WATER POTENTIALS OF WEATHER MODIFICATION

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INTRODUCTION

Weather modification is a term that refers to the alterations of any of several physical dynamic processes that occur naturally in the atmosphere. It includes hail suppression, cyclone deterioration, fog dissipation and precipitation augmentation. It is the latter that will be discussed in this paper.

Vincent J. Schaefer (1) and Irving Langmuir at the General Electric Laboratories in Schenectady, New York, demonstrated that certain types of storm systems produced more rainfall when seeded with dry ice. Bernard Vonnegut (2) used silver iodide crystals in his studies and concluded that they were more effective nucleants than soil particulates normally found in the atmosphere. Tor Bergeron (3), a Swedish meteorologist, and Walter Findeisen, a German physicist, determined that clouds would begin precipitation if they contained the right mixture of ice crystals and super-cooled water drops. The exact mechanism by which raindrops or snowflakes are produced from tiny cloud droplets or ice particles is not fully understood.

Cloud Physics

The clouds that produce appreciable precipitation are formed when moist storm systems are forced to rise either by topographical features or by interaction with a colder air mass. The rising system is cooled by expansion and billions of tiny water droplets are formed.

These droplets are extremely small, their diameters ranging from 1×10^{-5} to 1×10^{-3} centimeters, and are too light to be effectively removed from the clouds as precipitation. The buoyancy force due to air turbulance and the gravity force are approximately equal. Thus an additional process must occur to form water drops large enough to fall from the cloud and reach the ground without evaporating.

In the ice crystal process the cloud must exist in a temperature regime colder than freezing so both ice crystals and super-cooled water drops will be present. The vapor pressure over the ice crystal is less than over water, so the ice crystals will grow at the expense of the water drops.

Extensive laboratory research has conclusively shown that water vapor requires a nucleus of solid matter about which to freeze if the temperature is warmer than -40°C. The freezing nuclei are quite

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variable in their behavior and their numbers may vary a thousandfold or more from day to day and from place to place. The natural nuclei are dusts,or combustion particulates. The particulates are unable to serve as freezing nuclei until the temperature has fallen to some value much colder than freezing. Each type of particulate has its own specific freezing value.

Precipitation augmentation depends upon using artificial nuclei such as silver iodide to provide the proper nuclei concentration and a warmer freezing temperature. Figure one (4) indicates the theoretical relationships between elevation, temperature and type of freezing nuclei. Water content of Zone A can be affected by silver iodide nucleation while water in Zone B will remain unaffected.

Practical Application

In 1952, Dr. Irving P. Krick, (5) a meteorologist, initiated a contract with the City of Dallas, Texas to augment their municipal water supplies. He used ground based silver iodide generators and claimed a 40% increase over a period of two years. In 1953 and 1954 he claimed an increase of 23,000 acre feet for Oklahoma City at a cost of fifty cents per acre foot.

In 1961 the U. S. Congress (6) appropriated $100,000 and commissioned the U. S. Bureau of Reclamation to initiate concentrated laboratory research in the physical processes of precipitation. In 1964 the Bureau of Reclamation started a series of research programs in outdoor laboratories. Contracts were made with several universities and private corporations for the actual research programs. New Mexico State University (7) presented a proposal to the Bureau of Reclamation for a feasibility study within the Rio Grande Basin in 1965. The study indicated the Jemez and Sierra Nacimiento mountain ranges near Cuba, New Mexico were suitable as an outdoor experimental project. The Bureau of Reclamation requested, received and funded a three-year research proposal for study, design, establishment, operation and evaluation of the precipitation augmentation program in New Mexico.

The research area is bounded on the west near Cuba, on the north by Coyote, on the east by the Baca Location and on the south by Jemez Springs (Figure 2).

