DISTRIBUTED DATA ACQUISITION FOR MONITORING STORMWATER RUNOFF

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INTRODUCTION

Until recently, livestock producers could legally discharge wastewater from treatment lagoons. While a grandfather clause will allow some producers to continue to discharge, ultimately all agriculturally based livestock wastewater discharge permits will be converted to no-discharge permits. This brings up many questions with regard to the land resources necessary to effectively and efficiently land-apply lagoon wastewater in an environmentally acceptable manner.

Land application of swine lagoon effluent lends itself to sustainability, since water and inorganic fertilizer inputs can be decreased. However, results from several studies have cautioned against overloading agronomic ecosystems (Edwards and Daniel 1993; Vollenweider and Kerekes 1980; Sharply and Menzel 1987; Powers et al. 1975; and Smith et al. 1987). While nitrogen (N) has been the wastewater nutrient of primary concern, recently phosphorus (P) has received additional attention from an environmental perspective. This is due to its potential to cause eutrophication of water bodies (Daniel et al. 1993). Best Management Practices (BMPs) for nitrogen and sediment bound phosphorus (particulate phosphorus, P_p) are well documented; however, less is known about the fate of dissolved P in surface runoff (Daniel 1993; Donigan et al. 1977). Particulate forms of P are usually associated with sediment and, therefore, can usually be controlled with BMPs which limit soil erosion. Dissolved P, on the other hand, is more difficult to manage.

While Sharpley and Smith (1989) found that runoff dissolved P (P_r) and P concentration in the soil surface (P_s) are generally related, they found that the mathematical relationships used for predicting soil P desorption kinetics could overestimate Pr by as much as 4415 percent. Tests conducted by Daniel et al. (1993) found that P_s alone was not a reliable estimator of P_r for either pasture or tillage plots (with and without residue).

These findings point to the need for additional research with regard to application methods and mathematical modeling of nutrient processes. This is particularly true for developing accurate models of nutrient transport processes occurring in heavy west central Mississippi soils (vertisols).

In July 1993, the Appalachian Regional Commission funded a research project to help identify proper methods to land apply swine wastewater in an environmentally sound manner. The research has three major objectives: (1) determination of soil storage and forage utilization of applied wastewater nutrients; (2) to determine offsite nutrient movement by measuring and sampling surface runoff; and (3) to determine associated economics from data obtained in objectives one and two.

Identifying soil storage and forage uptake of wastewater applied nutrients (objective 1) is well underway. One full year of data has been collected. Adeli et al. (1995) reported on first year results from the nutrient utilization component of the project. Initial results indicate that nutrient uptake by the forage is similar for plots receiving commercial fertilizers and swine wastewater. A relationship between quantity of wastewater applied and phosphorus accumulation in the upper 5-cm of the soil profile was found.

Measurement and sampling of surface runoff (objective 2) is difficult due to the complexity and cost of required equipment. In order to facilitate replication in the offsite nutrient movement component of this research, innovative technologies have been sought and are being implemented to measure and sample surface runoff from eight research plots (four treatments with two replications). Presented here are apparatus and methods to achieve cost effective flow-weighted sampling on multiple runoff plots.

APPARATUS

Runoff Plots

Eight runoff plots (Mutchler et al. 1988), 4.05 x 11.05 meters [13.3 ft x 36.3 ft] (½ USLE), are located at the research site and are arranged as shown in Figure 1. The slope on plots one through four is two percent, while plots five through eight have a three percent slope. Plot borders are 10.16-cm [4-inch] PVC tubing (sewer and drain). The PVC tubing was installed by excavating small trenches, 5-cm deep, for the tubing. Soil was then mounded on the exterior sides of the tubing as shown in Figure 2. All external runoff water is routed away from the plots by perimeter trenches. The tubing is attached to the collector end-plate with a galvanized sheetmetal bracket. Collector end-plates are constructed from treated pine boards 5-cm x 25-cm x 4.05-m [2-in x 10-in x 13.3-ft].

Utility Shelter

A 3.65-m x 3.65-m [12 ft x 12 ft] utility building, shown in Figure 3, was constructed near the runoff plots by personnel from the Agricultural and Biological Engineering Department. The building provides a suitable environment for the master data acquisition computer and battery charging equipment. The ability to charge the many (approximately 16 batteries will be needed when all eight plots are on-line) 12-volt batteries on-site reduce problems associated with battery transportation. Since the utility building has AC power, heating and cooling are included to allow the master computer to operate within stated temperature and humidity ranges. A small freezer will be located in the building for storage of wastewater samples until they can be properly analyzed.

H-Flumes

Four 0.15-m [0.5-ft] HS-Flumes were constructed according to procedures in Agricultural Handbook 224 (Brakensiek et al. 1979). Flumes were constructed from 22-gauge galvanized sheet steel. Flume approaches feature a 1-on-8 sloping false floor for enhanced sediment removal. Flume capacity is 0.0049 m^3/sec [0.173 cfs] and can measure flows as low as 15 cm^3/sec [0.00053 cfs]. Figure 4 shows a flume being installed. Proper installation is critical for obtaining good performance from an HS-Flume.

