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METEOROLOGICAL CHARACTERISTICS OVER THE GRASSLAND BIOME'S PAWNEE SITE

John R. Nunn

Plant Science Department

University of Wyoming

Laramie, Wyoming

GRASSLAND BIOME

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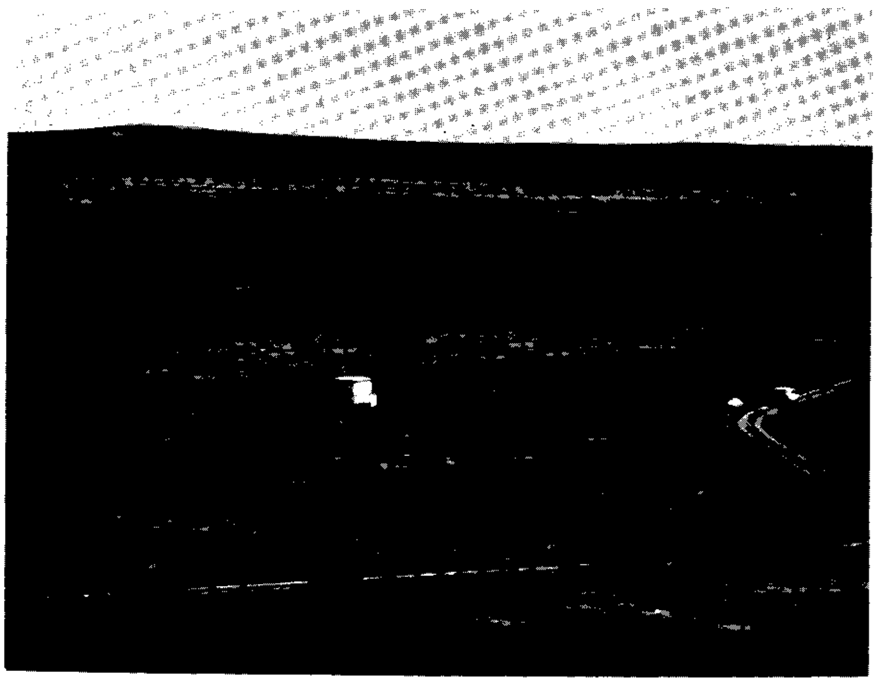

Frontispiece: Aerial view of grassland site with instrumentation system comparing upland and bottomland treatments.

ABSTRACT

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A data acquisition system was designed and constructed for securing meteorological data on a simultaneous and continuous basis at the Pawnee Site of the Grassland Biome. Meteorological transducers, system calibration procedures, and data reduction techniques are described.

Temperature, radiation, and wind speed characteristics for two grazing treatments are included. An informatic meteorological data availability chart was developed for 1970 and 1971.

A method for estimating net radiation from solar radiation by regression was developed. Evaporation rates from non-grazed and heavily grazed treatments were explained by plant phenology and canopy resistance.

ACKNOWLEDGMENTS

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INTRODUCTION

The biological world cannot be separated from the physical processes of the universe since the atmosphere is resting on the biosphere and organisms interact with their physical environment (Gates, 1962). An understanding of the microclimate is necessary in order to understand the biological processes within an ecosystem. Rogers, Qushu, and Kisiel (1970) attribute the lack of quantitative definitions of biotic-abiotic interactions to the failure of incomplete descriptions of available hydrologic models (Linsley and Crawford, 1966; Huggins and Monke, 1966; Claborn and Moore, 1970; and others). The Grassland Biome of the International Biological Program (IBP) is structured to analyze the fundamental relationships within the grassland system. In order to establish relationships such as net radiation to solar radiation and evapotranspiration to plant phenology, the design and evaluation of a continuous monitoring data system for abiotic variables used in vertical energy balance studies, as well as a compatible data reduction program, were necessary. Such information would include radiant energy and air and soil phenomena.

There were 50 to 60 abiotic and biotic Grassland Biome scientists who were potentially interested in utilizing environmental data; therefore, it was necessary to provide several types of transducers and a variety of data output formats. Planned interdisciplinary research at the Grassland Biome Intensive Site, Pawnee (in northeastern Colorado), required year-round monitoring of abiotic variables with a minimum amount of failures. The diverse data needs of participating scientists necessitated 1-min integrated averages of net radiation and monthly mean dry-bulb temperatures. Such variation in data collection suggested a need for rapid data collection and ease in processing the data into several formats.

This discussion, then, will include:

1. Considerations for data system design.
2. Development of a satisfactory recording unit.
3. Selection, calibration, and use of various sensing units.
4. Development of a data storage, retrieval, and analysis program.
5. Evaluation of the working unit after 2 years of continuous operation.
6. An analysis of abiotic and biotic data to characterize plant-water relationships on various grazing treatments.

CHAPTER I

DESIGN CRITERIA

Overview

Meteorological data acquisition systems for research work can be classified as one of two general types based on the way the data is secured and recorded: (i) frequent observations during short intervals of time or (ii) continuous observations for long intervals of time. Although the ultimate use of data may be different, automation for both would be advantageous. Automation presents the data in a form compatible with rapid machine computation with potential for reducing labor requirements and human errors.

Parameters recorded at meteorological, climatological, and agricultural stations vary from general observations of wind velocity, wind direction, and rainfall to radiation and low level vertical gradients of wind speed, vapor pressure, and air temperature. The diversity of transducers, resolutions required, and frequency of record dictate a need for flexibility, dependability, and accuracy in a data acquisition program.

Environmental data systems have been the subject of various researchers (Lettau and Davidson, 1957; Lemon, 1963; Tanner, 1963; van Bavel, Fritschen, and Reginata, 1963; Valli, 1966; Ferguson, 1966; Nunn, 1968). These systems have lacked the essential characteristics for long-term continuous operation.

Design Considerations

Analog and Physical Units of Output

It was decided to provide for an analog readout from the various transducers with appropriate tables for conversion to physical units. This would provide a means of checking to see if reasonable results were being secured in connection with checking, calibrating, and troubleshooting the total system. It is possible to construct the system so that output would be in physical units, but this would result in additional equipment such as voltage dividers and increased possibility of error.

Sampling Techniques

Observations from various sensors at predetermined intervals of time can be recorded serially by a common monitoring device (Moses and Kulhavek, 1963; Fritschen and van Bavel, 1963) and thus reduce the cost per data channel. The technique results in an uncommon data time frame which is unsatisfactory and restricts rapid measurements when biotic and abiotic interactions are to be developed in a limited sample time. Variability in meteorological parameters such as radiation under partly cloudy conditions and wind speed demands frequent sampling which will approximate integration; however, large amounts of data result.

The voltage-controlled oscillator (VCO) (Weeks, 1967) was chosen as an integrator for each meteorological parameter. It offers low drift characteristics and low cost, factors which are unavailable in commercially available integrators (Baker and Williams, 1966).

Sequential and Simultaneous Measurements

Rogers, Qushu, and Kisiel (1970) and Valli (1966) have shown that sequential sampling of meteorological parameters can be detrimental in both watershed modeling and in agricultural research due to the uncommon time base. Clayton and Merryman (1960), Allen (1970), Backlund and Perttu (1971), Fritschen and van Bavel (1963), and Reifsnyder (1962) have found frequent sequential sampling satisfactory, but voluminous data and increased costs resulted. The additional cost ($25) per data channel for simultaneous sampling was not prohibitive and was chosen as a desirable feature to include in the data system.

Recording

Field data can be secured on strip charts, typewritten charts, punch cards, punch paper tape, or magnetic tape, although punch paper tape or magnetic tape are preferred for automated data processing of climatological data. Gay (1971) has experienced difficulties in the field with paper tape recorders, and automated data processing centers have illustrated inadequacies in paper tape for processing and storage. As a result, computer compatible magnetic tape was chosen for field recording of all meteorological data.

Shielding and Grounding of Transducer Leads

Malmstadt, Enke, and Toren (1963) have demonstrated electromagnetic pickup from radio transmitters and 60-cycle/sec power lines, and ground loops are a common source of error as they can inundate the input signal and are often undetected. Twisted lead wires to eliminate voltage pickup on cables, separation of voltage inputs from the guard area (shielding) by guard area grounding, and low input grounding to earthen ground via a capacitor to prevent ground loops have been unsatisfactory and costly.

An isolated data system ground independent of earthen ground and paired input cables from each transducer to a differential voltage amplifier was chosen. This, coupled with the VCO integration technique, should provide noise-free data.

Synopsis

An environmental data acquisition system with flexibility, versatility, and accuracy was desired. Nonvoluminous data recording compatible with machine processing was necessary. Thus, the following design criteria were to be used in constructing the data system:

1. Digital display of analog units for each transducer.
2. Simultaneous, continuous, and integrated sampling.
3. An independent, isolated grounding system.
4. Magnetic tape recording.

CHAPTER II

RECORDING DATA SYSTEM

On the basis of the established criteria, a versatile, high resolution environmental data recorder was built by the Natural Resources Research Institute (NRRI), University of Wyoming, under the direction of Mr. Richard Weeks. Simultaneously measured analog data from 36 meteorological transducers, as well as month, day, hour, minute, and experiment number, are digitally recorded at 200 bits per inch (BPI) on ½-inch computer compatible magnetic tape for each 1-min interval. Thus analog curves for each meteorological parameter can be produced by a digital computer and graphic plotter. This modularly constructed system has a resolution of 0.1%.

Monitor, Control, and Display Features

There are two 40-position rotary switches with corresponding displays that can be used to interrogate individual data channels. A simple needle-type meter displays incoming analog signals, and a three-digit decimal display shows the corresponding recorded integrated value (Figure 1). These displays help locate malfunctioning transducers, integrators, and storage registers. Time coding and experiment number are also reviewed on the digital display.

Miniature thumb wheel switches and a momentary push-button switch are incorporated to control clock setting and to insert experiment

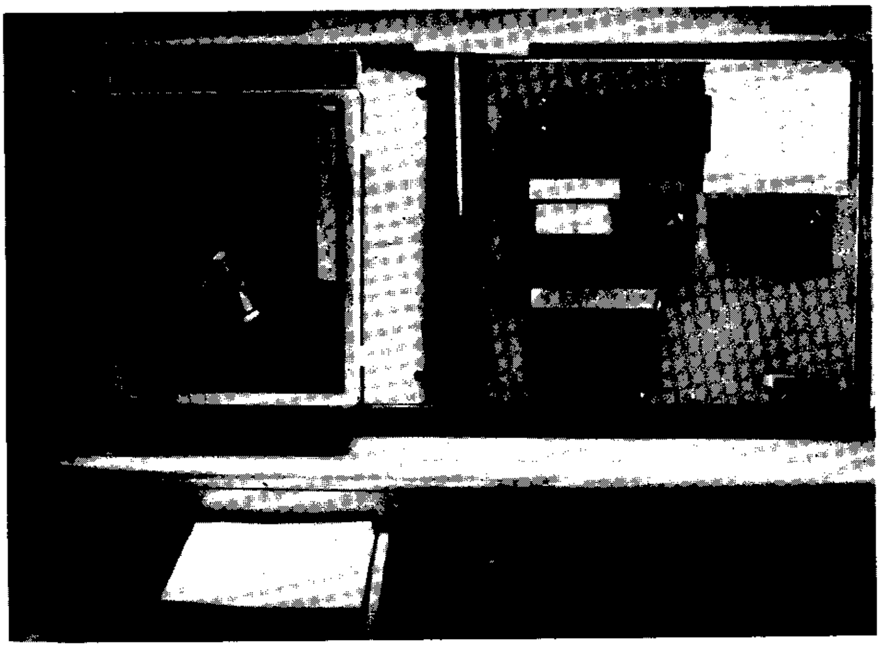


Figure 1. The analog and digital display and recording unit of the data acquisition system.

number and month and day into their respective channels. Time (hour and minute) is continuously displayed in digital form on the front panel. Parity error, loss of tension, or end of tape are malfunctions of the incremental recorder which are indicated by flashing lights. Switches and indicating lights for ±12-v power, an AC voltage meter, and a digital end-of-file counter are mounted on the display panel.

Recording Operation

This system is characteristic of a straightforward parallel recording system, i.e., each data channel is composed of an individual amplifier, integrator, and counter-storage circuit. Output from each transducer is amplified from an analog level (usually millivolts) to a standard 0- to 5-v level. For example, incoming solar radiation is calibrated to read 0 langleys/min for 0 mv of analog input and 2 langleys/min for 15 mv of analog input, thus the 0- and 15-mv signals are amplified to 0- and 5-v, respectively.

Output from 36 individual amplifiers are fed to their respective VCO's for voltage-to-frequency conversion. An output frequency (square wave) proportional to the input voltage is thus generated such that a VCO input voltage of 5 v will yield an output frequency of 1000 cycle/min. A counter-storage circuit counts the VCO output frequency and stores a value for each 1-min interval. Therefore, this measured analog to digital conversion value of the VCO output is the true integrated average of the transducer output over a 1-min period. The time required for a change in the VCO frequency is shorter than any anticipated rate of change for an environmental parameter.

The 1-min values are multiplexed from the storage circuits to the recorder where they are serially recorded in sequence on magnetic tape, during which time the counters are reset to zero and proceed to count. Upon completion of recording the record (36 data points and edition information), a 3/4-inch interrecord gap is generated on the tape.

Long-term stability of 0.1% of full scale for the amplifiers and VCO's results in a system resolution of approximately 0.1%.

Shelter

The recording system is housed in a temperature-controlled, 16-ft mobile camping-type trailer. Gold Star Mobile Homes of Loveland, Colorado, custom-built the shelter with a 7-ft ceiling instead of the usual 6 ft-4 inch height. Polyurethane (1 3/4-inch) is used to insulate the walls, floor, and ceiling in order to minimize heating and cooling requirements. Thermal pane windows are placed in the front and side walls to augment working conditions. Instrument storage closets and a workbench are provided (Figure 2).

There are eight individual 110-VAC electric circuits wired into the housing facility. The data system, heating unit, and workbench outlets require separate circuits to prevent excessive current loads on individual circuits. A 220-v outlet is provided inside the housing unit.

An Onan 2500-w generator is located beneath the workbench in a sound-dampened compartment. This power unit supplies the necessary energy to operate the data system when commercial power is not available. A Westinghouse reversible heat pump is used to control the

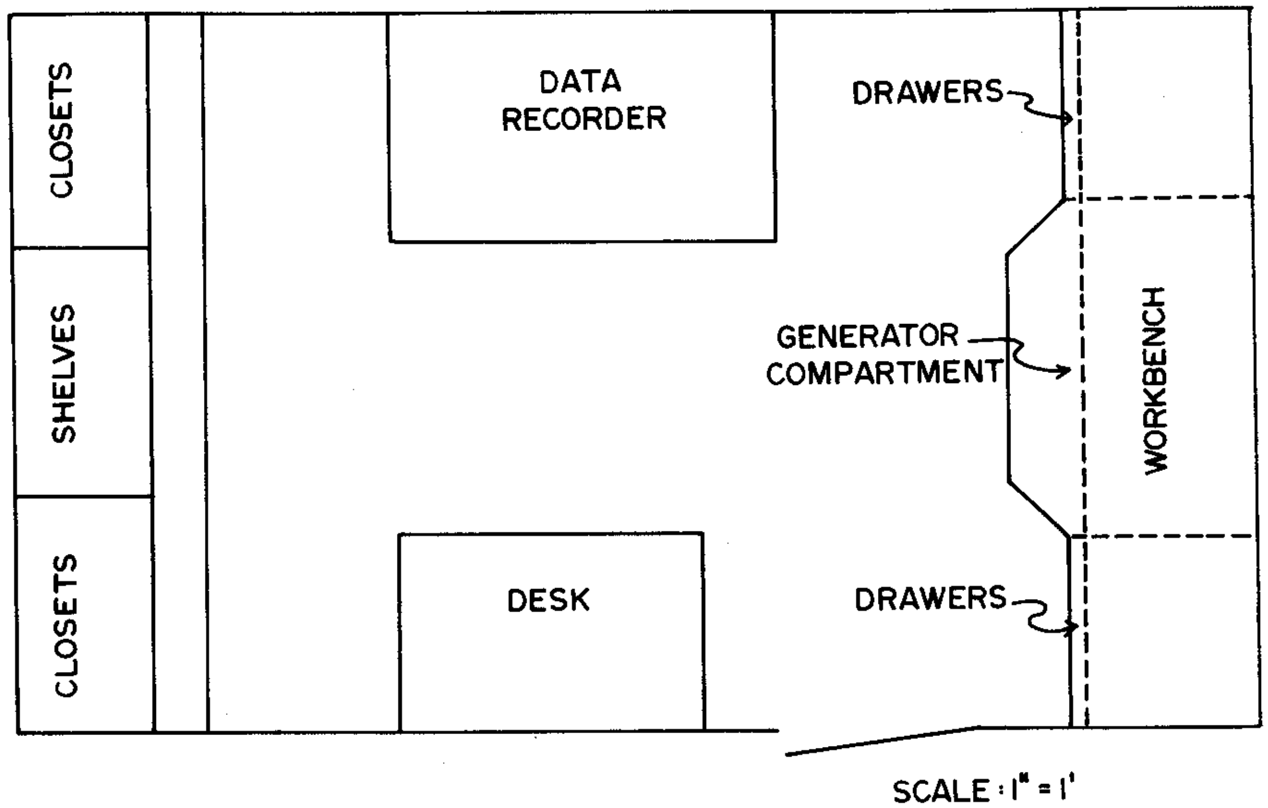


Figure 2. Floor plan of data acquisition system shelter.

temperature within the shelter. This unit supplies 2300 BTU's when heating and 2100 BTU's during cooling.

Interphase System

The interphasing between the recording shelter and the sensors must provide easy assembly and disassembly, flexibility for a variety of experiments, weatherproof connnectors with minimal thermal offsets, and high quality transmission characteristics.

There were four 500-ft multiconductor cables laid on the ground which carried transducer signals from the field to the recording shelter. Each multiconductor cable contains 19 individual conductors (no. 18 stranded copper wire) and is enclosed in a 3/4-inch plastic water pipe to limit damage from rodent gnawing, and livestock and human traffic. Figure 3 shows the multiconductor cables connected to a weatherproof junction box from which twisted and shielded pairs of no. 18-gauge copper wire run above ground to each sensor. Weatherproof Amphenol connectors link all instrument and multiconductor cables to the appropriate junction boxes and trailer wall. The above cable arrangement allows 18 transducer signals to be recorded from each plot (maximum of two and up to 1000 ft apart). The multiconductor cables and the individual sensor cables are hand-coiled for transporting.

Interphasing between the outside trailer wall, the inside wall, and the recorder consists of a master junction box and two 90-pin connectors. A series of terminal strips, arranged by plot within

Figure 3. Main junction box with weatherproof connectors.

the junction box, aids in manual monitoring and calibration of the recording system and meteorological transducers.

Sensor Stands

The transducer support system provides for a variety of configurations and yet resists livestock activities in grazing areas. All stands were constructed using 1-inch square tubing. Three guy lines made of 1/8-inch cable with center turnbuckles are used to hold the stand upright. Special platforms and connecting devices were fabricated to the stands to accommodate specific transducers. Base plates for each leg of the stands were utilized to prevent the stand from shifting laterally and from penetrating the ground surface.

CHAPTER III

SENSING DEVICES

Year-round meteorological data collection in northeastern Colorado requires transducers capable of withstanding extreme climatic conditions. Such a transducer should have a small response time, high sensitivity, and yield high quality data without a lagging network.

Radiation Devices

The selection of transducers for measurement of radiation was based on the need to measure the components of the basic radiation balance model suggested by Becker (1966), e.g.,

$$Rn = R_{si} - R_{so} + R_{Li} - R_{Lo}$$

where

Rn = net all-wave radiation

R_{si} = incoming shortwave radiation

R_{so} = outgoing shortwave radiation

R_{Li} = incoming long wave radiation

R_{Lo} = outgoing long wave radiation

A Beckman and Whitney radiometer (designed by Gier and Dunkle, 1951) is used for measurement of total net radiation (Figure 4). The sensing element consists of a thermopile embedded in a 115 mm × 115 mm Bakelite plate. Optical black paint on the upper and lower

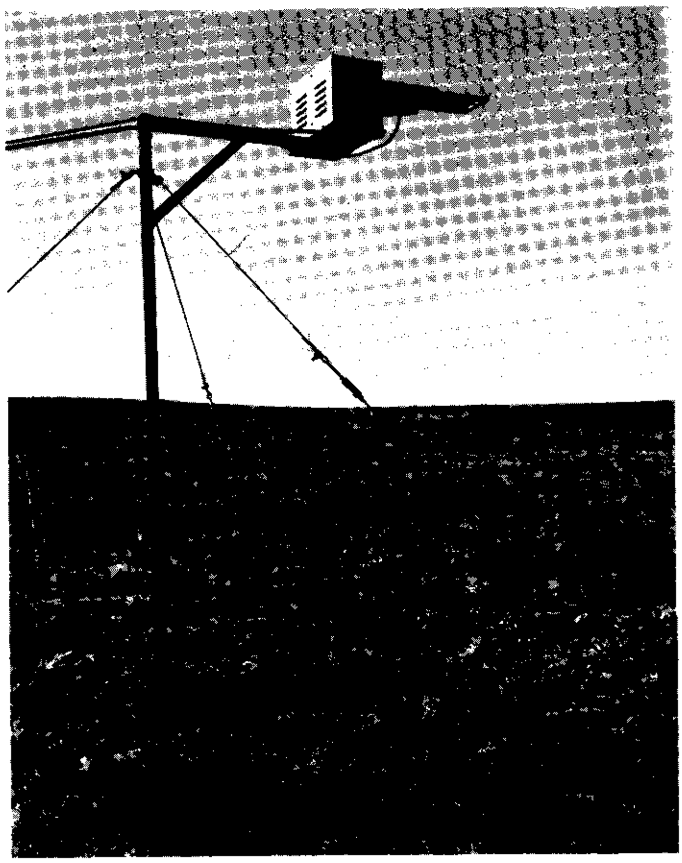


Figure 4. Net radiometer in place over a bottomland area of the Pawnee Site.

surfaces of the plate results in a sensor response relatively independent of radiation wavelength. A thermistor is embedded in the same plate and is connected to a compensating network which corrects for ambient temperature effects.

An interior mounted fan forces air across the upper and lower surfaces to eliminate localized heating. The millivolt output from the radiometer is converted directly to calories per square centimeter per minute by applying the appropriate instrument calibration constant. An accuracy of ±5% is claimed by the manufacturer of the net radiometer.

Total incoming shortwave radiation is measured with a 50-junction Eppley pyrheliometer. Figure 5 shows the standard U.S. Weather Bureau radiation device installed in the field. A flat disk with alternate pie-shaped sections and coated with magnesium oxide and Parson's optical black is hermetically sealed in a glass hemisphere to sense the radiation. The old style "bell-shaped" dome was replaced with this hemisphere due to gas deterioration within the dome. An output of 6 to 7 mv/langley/min with ±2% accuracy is reported.

A Kipp-Zohnen solarimeter manufactured in Holland was desirable for measurement of outgoing reflected shortwave radiation (Figure 6). Two concentric glass domes cover the sensing element to prevent undesirable thermal eddy currents within the dome when the transducer is in the inverted position. The output signal of 7 to 9 mv/langley/min is normal, and the transducer accuracy is comparable to the Eppley pyrheliometer.

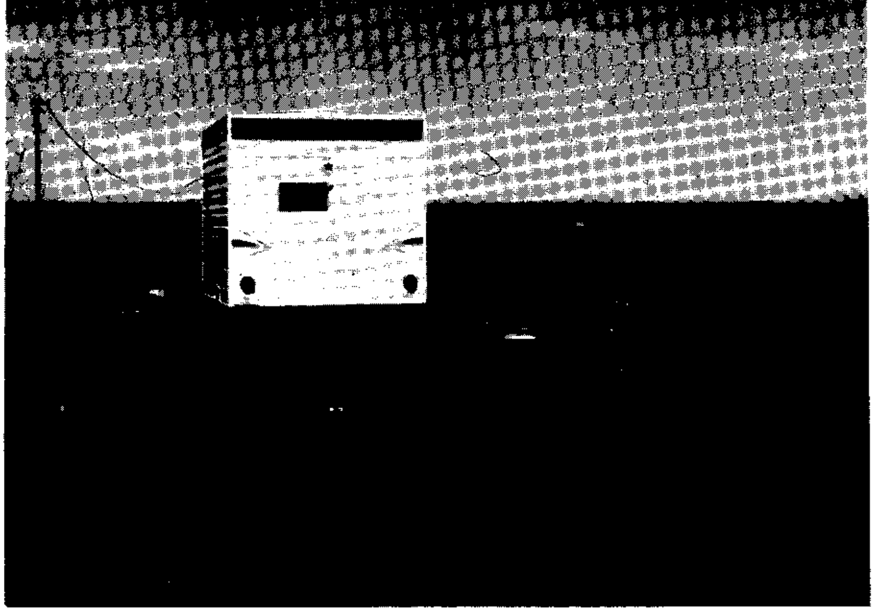


Figure 5. Eppley pyrheliometer in place for measurement of solar radiation.

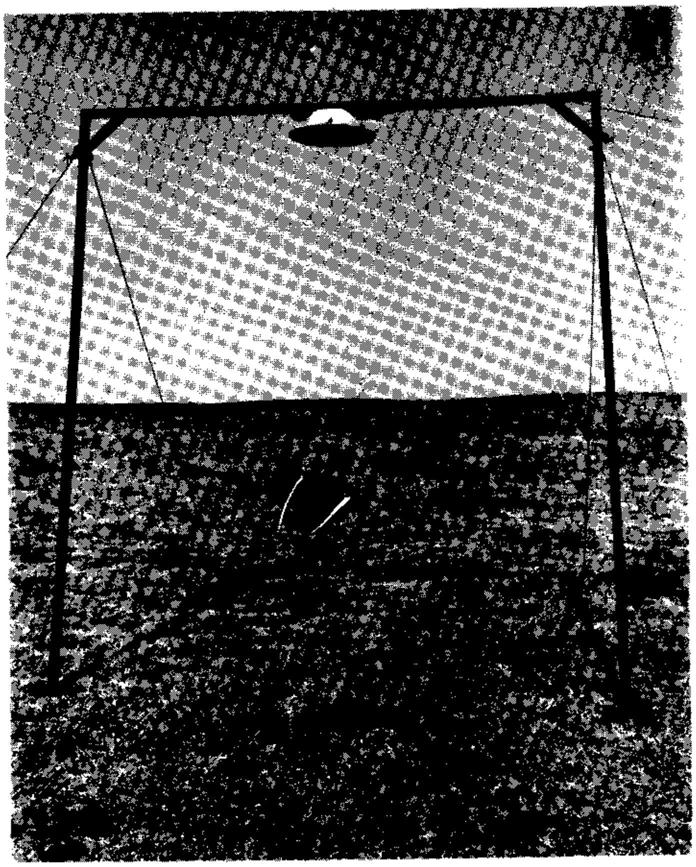


Figure 6. Kipp-Zohnen solarimeter used for measuring reflected shortwave radiation.

Measurement of incoming and outgoing long wave radiation is accomplished with a custom-made Eppley pyranometer. Transmittance characteristics of the hemisphere covering the sensing element are controlled by a special KRS-5 toxic hemispherical coating. This coating results in a distinct wavelength cutoff at 3.0 μ, thus allowing only radiation of wavelengths greater than 3.0 μ to be transmitted. Some 3 to 4 mv/langley/min are produced by the thermopile mounted in the Parson's optical black receiver. The manufacturer guarantees a ±5% accuracy.

Due to the sparse vegetative pattern of the prairie grass at the Pawnee Site, a 200-cm sampling height permits maximum sampling area and easy access to inverted solarimeters, inverted long wave pyranometers, and the net radiometers. Incoming long wave and shortwave radiation measurement devices are placed at 300 cm above the ground surface to allow for an unobstructed horizon.

Temperature Devices

A satisfactory transducer for general temperature measurements is the P-N junction. The RCA diode-type, IN3193, is linear to within 0.1°C over a -50° to a +50°C range. Other temperature characteristics of this diode have been the theses subjects of Archibald (1967) and Best (1969). A 100-μamp current through the diode results in a 0.5-v drop at 70°C and varies approximately 2 mv/°C change. A waterproof sealer is used to coat the individual diodes and a laboratory test verifies their linearity for amplifier calibration.

