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I am submitting herewith a thesis written by Nathan Randy Rainwater entitled "An Automatic Sampling System to Monitor Perched Water in the Vadose Zone." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Engineering.

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AN AUTOMATIC SAMPLING SYSTEM TO MONITOR PERCHED WATER IN THE VADOSE ZONE

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Nathan Randy Rainwater
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DEDICATION

This thesis is dedicated to the members of my immediate and extended family who were all supportive of my decision to return to college and acquire a graduate degree and who helped make it a reality.

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I especially must thank my wife Priscilla. She married an engineer, loved him through two income reductions, two graduate degrees, and twelve years of mission work. Truly, she is a *virtuous woman.*

ABSTRACT

Increasing concern about ground water movement and solute transport in the vadose zone requires further development of monitoring systems to characterize subsurface hydrology. An interdisciplinary team of researchers at The University of Tennessee has developed a research facility on a 994-ha agricultural watershed in West Tennessee. Since the fall of 1990 a 10-ha test site of the watershed has been in conservation tillage. A square 0.4-ha test plot has been established within the 10-ha site. A monitoring system is installed in, and surrounding, the field-test plot to characterize surface and subsurface hydrology. Shallow wells are installed with a screen at the loess-paleosol interface to collect perched water caused by differences in the physical characteristics of the soil layers. Shallow wells were installed, in 1992, at 23 locations on concentric circles with radii of 45, 60, 90, and 150 m from the center of the 0.4-ha test plot (Yoder et al., 1994).

On March 9, 1993, a bromide tracer was surface applied to the plot at the rate of 300 kg/ha. Monitoring of the bromide movement began immediately after the application and is continuing (Yoder et al., 1994). Based on the spatial distribution of the shallow wells that have yielded bromide, 17 additional shallow wells were installed in April 1995 to more accurately characterize the loess-paleosol interface and subsurface hydrology. These additional shallow wells were installed on the west side of the 0.4-ha test plot. An automatic sampling system was installed to collect samples from 21 shallow wells, including the 17 additional shallow wells. The system is divided into three separate sampling systems, each monitoring seven shallow wells.

The primary components of each sampling system include a microcontroller card with 32K of memory and 24 input/output lines, liquid level switches, flow sensors, isonic valves, two vacuum tanks, a 12-V battery, and a solar panel. The automatic sampling system records the time each sample is taken.

Several operational problems during the first six months of operation and a generally dry season resulted in a limited amount of data being acquired. The data suggest the new shallow wells on the 45-m radius are approaching the spatial resolution necessary to define possible flow paths of lateral subsurface flow at the interface.

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CHAPTER 1

INTRODUCTION

The Vadose Zone

The vadose zone extends from the soil surface to the upper surface of the principal water-bearing formation (Wilson, 1980). Vadose zone is a better term than unsaturated zone because saturated regions are frequently present in the vadose zone. Understanding vadose zone hydrology is vital to developing regulations and best management practices that will protect ground water and surface water quality. Understanding vadose zone hydrology requires sophisticated monitoring techniques due to the complexity of vadose zone hydrologic phenomena. A review of the literature shows that our conceptual knowledge of the vadose zone exceeds our technological ability to measure vadose zone phenomena.

Many researchers recognize the significance of lateral flow in the vadose zone. Accounting for lateral flow in the vadose zone is critical when attempting to relate a specific land use to ground water quality data (Staver and Brinsfield, 1991). Sampling the vadose zone is required to quantify and predict the rate of reaction, transformation, and movement of chemicals downward to ground water, and laterally along inclined textural layers and in phreatic layers to drainage ditches, streams, etc. (Starr et al., 1991). Perching layers intercepting downward moving water may transmit water laterally at substantial rates (Everett and Wilson, 1984). Vadose zone water can build up to saturation on top of an impermeable zone and flow under a lateral component of gravity for a long distance (Davis, 1995). However, research of lateral flow and other vadose zone phenomena is limited by the lack of monitoring technology and adequate test sites.

To conduct meaningful research on the interaction of farming practices and the off-site movement of agricultural chemicals, it is necessary to control management over large land areas. Because water and chemicals often move laterally beneath the soil surface, typical field plots are generally too close together to permit differentiation of the effects of various cultural practices on water quality. A large holding of land is available to The Tennessee Agricultural Experiment Station at the Ames Plantation in West Tennessee, this holding provides an opportunity to develop vadose zone monitoring technology and to do extensive research of vadose zone phenomena. An automatic shallow well sampling system was developed to monitor perched water in the vadose zone at the Ames Plantation. The sampling system records the time each sample is taken. Developing monitoring technology that will collect time data of perched water and lateral flow in the vadose zone is important for the characterization and modeling of vadose zone hydrologic phenomena. Accurate time data collection and management will improve future designs of vadose zone monitoring systems.

CHAPTER 2

PROBLEM DEFINITION

The Ames Plantation Water Quality Research Project

Monitoring Agrichemical Movement

In 1990, an interdisciplinary team of researchers at The University of Tennessee was formed to conduct a water quality research project located at the Ames Plantation in West Tennessee. This team continues to conduct research and is lead by the Agricultural Engineering Department. The Ames Plantation is a holding of 7,300 ha available to The University of Tennessee for research purposes (Yoder et al., 1994).

The Ames Plantation Water Quality Project Research Team has developed two, 10-ha test sites within a 994-ha watershed at the Ames Plantation. The initial research objectives were to: (1) compare the effects of no-tillage and tillage on the movement of nitrogen and bromide tracer out of the root zone (Wilson et al., 1994), (2) to evaluate the extent of preferential flow and soil matrix movement simultaneously (Wilson et al., 1994), and (3) to evaluate the effectiveness of the monitoring scheme installed on each of the 10-ha sites (Yoder et al., 1994).

Description

The soil profile in the test area consists of 0 to 3 m of loess over Tertiary-aged Claiborne and Wilcox geologic formations (Hardeman, 1966). The two 10-ha sites are separated by an intermittent stream. Since 1990, cropland north of the stream has been in no-tillage while that south of the stream has been in tillage. A square 0.4-ha test plot has been established within each 10-ha site. The 0.4-ha test plots are surrounded by a low bank to exclude surface water flowing from other parts of the field and to direct plot runoff into an H-flume for runoff measurement and automatic water sampling. A buried drain line carries flume discharge to an off-site location. A monitoring system is installed on each of the 10-ha sites to sample runoff from the 0.4-ha test plots, water in the vadose zone, and ground water in the underlying aquifer (Yoder et al., 1994). The test site monitoring scheme is shown in Figure 2.1.

To obtain samples from all parts of the soil profile, vacuum operated solution samplers, tension-free pan lysimeters, and shallow wells are installed. The tension-free pan lysimeters collect an integrated water sample, the solution samplers collect water from the soil matrix, and the vadose zone wells collect water that perches at the loess-paleosol interface (Yoder et al., 1994). This perched water is caused by differences in the physical characteristics of the soil layers at the loess-paleosol interface (Figure 2.2). The shallow wells are screened at the interface allowing water to flow into the well casing when saturated conditions exist.

The shallow wells were installed by a pedologist who obtained soil cores and identified the location of the loess-paleosol interface. Soil characterization information for the no-tillage site is included in Appendix A. The shallow wells are completed with 1.5-in. (38-mm), schedule 40 PVC casing. The slotted PVC screens are sand packed and the bore hole is sealed to the soil surface with a Portland cement grout. The casing extends 0.38 m below the screen to provide a 0.5-L storage reservoir for water entering the well. Samples are retrieved from the reservoir with a vacuum pump. Depth from the soil surface to the loess-paleosol interface ranges from 1.93 to 2.67 m at the tillage site and 1.85 to 2.76 m at the no-tillage site. These wells are installed on concentric circles with radii of 45, 60, 90, and 150 m from the center of the 0.4-ha test plots (Yoder et al., 1994).

Ground water wells are located at 12 locations outside each 0.4-ha test plot. The ground water wells are located on concentric circles with radii of 60, 120, and 180 m around the 0.4-ha test plots. There is also one well located near the upper end and one well near the lower end of the watershed to sample water in the larger aquifer (Yoder et al., 1994).

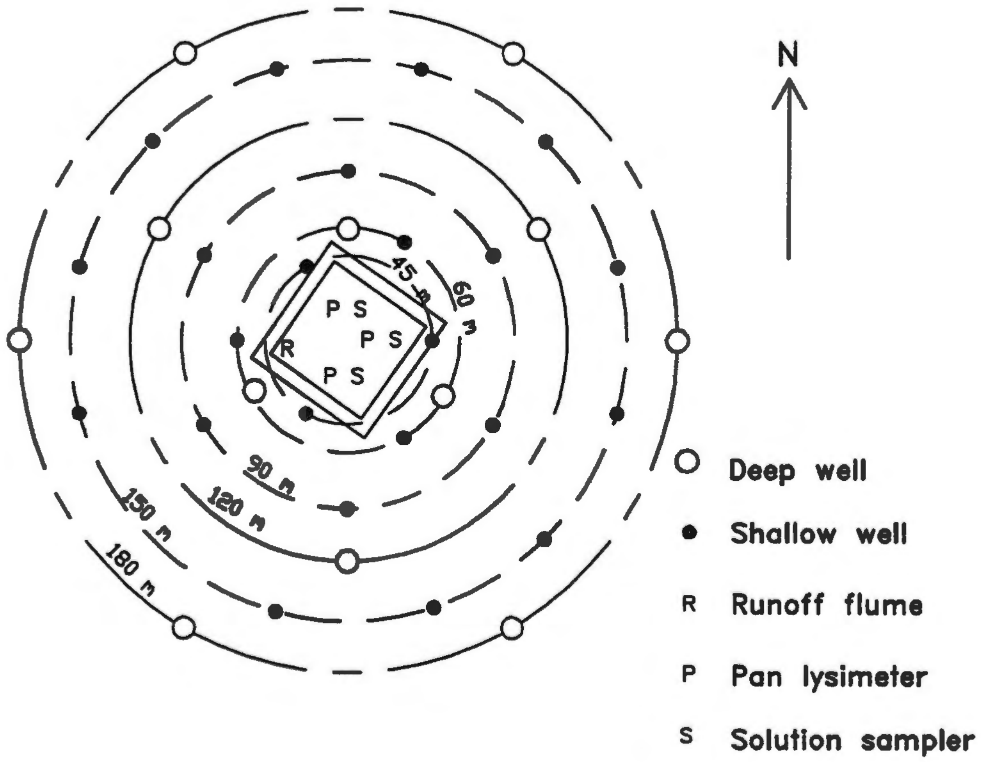

Figure 2.1. No-till test site monitoring scheme, the tillage site has a similar monitoring scheme.