Flume Stage Recorder

An electronic stilling well (ESW) was designed and constructed to make digital stage height data available. The ESW utilizes a linear Hall-effect sensor to measure stage height. The sensor produces an output voltage proportional to the strength of an induced magnetic field. While environmental conditions such as moisture and vibration can adversely affect optical and mechanical devices, Hall-effect units are immune to most environmental conditions. Traditionally, engineers have not used Hall-effect sensors because their cost was much higher than optical and mechanical components. Cost for Hall-effect sensors has decreased dramatically in recent years and is not a significant cost in most electronic systems. The sensor used in the ESW (Micro-Switch SS94A2) can be readily obtained for less than $25. The SS94A2 is temperature compensated and is rated at ± 2.5 percent error over a range of -40 to 140 °C. Figure 5 shows the stilling well and its components.

The Hall-effect sensor is located above the water level and is completely sealed from the environment by an epoxy coating. The magnets used in conjunction with the Hall-effect sensor are rated at 470 Gauss at 25 °C. The sensor has a 1.8-cm [0.7-inch] displacement limit for head-on (unipolar arrangement) sensing, but usable displacement can be doubled by placing a magnet of the same polarity on each side of the sensor (bipolar arrangement). The 3.6-cm [1.4-inch] range available using the bipolar arrangement is still much less than the 0.15-m [0.5-ft] range needed to work with the HS-flumes; therefore, a fulcrum arrangement was used to reduce the motion. As can be seen is Figure 5, the float arm is longer than the arm with the magnets, and the length of either arm can be adjusted to give optimal float-to-magnet motion ratio. Initial field testing indicates that stage can be measured to within ±2.5 mm.

Data Acquisition

Centralized Data Collection. Measurement and sampling of surface runoff is difficult due to problems associated with open channel flow measurement and the extreme environmental conditions under which most runoff data is collected (during severe storms). A standard research runoff plot typically includes the following: a plot border, a flow measurement device (typically a flume), a stage measurement device (mechanical or electronic), a wastewater sampler (to remove samples from the runoff stream at predetermined intervals or on a flow weighted basis), and a data recording device which may be mechanical or electronic.

Cullum et al. (1992) describe current technology and equipment associated with measuring runoff and subsurface flow parameters. Their implementation includes: collectors, approaches, end plates, 0.15-m [0.5-ft] H-flumes, Belfort FW-1 water-level recorders with potentiometers (Belfort Instrument Co., 1600 South Clinton St., Baltimore, MD 21224), runoff splitters, Isco composite wastewater samplers, and three separate data loggers. Three shelters (3.04-m x 3.65m) are provided for six runoff plots. Each shelter contains a data logger, four Isco wastewater samplers, and 12-volt batteries. Multiple buildings are required due to the FW-1 stage recorder that must be located in close proximity to the data logger so that excess voltage drop is minimized. This configuration is a typical centralized data acquisition system where all signals from the plot are routed to a single multi-channel data logger.

While a centralized system has advantages, the cost associated with implementation can be relatively high. In addition, data from each data logger must be individually downloaded and composited on a frequent basis, thus increasing labor requirements and possibly increasing the opportunity for data loss.

Decentralized Data Acquisition. A decentralized data acquisition system is composed of a central data logger (master computer) connected to remote micro controllers (slaves). These micro controllers are typically called remote sensor-to-computer interface (RSCI) modules. They are slaves in the sense that one initiator, the master computer, is used to issue commands that are addressed to particular

RSCI modules (addressed slaves). The decentralized system is distinguished from a centralized system by implementing a single master computer that communicates with the RSCI modules (slaves) via a serial network. A daisy chain network, as shown in Figure 6, is being implemented in this study. A decentralized system has one major disadvantage: a master computer failure will compromise the entire data collection system.

The master computer communicates with the RSCI modules via RS-485 serial protocol. This is the industry's most widely used bidirectional, balanced transmission line standard. It is specifically developed for industrial multidrop systems that must be able to transmit and receive data at high rates over long distances. Following is a list of RS-485 protocol specifications:

- Maximum line length per segment: 1200 meters;
- Throughput of 10 Mbaud and beyond;
- differential transmission (balanced lines) with high noise resistance;
- maximum of 32 nodes per segment;
- bi-directional master-slave communication over a single set of twisted pair cables; and
- parallel connected nodes, thus providing a true multi-drop arrangement.

The RSCI modules used in this research are fully opto-isolated and use a single set of twisted pair wires to send and receive data. Since nodes are connected in parallel they can be freely disconnected from the host without affecting the functionality of the remaining nodes.

When nodes communicate through the network, no sending conflicts can occur, since a simple command/response sequence is used. There is always one initiator that has no address and many addressed slaves. In this case, the master is an IBM-compatible notebook computer that is connected with its serial RS-232 port to an RS-232/RS-485 converter module. The slaves are the RSCI I/O modules. When modules are not transmitting data, they are in a listen-mode until the master computer initiates a command/response sequence with one of the RSCI modules. Commands contain the address of the module that the master is signaling. The module with the matching address carries out the command and sends its response to the master computer.

Since RSCI modules are small (56-mm x 122-mm) and communicate through a twisted pair network, they can easily be placed in close proximity to the sensor being monitored. Analog-to-digital conversion is performed at the module, and the resulting digitally encoded voltage is sent to the master computer with no signal loss due to line impedance. Centralized data loggers, on the other hand, require sensor leads to be routed directly to the data logger. This routing can be cumbersome and may lead to signal degradation. Figure 7 shows how an ADAM 4012 is wired to monitor Hall-effect voltage from the Electronic Stilling Well (ESW).

