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THE UNIVERSITY OF MICHIGAN
COLLEGE OF ENGINEERING
Department of Atmospheric and Oceanic Science

First Annual Progress Report
METEOROLOGICAL STUDY OF POWER PLANT THERMAL DISCHARGES

Dennis G. Baker
Assistant Professor of Meteorology

Edward Ryznar
Research Associate

ORA Project 320157

under contract with:

AMERICAN ELECTRIC POWER SERVICE CORPORATION
NEW YORK, NEW YORK

administered through:

The University of Michigan Sea Grant Program

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ABSTRACT

The first year of work on an investigation to determine what effects a once-through lake cooling system at the Donald C. Cook Nuclear Plant may have on several meteorological variables inland from Lake Michigan is described. It included establishing 12 climatological stations and installing equipment for measuring temperature, relative humidity and precipitation at all stations, and thermal radiation, visibility and wind velocity at two main stations. The locations of stations, equipment used, and data collected and processed are described in detail. Work on a fog prediction model is discussed.

ACKNOWLEDGEMENTS

The cooperation of 11 property owners in the Cook Nuclear Plant area in permitting the use of a small area of their property for the location of a weather shelter and a precipitation gage is appreciated. Most property owners were quite knowledgeable about the nuclear plant and were willing to help.

Mr. Jack Druckemiller and Mr. Patrick Greene of the Indiana & Michigan Power Company provided assistance in several aspects of the establishment of the network. They made the necessary arrangements to supply power to the main sites and to establish the roof of the Cook Nuclear Plant Visitor Information Center as a site for a precipitation gage.

The assistance of Mr. Jerry Sarno in permitting the use of his premises for the delivery of equipment and his produce market building as a calibration chamber for the hygrothermographs is appreciated.

We consider ourselves fortunate to have found and hired a person with the qualities of Mr. Donald Pearson to fill the all-important job of our "man in the field". Having lived in the area for many years and having retired from the U.S. Air Force as a pilot, he not only knows the territory covered by networks but he is also acquainted with many operational aspects of meteorology as well as some of the terminology.

Most of the equipment used in the study was new to him at the outset, but he has progressed very well in understanding it. He has capably handled the weekly tasks of changing recorder charts (one day at the Palisades network and one day at the Cook network), entering calibration checkpoints every week on recording equipment, and generally monitoring equipment performance. He has been quick to notify us of equipment malfunctions and submits a weekly status summary of equipment performance. In addition to his technical work, he has the important quality of getting along well with the people he frequently meets at the stations. From all reports, his yellow Volkswagen emblazoned with the Great Seal of the United States enclosed by the words "Official U.S. Taxpayer" in large letters on the door is becoming well-known in the network areas.

The work of Paul Titus in developing and applying data processing techniques with the digitizer, Fred Keyes in equipment set-up and data processing and Jeff Baron and Tim Oster in data processing is appreciated. Ms. Bonnie Beasley did her usual excellent job in typing the report.

Mr. Robert Kessler, a graduate student in meteorology, contributed significantly to the research on fog.

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I. INTRODUCTION

This is the first annual progress report for a five-year investigation of the meteorological impact of a once-through lake water cooling system; in particular, that to be used at the Donald C. Cook Nuclear Plant. The heat from the once-through system is ultimately released to the atmosphere, mainly by long-wave radiation and the turbulent transfer of latent and sensible heat. The purpose of this investigation is to determine whether the heat and moisture gain of the atmosphere is of sufficient magnitude to be detected at the earth's surface inland from the lake. If these gains are detected, then the investigation is designed to establish the extent and magnitude of the detectable modification. The study concentrates on accurate measurements of variables most likely to be affected; namely, temperature, relative humidity, precipitation, and fog.

Because of the lack of adequate climatological data in the vicinity of the power plant, and the inadequacies of present mathematical models for assessing meteorological effects, the most promising approach is a statistical analysis of data from a network of meteorological stations. Since the power plant will go into operation sometime during the study, a comparison will be made of the observed conditions at each station before and after the plant and its cooling system begin operation.

The first year of this study has been devoted mainly to (1) establishing measurement sites, (2) obtaining the permission of land owners where necessary, (3) procuring, installing, and calibrating equipment, (4) developing data processing techniques, (5) collecting and processing data, and (6) the development of a fog prediction model. Each of these is described in the sections that follow.

II. CLIMATOLOGICAL STATIONS

Selection and location

Locations of the climatological stations are shown in Figure 1. The basic network consists of 12 sites. Each site has a recording precipitation gage, and a hygrothermograph enclosed in a standard weather shelter. The selection of each site was based upon there being (1) suitable exposure* for precipitation measurements, (2) accessibility to the station from a nearby road, and (3) some surveillance of the station by occupants of dwellings in the area.

The particular network configuration shown in Figure 1 is thought to be the one most suitable for detecting any changes in the local meteorology which may be caused by the once-through system. The Nuclear Plant will release warm water off-shore into the lake. The warm water will float on the colder lake water and be carried along with the lake currents, forming a long, narrow plume of warm water. Because the plume is warmer than the lake water, heat and moisture transfer into the atmosphere is enhanced over the plume. If the wind is onshore, the modified air will be advected

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* As described in Weather Bureau Observing Handbook No. 2.

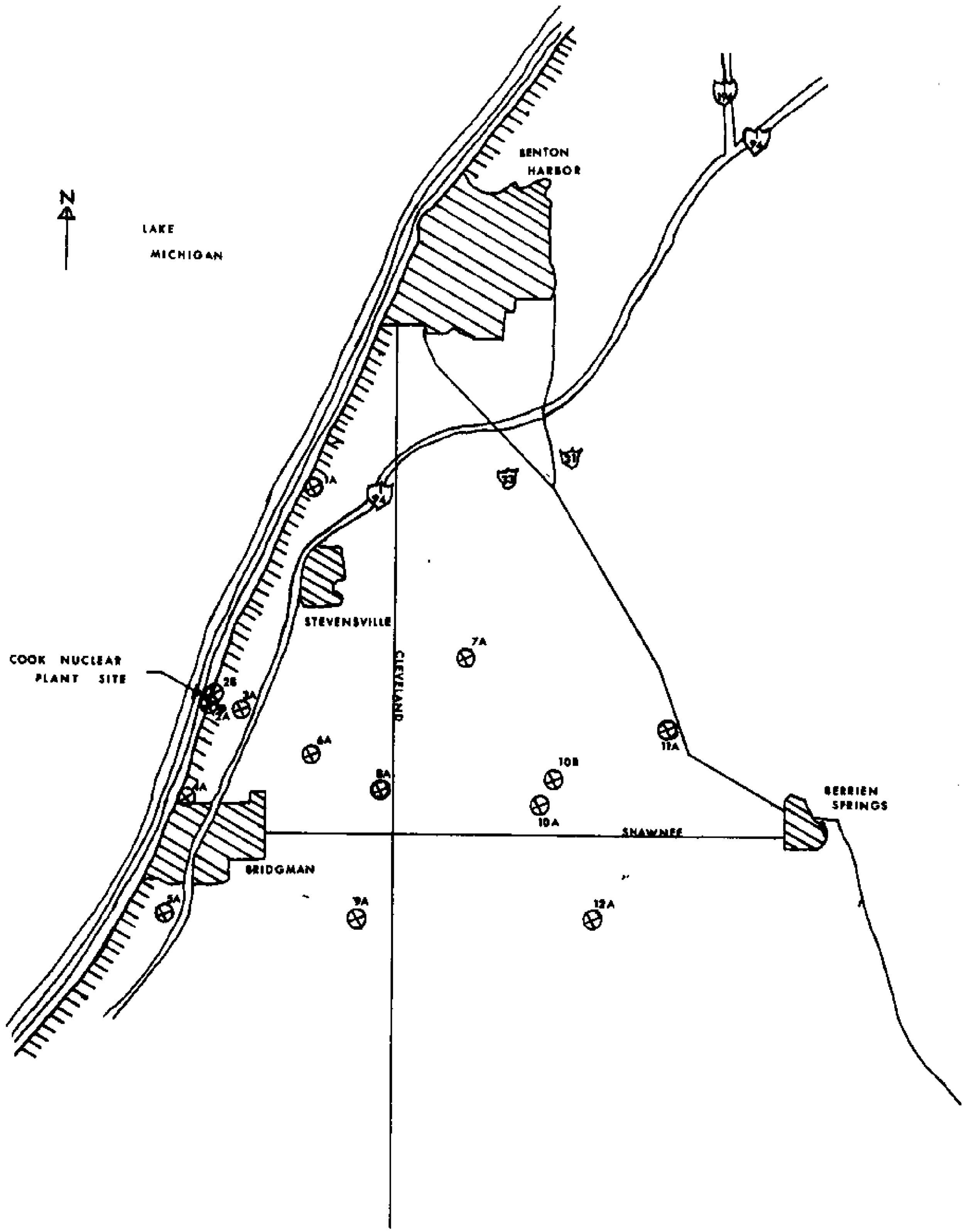

Figure 1. Locations of climatological stations

inland.

