Development of Spring Creek data acquisition system
by Robert Matthew Williams

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Electrical Engineering
Montana State University

Abstract:
The subject of this thesis is the development of a computeroperated remote data acquisition system located on Spring Creek.

The experimental Spring Creek station is the location of various weather and stream monitoring instruments all interfaced to the data acquisition system for remote interrogation by an HP 2115-A computer. A user may also call the computer from his location and obtain reports from the computer by using an acoustic coupler and teletype.

This thesis may be summarized as follows: First a physical description of the Spring Creek station and data communications link is made. Second, a hardware description including instruments, interfaces, and modifications is presented. Third, the software development for the system is described followed by some details on the real-time use of the system. Finally, a few remarks on the present and future systems are made.

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Date August 20, 1977

DEVELOPMENT OF THE SPRING CREEK DATA ACQUISITION SYSTEM

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ROBERT MATTHEW WILLIAMS

A thesis submitted in partial fulfillment
of the requirements for the degree

of

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Electrical Engineering

Approved:

Head, Major Department

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MONTANA STATE UNIVERSITY
Bozeman, Montana

August, 1974

ACKNOWLEDGEMENT

The development of the Spring Creek system has involved many individuals including those who have worked on previous data acquisition systems developed at Montana State University. The writer would especially like to thank Dennis Smith for working on software, Jim Earle for the thermistor development, and Dave Shema for his work in a great number of areas. Of course, the author is especially grateful to Dr. Donald K. Weaver for his assistance and support of the project.

R. M. W.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The subject of this thesis is the development of a computer-operated remote data acquisition system located on Spring Creek. The experimental Spring Creek station is the location of various weather and stream monitoring instruments all interfaced to the data acquisition system for remote interrogation by an HP 2115-A computer. A user may also call the computer from his location and obtain reports from the computer by using an acoustic coupler and teletype.

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DEVELOPMENT OF THE SPRING CREEK DATA ACQUISITION SYSTEM

Chapter I

INTRODUCTION

A data acquisition system is a term ascribed to various systems capable of obtaining information or data from various instruments, sensors, or transducers. Exactly how the information is obtained and what is done with it is dependent on the requirements for a given system. For example, the information may only be used for record keeping and not needed directly for weeks or months at a time. Other systems, such as those used in industrial plants, may use the results immediately to control some manufacturing process. The complexity of a system is also dependent on sampling rates, number of sensors monitored, and accuracy required.

The Spring Creek data acquisition system has been developed to provide an economical system for meteorological and hydrological monitoring. One particular requirement met in developing the system is that of automatically obtaining a daily report or summary containing useful data concerning a given instrument.

HISTORICAL BACKGROUND

Data acquisition systems have been built since the early 1950's. Early systems used mechanical multiplexing crossbar switching and vacuum tube technology. By the early 1960's, data could be stored on magnetic tape for later processing on such computers as the IBM 701 or 704. This type of arrangement precluded any immediate use of meaningful data.[1] By the late 1960's, the cost of computers had reduced to the point that data acquisition systems could be connected to computers in real-time. A system of this type is capable of obtaining data and processing it into a useful form on an immediate basis. This information could be used for automatic control. Industrial plants have made great use of computer-controlled data acquisition systems.[2] The Spring Creek system does not use the obtained data for control but has been developed as a real-time computer-controlled system for ease of obtaining useful environmental data in final form. An additional feature of this system is the capability of providing current environmental data for other people via the telephone system using an acoustic coupler and teletype.

The data acquisition system at Spring Creek has evolved from previous systems developed at Montana State University. In 1966, the Bridger data acquisition system was developed for the Montana Water Resources Reserach Center. Refer to Cannon (1967) for report

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1. Westwick (1972)
2. Rigby (1968)

on the system. The system was designed to measure various weather parameters in the Bridger Range and to transmit the corresponding data back to Montana State University using VHF radio. "Data acquisition system" was the terminology ascribed to the collection of electronic instruments and modules located at Bridger. This included an electronic clock, event counters, analog scanner, digital voltmeter, and digital translater. In addition, a controller was added that could be programmed to initiate the system at various intervals of time by the electronic clock. The scanner gated various analog instrument signals to the digital voltmeter and the translator would encode the data in ASCII serial form to be transmitted by the telemetry system. The translator also encoded the event counter values and the clock output for record keeping. At Montana State University, a VHF radio receiver and teletype were operated automatically to obtain a printout and punched paper tape of the data from Bridger. However, all the data was in the form of the voltage read by the digital voltmeter at Bridger. It was necessary to convert each value to meaningful data such as degrees fahrenheit, wind speed in miles per hour, etc. Programs were written for IBM 1620 II computer to perform this conversion. The cost of this subsequent processing was high and the conversion was frequently delayed many months. The remoteness of the site made it difficult to check the system and provide adequate maintenance. Calibration of the instruments was a problem and generally done infrequently or incorrectly. As a result, data records had little value. Some of these factors prompted the evolution of the present Spring Creek data acquisition system.

The Spring Creek site was chosen for its accessibility as well as for the opportunity to develop water quality monitoring equipment. Communications between the Spring Creek site and Montana State University uses telephone rather than radio. Other differences will be noted later, but the most fundamental change is the complete control and operation of the system by an HP2115A computer located in a laboratory at MSU. The term "data acquisition system" will be referred to in this thesis as the remote equipment located at the Spring Creek site. Much of this came from Bridger and was modified as described below. The overall operating system includes the computer, and the remote data acquisition system at Spring Creek.

ORGANIZATION OF CHAPTERS

This thesis will discuss in greater detail the various aspects and parts of the Spring Creek data acquisition system. Chapter II will cover the location of the site and available resources. A description of hardware development as it pertains to modification, instruments, and interfaces will be contained in Chapter III. Software development for the computer is covered in Chapter IV with a look at the complete operating system from a data gathering standpoint in Chapter V.

Chapter II

PHYSICAL DESCRIPTION OF SYSTEM

This chapter presents a description of the location and some physical components of the Spring Creek system. The data acquisition system itself is covered in Chapter III.

DESCRIPTION OF THE SPRING CREEK STATION

The Spring Creek experimental station is located one mile southeast of MSU in an undeveloped city park. An agreement with the city was made to make use of the park for a field station. Figure 1 shows the present physical layout of the Spring Creek Station. A thirty foot square fenced-in enclosure is located 100 feet from Spring Creek itself. An eight foot square building was built in the center of the enclosure for an instrument shelter and contains instruments, a pump, and the data acquisition system. It is provided with 220 volt commercial power and telephone. In 1971, a concrete dam was built on the stream so that it could be controlled. There is a small pond upstream and a by-pass ditch used to route the creek around the dam. A V-notch weir has been installed between the concrete walls for flow measurements to be discussed in more detail later. About twenty feet downstream from the pond a Parshall flume was installed with stilling well, float, and Stevens type F recorder. The flume is not accurate at low flow rates so that the V-notch weir setup is presently used. Next

