times \$1.2 \text{ million} + 0.7 \times \$2.5 \text{ million} + 0.1 \times \$5.2 \text{ million} \\ &= \$2.5 \text{ million} \end{aligned}$$

The final step in this example involved comparing the stream of these future benefits with their associated development costs. Operational costs of the hail suppression technologies were assumed to be paid by the individuals receiving the benefits — the area farmers — and these costs were deducted, giving the net benefit estimates of *Table 60*.

For purposes of illustration only, we also assumed that the experimental effort in Kansas (regardless of the outcome) would be completed after five years of research costing \$3 million per year. Further, we assumed that a 25-year period is proper for the use of the resulting technology.

*Assumptions  
for costs,  
time*

Since a technology is unlikely to "wear out," the 25-year period would be justified 1) if a new technology could be expected to replace it after this period or 2) if it is reasonable that in 25 years the commercial sector could have developed such a technology in absence of the proposed experiment-developmental effort.

The income stream was estimated to generate benefits of \$62.50 million over a 30-year period (no benefit for five years and then the calculated annual benefit of \$2.5 million times 25 years) at a cost of \$15 million over the five-year experimental period. Because these estimates involve differing time periods, the "present value" concept (see previous section) was used for standardizing future benefit and cost streams. Basically, this concept tries to determine what amount of money one would take today in place of a future stream income.

*Adjustment  
to common  
time period*

*Discounted  
cost is  
\$11.4 million*

The expenditure stream for development costs assumed in this example (\$3 million per year for five years) was converted to a present value figure with a 10% social discount rate in the present value computations. The discounted total was \$11.4 million, revealing that converting future development costs to their present value apparently reduces the magnitude of these costs. Of course, this apparent reduction to present value does not change the expected expenditure pattern of \$3 million per year for five years.

A similar calculation was done for the stream of future benefits. The benefits from the research were assumed to be zero for the five years the research was being conducted and then would have an expected value of \$2.5 million per year for the next 25 years. When converted to present value terms, the discounted value of that income stream is \$14.1 million.

*Benefit-cost  
ratio is  
not high*

Although the present value of the expected stream of net benefits is still greater than that of development costs, conversion to a present value basis has reduced the ratio of benefits to costs from \$62.5 million: \$15 million (~4:1) to \$14.1 million: \$11.4 million (1.2:1). The sharp reduction in the benefit estimate for the present value figure occurs because of the longer period over which these benefits would occur (30 years) and the assumption that no benefits accrue in the first five years when the research is being conducted.

*Now let us look at procedures that relate to developing better estimates of the present technology.*

*Better estimates  
of present  
technology*

The previous example revealed outcomes for evaluating research to develop a new technology for northwestern Kansas with "new" defined as a technology not presently available. In that case, the decision makers needed to know the value of the research given a variety of effectiveness levels it might generate.

We now hypothesize that the future research is an attempt to develop a better estimate of the effectiveness of a currently available technology. In this situation, the decision maker desires to know the value of future research given its ability to generate better estimates of the technology's effectiveness. The evaluation of this question is conceptually different from the prior example, although much of the same data was used.

*When does  
value start?*

The first step in this second illustration was to determine *when* a better estimate of effectiveness has value. The value of better estimates of hail suppression effectiveness would be in keeping the farmers from making a "wrong" decision (*Havlicek and Seagraves, 1962; Dillon, 1971; Reutlinger, 1970*). If we assume the net benefit estimates of *Table 59* —and that the equally likely prior probability distribution of *Table 60* accurately reflects the perceptions of farmers —we first need to indicate what decision farmers would make given their present knowledge.

The expected net income of farmers with hail suppression, and present informa-

tion, was estimated to be \$26.67 per harvested acre. This compares with a net income estimate of \$25.58 per harvested acre if hail suppression did not take place (this figure is the \$24.58 estimate with no weather change in *Table 59* plus the \$1 per acre operational cost).

From the standpoint of economics alone, the farmer given these two estimates could be expected to support the adoption of hail suppression because this action involves a somewhat higher net income.

But the decision to adopt may be wrong if the true effectiveness of hail suppression corresponds to one of the net income estimates in *Table 60* that is less than \$25.58 per acre.

*Decision  
may be  
wrong*

In this instance, the value of a better estimate of effectiveness would involve saving the farmer from *incurring lesser incomes* because of the decision to suppress hail. Unfortunately, no estimate of an "expected" savings can be made before the experiment is conducted.

However, an estimate of the maximum savings can be made if the worst outcome from suppressing hail is the case with no change in crop damage due to hail and the 10% reduction in rainfall (first row of *Table 60*). The estimated net income for this physical outcome is \$21.56 per acre, \$4.02 per acre less than without hail suppression.

*'Worst'  
outcome  
costly*

If a program with such an "effectiveness" level were operating throughout the 12-county Kansas region, the total reduction in net income could reach \$6,834,000 per year. Therefore, the maximum loss from deciding to adopt when in fact that was a wrong decision would be substantial.

But the experiment to provide this information would undoubtedly involve some costs. And these costs must be weighed against the maximum savings it could cause, as well as other potentially beneficial solicitations to the support group for research monies. Because of these other uses for research funds and the time involved in accomplishing the proposed research effort, the costs and maximum benefit estimates for this situation need to be converted to a present value basis.

*Acquiring  
information  
also 'costs'*

Before this conversion could be made, the time requirements of the situation had to be specified. For illustrative purposes, we assumed that research expenditures would be \$2 million per year for four years and that without the proposed research ten years of experience would be required before the decision to suppress hail would be revoked. Also, we assumed that once the unfavorable research results become known, the hail suppression effort would be terminated.

The present value of the cost of conducting the four years of research is calculated to be \$6,338,000 with a 10% discount rate. In calculating the present value of the maximum benefits, no benefits occur in the first four years when the research is being conducted. Rather, the benefits occur only from years five through ten of the period, when farmers would be making a wrong decision in the sense of the research project. The present value of these maximum benefits is \$20,331,150, which yields a maximum benefit ratio of 3.2:1.

*The value  
of discerning  
a mistake*



However, considerable caution must be attached to the maximum benefit figure. By its nature of being a maximum, it really represents the outside estimate of potential rewards. Indeed, the proposed research may find that the decision to adopt hail suppression was economically sound. It is interesting that the procedure used here gives no rewards for an experiment that tells us a decision was sound.

*Summary  
of Kansas  
analysis*

A hopefully realistic example of the value of results to be expected from a future five-year experiment (at \$3 million costs per year) to a 12,000-square-mile area in Kansas revealed a benefit-cost ratio of 1.2:1. This could be as high as 3.2:1 if other assumptions are made as to the current status of the technology.

In contrast, the national model results reveal more sizeable benefit-cost ratios, up to 16:1, for the larger multistate hail regions. Thus, the economic value of the outcome of future experimentation is strongly dependent on the extent of the area that the technology can be successfully translated to and used.

*Size of area  
important*

The illustrations presented provide three important facts about hail suppression research and development efforts.

- First, the results of an experiment must have wider application than the tested Kansas area in order to have a sizeable benefit-cost ratio. Thus, it is important to establish the areal representativeness and transferability of any experimental area's weather conditions and modification techniques. A key question that must be answered is "Where do experimental results from a site like northwestern Kansas extend?" Hence a well-designed site-specific national experiment should also be doing research sufficient to answer this question.
- Second, a detailed economic evaluation of the impact of hail suppression is needed for all areas and all crops. This allows a better estimate of the total economic impacts and value of a hail suppression technology with transferability.
- Third, the entire process demonstrated by this economic procedure rests on the best possible scientific estimates of the existing status of hail suppression, the experimental periods and costs, and the area of transferability.

*Need extensive  
assessment  
of existing results*

If the value of new information about hail suppression generated by future research is to be properly estimated, three estimates are needed. First, the outer bounds of the possible modification of hail and other associated weather conditions, like rain, need to be set; second, various reasonable combinations of possible outcomes (-20% hail with 0% rain change) need to be estimated; and third, estimates of the likelihoods of these outcomes need to be made. All of this calls for an in-depth assessment of findings from existing hail suppression programs. This should be a more extensive effort than that performed in this study.

How would the research policy decisions concerning the NHRE have been affected by an approach such as the one illustrated here? We think the resources might have been allocated to field studies at two or three different sites known to experience high hail losses. Second, an in-depth review and assessment of our knowledge of hailstorms would have led to a serious effort involving fundamental studies of severe storms in those areas before any seeding experiments commenced. Studies in affiliated disciplines would have been conducted in the experimental areas. Perhaps these retrospective lessons are also part of the value of the NHRE.

## EFFECTS ON HAIL SUPPRESSION INDUSTRY\*



The commercial firms that conduct hail suppression activities — as we described in Chapter 5 — will have a direct stake in the future of the technology. The 1975 hail suppression industry was small — only 4 of the 15 weather modification firms in the United States conducted hail suppression projects, and these efforts comprised a fairly small part of their modification activities.



The owners of these four companies, who provided information about the size of their hail suppression activities for TASH (see *Table 19* in Chapter 5), were also interviewed to measure their attitudes about the future of hail suppression and weather modification in general. All revealed a "bullish" positive attitude. Each indicated a belief in growth — as opposed to "stay even" or "decrease" — over the next 20 years for hail suppression and all other facets of their business.

### INDUSTRY OPINIONS ABOUT FUTURE

They were asked about future hail suppression efforts over three sizes and types of areas:

- Over 100,000 square miles in one large area or many small areas
- Over 300,000 square miles in one large area or in scattered smaller areas
- Over 1,000,000 square miles

*They believe  
hail suppression  
will grow*

The question asked was: *If utilization of hail suppression grows in the U.S., how do you think a) it will affect your company, and b) the government will act?*

All answers on the effect on the company, regardless of areal extent or type of areal distribution, indicated growth would "help" their companies.

*'Growth' would  
help companies*

Responses about government action did not vary with areal extent or distribution of hail suppression. One respondent felt he could not predict the governmental role — one indicated the government would continue to focus on research — two indicated they expected greater governmental involvement (takeover) in all aspects including operations, regulations, and research.

*Some expect  
government  
'takeover'*

A large variety of responses were obtained to the question, *What is needed to help improve the field of hail suppression?* The most common responses are summarized by these statements:

- The government should perform research and evaluate past and current operational (commercially supported) projects.
- The federal government should withdraw from the actual operational aspects of weather modification projects.
- Local-state groups (not the federal government) should choose and control hail suppression projects.

\*These sections contributed by Stanley A. Changnon, Jr.

A final opinion was sought from each company: *What do you think the business aspects of hail suppression will be in 1985 and 1995?* The opinions expressed in two or more of the responses were:

- There will be more hail suppression projects to augment future food demands.
- The typical hail suppression project will be larger than those now.
- The staff and equipment will be more sophisticated than now.
- There will be a few more companies.
- The companies will be larger than now.

## FUTURE OUTLOOK



Clearly, by most standards, the present hail suppression industry is not a large one. Four companies grossed \$1.45 million in 1975 using a portion of \$2.1 million worth of their field equipment. Hail suppression represents only about 25% of the total business income of these four companies. The year-to-year fluctuations in projects require considerable business flexibility. The supporting industries who supply seeding materials and equipment are generally well diversified into endeavors other than hail suppression.

*Industry  
expects growth,  
benefits*

The industry attitudes toward the future are for growth in hail suppression with accompanying benefits to them. They do fear governmental encroachment in their speciality areas — seeding techniques and operations. Conversely, they desire more federal support of research directly involved in their projects and in evaluation of their results.

Clearly they believe in their seeding techniques, albeit the general empiricism involved, and believe more scientific involvement would prove the reliability of their efforts.

A major question pertaining to the hail suppression business of the future is, *Who will be the controlling industry?* The Domestic Council (1975) recommends a federal control of operations for multistate weather modification projects, as well as federal support and control of research and monitoring.

*Government  
may be  
'industry of  
future'*

The small monetary and political power of the current small commercial industry also makes its fears of big government takeover (in which the companies are subcontractors for various pieces of a project) appear realistic. The business may grow with increasing use of hail suppression, but the growing dominance of state and federal governments in weather modification, as reflected in the Dakotas (Farhar, 1975), suggests that the "future hail suppression industry" would be the federal government, not the private companies. The companies may inherently expect or realize this shift in control, but most still expect it to bring beneficial growth to them on an individual basis.

## EFFECTS OF FUTURE SUPPRESSION ON HAIL INSURANCE\*



Although hail insurance is a relatively small portion of the insurance industry business —less than 1% of the total, as we described in Chapter 5 —it remains an important factor in the solution to the hail problem, and therefore a stakeholder in future hail suppression.

Currently, insurance is the most widely used adjustment to crop and property damages due to hail. Yet, in the high hail loss areas, the risks are so great that insurance rates are high in relation to crop value and losses so frequent that many farmers do not buy hail insurance and essentially self-insure (Chapters 2 and 5). Widespread losses from severe hailstorms may be a problem to companies from time to time, and may be disastrous to small companies operating in a limited area.

*If effective hail suppression is widely used in the future, what effect will it have on hail insurance? Will there be no need for hail insurance? What changes in forms of coverage and rates might be expected? What problems can be anticipated?*

Answers to these key questions were sought by the TASH team in assessing the impacts of future hail suppression. The salient points in regard to private and federal crop insurance — and property insurance as well — are summarized in this section.

Two additional questions were asked and are also considered here. *How does the insurance industry view future hail suppression? And, would the industry see suppression as a means to alleviate severe hail losses and therefore consider, as a worthy investment, its support in research, development, or operational programs?*



Widespread effective suppression of hail damage to crops would affect the crop-hail insurance industry by requiring modified forms of coverage and modified prices but it would not, as we shall see later, eliminate the use of crop insurance. It could increase the use of insurance. Problems for the industry might arise from pricing adjustments, from possible adverse effects from hail suppression such as increased wind and lightning, and, of more importance, from demands for liability protection by applicators and supporters.

Effective hail suppression is expected to call for changes in the forms of coverage for crops, particularly in the high risk areas, but such modifications would not be a problem to the insurance industry because a variety of existing forms can be used.

### IMPACTS ON CROP-HAIL INSURANCE

*First —  
modified  
forms of  
coverage*

\*These sections contributed by J. Loreena Ivens and Barbara C. Farhar, based partially on Fosse (1976) and Friedman (1976).

The insurance industry offers both full coverage and deductible forms of coverage, at various levels. In most cases, purchases can be made at any time during the season to allow for varying values of crops and the farmer's available resources for insurance.

*The 'excess of loss' form*

In crop-hail insurance the device by which the policyholder carries part of the risk (self-retention) is called an *excess-of-loss* (XS) form rather than a "deductible," because it refers to the whole crop rather than to each occurrence. For example, a 10% excess-of-loss (XS10) means that only the loss in excess of the first 10% of loss is payable.

In low-rate areas such as the Midwest, the XS5 is the most common form; in medium and high rate areas like the Great Plains, the XS10 and XS20, or versions thereof, are common. Typical rate credits for these options are illustrated by the following 1975 published rates per \$100 of insurance coverage:

XS5	Iowa corn	\$4.70 versus \$6.00 for full coverage
XS10	Kansas wheat	\$7.30 versus \$10.00 for full coverage
XS10	Texas cotton	\$10.00 versus \$14.00 for full coverage
XS20	Texas cotton	\$7.50 versus \$10.00 for XS10
XS10	N. Dakota wheat	\$7.40 versus \$10.00 for full coverage

*'Increasing payment' versions*

"Increasing payment" versions of these forms are also offered, in which at some level, say 70%, the excess-of-loss begins to disappear and if there is a total loss, 100% of the policy may be paid out. The rate credit is somewhat less than for the flat excess-of-loss form.

Even in relatively high loss-cost areas, there is a *preference for full coverage* forms. For example, in 1975 in Cheyenne County, Kansas — with rates for full coverage at \$20 — 87% of the business was for full coverage and only 9% for XS10 and 4% for XS20.

*'Farm unit' catastrophe plan*

A "farm unit" plan of hail insurance is also available, though very little used. In standard coverage, the acre is the unit insured and if one acre is totally destroyed but all others untouched, then that acre would be paid. In the farm unit plan, the total acreage of a crop is taken as the unit, and the loss is determined as a percent of the crop on all acres. A larger than usual excess-of-loss provision applies again to the whole crop, with options from XS20 to XS40.

Thus, some significant acreage of the crops could be severely damaged or destroyed, but the remainder so lightly damaged that the percent of loss for the whole acreage would be less than the XS percent, and no award would be payable.

The intent of the farm unit plan is to provide only *catastrophe* protection. The rate credits are substantial — for example, in North Dakota where the full coverage rate may be \$10 and the XS10 rate \$7.40, the farm unit XS20 rate is \$6 and its XS40 rate is \$3 per \$100 insurance.

Although presumably hail suppression will inspire confidence that there will be little or no seriously damaging hail, so long as it is possible for *some hail* to

occur, *some insurance* protection will be desired. The available "catastrophe" forms of coverage, with the substantial rate credit, should meet this need now and in the future.

A third possibility for modified forms of coverage arises out of the growing needs for more comprehensive forms of protection, that is, "all-risk" insurance. Many in the industry believe a transition toward such coverage is already in process (*Fosse, 1976*), although there are a number of key problems to be resolved.

*'All-risk'  
insurance  
forms*

The insurance industry calls its all-risk crop insurance Multiple Peril Crop Insurance (MPCI). It is patterned after the policies of the Federal Crop Insurance Corporation (FCIC) and both guarantee a yield approaching 75% of a base representing "normal yield." The difference between 75 and 100% is not a deductible but a recognition of normal variation in annual yields. All the perils of nature including hail are covered, as illustrated in *Figure 62*, but on the basis of the farm as a unit — if the whole farm acreage of an insured crop yields the guarantee —there is no loss under the policy.

Until recent years, the guarantee levels were relatively low and almost all users of all-risk forms of crop insurance also purchased hail insurance. As was shown in *Figure 26* (Chapter 5), most hail loss payments are too small to be payable under the all-risk forms of coverage. Even today —with higher guarantees offered by both FCIC and industry's experimental program —most users buy hail insurance in addition to FCIC or MPCI.

*Most buy  
both forms  
of insurance*

Two developments could hasten the transition to greater reliance on all-risk forms of coverage and less on the present standard forms of hail-fire insurance, for some regions.

- First is the farmer's growing need of production financing and the concomitant requirement for collateral. If the farmer cannot afford both all-risk and a parallel hail policy, he will probably choose the more comprehensive all-risk policy.
- Second is effective ongoing hail suppression. If the residue of risk becomes small enough, the all-risk form (with its implicit self-retention) might be adequate for the farmer's financial protection.

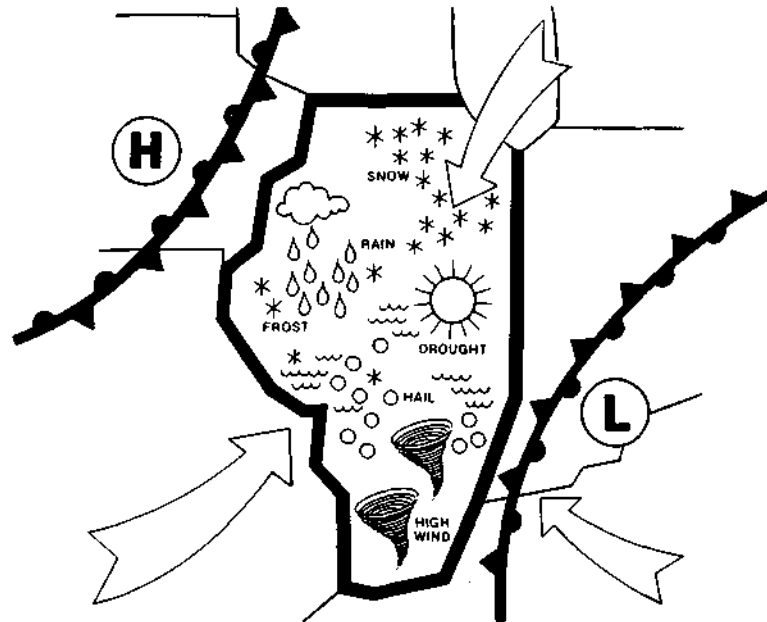
Anticipating at least the first of these potentials, the industry is developing plans by which, with access to federal reinsurance, it can more widely offer MPCI without undue risk of catastrophe occurrences (*Fosse, 1976*). Both FCIC and the industry see expansion of premium-sustained individually tailored insurance not only as better protection for the farmer but also as an alternative to the disaster feature of the present Farm Act (of 1973) —which cost more than \$500 million in 1974 and over \$200 million in 1975 (see Chapter 5). As yet, there is no evidence that a shift to all-risk forms of insurance has resulted from hail suppression.

*'Individually  
tailored  
insurance'*



FIGURE 62

Atypical insurance advertisement of hail and other forms of weather hazard coverage



### The long-range forecast includes drought, floods, high winds, frost and hail

Along with disease, insects and other catastrophes, they bring financial hardship to many farmers.

Mother Nature hasn't been giving farmers any breaks lately. So why take chances? Especially when all-risk insurance from Country Mutual costs so little.

You can protect against drought, freeze, frost, insects, disease, wind, snow, tornado, and excessive rain for as little as \$1.50 an acre above the cost of your Country Mutual hail policy.

You've got a lot to protect. Especially now that the prices of fertilizer, seed, chemicals and fuel have

climbed so high. An all-risk policy makes sure you get everything out of the ground that you sink in it. It's such good protection, many banks accept all-risk insurance as collateral for loans.

When you talk with your Country Companies agent about hail insurance, ask him about all-risk protection, too. He can't predict drought, early frost, or other problems. But he can show you how to stay on your feet when they come.

Country Mutual—one of the Country Companies. We're a little different than most insurance people.



The Country Companies

COUNTRY MUTUAL, COUNTRY CASUALTY, COUNTRY LIFE, COUNTRY FIRE AND MARINE INSURANCE COMPANIES

Printed by permission of The Country Companies

Second — insurance rate modifications

As hail losses become less under successful hail suppression, the rates for standard forms of coverage will be reduced. However, the reduction in rate will not be directly proportionate to the reduced loss cost, since some other costs entering into the pricing formulas remain relatively fixed. Certain variable costs, such as commissions, decrease with rate increase.

These factors may be illustrated by actual rate examples taken from published 1976 rates, showing how loss amount varies with rate. Thus, as shown, a 30% reduction in hail loss would produce only a 20% reduction in rates over \$15.

Rate (dollars)	Percent of rate going to loss	Percent rate reduction for given hail reduction	
		30%	80%
3.00 and under	50	15	40
6.01 to 10.00	60	18	48
15.01 and over	65	20	52

On the other hand, insurance costs per unit are amenable to economies of scale. For example, since 1973 premiums and costs of doing business have both increased. But the premium increase is largely from insuring greater values rather than from more policies, and has been more rapid than inflation-pushed administrative costs. Even though that lag will partially disappear, increasing insurance activity could serve to provide lower cost factors as a percent of premiums, and this would ultimately be reflected in the expense component of the rate.

*'Economy of scale' per unit*

It is believed that a major (25 to 50%) reduction of hail loss through suppression in some areas, such as Colorado and Texas, could serve to increase the use of insurance, in which case the expense *as a percent of rate* could be reduced enough to have an impact on rates.

*Suppression could increase insurance use*

The reason that effective hail suppression is viewed as possibly increasing the use of insurance in the high risk areas lies in the possibility of changing the regularity of loss on a farm to an irregular or infrequently severe event.

*Farmer's loss would become 'irregular'*

For example, in the areas of high and frequent loss from hail, the farmer has relatively regular loss and can set aside funds for it without purchasing insurance. After all, the motivation for insurance is the unpredictability of a harmful event.

*When his "regular" loss becomes unpredictable* because of suppression, the farmer may find insurance more attractive. Thus, reduced losses may serve to reduce the rates and hazard to the level not only of risk acceptance on the part of the industry, but also *the use of insurance by the farmer.*

The most serious "rate" problem for the industry evolving out of growing adoption of hail suppression technology will be pricing hail insurance during the transition from the "natural" regime to the moderated regime.

*Transition pricing a problem*

For rate analysis, the industry relies heavily on its *historical* insurance statistics and national weather service records of hail. Historically, there have been significant variations in hail frequency and severity — and these are indicated in rate-level adjustments through the years. However, the industry reacts — to both severe and moderate hail losses — usually with only modest adjustments in rates. Although a change as high as 15% has been made, the frequency of adjustments in any year in excess of 5% is small.

*Usual rate adjustment less than 5%*

Rates, depending on the state, are changed every two or three years or less often. One of the aims of any ratemaker is relative stability, and the use of "all-time" experience serves to ease the effect of the occasional catastrophe. For the same reason, a precipitous decline in hail losses would only nominally affect the all-time loss cost, and thus it would be a period of some time, perhaps ten years, before the rate would be affected.

*Could be ten years before suppression affects rates*



*Public will expect lower rates earlier*

*Thus, for a few years, perceived suppression effectiveness is most likely to generate a public demand for rate reductions before standard rating practice would produce it.*

*Techniques that could help transition*

This could be remedied in two ways — by techniques that exist but are not generally used in crop insurance rating. The first technique is to *discount the historical experience* by an arbitrary amount presumed to equal the level of hail suppression effectiveness. The second device is to *apply a trend procedure* that would give greater than proportionate weight to recent annual experience. Any more drastic departure from historical statistics might cause underwriters to refuse to accept the risk.

A final alternative might be the general use of *participating policies*, which would include a provision entitling the policyholders to a return of premiums of some amount, as fixed by predetermined factors for a hail suppression area. This would be a form of retrospective rating applied to a large group of policyholders subject to a standard rate; normally, "retro" plans are applied to a single risk with a deposit premium that is adjusted up or down at specified periods. This approach would mean an additional cost of handling, but it would be preferable to risking understated rates from which regulators generally deny recoupment (Fosse, 1976).

*Have any changes in rates or in use of insurance occurred in areas using hail suppression?*

*Example of rate changes in seeded area*

One analysis of the county rates in and around an area of North Dakota where hail suppression has been practiced for 15 years (see *Table 11* in Chapter 3) and where loss costs are the nation's highest, about \$12, shows a decline in rates in the seeded counties ranging from 5 to 50%, compared with those of surrounding nonseeded western counties. Rates of most other North Dakota counties have also declined in the past ten years, but at a lesser rate.

*Rates decreased*

If these greater rate reductions in the seeded area in part reflect successful hail suppression, the actual reduction in loss is greater than the values shown (*Table 11*). This would occur because, as previously discussed, the rate reductions are less than the loss reductions due to fixed costs in the rate structure and the use of historical, presuppression loss statistics (plus judgment) in the rate-setting procedure.

*Liability increased*

Adams and Hettinger Counties in North Dakota became areas seeded for hail suppression in 1968. Their liability for the 1966-1968 period, expressed as a percent of that for four surrounding counties, was 67%. This seed-area/no-seed-area liability ratio increased slightly to 69% in the 1969-1971 period but grew to 84% for 1972-1975. Clearly the amount of liability increased greatly in the seeded counties after hail suppression was practiced.

This supports the earlier stated concept of *increased use of insurance* in areas with successful hail suppression. There also have been local and state inquiries about additional rate decreases in and around the seeded area.

Among the inadvertent side effects considered by the scientific investigations into hail suppression (see Chapter 4) were possible changes in precipitation and two others that are seen as a problem for insurers of crops — increased wind velocities and increased incidence of lightning. Some meteorologists consider both as possible outcomes, but very little information is available, as was indicated in Chapter 4.

*Third —  
side effects  
feared by  
crop insurers*

Tobacco, for example, is insured to cover wind damage when accompanied by hail causing 5% or more loss. Since the leaf is the product of the tobacco plant and it is highly susceptible to wind damage, any increase in wind velocity would materially affect the losses.

*Tobacco  
insured for  
wind damage*

While other crops are not commonly insured for wind loss, with or without hail, it is a rare hailstorm in which wind is not a contributing factor in hail-caused damage (*Changnon, 1967*). In fact, adjusters generally observe that the velocity with which hail is wind driven is much more of a factor in damage than size or volume of hail. Even modest wind velocity increases would offset the benefit of reduced hail.

This is another reason for caution in any early attempt to recognize hail suppression effectiveness in insurance rating.

Increased wind also would aggravate claims handling and perhaps result in increased litigation. Very few hail insurance claims get so far in contention as arbitration or suit, and most of those which do center around the issue of the *cause* of the reduced yield and/or how much reduction is attributable to the insured peril.

*Would also  
affect claims  
handling*

Experienced adjusters can distinguish between wind and hail damages, yet most any season there are claims for hail loss on crops which were affected solely by wind, or by wind and so little hail as to be not measurable. In 1974, one company lost a suit brought by a policyholder alleging a hail loss whose wheat was badly lodged by wind and rain. The expert testimony of adjusters and of an agronomist that there *was no hail* was ignored by the jury, which instead reacted sympathetically to commentary about "insurance companies that take premiums but never pay benefits" (*Fosse, 1976*).

*Jury ignored  
expert testimony*

Since juries may not be impressed with the contractual distinction between perils insured against and those not covered, and since there are indications that much of our society regards any misfortune as due a remedy from whatever sources may be at hand, any adverse effect from hail suppression such as increased wind could be troublesome for the insurers of growing crops.

With only a few exceptions, crop-hail insurance policies also cover against fire and lightning until the crop is harvested. Occasionally a strike by lightning damages a small plot of a crop, but the known cases of a major crop fire being ignited by lightning are few, if any. However, lightning damage, including fire, to farm buildings and livestock is not uncommon.

*Increased  
lightning  
also a problem*

Any increase in its incidence would have impact on not only the specific insur-

ance for those properties, but also on the liability coverages of applicators, sponsors, and others responsible for suppression programs. The principal difficulty would be in disproving responsibility for alleged occurrences, whether or not of increased frequency.

## LIABILITY COVERAGE PROBLEMS



Liability insurance refers to the line of casualty coverage in which the insurance company contracts to defend the insured and/or to pay (subject to specified limits) compensations that he might owe as a result of allegedly causing an injury or damage to a third party or his property.

There are many kinds of liability coverage which may be included in standard policies such as the Homeowners policy (Comprehensive Personal Liability) and the Farmowners policy (Farmers Comprehensive Personal Liability), among many others. Malpractice insurance falls under this general category and the public has recently become aware of the consequences of abuses of this form of insurance.

### *Suppression liability exposures*

Large-scale adoption of hail suppression technology poses an uncertainty in insurance. Briefly, the exposures to liability arising from hail suppression activity will include:

- Allegations of deprivation of precipitation (with recourse sought against the applicator and those who sponsor the application)
- Allegations of excess precipitation
- Allegations of failure to effectively deliver the contracted-for service, or of delivery to other than an intended area
- Allegations of increased hail damage
- Allegations of such adverse effects as increased wind velocity or lightning that cause unusual loss or damage to life or property

There would also likely be considerable subrogation activity, when losses paid on primary policies were caused (or alleged to be caused) in part or wholly by the suppression activity. This would tend to enlarge the scope of effects of suppression because companies paying such losses might seek recovery from the suppression operators or their insurers.

### *Large areal exposure serious*

While these exposures are not new to the underwriters, they do present one serious characteristic: *the areal exposure and potential for class action defense will exceed anything the underwriters have experienced* — not only for the designated target area but also for the relatively unlimited peripheral area (down-wind effects). The risk is further complicated by the known existence of some opposition to weather modification (*Farhar, 1975*).

### *Class action suits long, expensive*

It is no comfort to the underwriter that thus far no adverse effects have been proven or judgments rendered — the drawnout defense of class action suits can be expensive to insurance companies, whether they support hail suppression or not. Such legal activities could consume considerable portions of the premiums charged.

In short, insurance will not be a feasible means of handling these new dimensions and uncertainties to liability insurance. As pointed out in Chapter 5, the costs of insurance benefits and of administering the business are paid from only one source — the premiums collected from policyholders. When the losses incurred under one form of coverage increase, companies have only one alternative to seeking rate increases, and that is to withdraw from the field. Other premium sources may not indefinitely support the gross losers.

*No liability insurance for suppression*

Underwriters and actuaries may exercise that alternative in advance and decline to enter a field, which they indeed do when there is great uncertainty about the exposure involved in a new venture like widespread hail suppression.

*Insurance may not be offered*

Various weather modification organizations have experienced difficulty in obtaining liability insurance. Once insurance has been obtained, rates have sometimes decreased following litigation in which the weather modifiers prevailed. However, in other cases, insurance has allegedly been cancelled when a lawsuit was filed against a weather modifier (even though he later won the case). The legal expense alone of liability insurance for weather modifiers is likely to be quite high. Some form of government insurance might need to be considered, and possibly accepted, for adequate liability insurance.

Thus it may be necessary that large-scale hail suppression be undertaken *only by government* or government corporations. The alternative would be government grants of immunity as to some minimum of specified actions.

*Large-scale suppression to government*



A general view of the impacts of hail suppression on their industry is given by 19 members of the crop-hail insurance companies in managerial roles. The sample was not randomly drawn, but the companies represented accounted for 60% of the 1975 industry-wide premiums. For most companies, hail insurance is only a small fraction of their business.

**CROP INSURERS' VIEWPOINTS ON FUTURE SUPPRESSION\***

The basic assumptions of the questionnaire included widespread effective hail suppression in 1995 with hail damage down by 50% and no rain changes. Nevertheless, some evidence existed that respondents were skeptical concerning the effectiveness of hail suppression technology, a sentiment that could affect their responses to the questionnaire.

The results reveal, in general, a belief that the industry would not be significantly affected. The modes of most answers show no change. About a third of the respondents thought the industry would see a decline in earnings, and while a majority disagreed with them on this point (53%), such a decline would be consistent with the prediction that insurance rates would decline. However, farmers might buy more insurance if the rates were more financially manageable.

*Believe no significant changes*

A majority of respondents indicated that competition in the industry would increase, but most predicted no significant change in their company's share of the business. These results, coupled with the 95% prediction that the proportion of farmers pur-

*Major companies will not support suppression*

\*This section contributed by J. Loreena Ivens, Martin V. Jones, and Ronald Rinkle.

chasing hail insurance would remain the same or decline, are based on respondent expectations of future rural out-migration.

A reduction in the number of farmers means the same number of companies will be competing for the business of fewer purchasers. (The TASH study findings show that hail suppression would likely reduce out-migration slightly, so this perception on the part of insurers may not come to pass.) Increased sales of "all-risk" insurance might offset the disbenefit of increased competition.

New marketing methods and some retraining of employees would most likely entail additional costs for the companies. But if over time the industry had greater assurance of less variation in loss ratios (the ratio of collected premiums paid out in losses), costs of doing business would decrease as the need for reinsurance would decline. On balance, an effective hail suppression capability would be somewhat beneficial. Increased government regulation would be negligible in impact, since the industry is not currently highly regulated.

*Small, one-state companies might be interested*

The benefits to be expected, however, would not be of sufficient magnitude to warrant major industry support of hail suppression technology. It would be possible that crop-hail companies in the high-loss areas chartered to do business in only one state, and particularly those without considerable diversification into other types of insurance (auto, life, fire, etc.), might view hail suppression that has demonstrable capability as a desirable activity. Suppression could help to reduce the larger, catastrophic annual losses that can occur in multiyear sequences in the Great Plains states.

