A PROGRESS REPORT ON THE OFF-SITE MOVEMENT OF NUTRIENTS FROM RUNOFF PLOTS TREATED WITH SWINE LAGOON EFFLUENT

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INTRODUCTION

During fiscal year 1995-96, eight runoff plots were installed at a commercial swine production facility located in Crawford, Mississippi. Each research plot is equipped with a sequential wastewater sampler (American Sigma Model 800 SL) controlled by a central host computer. Plots were paired; that is, one plot from each pair was equipped with a HS-flume and flowrate measurement instrumentation, while the other plot in the pair was a "slave" under control of the flume-equipped plot. The instrumented and non-instrumented plots will be referred to as master plots and slave plots, respectively. A weather station was placed on the site to provide correlation between climate, runoff, and nutrient movement. Individual plot instrumentation and the weather station are monitored by a distributed data acquisition system driven by a notebook sized personal computer (the host). Remote Sensor to Computer Interface (RSCI) modules allow analog input signals to be digitized and transmitted to host computer. The entire system is powered by 12-volt deep cycle batteries, so that AC power outage does not affect the operation of the system. The instrumentation system is controlled using object oriented Windows-based programming and, thus, provides real-time monitoring of flowrate and weather conditions. A detailed description of the apparatus can be found in the 1995 Mississippi WRRI *Proceedings* (Burcham and Wren 1995).

APPARATUS

The data acquisition system is the heart of any stormwater monitoring project; it is responsible, with no supervision, for collecting data and runoff samples during storm events. The programmer must carefully select components and software that can be relied on to function properly during adverse (storm) conditions. Flexibility is another important consideration, with the ability to add sensors of primary importance. A distributed data acquisition system with Remote Sensor to Computer Interface (RSCI) modules like those used in many industrial control and automation applications can provide many of the attributes described above.

Stage Measurement with Potentiometer Equipped Belfort Recorders

The stage height was recorded using Belfort FW-1 (Belfort Instrument Co.) stage recorders equipped with potentiometers. There are several advantages to using a potentiometers for stage measurement. They are easy to calibrate, simple, and reliable.

Distributed Data Acquisition System

A distributed data acquisition system is composed of a master computer connected to multiple remote micro-controllers in a network configuration as shown in Figure 1. The network shown is an RS-485 serial network. Each RSCI module has a unique address and can be accessed by the master computer. To connect to a personal computer, one need only have proper software and an RS-485 to RS-232 converter that connects to the PC through an RS-232 serial port. Standard RS-232 protocol allows only point to point communication with only one external device at a time, while RS-485 protocol allows up to 256 remote devices to share a multi-drop communication line. The protocol used guarantees that there will be no contention in communication. There is always one initiator (the host computer) and only one RSCI module at a time responds when its address is polled.

This type of system eliminates the need for multiplexing and facilitates system expansion. To communicate with additional plots, RSCI modules can be added to the system at any location by connecting additional wire to the communication line. The small size of RSCI modules allows them to be placed close to the sensor, thus reducing signal loss due to line noise and other factors. Using the RSCI modules, a communication line up to 1200 meters long can be used before a signal booster is required. In addition, this type of system allows a weather station to be included in the network so that weather data and runoff data are recorded together and can be easily correlated.

Remote Sensor to Computer Interface Modules

The data acquisition modules used on this project were purchased from American Advantech® (Advantech, Inc., 750 East Arques AV., Sunnyvale, CA 94086) and are called ADAM (Advantech Data Acquisition Module) modules. They provide A/D (analog to digital) conversion, signal conditioning, data comparison, and digital communications functions. Configuration parameters are stored in Electrically Erasable Programmable Read Only Memory (EEPROM). The ADAM modules operate on unregulated +10 to +30 DC volts. They provide opto-isolation of the A/D input, transformer based isolation up to 500 volts DC, and an operating range of -20 to 70°C and 0 to 95% humidity. Descriptions of individual modules are in Table 1.

Plot Electronic Setup

The electronic components for the individual plots were housed in 1.21 x 0.91-m [3.0 x 4.0-ft] plot boxes made of treated plywood. Wastewater samplers, RSCI modules, and batteries are housed in the plot boxes. This arrangement prevented problems with tampering and provided harsh weather protection. The wooden plot boxes served as a junction point for communication and power wiring. Terminal strips served to keep all connections separate and allowed easy access for trouble-shooting.

The RSCI modules and relays were mounted inside weatherproof (Nema 4X) enclosures. There was only one wire connected to the slave plots. It was connected to a relay at the master plot and was used to trigger the sampler at the slave plot. The wiring diagram for the master plots is shown in Figure 2

All of the electronic components in the data acquisition system, including the host computer, were powered by 12-volt deep cycle marine batteries. The batteries were charged by automatic battery charger/monitors. Batteries were charged with 10-amp current, and 2-amp current maintained them until they were needed. The samplers and RSCI modules used unregulated 12-volt DC power and the sensors used regulated 8.5-volt DC power. The ground terminal of each master plot battery was connected directly to a 3.05 m [10 ft] ground rod. The ground wire of the communication network was also connected to the ground rod at each master plot.

As mentioned previously, the host computer used 12-volt DC battery power. The battery was attached to a charger/monitor that would keep the battery fully charged until a power outage occurred. Experimentation revealed that about three days of computer operation was available when AC power was discontinued.