Four diodes for air temperature measurements at the 50-cm and 200-cm level are placed within aspirated radiation shields similar to those discussed by Tanner (1963). Under normal operation (Figure 7), all air temperature transducers are operated to sense ambient dry-bulb temperature; however, for wet-bulb temperature determinations two diodes (one at each level) are moistened by a cloth wick from a reservoir of distilled water.

Similar transducers are used for soil temperature measurements at depths concurred by World Meteorological Organization standards (2.5, 5.7, 10.2, 20.4, 50.8, 101.6, and 182.9 cm). Separate 3/8-inch diameter holes are punched into the ground surface for placement of the temperature sensors at the 2.5- and 5.7-cm depths. The remaining soil temperature transducers are installed at the appropriate depth in vertically drilled holes which are then refilled with dry, fine soil.

Air Humidity Determinations

The method used most for determining relative humidity involves the measurement of one wet-bulb temperature; however, dew point measurement with a Cambridge model 880 hygrometer is more desirable for year-round operation. This unit measures dew point by the Peltier effect, e.g., by thermoelectrically cooling a gold-plated mirror over which air is drawn until moisture condenses on the mirror. A photo cell notes a change in reflectance of the mirror as a result of the condensation and triggers a temperature measurement of the polished mirror. This temperature is, in fact, the dew point temperature. A

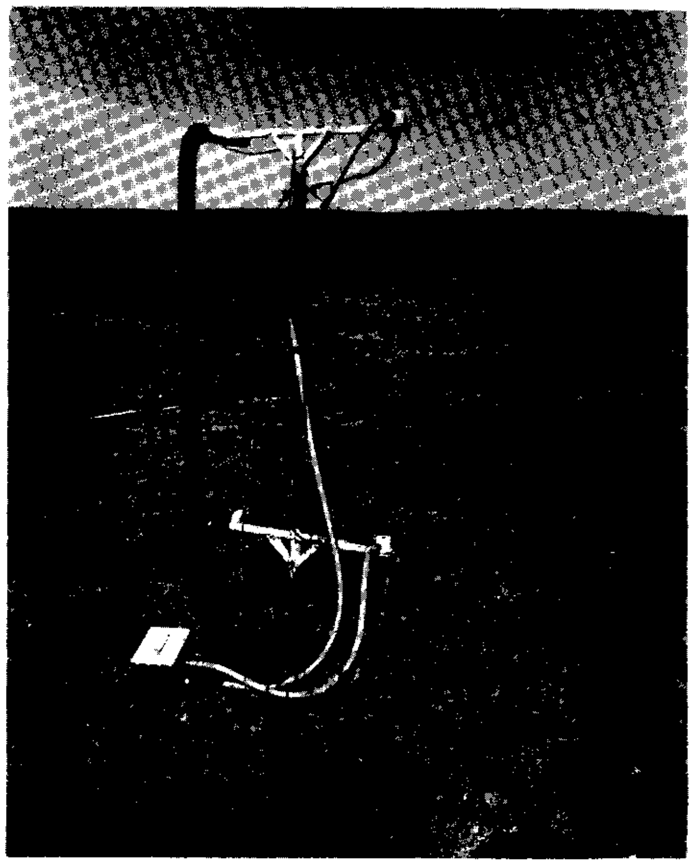


Figure 7. Cambridge hygrometers and electrical diodes for measuring dew point and air temperature at two levels.

0- to 50-mv output denotes dew point temperatures between -40° and +120°C at the 50- and 200-cm levels. Cambridge manufacturers note ±0.5°C accuracy.

Wind Speed and Direction

Air movement is generally measured with a cup-type anemometer from which the output is a voltage pulse or voltage level. A voltage generator-type anemometer manufactured by the Electric Speed Indicator Company was selected for measurement of wind speed at the 50- and 200-cm levels. A transducer output voltage between 0- and 5-v direct current represents a wind velocity from 0 to 100 mph. This transducer is noted for its ruggedness, dependability, and full-scale accuracy of ±1%. A similar potentiometric wind direction indicator designed by the same company is compatible with the data system.

Soil Heat Flux

Figure 8 shows a soil heat disk manufactured by National Instrument Laboratory for measurement of soil heat flux. The validity of this measurement is questionable due to the disturbance resulting from the placement of the transducer, as well as differences in thermal conductivities for the soil and disk. A relatively larger error can be accepted in measurement because soil heat flux is normally low compared with the other energy balance parameters (approximately 10% of the net radiation). The output from this disk is generally around 40 mv/langley/min.

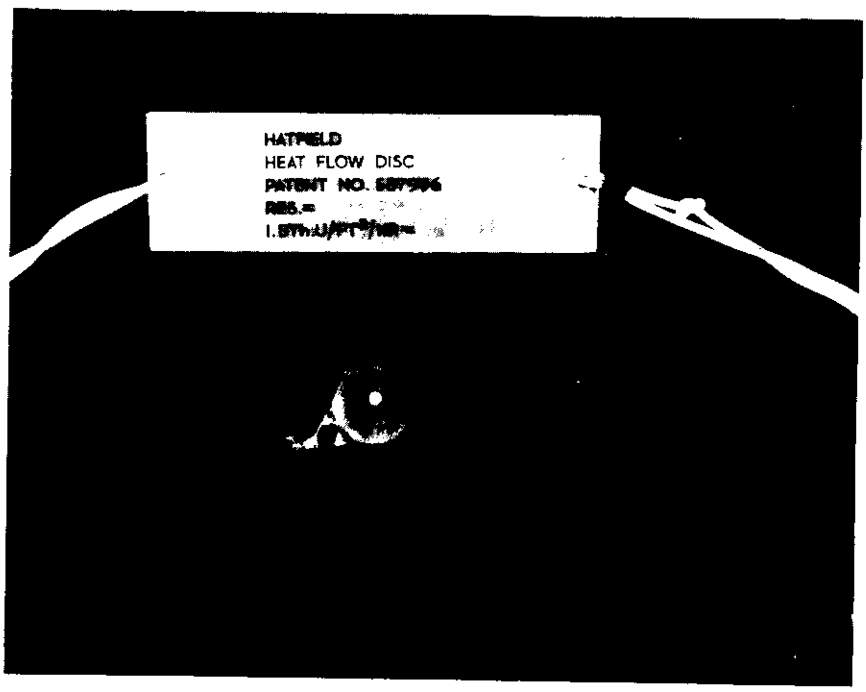


Figure 8. National Instrument Laboratory's heat disk for measuring soil heat flux.

Tanner (1963) suggests placement of the disk as close to the evaporative front of the soil as possible. Location of this front is difficult to determine in a dry climate and is expected to change with the season. A theoretical method for calculating soil heat flux may be advantageous, although to date this is not readily available.

CHAPTER IV

DATA REDUCTION SYSTEM

Continuous operation of multichannel data acquisition systems has generally been prohibitive due to the large time and labor requirements in reducing the data to usable form. The researcher has resorted to shortening his overall measurement period or has reduced his frequency of sampling environmental parameters. The following chapter describes a satisfactory data reduction and retrieving system capable of handling 21 million data points per year with a minimum of physical labor and time. The use of digital recording on computer compatible magnetic tape and automatic machine processing has resulted in this culmination.

Data Format

Field data are recorded on ½-inch, seven channel magnetic tape at a density of 200 BPI. Incremental recording of one data record (36 data points plus time and experiment code representing 1 min of sampling) is followed by a ½-inch interrecord gap. Each data point represented by a digital number between 0 and 1000 requires three physical frames on the tape in order to be properly recorded in a binary coded decimal (BCD) format (see Figure 9).

A physical frame on the tape is 1/200 inch in length and ½-inch wide. There are seven information channels passing through this frame

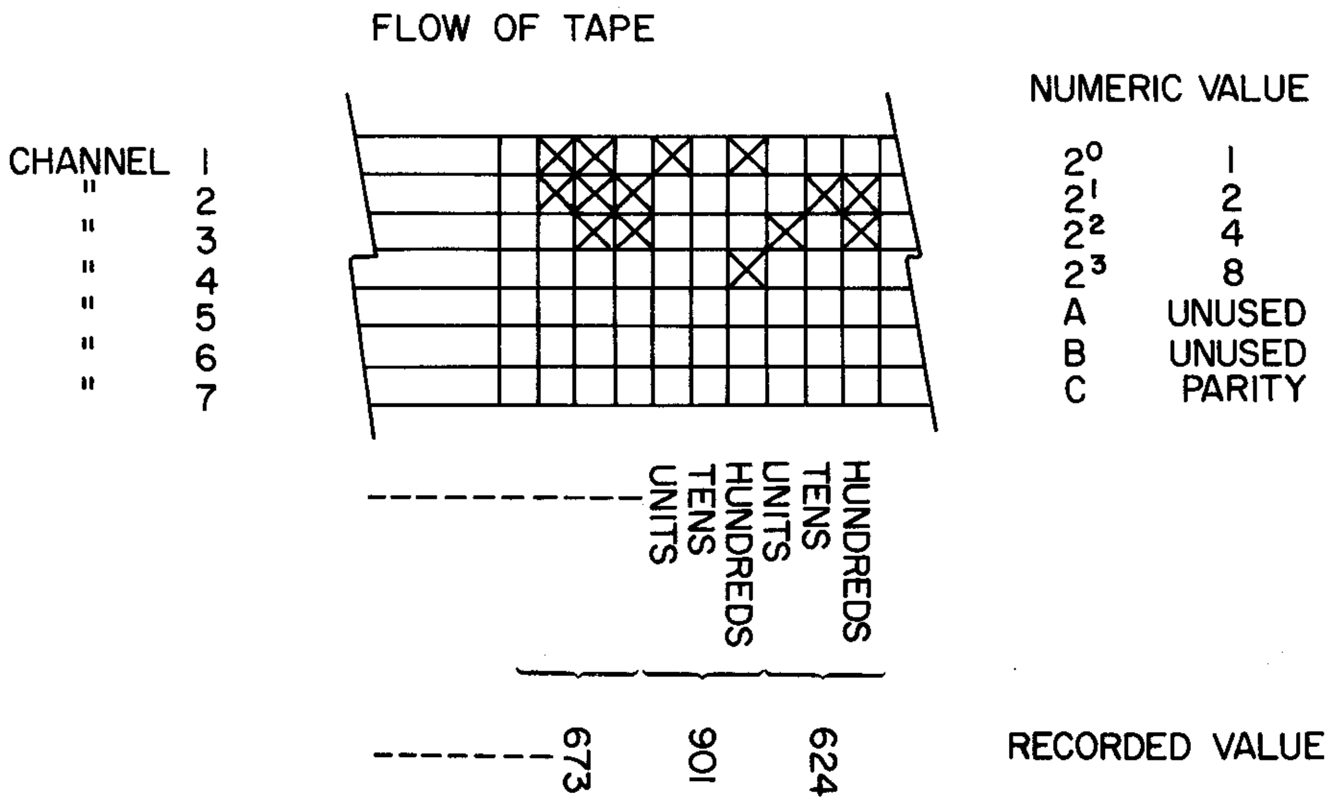


Figure 9. 200 BPI field tape format.

longitudinally as depicted in Figure 9. These channels are documented according to the standard BCD format. Channels 1, 2, 3, and 4 represent numerical values of 2^0, 2^1, 2^2, and 2^3, respectively. Channels A and B represent special events unused in this system, and channel C represents parity. The numerical channels within one frame can depict any decimal number between 0 and 9, depending on bit arrangement, and thus the requirement of three frames to record one data point ranging between 0 and 1000--one for the units portion of the number, one for the tens, and one for the hundreds. A combination of bits resulting in a decimal number greater than 9 is unacceptable to the format. One data record plus the interrecord gap occupies slightly more than 1 inch of magnetic tape.

End of file (EOF) marks are placed on the data tape at the end of a logical data file which is terminated manually because of recording, interphasing problems, or calibration needs. EOF's are automatically generated and placed on tape when the system power fails. An EOF counter on the front display panel records the number of EOF marks on each data tape.

Data tape reels (10½-inch diameter) are used to record the field data. The 2400-ft tape allows for 14 days of continuous data acquisition without replacement.

Development of Edited, Compacted, and Labeled Tapes

Meteorological data recorded with this system is further compacted on ½-inch magnetic tape at 800 BPI for use in the central data bank of the Grassland Biome. Keyed label tapes are developed for data analysis work within the Agricultural Engineering Division of the University of Wyoming. Complete listings of all programs are included in Appendix I.

Program "Compact 800"

A computer program entitled "Compact 800" was developed to read the 200 BPI field tape and write an edited and compacted 800 BPI tape. A commentary, similar to that shown in Figure 10, was written on each 800 BPI tape and contains the following information:

1. Location where data were secured.
2. Personnel responsible for data acquisition.
3. Starting and ending times of the compacted data.
4. Number of data files.
5. 200 BPI tape number from which the data were transferred.
6. A list of parameters measured, sensing elevations, and conversion constants for determining physical units.

During the read-write process, each numerical value is checked against the appropriate screening limit, and if the value is not within the specified limits a numeric value of 999 is written on the compacted 800 BPI tape and is interpreted as an invalid data point. This screening provision allows scientists unfamiliar with meteorology to use and interpret the data more readily.

Additional printed outputs from "Compact 800" aid in the general operation of the data acquisition system. These include:

1. Starting and ending times of each data file on the 200 BPI tapes.

```
TAPE 71 09 20
DATA GOOD
  TAPE CONTAINS 1 FILE STARTINF 09 20 71 AT 12:30
ENDING 09 28 71 AT 10:52
METEOROLOGICAL WEATHER STATION DATA TAPE (DENSITY 800 BPI)
MINUTEIY DATA RECORDINGS
RESPONSIBLE PARTY: J.R.NUNN & C.F.BECKER   UNIVERSITY OF WYOMING
    AG. ENGINEERING PO BOX 3354,UNIVERSITY WYOMING,LARAMIE WYOMING
PAWNEE SITE, NORTHWEST COLORADO
PROGRAMER: ALICE MC COLLOCH, UNIVERSITY OF WYOMING
.    LOW DENSITY TAPE 17A  71 20 09
     DATA GOOD
  TAPE CONTAINS 1 FILE STARTING 09 20 71 AT 12:30
          ENDING  AT 09 28 71 AT 10:52
CONTENTS OF THE 36 PARAMETERS ARE AS FOLLOWS:
 PLOTS: A = LIGHT GRAZED   B = HEAVY GRAZED   O = INDEPENDENT
```

METER NO.	PLOT	PARAMETER	LEVEL (CM)	ENGINEERING UNITS
1	A	AIR TEMPERATURE	200	DEG CENTIGRADE
2	B	AIR TEMPERATURE	200	DEG CENTIGRADE
3	A	AIR TEMPERATURE	50	DEG CENTIGRADE
4	B	AIR TEMPERATURE	50	DEG CENTIGRADE
5	A	SOIL TEMPERATURE	-122	DEG CENTIGRADE
6	B	SOIL TEMPERATURE	-122	DEG CENTIGRADE
7	A	SOIL TEMPERATURE	-51	DEG CENTIGRADE
8	B	SOIL TEMPERATURE	-51	DEG CENTIGRADE
9	A	SOIL TEMPERATURE	-20	DEG CENTIGRADE
10	B	SOIL TEMPERATURE	-20	DEG CENTIGRADE
11	A	SOIL TEMPERATURE	-10	DEG CENTIGRADE
12	B	SOIL TEMPERATURE	-10	DEG CENTIGRADE
13	A	SOIL TEMPERATURE	-6	DEG CENTIGRADE
14	B	SOIL TEMPERATURE	-6	DEG CENTIGRADE
15	A	SOIL TEMPERATURE	-3	DEG CENTIGRADE
16	B	SOIL TEMPERATURE	-3	DEG CENTIGRADE
17	A	LYSIMETER	0	MILLIMETERS
18	A	BAROMETRIC PRES.	300	MILLLIBARS
19	A	WIND SPEED	50	CM/SEC
20	B	WIND SPEED	50	CM/SEC
21	A	DEW POINT	200	DEG CENTIGRADE
22	B	DEW POINT	200	DEG CENTIGRADE
23	A	DEW POINT	50	DEG CENTIGRADE
24	B	DEW POINT	50	DEG CENTIGRADE
25	A	NET RADIATION	200	GM-CAL/CM2/MIN
26	B	NET RADIATION	200	GM-CAL/CM2/MIN
27	A	LONG WAVE RADIATION	200	GM-CAL/CM2/MIN
28	B	LONG WAVE RADIATION	200	GM-CAL/CM2/MIN
29	O	LONG WAVE RADIATION	300	GM-CAL/CM2/MIN
30	A	REFLECTED SHORT WAVE	200	GM-CAL/CM2/MIN
31	B	REFLECTED SHORT WAVE	200	GM-CAL/CM2/MIN
32	O	TOTAL INCOMING SOLAR	300	GM-CAL/CM2/MIN
33	A	WIND DIRECTION	200	DEGREE AZIMUTH
34	B	WIND DIRECTION	200	DEGREE AZIMUTH
35	A	WIND SPEED	200	CM/SEC
36	B	WIND SPEED	100	CM/SEC

```
DATA SCREENED: DISREGARD ALL DATA CHANNELS INWHICH A NUMERIC DECIMAL
               VALUE OF 999 APPEARS:
$
```

Figure 10. Commentary furnished with each 800 BPI compacted tape.

2. Number of bad records within each file and a binary printout of such records.

3. Number of files written on the 800 BPI tape.

The order of cards for utilizing "Compact 800" is shown in Table 1. The job card is a standard job card for running the Sigma 7 computer. The LIMIT card is used to limit the time in which the program is allowed to run and the number of pages of printed output. Both features are safety precautions against endless loops. The input and output tapes are designated by the ASSIGN cards. ASSIGN F:2 assigns the 200 BPI tape from which the data is being transferred. The proper 200 BPI tape number is punched in columns 31 to 34. Similarly, ASSIGN F:1 is used to note the 800 BPI tape onto which the data is being written. Columns 44 to 47 are used for the 800 BPI tape number. The balance of information on the ASSIGN cards remains unchanged.

The screening limits (a number between 0 and 999) which screen field data on the 200 BPI tapes are punched on cards by the hour. The minimum and maximum values within which the valid data points must range require two data cards (72 columns) per data channel. For hour 1, the minimum value is punched in columns 1 through 3 and the maximum value is punched in columns 4 through 6. Hour 2 is done in the same format, only in columns 7 through 12; screening limits for the remaining hours are punched accordingly (card one contains hours 1 through 12, card two contains hours 13 through 24). The resulting 72 data cards are placed in order beginning with channel 1 (hours 1 through 12)

Table 1. Card order for the "Compact 800" program.

```
JOB

LIMIT(TIME20), (LO,20)

ASSIGN F:1, (DEVICE,7T), (OUTSN,3090), (UNPACK), (BIN), (OUTIN)

ASSIGN F:2, (DEVICE,7T), (INSN,3064), (BIN), (UNPACK), (TRIES,0)

Main Program Deck

Screening Limits

  Data

Commentary

$
02      Number of files on 200 BPI tape
01      Number of files on 800 BPI tape
```

and ending with channel 36 (hours 13 through 24). A blank data card denotes the end of the screening limits.

Commentary information is arranged as shown in Figure 10 and can be of any length; however, the last card must contain a particular sign ($) in column 1. Columns 1 and 2 of the last two data cards contain the number of files on the 200 BPI tape and the number of files already written on the 800 BPI tape, respectively. In order to make the first transfer to an 800 BPI tape, a zero must be typed in column 2 of the second data card.

Program "Compact 556"

A labeled tape of a density of 556 BPI is made from the 200 BPI field tapes by utilizing "Compact 556." This keyed tape contains screened data and expedites routine data analysis and processing because of its labeled format. Each label consists of a key containing six digits representing month, day, and hour. For example, the key "060312" equals the sixth month, the third day, and the twelfth hour. Therefore, all available data for each hour of each day is contained under a label (key) in a BCD format.

Cards for the program "Compact 556" are arranged as shown in Table 2. The JOB card, the two ASSIGN cards, and the screening limit cards are utilized and arranged exactly as those in "Compact 800." The above cards are followed by one data card of the following format: (i) columns 1 through 5, number of files on the 200 BPI input tape; (ii) columns 6 through 15, the last key written on the labeled tape from subsequent transfers (000000 is used for the first transfer); and (iii) columns 16 through 25, the 556 BPI output tape number.

Table 2. Card order for the "Compact 556" program.

JOB

ASSIGN F:1, (DEVICE,7T), (OUTSN,3090), (UNPACK), (BIN), (OUTIN)

ASSIGN F:2, (DEVICE,7T), (INSN,3064), (BIN), (UNPACK), (TRIES,0)

Program Deck

Screening Limits

2	Number of files on 200 BPI input tape
121212	Last key written
3076	Tape number

Program "List Keys"

Table 3 illustrates the card arrangement for this program. The JOB card and ASSIGN card are similar to those previously mentioned, and the data card contains the INSN tape number in columns 1 through 4. "List Keys" prints all labels from the INSN tape for usage in controlling data analysis programs.

Program "Average 556"

Numerical averages for time intervals ranging from 1 min to 24 hr are computed from meteorological data on labeled tapes with this program. The number of intervals over which averages are computed is limited to 100 for each starting and ending key on the data tape. For example, if hourly averages are desired from June 3 at 12:00 noon to June 15 at 12:00 noon, three sets of starting and ending keys would be required--060312 to 060712, 060713 to 061112, and 061212 to 061512. The number of sets of keys is unlimited provided all keys are on the same 556 BPI labeled tape. The appropriate conversion constants for each meteorological parameter must be included in the program deck. The card arrangement for this program is shown in Table 4.

Program "D-Plot"

"D-Plot" is capable of plotting average values for various time intervals from a 556 BPI labeled tape by utilizing keys. Any combination of two parameters can be plotted on a single graph; however, the number of plotted points (average values for time intervals of 1 min to 24 hr) for a given channel is limited to 100. A typical plot of hourly averages of solar and net radiation is shown in Figure 11.

Table 3. Card order for the "List Keys" program.

JOB

ASSIGN F:1, (DEVICE,7T), (LABEL,MCC), (INSN,3075), (KEYED), (SEQUEN),
(IN)

Deck

RUN

3075

Table 4. Card order for the "Average 556" program.

JOB

ASSIGN F:1, (DEVICE,7T), (LABEL,MCC), (INSN,3076), (KEYED), (SEQUEN),
(IN)

Deck

Comments

$

3076

2	60				
10	20	16	10	20	18
10	21	06	10	21	18

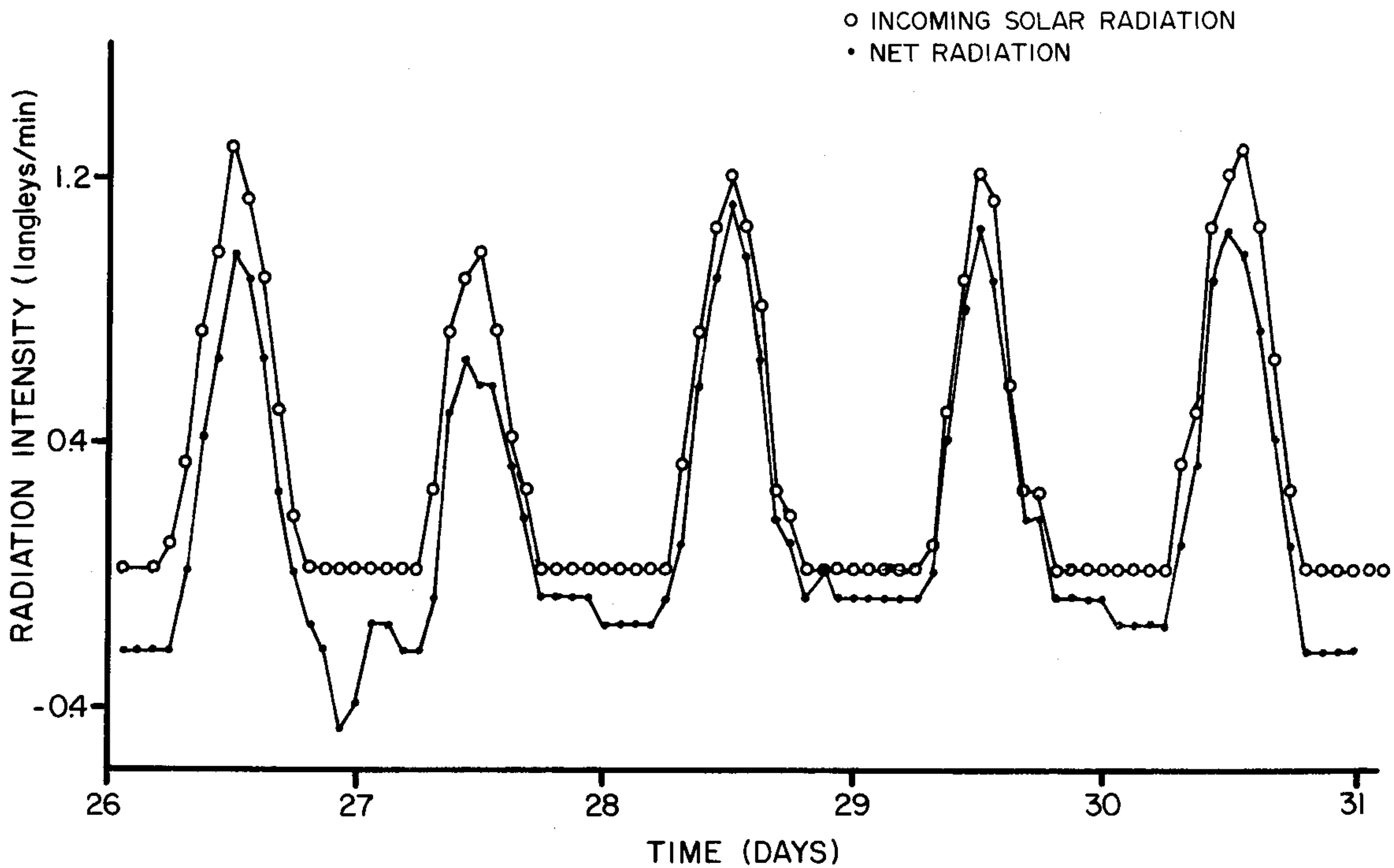


Figure 11. Plot of incoming solar radiation and net radiation, August 1972.

Starting and ending keys, as well as minimum and maximum limits for the ordinate for each plot, are included on data cards.

The first data card following the comments section of "D-Plot" (Table 5) contains the INSN tape number in columns 1 through 4. The starting and ending keys and time interval for each plotted point are contained on the second data card in columns 1 through 10, 11 through 20, and 21 through 25. The third and subsequent data cards contain the channels to be plotted and the ordinate limits for each plot. Any number of plots can be produced for a given interval by adding data cards. The program is terminated by two blank cards.

Table 5. Card order for the "D-Plot" program.

```
JOB
ASSIGN F:1, (DEVICE,7T), (LABEL,MCCOLLOCH), (INSN,3075), (KEYED),
  (SEQUEN), (IN)
Deck
Any number of comment cards explaining individual plots
$
3076
   102006    102018    15
   1    2        00           100
   3    4        00           100
   5    6        00           100
Blank card
Blank card
```

CHAPTER V

DATA SYSTEM CALIBRATION

A complete calibration of the data system consists of calibration of the recording system and the individual transducers.

Recording System

Calibration of the recording system involves calibrating one VCO and one amplifier per channel of analog data. VCO calibration is accomplished by removing the amplifier card from the channel to be calibrated, substituting an extender card for the amplifier, connecting a precision voltage source to the output pin of the amplifier, and connecting the ground terminal of the precision voltage source to the extender card. This procedure is necessary because of offset voltages between the amplifier chassis and the VCO chassis which are due to ground currents in the ground bus bars. Secondly, a precision voltage source is set to .0500 v, and the VCO frequency trim potentiometer is adjusted until the digital indicators on the control panel read 100 ± 2. Thirdly, the precision voltage source is set at 4.500 v, and the high frequency potentiometer on the VCO is adjusted until the indicators read 900 ± 2. Steps two and three are repeated until the indicators yield 100 and 900, respectively.

A procedure is established for the calibration of the amplifiers of individual transducers. Because the amplifiers are linear devices, the point-slope method of calibration is used. Calibration consists of disconnecting the transducers and connecting a precision voltage source to the input pin of the amplifier. The voltage source is set to correspond with the lowest voltage output of the associated transducer, at which time the appropriate potentiometer is set to give an output voltage equal to 0.000 ± 0.005 v. Then the voltage source is set at a voltage which is nearly equal to the highest (Table 6) expected from the transducer, and the amplifier slope potentiometer is adjusted to give an output value of 5.000 ± .0050 v. The two steps are repeated until the end points remain at 0.000 and 5.000 v, respectively.