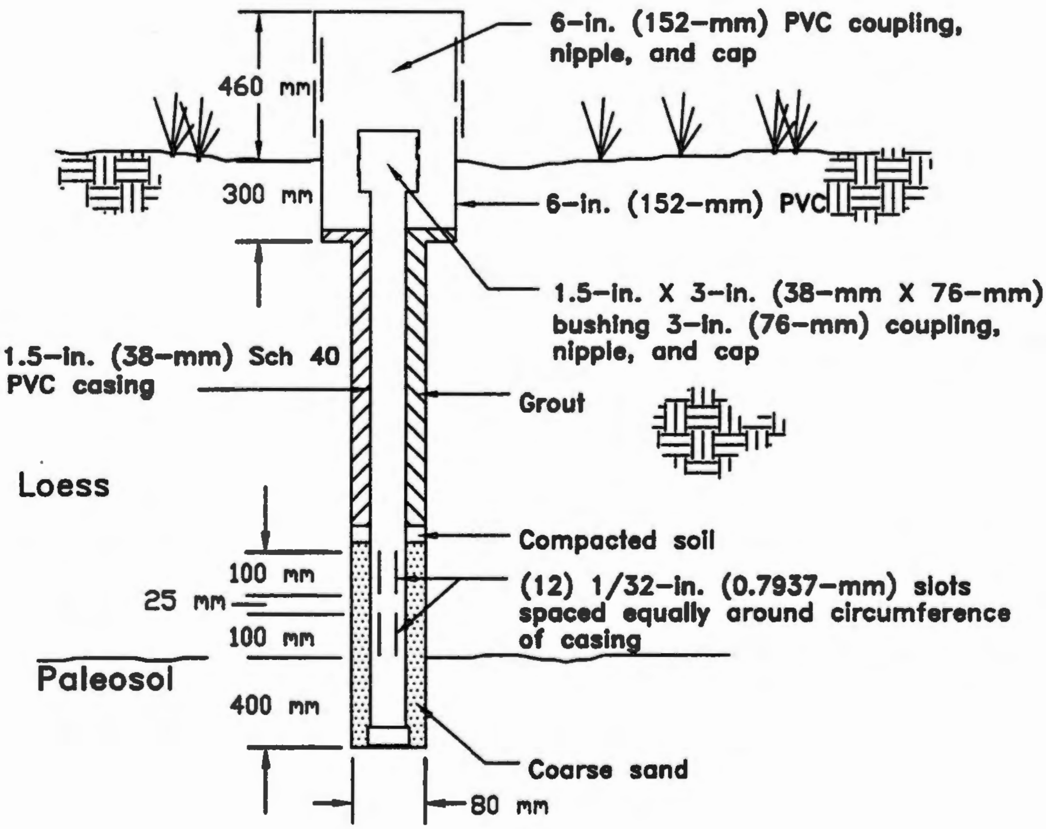

Figure 2.2. Shallow well design screened at the loess-paleosol interface.

Sample Collection

To eliminate the possibility of cross contamination between sampling sites all equipment and tubing that comes into contact with the sampled water is permanently installed. Sample handling and analysis procedures are designed to reduce the possibility of any contamination (Yoder et al., 1994).

A sampling schedule tied to precipitation events was begun September 1, 1992. Sampling is initiated when more than 12 mm of precipitation infiltrates the soil in one day, or when the cumulative infiltration since the last sampling reaches 75 mm. Composite, flow proportional, runoff samples are collected during the event and retrieved as soon as possible after an event. Pan lysimeter and perched water samples are collected two days after an event. Vacuum is drawn on the solution samplers the first day after an event. Because ground water samples are likely not effected by individual precipitation events, samples were initially collected on a regularly biweekly schedule (Yoder et al., 1994). That frequency was decreased to monthly in 1995.

Tracer Application

A chemically conservative soil water tracer, potassium bromide (KBr), was applied March 9, 1993 to evaluate the sampling equipment and schedule. The tracer was applied in a granular form at 300 kg/ha Br^- only within the 0.4-ha test plots. The standard sampling protocol and schedule were initiated six months prior to the bromide application. Data from this period indicate that bromide does not exist naturally in detectable concentrations at Ames Plantation, therefore bromide is a reasonable indicator of solute movement from the test plots (Yoder et al., 1994).

Data for both test sites have been reported by Yoder et al. (1994), and Wilson et al. (1994), and will continue to be reported. Tables 2.1 and 2.2 contain a summary of data from September 1, 1992, to December 13, 1994. The research team carefully studied these data in March 1995 and made recommendations that will be discussed later in this chapter. Figure 2.3 shows the location of the sample sites, as numbered in Tables 2.1 and 2.2, for the no-tillage site.

Water collects in the shallow wells only when the soil surrounding the well is saturated. Some wells have consistently yielded water samples while others have never yielded water, suggesting the need for more information about the loess-paleosol interface and how it controls the flow of water on this watershed. At the tillage site, 18 of 24 wells yielded water and 16 of the 18 had yielded bromide as of December 1994. At the no-tillage site, 12 of 23 had yielded water and 11 of those 12 had yielded bromide as of December 1994. The detection of bromide in the water taken from the shallow wells varied considerably. At the no-tillage site, well 21 had yielded water on 22 occasions without any detectable bromide while adjacent well 22 had only yielded water three times, but with detectable bromide in all three samples. At both sites, the bromide concentration in the shallow well samples has always been less than 4.5 mg/L, usually less than 1.0 mg/L (Yoder et al., 1994).

The time of the arrival of bromide at the wells is also of interest. The first detection of bromide at the tillage site occurred approximately two weeks after application. At the no-tillage site the first detection in the shallow wells occurred about two months after application. Both detections were in wells on the outer radius of shallow wells, 150 m from the center of the test plot. The detection of bromide in wells on the outer ring without detection in wells on any of the inner rings suggests the water and bromide moved in well defined flow paths, missing the inner wells (Yoder et al., 1994). The number of water samples from shallow wells at the no-tillage site that yielded bromide from March 9, 1993, when the tracer was applied, to December 13, 1994, are shown in Figure 2.4.

Table 2.1. Shallow Well Data at the Tillage Site as of 12/13/94.

Shallow Well	Water			Bromide						
	Total Samples	first	last	Total Samples	first		high		last	
					mg/L	date	mg/L	date	mg/L	date
1	4	1/5/93	3/29/94	2	0.25	1/31/94	0.25	1/31/94	0.02	3/27/95
2	13	11/9/92	9/23/94	5	0.93	11/9/92	0.93	11/9/92	0.31	9/23/94
3	0			0						
4	18	9/21/92	10/12/94	3	0.06	12/5/93	0.07	1/24/94	0.01	3/27/95
5	0			0						
6	6	11/9/92	1/24/94	5	0.92	11/9/92	4.53	1/24/94	4.53	1/24/94
7	12	9/21/92	6/12/94	2	1.32	1/31/94	1.32	1/31/94	0.15	3/12/94
8	26	9/21/92	12/13/94	15	0.52	12/5/93	0.71	7/11/94	0.04	9/16/95
9	34	9/21/92	12/13/94	9	0.14	6/13/93	0.19	9/27/93	0.02	4/20/95
10	3	9/21/92	11/29/94	2	2.81	1/31/94	2.81	1/31/94	2.46	11/29/94
11	1	1/31/94		1	2.00	1/31/94				
12	7	12/5/93		2	0.14	12/5/93	0.14	2/6/94	0.14	2/6/94
13	0			0						
14	1	1/31/94		1	0.21	1/31/94				
15	1	10/12/94		1	1.12	10/12/94				
16	7	3/1/93	5/2/94	0						
17	35	9/21/92	12/13/94	9	0.25	1/5/93	1.52	12/13/94	1.52	12/13/94
18	15	9/21/92	9/23/94	2	0.22	1/24/94	0.22	1/24/94	0.05	9/23/94
19	15	9/21/92	12/5/94	4	4.00	3/26/93	4.00	3/26/93	0.04	12/5/94
20	1	1/31/94		0						
21	0			0						
22	3	3/12/94	4/7/94	1	0.16	4/7/94				
23	0			0						
24	0			0						

Table 2.2. Shallow Well Data at the No-Till Site as of 12/13/94.

