UNITED STATES
DEPARTMENT OF
COMMERCE
PUBLICATION

NOAA Technical Memorandum NWS ER—42

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service

A CASE STUDY OF RADAR DETERMINED RAINFALL AS COMPARED TO RAIN GAGE MEASUREMENTS

Martin Ross

Eastern Region

Garden City, N.Y.

1971

NOAA TECHNICAL MEMORANDA
National Weather Service, Eastern Region Subseries

The National Weather Service Eastern Region (ER) Subseries provides an informal medium for the documentation and quick dissemination of results not appropriate, or not yet ready, for formal publication. The series is used to report on work in progress, to describe technical procedures and practices, or to relate progress to a limited audience. These Technical Memoranda will report on investigations devoted primarily to regional and local problems of interest mainly to ER personnel, and hence will not be widely distributed.

Papers 1 to 22 are in the former series, ESSA Technical Memoranda, Eastern Region Technical Memoranda (ERTM); papers 23 to 37 are in the former series, ESSA Technical Memoranda, Weather Bureau Technical Memoranda (WBTM). Beginning with 38, the papers are now part of the series, NOAA Technical Memoranda NWS.

Papers 1 to 22 are available from the National Weather Service Eastern Region, Scientific Services Division, 585 Stewart Avenue, Garden City, N.Y. 11530. Beginning with 23, the papers are available from the National Technical Information Service, U.S. Department of Commerce, Sills Bldg., 5285 Port Royal Road, Springfield, Va. 22151. Price: $3.00 paper copy; $0.95 microfilm. Order by accession number shown in parentheses at end of each entry.

ESSA Technical Memoranda

ERTM 1 Local Uses of Vorticity Prognoses in Weather Prediction. Carlos R. Dunn. April 1965

ERTM 2 Application of the Barotropic Vorticity Prognostic Field to the Surface Forecast Problem. Silvio G. Simplicio. July 1965

ERTM 3 A Technique for Deriving an Objective Precipitation Forecast Scheme for Columbus, Ohio. Robert Kuessner. September 1965

ERTM 4 Stepwise Procedures for Developing Objective Aids for Forecasting the Probability of Precipitation. Carlos R. Dunn. November 1965

ERTM 5 A Comparative Verification of 300 mb. Winds and Temperatures Based on NMC Computer Products Before and After Manual Processing. Silvio G. Simplicio. March 1966

ERTM 6 Evaluation of OFDEV Technical Note No. 17. Richard M. DeAngelis. March 1966

ERTM 7 Verification of Probability Forecasts at Hartford, Connecticut, for the Period 1963-1965. Robert B. Wassall. March 1966

ERTM 8 Forest-Fire Pollution Episode in West Virginia November 8-12, 1964. Robert O. Weedfall. April 1966

ERTM 9 The Utilization of Radar in Meso-Scale Synoptic Analysis and Forecasting. Jerry D. Hill. March 1966

ERTM 10 Preliminary Evaluation of Probability of Precipitation Experiment. Carlos R. Dunn. May 1966

ERTM 11 Final Report. A Comparative Verification of 300 mb. Winds and Temperatures Based on NMC Computer Products Before and After Manual Processing. Silvio G. Simplicio. May 1966

ERTM 12 Summary of Scientific Services Division Development Work in Sub-Synoptic Scale Analysis and Prediction - Fiscal Year 1966. Fred L. Zuckerberg. July 1966

ERTM 13 A Survey of the Role of Non-Adiabatic Heating and Cooling in Relation to the Development of Mid-Latitude Synoptic Systems. Constantine Zois. July 1966

ERTM 14 The Forecasting of Extratropical Onshore Gales at the Virginia Capes. Glen V. Sachse. August 1966

ERTM 15 Solar Radiation and Clover Temperature. Alex J. Kish. September 1966

ERTM 16 The Effects of Dams, Reservoirs and Levees on River Forecasting. Richard M. Greening. September 1966

ERTM 17 Use of Reflectivity Measurements and Reflectivity Profiles for Determining Severe Storms. Robert E. Hamilton. October 1966

ERTM 18 Procedure for Developing a Nomograph for Use in Forecasting Phenological Events from Growing Degree Days. John C. Purvis and Milton Brown. December 1966

ERTM 19 Snowfall Statistics for Williamsport, Pa. Jack Hummel. January 1967

ERTM 20 Forecasting Maturity Date of Snap Beans in South Carolina. Alex J. Kish. March 1967

ERTM 21 New England Coastal Fog. Richard Fay. April 1967

ERTM 22 Rainfall Probability at Five Stations Near Pickens, South Carolina, 1957-1963. John C. Purvis. April 1967

WBTM ER 23 A Study of the Effect of Sea Surface Temperature on the Areal Distribution of Radar Detected Precipitation Over the South Carolina Coastal Waters. Edward Paquet. June 1967 (PB-180-612)

WBTM ER 24 An Example of Radar as a Tool in Forecasting Tidal Flooding. Edward P. Johnson. August 1967 (PB-180-613)