Transducers

Calibration constants for all meteorological transducers are verified twice each year. The resulting constants are entered directly into the data reduction programs and do not influence calibration of the recording system per se.

Temperature Sensors

The P-N junction used for all temperature measurements is calibrated to examine the response characteristics of the transducer (Table 7). The diodes are placed within a plexiglass container which is, in turn, placed within a refrigerated oven capable of producing temperatures between -10° and +50°C. A voltage reading is taken from each diode at each of seven temperatures (-10, 0, 10, 20, 30, 40, and

Table 6. Transducer voltages for amplifier calibration.

Sensor Type	Parameter	Transducer Voltage	
		Minimum	Maximum
Beckman and Whitney Radiometer	Net radiation	-.002	.003
Eppley Pyrheliometer	Total incoming short-wave radiation	0	.015
Kipp-Zohnen Solarimeter	Outgoing reflected shortwave radiation	0	.010
Eppley Pyranometer	Incoming and outgoing long wave radiation	0	.003
National Instrument Laboratory Disk	Soil heat flux	-.010	.010
Cambridge model 880 Hygrometer	Dew point	0	.050
Electric Speed Indicator Anemometer	Wind velocity and direction	0	5
Electric Diode IN3193	Air and soil temperature	See Table 7	

Table 7. Temperature-voltage relationships for individual temperature transducers.

Diode No.	Voltage at +50°C (v)	Voltage at -50°C (v)	Midpoint	
			Temp (°C)	Voltage (v)
4-6	.4014	.6596	18.5	.483
83	.3958	.6493	18.5	.476
101	.3986	.6525	18.5	.479
56	.3942	.6508	18.5	.475
60	.3776	.6317	18.5	.457
128	.3946	.6531	23.8	.462
139	.4008	.6607	23.8	.468
129	.4009	.6585	23.8	.469
124	.4165	.6759	23.8	.486
22	.4087	.6793	23.8	.483
133	.3954	.6571	18.5	.478
105	.3904	.6556	23.8	.460
115	.4103	.6692	23.8	.477
66	.3843	.6511	23.8	.454
81	.3932	.6489	18.5	.474
138	.4119	.6657	18.5	.492

50°C) with a precision voltmeter. The data secured are used to determine the coefficient regressing voltage and temperature (Appendix II). This coefficient is the slope of the temperature response curve of the diode and is utilized to adjust the temperature amplifier. A precision thermometer is utilized in the field to point-adjust the temperature of each diode while in its respective sensing media.

Radiation Sensors

The radiation sensors are calibrated in the field on clear days during a period of uniform radiation exchange, normally when the solar angle is high. The Eppley pyranometer, used for routine daily solar energy measurements, is compared against a temperature-compensated pyranometer, "Super Eppley," to verify its calibration constant to a precision of .01 langleys/min. The Kipp-Zohnen solarimeter used for measurement of reflected shortwave radiation is calibrated by orienting the transducer to the upright position and comparing the output to that of the "Super Eppley" (model no. 2).

A shading technique is required for calibration of the net radiometers. The net radiometers and the temperature-compensated pyranometer are shaded simultaneously until both sensors have reached equilibrium. At this time, output readings are taken from both transducers. The shades are then removed and the sensors are allowed to again come to equilibrium. A second set of output readings are then obtained. The amount of energy shaded from each transducer is assumed to be equal, thus allowing the new calibration constant to be calculated from the expression

$$\frac{\Delta E_{NET}}{K_{NET}} = \frac{\Delta E_E}{K_E}$$

where

ΔE_{NET} = difference due to shading in millivolts output readings from net radiometer

K_{NET} = calculated net radiometer calibration constant in millivolts per langley per minute

ΔE_E = difference due to shading in millivolts output readings from the pyranometer

K_E = calibration constant of pyranometer in millivolts per langley per minute.

Simultaneous readings from a Barnes infrared thermometer and the long wave transducers are utilized to check the calibration constant of the long wave radiation sensors.

Dew Point Sensors

The dew point sensor used to determine humidity at the 50- and 200-cm levels is furnished with a calibration noted to be valid for an indefinite period of time due to the principle of operation used. However, periodic comparisons are conducted against an aspirated wet-bulb psychrometer or sling psychrometer.

Air Movement Sensors

Wind velocity and wind direction transducers are compared against a known standard for verification of their calibration to .96 m/sec or are compared against each other at a common height.

Soil Heat Flux

To date, calibration of soil heat flux disks has not been worked out. The inherent accuracy of the disk is felt to be satisfactory when considering the amplitude of soil heat flow.

CHAPTER VI

FIELD OPERATION

Continuous operation of the data acquisition system during 1970, 1971, and 1972 resulted in several electrical and operational difficulties that necessitated additional displays of outputs for monitoring purposes to aid in finding electronic problems.

During 1970 failures in the integrated circuit logic (chips) were experienced when temperatures exceeded 70°F, even though design specifications allowed -30° to +100°F. This was corrected by installing ventilation fans in the cabinets that housed the circuit logic. Additionally, several of the integrated circuits were defective as received from the manufacturer. This resulted in considerable time in making the entire system operational.

Initially, the VAC power required to operate the data system was supplied by a generator mounted within the trailer. This resulted in constant vibration of the electronic parts and in noise which became annoying to persons checking and operating the system. A remotely located generator proved to be more satisfactory. During 1971 and 1972 power was secured from the Rural Electric Association of Fort Collins, Colorado; however, a 110-VAC transformer had to be used to insure constant voltage and eliminate power spikes, both necessary to eliminate damage to electronic components and to insure proper operation of the magnetic tape recorder. Interruption of the 110-v power supply resulted in improper time coding of the recorded data. This problem was remedied by using a 12-v automobile battery to power the time clock.

Lightning strikes during the latter part of each summer season damaged several soil temperature amplifiers and the sensing units of various radiation transducers. This resulted in a need for returning the radiation transducers to their respective manufacturers for repair and for placing electric diodes on the soil amplifier cards.

Deterioration of the hemisphere and the electrical wiring of the long wave radiation transducers was experienced. Repair of these transducers was lengthy and resulted in limited data during the first 2 years of operation.

Processing of field data tapes was expedited by cleaning the tape before and after each recording. Considerable care in updating the day after each EOF mark by utilizing thumb wheels on the control panel was found essential because data reduction programs are dependent upon correct time coding. Special computer programs were designed to correct for improper coding; however, this resulted in the use of a great deal of additional computer time.

During the 3 years of operation it was necessary to visit the recording facility three times per week. Upon arrival, the operator followed a prescribed sequence in checking the system for proper operation. Each data channel was observed for proper functioning by making comparisons of the analog and digital displays. Each display was allowed 2 min (two digital readings) per channel in order to check for counter-storage boards that may have been oscillating. Upon the completion of checking all data channels, the time and indexing channels were displayed digitally to determine if they were operating correctly. A visual check of the voltage meter, number of EOF's, and magnetic tape recorder was then completed. A Hw-Cw multiband radio within the recording shelter was used to obtain national standard time for comparison with the data system clock. If at any time during the above procedures an error or improper function was discovered, a special procedure was followed to make corrections (Table 8).

The time required to complete a system check and to clean and visually check all transducers was approximately 3 hr provided no improper functions were found. The equipment required to troubleshoot and repair any failure is included in Table 9.

Table 8. Sequence for repairing the data acquisition system.

1. Place EOF on tape.
2. Turn record ENABLE off.
3. Repair improper function.
4. Update the date on thumb wheels and check clock for correct time.
5. Turn record ENABLE on.
6. Recheck all data channels.

Table 9. Electronic test equipment for on-site troubleshooting and repair.

Item	Quantity	Supplier	Model
Power supply	2	Power Design Inc. 3381 Junipero Serra Palo Alto, California	2015R
Signal generator	1	Wavetek 8159 Engineer Road San Diego, California	111VCG
Potentiometric bridge	1	Electro Scientific Industry 13900 N. W. Science Park Drive Portland, Oregon	300
Digital voltmeter	1	Data Technology Corporation 1050 East Meadow Circle Palo Alto, California	350
Oscilloscope	1	Tektronix 2120 South Ash Street Denver, Colorado	323

CHAPTER VII

DATA ANALYSIS

Development of a chart to depict data availability, descriptions of various meteorological parameters for upland and bottomland treatments, and the dependence of net radiation on solar radiation are discussed in this chapter. Soil water depletion differences between grazing treatments are explained by canopy resistances as determined by an evapotranspiration model.

Data Availability

Difficulty in acquainting and making available meteorological data to other scientists was experienced during 1970. In order for the scientist to use the data, it was necessary to manually sort through voluminous computer output. Even after considerable time and effort was spent examining the output, visualizing data availability for selected time periods was impossible. In order to alleviate the problem, a chart was developed to depict, in relatively simple fashion, the availability of meteorological data. It is doubtful that any new form of numbers will be found at this late date; however, it may be possible for man to interpret new forms of data numbers.

At the time data are secured, it is generally unknown how someone at a later time may want to use the data; however, cross-indexing and interrelating kinds of environmental data should be of great value to the integrated ecosystems analysis programs such as the Grassland Biome's. It is necessary to have forms of data which are universally useful in order that general or qualitative patterns of material be represented.

An informatic data form (Bellamy, 1961) is utilized to summarize the meteorological data secured from the Pawnee Site. Incremental notation concisely portrays a tremendous amount of information for direct manual interpretation. A 1-month time period is used for the basic component of the format to depict the availability of data. As shown in Figure 12, notations are made to designate monthly, daily, and hourly data blocks. A collection of these data blocks, arranged such that the rows and columns represent individual months and measured meteorological parameters, are condensed on a sheet of legal-sized paper and depict hourly meteorological data availability (see inserts).

Scientists interested in particular parameters and/or particular time periods can determine the availability of the data by utilizing the charts. If the data are available, they can be secured from the Grassland Biome's central data bank at the Natural Resource Ecology Laboratory, Colorado State University, Fort Collins.

Comparison of Meteorological Parameters over Upland and Bottomland

Radiation

The percent radiation which is reflected from the grassland canopy is commonly termed albedo. This average daily percentage was

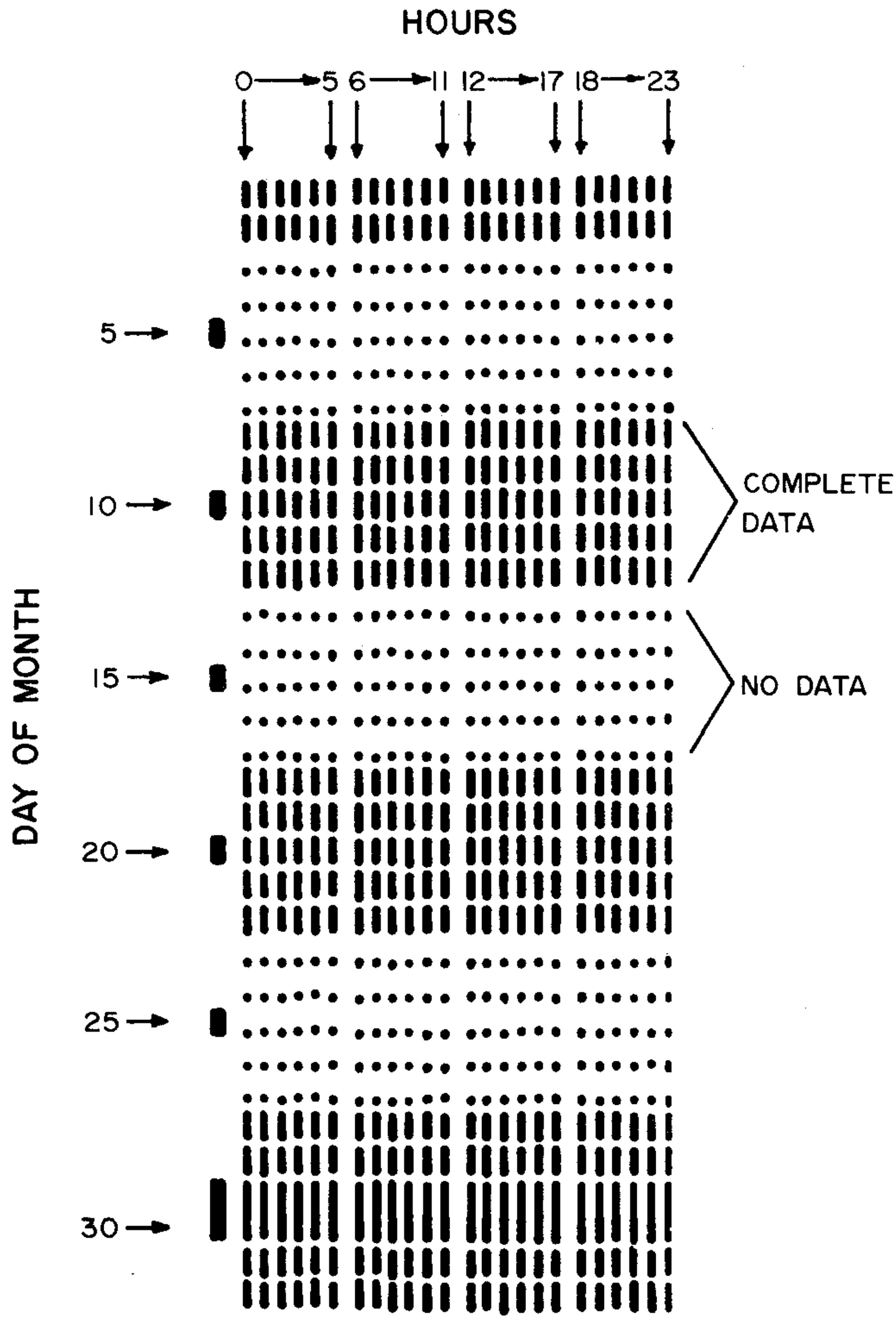
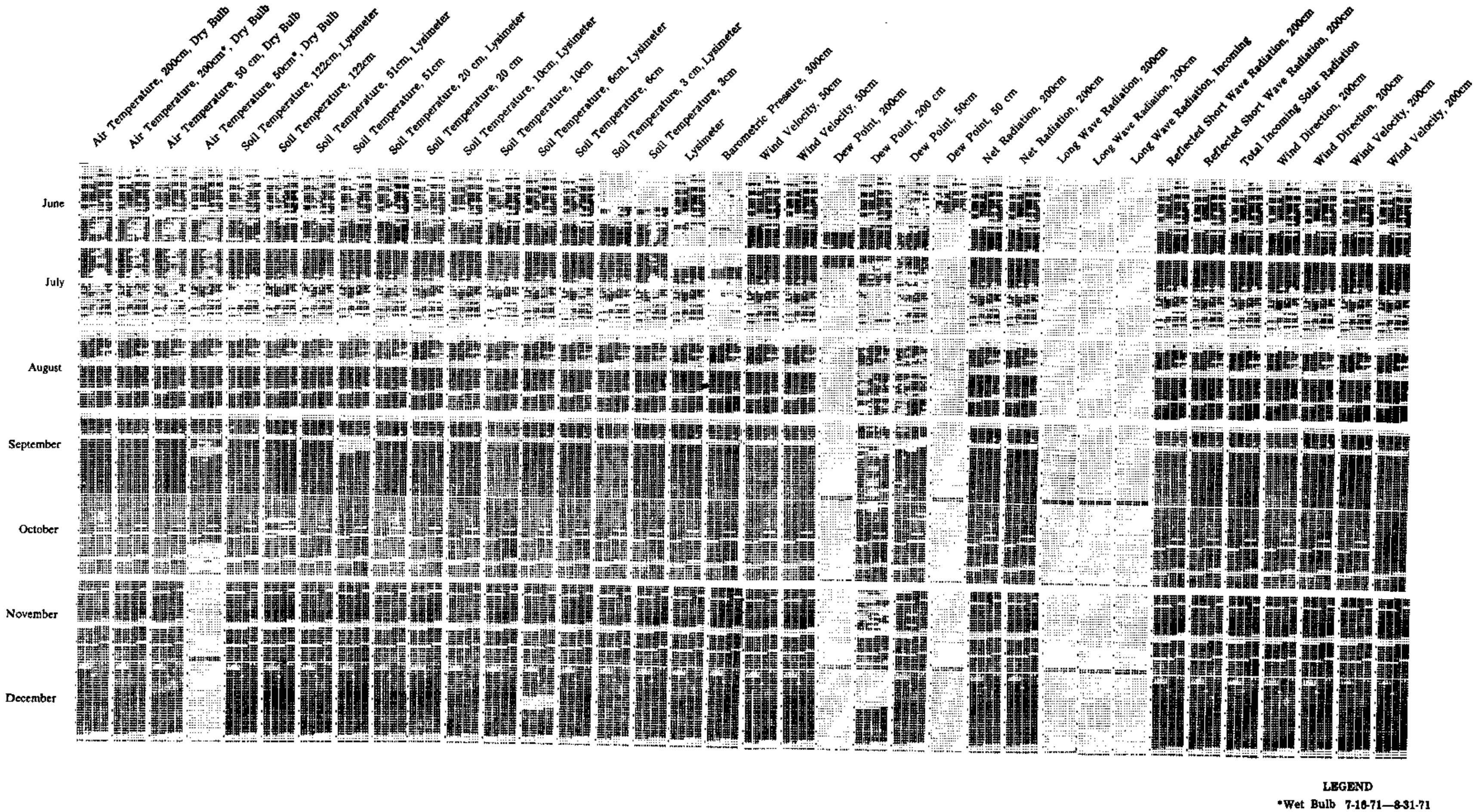


Figure 12. Example format to depict data availability.

Grassland Biome Meterological Data Availability

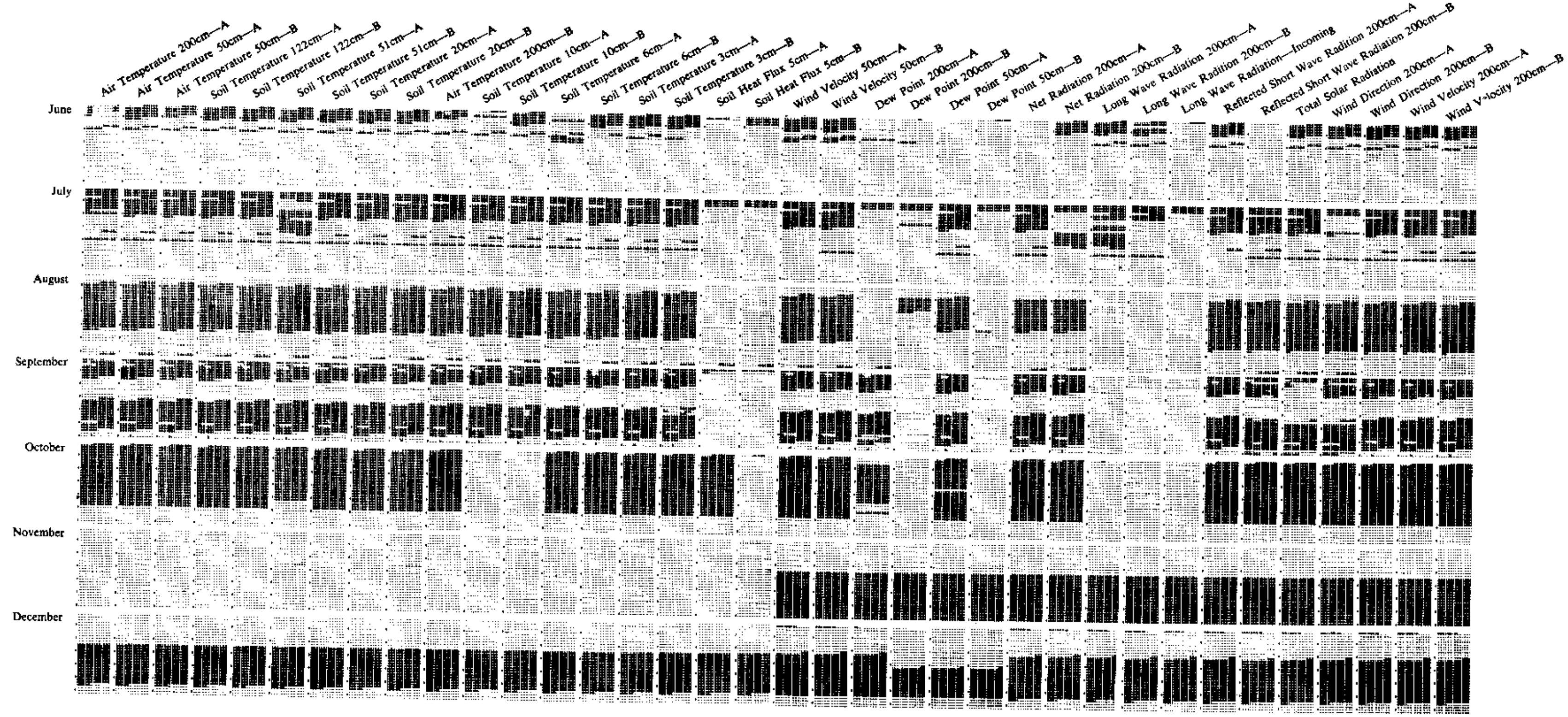
Pawnee Site — Nunn, Colorado

HOURLY ANALYSIS 1971



Meteorological Data Availability

HOURLY AVERAGES 1970



LEGEND

June 1 — July 2 &
November 12 — December 28: A—Light Grazed Pasture
B—Heavy Grazed Pasture

July 3 — October 24: A—Upland
B—Bottomland

found to differ between the upland and bottomland treatments by up to 3% (Table 10).

Increased reflectance from the bottomland is apparently due to a greater amount of vegetative cover present on the bottomland.

Net radiation (the difference between total incoming and total outgoing radiation) over the upland (Figure 13) was found to be approximately 0.1 langley/min greater than that from the bottomland during midday. This difference is, in part, contributable to the lesser reflectance from the upland plus differences in surface temperatures, soil thermal diffusivities, and suspected differences in evaporative rates from the two areas.

Wind Speed

Wind velocities shown in Figure 14 for the two areas of interest were very similar in magnitude and direction. No significant difference was detected between the two sites with the present sensing equipment. Differences in wind speeds from 50 cm/sec to 75 cm/sec were noted between the 50-cm height and 200-cm height.

Air Temperature

Differences in air temperatures were noted between the upland and bottomland (see Figure 15). The air temperature at 200 cm over the surface of the upland tends to be 3° to 5°F warmer than over the bottomland. This was probably due to the fact that the upland had a greater percentage of exposed bare soil that could result in a greater amount of sensible heat transfer to the atmosphere. The temperature gradient as measured at the 50-cm and 200-cm levels was greater over

Table 10. Comparison of albedo (%) for upland and bottomland treatments.

Military Time	Albedo	
	Upland	Bottomland
0600	0.0	0.0
0700	5.0	10.0
0800	9.0	13.0
0900	12.0	14.0
1000	12.0	14.0
1100	12.0	14.0
1200	12.0	15.0
1300	12.0	15.0
1400	11.0	15.0
1500	8.0	15.0
1600	2.0	9.0
1700	0.0	0.0
Daily Average	10.7	13.8

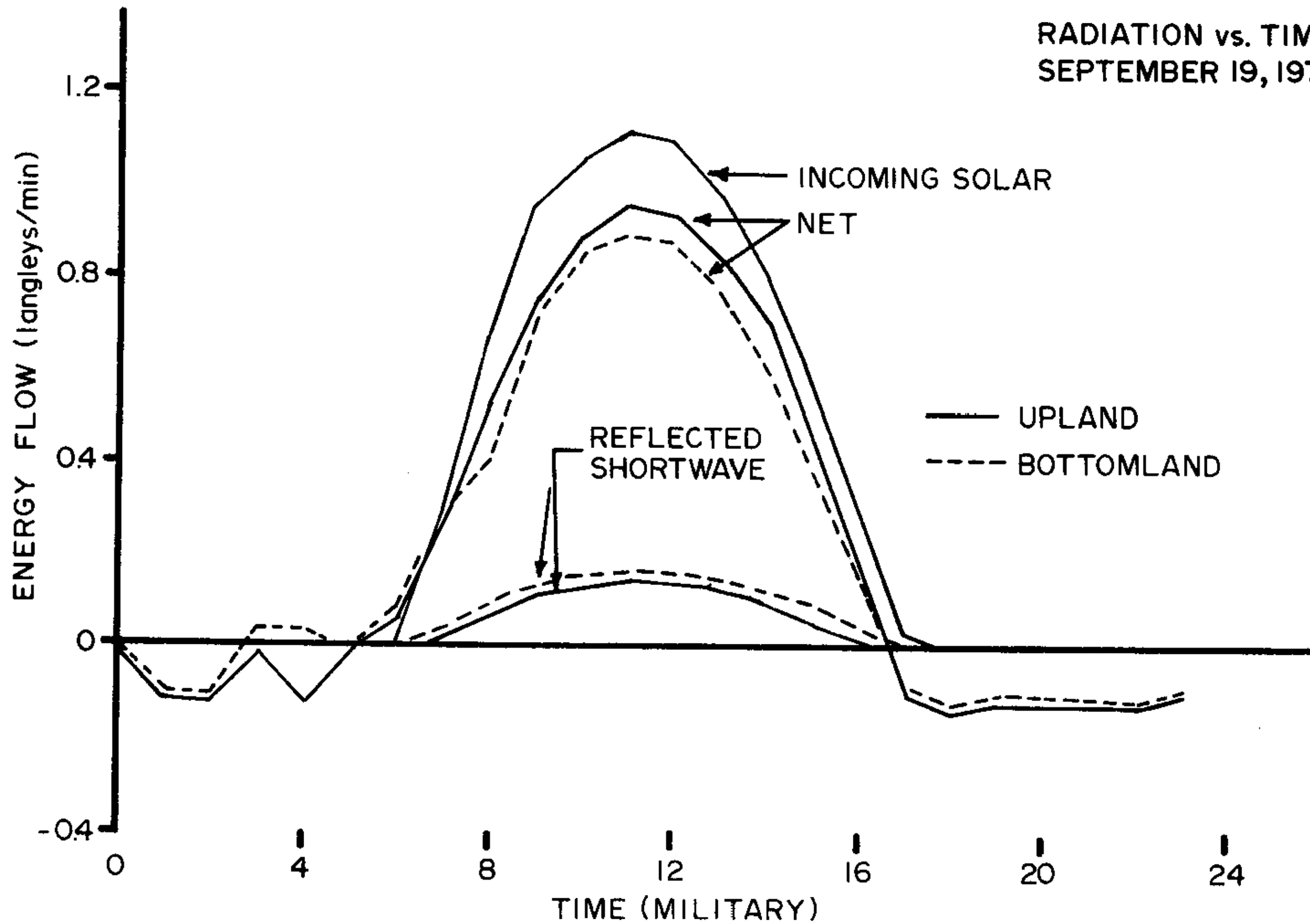


Figure 13. Radiation parameters for September 19, 1970.