Shallow Well	Water			Bromide						
	Total Samples	first	last	Total Samples	first mg/L	first date	high mg/L	high date	last mg/L	last date
1	0			0						
2	1	2/16/94		1	0.08	2/16/94				
3	0			0						
4	5	2/24/94	12/13/94	5	2.91	2/24/94	2.91	2/24/94	1.41	12/13/94
5	0			0						
6	0			0						
7	17	1/22/93	4/18/94	4	0.08	12/5/93	0.5	2/24/94	0.5	2/24/94
8	0			0						
9	3	1/28/94	3/29/94	1	0.34	2/16/94				
10	0			0						
11	1	2/16/94		1	0.25	2/16/94				
12	0			0						
13	35	9/21/92	4/18/94	10	0.26	6/30/93	0.86	2/24/94	0.03	12/13/94
14	7	4/22/93	12/13/94	3	0.06	4/14/94	0.06	4/14/94	0.04	5/3/94
15	17	3/1/93	6/1/94	3	0.09	2/21/94	0.23	2/24/94	0.12	3/29/94
16	0	3/7/95		0						
17	0			0						
18	0			0						
19	15	1/21/93	4/14/94	3	0.07	12/22/93	0.15	2/14/95	0.15	2/16/94
20	6	5/13/93	2/24/94	4	4.02	5/13/93	4.02	5/13/93	0.09	2/16/94
21	0			0						
22	26	9/21/92	7/30/94	0						
23	3	5/13/93	9/27/94	3	0.34	5/13/93	3.56	9/27/93	3.56	9/27/93
24	Not Installed									

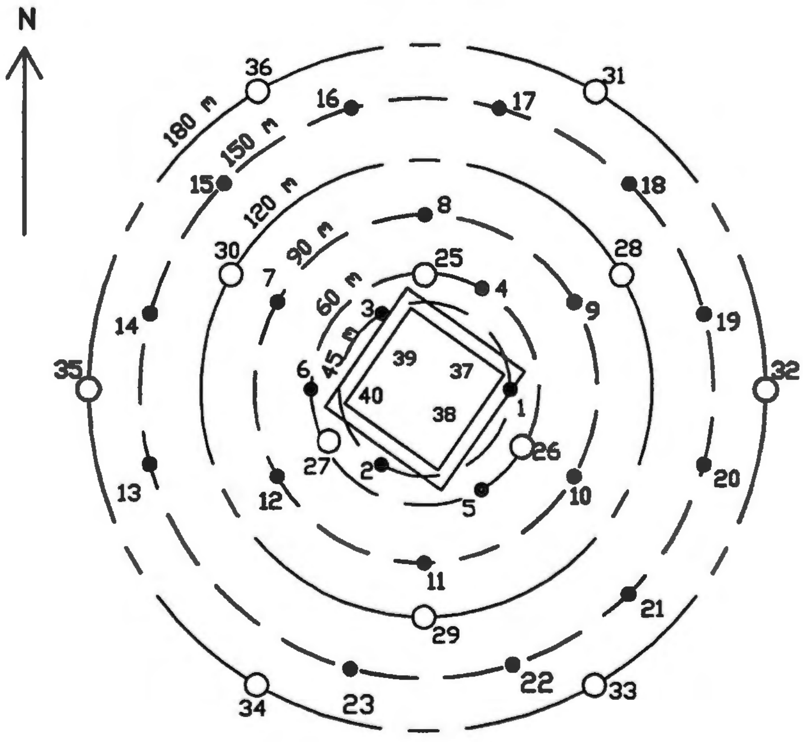

Figure 2.3. Location of sample sites as numbered in Tables 2.1 and 2.2 for the no-till site.

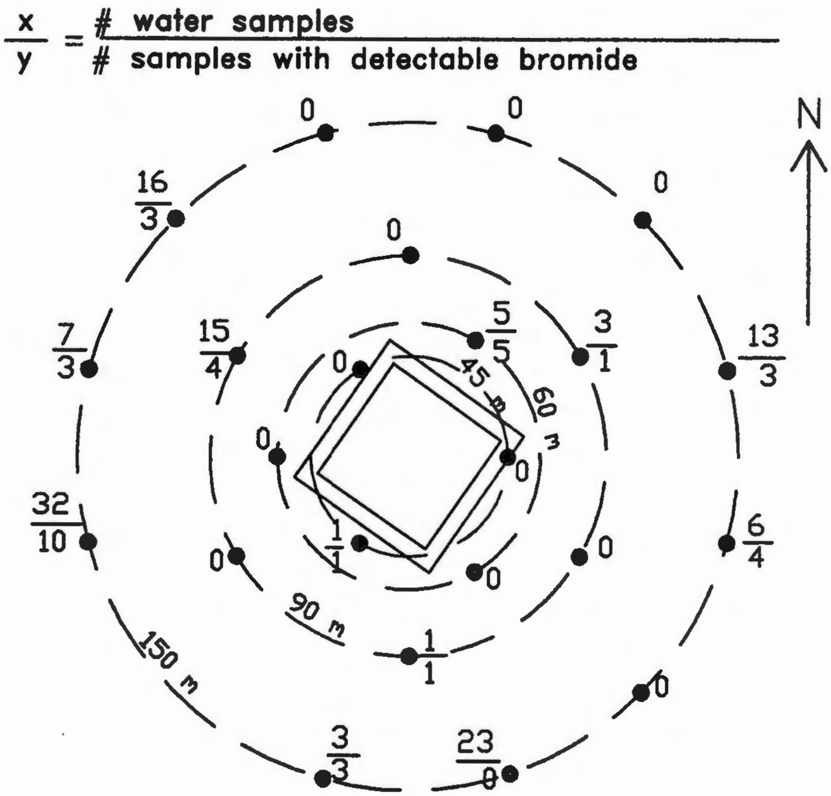

Figure 2.4. The number of water samples and number of samples that yielded bromide from March 9, 1993, to December 13, 1994 at the no-till site.

Questions Raised by the Data

Data were reported to the research team October 10, 1994, and March 6, 1995. Most of the research team's attention was given to the shallow well data. These data raised several questions about subsurface flow at the sites (Rainwater, 1994). What is the best sampling method to determine how and where subsurface water moves? What controls the movement of water and bromide at the loess-paleosol interface? What is the topography of the interface and how does it differ from surface topography? Can data be collected to produce a hydrograph of the perched water? Despite the closely spaced and carefully designed sampling layout, the researchers could not definitively describe how and where subsurface water moves on these two sites.

Conclusions and Recommendations of the Researchers

After considering the data, it was evident that a finer spatial resolution was needed for shallow well placement and that a thorough knowledge and understanding of the soil morphology of a site is crucial to determining the best location for shallow wells. The consensus of the research team was to concentrate resources on the no-tillage site. The team recommended installing more shallow wells between shallow well 3, shallow well 6, and shallow well 8. The research team also agreed that automatic sampling may give better data and should be considered for the proposed shallow wells (Rainwater, 1994). After consulting with statistician Dr. W. L. Sanders (Yoder, 1995), the layout shown in Figure 2.5 was used to install 17 new shallow wells in March 1995, to more accurately characterize subsurface hydrology and the loess-paleosol interface.

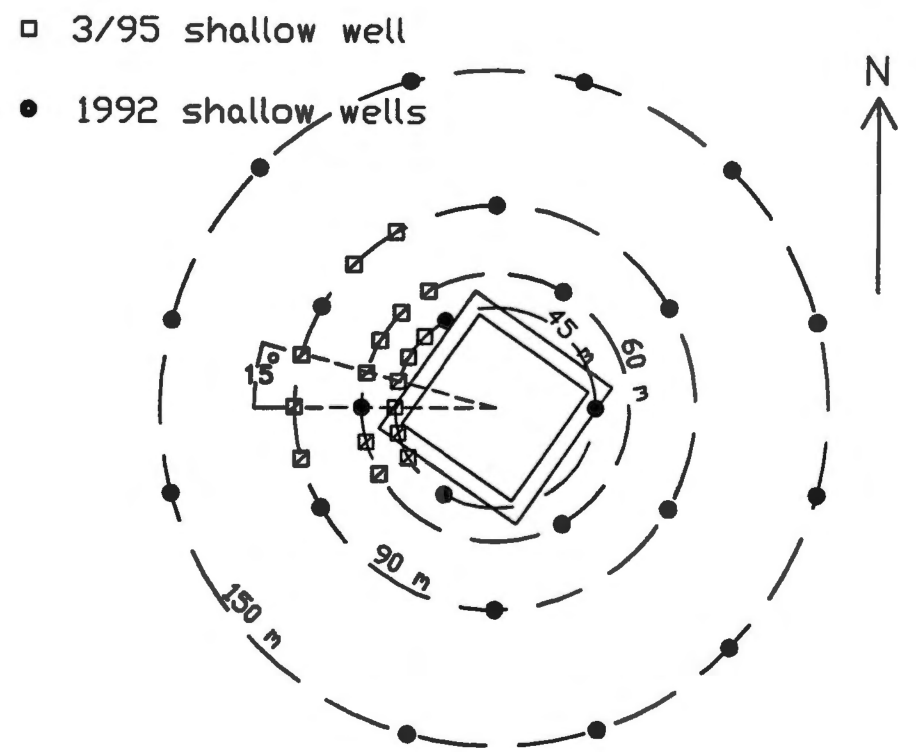

Figure 2.5. Location of shallow wells installed in March 1995 at the no-till site.