*Example of insurance participation*

Some evidence of such an outcome exists in South Africa (*Davis, 1975*) where a local tobacco cooperative insures against production costs and for four years has hired an American weather modification firm to perform hail suppression (and signed this firm in 1975 to a new eight-year contract). The insurance-plus-suppression coverage is over a 300-square-mile area where annual loss can be extensive and quite excessive (see Chapter 3).

*Underwritten by Lloyd's of London*

An interesting aspect of this insurance company's use of hail suppression is that Lloyd's of London, because of the use of hail suppression, underwrites with a low fee the annual extremes of loss above some level that could be classed as catastrophes.

*Reasons for state-scale company interest*

It would appear then that companies selling only on a local-regional scale (state or smaller) might be more attracted to hail suppression as an integral part of their business than companies which sell coverage widely and diversify their risk areally. The state-scale insurance company involvement could include:

- Their promotion of it without marginal financial involvement
- Their direct financial support of the program, either partially or wholly (as in South Africa)
- Their indirect financial support achieved by setting relatively low rates to those who support hail suppression

Note that 6 of the 19 insurance executives (*Table 62*) thought that by 1995 a small

**TABLE 62**

**Expectations of impacts of successful hail suppression by the crop-hail insurance industry  
(Total number of respondents to questionnaire [N] equals 19.)**

Basic assumptions of the questionnaire: a) that by 1995 hail suppression systems will be effective and widely operational  
b) that hail damage to crops will be reduced on the average by 50%  
c) that there will be no resultant change in precipitation

Item	Increase greatly		Increase slightly		Not change significantly		Decrease slightly		Decrease greatly		No opinion	
	%	N	%	N	%	N	%	N	%	N	%	N
The percent of farmers buying hail insurance would	0		5+	1	53-	10	32-	6	10+	2	0	
The market for crop-hail insurance for most companies now writing it would	0		16-	3	42+	8	26+	5	11-	2	5+	1
Sales of FCIC "all-risk" crop insurance would	10+	2	26+	5	37-	7	11-	2	11-	2	5+	1
Diversity of types or kinds of insurance purchased by farmers would	26+	5	47+	9	16-	3	5+	1	0		5+	1
The percentage of insureds who in a typical year would file hail loss claims would	0		11-	2	58-	11	26+	5	0		5+	1
Earnings of crop-hail writers would	0		10+	2	53-	10	16-	3	16-	3	5+	1
The degree of competition among companies selling crop-hail insurance would	21+	4	42+	8	27-	5	5+	1	0		5+	1
Share of crop-hail business for companies now writing the most premiums would	0		5+	1	69-	13	10+	2	5+	1	10+	2
Rates for crop-hail insurance would be expected to	0		0		16-	3	42+	8	37-	7	5+	1
Government (all levels) regulation of crop-hail insurance would	0		37-	7	42+	8	10+	2	0		10+	2
Customer good-will of those companies selling crop-hail insurance would	0		15+	3	74-	14	0		0		10+	2
The complexity of procedures for settlement of crop-hail claims would	0		32-	6	68+	13	0		0		0	
In the long run, the accuracy with which companies would predict hail losses would	5+	1	21+	4	53-	10	16-	3	5+	1	0	
			Change greatly		Change slightly		Change insignificantly		No opinion			
			%	N	%	N	%	N	%	N		
Terms, coverages, and other policy conditions of crop-hail insurance would			10+	2	47+	9	42+	8	0			
The regional distribution of crop-hail insurance sales would			21+	4	42+	8	37-	7	0			
The distribution of crop-hail insurance as to crops would			5+	1	42+	8	53-	10	0			
Marketing and merchandising methods of companies selling crop-hail insurance would			32-	6	53-	10	15+	3	0			
The need for retraining employees of companies now selling crop-hail insurance would			26+	5	21+	4	48-	9	5+	1		
Companies selling crop-hail insurance would take which of the following positions toward efforts to establish hail suppression systems?												
	%	N										
	0		Agressively resist									
	5+	1	Slightly resist									
	58-	11	Take no stance on the issue									
	27-	5	Mildly assist efforts to implement									
	5+	1	Agressively assist efforts to implement									
	5+	1	No opinion									
The number of companies now selling crop-hail insurance that would become operators of hail suppression systems (in addition to continuing their hail insurance business) would be												
	%	N										
	0		A large number									
	32-	6	A small number									
	53-	10	None									
	15+	3	No opinion									

number of insurance companies would also become the operators of hail suppression. This local-to-state use of hail suppression could also offer the state-focused companies a better means for reinsurance or catastrophe underwriting, as in South Africa.

State insurance departments, which through regulation effectively and ultimately set the hail insurance rates used in any state, could also act to encourage or discourage hail suppression. The view of these departments toward new rate applications of a firm could vary according to whether hail suppression is involved, particularly if there is public pressure for rate-recognition of suppression effects.

*Insurance departments can affect suppression*

**EFFECTS ON  
GOVERNMENT  
INSURANCE\***



Whatever the impact of effective hail suppression on the private insurance industry, the effect on Federal Crop Insurance Corporation (FCIC) activity can be of only marginal consequence because of the nature of the crop insurance it provides. As was described in Chapter 5, FCIC insures against all the perils of nature but its policy guarantees only a maximum of 75% of "normal yield," and the guarantee applies to farm unit yield rather than to the acre unit.

*Comparison of  
hail policy  
and 'all-risk'*

To illustrate the contrast in insurance coverage, let us look at a farm operation consisting of 200 acres of corn, with an expected yield of 125 bushels per acre. Under the standard hail policy the crop may be insured for 100% of anticipated yield, at the probable market price. A total value might commonly be 125 bushels, at \$1.60 per bushel or \$200 per acre, for a total crop coverage of 25,000 bushels.

In contrast, the maximum FCIC coverage would be 75% of 125 bushels or 93.75 bushels — or a total farm crop guarantee of 18,750 bushels. (Various price-per-bushel options are available.)

In event of a hail loss, under the standard hail policy each field would be examined for percent of loss. Irrespective of the variation in percent of yield reduction, the hail policy would pay, on an acre-by-acre basis, as determined by the adjuster. The loss might vary from 0 to 100%, and such percentages are applied to the amount of insurance per acre.

Under the FCIC policy there would be a loss from hail *only if the total farm yield was less than the 18,750 bushel guarantee*, and then only to the extent of the difference between actual yield and the guarantee. Thus, it will be seen that only if the hail loss exceeds an average 25% of the total farm crop of corn would the FCIC (or the commercial MPCI) all-risk policy pay. But a 20% farm average loss might be composed of variation from 0 to 100% loss on some acres.



**TABLE 63**

**Major causes of loss to crops covered by FCIC**

Cause of loss	Percent of all indemnities (1948-1974)				
	Wheat	Corn	Soybeans	Cotton	Tobacco
Drought	41	45	43	27	22
Hail	16	7	17	9	20
Excess moisture	6	24	28	30	35
Low temperature	13	10	6	7	3
Flood	3	2	3	3	2
Wind	8	6	2	6	5
Insect and disease	11	5		16	9

**Note:** *Hail ranks 2nd for wheat because much of wheat acreage is in high risk areas; it is relatively great on tobacco since the average unit size of tobacco crop is relatively small.*

As was seen in *Figure 26* (Chapter 5), much of the hail loss is of magnitudes less than would be payable under all-risk policies, so that only in the very high hazard areas would hail suppression have a significant impact on FCIC. From 1948 through 1974 the total cause of loss attributable to hail (as a principal cause) was third in rank of all causes, as we show in *Table 63*.

While there would generally be only marginal benefit from *hail suppression*, it is obvious from the cause-of-loss data that the larger subject of *weather modification*

could be of very real benefit. Drought, in terms of both lack of water and excess heat, is FCIC's principal cause of loss. It is also of *great areal*

These sections contributed by J. Loreena Ivens, based partially on Fosse (1976) and Friedman (1976).

*consequence*, in contrast to the relatively "local" characteristic of most hailstorms. Even modest precipitation enhancement could make very significant differences in yields over great areas.

*'More rain'  
significant  
to FCIC*

Thus, FCIC is potentially a prime stakeholder in total weather modification. Since its program is subsidized for administrative costs, and its capital is provided from tax resources, there is ample reason for FCIC to be at least *sympathetic if not supportive* of progress in weather modification development.

However, FCIC is but one of several entities in the U.S. Department of Agriculture (USDA) and there are probably numerous interagency and interdepartmental relationships to be considered before any meaningful attention can be expected from any single unit.

Under the 1973 Farm Act the ASCS is responsible for administering the farm disaster relief, applicable to certain producers of cotton, wheat, and feedgrains (see page 102, Chapter 5). This program has a potential of considerably greater annual pay-out than does FCIC. As an example of interaction, the research and development of hail suppression could conceivably be shared by Agricultural Research Service and the resultant altered production statistics would impinge on the activities of the Statistical Reporting Service. So, several USDA entities may be affected by real progress in weather modification.



The possible impact of hail suppression on the property insurance industry must be viewed in the light of the fact that the estimated total annual average loss from hail is \$75 million, which represents only 9/10th of 1% of the total loss in 1974 that was shown in *Table 7* (Chapter 2). A 30% reduction in hail losses due to suppression would lower this percentage to about 6/10ths of 1% (*Friedman, 1976*).

## **IMPACTS ON PROPERTY INSURANCE**

Although the hail hazard is not greatly important for the property insurance industry on a national scale, it can be of considerable significance in regions of high hail frequency.

*Property loss  
important  
regionally*

The percentages of population and dwellings in a hail region are indicators of the size of the property insurance market in that region. Comparisons are illustrated in *Figure 63* and *Table 64* for the 13 hail regions. The relatively low percentages in Regions 3 and 4, the Rocky Mountain major hail frequency areas, compared with those in Region 9, where hail is a much smaller threat, indicate the considerable variation in the impact of hail suppression by region.

Since the impact of hail suppression over the next few decades could be affected by shifts in the industry market, 1972 population projections from the U.S. Water Resources Council (*Friedman, 1976*) are also given in *Table 64*. These indicate that no major market shifts are likely to occur.

*No major  
market shifts*





**TABLE 64**

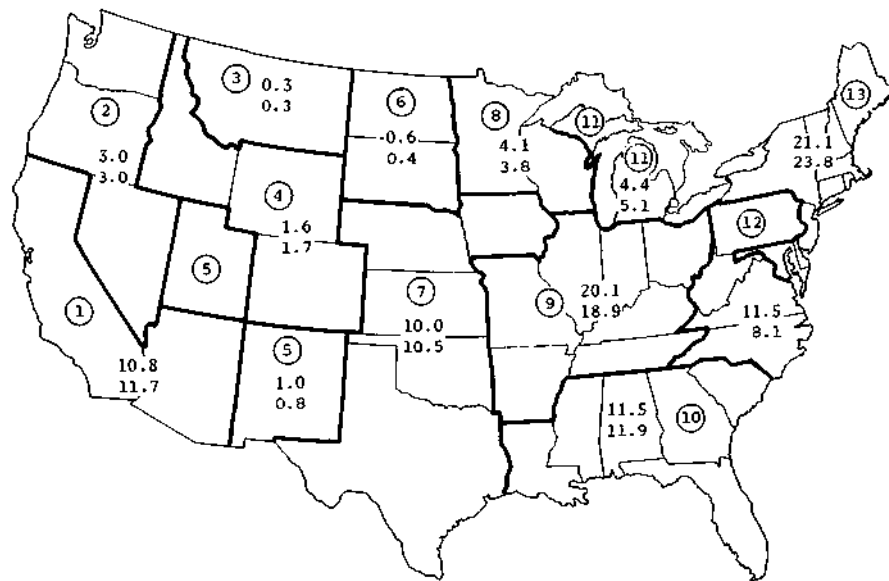
Comparative areas, dwellings, and population in hail regions

Region	Percent of land area	Percent of single-family dwellings	Percent of population			
			1970	1980	1990	2000
1	9.1	11.3	10.8	11.3	11.9	12.3
2	9.2	3.1	3.0	3.0	3.1	3.1
3	4.9	0.3	0.3	0.3	0.2	<b>0.3</b>
4	9.6	1.6	1.6	1.6	1.6	1.6
5	6.9	0.9	1.0	1.0	1.0	1.0
6	4.9	0.6	0.6	0.6	0.5	0.5
7	18.4	10.1	10.0	9.7	9.6	9.6
8	4.5	3.9	4.1	4.0	4.0	4.0
9	11.3	20.2	20.1	20.1	20.0	19.9
10	9.6	11.3	11.5	11.4	11.4	11.5
11	1.9	4.2	4.4	4.5	4.5	4.5
12	5.3	11.3	11.5	11.4	11.1	10.9
13	4.4	21.1	21.1	21.1	21.1	21.0



**FIGURE 63**

Percentage distributions of population and property insurance premiums by hail region



10.8 PERCENTAGE DISTRIBUTION OF CURRENT U.S. POPULATION  
 11.7 PERCENTAGE DISTRIBUTION OF PREMIUMS FOR HOMEOWNERS MULTIPLE PERIL INSURANCE PACKAGE  
 ⑤ REGION NUMBER

Thus, the property target is greater in Region 9 than in Region 4, but hail is less frequent and intense in 9 than in 4 (see *Figure 7* in Chapter 2). This tends to nullify the regional differences in hailstorms.

*Property 'targets' different*

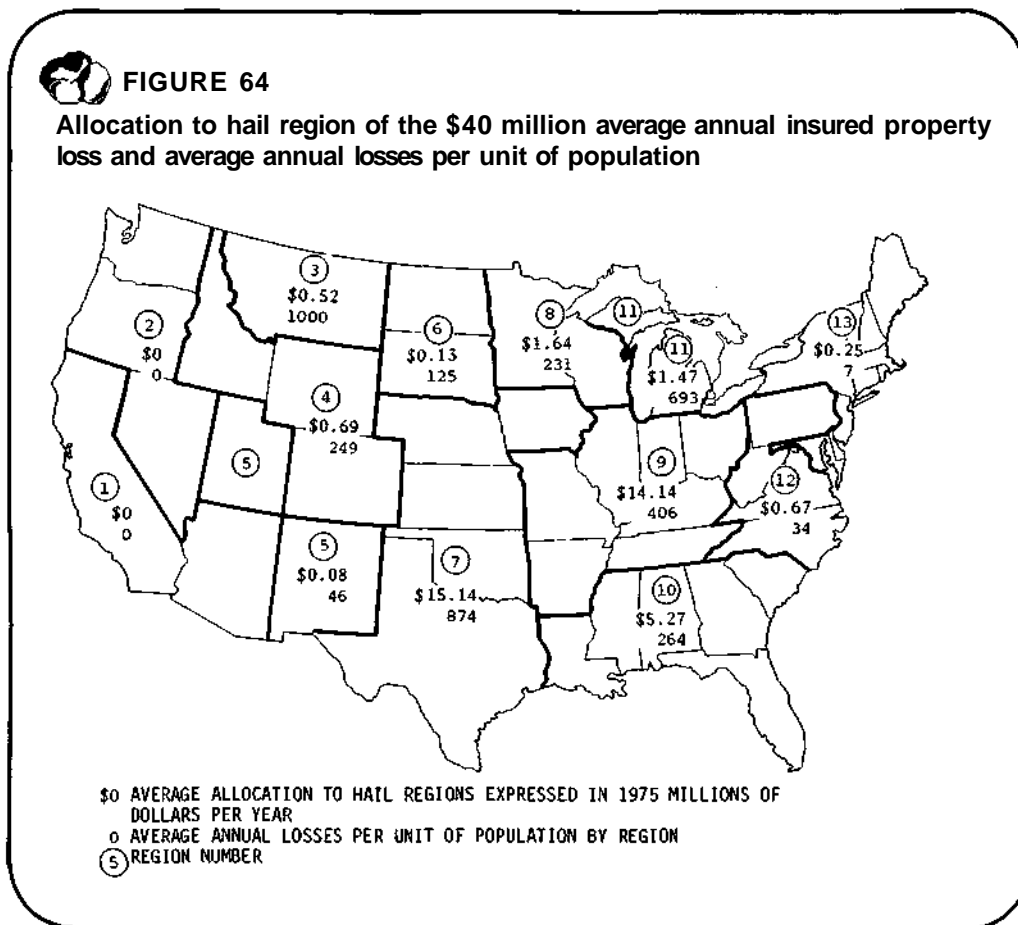
A \$40 million annual average insured property loss to hail (during weather catastrophes) was given in *Table 18* of Chapter 5. Allocation of this loss to the 13 hail regions is shown in *Figure 64*. This indicates that 35% of these losses occur in Region 9, whereas only 3% occur in the Rocky Mountain area, Regions 3 and 4.

The annual hail loss divided by population provides an index, also shown in *Figure 64*, that reflects the loss per unit of population, which is important as an indicator of the property insurance market in each area. This shows Montana (Region 3) with the most severe hail losses per unit of population, though its property insurance market is only 3/10th of 1% of the national total.

Thus, the potential for possible damage reduction with hail suppression is much greater in Regions 7 and 9, where the damage production by hail is relatively high and the property insurance market is sizeable.

*Damage 'target' greater in Regions 7, 9*

Initial indications are that the *direct* impact of suppression of hail, as an individual hazard, upon countrywide loss experience of the property insurance industry would be small. The present state of knowledge does not provide an



*Indirect impacts uncertain*

indication of whether *indirect* impacts of hail suppression 1) will *decrease* insured property losses by reducing the severity of the other thunderstorm hazards (wind, lightning, tornadoes) named in the insurance packages; 2) will *not affect* the magnitude of these other insured hazards; or 3) will *increase* property losses by increasing the concurrent severity of the other thunderstorm hazards.

A large percentage of the hail-caused property losses occurs in hail regions encompassing the set of five states from Texas to Iowa and a cluster of seven states running from Missouri to Ohio, Regions 7 and 9. Catastrophes caused by severe thunderstorm activity in these hail regions are characterized by damaging hailstorms frequently accompanied by *strong winds and tornadoes*, as discussed in Chapter 5.

*Problem of tornadoes on hail days*

In 85% of the thunderstorm catastrophes in the past five years, tornadoes have been named as a cause of loss (Friedman, 1976). Therefore, *if hail suppression cannot be attempted on days when tornadoes are likely*, only a small percentage of total hail-caused losses on catastrophe days probably can be prevented in these regions.

*Strong winds also factor in property damage*

The interaction of other thunderstorm-produced hazards with hail is as critical on property loss ascribed to hail as it is in crop-hail losses. Hailstones of relatively small diameter, if accompanied by strong winds, can be driven into the sides of structures exposing window surfaces and siding to possible breakage or damage. Rain entering the building through breaks in its outer shell, such as roof and windows, contributes to damage amounts. Increased rainfall caused by the suppression process could appreciably increase this type of insured loss.

A decrease in thunderstorm rainfall due to hail suppression could reduce the size of this class of incurred property loss, but it could at the same time have a detrimental effect on crop yields. This could hurt an insurance company's agricultural investment activities such as farm mortgage loans.

*Hail damage greater with wind*

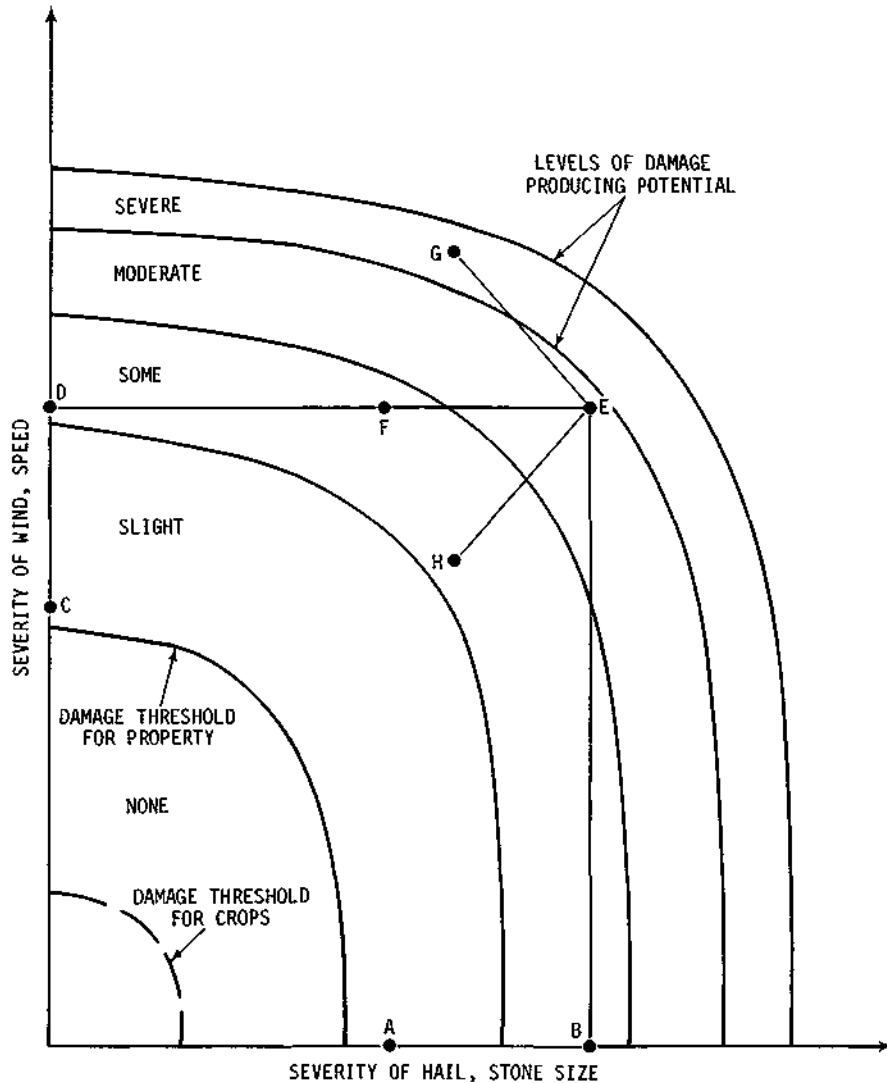
Table 18 in Chapter 5 indicates that straight line winds alone produce considerable property loss, roughly two-thirds of that from hail. However, the hail loss value has buried in it the effect of the wind blowing with the hail. Friedman (1976) shows that the 1949-1975 property losses due to hail and wind events (non-tornadic) were \$819 million, as opposed to those labeled hail only, a value of \$319 million. This indicates that losses due to winds when hail occurred more than doubled the losses when hail occurred without damaging winds.

*Examples of hail-wind property loss*

A careful survey of a damaging hailstorm in a small Colorado community (Borland, 1973) showed \$31,850 in losses to residences, commercial structures, vehicles, plants, and animals. Forty percent of the \$17,590 in losses to houses and buildings was done to their vertical sides (walls, windows, doors, etc.), which helps indicate the key role that the wind played in producing "hail loss." In addition, strong winds (downdrafts) increase the downward velocity of hail and hence its impact energy, increasing the damage to roofs.

**FIGURE 65**

Schematic of relationships between the severity of wind and hail, and the resulting damage producing potential to property



Clearly, a rather delicate balance exists between hail severity, wind severity, and resulting property damage. *Figure 65* is a schematic representation of observed relationships between the combined effects of these hazards and the average degree of damage to a particular type of structure that is susceptible to these wind and hail caused damages.

*Relation of hail, wind, damage severity*

Points A and E depict levels of severity. When there is no wind, the damaging effect of hail increases nonlinearly with an increase in stone size (A to B). When wind is not accompanied by hail, its damaging effect also increases in a nonlinear fashion with an increase in speed (C to D).

For hail of a given size, the damage-producing potential increases rapidly with an increase in an accompanying wind (B to E). Damage potential of wind-driven hail (E) is greater than that of hail (B) or wind (D) taken individually. This damage threshold varies with the type of insured property.

*Crops more easily damaged*

In general, thresholds for property damage are much greater than those for crops. For some types of property, hail must be at least 2 inches in diameter, when not accompanied by wind, to cause damage. Crops are damaged by stones of 1/2 inch or greater.

*Suppression a benefit — or problem*

The relationship shown in *Figure 65* helps reveal why hail suppression could be a benefit or a problem to the property insurance industry. It is usually assumed that suppression would move loss from point E to point F (smaller hail with no wind change). However, if suppression reduced hail severity (size) but increased wind, going from point E to G, damage would increase and a net disbenefit would occur. The scientific modeling results (Eastern Model 1) suggest a decrease in hail would produce a decrease in wind, taking point E to H, a better outcome than point F.

### **WILL INSURANCE SUPPORT SUPPRESSION?**



There is no expectation that the insurance industry, as a whole, will assume any initiative in the operation or support of hail suppression programs, either directly or indirectly.

Nor, however, is the industry expected to oppose suppression activities. Realistic considerations of courses of action must be based on an understanding of insurance and the financial circumstances in the industry.

*Profit motive not there*

The reasoning that the insurance industry might logically support research and development of hail suppression stems from the assumption that if losses are reduced the companies will realize *greater profit* — and thus out of self-interest would actively pursue such ends. The flaw is that when loss trends are downward, rates also are adjusted downward.

There might be some small financial interest if suppression lowered the peaks of losses so that there are fewer if any catastrophe occurrences. As a protection from catastrophes, companies now pay for reinsurance (or must invade the surplus account for recovery), and *those* costs might be reduced.

*Investment too great for incentive*

The reasoning for presumed industry initiative in delivering hail suppression is based on a perception of imaginative seizure of economic opportunity and the appeal of a prevention-insurance combination. What is omitted is an appreciation for the limited incentive and the investment requirements.

The combination prevention-insurance service is illustrated by Steam Boiler Inspection and Insurance, in which more of the premium is applied to inspection and prevention efforts than is required to pay losses. However, the involvements of hail suppression are not comparable.

Also, the charters of insurance companies limit the activity of a company to the conduct of insurance, and the management of investments is subject to regulatory scrutiny. However, insurance companies are not infrequently held by conglomerates which may have greater (but not unlimited) leeway for diversified enterprises.

*Companies limited to 'insurance'*

As noted previously, hail insurance on growing crops is a fraction of 1% of the total property and casualty business in the United States. Although it is important to agriculture and to the industry people themselves (or to insurance salespeople), it is obviously not a source of operating income of great concern.

For example: If the underwriting gain on insurance operations is 5% of \$300 million (the 1975 crop-hail premium income level), the industry could look to something less than half (after taxes) of \$15 million as the annual contribution to profit for distribution to stockholders, reserves, and surplus. The largest single crop-hail writer is looking at no more than 10% of that sum.

If some small portion of this annual earnings *might* be disposed to investment in a new enterprise, the incentive, the risk, and the collateral potentials would need to be considered.

*Consider the incentive, the risk, the collateral*

Economic incentive must be measured in terms of, first, a scope of operation worth the bother, and second, the yield on investment. A problem for hail suppression considerations is that annual loss from hail is usually expressed as a national aggregate and cost rationales are aimed at gross acreage. The case for hail suppression would be much more dramatically made and perceivable if analyses were concentrated on high hazard areas, rather than on United States averages. The practical facts are that:

- Only 21% of the United States (1969 census) is devoted to crop production — another 27% to grassland and range
- While the crop land is widely distributed over the total land area, much of it lies in regions where hail suppression is highly unlikely to be economically feasible, at any level of effectiveness
- It remains to be seen whether the agricultural public in any but localized and the most hazardous hail areas will rank hail suppression high enough on their scale of priorities to elect it as an ongoing program

Reduced to this scale there is little to suggest that there will be any inclination to divert available investment funds from insurance operations to hail suppression research or operations.

*'Scale' does not suggest investment*

Enterprisers must ever beware of risk, both to foresee and to allow for the unforeseen. The most serious risk to hail suppression operations, as we noted before, is the *liability exposure*. The industry is now fully aware of the consequences in liability underwriting that can and do result from exposures. As an operator of a suppression program, or even as the sponsor or employer of the applicators, an insurance company would be in double jeopardy for:

*'Double jeopardy' as operator*

- 1) Its exposure to the allegations previously noted, for which it might self-insure or obtain insurance from other carriers, but at considerable expense

- 2) Its target exposure to a public which not infrequently through juries regards insurance companies as a logical source of remedy for whatever ails it, irrespective of contract (at the public's ultimate own expense in higher premiums for insurance)

*Insurance is 'risk enough'*

Insurance management will not ignore these risks; while they specialize in "risk-taking," they do so with prudence (i.e., with high survival expectancy) and a wholesome respect for their stockholders and their surplus. For the next decade there is risk enough in insurance alone.

*Condition of insurance finances*

As a final understanding to be desired, the financial circumstances of the insurance industry have seldom been more critical than at present. It is expected that at least five years — and more likely ten — will be required for recovery from two developments.

*Its surplus was eroded*

First, the decline of the stock market in 1973 so eroded the surplus of the industry that capacity for existing demands for insurance is strained. No considerable increase in growth capacity will occur without a rebuilding of surplus, which must come primarily from profitable insurance operations.

*Underwriting results were poor*

Second, underwriting results for 1974 and 1975 were bad, and this was compounded by a decline in investment income, which in recent years had partly obscured deteriorating underwriting results. While improved underwriting and administrative practices may help, only massive increases in insurance rates can overcome inadequate premium income which is further aggravated by inflation. Buyers of insurance are regularly becoming aware of industry actions to implement this recourse.

*Some companies will not survive*

Whatever the inclinations of insurance management, the financial facts are that for the next decade the industry will be obliged to husband and restore surplus for the growing needs of insurance, to the exclusion of disposal to new enterprises. Some insurance companies will not survive. Beyond the next decade, one may speculate that the industry may again be caught up in the cycles of conglomerate diversification. But the lack of incentive and the excessive risk characteristics of hail suppression operations is unlikely to attract most companies.

- Agricultural Research Policy Advisory Committee
- 1974 *Estimating crop losses due to hail.* USDA ERS, Washington, D.C., Agricultural economic report 267, 40 pp.
- 1975 *Research to meet U.S. and world food needs: Report of a working conference: Volume 1.* Washington, D.C., 332 pp.
- Boone, L. M.
- 1975 *The impact of hail suppression on cropping patterns in a multi-area producing region.* Unpublished manuscript, Economic Research Service, U.S. Department of Agriculture, Washington, D.C.
- Borland, S.
- 1973 *Analysis of hail losses in Grover, Colorado.* Environmental and Societal Impacts Group, NCAR, Boulder, Unofficial report, 4 pp.
- Changnon, S. A.
- 1967 *Areal-temporal relations of hail intensity in Illinois.* Journal Applied Meteorology, 6(3), 536-541.
- 1973 *Weather modification in 1972: Up or down?* Bulletin American Meteorological Society, 54, 642-646.
- 1975a *Climate, is it changing? What will change mean to agriculture?* Crops and Soils Magazine, October, 9-12.
- 1975b *The paradox of planned weather modification.* Bulletin American Meteorological Society, 56(1), 27-37.
- Clark, R. T., R. R. Fletcher, and H. J. McKinney
- 1974 *The Star Valley economy: An interindustry analysis.* Agricultural Experiment Station, University of Wyoming, Laramie, Research journal 85.
- Davis, L. G.
- 1975 *Recent advances in hail suppression operations.* Paper presented at International Association of Hail Insurers Congress at Copenhagen, Colorado International Corporation, Boulder, 6 pp.
- Dean, R. D., W. H. Leahy, and D. L. McKee
- 1970 *Spatial economic theory.* The Free Press, New York.
- Dillon, J. L.
- 1971 *An expository review of Bernoullian decision theory in agriculture: Is utility futility?* Review of Marketing and Agricultural Economics, 39(1), 3-80.
- Doeksen, G. A., and D. F. Schreiner
- 1974 *Interindustry models for rural development research.* Agricultural Experiment Station, Oklahoma State University, Stillwater, Technical bulletin T-139.
- Domestic Council
- 1975 *The federal role in weather modification.* Subcommittee on Climate Change, Environmental Resources Committee, Washington, D.C, 29 pp.
- Farhar, B.
- 1975 *Weather modification and public opinion in South Dakota, 1972 and 1973.* Journal Applied Meteorology, 14, 702-709.
- Fosse, E. R.
- 1976 *Impacts of effective hail suppression on crop insurance industry and probable policy actions responses.* Illinois State Water Survey, Urbana, TASH working paper 8.
- Friedman, D. G.
- 1976 *Hail suppression impact upon property insurance.* Illinois State Water Survey, Urbana, TASH working paper 11.



- Grant, L. O., and J. D. Reid  
 1975 *Workshop for an assessment of the present and potential role of weather modification in agricultural production.* Colorado State University, Ft. Collins, Atmospheric science paper 236, 236 pp.
- Griliches, Z.  
 1964 *Research expenditures, education, and the agricultural production function.* American Economic Review, 54(5), 961-974.
- Havlicek, J., Jr., and J. A. Seagraves  
 1962 *The 'cost of the wrong decision' as a guide in production research.* Journal Farm Economics, 44, 157-168.
- Henderson, J. M., and R. E. Quandt  
 1971 *Micro-economic theory.* McGraw-Hill Book Company, New York.
- Institute of Ecology  
 1976 *Impact of climatic fluctuation on major North American food crops.* Washington, D. C., 26pp.
- Little, C. H., and G. A. Doeksen  
 1968 *An input-output model of Oklahoma's economy.* Agricultural Experiment Station, Oklahoma State University, Stillwater, Technical bulletin T-124.
- Mann, D. E.  
 1975 *Weather modification priorities and the political process.* Department of Political Science, University of California at Santa Barbara.
- McElheny, V. K.  
 1976 *Scientific deadend faces U.S. in its agricultural technology.* In New York Times, New York, Monday, May 31.
- National Academy of Sciences  
 1973 *Weather and climate modification: Problem and progress.* Committee on Atmospheric Sciences, Washington, D.C., 100-106.  
 1975 *World food and nutrition study.* Steering Committee, Study on World Food and Nutrition, National Research Council, Washington, D.C., Interim report, 55 pp.  
 1976 *Climate fluctuations and the demand for food.* Board on Agriculture and Renewable Resources, Committee on Climatic Fluctuation and Agricultural Production, Commission on Natural Resources, National Research Council, Washington, D.C., 287 pp.
- National Advisory Committee on Oceans and Atmosphere  
 1975 *A report to the President and the Congress: 4th annual report.* Washington, D.C., 49 pp.
- Palmini, D. J., C. R. Taylor, and E. R. Swanson  
 1977 *Economic impact of selected agricultural pollution controls on rural communities.* Department of Agricultural Economics, University of Illinois at Urbana-Champaign, Urbana, Report AERR forthcoming.
- Peterson, T. A.  
 1972 *An analysis of thirteen years of commercial hail suppression in central Alberta.* Faculty of Forestry and Agriculture, University of Alberta, Edmonton, AE & RS bulletin 13.
- Peterson, W.  
 1967 *Return to poultry research in the United States.* Journal Farm Economics, 49(3), 656-669.