Although the actual path of the plume will vary greatly, it could extend at times for several miles along the coast. Hence, instead of there being a concentrated source of heat and moisture such as that of a cooling tower, there is a continuous, less intense area source extending along the coast. The thermal contrast of the plume will probably decrease to the north and south of the plant, and hence the magnitude of any significant modification will also decrease. Because of the extended nature of the source, a rectangularly-shaped network was chosen, with the greatest concentration of stations along the coast. Since the magnitude of any effects should decrease as one goes inland, the density of stations also decreases. The network extends 8 miles inland; i.e., far enough so that no detectable effects are likely to be observed at the stations farthest inland. The data from these stations will serve as "control" data.

To monitor the changes in fog in the area, a visiometer site is established at station #3. Since the fog modifications inland are expected to be small, one station is thought to be sufficient.

It would be impossible to make a careful analysis of the basic network data without a knowledge of the variations in other meteorological variables, especially wind and radiation. These variables are measured at stations #3 and #10A (called main sites), enabling changes in these variables across the network to be monitored.

Site #3 is the closest adequate site to the nuclear plant. Any effect on the local meteorology will probably be detectable at this site.

Site #10A is near the outer edge of the network where any modification should be undetectable. Site #10A is considered as representative of the far inland stations topographically and is located approximately midway among these stations.

Main Stations

Station #3 is located at the southern guard gate, 1 mile ESE of the Donald C. Cook Nuclear Plant and about 300 feet west of I-94. The instruments are located on a rise in terrain with higher tree-covered dunes to the north and south. The site is not ideal but represents a compromise among the requirement for flat terrain, good protection for the instruments, and nearness to the power plant.

Figure 2 shows a view of the station as seen facing NW. From left to right in the figure are (1) an anemometer and wind vane on a 3-meter mast, (2) a post for the visiometer (which wasn't installed at the time of the picture), (3) a recording precipitation gage, (4) a total hemispherical radiometer for total solar and atmospheric radiation (hidden behind the raingage), (5) a heated 5' x 7' shelter for housing recording equipment, (6) a pyranometer for total solar radiation, (7) a weather shelter for the hygrothermograph.

Station #10A is located in an open field shown in Figure 3, as seen facing NW. The terrain in this region is one of rolling hills, with forested land interspersed with open cultivated fields. Station #10A is located at the top of an open gentle slope for best exposure. The instrumentation visible in Figure 3 is the same as for #3 except that there is no visiometer at this site and the recorder shelter is not visible in the picture.

Figure 2. Equipment at station #3. From left to right are (1) an anemometer and wind vane on a 3-meter mast, (2) a post for the visiometer (not installed at time of photograph), (3) a recording precipitation gage, (4) a total hemispherical radiometer (slightly obscured by precipitation gage, (5) a shelter for the recording equipment, (6) a pyranometer, and (7) a standard weather shelter for the hygrothermograph.

Figure 3. Equipment at station 10A.

A few sites were established on a temporary basis to answer specific questions. Site #2, for example, was to be the closest possible site to the release point of the warm water. To fulfill this criterion, the site had to be along the coast opposite the warm water discharge. Because of space allocations in plant construction, however, no acceptable sites which could be maintained for 5 years were found. Rather than abandon one of the most important stations, a compromise was made. A recording raingage was located on top of the Visitor Information Center. It is the best site whose location could be guaranteed for 5 years, but it is adversely effected by the building. Another stand-by recording raingage was located in a proposed conference building area. This site has good exposure, but has the drawback that construction is to begin at that site within one year. By having two raingages close to each other, one with suitable exposure, a comparison can be made to determine the accuracy of the raingage data at the Visitor Information Center.

Station #10B was instrumented because a National Weather Service volunteer had been accumulating data at this location for many years. The station has the closest climatological records to the plant site. Because a recording raingage already existed at this site, a project raingage was not necessary, but one of the stand-by hygrothermographs was installed to check the accuracy of the observer's maximum-minimum temperature records and their comparability with the hygrothermograph data.

III. EQUIPMENT

Hygrothermograph

Temperature and relative humidity are measured with Belfort Instrument Company Model 5-594 hygrothermographs. The instrument measures these variables accurately and requires no electrical power. A unit is shown in Figure 4 . Both variables are recorded on a chart clasped to a cylinder which is rotated once per week by a spring-wound clock. One week of records of both variables per chart is obtained. Each horizontal scale division is 2F for temperature and 2 percent for relative humidity. Each curvilinear vertical time line is 2 hours.

Temperature sensor. The temperature sensing portion of the instrument used here is a Bourdon tube. It consists of a curved, chrome plated phosphor-bronze tube, completely filled with an organic liquid, which expands or contracts with changes in temperature. An increase in temperature causes the liquid to expand and bends the Bourdon tube, which moves a link and lever assembly. This in turn causes the upper pen in Figure 4 to move upward on the temperature section of the chart. A decrease in temperature causes a reverse action. Charts with a temperature range of +10 to +110F are used in summer and a range of -30 to +70F are used in winter. According to manufacturer's specifications, the accuracy of the Bourdon tube is ±1F between -20 and 110F.

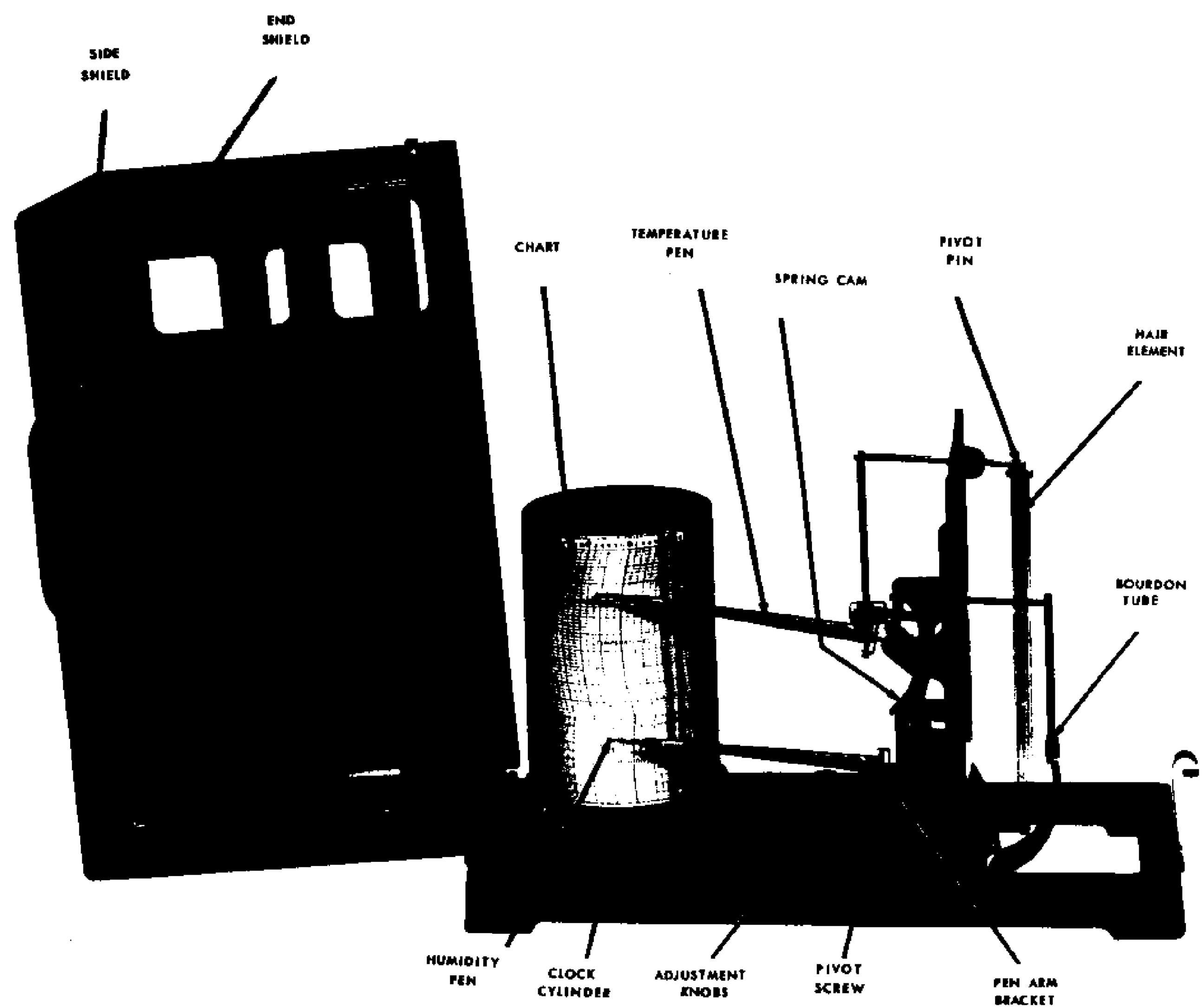

Figure 4. Belfort Instrument Company Model 5-594 Hygrothermograph.

