Report of Investigation No. 3 1949

STATE OF ILLINOIS
ADLAI E. STEVENSON, Governor

RADAR AND RAINFALL

G. E. STOUT and F. A. HUFF

Prepared in Cooperation With
PFISTER HYBRID CORN COMPANY

DEPARTMENT OF REGISTRATION AND EDUCATION

NOBLE J. PUFFER, Director

STATE WATER SURVEY DIVISION

A. M. BUSWELL, Chief

URBANA, ILLINOIS

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CONTENTS

March 1, 1949

FOREWORD

For effective use of water resources, reasonably complete Information is essential. There are relatively simple ways to secure this information on existing lakes and ground water sources. But where it is necessary to establish a new water use, as for example constructing an impounding reservoir, engineers find themselves faced with a lack of detailed local data, so that it has often become necessary to hope that a design, successful elsewhere, will be applicable to the local situation.

To secure the detailed, basic data for water resource use, the State Water Survey has heretofore followed this program:

1. Sponsorship of stream gaging, in co-operation with the U. S. Geological Survey, and analysis of the data obtained.

2. Measurement and study of ground water conditions.

7.. Operation of rain gages in connection with surface and ground water studies.

4. Measurements of water losses through evaporation.

In these fields, the most obvious weakness has been in the measurement of precipitation.

In some areas, notably the Lake Bloomington watershed, the Water Survey rainfall records were not in close agreement with those of the Weather Bureau. The Survey augmented its field equipment with accurate precipitation recording instruments and found that the disagreement still held, The Weather Bureau gages, spaced approximately 25 miles apart, measure the general distribution of regional precipitation whereas the Water Survey gages, located only a few miles apart, indicated different rain patterns within a few square miles.

The principal weakness in the precipitation data appeared to be in the measurement of thunderstorms occurring in May through August each year. These storms, often isolated, account for about 40 per cent of Illinois[1] annual rainfall. These are the storms that usually designate the flood hazards on small watersheds and hence, the spillway design. Yet because of their frequently small areal size, incomplete data are secured by conventional rain-gaging techniques.

Closer spacing of raingages would be desirable, but preliminary examination indicated such a program to be very costly. Doubling the number of gages would cost approximately $50,000 the first year and the gages would be approximately 10 miles apart. This is still too sparse a network to observe a thunderstorm of one- or two-mile diameter. A fairly satisfactory rain-gage spacing in Illinois would cost about $2,500,000 the first year.

I. SUMMARY

A project was organized for the intensive study of the precipitation pattern in a small area in Central Illinois. Data were collected on (1) the variation of rainfall over a small area, *(z)* the application of radar for precipitation studies, and (3) on the relation between corn yield and rainfall. The project was prepared to evaluate any attempts at inducing precipitation in the area.

The forecasting, raingaging, radar, aircraft and communications facilities used are described.

During June, July and August 1948 the total rainfall varied from 8.5 to 14.5 inches within a distance of 17 miles. These dry and wet areas appear to persist quite frequently.

The practical usefulness of radar in detecting and tracking rain was proven. The radar equipment paid for itself through short-period warnings of incoming precipitation.

No induced precipitation flights were made during the summer of 1948 due to the adequacy of the natural rainfall.

A detailed study was made of synoptic conditions during the summer months. The data indicate that precipitation depends more upon the stability of the atmosphere than on the actual moisture content at a given location.

The advent of radar for observing thunderstorms therefore offers an opportune solution to the problem of detailed rainfall observation over large areas. This report evaluates the pioneer use of radar for rainfall study in Illinois. The results should fill a real need in the development of Illinois' water resources.

A. M. Buswell, Chief

RADAR AND RAINFALL

II. INTRODUCTION

This report reviews the organization, operation during 1948, and data collected in a Jointly sponsored study of radar and rainfall between the Pfister Hybrid Corn Company of El Paso, Illinois and the State Water Survey Division of the Department of Registration and Education, State of Illinois. The study has been designated as Project PFISTER.

During the latter part of 1947, William and Jack Kraft of Peoria, Illinois furnished the State Water Survey copies of their logs of flights made to induce precipitation. These flights were sponsored by the Pfister Hybrid Corn Conroany. Realizing the importance of induced precipitation with relation to water resources, attempts were made to evaluate these logs. The data observed and reported were limited and a complete meteorological analysis was impossible. It was concluded that the problem of induced precipitation warranted further study.

The Pfister Hybrid Corn Company volunteered to assist in conducting a study of both natural and induced rainfall. It was thought that a network of raingages and a radar set would be essential field equipment for such a study. Early in January 1948, Mr. Lester Pfister, President of the Pfister Hybrid Corn

Company, supplied funds to purchase a radar set.

The essential elements of an APS-15 radar set were purchased from a war-surplus dealer in Chicago. The task of building cables to connect the various elements together was carried out by John B. Roche, a student in Electrical Engineering at the University of Illinois who had experience in the Navy with this set. During this period Assistant Prof. T. A. Murrell, of the U. of Illinois served as a consultant on radar problems.

Only daylight hours of operation was planned since the newly constructed landing strips on the Pfister farm were not equipped with lights. Operational plans called for collecting data on natural rainfall from 1 May to 15 September and induced rainfall from 1 July to 1 September.

During early 1948 the organization was busy procuring and setting up equipment. Those engaged in that work are mentioned above, with the exception of ¥. J. Roberts, Associate Engineer, who initiated the study and supervised it until June 1948, After that date, the following group carried on the operations:

1. Glenn E. Stout, Senior Assistant Meteorologist, was engaged in coordinating the El Paso installation with the Urbana office, supervised the collection and evaluation of data with emphasis on the radar data.

2. Floyd A. Huff, Assistant Meteorologist, was engaged in the preparation of weather maps and charts, the issuance of forecasts from the Urbana office and the analysis of the rainfall data.

3. Richard C. Price, a Junior in the Electrical Engineering Dept. of University of Illinois, operated the radar and set up the radio equipment.

4. Wm. G. Albright, Head of the High Frequency Radio Lab, of the University of Illinois, became the radar consultant. He supervised the testing and maintaining of the equipment.

5. Lester Pfister, President of the Pfister Hybrid Corn Company, was very active in planning and working out various operations.

6. Boniface J. Mayer and John P. Kearney were employed by the Pfister Hybrid Corn Company to pilot the aircraft.

7. Richard D. Gilroy assisted in the preparation of weather maps and charts.

8. Jerome, Walter and Daniel Pfister checked and maintained the automatic raingages.

Much of the success of the work has been due to the continuing interest and the useful suggestions of Dr. A. M. Buswell, Chief of the Survey. The authors are indebted to Mr. H. E. Hudson, Jr., Head of the Engineering Sub-Division of the Survey, for his aid in the conduct of the study and for his detailed review of this report.

In addition to these individuals, the following residents in the El Paso area served as rainfall observers:

Dallas Schuler, Lynn Ripoel, Clay Holt, J. A. Etscheid, Ed Ioerger, George Adams, Leo Kearney, Ray Baker, '.7. A. Barth, Robert McHugh, Clyde Stotler, M. J. Cleary, Ed Kearney, Clarence Fever, L. B. McCarthy, Wallace Kapraun, Ralph Poorbaugh, Harold Remmers, James McWilliams, Dan T. Kearney, Parks Bohlander, J. K. Walker, Lloyd Wagoner, Paul Cunningham, Glenn Menton, Arthur Sparks, James Delaney, Clyde Brovrn, Kelly Mounce, Carl Barth, Clark Hart, Carl Quiram, Lewis Martin, E. T. Carr, Lewis Clausen, J. Ulrich, Lester Bachman, Hugh Brock, Lester Davison, Albert Frey, Alvin Albrecht, Lester Litwiller, C. T. Gildersleeve, Wilbert Funk.

For counsel and in several cases, material aid, we are also indebted to personnel from the following organizations:

Physics Dept., Agronomy Dept., Electrical Engineering Dept., U. of Illinois; Dept. of Meteorology, U. of Chicago; M.I.T. Weather Radar Research Project; Chanute Air Base; Glenview Naval Air Station; Philco Corporation; Project CIRRUS, General Electric Research Laboratory; Cloud Physics Project, U. S. Weather Bureau; Library of Congress and Pfister Hybrid Corn Company.

III. SCOPE

The original purpose of this study was to evaluate the results obtained by any induced precipitation flights of the Pfister Hybrid Corn Company in the immediate vicinity of El Paso, Illinois, during each growing season over a three-year period. In view of the equipment used, plans were made to employ the data for several other studies.

The measurement of the areal distribution of rainfall has been of vital concern to those engaged in the design of dams and lakes for a given area or watershed. Having a concentrated network of raingages, a study of the variation of rainfall within a limited area was planned.

The usefulness of radar as a means of detecting and measuring rainfall was to be studied.

Since the El Paso area is the headquarters for the growing of hybrid seed corn by the Pfister Hybrid Corn Company, the Agronomy Dept. of the University of Illinois was asked to correlate the rainfall and corn yield data. Both records of rainfall and corn yields would be available at the close of the fall season.

It was also planned to study the weather conditions to learn the frequency of conditions favorable for inducing precipitation.

This report for the summer of 1948 includes a discussion of results of all phases of the project except the original objective and the rainfall versus corn yield study. Due to the abundance of natural rainfall in the El Paso area, no flights were made to induce precipitation. The study of corn yield versus rainfall will not be published until more data have been collected.

IV. INSTALLATIONS AND EQUIPMENT

RADAR

A 3-cm. wave length radar set, designated by the Navy as an AN/APS-15B Radar, was installed on the third floor (Fig.1) and roof (Fig. 2) of the factory building of the Pfister Hybrid Corn Company at El Paso, Illinois.

The word radar is formed from "Radio Direction Finding and Ranging." By using radar it becomes possible to detect the presence of objects such as rainstorms and to determine their location and movement.

Radar transmits a high power pulse of radio energy for a very short duration by an antenna which focuses the energy to a very narrow beam. When the transmitted radio energy strikes an object having certain characteristics, a portion of the energy is reflected from the object to the point of transmission. This is referred to as an "echo". The time required for the transmitted pulse to be sent out and returned from a target is so measured by the equipment that the distances are recorded accurately. Received echoes are picked up by the same antenna assembly, separation taking place at the "mixer" unit so that the received echo is isolated from the transmitted signal. Thus a common antenna assembly is used for both transmission and reception. In an AN/APS-15B, the antenna revolves through 360°,

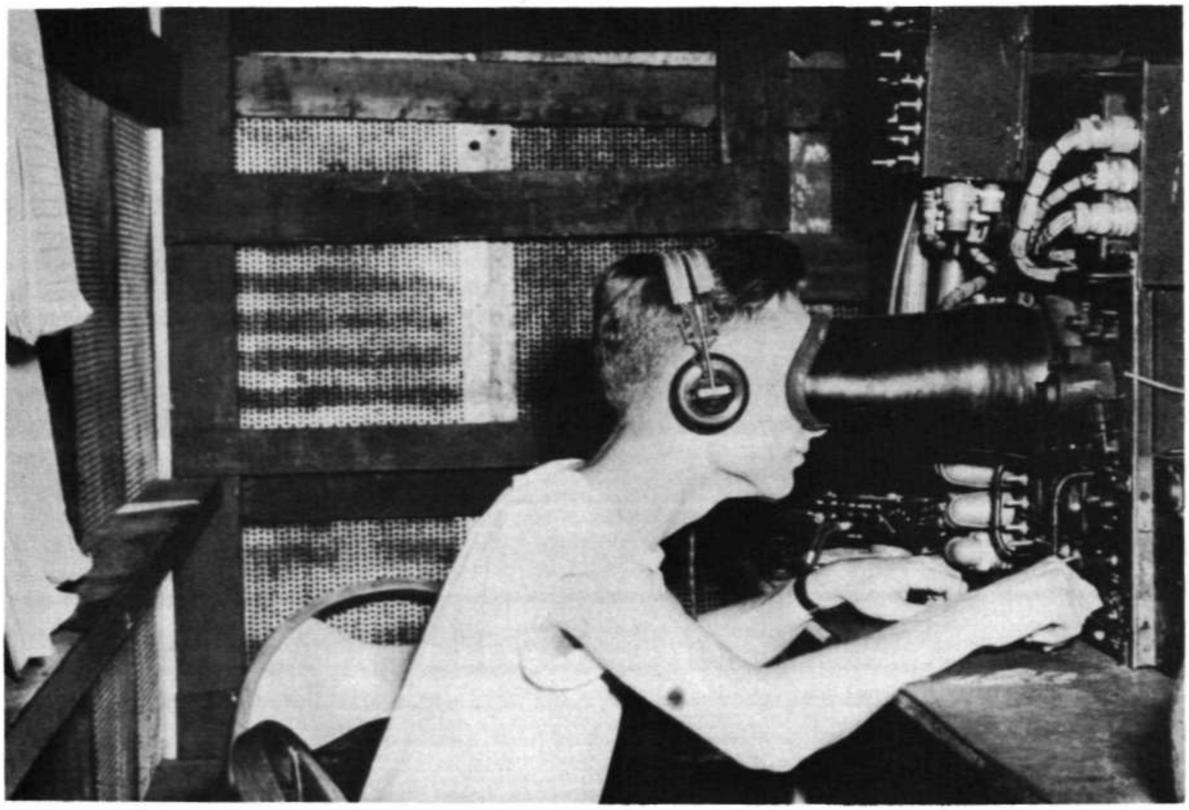

Fig. 1. Radar operator studying the PPI scope. Earphone indicate readiness to communicate with the aircraft.

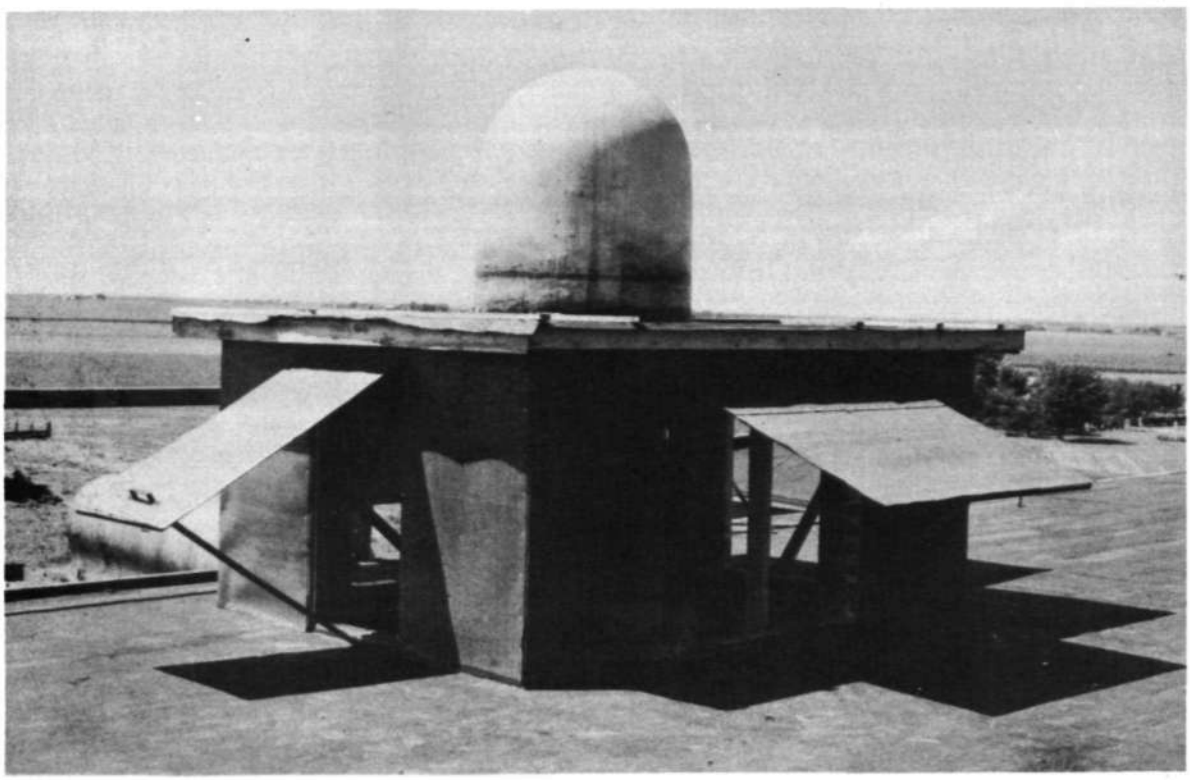

Fig. 2. Penthouse with radome on top, housing the antenna, approximately 50 feet above the ground.

about a vertical axis. The antenna system consist of a 29-inch diameter parabolic reflector with a double dipole radiator located at the focal point of the parabola.

Received echoes are presented on various types of "scopes" or indicators. One of the most useful scones is the PPI or plan position indicator. The echo appears as a bright spot on the circular fluorescent screen of a cathode-ray tube. The radar's position is located in the center of the scope and presents the range and azimuth in polar coordinates. The range is shown in concentric circles about the center. When the radar beam is not sufficiently elevated, nearby buildings reflect some of the pulsed energy (See Chapter VIII). Since the antenna rotates constantly, it furnishes a complete azimuth picture at all times on the scope.

The equipment as a whole contains 84 assorted vacuum tubes and 2 crystals. It requires 28-volt d.c. and 115-volt, 400-cycle current for operation. Detailed description of the equipment is published elsewhere[(1)]

The radar was originally purchased to be used in tracking the seeding aircraft and to verify whether or not precipitation occurred in the seeded area. It was actually used to track the natural rainstorms, since induced precipitation flights were not attempted during 1948.