The primary purpose of the New Mexico engineering research program is to develop and use precipitation augmentation and management procedures to increase the quantity of celestial waters that can be contained and used for beneficial purposes within the Rio Grande Basin. In addition, the technology developed in this specific basin can be integrated with the technologies developed from other research projects within "Project Skywater" to allow the creation of a national program to enhance the nation's total water resources. The region offers the opportunity to develop techniques for precipitation augmentation where water supplies are very critical and where the physical constraints enhance the probability of a successful program.

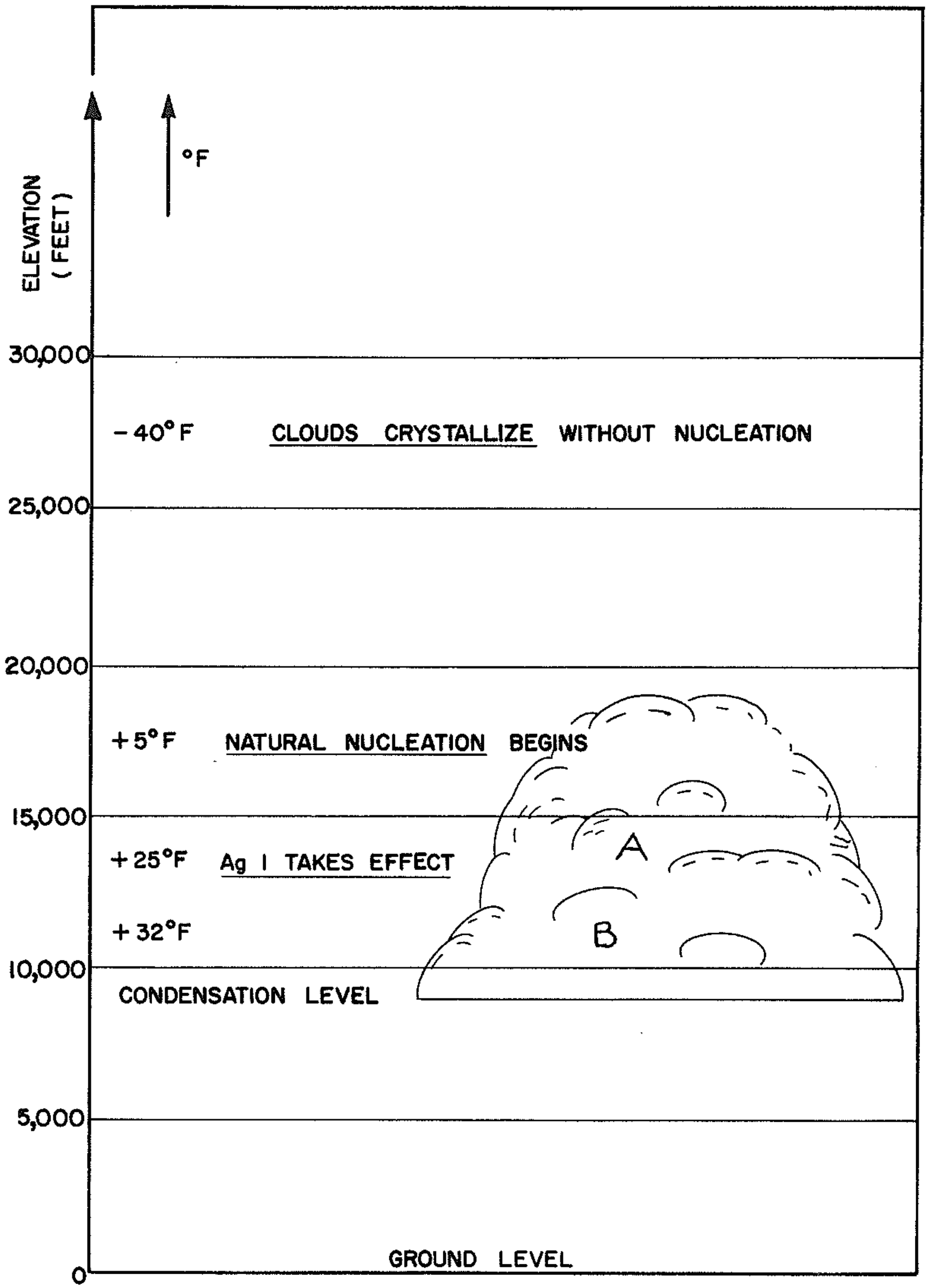

FIGURE 1 NUCLEI TYPE AND TEMPERATURE INTERACTION (4)

The drainage basin is very well defined and contains approximately 350 square miles. The climate, hydrology, geology, and logistics are very unique in the New Mexico program.

