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A National Program for Accelerating Progress in Weather Modification

Interdepartmental Committee for Atmospheric Sciences

This Program was approved by the Federal Council for Science and Technology on July 27, 1971

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SUMMARY

This report proposes a program for accelerating national progress in the management of our national resources through a structured attack on certain defined objectives in the area of weather modification. National needs have been identified. Research efforts which have clear near term potential for meeting these needs have been identified as National Projects. A special designation of National Pilot Project has been assigned for one activity designed to gain experience with operational problems. Lead agencies have been recommended and pertinent multiagency assistance has been proposed to accelerate progress in each Project.

National Projects represent an increased emphasis on about one-half of the existing weather modification research and development programs; some $9 million of a FY 1972 $20 million program. The fact that socioeconomic, legal and ecological considerations must play the dominant role in determing the operational readiness of any technological system which may affect the environment of large segments of the population is recognized.

The proposed National Projects and Lead Agencies are:

National Colorado River Basin Pilot Project - Bureau of Reclamation
To test the feasibility of applying a cloud seeding technology, proven effective under certain conditions, to a river basin for a winter season to augment the seasonal snowpack.

National Hurricane Modification Project - National Oceanic and Atmospheric Administration
To develop a seeding technology and associated mathematical models to reduce the maximum surface winds associated with hurricanes.

National Lightning Suppression Project - Forest Service
To develop a seeding technology and associated physical and mathematical models to reduce the frequency of forest fire-starting lightning strokes from cumulonimbus clouds.

National Cumulus Modification Project - National Oceanic and Atmospheric Administration
To develop a seeding technology and associated mathematical models to promote the growth of cumulus clouds in order to increase the resulting natural rainfall in areas where needed.

National Hail Research Experiment - National Science Foundation
To develop a seeding technology and associated mathematical models to reduce the incidence of damaging hailfall from cumulonimbus clouds without adversely affecting the associated rainfall.

National Great Lakes Snow Redistribution Project - National Oceanic and Atmospheric Administration

To develop a seeding technology and associated mathematical models to spread the heavy snowfall of the Great Lakes coastal region farther inland.

National Fog Modification Project - Federal Aviation Administration
To develop seeding or other technology and associated physical and mathematical models to improve the visibility in warm and cold fogs where and to the extent needed.

Each of the National Projects has a background of years of research. That research has, within the last few years, developed a combination of theoretical knowledge and associated mathematical models, supported in varying degrees by field experimental data, which indicates that technology now available is nearly ready for regular application. Organization of these activities into National Projects has been recommended, with specific multi-agency participation, to insure the earliest practicable availability of operational technology.

In addition to the special support for these National Projects a significant increase in relevant broad background research and development support is also needed. This is particularly needed in the areas of nuclei counting and efficiency assessment, the physical chemistry of nucleating agents, the microphysics and dynamics of mesoscale systems, mesoscale mathematical models, and cloud physics instrumentation, such as doppler radars and microwave sensors.

Specific recommendations are also made to establish a national depository for weather modification data, for the study of and effective handling of the socioeconomic legal aspects for the future, and for certain ecological and hydrological studies to be performed.

Chapter I.

INTRODUCTION

Bjerknes said, "Man is born, lives, and dies in an ocean of air called the atmosphere."

The extent and capricious behavior of this atmosphere has amazed and terrified man throughout the ages. Over the same period, it has sustained him with water for his crops and with power to drive his mills. Today, under the pressure of the social needs of a burgeoning population man can no longer be content to bear stoically the extremes of nature's favors.

In the recent past, many individuals, groups, and organizations have conducted weather modification studies and carried out field experiments, cooperatively and otherwise, on behalf of their individual and often mutual interests. This storehouse of scientific knowledge, and the extensive field experience, derived over the past 25 years by the Federal, academic, and industrial community combined with newly developed instrumentation and computer technology, must now be applied to the problem of managing effectively one significant segment of our environment for the benefit of mankind.

Specifically, the areas considered for a coordinated national effort to meet identified national needs are precipitation management for water resources, reduction of damage from hail, lightning, and violent storms, and improvement of visibility in fogs. Our state of knowledge and operational readiness is greater in some areas than in others. However, some beneficial results can now be achieved for our economy and ecology. Attainment of these goals will provide man with more food, more power, and better environment and, above all, more peace of mind. The estimated cost of such a program is small compared to the cost of inaction.

The potential benefits to various segments of the national economy are reasonably clear, although not quantitatively precise. It appears, however, that the ultimate application of the technologies under development to the pertinent problems involved, could result in benefit-cost ratios of from 2 to 1 up to 20 to 1.

In areas served by the Colorado River Basin, where, for just the irrigation benefits, increased water is worth up to $50 per acre-foot per year, conservative indications are that the increase in runoff resulting from the planned snowpack augmentation program will amount to over 2,000,000 acre-feet at a cost of about $1.50 per acre-foot. The increased capability for power generation, alleviation of critical shortages, and salinity control are bonuses which would insure the maintenance of very favorable benefit-cost ratios.

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Hurricane damage in the United States averages about $500 million per year. Recent results of the joint hurricane modification Project Stormfury indicate a potential for reducing maximum surface winds by 10 to 20%. Possible reductions in damage of considerably more than 10%, coupled with the possibility of saving even a few lives, indicate a favorable return on funds supporting Stormfury.

Over two million acres of forests in the western United States are burned annually by lightning-caused fires. To the terrible although indeterminate cost of such forest fires must be added the cost of about $100 million and some human lives each year fighting the fires. Experiments conducted over a limited area of the Northern Rocky Mountains by the Forest Service Project Skyfire indicate a reduction of over 50 percent in fire-starting lightning activity. These results promise a very favorable benefit-cost ratio for a lightning suppression program.

In certain areas, such as the Florida peninsula, traversed by moisture-laden but sometimes nonprecipitating or very lightly precipitating cumulus clouds, increases in precipitation can be accomplished by cloud seeding. In some areas during periods of local need, such augmentation of rain can be worth $50 per acre-foot and recent experiments indicate that in limited areas, rainfall augmentation can be accomplished for less than $1 per acre-foot.

Annual hail damage in the United States amounts to over $300 million. Where limited areas of certain crops have been "protected" by commercial seeding operations, reported benefit-cost ratios have been generally better than 2 to 1. The development of adequate models of hail producing clouds and consistently effective seeding techniques should insure effective protection of high priority areas at very favorable benefit-cost ratios.

Annual snow removal costs for the City of Buffalo amount to about $2 million. Potential amelioration of associated social and economic problems in a high population density area added to the reduction of excessive snow removal costs calls for continuing experimental efforts to delineate the capability and to develop an economically effective technology for reducing the intensity of major lake-effect snowstorms.

Annual costs to the U. S. airlines of delays caused by warm fogs at airports are over $75 million. Highway and harbor fogs add considerably to this figure in terms of transportation delays, damages, injuries and deaths. Thus warm fog modification possibilities under investigation warrant intense efforts to develop effective techniques which can approach the better than 5 to 1 benefit-cost ratio for current cold fog modification activities at frequently affected airports.

If a program for accelerating progress in weather modification is to be successful, it must include careful consideration of the role that public perception of weather modification will play. In the past, public acceptance

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OFFICE OF SCIENCE AND TECHNOLOGY
Washington, D. C. 20506

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For further information contact:
Capt. W.S. Betts
Interdepartmental Committee for
Atmospheric Sciences, Wash., D.C.
(202) 967-2310

WASHINGTON -- The Federal Council for Science and Technology today consolidated a number of prime government weather modification efforts into seven key projects as a prelude to actual operational weather control.

One now underway actually involves weather manipulation. It is a pilot project of controlled cloud seeding by which the Bureau of Reclamation of the Department of Interior is attempting to increase the snowpack in the Colorado River Basin for five consecutive winters.

According to Dr. Edward E. David, Jr., Chairman of FCST and the Science Adviser to the President, the seven projects should remove most of the remaining technical barriers to operational snow diversion, rain-making, fog dispersion, hurricane modification and lightning and hail modification.

The Colorado River pilot project's aim is to store water in the form of snow. As the snow melts, towards the spring runoff, it then recharges the reservoirs from which water is distributed for use throughout the Southwest and Mexico during dry seasons.

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Colorado River snowpack is concentrated at altitudes of 9,500 feet or more in a 14,000 square mile area. This represents some 10 per cent of the entire river basin. The pilot project involves only 2,200 miles of that total, part of the San Juan Mountains of Colorado.

Planners anticipate a 15- to-20 per cent increase in water runoff in the test section.

If the same augmentation were achieved operationally over the entire snowpack area, some 400,000 acre/feet of water (the amount required to cover an acre to a depth of one foot) in an area where water costs up to $50 per acre/foot, it would not only add to the water available but might even bring the price down.

The estimated cost for producing each additional acre foot is only $1.50. If the entire 14,000 mile area of the upper Colorado were seeded, as much as two million acre/feet worth $100 million could be produced.

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The FCST report also called for a national repository of weather modification data and additional support of basic research in the chemistry and physics of weather modification which are not part of the seven key projects. Both, it felt, would "insure the earliest practical availability of operational technology."

Weather modification is now being widely used abroad, particularly in the Soviet Union for hail suppression. The FCST report contains a section on the state of weather modification both here and abroad.

All seven projects are keyed to the fact that silver iodide crystals introduced into clouds form nuclei around which ice crystals form. How and where they form has important implications for cloud dynamics and the release of both heat and moisture, the controlling factors in weather systems.

The six remaining projects are more research-oriented. Three of them are being conducted with the National Oceanic and Atmospheric Administration as lead agency. They are:

A hurricane modification project designed to work out seeding techniques which will reduce the maximum wind velocities of these storms and development of mathematical (computer) models of hurricanes;

A snow redistribution experiment designed to test the feasibility of directing snowfall inland from -- rather than on -- the shores of Lake Erie, and;

A cumulus cloud modification project to increase rainfall in specific areas.

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A cumulus cloud modification project to increase rainfall in specific areas.

The U. S. Forest Service of the Department of Agriculture will try to modify the lightning potential of summer storms as a means of preventing forest fires.

The Federal Aviation Agency of the Department of Transportation will try to develop a low cost fog dispersion system involving mathematical modeling and work out a basic understanding of how and why fog forms. The National Science Foundation will attempt to work out seeding technology and mathematical models aimed at reducing hail damage without interfering with rainfall.

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(The report is available from Capt. W. S. Betts, Interdepartmental Committee for Atmospheric Sciences, Department of Commerce, Washington, D. C. 20230.)

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of weather modification has varied widely across the nation. Indifference, amused tolerance, ardent advocacy, and violent opposition have all been evidenced. In the same year that citizens of South Dakota asked for Federal help in the institution of a statewide precipitation augmentation and hail suppression program, citizens of some eastern states were reported to be shooting at transient aircraft assumed to be conducting cloud seeding as part of a suspected Federal "plot" to cause widespread drought.