[(1)] Handbook of Maintenance Instructions for Models AN/APS-15A and AM/APS-15B Aircraft Radar Equipment, U. S. Navy, Revised 1 May 1946.

Control of Seeding Plane

Radar offers a very effective means of controlling and tracking the movements of the seeding plane. On most occasions the Diane would be flying above an overcast of clouds and might be unable to determine its position without the aid of radar. The seeding altitude can be determined from the air temperatures and the proper seeding point upwind from the target can be established from the winds aloft pattern. The plane can then be vectored by voice communications to this point by watching its position on the radar scope.

Wartime research indicates that the detectable range of an AT-6 aircraft is only 5 to 10 miles with the APS-15 radar* Test flights were not conducted to verify these figures.

Indication of Precipitation

Radar has been used for several years to locate and track the movement of rainfall areas[2]. Actual drops of moisture (a particle of sleet, hail or snow) must be present and some of these drops must be 1 mm or more in diameter in order to produce a visible echo on the radar scope.

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*Unpublished Report.

(2) M.I.T. Weather Radar Research, "First Technical Report Under Signal Corps Project", Army Contract Ho. W-36-039-SC-32038, December 31, 1946.

The radar Itself will not ordinarily detect clouds, unless they are precipitating moisture. Therefore, any seeding of clouds that results in a significant amount of precipitation will appear on the scope. The exact location of any precipitation, along with the position of the aircraft, will be recorded. As the precipitation area increases, the radar echoes will increase so that the spatial extent of the rainfall will be shown.

The relative intensity of precipitation can be determined by the strength of the reflections from the storm area. For instance, thunderstorms and heavy rain squalls give a much stronger image on the radar scope than do light showers.

Maintenance

Troubles encountered in the radar unit have been varied. The rectifier crystal that is used in converting the micro-wave signal to a much lower frequency of 30 mc. was replaced frequently. This crystal is highly sensitive and may be damaged by the static electricity present on one's body. Failure of some other component has usually been the cause of a crystal burning out.

Three vacuum tubes have been replaced after becoming defective and several others have been switched during the time the gear has been in operation.

Bad connections have been the source of trouble in two cases. A break down of a high-voltage condenser in another case kept the equipment inoperative for two weeks.

Early difficulties in reception were largely due to improper tuning. The original tuning must be made with the aid of elaborate test equipment. However, once it has been adjusted, it can be kept in tune without the use of this equipment.

The equipment was operated frequently during July and August. The actual operating time of the radar was 108.75 hours (log in Appendix A-1). About one-third of the days the equipment was out of order. This is a rather large percentage, but equipment failures were not overcome rapidly because there was little need for the equipment. Generally, test equipment or spare parts had to be procured before making repairs,

CAMERA

A kodak "35" camera was used for photographing the PRI*. A supplementary lens (Kodak Portra 1+) was placed in front of the camera to step up its power and permit a "close-up of the radar scope. The camera was focused for 21 inches and set at f4.5. A bulb attachment permitted opening of the lenses for 5 seconds while the radar antenna made a complete sweep.

*Plan Repeater Indicator, an extra plan position indicator.

A 12-hour watch with luminous figures and hands, and a data card were placed to the left of the radar scope for photographing. The date, a.m. or p.m. and range mark interval were recorded on the data card. A small light was directed onto the clock and data card. The space between the face of the camera and scope panel was covered with a hood as shown in Fig. 3.

The photographs show the exact position of rainfall in the area at the time of photographing. If seeding of clouds had been performed, the position of the aircraft with respect to rainfall would be shown. The photographs would be valuable in verifying whether the rainfall was natural or artificial.

RADIO

Radio was used to convey information between the plane and the ground. The ground radio was used to inform the aircraft of its position. In turn, the plane would report its activity, the time of seeding, the amount, and results of seeding.

Frequencies high in the radio-frequency spectrum were used because of less interference from atmospheric disturbances such as static. Such disturbances frequently prevail when the radio is in operation. The frequency used was 154.49 megacycles which lies in the VHF (Very High Frequency) band. This frequency is characterized by being limited to "line-of-sight" transmission. Since all operations were to be within a limited radius of the station, long-range communication by radio was not necessary. Other factors favoring the use of this frequency were the lack of interference from other stations, greater ease in obtaining the license required by the Federal Communications Commission, and the availability of the proper equipment on war surplus.

The equipment (Fig. 4) used was the SCR-522, a Bendix war-surplus two-way radio which operates in the band from 100 mc. to 156 mc. The average power output is approximately 8 watts giving an approximate range of 30 miles with the plane at 1,000 feet and 70 miles at 3,000 feet. The principal components include the transmitter-receiver, the power supply, the control box, and the antenna.

The transmitter-receiver assembly, when interconnected to the other components, provides transmission or reception of amplitude-modulated radio-frequency energy. The audio-frequency amplifier portion of the receiver is designed so that interphone communication between two or more stations is possible. The average sensitivity of the receiver is 3 to 4 microvolts for a 10-decibel signal-to-noise radio.

The receiver is a sensitive superheterodyne receiver employing a heterodyne oscillator whose frequency is controlled by crystals. A carrier-operated squelch circuit reduces

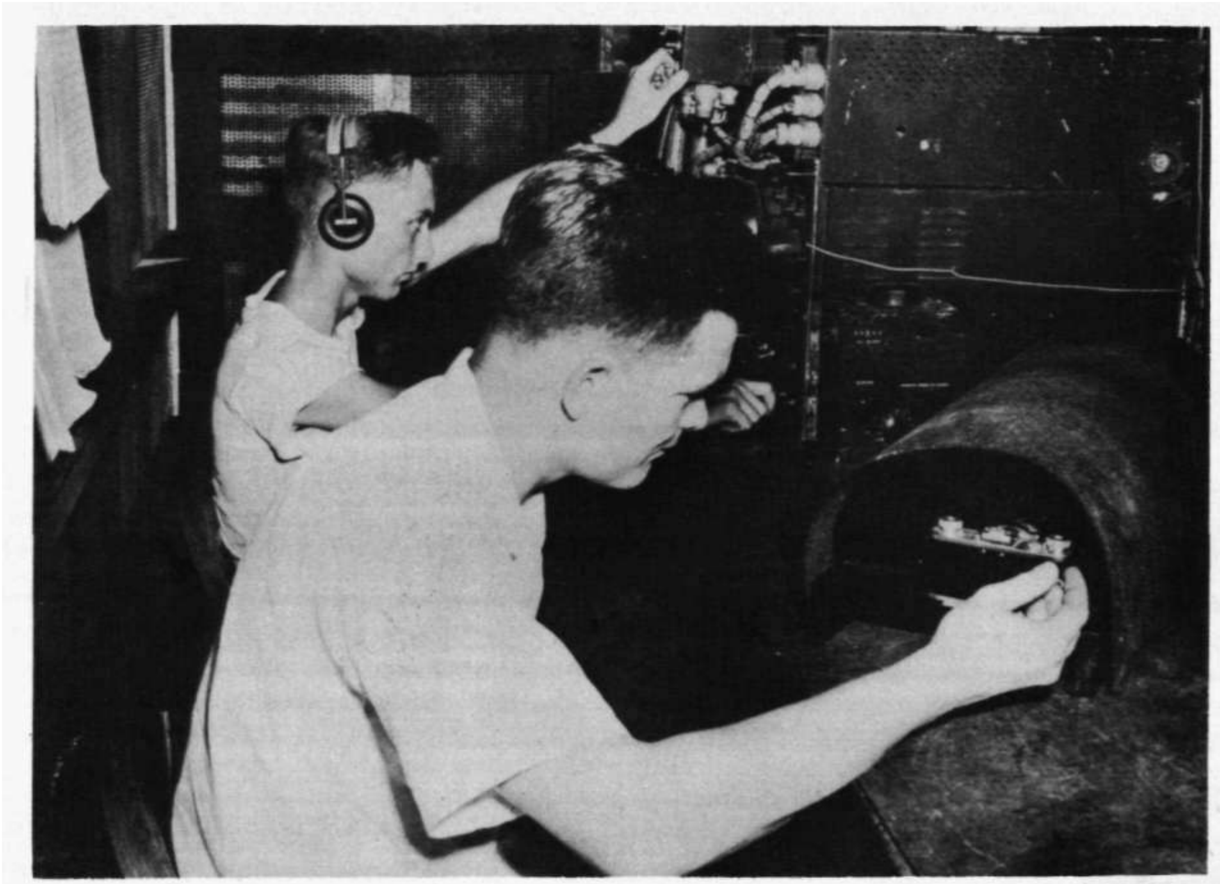

Fig. 3. Camera installation with PRI scope under hood alongside radar set.

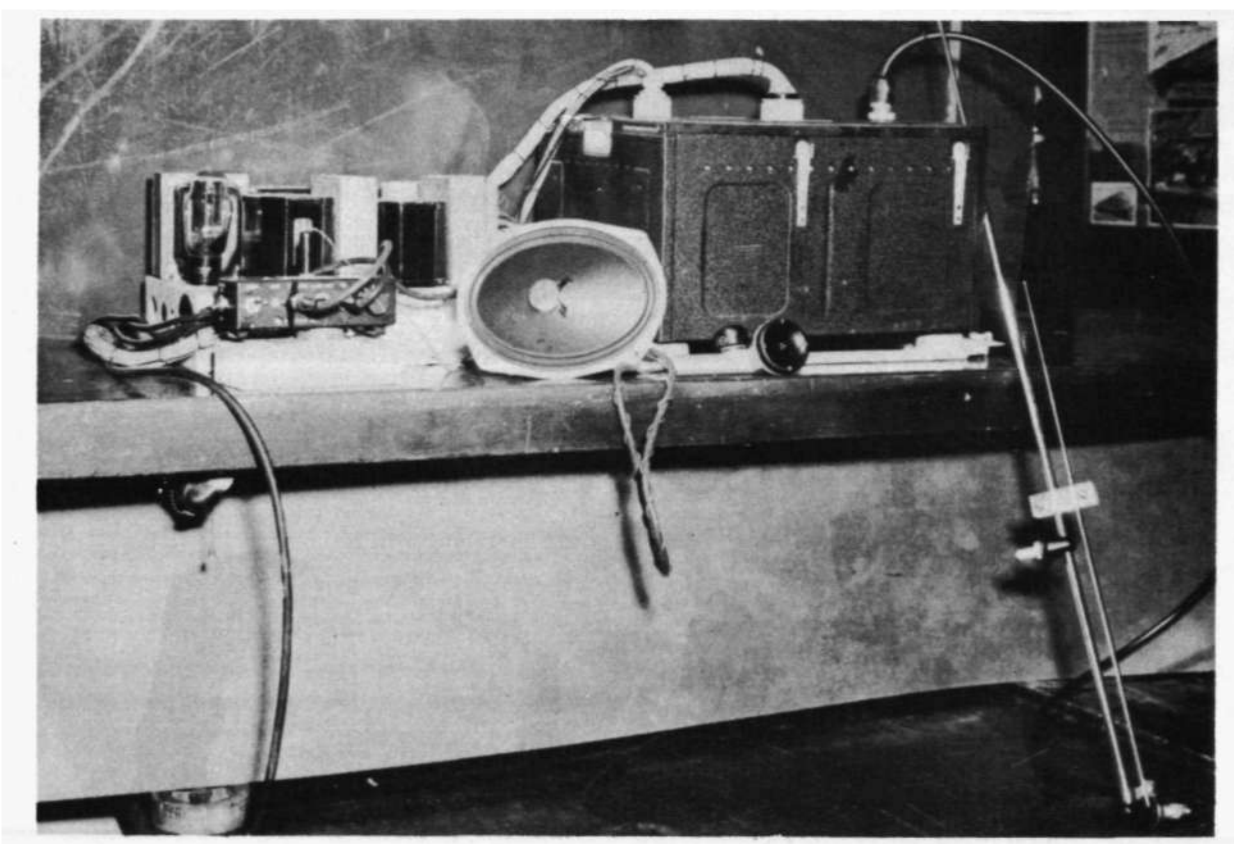

Fig. 4. Electronic power supply (left) with control box and speaker in foreground. SCR 522 transmitter-receiver (right) and antenna for mobile unit.

extraneous receiver noises to a low level and prevents difficulties in interphone communication due to ignition noises, etc.

The transmitter-receiver requires three voltages for operation: 300V d-c for the plates and screens of the vacuum tubes in the transmitter and receiver, -150V d-c for grid bias in the transmitter, and 13V d-c for all tube heaters, control relays, the channel-control motor, indicator lamps, etc.

In the case of the aircraft and mobile installation these voltages are all provided by the 12V dynamotor that is designed for use with this equipment.

In the case of the ground unit the available power is 110V, 60 cycle a-c. For this reason an electronic power supply using this power was designed and constructed which provides the three necessary voltages.

The control box used in the aircraft installation provides complete remote control of communication functions. Interphone communication is available as long as the OFF button is not in the depressed position. Two installations for the connection of microphone and headphones with volume control are provided in the plane. Unlike those in the aircraft, the control boxes used for the ground and mobile installations are similar.

The antenna used in all cases is a quarter-wave length type, connected to the transmitter-receiver by RG 8/U coaxial cable.

The present range of the ground-to-aircraft communication is well over 40 miles (the greatest distance tested). The range of the ground-to-mobile unit is approximately 9 miles.

LICENSES

Any radar or radio station, with the exception of the military and some governmental services, must be licensed by the Federal Communication Commission. This license sets forth the restrictions and limitations for the operation of licensed equipment. Licenses for this project were assigned on a temporary basis and subject to change at any time by the FCC without hearing, if such action should be necessary. The personnel operating the equipment must have a valid restricted radiophone license or one of higher class.

The FCC requires that a log be kept of all operations. A mimeographed log form was set up for recording the information required by the FCC, and also information that should be recorded in connection with our experimentation. Special test equipment was borrowed from the High Frequency Laboratory of the University of Illinois for checking the frequency.

The frequency assigned for the radar operation was 9275 mc., plus or minus 20 mc. Call letters were assigned as W9XVM. The power is not to exceed 40 KW instantaneous (peak). The emission is the pulse type with a pulse duration of 1.0 microsecond, and a pulse repetition rate of 622 pulses per second.

The frequency assigned for the voice radio operation was 154.49 mc. Call letters were assigned as K9XAN for the base station and K9XAO for the mobile units. The maximum authorized input pover is 25 watts.

AIRCRAFT

An AT-6 aircraft (military designation for a single-engine advanced trainer) was purchased by the Pfister Hybrid Corn Company for the seeding operations as shown in Fig. 5. It has dual controls and the rear seat permits a second pilot to seed the clouds and take photographs. The aircraft was originally designed for photographic training and has a hatch in the bottom of the fuselage useful for dispensing dry ice or water,

A supercharger was installed which permitted the AT-6 to climb to an altitude of at least 27,500 feet. Oxygen was provided for the pilots. An SCR-522* was installed in the plane for communication with the ground and between the pilots.

Two runways each 3,000 feet long, were laid out on the Pfister farm, Fig. 6. A 2000-gallon gasoline tank was installed and gas pit built.

Flights were limited to testing equipment and training since no actual seeding flights were made. The log of the

*Very high frequency radio, see page 8.

Fig. 5. AT-6 Aircraft with super-charger. CO_2 extinguisher producing small particles of dry ice.

Fig. 6. The T-shaped landing strip, located northeast of El Paso at the Pfister farm.

aircraft shows that the aircraft was in the air 10 1/4 hours on 15 occasions.

One method of dispensing dry ice from an aircraft is shown in Fig. 5. This method would be most successful in flight through the top of a supercooled cloud.

RAIN GAGE NETWORK

Precipitation data for the project were obtained from a concentrated network of rain gages, as shown in Fig. 7. A total of twelve 7-day recording gages and 35 stick gages was installed in April, May and June over the experimental area, which included approximately 200 square miles. U. S. Weather Bureau gages at Minonk and Gridley, and two permanently installed Water Survey gages on the Lake Bloomington watershed fell within the limits of the area boundaries, providing a grand total of 51 rain gages from which data were available. The majority of these gages were concentrated in the area bounded by Eureka to the west, Minonk to the north, Gridley to the east, and Kappa to the south. Additional rainfall data were provided by several Weather Bureau and Water Survey gages located in the vicinity of the experimental area.