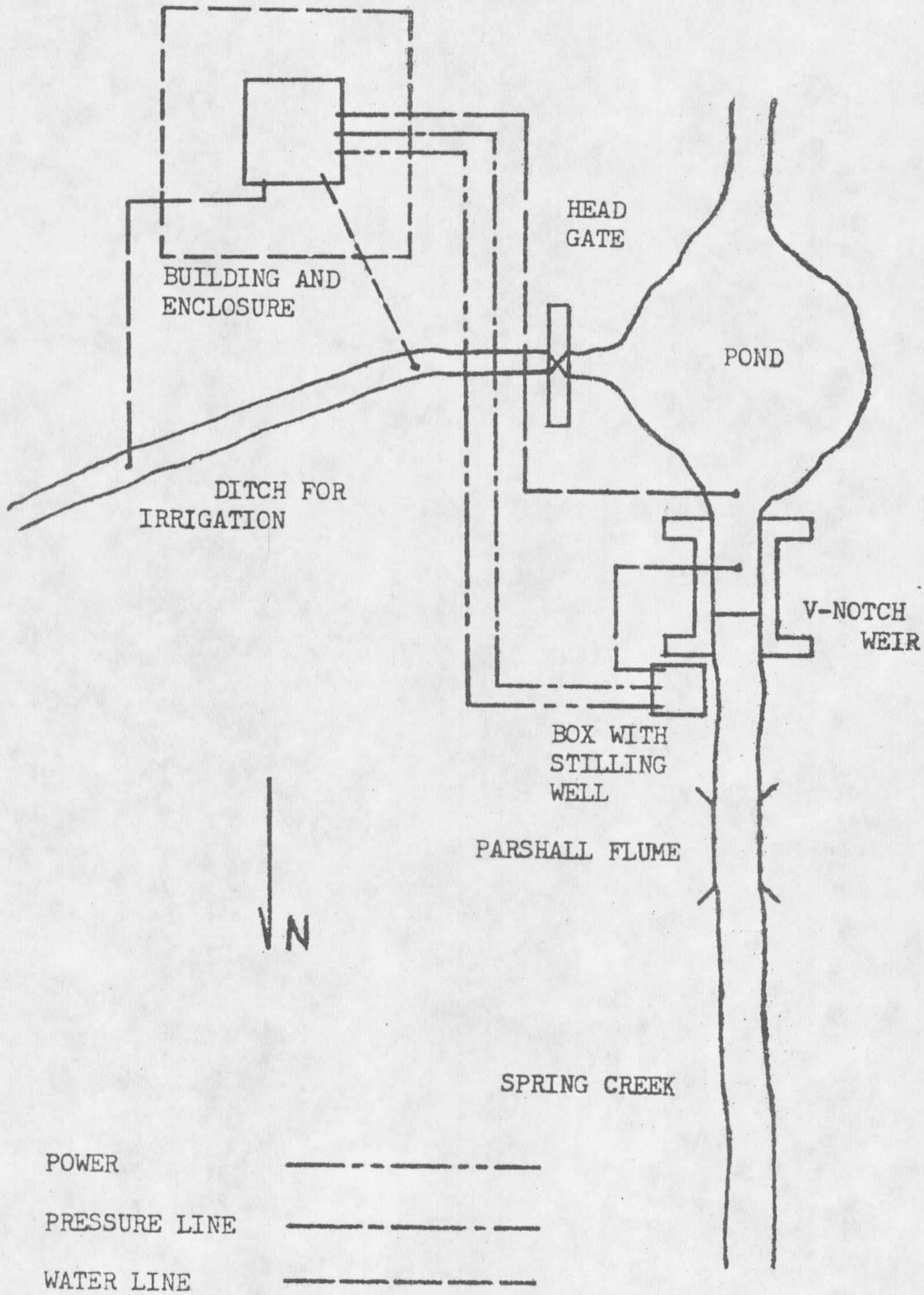

Figure 1. Present Layout of Spring Creek Station

to the concrete walls a four foot square wooden box was installed in the ground for the purpose of placing valves, stilling well, power outlet and pump for summer irrigation of the city park. There are instrument cables, a water pipe and a pressure transmitting line buried from this box to the instrument shelter. Water is pumped from an inlet located above the dam to the shelter so that various water parameters may be measured in the building. The instrument cables connect temporary instruments near the stream to recorders or data acquisition system located in the building. The pressure transmitting line is part of the flow measurement system and will be covered in a later chapter.

A 1/2 horsepower Jacuzzi centrifugal pump was purchased for the project. After making lab tests on the pump, it was determined that the pump would work successfully in the building where it is sheltered and protected. There is a three foot elevation difference between the pump in the building and pond. Losses in the one inch 150 foot plastic pipe increases the total head loss to about six feet. A foot valve had to be placed at the intake to keep the pump primed. It is suggested that the pipe be completely drained in the fall to avoid damage from freezing. The pipe has a slight dip in it so that water can stay frozen in it for some time in the spring. The irrigation pump is used to initially prime the system. After the air bubbles have cleared the building, the pump valve in the building is closed, the valve in the box is then closed and the pump can be turned on and its valve opened slowly. The water drainage pipe is buried to the irrigation ditch about fifty feet north of the building. The surface-scatter turbidimeter located in the building has a separate drain behind the building. Water had a tendency to spray the inside of the building when the drainage pipe to the irrigation ditch was used for the turbidimeter. Since the turbidimeter is open ended, care must be taken when opening the valve to the turbidimeter in order to keep the drain from overflowing. There are two ten amp circuit breakers for the power coming into the building. A third breaker switch controls power to the box. One outlet is thermostatically controlled to operate a portable heater in the winter. Another set of circuit breakers are located on a utility pole 200 feet west of the station.

DESCRIPTION OF COMPUTER AND TERMINAL FACILITIES

The computer and terminal are located in room 502 Cobleigh Hall at Montana State University. There is sufficient space to store unused equipment and to provide lab space for students working on the project. The Hewlett Packard 2115A is a small general purpose 8K word memory, 16 bit computer with a 2 microsecond memory cycle. Peripheral devices used are a photo tape reader, ASR33 teletype, and a MU391 originate/auto-answer modem. Plug-in I/O interface boards for the computer consist of a time base generator, teletype board with one control bit, photo tape reader board, and a communication interface board (WTC-300 Model 101) made by Western Telecomputing of Bozeman. This last board has two control lines and two status bits and operates full-duplex in bit-serial mode. The board is being used in conjunction with the automatic modem. The two control lines are for dial control (CX) and terminal busy (CN) signals. Status bits are for the ring indicator (CE) and clear to send (CB) signals. Input and output of data over the phone is also interfaced through this board. The teletype and photo reader boards are operated normally with the exception that the control bit on the teletype board is used for motor control on the local teletype. This allows the teletype to remain on standby without running.

DESCRIPTION OF DATA COMMUNICATIONS SYSTEM

The MU391 automatic modem is capable of originating and answering a call. It is used with the general purpose board described previously. Specifications on procedure for originating and answering a call are found in the manual on MU391 and MU294 Automatic Modems Specification by Anderson Jacobson, Inc., 1971. A 1001B data coupler is required to provide the electrical connection between the automatic modem and the Bell System. Its purpose is mainly to provide protection to the customer equipment and telephone personnel.

A complete description may be found in 1001B Data Coupler-Description, Installation, Maintenance, and Tests by American Telephone and Telegraph Company, 1970. At the Spring Creek station, a MU294 modem and 1001B data coupler are in use. The only difference between the MU294 and the MU391 is that the MU294 is auto-answer only and cannot originate calls. The signals from the data acquisition system are open collector and so an open collector to EIA interface is used between the data acquisition system and modem. The EIA (Electronic Industries Association) standard is used in most data communication equipment. EIA Standard (RS-232-B) manual published by the Electronic Industries Association, 1965, gives further detail on the types of signals used by the data communication equipment in use for the Spring Creek data acquisition system. The phone number for the Spring Creek station is 994-2041 and the number for the computer at Montana State is 994-3382.

Chapter III

HARDWARE DEVELOPMENT

The Spring Creek data acquisition system is essentially a hardware modification of the Bridger system described in Chapter I. The system was built by the Electronic Research Laboratory of Montana State University with the exception of a Honeywell 620B digital voltmeter used to digitize the analog signals coming from the instruments and transducers. Basically, the system included the digital voltmeter, digital translator, mechanical event counters, and analog scanners.