Remote Sensor-to-Computer Interface Modules. Data acquisition modules provide access to distantly located equipment through an RSCI module controlled by commands issued in RS-485 protocol. RS-485 protocol has several advantages over RS-232 protocol. RS-232 protocol will only interface with one periphal device at a time while with RS-485 protocol, a single computer can send and receive digital data from up to 256 RSCI modules located up to 1200 meters away from the master computer. RS-485 protocol is faster, works over a longer range, and has greater networking capabilities.

The particular modules used in this study are from American Advantech and are called Advantech Data Acquisition Modules (ADAM). They provide A/D and D/A conversion, signal conditioning, data comparison, and digital communication functions. Configuration parameters are stored in nonvolatile Electronically Eraseable Programmable Read Only Memory (EEPROM). The modules operate on a nonregulated voltage from +10 to +30 volts DC. They provide optoisolation of the A/D input and transformer based isolation up to 500 volts DC. They have an operating range of -20° C to 70° C and 0 to 95% humidity.

The costs of the five types of ADAM modules used in this study are listed in Table 1.

Table 1. ADAM RSCI Modules.

Advantech RSCI Module	Cost
Adam 4520 isolated RS-232/405 converter module	$96.00
Adam-4510 Repeater module	$96.00
Adam-4050 digital I/O module	$128.00
Adam-4012 analog input module: MV, MA, Voltage	$176.00
Adam-4017 8 channel analog input module	$224.00

ADAM Module Descriptions

Adam 4520 Isolated RS-232 to RS485 Converter. The 4520 accepts RS-232 input and outputs in RS-485 or RS-422 protocol. It will output at the following baud rates: 1200, 2400, 4800, 9600, 19200, or 38400. It consumes 1.2 W of power.

Adam 4510 RS-485 Repeater Module. The 4510 accepts RS-485 or RS-422 inputs. It outputs in RS-485 or RS-422 protocol at the following baud rates: 1200, 2400, 4800, 9600, 19200, or 38400. It consumes 1.0 W of power.

Adam 4050 Digital input/output module. The 4050 has 7 digital input channels and 8 digital output channels. It consumes 0.4 W of power.

Adam 4012 Analog input module. The 4012 has the following input ranges: ±150 mV, ±500 mV, ±1 V, ±5 V, ±10 V, ±120 mA (requires a resistor). It also has two digital output channels and one digital input channel. The 4012 consumes 1.2 W of power.

Adam 4017 analog input module. The 4017 provides 8 analog inputs with the following input ranges: ±150 mV, ±500 mV, ±1 V, ±5 V, ±10 V, ±120 mA (requires a resistor). It consumes 1.2 W of power.

Master and Control Computer

A central personal computer is necessary to control the system and to record data. It also allows access to data and the capability to make remote software revisions via a cellular modem. A Toshiba T1910 33 megahertz Intel i486 laptop computer with a monochrome display is being used (Toshiba America Information Systems, Inc.). The T1910 has a 200 megabyte hard drive, one 1.44 megabyte 3.5 inch floppy disk drive, and one 14.5 mm Personal Computer Memory Card International Association (PCMCIA) expansion slot that will support a Type I, II, or III card. The PCMCIA slot allows connection with an external modem or other device of the user's choice. The T1910 requires an 18 volt DC input and draws a maximum of 1.1 amperes. The T1910 has one removable, rechargeable nickel metal hydride battery on which it can operate for a short period of time. The T1910 has an environmental operating range of 5 to 35 °C and 20 to 80% relative humidity.

Object Oriented Programming

The data acquisition modules are being controlled by process control and data acquisition software available from American Advantech and is called Genie (version 1.1c). Object oriented programming allows the user to more easily visualize the control system. This type of programming is much like creating an active flowchart. As an example, Figure 8 shows the idealized flowchart for the weather routine currently in use, and Figure 9 shows the actual Genie implementation.

A set of icon blocks containing standard mathematical and control functions are provided in an on screen toolbar. By connecting blocks by "wires," a control program is created. Data flows serially from one block to another through the wires. For example, an analog input block is programmed to get data from a specific RSCI module. The data can then be output to the master computer display or to another program block for further manipulation. Data is easily stored using file output blocks. Multiple graphic or numeric displays can be used to evaluate the data in real-time.

Genie is very flexible and thus encourages on-the-fly changes to the control program. Entire data acquisition and control routines can be assembled in a matter of minutes. On the negative side, as with most Microsoft Windows compatible software, bugs have been encountered. Fortunately, they have not been numerous or severe in nature. Stable routines for both weather and runoff plot monitoring have been developed.

Cellular Modem Interface

One of the more attractive features of implementing a distributed data acquisition system is the use of standard PC-compatible computers. This feature allows users to operate the data acquisition system and analyze the data on a single system. In addition, communication with the master computer is easily performed through a modem. In order to test the applicability of the distributed data acquisition in remote locations, cellular communications are being used at the research site. Since the RS-232 serial port of the master computer is already used to send and receive data to the RSCI modules, the PCMCIA slot is utilized for modem connection.

AT&T Paradyne's KeepInTouch™ Model 3762 PCMCIA modem was selected due to its built-in cellular data pump [Enhanced Cellular Throughput (ETC™)]. In addition, it allows direct connection with the cellular handset for maximum signal integrity.

