Technical Report No. 216

METEOROLOGICAL CHARACTERISTICS OVER THE
GRASSLAND BIOME'S PAWNEE SITE

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


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 informative 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 north-
eastern Colorado), required year-round monitoring of abiotic variables
with a minimum amount of failures. The diverse data needs of partic-
ipating 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, Quashu, 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 Pelttu (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 tech-
nique, 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.
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 1/2-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 connectors 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.,

\[ R_n = R_{si} - R_{so} + R_{li} - R_{lo} \]

where

- \( R_n \) = 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 Sier 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-Zoehnlen 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°C 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.
FLOW OF TAPE

<table>
<thead>
<tr>
<th>CHANNEL</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>NUMERIC VALUE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$2^0$</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>$2^1$</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$2^2$</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$2^3$</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>UNUSED</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>UNUSED</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>PARITY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

HUNDREDS | TENS | UNITS

673 | 901 | 624

RECORDED VALUE

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 STARTING 09 20 71 AT 12:30
ENDING 09 28 71 AT 10:52
METEOROLOGICAL WEATHER STATION DATA TAPE (DENSITY 800 BPI)
MINUTELY DATA RECORDINGS
RESPONSIBLE PARTY: J. R. NUNN & C. F. BECKER UNIVERSITY OF WYOMING
AG. ENGINEERING PO BOX 3354, UNIVERSITY WYOMING, LARAMIE WYOMING
PANCE SITE: NORTHWEST COLORADO
PROGRAMER: ALICE MCCOLLOCH, UNIVERSITY OF WYOMING

DATA GOOD
TAPE CONTAINS 1 FILE STARTING 09 20 71 AT 12:30
ENDING 09 28 71 AT 10:52

CONTENTS OF THE 36 PARAMETERS ARE AS FOLLOWS:
PLOTS: A = LIGHT GRAZED  B = HEAVY GRAZED  O = INDEPENDENT

<table>
<thead>
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<th>NO.</th>
<th>PLOT</th>
<th>PARAMETER</th>
<th>LEVEL (CM)</th>
<th>UNITS</th>
</tr>
</thead>
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<tr>
<td>1</td>
<td>A</td>
<td>AIR TEMPERATURE</td>
<td>200</td>
<td>DEG CENTIGRADE</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>AIR TEMPERATURE</td>
<td>200</td>
<td>DEG CENTIGRADE</td>
</tr>
<tr>
<td>3</td>
<td>A</td>
<td>AIR TEMPERATURE</td>
<td>50</td>
<td>DEG CENTIGRADE</td>
</tr>
<tr>
<td>4</td>
<td>B</td>
<td>AIR TEMPERATURE</td>
<td>50</td>
<td>DEG CENTIGRADE</td>
</tr>
<tr>
<td>5</td>
<td>A</td>
<td>SOIL TEMPERATURE</td>
<td>-122</td>
<td>DEG CENTIGRADE</td>
</tr>
<tr>
<td>6</td>
<td>B</td>
<td>SOIL TEMPERATURE</td>
<td>-122</td>
<td>DEG CENTIGRADE</td>
</tr>
<tr>
<td>7</td>
<td>A</td>
<td>SOIL TEMPERATURE</td>
<td>-51</td>
<td>DEG CENTIGRADE</td>
</tr>
<tr>
<td>8</td>
<td>B</td>
<td>SOIL TEMPERATURE</td>
<td>-51</td>
<td>DEG CENTIGRADE</td>
</tr>
<tr>
<td>9</td>
<td>A</td>
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<td>-20</td>
<td>DEG CENTIGRADE</td>
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<tr>
<td>10</td>
<td>B</td>
<td>SOIL TEMPERATURE</td>
<td>-20</td>
<td>DEG CENTIGRADE</td>
</tr>
<tr>
<td>11</td>
<td>A</td>
<td>SOIL TEMPERATURE</td>
<td>-10</td>
<td>DEG CENTIGRADE</td>
</tr>
<tr>
<td>12</td>
<td>B</td>
<td>SOIL TEMPERATURE</td>
<td>-10</td>
<td>DEG CENTIGRADE</td>
</tr>
<tr>
<td>13</td>
<td>A</td>
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<td>-6</td>
<td>DEG CENTIGRADE</td>
</tr>
<tr>
<td>14</td>
<td>B</td>
<td>SOIL TEMPERATURE</td>
<td>-6</td>
<td>DEG CENTIGRADE</td>
</tr>
<tr>
<td>15</td>
<td>A</td>
<td>SOIL TEMPERATURE</td>
<td>-3</td>
<td>DEG CENTIGRADE</td>
</tr>
<tr>
<td>16</td>
<td>B</td>
<td>SOIL TEMPERATURE</td>
<td>-3</td>
<td>DEG CENTIGRADE</td>
</tr>
<tr>
<td>17</td>
<td>A</td>
<td>LYSIMETER</td>
<td>0</td>
<td>MILLIMETERS</td>
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<td>18</td>
<td>A</td>
<td>BAROMETRIC PRESS.</td>
<td>300</td>
<td>MILLIBARS</td>
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<td>19</td>
<td>A</td>
<td>WIND SPEED</td>
<td>50</td>
<td>CM/SEC</td>
</tr>
<tr>
<td>20</td>
<td>B</td>
<td>WIND SPEED</td>
<td>50</td>
<td>CM/SEC</td>
</tr>
<tr>
<td>21</td>
<td>A</td>
<td>DEW POINT</td>
<td>200</td>
<td>DEG CENTIGRADE</td>
</tr>
<tr>
<td>22</td>
<td>B</td>
<td>DEW POINT</td>
<td>200</td>
<td>DEG CENTIGRADE</td>
</tr>
<tr>
<td>23</td>
<td>A</td>
<td>DEW POINT</td>
<td>50</td>
<td>DEG CENTIGRADE</td>
</tr>
<tr>
<td>24</td>
<td>B</td>
<td>DEW POINT</td>
<td>50</td>
<td>DEG CENTIGRADE</td>
</tr>
<tr>
<td>25</td>
<td>A</td>
<td>NET RADIATION</td>
<td>200</td>
<td>GM-CAL/C M2/M IN</td>
</tr>
<tr>
<td>26</td>
<td>B</td>
<td>NET RADIATION</td>
<td>200</td>
<td>GM-CAL/C M2/M IN</td>
</tr>
<tr>
<td>27</td>
<td>A</td>
<td>LONG WAVE RADIATION</td>
<td>200</td>
<td>GM-CAL/C M2/M IN</td>
</tr>
<tr>
<td>28</td>
<td>B</td>
<td>LONG WAVE RADIATION</td>
<td>200</td>
<td>GM-CAL/C M2/M IN</td>
</tr>
<tr>
<td>29</td>
<td>O</td>
<td>LONG WAVE RADIATION</td>
<td>300</td>
<td>GM-CAL/C M2/M IN</td>
</tr>
<tr>
<td>30</td>
<td>A</td>
<td>REFLECTED SHORT WAVE</td>
<td>200</td>
<td>GM-CAL/C M2/M IN</td>
</tr>
<tr>
<td>31</td>
<td>B</td>
<td>REFLECTED SHORT WAVE</td>
<td>200</td>
<td>GM-CAL/C M2/M IN</td>
</tr>
<tr>
<td>32</td>
<td>O</td>
<td>TOTAL INCOMING SOLAR</td>
<td>300</td>
<td>GM-CAL/C M2/M IN</td>
</tr>
<tr>
<td>33</td>
<td>A</td>
<td>WIND DIRECTION</td>
<td>200</td>
<td>DEGREE AZIMUTH</td>
</tr>
<tr>
<td>34</td>
<td>B</td>
<td>WIND DIRECTION</td>
<td>200</td>
<td>DEGREE AZIMUTH</td>
</tr>
<tr>
<td>35</td>
<td>A</td>
<td>WIND SPEED</td>
<td>200</td>
<td>CM/SEC</td>
</tr>
<tr>
<td>36</td>
<td>B</td>
<td>WIND SPEED</td>
<td>300</td>
<td>CM/SEC</td>
</tr>
</tbody>
</table>

DATA SCREENED: DISREGARD ALL DATA CHANNELS IN WHICH 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.

<table>
<thead>
<tr>
<th>JOB</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIMIT(TIME20), (L0,20)</td>
</tr>
<tr>
<td>ASSIGN F:1, (DEVICE,7T), (OUTSN,3090), (UNPACK), (BIN), (OUTIN)</td>
</tr>
<tr>
<td>ASSIGN F:2, (DEVICE,7T), (INSN,3064), (BIN), (UNPACK), (TRIES,0)</td>
</tr>
</tbody>
</table>

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**

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Number of files on 200 BPI input tape</td>
</tr>
<tr>
<td>121212</td>
<td>Last key written</td>
</tr>
<tr>
<td>3076</td>
<td>Tape number</td>
</tr>
</tbody>
</table>
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

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
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</tr>
<tr>
<td>5</td>
<td>6</td>
<td>00</td>
<td>100</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Sensor Type</th>
<th>Parameter</th>
<th>Transducer Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beckman and Whitney Radiometer</td>
<td>Net radiation</td>
<td>-.002  .003</td>
</tr>
<tr>
<td>Eppley Pyrheliometer</td>
<td>Total incoming shortwave radiation</td>
<td>0   .015</td>
</tr>
<tr>
<td>Kipp-Zohnen Solarimeter</td>
<td>Outgoing reflected shortwave radiation</td>
<td>0   .010</td>
</tr>
<tr>
<td>Eppley Pyranometer</td>
<td>Incoming and outgoing long wave radiation</td>
<td>0   .003</td>
</tr>
<tr>
<td>National Instrument Laboratory Disk</td>
<td>Soil heat flux</td>
<td>-.010  .010</td>
</tr>
<tr>
<td>Cambridge model 880 Hygrometer</td>
<td>Dew point</td>
<td>0   .050</td>
</tr>
<tr>
<td>Electric Speed Indicator Anemometer</td>
<td>Wind velocity and direction</td>
<td>0   5</td>
</tr>
<tr>
<td>Electric Diode IN3193</td>
<td>Air and soil temperature</td>
<td>See Table 7</td>
</tr>
</tbody>
</table>
Table 7. Temperature-voltage relationships for individual temperature transducers.