Weather Station

An on-site weather station provided real-time weather data. The station consisted of a rain gauge, relative humidity sensor, temperature sensor, wind speed sensor, and wind direction sensor. The tipping bucket rain gauge output a digital pulse every 0.025 cm [0.01 inches] of rain. The pulses were counted by an ADAM 4012s event counter function. Wind speed and direction were monitored through two analog inputs of an ADAM 4017. Scaling routines scaled 0 to +5 Volts to the wind speed scale of 0-90 kilometers per hour and the direction scale of 0 to 360 degrees. For relative humidity and temperature, a 125 ohm resistor was used in conjunction with the current inputs on two ADAM 4012's. Scaling routines scaled 4-20 mA into the humidity scale of 0-100% and the temperature scale of 0 to +70° C. Figure 3 shows the wiring diagram for the weather station.

Except for the rain gauge, all the weather station components operated on regulated 12 volts DC current. The rain gauge did not require a regulated voltage. Due to the "drop down" voltage effect associated with the use of voltage regulators, two 12-volt batteries were wired in series. The resulting 24-volt power was regulated down to 12-volts. This procedure was necessary because the weather station components were calibrated at the manufacturer using a 12-volt DC power supply. The frame of the weather station and one negative terminal in the serial battery arrangement were connected to a ground rod.

Sample Collection

The components discussed above existed for only one purpose: to collect runoff samples. There was a specific series of steps that must occur before a sample was taken; each step and piece of equipment was crucial. The steps are outlined in the following paragraphs.

After enough rain had fallen, runoff would occur. The runoff water flowed down-slope and into the wings of the collector. The collector ran the width of the plot and served to funnel the runoff water into the flume approach and on through the flume itself. When water was flowing through the flume notch (the open V-notch at the downslope end of the flume), it backed up behind the notch to a degree determined by the flow rate of the water through the flume. A groove cut into the flume sidewall allowed water to flow into the stilling well. This created a static water level equal to that in the flume. This water level was measured by the potentiometer/Belfort FW-1 discussed earlier. The analog voltage provided by potentiometer was converted to a digital signal by the RSCI module at that plot. After a module was polled, the digital data was sent to the host computer where its analog value was converted to stage height inches. The Belfort/potentiometer arrangement created a voltage versus displacement curve that was a straight line. The equation of a line, y=mx+b, was used with constants determined during calibration to make the conversion. Stage was the height of water in the flume itself and was used to find the rate of flow through the flume. Rate of flow through the flume was calculated from an equation for flow rate as a function of stage height. Data for stage and flow rate for HS-flumes was obtained from the Field Manual for Research in Agricultural Hydrology (USDA-ARS 1979). A curve for stage versus flowrate was created, and a function was fitted to it using TableCurve® (Jandel Scientific), a curve fitting software package. Equation 1 shows the function, its constants, and variable assignments.

$$Y = l + (m*e) + (n*z^2) + (o*z^3) + (p*z^4) \qquad \text{(Eq. 1)}$$

where: l=0.0000123; m=0.026932275; n=0.43473611; o=0.29435185; p=0.1125; y=flowrate in cubic feet per second; and z = stage height in inches.

By knowing the rate of flow and the time, the volume of flow could be determined. Sampling rate was based on flow volume. For every 18.9 liters [5 gal] (approximately 0.01 acre-inches) of flow through the flume, a digital pulse was sent to the sampler at a master plot and the slave plot paired with it. The sampler was programmed to take a sample after a pre-determined number of digital pulses had been sent. By changing this number, the volume of flow between samples could be varied in 18.9 liter increments. The sampler finished the process by pulling a sample from the flow-stream. The sample was drawn through a flexible plastic tube whose end was in a small bucket below the outfall of the flume. On the end of the tube was a strainer that prevented foreign objects from being sucked into the sampler. The strainer was spring clipped 3.8-cm [1.5-in] from the bottom of the bucket. This arrangement helped to prevent settled particles from being drawn in with the sample and provided a uniform location for sample collection on all plots.

Nutrient Application Methods

Effluent from the anaerobic lagoon was applied to the runoff plots. Treatments were: control (no effluent), 1X, 2X, and 3X assigned randomly to pairs of plots. Effluent was pumped from the lagoon into a trailer with a 1514 liter (400 gal) tank to be transported to the plots. Effluent was pumped from the tank onto the plots using a small gasoline engine and a centrifugal pump. After several problems with nozzle stoppage on an experimental boom, it was decided to use a standard garden hose to hand apply the effluent. Flowrate was calculated by filling an 18.9-liter [5-gal] graduated bucket and recording the time. Flowrate varied little from full tank to nearly empty.

Treatments were based on kilograms of nitrogen per hectare. The 1X treatment was to correspond to 100 Kg N/Ha, the 2X was to be 200 Kg/Ha, and the 3X was to be 300 Kg/Ha. After analyzing effluent samples, it was found that the actual application was very close to that planned. The applications were 104 Kg/Ha, 213 Kg/Ha, and 313 Kg/Ha for 1X, 2X and 3X, respectively.

PROGRAMMING AND SOFTWARE

This project would be impossible without the help of computers and several software packages. Word processors and spreadsheets were used to analyze and record data, but because of their standard nature, they will not be discussed. Data acquisition and control software were the most important type of software used on the project. This software allows a PC to control operations using remotely located modules. ADAM (Advantech® 1994) and Genie (Advantech® 1994) were used for this function. Both ADAM and Genie allow the computer to communicate with external modules through its serial port and an RS-485 to RS-232 adapter. TableCurve® (Jandel Scientific) was used to fit equations to voltage versus displacement curves. Each of these packages will be discussed more thoroughly below.