- Prest, A. R., and R. Turvey  
 1965 *Cost-benefit analysis: A survey.* The Economic Journal, 95(300), 683-735.
- RANN-UCAR Panel  
 1974 *Report of the national hail research experiment.* NSF, Washington, D.C., 31 pp.
- Reutlinger, S.  
 1970 *Techniques for project appraisal under uncertainty.* The Johns Hopkins Press, Baltimore.
- Schmitz, A., and D. Seckler  
 1970 *Mechanized agriculture and social welfare: The case of the tomato harvester.* American Journal Agricultural Economics, 52(4), 569-571.
- Science  
 1976 *Hail suppression up in the air.* 191(4230), 932.
- Simpson, J. S., and A. S. Dennis  
 1972 *Cumulus clouds and their modification.* National Oceanic and Atmospheric Administration, Environmental Research Laboratory, Boulder, Technical memorandum ERL OD-14.
- Swanson, E. R.  
 1969 *Price expectations and 1969 acreages of corn and soybeans in Illinois.* Illinois Research, 11(2), 3-4.  
 1976 *National and regional impact of adoption of hail suppression.* Illinois State Water Survey, Urbana, TASH working paper 14, 44 pp.
- Taylor, C. R., and E. R. Swanson  
 1975 *The economic impact of selected nitrogen restrictions.* Department of Agricultural Economics, University of Illinois at Urbana-Champaign, Urbana, Report AERR-133.
- Taylor, C. R., P. J. van Blokland, E. R. Swanson, and K. K. Frohberg  
 n.d. *A description of two national spatial-equilibrium models of crop production.* Department of Agricultural Economics, University of Illinois at Urbana-Champaign, Urbana, Report AERR 147.
- Thompson, L. M.  
 1975 *Weather variability, climatic change, and grain production.* Science, 188(4188), 535-541.
- U.S. Bureau of the Census  
 1972 *1969 census of agriculture: Volume 1, area reports: Part 21, Kansas.* Government Printing Office, Washington, D.C.
- U.S. Department of Agriculture  
 1968 *A national program of research for weather modification.* Joint Task Force, Washington, D.C., 35 pp.
- van Blokland, P. J.  
 1976 *The economic consequences of hail suppression and varying export demands on eight crops in the U.S.A., estimated with a national LP model with stepped demand functions that maximize surplus.* Unpublished doctoral dissertation, Department of Agricultural Economics, University of Illinois at Urbana-Champaign, Urbana.
- Weinschenck, G., W. Heinrichsmeyer, and F. Aidinger  
 1969 *The theory of spatial equilibrium and optimal location in agriculture: A survey.* Review of Marketing and Agricultural Economics, 37(1), 3-70.

## SUMMARY OF CHAPTER 10

### EFFECTS OF ADOPTION



The evaluation of the economic benefits in this chapter relates to the national level. The following question is addressed: Given the adoption patterns projected in Chapter 9, what will be the savings in the resources required to meet the projected domestic and foreign demand for crops? The resource savings are indicated by the reductions in cost of production and transportation to points of processing that occur as the hail suppression technologies are adopted. In addition to projecting domestic and foreign demands for 1985 and 1995, yield increases from other technologies are also projected. Model 1 results in a reduction of production and transportation costs of approximately 1% in 1985 and 5% in 1995. Model 3 has such a low adoption rate that there is no reduction in costs.

*High technology saves 5% in costs of production*

*Slight reduction in land rents*

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

*Little change in crop patterns*

The adoption of hail suppression technology also affects the comparative advantage of the crops in the various regions. The resulting changes in the location of crop production do not appear substantial when compared to recent year-to-year changes in crop acreages by states.

*High technology most beneficial*

A benefit-cost analysis sought to answer the following question: Which of the three technology models promises to be the best investment for public funds? The benefits associated with each of the three models were based on the resource savings (cost reductions) accomplished by adoption of each of the technologies according to the patterns estimated in Chapter 9. The costs included the research and development costs as well as the design, evaluation, and program information costs judged necessary to generate each of the three levels of technology. Using an 8% discount rate, Model 1 has an estimated benefit-cost ratio of 14.6:1, Model 2 a ratio of 16.6:1, and Model 3 a ratio of -0.4:1. However, Model 1 resulted in the greatest economic benefit because it would be more widely adopted.

Use of substantially higher discount rates did not affect the ranking although it did reduce the benefit-cost ratios. These ratios appear high for several reasons, including the fact that much prior research has been done to provide a base for the expected development under each assumed funding level. Also, there is no risk discounting to reflect the uncertainty of obtaining the specified technology level, given the funding level.

The research "industry" consists of those who perform the research and support it. A dramatic and rapid scientific breakthrough is not expected because of the level and nature of funding. Although research and development related to hail suppression are expected to continue, the major issue will be the rate of progress and the factors influencing this rate. The question of division of responsibilities among federal agencies for research and development in hail suppression needs to be resolved.

*Dramatic  
breakthrough  
not anticipated*

The problem of assessing the value of research is very complex but an illustration of a method that could be used for partial evaluation of future weather modification research reveals key facts. The hypothetical data used relates to a wheat production area in western Kansas, and results indicate the need to assess the current status of hail suppression and the economic importance of an experiment's having application over broad regions.

*Value  
of future  
research*

The present hail suppression industry is small. Four companies grossed \$1.45 million in 1975 and hail suppression represented only 25% of their total business. A survey of these four companies in the hail suppression industry indicated their preference that the government should perform research and evaluation but should not become involved in operational aspects and that local-state groups should have control of hail suppression projects. The survey also indicated that commercial operators felt there would be increased activity in hail suppression by 1985 and 1995, and even with increased government control they anticipated that they would prosper.

*Industry  
will  
survive*

The probable impacts of hail suppression activities on the insurance industry may be summarized as follows:

- 1) Effective suppression of hail damage to crops or property will not displace the need or use of insurance. It could increase the use of all-risk insurance, especially in the high-risk areas where the lowered risk of catastrophe events (because of suppression) would eventually lower insurance rates.
- 2) Effective operational hail suppression would probably require modified forms of coverage and modified pricing structures and could make it possible for the industry to offer more comprehensive forms of coverage. Pricing would be difficult in the early stages because insurance rates are based on all-time historical records of losses and hail occurrences. *This problem could be overcome and rates lowered, but this improvement would not take place as rapidly as the public might expect.*
- 3) Adverse effects of hail suppression, such as increased wind and lightning, could be a problem in both crop and property coverage. An increase in wind velocity might offset reduced hail, and increases in either wind or lightning could aggravate claims handling and possibly result in increased litigation.
- 4) Demand for third-party liability protection from applicators, financial supporters, or bystanders and opposers of suppression will be a serious problem to the insurance industry because of the numerous allegations of

*'Use' could  
increase*

*Lower  
rates  
eventually*

*Concern  
for adverse  
effects*

*Liability  
a serious  
problem*

harm that could be made in hail suppression operations and the difficulty of disproving them. *The areal exposure involved and the potential for class action may make such liability protection impossible.*

*Small companies  
may 'support'*

5) The hail insurance companies whose business is confined to one state are more affected by major losses in hail (which can concentrate in a given state over several years) and could more actively seek to promote and become involved in financial support of hail suppression than companies selling over multistate areas. The attitude of state insurance departments toward hail suppression could also affect the industry's position toward involvement in hail suppression.

*The industry  
will not support,  
nor oppose*

6) It is not expected that most of the insurance industry will take any initiative in the research, development, or operation of hail suppression programs. The main reasons are: lack of economic incentive because of the small size of crop production that could be benefited, the serious risk in liability exposures, and the current lack of money for new ventures. However, the insurance industry is not expected to oppose hail suppression.

*Federal help  
may be needed*

7) If hail suppression grows very large, federal operations, evaluation, and control of hail suppression activities would minimize threats to liability insurance and help insurance companies set rates through careful evaluation of the hail decreases.

# 11

## Future constraints



The socio-political, legal, and environmental influences and constraints that were described and discussed in Chapter 6 were analyzed as to factors affecting the future adoption of hail suppression — and these factors were then integrated to provide the future adoption patterns of Chapter 9.

In this chapter we look forward to likely developments in institutional arrangements and legal constraints for expanded hail suppression activities of the future. We also consider the possible secondary impacts and future needs concerning the environment.

### INSTITUTIONAL ARRANGEMENTS FOR HAIL SUPPRESSION\*



With increased certainty concerning the effectiveness of hail suppression technology, it may be expected that its use will increase.

Adoption of the technology, as discussed in Chapter 9, will most likely occur in the regions where hail poses the greatest threat to the crops of farmers — the Great Plains, the Rocky Mountains, and perhaps other heavily agricultural regions such as the Midwest.

Economies of scale could then lead to consideration of *regional* hail suppression efforts. As the incidence of hail does not respect state boundaries, hail suppression technicians may find advantages in not respecting state boundaries, either.

*Efforts will  
cross state  
boundaries*

The consequence of expanding operations is the necessity to consider organizational and legal arrangements that will make possible operations across state boundaries. Contrariwise, interests within states downwind of the hail suppression operations who feel threatened by such operations will consider means to protect their interests.

\*These sections contributed by Dean Mann.

Whatever the motivation, it may be expected that various local groups, local public agencies, and state administrative agencies responsible for weather modification will seek some resolution of these matters, either in the interest of economy or in the interest of protecting property rights.

*Will need  
multistate  
administration*

In many and perhaps most situations the direct and indirect effects will require approval and regulation by more than one state and thus lead to *multistate administration*. The options for such administration are numerous, ranging from each state authorizing local or special units of government to undertake agreements for the hail suppression activity to federal preemption of responsibility to regulate all hail suppression. Constitutional authority for the federal government to do so seems ample — the issue will be whether and to what extent federal involvement is required.

*States'  
officials  
will confer*

There are numerous avenues the various interests might explore in dealing with this mutual problem or opportunity. Undoubtedly, the first approach will be some form of negotiation among state officials, in which the issues are sharpened and areas of agreement and disagreement are delineated. If several states are involved, a conference may take place to consider the role of hail suppression in their economies.

*Differences  
in statutes  
of concern*

If the states have weather modification statutes, there may be efforts to reconcile the differences among those statutes, particularly with respect to standards for *licensing of operators, for liability, for reporting, and for performance*. Despite some efforts to develop uniform weather modification laws to this date, weather modification law remains essentially "balkanized" (*Davis, 1975*).

*National  
effort to  
establish  
uniformity*

The increasing utilization of hail suppression (and other weather modification) would probably provide the catalyst to generate legislative activity at the national level with regard to establishment of some uniformity among the states. There was considerable activity in this respect during the late 1960s, but only one federal statute — requiring reporting of weather modification activities — presently exists.

This lack of uniformity may reflect the lack of certainty concerning the character of an appropriate statute and the role the federal government should play in controlling weather modification. No doubt, there is considerable preference among the states and private operators for state control of the industry. The character of federal action would probably develop along the lines of establishing minimum standards for state regulations, similar to existing water pollution control legislation.

*Would protect  
other federal  
activities*

Federal agencies would probably insist on imposing some regulatory authority over state-authorized operations to ensure that such operations did not conflict with federal activities, particularly those research activities that required the avoidance of contamination for the realization of desired results.

State officials will undoubtedly give consideration to various other approaches to multistate problem solving, including interstate compacts, multistate consultative organizations, and regional corporations. All of these options have attractive features and drawbacks and their legal arrangements are discussed in the next section.

*Interstate compacts and other approaches*

Discussions of multistate cooperation and consideration of federal regulation of weather modification will probably deal with several kinds of weather modification programs, including precipitation augmentation, severe storm modification, hail suppression, and lightning suppression. Thus, hail suppression will be dealt with in the context of other weather modification technologies.

*Suppression considered with other weather modification*

### MULTIJURISDICTIONAL CONTROLS OF HAIL SUPPRESSION\*



The main thrust of legal control of hail suppression is toward the protection of the public interest. To date that consideration of the rights of the public has been primarily accomplished on the state level, as we described in Chapter 6.

But, weather conditions and political boundaries do not conform to each other. Hailfall and hail suppression both have impacts across state and national boundaries. Efforts by one jurisdiction to bring about legal control of hail suppression also can involve other states and nations. Such involvement can be expected to increase in the future if hail suppression operations expand into large regional programs. The interstate and international regulations and solutions that might apply are discussed here.



Figure 66 shows ten numbered sites in the western portion of the United States in which interstate hail suppression regulation problems and solutions are indicated. Sites 1, 2, and 3 are places at which the three basic approaches to handling interstate water rights are illustrated. Sites 4, 5, and 6 are locations in which *cooperative approaches* have been taken for resolution of potential interstate weather modification problems. The other four sites show locations in which there have been *unilateral efforts* by states to deal with interstate weather modification control.

### INTERSTATE PROBLEMS, SOLUTIONS

As in the case of disputes among individuals for the right to atmospheric waters, commentators on *interstate disputes* over atmospheric waters have turned to prior law concerning interstate allocation of ground and surface waters (*Pierce, 1967*). The devices which have been used are:

*Water rights analogies*

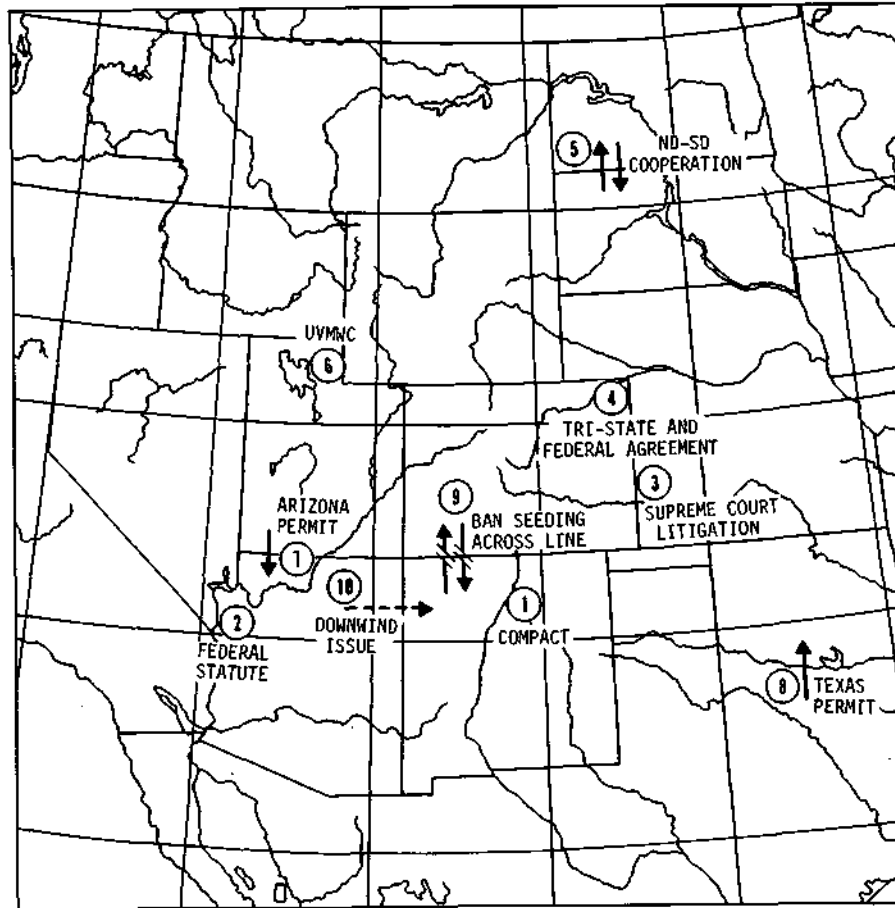
\*These sections contributed by Ray Jay Davis.





FIGURE 66

Interstate weather modification legal ramifications



- |                             |                                  |
|-----------------------------|----------------------------------|
| 1. Compact                  | 6. Interstate Corporation        |
| 2. Federal Statute          | 7. Out of state permit           |
| 3. Supreme Court Litigation | 8. Out of state permit           |
| 4. State-Federal Agreement  | 9. Ban seeding across state line |
| 5. Interstate cooperation   | 10. Downwind issue               |

- Interstate compact
- Federal legislation
- Supreme Court litigation

*Interstate compacts*

The Colorado River Compact, which allocated the waters of the Colorado River between the Upper Basin and the Lower Basin of that river, was the first interstate compact dividing water resources among riparian states. The compact is named for the site where it was negotiated and drafted. Before it could become operative, it also required congressional consent and ratification by the states.

A compact legally binds all of the party states and their citizens. But at the

drafting and negotiation stage it is quite flexible (Cox, 1976). Multistate hail suppression operations and regulation could be realized by the compact device. However, it would take legislative commitments from Congress as well as from the affected states.

The waters in the Lower Colorado River Basin were held in *Arizona v. California* to have been made subject to interstate allocation by the Secretary of the Interior by the Boulder Canyon Project Act, a federal statute (Haber, 1964). The power of Congress to create an allocation system for interstate streams is analogous to congressional authority to allocate atmospheric waters among states and to regulate hail suppression that has interstate consequences (Cox, 1976).

Federal  
statutes

Acts of Congress have been used to create *federal corporations* which have been given a variety of operational and regulatory powers. Among such corporations are the post office (Resh, 1971), the Federal National Mortgage Association (Barke, 1971), the Tennessee Valley Authority (Haimbaugh, 1966), and the Communications Satellite Corporation (Schraeder, 1965).

Similarly, an act by Congress could set up a federal hail suppression corporation and delegate to it regional or nationwide regulatory or operational authority.

In the event states fail to reach agreement and Congress does not act, *states may sue each other* in the Supreme Court of the United States seeking a decree allocating interstate streams. The Court, starting in 1907 with *Kansas v. Colorado*, has developed the doctrine of "equitable apportionment" (Friedrick, 1947). It considers a wide variety of relevant factors which are weighed together to lead to a delicate adjustment of interests in a fair and equitable manner.

Supreme  
Court  
litigation

The doctrine could be applied to resolve interstate conflicts over allocation of moisture in the atmosphere, over supplemental water in interstate streams allegedly put there by increased precipitation, or over other interstate hail suppression problems.

Site 4 in *Figure 66* illustrates one means for states to cooperate among themselves and with the federal government in bringing about smooth working arrangements for interstate hail suppression efforts.

Cooperative  
approaches

Kansas, Nebraska, and Colorado signed a "memorandum of understanding" with the Bureau of Reclamation, wherein the parties agreed to work together toward a program plan with the Bureau's assistance. The memorandum can be amended if all the parties agree, and any party can terminate by giving the other parties 120 days notice of its intent to do so (Davis, 1976a).

North and South Dakota, Site 5 in *Figure 66*, have had informal agreements concerning hail suppression operational activities across state boundaries. Such an agreement does not require legislation to make it operative, and otherwise is useful in avoiding red tape (Cox, 1976).

An example of the interstate agreement device is the North American Interstate Weather Modification Council. The main purpose of the organization is:

". . . to achieve and maintain state and local control of weather modification activities while endeavoring to attain a high degree of legislative uniformity and an effective information exchange mechanism."

States or provinces can be permanent or temporary regular members, or affiliates (Keyes, 1976).

*Uniform,  
or model  
laws*

Uniform legislation provides another example of interstate cooperation. Such devices as model or suggested laws give the states sources from which they can draw uniform rules concerning weather modification (Davis, 1975).

*Nonprofit  
corporation*

In 1976 formal articles of incorporation were filed in Utah of the *interstate nonprofit corporation* which had earlier been set up for sponsoring hail suppression activities in three Utah and three Idaho counties. Each county is a member of the corporation, and membership is open to all counties in Idaho, Utah, and Nevada. Financial contributions from member counties underwrite the costs of the hail suppression seeding (Warburton, 1975).

*Unilateral  
approaches*

Although the states might not agree on means of dealing with interstate hail suppression problems, they might nevertheless attempt to resolve them, but in a unilateral manner.

When operations are carried on in one state to bring about seeding of a target in another jurisdiction, the state in which the seeding takes place could approach the permit process in several ways. At Site 7, Utah requires full compliance with Arizona as well as Utah law in order to seed from Utah into Arizona. Texas, at Site 8, merely has the applicants get a Texas permit to seed Oklahoma targets. Both Colorado and New Mexico would ban seeding that would affect the weather in any state that had banned seeding for the benefit of Colorado or New Mexico (Davis, 1974).

*Unintended  
effect a  
problem*

Sometimes operations are carried on in one state to affect a target in that state, but are alleged to impact on another state as well. This problem of an *unintended* downwind effect out of the jurisdiction was alleged by New Mexicans who asserted that emergency drought relief seeding in Arizona "rustled" clouds that would otherwise have precipitated in New Mexico (Davis, 1972). There is no provision under Arizona law to handle the problem. States unilaterally issue permits irrespective of possible out-of-state downwind effects.

INTERNATIONAL  
PROBLEMS,  
SOLUTIONS

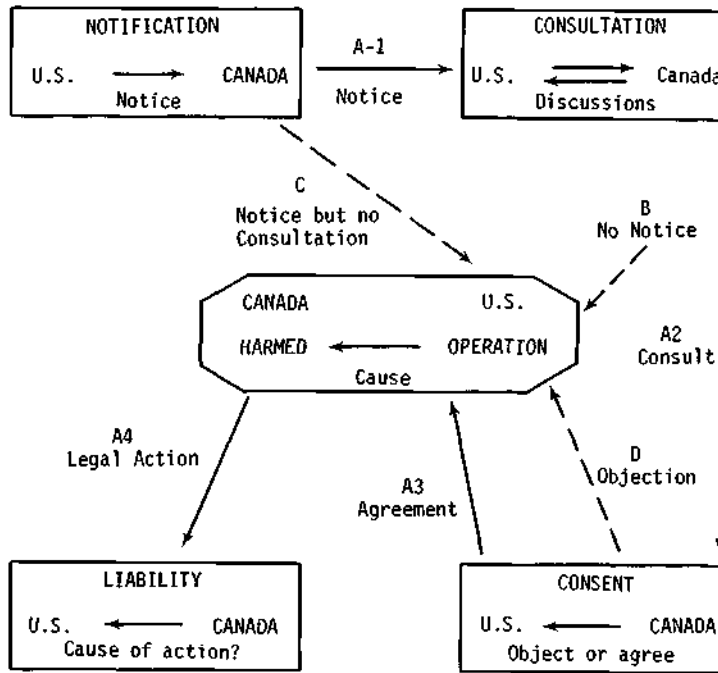


American weather modification technology has been exported abroad in successful instances of technology transfer (St. Amand et al., 1971), and has been used abroad by our armed forces as a weapon (Davis, 1973). Hail suppression technology can be exported (see Chapter 3) but does not seem to be adaptable as a weapon.

The international legal complications from application of the technology would appear to be operations carried on in one nation with the intent of seeding a target there, but with an asserted impact in another country. Thus Alberta seeding (Krick, 1975) might be blamed for rainshadow in the United States, or



**FIGURE 67**  
International legal obligations



POSSIBLE COURSES OF ACTION BETWEEN THE UNITED STATES AND CANADA

- A1 -- Notification by the United States of project
- A2 -- Consultation with Canada concerning project
- A3 -- Agreement by Canada to carrying out project
- A4 -- Legal action by Canada for harm caused by project
- B -- No notification given by the United States of project
- C -- Notification given, but no consultation with Canada
- D -- Notification and consultation, but Canada objects to project

North Dakota seeding (*Johnson and Beck, 1974*) might be claimed to have an adverse impact in Canada.

*Figure 67* looks at the latter situation and considers four possible steps in the process of the international legal interaction between Canada and the United States. They are:

- 1) Notification by the United States to Canada of the project
- 2) Consultation between the United States and Canada concerning the project
- 3) Consent by Canada (or objection by it) to the seeding

*Legal  
interaction  
process*

- 4) Liability of the United States to Canada in a legal action brought by it against the United States for harm caused by implementation of the hail suppression operation

There is—in customary international law—an obligation on the part of the nations to give warning to other countries of dangerous conditions of which they are aware. The United States gave notice to Caribbean countries and other potentially affected nations when it proposed to conduct hurricane suppression seeding operations.

The United States and Canada have an informal executive agreement calling for transmitting information relating to weather modification activities to the other country (*Davis, 1976b*).

*Consultation  
with others*

If the United States gives notice, or if Canada otherwise learns of the hail suppression project, the next issue would be whether international law would require the United States to enter into consultation with the Canadians.

It is reasonable to conclude from what international law applies that the United States should receive such information, suggestions, and objections as the Canadians might wish to send to us (*Davis, 1976b*).

*Agreement  
not needed*

Assuming the Canadians learn of the seeding and enter into consultations with the United States, is this country obligated to seek Canadian agreement before going forward? Does international law give the Canadians the right to grant consent or to veto the American hail suppression project?

International water law indicates that an upstream country has the right of initiation of a project and need not associate a downstream state with its projects. Application of this principle to weather modification would *not* give the veto power to Canada (*Taubenfeld, 1967*).

*LIABLE  
for harm*

Arbitration between the United States and Canada in the *Trail Smelter Case* established that Canada was obligated to pay for harm done in the United States by air pollutants which drifted across the international border from that country. This case has been cited by commentators for the proposition that a country would have a legal obligation to pay another nation for harm done to it by weather modification activities which have a transnational impact (*Taubenfeld, 1967; Davis, 1976b, 1974, 1972*).

There is one very important limitation upon the liability rule—causation. As was indicated in Chapter 6 in the discussion of the legal liability of cloud seeders for harm complained of, it is necessary for the party seeking relief to *prove the causal link* between the activity of the defendant and the damage assertedly done by that effort. Canada would have to prove that hail suppression in North Dakota caused harm in one of its provinces.

## THE ENVIRONMENT - SECONDARY IMPACTS AND NEEDS\*



Our discussion in Chapter 6 concerning hail suppression and the environment concentrated on the direct effects of accumulation of silver-iodide-based seeding agents on ecosystems. In addition to these direct effects which have been observed and which can be postulated, a series of secondary effects may need to be considered.

### SECONDARY IMPACTS

The possible ecological impact of silver iodide (AgI) nucleants has led to the development and testing of a series of additional nucleating agents. To be as well accepted as AgI, these new agents will have to be shown to have at least equal effectiveness, or a delivery efficiency-cost relationship which will make them more economical and equally convenient to use.

*New, different nucleating agents*

The continuing quest for improved seeding agents will lead to additional requirements for evaluation of possible ecological impacts, and for testing of potential bioconcentration in higher trophic levels.

The presence of additional silver or iodide in ecological systems may lead to a potentiation or increased synergistic effect with *other metals* present in the environment. A case in point may be the close relationship which has been observed between copper and silver in aquatic and marine sediments. It may be necessary to evaluate the possible effects of metal mixtures with the presence of excess halides, especially iodide, which can provide a critical component in predicting the fate or movement of metals in terrestrial or aquatic ecosystems.

*Problem of mixtures*

The ability of AgI seeding agents to be attached to plant surfaces (*see Chapter 6*), followed by release on subsequent days where it can act as a nucleating agent, will make it necessary to reevaluate the randomization of seed-no seed events in weather modification programs, especially in mountainous areas.

*Seed-no seed randomization*

Increased movement of silver into plants may influence growth, development, or reproduction of insects which might utilize these materials as nutrients. If this were to occur, it might be necessary to consider possible silver effects on reproduction of granivorous or insectivorous birds.

*Birds and insects*

If slight increases in soil organic matter levels could be expected, this could lead to several effects upon the plant-soil system:

*Effects on plant-soil system*

- It could be possible to have minerals required for plant growth bound up in soil organic matter. This would appear to be a *minimal* effect, as water is usually the major factor controlling plant growth in arid regions.
- With increased soil organic matter levels, increased water retention could allow *more intense plant growth*. This might alter the reflectance characteristics of the soils and lead to subtle changes in atmospheric conditions.
- The increased presence of metals in the soil-plant zone could lead to an *increased population of microorganisms* which would be capable of metal reduction. This could lead to the more rapid inactivation of other metals which might be added to these systems.

These sections contributed by Donald A. Klein.

*Effects on  
fish minimal*

The possible effects on fish populations would be expected to be minimal, due to the lack of proven effects of silver on fish from research to date, and the gradual accumulation of silver in anaerobic bottom muds. This could, however, lead to periodic release of silver through violent storm activities where the bottom mud layers in a lake or pond might be *resuspended* and released to the downstream waters. Under these conditions, transient higher silver concentrations could occur to interact with plant-organism systems.

*Respirable  
particles*

The increased use of coal-fired power plants, particularly in the high mountain and western states, will lead to increased airborne particulate burdens. In combination with hail suppression program release of AgI, this may lead to an increased silver content in respirable particles. With the smaller particle size of nucleating agent burn-materials, this may lead to subtle changes in the type of materials which could be respired, leading to *altered metal burdens* in animal and human populations.

*Interaction  
with other  
metals*

If slightly increased silver levels gradually occur in feed grains and fowls, in spite of minimal effects on humans ingesting these materials, they may lead to higher silver levels in sewage treatment plant sludges. A major concern with re-use of sludge as fertilizers in agriculture is possible heavy metal bioconcentration.

The presence of increased silver, while of itself perhaps not of direct importance, may lead to increase of the movement and biological activity of other metals, possibly including mercury, cadmium, and zinc.

*Legal  
complexities*

Comparison of silver in rainwater in the industrial Midwest, where there has been no planned weather modification, with the amounts of silver in rainwater in some western areas with considerable intentional weather modification indicates that inadvertent cloud seeding has produced conditions with two to five times the silver concentrations derived from cloud seeding (*Gatz, 1975*). Thus, separating the effects of silver to identify those derived from intentional seeding will be difficult in any legal action. Slight silver changes over wide areas and long periods of time will be difficult to prove. Indeed, it will be harder still to establish the ecological effects from these changes in silver concentration. Additional information will be needed in any lawsuit.

*Need information  
on what is  
occurring*

As possible effects may be longer term and more subtle, it will be necessary to have improved information on ecosystem functions in the absence of AgI imposition to be able to show conclusively that effects are occurring. This will require an *additional level of expertise* in ecosystem function analysis which is not presently available. In most cases, it will be necessary to predict possible effects in a 30 to 50 year ecological time frame, for which data on background trends in plant-soil-aquatic community relationships must be known.

*Releases of  
silver, other metals*

Because silver can be added to the biosphere by other activities, including industrial and mining processes, effective evaluation of the impact of weather modification will require *improvement of our information* on release of silver and other metals in impact areas.

As we have noted elsewhere in this report, the success of weather modification programs depends upon public acceptance of these efforts. Some previous programs have involved litigation over the potential toxic effects of nucleating agents. In spite of possible litigation once the public becomes aware of ecological consequences of hail suppression, there is a need to make such information available to the public. Only through education of the nonscientific audience can the people properly interpret accounts that will in any event be circulated about hail suppression.

*Getting  
information  
to public*

A major policy decision will be whether to disseminate information and bring attention to potential ecological problems, or whether to simply hold information until an outside group might make this a point of concern. This becomes a problem in the political realm, which will be resolved by the philosophical viewpoints of the individuals concerned or by the unique set of political and social circumstances which might occur at any time.

*Policy  
decision on  
information*



On the basis of our present knowledge it is unlikely that widespread, operational hail suppression programs would have serious, adverse environmental impacts — especially impacts that would importantly affect man in the discernible future.

GENERAL  
CONCLUSIONS

The possibility of such adverse impacts should not, however, be completely discounted.

The geographic regions in which such programs would probably be used are agriculturally productive, and adverse environmental impacts could influence food supplies and agricultural markets not only in this country but throughout the world. It has been noted, in considering the possibility of such adverse impacts (*Cooper and Jolly, 1970*), that a consensus of professional opinion 20 years ago would have "*almost certainly not anticipated the recent discovery that DDT lowers the reproductive rate of many bird species by reducing the thickness of their eggshells.*"

*Impacts  
could be  
important*

However, the long-term historical use of silver by man suggests that it may not be possible to extrapolate too strongly from this type of example to the possible effects of silver compound use in weather modification.

The case for possible adverse environmental impacts rests on the fact that a number of responsible researchers have cautioned that in the very long run the use of AgI as a nucleating agent *might* produce specific adverse environmental impacts.

*Adverse  
impacts not  
shown*

Most research to date has *not* revealed in present experimental hail suppression programs that such adverse impacts have emerged, or how serious they might be in terms of "morbidity-mortality rates" for either man or other forms of life.

The reduction of hail, *per se*, would very likely reduce the hail-induced injury and mortality of certain species of wildlife and plants — to what extent is also presently unknown. Future research, including both laboratory and field

*Hail reduction  
would reduce  
wildlife injuries*



studies covering experimental and operational hail suppression programs, will reduce some of the numerous current uncertainties about future environmental impacts of hail suppression.

At the same time, some of this future research, following the tradition of past scientific inquiry, will undoubtedly disclose new uncertainties not presently evident.

Some of these new uncertainties will follow in the wake of new research and experimentation in the technology of hail suppression. In addition, AgI may eventually be supplanted as the major nucleating agent in cloud seeding. The potential adverse ecological-environmental impacts of these other agents, however, may be greater than those of AgI.

*Complex ecological interactions*

As noted in Chapter 6 and elsewhere in this report, the kinds of future impacts that hail suppression would cause, and society's assessment of these impacts, would depend on numerous considerations, perhaps not directly related to hail suppression. One such possibility would result from complex ecological interactions that might occur in the future between hail suppression, on the one hand, and pesticide applications, air pollution, and other weather modification programs (Cooper, 1973).

*Possible aid to ecosystem stability*

The complexity of making definitive judgments at this time is related to the possibility that AgI dispersal into the air might eventually *inhibit soil microorganism activity*. If this occurred, there could be a *slowing in the rate of organic carbon return to CO<sub>2</sub>*.

However, other ecologists are concerned that the large-scale utilization of fossil fuels and the subsequent release of CO<sub>2</sub> may result in an *increase* in the CO<sub>2</sub> content of the air beyond acceptable limits, and thus create a "greenhouse effect." If this were to occur, an increased organic matter retention resulting from the use of AgI *could aid* in maintaining ecosystem stability.

## **SUGGESTED ACTIONS**



On the basis of available information, the use of excess iodide or other halides in combination with AgI should be minimized. Hail suppression programs that use rockets and other pyrotechnic devices with solid propellant mixtures should avoid the need to solubilize AgI with such excess halides.

*Review new agents carefully*

If other seeding agents are proposed or used on an operational basis, their possible ecological impacts should be reviewed carefully. The confidence which the weather modification profession has in AgI as a nucleating agent, together with the extensive if not uniformly relevant literature which is available on silver, makes it mandatory that other agents have *markedly improved operational characteristics or demonstrably lesser environmental risks* before they are accepted. The Toxic Substances Control Act gives EPA new authority with respect to control over marketing new chemical compounds. See page 173.

To aid in better prediction of long-term, low-level effects of seeding agents in representative ecosystems, treatment plots and reference vegetation areas should be established in or adjacent to major impact zones.

*Long studies  
needed*

These should be available for monitoring on 2 to 3 year intervals over perhaps 40 to 50 year time periods. To carry out this type of work a long-term commitment of weather modification operators and regulatory agencies is required.

The hail suppression profession should assist in organization of a general conference on weather modification — and specifically on hail suppression effects — to allow a meaningful summation of our current knowledge on ecological impacts of hail suppressing programs. In addition, this conference should serve to delineate research needs.

