PROJECT SKYWATER--

THE BUREAU OF RECLAMATION'S

ATMOSPHERIC WATER RESOURCES PROGRAM 1/

By

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Introduction

With increasing social and political pressure for both more rain and more effective rainfall, the Bureau of Reclamation through the Office of Atmospheric Water Resources has organized a broad research and development program directed at learning how to get more rain or snow to fall and to put it where it can do the most good.

"Project Skywater" as we call this program is generating an all-out effort to accomplish these goals. It should be pointed out that Project Skywater includes within its scope the consideration of the social, ecological, economic and legal problems generating from weather modification efforts. However, the primary objective of the Skywater program is to learn how, and to develop the capability, to make more rain or snow to fall, and to put it where it does the most good. In the immediate future, the primary objective of the program is to learn how to make more rain or snow in those regions where the water will filter into the lakes behind dams or into reservoirs.

It is also important to point out that the Skywater program is only a part of the National Weather Modification program. Other components of the National program include fog control, lightning and hail suppression, severe local storm elimination or control, and hurricane modification which are primarily being conducted under the auspices of other Federal agencies.

The basic nature of Project Skywater is a contracted program directed by the Bureau of Reclamation through the Office of Atmospheric Water Resources. Its current funding is three and three-quarter million dollars and the work is being performed through 10 universities, 1 nonprofit research foundation agency, 5 Federal agencies and 6 private research groups.

Primary Study Areas

The work of Project Skywater has evolved into nine problem areas as follows: (1) Problem Identification and Approach, (2) Program Studies, (3) Background Studies, (4) Instrumentation, (5) Cloud and Precipitation Processes, (6) Cloud Treatment Materials, (7) Cloud Treatment Systems, (8) Weather Modification Evaluation and (9) other studies such as Social, Economic, Ecological and Legal aspects of weather modification.

Under problem identification, we include such items as the definition of a weather modification system which includes outlining and examination of components of a total weather modification system. It also includes the identification of problem areas and gaps in knowledge or technology. It includes the establishment of priority needs and program planning for the program.

In the program study area, we include the definition and selection of weather modification experimental areas, regional analyses, augmentation of river basin streamflow through weather modification, and the coordination and integration of programs with other groups or agencies.

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Background studies are of many types. In the meteorological area they include such things as nuclei climatology, cloud and storm climatology, synoptic climatology, diffusion studies, water budget studies and the development of water yield estimation procedures. Other studies include area economic studies, water value, ecological studies, sociological studies and personnel requirements.

Instrumentation is also of special concern to the Skywater program. Priority needs include new or better airborne nuclei counters, snow measurement devices, radar, instrument systems with real-time research and display systems, the improvement of all types of standard sensors, and new and better remote sensing devices.

The Skywater program is concerned with all aspects of cloud and precipitation processes. The program includes work on cloud dynamics, cloud physics, cloud and storm modeling, terrain effects on storms or clouds, trans-sky diversion and many other factors.

In the area of cloud treatment materials, the Bureau is interested in any of the new and better seeding agents along with increasing the efficiency in the use of the primary seeding agents, silver iodide and dry ice.

Along the lines of cloud treatment systems it is concerned with the development of variable output generators and dispensers, automated treatment systems, real-time monitoring of research or operational systems and new treatment systems. Such new systems might include napalm mass seeding generators, jet engine nuclei injection systems, and rocket or other launched systems.

Weather modification evaluation continues to be a very important part of the Skywater program. Some aspects of this work include the detection of seeding agents in precipitation, cost to benefit studies, pollution studies, downwind effects, carryover effects and project rain-on-the-ground evaluations.

Components of the Cloud Treatment Problem

The heart of the Skywater program is the cloud treatment problem. This problem has four basic components. They are: (1) treatment of the clouds, (2) physics and dynamics of natural and treated clouds, (3) measurement of the required parameters for the study and evaluation of what is going on in the clouds and (4) the evaluation of the results of the treatment.