Experience has shown that adverse public reaction can easily force changes in the design or outright termination of weather modification projects. Acceptance of weather modification has been greatest where it has resulted from the initiative of local interests with local benefits in mind. Weather modification imposed from afar with no obvious local benefits, and perhaps even likely disbenefits in the experimental area, can be expected to generate intense public opposition.

Inclusion at an early time of respected local citizens in the planning and monitoring of weather modification activities has proven effective both in improving scheduling and design and in forestalling development of uninformed opposition.

Workable systems for weather modification must include three considerations. These are:

1. Scientific and engineering variables
2. Human variables
3. Resource variables

The program described in the following pages aims at accelerating progress in weather modification with due regard for all three.

Chapter II.

WHERE WE ARE NOW IN WEATHER MODIFICATION

Many people consider the terms weather modification and rainmaking to be synonymous because of the publicity given to the discovery of cold cloud modification to produce precipitation in the mid-1940's. In the mid-1930's, however, Massachusetts Institute of Technology scientists demonstrated a capability to dissipate warm fog by the application of calcium chloride solution distributed into a fog bank by spray nozzles. The uses of both freezing and hygroscopic nuclei to modify weather are still the primary tools of weather management to augment our atmospheric water resources and to reduce the hazards produced by weather.

Atmospheric Water Resources Management

Much of the present effort in weather modification today is being devoted to the objectives of clean water augmentation. Years of experience of private and public groups in efforts aimed at increasing the winter snowpack over mountain ranges for water and recreational use have now been acquired. In the spring the snowpack melts and provides the runoff for the river basin areas which produce water for urban use, electrical power generation, and irrigation. The meteorological circumstances under which cloud seeding will effect snowpack increases over the mountains have now been reasonably well identified, and in several locations this knowledge is well enough established to justify the initiation of pilot or preoperational tests directed toward obtaining answers to the economic aspects of water increases, operational procedures, and ecological consequences of such augmentation. At Climax, Colorado, where research on snowpack augmentation over the mountains has been conducted for a period of 6 years, it has been found that increases of over 100 percent in individual storm snowfalls can be expected if the temperature at the 500 millibar level, which is usually also the level of cloud tops, is between minus 12°C and minus 23°C when seeding is conducted. If the 500mb temperature is colder than minus 25°C, the effect of seeding is to reduce the amount of snow which would normally fall on the windward slopes. In some of the colder cases, snow reduction of up to 50 percent was observed. This is consistent with the physical behavior of natural and artificial ice nuclei. More important, it explains the sometimes erratic results of earlier tests in which seeding was done indiscriminately. Stratification of seeding criteria has also been made for various conditions of wind velocity, wind direction, lapse rate and other meteorological parameters, and optimum seeding limits have been established. If these criteria are carefully observed, positive augmentation due to seeding is almost assured in this locality.

Much remains to be learned of the basic meteorological processes which take place in the atmosphere before these successful techniques can be applied directly to other geographical areas having somewhat different meteorological environments. The establishment of adequate mathematical models to describe and forecast the reaction of orographic clouds to seeding are now under development and show considerable promise of providing this universal capability in the near future. Improved methods of evaluating the results of modification are expected to also emerge from these basic model studies.

The augmentation of water from summer convective cloud systems has been tested in areas such as Florida, Arizona, and the midwestern Great Plains with mixed but lately encouraging results. Due to the fact that precipitation from these cloud systems is not confined to any particular groundwater system and normal precipitation patterns are so variable on an areal and temporal basis, it is difficult to evaluate either the economic or ecological impact of potential artificial augmentation attempts. In experiments conducted in Florida, observations of selected tropical clouds which have been seeded with silver iodide according to mathematical model prediction have indicated a growth in height averaging more than 10,000 feet over the unseeded systems and an increase of precipitation as deduced from radar measurements of approximately 100 acre-feet of water per cloud. This is a statistically significant increase in normal precipitation expectations of approximately 100 percent. With the improved capability to measure cloud parameters directly from instrumented aircraft or indirectly from the ground and the further development of forecasting capabilities using mathematical models, it would appear reasonable to expect that the stimulation of convective clouds in general will be advanced to operational usefulness if a national effort is focused on this problem.

In addition to stimulating increased quantities of precipitation from existing cloud systems, there is also the possibility of diverting precipitation from areas already receiving more than an adequate water supply to those in need of additional precipitation. In many cases, this could take the form of suppressing the formation of precipitation on the upslope of a mountain chain and the stimulation of rainfall on the downslope, thus reducing the effects of the natural rain shadow. By diverting the precipitation from one side of the mountain to the other, an entirely different watershed distribution could be obtained.

Over the Great Lakes, seeding experiments are being conducted to redistribute snowfall from large accumulations on the shoreline to a more even distribution over many thousands of square miles inland. This is being accomplished by supplying freezing nuclei to the cloud system over the Great Lakes in accordance with a three-dimensional mathematical model. The seeding is designed to convert supercooled water droplets in the cloud into ice crystals which drift miles inland instead of forming rimed snow pellets which fall out on the shoreline and create highway hazards and power distribution failures.

Although research is still in the exploratory stages in this field of precipitation mangement, there is reason to believe that it will eventually result in a practicable form of water resource management.

It should be noted that the emphasis of the present program of atmospheric water management is directed toward increasing or diverting precipitation from existing cloud systems which nature provides. The alleviation of long-term drought is, unfortunately, beyond the reasonable expectation of these techniques because they require the presence of cloud systems containing adequate water budgets. In many long-term drought situations, the lack of precipitation is caused by the persistence of dry air masses over the distressed area, and the means to divert moisture-laden air masses over these arid regions contrary to the naturally established global circulation patterns have not yet been developed. Studies of these large-scale circulations and their modification potential at present are being performed largely through computer simulation based upon worldwide data supplied by satellite, aircraft, ship, and ground network observations. Projects such as the Barbados Oceanographic and Meteorological Experiment (BOMEX) and Global Atmospheric Research Program (GARP) will add to our knowledge of these energy exchange processes. The development of a new generation of computers starting with ILLIAC IV will greatly accelerate our understanding.

The increasing capability to manage our atmospheric water resources is being developed largely by the Department of the Interior's Bureau of Reclamation, and is based upon the research information in basic atmospheric mechanisms provided by programs of the National Science Foundation (NSF), the National Oceanic and Atmospheric Administration (NOAA), and the Department of Defense (DOD). A close working relationship among these Federal agencies, coupled with the experience and expertise developed over the years by the academic and industrial sector of the atmospheric science community, has brought us today to the threshold of application of weather modification technology for the benefit of mankind.

Weather Hazards

Since the beginning of time, man has learned to respect and fear the destructive powers of the weather. The loss of property and lives due to floods, winds, lightning, and hail has been reduced by the increased accuracy and lead time of forecasting, but the basic problem of alleviating the forces of severe storms remains one of the primary objectives of weather modification research. In these times of high speed travel in the air, on the land, and on the sea, the reduction of visibility due to fog has also become a hazard which must be lessened.

In the past decade, the loss of life due to hurricanes has decreased because of improved warning capabilities, but the loss of property has continued to soar, reaching 1.5 billion dollars in 1969. Airborne, ship, and shore based instrumentation, including powerful radar installations, have provided sufficient information on the structure of hurricanes to develop mathematical models of their behavior. These lead to the expectation that the maximum wind speeds, which sometimes exceed 200 miles per hour in the central eyewall, could be significantly reduced if the diameter of the eye could be enlarged. Computations indicate that massive seeding of the cloud region just outside of the eyewall of the storm with silver iodide should produce this effect.

On August 18, 1969, research aircraft and scientists of the National Oceanic and Atmospheric Administration and the Department of Defense seeded hurricane "Debbie" with massive quantities of silver iodide with five seeding flights over an 8-hour period. The treatment was applied to the storm in accordance with the computer model recommendations. Aircraft penetrations of the storm before, during, and after treatment showed an overall reduction of 30 percent in maximum wind speed several hours after the last seeding.

Forty-eight hours after the first seeding, reconnaissance flights through Debbie showed the existence of a concentric double eyewall near the center of the storm which had by then reintensified in wind velocity. A series of five additional seeding flights at 2-hour intervals were followed by a reduction of 15 percent in maximum wind velocity. Tests in earlier years showed qualitatively similar results. This provides hope that the reduction in the destructive power of the hurricane, without affecting its overall beneficial rainfall aspects, may become an operational reality in the near future. Modeling efforts and open sea seeding tests on hurricanes are being accelerated.

Damage to property and agricultural crops by severe hail in the contiguous United States amounts to over $300,000,000 each year. A cooperative program of research on the formation of hail in severe thunderstorms has been established in Colorado under leadership of the National Science Foundation and in cooperation with the National Oceanic and Atmospheric Administration, the Department of Agriculture, the Department of Interior, Atomic Energy Commission, the National Aeronautics and Space Administration, the Department of Transportation, and the Department of Defense.

The objective of the field experiments, which are being coordinated through the National Center for Atmospheric Research, is to understand the natural mechanism of hail formation in severe storms sufficiently well to recommend, develop, and test techniques for suppressing the formation of hail. With the assistance of the academic and industrial sectors of the scientific community, mathematical models of the various types of hailstorms encountered in South Dakota, Nebraska, Illinois, and Colorado are being constructed and the prediction of the results of ice nuclei injection upon the dynamics and hail-forming mechanism of the storm is being tested.

Preliminary evidence of hailstorms investigated to date indicate that the two distinct types, namely airmass and squall line storms, will require different treatments.

Impressive success has been reported by the Soviet antihail field program which operates in nine different areas protecting millions of acres by radar-targeted projectiles carrying nucleating agents.

Some success in suppressing hail on an operational basis has also been reported by commercial operators in North Dakota, Texas, Canada, Kenya, and other areas, but the basic system for the evaluation of results still remains one of the problems yet to be resolved. While the suppression of hail may now appear to be possible by massive over-seeding of growing convective cloud cells to destroy their growth, this is not considered an acceptable solution if the end result is a deficiency in regional rainfall. More sophisticated techniques must be developed, based upon mathematical modeling, which will stimulate or not affect rain production at the same time that hail is suppressed.

The large losses in forest resources each year caused by lightning-induced forest fires has prompted the U. S. Forest Service of the Department of Agriculture to conduct a series of experiments in Montana which are directed toward the reduction of ignition-causing lightning strokes by massively seeding "dry" thunderstorms over the national forests.

These tests have produced statistical evidence which has suggested a substantial reduction in the number of cloud-to-ground lightning strokes. Moreover, this treatment modifies the long duration cloud-to-ground lightning strokes believed to be responsible for the ignition of lightning fires. Basic research to shed further light on the mechanisms of lightning suppression is being conducted by both the National Science Foundation and the National Oceanic and Atmospheric Administration. In addition, the Bureau of Land Management, and the Bureau of Reclamation of the Department of the Interior, the Forest Service of the Department of Agriculture, the National Oceanic and Atmospheric Administration of the Department of Commerce and the Air Force are collaborating on a study of means to stimulate precipitation for controlling forest fires through cloud seeding. A test program is now being carried on in the the forests of Alaska. In addition, during the 1970 forest fire emergency in the Pacific Northwest, the Forest Service performed pioneering operational trials of seeding technology for both lightning suppression and reduction of fire danger.