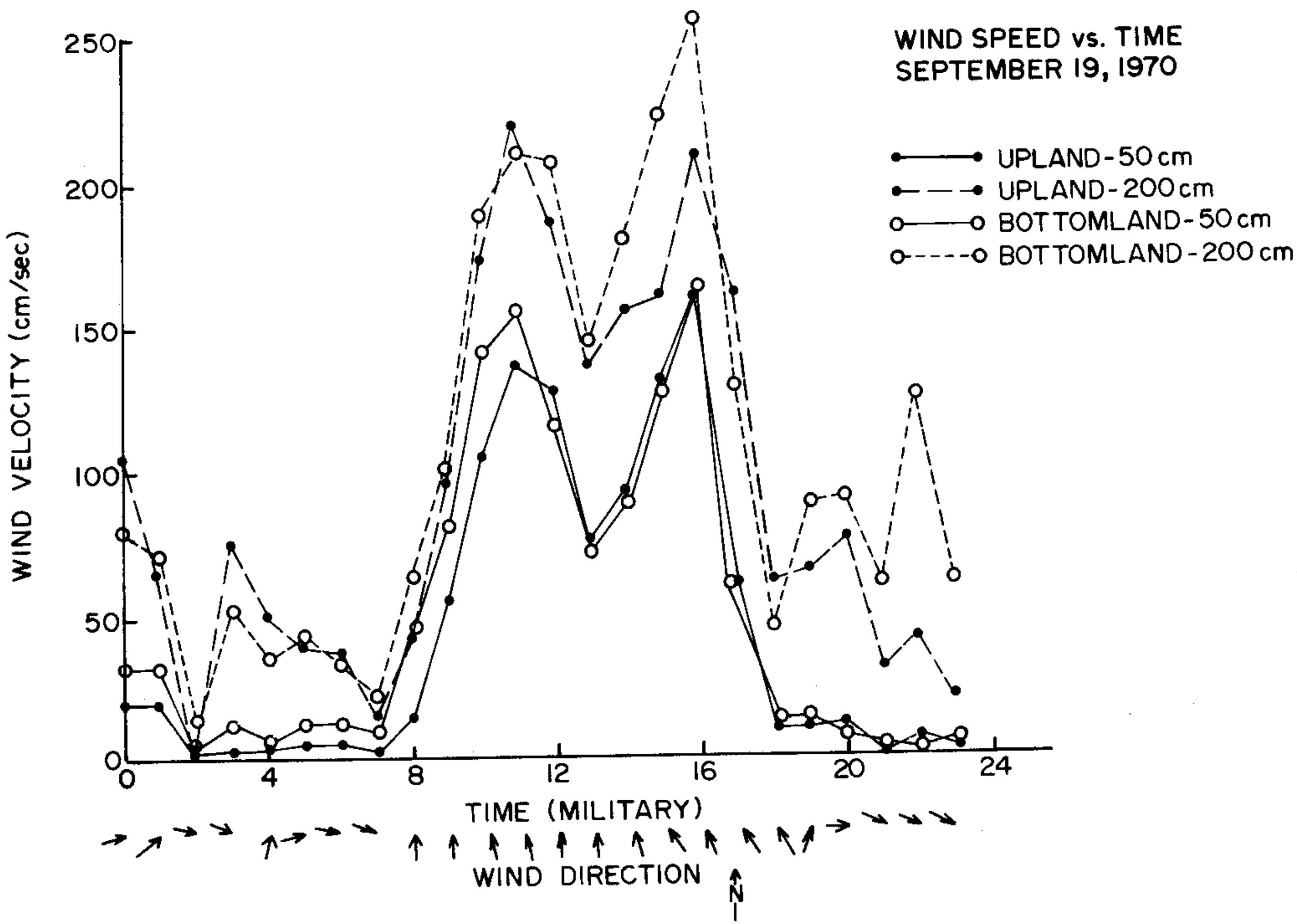


Figure 14. Wind velocity and direction for September 19, 1970.

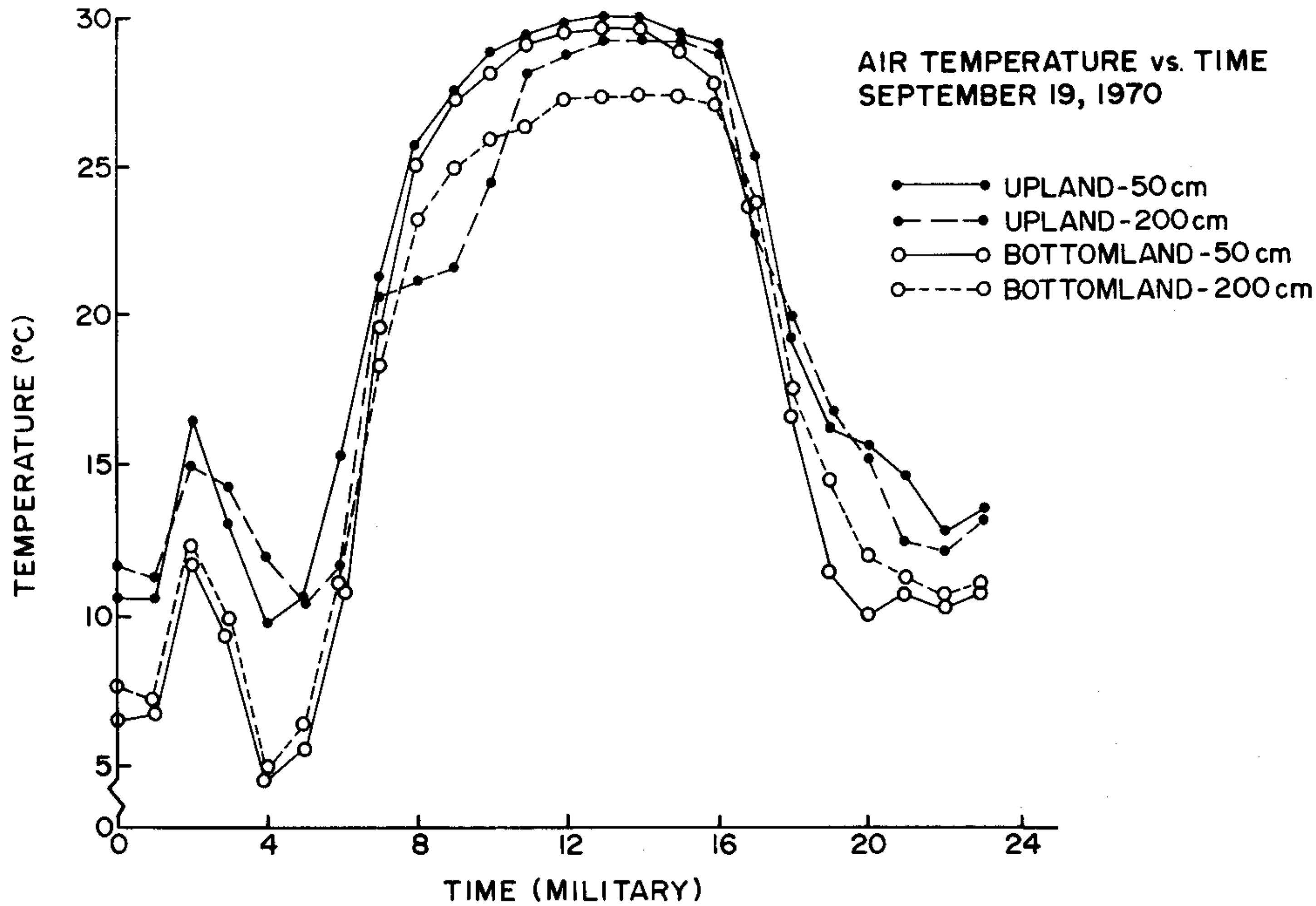


Figure 15. Air temperature for September 19, 1970.

the bottomland. This also suggested that the sensible heat transfer to the atmosphere is less for the bottomland.

Soil Temperature

At soil depths greater than 50 cm, no noticeable difference in soil temperature was measured. Diurnal variation in soil temperature at the shallower depths was greater by 5°C for the upland area (Figure 16). This difference can be attributed to differences in vegetative cover. The bottomland has a more dense vegetative cover and greater litter. This boundary limits the heat flow into and out of the soil profile by controlling net radiation, sensible heat transfer, and evaporation.

Estimation of Net Radiation

Estimation and/or measurement of net all-wave radiation, hereinafter termed net radiation, is of great importance in the fields of forestry, hydrology, meteorology, and agriculture, as indicated by Penman (1948) and House, Rider, and Tugwell (1960). Surface energy balance studies depend upon net radiation as an essential parameter, but long-term records for particular areas of interest are seldom available; however, total incoming solar radiation is more frequently available. Davies (1967) and Linacre (1968) have indicated that net radiation over irrigated crops depends largely on global solar radiation. This analysis deals with the above dependence for the purpose of estimating daytime net radiation intensities over native grassland from global radiation measurements.

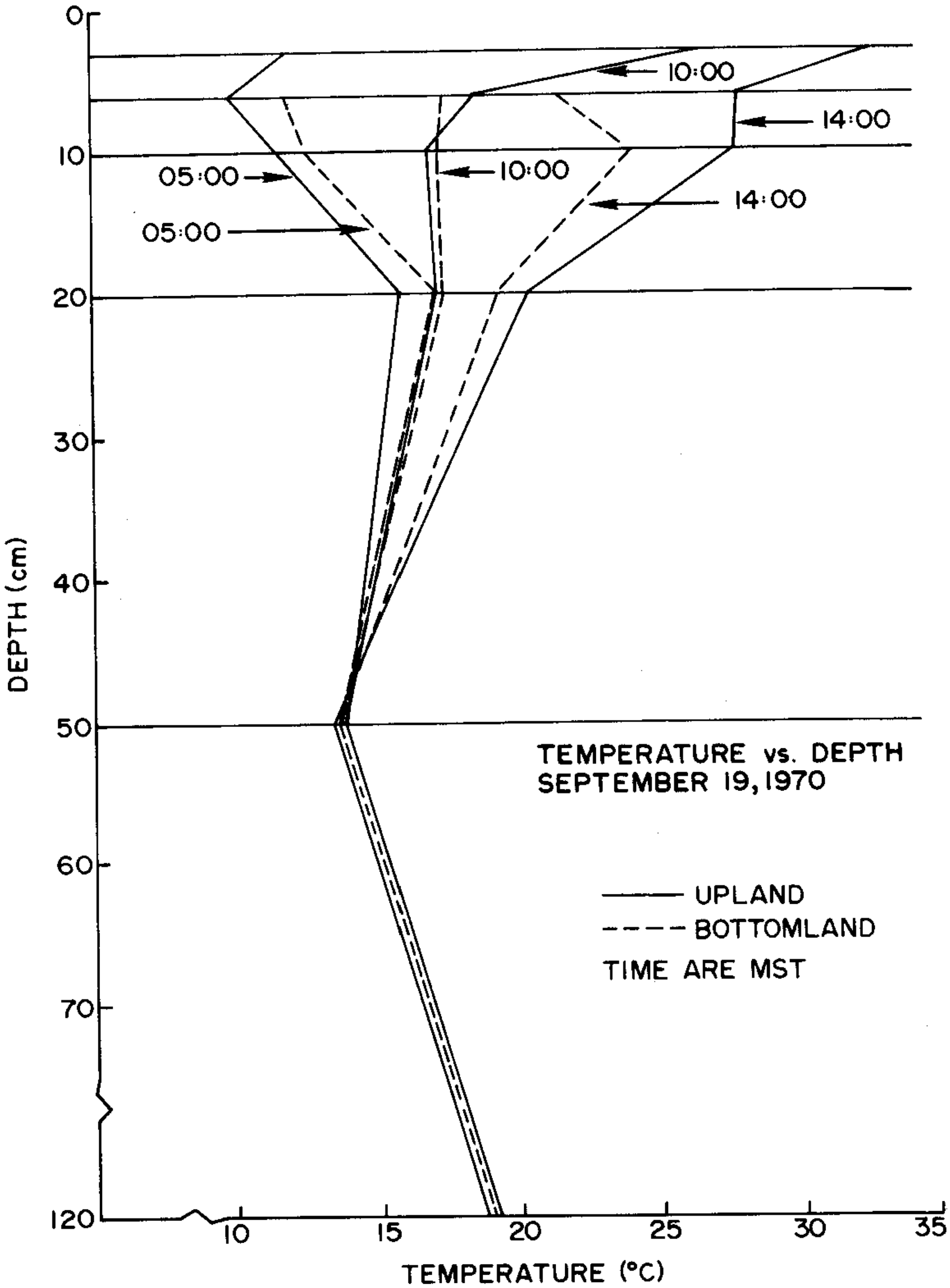


Figure 16. Soil temperature profile for September 19, 1970.

Data

Measurements of global solar radiation, net radiation, and reflected solar radiation measured on a continuous basis at the Pawnee Site were used for this analysis. Approximately 1000 radiation observations (integrated hourly averages for every day) from the months of June, July, and August of 1971 were summarized.

Analysis

The total energy available at the ground surface is measured as the balance between incoming and outgoing solar and terrestrial radiation, normally net radiation. Given the conventional sign notation, i.e., radiation received at the surface is positive, net radiation (R_n) may be shown as:

$$R_n = (1 - \alpha)\ R_s + L_n \tag{1}$$

where R_s is the global solar radiation, L_n is the net long wave radiation, and α is the albedo of the ground surface. The daily reflection coefficient may be considered as nearly constant from June to September (Monteith, 1959) if one neglects the albedo changes due to changes in solar elevation with season. The net radiation on clear days with a given amount of incoming solar radiation depends mainly on net long wave radiation. The net long wave radiation is dependent upon the emissivity of the ground surface and its radiative temperature, amount of precipitable water, air temperature, and the carbon dioxide content of the atmosphere. Increases in radiative temperature of the ground surface are noted with decreasing soil water content or wind speed when all other factors remain constant.

It was assumed that net radiation depends on global solar radiation and that net long wave radiation is a linear function of R_s. Therefore:

$$L_n = a_1R_s + b \tag{2}$$

By the combination of equations (1) and (2):

$$R_n = aR_s + b \tag{3}$$

where $a = (1 - \alpha + a_1)$. Note that a_1 and b are regression constants. From the data points of incoming shortwave and net radiation, the regression coefficients and correlation index were computed and are given in Figure 17. The estimated net radiation values were then compared with those measured (Figure 18), and the results are summarized in Table 11 and Figure 19 together with the line of unit slope.

Results

Considering that Tanner and Pelton (1960) and Robinson (1962) have indicated errors in measuring net radiation may be typically 10% as the scatter shows in Figures 17, 18, and 19, it appears that the empirical formulas for estimating net radiation from global radiation may be nearly as accurate as measuring the net radiation. At any rate, it seems practical to fill in missing data due to instrument failure using an empirical formula developed at the particular site in question. Gay (1969) explains possible errors associated with this type of estimation that must be recognized.

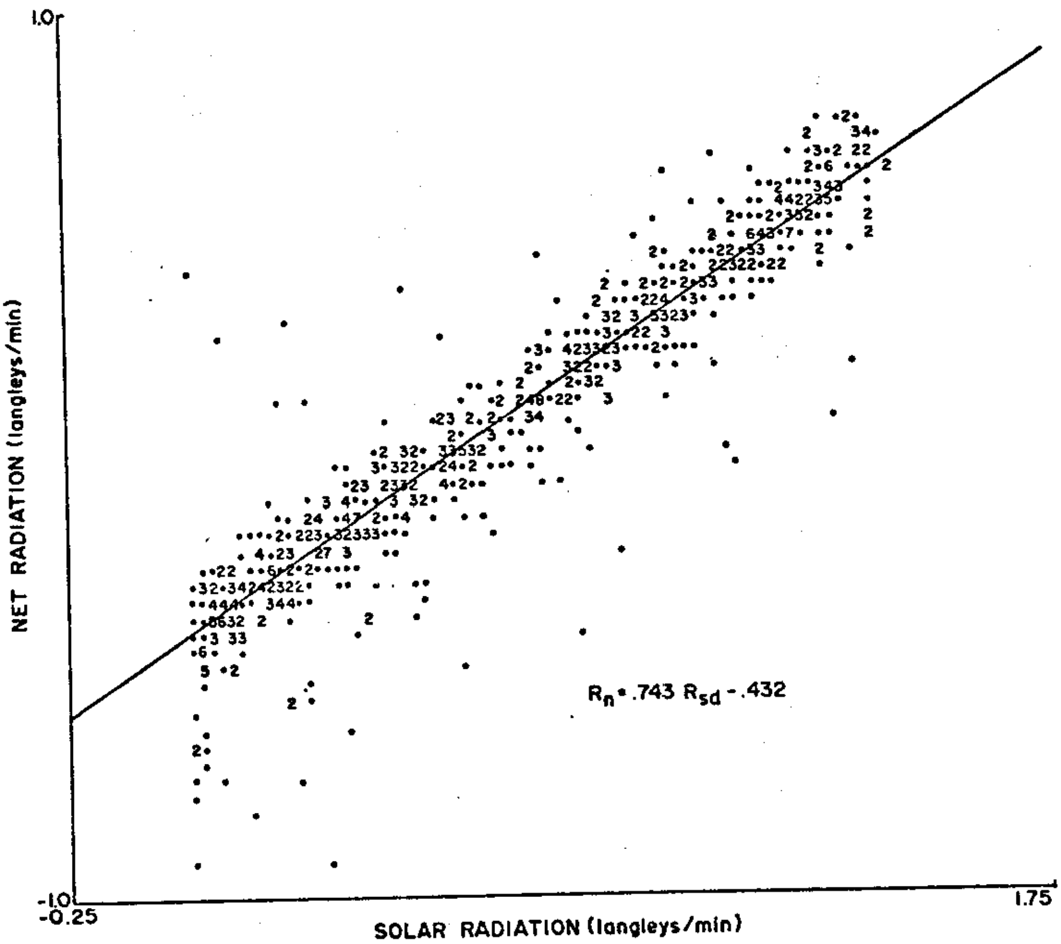


Figure 17. Regression of net radiation on total incoming solar radiation.

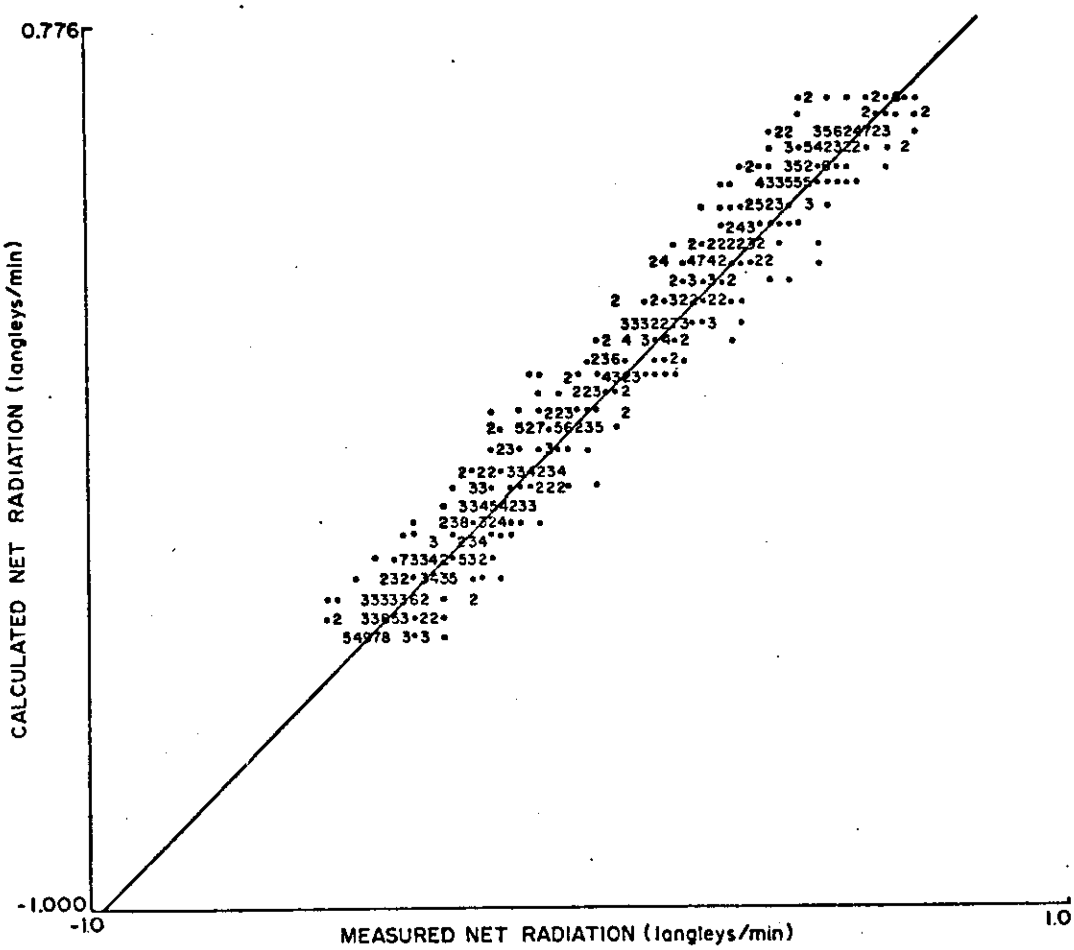


Figure 18. Comparison of calculated net radiation with measured net radiation by regression.

Table 11. Comparison of net radiation estimated by regression to measured net radiation.

Radiation Values	Mean Albedo	Mean Net Infrared Flux (langleys/min)
Regression	.26	-.43
Measured	.19	-.47

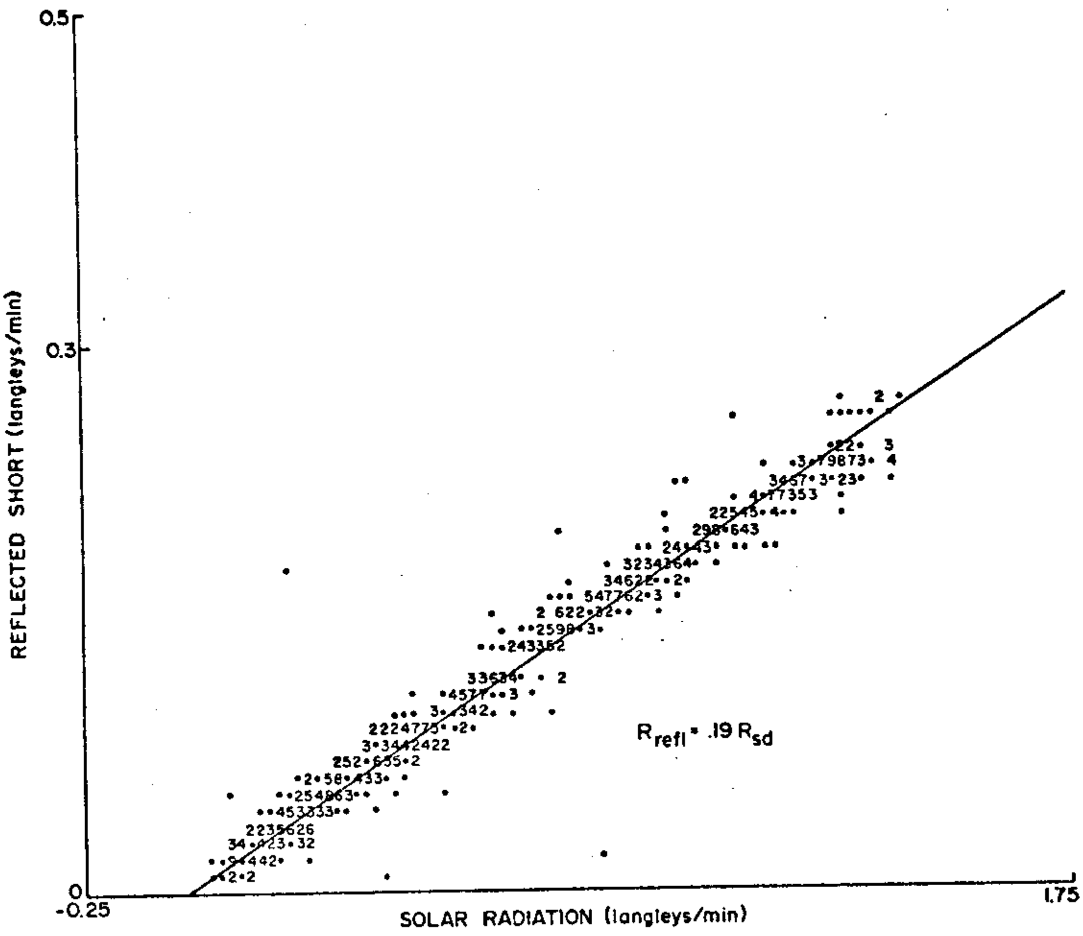


Figure 19. Regression of reflected shortwave radiation (R_{refl}) on total incoming solar radiation.

Evapotranspiration

A study of the water balance on the Pawnee Grassland is difficult due to the low magnitudes of water loss. The persistent drought condition of the natural prairie sod results from the annual rainfall of approximately 12 inches. The vegetative canopy is different from canopies where soil water is sufficient to minimize plant stress.

A brief attempt was made at the latter part of the 1971 growing season to determine evaporation from the lysimeter exclosure. The results of this effort (Appendix III) were unsatisfactory. The Bowen's (1926) ratio theory explained only 60% to 80% of the evaporation when compared to measurements made with a precision lysimeter (Blad and Rosenberg, 1972). The instrumentation used (Chapter I) measured temperature and humidity gradients with a precision of ±0.5°F, whereas Tanner (1963) suggested they should be measured to within 0.1°F for accurate evapotranspiration measurements.

The system was changed during 1971 and 1972 to measure additional parameters with increased precision due to the needs of other investigators at the site. Appendix IV lists the parameters measured after the change of the system was completed in April, 1972.

C. H. M. van Bavel was contacted and asked to visit the Pawnee Site for his ideas and suggestions regarding evapotranspiration. His review of the meteorological instrumentation and the grassland area resulted in the application of the following evapotranspiration theory. The reader is referred to Rosenberg, Hart, and Brown (1968) and Bartholic, Numken, and Kliegand (1970) for an extensive review of evapotranspiration theory. This section thus contains an evapotranspiration study of the grassland area with special attempts to merge biotic and abiotic data on different grazing treatments.

Theory

Potential evaporation from a vegetative surface can be defined accurately by utilizing ambient weather data and the aerodynamic nature of the evaporating surface. A combination model which can be utilized is best described by van Bavel (1966) and takes the following form:

$$E_o = \frac{\frac{\varepsilon H}{L} + \frac{\rho e d_a}{p R_a}}{\varepsilon + 1} \qquad (4)$$

where

E_o = potential evaporation rate $(g/cm^2/sec)$

ε = dimensionless parameter (Δ/γ)

H = sum of energy inputs at surface exclusive of sensible and latent heat $(cal/cm^2/sec)$

L = latent heat of vaporization

ρ = density of air (g/cm^2)

e = water/air molecule ratio (.622)

d_a = saturation vapor pressure deficit of air (mb)

p = ambient pressure (mb)

R_a = turbulent diffusion "resistance" (sec/cm), following Monteith and Szeicz (1962) as:

$$R_a = \frac{\ln (Z_a/Z_o)^2}{k^2} \cdot \frac{1}{u_a}$$

where

Z_a = elevation of measurements above ground

Z_o = roughness parameter (cm)

k = Von Karman coefficient (.41)

u_a = wind speed at level Z_a (cm/sec)

Equation (4) defines the potential rate of evaporation from a vegetative canopy in which soil water is unlimited (a surface covered with a thin layer of water exposed to ambient conditions). Under natural conditions, the water evaporated from a vegetative canopy comes from within the plant and is, therefore, transported by diffusion through the plant. The route of water vapor flow can be restrictive, thus resulting in a resistance to transpiration more commonly termed "canopy resistance." This inherent plant characteristic has resulted in a modification of equation (4) in order to define actual evaporation. Monteith, Szeicz, and Waggoner (1965) have written this equation as follows:

$$ET = \frac{\frac{\varepsilon H}{L} + \frac{\rho ed_a}{pR_a}}{\varepsilon + 1 + R_s/R_a} \qquad (5)$$

where R_s is canopy resistance and other symbols are as previously defined. Assumptions made in equation (5) are neutral stability of the atmosphere, and the exchange coefficients for water vapor and sensible heat are equal.

As soil drying proceeds under any vegetative canopy, the stomata of plants may close either rapidly or gradually in an effort to maintain a water balance in the plant. Determination of R_s is suggested as a logical method to characterize grassland plant response to drought, using the following form of equation (5):

$$R_s = \frac{\varepsilon H R_a}{LET} + \frac{\rho e d_a}{ET} - \varepsilon R_a - R_a \quad (6)$$

where L is latent heat of vaporization and ET is actual evaporation. Equation (6) can be used to describe quantitatively the response of the Pawnee Grassland to drought throughout the growing season. Earlier studies (van Bavel, 1966; Monteith, 1965) have characterized canopy resistances for alfalfa and barley. These crops were artificially watered, and R_s was not determined by equation (6) but by utilizing a combination of potential and actual evaporation theory and profile data. According to Monteith (1963), there is some question relative to the validity of using this method.

Procedure

The meteorological parameters measured are described in Chapter VII and Appendix V. Hourly and daily evaporation rates (for the lysimeter exclosure) were measured utilizing a high precision lysimeter as described by Armijo (1972). Neutron probe readings and rainfall data collected from the non-grazed and heavily grazed micro-watersheds (Smith and Striffler, 1969) were used to determine evaporation rates according to the following formula:

$$E = P - \Delta S \quad (7)$$

where

E = evaporation rate (mm/day)

P = rainfall (mm/day)

ΔS = change in soil water in top 120 cm of soil profile (mm/day)

The data acquisition system was run continuously throughout the study period of May through July at the lysimeter exclosure.

R_s was computed for the lysimeter exclosure and the grazing treatments by utilizing equation (5) and the appropriate meteorological measurements. Meteorological data secured at the lysimeter exclosure were assumed to be valid for usage on the grazed treatments because of the homogeneity of the Pawnee Site. Phenology, percent bare soil, aboveground biomass, and leaf area index (LAI) data were secured from the U.S. Grassland Biome data bank, Colorado State University, Fort Collins.