Cloud treatment is a complex process. Currently it is primarily accomplished with seeding, generally with Ag I through the use of airborne or ground generators. Important concerns in the treatment of clouds are: (1) were the proper materials produced? (2) if so, did the material reach the cloud in the right amount? (3) if so, was the material involved in the precipitation process? (4) if so, did it work in the desired direction? (5) if so, did the rain reach the ground? and (6) if so, did it fall in the right place? When all of these things are accomplished, the treatment can be considered a success.

At the present time, based on our present technology, two effects of cloud treatment are considered to be of primary importance to rainfall augmentation or targeting. The first is affecting the microphysical processes within clouds to enhance the precipitation process, and the second is to affect the microphysical process to enhance the buoyancy of the clouds through release of latent heat and make clouds bigger and live longer to act as rain manufacturing systems. Much research is required before scientists will be able to fully exploit the manipulation of either or both these rain enhancing processes.

Measurement and evaluation of what is going on within the clouds are closely linked. Instrumentation is currently being developed at a rapid rate, but much still remains to be desired in this area. As new instrumentation becomes available, we are able to monitor and evaluate new aspects of treated and untreated cloud processes. When these measurements become available, better evaluations will become possible. In some aspects of the weather modification problem we are still learning what needs to be measured and in others we are just beginning to get ideas of what is required to make these measurements. Our primary sensoring platform remains the small plane. In addition to the problem of inadequate sensoring device, the platform has problems in positioning, altitude, and structural limitations. We must further consider the problem of modifications induced on the environment by our very attempts to make measurements.

Bureau of Reclamation Program

The direction and overall planning for Project Skywater is done from the Office of Atmospheric Water Resources in the Bureau of Reclamation. The field, laboratory and computer weather modification experiments are being done through contracts. The social, ecological and legal aspects of weather modification are also being performed by contract.

Field experiments are performed to learn the best methods to apply the available knowledge, make basic measurements, develop and test new techniques and procedures. Laboratory studies include research activities which can be best studied under laboratory conditions, the physical or scale modeling of atmospheric or cloud processes, and the testing and development of treating materials. Computer experiments include the mathematical modeling of cloud and atmospheric processes and the evaluation of critical factors affecting field and laboratory experiments. As each program proceeds, valuable interactions and feedbacks from the various experiments are expected.

Field Experiments

Within the Skywater program, field experiments are being conducted in six geographical locations. Evaluations are being made for other project sites and planning studies are proceeding for others.

Colorado River Basin. For the past three winter seasons, E. Bollay Associates, Inc. (EBA), has been conducting research experiments in the Park Range of Colorado, near Steamboat Springs. The first year's work was devoted to studying the natural nuclei diffusion and precipitation characteristics for the target area. The emphasis in the second year was to determine how these characteristics, and in particular the precipitation rate, change when storms are artificially nucleated through the use of ground-based silver iodide generators. Data indicate that in many cases only portions of a given storm are seedable. Storms which have temperatures colder than -6°C at the generator altitude (8,300 feet m.s.l.) and a cloud base at or below 10,000 feet m.s.l. are most likely to be seedable in this experiment.

The original hypothesis for the experiment was that the amplitude of the power spectrum of the precipitation rate would be a sensitive indicator of seeding effects. As the experiment progressed, it was found that the coherence, or degree of systematic connection between the power spectrum of precipitation rate and the power spectrum of a periodic seeding function, was a better indicator and used properly could detect a change of ±5 percent of the average precipitation rate. The analysis of the 1965-66 snow season did not detect a significant increase in precipitation. Further study suggested that uncertainties in the transport time (time required for ice nuclei from the generator to arrive as snow in the target area) could be the problem, because this would affect the phasing of the computed effect without changing the amplitude. After the experiment was completed there was no practical way to determine the actual transport time for the various analysis periods, but the operating design for the 1966-67 season was modified to enable better determination of this parameter. Conclusive results from this season are not yet available.