The stick gage observations were made by local residents, most of whom are hybrid-seed-corn growers. At 7:00 P.M. each day, these observers completed a record of the total rainfall for the past 24 hours. This rainfall amount was recorded

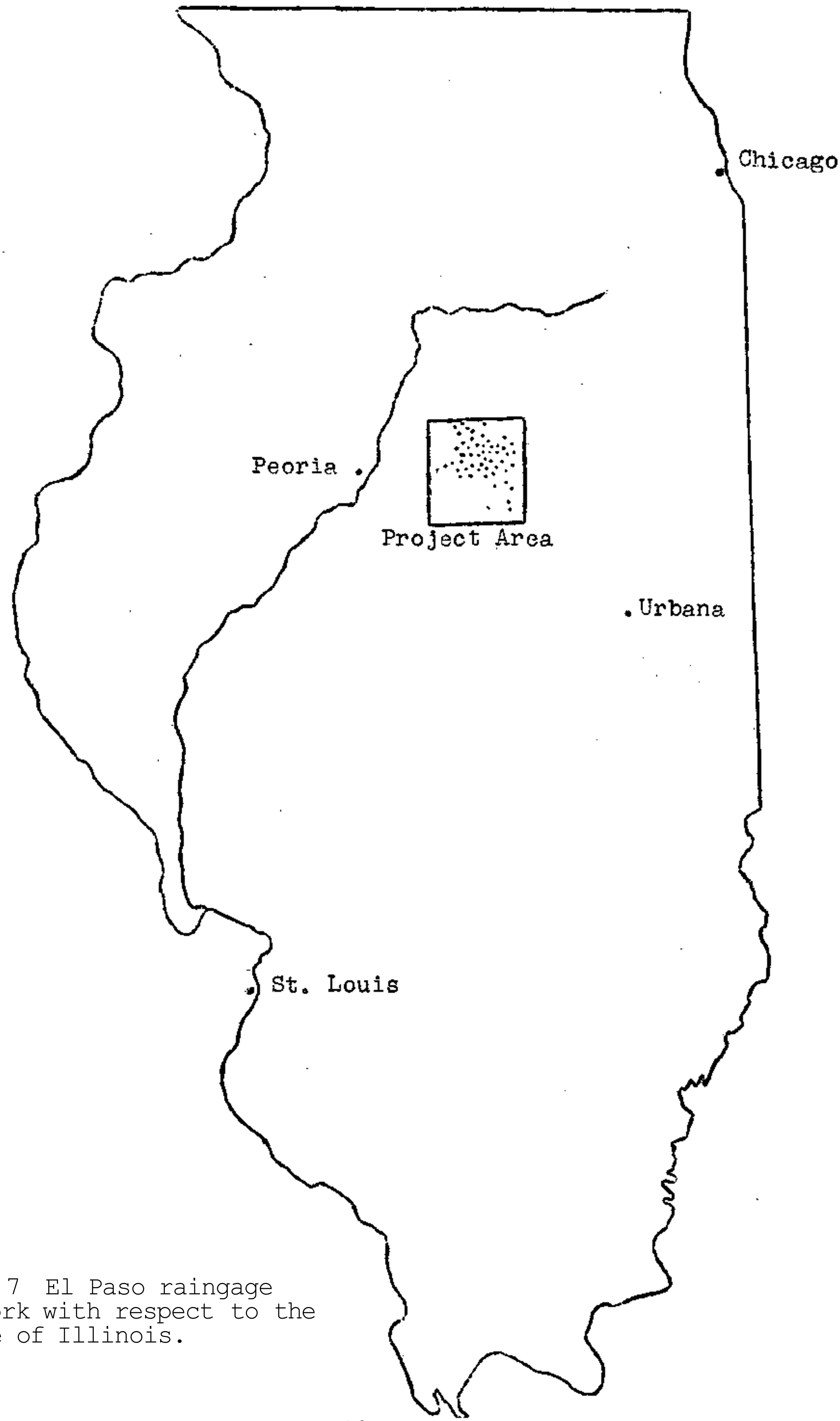

Fig. 7 El Paso raingage network with respect to the State of Illinois.

on a post card which was mailed to the Water Survey at the end of each week. In addition to the 24 hourly amount, information such as the time of beginning and ending of the precipitation, the type of precipitation, and the occurrence of strong winds, was recorded on the post card. To obtain more detailed information when more than one rainstorm occurred during the day, a second form (see Appendix C-1) was left with each observer to be filled out in as much detail as time permitted. The tyne of information entered on this form was essentially the same as that on the post card form, but gave details concerning individual showers or thundershowers occurring during the day. These forms were picked up at the end of each month by a project representative.

Installation of the rain gages was begun in April. When observations for the rainfall study were inaugurated on May 1, thirty gages had been installed. During May and June, seventeen more gages were added to complete the network. Daily observations were made from May 1 to September 15, the end of the growing season. At that time the project was formally discontinued for the present year. Those observers who expressed a desire to continue the observations for the remainder of the fall were allowed to do so. A considerable number carried on, as evidenced by the 21 complete reports received for the month of September (Appendix C-6).

WEATHER STATION

Inauguration of Project Pfister created a need for daily weather forecasts to be used in conjunction with the planning and evaluation of seeding missions. To meet this need, the Water Survey set up a weather station (Fig. 8) at their Urbana offices during the spring of 1948.

Application was made to the U. S. Department of Commerce in Washington, D. C., via U. S. Weather Bureau, for authority to install weather teletype circuits "A" and "C" in the station. These circuits furnish the weather data used in the preparation of the various weather maps and charts, from which forecasts are made. Upon receiving a license to install the teletypes, contracts were entered into with A.T. and T. and Western Union for installation and maintenance of the machines. Circuit "A" was installed by the local Bell Telephone Co. on May 20 and Circuit "C" by Western Union on June 24. Electrical timers were attached to each of the two machines, so that pertinent weather data coming over the circuits during the night, when the weather station was not in operation, would be automatically received.

In drawing up plans for the station, decisions had to be made regarding hours of operation, the number and type of weather maps and charts to be analyzed, the type of forecasts to be made, the time of issuance of the forecasts, and

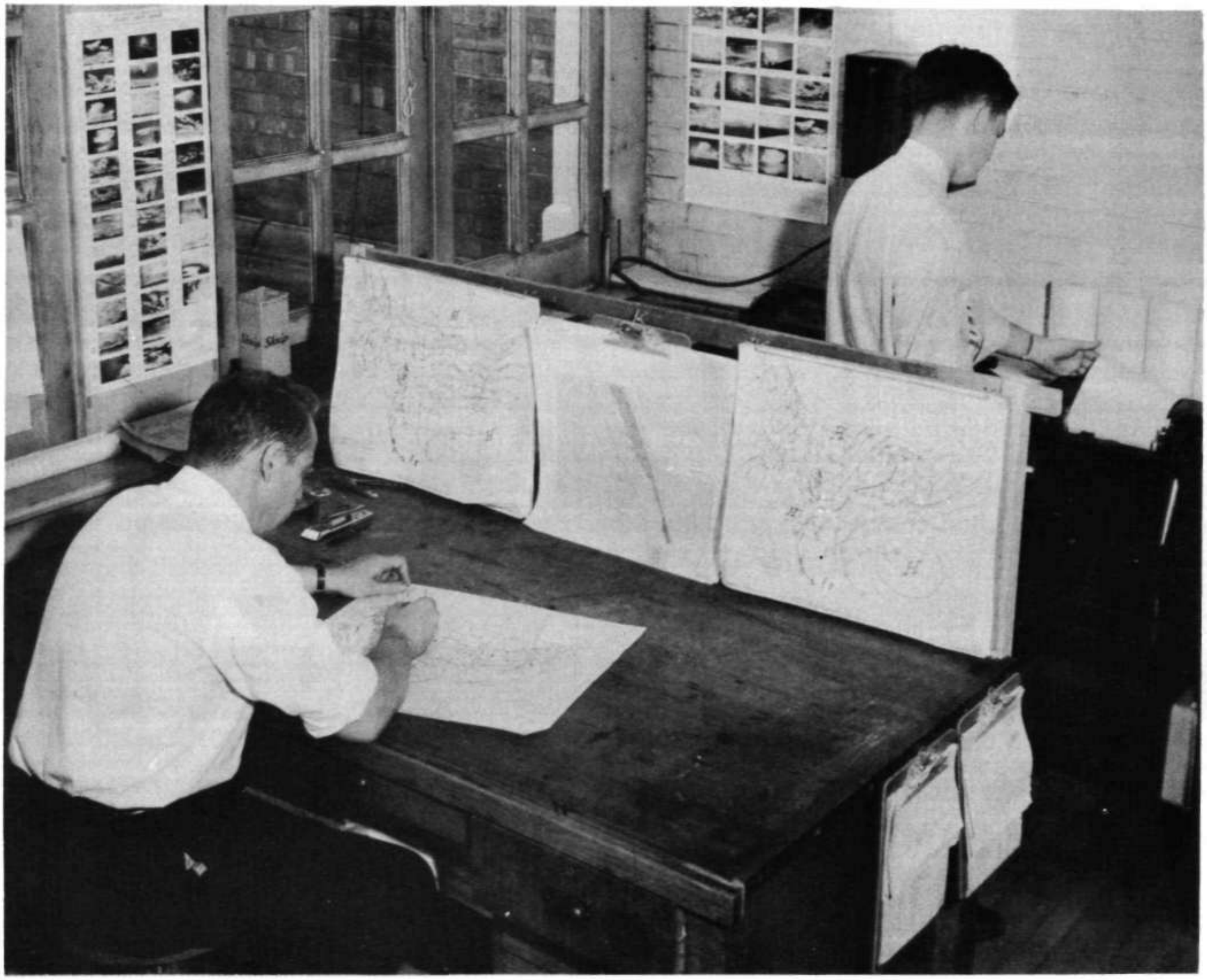

Fig. 8. Weather station at Urbana, showing analysis desk and one of the teletypes. The other teletype is obscured by the maps.

the period to be covered by each forecast. It was not deemed necessary to operate the station on a 24-hour daily schedule, since the primary interest was in weather conditions during the daylight hours, with special emphasis on afternoon cumulus activity. Daily hours of operation from 6:00 A.M. to 4:00 P.M. were settled upon as sufficient. It was decided that a forecast should be issued each day by 10:00 A.M. covering the remainder of the day and the ensuing day. The forecast (example in Appendix B-1) was to include a brief discussion of the synoptic weather conditions, a general forecast of cloudiness, precipitation and temperature, and a specific forecast of the elements pertinent to the planning and carrying out of seeding missions. Factors to be discussed in the specific forecast included types and amounts of clouds, height of the cloud bases and tops, height of the freezing level, the direction and speed of the winds aloft, and the general outlook for seeding.

To accomplish these forecasts, the following weather maps and diagrams were plotted and analysed daily:

1. 1230Z* surface map.
2. C300Z 700 mb. map.
5. 0900Z winds aloft map.

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*Z is symbol used to indicate Greenwich Civil Time.

4. Pseudoadiabatic diagramsfrom the 0300Z and 1500Z radiosonde data, for stations representative of existing or approaching atmospheric conditions.

5. Representative Rossby Diagrams, when air mass lifting was involved in the forecasting considerations.

In addition, the 700 mb. map for 1500Z was plotted and analyzed, and the U. S. Weather Bureau 1830Z surface analysis drawn up, when deemed necessary by the forecaster on duty. Hourly weather sequence reports were checked throughout the day for indications of unexpected changes in the synoptic weather picture.

The daily forecasting service was begun on June 29 and continued until September 3. It had been intended to inaugurate the service on June 1, but delays in the installation of the teletypes prevented doing this.

The various weather maps and charts, used in the preparation of the forecasts, served other important purpose's. They were available for analysis and evaluation of the results of cloud seeding missions, and for studying the frequency of occurrence of possible seeding days. Their use in determining possible seeding days is discussed later in this report. Due to the abundance of natural rainfall, no actual seeding missions were accomplished this summer, and the maps and diagrams were not needed for analysis of seeding operations. However, when seeding experiments are carried out in the future, these maps and charts, along with present weather observations, rainfall measurements, and radar scope photographs, should wove invaluable in determining the causes for success or failure of each seeding mission, and the feasibility of cloud seeding in general.

V. INDUCED PRECIPITATION POSSIBILITIES

SUMMER OF 1947*

Induced rainfall by the seeding of clouds during the summertime with dry ice created much newspaper publicity in 1947, hope for the farmer that his crops might be saved, and differences of opinion among scientists as to the possibility of controlling Mother Nature.

To evaluate the possibilities of artificially-induced rainfall during the summer of 1947, (a very dry growing season in the Midwest) the synoptic weather conditions at three observation points in Central Illinois were studied: Chanute Field, Peoria and Springfield. The data were available at the U. S. Weather Bureau office at Springfield, Illinois. The hourly weather observations, as recorded on the WBAN 1130 data sheets, were reviewed for the months of June, July and August, 1947. First, the total number of days of rainfall, when more than 0.01 inch occurred, were tabulated. Then the number of days when less than 0.01 inch were listed. The third category was dry days on which the following conditions were considered as favorable for rainfall:

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*Prepared in Dec. 1947.

a. 70% of the sky covered by clouds.

b. The type of cloud including some altostratus or altocumulus, indicating moisture near the freezing level, and at least 50% of the sky covered by cumulus.

c. The alto-type cloudiness prevailing over a period of at least six hours and the cumulus cloudiness prevailing for several hours during the afternoon or early in the evening.

d. High relative humidity at the surface.

e. General synoptic situation favorable.

The following table summarizes the data at each station:

Month	Actual days when rain fell	Days when more rain might have fallen	Dry days when rain might have been induced	Total possible rainy days	Actual days / Total days	Inches Actual Rainfall
CHANUTE FIELD						
June	10	4	4	18	.55	3.15
July	5	3	3	11	.45	1.26
August	5	3	2	10	.50	0.98
	20	10	9	39	.51	5.39
PEORIA						
June	12	3	3	18	.67	7.13
July	6	3	2	11	.55	1.64
August	6	5	1	12	.50	1.39
	24	11	6	41	.58	10.16
SPRINGFIELD						
June	16	5	2	23	.70	6.41
July	9	2	2	13	.69	1.32
August	9	3	4	11	.36	0.96
	29	10	8	47	.51	8.69

The data for Chanute Field are similar to those of Peoria with the exception that Peoria recorded about twice as much rainfall as Chanute Field for the period in question. To compensate for this, the data show that Chanute had more dry days that could have been fruitful than Peoria. The actual rainfall at Chanute was much below normal for that period. The rainfall in June at Peoria and Springfield was about double the normal amount. This contributed to the floods of the Mississippi River during this month. The amount of rainfall in July and August at all three stations was well below normal. The number of days of little prepipitation, when more rainfall might have occurred, are similar at all the stations.

During the summer period, appreciable rainfall (more than 0.01 inch) occurred on 26% of the days. On 11% of the days studied, less than 0.01 inch was recorded. The reported weather conditions indicate that substantial rains might have been induced on these days. On 8% of the days studied when no rainfall occurred, conditions were such that a "trigger" action might have produced rainfall.

In August at Peoria only one dry day appeared favorable for making rain. William and Jack Kraft, Peoria flyers, reported that during the latter part of August they produced substantial showers on three different days. These showers were produced over a large area rather than over a particular point. On a couple of these days there were no records of rainfall occurring at any of the U. S. Weather Bureau or State Water Survey rain gages. These gages are located sparsely in the area involved. Due to the small diameter of summertime showers, it is probable that the rainfall occurred between the gages and consequently the quantity of artificial rainfall c?nnot be evaluated.

In summary, rainfall or additional rainfall at a particular observation point might have been induced once every fifth day. This is based upon the fact that there were about 18 days during June, July and August that were favorable for creating man-made rainfall. At the three stations studied in Illinois, rains fell on only a little more than half the days when there were good rainfall possibilities. This might be taken to indicate the possibility of increasing the precipitation at a given point by artificial inducement.

Insufficient information is available at the present time to determine the accuracy with which rainstorms can be produced. The usefulness of artificially induced rainfall to private sponsors will depend on the precision that can be developed in the process. Lack of precision will necessitate use of the process only on a very large scale - such as county-wide, state-wide, or world-wide.

The above data indicate that induced precipitation warrants further study and field experiments.

SUMMER OF 1948

Synoptic weather conditions were studied during the month of July and August 1948 in an effort to determine the number of days on which cloud seeding might have given positive results. It would have been desirable to include June in this analysis, but a complete set of synoptic data was not available, since the installation of the weather teletypes was not completed until June 24.

The purpose of this portion of the investigation was to develop methods of analyzing we?ther data for cloud seeding possibilities and to furnish certain information for correlation with future seeding experiments. The results are suppositions arrived at by taking into consideration the various meteorological factors thought to be necessary for successful cloud seeding.

To determine the days on which seeding might have produced favorable results, an analysis was made of all available data for the applicable neriods. These included surface weather maps, 7.00 mb. charts, winds aloft maps, RAOB* data, hourly weather sequence reports, rainfall records, and radar scope pictures. The analysis was made only for the daylight hours, since the project was not set up for night operations. Favorable seeding days were divided into two categories as follows:

*Radiosonde observations.

1. Days on which some rainfall occurred over the experimental area, but on which the synoptic analysis indicated additional precipitation might have been induced over certain portions of the area by timely seeding.

2. Days on which no rainfall was recorded in the experimental area, but on which conditions appeared favorable for induced precipitation.

The results of this analysis of seeding possibilities are tabulated in the following table:

	July	August
1. Average area rainfall.	6.63"	1.20"
2. Total number of days rainfall was reported in the area.	15	5
3. Number of rainy days favorable for inducing additional precipitation.	9	2
4. Number of dry days favorable for inducing precipitation.	0	3
5. Total number of favorable seeding days.	9	5

During July, favorable seeding days occurred with much greater frequency than during August. This would be a logical expectation considering the natural rainfall occurrence for the two months. The average rainfall for July was more than five times greater than in August, and rainfall was reported by one or more stations in the area on fifteen days in July compared to five days in August.

The results of the 1948 analysis compare quite favorably with the 1947 analysis, mentioned earlier in this report, which was made on a more limited scale since the necessary data for making the 1948 type of analysis was not available at that time. Tabulated below are the results of the two analyses for the months of July and August. The 1947 results are averages based upon data compiled for Peoria, Chanute Field, and Springfield, while the 1948 data are compiled for the El Paso area only.