WBTM ER 25 Average Mixing Depths and Transport Wind Speeds over Eastern United States in 1965. Marvin E. Miller. August 1967 (PB-180-614)

WBTM ER 26 The Sleet Bright Band. Donald Marier. October 1967 (PB-180-615)

WBTM ER 27 A Study of Areas of Maximum Echo Tops in the Washington, D.C. Area During the Spring and Fall Months. Marie D. Fellechner. April 1968 (PB-179-339)

WBTM ER 28 Washington Metropolitan Area Precipitation and Temperature Patterns. C. A. Woollum and N. L. Canfield. June 1968 (PB-179-340)

WBTM ER 29 Climatological Regime of Rainfall Associated with Hurricanes after Landfall. Robert W. Schoner. June 1968 (PB-179-341)

WBTM ER 30 Monthly Precipitation - Amount Probabilities for Selected Stations in Virginia. M. H. Bailey. June 1968 (PB-179-342)

WBTM ER 31 A Study of the Areal Distribution of Radar Detected Precipitation at Charleston, S. C. S. K. Parrish and M. A. Lopez. October 1968 (PB-180-480)

WBTM ER 32 The Meteorological and Hydrological Aspects of the May 1968 New Jersey Floods. Albert S. Kachic and William Long. February 1969 (Revised July 1970) (PB-194-222)

WBTM ER 33 A Climatology of Weather that Affects Prescribed Burning Operations at Columbia, South Carolina. S. E. Wasserman and J. D. Kanupp. December 1968 (COM-71-00194)

WBTM ER 34 A Review of Use of Radar in Detection of Tornadoes and Hail. R. E. Hamilton. December 1969 (PB-188-315)

WBTM ER 35 Objective Forecasts of Precipitation Using PE Model Output. Stanley E. Wasserman. July 1970 (PB-193-378)

WBTM ER 36 Summary of Radar Echoes in 1967 Near Buffalo, N.Y. Richard K. Sheffield. September 1970 (COM-71-00310)

WBTM ER 37 Objective Mesoscale Temperature Forecasts. Joseph P. Sobel. September 1970. (COM-71-0074)

NOAA Technical Memoranda NWS

NWS ER 38 Use of Primitive Equation Model Output to Forecast Winter Precipitation in the Northeast Coastal Sections of the United States. Stanley E. Wasserman and Harvey Rosenblum. December 1970 (COM-71-00138)

NWS ER 39 A Preliminary Climatology of Air Quality in Ohio. Marvin E. Miller. January 1971 (COM-71-00204)

(Continued On Inside Rear Cover)

UNITED STATES DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE EASTERN REGION
Garden City, New York

NOAA TECHNICAL MEMORANDUM NWS ER-42

A CASE STUDY OF RADAR DETERMINED RAINFALL AS COMPARED TO RAIN GAGE MEASUREMENTS

Martin Ross
Weather Service Office, Atlantic City, N. J.

Scientific Services Division
Eastern Region Headquarters
July 1971

F O R E W A R D

Mr. Ross's study of rainfall measurements by radar contains useful information for all radar operators, hydrologists and other users of radar data for hydrologic purposes. It is important to remember that this study covers only one storm and that many more cases of different types of precipitation would need to be studied before definite conclusions could be reached. We cannot recommend at this time any changes in the current Weather Service Rainfall Rate-Echo Intensity diagram until additional data and statistics can be collected.

Robert E. Hamilton
Regional Radar Meteorologist

A B S T R A C T

WSR-57 radar-estimated rainfall amounts during a 36 hour storm period are obtained by using Wilson's Rainfall Rate-Echo Intensity RR-EI, chart. These estimates are compared with rainfall data from three tipping buckets. These tipping buckets are located within 60 nautical miles of the Atlantic City radar and cover a 4.8 square mile area. Estimates of rainfall from radar measurements were within 2 percent of the total rain gage average:. Use of the National Weather Services RR-EI chart would have underestimated the average areal precipitation. Hourly rainfall amounts of 0.01 inches were detected by radar in 80 percent of the cases. Hourly amounts of 0.02 inches or more were detected in 100 percent of the cases.

A CASE STUDY OF RADAR DETERMINED RAINFALL AS COMPARED TO RAIN GAGE MEASUREMENTS

I. INTRODUCTION

Wilson (1) indicated that a dense network of rain gages within range of a WSR-57 would be a valuable aid for further clarification of the radar's ability to measure rainfall over area and point locations. The results of Wilson's study indicated that the RR-EI chart as given in the Weather Radar Manual (2) underestimates rainfall. In his study, Wilson suggests determining and using the best relationship of RR-EI for each storm. However, this procedure is not practical on an operational basis; therefore, Wilson's average relationship (1) for all storms was used. Wilson's chart adjusts by about 8 decibels (db) the underestimate of precipitation based on the RR-EI chart in the Weather Radar Manual. For example, Wilson's chart at a range of 50 nautical miles and a gain reduction of 36 DB would result in a theoretical rainfall rate of 1 inch per hour as compared to .3 of an inch using the National Weather Service chart.