<table>
<thead>
<tr>
<th>Diode No.</th>
<th>Voltage at +50°C (v)</th>
<th>Voltage at -50°C (v)</th>
<th>Midpoint</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-6</td>
<td>.4014</td>
<td>.6596</td>
<td>18.5</td>
</tr>
<tr>
<td>83</td>
<td>.3958</td>
<td>.6493</td>
<td>18.5</td>
</tr>
<tr>
<td>101</td>
<td>.3986</td>
<td>.6525</td>
<td>18.5</td>
</tr>
<tr>
<td>56</td>
<td>.3942</td>
<td>.6508</td>
<td>18.5</td>
</tr>
<tr>
<td>60</td>
<td>.3776</td>
<td>.6317</td>
<td>18.5</td>
</tr>
<tr>
<td>128</td>
<td>.3946</td>
<td>.6531</td>
<td>23.8</td>
</tr>
<tr>
<td>139</td>
<td>.4008</td>
<td>.6607</td>
<td>23.8</td>
</tr>
<tr>
<td>129</td>
<td>.4009</td>
<td>.6585</td>
<td>23.8</td>
</tr>
<tr>
<td>124</td>
<td>.4165</td>
<td>.6759</td>
<td>23.8</td>
</tr>
<tr>
<td>22</td>
<td>.4087</td>
<td>.6793</td>
<td>23.8</td>
</tr>
<tr>
<td>133</td>
<td>.3954</td>
<td>.6571</td>
<td>18.5</td>
</tr>
<tr>
<td>105</td>
<td>.3904</td>
<td>.6556</td>
<td>23.8</td>
</tr>
<tr>
<td>115</td>
<td>.4103</td>
<td>.6692</td>
<td>23.8</td>
</tr>
<tr>
<td>66</td>
<td>.3843</td>
<td>.6511</td>
<td>23.8</td>
</tr>
<tr>
<td>81</td>
<td>.3932</td>
<td>.6489</td>
<td>18.5</td>
</tr>
<tr>
<td>138</td>
<td>.4119</td>
<td>.6657</td>
<td>18.5</td>
</tr>
</tbody>
</table>
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 Klpp-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
\[ \frac{\Delta E_{NET}}{K_{NET}} = \frac{\Delta E}{K_E} \]

where

\( \Delta E_{NET} \) = difference due to shading in millivolts output readings from net radiometer

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

\( \Delta E_E \) = 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.

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Place EOF on tape.</td>
</tr>
<tr>
<td>2.</td>
<td>Turn record ENABLE off.</td>
</tr>
<tr>
<td>3.</td>
<td>Repair improper function.</td>
</tr>
<tr>
<td>4.</td>
<td>Update the date on thumb wheels and check clock for correct time.</td>
</tr>
<tr>
<td>5.</td>
<td>Turn record ENABLE on.</td>
</tr>
<tr>
<td>6.</td>
<td>Recheck all data channels.</td>
</tr>
<tr>
<td>Item</td>
<td>Quantity</td>
</tr>
<tr>
<td>---------------------</td>
<td>----------</td>
</tr>
<tr>
<td>Power supply</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Signal generator</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Potentiometric bridge</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Digital voltmeter</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Oscilloscope</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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 Meteorological Data Availability
Peavine Site - Nune, Colorado
HOURLY ANALYSIS 1971

<table>
<thead>
<tr>
<th></th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
<th>November</th>
<th>December</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Legend**
* Wet Bulb 7.18-7.1-8.31-71
### Meteorological Data Availability

#### Hourly Averages 1970

<table>
<thead>
<tr>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
<th>November</th>
<th>December</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Legend:**
- June 1 — July 24
- November 22 — December 24
- A — Light Graded Pattern
- B — Heavy Graded Pattern
- July 3 — October 24
  - A — Dished
  - B — Bottomed
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.

<table>
<thead>
<tr>
<th>Military Time</th>
<th>Albedo</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Upland</td>
</tr>
<tr>
<td>0600</td>
<td>0.0</td>
</tr>
<tr>
<td>0700</td>
<td>5.0</td>
</tr>
<tr>
<td>0800</td>
<td>9.0</td>
</tr>
<tr>
<td>0900</td>
<td>12.0</td>
</tr>
<tr>
<td>1000</td>
<td>12.0</td>
</tr>
<tr>
<td>1100</td>
<td>12.0</td>
</tr>
<tr>
<td>1200</td>
<td>12.0</td>
</tr>
<tr>
<td>1300</td>
<td>12.0</td>
</tr>
<tr>
<td>1400</td>
<td>11.0</td>
</tr>
<tr>
<td>1500</td>
<td>8.0</td>
</tr>
<tr>
<td>1600</td>
<td>2.0</td>
</tr>
<tr>
<td>1700</td>
<td>0.0</td>
</tr>
<tr>
<td>Daily Average</td>
<td>10.7</td>
</tr>
</tbody>
</table>
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, herein-after 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:

\[
R_n = (1 - \alpha) R_s + L_n
\]  

(1)

where \( R_s \) is the global solar radiation, \( L_n \) is the net long wave radiation, and \( \alpha \) 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:

$$L_n = a_1 R_s + b$$  \hspace{1cm} (2)

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

$$R_n = a R_s + b$$  \hspace{1cm} (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.

<table>
<thead>
<tr>
<th>Radiation Values</th>
<th>Mean Albedo</th>
<th>Mean Net Infrared Flux (langley/s/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>.26</td>
<td>-.43</td>
</tr>
<tr>
<td>Measured</td>
<td>.19</td>
<td>-.47</td>
</tr>
</tbody>
</table>
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:

\[ E_0 = \frac{eH + \rho \text{ed}_a}{L + \rho R_a} \varepsilon + 1 \]

(4)

where

- \( E_0 \) = potential evaporation rate \((g/cm^2/sec)\)
- \( \varepsilon \) = dimensionless parameter \((\Delta/\gamma)\)
- \( H \) = sum of energy inputs at surface exclusive of sensible and latent heat \((\text{cal/cm}^2/\text{sec})\)
- \( L \) = latent heat of vaporization
- \( \rho \) = density of air \((g/cm^2)\)
- \( e \) = water/air molecule ratio (.622)
- \( \text{ed}_a \) = saturation vapor pressure deficit of air \((\text{mb})\)
- \( p \) = ambient pressure \((\text{mb})\)
- \( R_a \) = turbulent diffusion "resistance" \((\text{sec/cm})\), following Monteith and Szeicz (1962) as:
\[ R_a = \frac{\ln \left( \frac{Z_a}{Z_o} \right)^2}{k^2} \cdot \frac{1}{u_a} \]

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:

\[ \text{ET} = \frac{cH + \frac{\rho_{ed}}{L} \left( \frac{pR_a}{R_s} \right)}{\varepsilon + 1 + \frac{R_s}{R_a}} \]  

(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):

$$R_s = \frac{eH}{L} \frac{R_a}{E} + \frac{p \varepsilon d}{E} - \varepsilon R_a - R_a$$

(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 microwatersheds (Smith and Striffler, 1969) were used to determine evaporation rates according to the following formula:

$$E = P - \Delta S$$

(7)
where

\[ E = \text{evaporation rate (mm/day)} \]
\[ P = \text{rainfall (mm/day)} \]
\[ \Delta S = \text{change in soil water in top 120 cm of soil profile (mm/day)} \]

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

\( R_s \) was computed for the lysimeter enclosure and the grazing treatments by utilizing equation (5) and the appropriate meteorological measurements. Meteorological data secured at the lysimeter enclosure 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>
<thead>
<tr>
<th>Date</th>
<th>Potential Evapotranspiration (mm/hr)</th>
<th>Actual Evapotranspiration (mm/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 14</td>
<td>.70</td>
<td>.27</td>
</tr>
<tr>
<td>May 20</td>
<td>.90</td>
<td>.35</td>
</tr>
<tr>
<td>June 9</td>
<td>1.00</td>
<td>.37</td>
</tr>
<tr>
<td>July 12</td>
<td>3.46</td>
<td>.31</td>
</tr>
<tr>
<td>July 17</td>
<td>1.50</td>
<td>.16</td>
</tr>
<tr>
<td>July 23</td>
<td>5.00</td>
<td>.13</td>
</tr>
<tr>
<td>July 30</td>
<td>5.56</td>
<td>.09</td>
</tr>
<tr>
<td>August 5</td>
<td>2.00</td>
<td>.21</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Date</th>
<th>Evapotranspiration (mm/day)</th>
<th>Canopy Resistance (sec/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-grazed</td>
<td>Heavily Grazed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>May 5</td>
<td>0.92</td>
<td>0.59</td>
</tr>
<tr>
<td>June 1</td>
<td>1.09</td>
<td>0.74</td>
</tr>
<tr>
<td>June 15</td>
<td>2.70</td>
<td>2.45</td>
</tr>
<tr>
<td>July 5</td>
<td>2.93</td>
<td>2.44</td>
</tr>
<tr>
<td>July 15</td>
<td>2.55</td>
<td>1.93</td>
</tr>
<tr>
<td>July 30</td>
<td>1.47</td>
<td>1.36</td>
</tr>
</tbody>
</table>
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 $R_5$ 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.

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


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Trlica, J. Verbal communication, Colorado State University, Fort Collins, 1972.

Valli, V. J. *A Biometeorological Data Logging System for Agricultural Research*. Mimeograph Series N.S. 244: Georgia Agricultural Experiment Station, 1966.