ADAM Software

ADAM is an MS-DOS® based program that scans all available addresses for on-line RSCI modules and allows the user to view their configuration. Electrically Erasable

Programmable Read Only Memory (EEPROM) allows configuration parameters such as addresses, voltage ranges, and alarm settings to be changed easily. The ADAM program has a simple interface and was used mainly as a utility for setup and troubleshooting.

Genie

Genie is a Microsoft Windows® based program that uses an icon-based, mouse driven system for designing automation and control strategies. The Genie interface consists of a strategy editor and a library of icon blocks that represent standard mathematical and control functions. These blocks are placed in a workspace called the strategy editor and connected by "wires" that denote the flow of data from one block to another. Programming in this manner is like making a working flowchart where the flow of data can be easily visualized. Genie also takes care of communications protocol and addressing of modules, freeing the user from the tedious syntax needed with lower level programming languages.

For research applications, data logging is an important function. Log files are easily created by using the “log file” icon. When activated, it automatically opens a file and prepares it for inputs. Information is stored when it is output to the block. Data can be recorded in standard ASCII, float, byte, integer, or long integer format. In ASCII storage mode, the delimiter (comma, tab, or space) can also be chosen.

Genie is an iterative program. Unless otherwise specified, each function in a program is performed once during each scan period. Scan period is user controlled and is limited by the number of calculations and modules involved.

Project Control Program

Over a period of several months, a project control program was written using Genie. The program accepted input from the sensors at each plot and those at the weather station. The information was scaled and converted to usable data based on previous calibrations. Once the data had been converted, it was output to numeric displays and data files. The control program was divided into two major routines. One routine interfaced with the weather station while the other interfaced with the plot instrumentation. The routines are described below.

Weather Routine

The flowchart for the weather routine is Figure 4. Figure 5 shows the routine as it appears in Genie. The wind direction, wind speed, relative humidity, and temperature were all accessed via analog input (labeled "AI") blocks. Each block accessed the one remote module for which it was addressed. If specified, analog input blocks would automatically scale voltages into physical parameters such as temperature or relative humidity.

Wind direction, wind speed, relative humidity, and temperature were all logged once every 15 minutes. This was accomplished with a user program (labeled "user prog") block and a timer (clock icon). User program blocks allowed the user to create routines for specific situations by using a C-like programming language. When the timer passed the 15 minute mark, the user program block would output a "1." When the log control blocks (labeled "temp logger," "rel hum logger," etc.) received a 1, they allowed data to enter the weather log block. As described above, a log file stored data that entered it. Each time data entered the log file block, it was stamped with the date and time (stamp icon). Data from the rain gauge was accessed by an event counter block (square wave icon). This block would add one to the previous count each time it received a digital pulse. The rain gauge sent a pulse for each tip of its bucket. A tip equaled .025 cm [.01 inches] of rain, so the pulses were converted to inches of rain by multiplying the pulse count times .025. At the end of each minute, a user program block checked present rain count against that from the previous minute. If the present value was larger, it was logged and time stamped.

Flow Routine

The flowchart for the flow routine is Figure 6. Figure 7 shows the routine as it appears in Genie. There were four instrumented plots and four identical flow routines to access them. Genie does not allow the use of subroutines due to possible address conflicts. In the flow routine, there was only one input. An analog input block accessed the voltage from the potentiometer at one plot. As discussed previously, a series of equations converted the voltage into stage, flowrate, and total flow. Total flow was calculated by integrating the flowrate in gallons per second. The total flow was converted to gallons per minute and divided by five during each program iteration. If there was no remainder from the division, then the total flow must have been a multiple of five. For total flows that were multiples of five, the digital output block (labeled "DO") sent a pulse to one pair of samplers. Each time a pulse was sent, stage, total flow, and flow rate information was logged and time stamped.

The timer block (labeled "ET6") in the upper line of Figure 7 served to limit the length of the digital pulse sent to samplers. At low flows, a total flow of, say, five gallons could exist for a long period of time before the six gallon level was reached. The flow routine would only allow the pulse to continue for two seconds, thus preventing damage to relays and other equipment. This process was accomplished by resetting the clock at the beginning of each pulse. When the clock reached two seconds, the signal was halted.

DATA COLLECTION PROCEDURE AND RUNOFF ANALYSIS

The purpose of the equipment and methods described in the preceding sections is to quantify nutrient movement from runoff plots irrigated with swine lagoon effluent. Once the volume of runoff has been measured and the concentrations of samples have been found, the total movement of nutrients can be quantified. Preliminary data is included in this paper primarily to validate the data acquisition system. The following sections outline the procedures for handling samples and data.

Hydrographs

Runoff hydrographs and rainfall intensity graphs yield useful information about the behavior of runoff and the equipment being used to collect it. The most useful type of graph is one that includes both runoff and rainfall data. This allows the difference in time between the storm beginning and the beginning of runoff to be clearly seen. A rainfall/runoff graph is made by plotting rainfall intensity and runoff flow-rate versus time. Examination of these graphs can reveal how certain types of storms may cause variations in nutrient movement. Rainfall/runoff graphs were made for all of the storm events for which runoff samples were taken. The following paragraph explains the graph format.

Figure 8 shows a graphical representation of a rainfall/runoff event. It can be seen that runoff for plot three begins earlier and has a higher flow-rate than the other plots. Plot three was repaired with a concrete seal as an experiment. In plots one, two, and four, runoff from frequent rains undercut the collectors, so the quantity of runoff being measured in these plots was inaccurate. As can be seen in Figure 8, the quantity of runoff moving through the flume on plot three was much higher than in plots one, two, and four. Subsequently, the other plots were repaired with the results shown in Figure 9. For this runoff event, plot four has the highest rate of flow. This is expected since it is on a slightly steeper slope than the other three pairs of plots.