The reduction of visibility over airport runways due to fog is responsible for many lost hours in aircraft traffic. The dissipation of fogs containing supercooled water droplets is reasonably well understood. Such cold fog dissipation programs particularly those utilizing airborne techniques to seed the fog with dry ice are operational at several commercial and military airports.

The more difficult dissipation of warm fog is receiving increasing attention. There are many studies being made, largely in the Department of Defense, with significant contributions by the National Aeronautics and Space Administration, on techniques for dissipating warm fog which involve the use of heat along the runway or the use of hygroscopic nuclei to precipitate the water vapor in the fog and produce fog droplet evaporation. Several of these methods have been successfully demonstrated from time to time, but economic considerations or the possibility of corrosive contamination have restricted their operational use. The use of helicopter downwash to clear ground fog has been tested by cooperating agencies in the Department of Defense and has been given limited operational tests in areas of military operations with some success. The U. S. airline operators have tested various warm fog dissipation techniques using hygroscopic nuclei, polyelectrolytes, and surfactants on an experimental or semioperational basis. The lack of adequate scientific measurement techniques for fog and the need of a more adequate evaluation system has retarded the consideration of warm fog dissipation techniques for operational use in the immediate future. The Federal Aviation Administration (FAA) of the Department of Transportation is developing a systematic approach to the problem considering all aspects of fog dissipation, including fog inhibitors, measurement techniques, mathematical modeling, laboratory experiments, ecological impact, and particularly test and evaluation techniques.

The most violent of all severe storms are those which give rise to tornadoes. These funnels, however, are of such transient nature that new techniques involving remote sensing from the air or the ground must be developed before experiments to investigate them and explore possible modification procedures can be accomplished. Most of the tornado suppression research today is confined to theoretical study, computer simulation, and to laboratory experiments in rotating water tanks or wind tunnels. The probability of devising a field procedure for testing tornado suppression is small for the next 3 to 5 years, since the nature of tornadoes is not sufficiently understood and no convincing suppression concept exists at this time. The future outlook will be influenced strongly by studies of severe storm mechanisms. Efforts are also under way to track tornadoes and to investigate the circumstances under which a milder form, the waterspout, is generated over the warm waters of the Florida Keys.

Techniques to modify the microclimate from treetop level to the ground have been used to provide field crops and orchards with a protected environment. It has long been the practice to use rows of sturdy trees to break the force of winds that can damage crops. Heaters and large fans have long and widespread use in frost protection. More recently, artificial fogs, stabilized against evaporation with small amounts of chemicals such as hexadecanol, have been used to reduce radiant heat loss as a means of fighting frost. Sprays of plain water are used to provide evaporative cooling to protect crops from extreme heat. These practices will continue to be improved as our knowledge of the surface boundary layers of the atmosphere increases and our engineering and agricultural knowledge continues to grow.

Pollution and Weather Relationships

Atmospheric scientists have long recognized the important role of solar radiation in providing the source of energy to drive our global atmospheric circulation system. Recently it has become evident that there is a strong interaction between the composition of the atmosphere and solar-induced weather behavior. Observations made by the Mauna Loa Observatory at Hawaii have shown an increase in carbon dioxide content of the atmosphere of approximately 0.2 percent per year apparently due to the combustion of fossil fuels by man. Calculations show that an eventual doubling of the amount of carbon dioxide in the atmosphere could result in a 2°C rise in average temperature of the earth's surface and a drop in temperature at the 40,000-foot level of approximately 15°C.

Increased quantities of particulates in the atmosphere could produce the opposite effect at the earth's surface. Over the past 10 years, a decline in temperature has replaced decades of gradual warming. This has been interpreted by some scientists as evidence that the particulate increases due to pollution are now sufficiently high to have reversed the long-term warming trend. Atmospheric scientists have reported over the past 5 to 10 years visual changes in the appearance of clouds over the heavily populated northeastern portion of the United States which they believe are caused by the increased glaciation of supercooled clouds by surface released pollution. There has been considerable speculation that the source of these increased ice-forming nuclei can be traced to lead released by the combustion of fuels in automotive and aviation engines. There are special efforts under way to evaluate the potential long-term effects of future Super-Sonic Transport operations on the world's weather through the concentration of added particulates in the lower stratosphere.

Studies of freezing nuclei over the Great Lakes in 1969 have shown concentrations of approximately 10 times normal background in the downwind plumes of cities such as Cleveland and Toronto, and in some instances it was possible to observe snow showers which may have been triggered by these pollution plumes. Climatological studies of anomalous rainfall associated with industrial complexes, have been reported in the scientific literature, and correlations between rainfall and steel mill operations are impressive. The burning of sugarcane slash in Tasmania has been correlated with the reduction in rainfall in that area, and a similar phenomenon was noted by research workers in the Philippines. Although more information is required to confirm these observations, it does appear that a delicate balance exists between the composition of the atmosphere and the weather patters which occur.

It is evident that we must intensify our efforts to minitor globally the ever-increasing burden of atmospheric pollution. At present, a number of atmospheric constituents are being monitored in Hawaii, at the South Pole, and in Boulder, Colorado. Additional stations are planned for the eastern United States and Canada. Further ground-based, airborne, and satellite atmospheric observations must be initiated at the earliest possible date over the entire surface of the earth and oceans in order that we may properly evaluate the extent of the interaction between pollutants and the weather and find ways to combat their deleterious effects by more effective atmospheric management procedures.

Technology and Tools

A great deal of the technology of weather modification is based upon the understanding of smaller scale physical processes than those of concern to the weather forecaster.

In the identification and measurement of parameters, the chemist, the physicist, and the engineer have all made important contributions to our understanding of atmospheric mechanisms. The mathematicians and statisticians have assisted in the design and interpretation of experiments and are now developing a capability to construct mathematical models from which a quantitative approach to weather modification is emerging

Instrumentation - Aircraft instruments are now in existence to measure in situ: water vapor, liquid water, rate of riming, cloud drop size and number density, ice crystal type and size and number density, ice nuclei concentration as a function of activation temperature, condensation nuclei as a function of activation supersaturation, temperature in cloud, vertical and horizontal wind, turbulence, cloud particle charge, strength and direction of the electrical field, etc. There is difficulty in making the instruments work reliably in the severe environment in which they must perform, and the data collection and analysis are tedious and difficult. Unfortunately, the accuracy to be achieved with many of these instruments is open to question and much further research is required.

Remote sensing is an ideal way to collect information for real-time decision making. Weather modifiers have in general adapted surplus military radars for mapping precipitation in space-time and found them to be invaluable though not ideal for their purposes. Doppler radars which use precipitation particles as targets and which measure the flow field inside large convective clouds have been successfully developed and will soon come into use.

Increasing use is being made of telemetered information from remote weather stations in the nearly inaccessible mountain snowshed regions. These measure: snow accumulation, wind direction and speed, air temperature, rime accumulation, etc. The Forest Service's Project Skyfire has developed systems to sense information about the electrical characteristics of lightning strokes simultaneously from a number of observation stations and from aircraft. In some projects, cloud physics information is telemetered from aircraft back to the project command and control center.

Seeding Materials - Most cloud modification practiced at present uses ice-phase seeding, but warm cloud seeding is potentially very important. For ice forming nuclei, such substances as silver iodide, complexes of silver iodide and alkali iodides, lead iodide and its degradation products and complexes have been used. A study of cupric sulfide has been made by Soviet Scientists, and this material has been proposed for more extensive evaluation, but no practical means of dissemination is apparent. Organic nucleating materials cometimes show excellent promise in laboratory experiments but so far have yielded less attractive results in field experimentation. Attention is also being directed toward the assessment of the ecological impact upon the environment which might result from the widespread release of these materials into the atmosphere in future operational programs. Materials which provide minimal impact upon the environment when used in the usual dilute concentrations will be favored for large seeding projects, and work will continue on the development of suitable nucleants with biodegradable properties.

Much confusion in the field has resulted from a lack of appreciation of the role of nuclei chemistry. For instance, it has been generally considered that the ice nuclei activity of silver iodide-sodium iodide-acetone burner products is attributable to the silver iodide alone and that the sodium iodide played no role, other than perhaps a simple hygroscopic enhancement. Recent laboratory experiments have shown that silver iodide from the silver iodide-ammonium iodide system is markedly superiod to the much used silver iodide-sodium iodide system at temperatures above minus 10°C.

In warm cloud and warm fog seeding, sodium chloride is effective, but other substances that are beneficial to agriculture, noncorrosive to metals, and harmless to humans must be employed. Here it is important to achieve the optimum placement, size, and number density of the dust or spray if the treatment is to be effective and the costs of materials are to be kept in line with benefits.

Delivery Systems - Delivery systems of ice nuclei generation have evolved over 25 years, from techniques for crushing and dispensing "dry ice" through techniques of igniting and dispensing charcoal pellets impregnated with silver iodide-sodium iodide mixtures to ground and aerial burners and systems for dropping pyrotechnic generators of silver iodide into the cloud from aircraft.

Aerial pyrotechnic generators are being used to produce a horizontal line source of nuclei. Free-falling flares and cartridges are being used to produce a vertical line source. Development of rocket and gun systems and related aircraft hardware, such as wing racks, dispensing pods, and associated electrical circuitry is also under way. Versatility is the outstanding feature of the pyrotechnic system: dispensing hardware, nuclei types, generation rates, and total quantities of nucleants can be tailored to suit the experiment.

Ecological and Hydrological Aspects

Weather is a dominant element in ecology. Soil-plant-animal interrelationships are influenced by a wide variety of atmospheric factors including long period climatic patterns and short period variations in weather parameters. More recently, accelerated efforts have been made to enlarge understanding of the impact of man, his industries, machines, materials and mode of living on the total ecology of the earth.

Development of an understanding of ecological systems has been a long-standing activity of many research groups. For example the Department of Agriculture has ongoing programs to study ecological aspects of agricultural, forest, range and wild land environments. The Department of the Interior has research programs focused on fish and wildlife ecology, water, and public lands. The Department of Commerce is concerned with the ecological aspects of marine fisheries. The Environmental Protection Agency and the Department of Commerce have programs to study air pollution-atmospheric-human relationships. Many universities have efforts in ecological research, which are pertinent to weather modification programs.

These efforts provide a foundation of knowledge for specific aspects of a national weather modification program which must now include indepth examination of ecological impacts. The following are a few examples of the status of weather modification-related knowledge of ecology.

Insect Populations - Biologists have developed some initial understanding of the effects of weather upon the incidence of insect epidemics. Alteration of weather patterns by weather modification activities might tend to exert an influence on the development of the insect population. For example, it is possible that local augmentation of June rainfall could aid in control of the spruce budworm, a forest insect that periodically causes severe damage. For this insect, knowledge has been developed on the importance to population growth of the timing of early winter snow, continuing snow and cold temperatures during the winter, spring rainfall and temperature, and dry summer weather during the period of establishment of larvae.