The research site is located 25-km from a cellular tower and cellular signal strength at the site is excellent. Cellular service is being provided by Cellular South (2211 Highway 45 North, Columbus, MS 39701).

In order to provide maximum accessability to the master computer from remote locations, remote communications software is utilized (CloseUp, v6.0: Norton Lambert Corporation, P.O. Box 4085, Santa Barbara, CA 93140). Not only can data files be sent and retrieved, but data acquisition control programs can be stopped, started, and/or modified remotely. This utility allows routine checks of system performance without actually going to the site. This will prove invaluable, with regard to personnel requirements.

EQUIPMENT INSTALLATION

Paired AWG 14 shielded data cable was run through 25.4-mm [1-inch] PVC pipe to the fully instrumented runoff plot and weather station. Every attempt was made to avoid any exposure of wire, so as to minimize the risk of breakage, sabotage, etc. The PVC tubing was buried 20-cm deep in a 10-cm wide trench.

The flume was placed in an excavation to allow the collector to be placed below the ground level at the end of the plot. The collector is supported by a 5-cm x 25-cm x 4.05-m [2-in x 10-in x 13.3-ft] treated board. The flume and stilling well are supported on 9.5-mm [0.375-inch] steel threaded rods mounted on wood anchors. After placing the flume and stilling well in the excavation and preliminary leveling is performed, the anchors are secured with concrete. This step must be done carefully due to the sensitivity of the electronic stilling well. Movement of the flume after stilling well calibration may cause calibration data to be invalid. After the concrete dries, final leveling is completed and the approach is set to two percent. The flume is now ready to be calibrated.

Calibration is accomplished by first plugging the end of the flume so that a static water level can be achieved. A multimeter is attached to the output of the Hall-effect sensor monitoring stage height. The depth of water in the flume is measured using a dial-micrometer and the voltage that corresponds to a measured depth is recorded. Numerous voltage/stage measurements are taken from zero stage to maximum stage (0.15-m). An equation is fitted to the collected data. This equation is inserted into a Genie user programmable block, thus allowing real-time voltage-to-stage conversion and output. A typical calibration curve is shown in Figure 10.

Real-time measurement of stage and time allows flowrate to be computed. This facilitates flow-weighted sampling at user defined rates for all eight runoff plots.

SUMMARY

A distributed data acquisition system was designed and installed to monitor stormwater runoff. The system allows runoff measurement and flow-weighted wastewater sampling for eight research plots. Plot data acquisition and control is accomplished by a single IBM-compatible notebook computer. The computer communicates with remote sensor-to-computer interface (RSCI) modules via RS-485 serial protocol. Object oriented control software eases programming and manipulation of data. The system can be remotely accessed via a cellular modem, allowing the system to be routinely checked for proper operation. If needed, software revisions can be accomplished remotely. Data files can be sent and retrieved through the modem connection. An onsite weather station is also monitored by the data acquisition system.

Plots one and two are currently operational, and plots three through eight will be operational by June 1995.

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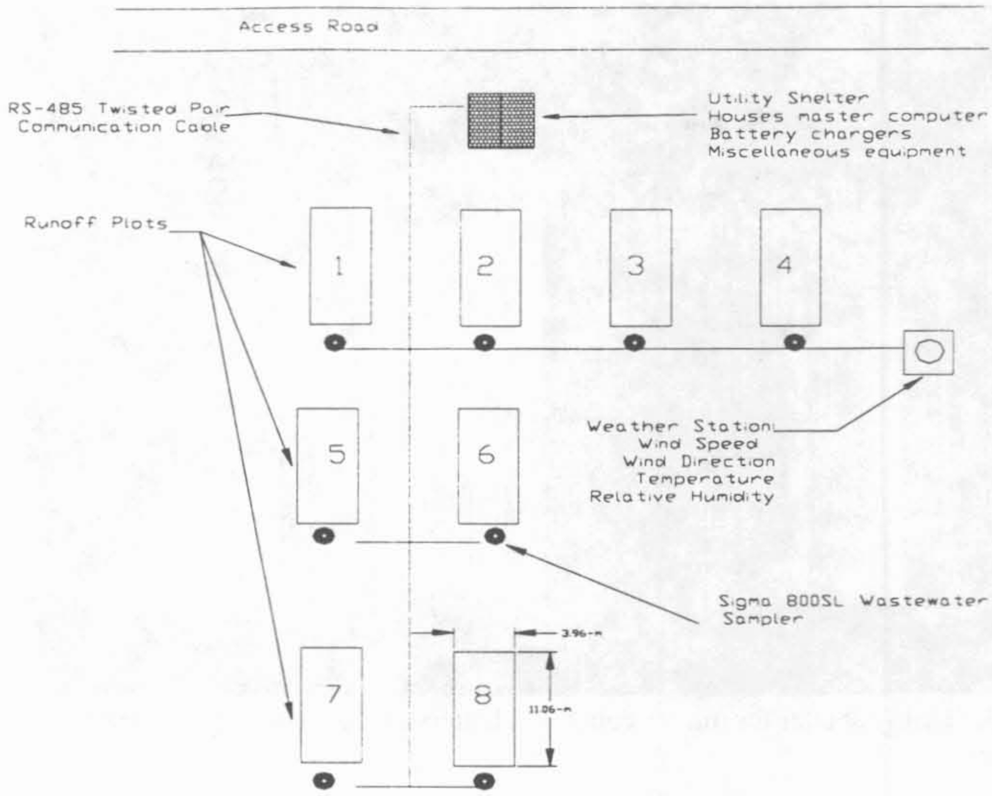

Figure 1. Schematic of plot layout, utility shelter, weather station, RS-485 communication cable, and wastewater samplers.