Objectives

The project reported in this thesis focuses on the additional shallow wells and on answering the questions raised by the initial data of the Ames Plantation Water Quality Project. With these questions in mind, an automatic shallow well sampling system was designed and implemented with the following objectives: (1) automatically sample water from 21 shallow wells as it is collected in the well casing, (2) provide the capability to record the time the sample is taken, and (3) provide in situ collection devices insulated from the weather. The 21 wells included the 17 shallow wells installed in March 1995, and 4 of the existing shallow wells located in the same area (Figure 1.5). The time data may provide enough information to generate a hydrograph of the perched water and will provide data on the time of arrival if a new tracer is applied. Also, soil core data from the new shallow wells will be used to improve the spatial resolution of the loess-paleosol interface plot.

CHAPTER 3

REVIEW OF THE LITERATURE

Vadose Zone Monitoring

The fate of agricultural chemicals has become a major concern of research since the late 1970's and early 1980's due to traces of agricultural chemicals being found in ground water samples and drinking water wells across the nation (Behl and Eiden, 1991; Jones and Norris, 1991; Staver and Brinsfield, 1991). Since 1980, extensive ground water monitoring research has been conducted (Behl and Eiden, 1991; Jones and Norris, 1991; Staver and Brinsfield, 1991). The federal government has also mandated the monitoring of ground water near waste facilities and other industries which could threaten ground water quality (Guerra, 1992).

Most of the reported research has been primarily concerned with the vertical movement of water and contaminates toward the underlying aquifer and the resulting concentrations of contaminants in the aquifer (e.g., Wietersen et al., 1993; Bottcher et al., 1990; Jones et al., 1990; Asmussen and Smith, 1991; Behl and Eiden, 1991; Graham and Downey, 1992). Little attention has been given to monitoring the movement of water and pollutants in the vadose zone above the aquifer:

> At present, the primary concern with regard to the leaching of nitrate, as well as other potential groundwater pollutants used in agricultural systems, is not the rate of leaching but the resulting concentration of that pollutant in groundwater.
>
> ....
>
> As a result, groundwater concentration studies generally rely heavily on groundwater concentration data, with little consideration given to vadose zone parameters.
>
> ....
>
> Groundwater solute concentration data alone will provide little information on rates of agrochemical leaching associated with specific land use practices (Staver and Brinsfield, 1991).

The concept of vadose zone monitoring as a ground water contaminate prevention strategy began developing about 20 years ago (Cullen et al., 1995). The vadose zone extends from the soil surface to the upper surface of the principal water-bearing formation (Wilson, 1980). The term vadose zone is preferable to the term unsaturated zone because saturated regions are frequently present in some vadose zones. Researchers have divided the vadose zone into three regions designated as the soil or root zone, the intermediate vadose zone (IVZ), and the capillary fringe (Davis and deWiest, 1966; Staver and Brinsfield, 1991).

Unsaturated pore-liquid flow in the vadose zone is controlled primarily by negative pore-liquid pressure gradients, referred to as pore-liquid tension or matric potential. Saturated, or near saturated, flow occurs primarily under the influence of gravity, referred to as free drainage (Dorrance et al., 1991). In situ samplers extract liquid from saturated and unsaturated zones. Samplers designed for sampling in saturated zones cannot be used in unsaturated conditions. This is because the negative pore-liquid pressure in unsaturated zones prevent free-drainage into an air-filled cavity at atmospheric pressure. The openings in saturated samplers are too large to prevent air from entering when suction is applied. Most samplers designed to sample from unsaturated soils also sample from saturated soils (Dorrance et al., 1991). Using this distinction, Dorrance et al. (1991), have categorized pore-liquid samplers as follows:

- suction samplers (unsaturated/saturated sampling)
    - vacuum lysimeters
    - pressure-vacuum lysimeters
    - filter tip samplers
    - experimental suction samplers
    - cellulose-acetate, hollow fiber samplers
    - membrane filter samplers
    - barrel lysimeters
    - vacuum plate samplers
- experimental absorption samplers (unsaturated/saturated sampling)
    - sponge samplers
    - ceramic rod samplers
- free drainage samplers (saturated sampling)
    - pan lysimeters
    - glass block lysimeters
    - caisson lysimeters

wicking soil pore-liquid samplers
trough lysimeters
vacuum trough lysimeters
sand filled funnel samplers

- perched ground water samplers (saturated sampling)
    - point samplers
    - wells
    - cascading water samplers
    - drainage samplers

Vadose zone samplers and their respective advantages and disadvantages, have been reported in the literature and the interested reader is referred to those sources for more information (e.g., Dorrance et al., 1991; Wilson, 1980, 1981, 1982, 1983; Angle et al., 1991; Everett et al., 1984; Peters and Healy, 1988; Fausey et al., 1992).

A stronger interest in IVZ sampling began appearing in the literature around 1980 as concerns about ground water pollution were increasing. L. G. Wilson, an early proponent of improved vadose zone sampling, authored or coauthored several articles about methods and objectives of vadose zone sampling (e.g., Wilson, 1980, 1981, 1982, 1983, 1990; Everett et al., 1984). In his report for the EPA, Wilson (1980), stated that,

> In contrast to the advanced state of the art for sampling from the zone at saturation, vadose zone monitoring is still in its infancy. The discrepancy in technology in part reflects the greater complexity of flow in the vadose zone, compared to saturated zone flow, and the associated problem of obtaining a representative water sample for analysis. The lack of a comprehensive methodology for vadose zone monitoring is a serious impediment to federal and state personnel charged with promulgating or enforcing monitoring regulations for best management practices in agriculture, for hazardous waste disposal programs, and for 208 programs.

Research in vadose zone hydrology increased into the 1990s. However, much of the research was limited to agricultural sciences primarily interested in the root zone, to bench scale or small plot studies, and to hazardous waste land treatment sites (e.g., Lowery et al., 1982; Wietersen et al., 1993; Blume et al., 1987; Unruh et al., 1990; Nielsen et al., 1990).

A more interdisciplinary interest in vadose zone hydrology began to take hold around 1990. Increasing concern about contaminants in ground water along with the difficulty in quantifying and predicting their transformations and movement, has recently led to several symposia on the vadose zone (Starr et al., 1991). Other researchers indicated increasing concern about understanding ground water movement and solute transport in the vadose zone (e.g., Herrman and Eyrich, 1990; Nash et al., 1991; Unruh et al., 1990; Nielsen et al., 1990).

Monitoring Perched Water in the Vadose Zone

One phenomena of vadose zone hydrology that is gaining more attention is perched water. The horizontal permeability of the vadose zone is often greater than the vertical permeability, especially in layered soils. "Consequently, the presence of flow-impeding layers in the vadose zone, such as clay lenses, causes water to flow preferentially in the horizontal direction within the material above the impeding layer" (Wilson, 1982). Vertical percolation rates are decreased and the resultant saturated water body is called perched ground water. Dorrance et al. (1991), recommend sampling perched water:

> Sampling perched liquid is attractive because the perching layer collects liquid over a large area. Such integrated samples are more representative of areal conditions than suction samples [Wilson and Schmidt, 1978]. This also allows the sampler to potentially detect contaminants which may not be moving downward immediately adjacent to the sampler. In addition, larger sample volumes can be collected than those which can be obtained by suction samplers.

Techniques for sampling shallow, perched water include tile line outflow samplers, open-ditch water samplers, piezometers, wells, multi-level samplers, ground water profile samplers, collection pans, manifolds, and air-lift samples (Wilson, 1983).

Some researchers recognize the significance of lateral flow in a perched water table. However, little research has been done concerning the extent of lateral flow in layered soils (e.g., Nash et al., 1991; Staver and Brinsfield, 1991; Starr et al., 1991). Accounting for lateral flow in the vadose zone is critical when attempting to relate a specific land use to ground water quality data (Staver and Brinsfield, 1991). Sampling the vadose zone is required to quantify and predict the rate of reaction, transformation, and movement of chemicals downward to ground water, and laterally along inclined textural layers and in phreatic layers to drainage ditches, streams, etc. (Starr et al., 1991). Perching layers intercepting downward moving water may transmit water laterally at substantial rates (Everett and Wilson, 1984). Vadose zone water can build up to saturation on top of an impermeable zone and flow under a lateral component of gravity for a long distance (Davis 1995).

> The assumption of one dimensional (vertical) flow becomes questionable and perhaps invalid in the case of a soil profile with distinct impeding layers, over which temporary perched water table conditions can develop, leading to subsurface lateral flows beyond the boundaries of the test plot (Hillel, 1982).

Hillel's statement partially explains the lack of research on the extent of lateral flow in layered soils - it requires large test plots.

A review of the literature suggests that research studying lateral movement in the vadose zone usually consists of small test sites with significant slopes. Chappell et al. (1990) reported how riparian areas along forest streams may be rapidly recharged during storm events by lateral flow in perched water tables developed in steep hillslopes by the streams. Their method of tracing the origin of the stream recharge water was by comparison of the ionic concentration of water within each component of the hydrologic system.

Lowery et al. (1982) reported the effects of perched water tables and subsurface drains on overland flow from sloping land. Their largest test site was a 1.4-ha subwatershed with a 5% slope located in Polk County, Oregon. Their monitoring system included piezometers equipped with float type stage indicators, tensiometers, H-flumes, ISCO flow meter, 90° V-notch weir, and rain gauges.