Many insects causing impacts on agriculture could possibly be affected by weather modification. Generally, most insects are influenced more by temperature than by precipitation, although interactions of precipitation and temperature are important. For example, grasshoppers are strongly affected by warm, dry, sunny weather that favors egg production, high survival and rapid development. Cool, moist conditions, especially in the spring will aid in retarding their populations. For a large variety of insects, it is known that rainfall frequency is a critical factor. This knowledge can provide an important guide for planning and managing weather modification operations with the objective of providing net benefits and reducing possible adverse effects.

Plant Diseases - Pathologists have identified the great importance of weather factors to the spread and intensification of a variety of plant diseases. From the results of research in plant pathology, it is possible that weather modification might have different effects on diseases of annual agricultural crops and on diseases of perennial shrubs and trees. Timing of precipitation is critical to the severe outbreak of diseases in grain. High humidity, rather than amount of rainfall is known to be a major factor in the development of potato blight. Some seedborne diseases in cabbage such as black leg and black rot develop to epidemic stages only when there is summer rain. Weather conditions needed for heavy infestations of most forest diseases are so highly variable that generalizations are meaningless. However, for some forest disease situations, weather factors have been identified and these indicate some of the decisions factors in weather modification. For example, molds favored by deep snow remaining on the ground well into spring may damage spruce in the Rocky Mountains. On the other hand, the type of herbaceous ground vegetation might be shifted to species more resistant to snow-mold attack.

From the body of knowledge now available on plant disease and weather relationships, several critical areas for special ecological studies can be identified.

Watershed Hydrology - Many years of research have advanced the needed understanding of some of the complex soil-vegetation-weather relationships in the storage, use, and runoff of precipitation. We know that the amount and type of forest cover, the balance between open ground and dense forests, and soil-geographic characteristics all influence the amount, quality, timing, and duration of flow of water from mountain watersheds. Although this knowledge is far from complete, it provides a rational basis to assist in planning weather modification programs. Moreover, the strength already developed in watershed research provides a background for enhancing and beneficially applying the results of weather modification programs.

Ecosystems - During the last 60 years, considerable information has been assembled on the relationship between organisms and environment. A general understanding has been developed of baseline ecology in several major plant-animal-climatic communities. The International Biological Program is attempting to refine understanding of the function of ecosystems. This research is now on the threshold of development of predictive models for evaluating effects of environmental change on whole ecosystems. These models can become important elements in weather modification decision making.

Although the foregoing are only examples of available knowledge on ecological and hydrological aspects of weather factors, it is evident that a basic understanding is being developed of these interrelationships. Within the near future, man should have sufficient understanding of how major ecosystems work to permit weather modification to proceed with the necessary safeguards against possible adverse effects. Moreover, a nucleus of basic knowledge is available to aid in selecting the times and situations where weather modification can contribute to environmental protection and can yield substantial economic benefits. Man knows that ecological and hydrological factors must have major emphases in weather modification. The important thing now is to enlarge our understanding of these factors through indepth studies on specific weather modification projects.

Socioeconomic and Legal Considerations

Now that man has arrived at the threshold of a potential capability to influence the vagaries of his environment, he is faced with the necessity of making decisions on how to use this newly developed management capability. It is in this area of decision making where much study remains to be done. In December 1967, a 2-day workshop was supported under a National Science Foundation grant at the Southern Methodist University to explore the state of law in the field of weather modification and the implications for society of the interplay of science, technology, and law. The conferees concluded that there was a need to establish a new legal framework to cover the practice of weather modification, as the application of existing water right laws could not be applied with any degree of consistency from state to state.

A study on the legal guidelines for atmospheric water management which was made at the University of Arizona for the Bureau of Reclamation further emphasizes the inadequacies of our legal system to cope with problems of weather modification. This applies primarily to liability and indemnification for damages believed to have been caused by cloud seeding activities.

A Task Group on the Legal Problems of Weather Modification was recently sponsored by the National Science Foundation at the Law School of the Southern Methodist University. The purpose of the task group was to build upon these past studies and to make creative suggestions as to how the promising field of weather modification might be regulated by society to advance the public interest. The work has now been completed and the report has been published in a book, "Controlling the Weather," Dunnellen Publishing Co.

The human aspect of weather modification has not been neglected. Under the support of the National Science Foundation's Special Commission on Weather Modification, a Symposium on the Economic and Social Aspects of Weather Modification was held in Boulder, Colorado, in July 1965 at the National Center for Atmospheric Research. This conference pointed out the necessity for the social scientist to become aware of the social problems inherent in weather modification and to take part in the planning for the future.

As a follow-up to this conference, the National Science Foundation requested the National Center for Atmospheric Research to establish a Task Group on the Human Dimensions of the Atmosphere to follow up on the original study and to identify specific areas for research in human uses of the atmosphere and to foster and stimulate interest in these problems among both social and physical scientists. The conclusions and recommendations of this 13-man task group of experts from the field of economics, geography, sociology, political science, law, ecology, and meteorology has been published by the National Science Foundation as NSF Report 68-18 entitled "Human Dimensions of the Atmosphere." Research projects have been, and are now being sponsored by Federal agencies such as the National Science Foundation. Bureau of Reclamation, and the National Oceanic and Atmospheric Administration to proceed with the studies recommended by this report at various universities such as the University of Colorado, University of Michigan, University of Missouri, Montana State University, and many other academic institutions.

The economic potential of weather modification is impressive. Where rainfall is marginal, an increase of only 5 percent rainfall at the right time of the year may mean the difference between crop failure and a bountiful harvest. In Florida in a summer month, for instance, mathematical model computations indicate that the seeding of convective clouds in the vicinity of Miami and Tampa could increase the rainfall by 0.7 inches which would result in an additional 64,000 acre-feet of water in each location. This would mean an increase in rainfall for Tampa of 18 percent and for Miami 11 percent during this 1-month period.

Snow augmentation in the Colorado River Basin is estimated to produce an increase runoff of 1,870,000 acre-feet of water. In addition to the gain of approximately $100 million in water for irrigation purposes, a small incremental income from existing Federal hydroelectric plants at established power rates of about $7.5 million would also be produced. If all this water were diverted for use in either California or Arizona, an additional annual income of $6.9 million from power production could be obtained. Estimates of 15 percent precipitation augmentation from a managed atmospheric water resource system in the Connecticut River Basin have indicated an incremental runoff of 2,000,000 acre-feet of water.

In one area of the North Caucasus of the Soviet Union where hail suppression has been in operational use for more than 5 years, several millions of acres of farmland are being protected by the use of silver iodide injected into critical parts of storm systems by means of rockets or artillery shells. It has been reported that the value of crops being saved by this technique exceeds the cost of the seeding operation by a factor of 10 or greater.

Airlines in the United States have been conducting cold fog dissipation programs at several airports with a benefit-cost ratio of better than 5 to 1 in savings on delayed or diverted traffic. Most fogs which impede air travel, however, are warm fogs, and the Airline Transport Association estimates that the elimination of delays due to warm fogs at airports would result in an annual savings of over $75 million. The cost of cancellation of a single transcontinental jet flight is in excess of $3,000.

In the Rocky Mountain and Pacific Coast States an average of 1,300,000 acres of forests including 262,000 acres of valuable commercial timber lands are burned annually by lightning-caused fires. Weather modification technology for lightning suppression has the potential of saving up to 50 percent of the lightning fire losses and could add more than 1 billion board feet annually to timber supplies and reduce fire control costs by as much as $50 million.

Finally, the losses in property sustained by major hurricanes when they strike land may exceed $1 billion for each major event. A reduction of 30 percent in wind velocity could possibly reduce property losses by 50 percent and save many lives. Even a reduction by only 10 percent in losses, would offer benefit-cost ratios far in excess of 10 to 1.

Chapter III.

HOW WE CAN ACCELERATE PROGRESS

Weather modification has progressed along many avenues as a result of the efforts of groups that have often been small and occasionally independent of each other. Progress can be accelerated by making it easier for these groups to bring together their skills, resources, and mutual interests. Early focusing of combined efforts on the most promising areas can strengthen and speed up the advancement of the entire field of weather modification.

There is little doubt that our understanding of certain types of weather modification has reached the point where practicable application can become a reality in the very near future, provided that systematic progress is made, where possible, from research to operational status through a concerted national effort. An interdisciplinary multiagency approach will ensure that not only are the techniques perfected, but that all consequences, beneficial and detrimental, local, national and international, are fully assessed.

The suggested mechanism for accomplishing this is the establishment of National Projects.

National Projects are multiagency efforts of major national significance which have clear near term potential for meeting identified national needs. Each has as a base an on-going weather modification program with a potential for making a vital contribution to the solution of a national problem.

The National Projects are designed to learn about physical mechanisms and to test sciencific concepts, except for one with the special designation Pilot Project. The Pilot Project is primarily concerned with the development of efficient, operational techniques and the process of decision making. National Projects have the characteristic that the different departments, with differing missions, see a chance to advance their own, as well as national interests by formal collaboration with one another. Designation as National Projects should improve or accelerate their chances of success.

It is emphasized that this report does not address those aspects of weather modification which do <u>not</u> require formal collaboration between departments. The different aspects of weather modification research, ranging from stream flow augmentation to forest fire fighting to hurricane modification are <u>not</u> all best managed by a single central agency and each application has peculiar features justifying its own research efforts. There are also problem areas beyond these which, although important, are not expected to yield to formal management efforts. For example, the development of computer models requires a multiplicity of approaches and work on them proceeds in almost all projects. The nation benefits more from competition in this effort.

Recent successes reported by several researchers, particularly in the fields of mountain snowpack augmentation, rain augmentation from cumulus clouds and hurricane modification, give added significance to the work at this time. ICAS believes we are on the threshold of important results and offers these Projects at this time as representing the best way to further the national interests.

The proposed National Projects and Lead Agencies are:

National Colorado River Basin Pilot Project - Bureau of Reclamation
To test the feasibility of applying a cloud seeding technology, proven effective under certain conditions, to a river basin for a winter season to augment the seasonal snowpack.

National Hurricane Modification Project - National Oceanic and Atmospheric Administration
To develop a seeding technology and associated mathematical models to reduce the maximum surface winds associated with hurricanes.

National Lightning Suppression Project - Forest Service
To develop a seeding technology and associated physical and mathematical models to reduce the frequency of forest fire-starting lightning strokes from cumulonimbus clouds.

N l Cumulus Modification Project - National Oceanic and Atmospheric Administration
To develop a seeding technology and associated mathematical models to promote the growth of cumulus clouds in order to increase the resulting natural rainfall in areas where needed.

National Hail Research Experiment - National Science Foundation
To develop a seeding technology and associated mathematical models to reduce the incidence of damaging hailfall from cumulonimbus clouds without adversely affecting the associated rainfall.

National Great Lakes Snow Redistribution Project - National Oceanic and Atmospheric Administration
To develop a seeding technology and associated mathematical models to spread the heavy snowfall of the Great Lakes coastal region farther inland.

National Fog Modification Project - Federal Aviation Administration
To develop seeding or other technology and associated physical and mathematical models to improve the visibility in warm and cold fogs where and to the extent needed.