For the past 8 years, Meteorology Research, Inc., (MRI) has been active in field experiments near Flagstaff, Arizona. These activities have been focused primarily on summer convective clouds which form in the vicinity of the San Francisco Peaks. One important aspect of this program as in any cloud seeding program is determining the dimensions and location of the plume of the seeding material. MRI was able to track the plumes of fluorescent particles and also ice nuclei by means of airborne continuous counters. Surveys performed with an aircraft-mounted cold box have verified the presence of high concentrations of ice nuclei in clouds which, judging from balloon trajectories, were nucleated by ground-based silver iodide generators. Very low or zero counts were found in clouds which had not been seeded. Such positive identification of seeded clouds greatly increases the significance of the other in-cloud observations. For example, significant aircraft icing was not observed in heavily seeded clouds, but was regularly encountered in unseeded clouds. Strong potential gradients were found in seeded clouds, whereas slight electrification was noted in the unseeded clouds.

The effect of cloud seeding on buoyancy is also being studied by MRI. Studies have shown temperature increases up to several degrees Celsius and buoyant force increases of about 10 cm/sec^2 were produced in artificially glaciated cumulus clouds.

The MRI group has also conducted field experiments with seeding agents other than silver iodide and dry ice. For exapmle, metaldehyde, a promising organic, was used with positive results in the 1966 experiments.

Another important aspect of the field program at Flagstaff during the summer of 1966, was a cooperative effort by several Bureau contractors which resulted in a real-time acquisition, display, and utilization of data obtained from radar and airborne sensing elements. The development of such a real-time system has been a part of the University of Nevada's contract objectives. As an outgrowth of a Bureau-sponsored conference on data acquisition, two of our contractors, South Dakota School of Mines and Technology and Meteorology Research, Inc., joined with the University of Nevada to provide this data acquisition system involving telemetry, aircraft and radar. Because of similar interests, the Pennsylvania State University also supported this group. These four organizations, as well as others interested in weather modification research, met during the summer of 1966, for a concerted research effort on summer cumulus cloud systems. The data acquisition system included a number of instrumented aircraft which telemetered data to the ground, tracking radars, and an on-line computer which processed the data in real time. This was the first opportunity for a full-scale field test of this system, and the promising results suggested for additional study.

Missouri River Basin. At the South Dakota School of Mines and Technology, (SDSM&T) a group of scientists with a variety of interrelated interests is developing practical methods for seeding summer cumulus cloud systems in the Northern Great Plains. The Rapid Project has a randomized crossover design utilizing a high frequency of test cases. Silver iodide, dispensed from mobile ground generators or from airborne generators, is used in this experiment. Due to the rigorous statistical requirements of this study, definitive results are not yet available.

A climatological study of the experimental site revealed that the maximum precipitable water is found late in July, but that the precipitation peak is in June. One suggested explanation of this phenomena is that downslope surface winds and subsiding air aloft in late July effectively suppress precipitation despite the higher precipitable water content.

South Dakota cloud physics field studies included more than 300 aircraft passes through about 200 different clouds. Many of these cloud penetrations were at the -5°C level. It was found that ice particles do not naturally occur at the -5°C level in most of the cumulus clouds studied. Dry ice was used to seed individual clouds, and the seeded clouds were compared with unseeded clouds with respect to glaciation, vertical development, and precipitation falling from the cloud base. More cases are required before definitive results will be available.

The University of Wyoming's (UW) Natural Resources Research Institute is studying cap cloud phenomena at Elk Mountain, an isolated peak 50 miles northwest of Laramie. They have demonstrated that cyclic seeding of cap clouds results in cyclic precipitation from the cap clouds, and that moving the generator to different locations shifts the precipitation area. An observatory has been installed on top of Elk Mountain to permit better observation within the cap clouds. Evaluation of the data gathered so far suggests that a single silver iodide generator can be expected to provide, conservatively, 100 acre-feet of water in the form of additional high mountain snowpack per day of cap cloud occurrence. It is estimated that about 1,000 such generator-day units of operation are available during most winters in the mountains of Wyoming.