It is the intent of this study to use and evaluate Wilson's RR-EI chart (based on the average relationship for converting echo intensities measured with a WSR-57) and to compare radar computed rainfall estimates with the rain gage measurements for a single storm. Wilson's relationship is used to obtain radar estimates of rainfall using the WSR-57 radar at Atlantic City, New Jersey. These estimates are then compared to rain gage measurements obtained by Bell Laboratory in New Jersey. Bell Laboratory collected rainfall data on a multiple register from three tipping buckets placed within a 4.8 square mile area (Figures 1 and 2).

II. RADAR DATA COLLECTION AND PROCESSING

On September 19 - 21, 1966, a low pressure system moved northward along the Atlantic Coast. Several inches of rain fell over portions of northern New Jersey. During much of this period, the WSR-57 at Atlantic City was photographed on the 100 nautical mile range and the radar's sensitivity was automatically reduced, or stepped, at 6 db intervals to a maximum of 42 db. In general, a complete series of intensity step pictures was taken between 19 and 23 times an hour. However, due to faulty film advancing and other reasons, there were periods with only one stepped intensity series available during an hour. The photographic data were manually digitized over a square, 2.2 miles on a side, that covered

A CASE STUDY OF RADAR DETERMINED RAINFALL AS COMPARED TO RAIN GAGE MEASUREMENTS

I. INTRODUCTION

Wilson (1) indicated that a dense network of rain gages within range of a WSR-57 would be a valuable aid for further clarification of the radar's ability to measure rainfall over area and point locations. The results of Wilson's study indicated that the RR-E1 chart as given in the Weather Radar Manual (2) underestimates rainfall. In his study, Wilson suggests determining and using the best relationship of RR-E1 for each storm. However, this procedure is not practical on an operational basis; therefore, Wilson's average relationship (1) for all storms was used. Wilson's chart adjusts by about 8 decibels (db) the underestimate of precipitation based on the RR-E1 chart in the Weather Radar Manual. For example, Wilson's chart at a range of 50 nautical miles and a rain reduction of 36 DB would result in a theoretical rainfall rate of 1 inch per hour as compared to .3 of an inch using the National Weather Service chart.

It is the intent of this study to use and evaluate Wilson's RR-E1 chart (based on the average relationship for converting echo intensities measured with a WSR-57) and to compare radar computed rainfall estimates with the rain gage measurements for a single storm. Wilson's relationship is used to obtain radar estimates of rainfall using the WSR-57 radar at Atlantic City, New Jersey. These estimates are then compared to rain gage measurements obtained by Bell Laboratory in New Jersey. Bell Laboratory collected rainfall data on a multiple register from three tipping buckets placed within a 4.8 square mile area (Figures 1 and 2).

II. RADAR DATA COLLECTION AND PROCESSING

On September 19 - 21, 1956, a low pressure system moved northward along the Atlantic Coast. Several inches of rain fell over portions of northern New Jersey. During much of this period, the WSR-57 at Atlantic City was photographed on the 100 nautical mile range and the radar's sensitivity was automatically reduced, or stepped, at 6 db intervals to a maximum of 42 db. In general, a complete series of intensity step pictures was taken between 19 and 23 times an hour. However, due to faulty film advancing and other reasons, there were periods with only one stepped intensity series available during an hour. The photographic data were manually digitized over a square, 2.2 miles on a side, that covered

the area where the three tipping buckets were located. The highest echo intensity during each stepping series was then converted to rainfall rate by using Wilson's RR-EI chart. Intensity measurements on PPI photographs are approximately 3 db below those measured on the A scope (1). Thus, to compensate for this loss, 3 db were added to the highest intensities prior to rainfall conversion. Rainfall for all the stepped series in each hour was totalled to obtain the radar determined hourly rainfall.

$$\text{Theoretical Hourly Rainfall} = \frac{1}{n} \Sigma R_1 + R_2 + \ldots\ldots + R_n$$

where n = number of radar observations, R_i, in an hour.

III. RAIN GAGE COLLECTION

During this storm, Bell Laboratory at Holmdel, New Jersey, collected hourly rainfall data on a multiple register from three tipping buckets within a 4.8 square mile area (Figure 1).. Hourly and total storm accumulations for the tipping buckets and radar rainfall estimates are given in Table 1.