Nutrient Analysis

Water samples taken during storm events were composited and placed in chemically inert polyethylene bottles. The samples were acidified to pH<2 with sulfuric acid (H_2SO_4) and frozen for preservation until they could be analyzed. Thawed samples were sonicated for one hour. Samples were analyzed for NH_4-nitrogen, total nitrogen, nitrates, total phosphorus, ortho-phosphate, and total organic carbon. At the time of this writing, nutrient analysis from runoff samples were incomplete.

Lab Techniques

NH4-nitrogen and digested total nitrogen were read at 625 nm on a Spec 5010 spectrophotometer. Nitrates were read on a Perstorp Autoanalyzer at 540 nm. Ortho-phosphorus and digested total phosphorus were read on a Perstorp Autoanylzer at 660 nm. Total organic carbon was determined by reading total carbon and inorganic carbon and subtracting to find the organic carbon content. Readings were taken using a Shimadzu Total Organic Carbon Analyzer model TOC-5000A.

Forage Yield and Nutrient Uptake

Forage samples were taken from each plot. Samples were analyzed by personnel at the plant fertility lab of the Plant and Soil Sciences Department of Mississippi State University. From Table 2 it can be seen that both yield and uptake generally follow the treatment application levels. Higher treatments have generally higher yield and uptake than lower treatments.

CONCLUSIONS

Overall, the instrumentation system performed well. The distributed data acquisition system did provide sampler control and data storage. Only a few storm events were missed during the long wet season. The primary advantage being virtually unlimited data storage. This allows detailed information to be gained with regard to the runoff processes.

Since this is the first application of a distributed data acquisition for monitoring outdoor environmental variables, some problems were encountered. It was determined that frequent maintenance of the data acquisition system was necessary until the system was debugged. With each maintenance procedure, the system became more and more reliable. By the end of the wet season, the system was operating with "standard" maintenance allowances. During the course of the project, many things were learned about proper installation of an outdoor computer network and associated equipment. The following observations about runoff collection instrumentation and equipment were reached during the 1995-96 fiscal year.

1. The distributed data acquisition system proved to be a good choice for runoff instrumentation. Its greatest advantage is flexibility and virtually unlimited data storage.

2. For better utility, flumes and runoff instrumentation should be placed in permanent (concrete) bunkers. The bunkers should be large enough to allow easy access to all instrumentation. Maintenance is rendered almost impossible during wet and muddy conditions.

3 Communication wiring should be rated for underground use and buried with no covering except for its own sheath. Problems with condensation were encountered when wire was placed in PVC pipe.

4. The potentiometer appears to be the ideal sensor for stage measurement due to its simplicity and ruggedness. The only mechanism necessary is one that converts linear motion into radial motion. The only critical component of the motion is avoidance of vertical play.

5. The mechanical arrangement used with the potentiometer should allow for calibration without the use of water. The use of water to perform calibrations was time consuming and caused some problems. In wet and muddy conditions, trucks cannot haul water to the plots. Thus calibration of the equipment was somewhat weather limited.

6. Extreme care must be taken to ground all components in the system. Early equipment failures were attributed to nearby lightning strikes. Proper grounding alleviated most problems of this type.

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Jandel Scientific Software. 2591 Kerner Blvd., San Rafael, CA 94901.

Table 1. Remote Sensor to Computer Interface (RSCI) Modules.

RSCI Module	Description
Adam 4520 isolated RS-232/RS-485 converter	Accepts RS-232 input. Outputs in RS-485 or RS-422 protocol at these baud rates: 1200, 2400, 4800, 9600, 19200, or 38400. Consumes 1.2 W of power.
Adam-4510 Repeater module	RS-485 or RS-422 input. Outputs in RS-485 or RS-422 protocol at these baud rates: 1200, 2400, 4800, 9600, 19200, or 38400. Consumes 1.0 W of power.
Adam-4050 digital I/O module	Features seven digital input channels and eight digital output channels. Consumes 0.4 W of power.
Adam-4012 analog input module	Has the following input ranges: +-150 mV, +-500 mV, +-1 V, +-5V, +-10 V, 4-20 mA (requires a 125 ohm resistor). Two digital output channels and a digital input channel. Consumes 1.2 W of power.
Adam-4017 8 channel analog input module	Provides eight analog inputs with the following input ranges: +-150 mV, +-500 mV, +-1 V, +-5V, +-10 V, 4-20 mA (requires a 125 ohm resistor). Consumes 1.2 W of power.