Blume et al. (1987) researched the influence of plinthite, an Fe-rich, humus poor material, that hardens irreversibly upon repeated wetting and drying, on subsurface water movement. Plinthite occurs in some coastal plain soils at depths of 1 to 1.5 m and is a suggested cause of reduction in vertical hydraulic conductivity. Their test site was less than 0.1 ha on a 4.4% slope. Potassium bromide (KBr) was placed at depths between 0.10 and 0.43 m and 0.60 and 1.02 m. Bromide content of water from piezometers at distances up to 60 m downslope was determined at specific intervals during periods of perched water. Data indicated that subsurface flow downslope occurred primarily above and within the plinthic horizon during periods when a perched water table was present; and that bromide moved slowly through the plinthic layer, was intercepted by subsurface layers of high density, and was retained in the watershed until removed by lateral flow. Their monitoring scheme included sampling water from piezometers and suction lysimeters at specific time intervals and collecting soil samples from the horizon.

Parlange et al. (1989) researched the flow of water in a shallow hillslope layer over a fragipan that has a network of cracks under the surface layer. The test plot was located on the Mt. Pleasant research farm of Cornell University, Ithaca, New York. The study area was roughly 700 m^2 with a 15% slope. The average depth of the layer above the fragipan was 0.50 m. Their monitoring scheme consisted of subsurface drainage pipe, tensiometers, a hand-held pressure transducer to measure the soil-water potential via a hypodermic needle, neutron probe, sprinkler system, and rain gages. Daily pan evaporation and solar radiance data were also collected. They found that the cracks within the fragipan carried a significant portion of the interflow and that the crack network may conduct most of the flow downhill.

Kramer and Keller (1995) reported research on the geologic framework of the vadose zone and its effect on storage and transmission of fluids:

> Changes in the depositional environment of sedimentary rocks may produce permeability contrasts that affect flow, with flow preferentially directed along sandier units... This effect has been observed in a number of different types of sedimentary deposits, including alluvium, marine sedimentary rocks, continental fanglomerates, and deltaic clays.

These researchers stressed the importance of geologic characterization of a site to properly design a monitoring scheme. "Proper identification of preferred flow paths allows placement of monitoring equipment in appropriate locations to detect potential contaminant flow." Their research included a pilot study for a soil flushing remediation project. The geologic material was flat-lying, fine-grained alluvial material, predominantly silty clays and clayey silts interbedded with silty sands. Neutron probe monitoring showed preferential flow through sandy layers overlying clay-rich layers. Kramer

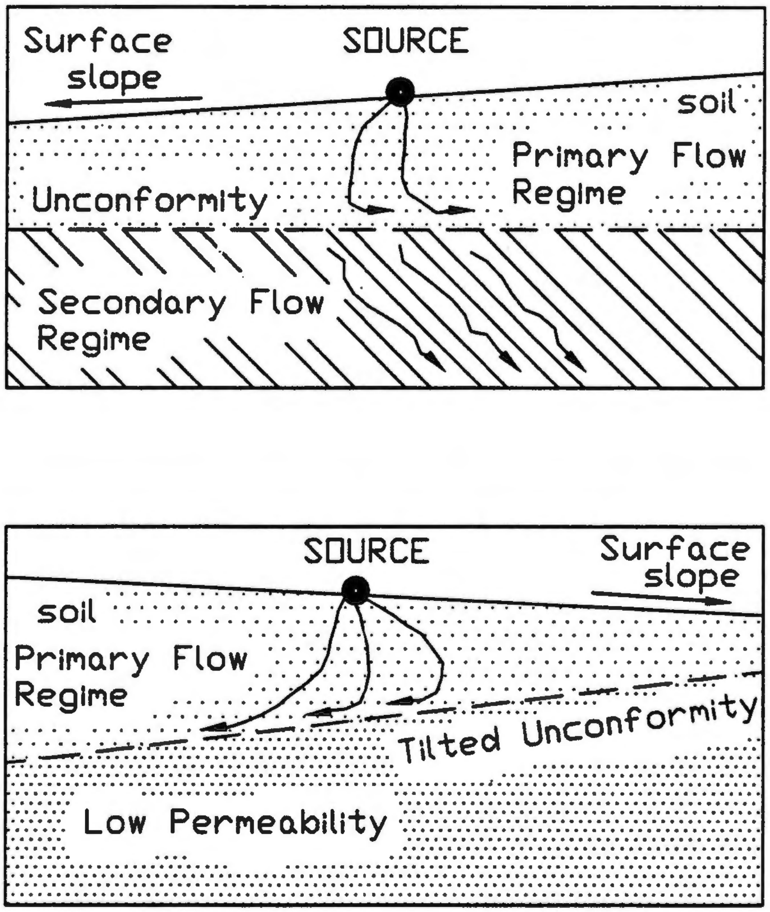

Figure 3.1. Potential effects unconformities have on vadose zone flow pathways. Adapted from Kramer, J. H. and B. Keller (1995). Understanding the geologic framework of the vadose zone and its effect on storage and transmission of fluids. Handbook of Vadose Zone Characterization & Monitoring, ed. L. G. Wilson, Lorne G. Everett, and Stephen J. Cullen. Ann Arbor: Lewis Publishers. p. 150.

and Keller (1995), concluded that monitoring stations designed to intersect contaminated liquids escaping this site should be placed in sandy layers immediately above clay-rich layers. Figure 3.1 illustrates potential effects of unconformities on vadose zone flow pathways.

Schmidt (1995) reported on monitoring and sampling perched water in arid lands. However, the perched water tables he reported are unconfined aquifers that can be pumped at rates of 100 gpm. Schmidt recommended sampling methods of air lifting, bailing, hand-pumping, and submersible pumping.

All the previously mentioned researchers used standard methods of sample extraction. Vadose zone water samples were extracted at specific time intervals by vacuum, pump, air lift, or tile drains. Lowery et al. (1982), used some automated equipment such as piezometers equipped with recording float type stage indicators, and an ISCO flow meter to sample tile drain effluent. A few researchers are reporting automation of vadose zone monitoring and more efficient methods of sampling from the vadose zone. These developments are motivated by a need for better data and more efficient use of field personnel

Emerging Technologies of Vadose Zone Monitoring

Sample Extraction Technology

Wilson (1983) suggested using automatic composite or discrete samplers, for sampling perched ground water collected with tile lines or open ditches. The tile lines must be placed at the interface of soil layers to collect perched water. This method requires much more disturbance of the soil than do shallow wells.

Stites (1993), reported a portable hand powered apparatus that is easily and inexpensively built and results in efficient sampling of vadose zone water. It consists of a l-liter per stroke hand vacuum pump and a unit that holds a 125-ml polyethylene storage bottle. The sample bottle unit is attached between the piezometer and vacuum pump. The water sample is pulled directly into the sample bottle and the design allows the bottle to overflow into a larger container without spilling onto the ground or reaching the vacuum pump. The apparatus did result in some cross contamination.

Welch et al. (1994) developed an innovative method of sampling aquifers that could be adapted to some perched water tables. Their objective was to sample for hazardous contaminants without risking contamination of the wellbore and to protect the sample from wellbore fluids. The system uses a subsurface-activated isolation device that is permanently installed as a part of a borehole completion. Suspect ground water sources are sampled by running a multi-function electromechanical tool on an electric line into the isolation device. A sequence of events initiated from the surface results in a sample being captured within the isolation device. The sample is brought to the surface and transported in a safe, pressurized container to a laboratory for analysis .

Non-Invasive and Minimally-Invasive Technology

Grinsven et al. (1988) reported a device for automated in situ measurement of unsaturated soil water flux. "Operation is controlled by a microprocessor which automatically adjusts the vacuum imposed on a porous filter cloth such that identical matric potentials are maintained just above the cloth and at the same depth in the neighboring soil." The matric potential difference, and the total amount of collected water were measured continuously by means of a Hewlett Packard-75 computer/Hewlett Packard-3421A datalogger combination. The device was field and laboratory tested in a loamy sand under steady and transient flow conditions. Grinsven et al. (1988) reported that cumulative water fluxes could be measured within 10% of values calculated from storage changes and from numerical and analytical flow models.

Atteia and Dubois (1993) developed a device for automatically measuring matric potential. The device consists of an inductive sensor that runs up and down the tensiometer's tubing; and an endless screw and stepping motor connected to a datalogger. The vertical movement of the sensor is precisely controlled by the stepping motor and screw. The height of the Hg meniscus is sensed by the inductive sensor. The datalogger counts the time from the motor's starting until each sensor signal vanishes. The time is translated into vertical distance. Atteia and Dubois (1993) reported that the device is not cost prohibitive, is impervious to weather conditions, and has low power requirements.

Unruh et al. (1990), studied vadose zone monitoring by fast neutron thermalization (FNT). This method has has been commonly used at solid waste landfills (e.g., Parlange et al., 1989; Kramer et al., 1995). The method uses a radioactive source to emit fast neutrons into the vadose zone. The emitted neutrons collide with particle matter and are slowed down, or thermalized, to their natural state. The greatest amount of thermalization occurs when neutrons collide with hydrogen atoms. The thermalized neutrons are detected at the receiver located above the source. The count of thermalized neutrons allows a qualitative measurement of the moisture present in soils (Unruh et al., 1990). The method detects moisture location but does not extract a water sample. Using radioactive sensing is regulated and requires licensing. The monitoring system must be securely protected and has liability risks associated with it.