HARDWARE MODIFICATION

Beginning winter quarter 1973, Steve Luther and the author set out to adapt the system to the Spring Creek requirements. After obtaining manuals on the various components of the system, it was possible to get the scanners and translator working. However, the digital voltmeter never worked properly even after hours of maintenance work. Then it was decided to purchase a Zeltex ZD461 A to D converter ($69) to replace the voltmeter. The converter is smaller, more reliable and more accurate than the Honeywell digital voltmeter. Its input range is zero to ten volts with ten bits resolution for binary serial or parallel output. Consequently, the ten-volt range is divided into 1024 parts encoded by the ten bits in binary fashion. The analog input can be represented to within .01 volt by the output bits.

Originally the digital translator encoded five digits from the voltmeter. Each digit was represented in binary coded decimal form. With the A to D converter, this was not possible so each digit was interfaced to three of the ten output bits of the converter. Thus the digits are octal rather than decimal. Three octal digits could thus be implemented with a fourth digit resulting from the tenth A to D bit.

In December, 1973, it was decided to replace the mechanical event counters by a new electronic counter also designed by Electronic Research Lab. The mechanical counters were unreliable due to heavy current drains resulting in pitted contacts. The replacement included four digital counters, one with five digits and the other three with three digits. The original electronic counters module had reset buttons on the back for each channel. However, with the back inaccessible, a single reset button was mounted on the front along with a logic reset button to be pressed whenver the power is disrupted. This resets logic that originally was controlled by a logic controller and translator not used now. A twelve volt battery and charger was installed in June of 1974 to avoid losing count when power interruptions occur.

The final modification was made to the data acquisition system using a regulated power supply (WTC-120 made by Western Telecomputing Corp. of Bozeman). Previously, each component of the system had its own power supply or no supply at all. The new power supply puts out

+13.5, -13.5 and +5 volts. The 5 volts operate the TTL logic presently in the system while the +13.5 and -13.5 volts are for the A to D converter, analog scanner, and most interface dircuits for the various instruments.

The digital translator has complete control over the rest of the data acquisition system. When an initiate signal is received, the translator makes a reading. An initiate signal can occur two ways, by physically pressing the initiate button on the front panel of the system or by receiving any ASCII character from the communications system. Normally, the second mode is used whereby the computer is the originator of the received character. A reading is the transmission of a code in ASCII form giving an indication of the present voltage value for each instrument.

There are four analog scanners for gating the output voltage of each instrument one at a time to the A to D converter. The first three scanners each have twelve magnetic relays. The first relay enables a read-only memory that contains a number code associated with that particular scanner. This is placed on a data bus and read for identification purposes. This code is know as the scanner address. The next ten relays are gated to ten different interface circuits each of which is associated with an instrument. The last relay allows the value of one of the four counters in the event counter module to be placed on the data bus. The fourth scanner has only two relays, the first associated with the address and the other to the fourth counter. In all, up to thirty analog channels can be used along with four event counters.

Each line of transmitted output contains the data from one scanner. Each channel within a scanner has an identifying alphabetical letter associated with it and is transmitted after each channel output which is in the form of five digits. Figure 2 shows a printout of a sample reading made. The first set of digits is the scanner address code. Analog inputs for channels A through J of each scanner is gated to and converted by the A to D converter discussed previously; hence that data is in octal form with 00000 representing zero volts, 00777 for five volts, and 01777 for ten volts. Output of the A to D converter is placed on the data bus three bits at a time for octal digits. The data for the K channels or counters is placed a digit at a time on the data bus. The counter with #4800@ address has five digits and can count to 99999 before resetting to 0 while the other three can count only to 999.

The digital translator also encodes the data from the data bus into ASCII form and transmits the bits at the standard 110 baud rate. It also supplies line feeds, carriage returns, and identifying letters with the output.

INSTRUMENTATION

Many of the instruments used are connected to the data acquisition

#4800@00302A00367B00053C00274D00374E00213F00715G00215H00355I01335J
73442K

#4801@00631A01000B00777C00777D00777E00777F00777G00777H00777I00777J
00000K

#4802@00777A00777B00777C00777D00777E00777F00777G00777H00777I00777J
00000K

#48032@00022K

Figure 2. A Sample Data Acquisition Reading

system using similar analog interface circuits. Generally these instruments output a voltage that is not in the 0 to 10 volt range. Also, the low 10K input impedance to the A to D converter requires a low source impedance of about three ohms for accurage conversions. These requirements for an interface circuit can be met by using a simple operational amplifier circuit. Such a circuit is shown in Figure 3. The input impedance of the amplifier is 1M ohms. Hence, an instrument can have an output impedance up to 10K ohms for 1% error. If impedances can not be held to these tolerances, the gain may be adjusted to compensate. Open loop output impedance of the 741 operational amplifier is given as 75 ohms. Closed loop output impedance is found from the equation Z = 75G/(K-G-(75/Rs)) where K is the open loop gain and G is the closed loop gain (1+Rf/Rs). For low frequency operation, the open loop gain is 10^5 so that the maximum closed loop gain with the 3 ohm impedance requirement met is 4000. The largest gain any of the present instruments require is 640 for the solar radiation measurement. All of the operational amplifier interface circuits have been built in one 4" x 4" x 6" box. There is room for nine circuits with three being used now. All circuits also make use of 10K trimming resistors to offset the output. This is adjusted so that a reading of zero volts output is obtained with a zero input. Calibration is easy and better use of the 0 to 10 volt range is made.

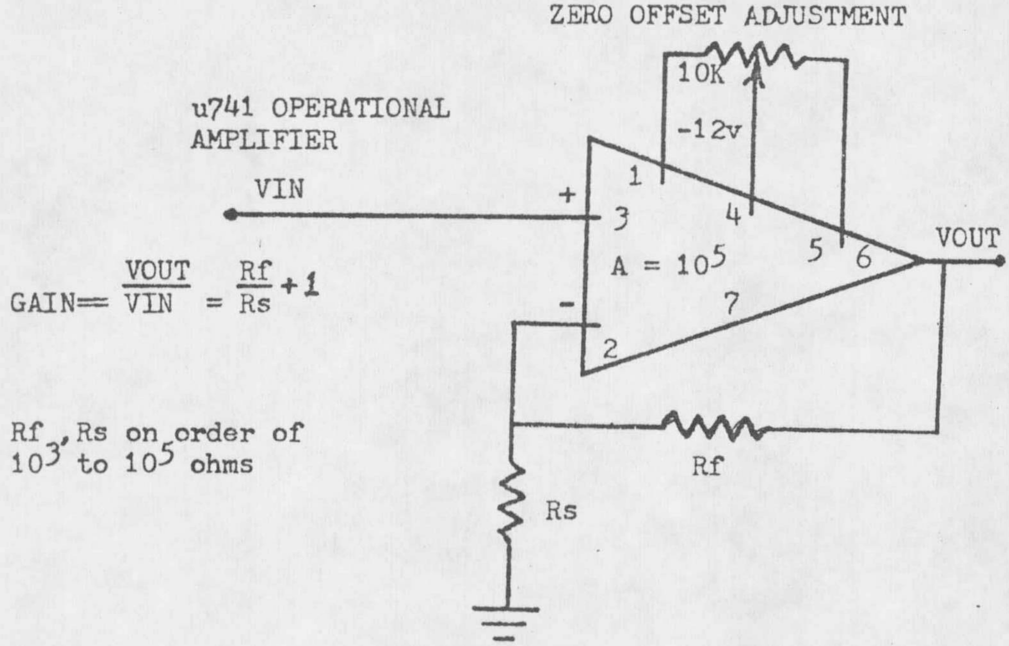

Figure 3. Simple Operational Amplifier Interface Circuit

The instruments using the operational amplifier interfaces previously discussed are the Epply pyrheliometer model 50, Belfort wind speed generator model 1250A, and Belfort wind direction model 1411A. The pyrheliometer was factory calibrated as 7.55 cal $cm^{-2}min^{-1}$/millivolt. Offset adjustment was made by covering the glass bulb with an opaque object and adjusting for zero volt output. Time constant is about fifteen seconds requiring a wait of about ten minutes between covering instrument and adjusting offset. Actual gain of the amplifier circuit was found by placing a known voltage on the input and measuring the output. All measurements and calibrations were made with a Hewlett-Packard 410B vacuum tube voltmeter. Actual gain was computed to be 642.6. With the data to be in watts-$meter^{-2}$, the final calibration coefficient was found to be 143.8 watts-$meter^{-2}$/volt. The wind speed transmitter generates one volt/25 mph of wind. It was decided a gain of about five would be adequate to provide a full scale range of 50 mph. Actual gain was measured to be 5.15 with final linear coefficient as 4.851 mph/volt.