*Delineate  
research  
needs*

The monitoring of hail damage should be improved, if possible, by use of satellite surveys of vegetation in affected areas, in conjunction with continued reporting of claims and insurance compensation activities.

*Monitoring  
important*

In conjunction with the Environmental Protection Agency (EPA) and the Food and Drug Administration (FDA) if possible, information which is available on silver levels in foods should be summarized. If necessary, a specific program to monitor trace metal amounts in foods should be initiated to include silver if such data are not available; The silver levels in or on wheat, corn, and other crops that are shipped from areas where hail suppression programs have been carried out should be measured. To carry out such a program, samples of food products from these areas also should be tested *before* starting the hail suppression programs.

*Summarize  
silver levels  
in food*



On the basis of the previous considerations, research in the following areas is needed:

## **RESEARCH NEEDS FOR ENVIRONMENT**

- 1) Study of possible ecological effects of combinations of silver from weather modification with other metals, pesticides, power plant emission products, and other pollution sources should be increased.
- 2) Work on the ecological effects of proposed new seeding agents (AgI-TiO<sub>2</sub>, *Pseudomonas syringae*, organic agents) should be carried out as much as possible before the materials are used in full-scale weather modification projects.
- 3) Additional work on analysis of silver levels and forms at the less than parts-per-million level is needed to more effectively monitor plant and microorganism-mediated silver transformations in impact ecosystems.
- 4) The monitoring of silver dynamics in the soil-plant-aquatic environment should be intensified, to allow a better understanding of seasonal and plant phenological effects on silver movement. It is recognized that this will be much more difficult in the extended downwind area, and first efforts should be devoted to the immediate target area.

*Study other  
metals*

*New seeding  
agents*

*Analyze  
silver levels*

*Monitor silver  
in plant-soil-water*

- Nucleants on plant surfaces* 5) Research on the fate of nucleants after falling on plant surfaces should be carried out. This is important in predicting possible secondary nucleation phenomena.
- Tracing nucleants* 6) Work on tracing the fate of nucleating agents in seeded storm cells needs to be improved. This can be carried out by use of tracers, compounds which normally occur in low concentrations in the impact ecosystem.
- Basic studies on acclimatization* 7) Basic studies on the ability of plants and microorganisms to accommodate or acclimate to the presence of a given level of seeding agents should be carried out. In essence, the plant-soil-microbe community *may be able to respond and counteract the effects of an added silver perturbation*. Over time, the ecosystem may respond to a lesser degree with additional increments of a perturbing chemical, an extension of Weber's law (*Adler, 1969*).
- Intensify monitoring* 8) Monitoring of nucleating agent levels in impact ecosystems should be intensified.
- Bio concentration studies* 9) Based on results of work carried out to date, major emphasis on possible bioconcentration studies should be directed toward the first consumer levels where such effects might easily be found. The study of herbivorous insects would appear to be a valuable starting point, and work has already been initiated on this question (*Pfadt, 1976*).

## REFERENCES

- Adler, J.  
1969 *Cbemoreceptors in bacteria*. Science, 166, 1588-1597.
- Bartke, R. W.  
1971 *Fannie Mae and the secondary mortgage market*. Northwestern University Law Review, 66, 1.
- Cooper, C. F.  
1973 *Ecological opportunities and problems of weather and climate modification*. In *Modifying the Weather, A Social Assessment*, by W. R. D. Sewell *et al.*, University of Victoria, Victoria, British Columbia.
- Cooper, C. F., and W. C. Jolly  
1970 *Ecological effects of silver iodide and other weather modification agents: A review.* Water Resources Research, 6(1), 88-98.
- Cox, S.  
1976 *Devices for regulation of interstate weather modification*. Illinois State Water Survey, Urbana, TASH working paper.
- Davis, R.J.,  
1972 *United States and Mexico: Weather technology, water resources, and international law*. Natural Resources Law Journal, 12, 530-544.  
1973 *Weather warfare: Law and policy*. Arizona Law Review, 14, 659-688.  
1974 *Weather modification litigation and statutes*. Weather and Climate Modification, edited by W. Hess, John Wiley and Sons, New York, 767-786.  
1975 *Uniformity among weather modification laws*. American Society of Civil Engineers

- Davis, R. J. (*continued*)  
 National Convention, November, Denver, Colorado, Preprint 2548.
- 1976a *Legal uncertainties of weather modification. In Legal and Scientific Uncertainties, of Weather Modification*, edited by W. Thomas, Duke University Press (in press).
- 1976b *International legal implications of project Stormfury-Americas*. Submitted to Environmental Research Laboratory, National Oceanic and Atmospheric Administration, Rockville, Maryland, Progress report 01-6-022-13027.
- Friedrick, J.  
 1947 *The settlement of disputes between states concerning rights to the waters of inter-state streams*. Iowa Law Review, 32, 244.
- Gatz, D. F.  
 1975 *Background silver concentrations in Illinois precipitation and river water*. Journal Applied Meteorology, 14,217-221.
- Haber, D.  
 1964 *Arizona v. California: A brief review*. Natural Resources Journal, 4, 17.
- Haimbaugh, G. D.  
 1966. *TVA cases: A quarter century later*: Indiana Law Journal, 41, 197.
- Johnson, J., and R. Beck  
 1974 *Legal aspects of creating weather modification authorities*. Extension Service, North Dakota State University, Fargo, North Dakota, ARE Series 2.
- Keyes, C. G.  
 1976 *NAIWMC —formation and its activities through 1975*. Journal Weather Modification, 8, 157.
- Krick, I.  
 1975 *Hail suppression in Alberta*. Journal Weather Modification, 7,13.
- Pfadt, R. E.  
 1976 *Personal communication*. University of Wyoming, Laramie.
- Pierce, J.  
 1967 *Legal aspects of weather modification snowpack augmentation in Wyoming*. Land and Water Law Review, 2,273.
- Resh, R. E.  
 1971 *Postal reform: Some legal and practical considerations*. William and Mary Law Review, 12, 766.
- St. -Amand, P., D. W. Reed, T. Wright, and S. D. Elliot  
 1971 *Gromet II: Rainfall augmentation in the Phillipine Islands*. Naval Weapons Center, China Lake, California.
- Schraeder, G. D.  
 1965 *Communications satellite corporation: A new experiment in government and business*. Kentucky Law Journal, 53, 732.
- Taubenfeld, H.  
 1967 *Weather modification and control: Some international legal implications*. California Law Review, 55, 493.
- Warburton, R.  
 1975 *Utah-Idaho weather modification corporation*. Paper presented at Cloud Seeding Seminar, Salt Lake City, Utah.

## SUMMARY OF CHAPTER 11

### FUTURE CONSTRAINTS

*Mechanisms  
to resolve problems  
across state  
boundaries*



More widespread adoption of hail suppression technology in the future will result in regional projects which will cross state boundaries. Such interstate operations will be subject to political and legal constraints beyond those affecting projects confined to a single jurisdiction. There are mechanisms available to governments which may be used to resolve these multistate administrative problems. Some of them are unilateral, such as one state issuing permits for cloud seeding activities within that state which are designed to effect consequences in another state; others are cooperative, such as interstate agreements and compacts.

*International  
obligation —  
discussions  
but no veto*

International issues will be raised by hail suppression projects which take place near enough national boundaries to have foreign impacts. International law now requires one country to notify other nations about projects which may affect them. There is also an obligation to enter into diplomatic consultation with nations wishing to discuss such projects. However there is no legal obligation to obtain foreign consent to hail suppression. No nation can veto seeding in another one. Although bringing about harm in another country is a basis for national legal liability, it will be difficult in most cases for the impacted nation to prove causal relationship between the cloud seeding and the harm complained of.

*Environmental  
consequences  
a constraint*

Complex ecological interactions from hail suppression will possibly constrain future suppression projects. Among matters which should be considered are the effects of new nucleants, the results of mixing in the atmosphere, water, and soils of nucleants and other chemicals, and the long-term environmental consequences of hail suppression. These should be studied and means devised for dissemination of information to the public about the findings.

# 12

## Future impacts



In this chapter we look to the future and estimate what the consequences will be if operational hail suppression programs are adopted. An effort was made to examine the full range of impacts that are likely to follow such an option. As will be seen, some of those impacts are broad in scope or represent a considerable change from the status quo, while others are so minor that they may be considered trivial.

A technology assessment requires that all of the impacts be identified so that the policy maker may take them into account if he so chooses.

There are three basic components to this chapter. First, we describe how the various impacts were identified and rated along several dimensions. Then — using the assumptions of Scientific Models 1 and 3 (see *Table 38* in Chapter 8) and our estimates of the extent of adoption of the technology by 1995 (see Chapter 9) — we describe in detail the full range of impacts that are expected to follow between now and 1995.

The final section of the chapter includes two scenarios that present our impact analysis in narrative or story form. One scenario follows the skeleton of assumptions in Scientific Model 1 and the estimated pattern of adoption flowing therefrom between now and 1995. The second scenario does the same for Scientific Model 3. In both scenarios we attempt to make the time sequences among impact events more explicit and to point to change processes that are anticipated over the next two decades.

### INTRODUCTION - AND BASIC ASSUMPTIONS\*



The reader should be aware that this chapter does *not* represent an attempt to forecast the future *per se*. Rather it is an effort to make explicit what the

This section contributed by J. Eugene Haas, Barbara C. Farhar, Stanley A. Changnon, Jr., and Earl Swanson, based on team evaluations of impacts.

consequences are likely to be if hail suppression capabilities are developed in certain ways and *if* the technology is then adopted in certain regions of the nation.

The ability of anyone to identify future impacts rests, of course, on current levels of knowledge concerning causal links in society. To the extent that knowledge is faulty or incomplete, the estimate of future impacts will miss the mark.

The best that can be done is to use the current knowledge base concerning technology — and societal forces and change — to project the how and why of the future, to point to the links and processes that will shape the future. We claim no special talent for prophesying the details of what the U.S. will be like in 1985 or 1995.

*Impacts could be altered*

It should also be noted that we do not see the impacts described in this chapter as *inevitable in every instance, nor necessarily desirable in every case*. Some of the impacts could be altered or softened if decisions are made in time, others could be broadened in scope if there were conscious efforts to do so.

*Impacts direct, secondary, and tertiary*

Finally, the reader should be aware that the anticipated impacts identified here flow from a broad gauge analysis which includes more than strictly economic considerations. Our work on benefit-cost analysis appears in Chapter 10. For this chapter on impacts our analysis started with the question: *If we assume certain specified levels of effectiveness for a hail suppression technology and adoption in specified regions of the country, what are the direct, secondary, and tertiary consequences or impacts likely to be?*

*Model 3 pattern a base*

In Chapter 8 we presented three different models of how hail suppression research and subsequent capabilities may develop in the next two decades. Scientific Model 1 represented the *most optimistic* view of how the technology might develop, Scientific Model 3 the *least optimistic* view, and Scientific Model 2 an *intermediate* perspective. Model 3, as described in Chapter 8, had been the least optimistic view of the technology, having in 1995 very little more capability than at present, but still being adopted in a few very high hail loss areas. It therefore seemed to be a base for estimating future impacts.

*Model 1 and Model 3 compared*

But we believed it would also be useful to ask: *What are likely to be the impacts if the technology of hail suppression develops more rapidly and reaches higher levels of effectiveness?*

Combining the technological models of Chapter 8 with important societal factors described in Chapter 9, our adoption analysis revealed how widespread the adoption of effective hail suppression would likely be. The adoption analysis indicated that with the six versions of technological advances (three in the West and three in the East), no adoption would occur in the East. Impacts following from the adoption patterns projected for the West are assessed for the most effective technology (Model 1) and the least effective technology (Model 3). The impacts of Models 1 and 3 are presented in complete form, whereas those of Model 2 are not since they lie between 1 and 3.

The impacts discussed in this chapter rest on a number of assumptions stated explicitly in Chapter 8, where Models 1 and 3 are presented. In addition, other assumptions have been used and should be kept in mind.

*Significant assumptions*

- There will be no significant "climatic changes" (shifts to much more or less rain, hotter or cooler temperatures, or altered hailfall), but there will be fluctuations and extremes in hail, rain, and other weather conditions that are similar to those of the past 70 years.
- Hail suppression will be applied earlier and more extensively in heavier crop loss areas.
- Demand for farm output over the next two decades will increase slowly with export demand rising more rapidly than domestic demand.
- The effect of weather (rainfall and temperature) on crop production will continue to be roughly the same as it has been in the past.
- The degree of use of hail suppression will depend upon the capability level and the related scientific consensus.
- In some form, farmers will be involved in the decision about use of hail suppression in their area, and the decisions and later responses will be based largely on their perception of direct economic gains or losses and a range of sociological considerations.

## IDENTIFYING AND RATING IMPACTS



Identifying the full range of likely impacts of a new technology is a complex process. As indicated, one must start with some set of assumptions. In our discussions, each team member attempted to be as explicit as possible about the assumptions being made about the nature of U.S. society and the values held by especially relevant interest groups. The key, catalytic assumptions were those that had earlier been incorporated in hail suppression Models 1 and 3.

For example, in Model 1 (West) there is assumed to be by 1995 a demonstrated capability to reduce damaging hail by 80% while increasing rainfall by 16%. To the general assumptions and those of each model we added assumptions about *adoption* of the technology. These latter assumptions came from our analysis of the factors affecting adoption in the various crop-producing areas of the U.S. (see Chapter 9). For example, using Model 3 (30% decrease in hail, no change in rainfall), our analysis suggested that only about five crop-producing areas would have adopted hail suppression programs by 1995 and these areas would all be in the West. With Model 1, our analysis indicated 36 crop-producing areas would have adopted hail suppression by 1995, again all in the West.

*Different assumptions combined*





**FIGURE 68**

**Matrix used to identify classes of impacts and system levels being impacted**

CLASSES OF IMPACTS	SYSTEM LEVEL IMPACTED						NATION	WORLD
	INDIVIDUAL		COMMUNITY		STATE			
	ADOPTING	NON-ADOPTING	ADOPTING	NON-ADOPTING	ADOPTING	NON-ADOPTING		
ECONOMIC								
POLITICAL-GOVERNMENTAL	X							
SOCIAL							X	
LEGAL			X				X	
ENVIRONMENTAL	X		X				X	
SCIENTIFIC	X		X					

In summary then, we had to make general assumptions about the nature of U.S. society, the values and propensities for action of relevant interest groups, specific assumptions about the effectiveness and cost of a hail suppression technology, and specific assumptions about adoption in light of all of the prior assumptions. These assumptions were made in conjunction with Model 1 and again for Model 3. The impacts are presented in that order.

*Impacts identified by class and level*

The basic approach used to try to identify the full range of likely impacts is reflected in *Figure 68*. For each class of impacts, we attempted to spell out all of the likely impacts and then to indicate for each impact what level(s) or components would be affected. It became clear that some impacts cut across several system levels while others would affect only one.

*Team provides wide range of impacts*

Within the team and its consultants the following specialties were represented: *atmospheric sciences, agricultural economics, sociology, political science, law, insurance, environmental science, and the weather modification industry*. It was possible, therefore, by having each participant using his/her own area of expertise, to spell out a wide range of impacts. These impact statements were then discussed and refined.

Estimating impacts 20 years into the future is no simple task. It involves extrapolating current knowledge into a future where many factors will be changing and important events cannot be predicted. Knowledge is, of course, incomplete and imperfect. Nevertheless, using current knowledge as a basis we believe that most impacts can be anticipated with a reasonable level of certainty at least as to general form. We have attempted to be cautious and thoughtful in formulating the impacts. We recognize that highly unlikely situations, such as some form of major natural weather disaster or discovery of totally unforeseen adverse ecological impacts, could develop and greatly alter our estimated adoption patterns and resulting impacts from hail suppression.

Next, each impact statement was examined to determine how many system levels were likely to be affected when the impact developed. With the matrix shown in *Figure 68*, an effort was made to see that each possible combination was treated as comprehensively as possible. Certain impacts occurring on the individual level also occur on the community and state levels. In most instances, these are repeated for each level for completeness. However, in a few cases they are listed only in the system level where they are most critically important, hence the crossed-out compartments shown in *Figure 68*.

*How many  
'levels'  
affected*

Finally, it seemed desirable to characterize each impact, regardless of its general classification, on some third dimensions. This effort to characterize each impact on the additional dimensions we refer to as "*ratings*." As will be seen in the tables interspersed in this chapter, the following ratings were made by the team:

*Team's  
system  
of 'ratings'*

- In column one of each table is an expression of likelihood of occurrence of the impact being considered. Each impact is rated as "very likely" (VL) or "likely" (L) to occur.
- The second column reflects an assessment of benefit or disbenefit for the group(s) to be impacted. A plus sign (+) indicates that the outcome will be primarily beneficial, a minus sign (-) reflects our judgment that the outcome will be mostly a disbenefit, and a zero (0) indicates that there is no significant benefit or disbenefit — or that the benefits and disbenefits balance each other out.
- Columns three and four deal with how large or important the impact is expected to be. We used the terms "major" and "minor" for the distinctions we wished to make. Column three is used for the major-minor designation for the *crop-producing area* and column four is used for those designations for the *nation* as a whole.
- The fifth column represents our characterizing of the causal and temporal sequence of each impact relative to the others. The designations used are first order (1), second order (2), and (3) for third order or beyond. For example, "reduction in crop loss due to hail" is a first order impact while an "increase in interstate arrangements" receives a third order rating or designation (note *Figure 70* in the next section).

*How likely?*

*Benefit, or not?*

*How important?*

*What order?*

Where there were differences in the rating given an impact by various team members, the final designation reflected majority opinion. Please note our word of caution in *Figure 69*.

## IMPACTS WITH A SIGNIFICANT MODIFICATION CAPABILITY - MODEL 1



Recall that the team estimated that there would be adoption by approximately 25% of the United States crop-producing areas if hail suppression Scientific Model 1 in fact developed approximately as outlined in this report — that is, reaching a capability by 1995 to reduce hail by 80% and increase rain by 16%. All of the adopting areas would be in the western two-thirds of the United States. Unless noted otherwise, the impacts discussed all relate to the *areas adopting* hail suppression.



**FIGURE 69**

**A word of caution to readers**

We wish to caution the reader as to the proper reading of the impacts sections of the text.

For both scientific models, we will be comparing outcomes IF that technology is adopted —relative to the situation if that technology were NOT adopted. Because the repetition would be cumbersome, such a phrase is not included at every instance.

However, it is extremely important that the reader remember that a phrase such as ". . . reduced land values" should be interpreted as ". . . reduced land values relative to what they would be if this hail suppression technology had not been adopted." The former phrase **MUST NOT** be read as a prediction that land values in the future are expected to be less than they are now.

Further, this impact section will compare the effects of specific improvements in hail suppression technology (Model 1 or Model 3) with a situation where no improvement in technology has occurred. Utilizing this approach isolates the effect of the hail suppression technique. Even though we concentrate on the suppression technique, however, other important factors in the agricultural sector, such as growth in domestic and foreign demand or other agricultural technological advances, are not ignored. Indeed, as described in Chapter 10, considerable effort was devoted to specifying likely levels for these factors. However, once these factors are specified, their levels are held constant. The use of constant levels for these other factors implies that the benefits of one hail suppression technology level *relative* to the benefits of an alternative suppression level are not altered by changes in these factors.

The key impacts under Model 1 are presented first, followed by local-through-state-level impacts that include those affecting first the individual in an adopting area, then the community and the state. At the national level, the impacts are presented by the major stakeholders —the government, hail research and development interests, agribusiness, hail suppression industry, and hail insurance industry. Finally, national-level impacts relating to international and general interests are presented.



Although many potential impacts might result if the development and adoption of Scientific Model 1 were to occur, we would like to highlight what we consider to be the four major impacts associated with the adoption of this rather advanced technology.

## MAJOR IMPACTS - MODEL 1

*The first of these impacts is the income effect to producers of crops grown in the adopting areas.*

*Producer's  
income*

Producers in adopting regions will receive immediate benefits from the increased production. The production gains on typical farms in the adopting areas would be between 9 and 16%. However, prices of the commodities will be *lower than they would have been without the hail suppression technology*, thus dampening somewhat the gains to producers in the adopting regions. The income advantage of the early-adopting regions would decline as more regions adopt. Producers of the same crops outside of the adopting region would suffer some decline in income in comparison to what it would have been without the hail suppression technology. Of course, these impacts on income in both the adopting and nonadopting regions will occur over a period of time and thus are likely to be obscured by other factors, such as year-to-year changes in production due to the influence of weather and also changes in the pattern of export demand. The income benefits experienced by the farmers in the adopting regions will be accompanied by some decreases in year-to-year income variability as the hail damage is reduced. This reduction in yield variability is, of course, not shared by the nonadopting regions.

*Second, the increase in agricultural production leads to benefits to the consumers of these products.*

*Consumer  
benefits*

Domestic and foreign consumers of grains would have greater quantities available and at slightly lower prices. The crops most severely damaged by hail in the U.S. are wheat, cotton, corn, soybeans, and tobacco. Although about 25% of these crops are usually insured, the amount of food lost to the nation is equivalent to that needed to feed about 520 million Americans a normal diet for one year. However, domestic consumers would gain primarily through increased livestock consumption resulting from increased, more stable supplies of grain and the increased capacity for beef production due to the additional rainfall.

*The third major impact is on governmental agencies.*

*Governmental  
changes*


State governments will feel pressure for such things as changes in state weather modification laws, new or expanded weather modification agencies, and pressure for interstate weather modification arrangements. Several federal agencies would be impacted — such as the USDA through changes in agricultural production conditions, NSF (or other research agencies) for support of additional weather-related research, and NOAA for increased monitoring and evaluation of the large operational modification programs. State and federal agencies would be involved in the development and administration of compensation schemes.

'Modification'  
stature

*The fourth major impact to be cited arises from the increased stature of weather modification in general.*

An increased stature for weather modification would result from the generally favorable experience with hail suppression in the adopting areas. This more favorable public and scientific attitude would be translated into increasing interest in additional research in other areas of weather modification.

**IMPACTS TO  
INDIVIDUAL -  
MODEL 1**

 As noted in the discussion above on major impacts, the individual producer in the adopting area will have an initial income gain, some of which may be dissipated as more and more regions adopt the hail-suppression technology. However, the increase in year-to-year income stability will be retained.

*Benefits in  
adopting  
areas*

Given increased income stability, long-range planning for farm family activities and for investments will become more feasible. Fewer farm families will suffer complete crop losses in one year. Lessened family and marital strain due to increased farm family income and stability was not included, even as a minor impact. Our assessment was that these secondary and tertiary effects were likely to be so insignificant and subtle as not to constitute genuine impacts of hail suppression.

Property losses due to hail damage will be reduced in the adopting areas.

Another side benefit from the envisioned Model 1 will be the availability of improved weather forecasts that will be necessary for the successful operational hail suppression effort. With improved forecasts, families in adopting areas can better plan daily activities.

*Disbenefits to  
nonadopters*

But there will be some negative consequences as well. As adoption becomes more widespread, there will be a depressing influence on the prices of commodities. Because there are no offsetting production increases in the nonadopting areas, incomes there will be lower than they would have been without the hail suppression in adopting areas. Again, demand factors may cause income actually to increase; nevertheless, the new technology will dampen such an increase.

Although many other factors will be influencing farm income, families in the adopting areas will have a somewhat smaller income than if the hail-suppression technology were *not* adopted. This will have a minor depressing influence on land values. Again, other factors are very likely to exert a much stronger influence on land values so that the impact of hail suppression may not be discernible.

The ratings in *Table 65* indicate that the impacts to individuals are largely considered of minor importance from the crop-producing area and national viewpoints. The only disbenefits are to individuals outside the adopting area.


*Figure 70* illustrates the interactions of various impacts resulting from a major modification ability in the future. Note that most lie in the tertiary level.

 **TABLE 65**

**Ratings of impacts on individuals. Model 1**

<i>Impact</i>	<i>Likeli- hood</i>	<i>Benefit, or not</i>	<i>Importance</i>		<i>Sequence order</i>
			<i>Crop area</i>	<i>Nation</i>	
<b>Adopting</b>					
Temporary increase in farm crop income and land values to early adopters	VL	+	Ma	Mi	- 2
Increased income stability for farm families	VL	+	Ma	Mi	3
Long-term investment planning more feasible	VL	+	Mi	Mi	3
Fewer farm families suffer total crop losses	VL	+	Mi	Mi	3
Reduction in noncrop property losses	VL	+	Mi	Mi	2
Farm crop income later is unchanged	L	0	Mi	Mi	3
Better planning daily activities	L	+	Mi	Mi	3
Litigation (allegations of harm) will be initiated	VL	0	Mi	Mi	3
<b>Nonadopting*</b>					
Farm crop income down	L	-	Mi	Mi	3
Crop land values down	L	-	Mi	Mi	3
Litigation concerning downwind effects (allegations of harm) will be initiated	VL	0	Mi	Mi	3

\*Nonadopting refers to agricultural areas with crops similar to those in adopting areas.

 With greater stability of farm income will come slightly increased stability in local business activity. Since there will be fewer families forced to leave the farm due to catastrophic financial loss, the trend to larger-sized production units (farms) could be dampened somewhat. However, a possible offsetting influence would be the increased ability of the operators of the larger units to acquire capital on more attractive terms than those operating smaller units. Banks and lending institutions will benefit and be more willing to supply capital for farm operators and expansion. The net effect on farm size is concluded to be unmeasurable.

A closely related impact deals with population movement. With greater income stability the economic pressures which tend to force financially marginal families off the farm and into the cities will be softened. Thus, rural population decline due to outmigration of farm families will slow slightly.

Additional rainfall on a given day within a particular community will often have mixed impacts, as is reflected in *Table 66*. For example, the heavy rain that nourishes the row crops of one farm will ruin the cut hay on another farm. So,

IMPACTS TO  
COMMUNITY -  
MODEL 1

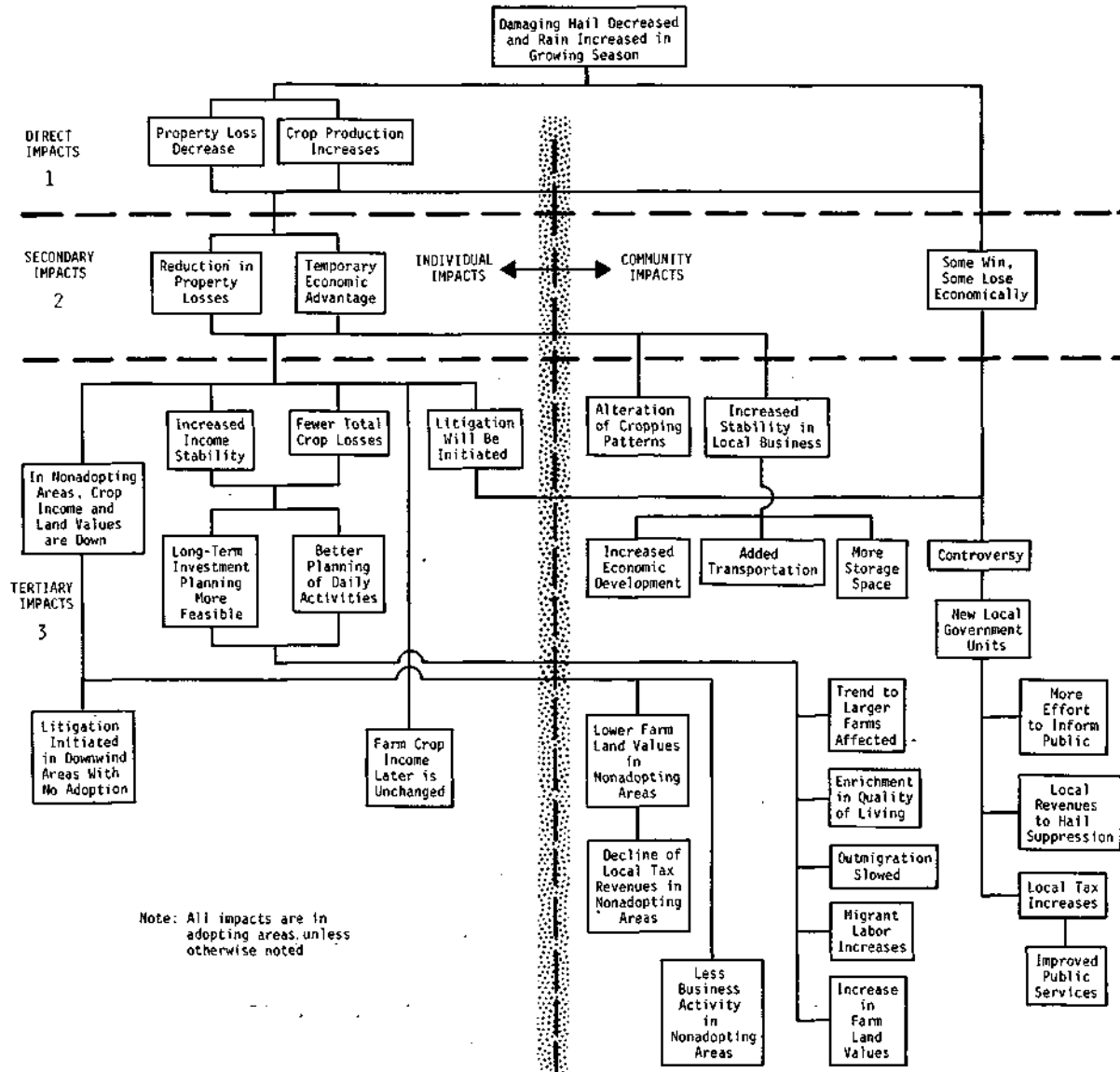
*Some gain,  
some lose*



FIGURE 70

The interrelationship of impacts resulting from Model 1 capabilities

Model 1 capability in 1995 = -80% hail, +16% rain



for the community as a whole, *some will lose* and *some will gain economically* as a consequence of the changed weather resulting from hail suppression efforts that alter rainfall.

If there continues to be an absence of a generally accepted compensatory mechanism, controversy between segments of the community — especially "losers" versus "nonlosers" — will occur (see *Figure 70*).

 **TABLE 66**

**Ratings of impacts on the community, Model 1**

<i>Impact</i>	<i>Likeli- hood</i>	<i>Benefit, or not</i>	<i>Importance</i>		<i>Sequence order</i>
			<i>Crop area</i>	<i>Nation</i>	
<b>Adopting</b>					
Increased stability in local business activity	VL	+	Mi	Mi	3
Some lose, others gain economically	VL	0	Mi	Mi	2
Increased economic development	VL	+	Mi	Mi	3
Alteration of cropping patterns	VL	0	Mi	Mi	3
More storage space for added production	L	+	Mi	Mi	3
Additional transportation for added production	L	+	Mi	Mi	3
Increase in farm land values	L	+	Mi	Mi	3
Local tax revenues increase	L	+	Mi	Mi	3
Improved public services	L	+	Mi	Mi	3
New, local government administration units	VL	+	Mi	Mi	3
Some local revenues diverted to hail suppression	VL	0	Mi	Mi	3
Controversy: opponents vs. supporters	VL	-	Mi	Mi	3
Population outmigration slowed	L	+	Mi	Mi	3
More effort to inform the public about hail suppression	L	+	Mi	Mi	3
Enrichment in quality of living	L	+	Mi	Mi	3
Proportion of migrant laborers increase	L	0	Mi	Mi	3
<b>Nonadopting*</b>					
Slight dampening of local business activity	L	-	Mi	Mi	3
Local tax revenues decline	L	-	Mi	Mi	3
Lower farm land values	L	-	Mi	Mi	3

\*Nonadopting refers to agricultural areas with crops similar to those in adopting areas.

Thus, in most cases local government will become involved in any ongoing hail suppression effort. In many instances there will be new or enlarged local government administrative units to handle various aspects of the hail suppression operation. In most, if not all, instances, some part of local government revenues will be diverted to support the hail suppression program. The actual amount may be small in some cases, but those same funds could be used for other public services and in that sense the monies will be diverted.

*Local  
government  
involved*

It is likely that there will be increased efforts at public education and communication of information on weather, weather modification, and its effects on a rather continuous basis.

*Information  
efforts increase*



*Some crop patterns altered*

There will be some alteration of cropping patterns due to readjustments in market price of farm products. Also, the added production under hail suppression will necessitate more storage space, and, to a limited extent, additional transportation equipment will be used.

Some organizational changes may be expected. Some regional equivalent of water conservancy districts is likely to emerge to deal with one or more administrative or financial aspects of operational hail suppression programs.

Where crop growing and harvesting are dependent on migrant laborers — sugar beet production in Colorado, for example — there will be a change in the ratio of permanent to transient residents in the area with concomitant social effects. The proportion of migrants will increase.

*Mixed effects on environment*

Environmental impacts will include less loss (due to decreased hail) of wild plants and small animals; more runoff and erosion plus greater growth of wild plants (due to more rain); and marginal uncertain effects on soil microorganisms (due to silver used in seeding). The net effect on the nonfarm environment is expected to be slight.

*Nonadopting areas are disadvantaged*

Finally, it should be noted that following fairly widespread adoption of the effective technology, the nonadopting parts of the country will be disadvantaged economically. These regions will not have increased productivity due to hail suppression, but they will be receiving lowered prices for their products. Thus, while net income from farm products will not change in adopting areas (increased production will offset lower prices), the nonadopting regions will have lowered income which will in turn be reflected in lowered property values for farm land and hence in lowered property tax revenues to local government.

Presumably business in general in these nonadopting regions of similar crops will be negatively affected, but the impact is likely to be small.

At the level of the community, most impacts are not felt immediately — all but one are third-order — as indicated by *Table 66*.

## **IMPACTS TO STATES - MODEL 1**

*Legislation, administration changes*



Where several communities or areas within a state wish to participate in a hail suppression program, it is likely that there will be a minimum state statutory authorization of existing agencies to be involved. That being the case, it is likely that in most states where adoption is occurring, state-level weather modification administrative units will come into existence or will be enlarged. Thus, some state revenues which would otherwise be used for other public services will be diverted to the hail suppression effort in one form or another.

Since adopting areas will often be on state boundaries, there will be increased state government involvement with other states via interstate compacts or their functional equivalents.

For the state as a whole, problems of air traffic control will increase somewhat, especially on a few peak hail suppression activity days. Although it may be too small to measure, there will be some slight increase in business activity within the state due to the hail suppression program.

For insurance companies operating within states where there are several adopting areas, the following impacts appear to be likely:

*Insurance impacts*

- 1) The pricing of insurance will become more difficult as experience and statistical bases become relatively outdated by the alteration of the frequency and intensity of hail damage.
- 2) Especially in the formerly very high hail-loss areas, these insurance companies will have slightly increased profitability (at least for a few years) because overall insurance sales will be higher and there will be less fluctuation in sales from year to year (as premiums become more moderately priced and losses become less regular, the proportion of farmers purchasing insurance is expected to rise).
- 3) Unusual problems associated with ascertaining the existence and extent of losses will be encountered by these companies in the handling of liability insurance for hail suppression program operators.

Although not a certainty, it seems likely that potentially opposed groups will have actively participated in the hail suppression adoption decision process, thus obviating a later expenditure of resources on their part to prevent or stop hail suppression projects.