	July		August	
	1947	1948	1947	1948
1. Average area rainfall	1.41"	6.63"	1.11"	1.20"
2. Total number of favorable seeding days	5	9	6	5

For the months of July 1947 and August 1947-48, when the average rainfall was light and within a sm?ll range of variation, the number of favorable seeding days were practically the same. During July 1948, when the average rainfall increased greatly, the number of favorable seeding days followed the same trend. The results of the analyses indicate seeding possibilities increase with improving conditions for natural rainfall, as might be expected.

An example of the method of analysis used in determining seeding possibilities during the summer of 1948 is found in Appendix B-3.

ATMOSPHERIC MOISTURE-PRECIPITATION RELATIONSHIPS

At this point, a brief discussion of the relationship between atmospheric moisture and the amount of precipitation (7), received at the surface is of interest. From published data ??, the average depth of precipitable water in the atmosphere over Illinois was computed for January through November 1948. The total precipitable water in the atmosphere is the amount of precipitable moisture existing from the earth's surface to the upper limit of water vapor[4].

For the purpose of this study, the upper limit of moisture has been taken as 5 kilometers (16,368 ft.). The amount of water vapor above this level is small, so that the amount below this elevation may be used as the total precipitable moisture without appreciable error. The amount of moisture is measured in terms of depth of water in inches.

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[3] Monthly Weather Review, Jan.-Nov. 1948. U. S. Department of Commerce, Weather Bureau.

[4] Rainfall and Runoff, E. E. Foster, MacMillan Company, New York, 1948.

The following table gives a comparison of the average depth of precipitable water present in the atmosphere above Illinois, and the average daily Illinois rainfall for each month. during 1948.

Month	Average Depth Precipitable Water (inches)	Average Daily Precipitation (inches)
January	0.23	0.056
February	0.36	0.071
March	0.42	0.167
April	0.62	0.068
May	0.75	0.125
June	1.22	0.12b
July	1.42	0.192
August	1.24	0.061
September	0.96	0.093
October	0.54	0.058
November	0.44	0.115

A large amount of precipitable water indicates the presence of moist and -orobably warm air, with the possibility of heavy rainfall present.[4] However, a relatively high moisture content does not necessarily result in heavy precipitation. Large amounts of precipitation occur only when continuous large scale lifting of moist air masses, or appreciable vertical convection arising from thermal sources, takes place[5] Both of these processes imply the constant transport of new air and moisture into a given area, so that the moisture appearing in the form of precipitation is continually replaced.

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(5) First Partial Report on the Artificial Production of Precipitation, by Richard D. Coons, R. C. Gentry, and Ross G-unn, Research Paper No. 30, U. S. Department of Commerce, Weather Bureau, August 1948.

A comparison of the precipitable water-precipitation relationships for the months of July and August 1948, with the synoptic weather conditions during these months, illustrates the importance of lifting and thermal convection in the production of precipitation. Although there was little difference in the average depth of precipitable water during these two months, the average precipitation for July was approximately 3 times that for August. A study of the synoptic weather conditions showed that July was characterized by considerable cold frontal activity and air mass instability showers. Thus, air mass lifting and thermal convection were quite prevalent. Except for the last 5 days, August was largely dominated by stable, polar air masses and little frontal activity.

The preceding discussion has emphasized the importance of air mass lifting and thermal convection in the production of precipitation. While atmospheric moisture is important in the production of precipitation, it is only one of the determining factors. Referring to the table on page 32, it is seen that the greatest average precipitation occurred in July. During this month, a relatively moist atmosphere was combined with relatively unstable atmospheric conditions.

The analysis of the 1948 seeding conditions indicated the number of favorable seeding days in July was nearly double that in August. The preceding discussion indicates the reason for the fewer number in August lies chiefly in the more stable atmospheric conditions existing during the latter month. As mentioned previously, the occurrence of favorable seeding conditions apparently increases with increasingly favorable conditions for natural precipitation.

However, during such months as August, when considerable moisture is present, and when little rainfall occurs, the possibility of occasionally inducing appreciable amounts of precipitation through seeding may exist. Afternoon cumulus build-ups, resulting from diurnal heating, which often appear to approach the precipitation stage and then dissipate during the late afternoon or evening without releasing their moisture, might be successfully tapped under these conditions. Thermal convection and moisture content may be sufficient in these clouds to cause rainfall if sufficient sublimation nuclei are produced through seeding.

VI. METEOROLOGICAL FACTORS INVOLVED

THEORIES

To date, dry ice has "been the seeding agent most commonly used in attempts to produce precipitation by artificial means. The dry ice, when introduced into a cloud, produces large numbers of sublimation nucleii (ice crystals) by spontaneous-cooling of the water vapor. The coexistence of water droplets and ice crystals in a cloud is widely accepted as a basic requirement for precipitation [(6)]

According to the theory developed by Dr. Vincent J. Schaefer and Dr. Irving Langmuir of the General Electric Research Laboratory, a number of favorable conditions must be present if any appreciable amount of precipitation is to fall from clouds seeded with dry ice . [(7)]

1. At least part of the cloud must consist of super-cooled liquid droplets. Ice crystals formed by dry ice evaporate unless formed in air colder than 32°F, The cloud must have sufficient vertical development in the super-cooled region so the ice nucleii, formed by the application of dry ice, grow to

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[(6)] Bergeron, T., On the Physics of Cloud and Precipitation, Mem. de 1'Union Geodesique Internationale, Lisbon, 1933.

[(7)] Schaefer, Vincent J., The Natural and Artificial Formation of Snow in the Atmosphere. Talk delivered to Western Snow Conference, Portland, Oregon, April 21, 1947.

eufficient size to continue falling when they enter the above-freezing portion of the cloud. According to Schaefer, the minimum thickness of the super-cooled cloud should be 500 feet.

2. If most of the cloud has a temperature above freezing, sufficient moisture must be present in the above-freezing portion of the cloud to sustain growth of the melted ice crystals, so that the falling velocity of melted particles (raindrops) exceeds the upward velocity of the air within the cloud. With sufficient falling velocity, raindrops will continue to grow in the warmer portion of the cloud through coalescence with intercepted cloud droplets and by condensation of water vapor on the particles due to their lower temperature and vapor pressure.

3. The clear air below the cloud base must contain sufficient moisture to prevent excessive evaporation of the raindrops before reaching the ground.

4. Efficient application of dry ice must be made. Excessive amounts will produce too many nucleii with the result that none will grow to sufficient size to fall to the ground. Conversely, sufficient seeding agent must be supplied to "trigger off" the precipitation process.

Some work has been done by the General Electric scientists using various foreign particle nucleii as seeding agents. Among these, silver iodide seems to present the best possibilities. Silver iodide has a crystalline structure closely resembling that of ice and serves as an "artificial seed". It appears to produce sublimation nucleii effectively at temperatures from 14° to 25°F., depending upon the size of the silver iodide particles used [8]. It probably has its best application in instances where it is not possible to seed Kith dry ice in the super-cooled region of clouds. Being persistent, the silver iodide nucleii can be released in the above-freezing portion of the cloud, or below the cloud base, and be carried upward into the super-cooled region by the existing air currents.

The theory of using ordinary water drops to induce precipitation from actively growing cumulus clouds has been introduced by Dr. Langmuir [9]. Unlike the dry-ice and silver iodide methods which require the presence of super-cooled clouds, this theory is applicable to cumulus clouds at any temperature. However, for successful application, certain meteorological conditions must exist. The cloud must have a vertical thickness of several thousand feet. The vertical upward velocities within the cloud, the size of the cloud droplets, and the liquid water content of the cloud must be sufficiently large to support a

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(8) First Quarterly Progress Report, Meteorological Research. General Electric Company, Schenectady, N.Y., 15 July, 1947.

(9) Occasional Report No. 1, Project Cirrus, Contract No. W-36-039-SC-32427, General Electric Company, Schenectady, N.Y. 15 April 1948.

a chain reaction within the cloud. This chain reaction is initiated in a cumulus cloud when a small amount of water in droplet form is introduced into the activity growing portion of the cloud.

According to the Langmuir theory, ordinary water drops, when introduced into the cloud, would grow at the expense of much smaller cloud droplets in their path as they fell. Upon reaching a certain critical size, these falling drops become unstable and shed smaller droplets. These smaller droplets would then be carried upward by the existing vertical currents within the cloud, growing by accretion until reaching a size large enough to fall a.gain, thus repeating the cycle. In a cloud of the proper characteristics, the falling drops would shed smaller droplets at a higher level each time they fell, so that a chain reaction would take place throughout the cloud. This chain reaction would continue until all the cloud water had collected into drops of sufficient size to fall out of the cloud as precipitation.

Dr. Langmuir has applied his theory in explanation of the results of some dry-ice seeding experiments in the Hawaiian Islands during September and October of 1947[(10)]. During these

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[(10)] Leopold, L. B. and Halstead, N. H., First Trials of the Schaefer-Langmuir Dry Ice Cloud Seeding Technique in Hawaii, BAMS, 29, 10, 525-534, 1948.

experiments, rain was observed falling from cumulus clouds seeded with dry ice, which did not have tops extending into the freezing zone. Therefore, the results were contrary to the theory involved in dry-ice seeding, which requires that a certain portion of the cloud be super-cooled at the time of seeding. According to Langmuir, the rain produced in these above-freezing clouds was not caused by the cooling effect of the dry ice, but by the water droplets introduced in the upper part of the cloud through the melting of the thin coating of ice which normally collects on crushed dry-ice fragments due to the condensation of moisture in the air.

In general it may be said that the induction of precipitation through artificial means is dependent upon the existence of certain specific atmospheric conditions. The reruirements for favorable seeding conditions closely parallel the requirements for the production of natural precipitation.

During periods of extended drouth there is ordinarily insufficient moisture available in the atmosphere to produce any precipitation of consequence. Since it is impossible to extract more water from the clouds or air than exists therein, cloud seeding would have diminished value during drouth periods. The chief advantages of cloud seeding for the induction of precipitation appear to be:

1. Speeding up of the precipitation process so that the cloud moisture falls on areas where it is badly needed, rather than occurring some time later through natural causes over regions where it is not essential or desirable.

2. Inducing precipitation to fall from clouds approaching the precipitation stage through natural processes, but which would eventually dissipate without releasing their moisture. This possibility may have special significance in the case of cumulus clouds which build up on the windward side of an orographic barrier.

OTHER PROJECTS

The U. S. Weather Bureau and the U. S, Air Forces organized a project at Wilmington, Ohio to determine in definite quantitative terms the practical limits and economic importance of cloud modification processes in producing precipitation from cumuliform clouds[11]. They were able to produce precipitation approximately one-fourth of the time, having conducted some 79 seeding flights. They pointed out that there was some natural rainfall in most cases within 30 miles. They concluded that (1) the artificial modification of cumuliform clouds is of doubtful economic importance for the production of rain, (2) there is no indication that seeding will initiate self-propagating storms and (3) the method is certainly not promising for the relief of drouth.

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[11] Coons, R. D., Jones, E. L., Gunn, R., Second Partial Report on the Artificial Production of Precipitation-Cumuliform Clouds, Ohio, 1948, BAMS, 29, 10, 544-546, 1948.

An Artificial Nucleation Project was conducted in Arizona during the past year by the Arizona Weather Research Foundation. Irving P. Krick of Pasadena, California served as Meteorological Consultant [12]. A number of seeding missions were performed over the watersheds of the Salt, Verde and Tonto Rivers. They reported the production of rainfall and snowfall on various occasions. Since it is difficult to accurately measure precipitation in mountainous regions with rain gages, run off data was employed in evaluating seeding effects. Runoff was greatly increased during the seeding periods as compared with other watersheds in the vicinity. The preliminary conclusions from this work indicate that induced precipitation is possible and practical in Arizona.

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[12] Krick, I. P., Preliminary Report on July Operations of Artificial Mucleation Project in. the Phoenix Area, August 1948 (Mimeographed).

VII. DISCUSSION OF PRECIPITATION DATA.

The May-September period was characterized by a series of relatively wet and dry periods. Abundant rainfall occurred during the first 15 days of May, when an average of 3.09 inches was recorded for the area. This was followed by exceptionally dry weather from May 16th through June 20th. No rainfall of consequence took place from May 16th through June 4th. Light showers on June 5th and 6th brought only slight relief. Showers again occurred on June 12th and 14th, but amounts were small. From June 1st through June 20th, the area averaged only 0.64 inch, despite the 4 days of shower activity. More frequent and heavier showers occurred from the 21st through the 30th, relieving the drought conditions and bringing the monthly average rainfall to near normal. The area averaged 3.09 inches of rainfall during the last 10 days of June, the majority of which occurred from the 21st to the 27th,

No extended periods of dry weather took place during July. A 5-day period from the 16th through the 2oth was the longest the area was without precipitation. However, the major portion of the month's rainfall occurred during the 14-day perlod from the 13th through the 26th when the area averaged 5.06 inches, compared to 1.57 inches for the other 17 days. The average for July was 6.63 inches.

In August, another extended dry period occurred. During the 15-day period from August 12th through August 26th, no rainfall was recorded in the area. On August 27th, showers took place in the Lake Bloomington-Gridley region, but most of the area received no relief until August 30th, when shower activity was widespread. During September, a dry period of 11 days occurred from the 9th through the 19th.

Fig. 9 is a graph of the average weekly rainfall for the area during the May-September period. This graph illustrates quite well the occurrence and duration of the periodic wet and dry spells during the season. The average weekly rainfall by months is also shown.

July was by far the wettest during the May-September period. This was largely due to intense thunderstorm activity during July. During this month, there were 6 days on which the area average rainfall exceeded 0.50 inch, while on 2 of these days, the average exceeded 1.00 inch. Only 3 days in June, 3 in May and September, and 1 in August had an average equal to or greater than 0.50 inch and none greater than 1.00 inch. Rainfall, mostly of light intensity, occurred over the area on only 5 days during August, the driest month during the summer season. The majority of the area received rainfall on only 3 of these days. A summary of the May-September rainfall data follows:

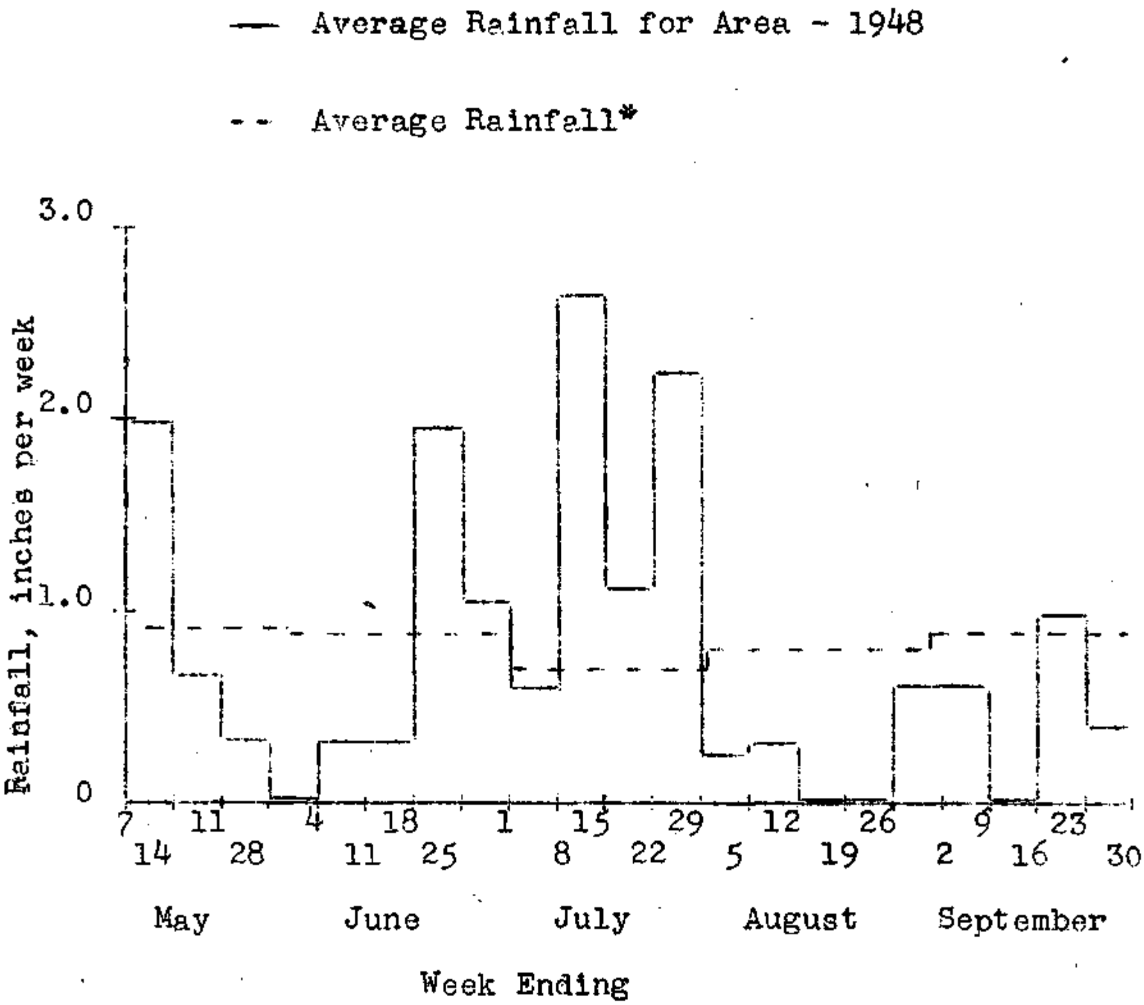

Fig. 9

*Based on 45 Yr. Average as Published by the U. S. Weather Bureau.