The wind direction instrument has eight segments with a different resistor ratio output for each segment or 45 degrees change. By placing 13.5 volts across the input, the output voltages were measured to be as follows:

Voltage	Wind Direction	Degrees
0.00	N	0
0.91	NE	45
1.87	E	90
2.74	SE	135
3.67	S	180
4.70	SW	225
5.95	W	270
7.57	NW	315

Chapter IV will explain how final calibration with this set of data is made for computer use.

Wind totalizing anemometer Belfort model 5-339A is used to measure the total increase of miles of wind in a given period of time. A contact closure is made for every 1/60 miles of wind. This instrument is directly connected to one of the counters. Thus a reading made by the computer is divided by 60 to obtain the increase in miles of wind. A Belfort model 5-405 tipping bucket raingauge is connected directly to another counter. Each .01 inch of rain is equal to one count. Thus dividing the increases on the counter by 100 will indicate inches of precipitation. A small coil heater and thermostat was added when it was used at Bridger to keep snow and ice from building up in the top of the raingauge. Presently, the raingauge is operating on the roof of the building at Spring Creek. The accuracy was checked before installation and was found to be within 3% when water was poured into the top of it at a slow rate corresponding to a heavy downpour. It is more accurate for light precipitation.

The measurement of temperatures at Spring Creek is fairly unique. Rather than interface a thermograph or some other type of temperature measuring instrument, thermistors were used to measure temperatures with greater reliability. A thermistor is a resistor whose resistance is a function of temperature. The thermistors used at Spring Creek are type #44005 made by Yellow Springs Incorporated. At -40 degrees F, the resistance is 101K ohms and at 125 degrees F, the resistance is 1K ohms. Building an interface circuit for the thermistor requires a few special considerations. For one, the power dissipated must be kept small or else internal heating will affect accuracy. A second consideration is the matter of calibration. Finally, it is important that the full range of temperatures can be read on the 0 to 10 volt range with equal accuracy over the entire range. Jim Earle, an undergraduate student in electrical engineering, worked on these problems during the past year and has designed an excellent circuit for interfacing thermistors to the data acquisition system. The circuit is shown in Figure 4. A constant current is supplied to the parallel combination of the thermistor and a resistor whose value is the geometric mean of the extreme values of the thermistor. The purpose of the parallel resistor is to weigh both ends of the range equally as far as accuracy is concerned. The voltage across the parallel combination is amplified by an operational amplifier. Mr. Earle has written a computer program to solve

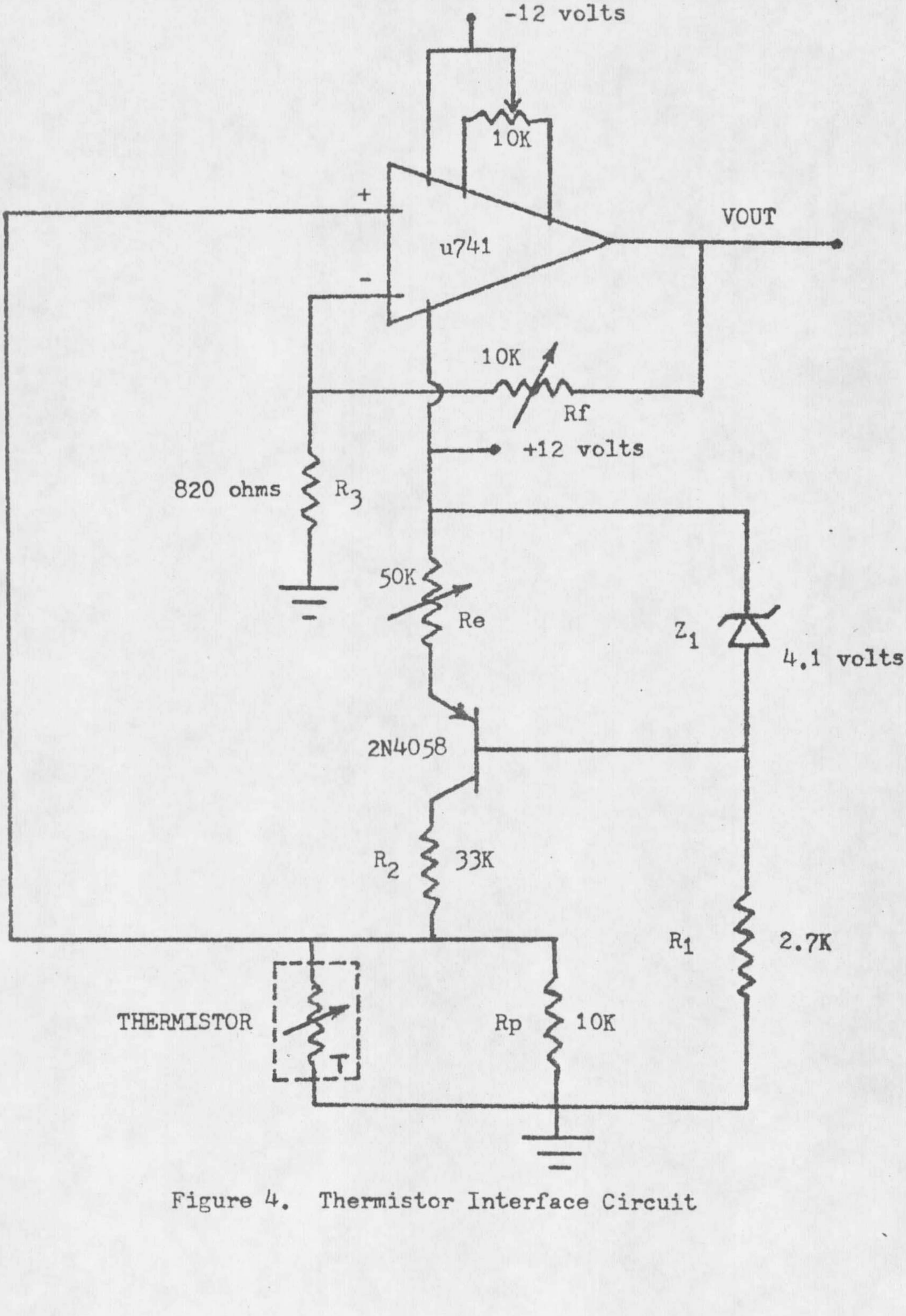

Figure 4. Thermistor Interface Circuit

the circuit for various temperatures to aid in calibration. Comparison of the circuit with conventional thermometers has shown the two not to differ by more than one degree F. Two thermistors are presently in use. One is mounted under a sun reflector with the wind instruments and is used to monitor air temperature. The other is mounted in the water sample system inside the building. The pump supplies water so that temperature of the water can be monitored.