Humidity sensor. The humidity sensing portion of the instrument is a banjo spread human hair element whose length changes with variations in relative humidity. An increase in relative humidity causes the hair element to lengthen, which moves a link and lever assembly. This in turn causes the lower pen in Figure 4 to move up scale on the relative humidity section of the chart. With a decrease in relative humidity, the length of hair shortens and the pen moves down scale. According to manufacturer's specifications, the accuracy of the humidity element is $\pm$3% RH between 20% and 95%, with a sensitivity of 1% at room temperature.

Case and shelter. The hygrothermograph mechanism is enclosed in a metal case that is open on three sides to allow free air flow to the sensors. It has a window for viewing the chart record. In field operation, each hygrothermograph is housed in a standard weather shelter located on a stand 5 feet above ground. The door of each shelter faces north to prevent solar radiation from striking the sensors when it is opened.

Calibration and installation. For several days prior to their installation in the field in February and March, 1973, the hygrothermographs were compared and calibrated in the Sarno Produce Stand, Covert, Michigan. The large (approximately 50 x 30 feet) enclosed unheated area comprising the building's interior served very well as a calibration chamber. On overcast days it responds very slowly to outdoor changes in temperature and relative humidity. In addition, spatial variations of these variables at one height in the portion of the building used for testing were minimal. On 5 February, 1973, for example, an overcast day with outdoor temperature of about 40F and a relative humidity of about 65%, the temperature inside the building was a steady 39F and the relative humidity remained near 69%. The range of temperatures and humidities over which the calibrations were performed was limited, but for the ranges experienced, the calibrations are considered to be quite reliable.

The calibration procedure was to allow the units to record side by side at the same height on a long table for at least two days during which temperatures and relative humidities were generally steady, but slightly different on each day. Periodic measurements of both variables were made with an Assman psychrometer drawing air from near the sensors. Adjustments were made when necessary so that the hygrothermograph readings finally conformed to the psychrometric measurements to within 1F and 1% relative humidity. They were then carefully transported in boxes and installed in the weather shelters at the various sites.

Seven units as part of an initial shipment were installed on 7 February at stations 1, 3, 6, 7, 10A, 11 and 12. Six units as part of a second shipment were installed on 14 March at stations 4, 5, 8, 9, 10B.

It is standard procedure for the observer to measure and log temperature and relative humidity at each station when he changes charts each week. These measurements supplement the recordings and, for steady conditions, give an indication of how well individual units are performing.

Precipitation gage. Precipitation in the form of either rain or snow is measured with a Universal type recording precipitation gage manufactured by Belfort Instrument Company. It is designed according to National Weather Service specifications and measures the rate of fall as well as the amount of precipitation. A unit is shown in Figure 5 .

The gage consists of a receiver opening exactly 8 inches in diameter through which precipitation is funneled into a bucket mounted on a weighing mechanism. The funnel is removed for wintertime measurements of snowfall. The weight of the precipitation collected in the bucket is transferred through a suitable lever system to a pen arm resting against a chart clasped to a cylinder driven by a spring-wound clock. Precipitation causes the pen arm to move up scale, with one vertical inch on the chart equal to one inch of precipitation. Charts measure 6 inches vertically for precipitation and 11.5 inches horizontally for time. If more than 6 inches of precipitation occurs, the pen begins a downward movement, so up to 12 inches of precipitation may be recorded by the dual traverse system. A chart drive giving one week of precipitation recording on one chart is used.

The accuracy of the precipitation gage is given by the manufacturer as ±1/2 of 1% (0.03 inches) in the first traverse (0 to 6 inches) and ±1% (0.06 inches) in the second traverse (6 to 12 inches.)

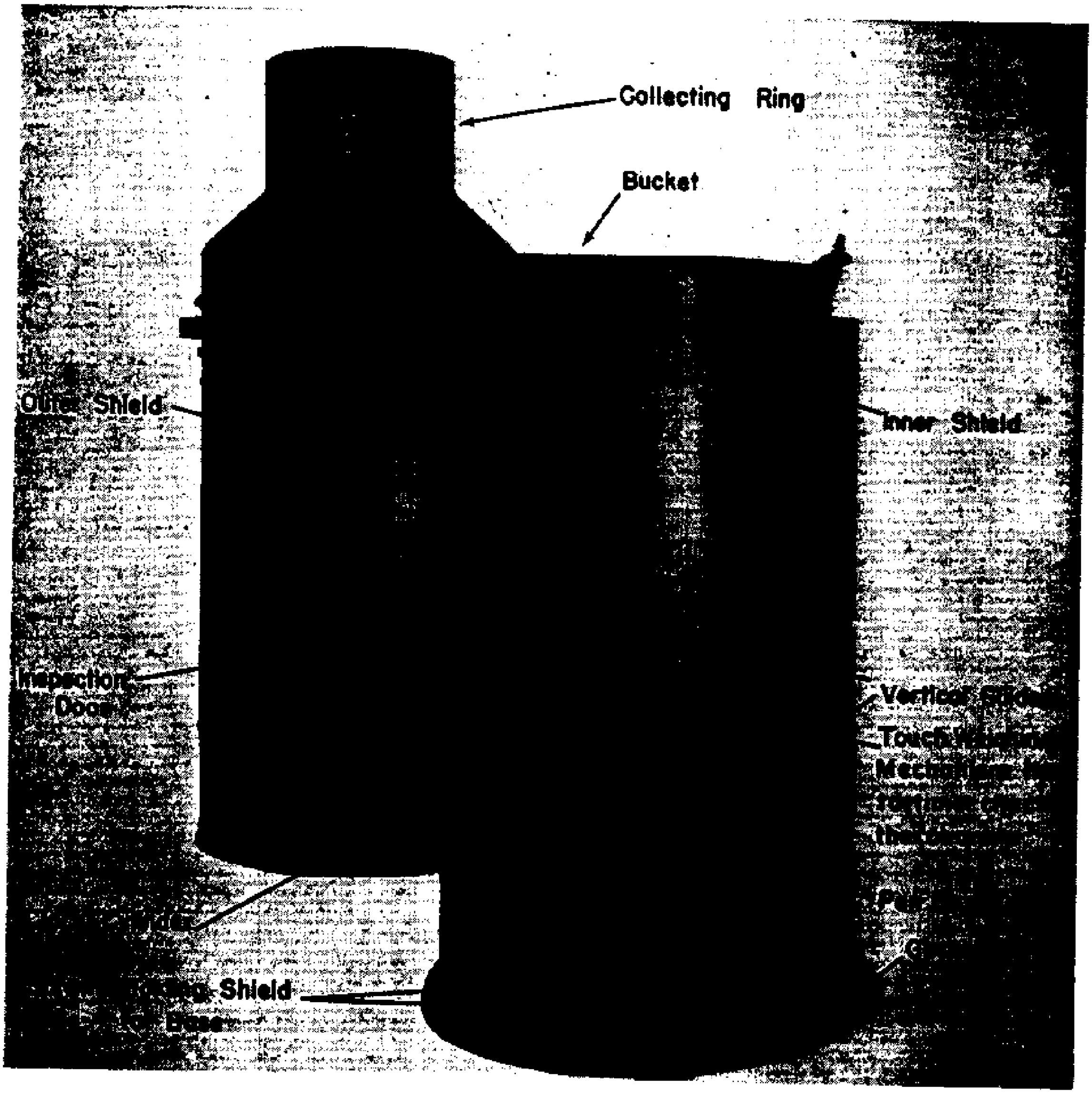

Figure 5. Belfort Instrument Company Recording Precipitation Gage.