		May	June	July	Aug.	Sept.
1.	Average rainfall(inches)	3.10	3.73	6.63	1.20	2.07
2.	Normal rainfall(based on Weather Bureau records for Gridley, Minonk, Hudson)	3.91	3.75	3.01	3.47	3.75
3.	1948 deviation from normal	-0.81	-0.02	+3.62	-2.27	-1.68
4.	Monthly variation in rainfall among individual stations	2.28 to 3.88	2.57 to 4.66	4.56 to 10.44	0.43 to 3.20	1.25 to 3.39
5.	Maximum 24-hour rainfall (area average)	0.80 1st-2nd	0.90 22nd-23rd	1.76 25th-26th	0.50 29th-30th	0.90 20th-21st
6.	Maximum 24-hour rainfall for an individual station	1.54 1st-2nd	1.50 25th-26th	3.59 13th-14th	1.47 29th-30th	1.60 7th-8th

The heaviest 24-hour rainfall for the area during the May-September period took place on July 25th-26th, when the average was 1.76 inches, see Fig. 10, Most of this rainfall was the result of two heavy thundershowers during the late afternoon and evening of the 25th, associated with a squall lino in advance of a cold front approaching from the west. A third shower occurred during the morning of the 26th, but was of much lighter intensity than those of the 25th.

The maximum 24—hour rainfall for a single station was recorded at station 36, south of Secor, on July 13th-14th, see Fig. 11, The rainfall, which was associated with the approach and passage of a cold front from the North, occurred in the form of two heavy thundershowers. The first of these showers began at 6:00 P.M. on the 13th and ended during the night, while the second occurred between 9:45 A.M. and 12:20 P.M. on the 14th. A total of 3.59 inches resulted from the two storms. Station 37, 2 miles to the northwest, received 3.05 inches from the same two showers. The area average rainfall on the 13th-14th was 1.6o inches, second highest of the May-September period.

In Fig, 11 note the difference in the 24-hour amounts between station 46 and the Gridley Weather Bureau station, only about 2.5 miles apart, and between stations 36 and 38 approximately 4 miles apart. A difference of 2.60 inches existed between the first two stations and 2.74 inches between the second pair. Comparison of Figs. 11 and 12 shows the more even distribution of the rainfall on July 25th-26th, giving rise to a greater area average rainfall on that day, although individual station amounts reached a season maximum on July 13th-14th.

The rate of rainfall in some of the thundershowers during the summer is of considerable interest. Table I shows the maximum 30-minute intensities, as indicated by the twelve recording rain gages distributed throughout the area. Some of the rainfall intensities at the stick gage stations may have equalled or exceeded these, but a breakdown of the individual storms is not available from these stations. Referring to

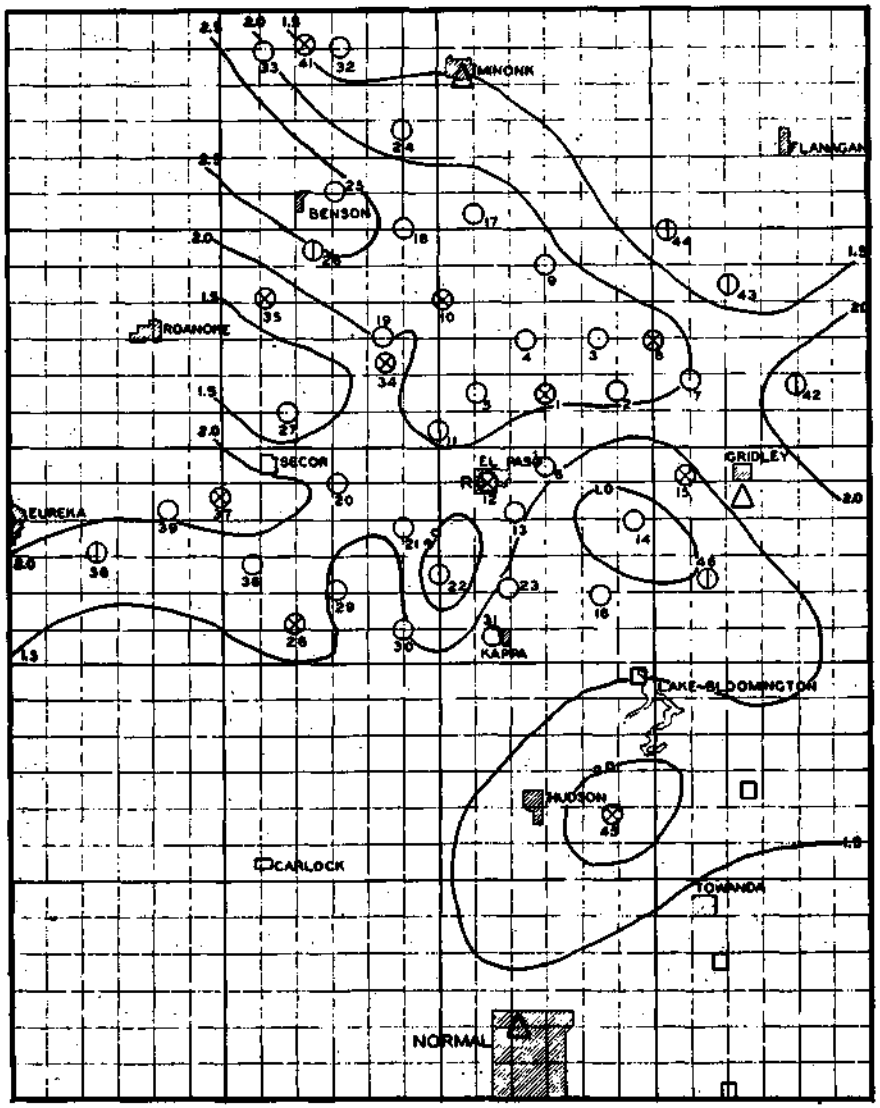

FIG. 10 JULY 25-26 1948 RAINFALL

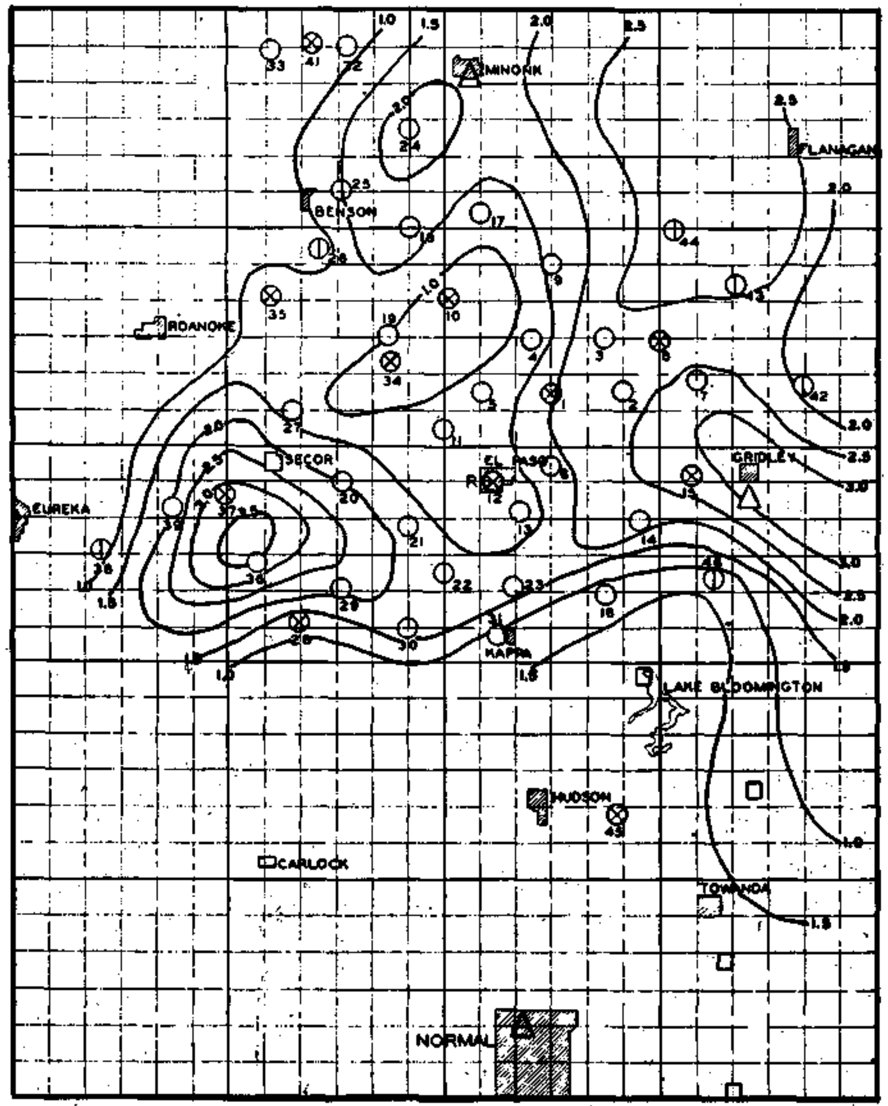

FIG. 11 JULY 13-14, 1948 RAINFALL

Table I, it is seen that the heaviest recorded 30-minute intensity occurred on July 10, when 1.70 inches fell at station 40 in Eureka. A total of 2.40 inches occurred with this thunderstorm during a period of two hours. Of this total, 2.25 inches fell during the first 45 minutes of the storm. It is interesting to note that on the afternoon when this storm took place at Eureka, absolutely no rainfall occurred at several stations in the northeast sector of the area, 18-22 miles away. The Eureka total of 2.40 inches for July 10th exceeds that of all 236 Illinois rainfall stations, whose records were published bv the U. S. Weather Bureau (13). The showers occurring on that day were the result of air mass instability, and consequently of a scattered nature. No fronts were located within several hundred miles of the experimental area, which was dominated by a southerly flow of moist, tropical air originating in the Gulf of Mexico.

Isohyetal maps showing the distribution of the area rainfall by months during the May-September period are shown in Figs. 12-16. With one exception, each map shows an area of light rainfall in the Minonk region, and heavier rainfall in the Secor and G-ridley areas. For September the picture is reversed at Minonk and G-ridley.

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(13) Climatological Data - Illinois, Vol. LIII, No. 7.

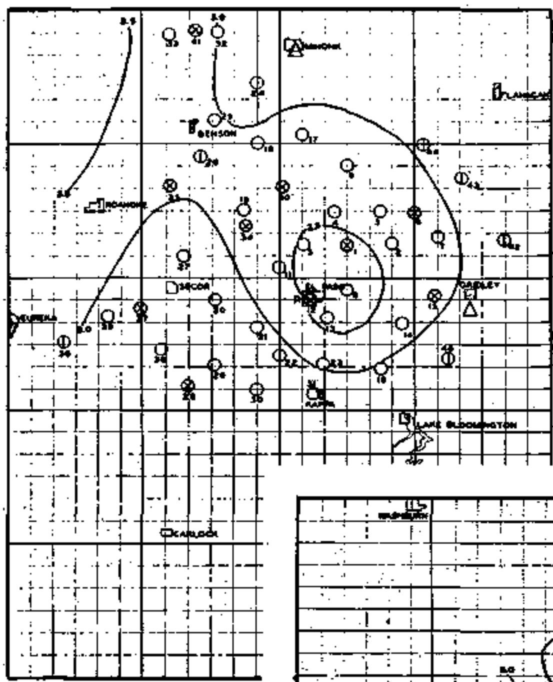

FIG. 12 MAY 2-31 1948 RAINFALL

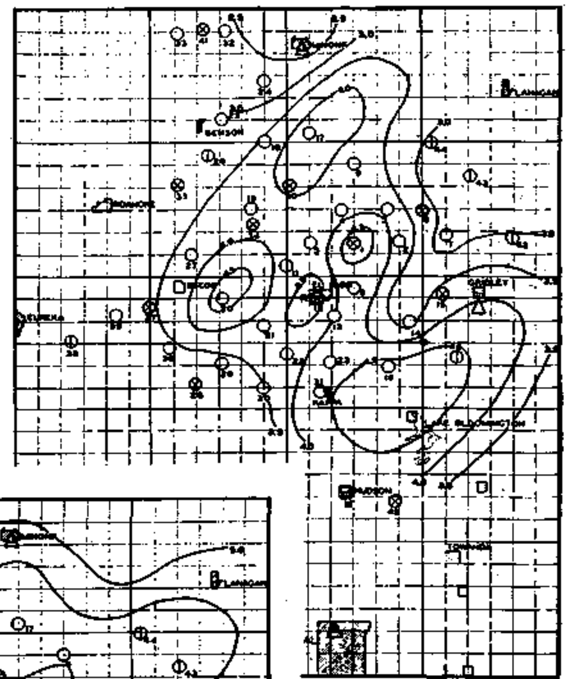

FIG. 13 JUNE 1948 RAINFALL

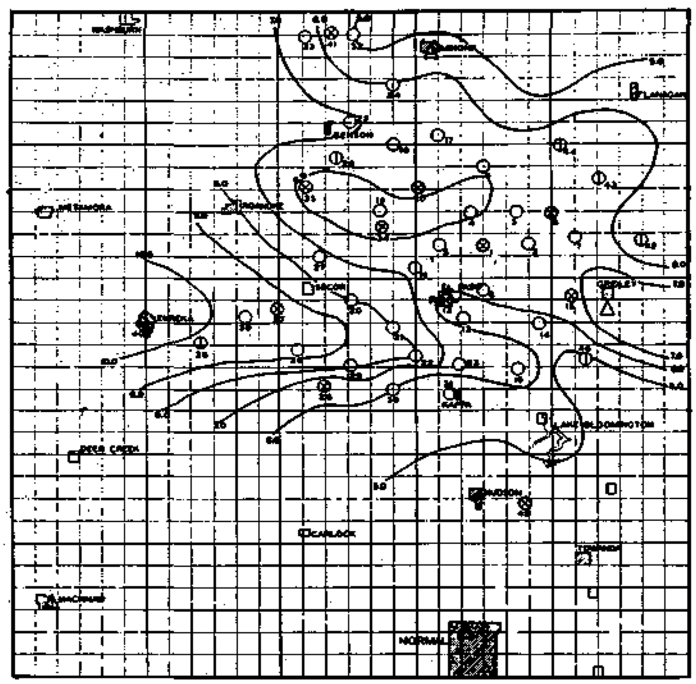

FIG. 14 JULY 1948 RAINFALL

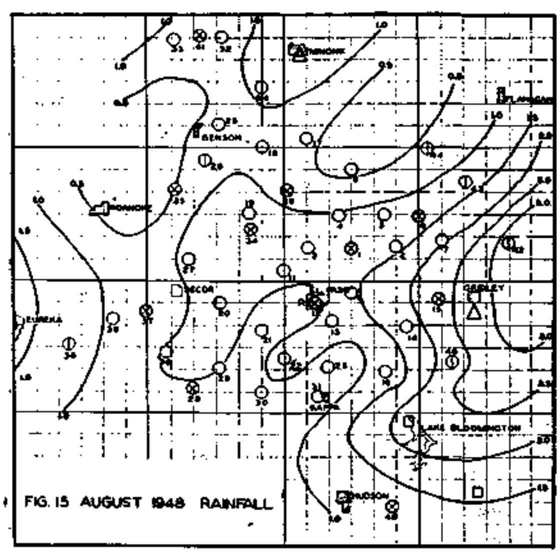

FIG. 15 AUGUST 1948 RAINFALL

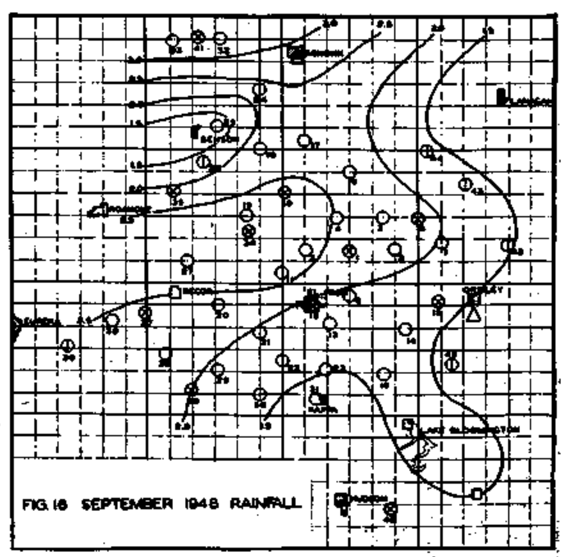

FIG. 16 SEPTEMBER 1948 RAINFALL

TABLE I

MAXIMUM 30-MINUTE RAINFALL AMOUNTS
PROJECT NETWORK

Date 1948	Amount (inches)	Station
June 23	1.02	8
June 26	1.05	10
June 26	1.20	1
July 10	1.70	40
July 13	1.00	37
July 13	1.12	1
July 14	1.08	8
July 14	1.60	37
July 22	1.00	28
July 22	1.00	37
July 25	1.10	10
July 25	1.10	37
July 25	1.00	1

Fig. 17 illustrates the distribution of the precipitation during the important June-August growing period. Note the maximum concentrations in the Sureka-Secor and G-ridley areas and the minimum concentration in the Minonk region. There was a variation of 6 inches of rainfall in 17 miles.