IV. RESULTS

Since areal mean rainfall is more meaningful and useful, especially to the hydrologist, no attempt was made to compare radar rainfall with point measurements at a single rain gage. The results of hourly and total storm average of three rain gage measurements versus radar estimated rainfall are shown in Table. 1. Comparisons were made of the radar estimated rainfall and the measured areal rainfall. The average of the tipping bucket gages was assumed to be the true areal mean. The radar total storm measurement was within 2 percent of the total storm rain gage average. Figure 3 shows a linear regression analysis for hourly radar rainfall estmates versus hourly averages of the three rain gages. The correlation coefficient is .91 and the equation for the least squares regression line is:

$$Y = .008 + .963X$$

Hourly rainfall amounts of 0.01 inches were detected by radar in 80 percent of the cases. Hourly amounts of 0.02 inches or more were detected in 100 percent of the cases. There were six cases where radar indicated rainfall with none recorded in any of the tipping buckets. Use of the National Weather Service's RR-EI

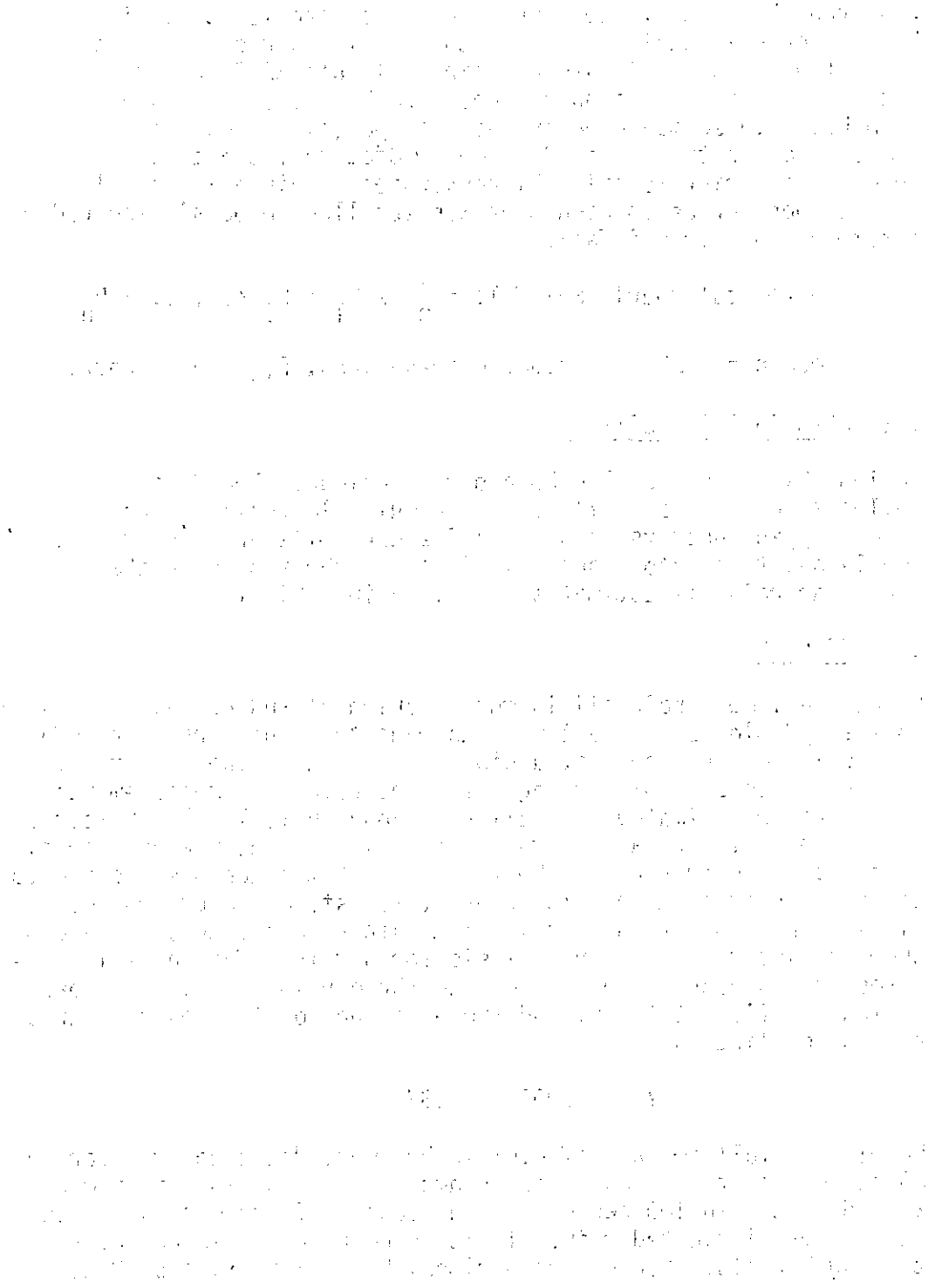


chart would have considerably underestimated the actual areal rainfall.

V. CONCLUSION

Radar can be of use to the hydrologist by providing information that is necessary for flood forecasting, such as rainfall, duration and movement of areas of heavier precipitation. Ideally, this should be done on a computer for real time use. Experiments are being conducted along these lines (3). However, by using hourly-prepared radar overlays that are contoured for given decibel values and range-corrected, broad categories of rainfall over river basins, such as R-, R, R+, and R++, can now be furnished to flood forecasting offices. In addition, rough estimates of rainfall amounts can be provided, and duration and movement of rainfall given.