An important water quality measurement being made is that of turbidity. Turbidity is a term used to described the amount of suspended matter in water. Turbidity measurements are made by a Hach Surface-Scatter Four Turbidimeter. It is calibrated in units called FTU's after the name formazin, a chemical solution used for calibrating the instrument. There are four ranges (0-1, 0-10, 0-100, and 0-1000) that the instrument operates in. A regulated light source is aimed at the surface of the water. The amount of scattered light from suspended particles is measured by a photo cell as shown in Figure 5. The wall-mounted instrument was built with a crude interface circuit for operating recorders in addition to a front panel meter for direct readings. Dave Shema is credited with replacing the original external output circuitry with a more reliable operational amplifier design for a 0 to 10 volt range output. In calibrating the output, the panel meter was first calibrated using Hach calibration slides. Next, the output voltage measurements were

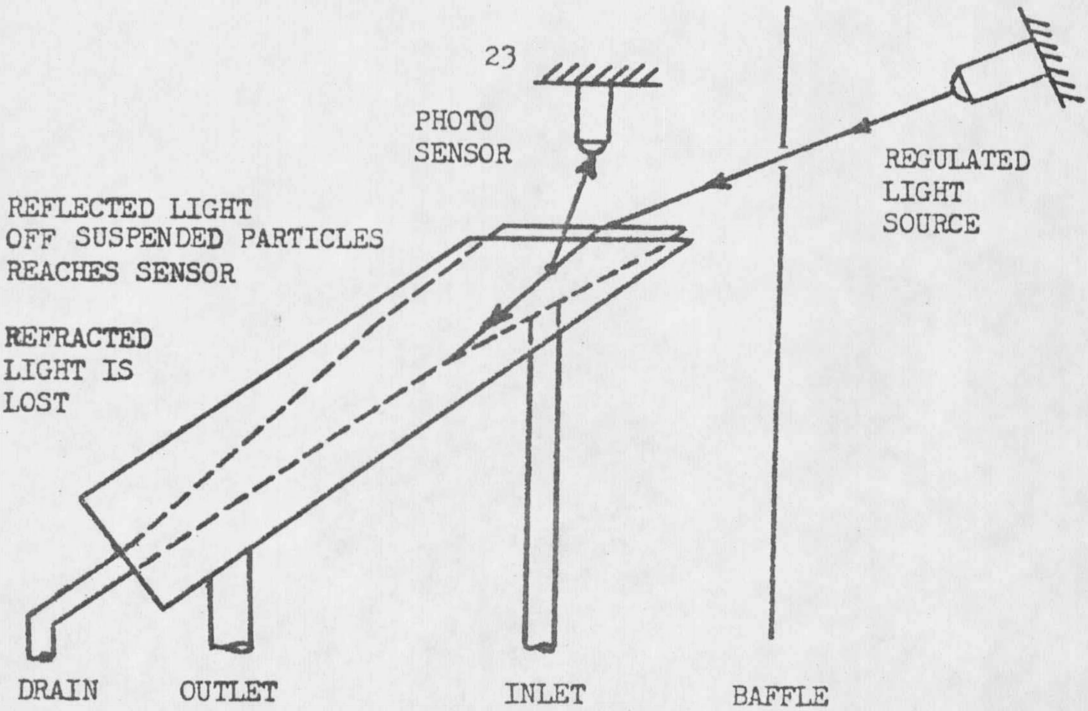

Figure 5. Diagram of Surface-Scatter Turbidimeter

made for ten different meter readings. This was repeated for each of the four ranges. Thus a curve relating output voltages to water samples measured in FTU's was obtained for each range. Accuracy of the system in use is comparable to the meter accuracy of 1% full scale.

Another water parameter being measured is water flow in cubic feet per second. There are many methods of measuring water flow such as current meters, weirs, flumes, and venturi meters. However, a V-notch weir was selected for installation at Spring Creek especially for its greater accuracy at low flows which is typical at Spring Creek most of the time. The weir is four feet wide and three feet high made of 1/2 inch iron plate. A 90 degree notch was cut into the plate with the bottom of the notch one foot from the bottom. An iron frame was installed between the existing concrete walls to hold the weir. To use the weir, the height of the standing water above the bottom of the notch is measured and applied to the following formula:

$$Q = 2.5\ H^{2.5}$$

where H is in feet and Q in cubic feet per second (CFS). The formula is a good approximation for measuring flow although various correction factors can be applied for specific installations. It did not seem worthwhile to try to improve the formula for the Spring Creek setup.

There are several methods for measuring the height of the standing water behind the weir. In any case, some type of stilling well is used to eliminate waves and rapid changes in water height. Two methods were examined for remote operation. One, a Stevens F chart recorder with float may be installed in the stilling well. Voltage levels may then be obtained by attaching a potentiometer to the float mechanism. A second method was selected to see how well it would perform. This method is a system of measuring the pressure required to pump air into the stilling well. This method is widely used by the U. S. Geological Survey. The stilling well was constructed of .063 gauge aluminum and formed in the shape 10" x 10" x 30". Four air line fittings five inches apart were installed into the side of the stilling well for reasons to be explained shortly. An inlet and drain were provided for at the bottom and the stilling well was installed in the wooden plumbing box located next to the stream. The bottom fitting is at the same elevation as the bottom of the weir notch. A good pressure transducer (model 2040-10WG-5 made by H. E. Sostman & Co.) was purchased in 1973. The transducer consists of a bellows capable of measuring air pressure equivalent to ten inches of water. A 5K ohm potentiometer is connected to the bellows for output. By applying ten volts across the potentiometer, the required 0 to 10 volt range is accomplished for interface to the data acquisition system. The reason the range of the transducer was selected to be only ten inches was to increase accuracy of the system. Since over a period of time the standing water behind the weir can change greater than ten inches, more than one fitting was mounted in the stilling well. However, the air line will not have to be changed from one fitting to another more than three or four times a year since most of the time the flow in Spring Creek varies within a short range. See Figure 6 for a layout of the flow measurement system. A small aquarium pump is located in the box next to the stilling well. It could be located in the building, but 150 feet of additional plastic line would be needed. The junction of the pump line to the pressure transmitting line must be close to the stilling well and above the highest water level as possible to minimize head loss in the line. The air located in the pressure transmitting line from this junction to the pressure transducer in the building 150 feet away is essentially static with no pressure drop. Bottled nitrogen may be used for powerless sites but in this case power was available and the initial cost of an aquarium pump is cheaper than bottled gas. A simple glass tube manometer was installed in the building and attached to the pressure transmitting line for two reasons. It offers a safety valve for protection of the transducer. Any pressure greater than ten inches water will empty the manometer and open the line. Second, it gives a simple means of observing in the building the height of water above the air fitting. The pressure transducer was accurately calibrated by the manufacturer and a table of resistance ratios was provided with an accuracy of one part in a thousand. A curve relating