The period of observation covered the usual time of spring storms followed by a dry summer spell and a period of moderate rainfall during the first week of August.

Results

A graphic summary of daily calculations using the lysimeter data is shown in Figure 20. The magnitude of the resistance suggests an average canopy resistance of between 8 and 15 sec/cm for the grasslands during periods of peak evapotranspiration. As the soil content is depleted, the plant stomata become more active in closure in order to conserve water, as indicated by an increase in resistance of up to 50 sec/cm during late July. When crop resistance (R_s) is very small,

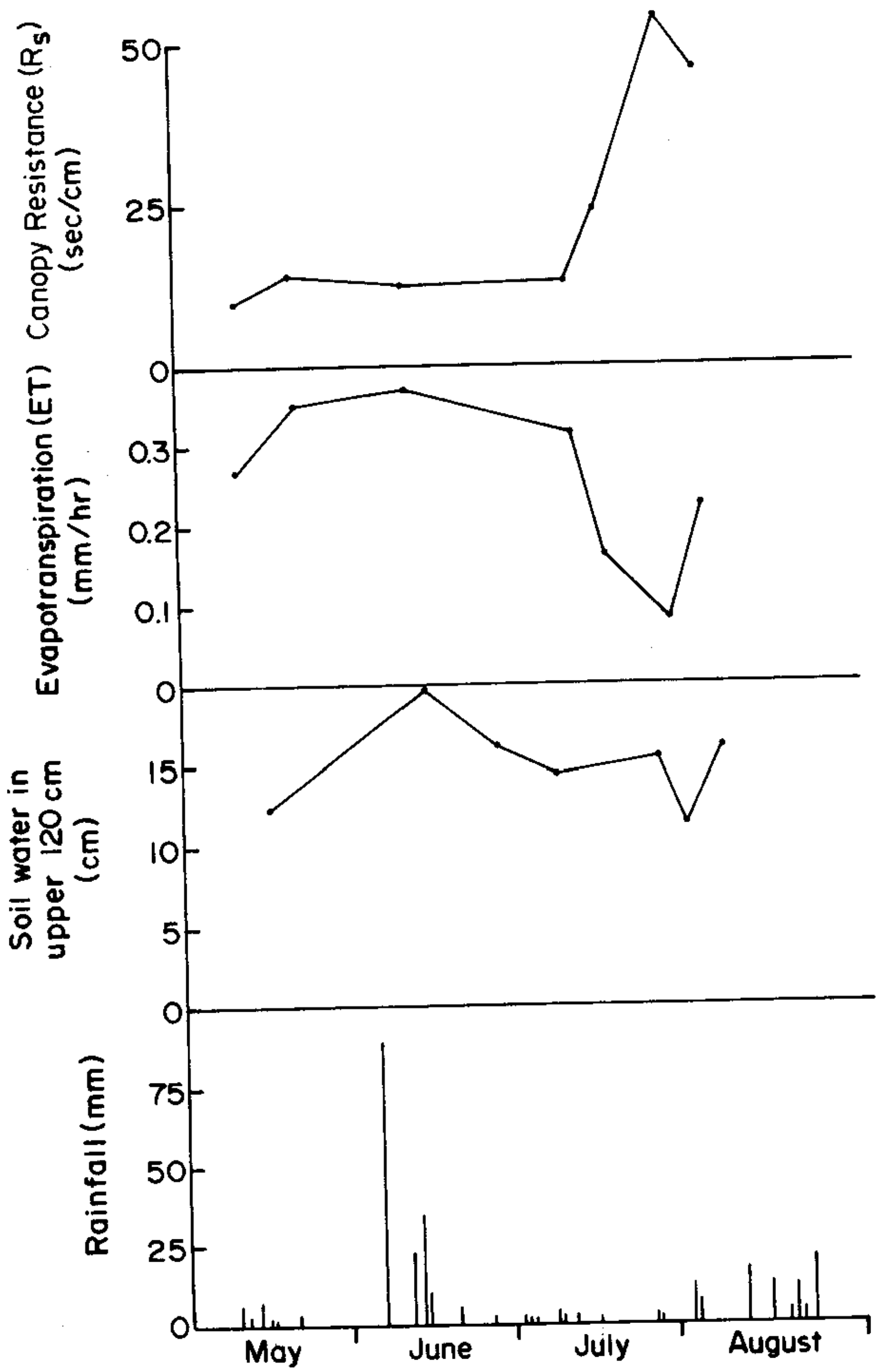


Figure 20. Canopy resistance, evapotranspiration, soil water, and rainfall for lysimeter exclosure, 1972.

actual evapotranspiration approaches the potential evapotranspiration. The above has been reported by van Bavel (1966) with irrigated crops. However, this condition does not prevail on the grasslands (Table 12).

The author suggests the grassland vegetation has a resistance to water vapor transport regardless of soil water conditions (stomata closure is not the only resistance, but the total R_s value is also composed of cuticle, substomatal cavity, and cell-wall resistance). This conclusion is supported by unpublished data (1972) of Dr. George Williams, Washington State University, who demonstrated in a laboratory experiment a notable leaf resistance for grassland vegetation under ideal growing conditions.

Effect of grazing. Galbraith (1971) illustrated a significant difference in evapotranspiration from various grazing treatments, and soil water potential could not completely explain the variation. A more detailed and biologically oriented approach was utilized, and a summary of canopy resistance values, phenology, and evapotranspiration rates is shown in Figure 20 and Table 13.

Canopy resistances for the heavily grazed treatment were from 5% to 20% greater than for the non-grazed area, thus suggesting that evapotranspiration from the heavily grazed area is less than for the non-grazed area. This difference cannot be explained by green LAI, for Knight (1972) has shown no significant difference in LAI between grazing treatments on the Pawnee Site; however, Knight did indicate that 86% of the green LAI on the heavily grazed treatment and 60% of the green LAI on the non-grazed treatment was *Bouteloua gracilis*.

Table 12. Daily potential and actual evapotranspiration rates for lysimeter exclosure, 1972.

Date	Potential Evapotranspiration (mm/hr)	Actual Evapotranspiration (mm/hr)
May 14	.70	.27
May 20	.90	.35
June 9	1.00	.37
July 12	3.46	.31
July 17	1.50	.16
July 23	5.00	.13
July 30	5.56	.09
August 5	2.00	.21

Table 13. Daily evapotranspiration and canopy resistance for non-grazed and heavily grazed treatments, 1972.

Date	Evapotranspiration (mm/day)		Canopy Resistance (sec/cm)	
	Non-grazed	Heavily Grazed	Non-grazed	Heavily Grazed
May 5	0.92	0.59	8.5	11.0
June 1	1.09	0.74	10.5	13.0
June 15	2.70	2.45	18.0	24.0
July 5	2.93	2.44	19.1	24.0
July 15	2.55	1.93	24.8	28.9
July 30	1.47	1.36	33.5	34.6

This suggests that phenology may play an active role in evapotranspiration on grazed treatments. Using phenology data (French, 1972), two curves were developed to show the phenology on the non-grazed and heavily grazed treatments. Green LAI was used to weight species differences on each treatment and is summarized in Figure 21.

The non-grazed area showed an average phenophase[1] of between six and seven [late leaves fully expanded and developing floral buds (Table 14)] during peak evapotranspiration, while the heavily grazed treatment showed about four (middle leaves fully visible). Also, the non-grazed treatment phenophase was consistently higher than the heavily grazed treatment. Using photosynthesis rates to depict transpiration rates [valid in a temperature regime less than 35°C (George Williams, personal communication)], maximum transpiration rates occur during a phenophase of six to seven (Trlica, 1972). The author, therefore, suggests that differences in evapotranspiration among grazing treatments can be explained by plant phenology. An attempt was also made to relate aboveground herbage and percent bare soil (Figure 22) to evapotranspiration rates. No obvious relationship was noted.

A comparison is shown in Figure 23 between R_s and ET for the Pawnee Site; O'Neill, Nebraska (Monteith, 1965); and Arizona (van Bavel, 1966). Generally good agreement was found between alfalfa under limited soil water conditions and the Pawnee Grasslands. Comparisons indicated that the canopy resistance at the Pawnee Site

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[1]Phenophase is the stage of development or maturity of plants at a particular point in time, analogous to expressions for wheat such as: two leaf, tillering, boot, flowering, milk, soft dough, hard dough, and ripe.

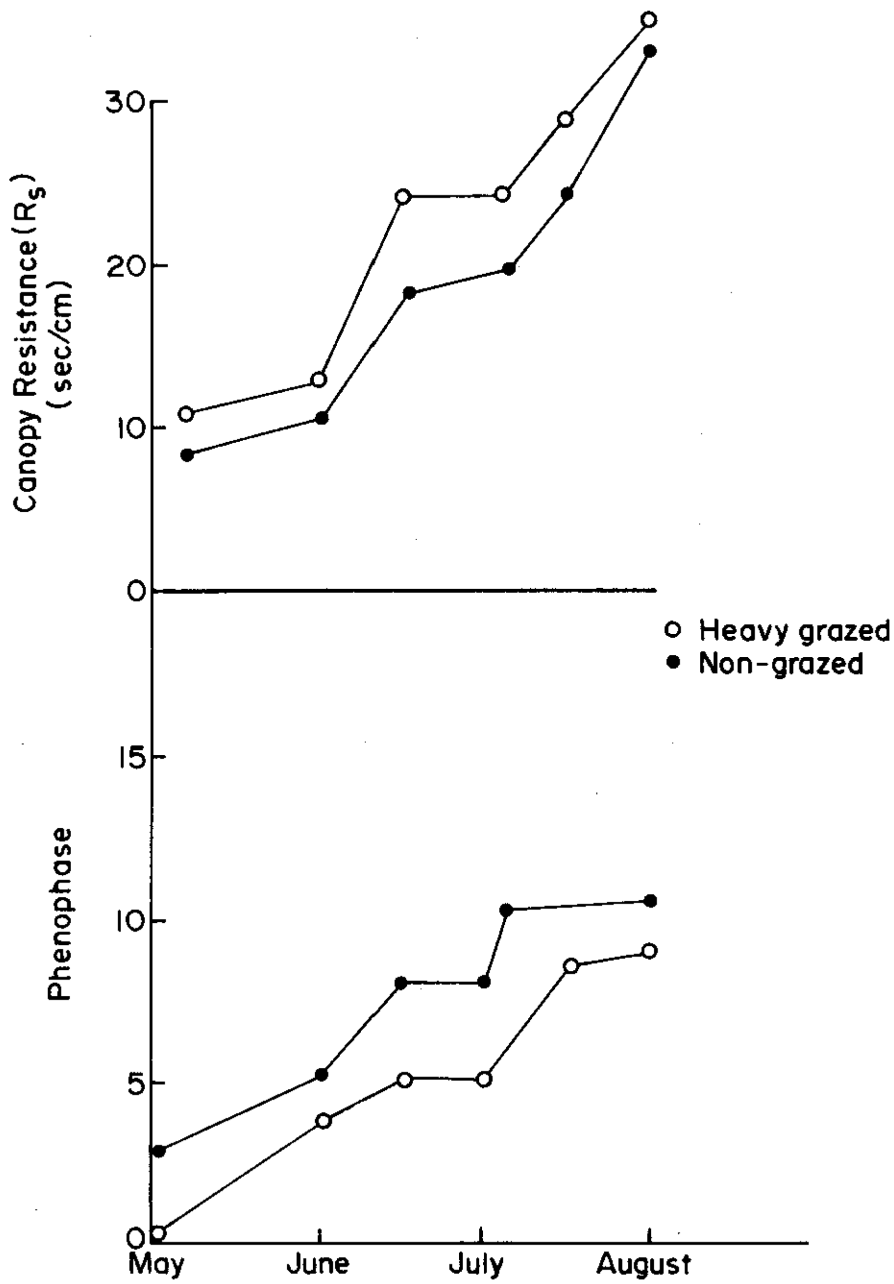

Figure 21. Canopy resistance and phenophase (Table 14) for non-grazed and heavily grazed microwatersheds, 1972.

Table 14. Definitions of 14 phenophases in the Grassland Biome.

1. Preemergence growth/winter dormancy
2. First visible growth
3. First leaves fully expanded
4. Middle leaves fully visible
5. First leaves senescent; middle leaves fully expanded
6. Late leaves fully expanded
7. Developing floral buds; middle-late vegetative
8. Mature floral buds; late vegetative
9. Floral buds and open flowers
10. Buds, flowers, and green fruit
11. Buds, flowers, green fruit, and ripe fruit
12. Green fruit and ripe fruit
13. Ripe fruit and dispersing seeds
14. Flowering induced dormancy

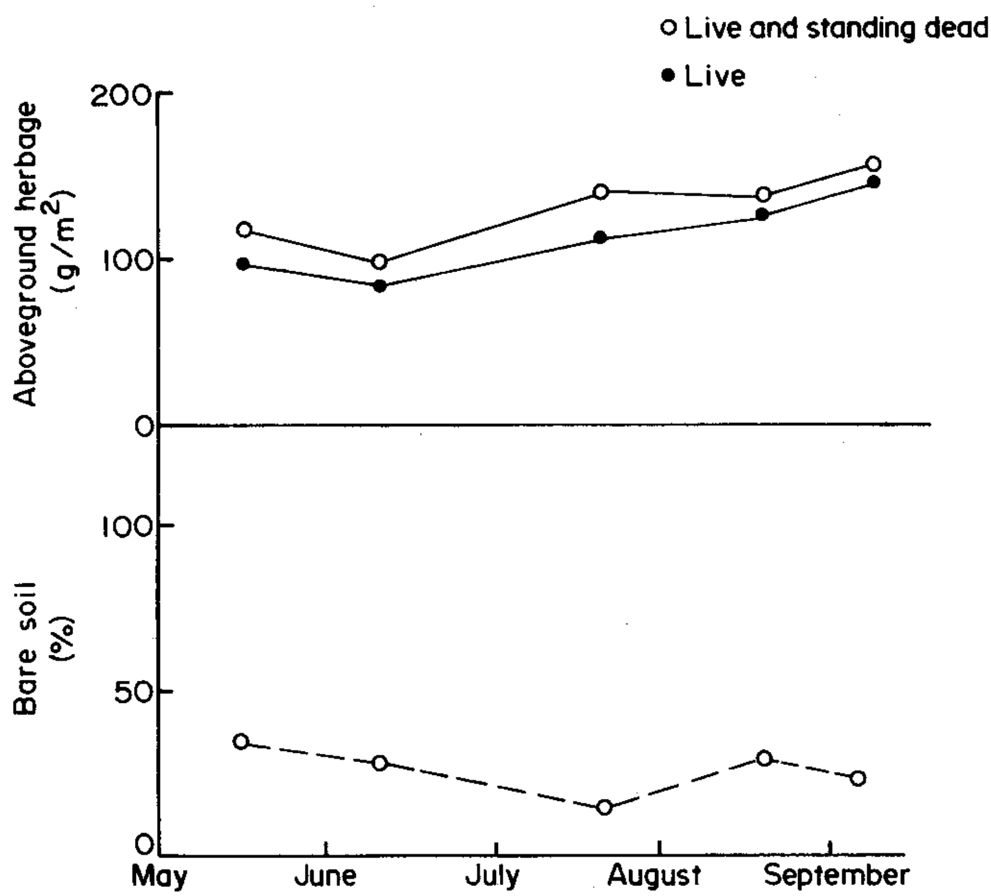

Figure 22. Aboveground herbage and percent bare soil for 1972 growing season.

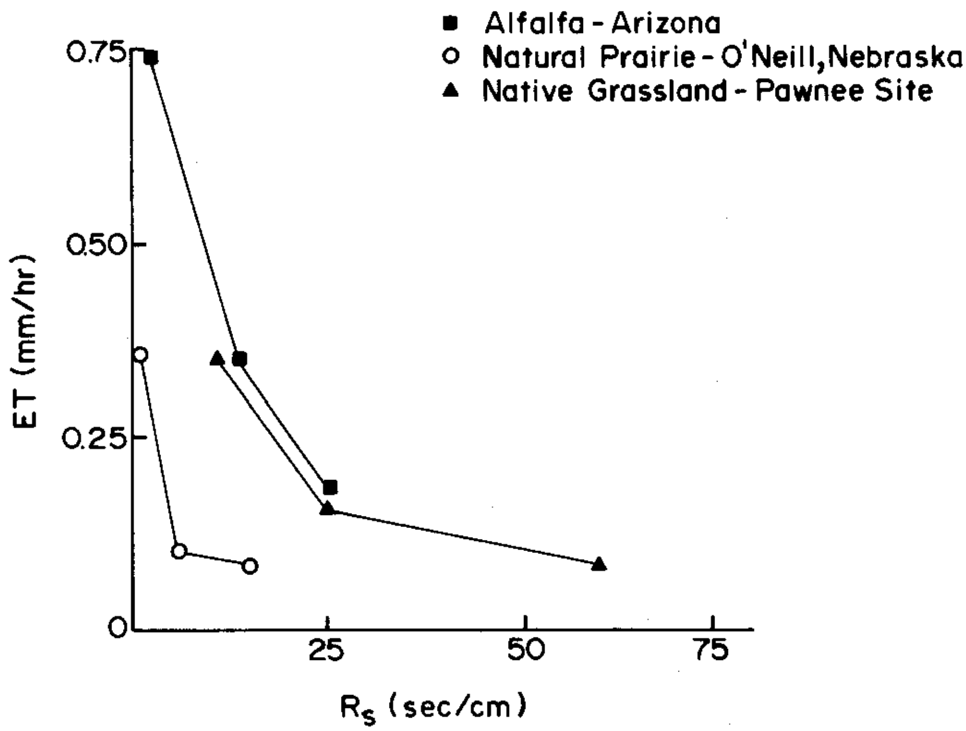

Figure 23. Relationship of evapotranspiration to canopy resistance.

was higher than at O'Neill, Nebraska. The difference could be explained by plant specie variation, greater relative moisture conditions in eastern Nebraska, and/or differences in application of evapotranspiration theory.

CHAPTER VIII

CONCLUSIONS

A human observer or a group of observers cannot read meters, counters, or charts as fast, or with the same resolution, as an electronic system can recognize a signal and transmit it to a digital readout device. This becomes even more weighted in favor of the electronic system if the words are integrated values. The enclosed data system has met the criteria established in Chapters I and II for interdisciplinary long-term research. The unit has proven dependable; however, several months of check-out and debug time was required to produce a reasonably trouble-free system.

Reliability as noted above does not include component reliability. That is, the automatic system is so designed that most failures when they do occur are large enough that they are obvious to an experienced operator. However, it is necessary to distinguish between signal presentation and correct operation.

With automatic data processing, immediate analysis of the data is possible, thus eliminating the need and expense for an intermediate data processing step. As the length of time for data collection increases, the advantage of using a system which provides for automatic data processing becomes more advantageous and necessary. It is not grossly inaccurate to say that data cost alone justified the construction of the automatic system, and, certainly, any additional project at the Pawnee Site would decidedly provide such justification.

The use of simultaneous and continuous measurement of all variables has been looked upon very favorably by simulation modelers at the Natural Resource Ecology Laboratory, Colorado State University, Fort Collins. True integrated values for any time interval has simplified interpretation of data and helped in establishing useful biotic and abiotic relationships.

Continuous operation of such a system requires a working knowledge of electronics for general maintenance. Calibration of the sensors and recording unit are required every 6 months.

Pictorial data availability has proven far superior to date for depicting data availability than any other summarized form where large volumes of data are stored and recorded.

The dependence of net radiation on solar radiation has resulted in a relationship for estimating net radiation with a reasonable degree of accuracy. This relationship reduces the need for frequent net radiation measurements which require special attention.

The combination evapotranspiration model utilizing canopy resistance is a satisfactory method for depicting plant-water relationships on contrasting grazing treatments. It is suggested that canopy resistance be used as an index to evapotranspiration when water depletion studies are made on dry land areas.

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APPENDIX I

DATA REDUCTION PROGRAMS

1. "Compact 800"
2. "Compact 556"
3. "List Keys"
4. "Average 556"
5. "D-Plot"
6. Resistance Coefficients

1. "Compact 800"

```
 09 29 DEC 14,'72 ID=C44012F1
 JOB AA03, JOHN NUNN  ,     .            COMPACT 200 BPI TAPE AT 800
 LIMIT (TIME,15),(LC,20),(UO,20)
 ASSIGN F 1,(DEVICE,7T),(OUTSN,3090),(UNPACK),(BIN),(OUTIN)
 ASSIGN F 2,(DEVICE,7T),(INSN,3038),(BIN),(UNPACK),(TRIES,0)
FORTRAN GO,S,X,LS
 EXT. FORTRAN IV, VERSION D00
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C
C
C     THIS PROGRAM READS LOW DENSITY PAWNEE SITE TAPES AND WRITES
C     CONVERTED,SCREENED DATA ON HIGH DENSITY TAPE TO BE STORED AND
C     USED AT CSU.
C     A HIGH DENSITY TAPE CONTAINS INFORMATION FROM MORE THAN ONE REEL
C     OF LOW DENSITY .  FOR EACH REEL TRANSFERRED THE FIRST RECORD OF
C     THE FIRST FILE IS COMMENTARY.  ONE END OF FILE MARK SEPARATES
C     FILES AND TWO EOFS INDICATE THE END OF THE LOW DENSITY REEL.
C     ON HIGH DENSITY TAPE - EACH PHYSICAL RECORD CONTAINS 42 LOGICAL
C     RECORDS,119 CHARACTERS LONG. PLUS 2 ZERO CHARACTERS TO MAKE
C     A 5000 CHARACTER PHYSICAL RECORD.
C     EACH LOGICAL RECORD REPRESENTS ONE MINUTES WORTH OF DATA.(119
C     CHARACTERS).
C     THE FIRST 36 SETS OF 3 CHARACTERS REPRESENT INSTRUMENT READINGS.
C     THE NEXT 10 CHARACTERS IN GROUPS OF TWO REPRESENT THE MINUTE,
C     HOUR,DAY,MONTH AND EXPERIMENT CODE FOR THE MINUTE BEING RECORDED.
C     THE 119TH CHARACTER IS A DOLLAR SIGN TO INDICATE END OF LOGICAL
C     RECORD
C
C
C     INPUT DECK
C     1  COMMENTS CARDS ENDING WITH $ IN COL 1
C        NOT MORE THAN 62 COMMENTS CARDS MAY BE USED
C     2  # OF END OF FILE MARKS IN I2 FORMAT TO BE FOUND ON INPUT TAPE
C     3  NUMBER OF FILES ALREADY WRITTEN ON TAPE IN I2 FORMAT
C
      DIMENSION WBUF(1250),INBUF(31),A(119),REG(16)
      IMPLICIT INTEGER(A-Z)
      DATA BLNK/1H /,DOLR/1H$/
  800 FORMAT(20A4)
  801 FORMAT(55H *** COMMENT INFO TOO LARGE--OR DOLLAR SIGN MISSING ***)
  802 FORMAT(1H ,5X,20A4)
  803 FORMAT(1H ,5X,49HI/O OPERATION COMPLETE BUT ERROR HAS OCCURRED ***,
     1  15HAT STATEMENT # ,I5)
  804 FORMAT(I2)
  806 FORMAT(1H1)
  807 FORMAT(1X,20A4)
  812 FORMAT(17H0STARTING TIME IS, I2,1H/,I2,1H/,I2,1H/,I2)
  813 FORMAT(15H ENDING TIME IS ,  I2,1H/,I2,1H/,I2,1H/,I2)
  814 FORMAT(25H NUMBER OF BAD RECORDS IS ,  I10)
  815 FORMAT (35H NUMBER OF EOFS  ON COMPACT TAPE IS,  I5)
C
C
C
C     BLANK OUT THE 5000 CHARACTER WRITE BUFFER(WBUF)
      DO 10 IDO=1,1250
   10 WBUF(IDO)=0
C
      NERR=0
C     READ COMMENT CARDS INTO WBUF AND THEN WRITE ONTO TAPE FILE
      BEG=1
```

```
          END=20
          PRINT 806
       20 READ 800,(WBUF(I),I=BEG,END)
          PRINT 807,(WBUF(I),I=BEG,END)
          IF(WBUF(1).EQ.DOLR) GO TO 39
          IF(WBUF(BEG).EQ.DOLR) GO TO 30
          BEG=END+1
          END=BEG+19
          IF(BEG.LE.1250) GO TO 20
          PRINT 801
          STOP 1
C
       30 CALL BUFFEROUT(1,1,WBUF(1),1250,N)

       35 GO TO (35,39,37,37),N
       37 ERR=37
          PRINT 803,ERR
C
C         READ NUMBER OF FILES ON INPUT TAPE
       39 READ 804,NEOF
          KEOF=0
C
C
C         READ 1 LOGICAL RECORD FROM 200 BPI TAPE.(124 BYTES)
C         STORE ONE BYTE PER WORD IN ARRAY A
C         REARRANGE THE DATA
C         PACK 119 BYTES INTO WBUF
C         REPEAT ABOVE UNTIL 4998 BYTES HAVE BEEN STORED.
C         DUMP WBUF (5000 CHARACHTERS-1 PHYSICAL RECORD)ONTO TAPE FILE
C
C         INITIALIZE START OF FILE FLAG
     9998 STFIL=0
C         COUNT THE RECORDS(1-42)
       40 RECNO=0
C
C         COUNT THE CHARACTERS(1-4998)
          CHARS=-119
C
C         ZERO OUT WBUF ARRAY
          DO 45 IDO=1,1250
       45 WBUF(IDO)=0
C
C
       50 RECNO=RECNO+1
C
C         READ INPUT TAPE
       53 CALL BUFFERIN(2,1,INBUF,31,N)
          TIME=TIME+1
       55 GO TO (55,60,69,57),N
       57 ERR=57
          NERR=NERR+1
X         PRINT 803,ERR
X         CALL PDUMP(INBUF(1),INBUF(31))
          GO TO 53
```

```
C
      60 CONTINUE
C
C         INLINE ASSEMBLY USED TO PUT ONE ONE BYTE PER WORD IN ARRAY A
C
S         LCI      0          SAVE REGISTERS
S         STM,0    REG
S         LI,1     119        R1 COUNTS # OF BYTES LEFT TO BE MOVED
S         LI,2     0          R2 GIVES BYTE AND WORD POSITION
S     62  LB,4     INBUF,2    GET THE BYTE
S         STW,4    A,2        STORE IT IN ARRAY A
S         AI,2     1          COUNT A BYTE
S         BDR,1    62S        DECREMENT AND TEST FOR END
S         LCI      0          RESTORE REGISTERS
S         LM,0     REG
C
C
          CALL CHANGE(A,MIN,HOUR,DAY,MO,STFIL,TIME)
C
          IF(STFIL.NE.0) GO TO 61
C         PRINT STARTING TIME
          PRINT 812,MO,DAY,HOUR,MIN
          STFIL=1
          GC TC 63
C         SAVE RUNNING TIME
      61  LMO=MO
          LDAY=DAY
          LHR=HOUR
          LMIN=MIN
      63  CHARS=CHARS+119
C
C         PACK BYTES FROM ARRAY A INT 119 BYTES OF WBUF
S         LCI      0          SAVE REGISTERS
S         STM,0    REG
S         LI,1     119
S         LI,2     0          R2 POINTS TO WORD IN A ARRAY
S         LW,3     CHARS      R3 POINTS TO BYTE POSITION IF WBUF ARRAY
S     64  LW,4     A,2        GET WORD FROM A
S         STB,4    WBUF,3     STORE BYTE IN WBUF
S         AI,2     1          ADD TO WORD COUNT
S         AI,3     1          ADD TO BYTE COUNT
S         BDR,1    64S
S         LCI      0
S         LM,0     REG
C
C
          IF(RECNO.LT.42) GO TO 50
C
C         PUT 5000 CHARACTERS OF WBUF ONTO TAPE FILE
C         THEN GET NEXT SET OF 42 RECORDS
C
          CALL BUFFER OUT(1,1,WBUF(1),1250,N)
      65  GO TO (65,40,67,67),N
      67  ERR=67
```

```
      PRINT 803,ERR                                                     CPT 1740
      GO TO 40                                                          CPT 1750
   69 END FILE 1                                                        CPT 1760
C                                                                       CPT 1770
C     PRINT THE LAST DATE READ                                          CPT 1780
      PRINT 813,LMO,LDAY,LHR,LMIN                                       CPT 1790
      PRINT 814,NERR                                                    CPT 1800
      NERR=0                                                            CPT 1810
C                                                                       CPT 1820
      KEOF=KEOF+1                                                       CPT 1830
      STFIL=0                                                           CPT 1840
      IF(KEOF.LT.NEOF) GO TO 40                                         CPT 1850
C                                                                       CPT 1860
      END FILE 1                                                        CPT 1870
      REWIND 1                                                          CPT 1880
      REWIND 2                                                          CPT 1890
C                                                                       CPT 1900
C     READ NUMBER OF FILESALREADY WRITTEN ON TAPE                       CPT 1910
      READ 804,EOFS                                                     CPT 1920
      KEOF=KEOF+EOFS+1                                                  CPT 1930
      PRINT 815, KEOF                                                   CPT 1940
      STOP                                                              CPT 1950
      END                                                               CPT 1960
```

```
      SUBROUTINE CHANGE(A,MIN,HOUR,DAY,MO, ST,TIME)                      CNG  10
      DIMENSION A(119),IDAT(12)                                          CNG  20
      IMPLICIT INTEGER(A-Z)                                              CNG  30
      DATA(IDAT(I),I=1,12)/31,28,31,30,31,30,31,31,30,31,30,31/          CNG  40
      DATA COLR/4Z0028/                                                  CNG  50
C     THIS SUBROUTINE CHANGES THE ORDER OF 119 WORDS OF ARRAY A          CNG  60
C     CHANGES THE TIME  AND RETURNS 119 WORDS IN A READY TO BE OUTPUT    CNG  70
C                                                                        CNG 100
C     CHECK AND CORRECT CLOCK DATA                                       CNG 110
C                                                                        CNG 120
      EXP=A(117)+A(118)*10                                               CNG 125
      MIN=A(109)+A(110)*10                                               CNG 130
      HOUR=A(111)+A(112)*10                                              CNG 140
      IF(ST.NE.0) GO TO 1                                                CNG 150
      MO=A(115)+A(116)*10                                                CNG 160
      DAY=A(113)+A(114)*10                                               CNG 170
      TIME=HOUR*60+MIN                                                   CNG 180
      GO TO 6                                                            CNG 190
C                                                                        CNG 200
    1 IF(TIME-1440) 3,2,4                                                CNG 210
    2 TIME=0                                                             CNG 220
      DAY=DAY+1                                                          CNG 230
    3 IF(DAY.LE.IDAT(MO)) GO TO 6                                        CNG 240
      DAY=DAY-IDAT(MO)                                                   CNG 250
      MO=MO+1                                                            CNG 260
      GO TO 5                                                            CNG 270
    4 TIME=TIME-1440                                                     CNG 280
      DAY=DAY+1                                                          CNG 290
      GO TO 1                                                            CNG 300
    5 IF(MO.GT.12) MO=MO-12                                              CNG 310
C                                                                        CNG 320
    6 A(109)=MIN/10                                                      CNG 330
      A(110)=MIN-A(109)*10                                               CNG 340
      A(111)=HOUR/10                                                     CNG 350
      A(112)=HOUR-A(111)*10                                              CNG 360
      A(113)=DAY/10                                                      CNG 370
      A(114)=DAY-A(113)*10                                               CNG 380
      A(115)=MO/10                                                       CNG 390
      A(116)=MO-A(115)*10                                                CNG 400
      A(117)=EXP/10                                                      CNG 410
      A(118)=EXP-A(117)*10                                               CNG 420
C     THE UNITS AND HUNDREDS DIGIT ARE INTERCHANGED 3 AT A TIME          CNG 430
C     FOR THE FIRST 108 WORDS                                            CNG 440
      J=-2                                                               CNG 450
      DO 10 IDO=1,36                                                     CNG 460
      J=J+3                                                              CNG 470
      IF(A(J).LT.0 .OR. A(J).GT.9) GO TO 7                               CNG 472
      IF(A(J+1).LT.0 .OR. A(J+1).GT.9) GO TO 7                           CNG 474
      IF(A(J+2).LT.0 .OR.A(J+2).GT.9) GO TO 7                            CNG 476
      TEMP=A(J)                                                          CNG 480
      A(J)=A(J+2)                                                        CNG 490
      A(J+2)=TEMP                                                        CNG 500
      GO TO 10                                                           CNG 510
```

```
    7 A(J)=9                                                      CNG  530
      A(J+1)=9                                                    CNG  540
      A(J+2)=9                                                    CNG  550
   10 CONTINUE                                                    CNG  560
      A(119)=COLR                                                 CNG  57C
      RETURN                                                      CNG  580
      END                                                         CNG  590
```