Williams, G. Verbal communication, Washington State University, Pullman.
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"
1. C
2. C THIS PROGRAM READS LOW DENSITY PAWEE SITE TAPES AND WRITES
3. C CONVERTED, SCREENED DATA ON HIGH DENSITY TAPE TO BE STORED AND
4. C USED AT CSU.
5. C A HIGH DENSITY TAPE CONTAINS INFORMATION FROM MORE THAN ONE REEL
6. C OF LOW DENSITY -- FOR EACH REEL TRANSFERRED THE FIRST RECORD OF
7. C FILES AND TWO ENTS INDICATE THE END OF THE LOW DENSITY REEL.
8. C A HIGH DENSITY TAPE -- EACH PHYSICAL REEL CONTAINS 42 LOGICAL
9. C RECORDS, 110 CHARACTER LENGTH PLUS 2 ZERO CHARACTERS TO MAKE
10. C A 5000 CHARACTER PHYSICAL RECORD.
11. C EACH LOGICAL RECORD REPRESENTS ONE MINUTES WORTH OF DATA. (119
13. C THE FIRST 36 SETS OF 3 CHARACTERS REPRESENT INSTRUMENT READINGS.
14. C THE NEXT 10 CHARACTERS IN GROUPS OF TWO REPRESENT THE MINUTE.
15. C HOUR, DAY, YEAR AND EXPERIMENT CODE FOR THE MINUTE BEING RECORDED.
16. C THE 119TH CHARACTER IS A DOLLAR SIGN TO INDICATE END OF LOGICAL
17. C RECORD.
18. C C INPUT DECK
19. C 1 COMMENTS CARDS ENDING WITH $ IN COL 1
20. C NOT MORE THAN 62 COMMENTS CARDS MAY BE USED
21. C 2 IF END OF FILE MARKS IN 12 FORMAT TO BE FOUND ON INPUT TAPE
22. C 4 NUMBER OF FILES ALREADY WRITTEN ON TAPE IN 12 FORMAT
23. C DIMENSION #BUF(125), INBUF(311), A(119), REG(16)
24. C IMPLICIT INTEGER(A-Z)
25. C DATA (3XR,1X) / DUR/1167/120
26. C 800 FORMAT(20A4)
27. C 901 FORMAT(55H *** COMMENT INF 3 TO 5 LARGE--OR DOLLAR SIGN MISSING ***)
28. C 902 FORMAT(5X,20A4)
29. C 903 FORMAT(1H,3X,40-1/7) CREATING COMPLETE BUT ERROR HAS OCCURRED ***
30. C 1 IS A STATEMENT # *15
31. C 904 FORMAT(12)
32. C DO IO I=1,1250
33. C WRKNO
34. C READ COMMENT CARDS INTO WBUF AND THEN WRITE OUT TO TAPE FILE
35. C REG=1
54.     END=20
55.     PRINT 206
56.     20 REAC ROG,(WBUF(1),I=BEGIN,END)
57.     PRINT RC1,1,(WBUF(1),I=BEGIN,END)
58.     IF (WBUF(1),EQ. ,O,L) GO TO 39
59.     IF (WBUF(BEG),EQ. ,O,L) GO TO 30
60.     BEG=END+1
61.     FAE-BEG+19
62.     IF (BEG,L.E. ,1250) GO TO 20
63.     PRINT 801
64.     STOP 1
65.     C
66.     30 CALL BUFFEROUT(1,1,WBUF(N),1250,N)
67.     C
68.     35 GO TO (35,19,37,37),N
69.     37 ERR=37
70.     PRINT 803,ERR
71.     C
72.     39 READ NUMBER OF FILES ON INPUT TAPE
73.     C
74.     KEF=0
75.     C
76.     C
77.     C
78.     C
79.     C
80.     C
81.     C
82.     C
83.     C
84.     C
85.     9998 SFILC
86.     C
87.     L
88.     C
89.     C
90.     C
91.     C
92.     C
93.     C
94.     C
95.     C
96.     C
97.     C
98.     C
99.     C
100.    C
101.    C
102.    C
103.    C
104.    C
105.    C
106.    C
107.    C
C60 CONTINUE
C
C INLINE ASSEMBLY USED TO PUT ONE BYTE PER WORD IN ARRAY A

LCI 0 SAVE REGISTERS
LUI 119 R1 COUNTS # OF BYTES LEFT TO BE MOVED
LUI 0 R2 GIVES BYTE AND WORD POSITION
62 LRT +2 INBUF,-2 GET 1BL BYTE
STW,4 A,2 STORE IT IN ARRAY A
ALU 1 COUNT A BYTE
BDR,1 625 DECREMENT AND TEST FOR END
LCI 0 RESTORE REGISTERS
LW,0 REG

CALL CHANGE(A,MN,HOUR,DAY,MO,STFL,TIME)
IF(STFL,NE,0) GO TO 61
PRINT STARTING TIME
PRINT 8124,HOUR,MN
STFL=1
GC IC 63
SAVE RUNNING TIME
61 LMP=MU
LDAY=DAY
LWR=HOUR
LWI=MN
63 CHARS=CHARS+119
PACK BYTES FROM ARRAY A INTO 119 BYTES OF WBUR
STW,0 REG
LUI 119 R2 POINTS TO WORD IN A ARRAY
LUI 0 R2 POINTS TO WORD IN A ARRAY
64 LW,3 CHAR
LW,4 A,2 GET WORD FROM A
STB,4 WBUR,3 STORE BYTE 1/4 WBUR
ALU 1 ADD TO WORD COUNT
ALU 1 ADD TO BYTE COUNT
DNU 1 645
LCI 0
LW,6 REG

1F(RECN,LT,42) GO TO 50

PUT 5000 CHARACTERS OF WRUF ONTO TAPE FILE
THEN GET NEXT SET OF 42 RECORDS
CALL BUFFER OUT(1,1,WRUF(1),1250,N)
65 GO TO (65,45,67,67,67)
67 ERR=67
162. PRINT 803, ERR
163. GO TO 40
164. 69 END FILE 1
165. C PRINT THE LAST DATE READ
166. C PRINT YES,NO,YDAY,LMN
167. C PRINT #14, YES, NO
168. C ERR=0
169. C KEOF=KEOF+1
170. C IF(KEOF.LT.NEOF) GO TO 40
171. C IF(KEOF.LT.NEOF) KEEOF=KEOF+1
172. C END FILE 1
173. C READ RECORD
174. C REWIND 1
175. C REWIND 2
176. C READ NUMBER OF FILESALREADY WRITTEN ON TAPE
177. C READ 804, EIFS
178. C KEEOF=KEEOF+1
179. C PRINT #15, KEEOF
180. C STOP
181. C END
1. SUBROUTINE CHANGE(A,MIN,HOUR,DAY,MO,ST,TIME)
2. DIMENSION A(119),I04(12)
3. IMPLICIT INTEGER(A-Z)
4. DATA(I01(1),I1=1,12),31,30,31,30,31,30,31,30,31,30,31,31/ 
5. DATA(GHR/(24*24)/)
6. C THIS SUBROUTINE CHANGES THE ORDER OF 119 WORDS OF ARRAY A
7. C TO CHANGE THE TIME AND RETURNS 119 WORDS IN A READY TO BE OUTPUT
8. C
9. C CHECK AND CORRECT CLOCK DATA
10. C
11. EXP=A(117) A(118)*10
12. MIN=A(105)+A(110)*10
13. HOUR=A(111)+A(112)*10
14. IF (ST.NE.0) GO TO 1
15. GE=A(115)+A(116)*10
16. DAY=A(113)+A(114)*10
17. TIME=HOUR*60+MIN
18. GO TO 6
19. C
20. 1 IF(TIME-1440)3,2,4
21. 2 TIME=0
22. DAY=DAY+1
23. 3 IF(DAY.LT.10) GO TO 6
24. DAY=DAY+1
25. Mo=Mo+1
26. GO TO 5
27. 4 TIME=TIME-1440
28. DAY=DAY+1
29. GO TO 1
30. 5 IF(MO.GT.12) Mo=Mo-12
31. C
32. 6 A(109)=MIN/10
33. A(110)=MIN-A(109)*10
34. A(111)=HOUR/10
35. A(112)=HOUR-A(111)*10
36. A(113)=DAY/10
37. A(114)=DAY-A(113)*10
38. A(115)=Mo/10
39. A(116)=Mo-A(115)*10
40. A(117)=EXP/10
41. A(118)=EXP-A(117)*10
42. C THE UNITS AND HUNDREDS DIGIT ARE INTERCHANGED 3 AT A TIME
43. C FOR THE FIRST 108 WORDS
44. J=2
45. DC 10 ICU=1,36
46. J=J+1
47. IF(A(J).LT.0) OR. A(J).GT.9) GO TO 7
48. IF(A(J+1).LT.0) OR. A(J+1).GT.9) GU TO 7
49. IF(A(J+2).LT.0) OR. A(J+2).GT.9) GO TO 7
50. TEMP=A(J)
51. A(J)=A(J+2)
52. A(J+2)=TEMP
53. GO TO 10
54. 7 A(J)+9
55.  A(J+1)+9
56.  A(J+2)+9
57.  10 CONTINUE
58.  A(119)=DLIR
59.  RETURN
60.  END

CNG 530
CNG 540
CNG 550
CNG 560
CNG 570
CNG 580
CNG 590
2. "Compact 556"
08 28 DEC 11, '72 [ID=00211221]

COMPACT AT 55633026

LIMIT (TIME, 15), (LOG, 20), (UOH, 50)
ASSIGN F 1, (DEVICE, 77), (INSN, '108C'), (LNPACK, 'BIN'), (TRIES, 0)
ASSIGN F 2, (DEVICE, 77), (LABEL, MCC), (OUTSN, '3027'), (KEYED), (SEQUEN), (OUT)