Each gage is attached to an anchor base which in turn is bolted to the tops of 3 redwood 4 x 4's oriented corner to corner, reaching 3 feet into the ground, and protruding 10 inches above it. The top of each gage, then, is about 3.8 feet above the ground.

All precipitation gages were initially installed and calibrated by Mr. Stanley Baldwin, field technician from the National Weather Service office, East Lansing, Michigan. The initial calibration in August, 1972, was followed up by a second in December, 1972. In addition to semi-annual calibrations, a weekly check of each gage's accuracy is made by the observer by placing an iron bar whose weight is equivalent to 2 inches of precipitation across the top of the bucket and marking the pen's new temporary position on the chart.

For summer operation, a small quantity of oil is maintained on top of the water in the bucket. Evaporation, which was found to be a significant amount in a week, is practically eliminated by an oil film on top of the water.

In the winter time, the solution had to be kept unfrozen. Initially, a solution of ethylene glycol was used. It was found, however, that density stratification occurred which left water at the top which then froze. The problem was solved by the use of a self-mixing solution of 60% methyl alcohol and 40% ethylene glycol, which is self-mixing because the addition of water, snow, or ice at the top causes an increase in density (Mayo, 1972).

Still to be resolved in the precipitation recordings is a slowly varying, generally diurnal, apparent decrease in precipitation as great as 0.05 inches at times, followed by an increase of an equal amount. It occurs frequently, and at this time unaccountably, but there is some indication that it is due to external effects, mainly temperature, on the weighing mechanism. The manufacturer indicates that such behavior is normal.

A study is being made of the problem. A gage was recently brought to the University of Michigan for testing so that the behavior can be observed as it occurs, while external variables that might cause it are being measured. If the tests disclose the variables causing it and the relative importance of each, it may be possible to eliminate any bias in the precipitation recordings by means of regression analysis.

Visiometer

Principle of operation. The instruments used for measurements of visibility were a Meteorology Research Incorporated (MRI) Model 1580 Fog Visiometer with a MRI Model 450 strip chart recorder. The visiometer is designed to measure visibility in conditions of fog, haze, smoke, smog, precipitation, or high concentrations of dust.

Figure 6 shows a visiometer as installed in the field. It operates on the principle that light is scattered by water droplets or solid particles in the atmosphere. Using this principle, the instrument lets air pass freely between a photomultiplier tube directed at a fixed light trap approximately 20 inches away. The sampling volume is illuminated about once per second by a pulsed xenon lamp and the light scattered by particles or droplets in the sampling volume is detected by the photomultiplier tube. The voltage

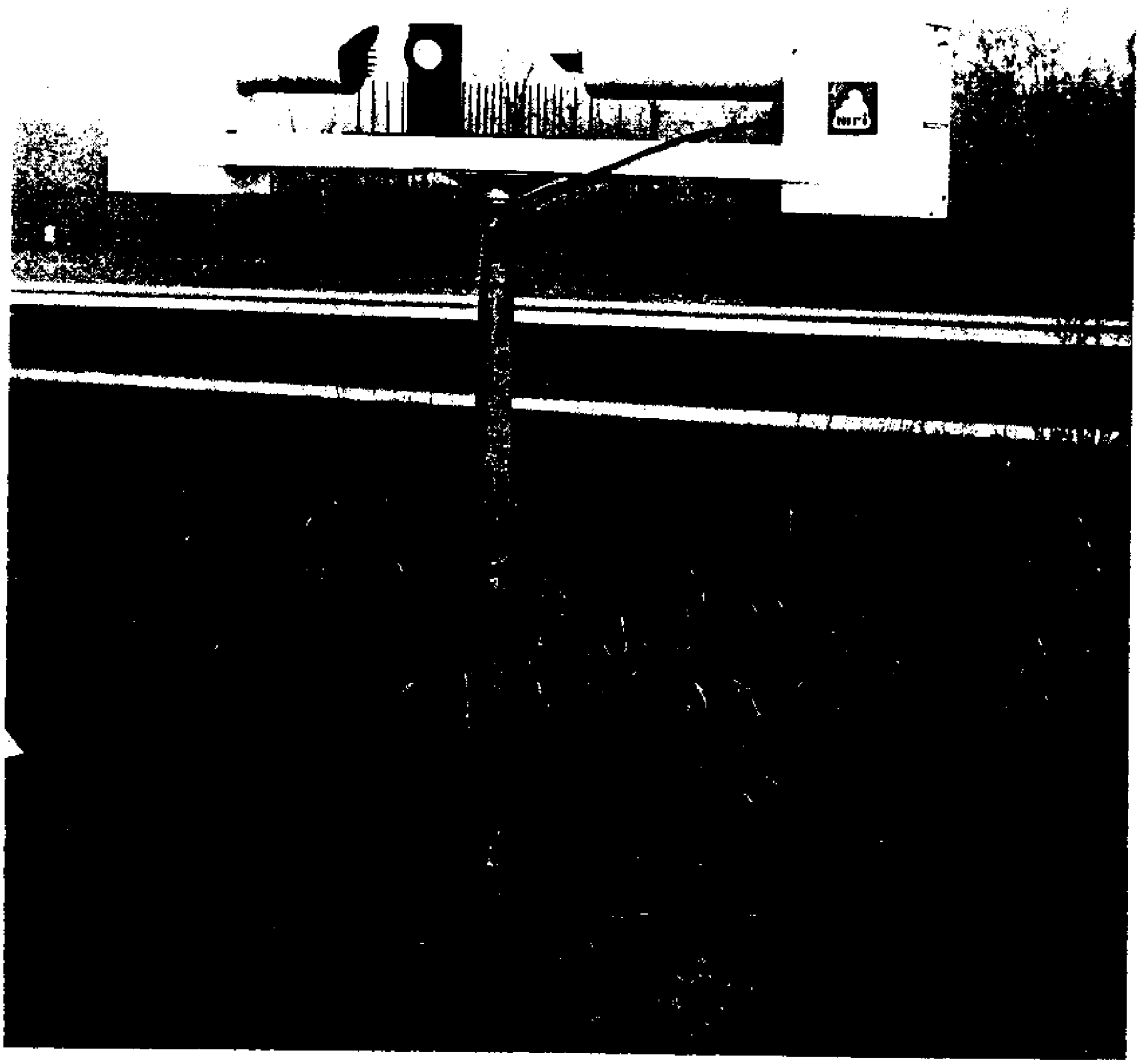

Figure 6. Meteorology Research Incorporated Model 1580 Visiometer.

output of the tube is proportional to the scattered light it receives, so the lower the visibility, the more scattered light is received by the tube, and the higher its voltage output. The voltage output is recorded on the strip chart recorder and is convertible to visibility according to tables provided by the manufacturer.

Installation. The visiometer was received at the University of Michigan in September and was allowed to record in an outdoor environment for about three weeks along with another visiometer purchased for a similar study at the Palisades Nuclear Plant. Satisfactory agreement among visibilities obtained from visiometer measurements, visual estimates by means of checkpoints, and measurements made by NWS equipment at nearby airports were obtained for conditions of moderate fog. Following the checkout period, the visiometer was installed at station #3, but failed to operate. The unit was then returned to the manufacturer for repair and upgrading while still under warranty.

Because of recurring failures, very few data have been obtained. The unit was recently repaired and is now operational.

Wind system

Each wind system consists of (1) a R. M. Young Co. Model 12101 3-cup anemometer, (2) a Weathermeasure Corp. Model 104 wind vane, (3) an Environmental Electronics Co. wind speed and direction translator, and (4) 2 Esterline-Angus Model 601C recorders; one for speed and one for direction. The sensors, located at the top of a 3-meter mast in the field are shown in Figure 7 . As described below, the system is durable and provides accurate measurements of wind velocity for speeds greater than about 1 mph. A semi-annual calibration of the sensors is planned. The translator-recorder system is checked weekly by the observer, who switches in calibration checkpoints from the translator onto the recorders.

Anemometer. The 3-cup anemometer has hemisphere-shaped cups formed of 0.01-inch thickness aluminum. It has a distance constant (63% recovery) of 8.9 feet and a threshold speed of approximately 1 mph. The rotation of the anemometer cups drives a miniature DC tachometer generator whose life expectancy is more than 750 million revolutions, which is about 3 to 4 years of normal operation.