*Potential opposers participate*

Despite that participation, it is likely that legal battles over alleged damages from hail suppression efforts will erupt from time to time, thus contributing to the clarification of legal issues and to the income of lawyers.

Somewhere along the way to a vastly improved hail suppression capability, perhaps in the 1990-1995 period, there will emerge one or more schemes to provide for compensation for losses suffered directly — such as unwanted added rainfall from a hail suppression project. The losers will receive compensation and those who represent them in the proceedings will earn additional income.

*Compensation to losers*

Finally, it should be noted that downwind areas may be subject to benefits and disbenefits from weather changes due to hail suppression, but these impacts are likely to be less than those for the adopting areas.

Table 67 indicates that, although these impacts at the state level are all of second order or higher, several impacts are considered to be of major size or importance.

**TABLE 67****Ratings of impacts on states, Model 1**

<i>Impact</i>	<i>Likeli- hood</i>	<i>Benefit, or not</i>	<i>Importance</i>		<i>Sequence order</i>
			<i>Crop area</i>	<i>Nation</i>	
<b>Adopting</b>					
Reduction in state requests for federal disaster aid	L	+	Mi	Mi	2
Slight increase in business activity	L	+	Mi	Mi	3
Insurance rates more difficult to compute	L	-	Mi	Mi	2
Some insurance companies increase profitability	L	+	Mi	Mi	3
Less yearly fluctuation in hail insurance sales	L	+	Mi	Mi	3
Liability insurance for weather modifiers more difficult	VL	-	Mi	Mi	3
Changes in state weather modification legislation	VL	+	Ma	Mi	3
New or enlarged state weather modification units	VL	+	Ma	Mi	3
Some state revenues diverted to hail suppression	VL	0	Mi	Mi	3
Increase in interstate arrangements	L	+	Ma	Ma	3
Air traffic control more complicated	VL	-	Mi	Mi	3
Increased comparability of state regulations	L	+	Ma	Mi	3
Pressure on insurance commissioners to lower rates	VL	0	Mi	Mi	3
Potential opposition involved in decision making	VL	+	Ma	Mi	3
A few court suits over hail suppression	VL	0	Mi	Mi	3
Compensation schemes developed and used	L	+	Ma	Mi	3
Reduced loss of wild plants, small animals	L	+	Mi	Mi	2
Increased runoff and erosion	L	-	Mi	Mi	2
Increased growth of wild plants, small animals	L	0	Mi	Mi	2
Marginal impact on soil microorganisms	L	0	Mi	Mi	3
<b>Nonadopting</b>					
Changes in state weather modification legislation	VL	+	Ma	Mi	3
Increase in interstate arrangements	L	+	Ma	Ma	3
Air traffic control more complicated	VL	-	Mi	Mi	2
Increased comparability of state regulations	L	+	Mi	Mi	3
Potential inter-community, inter-regional, interstate controversy concerning downwind effects	L	-	Mi	Mi	3
A few court suits over downwind effects	L	0	Mi	Mi	3
Imperceptible impacts downwind	L	+	Mi	Mi	3



From a societal point of view, the most important impact of an effective hail suppression technology will be on the United States consumer. Consumers of farm products will benefit slightly from lowered supermarket prices. This will be most noticeable with respect to food grains, such as wheat, and derivative products. While the reduction in the total food bill which a family will pay is almost certainly going to be small, the total number of such beneficiaries is, of course, exceedingly large.

In past decades in the United States, increased efficiency in food production has been a major contributor to better nutrition and a general improvement in the "quality of life" of Americans. A significantly improved hail suppression technology will make one more, albeit small, contribution to those generally lauded goals. In reviewing the many other impacts, the importance of this consumer impact should not be forgotten just because it is one of many.

Lowered and more stable prices for feedstuffs, primarily oil meals and feed grains, will be beneficial to domestic livestock producers. Also, increased rainfall in the adopting areas will result in greater rangeland carrying capacity and, therefore, additional supplies of beef to domestic consumers.

It is not clear what increased food production will do to federal policy regarding the subsidizing of production of farm crops. The trend in recent years has been toward decreasing the number of such subsidized crops. However, if there should be a series of three to five especially good crop-production years worldwide, or even something approaching such a situation, there is very likely to be widespread discussion among representatives of United States agriculture about the desirability of a "temporary" reversal of the subsidy trend.

Spread of agricultural production in hail-prone areas will require increased uses of energy, slightly aggravating the energy shortage.

On the other hand, water resources which are also highly critical for the "good life" in the United States will be somewhat enhanced by the additional rainfall that is a product of an improved hail suppression technology. Water resources — especially those used for irrigation — will gain a measure of "protection from depletion" because of the increased rainfall.

It should also be noted that hail suppression is a land-saving technology. Any dampening of the pressure to extend our cultivated land into areas less suitable for cultivation will in those areas tend to reduce soil erosion and its undesirable consequences on both production efficiency and environmental quality.

Glass-covered solar heating panels are extraordinarily susceptible to hail damage. An effective hail suppression technology will reduce such damage significantly. We believe it is likely that environmental interest groups will be moderately active during the period of rapidly increased adoption. Some of them are likely to produce sporadic publicity and attempt to generate political pressure in the

**NAT'L IMPACTS**

- GENERAL
- MODEL 1

*Small benefit  
— but to many  
people*

*Farm subsidies  
a question*

*Benefit to  
water  
resources*

*Environmental  
impact  
minimal*

face of widespread use of silver iodide as a seeding agent. In the absence of reasonably clear-cut evidence regarding the impact and long-term consequences of silver iodide, legal suits over the matter will likely be minimal.

It is also likely that some groups will publicly question the possible negative effects of weather changes produced by hail suppression. They will appeal primarily to the "balance of nature" theme. On the whole, their efforts will have relatively little impact except when unusually dry conditions exist.

*Science  
image  
enhanced*

Even the public image of science in the United States is likely to be impacted by a greatly improved hail suppression technology. The public image of science in general, and atmospheric science in particular, will be enhanced by the success of this new production of science — an effective hail suppression technology.

Ratings of these impacts in *Table 68* indicate all will be minor on the national level and most will be late developments, second-order or higher.

**NAT'L IMPACTS  
- GOVERNMENT  
-MODEL 1**



It is, of course, not easy to anticipate what the roles of the federal government (aside from research and development) will be in the increased use of a more effective hail suppression technology. It is very likely, however, that at least overall program monitoring — plus review, evaluation, and dissemination of information of the effectiveness of the seeding — will be performed as adoption becomes widespread in the next two decades.

*General  
regulations*

It is possible that some general regulations, especially regarding effects that may cross state boundaries, will be enacted. It is not inconceivable that federal licenses and permits may be required of weather modifiers.

*Special groups  
for design,  
evaluation,  
information*

It is likely that one federal agency will have the lion's share of such activities. Included, in addition to the functions mentioned above, would be the development of model designs for hail suppression operations, monitoring of weather impacts, evaluation of weather changes, and the dissemination of information on the results (including target and downwind areas). Special groups and facilities will be established for these design, evaluation, and information activities.

*Changes in  
weather records,  
forecasting*

For the areas adopting and continuing to use the improved hail suppression technology, there will indeed be what may be called an induced climate change (more rain, less hail). This will necessitate NOAA's conducting studies and thereafter making adjustments in some of its weather records and also altering aspects of forecasting for certain regions of the country.

There will be increased use of jet aircraft for seeding in project areas. As a consequence, the Federal Aviation Administration will add additional staff and may enlarge facilities to cope with the hail suppression program aircraft activity in the adopting areas.

 **TABLE 68**

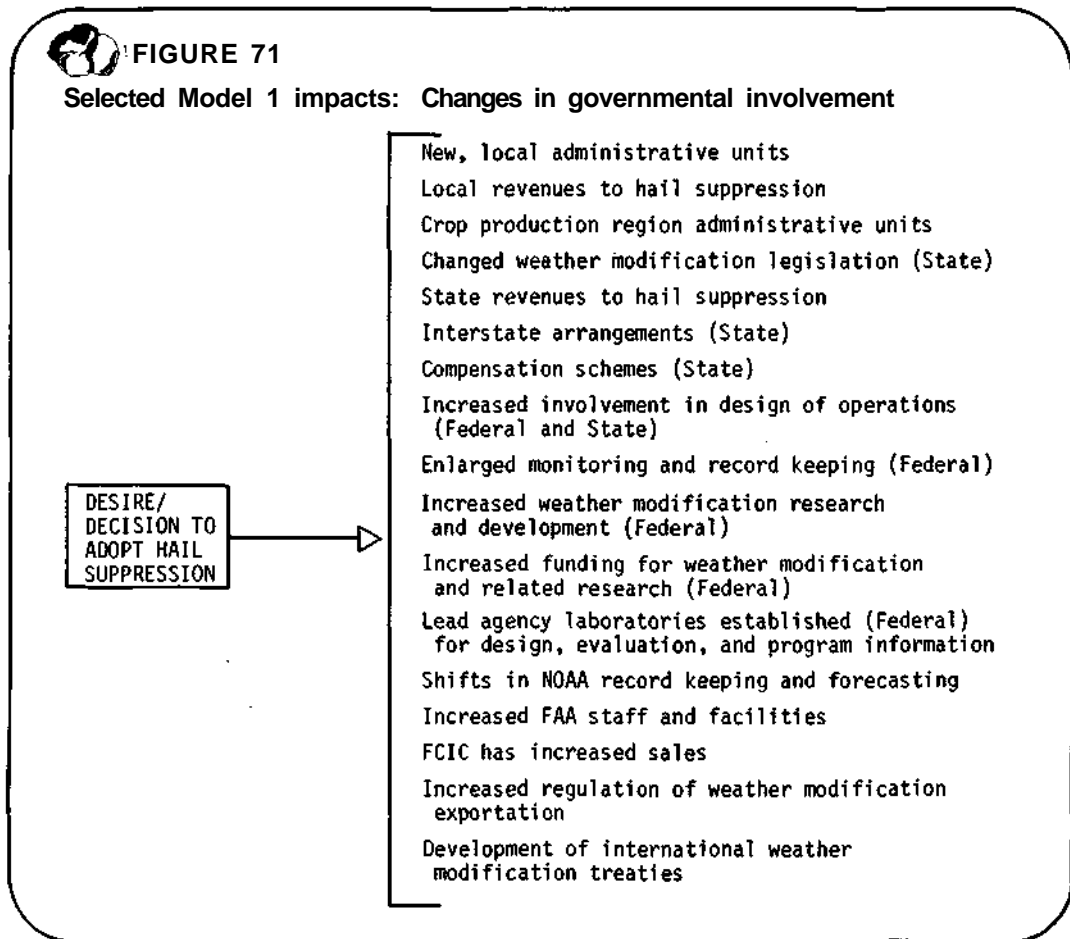
**Ratings of impacts on the nation, Model 1**

<i>Impact</i>	<i>Likeli- hood</i>	<i>Benefit, or not</i>	<i>Importance Nation</i>	<i>Sequence order</i>
<b>Economic</b>				
Consumer benefits from slightly lowered food prices	L	+	Mi	3
Farm subsidies might be increased	L	0	Mi	3
Water resources increased	L	+	Mi	3
Pressure to cultivate less desirable land reduced	L	+	Mi	3
Reduced damage to solar energy installations	L	+	Mi	1
<b>Political-Governmental</b>				
Weather modification firms reduced decision involvement	VL	-	Mi	3
Increased federal involvement in hail suppression evaluation and information	VL	+	Ma	2
Some federal involvement in hail suppression regulation	L	0	Mi	2
One federal agency plays prominent role	L	+	Mi	3
NOAA adjustments in records and forecasting	VL	0	Mi	2
Slight increase in FAA staff, facilities	L	0	Mi	3
FCIC has increased sales	L	+	Mi	3
FCIC becomes marginally supportive of hail suppression	L	+	Mi	3
<b>Social</b>				
Slight response from environmental interest groups	L	0	Mi	3
Improved nutrition and quality of life in U.S.	L	+	Mi	3
<b>Scientific</b>				
Increased weather modification research	VL	+	Ma	3
Federal lead agency sets up laboratory	L	+	Mi	3
Federal emphasis on applied research programs	VL	0	Mi	2
Positive spinoff for more speculative research areas	L	+	Mi	3
Slight increase in specialized university programs	L	+	Mi	3
Employment opportunities increase for meteorologists	VL	+	Mi	3
Slight increase in social, economic, legal and environmental research	L	+	Mi	3
Scientific image enhanced	L	+	Mi	3

All-risk crop insurance increases

The Federal Crop Insurance Corporation (FCIC) will have somewhat increased sales. As farm income becomes more stable in the adopting regions and as farmers come to see hail loss as a significantly reduced threat to their income, they will turn in increasing numbers to all-hazard crop insurance as an additional mechanism to protect themselves from large, unexpected losses of income. With this development, it is likely that the FCIC will become at least marginally supportive of hail suppression activity.

The ratings in *Table 68* show only two impacts to be of major importance. Selected impacts relating to likely changes in government involvements at all levels are depicted in *Figure 71*.



**NAT'L IMPACTS  
- RESEARCH -  
MODEL 1**

The increasing and demonstrable effectiveness of hail suppression programs will come from and lead to growing and more sophisticated research efforts. There will be increased weather modification research (particularly on rain and hail) both in governmental laboratories and in universities.

While some federal "lead agency" will eventually establish a weather modification research and development laboratory, also a larger number of university research groups will receive funding support than is now the case. This significantly increased federal support will emphasize both basic and applied programs, especially work on severe storms and forecasting.

*Weather  
modification  
laboratory*

Success in these research endeavors will help launch or increase weather modification research in some of the more "speculative" areas — such as severe winter storms and tornadoes.

*Severe storm  
modification*

There will be, along with these developments, a small increase in the number of university programs offering specialties in cloud physics and statistics related to weather modification.

As weather modification programs increase, enlarged employment opportunities will become available for operationally oriented meteorologists being released from NOAA-NWS because of ever-increasing automation of forecasting activities.

Finally, federally funded research and monitoring of social, environmental, legal, and economic aspects of weather modification will show a slight increase over the current situation.

*Social  
research*

As the ratings in *Table 68* indicate, improved hail suppression could eventually have a major impact on weather modification research and development.



The combination of reduced crop-hail loss and simultaneously increased rainfall during the growing season will have some identifiable impacts on what is now broadly defined as agribusiness. Perhaps most obvious is that increased farm crop production and more stable farm income will bring increased sales in farm equipment and concomitant profits to farm equipment manufacturers and dealers.

**NAT'L IMPACTS  
- AGRIBUSINESS  
- MODEL 1**

With increased rainfall available, especially in the High Plains, there could and probably will be greater use of fertilizer for crop production. It seems even more likely that under those conditions there will be increased use of herbicides and pesticides. The producers, distributors, and retail operators for these products will thereby find increased opportunities for profitability.

*More sales  
of farm  
equipment,  
fertilizer*

With increased production — of wheat and sugar beets, for example — the mobile harvesting industry will increase investment in equipment and will employ more personnel.

Also, the widespread use of hail suppression with the resulting increased stability of income and production will induce agricultural corporations and banking interests to make more loans and more favorable loans to farmers and other segments of agribusiness.

*Loans more  
favorable*




*New strains of crops developed*

It appears likely that the reduced threat of hail-induced crop loss will have an impact on the development of new strains of crops. In the breeding process, there will be less emphasis on hardiness and more on increasing yield at the expense of hardiness.


The expected increase in agricultural activity will put slightly added pressure on national energy resources.

All of the impacts to agribusiness at the national level would be delayed — third-order or higher — as indicated by the ratings in *Table 69*.

 **TABLE 69**  
**Ratings of national-level impacts on agribusiness, Model 1**

<i>Impact</i>	<i>Likelihood</i>	<i>Benefit, or not</i>	<i>Importance Nation</i>	<i>Sequence order</i>
Increased profitability to farm equipment firms	L	+	Mi	3
Increased sales of fertilizer	L	+	Mi	3
Increased sales of herbicides and pesticides.	L	+	Mi	3
More investment and personnel for mobile harvest	L	+	Mi	3
Increases in number and favorability of loans	L	+	Mi	3
Change in emphasis in new crop varieties	L	0	Mi	3
Additional pressure on national energy resources	L	-	Mi	3

**NAT'L IMPACTS - SUPPRESSION INDUSTRY - MODEL 1**

 Because various governmental entities will play an increasingly leading role in the design, evaluation, and control of hail suppression programs, today's hail suppression entrepreneurs will have less involvement in the design and implementation of hail suppression programs. Their work will be largely that of a contractor for field operations.

*Profits despite added costs*

There are expected to be greater costs for liability insurance attendant with a more identifiable technology, and a need for larger and better trained staff to handle sophisticated modification systems. Added staffs, including women, will be hired to handle routine work related to added national and international monitoring and record-keeping regulations. As indicated in *Table 70* increased monitoring and record keeping will be an early impact.

Despite these and other added costs, profits to weather modification companies will increase and there will be more companies and some larger companies than is now the case.

 TABLE 70

Ratings of national-level impacts on the hail suppression industry, Model 1

<i>Impact</i>	<i>Likeli- hood</i>	<i>Benefit, or not</i>	<i>Importance Nation</i>	<i>Sequence order</i>
Weather modification firms have reduced decision involvement	VL	-	Mi	3
Expenditures for liability insurance increase	VL	-	Mi	3
Larger, better trained hail suppression staffs	VL	+	Mi	3
Added monitoring and record keeping	VL	-	Mi	2
Weather modification firms increase profits	L	+	Mi	3
More and larger weather modification firms	VL	+	Mi	3
Some small firms bought by large corporations	VL	0	Mi	3
Increased income to aircraft and radar producers	L	+	Mi	3
Aircraft and radar rental firms have less income	L	-	Mi	3
Increased income to silver iodide producers and suppliers	VL	+	Mi	3
Small companies have increased stability	VL	+	Mi	3
Increased industry investment in research and development	L	+	Mi	3

With cloud seeding becoming more profitable and the demand for services more stable over time — and with a less questionable reputation — the industry will attract larger corporations and financiers and they will purchase some of the current small businesses.

Apart from the above, there will be three winners and one loser in related stakeholder groups. Purchase of high performance jet aircraft, special seeding apparatus, and digital weather radars will provide marginal increases in income to the aircraft and radar industries. Smaller companies will have increased stability. But companies having aircraft and radars for rent will lose business in the face of a tendency to purchase rather than rent as frequently.

*Most related industries benefit*

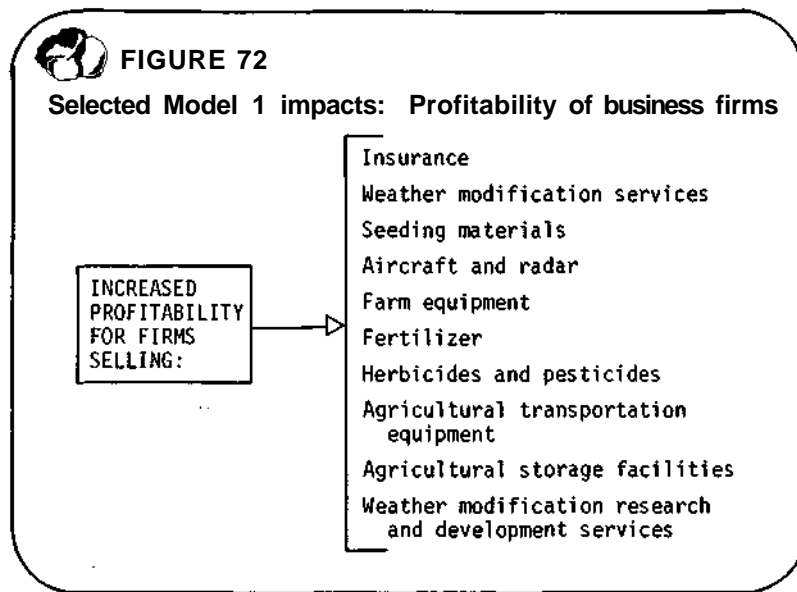
Increased use of silver iodide will boost income to the suppliers. However, the use of silver to make silver iodide and silver iodate, the primary seeding materials for hail suppression, could be a potentially critical issue, both as it relates to the silver market and costs and to the availability of silver. A near statewide modification program for hail suppression and rain enhancement in North Dakota for 1977 will use 246 pounds of silver to seed clouds over about 20,000 square miles. If evenly distributed in space, this represents a deposition of 0.1 pounds per square

*Impacts of silver price and availability*


mile for the summer. In the U.S. the prime manufacturer of seeding materials who produces about 75% of all materials, used 1991 pounds of silver in 1976. Hence, about 2650 pounds of silver were used to make weather modification seeding materials. This represents only 1.6% of the total national use of silver in 1976. The predicted adoption of hail suppression (Model 1 in 1995) calls for seeding over 650,000 square miles, which would relate to an estimated usage of about 6500 pounds of silver. This would only account for 4% of the 1976 use of silver. Hence, future use of silver for hail suppression would be very small on a national scale, and silver supplies would be adequate for weather modification requirements and purchases should not affect market prices.

The scientific breakthrough evidenced in this greatly improved technology with its widespread application in the West will lead to the investment of capital and staff by private industry (and the federal government), to develop new, more efficient, and cheaper seeding materials and seeding systems.

The profitability to various businesses expected to stem from a significant hail suppression technology is highlighted in *Figure 72*.



**NAT'L IMPACTS**  
 - **INSURANCE**  
 - **MODEL 1**

 A variety of adjustments will take place in the insurance industry, as indicated in the impacts on state-level insurance operations. Some of these will be due directly to the reduced hail loss to crops in adopting areas. After two or three years of application of the improved hail suppression technology, crop hail insurance rates will be lowered —but these rates will not fully reflect the reduction in losses. In part, this may be understood as a problem of sharply changed risk data which also still reflect the longer-term, pre-hail-suppression crop-loss data. Problems in rerating will occur as the risk is reduced.

Nevertheless, it is expected that the purchase of crop-hail insurance will increase slightly as people have less frequent loss and do not self-insure as often. This will affect only slightly the financial picture of the insurance industry as a whole.

*Financial effects minor*

Providers of property insurance in adopting areas will experience increased profits until histories of property loss in these areas justify reductions in premiums for property insurance. At some point, it is expected that property insurance records will begin to separate hail from "other" losses.

One other sales trend seems likely. As hail becomes a lesser problem, an increase is expected in the sales of all-weather peril policies (more such sales will particularly affect the Federal Crop Insurance Corporation), and this will stir the private companies to examine more carefully multiple peril rate determination.

The problems relating to liability insurance for hail suppression operators may parallel, on a much smaller scale, medical malpractice insurance today. Should that and associated serious problems develop, there could be pressure from the insurance industry and other interested parties for federal intervention in the evaluation of hail suppression results, possibly even calling for federal control of operations. It is difficult to estimate, however, the extent to which liability insurance may become a focal problem.

*Liability insurance a problem*

Finally, successful hail suppression is likely to attract new support, or at least a more positive attitude on the part of the insurance industry, toward scientific efforts to develop weather modification.

On the national level, as shown by *Table 71*, these minor impacts on the insurance industry will be delayed (third-order).



**TABLE 71**

**Ratings of national-level impacts on the insurance industry, Model 1**

<i>Impact</i>	<i>Likelihood</i>	<i>Benefit, or not</i>	<i>Importance Nation</i>	<i>Sequence order</i>
Delayed downward adjustment in insurance premiums	VL	+	Mi	3
Increased purchase of crop-hail insurance	L	0	Mi	3
Little financial impact on industry as a whole	L	+	Mi	3
Recording of various types of losses changed	L	0	Mi	3
Increase in sale of all weather peril policies	L	+	Mi	3
Hail suppression liability insurance becomes problem	L	-	Mi	3
New support from insurance industry	L	+	Mi	3

NAT'L IMPACTS  
- INTERNATIONAL  
- MODEL 1



As the success of an improved hail suppression technology is demonstrated in the United States by an increase in adopting regions, many private weather modification firms will use the attendant publicity to promote the sale of their services abroad. Because of high crop-hail loss in some developed as well as developing nations, there will be a strong latent interest in the potential use of hail suppression technology to cope with the hail hazard. As the United States firms become increasingly successful in selling their services abroad, their profitability and skills as weather modifiers also increase.

*Export,  
profits  
increase*

*Competition  
with Soviets*

Although it may turn out to be a minor consideration in the formulation and enactment of U.S. foreign policy, it seems possible that the exportation of hail suppression technologies will involve competition with the U.S.S.R. and Soviet-aligned nations who are and will be promoting their own version of an effective hail suppression capability. At some point it is likely that the United States will have an explicit posture regarding such competition with the Soviets.

*Foreign  
consumer  
also gains*

There will be at most a slight effect on international trade as a result of added crop production in the United States. Because lower prices will induce only a slight increase in domestic food consumption, the foreign consumer will be a relatively larger beneficiary of any increase in food production than the domestic consumer. Of course, domestic citizens gain from the more favorable trade balance arising from the increased food sales to other nations.

*Dealing with  
international  
dispute*

There is another and perhaps most important international consideration. There will be a gradual development of international compacts, mostly of a bilateral nature at first, but then through the United Nations and the World Meteorological Organization or the UN Environmental Program. These arrangements will be designed to deal with disputes over undesirable effects (real or perceived) of hail suppression programs and to insure the protection of the national sovereignty of the various interested nations.

Ratings for these impacts as shown in *Table 72* indicate the international "compacts" could be of major importance.

IMPACTS WITH A LIMITED MODIFICATION CAPABILITY - MODEL 3



We turn now to our estimates of the consequences that are likely to follow from Scientific Model 3, as described in Chapter 8. Recall that Model 3 outlines what is best described as an experimental focus with minimal application, and the technology reaches by 1995 a capability to reduce hail by 30% with no change in rainfall. Under these circumstances, our analysis indicated that hail suppression would be adopted by five crop-producing areas, mostly in the northern High Plains.

**TABLE 72****Ratings of impacts on world, Model 1**

<i>Impact</i>	<i>Likeli- hood</i>	<i>Benefit, or not</i>	<i>Importance Nation</i>	<i>Sequence order</i>
<b>Economic</b>				
Exports increase of hail suppression technology	VL	+	Mi	2
U.S.-U.S.S.R. competition in export of hail suppression technology	L	0	Mi	3
Slight "effect" on international trade (increased sale of food to foreign nations)	L	0	Mi	3
Gradual development of international compacts	L	+	Ma	3
<b>Political-Governmental</b>				
Increased regulation of weather modification activity abroad	VL	+	Mi	3
U.S.-Soviet competition	L	0	Mi	3
International agreements likely	L	+	Mi	3
<b>Scientific</b>				
Greater interaction among atmospheric scientists	VL	+	Mi	3
Transfer of scientific findings on weather	VL	+	Mi	3

Our presentation of the impacts under Model 3 is in the same order as that for Model 1, starting with the key impacts, continuing with the local-through-state-level impacts, and concluding with the national-level impacts relating to stakeholders. As with Model 1, these impacts relate to the areas adopting hail suppression unless otherwise noted, and must be read with the caution stated in *Figure 69*.



As was done for Model 1, we would like to highlight what we consider to be the major impacts associated with the development and adoption of Scientific Model 3. For this situation, two impacts are presented.

*The first of these is the increase in average income, as well as stability of income, in the adopting areas.*

Because only five crop-producing areas (representing about 1% of the national output) would have adopted hail suppression for this technology, their increase in crop production would not result in noticeable downward price pressures. Therefore, the benefits of increased production in these areas would not be diluted by offsetting price movements, and there would be an estimated increase in

**MAJOR  
IMPACTS -  
MODEL 3**

*Increased income  
and stability  
to producers*

net crop income of 1 to 2%. Further, reductions in hail loss would contribute to production stability in these areas.

*The second impact concerns a general disillusionment with the concept of hail suppression due to the inability to produce major decreases in hail damage.*

*Disillusionment with hail suppression*

This disillusionment would be intensified by controversies regarding the possibility of reduced precipitation during development of the technology. This disenchantment would be evidenced in sharply decreased federal research expenditures for hail suppression.

**IMPACTS TO INDIVIDUAL - MODEL 3**



The impacts to the individual in an adopting area are in most cases relatively insignificant, as indicated by the ratings in *Table 73*. However, for the farm family barely managing to survive, the 30% reduction in crop-hail loss suffered could make the difference in financial solvency. There will also be minor reductions in noncrop property losses due to hail.



**TABLE 73**

**Ratings of impacts on individual, Model 3**

Impact	Likelihood	Benefit, or not	Importance		Sequence order
			Crop area	Nation	
<b>Adopting</b>					
Increase in income and income stability	VL	+	Ma	Mi	2
Decrease in families leaving farm for financial reasons	L	+	Mi	Mi	3
Small reduction in noncrop property losses	L	+	Mi	Mi	2
More families with discretionary income	L	+	Mi	Mi	3
Increase in farm land values	L	+	Mi	Mi	3
Long-term investment planning more feasible	L	+	Mi	Mi	3
Better plan daily activities	L	+	Mi	Mi	3
Litigation (allegation of harm) will be initiated	L	0	Mi	Mi	2
<b>Nonadopting</b>					
No impacts					

There will be a slightly increased proportion of farm families having discretionary income and the added income will — to a very limited extent — increase land values. More productive land has a greater market value.

A few additional families, due to increased income stability, will be better able to engage in long-range planning for investments and activities.

Finally, it is expected that improved weather forecasts will be a part of a more effective operational hail suppression program. Such forecasts will make it a bit easier for families to plan daily activities.



If, as anticipated, income to farm families in adopting regions is up 1 to 2%, there are a number of impacts which will follow even though the "ripples" may be small.

At the community level, the added income will be seen in one or more of the following: increase in property tax revenues to local government (due to appreciation of land values) which will be reflected in the quality and/or quantity of public services available; some slight enrichment in "quality of living," such as more or more varied "cultural attractions"; and slightly increased economic development in some local towns and cities. In addition, the increased output means that slightly more personnel and equipment will be used for transportation of farm products and that more storage space will be developed.

The increased stability in farm income will mean somewhat greater stability in local business activity, reduction in the trend toward outmigration, and possibly even a stimulus to population growth.

With the threat of loss to hail slightly decreased in adopting areas, there is likely to be somewhat increased interest in and sale of all-hazard insurance in contrast to straight crop-hail insurance.

If, as hypothesized, there is a reduction in hail without any change in rain in the adopting regions, then for any given community there should in fact be few or no losers and mostly gainers, however small the gain. But, as has been the case in the past, there are likely to be those who believe that a hail suppression effort has harmed them economically. In the absence of a generally accepted set of procedures to be used when someone alleges damages from a hail suppression program, controversy between segments of the community is likely from time to time.

At least in some communities there will be new or enlarged local government administrative units involved in the hail suppression operation. And, in many of these communities, some part of local government revenues will be diverted to support the hail suppression program either directly or indirectly. There is also reason to anticipate that some regional equivalent of water conservancy districts will emerge to at least coordinate some aspects of hail suppression programs.

The operators of the hail suppression program and their supporters will show increased efforts at public education and communication of information on weather, weather modification, and its effects.

Environmental effects are likely to include less loss of wild plants and animals to hail and very marginal or uncertain effects of silver iodide on soil microorganisms.

### **IMPACTS TO COMMUNITY - MODEL 3**

*Local business  
has greater  
stability*

*Minor  
controversy  
occasionally*



The net effect on the natural environment is most likely to be minimal even if measurable.

Ratings in *Table 74* indicate that, although all of these impacts are minor and of third-order sequence, there are mostly benefits at the community level.



**TABLE 74**

**Ratings of impacts on community, Model 3**

<i>Impact</i>	<i>Likelihood</i>	<i>Benefit, or not</i>	<i>Importance</i>		<i>Sequence order</i>
			<i>Crop area</i>	<i>Nation</i>	
<b>Adopting</b>					
Increase in farm land values	L	+	Mi	Mi	3
More storage space for added production	L	+	Mi	Mi	3
More transportation for added production	L	+	Mi	Mi	3
Alterations of cropping patterns	VL	0	Mi	Mi	3
Increased economic development	VL	+	Mi	Mi	3
Increased stability in local business activity	VL	+	Mi	Mi	3
Farmers buy more all-hazard insurance	L	+	Mi	Mi	3
Improved public service	L	+	Mi	Mi	3
New, local government administration units	L	+	Mi	Mi	3
Some local revenues diverted to hail suppression	L	0	Mi	Mi	3
Increase in local tax revenues	L	+	Mi	Mi	3
Enrichment in quality of living	L	+	Mi	Mi	3
Reduction in outmigration	L	+	Mi	Mi	3
Some controversy over alleged losses	VL	-	Mi	Mi	3
More effort to inform the public about hail suppression	VL	+	Mi	Mi	3
<b>Nonadopting</b>					
No impacts					

IMPACTS  
TO STATES  
- MODEL 3



Given the small number of adopting regions, the impact trends described here will involve relatively few states. Nevertheless, such impacts should not be overlooked.

*State units  
involved*

It is expected that state level weather modification administrative units will come into existence or be enlarged and that some state revenues will be diverted to hail suppression programs. Further, there will be an increase in state government involvement with other states via interstate compacts or their functional equivalents. Such compacts may well entail movement toward standardization of operational designs and techniques, the provision of informa-

tion especially to downwind areas, and even increased comparability of state regulations.

In a few instances, legal battles over alleged damages from hail suppression efforts will develop thereby contributing to the clarification of some legal issues and slightly to the income of lawyers.

*A few legal battles*

In a somewhat related matter, potentially opposed groups will often be excluded from the hail suppression decision process. Where that is the case, they will expend money and energy trying to prevent or stop hail suppression projects. Although they will seek relief in judicial and administrative agencies, their principal thrust will be lobbying to repeal legislation favoring use of the technology and to enact restrictions on hail suppression.

*Opposers will seek restrictions*

Impacts in downwind areas are difficult to assess because of the near total lack of knowledge about the magnitude of downwind weather effects. Our best estimate is that they will not produce major impacts on the states beyond a seeded area.

Insurance companies operating within states where hail suppression is adopted will have slightly increased profitability at least during the first several years following adoption. Sales on the whole will increase slightly and there will be less fluctuation in sales from year to year. Partially as a consequence, some of these companies (especially the single-state companies) will take a policy position of support for hail suppression programs within selected regions. Again, for these companies the pricing of insurance will become more difficult as experience and statistical bases for certain areas become relatively outdated due to the change of the frequency and intensity of damaging hail.

*Insurance has more profitability*

Where there are several adopting regions within a state, pressure will be applied on the insurance commissioner to lower crop hail insurance premiums. For example, the crop-hail insurance industry in North and South Dakota recently has been queried about lowering rates because of the large hail suppression programs in both states.

The ratings in *Table 75* indicate that the only major impacts at the state level will concern controversy with the potentially opposed groups.



Because it was envisioned that Model 3 would mean adoption of hail suppression in only five crop-producing areas in the High Plains, the impacts at the national level are few. The national and world impacts are listed in *Tables 76, 77, and 78*.