In addition to special support for these National Projects a significant increase in relevant broad background research and development support is also recommended. This is particularly needed in the areas of nuclei counting and efficiency assessment, the physical chemistry of nucleating agents, the microphysics and dynamics of mesoscale systems, mesoscale mathematical models, and cloud physics instrumentation, such as doppler radars and microwave sensors.

National Colorado River Basin Pilot Project for the Augmentation of the Rocky Mountain Snowpack

The proposed project builds on the existing operationally oriented effort by the Bureau of Reclamation of the Department of the Interior to augment the snowpack in the Upper Colorado River Basin. By overlaying concentrated research on an ongoing project, time losses and costs will be minimized. The initial seeding, communication, and observation systems and the project forecasting headquarters are already established. The seeding and research techniques to be used are based on well-understood physical principles, and there is promise that the results will be highly beneficial to the social, economical, and ecological needs of an important part of our country.

The critical water shortage in the Colorado River Basin is well known. This basin serves the States of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming, in addition to the neighboring Republic of Mexico; among others it supplies 80 percent of the water needs of metropolitan Los Angeles. The primary source of this water is the snowpack accumulation during the winter on the crests of the Rocky Mountains. In the Upper Colorado River Basin, which has an annual runoff of approximately 15 million acre-feet, the snowpack is concentrated at levels above 9,500 feet in an area representing only about 10 percent of the total river basin. It is on this area that the snow augmentation effort can be most efficiently concentrated.

The planned pilot project operations will initially take place over some 2,200 square miles of the San Juan Mountains. There, it is estimated that randomized seeding will cause a 15 to 20 percent increase in local runoff. An expected additional 400,000 acre-feet of water will thus be produced by the pilot project and will help relieve existing shortages.

Present total cost of water is up to $50 per acre-foot in the Colorado River Basin. The estimated cost of water increase through orographic seeding in this area is about $1.50 per acre-foot. The resulting economic gains and cost-benefit ratios are impressive. If, at a later time, full-scale operations are extended to the total 14,000 square mile area of snowpack in the Upper Colorado River Basin, an annual water increase of almost 2 million acre-feet valued as high as $100 million may be expected.

It should be recognized that the cost figure of $1.50 per acre-foot and the value estimate of $100 million do not result from sophisticated economic analyses. Scholarly dissertations have been written on the complexity of performing valid economic evaluation of weather modification; such actual evaluations are not presently available. Careful economic studies have been undertaken in connection with the Upper Colorado River Pilot Project but no results are as yet available. Many more such studies are needed and should be undertaken as rapidly as qualified economists can be attracted to the task.

The techniques to be applied in the San Juan Mountains will take advantage of the temperature activation spectrum of natural ice nuclei. At cloud top temperatures, warmer than minus 23°C, the supercooled cloud systems forming over the windward slopes cannot precipitate efficiently due to a lack in effective ice nuclei. Seeding in proper quantities on days with cloud top temperature between minus 12°C and minus 23°C is expected to cause most of the available condensate to fall out and to double the natural snowfall rate. Seeding during all suitable days should add about 30 percent to the total San Juan snowpack. Indiscriminate seeding including days with could top temperatures colder than minus 25°C would reduce or neutralize this effect by adding artificial ice nuclei under conditions where natural ice nuclei are already abundant. Such overseeding would reduce snowfall by keeping the smaller ice crystals from reaching the ground before evaporation on the downwind side. Therefore, careful assessment of the given atmospheric conditions prior to a seeding operation will be an important ingredient of the project plans.

The Upper Colorado River Basin Project of the Department of the Interior is well planned and ideally suited to make it the focal point of a National Pilot Project. As such, it should be augmented to take full advantage of the opportunity for accumulating an unprecedented amount of information and experience for future operational programs.

A 3- to 5-year effort will be required to:

Develop optimum diagnostic methods
Perfect prognostic capabilities
Develop the most efficient operational techniques
Devise a clear picture of the full sequence of physical events and consequences
Assess the quantitative results in terms of water augmentation capability
Derive upwind conditions and downwind effects
Assess the total economic impact
Develop sociological relations and procedures
Devise the full spectrum of social and legal effects
Assess short- and long-range ecological consequences

To accomplish this expansion in scope, it is desirable to increase the presently planned density and areal extent of measurements; to bring in advanced meteorological field instrumentation and measuring platforms; to increase the project scientific staff; to enhance the real-time data acquisition and processing capabilities; to provide for a comprehensive meteorological mountain mesoscale analysis; to accelerate the development of advanced mathematical and cloud physics models; and to inject additional related research efforts, including snow hydrology and avalanche studies.

The National Pilot Project provides a meaningful, pertinent situation to investigate the sociological and environmental considerations of a large-scale weather modification effort. These vital considerations need to be studied to provide a sound basis on which public and legal policies of operational seeding can be formulated.

The pilot project area also offers an excellent opportunity for testing remote sensing equipment and application under the Earth Resources Technology Satellite (ERTS) Program. The project measurements provide ground-truth data from a rugged, mountainous area under severe winter conditions. The remote sensing of environmental parameters would be used in connection with the ecological investigations being made as part of the project.

The basic program currently involves Colorado State University, Colorado University and Ft. Louis College as well as the Soil Conservation Service, the Forest Service and the Geological Survey.

It is clear that the National Pilot Project will require a concerted effort by other government agencies, such as the Departments of Commerce, Defense, Transportation, the National Science Foundation, and additional segments of the Departments of Agriculture and the Interior as well as state agencies. Desirable supportive efforts from major components of the Federal Government are listed in Tables 1 and 1.a.

Table 1

Desirable Supportive Efforts for the National Colorado River Basin Pilot Project

Lead Agency - Bureau of Reclamation, Department of the Interior

Type of Effort	Possible Sources					
	Department of Agriculture	Department of Commerce	Department of Defense	National Science Foundation	Department of the Interior	Department of Transportation
Monitor cloud top heights and temperatures (airborne IR measurements)		X		X		
Precipitation and wind field in clouds						
Radar			X			
Doppler radar		X				
Nuclei characteristics up and down-wind (airborne counters)		X		X		
Additional upper air soundings		X	X			
Additional ground stations						
Snow depth	X					
Snow characteristics	X					
Precipitation		X				
Wind		X				
Advanced instrumentation						
Weather proof anemometers		X	X			
Mobile weather stations		X	X			
Soil moisture sensing devices	X					
Nuclei - activation measurements				X		
Real time satellite information		X				
Specialized local forecast		X				
Climatological and hydrological analysis	X	X				
Advanced mathematical models	X		X			
Special studies on the effects of:						
Water quality					X	
Stream morphology					X	
Forest fire probability	X					
Surface transportation						**
Sociology				X		
Legal aspects				X		
Multiple use forest management	X					
Flight space and control						X

** State Highway Department.

Table I-a

Required Research for National Colorado River Basin Pilot Project

Needed Cooperative Efforts	Additional Support Required	Redirection of Existing Efforts	Total Required Effort
	Thousands of Dollars Annually		
Expanded atmospheric research: Additional observation and research to provide increased understanding of physical and dynamic atmospheric processes important to winter orographic cloud seeding operations	<u>130</u>	<u>95</u>	<u>225</u>
Monitor cloud-top heights and temperatures with aircraft and satellite infrared sensor measurements	40 Commerce-NOAA	15 NSF-NCAR	55
Measure airborne nuclei concentrations and physical characteristics under natural and seeded conditions upwind and downwind of target areas and increased studies of nuclei activation	30 Commerce-NOAA	5 NSF-NCAR	35
Additional upper air soundings for determining vertical dynamic and water balance changes across the mountain profiles	20 Commerce-NOAA	20 DOD-AF	40
Additional local forecasts and verification using specialized information and techniques including real-time evaluation of advanced mathematical models	20 Commerce-NOAA	15 Commerce-NOAA	35
Detailed climatology and synoptic/hydro-meteorology of winter storms in San Juan Mountains	20 Comm-NOAA	40 Commerce-NOAA	60
Expanded snow and watershed studies: Determine effects of increased snow on watershed hydrology for evaluating efficiency of seeding in producing a usable augmentation of streamflow	<u>125</u>	<u>90</u>	<u>215</u>
Distribution of snowfall, drifting, and aerial extent of increased snowpack over selected mountain watersheds	70 Agri-For. Serv.	20 Agri-For. Serv.	90
Change in snowflake and snowpack structure and the resultant effects on avalanche potential and melt characteristics	30 Agri-For. Serv.		30
Soil moisture, water quality, and stream morphology investigations to assist watershed-hydrologic modeling of effects under natural and seeded conditions	25 Agri-SCS Interior-GS	10 Interior-GS	35
Comprehensive watershed-hydrological modeling studies of the project and downwind areas		60 Agri-For. Serv. Universities	60

Needed Cooperative Efforts	Additional Support Required	Redirection of Existing Efforts	Total Required Effort
	Thousands of Dollars Annually		
Specialized data acquisition and processing: Concentrate newly developed equipment and techniques to aid project operations, research and evaluations, and to test new developments where extensive verification data and severe operating conditions exist	<u>130</u>	<u>25</u>	<u>155</u>
Mapping precipitation and wind fields in orographic clouds by Doppler radar	50 Commerce-NOAA		50
Weatherproof snowmeters and other instrumentation to provide reliable operational data from remote locations	20 Comm-NOAA	5 Interior-BuRec	25
Mobile weather stations for economically providing concentrations of measurements in different areas according to forecast storm intensity	20 Comm-NOAA	20 DOD-AF	40
Use of satellite weather information, including furnishing special data receivers in project forecast and control center	25 Commerce-NOAA		25
Improved real-time data processing and establishment of an expanded project data storage and retrieval for enhancing early research on seeding effects	15 Interior-BuRec		15
Sociological and environmental investigations: To define problems and interrelated effects of increased snowfall in mountain areas and study means of resolving nontechnical questions of large-scale applications	<u>95</u>	<u>70</u>	<u>165</u>
An in-depth sociological case study of attitudes and effects on people in and near the San Juan Mountains and any changes during the project	40 NSF		40
Multi-use forest management studies on interrelated and possible synergistic efficiencies with additional snowpack on timber management, recreation, grazing, and forest fire prevention	35 Agri-For. Serv.	70 Agri-For. Serv.	105
Evaluation of surface transportation effects and costs, particularly snow removal, of additional snowfall	20 Interior-BuRec Colo. Highway Dept.		20
TOTAL BUDGET - National Pilot Project	480	280	760

National Hurricane Modification Project

The advances made in 1969 in the modification of hurricanes were described in the foregoing chapter. There is an urgent need to confirm these findings and to advance the physical concepts and mathematical models developed in Project STORMFURY. Because of the infrequency of hurricanes within reach of available test bases, a large statistical sample cannot be expected and emphasis has to shift to the testing of physical chains of events in concurrence with the prediction by refined computer models. Any opportunity, within safe limitations, must be used to test these concepts and every effort must be made to advance the existing mathematical models and technological tools at hand. This includes a better understanding and prediction of hurricane tracks and their inadvertent or deliberate alteration by artificial means.