Teague (4) believes that the largest contributor to the difference between radar estimated rainfall and rain gage values is the difference of respective volumes sampled. To clarify this difference, it is hoped that comparisons between radar and an extremely dense network of rain gages can be accomplished in the future. Bell Laboratory at Holmdel operates such a network, collecting rainfall data from 100 capacitor flow rain gages over an 84 square mile area.

REFERENCES

1. Wilson, J. W., 1964: "Evaluation of Precipitation Measurements with the WSR-57 Weather Radar", Journal of Applied Meteorology, Vol. 3, No. 2, pp. 164-174

2. Environmental Science Services Administration, U.S. Dept of Commerce, 1967: Weather Radar Manual, (WBAN) Part B, pp. 162

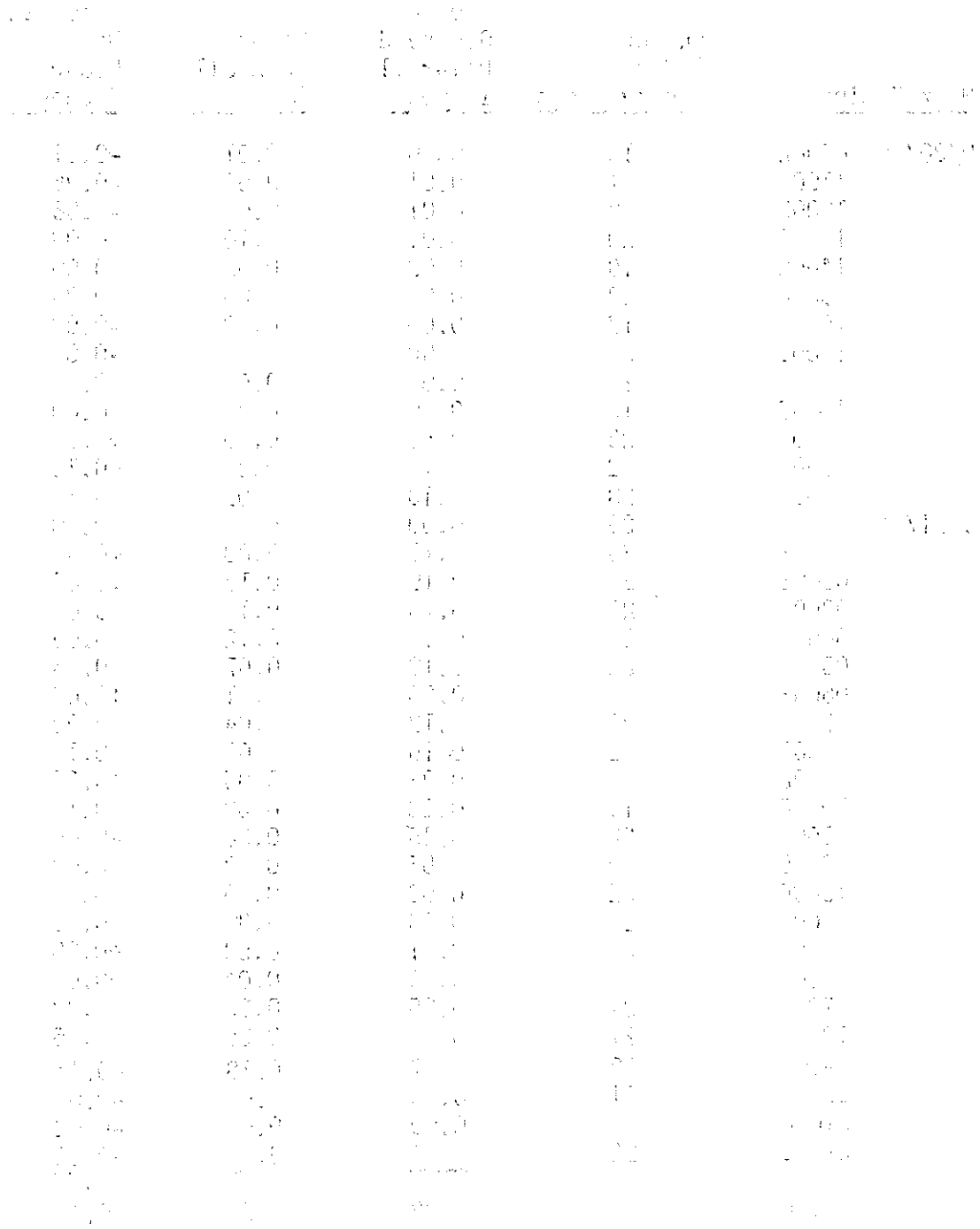
3. McCallister, J.P. and Jack L. Tague, 1968: "Radar Requirements for Operational Hydrologic Analyses", Proceedings 13th Radar Meteorological Conference, AMS, pp. 416-421

4. Teague, J.L., 1966: "The Use of Radar in Flash Flood Forecasting", manuscript of the U.S. Weather Bureau Southern Region, 21 pp.