A study of the U. S, Weather Bureau Records of Minonk and G-ridley for the past nine years indicates that the summer rainfall at Gridley was greater 7 out of 9 years. In these 9 years the cumulative difference of rainfall was 16 inches. Further study of this variation of summertime rainfall is planned

CONCLUSIONS.

The May-September precipitation pattern was characterized by (1) a series of relatively wet and dry periods, (2) great areal variations in storm rainfall, and (3) by wide variations in monthly and seasonal distribution of rainfall.

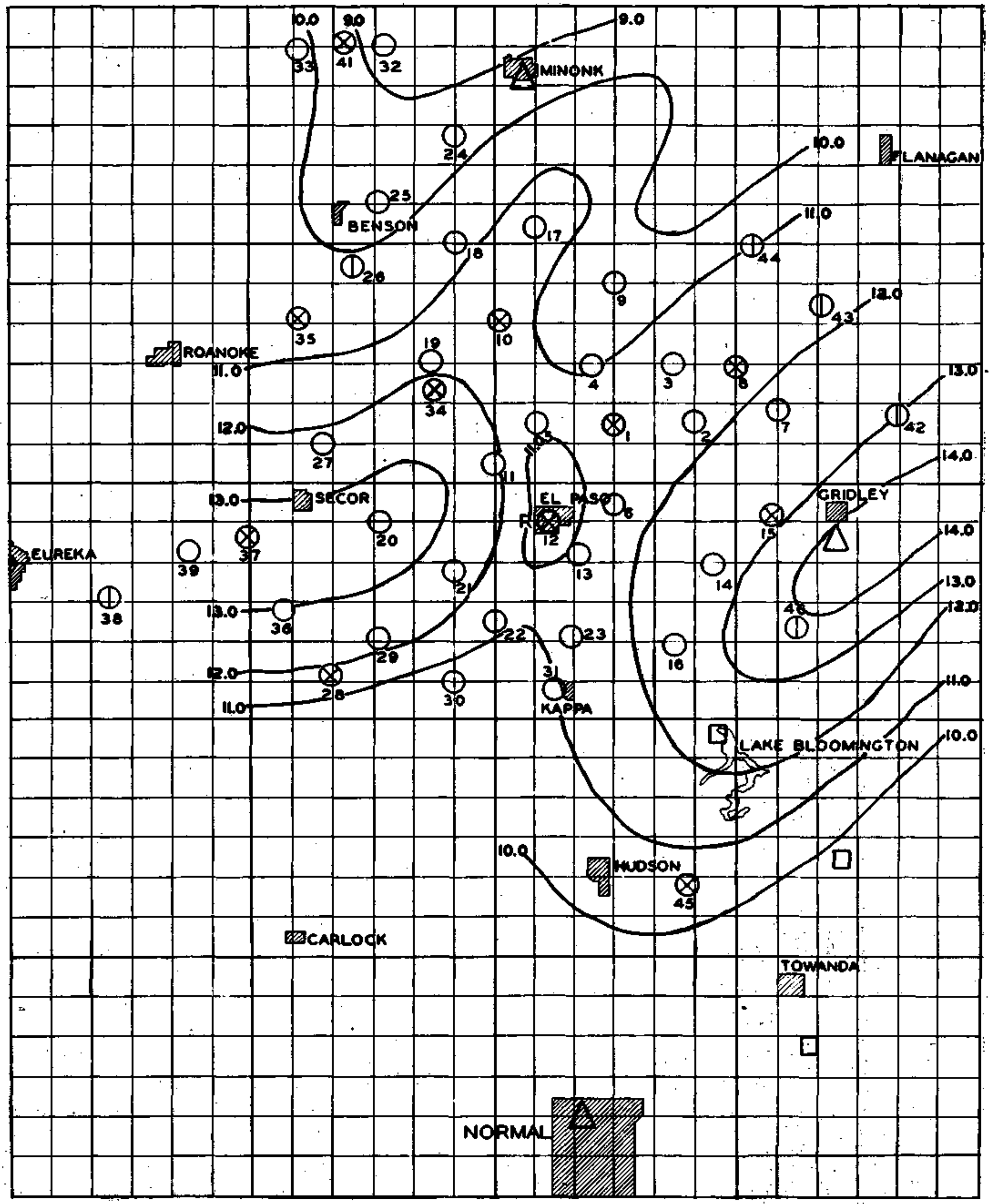

FIG. 17 JUNE, JULY, AUGUST 1948 RAINFALL

VIII. EXPERIENCES WITH APS-15 RADAR

OTHER INVESTIGATIONS

It was recognized in the early phase of the war that radar at certain wave lengths would detect rainfall. Actually, when radar systems were develoned for wave lengths shorter than 25 cm., the influence of certain atmospheric effects on wave propagation was found to be very pronounced. Most notable is the effect of water in its various phases. In the vapor phase it contributes to absorption and refraction. In the liquid and solid phases, it causes absorption and scattering.

The Massachusetts Institute of Technology Radiation Laboratory reported precipitation echoes with 10 cm. radar systems as early as 1942.[14][15] Research indicated that the scattering of the radiation by raindrops must account for the radar return as shown in later examples. The Radiation Laboratory has continued to study weather radar theory. This reouires rather complex instrumentation, both on the ground and airborne, in order to correlate accurately the radar observations with the associated hydrometeors.

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[14] Bent, Arthur E., "Radar Echoes from Atmospheric Phenomena," M. I.T. Radiation Laboratory Rep. No. 42-2, March 13, 1943.

[15] Bent, Arthur E., "Radar Detection of Precipitation," Jour. of Met. 3, 3, 78-84, 1946.

Similar weather-radar studies have been conducted by the Research Laboratory of General Electric Company, Ltd., England.

Evans Signal Corps Laboratory, Belmar, New Jersey studied the suitability of using an AN/APQ-13A radar (3cm.) for weather observation [16]. This radar is similar to the AN/APS-15 which was used during the past summer at El Paso. Although the performance was fairly satisfactory, both AN/APQ-13A and AN/APS-15 have certain characteristics which are undesirable as storm detection radar, such as limited antenna motion, lack of range-height scope, lack of 200 mile PPI sweep and the possibility of more frequent breakdown than would be expected with a system designed for ground operation. The Evans Signal Corps Laboratory found that the average maximum thunderstorm detection range for the summer of 1945 was 137 miles.

The Air Weather Service of the Air Forces and the Aerological Section of the U. S. Navy recognized the value of radar for storm detection and other meteorological purposes. Various projects and installations were organized to assist meteorologists in forecasting the weather so that today, most military establishments are equipped with radar for weather duty.

No attempt has been made here to mention all of the projects which have contributed to our observational knowledge

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[16] Brooks, Herbert B,, "Ground Weather Test of an AN/APQ-13A, " SCEL Tech. Memo. No. 193-R, April 17, 1946.

of weather radar, most of which have been summarized elsewhere.[17]

WEATHER-RADAR PRINCIPLE

It is commonly accepted that the radar echo due to Weather is caused by the reflection of the radar pulse by the water drops or particles in the atmosphere. Part of this reflected energy returns to the point of transmission. The strength of the returned energy depends upon the size of the water droplets and the number of droplets encountered[18], providing a number of variables are known.

Radar was placed in service on this project (1) to track and control the position of the seeding plane and to determine (2) if the cloud seeding was associated with rainfall or (3) if the rainfall began prior to seeding. This radar was subsequently found useful for defining the extent and location of rainstorms.

OBSERVATIONS

Although the radar installation was not completed until July and only one operator was kept on duty, several valuable sets of scope pictures were made during the summer. During the fall of 1948 the radar set was maintained by occasional operation by personnel from the Urbana office. More

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(17) See reference 2, p. 10.

(18) Maynard, R. H., "Radar Weather," Jour. of Met. 2, 4, 214-226, 1945.

data were collected during this period.

Since there were no scheduled induced precipitation flights during the summer, the radar was operated as much as possible to train the operator and to test the set for rainfall detection. Photographs were generally taken at 5-minute intervals. In the following discussion, selected photographs of the scope are described.

Fast Moving Squall Line.

On the night of July 21 at 8:30 pm. a small echo, as shown by the light spot, was detected some 70 nautical miles to the west of El Paso, see Fig. 18. This rain was verified by Mr. J. W. Durbin, State Water Survey rainfall observer on the Lake Bracken watershed. Each concentric circle is a 10-mile (nautical) range marker with north at the top. South is to the bottom of the picture, west to the left and east to the right. Subsequent pictures indicate that this single shower developed into a weak line squall, which released .16 inch of precipitation in Peoria. Both Figs. 18 and 19 were made with a 10 mile sweep delay which deletes the central 10-mile circle, in which most of the ground return appears. The rate of movement of this squall line was over 30 miles per hour until it began to dissipate, when, it showed down to about 20 miles per

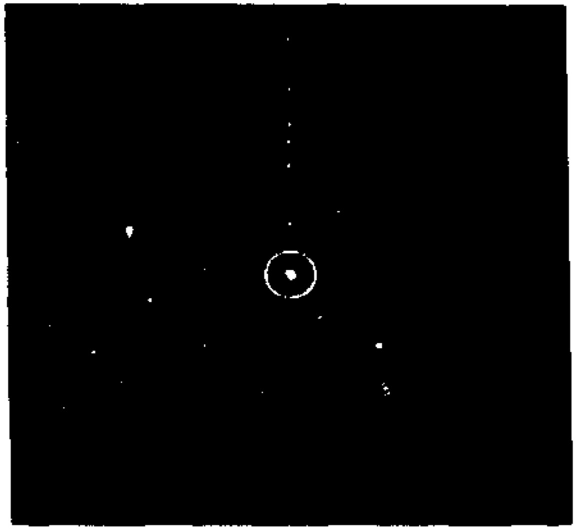

Fig. 18. 8:30 p.m. - 100 mile radius - 10 mile delay.

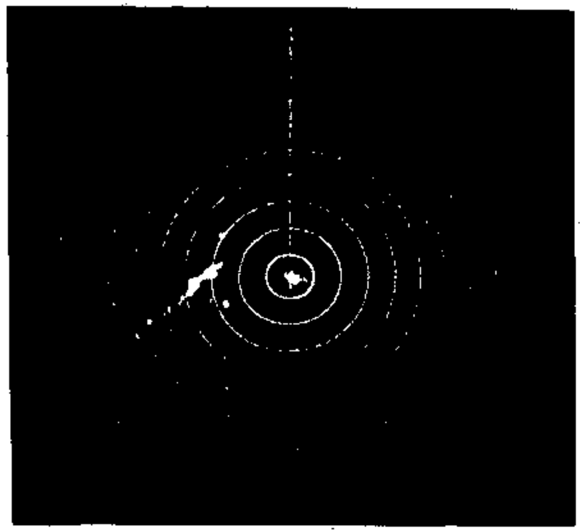

Fig. 19. 9:30 p.m. - 100 mile radius - 10 mile delay.

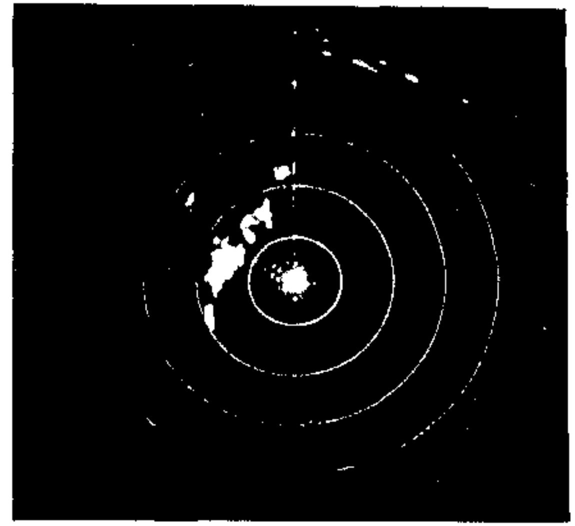

Fig. 20. 10:30 p.m. - 50 mile radius.

July 21, 1948

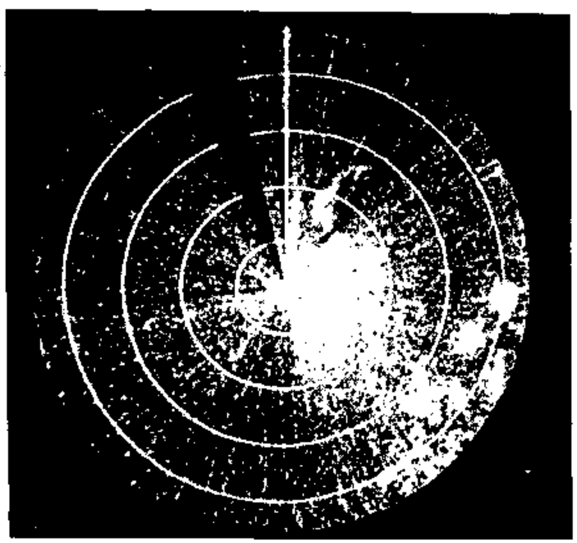

Fig. 21. 3:30 p.m.

Fig. 22. 4:00 p.m.

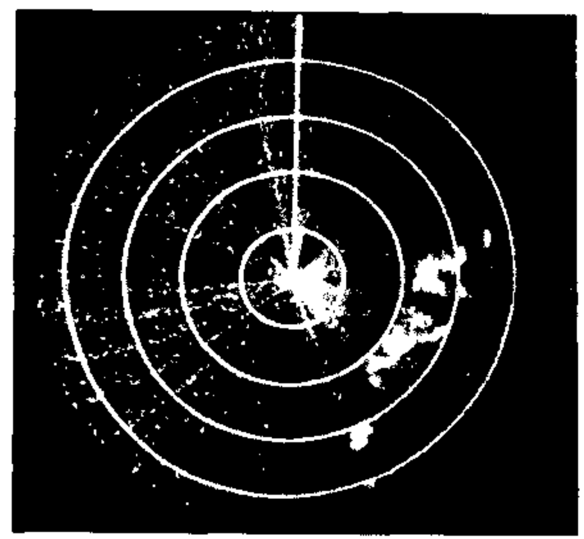

Fig. 23. 4:28 p.m.

50 mile radius - September 29, 1948 - 10 mile delay

hour. In the third picture (Fig. 20) of the group the echoes near the center of the scope and off to north-northeast are due to reflections from ground objects. Stations in the El Paso network reported only .03 inch or less.

Slow Moving; Squall Line.

Figs. 21, 22, and 23 are examples of another squall line that was lying 40 to 50 nautical miles to the southeast of station which moved slowly north-northwestward. The photographs were made using a 10-mile delay and 10-mile range markers. Reports indicated an average rainfall of .55 inch from this squall line.

Merging Showers.

Figs. 24, 25 and 26 show in detail the merging of two small showers into one rain area. The range marker is the 10 mile marker. Note that the two small showers to the southwest in Fig. 24 become one Just south of the station in Fig. 25. The showers grow in size as they move off to the east. This shower on July 29, 1948 produced about .05 inch rainfall. Note the size of echoes. Taking a diameter of the echo of about 3 miles and the rate of movement of 20 mph., the duration of rainfall is less than 9 minutes. Not much rainfall would be expected from such a shower (19). The other images on the scope are sma

(19) Byers, H. R. and. Collaborators. "The Use of Radar in Determining the Amount of Rain Falling over a Small Area". TAGU, 29, 2, 187-196, 1948.

showers that moved into the area.

Isolated Rainshowers.

Radar of 3 cm. wave length will detect small rainfall areas. The range at which these storms can be detected depends upon their vertical extent. Radar equipment located at the ground gives the following relation between the vertical extent and range[20]

Vertical 'Extent of Storm in Feet	Range in Miles (Approximate)
5,000	85
10,000	120
20,000	175

This is shown in Figs. 27, 28 and 29. On September 7, 1948 a cold front had passed the area earlier in the day leaving the skies generally clear except for a few scattered cumulus. However the radar picked up several small targets to the east approximately 50 nautical miles away (Fig. 27). Fig. .28 was made 33 minutes later, using a sweep delay of 30 miles. The targets, now between 56 to 61 nautical miles distance, have increased in number. The third photograph returns to the original presentation, and shows that the number of rain showers has decreased. This is substantiated by intermediate photograph, not reproduced in this report.

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[20] See reference 18, p. 51.

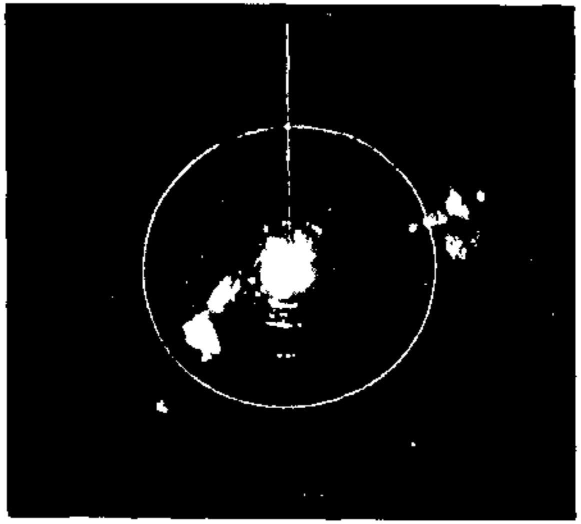

Fig. 24. 10:45 p.m.