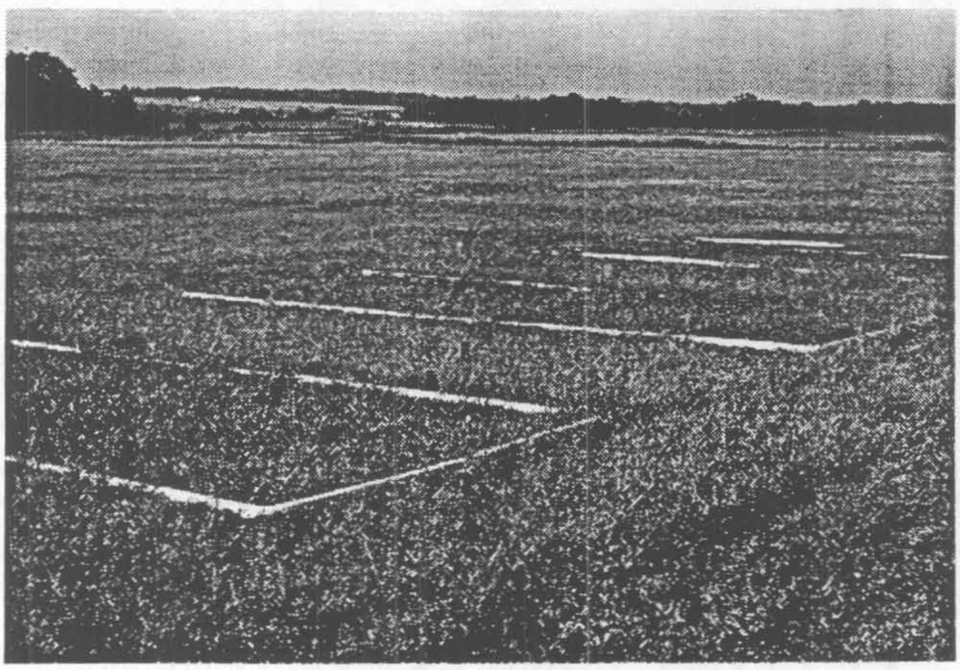

Figure 2. Runoff plots at the Crawford, MS research site.

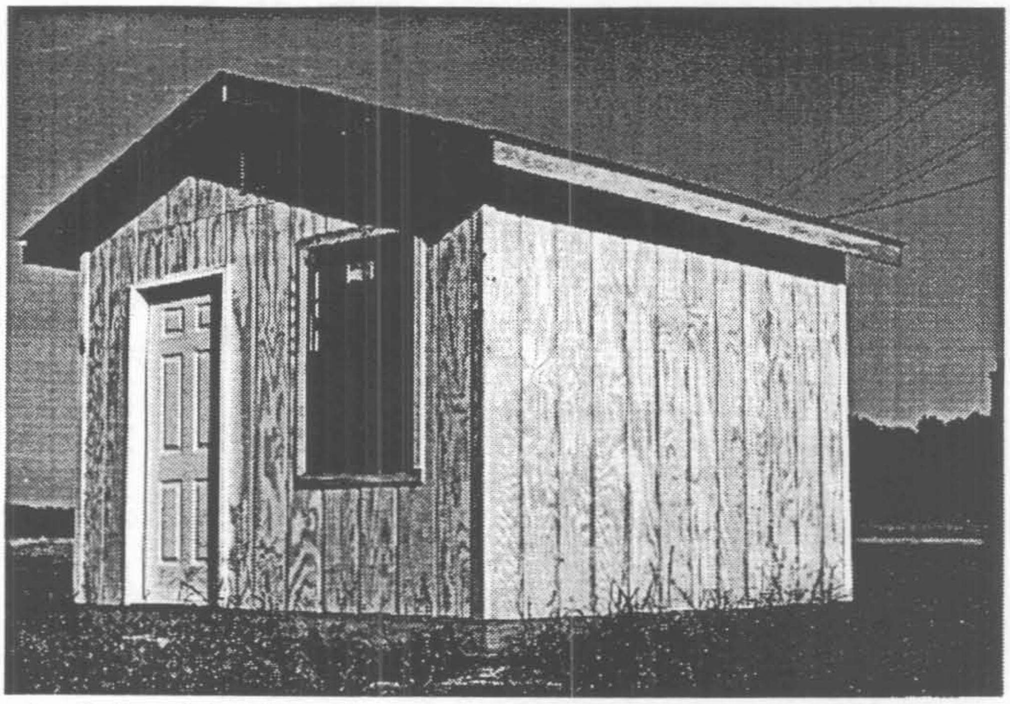

Figure 3. Utility shelter for master computer, battery chargers, and miscellaneous equipment.