Table 2. Crop yield and nutrient uptake data.

	plot 1a	plot 1b	plot 2a	plot 2b	plot 3a	plot 3b	plot 4a	plot 4b
Yield(Kg/ha)	5933	4334	3624	3781	3611	5386	4104	4357
N uptake(Kg/ha)	151	109	44	45	86	123	69	75
P uptake(Kg/ha)	14	11	6	7	6	11	7	9
K uptake(Kg/ha)	206	160	62	78	88	191	101	126

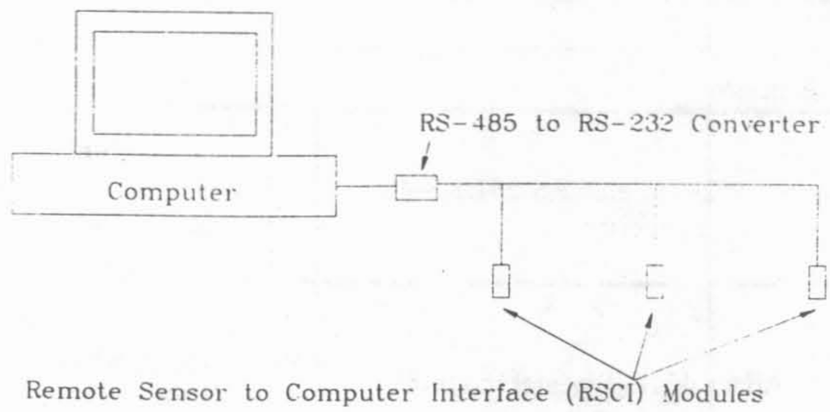

Figure 1. RS-485 network.

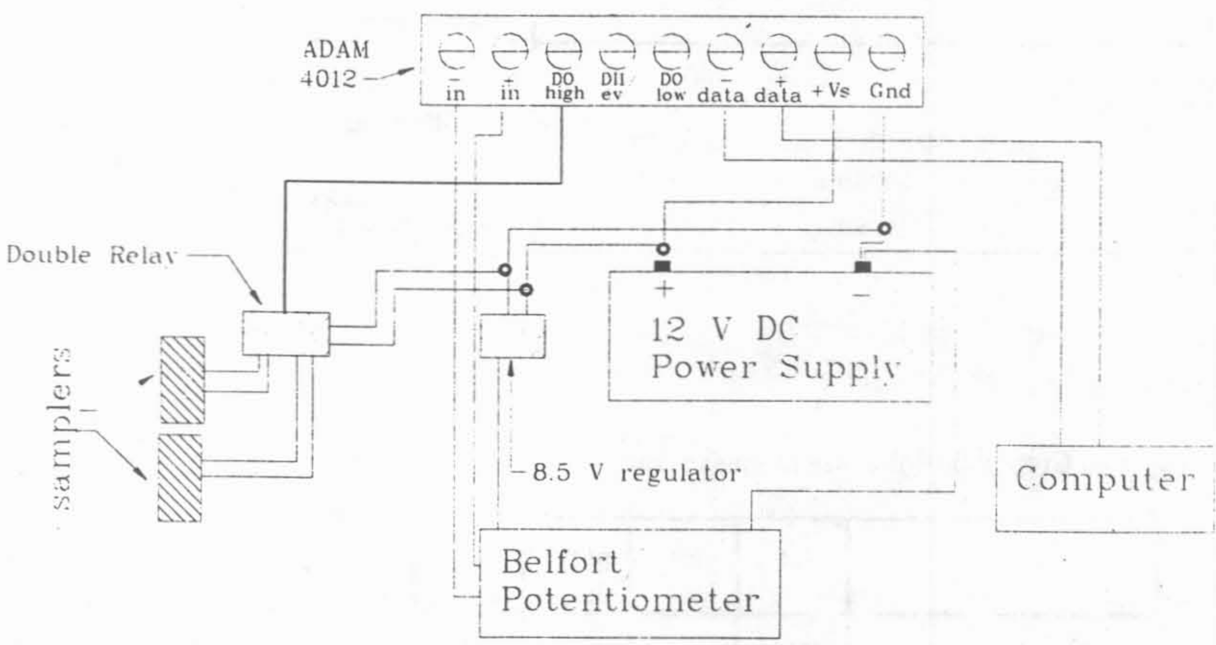

Figure 2. Master plot wiring diagram.

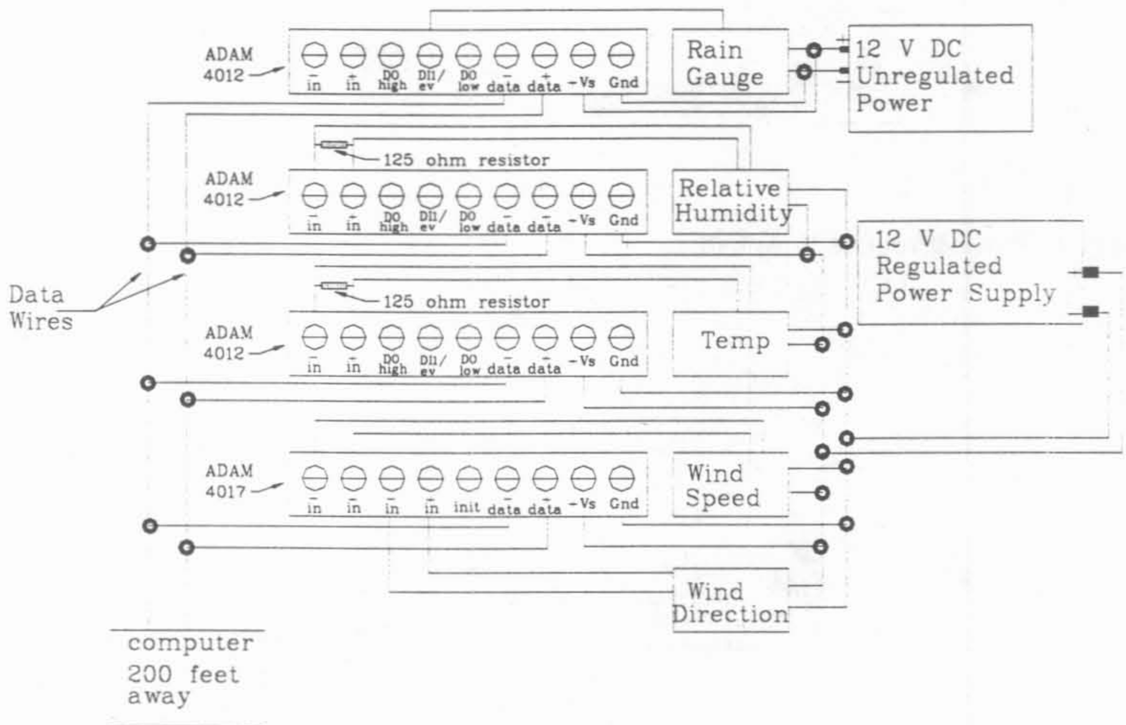

Figure 3. Weather station wiring diagram.