Wind vane. The wind vane consists of a foam plastic air-foil shaped tail coated with epoxy and bonded to a stainless steel rod, altogether weighing 38 grams. A counterbalance located near the center of rotation permits maximum response to wind direction fluctuations with minimum overshoot. The vane has a damping ratio of 0.4 and a distance constant of about 3.5 feet. Within the wind vane transmitter is a dual-wiper low torque potentiometer which provides the capability of recording wind direction from 0 to 540 degrees and eliminates a direction gap, a serious deficiency of vanes with a single-wiper potentiometer. The accuracy of the vane is about ±3 degrees.

Translator. The purpose of a wind speed and direction translator is to adapt and condition the signals from the wind sensors

Figure 7. R. M. Young Anemometer and Weathermeasure Wind vane on 3-meter mast.

to the requirements of two current-measuring recorders, one for wind speed and one for direction. Commercially available translators were considered for use with the sensors described above, but their main disadvantage was that they lacked a low enough wind speed range to provide the resolution desired for most wind speeds experienced. In addition, electrical loading effects of the recorders on the sensors were not eliminated to the degree believed necessary for accurate wind recordings. The building of a translator was assigned, therefore, to Environmental Electronics Company, Ann Arbor, who had designed and built similar translators for a study sponsored by The Detroit Edison Company. The translator has the following features:

1) It has wind speed ranges of 0 - 25 and 0 - 50 and 0 - 100 mph and automatically switches from one range to the next,
2) It eliminates electrical loading effects of the recorders on the sensor by means of voltage-to-current amplifiers in both the wind speed and direction circuits, and
3) It has provisions for the observer to enter calibration checkpoints for wind speed ranges and various wind directions onto the recorder strip charts.

The general operating characteristics of the wind speed portion of the translator are briefly described below.

The automatic wind speed range selection and switching is accomplished by means of 2 voltage level detectors and a voltage-to-current amplifier. When the level detector for the 0 - 25 mph range senses a voltage corresponding to a wind speed equal to or greater than 25 mph, it causes a change in the gain of the voltage-to-current amplifier and a switch to the 50 mph range. Any range change is indicated by an event pen on the side of the recorder chart. If the wind speed then decreases to less than 25 mph a switch back to the 25 mph range is prohibited until the level detector senses a voltage equivalent to a speed of about 6 mph. Without this feature, a wind speed fluctuating between 22 and 28 mph, for example, would cause intermittent range switching and a subsequent difficulty in determining the correct wind speed. If the wind speed exceeds 25 mph and continues to increase, the 50 mph range is maintained until the second level detector senses a voltage corresponding to a wind speed equal to or greater than 50 mph. It then causes a gain change in the voltage-to-current amplifier and a switch to the 100 mph range which activates a second event pen. A switch back to the 50 mph range is prohibited until the wind speed decreases to about 15 mph.

Recorders. The recorders for wind speed and direction were Esterline-Angus Model 601C single channel with a 0-1 ma range. A pair of recorders, one for speed and one for direction were used with each system. The accuracy of this type of recorder is 1% of the full scale reading and its good response is indicated by the fact that the time required for it to respond to 99% of the final value of an input signal is 0.5 second. Each variable is recorded on 6-inch wide strip charts. A chart speed of 3 inches per hour is used which gives a 2-week record length for each chart roll.

Radiometers

Equipment consisting of a pyranometer and recorder for measuring total solar radiation and a total hemispherical radiometer and recorder for measuring total solar plus atmospheric radiation was installed.

Pyranometer. Direct and diffuse solar radiation on a horizontal surface are measured by a Weathermeasure Model R411 Pyranometer, a close-up of which is shown in Figure 8 . In a pyranometer, thermocouples are used to measure the difference in temperature between the concentric rings shown, one of which is coated with lamp black and absorbs radiation and the other is coated with magnesium oxide and reflects radiation. There are 50 platinum rhodium and gold paladism thermocouples in thermal contact (but electrically insulated) alternately with the blackened and the whitened rings. Differential heating of the rings produces a voltage from the thermocouples proportional to the amount of incident solar radiation. The pyranometers currently in use produce between about 7 and 11 millivolts per langley.*

A 4.4-inch diameter glass dome transmits radiative energy in the 0.3 to 2.6 micron band. The dome is hermetically sealed and purged with dry air to prevent condensation on the sensitive rings. A bull's eye level attached to the base permits easy leveling of the pyranometer.

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* A langley is equivalent to one gram-calorie per square centimeter

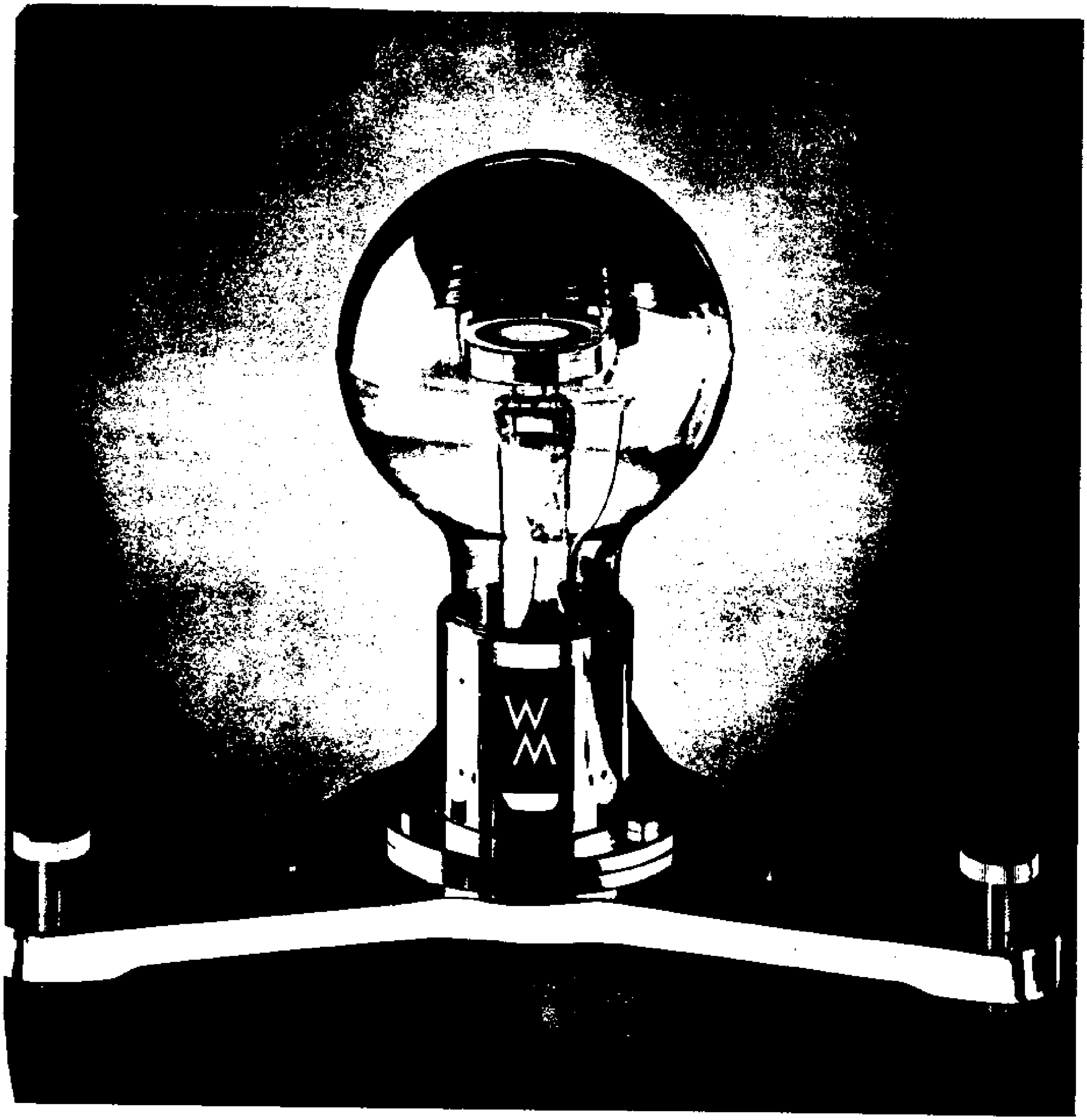


Figure 8. Weathermeasure Model R411 Pyranometer.