FORTRAN LS, GS, S

EXT. FORTRAN IV, VERSION 000
1. DIMENSION FILE(13),REC(60,411),INBUF(31),AIL(119),B(41),KEY(3)  
2. DIMENSION KOUT(36,242),ACCT(2),PASS(2),OUTSN(2),INSN(2)  
3. IPPLICIT INTEGER (A-Z)  
4. DATA FILE12,MCCOLLOCH  
5.  
6. 800 FORMAT (15.110,66,44)  
7. 800 FORMAT (2413,8X)  
8. 800 FORMAT (HL3X,10BH MIN MAX MIN MAX MIN MAX MIN MAX MIN MAX)  
9. 800 FORMAT (HL3X,10BH MIN MAX MIN MAX MIN MAX MIN MAX MIN MAX)  
10. 800 FORMAT (440HR,16,1119)  
11. 800 FORMAT (14,121,15,141)  
12. 812 FORMAT (17H0STARTING TIME IS + I2+1H/12+1H/12+1H/12)  
13. 813 FORMAT (15HENDING TIME IS + I2+1H/12+1H/12+1H/12)  
14. 901 FORMAT (33H0FIRST GOOD RECORD CF FILE IS EDF)  
15. 902 FORMAT (EH ERR =1,23)  
16.  
17.  
18. DATA DECK  
19.  
20. C  
21. C  
22. C  
23. C  
24. C  
25. C  
26. C  
27. C  
28. C  
29. C  
30. UNIT=2  
31. ACCT(11)=0  
32. PASS(11)=0  
33. ORG=2  
34. ACCES=1  
35. SIZE=2460  
36.  
37. IF (TAPE .NE. 0) GO TO 1  
38. C  
39. C  
40. C  
41. C  
42. C  
43. C  
44. C  
45. C  
46. C  
47. C  
48. C  
49. C  
50. C  
51. C  
52. C  
53. 3 LEOP=0
54. C READ ANC PRINT PIN ANC MAX CARDS
55. C READ 605, ((XOUTI(J,J,K),K=1,2),J=1,24),I=1,36
56. C PRINT 809, ((1,I=1,12))
57. C PRINT 809, ((1,I=1,12))
58. C DC 32 J=1,36
59. C 31 PRINT 810, ((XOUTI(J,J,K),K=1,2),J=1,12)
60. C PRINT 809, ((1,I=1,24))
61. C DC 32 J=1,24
62. C 32 PRINT 810, ((XOUTI(J,J,K),K=1,2),J=1,24)
63. C ONE HOUR INITIALIZED TO ALL 999
64. C 5 DC 10, JED=1,60
65. C DO 10 JED=1,61
66. C 10 REC(100,JDO)=999
67. C READ FIRST RECORD FROM FILE
68. C 17 STFIL=0
69. C 20 CALL BUFFERIN (1,1,INBUF,31,M)
70. C 30 GO TO (30,40,900,20),N
71. C 40 CALL ENTER(INBUF,A)
72. C CALL CHANGE(A,B,MIN,HOUR,DAY,MO,STFIL,XOUTI,TIME)
73. C IF(MIN.LT.0 .OR. MIN.GT.59) GO TO 20
74. C IF(HOUR.GT.23) GO TO 20
75. C PRINT STARTING TIME
76. C PRINT 812,Mc,DAY,HOUR,MIN
77. C STFIL=1
78. C GO TO 105
79. C PRINT ALL BUT FIRST RECORD FROM FILE
80. C 50 CALL BUFFERIN (1,INBUF,31,N)
81. C TIME =TIME+
82. C 60 GO TO (60,70,200,501,M)
83. C 70 CALL ENTER(INBUF,A)
84. C CALL CHANGE(A,B,MIN,HOUR,DAY,MO,STFIL,XOUTI,TIME)
85. C SAVE RUNNING TIME
86. C LPM=MO
87. C LDAY=DAY
88. C LHH=HOUR
89. C LMM=MIN
90. C TEST FOR BAD READING ON MINUTE
91. C IF(MIN.LT.0 .OR. MIN.GT.59) GO TO 50
92. C IF(HOUR.LT.0 .OR. HOUR.GT.23) GO TO 50
93. C ENTER DATA INTO REC
94. C 105 IROW=MIN+1
95. C DC 110 JDO=1,41
96. C 110 REC(IROW,JDO)=61(JDO)
97. C TEST FOR END OF REC
98. C IF(IROW,LT.60) GO TO 50
108. C WRITE KEYED RECORD ON TAPE
109. C KEY(1)=PD+10**4+DAY*10**2+HOUR
110. C IRDM=0
111. C REinitialize REC
112. C DO 120 100=1,60
113. C DC 120 JDO=1,41
114. C 120 RECIID,JDO=999
115. C GO TO 50
116. C C ECF WAS FOUND ON INPUT TAPE
117. C 200 IF (IRDM.EQ.0) GO TO 210
118. C IF(LPENF=1 .NE.NEDF) GO TO 210
119. C C WRITE AN INCOMPLETE ENDING RECORD
120. C KEY(1)=PD+10**4+DAY*10**2+HOUR
121. C CALL PUTUNIT(REC,SIZE,KEY,4)
122. C C 210 LEOP=LEOF+1
123. C C PRINT LAST CATE READ
124. C PRINT 813, LAY,LDAY,LMN,LM1N
125. C C TEST FOR LAST EOF
126. C IF (LEOF.EQ.NEOF) GO TO 300
127. C GC 10 17
128. C 300 PRINT 801,KEY(1)
129. C KEY(1)=999999
130. C CALL PUTUNIT(REC,SIZE,KEY,4)
131. C CALL CLOSEUNIT
132. C STOP
133. C C ENRCR PRINTS
134. C 900 PRINT 901
135. C LEOF=LEOF+1
136. C GC TO 20
137. C 500 PRINT 902,ERR
138. C OUTPUT KEY
139. C STOP
140. C 600 LINE =600
141. C OUTPUT LINE
142. C PRINT 902,ERR
143. C STOP
144. C ENA
1. SUBROUTINE ENTER(INBUF,A)
2. DIMENSION REG(16)
3. C INBUF AND A ARE ARRAYS BUT ARE NOT DIMENSIONED HERE
4. C BECAUSE FORTRAN ADJUSTS THE STARTING ADDRESSES TO WORD ONE
5. C AND I USE IT AS WORD ZERO IN THIS ROUTINE
6. C
7. C IMPLICIT INTEGER(A-Z)
8. C
9. C INLINE ASSEMBLY USED TO PUT ONE ONE BYTE PER WORD IN ARRAY A
10. C
11. S LCI 0 SAVE REGISTERS
12. S STM,0 REG
13. S LI,+1 119 R1 COUNTS # OF BYTES LEFT TO BE MOVED
14. S LI,+2 0 R2 GIVES BYTE AND WORD POSITION
15. S 62 LE,+4 #INBUF,2 GET THE BYTE
16. S SW,+4 *A,+2 STORE IT IN ARRAY A
17. S A1,+1 1 COUNT A BYTE
18. S RDR,+1 62S DECREMENT AND TEST FOR END
19. S LCI 0 RESTORE REGISTERS
20. S LM,0 REG
21. C
22. RETURN
23. EAC

ENT 10
ENT 20
ENT 30
ENT 40
ENT 50
ENT 60
ENT 70
ENT 80
ENT 90
ENT 100
ENT 110
ENT 120
ENT 130
ENT 140
ENT 150
ENT 160
ENT 170
ENT 180
ENT 190
ENT 200
ENT 210
ENT 220
ENT 230
SUBROUTINE CHANGES(A,B,MIN,HOUR,DAY,MO,ST,OUT,TIME)
DIMENSION A(119),IDAT(12),XOLT(36,4,2),B141
IMPLICIT INTEGER(A-Z)
DATA(DAT(1),1=1,121,31,30,31,30,31,30,31,30,31)/
C
GET TIME
10 MIN=A(109)+A(110)*10
11 HR=A(111)+A(112)*10
12 IF(ST.NE.0) GO TO 1
13 MO=A(115)+A(116)*10
14 DAY=A(113)+A(114)*10
15 TIME=HR*X60+MIN
16 GO TO 6
17 TIME=0
18 DAY=DAY+1
19 IF(DAY.LE.IDAT(MO)) GO TO 6
20 MO=MO+1
21 GO TO 5
22 TIME=TIME-1440
23 DAY=DAY+1
24 GO TO 1
25 IF(MO.GT.12) MO=MO-12
26 STORE CORRECT TIME AND EXP IN ARRAY B
27 B(37)=MIN
28 B(38)=HR
29 B(39)=DAY
30 B(40)=MO
31 B(41)=A(117)+A(118)*10
32 THE FIRST 108 WORDS OF A ARE COMBINED 3 AT A TIME AND ACTUAL
33 HEADINGS ARE STORED IN B.
34 IF(H.LE.0 .OR. H.GT.60) GO TO 20
35 J=2
36 LD 10 ICD=1,36
37 J=J+3
38 IF(IDC.AND.IDC+1.AND.IDC+2) IDC=0
39 IF(B(IIDC).GE.XOLT(IIDC,3,1)+0.01) GO TO 10
40 DC 30 IDC=999
41 IDC=999
42 DC 30 CONTINUE
43 RETURN
44 DC 30 RETURN
45 DC 30 EIC
3. "List Keys"
08 50 DEC 14, 72 IC=049412FL
JCO RAO3, JAH NUMA , = 2556 LIST KEYS FROM LANCL TAPE
LIMIT (TIME=15), (L(0,2)), (L(0,2))
ASSIGN F 3, (DEVICE=77), (LABEL=LINC), (INSN, JNAME), (KEYED), (SEQU), (IN)
PRINT LS, GO
EXT. FORTRAN IV, VERSION DOC
DIMENSION FILE(12),ACCT(2),PASS(2),LASH(2),KEY(8),REG(1004)

500 FORMAT(A1)  
B01 FORMAT(112,13F10.3,1F10.3) RECORDS READ 
802 FORMAT(112) 
803 FORMAT(4,3H:KEYS WRITTEN ON TAPE HAVE FOLLOWING FORMAT)  
804 FORMAT(11H COL 123456789)