Two criteria have been formulated by the University of Wyoming for successful cap cloud seeding. They are:

1. The average lapse rate between the generator elevation and the cap cloud elevation must approach or exceed the dry adiabatic rate, and
2. Riming must be occurring within the cloud (observed at the instrumentation site atop Elk Mountain).

A second cap cloud program was started during the fall of 1966, in the Wind River Mountain Range. Because this program is so new, no conclusive results are available from this project.

During the spring and summer of 1966, Montana State University completed the preliminary study phase of a field program designed to determine the downwind effects of artificial nucleation applied upwind of an orographic barrier. The area selected is about 180 miles long, and the existing precipitation gage network will be augmented by a number of recording gages. Several of the recording gages have been installed. The climatological study revealed little correlation between horizontal distance and precipitation variance, but a linear relationship between precipitation and altitude. An operating plan for the program has been developed; the first year will be devoted to determining the natural stability of precipitation east of the target area, the Bridger Range. The artificial nucleation operation is scheduled to begin in the second year.

Interior Basin. On opposite sides of the Great Basin, Utah State University and the University of Nevada are studying methods to produce, detect, measure, and evaluate the effects of weather modification.

Utah State University (USU) is developing a field program involving two remote-controlled silver iodide generators to be located on ridges of the Wasatch Front, and two others to be located at valley sites west of the mountains. Two target areas and four control areas have been selected. At present, the work of completing the analysis of climatological records, installing a dense network of precipitation gages and a telemetry system to transmit the data to the headquarters site is proceeding. No seeding has been undertaken to date. The bulk of the activity so far has been in the development of the instrumentation and the telemetry system.

The University of Nevada's desert research Institute (DRI) is attacking the problem on a broad front ranging from cloud physics to actual seeding experiments. DRI is using the wave clouds over the Sierra Nevada Mountains near Reno, Nevada, as a natural outdoor laboratory for applied research. They are using dry ice seeding exclusively in order to obtain "standard values" for later comparison with other agents.

A study was made of the feasibility of using the Federal Aviation Agency (FAA) radar system as an aid in the control and observation of weather modification experiments. The data from each of the radars in an area are transmitted to the Air Route Traffic Control Center and displayed. The FAA system has the desirable feature of eliminating the ground clutter which can obscure many details of the precipitation pattern. This weather radar network has been set up by the Environmental Science Services Administration (ESSA) and the FAA.

A data acquisition system is being developed for real-time processing and utilization of cloud data, the wind field, and aircraft positions. This requires coordination of calibrated radars, airborne sensors, telemetry systems, and an on-line computer. A prototype system was checked out successfully in 1965, at Flagstaff in cooperation with the DRI summer program.

The DRI cloud physics group has been gathering cloud data in connection with the field experiments. Cloud particle growth, under natural and seeded conditions, is being studied in storm and wave clouds. In one wave cloud, at a temperature of -23°C, uniform-sized droplets were observed to grow from a few microns to about 30 microns in diameter, apparently by condensation alone. In another case, samples taken before seeding showed the cloud consisting of scattered sizes of super-cooled droplets. After seeding, about 70 percent of the particles were large agglomerated ice crystals. Cloud data are also being incorporated into a numerical cloud model.

Pacific Northwest. The State of Washington Weather Modification Board has begun a program which hopefully will result in techniques for shifting precipitation from areas of excess to areas of deficit. The first winter's efforts were devoted to determining the characteristics of natural precipitation, the diffusion of seeding materials, and the various synoptic conditions associated with precipitation in the Snoqualmie Pass area. It was found that approximately 70 percent of the days between November 1965, and April 1966, produced significant precipitation at Stampede Pass. Precipitation occurred as snow on about half of these days. Diffusion tests indicate that seeding materials released from the ground have little likelihood of reaching the effective level, and therefore, the seeding agent will be released from aircraft. The past winter's activities were devoted to determining how natural precipitation characteristics are modified by artificial nucleation.