Total hemispheric radiometer. A Teledyne-Geotech Model TCH-188-D1 radiometer was used to measure incident radiation in both the visible and infra-red ranges. A unit is shown in Figure 9 . The flat-plate sensitive element of the radiometer contains a 720-junction silver constantan thermopile arranged so that its output is proportional to heat conducted perpendicularly through the plate. The receiving surface of the plate is coated with a special optical, matte black paint; the opposite surface is polished aluminum. The plate is mounted in a forced air stream supplied by an electric blower housed in the main support of the instrument. An aluminum radiating shield, one-half inch below the sensing element, is black on the upper surface and is polished on the lower one. An analysis of the energy balance of the sensing element shows that, given the calibration factor, the total incident thermal radiation can be determined from a measurement of the thermopile output and the temperature of the black receiving surface. To correct for temperature dependency of the thermopile and to measure radiation by the receiving surface of the plate, thermistors are also imbedded in the plate (MacKay, 1965). In this way, incident radiation can be measured directly.

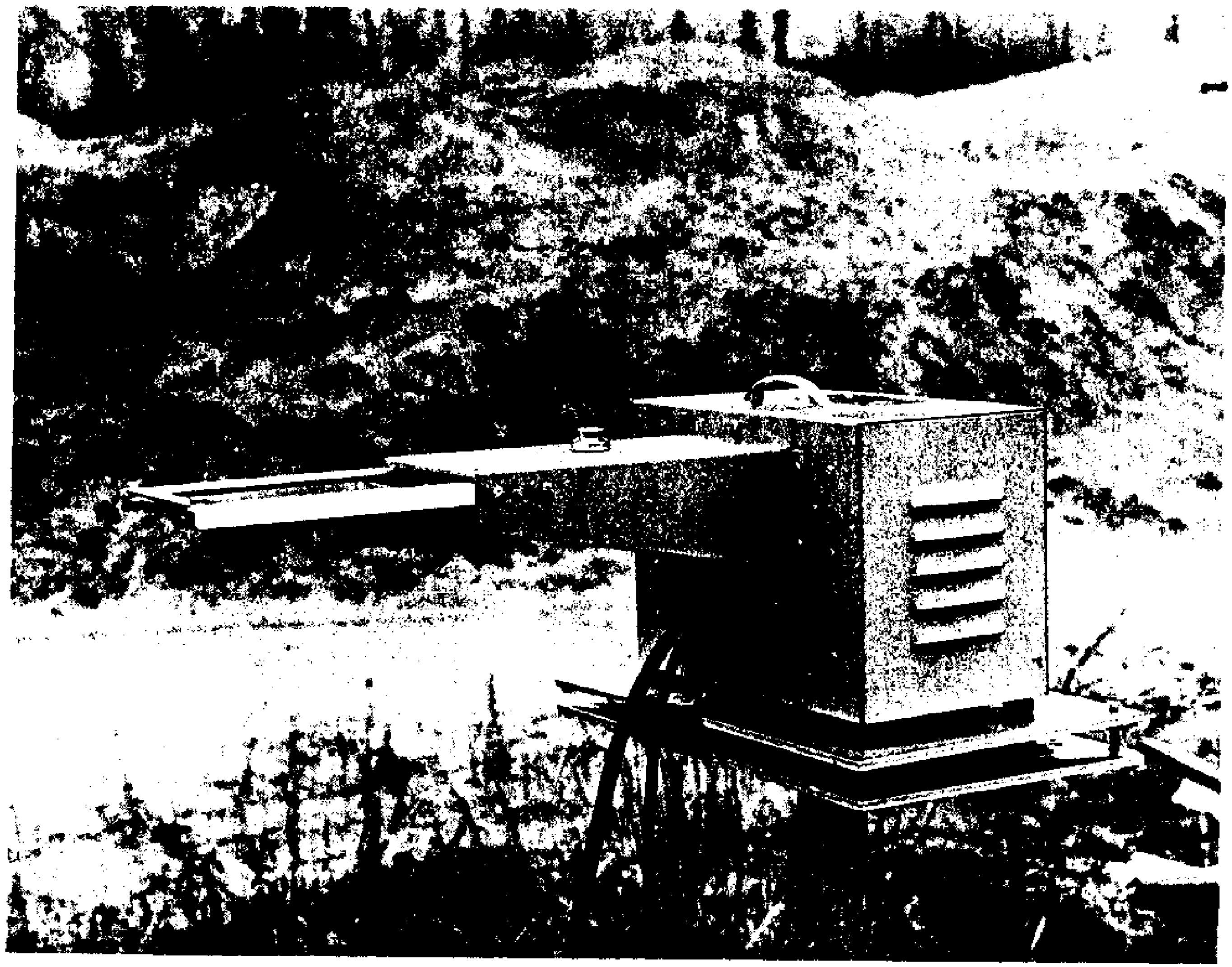


Figure 9. Teledyne-Geotech Model TCH-188-01 Total Hemispherical Radiometer.

A Leeds and Northrup Model potentiometer recorder was procured for use with each radiation sensor. The full scale span on each recorder is adjustable from 3 to 20 millivolts for two ranges: 1.5 to 5 and 3 to 10 millivolts per langley, so that it can accomodate radiation sensors having different output voltages per unit of radiative input.

The sensitivity of the measurements of total incident radiation is illustrated quite dramatically by a response to the formation or advection of low cloudiness over the sensor at night. Incoming long wave radiation on a clear night, for example, is usually steady at a value near about 0.4 langley/min. If low cloudiness forms, however, it increases abruptly to a value determined mainly by the temperature of the cloud base and the thickness and amount of cloudiness.

Calibration schedules

To maintain the accuracy of the equipment, periodic adjustments and calibrations are necessary, some of which were discussed above. In all cases, if any adjustments are made, a calibration is made both before and after the adjustments. Time checks are entered on recorder charts by the observer whenever possible.

Precipitation. Once per week, the observer places an iron bar, whose weight is exactly equivalent to that of 2" of precipitation, across the bucket of every gage. If it is malfunctioning, this procedure will detect it. In addition, every 6 months a technician from the National Weather Service calibrates the gages and resets them if necessary.

Temperature and relative humidity. When the charts are changed every week, the observer makes a simultaneous measurement with a psychrometer. These readings are later compared to actual recordings on the chart. Complete calibrations are conducted twice per year or as necessary.

Wind speed and direction. The wind translators have calibration circuits built into them. Every two weeks the observer calibrates the translator-recorder system by switching in calibration checkpoints. In addition, once per month a representative of Environmental Electronics Co. makes a complete calibration of the systems. For wind direction, calibration points of 0, 180, 360, and 540 degrees are used, and for wind speed, 0, 25 (low range), 25 (medium range), and 50 (medium range) miles per hour are used.

Visibility. Once per week the observer calibrates the system using the internal calibration of the visiometer. Once per month an electronic technician makes a calibration of the 5.0 volt recorder in one volt increments.

Radiation. Once per month an electronic technician calibrates the recording system. Calibration points are voltage equivalents of 0.0, 0.5, 1.0, 1.5, and 2.0 langleys per minute.

IV. DATA COLLECTION AND EVALUATION

The observer is responsible for forwarding all strip chart records on a weekly basis. When they are received, a preliminary evaluation is made of the quality of the data. Its purpose is to reveal missing or unreliable data which may be due to problems such as chart drive stoppages, power failures, or failure of the recorder pens. Statistics of these evaluations provide an overview of the total operation of the network.

A breakdown by station of the useable data for the period September, 1972 through March, 1973 is given in Appendix A. Table I summarizes these data by month and meteorological variable for the network as a whole. Listed is the percent of good data obtained to that which would be obtained if the network were completely operational. Some of the percentages are low because the sensor networks were still being installed during this period. In order to separate out the instrumentation performance, the percent of possible data for the installed instruments is given in parentheses for months where it differs from the percent for the whole network. For instance, in February for temperature there were 7 stations equipped during the month with hygrothermographs. The stations had 74% 76%, 74%, 74%, 77%, 75%, and 60% of the total possible data for the

TABLE I. Percent of total possible data

Month	Precip.	Temp.	Rel. Humid.	Solar Rad.	Total Incoming Rad.	Vis.	Wind Dir.	Wind Speed
# of stations	13	12	12	2	2	2	2	2
Sept., 1972	61	0	0	0	0	0	0	0
Oct., 1972	93	0	0	0	0	0	0	0
Nov., 1972	92	0	0	0	0	0	0	0
Dec., 1972	82	0	0	92(100)	0	0	0	0
Jan., 1973	91	0	0	98	80(98)	0	0	0
Feb., 1973	93	43(99)	42(99)	100	96	0	91(100)	88(98)
Mar., 1973	92	78(96)	79(97)	NA	NA	4(100)	70	64

NA - the complete month is not available yet.

whole month. Since the other 6 network stations had no data, the total percent of received data is $\frac{74 \times 3 + 74 + 77 + 75 + 60 + 6 \times 0}{13}$ = 43%. However, after installation, 5 of the hygrothermographs recorded 100% good data and the other two recorded 98%. Hence, the percent of data received from installed instruments was 99%.