If the evidence available at this time is substantiated in future tests and reductions in the kinetic energy of maximum winds as high as 30 percent can indeed be achieved, it may be expected that the pressure from the public sector will increase to apply hurricane modification techniques on an operational basis and to reduce the huge losses in property and life from catastrophes such as Hurricane "Camille" in 1969. It is in the national interest that preparations for the transition from research to operations are vigorously pursued and carefully planned taking all technical needs as well as the potential economic and legal implications into account. The additional support indicated in Table 2 will be instrumental in accelerating our progress towards hurricane control.

Table 2

Desirable Supportive Efforts for the National Hurricane Modification Project

Lead Agency - National Oceanic and Atmospheric Administration
Department of Commerce

Type of Effort	Possible Sources						
	Department of Housing and Urban Development	Department of Defense	NASA	National Science Foundation	Atomic Energy Commission	Department of the Interior	Department of Transportation
Increased aircraft support for monitoring hurricane parameters							
Two fully instrumented turbo prop research aircraft		X					
High altitude cloud physics probing		X		X			
Intensified high altitude cloud photography (60,000 feet)		X					
Airborne tracer studies		X			X		
Improved airborne radar		X					
Satellite monitoring of hurricane characteristics including cloud top temperature			X				
Ground monitoring							
Increased utilization of existing radar networks		X					
Flight space and control							X
Damage survey and analysis of wind velocity relationship	X			X			
Expanded Research studies and experiments							
Evaporation suppression studies and experiments		X		X		X	
Special economic and legal impact studies				X			

National Lightning Suppression Project

The efforts by Forest Service Project Skyfire of the Department of Agriculture are focused on lightning-caused forest fires. Lightning is the greatest single cause of forest fires in the western states and accounts for more than 60 percent of the fires on Federally protected forests and 50 percent of the fire loss to commercial timber. In addition, these fires generate air and water pollution, damage outdoor recreation and areas of scenic beauty, and often take a toll of homes, industries, and human lives. Continued advances in special weather modification technology now indicate that this may be the most fruitful approach to reduce the annual lightning fire control costs of some $100 million and the much greater costs of natural resource losses.

As described in Chapter II, carefully designed experiments performed over a long period of time indicate that cloud-to-ground lightning from individual thunderstorms can be reduced through application of massive seeding techniques. More important, the special type of lightning which now has been found to be almost exclusively responsible for forest fires was strongly affected. This so-called "hybrid" cloud-to-ground discharge combines the unfavorable characteristics of multiple return strokes and long continuous currents. In one experiment involving massively seeded lightning storms, the number of return strokes per hybrid discharge as well as the duration of the continuous currents were significantly reduced.

Although the physical mechanism by which massive seeding modifies lightning activity is not fully understood, the probability is high that the basic mechanism of charge generation in thunderstorms is affected. Extrapolation of the results of lightning modification to fire ignition probability in the relatively small Project Skyfire field experimental area suggests an appreciable reduction in forest fire starts from lightning.

The results now available and the potential economic gains are sufficent to justify a national project designed to establish operational feasibility and to fully ascertain the physical mechanisms involved.

The National Lightning Suppression Project will fulfill these aims. This project will extend the developed cloud seeding techniques over a much larger forest area in the northern Rocky Mountains having a known high incidence of fires. (Continued development of airborne instrumentation for seeding evaluation and numerical modeling techniques for determining where and when to seed are projected as a part of this program.) The project will be designed to continue investigation of lightning mechanisms and to evaluate operational application of weather modification techniques most likely to prevent fires and reduce forest fire danger under specific meteorological conditions.

Although the Forest Service plans to strengthen its resources for support of the National Lightning Suppression Project it has several sub-critical aspects. They need to be removed by the cooperation of other government agencies, universities, and private industries. Specifically, we recommend interagency participation in the areas listed in Table 3.

In addition to the efforts of the National project the Forest Service will continue its lightning research program including studies for the extension of lightning suppression systems to other forest regions.

Table 3

Desirable Supportive Efforts for the National Project on Lightning Suppression (Project Skyfire)

Lead Agency - Forest Service, Department of Agriculture

Type of Effort	Possible Sources: Department of Commerce	Department of the Interior	Department of Defense	Department of Transportation	NASA	National Science Foundation
Research and Development Support						
Lightning Storm Models	X	X	X			X
Predicting Amount and Type of Lightning from Thunderstorms	X					
Development of Radar Techniques	X					
Aircraft and Spacecraft Observations						
Joint Use of Aircraft for in-cloud measurements	X	X				X
High altitude aircraft for lightning sensing			X		X	
Spacecraft monitoring of lightning storms	X				X	
Services						
Special Fire-Weather Forecasting	X					
Point Six Radar Operation	X					
Rawinsonde operations	X					
Analysis of Seeding Devices and materials			X			X
Aircraft monitoring and control				X		
Micro and meso-scale weather analysis	X					

National Cumulus Modification Project

As pointed out in the previous chapter, rain augmentation from convective cloud systems in general requires a better scientific understanding of the complex convective processes. However, remarkable progress has been made during the last few years in the modification of certain types of cumulus clouds. This specific approach shows significant economical promise and appears nearly ready for operational application.

In tropical latitudes, as well as in certain regions of the temperate latitudes, the seedability of cumulus clouds can now be predicted by computer models, using as inputs the day-to-day atmospheric soundings and local observations. NOAA's present and planned efforts in Florida to augment precipitation from tropical cumulus clouds are based on mathematical models which take into account the effects of entrainment and waterload and are able to predict vertical cloud development, precipitation growth and fallout for seeded and unseeded clouds.

Seeding operations are guided by these objective predictions. It is now well established by physical and statistical tests that precipitation increases of more than 100 percent can be achieved in individual seedable clouds which grow explosively after massive seeding due to the liberation of large amounts of latent heat of freezing ("dynamic seeding"). Since seedability varies from day to day and from month to month, the monthly or seasonal increases in total precipitation are smaller. Systematic "area-seeding," however, promises to result in economically significant increases approaching the 20 percent level in certain months.

Also, tests in temperate latitudes, for example those in South Dakota sponsored by the Department of the Interior's Bureau of Reclamation, indicate that modifiers know how to produce substantial increases from a frequently recurring set of cloud types. Clearest demonstrations of this are when important amounts of rain are produced from cumulus that would not rain at all in the natural state. In these regions, this may or may not be associated with important induced changes in the dynamics of the cloud. The more advanced mathematical models used in these tests incorporate the effects of terrain, evaporation, and cloud shadows.

While the treatment of individual cumulus clouds has been strikingly effective, parallel attempts to treat systems of convective clouds are still in the early stages. Much more research is needed to develop adequate correlation during theoretical analyses, mathematical models and field experiments.

The dynamics of convective cloud systems are extraordinarily complicated and no satisfactory, three-dimensional model exists at this time. System seedability criteria readily available based on atmospheric parameters need to be established. Possible downwind effects must be investigated.

This project will make major strides in the clarification of many long-standing scientific problems such as the mechanism of entrainment and its dependence on cloud characteristics and environment, the mesoscale organization control of convective cloud systems, the action of hydrometeoric drag, nucleating mechanisms, efficiency of natural and artificial nuclei in warm and cold clouds and different climates, and artificial modification of buoyancy.

A number of criteria enter into the selection of optimum locations for field tests. Among these are:

Favorable and representative meteorological conditions offering a sufficient variety of typical convective phenomena and related atmospheric structures
Minimum interference with human activities
Favorable attitude of state and local authorities
Need for rain augmentation in the general area of field testing

Certain parts of Texas offer these conditions. Winds from the Gulf of Mexico or from Mexico itself produce a great variety of convective situations from arid to tropical (Florida type) regimes, with warm and cold cloud tops, shallow and large developments, organized and unorganized systems. Also, the remaining criteria seem to apply here. Other areas to be considered are Florida, Utah, Illinois, Oklahoma, and Soutn Dakota, where surveillance networks already exist.

The expanded project should be centered around NOAA's Tropical Cumulus Project in Florida. The Florida Project should be systematically expanded towards operational readiness. Areawide seeding techniques and ground control should be advanced to a fully operational stage, to be applied in regions and at times of strong economical or environmental needs. In this connection, the available techniques for suppression of precipitation during periods of flooding should also be developed.

Optimum methods to cooperate with local users and authorities and to deal with legal problems are expected to evolve from this important project.

Tne additional support listed in Table 4 is considered desirable to achieve these goals. Of special importance is the addition of reliably calibrated weather radar.

Table 4

Desirable Supportive Efforts for the National Project on Precipitation Augmentation from Cumulus Clouds

Lead Agency - National Oceanic and Atmospheric Administration
Department of Commerce

Type of Effort	Possible Sources				
	Department of Agriculture	Department of Defense	Department of the Interior	National Science Foundation	Atomic Energy Commission
Increased ground support					
Expanded precipitation network	X		X		
Increased aircraft support					
High altitude panoramic cloud photography		X			
Special studies					
Socioeconomic, legal studies				X	
Ecological studies	X				
Advanced mathematical models/ computer time			X		
Pyrotechnic Development			X		
Plume research and tracking					X
Standard Laboratory for nuclei tests/ nuclei counters				X	

National Hail Research Experiment (NHRE)

Damage to crops and property in the United States each year due to hail exceeds $300,000,000 per year. There is reason to believe that a significant reduction in the growth of this damaging hail in severe storms can be accomplished by suitable modification techniques. The injection of silver iodide into the liquid water accumulation zone of the storm using explosive artillery shells or rockets targeted by radar has been reported to be highly successful in the Soviet Union in reducing losses due to hail. Cloud base seeding from aircraft released into selected portions of the updraft of the storm by pyrotechnic silver iodide generators has been reported to be successful in reducing hail crop damage in Kenya, Africa, North and South Dakota, in Texas and elsewhere.

Although hail suppression has been believed to be successful in many instances, there is still a wide divergence in scientific opinion as to the mechanisms which are responsible in severe storms for the formation of hail and how they might be modified to suppress hail. Most evidence of successful hail suppression offered to date has been keyed to insurance statistics which compare crop losses in treated and untreated areas. Due to the sporadic nature of hail formation, such data have contributed very little scientific insight into understanding the actual hail suppression mechanisms in a storm.

The National Hail Research Experiment (NHRE) involves the intensive study of hailstorms over a target area using ground meteorological networks, instrumented aircraft, ground and airborne radar and infrared sensors, lidar, and synchronous satellite observations. From these observations, mathematical models of representative Great Plains hailstorms will be developed and a number of hail suppression techniques will be tested by simulation techniques. The most promising of these suppression techniques will then be applied to actual hailstorms over the test area and the results observed and compared to the model simulation. Penetrations will be made into the storm by specially instrumented aircraft including a T-28 aircraft which has been armored to withstand the direct impact of 3-inch hailstones in flight. Rockets containing silver iodide impregnated explosive nose cones will be launched into selected areas of the storm from jet aircraft to test the effect of glaciation upon the dynamics and hail-forming mechanism of the storm.