Under a cooperative agreement between the Bureau of Reclamation and Bonneville Power Administration, and funded by the Bonneville Power Administration, a contract was negotiated with North American Weather Consultants to design a weather modification research program for the drainage basin of the South Fork of the Flathead River above Hungry Horse Dam in Montana. The program design was completed in early September 1966, and was used as the basis for preparing specifications for the operation of the winter research experiment. The program is designed to restrict seeding effects to the Hungry Horse drainage basin. It is providing valuable information about natural nuclei concentration, is also augmenting the limited climatological data now available, and studying the effects of seeding on the precipitation regime. This program got underway in November, and seeding began early in December. Results of the program are not yet available.

Southern Sierra. The sourthern portion of the San Joaquin valley and Sierra Nevada mountains of California has long been a focal point of intense interest and activity in weather modification. Fresno State College Foundation, a nonprofit corporation which is affiliated with Fresno State College, has been retained to coordinate weather modification efforts in this region. A hoped-for result is a joint experiment involving many cooperative efforts between the various groups, public and private, operating in the area. This would minimize the conflict resulting from one group's control area becoming another group's target area and should help the programs of all concerned.

During the summer months of 1966, a cloud census program was undertaken, and limited seeding operations on summer cumulus clouds were conducted. It was found that clouds seeded with dry ice precipitate, while adjacent clouds do not. Hydrologic studies were initiated to determine the effect of precipitation from summertime cumulus over small basins in the Southern Sierra region. Atmospheric water budget studies and cloud pattern studies are underway. Analysis of the data is still in progress.

Rio Grande River Basin. During the summer of 1966, New Mexico State University completed the initial survey phase of a proposed field program to increase the understanding of atmospheric processes leading to precipitation and to develop techniques for augmenting precipitation in the Upper Rio Grande River Basin. During the initial 6-month program they developed the experimental design for the program which includes the identification of equipment, instrumentation and personnel requirements. The target area of the program is in the Sierra Nacimiento and Jemez Mountain Ranges, most of which is National Forest land. A statistical model, developed by Colorado State University, will be modified to suit the requirements of this program. The objective of the model is to make an analysis of weather modification efforts on a basin-wide scale. Climatic and hydrologic data were analyzed and the results used in determining the experiment design. New Mexico State University is planning a year-round program. While rainfall is slight in summer, it is significant. Therefore, the convective clouds of summer will be studied along with the frontal and cyclonic clouds of winter.

Field Support

Field support activities are conducted with the support of several Federal agencies to provide special measurements, additional measurements, and additional installations which, because of lack of equipment, trained personnel, or other causes, the contractor has not been required to supply. For example, the U. S. Geological Survey installed three stream gages as a part of the Park Range program. These gages have greater accuracy than those normally used in routine measurements. Several weirs were installed on small drainages by the Forest Service, and their scientists are conducting watershed management studies to determine how such practices influence runoff.

The Soil Conservation Service installed snow pillows for the Park Range program and provided the telemetry system for remote reading. They also installed new snow course sites to facilitate evaluation of results and take special measurements over the new and the existing snow courses after each storm.

Laboratory Studies

Laboratory studies are being conducted by a number of Bureau contractors. Some are intimately connected with on-going field programs, while others are essentially independent activities.

Utah State University's prior interest in telemetry has led to the development of a radio telemetry system for transmitting temperature and precipitation data from isolated mountain locations to the Water Research Laboratory at the mouth of Logan Canyon. These isolated locations require the installation of several mountaintop relay stations because the transmission is essentially line-of-sight. Each remote telemetry unit is responsive to one specific call signal, and is capable of sending several types of information from a single transmitter. The interrogator possesses a digital data readout system. Interrogation and printed readout of each station require about 10 seconds--the stronger the signal the shorter the time. Because of noise levels involved, an automatic tracking filter was designed and built as an integral part of the system. The system as it now exists transmits a signal from the laboratory to a repeater (which may then go to other repeaters) to a precipitation gage site where it turns on the data transmitter. The value of the desired parameter is then transmitted back along the same path. Eventually the data readout will be linked directly with a computer.