TABLE 1

HOURLY RADAR-COMPUTED RAINFALL AND OBSERVED RAINFALL

Hour Ending		Number Radar Observations	Average Observed Rainfall Inches	Radar Rainfall Inches	Observed Minus Radar Inches
9/20/66	0800E	16	0.00	0.01	-0.01
	1100E	1	0.01	0.06	-0.05
	1200E	8	0.01	0.07	-0.06
	1300E	20	0.01	0.10	-0.09
	1400E	19	0.02	0.02	0.00
	1500E	22	0.00	0.00	0.00
	1600E	17	0.00	0.02	-0.02
	1700E	23	0.00	0.02	-0.02
	1800E	22	0.00	0.06	-0.06
	1900E	16	0.00	0.00	0.00
	2100E	23	0.01	0.00	+0.01
	2200E	22	0.14	0.02	+0.12
	2300E	23	0.13	0.02	+0.11
9/21/66	0000E	23	0.09	0.09	0.00
	0100E	23	0.15	0.08	+0.07
	0200E	23	0.19	0.13	+0.06
	0300E	23	0.13	0.13	0.00
	0400E	22	0.12	0.12	0.00
	0500E	22	0.12	0.07	+0.05
	0600E	22	0.28	0.21	+0.07
	0700E	22	0.12	0.04	+0.08
	0800E	22	0.16	0.01	+0.15
	0900E	3	0.08	0.04	+0.04
	1000E	19	0.28	0.43	-0.15
	1100E	22	0.45	0.50	-0.05
	1200E	19	0.56	0.53	+0.03
	1300E	22	0.63	0.60	+0.03
	1400E	22	0.33	0.33	0.00
	1500E	23	0.81	0.53	+0.28
	1600E	21	0.06	0.04	+0.02
	1700E	21	0.25	0.33	-0.08
	1800E	21	0.10	0.36	-0.26
	1900E	22	0.07	0.18	-0.11
	2000E	21	0.00	0.01	-0.01
	2100E	22	0.00	0.02	-0.02
	2200E	22	0.01	0.03	-0.02
	TOTAL		5.32	5.21	+0.11