2. "Compact 556"

```
 08 28 DEC 11,'72 ID=002112F1
 JOB AA03,NUNN J R    ,    ,        COMPACT AT 55633026
 LIMIT (TIME,15),(LO,20),(UO,50)
 ASSIGN F 1,(DEVICE,7T),             (INSN,308C),(UNPACK),(BIN),(TRIES,0)
 ASSIGN F 2,(DEVICE,7T),(LABEL,MCC),(OUTSN,3027),(KEYED),(SEQUEN),(OUT)
FORTRAN LS,GO,S
 EXT. FORTRAN IV, VERSION D00
```

```
      DIMENSION FILE(3),REC(60,41),INBUF(31),A(119),B(41),KEY(3)          IBPK  10
      DIMENSICN XOUT(36,24,2),ACCT(2),PASS(2),OUTSN(2),INSN(2)            IBPK  20
      IMPLICIT INTEGER (A-Z)                                              IBPK  30
      DATA FILE/12HMCCOLLOCH    /                                         IBPK  40
  800 FORMAT (I5,I10,6X,A4)                                               IBPK  50
  801 FCRMAT(20H0LAST KEY WRITTEN IS, I8)                                 IBPK  55
  805 FCRMAT(24I3,8X)                                                     IBPK  60
  808 FORMAT(1H1,3X,108H  MIN MAX  MIN MAX  MIN MAX  MIN MAX  MIN MAX     IBPK  70
     1IN MAX  MIN MAX  MIN MAX  MIN MAX  MIN MAX  MIN MAX  MIN MAX  )     IBPK  80
  809 FORMAT(4H0HR ,I6,11I9)                                              IBPK  90
  810 FCRMAT(I4,12(I5,I4))                                                IBPK 100
  812 FORMAT(17H0STARTING TIME IS, I2,1H/,I2,1H/,I2,1H/,I2)               IBPK 110
  813 FORMAT(15H ENDING TIME IS ,  I2,1H/,I2,1H/,I2,1H/,I2)               IBPK 120
  901 FCRMAT(33H0FIRST GOOD RECORD CF FILE IS EOF)                        IBPK 130
  902 FCRMAT(6H ERR =,Z3)                                                 IBPK 140
C                                                                         IBPK 150
C     DATA DECK                                                           IBPK 160
C     1  COL 1-5 # OF FILES ON INPUT TAPE                                 IBPK 170
C        COL 6-15     0  OR KEY (RIGHT ADJUSTED)                          IBPK 175
C           0 FOR FIRST TAPE TRANSFER                                     IBPK 180
C           KEY OF LAST SUCCESSFUL RECORD WRITTEN FOR SUBSEQUENT TAPES    IBPK 190
C        COL 16 TO 25    # OF TAPE TO BE WRITTEN ON                       IBPK 195
C     2 MIN AND MAX CARDS                                                 IBPK 200
C                                                                         IBPK 210
C     NEOF IS # OF END OF FILE MARKS ON INPUT TAPE.                       IBPK 215
C     LEOF COUNTS THE # OF FILES WRITTEN DURING THIS RUN.                 IBPK 220
C                                                                         IBPK 225
      READ 800,NEOF,TAPE,OUTSN(1)                                         IBPK 230
C                                                                         IBPK 235
      UNIT=2                                                              IBPK 240
      ACCT(1)=0                                                           IBPK 245
       PASS(1)=0                                                          IBPK 250
      ORG=2                                                               IBPK 255
      ACCES=1                                                             IBPK 060
      SIZE=2460                                                           IBPK 265
C                                                                         IBPK 270
      IF (TAPE .NE.0) GO TO 1                                             IBPK 275
C                                                                         IBPK 280
C     OPEN IN  OUT  MODE FOR FIRST TAPE                                   IBPK 285
      MCDE=4                                                              IBPK 290
      CALL ERRSET(ERR,500S,600S,DCB)                                      IBPK 295
      CALL OPENF(UNIT,FILE,MODE,ACCT,PASS,ORG,ACCES,INSN,OUTSN)           IBPK 300
      GC TO 3                                                             IBPK 310
C                                                                         IBPK 315
C     OPEN IN THE UPDATE MODE AND FIND THE LAST KEY WRITTEN               IBPK 320
    1 MODE=6                                                              IBPK 325
      INSN(1)=OUTSN(1)
      CALL ERRSET(ERR,500S,600S,DCB)                                      IBPK 34C
      CALL OPENF(UNIT,FILE,MODE,ACCT,PASS,ORG,ACCES,INSN,OUTSN)           IBPK 430
      KEY(1)=TAPE                                                         IBPK 440
      CALL GET(UNIT,REC,SIZE,KEY,4)                                       IBPK 450
C                                                                         IBPK 455
    3 LEOF=0                                                              IBPK 460
```

```
C                                                                IBPK 470
C      READ AND PRINT MIN AND MAX CARDS                          IBPK 480
       READ 805,(((XOUT(I,J,K),K=1,2),J=1,24),I=1,36)            IBPK 490
       PRINT 808                                                 IBPK 500
       PRINT 809,((I),I=1,12)                                    IBPK 510
       DO 31 I=1,36                                              IBPK 520
    31 PRINT 810,(I,((XOUT(I,J,K),K=1,2),J= 1,12))               IBPK 530
       PRINT 809,((I),I=13,24)                                   IBPK 540
       DO 32 I=1,36                                              IBPK 550
    32 PRINT 810,(I,((XOUT(I,J,K),K=1,2),J=13,24))               IBPK 560
C                                                                IBPK 570
C      ONE HOUR INITIALIZED TO ALL 999                           IBPK 580
     5 DO 10 IDO=1,60                                            IBPK 590
       DO 10 JDO=1,41                                            IBPK 600
    10 REC(IDO,JDO)=999                                          IBPK 610
C                                                                IBPK 620
C      READ FIRST RECORD FROM FILE                               IBPK 630
    17 STFIL=0                                                   IBPK 640
    20 CALL BUFFERIN (1,1,INBUF,31,N)                            IBPK 650
    30 GO TO (30,40,900,20),N                                    IBPK 660
    40 CALL ENTER(INBUF,A)                                       IBPK 670
       CALL CHANGE(A,B,MIN,HOUR,DAY,MO,STFIL,XOUT,TIME)          IBPK 680
       IF(MIN.LT.0 .OR. MIN.GT.59) GO TO 20                      IBPK 682
       IF(HOUR.LT.0 .OR. HOUR.GT.23) GO TO 20                    IBPK 684
C                                                                IBPK 690
C      PRINT STARTING TIME                                       IBPK 700
       PRINT 812,MO,DAY,HOUR,MIN                                 IBPK 710
       STFIL=1                                                   IBPK 720
       GO TO 105                                                 IBPK 730
C                                                                IBPK 740
C      READ ALL BUT FIRST RECORD FROM FILE                       IBPK 750
    50 CALL BUFFERIN(1,1,INBUF,31,N)                             IBPK 760
       TIME =TIME+1                                              IBPK 770
    60 GO TO (60,70,200,50),N                                    IBPK 780
    70 CALL ENTER(INBUF,A)                                       IBPK 790
       CALL CHANGE(A,B,MIN,HOUR,DAY,MO,STFIL,XOUT,TIME)          IBPK 800
C                                                                IBPK 810
C      SAVE RUNNING TIME                                         IBPK 820
       LMO=MO                                                    IBPK 830
       LDAY=DAY                                                  IBPK 840
       LHR=HOUR                                                  IBPK 850
       LMIN=MIN                                                  IBPK 860
C                                                                IBPK 870
C      TEST FOR BAD READING ON MINUTE                            IBPK 880
   100 IF(MIN.LT.0 .OR. MIN.GT.59) GO TO 50                      IBPK 890
       IF(HOUR.LT.0 .OR. HOUR.GT.23) GO TO 50                    IBPK 895
C                                                                IBPK 900
C      ENTER DATA INTO REC                                       IBPK 910
   105 IROW=MIN+1                                                IBPK 920
       DO 110 JDO=1,41                                           IBPK 930
   110 REC(IROW,JDO)=B(JDO)                                      IBPK 940
C                                                                IBPK 950
C      TEST FOR END OF REC                                       IBPK 960
       IF(IROW.LT.60) GO TO 50                                   IBPK 970
```

```
      C                                                                 IBPK 980
      C       WRITE KEYED RECORD ON TAPE                                IBPK 990
              KEY(1)=MO*10**4+DAY*10**2+HOUR                            IBPK1000
              CALL PUT(UNIT,REC,SIZE,KEY,4)                             IBPK1010
              IROW=0                                                    IBPK1020
      C                                                                 IBPK1030
      C       REINITIALIZE REC                                          IBPK1040
              DO 120 IDO=1,60                                           IBPK1050
              DO 120 JDO=1,41                                           IBPK1060
          120 REC(IDO,JDO)=999                                          IBPK1070
              GO TO 50                                                  IBPK1080
      C                                                                 IBPK1090
      C       EOF WAS FOUND ON INPUT TAPE                               IBPK1100
          200 IF(IROW.EQ.0) GO TO 210                                   IBPK1110
              IF(LEOF+1 .NE.NEOF) GO TO 210                             IBPK1115
      C                                                                 IBPK1120
      C       WRITE AN INCOMPLETE ENDING RECORD                         IBPK1130
              KEY(1)=MO*10**4+DAY*10**2+HOUR                            IBPK1140
              CALL PUT(UNIT,REC,SIZE,KEY,4)                             IBPK1150
      C                                                                 IBPK1160
          210 LEOF=LEOF+1                                               IBPK1170
      C                                                                 IBPK1180
      C       PRINT LAST DATE READ                                      IBPK1190
              PRINT 813, LMO,LDAY,LHR,LMIN                              IBPK1200
      C                                                                 IBPK1210
      C       TEST FOR LAST EOF                                         IBPK1220
              IF(LEOF.EQ.NEOF) GO TO 300                                IBPK1230
              GO TO 17                                                  IBPK1250
          300 PRINT 801,KEY(1)                                          IBPK1252
              KEY(1)=999999                                             IBPK1255
              CALL PUT(UNIT,REC,SIZE,KEY,4)                             IBPK1260
              CALL CLOSEF(UNIT)                                         IBPK1265
              STOP                                                      IBPK1290
      C                                                                 IBPK1300
      C       ERROR PRINTS                                              IBPK1310
          900 PRINT 901                                                 IBPK1320
              LEOF=LEOF+1                                               IBPK1325
              GO TO 20                                                  IBPK1330
          500 PRINT 902,ERR                                             IBPK1340
              OUTPUT KEY                                                IBPK1350
              STOP                                                      IBPK1360
          600 LINE =600                                                 IBPK1362
              OUTPUT LINE                                               IBPK1364
              PRINT 902,ERR                                             IBPK1366
              STOP                                                      IBPK1368
              END                                                       IBPK1370
```

```
          SUBROUTINE ENTER(INBUF,A)
          DIMENSION REG(16)
    C     INBUF AND A ARE ARRAYS BUT ARE NOT DIMENSIONED HERE
    C     BECOUSE FORTRAN ADJUSTS THE STARTING ADDRESSES TO WORD ONE
    C     AND I USE IT AS WORD ZERO IN THIS ROUTINE
    C
          IMPLICIT INTEGER(A-Z)
    C
    C     INLINE ASSEMBLY USED TO PUT ONE ONE BYTE PER WORD IN ARRAY A
    C
    S     LCI     0          SAVE REGISTERS
    S     STM,0   REG
    S     LI,1    119        R1 COUNTS # OF BYTES LEFT TO BE MOVED
    S     LI,2    0          R2 GIVES BYTE AND WORD POSITION
    S  62 LB,4    *INBUF,2   GET THE BYTE
    S     STW,4   *A,2       STORE IT IN ARRAY A
    S     AI,2    1          COUNT A BYTE
    S     BDR,1   62S        DECREMENT AND TEST FOR END
    S     LCI     0          RESTORE REGISTERS
    S     LM,0    REG
    C
          RETURN
          END
```

```
      SUBROUTINE CHANGE(A,B,MIN,HOUR,DAY,MO, ST,XOUT,TIME)                CHG   10
      DIMENSION A(119),IDAT(12),XOUT(36,24,2),B(41)                       CHG   20
      IMPLICIT INTEGER(A-Z)                                               CHG   30
      DATA(IDAT(I),I=1,12)/31,28,31,30,31,30,31,31,30,31,30,31/           CHG   40
C                                                                         CHG   50
C     GET TIME                                                            CHG   60
      MIN=A(109)+A(110)*10                                                CHG   70
      HOUR=A(111)+A(112)*10                                               CHG   80
      IF(ST.NE.0) GO TO 1                                                 CHG   90
      MO=A(115)+A(116)*10                                                 CHG  100
      DAY=A(113)+A(114)*10                                                CHG  110
      TIME=HOUR*60+MIN                                                    CHG  120
      GO TO 6                                                             CHG  130
C                                                                         CHG  140
    1 IF(TIME-1440) 3,2,4                                                 CHG  150
    2 TIME=0                                                              CHG  160
      DAY=DAY+1                                                           CHG  170
    3 IF(DAY.LE.IDAT(MO)) GO TO 6                                         CHG  180
      DAY=DAY-IDAT(MO)                                                    CHG  190
      MO=MO+1                                                             CHG  200
      GO TO 5                                                             CHG  210
    4 TIME=TIME-1440                                                      CHG  220
      DAY=DAY+1                                                           CHG  230
      GO TO 1                                                             CHG  240
    5 IF(MO.GT.12) MO=MO-12                                               CHG  250
C                                                                         CHG  260
C     STORE CORRECT TIME AND EXP IN ARRAY B                               CHG  270
    6 B(37)=MIN                                                           CHG  280
      B(38)=HOUR                                                          CHG  290
      B(39)=DAY                                                           CHG  300
      B(40)=MO                                                            CHG  310
      B(41)=A(117)+A(118)*10                                              CHG  320
C                                                                         CHG  330
C     THE FIRST 108 WORDS OF A ARE COMBINED 3 AT A TIME AND ACTUAL        CHG  340
C     READINGS ARE STORED IN B.                                           CHG  350
      H=HOUR+1                                                            CHG  355
      IF(H.LE.0 .OR. H.GT.60) GO TO 20
      J=-2                                                                CHG  360
      DO 10 IDO=1,36                                                      CHG  370
      J=J+3                                                               CHG  380
      B(IDO)=A(J)+A(J+1)*10+A(J+2)*100                                    CHG  390
      IF(B(IDO).GE.XOUT(IDO,H,1) .AND. B(IDO).LE.XOUT(IDO,H,2)) GO TO 10CHG  410
      B(IDO)=999                                                          CHG  420
   10 CONTINUE                                                            CHG  430
      RETURN                                                              CHG  440
   20 DO 30 IDO=1,36
   30 B(IDO)=999
      RETURN
      END                                                                 CHG  450
```

3. "List Keys"

```
 08 50 DEC 14,'72 ID=043412F1
 JOB AA03, JOHN NUNN  ,    . 2356    LIST KEYS FROM LABEL TAPE
 LIMIT (TIME,15),(LO,20),(UO,20)
 ASSIGN F 1,(DEVICE,7T),(LABEL,MCC),(INSN,3025),(KEYED),(SEQUEN),(IN)
FORTRAN LS,GO
 EXT. FORTRAN IV, VERSION DOO
```

```
      DIMENSION FILE(3),ACCT(2),PASS(2),INSN(2),KEY(8),REC(60,41)
      IMPLICIT INTEGER (A-Z)
      DATA FILE/12HMCCOLLOCH   /
  800 FORMAT(A4)
  801 FORMAT(I10,13H RECORDS READ )
  802 FORMAT(I11)
  803 FORMAT(43H0KEYS WRITTEN ON TAPE HAVE FOLLOWING FORMAT/
     1 39H COL.1-2=MONTH/COL.3-4=DAY/COL.5-6=HOUR//)
  804 FORMAT(11H COL 123456/)
C
      PRINT 803
      PRINT 804
C     PREPARE TO READ KEYED RECORDS
      READ 800,INSN(1)
      UNIT=1
      MODE=2
      ACCT(1)=0
      PASS(1)=0
      ORG=2
      ACCES=1
      SIZE=2460
      OUTSN=0
      CALL ERRSET(ERR,600S,600S,DCB)
      CALL OPENF(UNIT,FILE,MODE,ACCT,PASS,ORG,ACCES,INSN,OUTSN)
C
C     COUNT NUMBER OF RECORDS READ
      NREC=0
C
    5 CALL GET(UNIT,REC,SIZE)
      NREC=NREC+1
      CALL GETKEY(UNIT,KEY,LGTH)
      IF(KEY(1).EQ.999999) GO TO 500
      PRINT 802,KEY(1)
      GO TO 5
C
C     END OF FILE WAS READ
  500 PRINT 801,NREC
      CALL CLOSEF(UNIT)
      STOP
C
C     ERROR EXITS
  600 PRINT 902,ERR
  902 FORMAT(6H ERR =,Z3)
      OUTPUT NREC
      GO TO 5
      END
```

4. "Average 556"

```
 12 37 DEC 08,'72 ID=0F4612F1
 JOB AA03, NUNN J R    ,    . 2356    AVERAGES FROM 3076 FOR RECORD
 LIMIT (TIME,15),(PAGES,500)
 ASSIGN F 1,(DEVICE,7T),(LABEL,MCC),(INSN,3027),(KEYED),(SEQUEN),(IN)
FORTRAN LS,GO,S
 EXT. FORTRAN IV, VERSION D00
```

```
      DIMENSION INBUF(60,41), ISUM(36,100,2),AVG(36,100,2),CRD(80)
      DIMENSION FILE(3),ACCT(2),PASS(2),INSN(2),KEY(8)
      INTEGER UNIT,ACCT,PASS,ORG,ACCES,SIZE,OUTSN,ERR
      EQUIVALENCE(ISUM,AVG)
      DATA FILE/12HMCCOLLOCH   /,                    DOLR/1H$/
C
  800 FORMAT(2I5)
  801 FORMAT(6I5)
  802 FORMAT(24H0END OF TAPE ENCOUNTERED)
  803 FORMAT(45H0MAX NO. OF INTERVALS EXCEEDED, 100 PROCESSED)
  804 FORMAT(8H1AVG. OF, I5, 7HMINUTES/
     1 16H STARTING AT MO=, I2, 5H,DAY=, I2, 6H,HOUR=, I2, 9H,MINUTE=1/
     2 16H ENDING   AT MO=,I2,5H,DAY=, I2, 6H,HOUR=,I2,10H,MINUTE=60//)
  805 FORMAT(28H0ENDING KEY WAS NOT FOUND OR/
     1       36H INTERVAL EXCEEDS LAST KEY REQUESTED)
  806 FORMAT(80A1)
  807 FORMAT( 1X,80A1)
  810 FORMAT(A4)
C
C     DATA DECK SETUP
C     1  COMMENTS CARDS ENDING WITH $ IN COL 1
C     1 PLUS  COL 1-4 TAPE NUMBER SAME AS INSN USED
C     2  COL.1-5 NUMBER OF SETS TO BE PROCESSED (N)
C            6-10 SIZE OF INTERVALS IN MINUTES
C     3  COL.1-5  STARTING MONTH
C            6-10          DAY
C            11-15         HOUR
C            16-20 ENDING MONTH
C            21-25         DAY
C            26-30         HOUR
C     REPEAT 3 (N TIMES)
C
C     INT IS THE # OF MINUTES TO BE AVERAGED
C     NINT COUNTS THE MINUTES BEING AVERAGED
C     JDO COUNTS # OF INTERVALS (MAY NOT EXCEED 100)
C     M COUNTS MINUTES (1-60)
C
C     READ AND PRINT COMMENTS
    2 READ 806,CRD
      IF(CRD(1).EQ.DOLR) GO TO 1
      PRINT 807,CRD
      GO TO 2
C
C     PREPARE TO OPEN FILE
    1 READ 810,INSN(1)
      UNIT=1
      MODE=2
      ACCT(1)=0
      PASS(1)=0
      ORG=2
      ACCES=1
      SIZE=2460
      OUTSN=0
```

```
C
      CALL ERRSET(ERR,900S,900S)
      CALL OPENF(UNIT,FILE,MODE,ACCT,PASS,ORG,ACCES,INSN,OUTSN)
C
C     READ NUMBER OF RUNS,NUMBER OF MINUTES TO BE AVERAGED
      READ 800,NRUNS,INT
C
C
      DO 40 MDO=1,NRUNS
C
C     INITIALIZE
C     ZERO OUT ISUM ARRAY
      DO 3 IDO=1,36
      DO 3 JDO=1,100
      DO 3 KDO=1,2
    3 ISUM(IDO,JDO,KDO)=0
C
      JDO=1
      NINT=0
C
C     READ STARTING AND ENDING DATES
      READ 801,MO1,IDAY1,IHR1,MO2,IDAY2,IHR2
      PRINT804,INT,MO1,IDAY1,IHR1,MO2,IDAY2,IHR2
C
C     CALCULATE STARTING AND ENDING KEYS
      KEY(1)=MO1*10000+IDAY1*100+IHR1
      LKEY  =MO2*10000+IDAY2*100+IHR2
C
C     READ FIRST RECORD USING KEY
      CALL GET(UNIT,INBUF,SIZE,KEY,4)
      M=0
      GO TO 20
C
C     READ ONE RECORD
   10 CALL GET(UNIT,INBUF,SIZE)
      CALL GETKEY(UNIT,KEY,LGTH)
      IF(KEY(1).GE.999999) GO TO 500
      M=0
   20 M=M+1
      IF(M.LE.60) GO TO 25
      IF(KEY(1).EQ.LKEY) GO TO 35
      IF(KEY(1) .GT. LKEY) GO TO 510
      GO TO 10
C
C     PROCESS THE NEXT MINUTE IN THE JDO INTERVAL
   25 NINT=NINT+1
      DO 30 NDO=1,36
      IF(INBUF(M,NDO).EQ.999) GO TO 30
      ISUM(NDO,JDO,1)=ISUM(NDO,JDO,1)+INBUF(M,NDO)
      ISUM(NDO,JDO,2)=ISUM(NDO,JDO,2)+1
   30 CONTINUE
C
C     TEST FOR END OF INTERVAL AND MAX NUMBER OF INTERVALS
      IF(NINT.LT.INT) GO TO 20
```

```
      NINT=0
      JDO=JDO+1
      IF(JCO.LE.100) GO TO 20
      GO TO 520
C
C     ORIGINAL DATA HAS BEEN SUMMED
   35 JDO=JDO-1
      CALL CALC(ISUM,AVG,JDO)
      CALL PRINT(AVG,ISUM,JDO)
C
   40 CCNTINUE
C
      CALL CLOSEF(UNIT)
      STOP
C     END OF TAPE WAS ENCCUNTERED
  500 PRINT 802
      GO TO 600
C     LAST KEY RECUESTED WAS JUST PROCESSED  ABNORMAL EXIT
  510 PRINT 805
      GO TO 600
C
C     MORE THAN 1CO INTERVALS WERE RECUESTED
  520 PRINT 803
      JDO=JDO-1
      GO TO 35
C
C     ERROR STOPS
  600 CALL CLOSEF(UNIT)
      JDO=JDO-1
      CALL CALC(ISUM,AVG,JDO)
      CALL PRINT(AVG,ISUM,JDO)
      STOP
  900 OUTPUT ERR
      STOP
      END
```

```
      SUBROUTINE CALC(ISUM,AVG,NINT)
      DIMENSION ISUM(36, 100,2),AVG(36, 100,2)
      DO 10 IDO=1,36
      DO 10 JDO=1,NINT
      IF(ISUM(IDO,JDO,2).NE.0) GO TO 5
      AVG(IDO,JDO,1)=0.
      GO TO 10
    5 AVG(IDO,JDO,1)=FLOAT(ISUM(IDO,JDO,1))/FLOAT(ISUM(IDO,JDO,2))
   10 CONTINUE
      DC 40 J=1,NINT
      AVG(1,J,1)=(AVG(1,J,1)-500.0)/10.0
      DO 20 I=2,4
   20 AVG(I,J,1)=(AVG(I,J,1)-500.0)/100.0
      DC 21,I=5,11
   21 AVG(I,J,1)=(AVG(I,J,1)-500.0)/10.0
      DO 22,I=12,16
   22 AVG(I,J,1)=(AVG(I,J,1))/40.0
      AVG(17,J,1)=AVG(17,J,1)*.028665
      AVG(18,J,1)=(AVG(18,J,1)*.17)+745.8
      AVG(19,J,1)=AVG(19,J,1)*2.5
      AVG(20,J,1)=AVG(20,J,1)*2.5
      AVG(21,J,1)=(AVG(21,J,1)-500.0)/10.0
      DO 23 I=22,24
   23 AVG(I,J,1)=(AVG(I,J,1)-500.0)/100.0
      AVG(25,J,1)=((AVG(25,J,1)-333.)/167.)/1.6818
      AVG(26,J,1)=(AVG(26,J,1)/66.67)/7.6
      AVG(27,J,1)=(AVG(27,J,1)/200.0)/4.10
      AVG(28,J,1)=(AVG(28,J,1)/200.0)/4.56
      AVG(29,J,1)=(AVG(29,J,1)/10C.0)/7.11
      AVG(30,J,1)=(AVG(30,J,1)/10C.0)/7.90
      AVG(31,J,1)=(AVG(31,J,1)-500.0)/3.33
      AVG(32,J,1)=AVG(32,J,1)
      AVG(33,J,1)=(AVG(33,J,1)) /2.78
      AVG(34,J,1)=AVG(34,J,1)
      AVG(35,J,1)=(AVG(35,J,1))/16.4
      AVG(36,J,1)=AVG(36,J,1)
   40 CCNTINUE
      RETURN
      END
```

```
      SUBROUTINE PRINT(AVG,ISUM,NINT)
      DIMENSION ISUM(36, 100,2),AVG(36, 100,2)
  801 FORMAT(1H0,I11,7I15)
  805 FORMAT(1H1)
  850 FORMAT(I3,F8.2,I5,7(F10.2,I5))
      IBEG=1
      IEND=8
   40 IF(IEND.GT.NINT) IEND=NINT
      PRINT 801,((J),J=IBEG,IEND)
      DO 50 IDO=1,36
   50 PRINT 850,IDO,((AVG(IDO,J,1),ISUM(IDO,J,2)),J=IBEG,IEND)
      IBEG=IEND+1
      IEND=IEND+8
      IF(IBEG.GT.NINT) RETURN
      PRINT 805
      GO TO 40
      END
```