A research and experimental program to objectively manage precipitation augmentation from winter orographic snow storms must include the following components:

A. A statistical design that will determine the experimental units, and procedures for data collection and analysis.

B. A scientific study of the meteorological parameters to determine treatability of natural storm systems.

C. An adequate treatment delivery and measurement system.

D. An adequate terrestrial precipitation measurement system.

E. Adequate support facilities, such as, transportation, communications, radar, radiosonde releasing and tracking, and emergency shelters.

F. Cooperative work agreements with other state and governmental agencies (U. S. Forest Service, U. S. Soil Conservation Service, U. S. Atomic Energy Corporation, U. S. Geological Survey, New Mexico Engineer Office, New Mexico Fish and Game Department).

G. A good public relationship with the citizens of the experimental area and its environs.

H. A comprehensive analysis system to evaluate data within a reasonable time.

I. Sufficient funds and personnel to adequately complete the experimental program within a reasonable time.

The New Mexico Project has been involved in the development and implementation of each of these components. The amount of effort expended has been limited by a lack of scientific personnel (Meteorologists), transportation facilities, precipitation and ice nuclei measuring equipment, and finances.

Each of the components of the program will be discussed briefly to enhance clarity of purposes and procedures.

The statistical model is completely randomized and employs separate target and control areas. Differences between precipitation effects produced naturally and artificially are analyzed. This model has been used by the research group at Colorado State University and has been proven to be very efficient.

The primary objectives of the statistical evaluations have been directed towards the following:

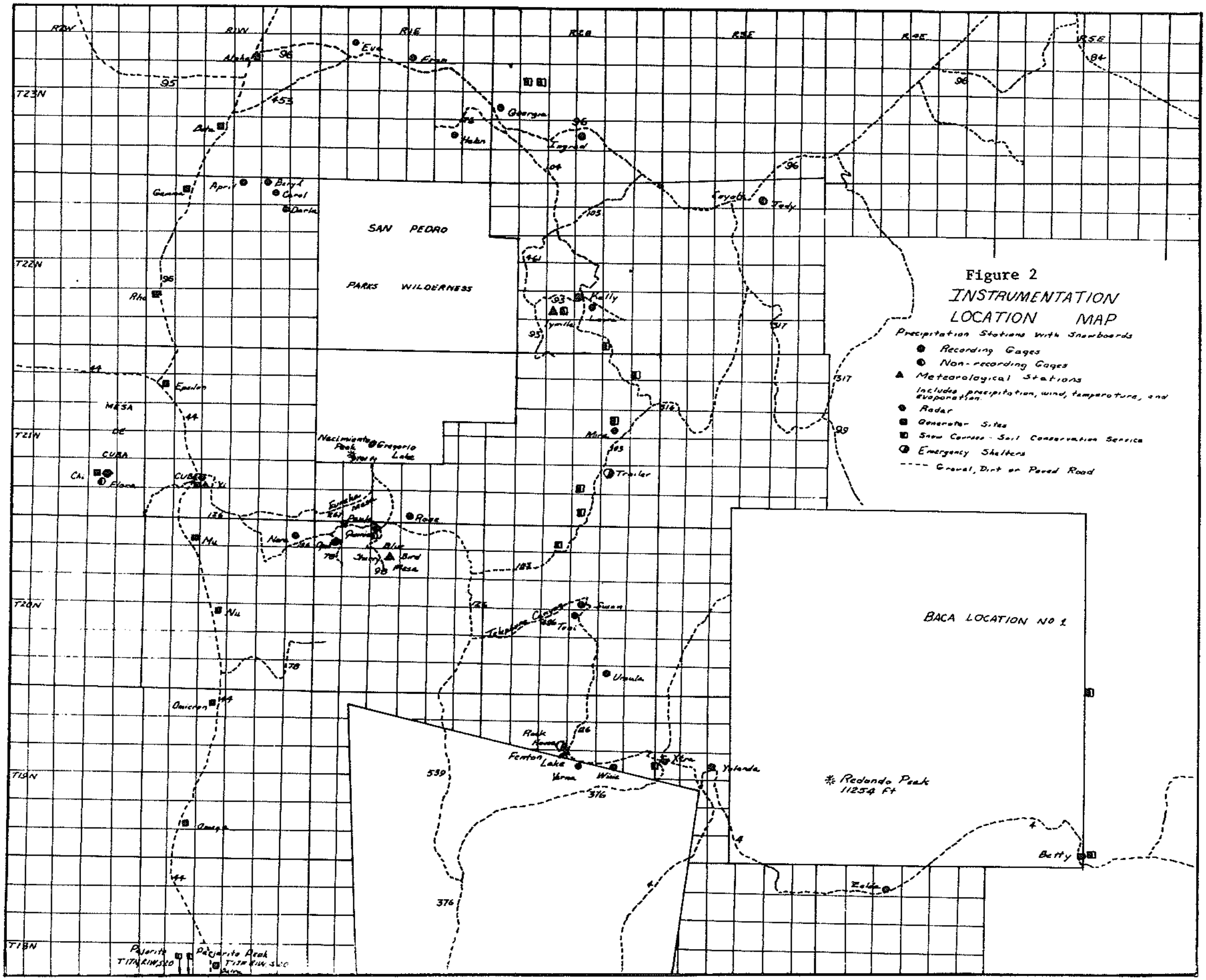

Figure 2
INSTRUMENTATION LOCATION MAP

1. To determine if there is an increase in the winter snow precipitation as a result of cloud seeding operations in the Jemez and Sierra Nacimiento Mountain Ranges. If so, what is its magnitude?

2. To determine if there is an increase in the flows of the Jemez Springs River as a result of cloud seeding in the watershed.

3. To determine if secondary effects have been initiated "down wind" from the cloud seeding operation in the target area. (Sangre de Christo Range).

Other evaluation methods will also be considered and investigated as the program progresses. Some of the methods are listed below in brief qualitative form:

1. Correlation between average precipitation (day, week, month, storm period, etc.) on the target and control areas.

2. Precipitation patterns in the target area will be correlated as a percent of normal of the adjacent areas.

3. Steamflow correlation studies.

4. Times Series Analysis.

A research and field experimental program just include a continued analysis of the types and classes of storm systems. Experimental prediction models must be developed for reliability and accuracy of weather forecasts. The New Mexico Project has personnel and equipment for locating and tracking storm systems as they approach and pass over the experimental area. Measurement of specific meteorological parameters are made to determine suitability for modification. These parameters are: winds aloft, temperature, relative humidity, pressure, natural nuclei concentrations and elevations of top and bottom of cloud system.

The nuclei delivery and measurement system is one of the most difficult components of the program. Five artificial (CSU Modified Skyfire) nuclei generators and one (NCAR) portable and acoustical nuclei counter are being used. Twelve generator sites and one mobile generator unit have been used near Cuba, New Mexico on Highways 44 and 96 as shown in Figure 2. The generators operate on a variable pressure system and can deliver from 0.2 to 0.4 gallons per hour of a 2% solution of AG I in acetone. A series of diffusion studies have been made to determine the longitudinal axis and band spread of the Ag I plume from each generator site. Vertical movement of plume has to be measured by kites or airplanes. Figure 3 indicates the ground level diffusion pattern for generator sites and wind direction shown. The winds aloft that accompany snow storm systems for our project usually come from $270 \pm 20^{\circ}$.