**IMPACTS AT  
NATIONAL LEVEL  
- MODEL 3**

*Insurance Industry.* While the major crop-hail and property insurance companies will not be actively involved one way or another in the hail suppression efforts, they will agree to furnish data to those conducting serious evaluations of hail suppression effectiveness (see *Table 76*). They will also have to handle a slight increase in the number of requests (primarily from those in adopting areas) for rate reductions.

*Insurance 'not involved,' but profits slightly*

**TABLE 75****Ratings of impacts on states, Model 3**

<i>Impact</i>	<i>Likelihood</i>	<i>Benefit, or not</i>	<i>Importance</i>		<i>Sequence order</i>
			<i>Crop area</i>	<i>Nation</i>	
<b>Adopting</b>					
Increased profits for insurance companies for awhile	L	+	Mi	Mi	3
Yearly insurance sales fluctuation reduced	L	+	Mi	Mi	3
Some insurance support for hail suppression programs	L	+	Mi	Mi	3
New or enlarged state weather modification units	L	+	Mi	Mi	3
Increase in interstate arrangements	L	+	Mi	Mi	3
Increased comparability of state regulations	L	+	Mi	Mi	3
Pressure on insurance commissioner to lower rates	VL	0	Mi	Mi	3
Increased emphasis on information dissemination	VL	+	Mi	Mi	3
Opposition excluded from decision making	L	-	Ma	Mi	3
Interest group controversy over hail suppression	VL	-	Ma	Mi	3
A few court suits over hail suppression	VL	+	Mi	Mi	3
Environmental effects imperceptible	L	+	Mi	Mi	3
Slight increase in standardization of designs and techniques	L	+	Mi	Mi	3
<b>Nonadopting</b>					
Imperceptible impacts downwind	VL	+	Mi	Mi	3

**TABLE 76****Ratings of impacts at the national level on major stakeholders, Model 3**

<i>Impact</i>	<i>Likelihood</i>	<i>Benefit, or not</i>	<i>Importance</i>		<i>Sequence order</i>
			<i>Nation</i>		
<b>Insurance industry</b>					
insurance companies cooperate with evaluators	L	+	Mi		3
Slight increase in rate reduction requests	L	0	Mi		3
Minor increase in profitability	L	+	Mi		3
Possible undesirable weather changes cause discussion	L	0	Mi		3
<b>Hail suppression industry</b>					
Few companies increase profits	L	+	Mi		3
Few companies expand	L	+	Mi		3
Producers of seeding materials profit	VL	+	Mi		3
Slight increase in aircraft and radar rentals	L	+	Mi		3
<b>Agribusiness</b>					
- No significant impacts occur	L	0	Mi		3

**TABLE 77****Ratings of impacts on the nation, Model 3**

<i>Impact</i>	<i>Likeli- hood</i>	<i>Benefit, or not</i>	<i>Importance Nation</i>	<i>Sequence order</i>
<b>Political-Governmental</b>				
No significant change likely in federal legislation or agency involvement	VL	0	Mi	3
<b>Social</b>				
Environmental interest group activity slight	L	0	Mi	3
<b>Scientific</b>				
Slightly tarnished image of the atmospheric sciences	L	-	Ma	3
Hail modification research shifted within National Science Foundation	L	0	Mi	3
Number of scientists in hail research decreases	L	-	Mi	3
Funding for related research sharply reduced	L	-	Mi	3

**TABLE 78****Ratings of impacts on world, Model 3**

<i>Impact</i>	<i>Likeli- hood</i>	<i>Benefit, or not</i>	<i>Importance Nation</i>	<i>Sequence order</i>
<b>Political-Governmental</b>				
U.S.-Canada bilateral agreement likely	L	+	Mi	3
Small increase in U.S. regulations of weather modification abroad	L	+	Mi	3

Providers of both crop and property insurance will experience slight increases in profitability in the adopting areas, until rates are reduced.

There will be increased discussion within the insurance industry about possible undesirable weather changes (flooding, winds, lightning) flowing from the hail suppression efforts. No real impacts are foreseen.

*Hail Suppression Industry.* A few companies will experience greater profits as a result of the adoptions (see *Table 77*). Some will expand slightly, but no new companies will enter the field. Producers of seeding materials will show slightly increased profits. Firms providing such equipment as radars and aircraft *for rent* will show increased income.

*A few  
firms  
profit*

*Only basic science research*

*Research and Development Activities.* Research and development related to hail modification is shifted back to the Atmospheric Sciences Division or whatever equivalent division is then handling basic science research within the National Science Foundation (see *Table 78*).

The number of scientists involved in any aspect of hail suppression research will decline sharply and many of those departing will shift to other sciences.

Finally, funding for what little research was being done on the social, economic, environmental, and legal aspects of weather modification will shrink to near zero and funding will be sporadic.

*Agribusiness.* No significant changes are seen as a result of the limited adoption envisioned in Scientific Model 3.

*Few changes in federal regulation*

*Federal Government Excluding Research.* There is unlikely to be any change in federal legislation, especially in regard to the monitoring or regulating of hail suppression projects. NOAA is expected to continue to perform a nominal data collection and evaluation function.

There may have been a lead agency designation among federal agencies, but by 1995 it seems unlikely that it will have much real power or resources to coordinate or advance research and development in weather modification.

*Bilateral agreement likely*

*International.* Because adoption will take place in a number of areas in the northern High Plains, there will be impetus to work out bilateral agreements of some kind. It seems likely that a broader agreement between the United States and Canada will emerge, and perhaps some type of U.S.-Mexico agreement, although that would seem less likely.

Some American weather modification firms will continue to do a modest business abroad. Some increased but relatively mild regulations and monitoring will be imposed by the U.S. Department of State.

*'Science' image slightly tarnished*

*General.* The lack of significant success in hail suppression research will not receive wide publicity, but for certain special interest groups such as physical scientists, farmers, and some federal government administrators the lack of a successful resolution to the hail suppression "puzzle" will leave a slightly tarnished image on the atmospheric sciences.

Environmental interest groups will show little and only occasional concern over hail suppression efforts. While the "balance of nature" theme will be raised from time to time, few law suits will develop and no serious efforts at generating political pressure against hail suppression will ever get under way.

## SCENARIOS - STORIES OF HAIL SUPPRESSION AT WORK\*



The comprehensive listing of the impacts just presented gave little emphasis to *why* and *how* the various impacts emerged over time.

Next, we use a scenario or story form to describe the impacts flowing from the two different conceptions of potential development of hail suppression skills set forth in Scientific Models 1 and 3, and the accompanying adoption patterns in Chapter 9. The emphasis here is on time sequences and processes. The basic conception of the impacts has not been altered in the scenarios — only the emphasis and the manner of presentation differ.

We envisioned and evaluated the possibility of a scenario that would forbid operational hail suppression until scientific findings were adequate to specify the outcomes from use of the technology. During this period there would be federal investment in a program of sound research in hail suppression. Once the scientific basis of an effective and reliable technology had been established and once the requisite decision processes and organizational structures existed for its implementation, operational programs would be allowed. In the team's view, this scenario for the technology's development was so unlikely and unrealistic that no assessment of this route of the technology's development was conducted. The team felt that any federal regulation of the technology for the next several years would not be likely to outlaw operational programs on a nationwide basis because of constituency interest in the "free enterprise" application of weather modification. Furthermore, there is considerable useful information that can be gleaned from a study of operational programs, as shown throughout this report.

*Possible  
scenario  
rejected*

We start our chosen scenarios with the story for Model 1.



The late 1970s followed the pattern of the early part of the decade. Here and there in the High Plains, agricultural areas the size of a few counties or larger were under operational hail suppression efforts. There continued to be scientific dissensus as to the effectiveness of the technology, primarily because of a lack of systematic evaluation of the results of the few ongoing projects that were in existence.

**MODEL 1  
DURING  
1976-1980**

The 1976 interpretation of the NHRE data did not clarify the situation. It was conceivable that the capability for a 30% reduction in hail damage, coupled with a 6% increase in rain, was at hand — but the hard evidence was too sparse and unconvincing for many influential scientists.

By the late 1970s, there was some indication that the paucity of evidence might soon be relieved by the results of the continued NHRE data analysis and some more careful analyses of a few operational programs in the High Plains.

*NHRE data  
helping*

The potential benefit of a possible rain increase with hail suppression was especially interesting to potential adopters.

\*Prepared by Eugene Haas.

*Some  
controversy*

Here and there controversy flared between proponents and opponents when a real or perceived dry spell was in effect in an adopting area. There were no significant court decisions, but a few states updated their weather modification laws, especially in regard to optional participation of local government and the use of local tax revenues for possible weather modification programs.

In the absence of reasonably definitive evidence, it was impossible to tell whether any or all of the handful of areas under hail suppression were benefiting therefrom.

### **MODEL 1 PROGRESS 1980-1985**



During the first half of the 1980s, two related trends became more and more apparent. First, there was a rapid increase in the understanding of the nucleation processes in convective storms —plus a dramatic increase in forecasting skills and in the identification of storm types. In retrospect, it would appear to have been almost like a jump from near ignorance to moderate atmospheric understanding.

*Scientific  
consensus  
emerges*

As a second resultant trend, increased scientific consensus began to emerge from a variety of influential science centers. Heated debates continued, but now a number of basic theoretical issues became increasingly clarified in similar ways to more and more scientists. These advances in no small measure resulted from consistent federal funding for both research and evaluation programs.

The emerging scientific consensus as 1985 approached was that a well-run hail suppression program in western states could decrease crop loss to hail up to 40% and simultaneously increase rainfall with hailstorms by about 8%.

*31 areas  
adopt  
projects*

Starting around 1982, there began to be increased adoption of hail suppression projects, mostly still in the High Plains. Gradually the momentum built into something akin to a bandwagon effect. By 1985, the number of crop-producing areas using hail suppression had grown from 8 in 1981 to 31 —with 14 areas starting new programs in 1985 alone.

The adopters ranged from the cotton-growing areas of southwest Texas to corn-production areas of Nebraska to grain-growing areas of the Dakotas and Montana, and even one potato-growing region in Idaho. For some crops, such as wheat, the adopting regions represented almost 40% of the wheat-producing acres of the country.

*Added rain  
a major  
factor*

**It** was the anticipated increase in rainfall from hail suppression which proved to be a major contributor to adoption. This was especially the case during the extended dry spell from 1982-1985. For the High Plains, this drought was comparable to the 1951-1954 drought — only now there appeared to be at least some hope that the added moisture would reduce the stress on the crops.

The increase in number of adopting areas seemed to flow from several sources. In the high hail loss areas (% of planted crop lost to hail) where some loss is usual, the cost of insurance is often thought to be too expensive or less worthy

than self-insurance. The threat of insufficient moisture also tends to be persistent, and in general farm income over the years tends to be very unstable. As scientific consensus began to emerge regarding what many farmers viewed as a reasonable level of hail suppression effectiveness (30 to 40% reduction in hail) and with the potential for increased moisture, "taking a chance" on hail suppression became attractive for more and more growers.

Many neighboring growers, watching the outcome from the earliest adopting areas, were impressed with what they perceived to be increased productivity and, more importantly, the avoidance of any near total crop losses from major hailstorms.

With increased adoption came increased production. But as production increased, farm prices began to decline. Thus, by the mid-1980s the farmers in the adopting areas had increased production, but the lower prices offset that advantage so that their total income received for crops was no larger than it would have been if hail suppression were not used at all in the country.

*Increased  
production  
lowers prices*

However, those farmers in regions adopting hail suppression early in the 1980s had indeed reaped a sizeable income advantage before farm prices were significantly affected by increased production. As with other effective technologies, early adopters have an advantage for a time.

*First adopters  
gained*

Perhaps the principal change that could be noted in the adopting areas was that there was slightly increased income stability for farm families. More accurately, it meant that the proportion of farm families undergoing catastrophic loss from hail in any given year was significantly reduced. Therefore, more families could, with more confidence, develop long-range plans for investment and activities, and though the change was not dramatic, it was significant for economically marginal farm families.

*Farm income  
becomes  
more stable*

Other bonuses included a reduction in noncrop property losses due to hail and the improved weather forecasts which became available as part of the operation of the hail suppression program.

Within communities in the adopting areas, changes could be noted. Each of the early adopting communities got a significant, if short-lived, economic shot in the arm when production rose and prices had yet to be affected by the increased output.

*Community  
benefits*

In many instances local government, having decided to participate in the operational hail suppression program, then established a simple administrative unit to continue participation in decision making and project monitoring. Similarly, at the level of the crop producing area, new organizational arrangements, often patterned after water conservancy districts, came into being.

*Governmental  
units are  
needed*

Although it did not become clear until later, during this period a lessening of the trend to increased farm size began. Within any adopting area the hail suppression technology was effective enough to reduce the number of financially marginal farm



families being "knocked out" by a few widespread hailstorms. Therefore, somewhat fewer farms were put on the market for possible purchase by nearby farmers who had both the desire and financial capability to enlarge their own farms.

At the state level, widespread adoption was paralleled by the development of new or enlarged state weather modification administrative units and, although the amount varied from state to state, state funds were being diverted from other programs to the new, promising hail suppression efforts.

*Air traffic increases*

While it was more of an annoyance than a major problem, it soon became apparent that the sporadic but occasional large increases in aircraft for seeding within a section of a state could and occasionally did create complications in air traffic control. The FAA accommodated this added burden.

*Opposers allowed to participate*

In many of the involved states there was a gradual opening up of the decision process. There was increasing recognition that a variety of interest groups wanted to express views and to have some say in the decision-making process.

It was remembered that a number of earlier hail suppression programs had foundered on the successful actions of opponents who felt that they had been ignored or kept out of the decision process. While organized opposition still emerged here and there, especially during the 1982-1985 dry spell, the potential opposition was sharply reduced because the decision process was opened up to them and to the public.

*Shortage of qualified personnel*

From a national perspective, it became clear that the six-fold increase in adopting areas within a five-year period was straining the pool of qualified, interested scientists and technicians required to carry out effective hail suppression efforts. Some hail suppression companies offered exceptional economic incentives to attract the needed personnel, and their businesses flourished. Further, aircraft and radar manufacturers saw a minor sales spurt as the need for additional equipment rose. A much larger percent increase in sales was enjoyed by the producers and suppliers of seeding materials.

*Related businesses profit*

Also, with the added crop production, farm equipment firms, especially those producing harvesting equipment, enjoyed increased profitability. And there was, in general, more investment in equipment and crews used in the mobile harvesting industry.

All of this added farm activity, of course, took more fuel but was not yet seen as having much impact on the national energy resources of the United States.

The change in farm prices did not go unnoticed by consumer interest groups. While some of these price effects were reflected in the supermarkets, the impact followed the usual pattern of an increase in the difference between farm and retail prices as farm prices decline.



The early 1980s had been heartening from a scientific perspective. While there had been generally level funding for hail suppression research and development, the sharp increase in the number of areas adopting operational hail suppression projects offered hope for a broader data base that could be used as a basis for getting much better answers to a number of questions.

**MODEL 1  
ADVANCES,  
1986-1990**

It was agreed that the increased monitoring of such projects, the keeping of more complete records, and the careful evaluation of all of the data contributed to the improving effectiveness of hail suppression projects during the mid-1980s. Also, the more recent NHRE findings showed encouraging results.

*Data base,  
evaluation  
improved*

The ability to demonstrate with reasonable certainty that hail suppression could be at least partially effective had its impact on federal funding for hail suppression research. Starting about 1986, such annual funding began to increase, eventually almost doubling the level of the previous decade. This funding made possible renewed and amplified field and laboratory research on hailstorms. The work led slowly but surely to improved effectiveness in the ongoing operational hail suppression programs.

As time passed, the increasing effectiveness of hail suppression efforts in adopting areas stood in sharp contrast to developments in other farming regions. As farm prices for crops grown in the adopting regions were pressured downward by the added productivity, farmers and landowners in nonadopting regions were economically disadvantaged because they had no increase in output to offset these price pressures. As this continued over a period of years it meant that the market value of crop land also suffered in these nonadopting regions. In time the assessed valuation for tax purposes of that crop land brought a reduction in property tax revenue to local government relative to what it would have been without this hail suppression technology.

*Economic  
disadvantage  
to nonadopters*

While the adopting areas were not now enjoying income benefits from hail suppression, there was greater income stability among farmers and that, in turn, contributed to stability of business activity in general for communities in the adopting areas.

*Farm income,  
business more  
stable with adoption*

Although it was often a modest amount, local government was now likely to be contributing local tax funds to the hail suppression programs. In many instances some of those funds had to be diverted from other potential public uses.

And, there was a nagging problem from time to time that kicked off real controversy. While nobody was upset by having less hail, there were some growers who did not want induced rainfall during certain periods. Rainfall during the "wrong" times could and did cause significant damage to certain crops such as hay, cotton, and even barley. This increased rainfall did have the benefit of allowing a greater carrying capacity for beef production on range land in the adopting areas.

In those states having a significant proportion of their area under hail suppression there was something of an economic stimulus in effect. A slight increase in business activity generally within the state became apparent.

*Additional interstate arrangements*

Once the number of adopting areas became significant, as it did by the mid-1980s, there was increased concern about the possible need for coordinating hail suppression efforts near, on, or straddling state lines. In part, the concern reflected uneasiness about possible downwind effects and, in some instances, a desire to have hail suppression programs which would be less expensive if the operational area could be enlarged across state lines. Thus, additional interstate arrangements were developed in several instances in the 1986-1990 period. Talk of federal control of operations developed in Washington.

The insurance industry was experiencing both benefits and problems from the continued application of hail suppression. Computing insurance rates became more difficult as the statistical bases for rating started to change in the early 1980s. Nevertheless, sales of crop hail insurance rose slowly as hail losses became less certain (and insurance more attractive), and some companies showed increased profitability. State insurance departments pressured companies into lower rates.

*A few court suits on liability*

On the other hand, liability insurance for hail suppression operators became more problematic since the number of would-be purchasers increased, but the basis for computing liability was far from adequate. There were a few court suits, some of which dealt with the liability of the weather modifiers *per se*, but the appeals consumed many years and a number of the cases were resolved on narrow, technical grounds.

*Modifier firms do less 'design'*

More and more during the latter part of the 1980s, persons hired by the state or regional administrative weather modification units designed, monitored, and evaluated the operational hail suppression programs. The commercial weather modification firms, as contractors, became less and less involved in the basic decisions, especially about the design of the program.

But, weather modification firms were able to increase profits. Feast or famine was no longer the order of the day. There were now more and, in some cases, larger firms than previously — since some of the smaller operators were purchased by large corporations.

In agribusiness several changes could be noticed. In adopting areas, sales of fertilizer, herbicides, and pesticides increased as the changed weather made their use more attractive and affordable.

*Foreign sales increase — are regulated*

This time period also saw a sharp increase in the export of hail suppression technology to other countries with significant hail damage problems. As the foreign sales increased, the United States government also tightened regulations imposed on the operations of overseas projects by U.S. weather modification firms.

In a somewhat related development, this U.S. export of technology played a small role in the U.S.-U.S.S.R. competition in the world arena. The U.S. government began developing and in the early 1990s took an explicit posture reflecting a determination to meet the Soviet hail suppression sales thrust head on.

Within the United States there were two additional trends that were generally lauded. As the skill in developing and applying the technology gradually improved, not only was there less hail damage but more rainfall. Especially in the semi-arid West the additional moisture provided a measure of increased protection from depletion of water resources. Further, increasingly effective (less hail, more rain) application of the technology tended to reduce the pressure to cultivate less desirable land. Land conservation was thus being served.

*Water resources protected*



Now the hail suppression technology began to reach what many scientists viewed as an acceptable level of maturity. The evaluation of the many years of operational effort complemented and contributed to the knowledge developed from more basic types of research.

**MODEL 1  
DURING  
1991-1995**

Actually, the increased federal funding (compared with a decade earlier) placed considerable emphasis on applied research programs. And the weather modification industry was beginning to invest in research and development also. The designated federal "lead agency" now established a specialized laboratory, even while field research was benefiting from slightly increased funding.

*Research continues to increase, spread*

*By the end of this period the scientific evidence taken as a whole reflected a remarkable increase in hail suppression effectiveness. It was now possible in the western United States to reduce hail damage by 80% and to simultaneously increase rainfall by 16%.*

The recognition of that achievement not only added luster to the public image of the atmospheric sciences but it produced a positive spinoff of support for some of the more speculative research areas in weather modification. Further, these developments coincided with a modest increase in the number of universities offering specialized programs dealing with the research and operational aspects of weather modification.

*Public image of the 'science' improved*

The number of adopting areas had increased only modestly since 1985 — from 31 to 36 areas — but these represented most areas in the western two-thirds of the country where hail losses had once been a serious problem. Prices for farm crops grown in these areas, however, continued to reflect the resulting increases in farm output. The downward price pressures were offset by increased output for producers in the adopting areas, but those in the nonadopting regions experienced some negative economic impacts. These regions were indeed less well-off than would have been the case if no hail suppression technology had existed at all.

*Income stable in adopting areas*

*The American consumer, however, was the prime beneficiary. Supermarket prices did indeed reflect much of the farm price decline. Additionally, greater supplies of beef, resulting from rainfall increases in range areas, were available to the U.S. consumer.*

*Consumers benefit two ways*

In communities in adopting areas there was continuing economic stability. Now with the effectiveness of hail suppression markedly increased, hail loss was no longer a major factor in pushing financially troubled families off their farms. This factor worked to slow down the trend toward population outmigration.

*Cropping patterns change*

In the crop-producing areas, a number of changes became clearer in this half decade. There were changes in cropping patterns as market prices reflected increased production of the major crops which were now largely protected from hail loss. More storage space and additional means of transportation were developed to handle the increased production. The proportion of migrants to permanent residents also changed slightly as increased production for certain crops required more human labor.

*Wild plants, small animals thrive*

Special studies now showed some interesting changes in the natural environment. Fewer wild plants and small animals were being killed by hail while the added moisture promoted their growth. But it was also the case that the added rainfall tended to increase runoff and soil erosion. Insofar as it could be determined from the monitoring efforts, there was little impact of any kind on soil microorganisms.

At the state level, a number of additional changes could be noticed. For states having areas using hail suppression there was a decrease in the frequency with which the state called on the federal government for a declaration of disaster due to severe and large-scale hailstorm losses. Also, the effectiveness of hail suppression resulted in less yearly fluctuation in hail insurance sales.

*Compensation mechanisms for 'losers'*

While there were still a number of sticky problems to be worked out, one of the most noticeable developments involved the treatment of damage claims. In several states it was recognized that a rain increase produced by publicly supported cloud seeding programs could and did, on occasion, cause significant economic loss to certain crops. Mechanisms were developed for estimating the loss and provision was made for compensation. Even with these mechanisms, however, problems concerning questionable claims and financing the compensation remained.

*'Downwind' question settled*

*In a related matter, the improved understanding of how to make hail suppression more effective also led to a clarification of the troublesome "downwind effects" issue. Increasing evidence now indicated that if there was both a careful delineation of what was intended as the "target" area and a conscientious following of the design for seeding, then downwind effects were indeed very modest.*

Despite the dramatic increase in the effectiveness of hail suppression over the past two decades and its rather widespread use in the western United States, there was little financial impact on the U.S. insurance industry as a whole. The industry responded cautiously and tended to delay downward adjustment in crop hail insurance premiums until convinced that the claims for increased hail suppression effectiveness were justified.

And, as the risk of loss to hail was recognized by farmers in adopting areas, they turned for further protection to the purchase of all-weather peril policies. Segments of the insurance industry finally began to show support for hail suppression as a technology that was here to stay at least for certain parts of the country.

*More 'all-weather peril' insurance*

Despite a couple of difficulties, the hail suppression industry was doing well. Commercial operators found their costs for liability insurance had risen steadily over a decade. The operators and the administrative personnel for the projects found that there was increasing involvement in required monitoring of effects and record keeping.

*Suppression industry does well*

*Those who were impressed by the benefits of hail suppression, as well as those who were concerned about possible negative impacts, urged more federal support for updating research on the social, economic, legal, and environmental aspects of hail suppression. There was a modest increase in funding of such research starting about 1990.*

*Funding for social research*

The increased stability in agribusiness was further reflected by the attractiveness of farming as seen by the lenders. There were now increases in the number and favorable terms of loans available to farmers and businesses in adopting areas.

*Favorable loans for agribusiness*

Although it was a minor shift, it became apparent that in the breeding of new strains of crops more emphasis was being placed on high-yield quality as contrasted to weather-resistant qualities.

There were several changes of note in federal government activities. NOAA, for example, had to take into account the weather changes resulting from the hail suppression efforts. Weather records for those areas using hail suppression continuously over a number of years showed "anomalous" trends. Thus, modest changes had to be made in the records and in the interpretation of trends. And, of course, weather forecasts for the adopting areas had to be altered to take the physical changes of cloud seeding into account.

*NOAA records changed*

*There was also a small increase in the involvement in weather modification of the federal government in general. While the government did not run operational hail suppression programs per se, there was an increasing trend toward some involvement in setting minimum standards for operations and requiring increasingly detailed record keeping and the reporting of activities. Facilities had to be set up to handle the large task of monitoring and evaluation.*

*Federals monitor, evaluate*

For the adopting areas of the country, the FAA found it necessary to enlarge slightly its staff and facilities to cope with the air traffic of the hail suppression efforts. Meanwhile, the Federal Crop Insurance Corporation (FCIC) reported increased sales as more farmers sought to reduce their risk to any weather-related cause of crop loss. In response to this trend, the FCIC became marginally supportive of hail suppression.

*FCIC offers support*

*'Quality of life' improves*

The U.S. consumer did continue to benefit from lower retail prices for many farm products, and for those families with very limited incomes, those prices meant improved human nutrition and a somewhat improved quality of life.

*Discuss farm subsidies*

The continued higher level of production of farm crops brought with it some concerns. While hail suppression was hypothetically available to all farmers in the U.S., it was not economically attractive in many areas. Most agricultural areas of the country, the nonadopting areas, had been disadvantaged by the adoption of hail suppression, and for the country as a whole the yearly supply ranged from adequate to the point where talk of "farm surpluses" was again being heard. Indeed, in the 1990s some serious efforts were made to get Congress to discuss the possibility of increasing the number of crops included under federal price support or subsidy programs. The increased energy use for the added crop production further aggravated the national energy shortage.

*Benefits to environment balance problems*

Environmental interest groups continued to take note of the hail suppression activity in the West, but serious challenges were not forthcoming because the few negative impacts seemed to be more than balanced by the benefits received. Further, once compensation schemes had been developed, the number of former opponents of hail suppression declined sharply.

*Nations make agreements*

And what of the international consequences of the new, effective technology? The effect on international trade of the consistently higher U.S. farm output was slight. One change was noteworthy, however. As one part of weather modification, hail suppression came of age and there was also a maturing of concepts and understandings which made possible multinational agreements regarding weather modification. Each nation no longer went its own way with little regard to downwind consequences and to the national sensitivities of other countries.

### **MODEL 3 DURING 1976-1995**



The future will be a mirror image of the past. That view comes close to telling the story of hail suppression activities in the 1976-1985 time period.

Throughout the 1970s and early 1980s, the scientific evidence remained essentially unchanged — despite the claims of commercial operators and a few enthusiastic proponents of hail suppression. There was no acceptable evidence that hail suppression efforts, as practiced, reduced hailfall on the average. Some leading scientists who became disenchanted over the uncertainties and lack of progress of NHRE cast such a pall of gloom that hail suppression research lost its glamour.

*Research has modest support*

Hail suppression research continued with modest support until about 1980. The evidence was still unclear and incomplete, but despite that fact annual funding by the federal government was increased by more than 50% in an effort to determine finally whether the earlier investment in research could be made to

pay off. Field experimentation was now being conducted in both Colorado and Illinois to test transferability, a major recommendation in the technology assessment of hail suppression. This led to increased funding costs.

Meanwhile, with only a few exceptions, operational hail suppression was not being adopted in the United States.

Around 1985, initial tentative findings from the experimentation suggested that in the West hail damage probably could be decreased by about 15% — but at a cost of a 10% rainfall decrease. The federal funding agencies now decided to discontinue most field research efforts and concentrate primarily on completing the intensive data analysis. The final results were disappointing and there was only minimal research thereafter.

*No adoption, research minimal*

The tentative findings released in 1985 did not provide any impetus for the adoption of hail suppression on an operational basis. The level of hail reduction was so minimal that it was unlikely to be worth the cost, and in the semi-arid West the thought of a 10% reduction in rainfall was anathema to the vast majority of farmers. Hail suppression was not being adopted anywhere during the 1980s.

*Rainfall decrease unacceptable*

*But the perceived need for hail suppression did not disappear just because the research evidence was not particularly encouraging. Farmers, especially in small areas of northern High Plains, still found the occasional — but persistent over 2 or 3 years — very heavy crop losses to hail unacceptable and the cost of crop-hail insurance was often perceived to be unacceptably high, especially for those with cash flow problems.*

*Still a need for hail suppression*

So, the desire for hail suppression continued — and when in the early 1990s there was some talk that the technology was now to the point where hail could be suppressed without decreasing rainfall, the farmers in a few of the crop-producing areas again became interested in possible operational programs. Gradually a few regions, mostly in the Dakotas and Montana, adopted hail suppression efforts.

The consequences of hail suppression under these circumstances were minimal, both in number and intensity.



For the individual farm family in the adopting areas the benefits were small but, nevertheless, significant in some cases. Income was up slightly because of increased productivity, crop losses were somewhat less extreme, and land values appreciated ever so slightly due to improved income stability and a modest farm income rise.

**MODEL 3  
IMPACTS**

A reflection of the same factors could have been detected at the community level if careful measurement had been attempted. In adopting communities there was increased stability in local business activity, a very slight increase in

*Benefits to the adopters*



local property tax revenues from the appreciated crop land, a consequent improvement in public services, and a gentle stimulus to economic development and population growth in the area.

*Occasional  
minor  
controversy*

Since it was now generally believed in the adopting areas that suppressing hail did not affect rainfall, no new compensation mechanisms to handle alleged damage were developed. As in the past, there were a few persons who blamed the then current "dry spell" on cloud seeding and insisted that they had actual "losses" from that cause. Such claims provided the basis for an occasional community controversy.'

*Form new  
government  
arrangements*

Since the hail suppression efforts were publicly financed in most instances, local and state government administrative units were formed and funded by taxes. In a few cases several crop areas joined in forming a specialized organizational arrangement. The three states involved developed increased comparability of regulations and local option financing arrangements. In one instance a three-state interstate compact was developed — but it was a modest effort, not much more than an agreement to exchange information and to take certain precautions.

*Insurance  
sales up  
slightly*

As 1995 approached, overall insurance sales in adopting areas were up slightly since the frequency of hail losses was less. The yearly insurance sales fluctuation was reduced a bit and some insurance companies expressed support for hail suppression. The insurance commissioner came under increasing pressure to lower rates for crop-hail insurance. Nationally, the insurance industry was unaffected and unconcerned.

*No impact  
on food  
for U.S.*

*Since the adopting areas represented only about 1% of the crop-producing acres in the U.S., there was no real impact in total U.S. production — nor on the price for groceries paid by the U.S. consumer.*

Because several of the adopting regions were adjacent to the U.S.-Canadian border, the two countries finally developed a comprehensive bilateral weather modification agreement.

In 1995, the scientific evidence generally accepted was that hail suppression could be effective up to 30% reduction in damage to crops, without affecting rainfall. That accomplishment by atmospheric scientists may have been important scientifically, but *it had almost no significant impact on American society*. Only the adopting areas seemed to have been affected, and for the few citizens residing therein the benefits were modest and the disbenefits largely absent.

SUMMARY OF CHAPTER 12  
FUTURE IMPACTS

⊕ If the impacts assessed for Models 1 and 3 seem surprising to the readers, it may be for several reasons. In our analysis we have not lost sight of the role of technology in increasing the prosperity among American farmers and other consumers. The huge exodus of farmers to urban centers during the 20th century, and especially since 1940, can be traced directly to technology. Out-migration from rural areas would not have occurred if farm income had been higher than off-farm incomes. If new technology had not been adopted at such a high rate, the resources needed in agriculture would not have decreased and might even have increased in order to meet increased demands from population growth and per capita income increases. The contribution of new technology has released resources, principally labor, for use in the industrial consumer sector of the economy.

In the evaluation of the impact of hail suppression technology, we first note that there are two basic types of agricultural technology —mechanical and biochemical. Mechanical technology has a primary effect of substituting for labor in order to reduce costs. This type of technology has only a minor effect on crop yields per acre. In contrast, biochemical technology increases output per acre and may even increase labor requirements. Hail suppression is a biochemical innovation which, in this project, is evaluated in terms of the reduction of costs it allows in producing a predetermined demand.

*Mechanical  
vs. bio-  
chemical  
technology*

In Chapter 10 we estimated crop yield increases due to technology other than hail suppression in 1985 and 1995. We also estimated domestic and foreign food requirements, based on population projections. Given these background assumptions, the economic effect of adoption of hail suppression was evaluated by comparing differences in costs of production with and without the hail suppression technology.

*Economic  
impact  
of hail  
suppression*

At any point in time (such as 1985 and 1995), the demand for farm products is price-inelastic. This means that the declines in prices resulting from hail suppression's application are greater than the increases in production. Thus the aggregate farm income is somewhat lower with the hail suppression technology. However, this effect is not uniform among farmers. Even with Model 1 in 1995, the increased output in the adopting regions is a small enough fraction of the national output that returns to landowners in the adopting regions increase while those in nonadopting regions decline.

*Impact  
on price  
of farm  
products*

Agricultural policy, as well as general economic and foreign policy, could affect the impact of hail suppression technology on agriculture. Impacts of the plethora of other possible policy adjustments, such as policy decisions on farm price supports, were not included in the analysis. Implementation of some of

*Impact of  
agricultural  
policy*

these policy options could change the impacts described in our impact analysis; e.g., farm price supports would dampen any technologically induced income disadvantage for farmers. Thus the burden of these price support programs on taxpayers would tend to offset the gains to consumers through reduction of food costs.

*Four  
societal  
impacts*

To summarize, four societal impacts of an effective hail suppression capability were judged to be significant or major. Agriculture would receive the most significant national effects. Producers in the earlier adopting areas would receive immediate benefits from increased farm output, and some of these benefits would be retained. Increased stability of income would remain over the long term. Consumers of agricultural products would benefit through slightly lower prices. Although the economic benefit to any one individual would be small, the number of individuals benefited would be large.