Freeland (1996), has evaluated ground penetrating radar (GPR) for nondestructive soil moisture reconnaissance within loess soils. Soil samples were obtained using a truck mounted core drill. The soil's physical properties were used for interpretation of the radar surveys at the test site. A 300-MHZ antenna was used to send bursts of energy into the soil. These pulses travel through the soil until they strike a layer where the relative dielectric constant (σ) changes. The dielectric constant is a measure of a material's ability to store an electrical charge. Dry soil has a σ ranging between 2 and 6, the σ of water is 81, and the σ of air is 0. Moisture within the soil is the primary factor affecting a layer's σ (Hamlett, 1996). Freeland (1996) used the GPR to locate interfaces of minimum and maximum moisture content at the Ames Plantation Water Quality Project in West Tennessee. "The technology shows promise in mapping the depth to the loess-paleosol interface" (Freeland, 1996).

Need For New Technologies

A review of the literature shows that our conceptual knowledge of the vadose zone exceeds our technological ability to measure vadose zone phenomena. The need for technological advances in vadose zone monitoring is well stated by Cullen et al. (1995):

> Because the demand for vadose zone monitoring equipment remains relatively low, the economic incentive to research, develop, and bring new products to the market also remains low. Thus, the innovative new instrumentation required to develop tomorrow's sophisticated vadose zone monitoring networks is not being brought to the marketplace fast enough. For example, there is a need to reduce monitoring network space and time gaps to detect small or short-lived contaminant transport events.

Much of the current effort in new vadose zone monitoring technologies is focused on developing tools used to generate data and information in near-real time (e.g., chemical sensors, miniaturized or field portable laboratory instrumentation, noninvasive characterization techniques, minimally-invasive techniques, and data and information management tools). "Effective, rapid, onsite data acquisition, data management and evaluation with capabilities for onsite, real-time visualization of the data could significantly improve overall decision-making and reduce the associated costs and schedule requirements" (Koglin et al., 1995).

Present Challenges for Vadose Zone Monitoring

The most critical element in a sampling system is the capability to accurately describe the distribution and movement of water in the vadose zone (Staver and Brinsfield, 1991). Sampling perched water is an important part of a good vadose zone sampling system. Perched ground water is an opportunity to obtain larger samples of vadose zone fluids than is possible with suction cup samplers (Wilson, 1983). However, there are limitations to sampling perched ground water. Perched zones do not occur everywhere and may be ephemeral where they do occur. "Thus, location of successful monitoring wells may in part be a matter of chance" (Wilson, 1983).

New technologies and data are needed to reduce the *chance* of successfully locating vadose zone monitoring wells in layered soils. Ground penetrating radar (Freeland, 1996; Hamlett, 1996) and other developing technologies, show promising possibilities to that end. Data from the 17 newest shallow wells and the automatic sampling system at the Ames Plantation Water Quality Project will assist researchers in predicting optimum locations for monitoring wells to sample perched water. The materials, methods, and results of developing the automatic sampling system will be a step toward improving vadose zone monitoring technology.

CHAPTER 4

MATERIALS AND METHODS

Objectives

This chapter includes the materials and methods for the automatic shallow well sampling system designed and implemented to accomplish the following objectives: (1) automatically sample water from 21 shallow wells as it is collected in the well casing, (2) provide the capability to record the time the sample is taken, and (3) provide in situ collection devices insulated from the weather.

The Automatic Shallow Well Sampling System

Design Criteria

In addition to the objectives, there were several important considerations guiding the selection of materials and methods. Due to the remote location, the sampling system would need to be powered by a 12-V battery or a similar type of portable and rechargeable power source. The sampling system would be serviceable by the field technician without foregoing other job responsibilities. The system would not be cost prohibitive. The system would not be a prototype but continue operation indefinitely. The system would maintain as natural as possible flow conditions.

Shallow Well Installation

Seventeen additional shallow wells were installed March 1995 at the no-tillage site (Figure 2.5). The 3-in. (76-mm) bore holes were cut by Dr. J. T. Ammons and assistants using a Giddings core sampler mounted on a truck bed. The depth of the loess-paleosol interface was identified (Table 4.1), but the soil cores were not characterized. The characteristics of the soil cores were similar to those obtained when installing the original shallow wells (Appendix A). The shallow wells were installed using the same design as the original shallow wells (Figure 2.2). The identification system used with the original shallow wells is continued with the new shallow wells. The identification number specifies the site (no-till or tillage), radius from the center of the test site, and azimuth of each shallow well location (Table 4.2). The identification system also uses a short number for simplification. The numbering system for the shallow wells is given in Table 4.2, Figure 4.1, and Figure 4.2.

Table 4.1. Installation depths used for shallow wells 71 - 87.

Shallow well	Bottom set at:
SW010045240 (71)	255 cm (backfill 15 cm to 240 cm)
SW010045255 (72)	351 cm
SW010045270 (73)	234 cm
SW010045285 (74)	249 cm
SW010045300 (75)	280 cm (backfill 42 cm to 238 cm)
SW010045315 (76)	243 cm
SW010060240 (77)	280 cm
SW010060255 (78)	269 cm (backfill 30 cm to 239 cm)
SW010060285 (79)	262 cm (backfill 24 cm to 238 cm)
SW010060300 (80)	245 cm
SW010045315 (81)	252 cm (baclfill 12 cm to 240 cm)
SW010060330 (82)	243 cm (backfill 10 cm to 233 cm)
SW010090255 (83)	234 cm
SW010090270 (84)	244 cm (backfill 20 cm to 224 cm)
SW010090285 (85)	238 cm
SW010090315 (86)	247 cm
SW010090330 (87)	259 cm (backfill 19 cm to 240 cm)

Table 4.2. Identification system used for the shallow wells. The H in the short number indicates the Hancock field (no-till), it is frequently omitted. The 01 in the identification number indicates the no-till site.

Identification No.	Short No.	Radius (m)	Azimuth
SW010045090	H01	45	90
SW010045210	H02	45	210
SW010045330	H03	45	330
SW010045330	H04	45	330
SW010060030	H05	60	30
SW010060150	H06	60	150
SW010060270	H07	60	270
SW010090300	H08	90	300
SW010090000	H09	90	000
SW010090060	H10	90	60
SW010090120	H11	90	120
SW010090180	H12	90	180
SW010150255	H13	150	255
SW010150285	H14	150	285
SW010150315	H15	150	315
SW010153345	H16	153	345
SW010150015	H17	150	15
SW010153045	H18	153	45
SW010150075	H19	150	75
SW010150105	H20	150	105
SW010150135	H21	150	135
SW010150162	H22	150	162
SW010150195	H23	150	195
SW010150225	H24 (Not Installed)	150	225
SW010045240	H71	45	240
SW010045255	H72	45	255
SW010045270	H73	45	270
SW010045285	H74	45	285
SW010045300	H75	45	300
SW010045315	H76	45	315
SW010060240	H77	60	240
SW010060255	H78	60	255
SW010060285	H79	60	285
SW010060300	H80	60	300
SW010060315	H81	60	315
SW010060330	H82	60	330
SW010090255	H83	90	255
SW010090270	H84	90	270
SW010090285	H85	90	285
SW010090315	H86	90	315
SW010090330	H87	90	330

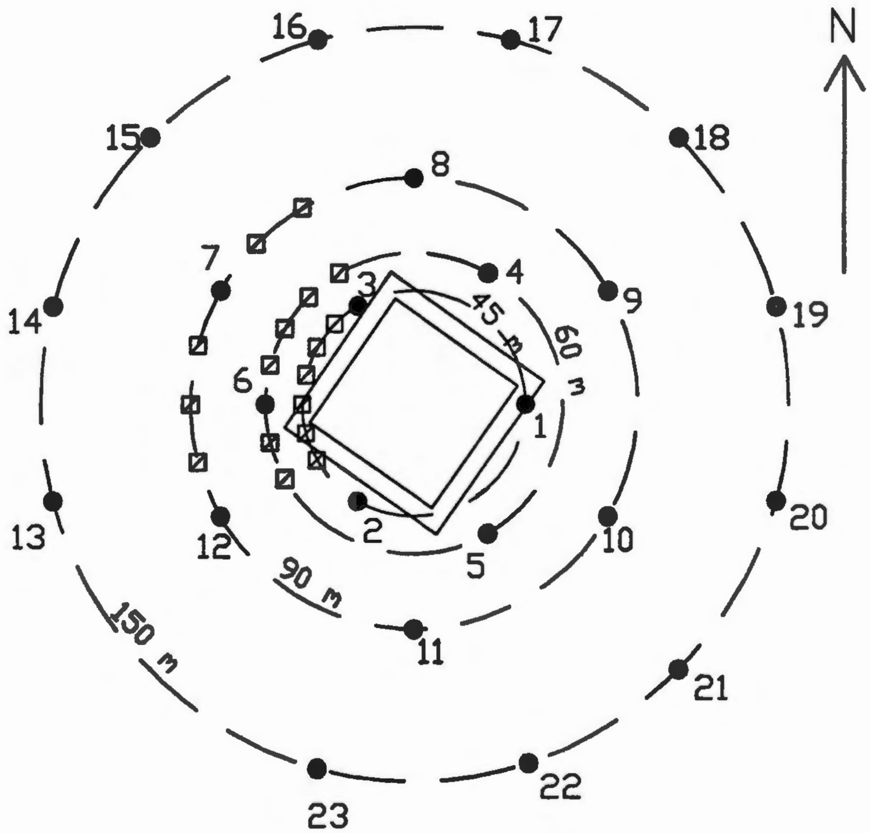

Figure 4.1. Shallow well numbers as identified in Table 4.2. See Figure 4.2 for shallow wells 71 - 87.