C

PRINT 803
PRINT 804
C

10. C PREPARE TO READ KEYED RECORDS
   11. READ 800,INSN(1)
   12. UNIT=1
   13. MODE=2
   14. ACCT(1)=0
   15. PASS(1)=0
   16. ORG=2
   17. ACCES=1
   18. SIZE=240
   19. OUTSN=0
   20. CALL ERRSET(TERR,6005,6005,DCB)
   21. CALL OPENFILE(FILE,MODI,ACCT,PASS,INSN,INSN,OUTSN)
   22. C COUNT NUMBER OF RECORDS READ
   23. NREC=0
   24. C
   25. C
   26. C
   27. C
   28. C
   29. S CALL GETUNIT(REC,SIZE)
   30. NREC=NREC+1
   31. CALL GETKEY(UNIT,KEY,SIZE)
   32. IF(KEY(1).EQ.999999) GO TO 500
   33. PRINT BC2,KEY(1)
   34. GO TO 5
   35. C
   36. C END OF FILE WAS READ
   37. 500 PRINT BC1,NREC
   38. CALL CLOSEUNIT
   39. GO TO 5
   40. C
   41. C ERROR EXITS
   42. 600 PRINT QC2,ERR
   43. 902 FORMAT ERR = 'Z31
   44. OUTPUT NREC
   45. GO TO 5
   46. END
4. "Average 556"
12 37 DEC 08, '72 ID-OF+612F1
JOB AAO3, NUNN JR  , - 2356  AVERAGES FROM 3076 FOR RECORD
LIMIT TIME;15), (PAGES, 500)
ASSIGN 1.(DEVICE,771). (LABEL,MCC), (INSN, 30271), (KEYED), (SEQUEN, (IN)
FORTAN LS,60,5
EXT. FORTRAN IV, VERSION 000
DIMENSION INBUF(60,413), SUM(36,100,2), AVG(35,100,2), CRO[80]
DIMENSION FILE(3), ACCT(2), PASS(2), INSN(2), KEY(8)
INTEGER UNIT, ACCT, PASS, ORG, ACCES, SIZE, OUTS, ERR
EQUIVALENCE(SUM, AVG)
DATA FILE/12K,CCLOCH/, DOLL/1MS/
C
800 FORMAT(215)
801 FORMAT(615)
802 FORMAT(24HO-END OF TAPE ENCOUNTERED)
803 FORMAT(45H) MAX NO. OF INTERVALS EXCEEDED, 100 PROCESSED
804 FORMAT(8H) AVG. OF: 15, 7HMINUTES/
105 FORMAT(28H) STARTING KEY WAS NOT FOUND OR/
1. 36H INTERVAL EXCEEDS LAST KEY REQUESTED/
806 FORMAT(60A1)
807 FORMAT(1X,80A1)
810 FORMAT(4A1)
C
DATA DECK SETUP
1. COMMENTS CARDS ENDING WITH # IN COL 1
2. PLUS COL 1-4 TAPE NUMBER SAME AS INSH USED
3. 2 COL.1-5 NUMBER OF SETS TO BE PROCESSED (MIN)
4. 6-10 SIZE OF INTERVALS IN MINUTES
5. 3 COL.1-5 STARTING MIN HOURS
6. DAY
7. HOUR
8. ENDING MONTH
9. DAY
10. HOUR
C
REPEAT 3 IN TIMES)
12. C
13. INT IS THE # OF MINUTES TO BE AVERAGED
14. C
15. MINT COUNTS THE MINUTES BEING AVERAGED
16. C
17. JOCOUNTS # OF INTERVALS, MAY NOT EXCEED 100
18. C
19. M COUNTS MINUTES (1-60)
20. C
21. READ AND PRINT COMMENTS
22. 2 READ 806, CRD
23. IF(CRD(11).EQ.DOLL) GO TO 1
24. PRINT 807, CRD
25. GO TO 2
26. C
27. PREPARE TO OPEN FILE
28. 1 READ 810, INSN(1)
29. UNIT=1
30. MODE=2
31. ACCT(11)=0
32. PASS(1)=0
33. ORG=2
34. ACCES=1
35. SIZE=2460
36. OUTSN=0
C
CALL ERRSET(ERRR,9005,9005)
C
CALL OPENUNIT(FILE,MODE,ACCT,PASS,ONG,ACCES,INSW,OUTSN)
C
READ NUMBER OF RUNS, NUMBER OF MINUTES TO BE AVERAGED
C
READ &NRUNS,INT
DO 40 MDO=1,NRUNS
C
INITIALIZE
ZERO OUT ISUM ARRAY
DO 3 JDD=1,100
DC 3 KDD=1,2
3 ISUM(100,JDD,KDD)=0
C
JDO=1
NINT=0
C
READ STARTING AND ENDING DATES
READ 801,MO1,IDOY1,IMHR1,MO2,IDOY2,IMHR2
PRINT04,INT,PO1,IDOY1,IMHR1,PO2,IDOY2,IMHR2
C
CALCULATE STARTING AND ENDING KEYS
KEY(1)=MO1*10000+IDOY1*100+IMHR1
LKEY =MO2*10000+IDOY2*100+IMHR2
C
READ FIRST RECORD USING KEY
C
CALL GETUNIT1,INBUF,SIZE,KEY,4)
M=0
GO TO 20
C
READ ONE RECORD
10 CALL GETUNIT1,INBUF,SIZE)
CALL GETKEY1(UNIT,KEY,LOGTH)
IF (KEY(1).LE.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
PROCESS THE NEXT MINUTE IN THE JDO INTERVAL
25 NINT=NINT+1
DO 30 NDO=1,100
IF (INBUF(1,NDO).EQ.999) GO TO 30
ISUM(NDO,JDO,1)=ISUM(NDO,JDO,1)+INBUF(1,NDO)
30 CONTINUE
C
TEST FOR END OF INTERVAL AND MAX NUMBER OF INTERVALS
IF (NINT.LT.INT) GO TO 20
108.       NINT=0
109.       JDO=JDO+1
110.       IF JDO.LE.100 GO TO 20
111.       GO TO 520
112.       C
113.       C ORIGINAL DATA HAS BEEN SUMMED
114.       35 JDO=JDO-1
115.       CALL CALC(ISUM,AVG,JDO)
116.       CALL PRINT(AVG,ISUM,JDO)
117.       C
118.       40 CONTINUE
119.       C
120.       CALL CLOSE(UNIT)
121.       STOP
122.       C END OF TAPE WAS ENCOUNTERED
123.       500 PRINT 802
124.       GO TO 600
125.       C LAST KEY REQUESTED WAS JUST PROCESSED ABNORMAL EXIT
126.       510 PRINT 805
127.       GO TO 600
128.       C
129.       C MORE THAN 100 INTERVALS WERE REQUESTED
130.       520 PRINT 803
131.       JDO=JDO-1
132.       GO TO 35
133.       C
134.       C ERROR STOPS
135.       600 CALL CLOSE(UNIT)
136.       JDO=JDO-1
137.       CALL CALC(ISUM,AVG,JDO)
138.       CALL PRINT(AVG,ISUM,JDO)
139.       STOP
140.       900 OUTPUT ERR
141.       STOP
142.       END
SUBROUTINE CALC(ISUM, AVG, NINT)
DIMENSION ISUM(36, 100, Z2), AVG(36, 100, Z2)
DO 10 I=1, 36
10 UD 10 JDO=1, NINT
IF(ISUM(I, I, JDO) .NE. 0) GO TO 5
AVG(I, I, JDO)=0.
GO TO 10
5 AVG(I, I, 100, 11) = FLOAT(ISUM(I, 100, 11)) / FLOAT(ISUM(I, 100, Z2))
10 CONTINUE
DC 40 J1, NINT
AVG(I, J1) = AVG(I, J1) - 500.01 / 10.0
DO 20 J = 1, 4
20 AVG(I, J1) = AVG(I, J1) - 500.01 / 100.0
DC 21 ! = 9, 11
AVG(I, J1) = AVG(I, J1) - 500.01 / 10.0
DO 22 J = 12, 16
22 AVG(I, J1) = AVG(I, J1) / 10.0
AVG(I, J1) = AVG(I, J1) * 0.28665
AVG(I, J1) = AVG(I, J1) * 0.17 / T45.8
AVG(I, J1) = AVG(I, J1) + 2.5
AVG(I, J1) = AVG(I, J1) + 2.5
AVG(I, J1) = AVG(I, J1) - 11
DO 23 J = 22, 24
23 AVG(I, J1) = AVG(I, J1) - 500.01 / 100.0
AVG(I, J1) = AVG(I, J1) / (AVG(I, J1) - 333.1) / 167.1 / 16810
AVG(I, J1) = AVG(I, J1) / 66.67 / 1.6
AVG(I, J1) = AVG(I, J1) / 200.01 / 4.10
AVG(I, J1) = AVG(I, J1) / 200.01 / 4.06
AVG(I, J1) = AVG(I, J1) / 100.01 / 4.11
AVG(I, J1) = AVG(I, J1) / 100.01 / 4.90
AVG(I, J1) = AVG(I, J1) / 500.01 / 1.33
AVG(I, J1) = AVG(I, J1) / AVG(I, J1) / 1.78
AVG(I, J1) = AVG(I, J1) / AVG(I, J1) / 1.16
AVG(I, J1) = AVG(I, J1) / AVG(I, J1) / 1.16
CONTINUE
RETURN
END
SUBROUTINE PRINT(AVG, ISUM, NINT)
DIMENSION ISUM(36, 100, 2), AVG(36, 100, 2)
801 FORMAT(I30, 111, 71I5)
805 FORMAT(I3, F6.2, 15, 7F10.2, 15)
IBEG=1
IEND=0
40 IF(IEND.GT.NINT) IEND=NINT
PRINT 801, ((J), J=IBEG, IEND)
DO 50 ICD=1, 36
50 PRINT 850, ICD, ((AVG(IDD, J, 1), ISUM(IDD, J, 2)), J=IBEG, IEND)
IBEG=IEND+1
IEND=IEND+8
IF(IEND.GT.NINT) RETURN
PRINT 805
GO TO 40
END
5. "D-Plot"
PLOTS OF LYSIEMETER DATA