In addition to telemetry, Utah State University has also developed several special transducers, fiberglass precipitation gage, and several snow pillows. At one site they have installed, for comparative purposes, a 12-foot butyl rubber pillow, a 4-foot steel pillow, a 4-foot rubber membrane over a steel plate, and a 2-foot rubber membrane pillow. The relative accuracies of all pillows are comparable; the diurnal fluctuations are much less pronounced with the smaller pillows. The 4-foot steel pillow appears to be the best compromise of cost, maintenance, accuracy and reliability.

The University of Nevada's cloud physics group is developing a numerical cloud model which incorporates the analysis of data gathered in their field experiments. The changes occurring in a droplet spectrum under the influence of the collection process are being studied. The production of large drops is very dependent upon the characteristics of the collection efficiency. The model is also expected to be able to study the combined effects of condensation and coalescence. A separate study has shown that Poisson statistics are sufficiently valid when considering collection problems in a real situation.

Other laboratory studies include determination of silver content in snow by neutron activation, autoradiographic techniques for ice crystal nucleant in clouds, effects of wetting on the ice nucleating efficiency of chemical compounds, the freezing of droplets, and the characteristics of airflow in vertical wind tunnels. These studies were begun during the summer of 1966, and conclusive results are not yet available.

South Dakota School of Mines and Technology is establishing a cloud physics laboratory to study the various crystalline states of silver iodide, and also a wind tunnel to test various kinds of cloud seeding generators. They are continuing work on a telemetry system, and the cloud physicists are modifying their cloud model to incorporate changing boundary conditons.

The ventilation system of the Homestake Mine in Western South Dakota has five vertical shafts operating between the surface and the 4,850-foot level, two subshafts operating between the 4,850-foot and 6,800-foot levels, and a net-like horizontal passageway at every level. Investigation revealed that clouds form in the exhaust shafts and that the precipitation process is well advanced by the time the air reaches the surface. South Dakota School of Mines explored the use of these ventilation systems for cloud physics experiments and concluded their use would benefit the program.

The U. S. Weather Bureau is studying the synoptic climatology of the West with special emphasis on precipitation-producing systems, and also case studies of storm types and associated precipitation patterns. Their studies have disclosed the relationship between the intensity of a 700-mb low and the distribution and amount of precipitation, the winter precipitation related to 500-mb maximum vorticity center, and the winter precipitation from 850-, 500-, and 300-mb lows. Through analyses of precipitation relationships in individual watersheds of the Upper Colorado River Basin have also been completed.

The Naval Ordnance Test Station (NOTS) is cooperating with the Bureau's program through their development of seeding materials and dispensing systems for light aircraft. Pyrotechnics ranging from a cartridge for the M-8 Very pistol to very large droppable charges have been developed. These charges burn for about 4,500 feet of vertical fall. NOTS has also made a detailed study of the reaction of silver iodide with alkali iodides. It has been suggested, but not clearly demonstrated, that the resulting complexes, such as $AgI \cdot 3KI$, serve first as condensation nuclei until the droplets grow large enough for a dilute solution to form, at which time AgI precipitates and causes the droplet to freeze.

Dr. T. G. Owe Berg is investigating the effect on the efficiency of seeding agents on passage through the warm base of a cloud where the temperature is warmer than $0^{o}C$ and the cloud composed of water droplets. He has developed specialized laboratory equipment to observe the interaction between water drops and silver iodide particles, between water vapor and silver iodide, and the effectiveness as a seeding agent of silver iodide particles after these interactions. The water drops and silver iodide particles are suspended in a nonuniform alternating-current field and observations are made microscopically and by high-speed photography. Equipment has also been developed to produce silver iodide particles of known charge along with charge analysis of the interactions with water vapor.