Fig. 25. 11:00 p.m.

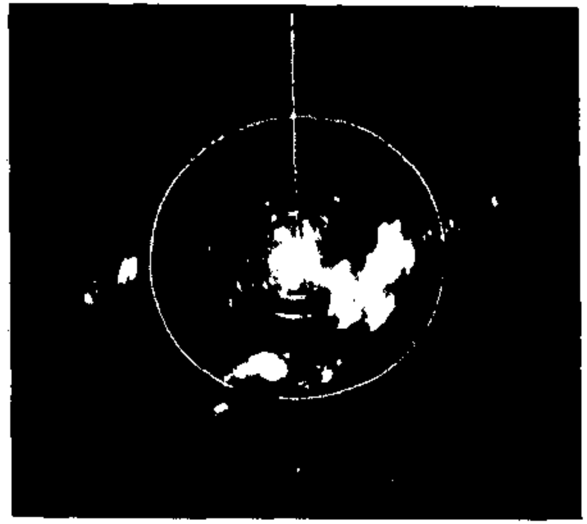

Fig. 26. 11:15 p.m.

17 mile radius - July 29, ,1948

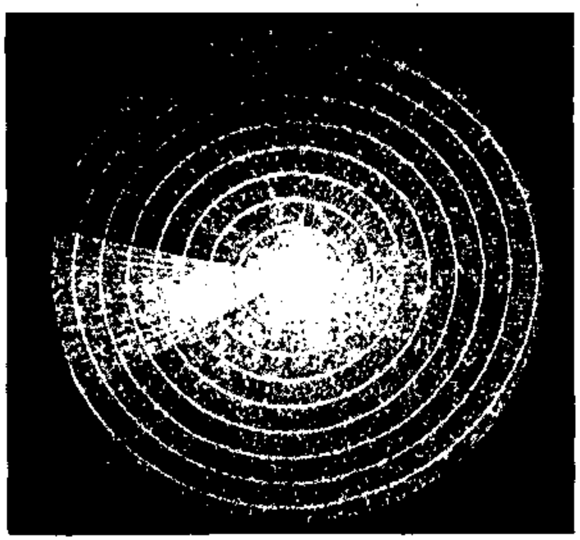

Fig. 27, 3:55 p.m. - 100 mile radius.

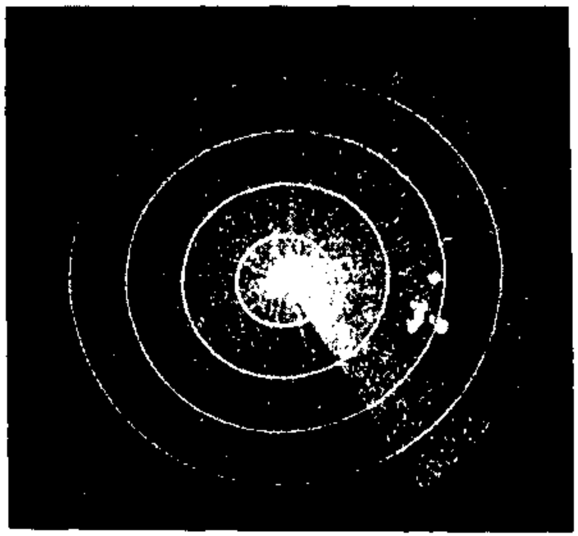

Fig. 28. 4:28 p.m. - 50 mile radius - 30 mile delay.

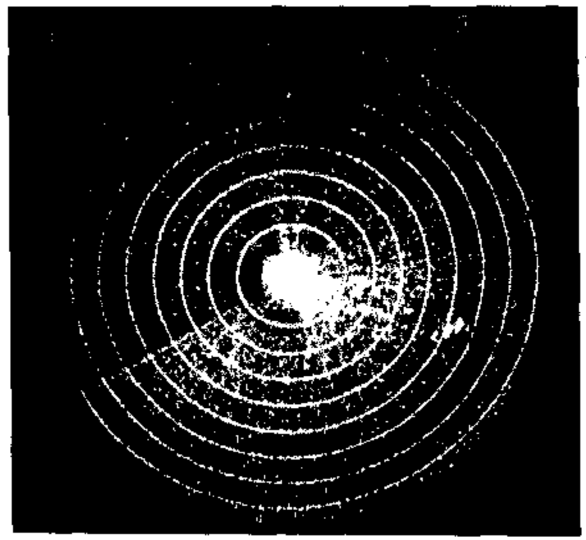

Fig. 29. 4:46 p.m. - 100 mile radius.

September 7, 1948

To our knowledge, this rainfall was not recorded by any U. S. Weather Bureau gages in the area. However, precipitation actually did occur from the echoes as reported to us by several residents along the path of the echoes. A U. S. Soil Conservation automatic raingage at Buckley recorded rainfall of .23 inch during the same period.

The teletype weather report from Chanute Field reported as remarks in a special transmission at 1705 "suspected tornado 20 mile ESE of Rantoul, moving eastward 4 mph." Although no tornado was actually reported in this area, the rain area was associated with the same targets that the radar at El Paso was tracking.

Large Rainstorm.

Fig. 30 is an example of a large area of light rain. Note the extensiveness of the rain area. The white mass in the center of the scope is the usual ground return picture. A light rain fell in El Paso one hour and fifteen minutes later as shown in Fig. 31. While the rain mass moved into El Paso from the northwest, a long band of showers developed to south of the station. Both rain areas became more or less stationary and persisted for some time.

Widely Scattered Showers.

On October 7, 1948 Central Illinois was constantly-encountering widespread light rainshowers as shown in Fig, 32. The showers were of short duration and moved rapidly from west to east. It was difficult to follow any one shower as they were very unstable, constantly changing size and disappearing when not precipitating.

Widespread Rain.

A light steady widespread rain, averaging about .05 inch per hour fell on November 9, 1948. Due to the rain on the radome, the power of the radar set was decreased greatly. The maximum detectable range on this occasion was not over 12 miles, see Fig. 33. Reconstruction of the antenna housing to eliminate rainfall from wetting the surface would improve the efficiency.

Misleading Observations.

On the evening of August 20, 1948 scope photographs were made of what appeared to be rain echoes, see Fig. 34. After checking the weather conditions for that time in the areas where the rain echoes appeared, it was found that there was no rainfall, but instead clear skies. The echoes did move but not in any systematic pattern. In fact, the echoes to the northwest moved slowly southeastward at 5 mph. and then retrograded. This was most unusual. Ordinarily, the radar beam travels in a straight line, only permitting detection of objects on the surface some 8 to 12 miles away. In this case, the radar was able to detect objects some 30 to 40 miles away on the surface in fairly level country. This "long-range detection" of objects on or near the surface of the earth is caused by the trapping or bending of the radar signal by the atmosphere.

The operator must be careful to avoid tracking ground return for rainfall, since the echoes are similar.

Ground Returns.

It has been mentioned previously that nearby buildings will reflect some of the radar energy and give an echo on the PPI scope. An example of this is Fag. 35. The absence of echoes to the east (from NE to SE) is due to absorption of the radar beam by trees that intercept the signal in that quadrant. The narrow sectors blanked out to the SSE, NNE, and NNW are due to absorption by a chimney and several peaks of buildings. Note how ground targets are ordinarily detected as far as 12 nautical miles.

APPLICABILITY OF RADAR FOR WEATHER WORK

Radar has been used on this project to detect and track natural rainstorms. It was used to determine whether or not it was advisable to send laborers into the field [21]

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[21] Stout, G. E. "Radar Goes Agricultural," Weatherwise, 1, 5, 112-113, 1948.

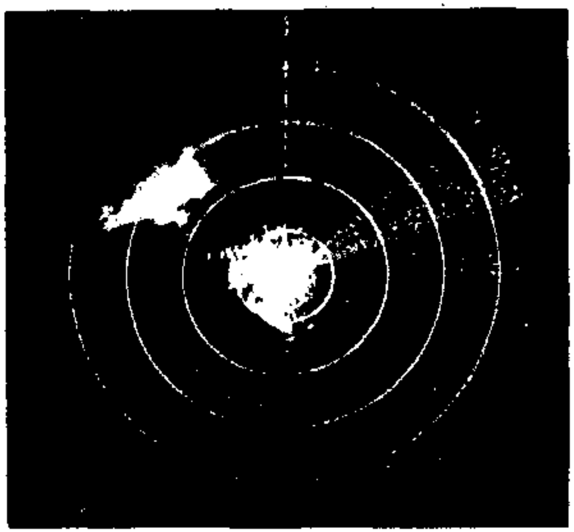

Fig. 30. 12:52 p.m. - 50 mile radius.

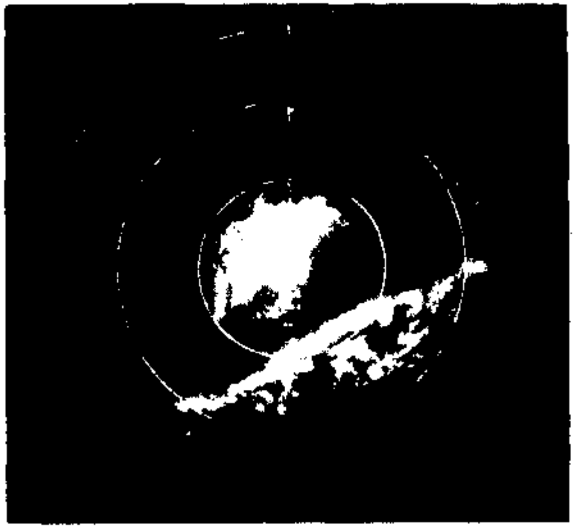

Fig. 31. 2:06 p.m. - 30 mile radius.

September 8, **1948**

Fig. 32. Scattered showers - 50 mile radius.

October 7, 1948

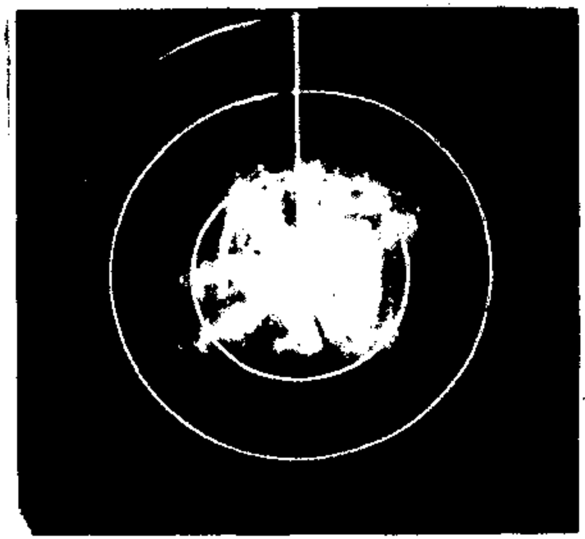

Fig. 33. Limited range -. 30 mile radius.
November 9, 1948

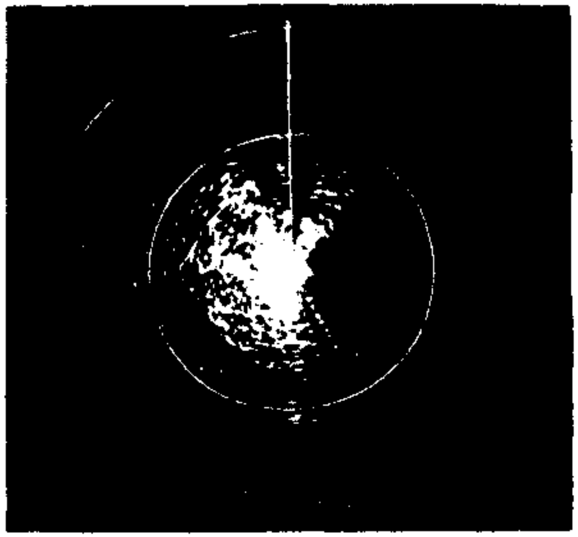

Fig. 34. False rain echoes - 50 mile radius.
August 20, **1948**

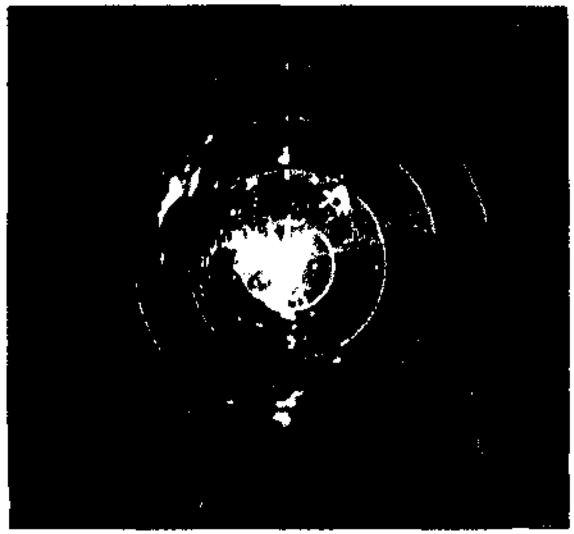

Fig. 35. Ground return - 20 mile radius.
July 16, 1948

Many man-hours were saved, since a definite picture of the weather was obtained. On one occasion, in spite of threatening skies, the radar showed that existing rainshowers were moving in such a direction that they would not affect the work area.

Radar is being used by the military forces in the planning of operations. It is being used by aircrafts in flight to determine the best flight path as they approach precipitation areas.

Radar is also used routinely on river boats for navigation at night and in foggy conditions.

Radar is being used by one oil company to enable adjusting operations to oncoming weather. Many outdoor activities such as construction, agriculture, athletic contests, public utilities, or even hanging out the laundry, would benefit from information that can be obtained by radar [22]

CONCLUSIONS

From the radar scope photographs reproduced, it is seen that radar is able to detect rainstorms during the summer and fall seasons.

The equipment used does not permit accurate study of rainfall intensities. Such studies are possible and should be initiated in Illinois.

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[22] "Radar Turned to Weather Forecasting", Engineering News-Record, 142, 7, 1949.

With radar, moving rainstorms can be kept under observation for several hours. This makes possible a warning system by which, some day, radar will serve our everyday needs.

Summary of the

W9XVM RADAR LOG

9275 Mc Special Radar Emission 40 kw Peak Watts

Date 1948		Time on CDST	Time off CDST	Time in operation		Operator	Remarks
June	25	3:15 P	4:00 P	.75	hrs.	RCP	Off due to failure.
"	27	6:00 P	8:15 P	2.25	"	"	Repaired.
"	28	4:30 P	6:15 P	1.75	"	GES	
"	28	10:10 P	10:40 P	.50	"	RCP	
"	30	4:45 P	6:00 P	1.25	"	"	
July	2	3:30 P	5:00 P	1.50	"	"	Picked up plane.
"	6	3:50 P	5:15 P	1.50	"	"	
"	6	7:00 P	11:00 P	3.00	"	WGA	Testing
"	10	12:50 P	6:45 P	6.00	"	RCP	4 hrs. test & rep.
"	12	1:20 P	3:40 P	2.25	"	"	
"	12	7:20 P	7:45 P	.50	"	"	Demonstration
"	13	1:40 P	2:00 P	.25	"	"	
"	13	7:10 P	9:38 P	2.50	"	"	
"	14	8:00 A	11:50 A	3.75	"	"	
"	14	12:25 P	2:40 P	2.25	"	"	
"	15	8:03 A	11:40 A	3.50	"	"	
"	15	12:50 P	4:15 P	3.50	"	"	
"	16	8:00 A	8:04 A	.00	"	"	
"	16	3:00 P	3:45 P	.75		"	Grnd. return pic.
"	17	7:00 P	8:00 P	1.00	"	"	
"	19	3:40 P	4:00 P	1.25	"	"	
"	20	8:40 A	10:30 A	1.75	"	"	
"	21	7:50 A	12:30 P	4.75	"	"	
"	21	6:35 P	11:30 P	5.00	"	"	Took pic.
"	22	7:55 A	10:20 A	2.50	"	"	
"	23	2:30 P	3:00 P	.50	"	"	Demonstration.
"	26	1:30 P	3:20 P	1.75	"	"	
"	27	8:00 A	9:30 A	1.50	"	"	Ob. for Pfister, pic.
"	28	2:40 P	5:55 P	3.25	"	"	
"	29	1:00 P	4:20 P	3.25	"	"	Tune
"	29	8:00 P	11:50 P	3.75	"	"	Arcing
"	30	1:55 P	3.45 P	1.75	"	"	Repairing
"	31	8:30 A	1:10 P	4.75	"	"	"
Aug.	2	9:35 A	4:00 P	6.50	"	"	"
"	4	8:05 A	9:30 A	1.50	"	"	Jumpy trace
"	9	2:00 P	4:30 P	2.50	"	"	" "
"	10	9:00 A	11:00 A	2.00	"	"	" " & tuning
"	12	7:10 P	11:05 P	4.00	"	"	O.K.

Summary of the
W9XVM RADAR LOG (Cont'd.)

Date 1948	Time on CDST	Time off CDST	Time in operation	Operator	Remarks
Aug. 16	5:00 P	5:40 P	.75 hrs.	RCP	
" 16	8:00 P	10:12 P	2.25 "	"	Took pic.
" 17	2:11 P	2:30 P	.25 "	"	
" 17	6:55 P	10:55 P	4.00 "	"	Flashes
" 18	9:00 A	10:20 A	1.25 "	"	
" 19	8:25 A	9:25 A	1.00 "	"	
" 19	1:20 P	1:40 P	.25 "	"	Insp. trip
" 19	2:30 P	3:30 P	1.00 "	"	Followed plane
" 20	6:40 P	12:30 A (next day)	5.75 "	"	
" 24	1:05 P	2:25 P	1.25 "	"	Flashes
			108.75 hrs.		