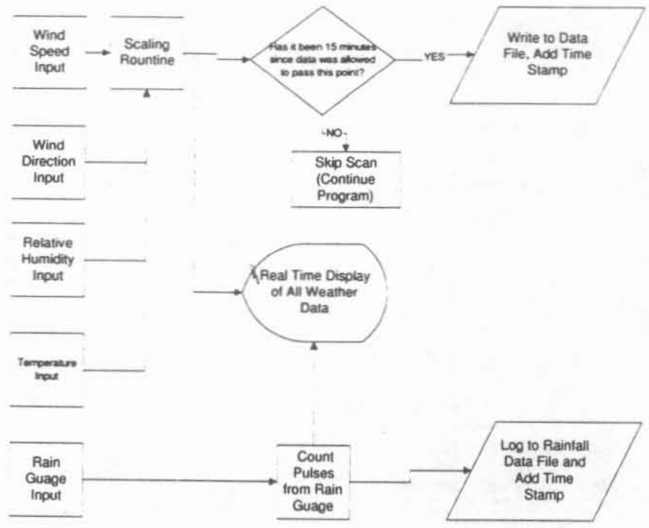

Figure 4. Weather routine flowchart.

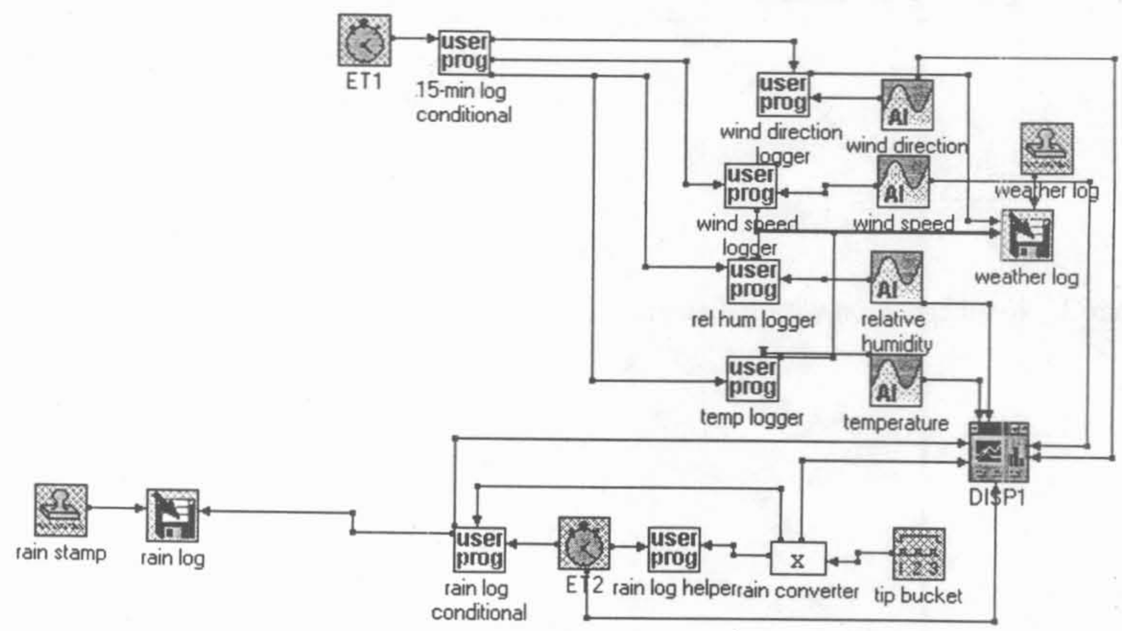

Figure 5. Actual weather routine.

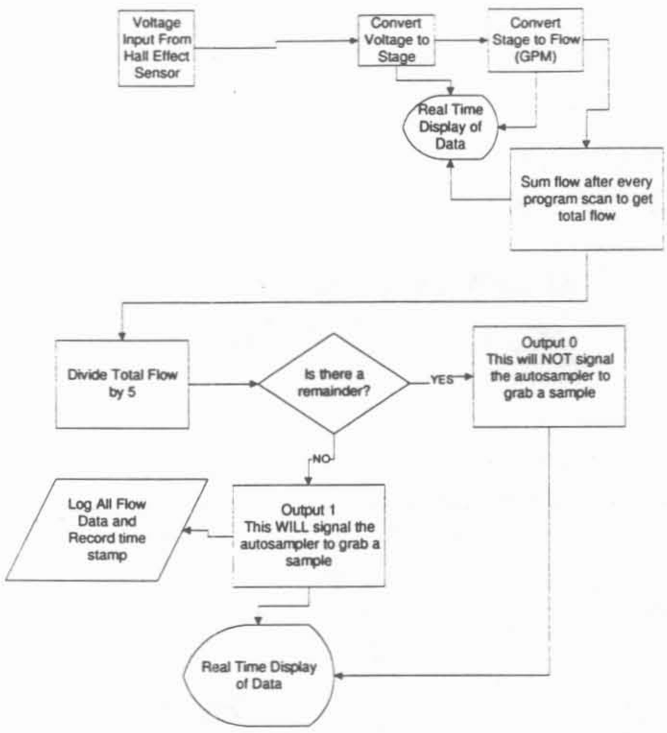

Figure 6. Flow routine flowchart.