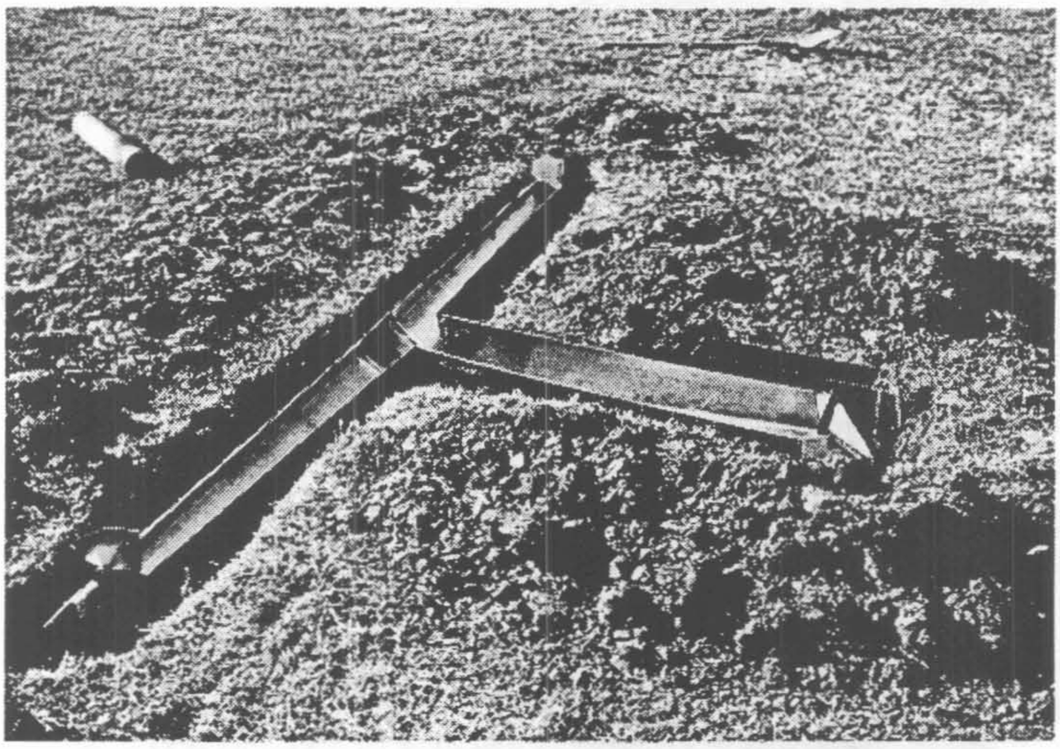

Figure 4. Installation of collector, approach, HS-flume, and electronic stilling well.

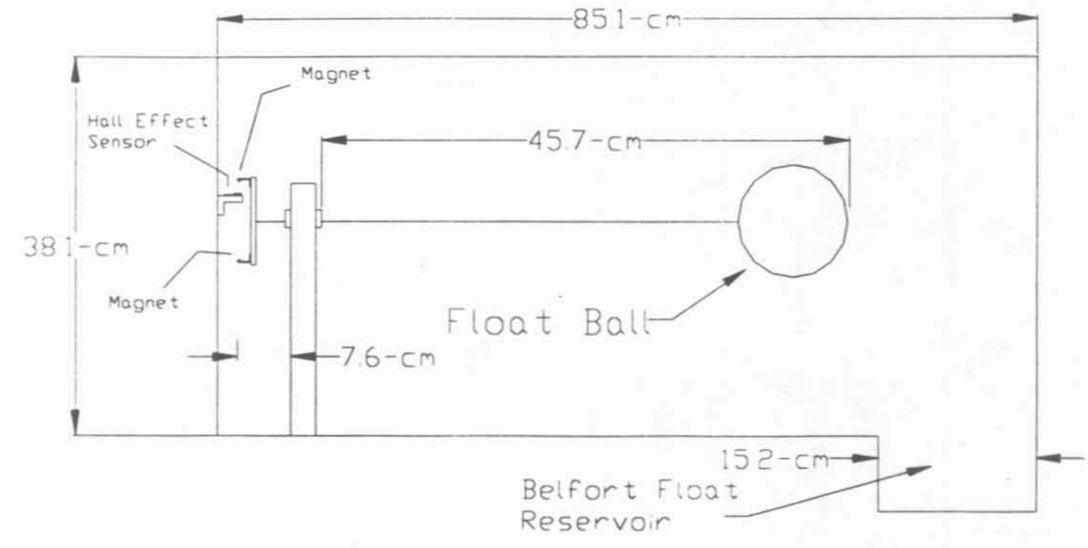

Figure 5. Cutaway illustration of Electronic Stilling Well (ESW).