10:00 A.M.
July 12, 1948

WEATHER FORECAST
(July 12-13, 1948}

SYNOPTIC CONDITIONS; Central Illinois lies in an area of weak pressure gradient today with a southerly flow of warm, moist air dominating the region. A weak cold front oriented NE-SW through Central Minnesota to Western Iowa is showing little movement at the present time.

GENERAL FORECAST: Partly cloudy and warm today with scattered thundershowers over the area late afternoon and evening. Tomorrow - partly cloudy with scattered showers.

PROJECT PFISTER FORECAST: Favorable seeding conditions. Scattered build-ups today and tomorrow. Bases 2,000-3,000 feet, tops 12,000 feet extending to 25,000 feet in thundershowers during afternoon and evening. Freezing level at 13,000-14,000 feet.

Winds Aloft Today: Light and variable.

Winds Aloft Tomorrow: 180-200 degrees, 10-15 nroh. at 10-20,000 ft.

Floyd A. Huff, Ass't. Meteorologist

Analysis of Seeding Conditions on August 27, 1948.

I. Surface Map,

At 0630 C.S.T., Illinois was lying on the west side of a high pressure cell, centered over West Virginia. Southeasterly to southerly circulation existed at the surface over Illinois, with no frontal action within several hundred miles. Conditions remained relatively stagnant throughout the day.

II, 700 mb. Chart.

At 0900 C.S.T., Illinois was lying in southerly circulation, with a relatively strong gradient immediately to the west and a relatively weak gradient immediately to the east. A strong high cell was centered in the vicinity of the New Jersey Coast and a trough was located about 500 miles west of Illinois. Winds aloft indicated the circulation was slightly anticydonic from the surface through the 700 mb. level.

III. RAOBS.

The 0900 C.S.T. RAOB for Joliet, most representative for the experimental area, was garbled*. The 2100 C.S.T. sounding of the 26th showed relative humidity averaging about 60% from the surface to the freezing level at 14,000 ft., lowering to 30-40% above this level. Above the surface layer, the sounding showed a dry adiabatic lapse rate to 4500 ft., with conditionally unstable air extending above this level to 12,000 ft. An absolutely stable layer existed from 12,000-15,000 ft., above which the atmosphere again assumed a conditionally unstable lapse rate. A surface temperature of approximately 90°F. was needed for the formation of convective clouds.

Twenty-four hours later (2100 C.S.T., 27th), the Joliet RAOB showed a considerable increase in moisture in the layer from the surface to 14,000 ft., the relative humidity averaging about 75%. Above this level, there was little change in moisture content from the previous' sounding. A conditionally unstable lapse rate dominated the sounding to 13,000 ft., where a slight inversion had developed in the region having an absolutely stable lapse rate on the previous sounding. Above the inversion, conditionally unstable conditions existed to about 18,000 ft. where the air became extremely stable again. The freezing level was near 14,500 ft. A surface temperature of about 90°F.

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*Message received via teletype was unintelligible.

was still required for formation of cumulus through thermal convection. Both soundings showed lapse rates closely approaching or less than, the moist adiabatic rate above 12,000-13,000 ft.

IV. Hourly Weather Sequences.

Since Peoria (30 miles to the west) and Chenoa (15 miles to the east) are the closest reporting stations to the experimental area, they have been chosen to give an indication of the trend of the weather on the 27th. Scattered cumulus formed by 1130 C.S.T. at Peoria and by 1230 C.S.T. at Chenoa. At 1230, Peoria reported thunder with swelling cumulus to the east and southeast. At 1330, they reported a thunderstorm to the east moving north. At 1430, cumulonimbus was reported to the northeast. Scattered swelling cumulus persisted throughout the afternoon at both Peoria and Chenoa, with a scattered to broken deck of altocumulus and cirrus at higher levels. By 1830, the cumulus had dissipated at Peoria, but Chenoa was having a rain shower at that time. Peoria had a maximum temperature of 91°F. that afternoon, while Chenoa reported as high as 96°F,

V. Rainfall Reports.

No rainfall was reported at Peoria. Chenoa recorded 0.07 inch with the early evening shower. The Project Pfister observers reported showers only in the southeast to northeast sections of the experimental area, in the Hudson-Lake Bloomington-Gridley region. Amounts varied from 0.08 to 1.34 inches. The U. S. Weather Bureau rainfall map for the 24—hour period ending 0030 C.S.T., August 28, indicated light amounts occurring over northern, extreme western, and southwestern Illinois, with the northern band extending down to the vicinity of the experimental area.

VI. Seeding Possibilities.

Due to the anticyclonic nature of the circulation at the surface and aloft, the development of the slight inversion aloft, and the relatively dry and stable conditions above the inversion, cumulus would have had difficulty in building past the freezing level. The maximum temperatures at Peoria and Chenoa were sufficient for the formation of convective clouds, but the critical temperature was barely reached at Peoria. In view of these factors, it is likely that only isolated cumulonimbus would have developed over the El Paso area that afternoon, and that these would not have built to great heights above the freezing level in most instances.

Rainfall reports for the day and visual observation of the radar scope during the afternoon bear out this supposition. As previously mentioned, the only showers reported that day over the experimental area were in the Hudson-Lake Bloomington-Gridley area. The thundershower reported east of Peoria occurred to the west of the raingage network. These were the only two areas of shower activity picked up by the radar during the afternoon.

Since the atmosphere was relatively moist below the freezing level, preventing excessive evaporation of the falling rain, and since some cumulus build-ups were definitely present, it is possible that seeding would have produced additional precipitation over certain portions of the area. However, it appears that these build-ups were of isolated nature, and that their tops for the most part did not extend to any great heights above the freezing level. Therefore, it appears likely that favorable seeding clouds would have been present only over scattered portions of the area, and that the amounts induced by seeding in these instances would have been relatively small.

Conditions on the 27th did appear quite favorable for attempting water seeding in the above freezing portion of late afternoon cumulus, which often develop into early evening showers. The built-up cumulus resulting in the early evening shower at Chenoa is at good indication of this type of cloud existing over the area that afternoon.

STATE WATER SURVEY
URBANA, ILLINOIS

COPY

Rainfall Observation Log

Location 26N, 2E, Sec.32 — Station 31 — Gage 2951 — F. Mounce Observer

1948 Date	Day of Week	Time of Obs.	Rainfall in Inches	Rain Started	Rain Ended	Remarks
5/1	Sat	6:30 A	0.05	D N	5:30 A	N.E. wind T 1 shower.
5/2	Sun	7:30 A	0.26	2:30 A	4:00 A	S.E. wind, low clouds.
5/2	Sun	6:30 P	1.28	11:45 A	3:00 P	Cold N.E. wind.
5/4	Tues	11:30 A	0.34	D N	11:30 A	Low clouds, E. wind.
5/6	Thurs	11:15 A	0.31	5:15 A	11:15 A	S. wind, low clouds
5/6	Thurs	7:00 P	0.70	3:35 P	7:00 P	Still raining, NE winds.
5/7	Fri	6:25 A	0.10	D N	D N	NE winds cold.
5/8	Sat	7:00 A	0.01	6:15 A	6:30 A	S. wind.
5/10	Mon	4:25 P	0.13	3:20 P	4:15 P	N. winds, 1 shower.
5/11	Tues	11:35 A	0.19	D N	11:15 A	E.wind, low clouds.
5/12	Wed	8:30 A	0.09	6:05 A	8:25 A	Low clouds, E. wind.
5/13	Thurs	7:35 A	0.11	D N	7:30 A	Misty all day, E. wind.
5/15	Sat	6:35 A	0.31	D N	D N	E. wind, T,L, all night.
6/5	Sat	6:30 A	0.12	D N	D N	E. wind, T,L
6/6	Sun	7:00 P	0.25	12:33 P	6:30 P	W. wind, T.
6/12	Sat	9:15 A	0.09	9:00 A	9:15 A	W. wind, T,L.
6/14	Mon	4:15 P	0.43	11:00 A	4:10 P	E. wind, T.

SWSM 1 — 4-48-500

May 1948 Rainfall Log

Sta. No.	Day of Month 1	2	4	6	7	8	9	10	11	12	13	14	15	17	21	28	Mo. Total
1	N	82	36	58		05			25				35				2.41
2	N	88	35	52	11	05		08	21	11		03	31				
3	08	71	40	48	05	06		25	28	19			28				2.78
4	N	95	35	42		06		25	26	14			37				
5	N	N	N	76	21	08		16	32	38			N				
6	02	53	50	60		02		02	15	09			35				2.28
7	N	84	34	73	11	10		05	17	09			N				
9	N	N	42	43	07	05		66	20	19		05	40				
11	50	68	41	65		10		20	28	08			35				3.25
12	N	78	36	58	02			06	16	05		08	20				
13	04	63	33	78		02		02	20	06		10	21				2.39
14	05	100	33	64		02		11	18	11	01	01	30				2.76
15	N	N	N	N	N	N	N	05	15	10	02	15	20				
16	05	102	31	100	08	01	05		12	13		01	30				3.08
17	N	48	35	50	08	06	01	38	22	30			54				
18	15	52	33	47	10	04	08	42	20	27		12	43				3.13
19	N	52	52	78	02	09		15	23	25			35				
20	N	60	41	92	11			28	25	12		11	24		04		
21	N	86	40	75	16	09		14	22	08		04	33		03		
22	N	N	35	79		04		02	16	05		01	33		02		
23	04	95	30	86		07		09	15	06		07	23				2.82
24	42	44	30	53		04	03	70	24	23		03	50			05	3.51
27	N	86	51	88		03	02	18	22	24			34				3.28
29	N	95	36	82		02		16	12	N	N	N	37		02		
30	05	140	34	81	08			04	21		06		38				3.37
31	05	154	34	101	10	01		13	19	09	11		31				3.88
32	24	49	29	46	07		07	73	18	27			44				3.24
33	28	53	27	40	08	02	08	40	17	28	02	01	48				3.02
39	N	89	30	79	05	02		14	24	23		03	32	01			

NOTE: N - No Report. Monthly Totals only for stations with complete reports.

June 1948 Rainfall Log

Sta. No.	Day of Month: 4	5	6	7	12	14	21	22	23	24	26	27	28	29	30	Mo. Total
1		12	20		03	24	81	22	112	02	130	45	02	03		4.56
2			21		08	21	79	21	109		70	37			11	3.77
3		10	09		03	20	80	19	106	02	86	47				3.82
4	11		14		10	13	76		100		132	31				3.87
6		12	45		03	30	85	22	101	02	89	31				4.20
7		02	05		03	10	78	23	93	01	75	10				3.00
9		10	06		08	10	80	18	55		147	30				3.64
11		15	40			32	75	20	104	02	70	34				3.92
12		12	28		02	22	85	18	75		65	38			04	3.49
13		09	35		04	35	86	26	79	04	93	29		10		4.10
14	05	10			12	32	115	06	76	08	41	22	05			3.32
15		10	18		10	30	100	21	95		63	20	02		05	3.74
16		01	25		01	45	110	40	114		85	35			10	4.66
17		13			23	07	66	20	111	42	55	105				4.42
18		11	19		08	09	68	22	106	28	58	20				3.49
19		20	30		08	18	67	19	87	04	108	15				3.76
20		09	32		05	33	78	19	138	04	99	40				4.57
21		07	33		02	34	84	22	86	02	68	41			07	3.86
23		06	26		06	40	91	23	88		94	29		05	12	4.20
24		12	02	15	12	06	54	52	68	18	09	09				2.57
27		10	41		10	28	68	18	58	20	83	12	01	02		3.51
29		08	24		08	37	92	20	65		29	39	10			3.32
30		07	27		10	44	96	23	71		48	24				3.50
31		12	25		09	43	102	11	123		79	28	06		09	4.47
32		03		03	10	05	45	60	115	04	08	03				2.56
33		08	10	12	15	15	45	65	81	04	08		02	01		2.66
39		16	26		03	35	66	16	55	05	95	13			06	3.36

July 1948 Rainfall Log

Sta. No.	5	6	10	11	12	13	14	15	21	22	23	25	26	27	30	Mo. Total
1	44		12	10		136	72	14	62	32	45	202				6.29
2	44		04	06			235	16	65	51	44		211			6.76
3	50						245	23		37	55	237				6.47
4	53		02	05			113	12	72	38	62	240				5.97
6	52		42	20			173		60	32	71	121	51			6.22
7	49		25		04		251	17	62	36	27	197				6.68
8	42					80	138	10	67	36	33	200	21			6.27
9	52		03		10	12	150		100	82		200				6.09
10	50		48		05	15	83	10	75	31	55	88	155			6.15
11	54		100	14	06	50	78	15	64	102		204				6.87
12	44		82	16			124	10	57	26	62	110	50		05	5.86
13	60		43	22		26	109	22	51	37	63	155				5.88
14	N		N	02			230	26	21	25	80	N				
15	38		98	08		105	150	15	53	32	54	80	55		04	6.92
16	50		210			20	70		60	30	70	126				6.36
17	60		20		58		143	29	62	38	21		220			6.51
18	61	04	49		11		150	18	58	39			243			6.33
19	60	05	40		35	45	63	25	76	43		95	110			5.96
20	73		35	46	29	55	153	22	71	42	79	196				8.01
21	62	09	51	137			176	21	67	28	83	77	78			7.89
22	47		78	142			160	16	51	38	70	200				8.02
23	62		160	08		30	120	15	55	35	55	105	14			6.59
24	73			08	24		200		78	49	16	161				6.09
25	68		15		55		150	15	46	100		275				7.24
26	71		42		61		99	14	53	126		222				6.88
27	70	03	153	16	27		113	21	71	48	82	141				7.45
28	60	07	102			51	68		50	13	100	145	25			6.21
29	71		56	120		180	52	22	44	120		138				8.00
30	78	06	23				158	19	50	37	82	98	45			5.96
31	60		50	30			91	44	46	119		123				5.63
32	73		66		04	80	N	15	45	84		126				4.93
33	67		96			17	48	16	83	38	71	220		08		6.64
34	40	10	44		30	21	65	10	73	40	47	92	74			5.46
35	70		63			29	94	12	50	35	60	85	95			5.93
36	96	01	78		10	147	212	21	72	43	93		177			9.50
37	75		136		18	120	185	15	55	34	100	202	08			9.48
38	125		N			85	N	93	55	134		175				
39	98		150	25	23		194	18	58	46	84	N			19	
40	170	14	242	02	88	07	67	25	80	41	90	200	18			10.44
41	65		88		08		75	20	55	35	67	122	23			5.58
42	40				08		194	12	50	39	16	220				5.79
43	40				110		250	09	86	35	10	140				6.80
44	42				69	115	153	07	74	35	12	143		07		6.57
45	20	05	30	25		10	05	15	56	15	57	190	35	03	03	4.69
46	35		86			10	51	15	46	95		118				4.56

August 1948 Rainfall Log

Sta. No.	Day of Month: 3	4	11	27	30	Mo. Total
1		25	55		31	1.11
2		27	73		43	1.43
3		27	53		47	1.27
4		30	36		48	1.14
6		31	63		53	1.47
8		25	21	08	56	1.10
9		03			40	.43
10		25	16		28	.69
11		37	76		35	1.48
12	T	25	26		33	.84
13		40	37		62	1.39
14		28	N		N	
15	02	40	75	30	65	2.12
16		29	03	25	80	1.37
17			33		34	.67
18		22	12		39	.73
19		33	51		N	
20		32	26		46	1.04
21		31	06		42	.79
22		35	49		49	1.33
23		29	11		47	.87
24		28	26		52	1.06
25		23			30	.53
26	T	N	42		29	
27		28	16		62	1.06
29		32	23		45	1.00
30		29	19		40	.88
31		27	26		45	.98
32		24	30		33	.87
33		29	33		30	.92
34		25	60		30	1.15
35		25	23		T	.48
36		33	17		51	1.01
37		21	14		44	.79
38		27	38		65	1.30
39		31	18		48	.97
40		40	63		54	1.57
41	02	22	27		35	.86
42		31	50	134	105	3.20
43		18	T		89	1.07
44		15			46	.61
45		10	07		95	1.12
46		29	14	47	147	2.37

T = Trace
N = No Report

September 1948 Rainfall Log

Sta. No.	Day of Month 1	6	8	20	21	29	Mo. Total
1		05	62		129	42	2.38
2		06	51		109	45	2.11
3			65		139	40	2.44
6			51		92	40	1.83
9	04	03	67		108	47	2.29
11		50	40		145	43	2.78
16			35		70	47	1.52
17	08	07	56	10	93	42	2.16
18	08	07	68	08	85	47	2.23
21	05	07	37	02	82	52	1.85
23	03	06	42		48	50	1.49
25			92		11	40	1.43
29		11	37		104	38	1.90
31			47		45	46	1.38
32	05	03	143	10	143	35	3.39
33	03		160	10	120	28	3.21
36	04	07	62	07	117	32	2.25
39	05	13	75		105	42	2.35
43			56		59	39	1.54
44			55		64	32	1.51
46		T	30		43	52	1.25

T = Trace