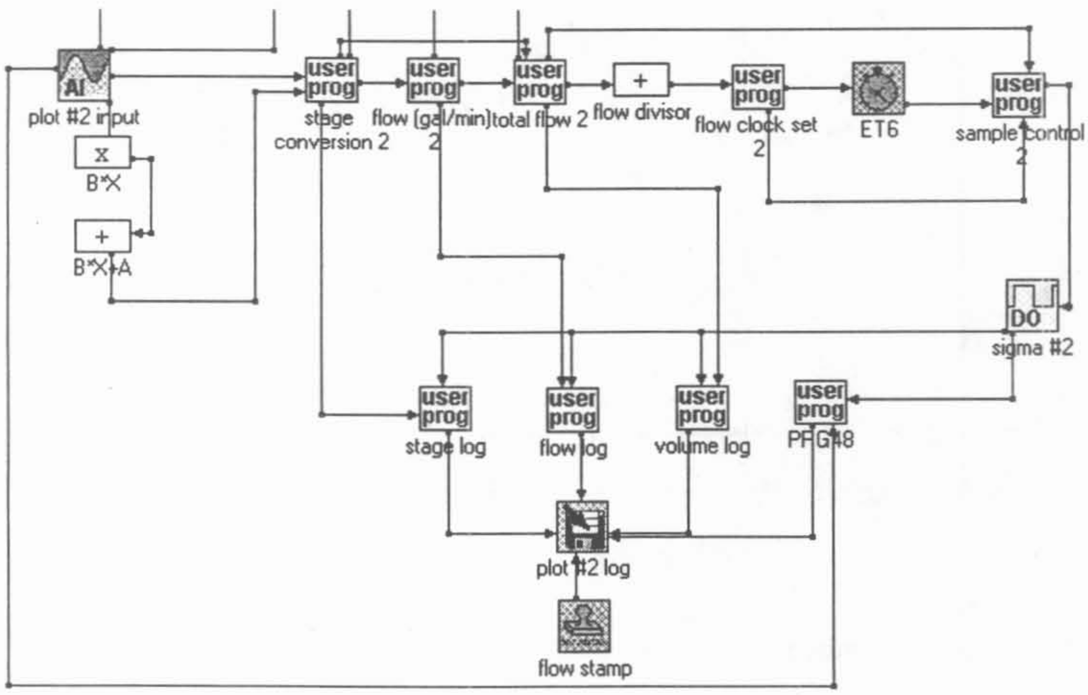

Figure 7. Actual flow routine as it appears on the Genie workspace.