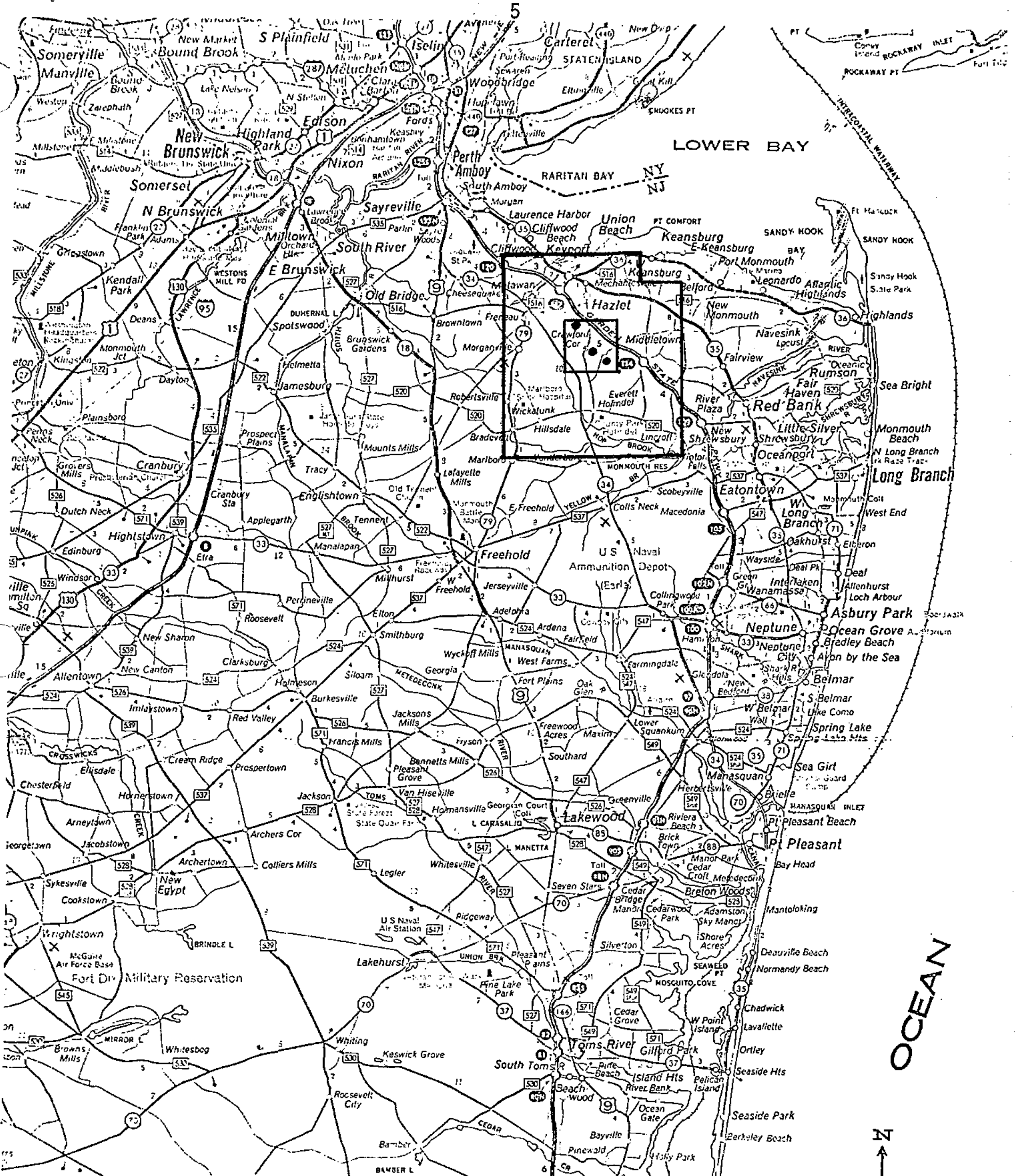


FIGURE 1. Location of Test Area. The larger outlined area is where 100 rain gages have been installed. The small square within this larger area indicates the 4.8 sq. mi. area sampled for this study. The three dots within this small square locates the positions of the three tipping-bucket rain gages used in the calculations.

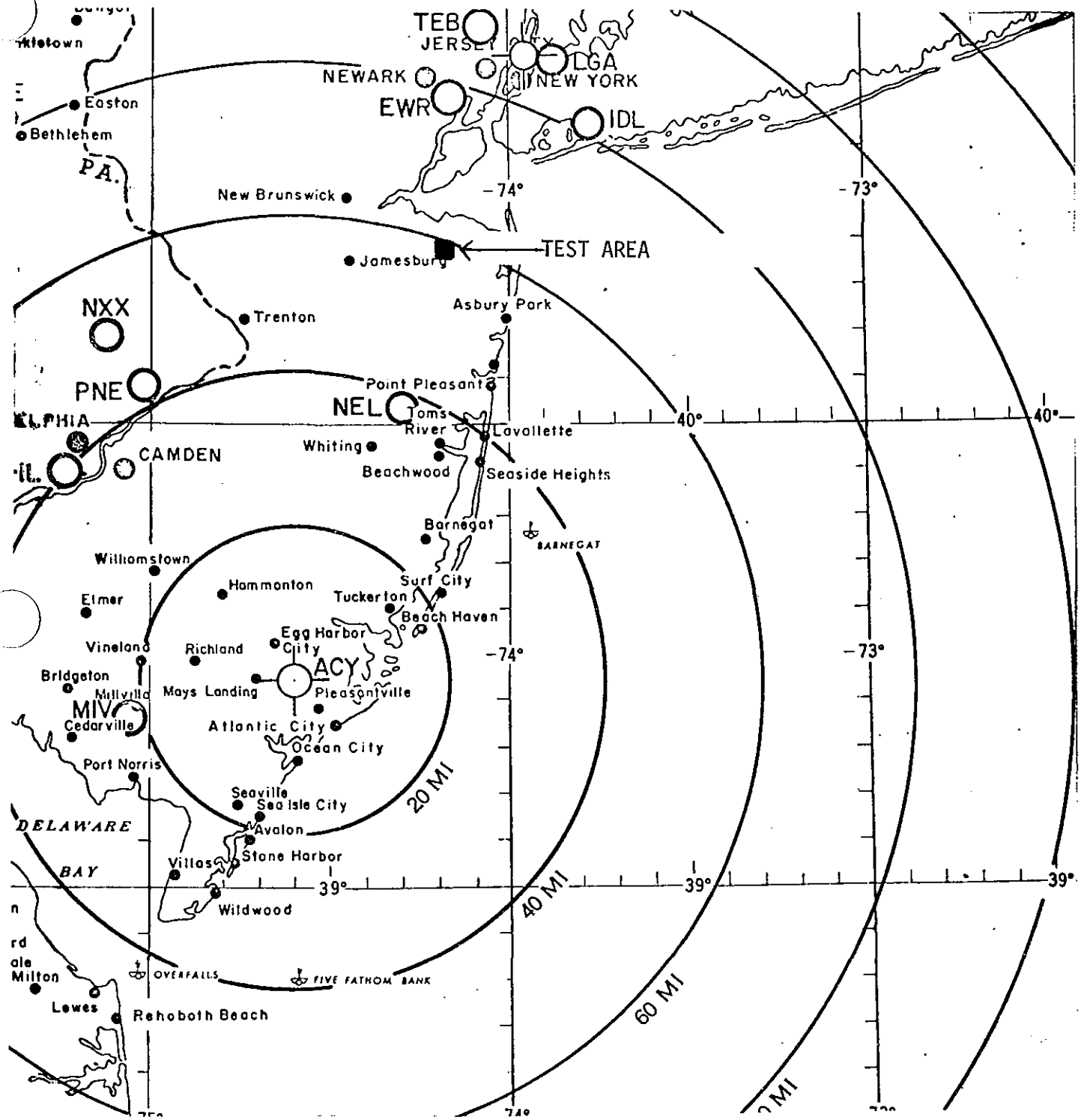


FIGURE 2. Location of Radar Site in Respect to the Test Area. This figure shows the distance (60 miles) from the Atlantic City radar site to the test area located in the northeast quadrant of the radar scope.