The areas chosen for selective glaciation will be determined from the computer model and the reaction of the storm will be observed by special dual wavelength radar, doppler radar, tracer materials and chaff injected into the storm, and the armored aircraft penetrating into the active storm center.

A major portion of the field effort will be conducted by the National Center for Atmospheric Research, academic and private institutions, under NSF support. Currently major contributions are planned from Colorado State

University, University of Wyoming, South Dakota School of Mines and Technology, the University of Chicago, and the University of Illinois. Many aspects of the field program, however, require the support, facilities, and expertise available only at other agencies of the Federal Government.

The NCAR basic program will be designed as a minimum adequate core program to which other agency participation will add effectiveness toward attaining the overall program goal as well as fulfilling other agency research requirements most efficiently. Desirable supportive efforts from major components of the Federal Government are listed in Table 5.

Table 5

Desirable Supportive Efforts for the National Hail Research Experiment

Lead Agency - National Science Foundation

Type of Effort	Possible Sources							
	Department of Commerce	Department of the Interior	Department of Agriculture	Department of Defense	NASA	Department of Transportation	Atomic Energy Commission	National Science Foundation
Personnel loan								
Scientific or engineering		X	X	X				
Technical supporting		X		X				
Equipment loan	X	X		X				
Aircraft observations	X			X		X		
Air trajectory studies							X	
Services								
Forecasting	X							
Assessment and evaluation	X		X					
Satellite observations	X				X			
Traffic control						X		
Doppler radar observations	X							
Seeding devices	X		X	X				
Ground monitoring network	X							
Electrical measurements			X					
University Instrumentation Support								X

National Great Lakes Snow Redistribution Project

As mentioned in Chapter II, experiments have been conducted over a number of years by NOAA to reduce the heavy snowfalls on the shores of Lake Erie and to redistribute them over a larger area further inland. The concept can be applied to other parts of the world where polar air with subfreezing temperature moves over open warm waters causing heavy snowstorms at the downwind shorelines.

Progress achieved to date is so encouraging that the efforts, presently subcritical, should be intensified. Airborne measurements have borne out the predictions of a mathematical model with surprising accuracy. This three-dimensional model takes into account the effects of terrain and water (sometimes 20°C warmer than the air) and the resulting changes in friction and vertical flux of water vapor. It indicates that the top of the cold air is lifted near the downwind shore to such an extent that deep snow-bearing clouds form. In theory, injection of the proper amount of artificial freezing nuclei changes the type of precipitation from fast-falling rimed particles to slowly drifting small ice crystals thereby lessening the rate of snowfall near the shoreline.

What is needed now is refinement of theory and computer models, as well as real-time application of the mathematical model in guiding the seeding operations; improved cloud physics measurements inside the "lake effect clouds;" expanded precipitation monitoring by radar and ground networks; systematic counts of freezing nuclei; and intensified studies of the economic impact, the conflicting interests, the legal aspects, and the ecological consequences.

Table 6 summarizes the additional support considered desirable to ensure vigorous progress of this important research project toward eventual operational application.

Table 6

Desirable Supportive Effort for the National Great Lakes Project

Lead Agency - National Oceanic and Atmospheric Administration
Department of Commerce

Type of Effort	Possible Sources: Department of Agriculture	Department of Defense	Department of the Interior	National Science Foundation
Increased Aircraft Support				
High altitude panoramic cloud photography		X		
Improved liquid water content recorder		X		
Seeding support		X		
Additional Ground Support				
Snowgages for surface network	X			
Mobile 3 cm radar		X		
Additional rawinsonde stations		X		
Special Studies				
Technological Assessment:				
Socio-economic-legal studies			X	X
Ecological Studies	X			
Great Lakes Watershed Management Study			X	
AgI scavenging study (Univ. Grant)				X
Heat and momentum transfer study - NCAR a/c				X

Table 6 Notes

Desirable Supportive Effort for the National Great Lakes Project

A. INCREASED AIRCRAFT SUPPORT:

(1) High altitude panoramic cloud photography to provide a high quality, detailed over view of entire winter lake storm systems before and during seeding operations.

(2) A liquid water content recording to provide important information pertaining to potential seeding efficiency and potential benefit in terms of snow out.

(3) Recommended use of droppable cannister-type pyrotechnic flare seeding with technical and field assistance provided by Naval Weapons Center scientific personal and equipments.

B. ADDITIONAL GROUND SUPPORT:

(1) Assistance in measurement and analysis of snow rate and total snow measurements.

(2) Mobile 3 cm radar stationed as needed to provide measurements within the target area where severe operational difficulties arise as the result of ground clutter return on present WSR 57 radar.

(3) Upwind meteorological data are required as input to the predictive model. Mobile rawinsonde measurements obtained in the target area and upstream will provide this basic meteorological data needed.

C. SPECIAL STUDIES:

(1) and (2) Socio-economic-legal, ecological, and watershed management studies need be conducted to determine the impact of possi-applied weather modification in this area.

(3) Crystal analysis for a determination of the magnitude of AgI scavenging by crystals for the evaluation of seeding efficiency and seeding requirements.

(4) Heat and momentum transfer study using the NCAR Buffalo aircraft.

National Fog Modification Project

Throughout history fog has been responsible for economic and human losses in aviation, on highways and at sea.

Detrimental effects of fog on surface and air transportation are problems of major proportions. Commercial air carriers alone now lose over 80 million dollars annually in aircraft diversions, delays and cancellations. Costs in excess of 300 million dollars per year are incurred by fog-associated vehicle accidents on the nation's highways. Fog is a serious factor to the military in the movement of personnel, cargo and combat material at airfields and staging areas in the United States as well as overseas. Successful airborne cold fog dispersal operations have been conducted for a number of years, and large dollar savings were recently realized and documented for a military ground-based cold fog dispersal pilot installation (Fairchild AFB near Spokane, Washington) to the amount of approximately $200,000. The national fog modification project will accelerate technological breakthroughs in the dispersal of warm fogs (temperature above 0^oC) and provide for greater efficiency in cold fog (temperature below 0^oC) dispersal techniques.

Means of overcoming the adverse effects of fog include, among others, modern electronic navigation aids, improved lighting, acoustic methods, such as bell buoys and fog horns at sea, and recently fog dispersal systems.

The above techniques, while permitting some flow of traffic through fog-bound areas on land, air, and sea require considerable improvement and refinement in order to make them operationally reliable and economically beneficial.

The current state-of-art technology indicates that fog dispersal systems can be developed which meet user requirements. The dispersal of cold fog by airborne and ground-based systems which use dry ice or propane as the nucleating agent has already been successfully demonstrated. Ground-based cold fog dispersal systems are already operational at Orly Field, Paris, France and at some U. S. Air Force installations. In the U. S., seeding aircraft, under contract to diverse segments of the aviation industry, currently use dry ice to dissipate cold fog utilizing various airborne seeding techniques. Measurement and evaluation of fog dispersal techniques will be made to determine the system efficiency and its impact on the National Airspace Air Traffic Control System.

Efficient warm fog dispersal techniques have seriously lagged behind cold fog modification work, mainly because of the expenditures required to produce even minimal dispersal results. The main efforts in warm fog dispersal in the past few years have been in computer simulation, fog modeling and limited field testing of a variety of dispersal techniques, devices and theories. A reliable, operational, cost-effective warm fog modification technique, either ground-based or airborne, does not yet exist. Several techniques, however, have shown some promise, i.e., heating devices to evaporate fog, airborne seeding of fog with sized chemicals and the removal of fog droplets by mechanical means have shown diverse levels of effectiveness.

The current trend in the U. S. is to disperse warm fog by seeding with chemicals from aircraft. To date, limited documentation exists on just exactly what effect such chemicals as urea, ammonium chloride, silver iodide, and polyelectrolytes, among others, have on warm fog droplet coalescence and fog dispersal. A scientific objective analysis of the dissipation capability of fog dispersal agents is urgently needed in order to eliminate those which are ineffective or may be potentially harmful to the environment and confirm those substances which can be successfully and safely used in fog dispersal. This is an area which will be investigated.

Numerous diverse techniques have been proposed for fog dispersal. To date, no suitable field test bed exists to measure and evaluate the capability of a proposed technique to dissipate fog.

An instrumented test bed will be developed on land at an area which has a high incidence of natural fog in order to field test proposed fog dispersal systems. An additional test bed will be developed in a high incidence of sea fog region to test and evaluate proposed fog dispersal systems for harbors, rivers, and sea approaches. Both of the above test beds will be used for research and development of fog dispersal systems.

Considerable basic research remains to be done on the history of fog formation, development, maturation and dissipation. Through the use of experimental data obtained from fog chambers, through computer modeling of fogs, and both theoretical and practical considerations, it is hoped to provide a deeper understanding into the basic physical, chemical, and electrical structure of fog and its geophysical interrelationships. This new knowledge will provide a base for improved second generation fog dispersal systems.

The operational techniques of fog dispersal which will be evaluated objectively will include, among others, airborne seeding, helicopter downwash, heat, electrical methods, ground-based seeding, mechanical techniques, and the use of jet engine blast. User requirements will be determined for specific cases and fog dispersal systems will be developed to satisfy those requirements. Both ground-based and airborne instrumentation will be employed as well as aerial photography to document fog dispersal efforts. Anomalies will be carefully analyzed to determine alternative methods of achieving maximum reliability for a fog dispersal system.

The use of tracer materials to determine airflow within a fog will provide additional information on fog droplet movement. The use of specially-designed Doppler radar may also provide an insight into the inner circulation of fogs.

A suitably equipped fog laboratory will include a fog chamber and supporting equipment. The effect of changes on the environment and ecology of an area subjected to fog dispersal operations will be investigated. Research will also be done on the micrometeorological effect of fog dispersal on plants, insects, etc.

An economic analysis of fog dispersal will be made for airports, highways, harbors, waterways and sea approaches. The economic losses due to fog projected over a ten-year period will be analyzed and cost-benefit ratios determined for developmental/installation costs of fog dispersal systems.

Fog dispersal at airports will affect current air traffic control procedures which may require revision when fog dispersal systems become fully operational. These relationships will be analyzed and, if needed, new FAA air traffic procedures will be proposed for the National Airspace System. A ground-based propane cold fog dispersal prototype system will be installed at a U. S. airport which has a high incidence of cold fog. The test, evaluation, and operation of the prototype system will provide specifications and advisory information for other airports qualifying for the installation of cold fog dispersal systems.

A systems engineering plan for a warm fog dispersal system will be developed from requirements for the fog dispersal system, terrain effects at airports, cost-benefit analysis, physical parameters of warm fog modification, and the measurement and evaluation of fog dispersal techniques. The systems engineering plan will be the basis for development and test of a prototype warm fog dispersal system installed at an airport which has a high incidence of warm fog. The test, evaluation and operation of the prototype warm fog dispersal system will provide specifications and advisory information for airports qualifying for the installation of warm fog dispersal systems.

This national project is designed to utilize the total thrust of the research and development communities to achieve a concentrated, coordinated attack on the modification of warm fogs and to develop more efficient cold fog dispersal systems.