For precipitation, over 90% of possible data was received for 6 of the 7 months. Most of the loss in September occurred in the first week of operation of the network. The major problem encountered was with clock drives not running for a full 7 days. For temperature and humidity, only February and March had significant amounts of good data. Even for these months, almost all of the lack of data resulted from an incomplete hygrothermograph network and not from instrumentation problems. The radiation networks have been operating satisfactorily. The amount of data received from the wind networks was quite low in March because the pens were not inking properly. This problem has been overcome.

V. DATA PROCESSING

The large quantity of data recorded requires that processing techniques be automated as much as possible. High speed computers can do the processing cheaply and accurately, but in order to use them, data recorded on strip charts in the field must first be converted to digital format. This conversion could be done by hand, but a more reliable and expeditious conversion can be obtained with electronic digitizing systems.

A survey of the available digitizers was made and the GRAF/PEN sonic digitizer, model GP-2, a product of Science Accessories Corporation was chosen. The GRAF/PEN measures the time it takes sound to travel from a spark on the pen shown in Figure 10 to two perpendicular linear microphone sensors. This time is then converted electronically to X and Y distances at increments of 0.01" and punched onto paper tape using a FACIT 4070 Tape Punch.

Various problems were encountered with the system when it was first purchased. Components had to be returned to the factory for repair or replacement. The system now operates satisfactorily. Several tests have been made, and a program of routine monitoring of the system has been developed. One of the tests showed, for example, that the system's performance was not affected by background noise around it.

The possibility that data may be inaccurately digitized was minimized by developing a method of checking digitized data against the original recording. Such a check is made in the following way. Once the data are digitized, they are loaded onto a disk file. From this file, a plot of the data is made on the CalComp plotter of the University of Michigan Computer Center at exactly the same scale as the original chart. The CalComp plot is then placed over the original strip chart, thus making any discrepancies between the original and digitized data easily discernible. Figure 11 is an illustration of such a comparison. If errors are found, a correction program is used to substitute the correct data on the disk file. Once the digital data are correct, the calibrations referred to

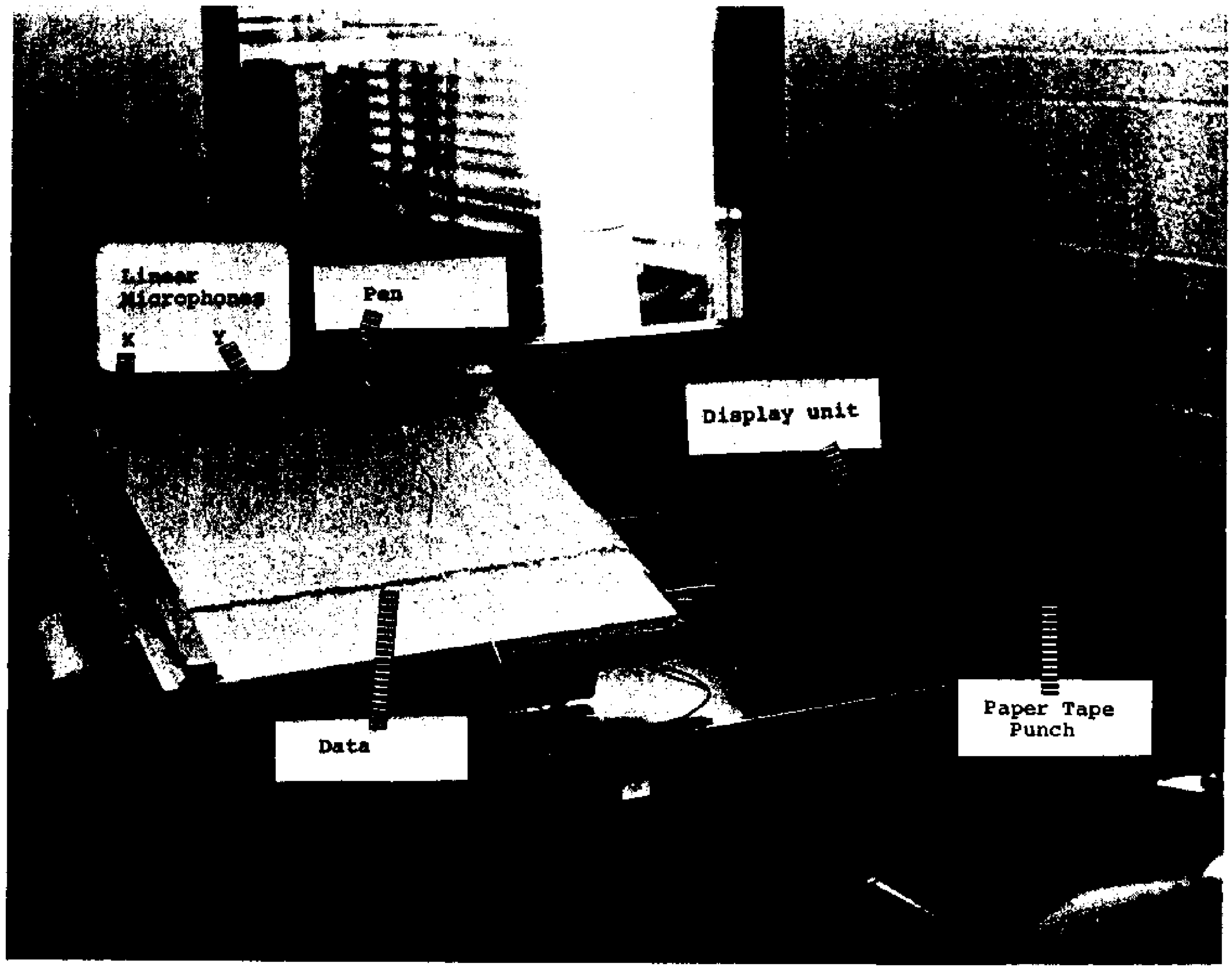
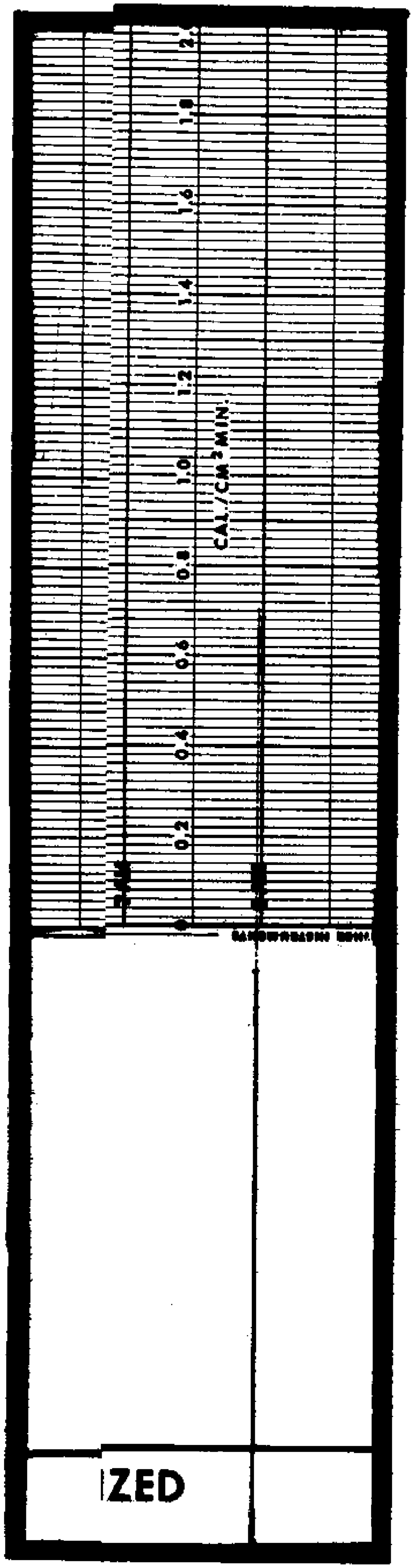


Figure 10. Graf/Pen Model GP-2 Sonic Digitizing System


CAL./CM² MIN.
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
ZED

above are used to convert the (x, y) data to time and magnitude of the variable. Each type of sensor record has its own special peculiarities, so conversion programs for each variable have been written. Once the data are converted, they are put onto magnetic tape for analysis and storage.