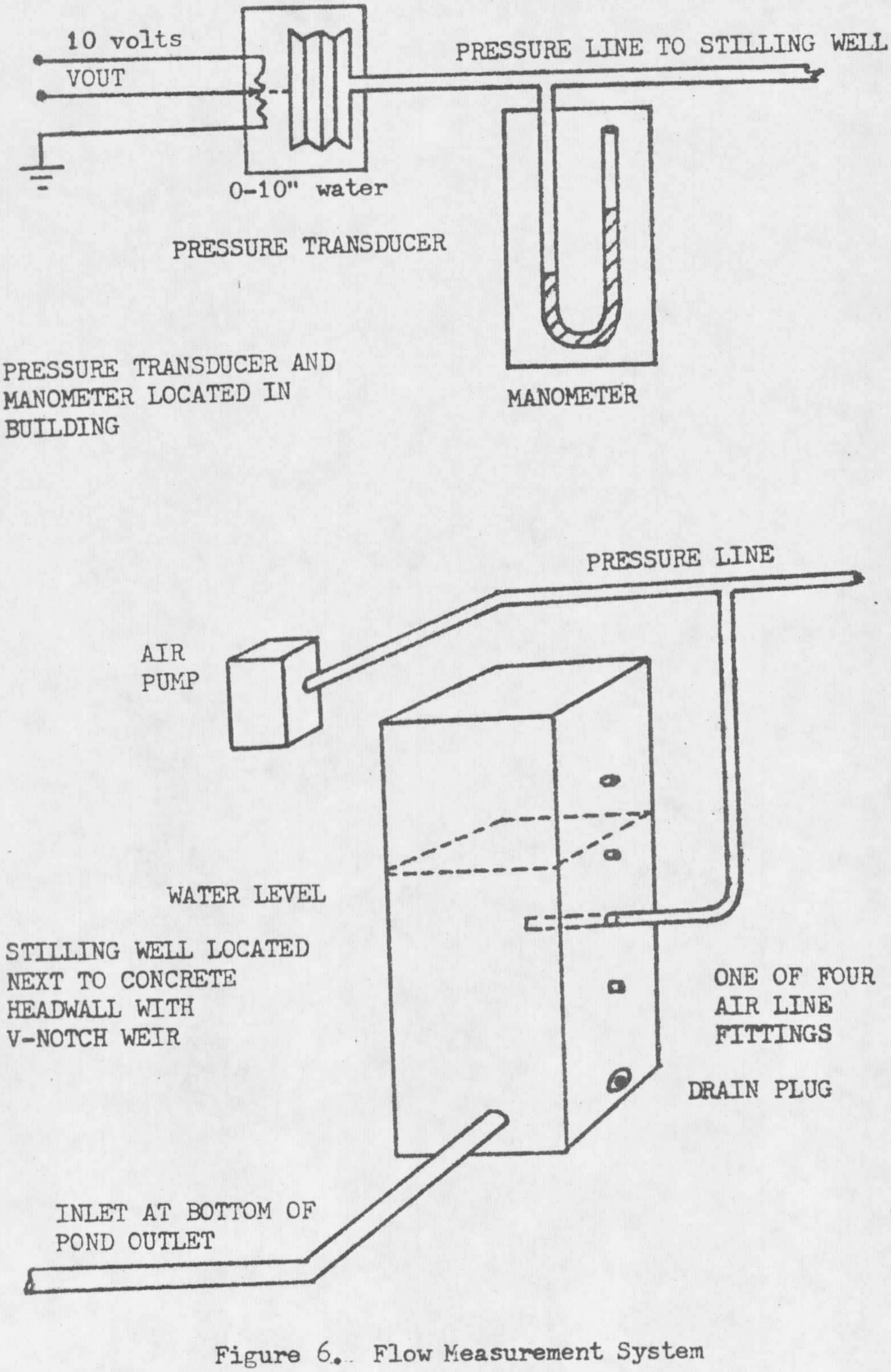

Figure 6. Flow Measurement System

output voltage from the transducer to the water flow in cubic feet per second was made for each air fitting. The overall time constant is approximately one second. Calibration is fairly easy once the location of stilling well and fittings with respect to the bottom of the weir notch has been determined. The system offers advantages over the conventional recorder float setup in remote areas where reliability is necessary. The mechanical parts associated with the pressure transducer are located at a more protective environment inside the building. It is also estimated that the overall cost of the recorder with float and installation is greater than for the pressure transmitting system used at Spring Creek. This flow measurement system has operated reliably with good accuracy.

CHAPTER IV

SOFTWARE DEVELOPMENT

The software system for use on the HP 2115A was completed by Dennis Smith during winter and spring quarters of 1974. Other programs have been written previously be the author to perform various tasks and to test the data communication link and data acquisition system. There are several tasks a software system must perform. The system must keep track of time to operate on a real time basis. It must call up the Spring Creek station at periodic intervals and interrogate the data acquisition system. Finally, it must present the obtained data in a form desirable by the user.

DATA CONVERSION

Before the data from Spring Creek is usable, it must be converted to the units of the particular parameter that instrument is measuring, such as degrees fahrenheit. As discussed previously, the data for each channel is transmitted in octal form and must be converted to a floating point decimal number. This is accomplished by dividing the binary representation of the octal data by the binary representation of the decimal number. The resultant number will be the voltage read by the A to D converter at the station. This voltage can then be applied to the calibration curve of an instrument to obtain the desirable value measured by that instrument. Unfortunately, the calibration curves are not linear and are certainly different for each instrument. For the computer to perform this task, it was decided to fit each calibration curve to a fifth-order polynomial using the least squares technique. All the computer needs are the coefficients of the interpolating polynomial. The polynomial is represented in the following form:

$$\text{Parameter measured by instrument} = A_0 + A_1(\text{volts}) + A_2(\text{volts})^2 + A_3(\text{volts})^3 + A_4(\text{volts})^4 + A_5(\text{volts})^5$$

There was no special reason for choosing a fifth-order polynomial over some other order. However, after using the least squares approximation on various calibration curves for different orders, it was found that a fourth or fifth order gives an acceptable standard deviation error in most cases. The reason for this is that round-off errors in the computer offsets the advantage of using a greater order. The least squares technique as it applies to a fifth-order polynomial is shown in Figure 7.

HOURLY AND DAILY REPORT PRINTOUT

The final problem that needed to be solved was the question of how the data should be presented to a user. With just the 8K of core memory available, it is not possible to store more than about 24 hours worth of data at a time with an interrogation every fifteen minutes.

Units measured by instrument $= A_o + A_1\,(\text{volts}) + A_2\,(\text{volts})^2 + A_3\,(\text{volts})^3 + A_4\,(\text{volts})^4 + A_5\,(\text{volts})^5$

Volts is the voltage applied to the data acquisition system (0 - 10 volts)

X_i are sample test voltages

Y_i are instrument measured units

$i = 1$ to K (K is number of data points made)

$n = 1$ to 5

$$S_n = \sum_{i=1}^{k} x_i^n \qquad T_n = \sum_{i=1}^{k} Y_i X_i^n \qquad \overline{C} = \overline{A}^{-1}\,\overline{B}$$

where

$$\overline{A} = \begin{vmatrix} S_o & 1 & 2 & 3 & 4 & 5 \\ 1 & 2 & 3 & 4 & 5 & 6 \\ 2 & 3 & 4 & 5 & 6 & 7 \\ 3 & 4 & 5 & 6 & 7 & 8 \\ 4 & 5 & 6 & 7 & 8 & 9 \\ 5 & 6 & 7 & 8 & 9 & 10 \end{vmatrix} \qquad \overline{B} = \begin{vmatrix} T_o \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{vmatrix} \qquad \overline{C} = \begin{vmatrix} A_o \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{vmatrix}$$

Figure 7. Least Squares Approximation (Fifth Order)

For this reason, the idea of presenting to the user some type of summary report every day for each instrument was considered. A simple statistical analysis such as averages, maximums, minimums, and totals could also be presented along with a list of the readings made during the day. Correlations and other data determined from the data of more than one instrument could also be implemented. For example, the chill factor is dependent on wind speed and air temperature.