Modification of the above systems to meet the requirements of other users on land and water will be accomplished.

Fog prevention techniques will be developed to reduce evaporation in harbors and other water bodies. The alteration of terrain by such techniques as tree planting, establishment of barriers etc. in order to develop operationally reliable fog preventive systems will also be investigated.

Thus, in terms of long-range planning the basic techniques developed for military and civil aviation use will provide a basis for total transportation fog dispersal systems development.

TABLE 7

Desirable Supportive Effort for the National Fog Modification Project

Lead Agency - Federal Aviation Administration
Department of Transportation

TYPE OF EFFORT	POSSIBLE SOURCES						
	Department of Commerce	Department of Agriculture	Department of Defense	NASA	Department of Transportation	Atomic Energy Commission	National Science Foundation
Research and Development Support							
1. Fog models			X	X			X
2. Fog prediction	X						
3. Cold/warm Fog Dispersal System Development			X		X		
4. Basic fog research				X			X
5. Development fog prevention techniques		X		X	X		
6. Climatology	X		X		X		
Increased Aircraft Support							
1. Measurement of fog parameters by aircraft	X		X				
2. Aerial photography	X		X				
3. Seeding support			X				
Ground Monitoring							
1. Instrumented fog test bed			X		X		
Services							
1. Analysis for dispersal techniques			X		X		
2. Fog measurements in harbors, waterways and at sea	X		X		X		
Special Studies							
1. Socio-economic, legal and ecological studies		X			X		X
2. Tracer materials in fog analysis				X		X	
3. Micro-meteorological effects of fog dispersal		X					
4. Economic analysis of fog dispersal at airports, highways, harbors and waterways					X		X
5. Interface of fog dispersal with Air Traffic Control, highway traffice, and harbor/river/ocean traffic procedures			X		X		

Background Research and Development Support

It is a matter of prime importance that basic research of the many natural weather processes be supported on a continuing basis. The emphasis in this report on activities for accelerating progress toward application should be viewed as advocacy of efforts which supplement rather than substitute for basic research. It is clearly not in the national interest to freeze weather modification technology at present levels. Future improvements in this technology can be expected only if improving foundations of understanding are constantly being sought.

Research and development are needed particularly in the following areas to insure the success of all of the foregoing projects:

Nuclei counting and assessment
Physical chemistry of nucleating agents
Microphysics and dynamics of mesoscale systems
Mathematical modeling
Tools and technology

The need to measure condensation and ice nuclei more accurately in the field and in the laboratory is most pressing. Recent comparative measurements by existing techniques show discrepancies in nucleating efficiencies of many orders of magnitude. It is obvious that an understanding of condensation and ice forming mechanisms cannot be achieved until a standardized method of nuclei measurements can be developed which provides some degree of confidence that the true nuclei concentrations are more accurately and consistently known.

The inherent difficulty of assessing the extent of efficiency of ice nucleation in field experiments has led to extensive laboratory investigations of nuclei generators. Such characterizations have been based on the assumption that a one-to-one relationship exists between active ice nuclei and ice crystals produced. It has become clear more recently that changes in liquid water content and nuclei concentrations cause marked change in both nuclei counts (ice crystal counts) and in the mechanisms of nucleation.

This problem can be solved only by understanding the relative effects of different agents as a function of temperature, moisture level, physical state, duration of action, and other operative variables. Inasmuch as the results of such research will have a considerable influence on field experimentation, a high priority should be attached to this area to improve the efficiency of future operation.

Although there has been a sustained systematic effort to develop cloud physics instrumentation needed for weather modification, the present instruments fall short of what is required.

An increased effort is required to develop Doppler radars that can map the wind field in space-time wherever there is precipitation reflecting the radar signal. Three Doppler radars synchronized through a computer are able to give the three-dimensional wind vector. This system will also give the precipitation size distribution throughout the space. Microwave radiometer sensors giving cloud temperatures and water vapor content as well as liquid water and ice content of clouds, remotely, need to be perfected.

The use of high resolution real-time satellite information in the field provides the possibility of continously surveying the side and observing the effects of weather modification operations.

In the future, it will be very important for the weather modifier to have computerized display systems to take advantage of the information that will be available to him for making real-time decisions.

Depository for Weather Modification Data

In the past, the statistical and physical assessment of weather modification results has been handicapped by the fact that many of the original data obtained during countless weather modification attempts in this country are practically unavailable.

A desirable addition to the national program for weather modification is the establishment of a depository for such weather modification data. It should be staffed by cooperating meteorologists, statisticians, and specialists in information retrieval. The depository would serve to collect, to organize, and to store all the observations (either originals or photo copies) made in the course of all experiments on weather modification conducted from public funds and such others as may be deemed appropriate and possible. A special regulation should be authorized, perhaps by Congress, requiring that experiments operating with the support of the Government provide the depository with copies of all the observations made, whether they are considered of permanent or only of transitory significance. Certain physical data, such as ice crystal replicas may have to be stored as stereoscopic photo pairs instead of the originals or as normal photos. The delivery of data to the depository should be effected at some reasonable intervals during the progress of an experiment and perhaps within 2 months after the close of each experimental season. Wherever possible, the data should be provided in a standardized format for computer processing.

After a reasonable period of time, during which each experimenter would have priority in using the data he collected, the observations in the depository should be considered public property, available at cost to all research workers. In a way, the proposed depository would be similar to the National Climatic Center in Ashville, North Carolina, which is used extensively by the scientific community. However, the collection of data by the depository would include many items specifically collected in the course of experiments that are presently unavailable at Ashville. It is recommended that the Weather Modification Depository be attached as a special unit to the National Weather Records Center.

Socioeconomic Legal Aspects for the Future

What the public thinks about weather modification, rather than what scientists know about it, will play the dominant role in the future of this science. The most expertly developed technology, whether it be for augmenting the water supply or for suppressing damaging weather phenomena, will find only limited future application in the absence of a strong public demand.

Prerequisites for the development of widespread public understanding are:

Convincing evidence that the benefits promised can be gained without risk of catastrophe and at true costs more attractive than those of other options.

Clear demonstration to Peter that he is not to be robbed for the benefit of Paul. Easily used administrative means of processing claims for damages resulting from weather modification operations must be provided so that court action is not routinely required.

Effective mechanisms for public participation in scheduling and control of operations.

Reliable communications though public media about the scale of effects to be expected.

Much research and organizational effort are needed to analyze public demand.

As pointed out by Sewell in NSF Report 68-18 "Human Dimensions of the Atmosphere," the issue facing us now is to outline directions which future research on human adjustment to the atmosphere should take. He outlines four main lines of inquiry:

(1) Sensitivity of activities to weather and climate. - We must gain a much better appreciation of the sensitivity of our society to such factors as temperature, precipitation, and wind. Broad types of investigations are needed to cover studies of the impact of weather and climate on particular industries and upon the social patterns which have evolved within specific regions of the country. We must be able to anser specific question such as the economic or social significance of an extra degree of temperature for a particular activity, or the economic impact of hailstorms or hurricanes on a given region.

(2) Impact of weather and climate on locational decisions. - How strongly has the factor of weather and climate influenced the decesions of individuals or corporations to locate in a given region? Will the ability to modify the weather have a major impact upon such locational decisions, or are other factors such as available labor pools, natural resources, and transportation facilities more important in this determination?

(3) The role of weather and climate in decision making. - How do people decide which of several alternative means of assessing the impact of weather is the most appropriate? For example, what factors condition the manner in which people interpret and respond to information given in a weather forecast? Why do some people welcome weather modification activity but others oppose it?

(4) Effects of human activities on weather and climate: What effect does the thermal, particulate, and gaseous contribution of man's activities to the atmosphere have upon weather patterns?

It is apparent that if we are to make use of our growing capability to manage our environment, we must gain a much better understanding of these four critical problem areas which link man to the weather. Much of this understanding will require the talents and abilities of the social scientist. Unfortunately, the participation of the social sciences community in problems involving weather and climate has been minimal in the past. A concerted effort to attract these talents to environmental and atmospheric management problems can be made by providing equal partnership to the social scientist on the management teams and giving him the resources which he needs to do the job.

Many legal problems face the successful application of atmospheric management practices which are not covered by existing law. The application of water law or riparian rights to atmospheric water resources raises many controversial questions which fail to fit the circumstances involved. Who, indeed, owns the clouds which pass over a state, a city, or a property owner's boundaries? Are clouds to be considered in the same light as wild game in the forest which belongs to anyone who can capture and take possession of it? Are clouds and atmospheric moisture really national resources such as oil and minerals, and should they be subject to Federal or state regulation?

A new body of law for weather modification practices should be defined at this time rather than to submit to the present chaotic practice of building precedents through case records. Unfortunately, there are few court cases on record, and these have done little to point the way toward an equitable law structure.

Ecological and Hydrological Studies

A continuing program of basic and applied research in ecology and watershed hydrology is needed to provide the necessary background knowledge for weather modification programs. In addition, specific ecological and hydrological studies must be established at the sites of weather modification projects. They must become a significant part of the decisions on when, where, and how to perform cloud seeding and on the evaluations of the results.

Specific efforts are required to:

Improve technology for identifying, measuring, and monitoring biological and hydrological changes at sites specifically known to be influenced by weather modification operations.

Assess the impact of weather modification upon biological systems. Analyses should be made of ecosystem responses to specifically identifiable types and amounts of weather modification. Identifiable ecosystem responses within the zones of influence of weather modification need to be related to responses that occur elsewhere due to natural variations in weather.

Assess the impact of weather modification upon the physical landscape and hydrological cycles. Analyses should be made of the influence of artificial changes in precipitation (frequency, intensity, duration), radiation, and temperature upon the hydrology of large agricultural, forest, and other wild land watersheds. Changes in erosion, sedimentation and stream channel stability may occur as a result of weather modification. Studies should be made of the interrelated effects of forest or agricultural practices (size of timber openings, crop patterns, etc.) and weather changes on watershed behavior. In mountainous country, studies should be made of possible changes in snow avalanche characteristics that may occur as a result of modification of orographic storms.

Learn how micrometeorological processes in the soil-plant-air regime interact with specific changes in weather systems. These studies need to relate specific kinds and levels of weather modification to such things as radiation, sensible heat, water, carbon dioxide, and chemical processes within vegetative systems. A comprehensive model should be developed that predicts microclimate characteristics produced through weather modification. Techniques should be developed for applying knowledge gained from these studies to a variety of land management and environmental protection activities including enhancement of plant growth, reduction of rural duststorms, control of forest fires, and dissipation of heat and smog in cities.

Chapter IV.

RECOMMENDATIONS FOR ACTION

Implementation of the suggestions for acceleration of progress will require the preparation of detailed action plans. ICAS member agencies indicated as Lead Agencies for the designated national projects, should create a coordination committee for each project. The chairman of each committee should be drawn from the lead agency for the particular project and each participating agency should be represented.

The work of these coordination committees should include early development and submission to ICAS of action plans as well as periodic progress reports after the project is underway.