1, (INSN, 3623), (KEYED), (SEQUENT), (IN)
1. DIMENSION INBUF(60,41), TSUM(36,100,2), AVG(36,100,2)
2. DIMENSION FILE(3), ACCT(2), PASS(2), INSN(2), KEY(8)
3. DIMENSION CRD(80)
4. DIMENSION H1(100), H2(100), V1(100), V2(100)
5. EQUIVALENCE (SUM, AVG)
6. EQUIVALENCE (INBUF, H1, V1), (INBUF, H2, V2)
7. EQUIVALENCE (INBUF, V1, V2)
8. DATA DLK/1HS/, START/1HS/, PLUS/1HS/
9. DATA FILE/12MCCOLLOCK /* END/1HS/
10. INTEGER UNIT, ACCT, PASS, ORG, ACCES, SIZE, OUTSN, ERR
11. C
12. C DATA DECK
13. C I. TAPE NUMBER
14. C II. COMMENTS ENDING WITH $ IN COL 1
15. C III. INTERVALS TO BE PROCESSED
16. C IV. CHANNELS TO BE PROCESSED
17. C V. BLANK CARD TO INDICATE END OF JOB
18. C
19. 1 800 FORMAT(8DA1)
20. 801 FORMAT(D15.15)
21. 802 FORMAT(2I10,15)
22. 803 FORMAT(4E40.16)
23. 804 FORMAT(4A6)
24. 805 FORMAT(2H0ENDING KEY WAS NOT FOUND OR/
25. 1 36H INTERVAL EXCEEDS LAST KEY REQUESTED)
26. 806 FORMAT(30HOPAX NO. OF INTERVALS EXCEEDED)
27. 807 FORMAT(8DA1)
28. 808 FORMAT(6D0.0)
29. 809 FORMAT(10H CHANNEL, 13)
30. 810 FORMAT(10H + CHANNEL, 13)
31. 811 FORMAT(2F20.2)
32. 912 FORMAT (F20.2)
33. C
34. C PREPARE TO OPEN FILE
35. 2 READ 804, INSN(1)
36. 1 NSW=0
37. UNIT=1
38. MCEE=2
39. ACCT(1)=0
40. PASS(1)=0
41. DME=2
ACCS=1
SIZE=2460
OUTSN=0
CALL ERASE(FILE,9005,9005)
CALL OPENUNIT(FILE,MODE,ACCT,PASS,ORG,ACCS,INSN,OUTSN)

READ AND PRINT COMMENTS
4 READ B0C,CRC

IF ICHD(1).EQ.END GC TO 1010
IF ICHD(1).EQ.DLR GC TO 5
PRINT 007,240
GO TO 4

READ STARTING AND ENDING KEY AND NUMBER OF MINUTES TO BE AVERAGED

5 READ B01,KEY(1),LKEY,INT
PRINT 001,KEY(1),LKEY,INT
IF KEY(1).EQ.0 GO TO 1000

C
INITIALIZE
C
ZERO OUT ISUM ARRAY
DD 3 1DD(1),36
DO 7 JOG=1,100
DC N KDC=1,2
ISUM=100,JDO=KDO=0

JDO=1
MINT=0

READ FIRST RECORD USING KEY
CALL GETUNIT,INBUF,SIZE,KEY,41
M=0
GC TO 20

READ ONE RECORD
10 CALL GETUNIT,INBUF,SIZE)
CALL GETKEY(UNIT,KEY,LGTH)
IF KEY(1).LT.999999 GO TO 15
PRINT 003
M=0
GO TO 23

15 M=1
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 005

C
SKIP PLOT CARDS FOR THIS INTERVAL
23 READ 002,M1
GO TO 23

C
PROCESS THE NEXT MINUTE IN THE JOC INTERVAL
25 MINT=MINT+1
DO 30 MEO=1,36

GO
108. IF(INBUF(M,NDD).EQ.499) GO TO 36
109. ISUM=INDD,JOG,1)+ISUM(NDD,JOG,1)+INBUF(M,NDD)
110. ISUM(NDD,JOG,2)+ISUM(NDD,JOG,2)+1
111. 30 CONTINUE
112. C TEST FOR END OF INTERVAL AND MAX NUMBER OF INTERVALS
113. C IF(NINT.LT.INT) GO TO 20
114. NINT=0
115. JGO=JGO+1
116. IF(JGO.LE.100) GO TO 20
117. PRINT 605
118. GC TO 5
119. C ORIGINAL DATA HAS BEEN SUMMED
120. 35 JDD=JDD-1
121. C CALL CALC(SUM, AVG, JDD)
122. C PREPARE TO PLOT
123. 45 READ 802,M1,M2,VBOT,VTOP
124. HLEFT=0.
125. HRIGHT=100.
126. NPLINES=0
127. IPR=1
128. CX=STAR
129. NCHMN=0
130. 40 JGO
131. GO IF(M1.EQ.01) GO TO 4
132. K=M1
133. PRINT 803,K
134. DD 55 IDD=MOD,N
135. H1(IDC)=IDD
136. 55 V1(IDC)=AVG1(R,IDC,1)
137. IF(M2.EQ.01) GO TO 70
138. K=M2
139. PRINT 810,K
140. N2=JDD
141. CP=1
142. DO 60 IDD=1,N
143. 
144. 60 V2(IDC)=AVG2(IDC,1)
145. C PLOT 2 CURVES
146. C PLOT 2 CURVES
147. C CALL LEPL1(V1, M1, CH1, VTOP, VB0T, NPLINES, HLEFT, HRIGHT, IPR, N2, V2, H2, CM2)
148. 70 GO TO 45
149. C PLOIT CNE CURVE
150. C PLOIT CNE CURVE
151. 70 N2=0
152. PRINT 812, (V11, I=1,N)
153. CALL OPGPL1(V1, M1, CH1, VTOP, VB0T, NPLINES, HLEFT, HRIGHT, IPR, N2)
154. GC TO 45
155. C ERROR IN GETPUT SYSTEM SEE BPM MANUAL FOR I/O ERROR CODES
1. SUBROUTINE CALC(ISUM, AVG, NINT)
2. DIMENSION ISUM(36, 100, 2), AVG(36, 100, 2)
3. DO 10 JDO=1, NINT
4. IF (ISUM(ION, JDO, 2) .NE. 0) GO TO 5
5. AVG(ION, JDO, 2) = 0.
6. GO TO 10
7. 5 AVG(ION, JDO, 1) = FLOAT(ISUM(ION, JDO, 1))/FLOAT(ISUM(ION, JDO, 2))
8. 10 CONTINUE
9. DO 40 J=1, NINT
10. DO 20 I=1, 16
11. 20 AVG(I, J, 1) = AVG(I, J, 1) - 500. / 10.
12. AVG(17, J, 1) = AVG(17, J, 1) * 0.286865
13. AVG(18, J, 1) = AVG(18, J, 1) + 17 + 45.8
14. AVG(19, J, 1) = AVG(19, J, 1) / 10. + 1.511644472
15. AVG(20, J, 1) = AVG(20, J, 1) / 10. + 1.511644472
16. DC 30 I = 21, 26
17. 30 AVG(I, J, 1) = AVG(I, J, 1) - 44.44444444444444444444444444444
18. AVG(25, J, 1) = AVG(25, J, 1) - 333.1 / 107.7 / 1.6818
19. AVG(26, J, 1) = AVG(26, J, 1) - 333.1 / 107.7 / 1.6818
20. AVG(27, J, 1) = AVG(27, J, 1) - 333.1 / 107.7 / 1.6818
21. AVG(28, J, 1) = AVG(28, J, 1) - 333.1 / 107.7 / 1.6818
22. AVG(29, J, 1) = AVG(29, J, 1)
23. AVG(30, J, 1) = AVG(30, J, 1)
24. AVG(31, J, 1) = AVG(31, J, 1) / 100. / 1.7.9
25. AVG(32, J, 1) = AVG(32, J, 1) / 100. / 1.7.9
26. AVG(33, J, 1) = AVG(33, J, 1) / 1.66.67 / 7.52
27. AVG(34, J, 1) = AVG(34, J, 1) / 2.78
28. AVG(35, J, 1) = AVG(35, J, 1) / 2.78
29. AVG(36, J, 1) = AVG(36, J, 1) / 10.1 + 1.511644472
30. AVG(36, J, 1) = AVG(36, J, 1) / 10.1 + 1.511644472
31. 40 CONTINUE
32. RETURN
33. END
34.
SUBROUTINE D_PLOT(N,V,H,CH1,C2,K1,L1,C4,IPR,NZ,V2,H2,CH2) DPLD 1
C 105 FORMAT(1X,A11,F20.11) DPLC 3
C 120 FORMAT(19H POINTS A1,12H NOT PLOTTED/1X) DPLD 4
C 201 FORMAT(1H1) DPLD 5
C 202 FORMAT(1X) DPLD 6