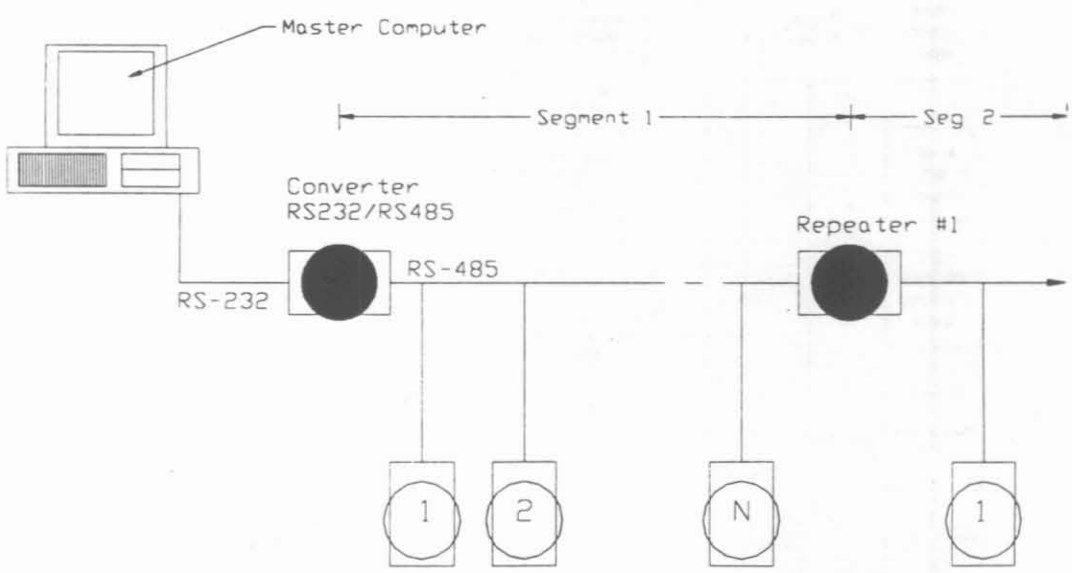

Figure 6. Schematic of a daisychained RS-485 data acquisition network.

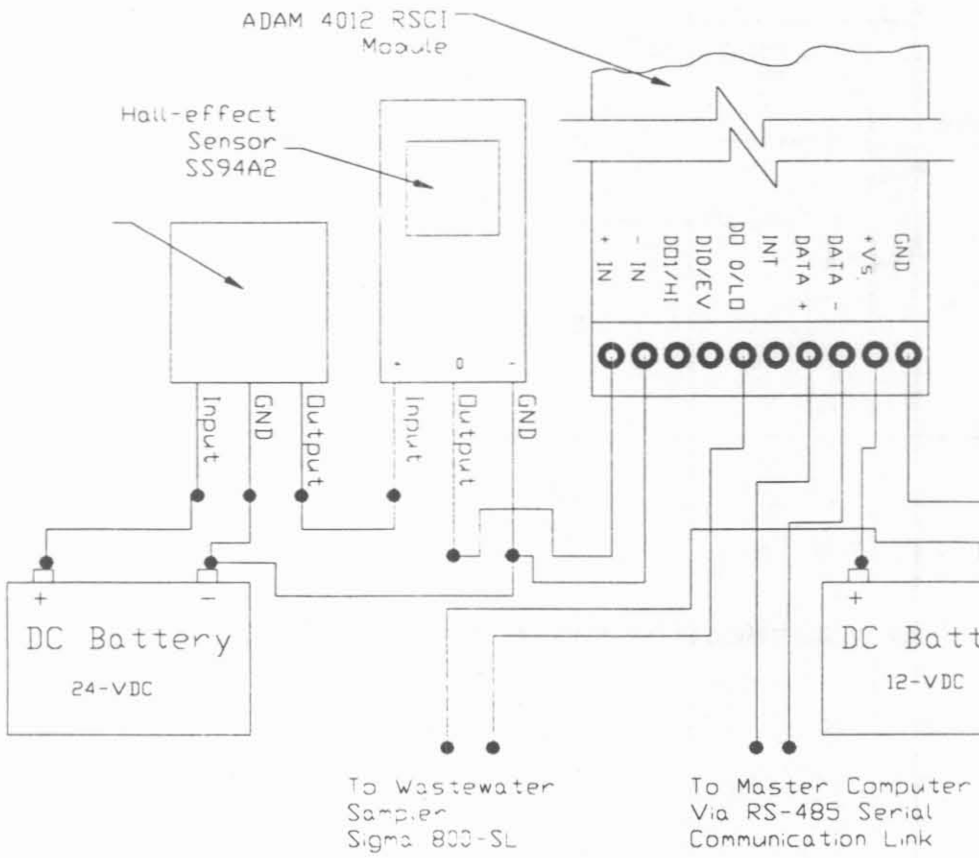

Figure 7. Schematic of ADAM 4012 wired to monitor Hall-effect output voltage.

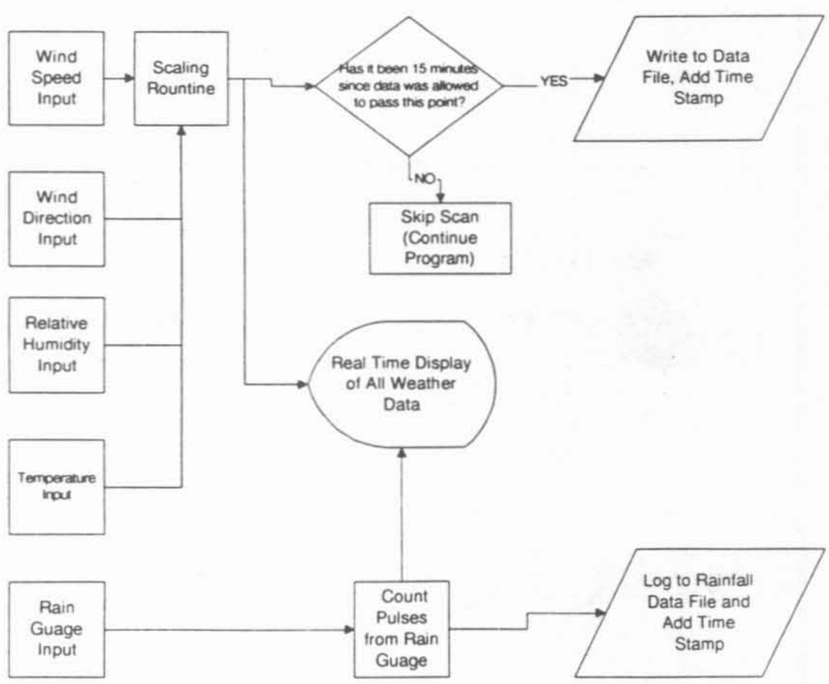

Figure 8. Standard computer flowchart for weather data retrieval and storage.