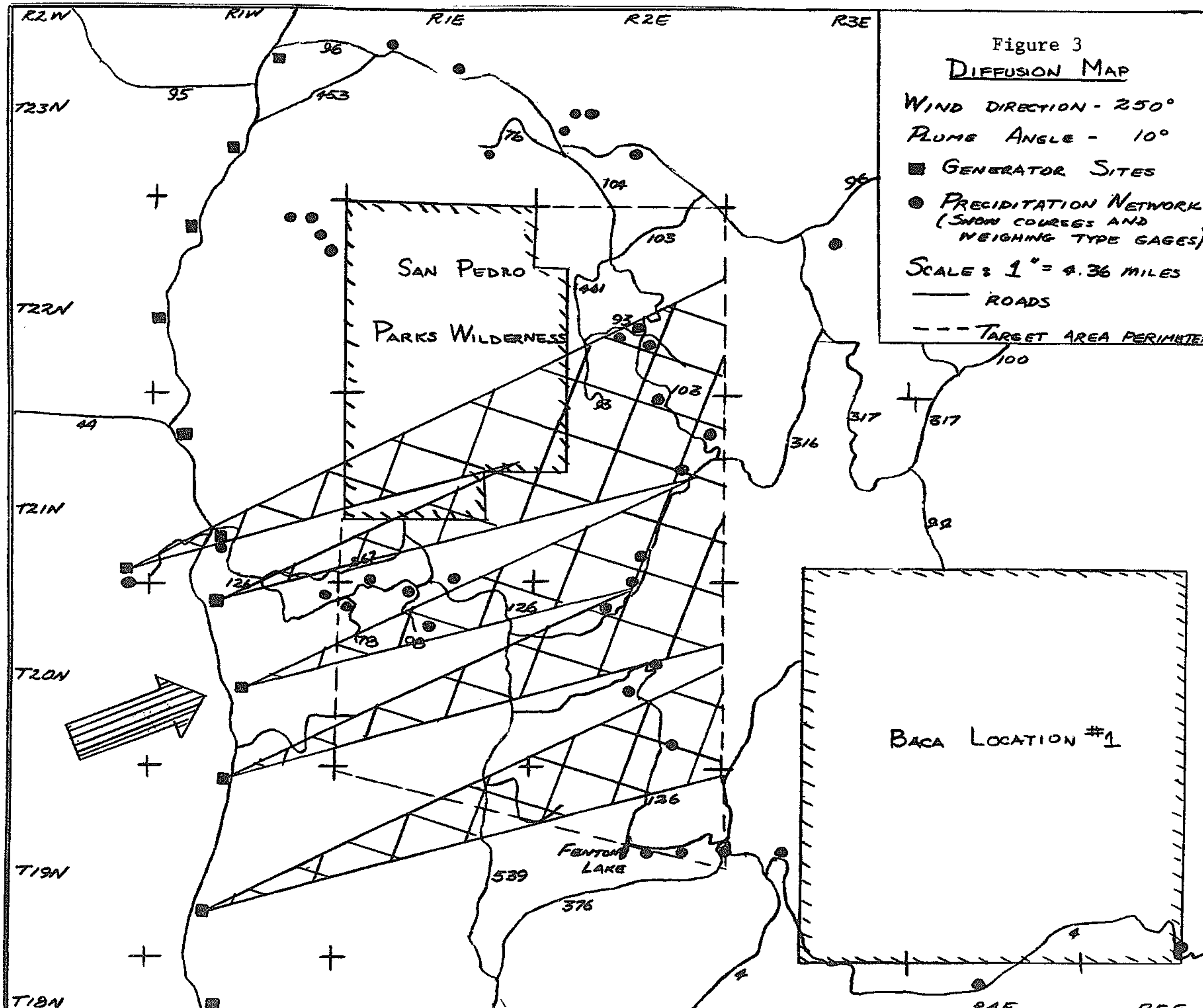

Figure 3
Diffusion Map

Precipitation on the ground is measured and used as the criteria to evaluate the efficiency of the project. Twenty-five recording snow precipitation gages have been installed to create a grid pattern within specific drainage basins and to present a spectrum of elevations. The locations are shown on Figure 2. A snow board and a snow pole are located adjacent to each recording precipitation station. They are used to provide additional independent measurements of total precipitation and precipitation per storm period.

The Soil Conservation Service has completed the installation of 12 snow courses within the target area and environs. Information received will be autocorrelated to provide an independent method of determining effects of seeding select storm systems. A snow pillow and attendant instrumentation has been located near an emergency trailer house on Road 103 to provide a secondary method of measuring precipitation rate and accumulated snow fall.

Adequate support facilities of radars, transportation, communications, living quarters and office facilities have been provided to assure an effective and safe operation.

A Wilcox 890 Series Radar is located on Cuba Mesa to locate intense storm cels (50Km), to track same, to measure antenna elevation angle, and to record time of day and day of month. A time-lapse camera has been mounted on the PPI scope for post-time analysis of storm systems.

A T9 Tracking radar unit is located at the Cuba highway yard and is used to track balloons and tin foils in special diffusion studies.

A contract has been made with the Director of the Physical Plant Facilities to lease two 4-wheel drive and one 2-wheel drive trucks. These vehicles have been fitted with wenches, special tires, canopies and emergency supplies. Road 103 and the interior of Road 126 are passable with a 4-wheel drive truck except for the period of January through March. A snow-kat is available on a cooperative basis from the U.S. Conservation Service, Snow Survey group. Two ski-doos and a portable trailer have been purchased and are used for servicing gages located off the main roads.

A complete radio communication system has been purchased and a unit has been installed in each vehicle and at the main office in Cuba. A relay station has been installed on Blue Bird Mesa. Two portable radios of the same receiving and sending frequencies are used in the ski-doos. All personnel make contact with the main office each hour on the hour. Safety of the personnel is of primary interest to all.