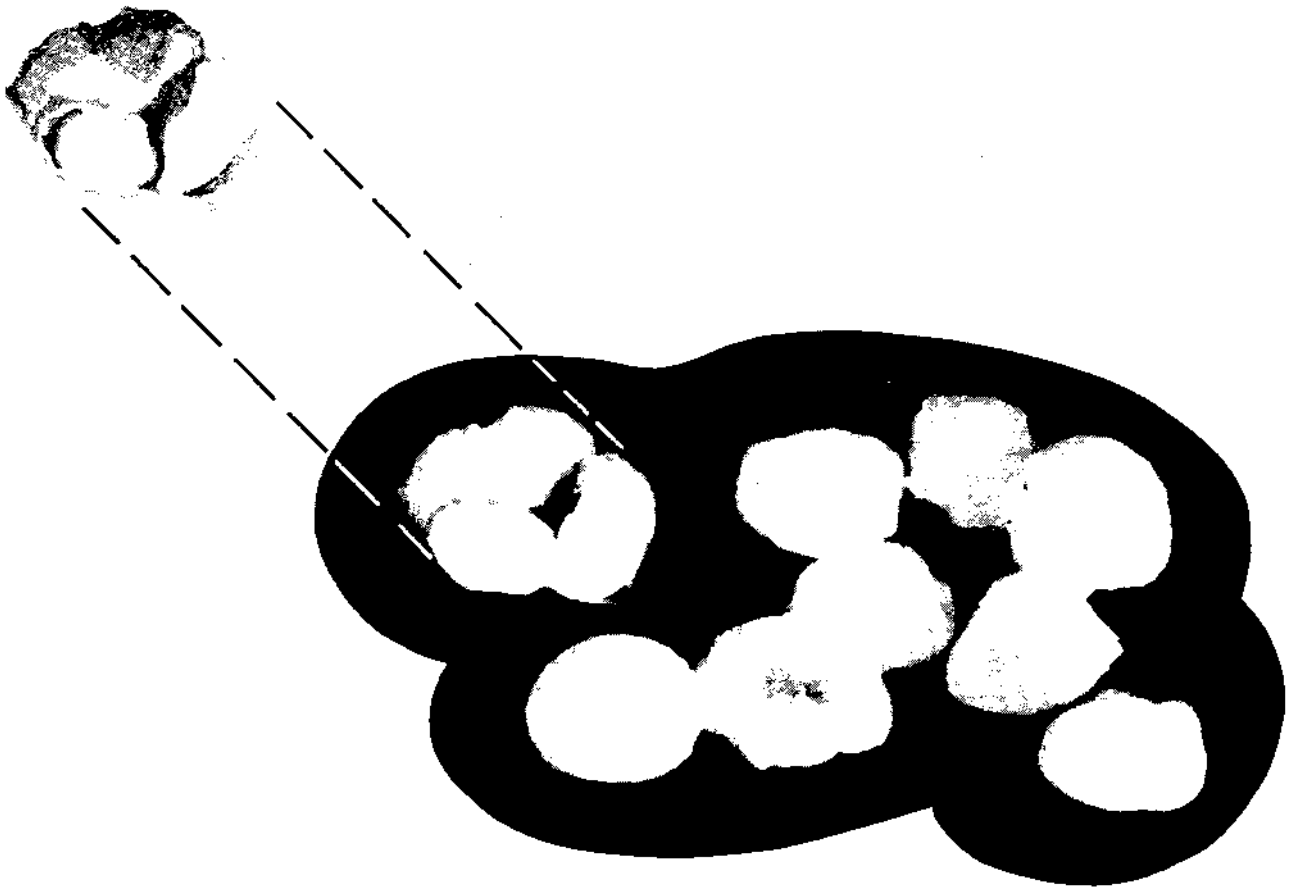
Governmental agencies involved in regulating hail suppression activity, in supporting research and development, and in working out interstate arrangements would experience pressure for implementing these changes.

*Positive  
impacts  
outweigh  
negative*

All other impacts of a high-level hail suppression capability were judged to be minor. The impacts identified included both positive and negative outcomes for various stakeholder groups in the nation. For the nation as a whole, the impacts in general were judged to be minor and beneficial, with positive impacts appearing to outweigh negative impacts if a high-level technology were developed.

# Part 4

What can and  
should be done



# 13

## Public policy options



Thus far in this report we have looked at the hail problem in the United States and, as one solution to that problem, we have looked at the technology of hail suppression — its past, its present situation, and its future possibilities.

We also have considered the full range of possible future impacts — at levels ranging from the individual farm family to the international scene — of a hail suppression technology that had given capabilities and was adopted for use according to given patterns emanating from social, economic, legal, and environmental factors.

In this chapter we consider the options for public policy — what might be done as a matter of policy choice to most equitably direct beneficial use of the technology of hail suppression.

### PUBLIC POLICY OPTIONS - AND THE FIRST ISSUE\*



The role of public policy options in a technology assessment is to identify and describe various potential public policies and programs that could maximize the net public benefit from a new technology. Several important premises underlie the public policy option concept:

- Chronologically, a discussion of public policy options in a technology assessment study follows an analysis of potential impacts of a new technology. Accordingly, public policy options typically seek to accelerate, intensify, and spread more widely any favorable impacts that are anticipated to result from the new technology.

*Enhance  
positive  
aspects*

\*This chapter contributed by Dean Mann and J. Eugene Haas.

*Curtail  
negative  
impacts*

- Other public policy options seek to avoid, delay, or attenuate any unfavorable impacts — or to compensate aggrieved parties for any burdens that a new technology may impose on them.

The terms "favorable" and "unfavorable" are used advisedly because these are value-laden terms. Frequently, a given impact will constitute one person's opportunity and another person's problem.

By definition, the term *public policy option* implies choice for deliberate, purposeful action on the part of some individual or some organization. Such actions may emanate from any level of government - federal, regional, state, or local. In addition, private groups and individuals, acting under incentives created by public decision makers, may be crucial actors in accomplishing public policy goals.

*Eight  
major  
issues*

We see eight major policy issues in connection with the application of hail suppression technologies. There are, of course, some minor or related issues, but our analysis led us to view these eight issues (*Figure 73*) as those requiring careful attention. However, the first issue must be answered before the others may be considered.

## **FIRST - WHAT EXTENT OF SUPPORT?**



The overarching issue facing policy makers at all levels of government — but especially at the federal level — is the extent of support — financial and institutional — for the development of hail suppression technology. The existing science and technology of hail suppression contains considerable uncertainty and its utilization is controversial.

*Scientists  
'don't know'*

Much of the modeling of the future done within this project has been based upon the assumption that a definitive capability, of varying levels, will exist in 1985 and 1995. However, a majority of 550 scientists sampled in 1975 about the status of hail suppression answered "*I don't know*" to the question, "*Do we have a definitive hail suppression technology?*"

*How valuable  
is it?*

The ultimate question for reacting to hail suppression and its uncertainty *is its value*. If the relatively high value of a good capability makes it a truly competitive agricultural technology, then, *removing the scientific and technical uncertainty is a major policy action to be taken*. It is an option to be addressed primarily through research and development, and, characteristically, it is a task of the federal government.

*How do we progress in a systematic well-designed effort to remove these uncertainties and achieve a desirable technology?*

*What the  
effort will  
require*

A more focused federal program in weather modification, including hail suppression, has been the subject of considerable debate and concern for the past several years. Removing the scientific and technological uncertainties will require:



FIGURE 73

Public policy issues for hail suppression

TO WHAT EXTENT SHALL THE DEVELOPMENT OF HAIL SUPPRESSION,  
WITH REMOVAL OF SCIENTIFIC UNCERTAINTIES, BE SUPPORTED?

IF SUBSTANTIAL SUPPORT

WHAT SOURCES  
OF FUNDING?

HOW INVOLVE  
STAKEHOLDERS  
IN POLICY  
DECISIONS?

COMPENSATE  
LOSERS?  
IF SO, HOW?

WHAT UNITS TO  
ADMINISTER  
OPERATIONAL  
PROGRAMS?

HOW TO DIVIDE  
REGULATION  
RESPONSIBILITY  
BETWEEN  
STATE/FEDERAL?

WHAT FEDERAL  
INVOLVEMENT  
IN MULTISTATE  
OPERATIONS?

WHAT EXTENT OF  
MONITORING,  
RECORD KEEPING,  
EVALUATION?

- 1) Orderly federal management with a lead agency addressing modification of severe convective storms
- 2) A well-designed, dedicated scientific research group which can systematically move forward with a realistic mixture of basic and applied research coupled with meaningful field experimentation

The present circumstance of lack of consensus among scientists about hail suppression can only be removed with adequate program leadership supported by adequate and assured long-term funding. Field research must embrace not only the university and national laboratory type scientists, but also the operationally focused scientists of the commercial firms. Simultaneously, every effort must be pursued to evaluate all ongoing operational, commercial programs wherever they occur.

New seeding concepts and technologies should be tested in areas of high hail frequency, including those beyond the boundaries of the United States. Particular attention should be given throughout the field research to measure the critical aspects of storms in different areas and hail regions of the United States so as to determine the transferability of experimental results and delivery techniques.

*Leadership,  
funding, and  
'good mix'  
of scientists*

*New tests,  
— different  
areas*

To remove the scientific uncertainty will require *sustained and increased funding* specifically for hail suppression research.

*Alternative:  
continue  
unfocused  
approach*

Alternatively, the federal government may continue its relatively decentralized, limited, and arguably haphazard approach to support for weather modification generally and hail suppression in particular. Given the existing doubts about the present viability and the future promise of weather modification and hail suppression, this relatively unfocused approach may be reasonable. The consequence, however, is to extend indefinitely the time required to determine the social value of hail suppression.

*Alternative:  
no  
support*

As a final option, the federal government may decide that hail suppression is of such limited capability at the present — and is beset by sufficiently serious scientific and social uncertainties — that its scarce resources should be used in other ways.

*Research  
would halt*

It is a certainty in that case that carefully controlled research would come to a virtual halt:

- Commercial firms would continue to sell their services, but no purchaser would be inclined to pay for *research* activities not having immediate pay-off in terms of reduced hailfall.
- State governments would be unlikely to assume the heavy costs of such research, the benefits of which would accrue to other states as well.
- For the federal government to eliminate or substantially reduce its commitment to hail suppression research would constitute a reversal of policy — but consideration of this alternative may be warranted.

*Disputes  
would  
continue*

The states might continue to facilitate hail suppression activities in response to public demand. The benefits and costs would continue to be the subject of dispute, and the result might be the elimination of hail suppression in some states where opponents were successful in convincing the legislature of the alleged costs to society. In other states, hail suppression programs might continue with widespread conviction about the benefits received — but with little consensus within the scientific community about the value of these activities.

## **SECOND - THE OTHER ISSUES**



Assuming that there will be hail suppression research at some substantial level — and some operations at various places throughout the United States — what are the policy options for society? The following are the seven additional issues we believe decision makers should consider:

- What shall be the sources of funding?
- Should compensation be provided the losers, and if so, through what mechanisms?
- What is the appropriate division of responsibility between states and the federal government in regulating hail suppression?



- In what way and to what extent shall the federal government be involved in multistate operations?
- How, if at all, shall stakeholders —including the general public and consumers —be involved in making the basic policy decisions?
- What administrative arrangements for operational hail suppression programs are most appropriate?
- To what extent shall monitoring, record keeping, and evaluation be required and utilized?

### WHAT SHALL BE THE SOURCES OF FUNDING?



Funds to support hail suppression can be divided into two purposive categories —for research and for operations. Funding for further research *per se* in hail suppression is likely to continue to come from the federal government as part of its general effort in weather modification and the atmospheric sciences.

FUNDING  
FOR  
RESEARCH

*The federal role in basic and applied research having benefits for the nation as a whole is well established — and is not likely to be altered except in terms of the fluctuations in levels of support.*

*Federal  
role to  
continue*

Financing research for hail suppression may have the appearance of asking the general taxpayer to support research of benefit to a limited number of regions of the country. But the evidence regarding economic benefits demonstrates that the chief beneficiaries of hail suppression operational programs in the long run are likely to be *the consumers of food and fiber wherever they may be* — and not merely the farmers in producing regions where hail suppression is adopted. Federal financing for research may therefore be justified as a benefit to the entire nation.

*Justified  
by consumer  
benefits*

States may play an active role in research in a number of ways. First, their universities may be recipients of federal grants for research, and legislatures may be called upon to share some of the cost of university research which is of clear benefit to the states.

*States share  
costs of  
university  
research*

Second, the states may finance adequate systems for monitoring hail suppression operations and record keeping, and evaluating the impacts of hail suppression programs.

*States may  
fund  
monitoring*

Realistically, however, if adequate research is to be conducted, the federal government will bear the major burden of research support —with the states providing marginal support that nevertheless demonstrates its stake in and commitment to the hail suppression effort.

*Major burden  
is federal*

## FUNDING FOR OPERATIONS

*Major funding by local/state*



Hail suppression operations, except as part of federal field research programs such as NHRE, have been largely financed by private groups, local units of government, and state governments. Given the pressures on the federal budget, the current tendencies to devolve tasks to the states through such devices as revenue-sharing, and the ideological preferences for local and state program control, one may expect the states and their communities to continue to share a major burden for hail suppression operations.

Lacking a national emergency which hail suppression might play an important role in resolving, the federal role in funding is likely to be restricted to research.

The specific sources of funds for operations are varied:

- 1) Private contributions by individuals or groups that perceive a benefit from hail suppression
- 2) Taxes imposed by state, regional, or local governments on the property of those who are in areas adopting hail suppression
- 3) General revenues of the state, regional, local, or federal governments
- 4) Combinations of the above sources

*Individuals won't volunteer*

Voluntary contributions by prospective beneficiaries would unquestionably be the most equitable arrangement. But, given the nature of hail suppression programs as a public good — and without compulsory requirements for financial support — there will be strong incentives for individuals *not to pay*, but nevertheless to reap the benefits of the program.

Taxes of some sort may be both preferable and necessary in order to provide sustained support and to ensure that all beneficiaries contribute their fair share of the cost. Taxes on property impose costs not only on the direct beneficiaries but also on those who benefit from the increased prosperity of those who receive the direct benefits.

*Property tax imposes cost to all*

On the other hand, property taxes are indiscriminant in that they impose taxes on people *who may not benefit* and who indeed may oppose hail suppression entirely. Such property taxes may be imposed at the state or local level — or by special units of government created for the purpose of operating hail suppression programs.

*Support from general revenues*

The general revenues of state and local governments — obtained through income, sales, or other taxes — may also be considered as a source of support for weather modification. Income and sales taxes are largely controlled by state governments. Their use for hail suppression would assume that the entire state would benefit from hail suppression and that such a program would justify statewide support.

*Income tax might be 'better'*

Such taxation makes it more difficult to relate costs and benefits, but the income tax is considered the least regressive of taxes and therefore in those states where such a tax exists, its use for hail suppression might impose fewer burdens on those least able to pay.

The options for funding described above are not mutually exclusive. Almost any combination of sources is conceivable. It is likely that adequate funding for a cost-effective program will require financial input from *more than one source*.

*Combined  
funding  
likely*

States, counties, or multi-county districts may share in the funding of the operational aspects of a given hail suppression program — while the federal government might support data collection, monitoring, and evaluation. The cost-sharing arrangement in South Dakota from 1972 to 1975 and in North Dakota in 1976 might provide instructive experience in this regard.

### SHOULD COMPENSATION BE PROVIDED THE LOSERS? IF SO, HOW?



If successful hail suppression is accompanied by either a reduction or an increase in rainfall on any given day, there may be damage to some crops for which rainfall is undesirable at that time. Moreover, even with vast improvements in the technology, it is conceivable that efforts to suppress hail may result in *more* hail rather than less.

**THE  
DAMAGE  
DILEMMA**

In other words, even though the hail suppression technology may be effective overall, it may not be a foolproof technology. Increased hail may result from inability to evaluate accurately the kind of storm system one is dealing with or the techniques required to deal with that particular storm.

*Technology  
may not be  
foolproof*

The possibility of damages resulting from hail suppression operations is a fact of life that must be faced.

One option is to continue the status quo, wherein a person alleging damages has the choice of simply bearing the cost resulting from the damages or of suing in court for compensation.

*One option:  
continue  
status quo*

The latter course of action in connection with hail suppression has never been successful in the United States. The lack of success has stemmed from the need to prove:

- 1) That the seeder was negligent
- 2) That his negligent conduct caused the loss complained of

The causation issue could become less difficult as hail suppression becomes a more widely accepted and understood technique. It would be necessary to sort out precisely the effects of hail suppression efforts from those effects that would have come about through natural weather conditions.

*'Causation'  
may be easier  
to prove*

At the present time, such powers of discrimination do not exist, but one must assume that the capability will develop with greater experience. Otherwise, the causation question may remain a *substantial stumbling block* to the development of a compensation mechanism.

*Either 'no one' or 'too many' compensated*

*Either no one would be given compensation for lack of ability to demonstrate causation, or many individuals — who may have suffered damage but not necessarily resulting from hail suppression — will claim compensation without justification.*

*Legislative action may be needed*

The question of the legal basis of liability remains unclear at this time and legislatures may wish to establish a clear affirmative stance on this issue rather than allowing the courts to make decisions as cases arise. There appear to be two alternatives :

- 1) Liability only on the basis of a demonstration of negligence
- 2) Liability without fault on the assumption that weather modification is sufficiently hazardous that it should not be necessary to prove negligence

*More successful claims*

A decision in favor of liability without fault would appear to increase substantially the need for some form of compensatory mechanism because of the greater likelihood of successful claims being established.

*Liability insurance could go up*

In the event that causation and liability questions are resolved, court decisions in favor of the plaintiffs could force the cost of the weather modifier's liability insurance up to a point where either he discontinues the business altogether or the total cost of hail suppression becomes so high that it is no longer economically feasible. It is hard to envision continued widespread use of an effective hail suppression technology under such circumstances. The option of continuing the status quo hardly seems to be a viable one.

## **WORKABLE SOLUTIONS**



The following would appear to be necessary for a minimum workable solution where hail suppression programs may be accompanied by increased rainfall or hail:

- Liability based either on a showing of negligence or without need for such proof
- Causation established by some sound, widely accepted method of assessing hail-suppression-caused crop losses with compensation to be paid promptly
- Some procedures for arbitration when there is a difference of view between the farmer and the official assessor of crop damage as to level of compensation to be paid
- A contingency fund to be drawn on to pay legitimate claims for damage produced by hail suppression efforts

The precise mechanism for creating and dispensing funds to pay for damage claims will require serious evaluation of alternatives. Payments into such a fund might be made voluntary but the difficulties inherent in such voluntary arrangements have already been alluded to above.

*More likely is some method to set aside tax money to create a fund from which to pay damage claims.*

*Tax fund likely*

The amounts of money required for such a fund are problematical but some guidance can be obtained from the insurance industry. If such a special fund were created, and the costs seem excessive for farmers — or experience is inadequate to provide sufficiently accurate estimates — the federal government might provide for *reinsurance* to protect the funds against disasters or wild swings in the claims incidence.

*Insurance experience a guide*

Consideration might also be given to extension of insurance programs that cover all forms of damage loss. Such programs do not require *proof* of source of damage but only the extent. It is not clear what hail suppression might do to rates of such insurance, and it might be necessary to *make adoption of such insurance mandatory* where hail suppression exists in order to spread the risk sufficiently broadly.

*Perhaps mandatory insurance*

Again, the federal government might wish to consider a reinsurance program to make the rates sufficiently low to reduce the uncertainties involved.

*Finally, a decision may have to be made by legislatures, or, in the absence of legislatures, by the courts, concerning the types of claims for compensation that will be paid.*

*Must decide who shall be paid*

Rain can be a mere inconvenience for some — they have to put on a raincoat or put equipment under cover — or it can be a serious economic and social burden. Tourist facilities may have large numbers of cancellations if rain comes inopportunately; individuals or families that had planned vacations may be forced to cancel. Does society believe that *all* those who suffer should be compensated? If not all, then how does one draw the line between those who deserve compensation and those who do not? Answers to such questions must be provided.

## HOW SHALL REGULATION RESPONSIBILITY BE DIVIDED?



To what extent shall hail suppression activities be regulated and by whom? What is the appropriate division of responsibility between states and the federal government in regulating hail suppression?

**PRESENT REGULATIONS**

*Given that the atmosphere is a common property resource, public regulation is inevitable wherever hail suppression alone or weather modification generally is practiced.*

*Regulation inevitable*

Such regulation will apply to many conditions of doing business — assurance of professional training, safety precautions, reporting, and evaluation. These

*Applies to all concerned*

conditions will apply to all practitioners operating or wishing to operate in a given jurisdiction. The laying down of these conditions will unquestionably affect the cost of doing business for the weather modifier — indeed, these conditions could conceivably *jeopardize the economic attractiveness* of the weather modification industry.

*Operating permits, licensing*

Issuance of operating permits provides the basic element in the regulatory process. It is directed toward the establishment of required conditions for conducting a particular hail suppression project. Licensing establishes minimum qualifications of technical competence, professional integrity, and financial responsibility of an operator.

*Must both protect public, give it voice*

Most states require both operating permits and licenses for operators, but they are of varying degrees of stringency and breadth of coverage. Efforts should be made in all states in which weather modification — including hail suppression — takes place to ensure that these permits and licenses both protect the public and ensure that the public has adequate opportunity to display its wishes with respect to both programs and projects.

Experts from the American Meteorological Society and the Weather Modification Association may be of assistance in establishing standards, although the history of licensing in which professional groups establish the standards suggests the need to prevent standards from becoming tools for protecting the interests of those who draw them up.

*Will not include all states*

As indicated in previous sections, our analysis suggests that with the most effective technology hail suppression would be adopted in about one-quarter of the crop-producing areas of the United States. That represents about a dozen states. Thus, hail suppression is not likely to become a national concern in the sense that it is a technology which is being applied throughout most of the United States.

*Only states regulate at present*

At this time, only the states have experience in regulating hail suppression projects. And, there are opportunities for experimentation and borrowing among the states on the basis of that experience. The states also have the advantage of being in direct contact with those stakeholders most likely to be affected by the hail suppression activity.

## **FUTURE REGULATION POSSIBILITIES**

*Regulation may be both federal, state*



A much more extensive role for the federal government in the regulation of weather modification was once foreseen because of the interstate nature of the weather itself and the activities required to modify it. But, as noted in Chapter 6, public regulation of weather modification, including hail suppression, does not have to be an *either/or proposition* between the federal government and the states. The federal government might lay down certain minimum standards with respect to professional licensing and require federal permits when the activity appears to involve the interests of two or more states.

The circumstances that would justify more extensive federal involvement are difficult to perceive at the present time, given the current limited capability and impact of hail suppression. If other phases of weather modification — *precipitation augmentation, hurricane modification, severe storm modification* — become more promising as operational capabilities, and given the clear inter-state implications of many of these technologies, one may look for more federal involvement.

*More federal involvement in large projects*

There may well be demand for and acceptance of the need for federal licensing and permit-granting to ensure protection for broad regional interests affected by weather modification programs.

*Regional projects may require federal permit*

*Federal involvement in regulation might also come as an adjunct of its financial role in support of weather modification.*

If the federal government were to reinsure insurance companies for hail suppression policies or to pay for some aspect of hail suppression programs such as monitoring, data collection, and evaluation, the Congress might require the adoption of minimum professional and performance standards as conditions of granting the assistance. Such requirements would almost certainly be imposed were the federal government to become involved in support of hail suppression operations.

*Financial help may bring regulation*

Assuming hail suppression continues to be an economically viable option for farmers, it does not appear that public regulation at any level should involve control of price. Weather modification would not constitute a public utility service on any of the traditional grounds — need for uninterrupted service, level of capitalization required, or need to avoid costly duplication.

*No control of prices needed*

Thus, weather modification firms should be able *to sell their services at competitive prices* that remain attractive to clients and investors. From an economic standpoint, public regulation of price and essentially management decisions with respect to operational features of weather modification activities would be both unnecessary and counterproductive.

*Should remain competitive*

## WHAT FEDERAL INVOLVEMENT IN MULTISTATE OPERATIONS?



Because, as discussed above, the federal government may need to be involved in large regional modification projects crossing state boundaries, our next issue becomes: *In what way and to what extent should the federal government be involved in multistate operations?* The involvement that might stem from various mechanisms available for multistate action are discussed in this section.

**MULTISTATE  
VOLUNTARY  
COOPERATION**



The simplest means of cooperation across state lines among individuals and groups interested in hail suppression (or other forms of weather modification) would be through an organization of farmers interested in contracting the services of a professional weather modification organization. That contractor would be required to obtain licenses and permits to operate in both states, but in so doing would appear to satisfy the legal requirements in each state.

*No legal  
impediment  
between states*

There appears to be no legal impediment to carrying on hail suppression activities in more than one state when each state has authorized such operations under its laws, and in fact such cooperation is taking place in Utah and Arizona. Nor do the laws and administrative regulations issued under such laws appear to impede seriously a competent contractor from obtaining licenses and permits in any and all states.

Thus, the diversity of laws and rules does not preclude such multijurisdictional operations. Widespread acceptance of model state statutes on hail suppression and/or weather modification generally would to a large extent obviate the need for federal involvement.

**INTERSTATE  
COMPACTS**



One alternative is the possibility of creating interstate compacts as a means of facilitating hail suppression activities.

*Compacts  
a useful  
mechanism*

Given the wide variety of forms and the extensive experience with compacts it seems reasonable to conclude that interstate compacts could provide a mechanism for interstate cooperation in the field of hail suppression. A compact that dealt with hail suppression would more than likely also deal with other forms of weather modification, especially with precipitation augmentation. As noted in Chapter 6, compacts require congressional consent as well as state ratification.

An agreement might take several forms, depending on the goals sought by the compact agreement.

*Various  
kinds of  
agreements*

The compact might call for the compact agency to actually *engage* in hail suppression activities, either through its own personnel or through contract. It might be authorized to *impose taxes* in areas determined by the compact. It might be authorized to obtain revenue through other devices, such as *bonds*. It could be given the authority to *grant licenses and permits* under circumstances similar to those prevailing in each of the member states.

The compact agency could presumably contract with a federal agency such as the Bureau of Reclamation or the Department of Agriculture to undertake cloud seeding for hail suppression or precipitation augmentation.





In recent years, Congress has authorized a number of corporations for purposes of engaging in activities such as communication satellite operations, passenger train operations, fund raising for housing, and broadcasting.

## FEDERAL CORPORATIONS

The advantage of the corporate device lies in its freedom from normal financial and political restrictions. Such corporations might be authorized as part of legislation creating an interstate compact and to serve as instruments of that compact, or authorized to permit the federal government and units of local government within two states to undertake a project of common interest or concern.

*Would be free from political restrictions*

The utility of a federal corporation remains unclear as a device for dealing with hail suppression operations and regulation. Such a device would probably provide less acceptable *regulation*, but if units of local government and federal agencies did develop a common interest in an *operational* program, the corporate approach might prove feasible.

*Useful for operations*

## HOW INVOLVE STAKEHOLDERS IN POLICY DECISIONS?



How, if at all, shall stakeholders—including the general public and consumers—be involved in making the basic policy decisions?

## PROBLEMS IN SHARING DECISION MAKING

The analysis of potential impacts revealed that there are many different stakeholders (Chapters 5 and 12). They range from the total United States population of consumers of farm products, to the small weather modification industry, to migrant laborers. Among the stakeholders having the most to gain or lose are the farmers over whose land the hail suppression activities would take place.

It is virtually impossible to devise a decision-making system that permits all stakeholders to have a share—equitable or not—in the decision-making process.

*Not all can share*

Federal and state taxpayers, for example, cannot discriminate with respect to the way their income or sales taxes are spent. Consumers cannot influence decisions regarding the adoption of a technology that may influence them economically.

*Nevertheless, decision-making systems can be devised which will broaden the scope of representation beyond those who may benefit directly from such a technology as hail suppression.*

Typically in the United States, some or all of the farmers have been involved in one of two ways in decisions about operational hail suppression efforts in their area:

*Typical local options*

- Elected local officials, presumably in close touch with local citizens, make many of the basic decisions.
- Local farmers form an association and select leaders who in turn make decisions on their behalf.

But, we need not be bound by the past. There are several broad policy options which ought to be considered.

*Representation needs to be broad*

In keeping with authoritative requirements for public participation in decision making found in numerous laws passed by Congress and state legislatures in recent years, it may be desirable to broaden considerably the representation of interests with respect to decisions on hail suppression. *But the specific institutional arrangements by which that might be accomplished may be left to states and perhaps even local communities.*

Some states may prefer widest possible participation through the adoption of the referendum while others may be satisfied with public hearings and decisions made by public commissions.

Some states may prefer local option arrangements while others may mandate state-wide programs with no local options.

Some communities may prefer to rely on their regularly elected officials such as county supervisors or state legislators to make their decisions.

## AVAILABLE OPTIONS



The following appear to be the available options, though many specific nuances or combinations of features may be incorporated in any given set of institutional arrangements:

*Electoral mechanisms*

*Election.* The voters in the appropriate jurisdiction may be permitted to participate in a number of ways:

- 1) On decisions to embark on a program in that area
- 2) On decisions to have a program in a given year
- 3) On issues of taxation to support the hail suppression program
- 4) On the creation of a district to operate a hail suppression program and on the election of a district board

*Sets up 'all or nothing' decisions*

The electoral mechanism permits broad participation on relatively structured propositions — but tends to provide all-or-nothing choices. Reliance on elections must be accompanied by careful negotiations among interested parties to ensure that a *wide spectrum of interests* is represented in the proposition presented to the electorate.

*Could further 'divide' community*

If there is not a consensus, an election may further splinter or divide a community on the issue. If there is concern that minority interests should be given added protection, greater than a simple majority might be required to approve a program.

*Board may make decisions*

*Decision-Making Board.* A countywide, multicounty or statewide board may be created — either by appointment by the governor or by election — for the purpose of making decisions on licenses, permits, and programs. This board

may by law be required to represent a multiplicity of interests — stakeholder and geographical.

Such a board may be required to hold hearings and hear testimony of interested parties and their decisions may be subjected to some appeals mechanism — including a referendum among the voters in a given area.

*May have to hold hearings*

The advantage of a board is its capacity for deliberation and negotiation among the interested parties. It may also take into account broader societal interests, particularly if some members are representative of the general public.

*Advantages*

Its disadvantages are its necessarily bureaucratic nature — and the difficulty in representing all interested parties.

*Disadvantages*

*General-Purpose Officers of Government.* Some communities may rely on general-purpose officers of government — such as boards or supervisors — to make the decisions.

*'General-purpose' officers*

As in most other situations, their decisions may be made subject to referendum. The advantage of this arrangement is that it allows the agency concerned with overall community policy *to relate hail suppression to other public policy priorities.* The disadvantage lies in the fact that they are less clearly responsible to the electorate or other interested parties in terms of the specific issue of concern here — hail suppression.

*Voluntary Organization.* This arrangement has the advantage of permitting only those to participate who see the advantage in hail suppression and are therefore willing to support it financially.

*Voluntary organization*

No one participates who does not wish to. On the other hand, hail suppression may affect those who are not supportive of the hail suppression effort and these individuals and groups are effectively excluded.

*Nonsupport groups excluded*

Although not normally considered a device of public participation, one should recognize that the courts are available in the event one considers himself wrongfully injured. Resort to the courts may be expensive but all participative arrangements are costly in some sense — either in money, time, or commitment.

*Courts also available*

## WHAT ADMINISTRATIVE ARRANGEMENTS FOR OPERATIONAL PROGRAMS?



Arrangements for public and stakeholder participation necessarily imply certain administrative arrangements. A number of options seem reasonable.

### ADMINISTRATIVE UNIT OPTIONS

As was the case in South Dakota from 1972-1975 — and is now the case in North Dakota and Utah — each state could organize and administer hail sup-

State  
designates  
an agency

pression projects within its own borders through a designated state agency or special administrative unit. Depending on the extent of adoption, this might entail anywhere from a couple of states up to a dozen, all in the western United States.

Because most of these states are predominately agricultural in character and have small populations, communication between citizens in the adopting areas and administrators of the projects would be easier and more direct.

Since licensing and permit granting are likely to continue to be state or state-plus-federal activities, there would be a ready continuity between providing the basic regulatory function and providing whatever degree of administration was thought to be appropriate.

Since almost any *economically and logistically feasible* hail suppression program would include parts or all of several counties, a state administrative unit would make sense.

Hail  
suppression  
'district'

With appropriate legislative authorization, a crop-producing area made up of several counties could form an administrative unit to design and supervise the operation of a project within what might be thought of as a *hail suppression district*.

A hail suppression district would have the advantage of more grass roots participation but it might have the disadvantage of lacking economy of scale.

Personnel,  
compensation  
problems

Unless the program was well financed, it might be difficult to attract and hold qualified personnel to administer the project. Furthermore, a single district might have a very difficult time securing the resources for a compensation mechanism of some type which will almost certainly be necessary for a program to continue for a period of time.

*Some joint arrangement between hail suppression districts and a state administrative unit would therefore seem to be more feasible.*

## LIKELY PROBLEMS



Clearly, the questions of administering a program and funding a program are closely tied. It is unlikely that any governmental entity is going to appropriate money for a hail suppression effort and turn over entirely the responsibility for administering those funds to another entity.

Too costly  
for small  
units

*Because the costs involved in equipment purchase and/or basic working capital are sufficiently large, it is not likely that hail suppression districts can go it alone except in rare cases. Thus, the state or at least several cooperating districts are likely to be the smallest administrative units.*

Special skills  
needed for  
short time

It does not seem likely that any governmental unit, whatever its size, will operate a hail suppression program entirely on its own. It would be hard to justify the hiring and retaining of government personnel with the necessary

special skills needed *only for the length of the local hail season*. Only a federal agency which moved its operations from state-to-state throughout a longer season could begin to overcome such questionable expenditures.

Weather modification firms which operate in the United States and abroad have the best possibility of keeping their specialized personnel more nearly fully employed throughout much of the year.

A federal agency such as the U.S. Department of Agriculture or the Bureau of Reclamation could provide for the design and operation of operational hail suppression projects wherever they are requested. Such an agency would have personnel and facilities in most of the areas where hail suppression is likely to be desired.

*Federal agency  
could operate  
'on request'*

By having a single agency take responsibility, it is more likely that project designs, seeding methods, and record keeping would be *standardized*. Comparison of outcomes would be aided by such an approach. Also, the agency would build up experience —presumably efficiency —and provide continuing employment for its administrative personnel.

*Single  
agency  
advantageous*

The actual cloud seeding would in all likelihood be carried out by contracting with weather modification firms. As indicated before, federal involvement in operations *per se* does not appear to be likely in the foreseeable future.

## WHAT EXTENT OF MONITORING, RECORD KEEPING, AND EVALUATION?



Controversy over weather modification almost always centers on whether physical changes have in fact been produced by cloud seeding. In the absence of adequate objective evidence —which is now usually the case —strongly held opinions form the basis for arguments and even attempted legal action.

**WHAT IS  
NEEDED**

*If an effective hail suppression technology is to be utilized, there will have to be some minimal level of monitoring and evaluation, plus record keeping, of the cloud seeding operations and the physical changes flowing therefrom.*

*Necessary  
for effective  
technology*

Such monitoring and evaluation will provide critically needed information for the handling of claims for compensation. Without rather specific data it will be impossible in many cases to distinguish between damage —such as rain during the harvesting of hay —flowing directly from the cloud seeding and damage which is unrelated to cloud seeding. The acquisition of data on downwind effects will also be imperative.

*Physical  
changes  
must be  
known*

In addition to data on changes in weather parameters, there will be a need for periodic data on environmental, economic, and social impacts of the hail sup-

*Social data  
needed also*

pression effort being conducted in an area. An array of professional skills will be needed to collect the various types of data.

The monitoring and evaluation of physical changes will be by far the most costly.