5. "D-Plot"

```
 08 29 DEC 11,'72 ID=002212F1
 JOB AA03,  J R NUNN  ,    .                PLOTS OF LYSIMETER DATA
 LIMIT (TIME,15),(LC,30),(UO,10)
 ASSIGN F 1,(DEVICE,7T),(LABEL,MCC           ),(INSN,3C23),(KEYED),(SEQUEN),(IN)
FORTRAN LS,GO
 EXT. FORTRAN IV, VERSION DOO
```

```
      DIMENSION INBUF(60,41), ISUM(36,100,2),AVG(36,100,2)
      DIMENSION FILE(3),ACCT(2),PASS(2),INSN(2),KEY(8)
      DIMENSICN CRD(80)
      DIMENSION H(100),H2(100),V(100),V2(100)
      EQUIVALENCE(ISUM,AVG)
      EQUIVALENCE (INBUF(1),H),(INBUF(101),H2),(INBUF(201),V)
      EQUIVALENCE (INBUF(301),V2)
      DATA DLR/1H$/, STAR/1H*/, PLUS/1H+/
      DATA FILE/12HMCCOLLOCH   /,END/1HX/
      INTEGER UNIT,ACCT,PASS,ORG,ACCES,SIZE,OUTSN,ERR
C
C     DATA DECK
C     I. TAPE NUMBER
C     II. COMMENTS ENDING WITH $ IN COL 1
C     III. INTERVALS TO BE PROCESSED
C        COL 1-10 STARTING KEY
C        COL 11-20 ENDING KEY
C        COL 21-25 INTERVAL
C     ALL NUMBERS IN ITEM III MUST BE RIGHT ADJUSTED IN THEIR FIELD
C     IV.  CHANNELS TO BE PLOTTED
C     TWO CHANNELS AND MIN AND MAX PLOT POINT ON EACK CARD
C     COL 1-5 FIRST CHANNEL
C     CCL 6-1C SECOND CHANNEL OR ZERO
C     COL 11-20  MINIMUM VALUE TO BE USED ON GRAFH
C     COL 21-30 MAXIMUM VALUE TO BE USED
C        REPEAT CARD IV
C     V.  BLANK CARD TO INDICATE END OF CHANNELS PLOTTED FOR THIS INT.
C     REPEAT II THRU V
C     X IN COL 1        TO INDICATE END OF JOB
C
  800 FORMAT(80A1)
  801 FORMAT(2I10,I5)
  802 FORMAT(2I5,2I10)
  803 FORMAT(24H0END CF TAPE ENCOUNTERED)
  804 FORMAT(A4)
  805 FORMAT(28H0ENDING KEY WAS NOT FOUND OR/
     1       36H INTERVAL EXCEEDS LAST KEY REQUESTED)
  806 FORMAT(30H0MAX NO. CF INTERVALS EXCEEDEC)
  807 FORMAT(1X,80A1)
  808 FORMAT(6H0ERR=  Z5)
  809 FORMAT(10H *=CHANNEL, I3)
  810 FORMAT(10H +=CHANNEL, I3)
  811 FORMAT(2F20.2)
  812 FORMAT (F20.2)
C
C     PREPARE TO OPEN FILE
    2 READ 804,INSN(1)
    1 NSW=0
      UNIT=1
      MODE=2
      ACCT(1)=0
      PASS(1)=0
      ORG=2
```

```
      ACCES=1
      SIZE=2460
      OUTSN=0
      CALL ERRSET(ERR,900S,900S)
      CALL CPENF(UNIT,FILE,MODE,ACCT,PASS,ORG,ACCES,INSN,OUTSN)
C
C     READ AND PRINT COMMENTS
    4 READ 80C,CRC
      IF(CRC(1).EC.END) GC TO 101C
      IF(CRD(1).EQ.DLR) GO TO 5
      PRINT 807,CRD
      GO TO 4
C
C     READ STARTING AND ENDING KEY AND NUMBER OF MINUTES TO BE AVERAGED
C
    5 READ 801,KEY(1),LKEY,INT
      PRINT 8C1,KEY(1),LKEY,INT
      IF(KEY(1).EQ.0) GO TO 1000
C
C     INITIALIZE
C     ZERO OUT ISUM ARRAY
      DO 3 IDO=1,36
      DC 3 JDO=1,100
      DC 3 KDC=1,2
    3 ISUM(IDO,JDO,KDO)=0
      JDO=1
      NINT=0
C
C     READ FIRST RECORD USING KEY
      CALL GET(UNIT,INBUF,SIZE,KEY,4)
      M=0
      GC TO 20
C
C     READ ONE RECORD
   10 CALL GET(UNIT,INBUF,SIZE)
      CALL GETKEY(UNIT,KEY,LGTH)
      IF(KEY(1).LT.999999) GO TO 15
      PRINT 803
      GO TO 23
   15 M=0
   20 M=M+1
      IF(M.LE.60) GO TO 25
      IF(KEY(1).EQ.LKEY) GO TO 35
      IF(KEY(1) .LT. LKEY) GO TO 10
      PRINT 805
C
C     SKIP PLOT CARDS FOR THIS INTERVAL
   23 READ 802,M1
      IF(M1.NE.0) GO TO 23
      GC TO 5
C
C     PRCCESS THE NEXT MINUTE IN THE JDO INTERVAL
   25 NINT=NINT+1
      DO 30 NDO=1,36
```

```
      IF(INBUF(M,NDO).EQ.999) GO TO 30
      ISUM(NDO,JDO,1)=ISUM(NDO,JDO,1)+INBUF(M,NDO)
      ISUM(NDO,JDO,2)=ISUM(NDO,JDO,2)+1
   30 CONTINUE
C
C     TEST FOR END OF INTERVAL AND MAX NUMBER OF INTERVALS
      IF(NINT.LT.INT) GO TO 20
      NINT=0
      JDO=JDO+1
      IF(JDO.LE.100) GO TO 20
      PRINT 805
      GO TO 5
C
C     ORIGINAL DATA HAS BEEN SUMMED
   35 JDO=JDO-1
      CALL CALC(ISUM,AVG,JDO)
C
C     PREPARE TO PLOT
C
   45 READ 802,M1,M2,VBOT,VTOP
      HLEFT=0.
      HRIGHT=100.
      NLINES=0
      IPR=1
      CH=STAR
      NCHN=0
      N=JDO
   50 IF(M1.EQ.0) GO TO 4
      K=M1
      PRINT 809,K
      DO 55 IDO=1,N
      H(IDO)=IDO
   55 V(IDO)=AVG(K,IDO,1)
      IF(M2.EQ.0) GO TO 70
      K=M2
      PRINT 810, K
      N2=JDO
      CH2=PLUS
      DO 60 IDO=1,N
      H2(IDO)=IDO
   60 V2(IDO)=AVG(K,IDO,1)
C
C     PLOT 2 CURVES
      PRINT 811,(V(I),V2(I),I=1,N)
      CALLDPLOT(N,V,H,CH,VTOP,VBOT,NLINES,HLEFT,HRIGHT,IPR,N2,V2,H2,CH2)
      GO TO 45
C
C     PLOT ONE CURVE
   70 N2=0
      PRINT 812,(V(I), I=1,N)
      CALL DPLOT(N,V,H,CH,VTOP,VBOT,NLINES,HLEFT,HRIGHT,IPR,N2)
      GO TO 45
C
C     ERROR IN GETPUT SYSTEM SEE BPM MANUAL FOR I/O ERROR CODES
```

```
      SUBROUTINE CALC(ISUM,AVG,NINT)
      DIMENSION ISUM(36, 100,2),AVG(36, 100,2)
      DO 10 IDO=1,36
      DO 10 JDO=1,NINT
      IF(ISUM(IDO,JDO,2).NE.0) GO TO 5
      AVG(IDO,JDO,1)=0.
      GO TO 10
    5 AVG(IDO,JDO,1)=FLOAT(ISUM(IDO,JDO,1))/FLOAT(ISUM(IDO,JDO,2))
   10 CONTINUE
      DO 40 J=1,NINT
      DO 20 I=1,16
   20 AVG(I,J,1)=(AVG(I,J,1)-500.)/10.
      AVG(17,J,1)=AVG(17,J,1)*.028665
      AVG(18,J,1)=(AVG(18,J,1)*.17)+745.8
      AVG(19,J,1)=(AVG(19,J,1)/10.)*1.5116*44.72
      AVG(20,J,1)=(AVG(20,J,1)/10.)*1.5116*44.72
      DO 30 I=21,24
   30 AVG(I,J,1)=(AVG(I,J,1)-444.44)/11.11
      AVG(25,J,1)=((AVG(25,J,1)-333.)/167.)/1.6818
      AVG(26,J,1)=((AVG(26,J,1)-333.)/167.)/1.6818
      AVG(27,J,1)=(AVG(27,J,1)/333.)/3.69
      AVG(28,J,1)=(AVG(28,J,1)/333.)/3.05
      AVG(29,J,1)=AVG(29,J,1)
      AVG(30,J,1)=(AVG(30,J,1)/100.)/7.9
      AVG(31,J,1)=(AVG(31,J,1)/100.)/7.9
      AVG(32,J,1)=(AVG(32,J,1)/66.67)/7.52
      AVG(33,J,1)=AVG(33,J,1)/2.78
      AVG(34,J,1)=AVG(34,J,1)/2.78
      AVG(35,J,1)=(AVG(35,J,1)/10.)*1.5116*44.72
      AVG(36,J,1)=(AVG(36,J,1)/10.)*1.5116*44.72
   40 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE DPLOT(N,V,H,CH1,C1,C2,K1,C3,C4,IPR,N2,V2,H2,CH2)         DPLO   1
C     ****************************************************************DPLO   2
  105 FORMAT(1X,6F20.1)                                                   DPLO   3
  120 FORMAT(9H1 POINTS A1,12H NOT PLOTTED/1X)                            DPLO   4
  201 FORMAT(1H1)                                                         DPLO   5
  202 FORMAT(1X)                                                          DPLO   6
C     ****************************************************************DPLO   7
      DIMENSION V(N),H(N),HPR(6),LINE(101),L10(101),V2(N2),H2(N2)         DPLO   8
      DATA (LINE(I),I=1,101),(L10(I),I=2,100,2)/151*1H /                  DPLO   9
      DATA (L10(I),I=1,101,2),LDOT/52*1H./                                DPLO  10
      VL=C1                                                               DPLO  11
      VU=C2                                                               DPLO  12
      NL=K1                                                               DPLO  13
      HL=C3                                                               DPLO  14
      HU=C4                                                               DPLO  15
      DO 12 I=1,101,20                                                    DPLO  16
   12 LINE(I)=LDOT                                                        DPLO  17
      IF(HL.GT.HU .OR. N.LT.2) STOP
      EPS=0.                                                              DPLO  19
      ASIGN=+1.                                                           DPLO  20
      IF(VL.LE.VU) GO TO 11                                               DPLO  21
      EPS=2.**(-34)                                                       DPLO  22
      ASIGN=-1.                                                           DPLO  23
      VL=-VL                                                              DPLO  24
      VU=-VU                                                              DPLO  25
      DO 16 I=1,N                                                         DPLO  26
   16 V(I)=-V(I)                                                          DPLO  27
      IF(N2.LE.0) GO TO 11                                                DPLO  28
      DO 18 I=1,N2                                                        DPLO  29
   18 V2(I)=-V2(I)                                                        DPLO  30
   11 CALL SORTUP(V,H,N)                                                  DPLO  31
      IF(N2.GT.0) CALL SORTUP(V2,H2,N2)                                   DPLO  32
      IF(NL.LE.0) NL=51                                                   DPLO  33
      IF(MOD(NL-1,10).NE.0) NL=NL+10-MOD(NL-1,10)                         DPLO  34
      IF(VL.NE.VU) GO TO 17                                               DPLO  35
      VL=V(1)                                                             DPLO  36
      VU=V(N)                                                             DPLO  37
      IF(N2.LE.0) GO TO 17                                                DPLO  38
      VL=AMIN1(VL,V2(1))                                                  DPLO  39
      VU=AMAX1(VU,V2(N2))                                                 DPLO  40
   17 DV=(VU-VL)/FLOAT(NL-1)                                              DPLO  41
      VMIN=VL-.5*DV                                                       DPLO  42
      VMIN=VMIN+ABS(VMIN)*EPS                                             DPLO  43
      VDIF=VU-VL+DV                                                       DPLO  44
      NHOUT=0                                                             DPLO  45
      NH2OUT=0                                                            DPLO  46
      DO 19 NVC=1,N                                                       DPLO  47
   19 IF(V(NVC).GE.VMIN) GO TO 20                                         DPLO  48
      NVC=N+1                                                             DPLO  49
   20 NV1=NVC-1                                                           DPLO  50
      IF(N2.LE.0) GO TO 49                                                DPLO  51
      DO 21 NV2C=1,N2                                                     DPLO  52
   21 IF(V2(NV2C).GE.VMIN) GO TO 22                                       DPLO  53
```

```
   49 NV2C=N2+1
   22 NV21=NV2C-1
      IF(NV1.EQ.N.AND.NV21.EQ.N2) GO TO 50
      IF(HL.NE.HU) GO TO 25
      HL=H(1)
      HU=H(1)
      DO 23 I=2,N
      IF(H(I).LT.HL) HL=H(I)
   23 IF(H(I).GT.HU) HU=H(I)
      IF(N2.LE.0) GO TO 25
      DO 24 I=1,N2
      IF(H2(I).LT.HL) HL=H2(I)
   24 IF(H2(I).GT.HU) HU=H2(I)
   25 DH=(HU-HL)/100.
      HMIN=HL-.5*DH
      HMAX=HU+.5*DH
      PRINT 201
      IF(NL.GT.51) GO TO 40
      LI=(55-NL)/2
C     DO 41 I=1,LI
C  41 PRINT 202
   40 DO 27 I=1,6
   27 HPR(I)=HL+(HU-HL)*FLOAT(I-1)/5.
      IF(ASIGN.EQ.+1..OR.NL.GT.51) PRINT 105, HPR
      DO 35 LO=1,NL,10
      IF(LO.EQ.1) GO TO 33
      DO 30 LI=1,9
      VC=VMIN+VDIF*FLOAT(LO-10+LI)/FLOAT(NL)
   30 CALL LINPLT(LINE,2,VPR,V,H,NVC,N,VC,HMIN,DH,NHOUT,CH1,
     1 V2,H2,NV2C,N2,NH2OUT,CH2)
   33 VC=VMIN+VDIF*FLOAT(LO)/FLOAT(NL)
      VPR=ASIGN*(VL+(VU-VL)*FLOAT(LO-1)/FLOAT(NL-1))
   35 CALL LINPLT(L10,1,VPR,V,H,NVC,N,VC,HMIN,DH,NHOUT,CH1,
     1 V2,H2,NV2C,N2,NH2OUT,CH2)
      PRINT 105, HPR
   50 IF(ASIGN.EQ.+1.) GO TO 65
      DO 66 I=1,N
   66 V(I)=-V(I)
      IF(N2.LE.0) GO TO 65
      DO 67 I=1,N2
   67 V2(I)=-V2(I)
   65 IF(IPR.EQ.0) GO TO 99
      IF(NV1.EQ.0.AND.NHOUT.EQ.0.AND.NVC.GT.N) GO TO 55
      PRINT 120, CH1
      CALL NOTPLT(V,H,N,NV1,NHOUT,NVC,HMIN,HMAX)
   55 IF(NV21.LE.0.AND.NH2OUT.EQ.0.AND.NV2C.GT.N2) GO TO 99
      PRINT 120, CH2
      CALL NOTPLT(V2,H2,N2,NV21,NH2OUT,NV2C,HMIN,HMAX)
   99 PRINT 201
      RETURN
      END
```

```
      SUBROUTINE LINPLT(LINE,NFMT,VPR,V,H,NVC,N,VC,HMIN,DH,NHOUT,LCH1,
     1 V2,H2,NV2C,N2,NH2OUT,LCH2)
C     *****************************************************************
  101 FORMAT(1H , F11.2 ,3X,101A1)
  102 FORMAT(1H ,14X,101A1)
C     *****************************************************************
      DIMENSION V(N),H(N),LINE(101),LTEMP(2,101),V2(N2),H2(N2)
      IC=0
      IF(NVC.GT.N) GO TO 30
      N1=NVC
      DO 25 NVC=N1,N
      IF(V(NVC).GE.VC) GO TO 30
      I=IFIX((H(NVC)-HMIN)/DH)+1
      IF(I.GE.1.AND.I.LE.101) GO TO 20
      NHOUT=NHOUT+1
      GO TO 25
   20 IF(IC.EQ.0) GO TO 24
      DO 22 J=1,IC
   22 IF(I.EQ.LTEMP(1,J)) GO TO 25
   24 IC=IC+1
      LTEMP(1,IC)=I
      LTEMP(2,IC)=LINE(I)
      LINE(I)=LCH1
   25 CONTINUE
      NVC=N+1
   30 IF(NV2C.GT.N2) GO TO 90
      N1=NV2C
      DO 55 NV2C=N1,N2
      IF(V2(NV2C).GE.VC) GO TO 90
      I=IFIX((H2(NV2C)-HMIN)/DH)+1
      IF(I.GE.1.AND.I.LE.101) GO TO 53
      NH2OUT=NH2OUT+1
      GO TO 55
   53 IF(IC.EQ.0) GO TO 54
      DO 51 J=1,IC
   51 IF(LTEMP(1,J).EQ.I) GO TO 55
   54 IC=IC+1
      LTEMP(1,IC)=I
      LTEMP(2,IC)=LINE(I)
      LINE(I)=LCH2
   55 CONTINUE
      NV2C=N2+1
   90 GO TO (31,32),NFMT
   31 PRINT 101,VPR,LINE
      GO TO 33
   32 PRINT 102,LINE
   33 IF(IC.EQ.0) GO TO 99
      DO 40 I=1,IC
      J=LTEMP(1,I)
   40 LINE(J)=LTEMP(2,I)
   99 RETURN
      END
```

```
      SUBROUTINE NOTPLT(V,H,N,NV1,NHOUT,NVC,HMIN,HMAX)                  NOTP   1
C                                                                       NOTP   2
C     FIND AND PRINT POINTS (V,H) NOT PLOTTED                           NOTP   3
C                                                                       NOTP   4
      DIMENSION V(N),H(N)                                               NOTP   5
  100 FORMAT(1X,1P2E13.4)                                               NOTP   6
      IF(NV1.GT.0) PRINT 100, (V(I),H(I),I=1,NV1)                       NOTP   7
      IF(NHOUT.EQ.0) GO TO 30                                           NOTP   8
      NV1=NV1+1                                                         NOTP   9
      DO 25 I=NV1,N                                                     NOTP  10
      IF(H(I).GE.HMIN.AND.H(I).LT.HMAX) GO TO 25                        NOTP  11
      PRINT 100, V(I),H(I)                                              NOTP  12
      NHOUT=NHOUT-1                                                     NOTP  13
      IF(NHOUT.EQ.0) GO TO 30                                           NOTP  14
   25 CONTINUE                                                          NOTP  15
   30 IF(NVC.LE.N) PRINT 100, (V(I),H(I),I=NVC,N)                       NOTP  16
      RETURN                                                            NOTP  17
      END                                                               NOTP  18
```

```
      SUBROUTINE SORTUP(X,Y,N)                                          SORT   1
C                                                                       SORT   2
C     SORT X IN ASCENDING ORDER AND CARRY Y                             SORT   3
C                                                                       SORT   4
      DIMENSION X(N),Y(N)                                               SORT   5
      INTEGER FIRST                                                     SORT   6
      FIRST=1                                                           SORT   7
      LAST=N-1                                                          SORT   8
   10 NEXT=1                                                            SORT   9
      J=MAX0(1,FIRST-1)                                                 SORT  10
      K=MIN0(N-1,LAST+1)                                                SORT  11
      DO 20 I=J,K                                                       SORT  12
      IF(X(I).LE.X(I+1)) GO TO 20                                       SORT  13
      GO TO (12,13),NEXT                                                SORT  14
   12 FIRST=I                                                           SORT  15
      NEXT=2                                                            SORT  16
   13 LAST=I                                                            SORT  17
      T=X(I)                                                            SORT  18
      X(I)=X(I+1)                                                       SORT  19
      X(I+1)=T                                                          SORT  20
      T=Y(I)                                                            SORT  21
      Y(I)=Y(I+1)                                                       SORT  22
      Y(I+1)=T                                                          SORT  23
   20 CONTINUE                                                          SORT  24
      IF(NEXT.EQ.2) GO TO 10                                            SORT  25
      RETURN                                                            SORT  26
      END                                                               SORT  27
```