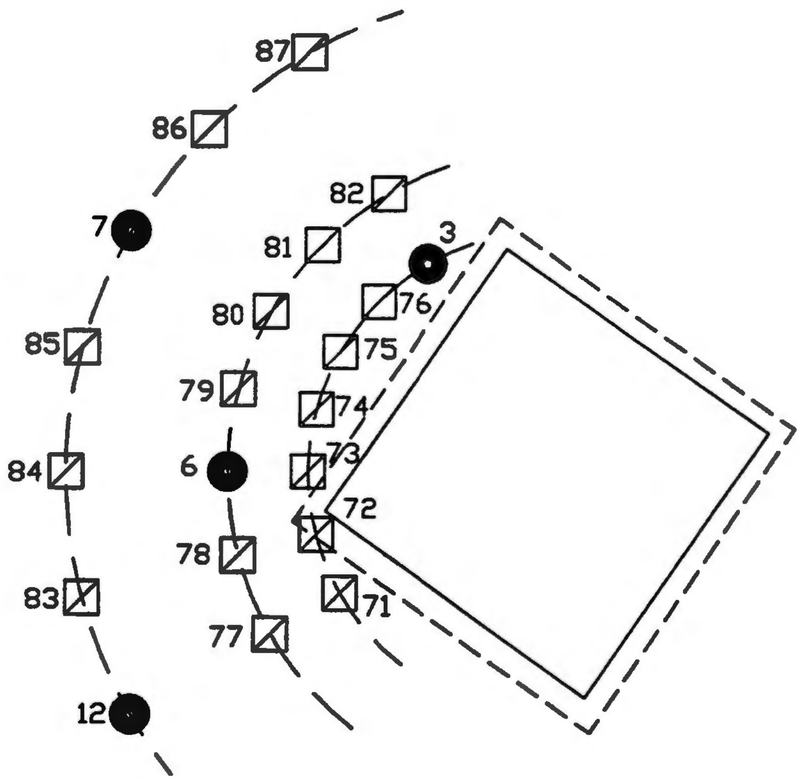

Figure 4.2. Shallow wells installed March 1995 and original wells included in the automatic sampling system.

The original shallow well design collects perched water samples of 0.5 L in the casing below the screen. The 17 additional shallow wells and four original shallow wells included in the automatic sampling system are modified to collect approximately 0.1 L of perched water below the screen. This is to prevent an unnatural flow condition caused by a cone of depression and drawdown of the perched water table. A device was constructed by the Agricultural Engineering Shop Personnel using a 1.5-in. (38-mm) test plug (Oatey No. 33420)[1], that decreased the depth of the casing below the screen from 0.4 m to 0.1 m (Figure 4.3). This device was placed inside the casing of each shallow well in the sampling system. A 10-ft (3-m) tool was constructed to install the devices. Several of the devices were installed in PVC pipe in the lab to test for leaks and to determine the torque required for a water tight installation. Two of the devices were placed in distilled water for several days and the water was tested in the laboratory for contaminants. Analysis determined that the components of the device will not compromise the integrity of the water samples collected from the shallow wells (Roy, 1995).

Electronic Components

Several miniature 12-V pumps were considered for providing the vacuum required to lift the sample out of the well casing into a container. An automobile windshield washer pump and a miniature gear pump were tested in the laboratory for possible use. The windshield washer pump was self priming up to approximately 0.45 m. The gear pump was self priming up to approximately 2.13 m. The depths of the original shallow wells range from 1.93 m to 2.76 m. Neither of the pumps will fit inside a 1.5-in. (38-mm) PVC well casing.

Peristaltic pumps, submersible bilge pumps, and marine and camper pumps were also considered. Each pump presented at least one of four problems for use in the automatic sampling system: (1) self-priming height, (2) power requirements, (3) size, or (4) cost.

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1 The use of brand names in this report does not imply endorsement of these products by The University of Tennessee. The inclusion of manufacturer's names and product models is for clarification.

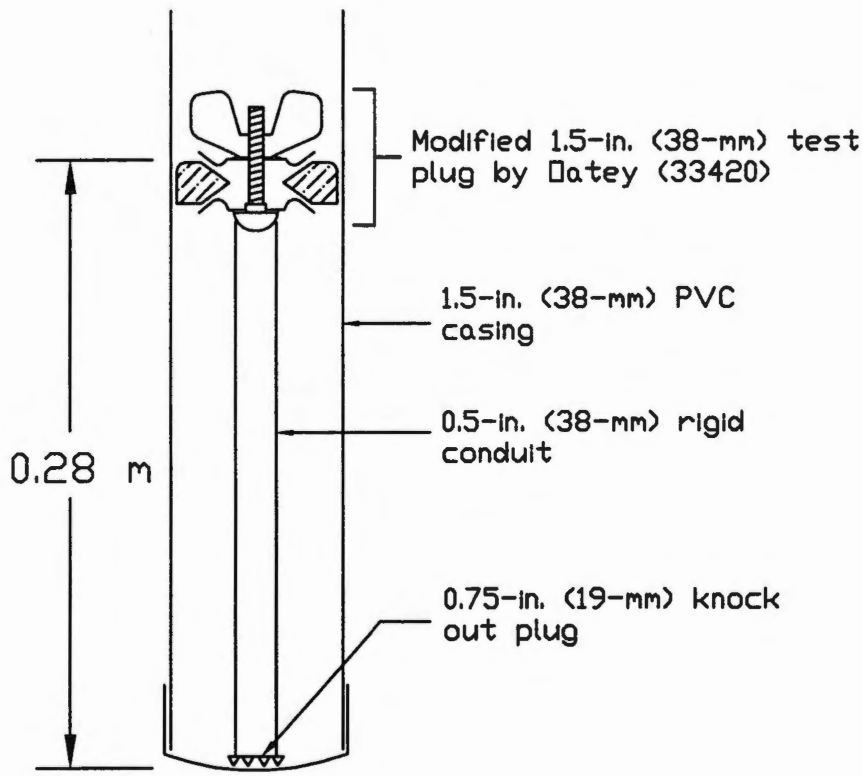


Figure 4.3. Cross section of device used to reduce volume of sample collected in the shallow well casing.

Technical data on various pumps, solar panels, and solar radiation for West Tennessee are included in Appendix B1, B2, and Table B1.

An alternative design was considered that used vacuum extraction. The design required a vacuum source, a liquid level switch in the well, a flow sensor to indicate when sampling was completed, a sample collection jug, a datalogger/controller, and a solenoid valve to control the vacuum applied to the sample (Figure 4.4). A test model of the automatic sampler was constructed in the laboratory in November 1994 to determine the optimum materials and methods. After thorough testing, described throughout this chapter and in Appendix C, this basic design was used for the sampling system.

The liquid level switch is activated when the float is lifted approximately 19 mm by water entering the shallow well casing. The activated liquid level switch sends an input signal to an input port of the datalogger/controller which opens the solenoid valve by setting an output port high. The vacuum source pulls the sample from the well into a sample collection jug. A flow sensor between the well and sample jug sends an input signal to an input port of the datalogger/controller to signal when the sampling is complete. When the water is completely sampled, the solenoid valve is closed.

Liquid Level Switch

A liquid level float switch by Omega Engineering Inc. (LV60), is installed in the shallow wells to signal when approximately 0.1 liters of water are in the well. Technical information on the liquid level switch is included in Appendix B3. The level switch is mounted on the end of ½-in. (13-mm) CPVC pipe using a 1/4-in. X 1/8-in. (6.3-mm X 3.2-mm) brass reducer bushing (Figure 4.5). The level switch is set to close when the depth of water in the shallow well reaches approximately 0.1 m (0.1 liters). Stainless steel tubing, 1/4-in. (6.3-mm) outside diameter, is mounted to the CPVC pipe using two small hose clamps. The hose clamp adjusting screws and stainless steel tubing are arranged around the perimeter of the CPVC pipe

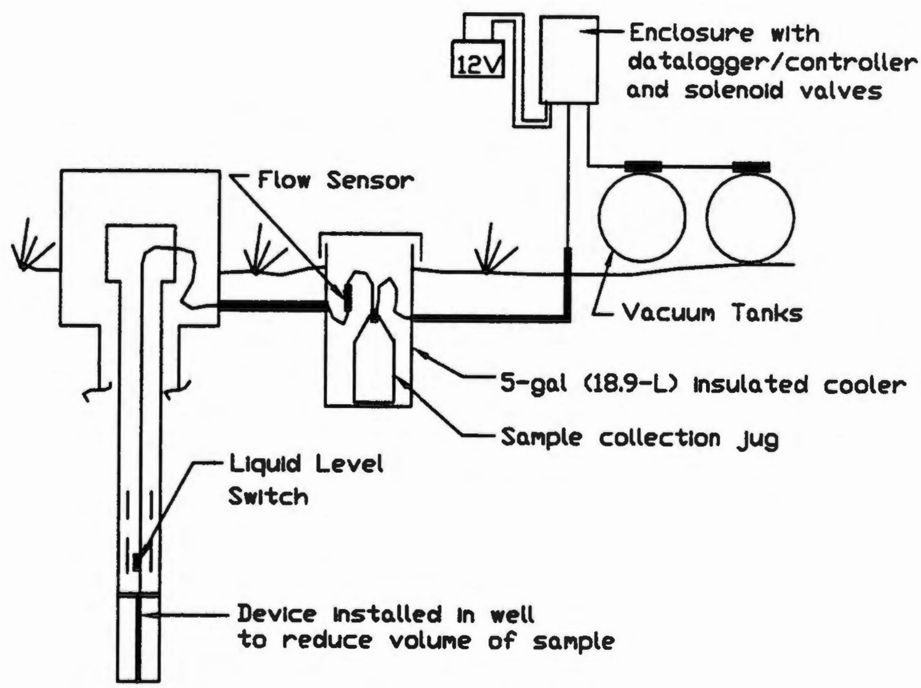


Figure 4.4. The initial design used for the automatic shallow well sampling system.