*Monitoring, evaluation must be 'credible'*

In addition to cost, the reputation of those doing the monitoring and evaluation will be very important. Those doing the research might be from a federal agency or a university, part of a state weather modification unit, or other researchers who contract to carry out the necessary monitoring and evaluation functions. *Whatever their affiliation, however, they need to have an unimpeachable reputation for objectivity, expertise, and integrity.* A great deal will ride on their findings and conclusions.

## **OPTIONS FOR HANDLING**



Clearly, one option would be to have a single federal agency, using federal tax funds only, responsible for the full range of monitoring, record keeping, and evaluation activities wherever hail suppression is being conducted.

*Could use 'matching funds'*

Such a possibility might be attractive for many counties and states for obvious financial reasons. A minor variation would be to have the work conducted by or at least designed and supervised by the federal agency with each adopting county and state contributing nominal *matching funds* for the federal dollars provided.

*State could be responsible*

A second option would be for the state to serve as the responsible party for monitoring and evaluation. Many state universities have generally recognized expertise for these types of research activities. If the necessary funding was provided by a matching arrangement between the state and participating counties, there would not need to be any significant federal involvement — except possibly for associated record keeping.

*Region could take charge*

There is a third option which seems somewhat less feasible. A group of counties — for example, the counties making up a hail suppression region — might finance and arrange for the monitoring and evaluation work.

*Might be dropped as 'costly'*

If there are going to be multicounty hail suppression administrative units, as seems likely, the unit that represents the cooperating counties in the operation of the hail suppression effort could also do the same for the monitoring and evaluation effort. In most cases the work would likely be done through a contract arrangement. But given the emphasis on producing results as economically as possible, local units are likely to dispense with monitoring and evaluation whenever money becomes scarce.

*Record keeping required*

Federal law now requires rather detailed record keeping and reporting for all weather modification projects. The National Oceanic and Atmospheric Administration is the agency responsible for administering the law.

Most states require reports on projects. These are intended to provide the basis for evaluating compliance with the terms of permits and professional licensing requirements. The regional reports are not very comprehensive, and there are few funds for evaluation of reports already received.

If monitoring and some form of evaluation of the physical effects of cloud seeding are going to be necessary — as seems likely — then the concept of record keeping can and probably should be combined with those activities.

*Three jobs  
likely  
combined*

Once the hail suppression technology has matured so that the extent of physical effects can be estimated with considerable accuracy, some or most of the justification for reporting details of a hail suppression project to the federal government *will no longer be present*.


*May not  
need detailed  
reports*

Notification in advance of *intent to conduct a program* would still be important, however, for a variety of reasons, not the least of which is to allow time to plan properly for air traffic control in the project area. Required reporting to the federal government makes sense now. It will be interesting to see if the requirement is eased when the justifications decline.

## SUMMARY OF CHAPTER 13

### PUBLIC POLICY OPTIONS

*Public policy option defined*

 The term *public policy option* implies choice for deliberate, purposeful action on the part of some person or organization. Policy actions emanate from any level of government as well as from private groups and individuals who may be crucial actors in accomplishing public policy goals.

*Must remove technical uncertainties of hail suppression*

The most significant policy question with regard to hail suppression at all levels of government is to what extent the development of hail suppression technology should be supported, both financially and institutionally. Assuming that national goals of adequate food supplies for the entire population while maintaining environmental quality and other societal values are served by (or at least not violated by) an effective hail suppression technology, then removing the scientific and technical uncertainty is the major policy action to be taken.

Removing these uncertainties will require 1) orderly federal management and adequate long-range funding with a lead agency addressing the modification of severe convective storms and 2) a scientific research group dedicated to a well-designed program of basic and applied research.

*Other policy questions*

Other important policy questions identified in the chapter related to the primary policy decision of the technology's development are:

*Sources of funding?*

1) What shall be 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.

*Compensation to losers?*

2) Should compensation be provided the losers? If so, how? Since some may gain and some may lose as a result of hail suppression activity, the possibility of compensating losers must be considered. The question of causation of effects has been a substantial barrier to the development of a compensation mechanism, but this difficulty may 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.

*Regulation — state and/or federal?*

3) What is the appropriate division of responsibility between the states and the federal government in regulating hail suppression? Throughout this study the atmosphere has been considered a common property resource, and thus public regulation of its intentional modification has been viewed as inevitable. Heretofore, regulation has resided at the state level; however, regulation need not be viewed as an either/or proposition between the federal government and the states. Federal involvement in regulation might arise in conjunction with its financial role in support of hail suppression.

*How regulate multi-state operations?*

4) In what way and to what extent shall the federal government be involved in multi-state operations? Various options for such federal involvement include the creation of multi-state voluntary cooperative agreements, the develop-



ment of more formal interstate compacts, and the authorization by Congress of a federal corporation for the management of operational programs.

5) How, if at all, shall stakeholders be involved in hail suppression policy decisions? Decision-making systems can be devised which broaden public representation beyond those most directly interested. The development of specific institutional arrangements to accomplish broad public participation may be left to states and local communities.

*How involve stakeholders in decision making?*

6) What administrative arrangements for operational hail suppression programs are most appropriate? Various options include federal agency administration, local districts, and state agency management, or combinations of these. In part, the most appropriate policy choice would depend on the scope of the projects being administered.

*Who should administer?*

7) To what extent shall monitoring, record keeping, and evaluation be required and utilized? 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.

*How much evaluation by whom?*

In general, policy decisions on hail suppression revolve around two basic issues: whether to stimulate the further development of hail suppression technology, and how to handle the normative questions concomitant with its development and application.

# 14

## Conclusions and recommendations



From our interdisciplinary study of hail suppression and its impacts, we reached a number of conclusions and derived recommendations for action that would most nearly achieve the objectives of beneficial use and minimum harm from the technology. Our conclusions cover in broad brush strokes the detailed findings of the study and what the team inferred from them. They are presented first as a basis for understanding how the recommendations were derived.

### CONCLUSIONS\*

- 1) The United States experiences about \$850 million in direct crop and property hail losses each year, not including secondary losses from hail. The key characteristic of hail is its enormous variability in size, time, and space. It is difficult to accurately separate hail damage from other factors such as wind damage because of the methods used by insurance companies in recording damage data.
- 2) Among the alternative ways of dealing with the hail problem (including insurance), hail suppression, given a high level of development, appears to provide a promising future approach in high-hail-loss areas. However, from the farmer's view of economic benefits from hail suppression, great regional differences exist. If a moderate (-50%) hail suppression capability without changes in associated rainfall existed in the future, it would be economically very advantageous for Texas cotton farmers and for Kansas and North Dakota wheat farmers. Any alterations in associated rainfall ( $\pm 10\%$ ) would considerably alter the gains from 50% levels of hail suppression in the Great Plains. However, even a suppression capability of 80% would offer little advantage, particularly over insurance, for the Illinois corn-soybean farmer or the tobacco farmer in North Carolina.

\*This chapter contributed by Barbara C. Farhar, based on team decisions.

- 3) At the present time there is no *established* hail suppression technology. Too little is known about the intricacies of hail growth in various types of storms and about the diffusion and actual effects of seeding material inside storms. It may be possible to reduce damaging hail about 25% over the growing season in a properly conducted project. Future levels of hail suppression effectiveness are difficult to predict because of current uncertainties as to status, the wide ranges of possible research and development support that may come from federal agencies, and the large uncertainty about possible major advances in scientific knowledge. Hence, future levels of capability could vary anywhere from 15 to 45% reduction in hail damage in 1985 (with rain changes of -10 to +8%), and in 1995 hail suppression could be anywhere from 30 to 80% with rain changes of 0 up to increases of 16%.
- 4) Removing the scientific uncertainties about hail suppression will require a substantial commitment by the federal government for long-term funding of a systematic, well-designed program that includes a realistic mixture of basic and applied research, field experimentation, and evaluation of operational (commercial) programs. For the next decade or so, monitoring and evaluation will be almost as important as the operational programs themselves.
- 5) The benefit-cost analysis indicated a ratio of approximately 14:1 for investment in the highest capability technology considered. The present value of benefits is estimated to be \$2.8 billion for twenty years with the present value of costs about \$2 million. Although the intermediate technology had a slightly higher benefit-cost ratio, the present value of its benefits is much lower, \$1.7 billion, than that from the high-level technology. The lowest performance technology showed a negative benefit-cost ratio. Based on the benefit-cost analysis of these three alternatives, research and development to provide the high-level technology is the best choice; the lowest level of support is nonbeneficial from an economic standpoint. In a word, if it is to be done, it must be done right!
- 6) Effective hail suppression levels will, because of the nature of the hail hazard, technological approach, patterns of adoption, and institutional arrangements, lead to regional programs that embrace groups of states. These regions will exist largely in the Great Plains and will be coherent in their technological system and institutional arrangements.
- 7) Some would gain and others would lose from widespread application of an effective hail suppression technology. This is true both within the adopting regions and between adopting and nonadopting regions. Farmers in the areas adopting hail suppression would receive immediate benefits from increased production, but after a few years the national commodity prices would reflect the production increases and the farmers would lose that temporary income advantage. However, they would continue to benefit from increased stability of production. Farmers outside the adopting areas would have no

advantages and would be economically disadvantaged by the lower commodity prices. Consumers would benefit from slightly decreased food prices. The impacts generated by a highly effective technology include both positive and negative outcomes for various other stakeholder groups in the nation. For the nation as a whole, the impacts would be minor and beneficial. On balance, the positive impacts appear to outweigh the negative impacts if a high-level technology can be developed.

- 8) An adequate means has not been developed for providing equitable compensation on an economically sound basis for persons suffering from losses due to cloud seeding. Some procedure for compensating losers will be necessary, especially if rainfall is altered.
- 9) The public is not well acquainted with hail suppression, and activities to date have sometimes aroused organized opposition and have created community polarization. Until the technology of hail suppression is proven scientifically, its use will remain controversial in some areas, with disputes over its benefits and costs and claims of harm (as from decreased rainfall).
- 10) Present decision mechanisms and institutional arrangements are inadequate to implement the technology in a socially acceptable manner. Some mechanism for including potential opponents in the decision-making process will be required.
- 11) Weather modification (and hail suppression) have been regulated minimally at the state level. Although 60% of the states have laws respecting weather modification, those laws widely vary in their coverage and effectiveness as means of regulation in the public interest. Patterns of regulation have emerged, but striking differences among statutes and administrative laws remain, and inadequate financing for their administration is the norm. Federal regulation of hail suppression is minimal, providing only for an activity-reporting requirement.
- 12) Interstate and international agreements concerning weather modification control are still in an early development stage. These multi-jurisdictional arrangements will become necessary with widespread adoption. Various U.S. firms export hail suppression activity abroad, and this controversy-prone activity deserves to be monitored as part of maintaining proper international relations.
- 13) Belief in the technology's effectiveness is the single most important social-psychological variable in determining favorable social evaluation of experienced cloud-seeding projects in agricultural areas. Widespread citizen concern about the risks involved in adopting this uncertain technology is associated with opposition to projects and with preference for local decision control over its implementation.

- 14) Social systemic variables (including contingency factors, the flow of events, weather conditions during cloud-seeding projects, area heterogeneity of weather needs, economic factors, political conditions, and others) are probably more determinative of adoption than are individual characteristics.
- 15) The economic analyses showed that rain effects are more important than hail effects, so that minor reductions in hail without rain increases, or with rain decreases, would not be economically beneficial. Societal analyses showed that lack of precipitation is perceived as more seriously and widely damaging than hail.
- 16) It is unlikely that widespread operational hail suppression programs would have serious adverse environmental impacts, although lack of sufficient knowledge indicates that adverse impacts should not be ruled out. Long-term environmental effects are not known at the present time.

## GENERAL RECOMMENDATIONS



Any set of recommendations is likely to rest on a number of assumptions on the part of those formulating it. So that the reader may be better informed about the thinking that went into the recommendations presented in this chapter, we list here the assumptions on which our study was based.

Among the assumptions are the following:

- Although it may appear to be self-evident, it is worth reiterating that the atmosphere affects us all, whoever we may be and wherever we may live, but we tend to take the atmosphere for granted.
- With patience and consistent financial support it will be possible to ascertain with a reasonable degree of certainty whether or not damaging hail-fall can be significantly reduced.
- If an effective hail suppression technology is developed, it can be utilized in economically feasible projects.
- Proposed operational projects will be adopted in certain regions of the country if the social, political, and legal constraints are not insurmountable.
- Lower food prices at the consumer level will result in more adequate nutrition for disadvantaged families.
- The increased production of food will also make more available for consumption abroad.

The recommendations are presented in two major sections: recommendations concerning public policy and recommendations pertaining to research. Public policy recommendations deal with federal and state governmental actions regarding hail suppression; research recommendations consider needed interdisciplinary, scientific and technical, socio-political, economic, legal, and environmental studies.

## PUBLIC POLICY RECOMMENDATIONS - FEDERAL GOVERNMENT

- 1) **The federal government should attempt to develop hail suppression having a high level of effectiveness.**

We have concluded that, on a balance, a highly effective hail suppression technology would be of benefit to the nation. The costs of its development are likely to be outweighed by its economic benefits, and its adverse impacts are judged likely to be minor. Absence of a scientific consensus on an effective technology to the present has been caused, in part, by subcritical levels of research support. If the federal government follows this recommendation, support should be at a sizable level (at least \$3 million annually). This effort should be sustained for at least 20 years or until it is clear that a highly useful technology ( 80% loss reduction with physical understanding) is achieved or cannot be achieved. Careful monitoring of progress and achievement of goals is urged. Funding at a lower level, as represented by Model 3 in our study, is predicted to lead to a loss from a national economic standpoint, suggesting that such low-level support is not warranted.

*An effective  
technology  
should be sought*

- 2) **One federal agency should have the responsibility for the primary funding of research and development in hail suppression, providing the long-term stability in funding required to accomplish the needed experimental work. Agencies studying severe convective storms should attempt to better coordinate their programs.**

We found that ongoing operational projects have not been monitored and evaluated in a systematic fashion and that these projects could provide a data base for increasing our knowledge about hail suppression. One federal agency should be responsible for the collection, analysis, and integration of data from ongoing operational projects and for the provision of information on project effects to state agencies administering weather modification. We found that the primary stakeholder group in the nation — agriculturists — are not well informed about weather modification and its potential for increasing crop yields. One federal agency should have responsibility for cooperative research concerning the relationship of hail suppression and agriculture and in public information efforts. The logical agency for this role would be the U.S. Department of Agriculture, which could utilize its cooperative extension services in public information efforts on the effectiveness of hail suppression. The Federal Crop Insurance Corporation should identify its role in providing all-risk insurance in response to altered hail patterns (occurring with widespread adoption), and adopt a policy regarding reinsurance for private insurance companies.

*Roles for  
federal  
agencies*

- 3) **We need to define how hail suppression coincides with or contributes to national goals regarding health and safety, quality of life, protection of**

**environmental resources, production of food and fiber, national security, and foreign policy.**

*Relation of weather modification to national goals*

Such a policy analysis would serve as a foundation for determining the necessary level and priority of support for the development of hail suppression and other weather modification technologies if its development seems consistent with national goals. The policy analysis should be used as a basis for the formulation of a national policy for weather modification.

- 4) The role of the federal government should be largely one of stimulation and of providing financial support for research and development of an effective hail suppression technology.**

*Federal role to support research*

Traditionally, the federal government has supported basic and applied research in weather modification and other sciences. We have concluded that the development of an effective hail suppression capability would be in the nation's interest, and public appropriations provide the broad level of support necessary for the technology's development.

- 5) Monitoring and evaluation activities in connection with operational projects should be funded primarily from federal sources.**

*Evaluation another federal role*

It is to the particular advantage of residents, especially farmers, of the adopting areas to know in considerable detail just what the consequences of the local hail suppression effort are. Atmospheric scientists and federal agencies also need to know the weather effects of cloud seeding for a variety of purposes. Monitoring and evaluation data will be needed as the basis for determining the extent to which compensation should be made and traditionally evaluation of activities and products that affect the populace has been the responsibility of the federal government.

- 6) We recommend that operational hail suppression programs be permitted only under conditions of full disclosure to a governmental agency.**

*Full disclosure important*

"Full disclosure" includes revelation of all advertising, contract, and promotional material, as well as reports on project effects. Consumers ought to examine carefully the qualifications of firms offering to conduct operational hail suppression projects. Additionally, operational projects should be required by law to provide sufficient data to independent government agencies (on a cost-reimbursement basis) that monitoring and evaluation of project effects will be expedited.

- 7) Work begun on binational and interstate model agreements concerning the operation of planned weather modification programs, including hail suppression, should be continued.**

*Cross-boundary agreements*

Because the hail suppression technology of the future, if developed as recommended, is likely to be applied over wide areas (irrespective of

political boundaries), consideration of the interstate and international agreements necessary between political entities to make such programs politically and socially possible should be carried forward. Both states and foreign nations should be involved in the development of these agreements.

- 8) **Starting promptly, consideration should be given to the development of a comprehensive and coherent federal policy regarding the export of hail suppression efforts.**

We have concluded that no currently reliable hail suppression technology exists; therefore, the United States government should reconsider its tacit approval of exporting hail suppression services. We recommend that every five years the National Academy of Sciences be requested to compile and publish a "Status of Hail Suppression" report including recommendations regarding whether or not the United States government ought to encourage the exportation of the then current hail suppression capability. The United States government should develop and update its policy regarding the exportation of hail suppression services based on the content and recommendations of such a report.

*Evaluation of  
export of  
hail suppression*

## **PUBLIC POLICY RECOMMENDATIONS - STATES**

- 1) **Operational hail suppression programs should be financed by a combination of local and state funds. Direct beneficiaries should pay for operational costs.**

The impact analysis showed that the primary beneficiaries would be agriculturists and state and local governments, and tax-based funding provides the breadth of support necessary for adequate programs and the basis for state regulation (or control) of the technology's application. Farmers in nonadopting regions will eventually be at a competitive disadvantage in the market (their production will not have increased to offset the generally lower prices paid for their crops) and should not have to pay for hail suppression operations with their federal tax dollars.

*States support  
their own  
programs*

- 2) **Regulation of hail suppression projects should continue for the present to be a state responsibility. Present and future federal standards for monitoring and evaluation should be incorporated into state regulations. States should appropriate more funds for the administration of weather modification statutes.**

Major federal regulatory intervention is unlikely to occur until widespread adoption of weather modification has developed. For the immediate future, then, states should be the primary regulators of the technology. Most states have inadequate systems of monitoring field activity. The current federal reporting requirements (and any future federal monitoring and evaluation

*States regulate  
their own  
programs*



standards) should be incorporated into state administrative law. Those states without adequate weather modification legislation should remedy this lack of public regulation. We have found that state funding for administration of weather modification statutes is generally inadequate, and this situation requires correction through action of legislative and executive branches of state government.

- 3) **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, possibly all citizens within the potentially affected areas should vote in a referendum.**

*Public participation in state laws*

The form of public participation in the decision process should be left to the discretion of local and state governments, but public participation should be a basic component of state weather modification laws. This recommendation stems from study conclusions about trends toward public participation, concern about risk-taking with implementation of hail suppression, and citizen preference for local control over the technology's use.

- 4) **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.**

*Need for mechanism to compensate 'losers'*

If an effective hail suppression technology reduces rainfall, there will be little, if any, adoption. Hence, claims of loss due to hail suppression would be rare. If, however, an effective hail suppression technology also increases rainfall, there may be extensive adoption in the semi-arid West. But at certain times of the year some crops, such as hay or cotton, are damaged by rainfall. Any damage from the hail-suppression-induced rainfall cannot be considered an act of God, and equity requires that just compensation be paid.

Depending on a variety of possible events, such payments may run from a few tens of thousands to hundreds of thousands of dollars in a single season within any crop-producing area. The contingency fund to cover such payments should be financed by those who stand to benefit directly from the hail suppression program.

*Assessing damage from hail suppression*

Assessing crop loss for purposes of paying insurance claims is an established practice in the United States. Determining how much of the crop loss is due to the "extra rain" produced by a hail suppression effort is quite different —and it is going to be difficult to accomplish to the satisfaction of all interested parties. Furthermore, the cost of compensation must be taken into account in determining the social value of any proposed projects. But it must be done if hail suppression is to be a viable technology.

## RESEARCH RECOMMENDATIONS - INTERDISCIPLINARY

**We recommend that a national technology assessment study on the modification of precipitation be conducted.**

Based on our findings that rainfall effects were more important than hail effects in economic and socio-political impact, we feel strongly that a technology assessment on precipitation modification is needed.

*Assessment  
of precipitation  
modification*

## RESEARCH RECOMMENDATIONS - SCIENTIFIC AND TECHNICAL

**1) Advancement of the capability to suppress hail can be accomplished through a two-pronged effort.**

a) First should be a well-defined experimental-analytical effort with strong continuity and a focus on all the atmospheric science issues. There should be a parallel effort to monitor closely and evaluate ongoing operational hail suppression projects with a continuing program to integrate the findings from both efforts. A prelude to this is an evaluation of the current status of hail suppression of greater scope and depth than that conducted herein.

*Evaluation  
of current  
status*

b) Second, storm modification hypotheses should be developed to consider the whole convective storm process so as to attempt to suppress hail and reduce strong surface winds attendant with hail. Obviously, these hypotheses should also include a simultaneous goal (and study) of producing no change or an increase in rainfall and a decrease in cloud-to-ground lightning —and to address extra-area effects.

*Study of  
all storm  
processes*

**2) The actual processes whereby hail is modified need to be measured inside seeded storms by aircraft and radar during any hail-only experiments, and the related alterations to the rain process and rainfall production must be established. Particular attention should be given to the entire life cycle of storms and the outcomes from seeding at different stages from storm (cloud) conception to dissipation. Such experimentation with hail suppression also should carefully monitor possible changes in related conditions like rain, winds, and lightning at the surface.**

*In-cloud  
evaluation*

**3) In-depth experimentation should include sufficient sampling of varying storm types (and their physics) and existing technologies (delivery systems and seeding materials), coupled with selected storm sampling in other hail climate zones to ensure transferability of results with a minimum of experimentation elsewhere.**

*Experimentation  
must be  
adequate*

**4) Hail experimentation should include a meaningful mix of scientists with expertise in convective storms and members of operational commercial**

*Blend of  
basic and  
applied research*

companies to produce a good blend of basic and applied research, sensible project operations (directed by an applied-oriented scientist), and a meaningful transfer of the technology to the user.

*Research on  
reliable  
forecasting*

- 5) Synoptic weather conditions responsible for hailstorms should be carefully studied, and reliable objective procedures for adequately forecasting the occurrence, extent, and intensity of storm activity should be developed through research. Data bases from existing mesoscale meteorological projects around the nation should be examined for this effort. Attention should be given to defining those extreme situations where it may not be cost-beneficial to have a system adequate for total suppression effectiveness.

*Research on  
seeding  
technology*

- 6) The effectiveness of various seeding technologies (the delivery systems and the rates and types of seeding materials) must be established relative to the age of the cloud through controlled experimentation and meaningful in-cloud, sub-cloud, and surface measurements of critical phenomena (ice crystals, diffusion, liquid water content, and so forth). As part of this recommendation, methods for understanding and evaluating seeding effectiveness must be developed — involving at least radar echo studies, cloud data (aircraft and satellite), and cloud models.

*Research on  
delivery  
systems*

- 7) Continued research is needed to improve delivery systems and to develop new, more effective, and less expensive seeding materials, including research into broadcast seeding from the ground and aloft. This should be a parallel effort between government and private industry.

## **RESEARCH RECOMMENDATIONS - SOCIO-POLITICAL-ECONOMIC**

*Compensation*

- 1) We recommend a comprehensive study of potential compensatory mechanisms that would be economically feasible as well as socially and legally acceptable.

*Decision-  
making*

- 2) We recommend that research be conducted to further refine the parameters of feasible and socially acceptable decision-making mechanisms.

*Administration*

- 3) We recommend that analysis of alternative administrative arrangements for operational hail suppression programs be conducted. Administrative arrangements may need to vary depending on funding sources.

*Economic  
impact*

- 4) We recommend that economic studies on the effects of hail suppression on local area economies and on the agricultural market be conducted in conjunction with monitoring and evaluation of operational projects.

## RESEARCH RECOMMENDATIONS - LEGAL

**1) Work begun on the development of a model weather modification law for interested states should be continued.**

If hail suppression is to contribute significantly to the national benefit, model laws are needed in advance of the "certification" by scientists of an effective hail suppression technology. We have found that state statutes differ widely in their standards, and we feel that more standardization of state law would be beneficial to everyone.

*Model state  
weather  
modification  
law*

**2) We recommend that a special study be conducted to explore the legal problems involved in the adoption of weather modification (including hail suppression), with the purpose of determining the most appropriate legal theories and approaches to bring to bear and to aid in the development of model compensatory mechanisms.**

The problems of legal theories concerning hail suppression (e.g., proof of causation, need to prove negligence, and damage assessment) are complex, and clearcut solutions concerning them have not emerged from this technology assessment.

*Model  
compensatory  
mechanism*

## RESEARCH RECOMMENDATIONS - ENVIRONMENTAL



Our conclusions have indicated that widespread operational hail suppression would not result in any serious adverse environmental impacts, but that the possibility of adverse effects should not be discounted. The major areas of concern are the effects of silver and altered precipitation on the environment.

*No serious  
impact*

The following specific studies are recommended for initiation or additional attention:

- The effects of altered precipitation on ecosystems
- Basic studies on plant and microorganism adaptation to seeding agents
- The potential for combination of seeding agent silver with other metals, pesticides, power plant emission products, and other pollution sources
- Tracer studies of nucleants in seeded storm cells to locate their deposition in the environment
- Monitoring of silver levels and dynamics in the soil-plant-aquatic environment before and after cloud seeding activities

*Research on  
effects of  
silver needed*

# Subject Index

## ENVIRONMENTAL ISSUES

### Changed Precipitation

44, 47, 53, 55, 78, 83-86, 91, 93,  
94, 111,126,127, 143, 146, 150,  
151, 153,156,157,159, 169,  
170, 172, 184,202,214,215,  
244, 248, 250, 251, 266, 282,  
292,316,317,349,355,356,  
359, 361, 362, 376, 380, 383,  
385, 386, 401-403, 406, 411,  
417-419,421,424,425,427

### Impact Statements

111, 163, 170-172,343,344,346,  
350-355

### Legal Issues

146,151,160,163,170,171,  
340,341

### Seeding Material

78,80,83,91,93, 111,126, 161-168,  
173,184,224,226,230,291,  
339-344, 362, 367, 368, 373, 376,  
377, 382, 397, 411,418, 425-427

## HAIL CLIMATE

### Big Hailstorms

11, 14,17-19,21-24, 101, 106,  
214,320

### Equipment for Measuring Hail

110,112-116,230,278

### Hail Regions

10-12,14, 15 (map), 17,20-28,30,  
33, 41, 42, 216, 231, 241, 245, 248,  
262, 267-272, 291, 317-320, 323,  
331,397

### Variations with Time and Space

9-22, 24, 25, 33, 118, 192, 216,  
291,417

## HAIL ECONOMIC ASPECTS

### Crop Regions

28, 29, 59, 61, 77, 95, 99, 101, 103,  
118, 197, 202, 204, 206-208, 239-242,  
245-249, 251-253, 256, 261, 262-264,  
269-272, 306, 328, 349, 351, 370,  
371,380,386

### Crops Damaged

14, 16, 17, 20, 22-25, 27, 31, 33, 46,  
59,77,95,101, 103, 104,118, 190,  
202-206, 214, 261, 305, 320-322,  
329, 353, 368, 380, 417, 424

### Monetary Losses

14, 19-25,27,99,101,103, 104,  
118, 193-195, 230, 247, 248, 417

### Property Damaged

11, 12, 26-28, 33, 95,105-107, 118,  
214, 230, 305, 317-322, 329, 354,  
356, 372, 381, 417

Reductions in Loss from Hail Suppression

40, 55, 67-70, 77, 95-97, 190, 191,  
195,197, 201-208, 229, 239-245,  
250, 265-287, 293-324, 328, 356,  
361, 363, 371, 372, 374, 376, 380,  
383,386,389,391,417

Secondary Effects

3, 4, 88, 161, 165-170,185, 268,  
269, 274, 275, 320, 332, 354,  
356,417

Stakeholders

87, 95-118, 231, 259, 287, 303,  
305, 317, 350, 352, 365, 367, 368,  
371, 373, 375-377, 384, 386-389,  
392, 397, 399, 404, 407, 409, 415,  
418,419,421

**HAIL INSURANCE**

Crop

25, 26, 30, 33, 47, 96, 98, 99,  
102, 103, 118, 197-203, 283, 305,  
306, 323, 329, 368, 369, 377,  
386, 389

Federal

30,98, 101-104,118,146, 197,  
201,202,205,316,317,363,  
369,387,403,405,421

Impacts of Hail Suppression on Insurance

7, 30, 31, 67, 98, 104, 145, 276,  
305-324, 329, 330, 348-360, 363,  
367-369, 374-376, 380, 384, 386,  
390, 402, 403

Property

26,27,30,105-107,118,230,  
305,317-323,329

**HAIL SUPPRESSION**

Costs, Research and Operational

25,50,51,90,93, 108-113, 137,  
191,201,214,225-229,231,  
232, 236, 276-280, 283-285,  
288-290, 293-299, 301, 304,  
322, 329, 357, 364, 366, 397-403,  
410,412,414,418,421,423

Current Status

40,54,61,66-71,77,78

Downwind

111,214, 244, 246, 336-338, 356,  
360, 375, 383, 386,388,411

Evaluation

39-41, 53, 66-70, 77, 78, 89-92,  
94, 107,111, 123, 124,126, 143,  
213, 228-232, 236, 265, 276, 277,  
279, 289, 293-300, 329, 330, 339,  
363-367, 378, 380, 385, 387, 397,  
399, 401, 403, 405, 411-413, 415,  
418,421-423,425,426

Foreign Usage and Issues

38, 39, 63-66, 68-70, 82, 107, 110,  
145, 292, 314, 364, 370, 371, 378,  
384,388,419,423

Future Capabilities and Models

191, 192, 194, 198-237, 239-257,  
259-287, 290, 293-324, 328, 329,  
347-391,418,421

History of Cloud-Seeding Activities

1,37-60

Methods, Techniques, and Equipment

12, 51, 68, 69, 78, 82-85, 89-91,  
93, 107-109,114, 144,145, 161,  
162, 213, 214, 222-229, 231, 236,  
278, 304, 342, 354, 367, 368,  
376, 377, 382, 425, 426

Modification Industry

39, 40, 44, 46-50, 87-89, 91, 95,  
105-109,118,140,303,304,  
323, 329, 350, 364, 366-368,  
370, 378, 382, 384, 397, 404,  
405, 407, 411

Principles of Modification

28, 29, 37, 79-82, 84, 86, 93, 291

Research

16, 39-41, 50, 51, 67-69, 78, 87,  
88,90-93,95,97, 109-113, 118,  
123, 131,146, 149,195,213,  
214, 218, 230-232, 236, 277-279,  
283-302, 322, 328, 329, 363,  
364, 368, 377, 378, 380, 383,  
385, 388, 392, 396-399, 412, 414,  
418,421,422,425,426

Scientific Consensus

69-71,77,120,131, 132, 184,  
249, 252, 256, 288, 290, 349,  
371,380,381,397,421

## LEGAL ISSUES

### Federal

111, 138, 143-146, 149, 150,  
155, 170-173, 184, 314, 332-335,  
350, 353, 362, 363, 377-379,  
383, 388, 392, 397-399, 403-408,  
414, 415, 419, 423

### International

336-338, 346, 350, 351, 364, 370,  
371, 377, 378, 384, 388, 390,  
419, 423

### Licenses and Permits

140-145, 184, 332, 334, 362,  
403-406, 408, 410

### State

138-143, 146-149, 154, 155,  
157-159, 171, 184, 243-245,  
249, 252, 256, 311-313, 331-336,  
346, 350, 351, 358, 360, 362,  
364, 372, 374-378, 380, 383,  
384, 390, 397, 398, 402-404,  
406, 408, 414, 419, 423, 424,  
426

## SOCIETAL ISSUES

### Adoption

45, 46, 50, 54, 55, 59, 60, 62,  
119-123, 132-137, 144, 148, 149,  
184, 189, 192, 213, 214, 239-257,  
260, 265, 272-274, 280-283, 301,  
331, 347-390, 418-420, 423, 424,  
426

### Controversy

39, 43, 46-48, 52-57, 77, 132,  
143, 245, 287, 288, 356, 357,  
359, 360, 372, 375, 376, 380,  
383, 411, 419

### Opinion Surveys

45, 51, 52, 61-63, 71, 77, 78, 119,  
123-131, 141, 184, 232, 233, 236,  
303, 304, 313-315, 329, 395

### Opposition

43, 46-49, 52-60, 77, 120, 130,  
131, 136, 137, 143, 158, 244-246,  
251, 382, 409, 419

### Public Participation

45, 50, 52, 58-60, 120, 122-124,  
127, 128, 132-135, 141, 142,  
184, 382, 397, 399, 407-410,  
415, 419, 424

# Glossary of Acronyms

AMS	American Meteorological Society
ASCS	Agricultural Stabilization and Conservation Service
ASP	Advanced Studies Program
BWI	Better Weather, Incorporated
CAP	Chicago Area Program
CCC	Commodity Credit Corporation
CHIAA	Crop-Hail Insurance Actuarial Association
DEI	Design, Evaluation, and Program Information Activities
DESH	Design of an Experiment to Suppress Hail
EII	Economic Incentive Index
EPA	Environmental Protection Agency
ESIG	Environmental and Societal Impacts Group
FAA	Federal Aviation Administration
FCIC	Federal Crop Insurance Corporation
FDA	Food and Drug Administration
FRNW	Farmers and Ranchers for Natural Weather
HERS	Human Ecology Research Services
HIPLEX	High Plains Experiment
IAI	Impact Assessment Institute
I CAS	Interdepartmental Committee on Atmospheric Sciences
ISWS	Illinois State Water Survey
METROMEX	St. Louis Metropolitan Meteorological Experiment
MPCI	Multiple Peril Crop Insurance
NACOA	National Advisory Committee on the Oceans and Atmosphere
NAS	National Academy of Sciences
NCAR	National Center for Atmospheric Sciences
NDPP	North Dakota Pilot Project
NDWMP	North Dakota Weather Modification Program
NEPA	National Environmental Policy Act
NFS	National Forest Service
NHRE	National Hail Research Experiment
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service



NSF	National Science Foundation
OMB	Office of Management and Budget
PV	Present Values
PWIA	Plains Weather Improvement Association
RANN	Research Applied to National Needs
SDWMP	South Dakota Weather Modification Program
SELP	Social—Economic—Legal—Political
SESAME	Severe Environmental Storm and Mesoscale Experiment
TASH	Technology Assessment of the Suppression of Hail
TRIP	Total Revenue Increase Potential
TWDB	Texas Water Development Board
UCAR	University Corporation for Atmospheric Research
USDA	U. S. Department of Agriculture
USPHS	U. S. Public Health Service
WMO	World Meteorological Organization