VI. FOG INVESTIGATIONS

The possible modification of natural fog is one of the most important aspects of the meteorological impact of the cooling system being investigated. A significant effort in the past year has been directed toward developing a numerical fog model which is designed to be general enough to consider moisture added to the air by the cooling system. It is planned to use field data from the network as initial data and input parameters in working with the model. As part of the work on this topic in the last year, a literature search was conducted to review and evaluate existing knowledge of fog and efforts to model fog numerically. A short summary of both is given below.

Classification

Fogs have been classified according to the meteorological process from which they result; a typical classification scheme is that of Willett, given in George (1950).

A. Air-mass fogs
   1. Advection types
      a. Types due to the transport of warm air over a cold surface
         (1) Land and sea-breeze fog
         (2) Sea fog
         (3) Tropical-air fog

b. Types due to the transport of cold air over a warm surface
   (1) Steam fogs
2. Radiation types
   a. Ground fog
   b. High-inversion fog
3. Advection-radiation fog
4. Upslope fog

B. Frontal fogs
   1. Pre-frontal (warm-front) fog
   2. Post-frontal (cold-front) fog
   3. Front-passage fog

Processes responsible for the formation and dissipation of fog are of two general types: (1) dynamic and thermodynamic processes which affect saturation of the air and (2) microphysical processes of droplet nucleation and growth. A complete model of fog formation must include both types of processes. The literature review to date has concentrated only on the modeling of the former processes.

Fleagle (1953) describes fog formation in relation to the effects of radiation above a black body surface. While valid as a theoretical treatment of long-wave radiative transfer near the earth's surface, Fleagle's work cannot stand as a theory of fog formation, since radiation alone does not produce fog.

More inclusive treatments of fog formation are provided by the numerical models of Fisher and Caplan (1963) and Zdunkowski and Nielsen (1969). These two models, while similar in principle, differ in their treatments of (1) thermal radiation; (2) liquid water content and (3) the behavior of the eddy diffusion coefficient. It is difficult to evaluate the effectiveness of the approximations made by these two studies because neither study was systematically tested against actual observations. Aspects of both models, however, are being incorporated into the model currently being developed.

VII. WORK PLANNED FOR NEXT YEAR

Work planned for the next year includes data collection, processing and analysis.

Data Collection

A schedule of weekly servicing and periodic calibration of all recording equipment established in the past year will be maintained. This includes at least a semi-annual calibration of hygrothermographs and precipitation gages, in addition to the weekly calibration checks made by the observer, and monthly calibrations of radiation and visiometer recorders. Wind tunnel calibrations of the wind sensors are also planned. Whatever action is necessary to increase the operational reliability of the visiometers will be taken.

Data Processing

Data received will continue to be digitized. The computer programs for processing the digitized data will be completed. At this time, the remaining tasks are to (1) develop programs for making final data checks, adjustments, and corrections; (2) devise error analysis routines; (3) establish formats for the final data tapes.

It is hoped that the study of the problem with precipitation recording gage discussed above will lead to the elimination of any bias which might exist in the precipitation recordings.

Data Analysis

Once the procedures for putting the data on magnetic tape are completed, attention will be given to an analysis of them. First priority will be given to climatological tabulations of precipitation, temperature, and relative humidity. Individual case studies will be made for various synoptic weather situations. Special attention will be given to synoptic weather situations which produced fog as well as those which could have been expected to but did not. The information will be used in the fog model being developed.

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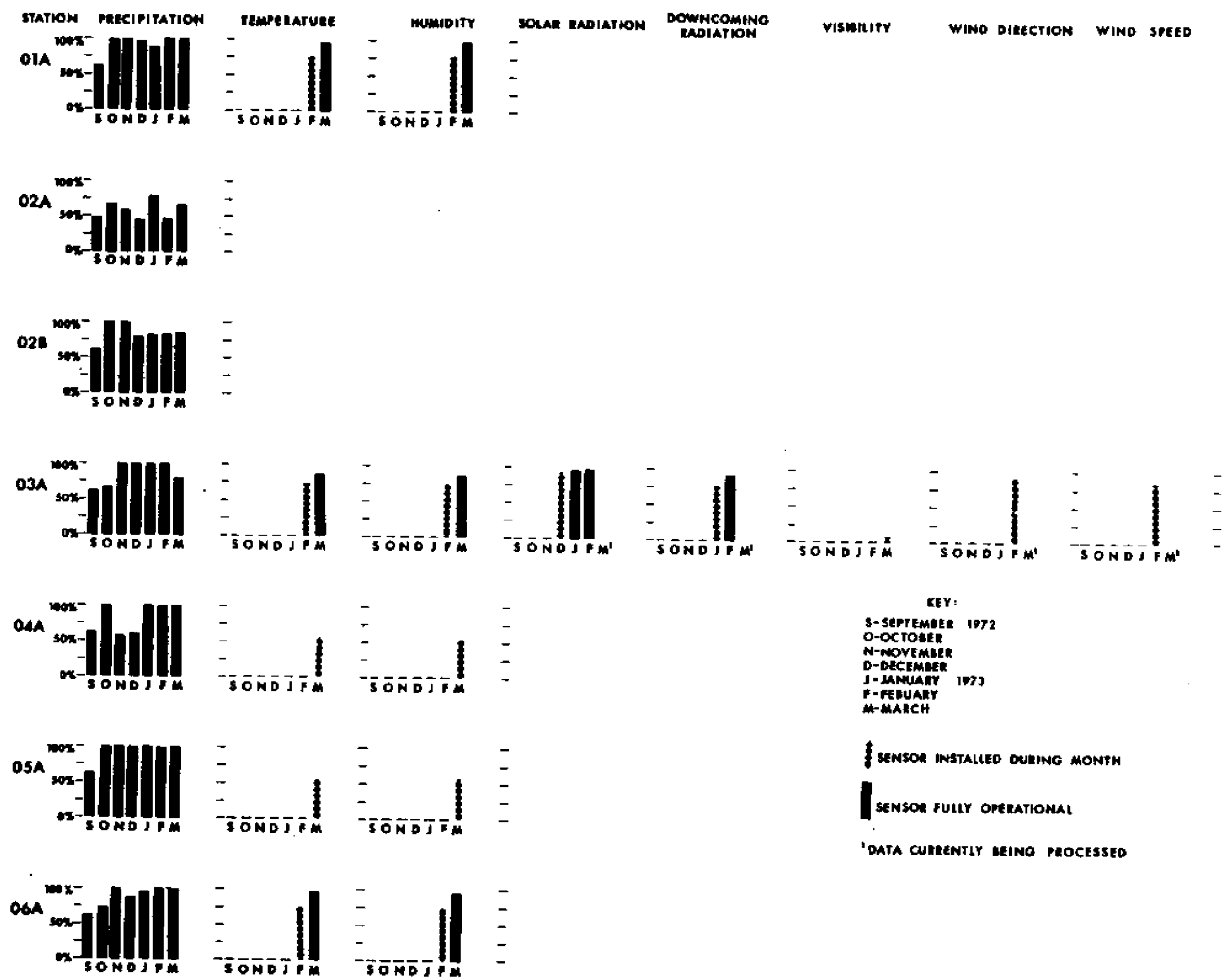
Appendix A

Cook Network

The accompanying graphs give the percent of possible data received from each station for each variable. The percent as shown is the number of hours of good data for a month divided by the total number of hours in that month multiplied by 100.

For the initial period of network operation, most of the loss of data is attributable to sensors and/or recorders not having been installed. If an instrument became operational during a month, a dotted line is shown on the graph after which a solid bar is used. Once a recorder is installed for a full calender month, any departure of a solid bar from 100% is caused by an equipment problem. The solid bars, therefore, give an indication of instrument performance.

APPENDIX A: PERCENT POSSIBLE DATA FROM COOK NETWORK BY STATION



APPENDIX A: PERCENT POSSIBLE DATA FROM COOK NETWORK BY STATION