The software system developed will print out on the local teletype a summary of each instrument at midnight. Included in each summary or report is a list of readings made along with average, maximum and minimum, or total increase if the instrument was connected to an event counter. The date and information about the instrument is also included. Each report is printed in 11 inch segments to facilitate the binding of such reports in a notebook for easy accessibility. Although no other analysis or information appears within the report, it would be possible to reprogram the daily report section of the software system to provide the type of information a user wants. Figure 8 shows a sample daily report. Two other features were added to the software system to present data to the user. If the data is needed sooner than at midnight, hourly reports can be obtained at the local teletype by placing the 0 bit of the switch register in the one position. The time, instrument information, and the readings made in the previous hour are printed for each instrument. The second feature

08 JUL 74

SOLAR RADIATION (WATTS/SQ METER)

AVERAGE	205
MAXIMUM	869
MINIMUM	0

00	0	0	0	0
01	0	0	0	0
02	0	0	0	0
03	0	0	0	0
04	0	0	0	0
05	0	0	0	0
06	7	24	44	73
07	100	124	149	178
08	240	288	293	263
09	319	435	470	507
10	546	574	598	625
11	670	614	744	778
12	751	754	469	440
13	345	869	718	572
14	397	395	310	296
15	324	381	470	272
16	265	726	235	187
17	322	213	406	156
18	147	174	125	84
19	86	80	66	63
20	34	32	39	32
21	13	0	0	0
22	0	0	0	0
23	0	0	0	0
24	0			

Figure 8. A Sample Daily Report

enables the user to access data from another teletype with an acoustic coupler. To use this feature, the computer is called by dialing MSU centrex number 994-3382 and placing the handset in the acoustic coupler when the tone is heard. Make sure the teletype is on. A question mark will be printed whereby the user should respond with a "T" and carriage return for the present date and time. An "R" followed by 0 - 3 (suffix of scanner address), A-K (channel identifier), and carriage return will cause a report for that instrument to be printed. The report will be identical to the daily report except only data from midnight to the present is used. Depressing the "Break" key will terminate the report printout followed by the question mark. To finish, just hang up. For more details on the software system including program listings, please refer to the report by Smith (1974). Instructions for preparing the calibration tape and initializing the software system are found in the Appendix.

CHAPTER V

REAL TIME USE OF THE SYSTEM

Previous data acquisition systems at MSU have never operated successfully as far as obtaining useful and reliable data. Reliability and accuracy of a system were always a problem. Intermediate reduction and conversion steps have been eliminated with the present system. Calibrating an instrument for use on the system is simple. Reliability, simplicity, and accuracy of various instruments will be examined further in this chapter and are the key points to a good data acquisition system from a user's point of view. These factors will be discussed further concerning the use of the present data acquisition system. A block diagram of the operating system is shown on Figure 9.

OPERATION

The data acquisition system controlled by the computer is operated on a real-time basis. Data acquisition system at the station is on constant standby. All instruments including the pump which circulates a sample of the creek through the building operate continuously.

With the battery and charger powering the event counters, power failure at the station causes no permanent interruption except for the fact that data cannot be obtained when the power is off. The pump will self recover without priming due to an installed foot valve at the intake. Software routines will handle cases where data is unobtainable

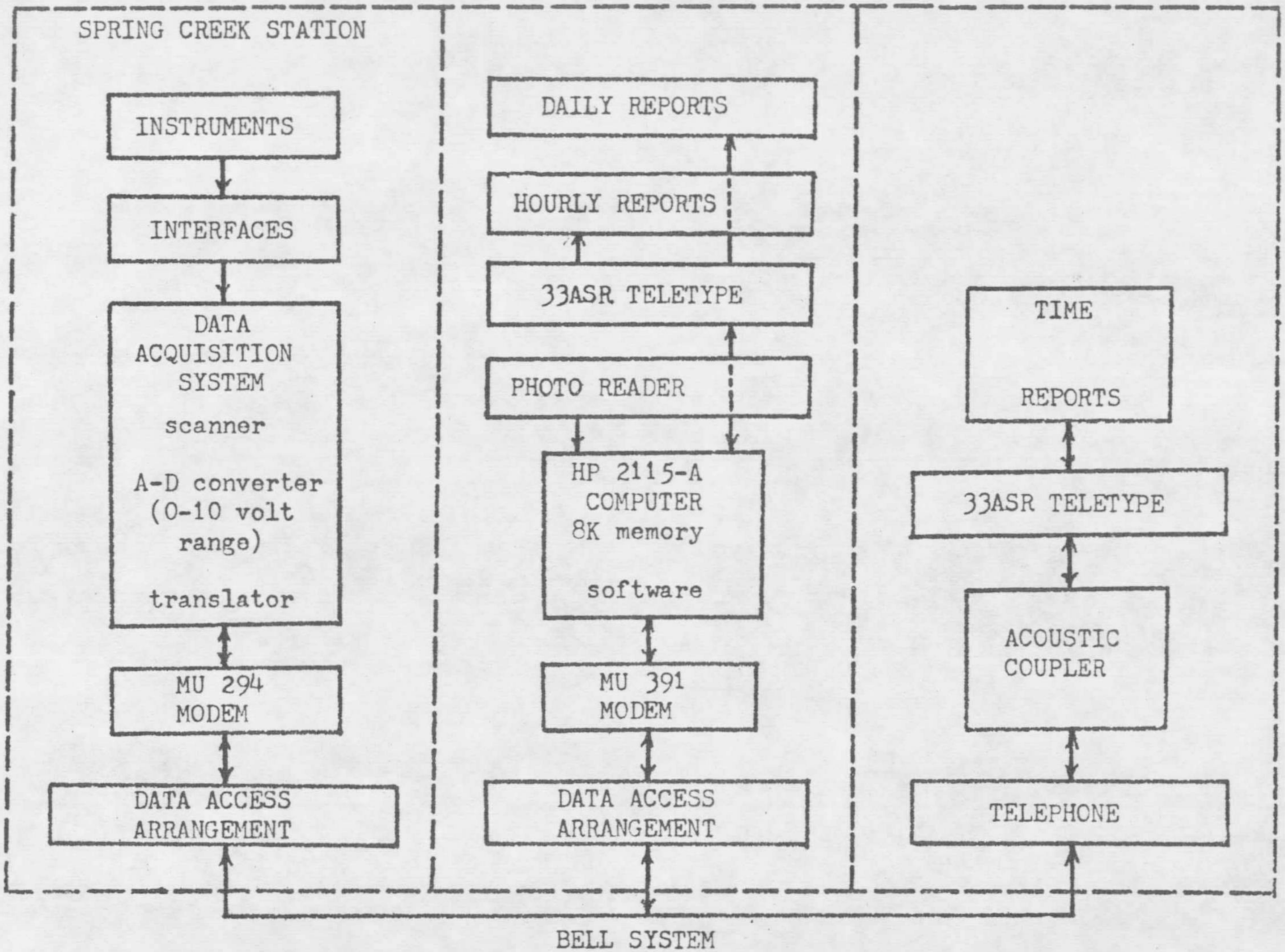

Figure 9. Block Diagram of Operating System

through power outages or break in data communication link by disregarding the particular reading. In all reports and printouts, a blank will occur for these readings and will not be used in the statistical calculations. However, the computer will halt resulting from any power interruptions. The 2115A computer is not presently equipped with a power-fail auto restart option which could enable recovery from such interruptions. When the computer halts, the present software system must be reloaded and initialized as detailed in Chapter V. All previous data is lost.

It is not difficult to add new instruments or change the calibration coefficients of a present instrument. An instrument is selected by the user according to various factors. First of all, it must measure the desired parameter within a given tolerance and with a certain degree of reliability. Environmental hazards, power considerations and electrical interfacing must also be considered. If the instrument or transducer does not put out the required signal for the data acquisition system, an interface circuit must be built. The interfacing of various instruments for use at Spring Creek have been covered previously. To calibrate, a set of data points is made consisting of the value of the measured parameter and the output voltage that will be connected to the data acquisition system. Depending on how smooth and linear the data is, anywhere from just a few to many points may have to be obtained to accurately describe the relationship of the measured parameter and output voltage. The tolerance of the A to D converter is about one in a thousand so an initial instrument of calibration error of greater than .1% is not advantageous. Using the least-squares calibration procedure discussed earlier, the coefficients of a fifth-order interpolating polynomial can be determined for use by the computer. A program to do this is discussed in Smith (1974). Once the coefficients are determined and the instrument is connected to an unused channel, the calibration tape for the system is readily edited with the new coefficients, a one line alpha description of the instrument, and the channel identification. Finally the system can be reinitialized as before.