6. Resistance Coefficients

```
09 24 DEC 14,'72 ID=043B12F1
JOB AA03,MCCULLOCH    ,     .          RESISTANCE COEFFICIENTS
LIMIT (TIME,15),(LO,50),(UO,50)
ASSIGN F 1,(DEVICE,7T),(LABEL,MCC),(INSN,3024),(KEYED),(SEQUEN),(IN)
FORTRAN LS,GO
EXT. FORTRAN IV, VERSION D0J
```

```
      C     COMPUT RESISTANCE COEFFICIENTS FROM EVAPOTRANSPIRATION EQUATIONS   RES  010
      C        (COMBINATION,RESISTANCE CONCEPTS)                               RES  020
      C     BY A.R.MCCOLLOCH  NOVEMBER,1972                                    RES  030
            DIMENSION CRD(80),INBUF(60,41)                                     RES  040
            DIMENSION FILE(3),ACCT(2),PASS(2),INSN(2),KEY(8)                   RES  050
            DIMENSION SUM(36,2),ANS(10)                                        RES  060
            INTEGER UNIT,ACCT,PASS,ORG,ACCES,SIZE,OUTSN,ERR,START,END,DAY      RES  070
            INTEGER CRD,DOLR                                                   RES  080
            DATA FILE/12HMCCOLLOCH   /                                         RES  090
            DATA DOLR/1H$/                                                     RES  100
        800 FORMAT(1H1)                                                        RES  110
        801 FORMAT(80A1)                                                       RES  120
        802 FORMAT(1X,80A1)                                                    RES  130
        803 FORMAT(A4)                                                         RES  140
        804 FORMAT(I6,1X,I6,1X,I4)                                             RES  150
        805 FORMAT(I6,1X,    ' CHANNEL 17 IS ALL BAD FOR THIS INTERVAL')       RES  160
        806 FORMAT(1X,I6,1X,I2,10F10.4)                                        RES  170
        807 FORMAT(' EXIT AT 950')                                             RES  180
        808 FORMAT(' EXIT AT 960')                                             RES  190
        809 FORMAT(' END OF TAPE,PROGRAM TERMINATED')                          RES  200
        810 FORMAT(//'  KEY  MIN          RS    RS(PHI)       RSATM      PC    RES  210
           1  RA    RA(PHI)          ET        RN+S          RI           DA'//)  RES  220
      C                                                                        RES  230
      C     DATA DECK                                                          RES  240
      C     ITEM 1.COMMENTS CARDS ENDING WITH $ IN COL 1                       RES  250
      C          2. TAPE TO BE USED                                            RES  260
      C             COL 1-4  TAPE NUMBER                                       RES  270
      C          3.KEYS AND MINUTES TO BE AVERAGED                             RES  280
      C             COL 1-6 STARTING KEY                                       RES  290
      C                   7 BLANK                                              RES  300
      C                8-13 ENDING KEY                                         RES  310
      C                  14 BLANK                                              RES  320
      C               15-18 INTERVAL TO BE AVERAGED                            RES  330
      C                     (MUST BE AN EVEN FRACTION OR MULTIPLE OF 60)       RES  340
      C                                                                        RES  350
      C     READ AND PRINT COMMENTS                                            RES  360
            PRINT 800                                                          RES  370
         10 READ 801,CRD                                                       RES  380
            PRINT 802,CRD                                                      RES  390
            IF (CRD(1).NE.DOLR) GO TO 10                                       RES  400
            PRINT 810                                                          RES  410
      C                                                                        RES  420
      C     PREPARE TO OPEN FILE                                               RES  430
            READ 803,INSN(1)                                                   RES  440
            UNIT=1                                                             RES  450
            MODE=2                                                             RES  460
            ACCT(1)=0                                                          RES  470
            PASS(1)=0                                                          RES  480
            ORG=2                                                              RES  490
            ACCES=1                                                            RES  500
            SIZE=2460                                                          RES  510
            OUTSN=0                                                            RES  520
      C                                                                        RES  530
```

```
      CALL ERRSET(ERR,950S,960S)
      CALL OPENF(UNIT,FILE,MODE,ACCT,PASS,ORG,ACCES,INSN,OUTSN)
      READ 804,START,END,INT
C     READ FIRST RECORD USING START
      KEY(1)=START
      CALLGET(UNIT,INBUF,SIZE,KEY,4)
      CALL GETKEY(UNIT,DAY,LGTH)
      IF(INT.GT.60) GO TO 300
C
C     CALCULATE FOR INTERVALS LE 60
   90 IST=1
      IEND=INT
C
C     FIND FIRST GOOD NUMBER IN CHANNEL 17
  100 DO 105 IDO=IST,IEND
  105 IF(INBUF(IDO,17).NE.999) GO TO 107
      PRINT 805,KEY
      GO TO 150
  107 BEG17=INBUF(IDO,17)
      END17=INBUF(IDO,17)
      IST=IDO
C
C     ZERO OUT THE SUM ARRAY
      DO 110 IDO=1,36
      SUM(IDO,1)=0.
  110 SUM(IDO,2)=0.
C
C     SUM ALL GOOD NUMBERS FOR THIS INTERVAL
      DO 120 IDO=IST,IEND
      DO 120 JDO=1,36
      IF(INBUF(IDO,JDO).EQ.999) GO TO 120
      END17=INBUF(IDO,17)
      SUM(JDO,1)=SUM(JDO,1)+FLOAT(INBUF(IDO,JDO))
      SUM(JDO,2)=SUM(JDO,2)+1.
  120 CONTINUE
C
C     CALCULATE AVERAGE FOR THIS INTERVAL
      DO 130 IDO=1,36
      IF(SUM(IDO,2).EQ.0.) GO TO 130
      SUM(IDO,1)=SUM(IDO,1)/SUM(IDO,2)
  130 CONTINUE
      CALL CNST(SUM)
      CALL CALC(SUM,ANS,BEG17,END17)
      MIN=IST-1
      PRINT 806,DAY,MIN,ANS
  150 IST=IEND+1
      IEND=IEND+INT
      IF(IEND.GT.60) GO TO 200
      GO TO 100
C
C     READ ANOTHER RECORD
  200 CALL GET(UNIT,INBUF,SIZE)
      CALL GETKEY(UNIT,DAY,LGTH)
      IF(DAY.GE.999999) GO TO 900
```

```
      IF(DAY.GT.END) GO TO 970
      GO TO 90
C
C     CALCULATE FOR INTERVALS .GT. 60
  300 KEYST=DAY
      MINST=0
      MULT=INT/60
      DO 360 MDO=1,MULT
      IF(MDO.NE.1) GO TO 330
      DO 310 IDO=1,60
  310 IF(INBUF(IDO,17).NE.999) GO TO 320
      GO TO 350
  320 BEG17=INBUF(IDO,17)
      KEYST=DAY
      MINST=IDO-1
C     ZERO OUT SUM ARRAY
      DO 325 IDO=1,36
      SUM(IDO,1)=0.
  325 SUM(IDO,2)=0.
C     SUM ALL GOOD NUMBERS IN THIS HOUR
  330 DO 340 IDO=1,60
      DO 340 JDO=1,36
      IF(INBUF(IDO,JDO).EQ.999) GO TO 340
      END17=INBUF(IDO,17)
      SUM(JDO,1)=SUM(JDO,1)+FLOAT(INBUF(IDO,JDO))
      SUM(JDO,2)=SUM(JDO,2)+1.
  340 CONTINUE
C     READ ANOTHER RECORD
  350 CALL GET(UNIT,INBUF,SIZE)
      CALL GETKEY(UNIT,DAY,LGTH)
      IF(DAY.GE.999999) GO TO 900
      IF(DAY.GT.END+1) GO TO  970
  360 CONTINUE
C     CALCULATE AVG
      DO 370 IDO=1,36
      IF(SUM(IDO,2).EQ.0.) GO TO 370
      SUM(IDO,1)=SUM(IDO,1)/SUM(IDO,2)
  370 CONTINUE
      CALL CNST(SUM)
      CALL CALC(SUM,ANS,BEG17,END17)
      PRINT 806,KEYST,MINST,ANS
      GO TO 300
C
C     END OF TAPE
  900 PRINT 809
      GO TO 970
C     ERR EXITS
  950 PRINT 807
      GO TO 970
  960 PRINT 808
  970 REWIND UNIT
      STOP
      END
```

```
      SUBROUTINE CNST(A)                                                RES 1610
      DIMENSION A(36,2)                                                 RES 1620
C     COL 1 OF A CONTAINS THE AVERAGES CALCULATED IN THE MAIN PROGRAM   RES 1630
C     COL 2 OF A CONTAINS # OF POINTS USED TO CALC THE AVERAGE          RES 1640
C     THIS ROUTINE RETURNS THE VALUES FOR EACH CHANNEL AFTER CONSTANTS  RES 1650
C     HAVE BEEN APPLIED                                                 RES 1660
C     IF NO AVG EXISTS , ENTER -10.**10                                 RES 1670
      A(1,1)=(A(1,1)-500.)/10.                                          RES 1680
      A(2,1)=(A(2,1)-500.)/100.                                         RES 1690
      A(3,1)=(A(3,1)-500.)/100.                                         RES 1700
      A(4,1)=(A(4,1)-500.)/100.                                         RES 1710
      DO 20 I=5,11                                                      RES 1720
   20 A(I,1)=(A(I,1)-500.)/10.                                          RES 1730
      DO 30 I=12,16                                                     RES 1740
   30 A(I,1)=A(I,1)/40.                                                 RES 1750
      A(17,1)=A(17,1)*.028665                                           RES 1760
      A(18,1)=(A(18,1)*.17)+745.8                                       RES 1770
      A(19,1)=A(19,1)*2.5                                               RES 1780
      A(20,1)=A(20,1)*2.5                                               RES 1790
      A(21,1)=(A(21,1)-500.)/10.                                        RES 1800
      A(22,1)=(A(22,1)-500.)/100.                                       RES 1810
      A(23,1)=(A(23,1)-500.)/100.                                       RES 1820
      A(24,1)=(A(24,1)-500.)/100.                                       RES 1830
      A(25,1)=(A(25,1)-333.)/167./1.6818                                RES 1840
      A(26,1)=A(26,1)/66.67/7.6                                         RES 1850
      A(27,1)=A(27,1)/200./4.1                                          RES 1860
      A(28,1)=A(28,1)/200./4.56                                         RES 1870
      A(29,1)=A(29,1)/100./7.11                                         RES 1880
      A(30,1)=A(30,1)/100./7.90                                         RES 1890
      A(31,1)=(A(31,1)-500.)/333.0
      A(32,1)=A(32,1)                                                   RES 1910
      A(33,1)=A(33,1)/2.78                                              RES 1920
      A(34,1)=A(34,1)                                                   RES 1930
      A(35,1)=A(35,1)/16.4                                              RES 1940
      A(36,1)=A(36,1)                                                   RES 1950
      DO 40 I=1,36                                                      RES 1960
      IF(A(I,2).EQ.0.)A(I,1)=-1E-50                                     RES 1970
   40 CONTINUE                                                          RES 1980
      RETURN                                                            RES 1990
      END                                                               RES 2030
```

```
      SUBROUTINE CALC(CH,ANS,BEG17,END17)
      DIMENSION CH(1),ANS(10)
      IMPLICIT REAL(A-Z)
C     ANS(1)=RATM IS RS
C     ANS(2)=RATMSIS RS(PHI)
C     ANS(3)=RSATM
C     ANS(4)=RSATMS
C     ANS(5)=ATM  IS RA
C     ANS(6)=ATMS IS RA(PHI)
C     ANS(7)=ET
C     ANS(8)=H    IS RN+S
C     ANS(9)=RI
C     ANS(10)=DA
C     CH(53) CONTAINS # OF MIN OF CHANNEL 17
      MIN=CH(53)
      CALL SDA(DA,ES,EA,CH)
      CALL SEPS(EPS,DELT,GAM,CH)
C
      RHC=.9?5E-3
      P=842.
      E=.622
C
C     CALCULATE H
      H=((CH(26)*.743-.43)+CH(31))/60.
C
C     CALCULATE ET
      ET=(BEG17-END17)/(10.*MIN*60.)
      ETT=(BEG17-END17)/((MIN)*10.*60.0)       *582.0
C
C     CALCULATE ATM AND ATMS
      CALL RA(ATM,ATMS,RI,PHI,CH)
C
      CALL RS(J,EI,CH)
      RATM=EPS*H*ATM/ET     +(RHO*E*DA/P*ET)-EPS*ATM-ATM
      RSATM=J*(EI-EA)/ETT-ATM
      PE =(((EPS*H)/582+(RHO*E*DA)/(P*ATM))/(EPS+1.0))*36000.C
      IF(ATMS.GT.-1E-50) GO TO 20
      RATMS=-1E-50
      RSATMS=-1E-50
      GO TO 30
   20 RATMS=EPS*H*ATMS/ET     +(RHO*E*DA/P*ET)-EPS*ATMS-ATMS
      RSATMS=J*(EI-EA)/ETT-ATMS
   30 ANS(1)=RATM
      ANS(2)=RATMS
      ANS(3)=RSATM
      ANS(4)=PE
      ANS(5)=ATM
      ANS(6)=ATMS
      ANS(7)=ET
      ANS(8)=H
      ANS(9)=RI
      ANS(10)=DA
      RETURN
```

54. END RES 2520

```
      SUBROUTINE SDA(DA,ES,EA,CH)                                       RES 2530
      DIMENSION CH(1)                                                   RES 2540
      IMPLICIT REAL(A-Z)                                                RES 2550
      P=842.                                                            RES 2560
      TD=CH(1)+CH(2)                                                    RES 2570
      TW=CH(21)+CH(22)                                                  RES 2580
      TO=TD*9./5.+32.                                                   RES 2590
      T1=TW*9./5.+32.                                                   RES 2600
      ESW=((.0041*T1+.676)**8-(0.000019*ABS(T1+16.))+.001316)*33.86     RES 2610
      EA=ESW-(.00066*(1.+.00115*TW))*P*(TD-TW)                          RES 2620
      ES=((.0041*TO+.678)**8- .000019*ABS(TO+16.)+.001316)*33.86        RES 2630
      DA=ES-EA                                                          RES 2640
      RETURN                                                            RES 2650
      END                                                               RES 2660
```

```
      SUBROUTINE SEPS(EPS,DELT,GAM,CH)                                  RES 2670
      DIMENSION CH(1)                                                   RES 2680
      IMPLICIT REAL(A-Z)                                                RES 2690
      K=7482.6                                                          RES 2700
      B=398.36                                                          RES 2710
      C=15.674                                                          RES 2720
      T=(CH(21)+CH(22))*9./5.+32.                                       RES 2730
      TW=CH(21)+CH(22)                                                  RES 2740
      GAM=.00066*(1.+.00115*TW)*842.                                    RES 2750
      DELT=(K/(T+B)**2*EXP(C)*EXP(-K/(T+B)))*33.86 *9./5.               RES 2760
      EPS=DELT/GAM                                                      RES 2770
      RETURN                                                            RES 2780
      END                                                               RES 2790
```

```
      SUBROUTINE RA(ATM,ATMS,RI,PHI,CH)
      DIMENSION CH(1)
      IMPLICIT REAL(A-Z)
C
      Z0=2.
      Z1=60.
      Z2=200.
      K=.41
      G=980.
      V1=CH(19)
      V2=CH(20)
C
C     CALCULATE ATM
      ATM=((LOG(Z1/Z0)**2)/K**2)*(1./V1)
C
C     CALCULATE ATMS
      T1=CH(1)+CH(2)
      T2=T1+CH(3)+CH(4)
      T=(T1+T2)/2.+273.
      RI=G/T*(T2-T1)*(Z2-Z1)/(V2-V1)**2
      IF(RI.GT. .0555) GO TO 10
      PHI=1./(1.-18.*RI)**.25
      ATMS=ATM*(1.+PHI)
      RETURN
   10 ATMS=-1E-50
      RETURN
      END
```

```
      SUBROUTINE RS(J,EI,CH)                                            RES 3070
      DIMENSION CH(1)                                                   RES 3080
      IMPLICIT REAL(A-Z)                                                RES 3090
      LV=582.                                                           RES 3100
      RHO=.000995                                                       RES 3110
      B=398.36                                                          RES 3120
      P=842.                                                            RES 3130
      J=.62*LV*RHO/P                                                    RES 3140
      K=7482.6                                                          RES 3150
      C=15.674                                                          RES 3160
      T=CH(11)*9./5.+32.                                                RES 3170
      EI=EXP(C)*EXP(-K/(T+B))*33.86                                     RES 3180
      RETURN                                                            RES 3190
      END                                                               RES 3200
```

APPENDIX II

REGRESSION COEFFICIENTS

Table A-1. Regression coefficients for temperature sensing diodes.

Diode	Regression Coefficient	Diode	Regression Coefficient	Diode	Regression Coefficient
122 (3rd)	-1.268908	124	-1.446264	86	-1.482768
1-4	-1.355414	2-6	-1.446266	2.2	-1.484968
2-10	-1.363590	115	-1.446285	122 (2nd)	-1.485967
4-12	-1.364562	116 (2nd)	-1.447808	75	-1.486584
99	-1.366182	118 (2nd)	-1.447966	134	-1.486877
58	-1.366440	83	-1.449577	126 (2nd)	-1.488332
4-10	-1.368826	6	-1.449791	96	-1.490163
100	-1.374952	10	-1.452692	119	-1.490604
4-2	-1.376337	90	-1.452692	118	-1.491779
1-2	-1.383803	92	-1.453138	130	-1.491844
1-10	-1.387511	84	-1.453138	1-8	-1.493532
76	-1.388279	64	-1.453240	137	-1.494630
3-13	-1.390542	22	-1.460278	127 (2nd)	-1.494639
4-5	-1.393330	121 (3rd)	-1.461225	3-2	-1.494978
1-12	-1.394279	1-3	-1.461747	72	-1.496440
136	-1.396701	56	-1.462599	3-3	-1.497998
14	-1.398806	133	-1.462644	3-8	-1.498983
87	-1.401607	62	-1.465389	120 (3rd)	-1.499790
3-7	-1.408753	131	-1.465866		
74	-1.409900	128	-1.465866		
2-3	-1.410080	139	-1.465866	28	-1.500910
2-12	-1.411203	129	-1.465866	112	-1.503560
2-13	-1.411475	105	-1.467550	59	-1.505405
1-9	-1.412516	1-5	-1.468527	67	-1.508789
4-7	-1.413569	119 (3rd)	-1.468662	116	-1.508893
3-5	-1.414792	66	-1.469384	5	-1.508936
1-6	-1.414850	135	-1.471761	120	-1.509060
3-12	-1.419845	104	-1.471978	114	-1.509449
4-3	-1.321079	10	-1.472417	102	-1.510678
3-6	-1.421402	2-9	-1.472997	123 (2nd)	-1.511352
1-13	-1.423818	106	-1.473081	132	-1.511714
79	-1.428610	61	-1.473422	127 (3rd)	-1.511935
2-8	-1.430962	78	-1.473644	26	-1.514095
138	-1.431865	116 (3rd)	-1.473850	126 (3rd)	-1.524561
29	-1.434111	117 (3rd)	-1.473850	123 (3rd)	-1.525040
85	-1.434158	121	-1.476007	8	-1.529775
60	-1.435495	103	-1.476456	126	-1.537752
81	-1.440035	108	-1.477284	127	-1.541779
1-7	-1.440088	109	-1.477284	123	-1.557383
117 (2nd)	-1.440397				
119 (2nd)	-1.440397	2-5	-1.478574	122	-1.607383
121 (2nd)	-1.440397	89	-1.478594		
4-6	-1.441319	120 (2nd)	-1.479659		
63	-1.441661	117	-1.479698		

Table A-1 (continued).

Diode	Regression Coefficient	Diode	Regression Coefficient	Diode	Regression Coefficient
101	-1.443290	25	-1.480071		
93	-1.444392	113	-1.482591		
98	-1.445447	118 (3rd)	-1.482847		
2-7	-1.445453	3-10	-1.483664		
107	-1.445856	2-7	-1.484968		
1-2	-1.383803	132	-1.511714	58	-1.366440
1-3	-1.461747	131	-1.465866	59	-1.505405
1-4	-1.355414	128	-1.465866	61	-1.473422
1-5	-1.468527	139	-1.465866	63	-1.441661
1-6	-1.414850	129	-1.465866	66	-1.469384
1-7	-1.440088	130	-1.491844	74	-1.409900
1-8	-1.493532	138	-1.431865	75	-1.486584
1-9	-1.412516	124	-1.446264	78	-1.473644
1-10	-1.387511	116	-1.508893	85	-1.434158
1-12	-1.394279	117	-1.479698	86	-1.482768
1-13	-1.423818	118	-1.491779	116 (2nd)	-1.447808
2-2	-1.484968	119	-1.490604	116 (2nd)	-1.440397
2-3	-1.410080	120	-1.509060	118 (2nd)	-1.447966
2-5	-1.478574	121	-1.476007	119 (2nd)	-1.440397
2-6	-1.446266	122	-1.607383	120 (2nd)	-1.479659
2-7	-1.484968	123	-1.557383	121 (2nd)	-1.440397
2-8	-1.430962	126	-1.537752	122 (2nd)	-1.485967
2-9	-1.472997	127	-1.541779	123 (2nd)	-1.511352
2-10	-1.363590	5	-1.508936	126 (2nd)	-1.488332
2-12	-1.411203	6	-1.449791	127 (2nd)	-1.494639
2-13	-1.411475	10	-1.472417	116 (3rd)	-1.473850
3-2	-1.494978	8	-1.529775	117 (3rd)	-1.473850
3-3	-1.497998	14	-1.398806	118 (3rd)	-1.482847
3-5	-1.414792	22	-1.460278	119 (3rd)	-1.468662
3-6	-1.421402	25	-1.480071	120 (3rd)	-1.499790
3-7	-1.408753	26	-1.514095	121 (3rd)	-1.461225
3-8	-1.498983	28	-1.500910	122 (3rd)	-1.268908
3-10	-1.483664	29	-1.434111	123 (3rd)	-1.525040
3-12	-1.419845	2-7	-1.445453	126 (3rd)	-1.524561
3-13	-1.390542	133	-1.462644	127 (3rd)	-1.511935
4-2	-1.376337	135	-1.471761	98	-1.445447
4-3	-1.421079	136	-1.396701	81	-1.440035
4-5	-1.393330	79	-1.428610	64	-1.453240
4-6	-1.441319	76	-1.388279	92	-1.453138
4-7	-1.413569	99	-1.366182	62	-1.465389
4-10	-1.368826	105	-1.467550	89	-1.478594
4-12	-1.364562	87	-1.401607	93	-1.444392
112	-1.503560	100	-1.374952	84	-1.453138

Table A-1 (continued).

Diode	Regression Coefficient	Diode	Regression Coefficient	Diode	Regression Coefficient
107	-1.445856	10	-1.452692	106	-1.473081
72	-1.496440	90	-1.452692		
83	-1.449557	96	-1.490163		
101	-1.443290	102	-1.510678		
56	-1.462599	104	-1.471978		
67	-1.508789	108	-1.477284		
60	-1.435495	109	-1.477284		
103	-1.476456	113	-1.482591		
134	-1.486877	114	-1.509449		
137	-1.494630	115	-1.446285		

APPENDIX III

EVAPOTRANSPIRATION ESTIMATES FOR 1971

Preceding and following the rain storm of August 9, 1971, an evapotranspiration study was conducted using Bowen's (1926) ratio method in the form shown by Ferguson (1966):

$$B = \frac{K_h}{K_v}\left(\frac{1}{[(\alpha + \delta)/\alpha][(\Delta T_W/\Delta T) - 1]}\right)$$

where:

B = Bowen's ratio

K_h = molecular diffusivity for air

K_v = molecular diffusivity for water vapor

α = psychrometric constant

δ = slope of vapor pressure-temperature curve

ΔT_W = differential wet-bulb temperature between heights Z_1, Z_2

ΔT = differential dry-bulb temperature between heights Z_1, Z_2

Other measurements necessary to complete the calculation of evapotranspiration (ET) were net radiation (R_n) and soil heat flux (S). The ET prediction then takes the form:

$$ET = \frac{R_n - S}{1 + B}$$

Results utilizing the above equation were compared against soil water changes as detected by the lysimeter (Figure A-1). It

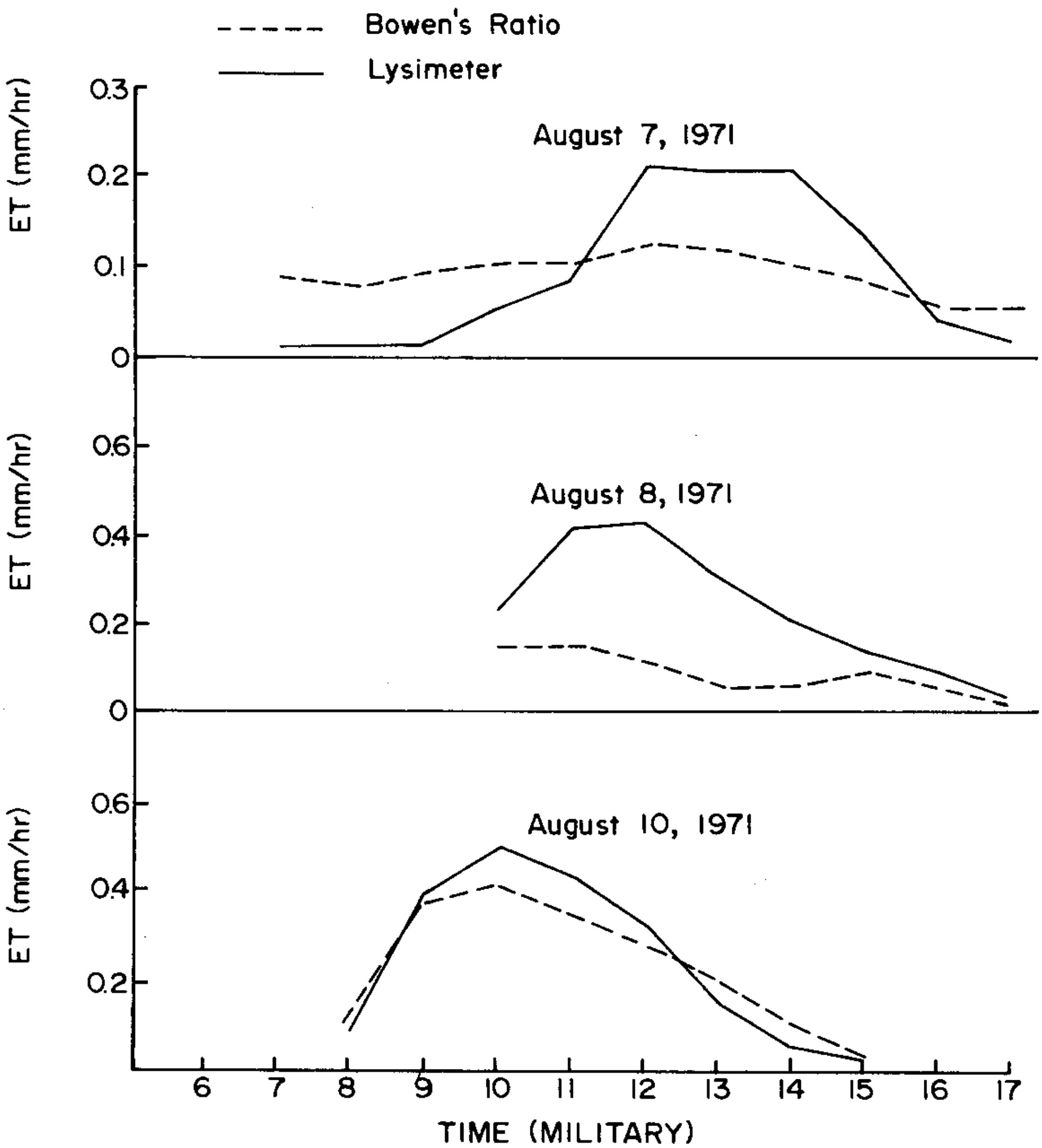

Figure A-1. Comparison between Bowen's ET prediction and ET as indicated by the lysimeter.

is noted that the Bowen ratio method tends to underestimate the actual evapotranspiration by 60% to 80%. Appendix III includes transducers for improved vapor pressure devices consisting of a thermistor housed within an aspirated ceramic wick similar to that described by Lourence and Pruitt (1969).

APPENDIX IV

DATA SYSTEM MODIFICATION

Table A-2 describes the necessary instrumentation changes, millivolt output ranges, and sensing heights for each transducer. This modification did not affect established demands for data and enhanced the entire grassland program. All operational, calibration, and data reduction routines were retained and utilized.

Table A-2. Transducers used after modification of the system during 1972.

Item	Quantity	Sensing Level (m)	Output Range	Sensing Range	Supplier
Rain gauge Model 5915	1	1	0 to 30,000 ohms	0 to 2.4 inches	Belfort Instrument 1600 S. Clinton St. Baltimore, Maryland
Soil water Model 314	6		0 to 5 v	0 to 30% saturation	Denver Mine & Smither Supply 3800 Race Denver, Colorado
Anemometer R/ASI - T	2	0.50,2.00	0 to 5 v	0 to 100 mph	Rauchfuss Instrument and Statt Pty., Ltd. 11 Florence Street Burwood, Victoria, Australia
Anemometer (Hot-Wire) 55D05	1	0.05	0 to 300 mv	0 to 10 ft/sec	DISA Electronics 779 Susquehanna Ave. Franklin Lakes, New Jersey
Carbon dioxide 315 A	1	0.10 to 4.00	0 to 50 mv	0 to 300 ppm	Beckman Instrument Lab 3835 Elm Denver, Colorado
Air temperature (Wet and Dry) (Thermistors)	8	0.05,0.50, 1.50,2.00	0 to 5 mv	±5°C	Newark Electronics 2170 South Grape St. Denver, Colorado

Table A-2 (continued).

Item	Quantity	Sensing Level (m)	Output Range	Sensing Range	Supplier
Soil heat flux (HF - 1)	1	-0.01	0 to 3 mv	±.5 langleys/min	National Instrument Laboratory 12300 Park Lawn Drive Rockville, Maryland
Spectral pyranometer	1	2.0	0 to 15 mv	.4 to .7μ	Eppley Laboratory Newport, Rhode Island

APPENDIX V

DATA TABLES

Table A-3. Precipitation, P (mm); change in soil water in top 120 cm of soil, ΔS (mm); and evapotranspiration, ET (mm and mm/day, respectively) for Pawnee Site microwatersheds.

Date	Parameter	Microwatershed							
		1	2	3	4	5	6	7	8
April 20 to May 14	P (mm)	19.3	27.6	27.6	30.4	30.4	36.1	33.9	31.2
	ΔS (mm)	9.0	7.0	9.0	10.0	12.0	10.0	9.0	9.0
	ET-total (mm)	10.3	20.6	18.0	20.4	18.4	26.1	24.9	22.2
	ET (mm/day)	.43	.86	.75	.85	.77	1.09	1.04	.93
May 15 to June 12	P (mm)	84.4	70.9	70.9	84.4	84.4	87.4	84.4	79.6
	ΔS (mm)	62.0	49.0	52.0	46.0	45.0	46.0	59.0	62.0
	ET-total (mm)	22.4	21.9	18.9	38.4	39.4	41.4	25.4	17.6
	ET (mm/day)	.80	.78	.68	1.37	1.41	1.48	.91	.63
June 13 to June 26	P (mm)	6.0	5.7	5.7	4.4	4.4	10.0	5.0	5.2
	ΔS (mm)	-26.0	-29.0	-47.0	-20.0	-41.0	-27.0	-21.0	-21.0
	ET-total (mm)	32.0	34.7	52.7	24.4	45.4	37.0	26.0	26.2
	ET (mm/day)	2.46	2.67	4.05	1.88	3.49	2.85	2.00	2.02
June 27 to July 10	P (mm)	11.6	16.9	16.9	28.0	28.0	24.4	23.6	23.0
	ΔS (mm)	-30.0	-16.0	-5.0	-34.0	-3.0	-1.0	-26.0	-5.0
	ET-total (mm)	41.6	32.9	21.9	62.0	31.0	25.4	49.6	28.0
	ET (mm/day)	3.20	2.53	1.69	4.77	2.38	1.95	3.82	2.15
July 11 to July 17	P (mm)	2.6	1.9	1.9	4.3	4.3	3.8	3.0	3.1
	ΔS (mm)	25.0	6.0	2.0	17.0	-11.0	-15.0	-20.0	-21.0
	ET-total (mm)	-22.4	-4.1	-.1	-12.7	15.3	18.8	23.0	23.1
	ET (mm/day)					2.55	3.13	3.83	3.85

Table A-3 (continued).

Date	Parameter	Microwatershed							
		1	2	3	4	5	6	7	8
July 20 to August 7	P (mm)	22.7	38.3	38.3	37.4	37.4	37.6	35.8	35.6
	ΔS (mm)	-18.0	3.0	25.0	7.0	38.0	7.0	8.0	30.0
	ET-total (mm)	40.7	35.3	8.3	30.4	-.6	30.6	27.8	5.6
	ET (mm/day)	2.26	1.96	.46	1.68	--	1.70	1.54	.31

Table A-4. Pawnee Site aboveground herbage and percent bare ground (light grazed treatment).

Date	Bare Ground (%)	Total Live and Standing Dead (g/m^2)	Total Live (g/m^2)
April 4	33.33	114.10	95.86
May 10	27.67	95.58	87.30
June 22	16.87	141.03	110.73
July 18	27.97	135.60	125.32
August 7	24.60	158.3	149.3
September 12	22.50	155.6	155.6

Table A-5. Weather data for lysimeter exclosure, 1972, daily averages.

Date	$R_n + S$ ($cal/cm^2/sec$)	ET (mm/hr)	E_o (mm/hr)	Soil Water (upper 120 cm)	d_a (mb)	R_s (sec/cm)
May 14	.0095	.27	.7	NA	15.1	9.73
May 20	.0094	.35	.9	NA	10.3	17.70
June 9	.0082	.37	1.0	NA	17.75	12.0
July 12	.012	.31	3.5	14.6	52.0	13.7
July 17	.012	.16	1.5	NA	19.8	24.8
July 23	.025	.13	5.0	18.65	56.0	43.4
July 30	.021	.09	5.6	16.05	62.8	62.8
August 5	.023	.21	2.0	13.95	22.3	46.7