It has been determined that silver iodide of the type normally used in cloud seeding is not wetted by warm (room temperature) water drops in collision. Experiments have indicated that the activation energy for the wetting of silver iodide particles and the coalescence of water drops is between 7.5 and 8 Kcal/mole. It has also been found that the delay between contact and coalescence is considerably shorter at temperatures near $0^{o}C$ than at room temperatures, indicating that supercooled water drops may wet silver iodide particles in collision.

Aerometric Research, Inc., has begun a study of the general effects downwind of seeded areas. Historical climatic and hydrologic data have been tabulated and testing has begun to select the best analysis technique. A tabulation of all weather modification projects on record in the 11 Western States has been completed. A total of 124 separate projects has been found.

The University of California at Los Angeles has obtained the complete meteorological and operational data from a Swiss hail suppression program. In the UCLA program it is not the hail suppression which is of interest, but rather the differences in precipitation which occurred. Analysis revealed that substantially more precipitation occurred on those occasions when one particular meteorologist forecast for hail occurrence than when another meteorologist was in charge. The purpose of the study is to identify the particular meteorological situations which existed when each of the two meteorologists was on duty, and the weather modification techniques that resulted in increased and decreased precipitation.

The use of streamflow as an evaluation method for weather modification experiments is being studied at Colorado State University. Streamflow has the advantage that it represents the water which is available for man's use. It also integrates the precipitation of an entire basin. The results of the first part of the study have been published as a Ph.D. dissertation, and include detailed analyses of several statistical approaches to the use of streamflow in evaluation.

W. E. Howell Associates, Inc., is developing an evaluation technique that involves an adaptation of a statistical technique set forth by G. P. Wadsworth. The approach eliminates the need for widely separated target and control areas and many years of seeding experience to determine effects. Initially, the work was confined to relatively simple topography, but will ultimately be applied to mountainous terrain. The distinguishing characteristic of this method is that the estimate of natural target precipitation does not depend on a climatological relationship between certain stations or sets of stations. A plane surface is fitted to the precipitation parameters in the vicinity of the seeded area, and the natural target precipitation is determined from the plane. The actual target precipitation can then be compared with the estimated precipitation. Thus, each individual storm furnishes all its own control data. Data are still being assembled, and no results are available at this time.

Negotiations have been completed with the University of Arizona for investigations of the legal aspects of operational weather modification programs, and with the University of Denver's Denver Research Institute to study the most effective experimental designs for statistical evaluation of weather modification experiments or operations. The Department of the Interior's Office of Ecology is studying the ecological effects of increased precipitation. Meteorology Research, Inc., is preparing a report on the status of cloud nucleation.

Future Plans

The combination of these many activities, in conjunction with research conducted by other nations or agencies within the United States, is bringing us much closer to our goal of a practical capability to increase precipitation for the improvement of water supplies. However, comprehensive management of the atmosphere requires continued and exhaustive development of scientific knowledge, technical skills, and sprecialized equipment The identification and solution of the many complex problems involve disciplines often far removed from the science of meteorology.

We have completed a planning report that outlines our future program in atmospheric water resources. As described in this report, we propose to develop a region-by-region capability for enhancing water supply, with early emphasis on those areas where water problems are critical. We expect to develop a practical, reliable capability in selected western mountain areas by about 1975. Supporting the regional development efforts will be an expanded series of research projects and studies resolving the many problems identified by current weather modification programs.

Conclusion

The Project Skywater program is now coming of age. We have learned much about the problem we are dedicated to solve; we have learned some approaches to the problem. We know much about some of the components of the problem, but little or nothing about others. For example, we have learned much about the inefficiencies of nature in precipitation production but practically nothing of why silver iodide works as a treating agent.

As new information, instrumentation, theories or hypothesis become available, we must be prepared to disprove, accept, reject or assimilate whatever becomes important to the program. We must identify the gaps in our knowledge, instrumentation, or procedures and take appropriate steps to get on with the job of learning how to make more rain and put it where it will do the most good.