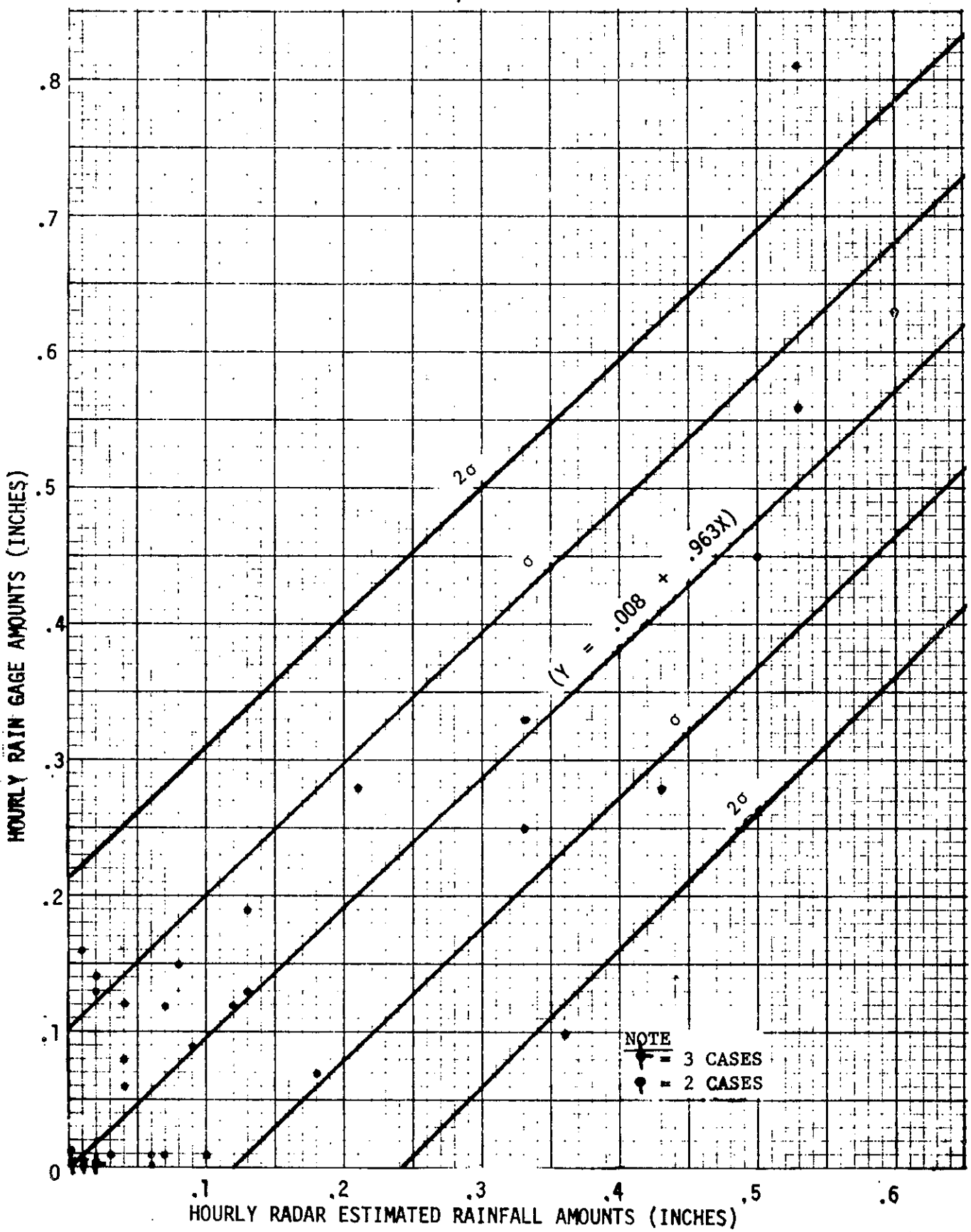


FIGURE 3. Radar-Computed Rainfall Versus Hourly Average of Three Tipping-Bucket Rain Gages.

List of Eastern Region Technical Memoranda
(Continued From Inside Front Cover)

NWS ER 40 Use of Detailed Radar Intensity Data in Mesoscale Surface Analysis. Robert E. Hamilton. March 1971 (COM-71-00573)

NWS ER 41 A Relationship Between Snow Accumulation and Snow Intensity as Determined From Visibility. Stanley E. Wasserman and Daniel J. Monte. May 1971 (COM-71-00763)