C *********************************************************************** DPLD 7
C DIMENSION V(N),H(N),HPR(16),LINE(101),L10(101),VZ(N2),H2(N2) DPLD 8
C DATA (LINE(I),I=1,101),(L10(I),I=1,100,2)/151*1H / DPLD 9
C DATA (L10(I),I=1,101,2),LDOT(52)*1H,/ DPLD 10
C VL=0.1 DPLD 11
C VU=0.2 DPLD 12
C VL=0.3 DPLD 13
C ML=0.4 DPLD 14
C MH=0.5 DPLD 15
C NU=0.6 DPLD 16
C DC 12 I=1,101,20 DPLD 17
C 1 L10(I)=DOT DPLC 18
C IF(VL,GT,HU .OR. N LT 2) STOP DPLC 19
C EPS=0 DPLD 20
C ASSIGN=1. DPLD 21
C IF(VL,LE,VU) GO TO 11 DPLC 22
C EPS=2. **(-34) DPLD 23
C ASSIGN=-1. DPLC 24
C VL=VL-DPLC 25
C VU=VU-DPLC 26
C DO 16 I=1,V DPLD 27
C 16 V(I)=V(I) DPLC 28
C IF(VZGE.0) GO TO 11 DPLD 29
C DC 18 I=1,V2 DPLD 30
C 11 CALL SORTUP(V,H,N) DPLD 31
C IF(VZGE.0) CALL SCRUTUP(VZ,H2,N2) DPLD 32
C IF(NL.EQ.0) NL=51 DPLD 33
C IF (MOD(NL-1,10).NE.0) NL=NL+10-MOD(NL-1,10) DPLD 34
C IF(VL,LE,VU) GO TO 17 DPLD 35
C VL=V1 DPLD 36
C VU=V1 DPLD 37
C IF(VZGE.0) GO TO 17 DPLD 38
C VL=AMNL(VL,VZ(I)) DPLD 39
C VU=AMNL(VU,VZ(I)) DPLC 40
C 17 DV=(VU-VL)/FLOAT(NL-1) DPLC 41
C VMNL=VL,-.5*DV DPLC 42
C VMN=VMNL+ABS(VMIN)*EPS DPLC 43
C VCV=VU-VMNL+DV DPLC 44
C NHOUT=0 DPLD 45
C NHOUT=0 DPLD 46
C DC 19 NV=1,N DPLC 47
C IF(VEN(WC).GE.VMIN) GO TO 20 DPLC 48
C YVC=NY1 DPLD 49
C 20 NV=NV-1 DPLD 50
C IF(NVGE.0) GO TO 49 DPLD 51
C DC 21 NV2=1,N2 DPLD 52
C IF(VZGE(NV2C).GE.VMIN) GO TO 22 DPLD 53
54. 49 NV2C=N2+1
55.   22 NV21=NV2C-1
56.   IF(NVL.EQ.N.AND.NV21.EQ.NZ1) GO TO 50
57.   IF(NL.NE.MU) GO TO 25
58.   HL=H(I)
59.   HU=H(I)
60.   DO 23 I=2,N
61.   IF(H(I).LT.ML) HL=H(I)
62.   23 IF(H(I).GE.MU) HU=H(I)
63.   IF(N2.LE.0) GO TO 25
64.   DO 24 I=1,N
65.   IF(VZ(I).LT.HL) HL=VZ(I)
66.   24 IF(VZ(I).GE.HU) HU=VZ(I)
67.   25 DH=(HU-ML)/100
68.   HMIN=ML-5*DH
69.   HMAX=HU+5*DH
70.   PRINT 201
71.   IF(NL.GT.51) GO TO 40
72.   L1=155-NL/2
73.   C DC 43 1=L1
74.   C 41 PRINT 202
75.   DO 27 I=1,6
76.   27 HPR(I)=HL(I)+HU-ML)*FLOAT(I-11)/5.
77.   IF(NAIGN.EQ.+1) OR.NL.GT.51 PRINT 105, HPR.
78.   DC 35 LD=NL+10
79.   (IF(LC.LT.1) GC TO 33
80.   DO 36 LC=1,9
81.   V)=VMIN+V=FLOAT(LD-10+11)/FLOAT(LD)
82.   30 CALL LINPL(I,LINE,2,VPR,VH,NVC,NSMC,HMIN,DH,NHOUT,CH1)
83.   1 VZ,NV,AVC,N2,NHOUT,CH2)
84.   33 VC=VMIN+V=FLOAT(LD-10+11)/FLOAT(LD)
85.   (VPR=ASSIGN(VL+(VU-VL)*FLOAT(LD-11)/FLOAT(LD)))
86.   35 CALL LINPL(I,L10,1,VPR,VH,NVC,NSMC,HMIN,DH,NHOUT,CH1)
87.   2 VZ,NV,AVC,N2,NHOUT,LM2)
88.   PRINT 105, HPR.
89.   50 IF(NAIGN.EQ.+1) GO TO 65
90.   DC 66 I=L1
91.   66 V(I)=V(I)
92.   IF(N2.LE.0) GO TO 65
93.   DC 67 I=L2
94.   67 W(I)=W(I)
95.   65 IF(NPR.EQ.0) GO TO 99
96.   IF(NVL.EQ.0.AND.NHOUT.EQ.0.AND.NVC.GT.N) GO TO 55
97.   PRINT 120, CH1
98.   CALL NOTPLTVWHN,NV1,NHOUT,NVC,HMIN,HMAX)
99.   55 IF(NVZ1.LE.GT.N.AND.NHOUT.EQ.0.AND.NVC.GT.N) GO TO 99
100.  PRINT 120, CH2
101.  CALL NOTPLTVH2,NV2,N2,NV21,NHOUT,NVC,HMIN,HMAX)
102.  PRINT 201
103.  RETURN
104.  EN
SUBROUTINE NOTPLOTVH,N,NVL,NHOLT,VVC,NVLC,NMAX)
C
C FIND AND PRINT POINTS (V,H) NOT PLOTTED
C
DIMENSION VIN(N),H(N)
100 FOR IX=1,IPZ(I),100
  IF(NVI.EQ.O) PRINT 100, (VIN(I),H(I),I=1,NVI)
  IF(NOUT.EQ.O) GO TO 30
  NVI=NVI+1
20   DO 25 I=NV1,N
  IF(N(VI,IE,LT,NH1),(NV1,VVC)) GO TO 25
  PRINT 100, (VIN(I),H(I))
25   NOUT=NOUT-1
26   IF(NOUT.EQ.O) GO TO 30
25 CONTINUE
30 IF(NVLC.EQ.N) PRINT 100, (VIN(I),H(I),I=NVLC,N)
RETURN
END
SUBROUTINE SORTUP(X,Y,N)

C SCRT. X IN ASCENDING ORDER AND CARRY Y

DIMENSION X(N),Y(N)
INTEGER FIRST
FIRST=1
LAST=N-1
NEXT=1

J=MAX0(1,FIRST-1)
K=MIN0(N-1,LAST+1)
DO 20 I=J,K
IF(X(I).LE.X(I+1)) GO TO 20
GO TO 12,NEXT

12 FIRST=1
NEXT=2

13 LAST=1
T=X(1)
X(1)=X(1+1)
X(1+1)=T
T=Y(1)
Y(1)=Y(1+1)
Y(1+1)=T

20 CONTINUE
IF(N-XT.EQ.2) GO TO 10
RETURN
END
6. Resistance Coefficients
RESISTANCE COEFFICIENTS

ASSIGN F 1, (DEVICE, IT), (LABEL, MCC), (INSY, 3024), (KEY:0), (SEQUEN), (IN)