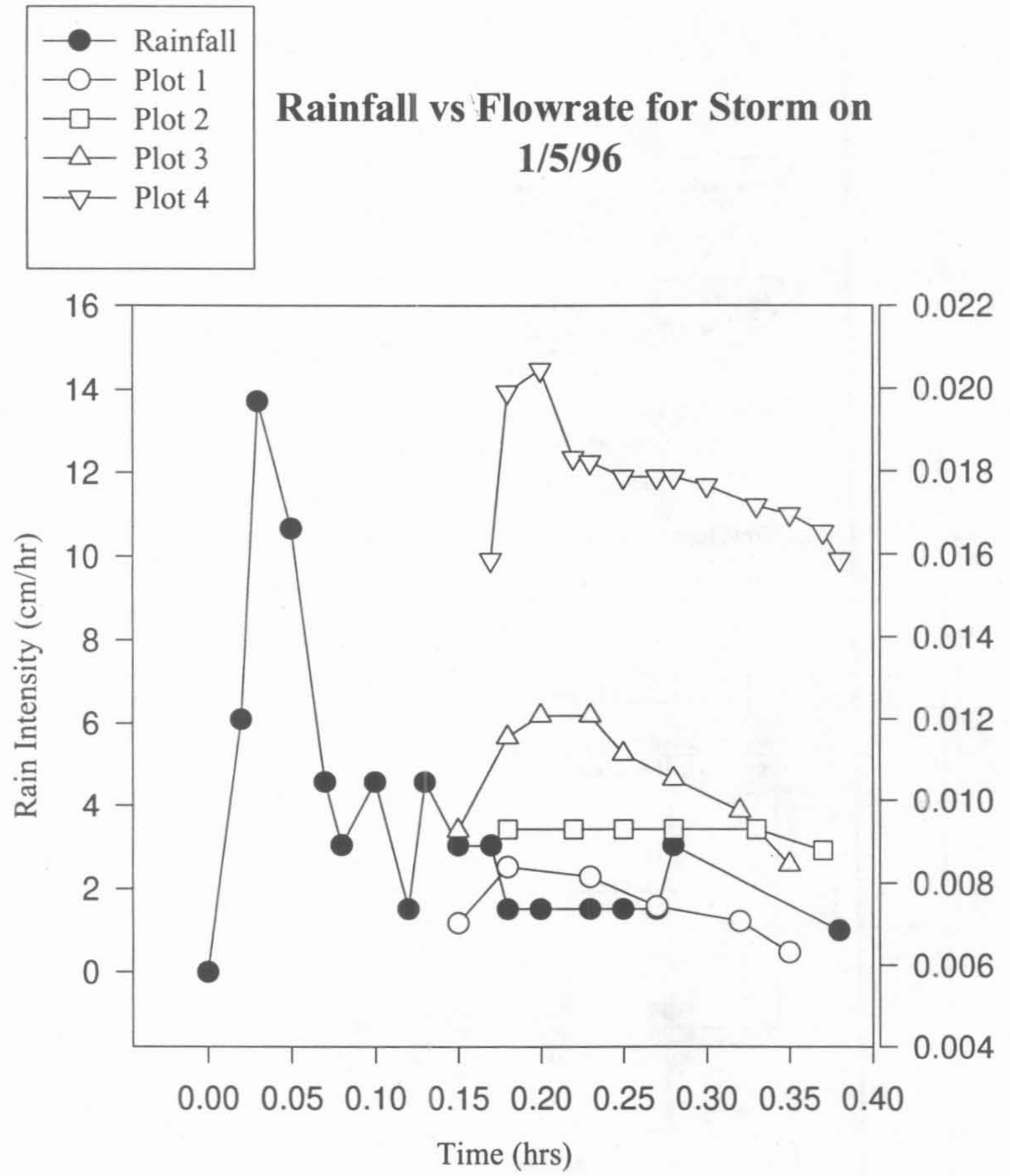

Figure 8. Rainfall and runoff from storm event on 1/5/96.

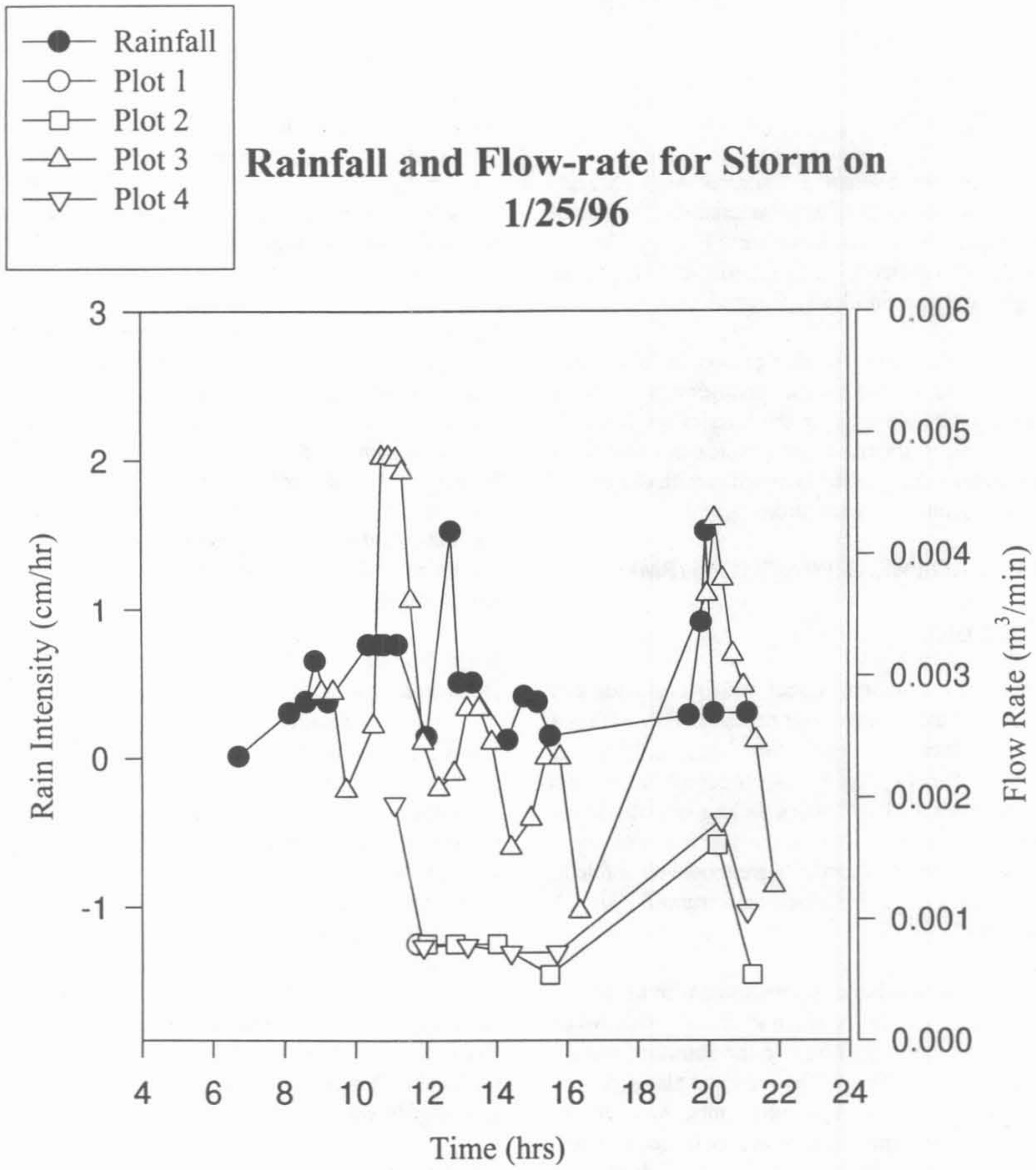

Figure 9. Rainfall and runoff for storm event on 1/25/96.