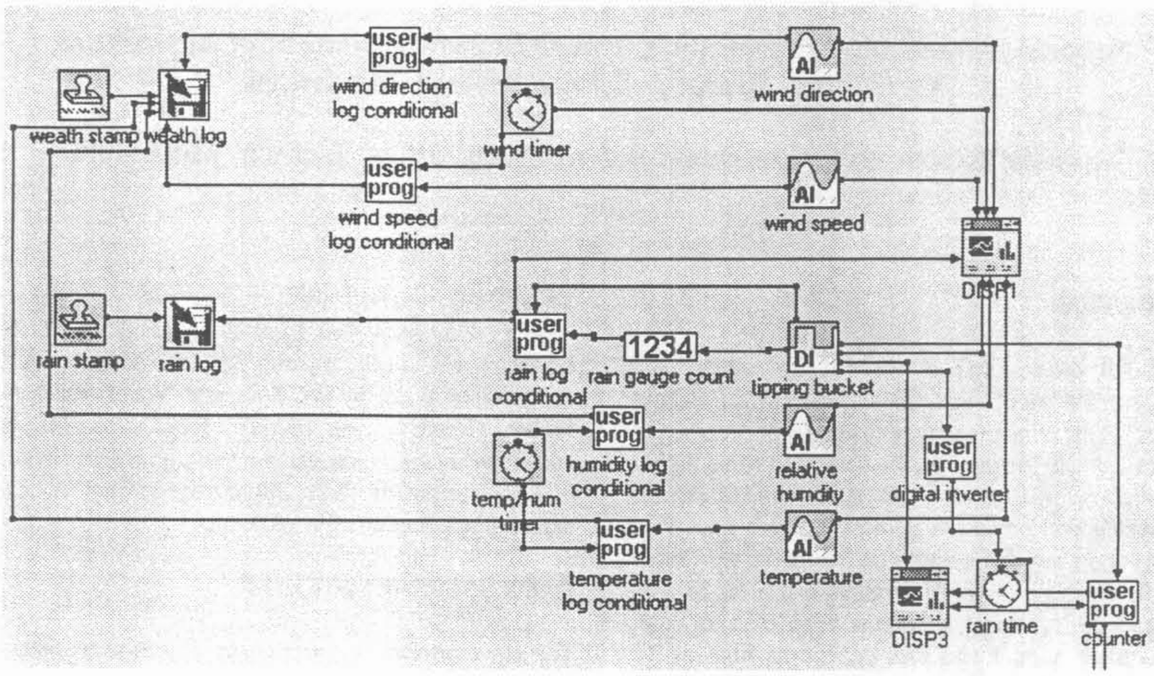

Figure 9. Actual weather routine written using Advantech Genie software.

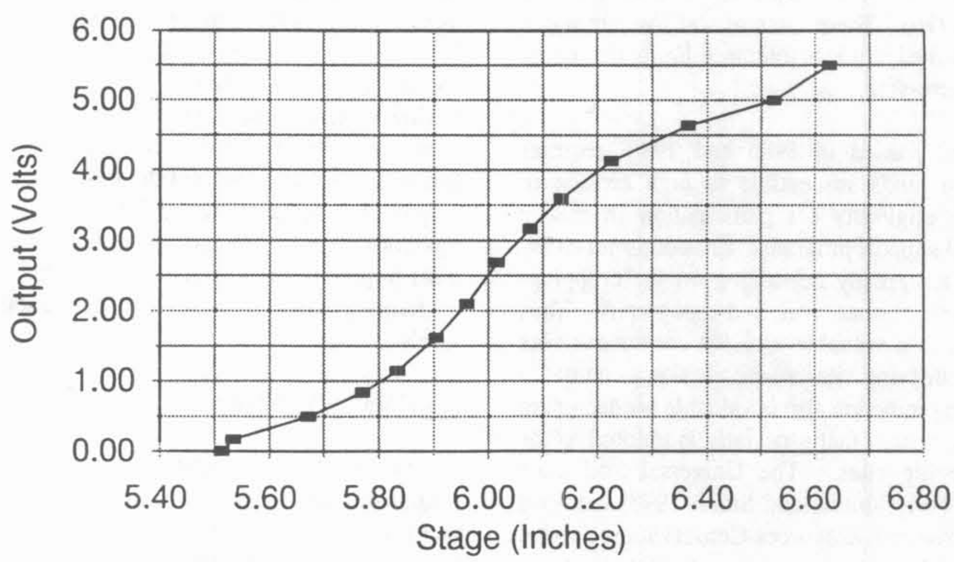

Figure 10. Hall-effect output versus HS-flume stage.