FORTRAN LS, GO
EXT. FORTRAN IV, VERSION DO
1. C COMPLT RESISTANCE COEFFICIENTS FROM LINEAR TRANSFORMATION EQUATIONS
2. C ICEMPHINITIC, RESISTANCE CONCEPTS
3. C BY A.R. MCCOLLOCH NOVEMBER, 1972
4. C
5. C
6. C
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45. C
46. C
47. C
48. C
49. C
50. C
51. C
52. C
53. C
56. CALL ERRSET(ERR, 95JS, 9ADS)
55. CALL OPENFILVIT(FILE, MODE, ACCT, PASS, ING, ACCES, INS, CUTSN)
56. READ 64, START, END, INT
57. C READ FIRST RECORD USING START
58. KEY(3)=START
59. CALLGETUNIT(INBUF, SIZE, KEY, 4)
60. CALL GETKEYUNIT(UNIT, DAY, LGMH)
61. IF(INT.GT.20) GO TO 300
62. C CALCULATE FOR INTERVALS LE 60
63. 90 IST=1
64. TEND=INT
65. C FIND FIRST GOOD NUMBER IN CHANNEL 17
66. 100 DC 10X 100=IST, TEND
67. C INBUF(IOC+17), INT, 95JS GO TO 107
68. 105 IF(INBUF(IOC+17).NE.95JS) GO TO 107
69. PLOT 105, KEY
70. GO TO 150
71. 150 BEG17=INBUF(IOU+17)
72. EXCL=INBUF(IOU+17)
73. IST=IST+1
74. C ZER0 OUT THE SUM ARRAY
75. DC 11D 100=0, 136
76. SUM(100, 1)=0
77. SUM(100, 1)+=2.5
78. C SUM ALL GOOD NUMBERS FOR THIS INTERVAL
79. DC 120 INDU=1ST, TEND
80. C INBUF(IOU+17), INT, 95JS GO TO 120
81. SUM(100, 1)+=EXCL-1
82. SUM(100, 1)+=SUM(100, 1)+FLATT(INDU(IOO+17))
83. SLV(100, 1)+=SUM(100, 1)+1
84. 120 CONTINUE
85. C CALCULATE AVERAGE FOR THIS INTERVAL
86. DC 130 100=136
87. IF(SUM(100, 1).LE.0.1) GO TO 130
88. SUM(100, 1)+=SUM(100, 1)/SUM(100, 1)
89. 130 CONTINUE
90. C READ ANOTHER RECORD
91. 200 CALL GETUNIT(INBUF, SIZE)
92. CALL GETKEYUNIT(UNIT, DAY, LGMH)
93. IF(LGAY.GE.9099999) GO TO 900
94. C END
108. IF (DAY.GT.END) GO TO 970
109. GO TO 90
110. C
111. C CALCULATE FOR INTERVALS .GT. 61
112. 300 KEYS=DAY
113. MINUS=0
114. MULT=INT(61/5)
115. DC J=0 L=1,5 MULT
116. IF (MILL.NC.1) GO TO 330
117. DC J=5 L=1,60
118. 310 IF (IND1D(J)-17).GE.9991) GO TC 320
119. GO TO 350
120. 320 REG1=INBUF(IDU,17)
121. KEYS=DAY
122. MINUS=100-1
123. C ZENO CUT SUM ARRAY
124. UD 325 UID=1,36
125. SUM(EODU1) = 0
126. 325 SUM(EODU2) = 0
127. C SUM ALL GOOD NUMBERS IN THIS HOUR
128. 330 UD 340 UID=1,36
129. DC J=0 L=1,36
130. IF (INBUF(IDC).EQ.9991) GC TO 340
131. ENDFD
132. SUM(UID)=SUM(UID)+FLAINE(IND1D(J),JDD)
133. SLNT(JDD)=SUM(JOD)+2)*1
134. 340 CONTINUE
135. C FLAG ANOTHER RECORD
136. 350 CALL GETRT (UNIT,CAY,LGSHA)
137. CALL GETKY (UNIT,CAY,LGSHA)
138. IF (DAY.GE.759.991) GO TO 900
139. IF (DAY.GT.END+1) GO TO 970
140. 360 CONTINUE
141. C CALCULATE AVG
142. UD 370 UID=1,36
143. IF (SUM(JOD)+2).LT.0) GC TO 370
144. SUM(JOD)=SUM(JOD)+SUM(JOD)+2)
145. 370 CONTINUE
146. C CALLENTSUM
147. CALL CALC (SUM,ANS,REG1,END,NO17)
148. PRINT REC,KEYS,MINUS,ANS
149. GO TO 360
150. C
151. C END OF TAPE
152. 900 PRINT 809
153. GC TO 970
154. C FAR EXITS
155. 950 PRINT 807
156. GC TO 970
157. 960 PRINT 808
158. 970 REWIND UNIT
159. STOP
160. END
1. SUBROUTINE CST(A)
2. DIMENSION A(36,2)
3. C C CEL 1 OF A CONTAINS THE AVERAGES CALCULATED IN THE MAIN PROGRAM
4. C C CEL 2 OF A CONTAINS THE weighing FACTORS USED TO CALCULATE THE AVERAGE
5. C C IF NO AVG EXISTS, ENTER -10.**10
6. C C HAVE BEEN APPLIED
7. C IF NO AVG EXISTS, ENTER -10.**10
8. A(1,1)=A(1,1)-500.1/10.
9. A(2,1)=A(2,1)-500.1/100.
10. A(3,1)=A(3,1)-500.1/100.
12. DC 2C 1=F, 11
13. 20 A(1,1)=A(1,1)-500.1/10.
14. UC 3C 1=F, 12, 14
15. 30 A(1,1)=A(1,1)/.6.
16. A(1,1)=A(1,1)/.628663
17. A(1,1)=A(1,1)/.619411.
18. A(1,1)=A(1,1)/.6458.
19. A(1,1)=A(1,1)/.6458.
20. A(1,1)=A(1,1)/.6458.
21. A(1,1)=A(1,1)/.6458.
22. A(1,1)=A(1,1)/.6458.
23. A(1,1)=A(1,1)/.6458.
24. A(1,1)=A(1,1)/.6458.
25. A(1,1)=A(1,1)/.6458.
26. A(1,1)=A(1,1)/.6458.
27. A(1,1)=A(1,1)/.6458.
28. A(1,1)=A(1,1)/.6458.
29. A(1,1)=A(1,1)/.6458.
30. A(1,1)=A(1,1)/.6458.
31. A(1,1)=A(1,1)/.6458.
32. A(1,1)=A(1,1)/.6458.
33. A(1,1)=A(1,1)/.6458.
34. A(1,1)=A(1,1)/.6458.
35. A(1,1)=A(1,1)/.6458.
36. 10 40.1=1.36
37. IF(A(1,1).EQ.EC.244I,11)==IE-50
38. 40 CONTINUE
39. RETURN
40. END
1. SUBCUTINE CALCICH, ANS, ANS17, ENC17
2. DIMENSION CM(11), ANS(31)
3. IMPLICIT REAL(A-Z)
4. C ANS11 = RATH * CM IS RS
5. C ANS(1) = RAMSES RS(PHI)
6. C ANS(3) = RSA
7. C ANS(4) = RSA17
8. C ANS(5) = ATM IS RA
9. C ANS(6) = AMS IS RA(PHI)
10. C ANS(7) = ET
11. C ANS(8) = H IS RN*S
12. C ANS(9) = R1
13. C ANS(10) = DA
14. C CH(55) CONTAINS * OF PIN OF CHANNEL 17
15. C MIN(CM(53))
16. C CALL SUADAE(ES, EA, CH)
17. C CALL SEPSI(EP, DELT, GAM, CH)
18. C
19. C RMC = 9 & 5E-3
20. P = 662
21. C ET = 622
22. C
23. C CALCULATE H
25. C
26. C CALCULATE ET
27. C ET = (ELG17 - ENC17) / (12.6 * MIN*66 * CM(31))
28. C ET = (ELG17 - ENC17) / (12.6 * MIN*66 * 0.4) * 5820.0
29. C
30. C CALCULATE ATM AND AMS
31. C CALL RA(ASTM, ARM, R1, PF1, CH)
32. C
33. C CALL RS(ASTM, CH)
34. C RAP = EPS*ATM / ET * (RH0*DE/PE - EPS*ATM / ATM)
35. C RAP = EPS*ATM / ET * ATM
36. C PE = (EPS*ATM / ET) / (EPS*ATM / ATM)
37. C IF (PGE - 1.0 - 50) GO TO 20
38. C RAP = EPS*ATM / ET * ATM
39. C RSATMS = EPS*ATM / ET
40. C GE TO 30
41. C 20 RAMS = EPS*ATM / ET * (RH0*DE/PE - EPS*ATM / ATM)
42. C RSATMS = EPS*ATM / ET * ET1-ATM
43. C 30 ANS11 = RAMS
44. C ANS(1) = RAMS
45. C ANS(3) = RAMS
46. C ANS(4) = RAMS
47. C ANS(5) = ATM
48. C ANS(6) = AMS
49. C ANS(7) = ET
50. C ANS(8) = H
51. C ANS(9) = R1
52. C ANS(10) = DA
53. C RETURN
1. SUBROUTINE SOAPDA, ES, EA, CH
2. DIMENSION CH(1)
3. IMPLICIT REAL(A-Z)
4. P=84.42
5. TC=CH(1)+CH(2)
6. TB=CH(21)+CH(22)
7. TC=TC*1.5+32.
8. T1=TW*1.5+32.
9. ES=(1.*C041*F1*676)**8-10*C0019*ABS(T1*16.)**.001316)**33.86
10. EA=ES*(.60066*(1.+0.0115*TW)*P*(P-10))
11. ES=(.0041*F1*676)**8- .C0019*ABS(T0*16.)**.001316)**33.86
12. DA=ES-EA
13. RETURN
14. END
SUBROUTINE SEPS(EPS,DELT,GAM,CH)
1.
2.
3.
4.
5.
6.
7.
8.
9.
10.
11.
12.
13.
DEPNSION CH(1)
IMPLICIT REAL(A-Z)
K=7482.0
H=798.36
C=15.676
T=(CH(21)+CH(22))**9.75*32.
T=CH(21)+CH(22)
GAM=0.0004*(1.+0.0115*T)**842.
DELT=T/(T+B)**2*EXP(C)*EXP(-K/(T+B))**33.86*9.75.
EPS=DELT/GAM
RETURN
END
SUBROUTINE RA(AM,ATMS,RI,PHI,CH)

DIMENSION CH(11)

IMPCLICIT REAL(A-Z)

C

C=2.
Z1=60.
Z2=203.
K=41
G=980.
V1=CH(19)
V2=CH(20)

C

CALCULATE ATM

AP=(1-LEG(1/20)**2)/(K++C)*(1./V1)

CALCULATE ATMS

T1=CH(1)+CH(2)
T2=CH(3)+CH(4)
T=(T1+T2)/2.+273.
R1=G/(Tz-1.)*(Z2-Z1)/(V2-V1)**2
IF(R1.GT.-555) GO TO 10
PP=1./((1.-10.*R1)**.25
AF=AP*(1.+PHI)

10 ATMS=1.E-50
RETURN

END
1. SUBROUTINE RS(J,E1,CH)
2. DIMENSION CH(1)
3. IMPLICIT REAL(A-Z)
4. L=282.
5. RJC=.C0C995
6. R=399.36
8. J=-6.*L*RHG/P
9. K=7482.6
10. C=15.674
11. T=CH(1)*9.75+.32.
12. E1=EXP(C)*EXP(-R/(T+B))*.33.86
13. RETURN
14. END
APPENDIX II
REGRESSION COEFFICIENTS
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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):

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

where:

- \( B \) = Bowen's ratio
- \( K_h \) = molecular diffusivity for air
- \( K_v \) = molecular diffusivity for water vapor
- \( \alpha \) = psychrometric constant
- \( \delta \) = slope of vapor pressure-temperature curve
- \( \Delta T_w \) = differential wet-bulb temperature between heights \( Z_1 \) and \( Z_2 \)
- \( \Delta T \) = differential dry-bulb temperature between heights \( Z_1 \) and \( Z_2 \)

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.
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APPENDIX V

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<td>P (mm)</td>
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<td>P (mm)</td>
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<td>1.9</td>
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Table A-3 (continued).

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<td>July 20 to August 7</td>
<td>22.7</td>
<td>38.3</td>
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<td>25.0</td>
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<tr>
<td>ET-total (mm)</td>
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<td>1.70</td>
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Table A-4. Pawnee Site aboveground herbage and percent bare ground (light grazed treatment).

<table>
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<tr>
<th>Date</th>
<th>Bare Ground (%)</th>
<th>Live and Standing</th>
<th>Total Dead (g/m²)</th>
<th>Total Live (g/m²)</th>
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<tr>
<td>April 4</td>
<td>33.33</td>
<td>114.10</td>
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<td>May 10</td>
<td>27.67</td>
<td>95.58</td>
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<td>June 22</td>
<td>16.87</td>
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<td>July 18</td>
<td>27.97</td>
<td>135.60</td>
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<td>August 7</td>
<td>24.60</td>
<td>158.3</td>
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<td>149.3</td>
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<tr>
<td>September 12</td>
<td>22.50</td>
<td>155.6</td>
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Table A-5. Weather data for lysimeter exclosure, 1972, daily averages.

<table>
<thead>
<tr>
<th>Date</th>
<th>( R_n + S ) (cal/cm²/sec)</th>
<th>ET (mm/hr)</th>
<th>( E_o ) (mm/hr)</th>
<th>Soil Water (upper 120 cm)</th>
<th>( d_a ) (mb)</th>
<th>( R_s ) (sec/cm)</th>
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</thead>
<tbody>
<tr>
<td>May 14</td>
<td>.0095</td>
<td>.27</td>
<td>.7</td>
<td>NA</td>
<td>15.1</td>
<td>9.73</td>
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<tr>
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<td>.0094</td>
<td>.35</td>
<td>.9</td>
<td>NA</td>
<td>10.3</td>
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<td>June 9</td>
<td>.0082</td>
<td>.37</td>
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<td>NA</td>
<td>17.75</td>
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<td>July 12</td>
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<td>14.6</td>
<td>52.0</td>
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<tr>
<td>July 17</td>
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<td>.16</td>
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<td>NA</td>
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<td>.09</td>
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