Two trailers have been located on the Cuba highway yard for personnel living quarters. Bunk beds, showers, refrigerators and cooking facilities are provided. The radar van on Cuba Mesa, a trailer on Road 103 and a rock house on Blue Bird Mesa have all been provided with emergency supplies, bunk beds and a stove.

In November 1968 the project personnel put the program into full operation. Fifty randomized yes-no envelopes were prepared and placed into the custody of the project engineer. The actual field seeding program has been initiated. The precipitation data can be analyzed on a year to year basis to determine snow fall rates, quantities and distribution on a storm and seasonal basis, however the determination of seed-no-seed snow fall differences require an accumulation of precipitation records for four to five years.

The project personnel were able to clearly define how many storm systems passed over the project area, how many of the units were seedable, the location of how many generators were needed, determination of plume axis and concentration of artificial nuclei in the storm systems were made, communications, transportation and all other systems performed quite well. As a qualitative measurement of artificial nuclei distribution, personnel have driven through seeded storms at ground level and have been able to detect a "concentration gradient wall" by eye and to confirm it by using the NCAR Nuclei Detector. Analysis of precipitation stations have also indicated the gradient effect.

The potential for increasing snow pack in selected areas by using artificial nuclei intelligently looks very promising. Dr. Lewis Grant (8) of Colorado State University has reported that he has augmented precipitation in the Climax Project by 10-80% in selected cases where temperature, pressure, relative humidity and winds were just right. Negative values were also obtained when seeding occurred during undesirable storm systems.

The scientific approach to precipitation augmentation will succeed, however, a total environmental analysis will have to be completed to determine its actual benefit to mankind. The long range plans of the New Mexico Project include ecological and sociological as well as economic studies of net benefits.