CORRELATION OF RESULTS

Some of the instruments lend themselves quite readily to verification by some other instrument. In this way, the overall reliability and accuracy of the instrument to final report output can be checked. Temperatures are easy to check with a thermograph. Water flow can also be checked indirectly by using the partial flume and V-notch weir. By observing the printout on wind direction directly, overall reliability and accuracy of this instrument can be made. It is self evident what the wind direction measurement was since the output is within two degrees of one of the eight compass points. Table 1 shows the wind direction read from one daily report as compared to the actual direction indicated by the wind vane in 45 degree segments. The amount of error or deviation from the real value or mean can be quoted in a number of ways. Standard deviation is not completely descriptive since it is determined only by the deviation of readings from a mean. The basis for evaluating error should rather be correlated to the full scale range the data can vary in order to weigh each reading equally over the range. The percent variation will be thus defined as the standard deviation divided by the full scale reading. These values are listed in the last column of Table 1. Table 2 shows a similar analysis with water flow and Table 3 for air temperature.

Table 1

Wind Direction Analysis in Degrees

Date	Time	Data Acquisition System	Actual Direction	% Deviation
June 20	0:00	135	135	0
	1:00	135	135	0
	2:00	226	225	.20
	3:00	180	180	0
	4:00	226	225	.20
	5:00	181	180	.20
	6:00	226	225	.20
	7:00	91	90	.20
	8:00	91	90	.20
	9:00	0	0	0
	10:00	316	315	.20
	11:00	316	315	.20
	12:00	271	270	.20
	13:00	227	225	.39
	14:00	227	225	.39
	15:00	227	225	.39
	16:00	181	180	.20
	17:00	227	225	.39
	18:00	271	270	.20
	19:00	226	225	.20
	20:00	271	270	.20
	21:00	226	225	.20
	22:00	270	270	0
	23:00	180	180	0
	24:00	226	225	.20

Data Acquisition System - Values obtained from daily report using Belfort wind direction model 1411A.

Actual Direction - Nearest 45 degree segment.

Table 2

Water Flow Analysis in CFS

Date	Time	Data Acquisition System	V-Notch Weir	Partial Flume	% Deviation
July 4	15:00	3.52	3.36	3.78	2.87
July 7	14:00	4.55	4.37	4.68	2.11
July 9	15:00	4.39	4.37	4.31	.56
July 16	15:30	6.11	6.42	6.66	3.74
July 23	16:30	6.02	5.97	6.24	1.92

Data Acquisition System - Values obtained from daily report using the pressure transmitting V-notch setup.

V-Notch Weir - Values obtained by measuring heigth of standing water above the V-notch weir (to nearest 1/4 inch) and using the V-notch formula.

Partial Flume - Values obtained by measuring height of water at flume-mounted gage (to nearest .01 foot) and using a table of free-flow discharges obtained from Thompson Pipe and Steel Company (Catalog B-31-E).

Table 3

Air Temperature Analysis in Degrees F

Date	Time	Data Acquisition System	Foxboro Thermograph	% Deviation
June 8	0:00	42	41	0
	4:00	40	42	.94
	8:00	40	43	1.41
	12:00	48	51	1.41
	16:00	58	61	1.41
	20:00	58	60	.94
June 9	0:00	41	42	.47
	4:00	34	33	.47
	8:00	48	53	2.36
	12:00	58	58	0
	16:00	64	65	.47
	20:00	64	66	.94
June 10	0:00	41	42	.47
	4:00	34	38	1.89
	8:00	52	57	2.36
	12:00	62	60	.94
	16:00	67	66	.47
	20:00	64	66	.94

Data Acquisition System - Values obtained from daily report using thermistor (#44005YSI).

Foxboro Thermograph - Values obtained from a Foxboro thermograph chart. Instrument was located in an instrument shelter 20 feet from thermograph.

CHAPTER VI

CONCLUSION

The computerized Spring Creek data acquisition system is successful. Data acquisition systems can be operated by a computer with a number of benefits. Manual data reduction is eliminated, the user can obtain the data in the type of report or summary he desires, and system initialization is easy. In addition, a clock is not needed with the other equipment at the remote site or station. The full capability of the computer-operated system can even be extended to more than one station. Data from various stations could be collected, analyzed, and reported. Essentially only more memory or a disk operating system and minor changes in the software are needed.

The ease with which a new instrument can be added to the system is also valuable. Long periods of calibration and testing are eliminated. However, the use of some other instrument as a standard is recommended for a while to check the stability and calibration of the instrument used in the system.

For future environmental data acquisition systems, the need for a self-powered station is great. Possibly solar calls and a storage battery could provide adequate power. CMOS logic, if implemented, demands very low power on standby. Size is another factor to be worked on. A smaller station could be installed and removed much easier. There is also a need to design a system in modular fashion so that a user can build the type of system to fit his needs. Data communications link by the Bell system is good and trouble-free if available. A different communications channel should be examined such as VHF radio or microwave for remote use.

Cost has been one factor not discussed in this thesis, but is very important in designing a system. In developing the Spring Creek data acquisition system, a good portion of the equipment was avilable from previous experimental work done and hence does not provide a good cost basis. However, it would be possible to estimate the cost of duplicating the system.

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REFERENCES

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APPENDIX

APPENDIX

Calibration Tape Preparation

Once the curves are in a polynomial form (procedure in Figure 7), the calibration tape can be prepared. This can be done off-line on a teletype or a disk file. After punching a leader on paper tape, the following records are punched as follows. Each record is terminated by a line feed and carriage return.

Record	Contents
1	Telephone number of the data acquisition system (2041).
2	List of channel identifiers for #4800 scanner in order (A-K).
3	Same for scanner #4801 (no entry if unused).
4	Same for scanner #4802.
5	Same for scanner #4803.
6	Alphanumeric description of first channel specified.
7	Contains number of counter digits if channel is K - otherwise omit this record.
8	Options for channel as follows: A - average, M - minimum and maximum, I - increase.
9	Format of data for report in either of the following forms: (a) integer number - number of integer digits desired. (b) floating point number - number to the left of the decimal point indicates total

Record	Contents
	character in output field, number to the right of the decimal point indicates number of digits to the right of the decimal point in output. (Same as the FORTRAN F format.)
10	Polynomial coefficient of X^5**5.
11	Same for X**4.
12	Same for X**3.
13	Same for X**2.
14	Same for X**1.
15	Same for X**0 (constant term).

Records 6 through 15 are repeated for each channel specified in records 2 through 5. Finish with a punched trailer.

System Initialization

The system is initializied by following the procedure given below:

LOAD ADDRESS 017700B

Load the system tape in the tape reader. Turn reader on.

ENABLE the loader,

PRESET,

Run.

The computer should halt with 102077B in the T register.

PROTECT the loader.

LOAD ADDRESS 000002B

Load the calibration tape in the tape reader.

Insure that the local teletype is in FULL DUPLEX and AUTO.

PRESET,

RUN.

The initializer will read in the calibration tape from the tape reader and store the information in memory. If any errors are detected, the computer will halt with 102011B in the T register. These errors should be corrected on the calibration tape and the initialization restarted by loading address 000002B again. If no errors are detected, the following dialogue is made after the teletype has been turned on by the computer:

READINGS PER HOUR?

Enter the desired number of readings per hour (1-4).

YEAR?

Enter the last two digits of the current year.

MONTH?

Enter the number of the present month (1-12).

DAY?

Enter the number of the present day of the month.

HOUR?

Enter the current hour (0-23).

MINUTE?

Enter the current minute (0-59).

The initializer will now turn off the teletype and enter the monitor to start the system operating.

75 1177 95 2AT