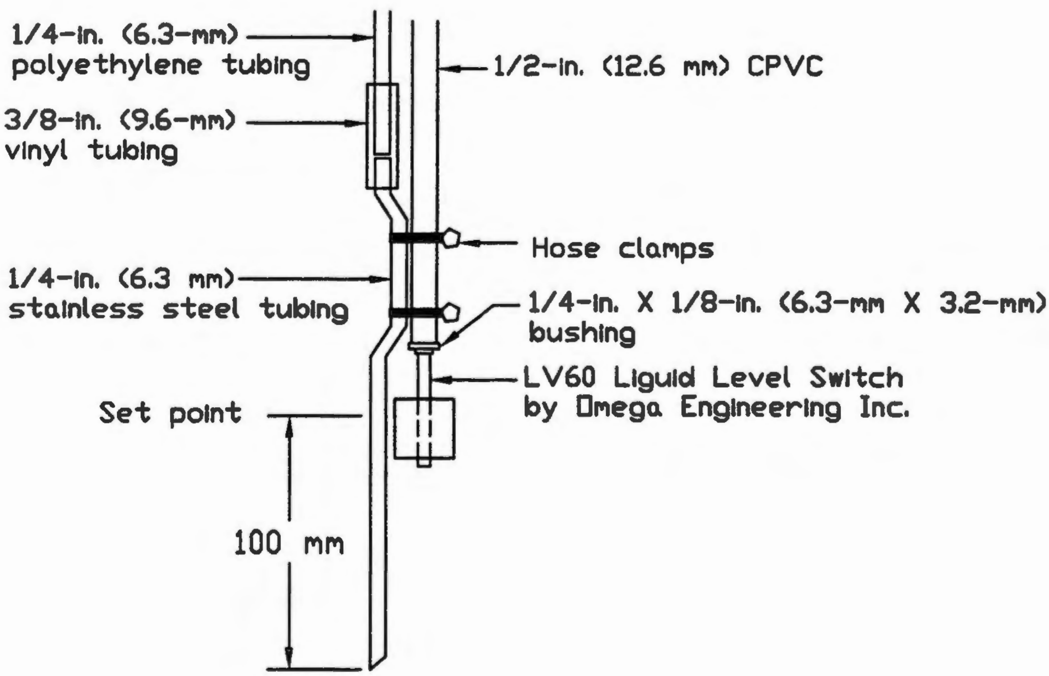


Figure 4.5. The liquid level float switch apparatus used to activate sampling.

to prevent the level switch from rubbing on the inside of the well casing. An additional sensor is needed to signal when the water is completely removed from the well and collected in a sample container. This is accomplished using a flow sensor.

Flow Sensor

The first flow sensor tested in the laboratory was a miniature vacuum switch by Whitman Controls Corporation (P117V). Technical data for this vacuum switch is given in Appendix B4. The theoretical basis for using a vacuum switch was that the switch would close when water was being pulled by vacuum into the tubing and open when all of the water was sampled. The vacuum switch was tested in the laboratory, using the prototype sampling system constructed for testing materials and methods, to determine the optimum set point adjustment. The prototype extracted samples through 1/4-in. (6.35-mm) polyethylene tubing against 3 m of suction head. The vacuum switch and height of water in the vacuum tubing were simultaneously monitored while pulling several samples of water. A set point had to be found that was between the vacuum of pulling water a vertical distance of approximately 1.9 m to 2.8 m and the vacuum of pulling air through the same 1/4-in. (6.35-mm) tubing. By trial and error a set point was found that closed the switch at approximately 2.3 m of water and opened immediately after the water was completely sampled. When the set point was adjusted to close at approximately 1.2 m of water, it would not open after the water was sampled until the tank vacuum was very low. The difference in these two set points was approximately 5 degrees in the adjusting ring. Using a larger tubing to reduce the vacuum resulting from pulling air through the tubing was considered. However, tubing larger than 1/4 in. (6.3 mm) resulted in turbulent flow and poor purging of the tubing. The set point repeatability of the vacuum switch is +/- 30 mm of Hg or +/- 412 mm of H_2O. Using this type of vacuum switch with the automatic sampling system would have required trial and error adjustment of the set point for each of the 21 shallow wells. Due to the repeatability data, varying environmental conditions, and poor resolution of the adjusting mechanism, an alternative flow sensor was considered.

Technical data was ordered from Micro Pneumatic Logic Incorporated on the series MPL-500 vacuum and pressure sensors (Appendix B4). The actuation tolerance of the set point for this application of the vacuum switch is +/- 10%. It is likely that this vacuum switch would present the same potential problems as the Whitman Controls vacuum switch.

An alternative design was considered that used an infrared emitting diode and phototransistor mounted in opposite sides of a section of thick wall vinyl or Tygon tubing (Figure 4.6). As forward current is applied to a diode, energy builds up in the diode. Light emitting diodes (LED), are designed to emit this energy in the form of light. Infrared emitting diodes (IED), emit light in the infrared range of 0.70 μm to 1000 μm which are longer wavelengths than visible light. The forward resistance of the phototransistor is reduced when light energy contacts the base of the transistor. Infrared light is used in this application instead of a (LED) because a narrow width of water in the flow sensor can disrupt the infrared wavelength but not wavelengths in the visible range. The resistor R_1 (Figure 4.6), reduces the forward current in the IED thereby reducing the emitted light energy. As R_2 increases, the amount of energy required to reduce the forward resistance of the phototransistor increases. Thus, optimum sizes of R_1 and R_2 can be found that will allow this design to be used as a flow sensor in this application. An SK 4937 IED and an SK 10325 NPN phototransistor were used in the initial prototype and in the flow sensors installed in the automatic sampling system. Technical specifications for the IED and the phototransistor are included in Appendix C1.

A prototype was fabricated and used to perform laboratory tests to determine the optimum size resistors for the flow sensor. Calculations were made to determine possible resistor sizes to begin laboratory testing with (Appendix C1). A volt meter was used to measure V_{out} with various sizes of R_1 and R_2 before pulling water through the flow sensor, while water was

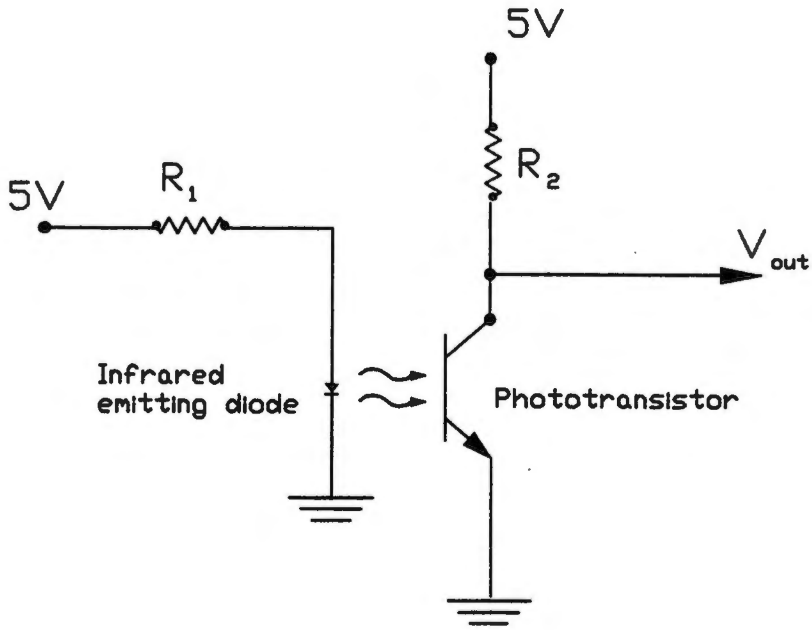


Figure 4.6. Sensor design used to sense flow in the sampling tube.

flowing through the flow sensor, and while purging the line with air after pulling the sample. Results of laboratory testing of the flow sensor (Appendix C1) indicated that an optimum combination of resistor sizes is R_1 = 1 KΩ and R_2 = 10 KΩ.

Flow sensors were assembled using thick wall norprene tubing, 150 mm in length, 4 mm inside diameter, and 14 mm outside diameter. The thick wall provides secure placement of the SK 4937 diode and SK 10325 phototransistor. The transistor and diode were sealed to the tubing by applying polyurethane caulk around the perimeter of the tubing. The flow sensors were plugged at each end and dipped in "plasti-grip" to provide a rubber coating.

Each flow sensor was tested using a voltage meter and a TTL logic probe to determine V_{out} with water flowing in the tube and with no water in the tube. Several of the flow sensors did not have adequate values of V_{out} for a microprocessor controller to read as high and low with TTL logic. With V_{in} = 5 V, V_{out} with water flowing must be more than 3 V; V_{out} with no water flowing must be less than 2 V. The inadequate values of V_{out} were apparently caused by improper alignment of the diode and phototransistor. If the phototransistor only receives a portion of the emitted light, the resistance required to adjust the signal will be less than if the diode and phototransistor are properly aligned. Each flow sensor was tested individually to determine the optimum resistor size to add in parallel with R_2 to reduce the resistance in that part of the circuit (Figure 4.7). Laboratory tests indicated that the optimum size resistance for R_3 was different for different flow sensors. Defective flow sensors required an R_3 of 22KΩ, 10KΩ, or 4.7KΩ.

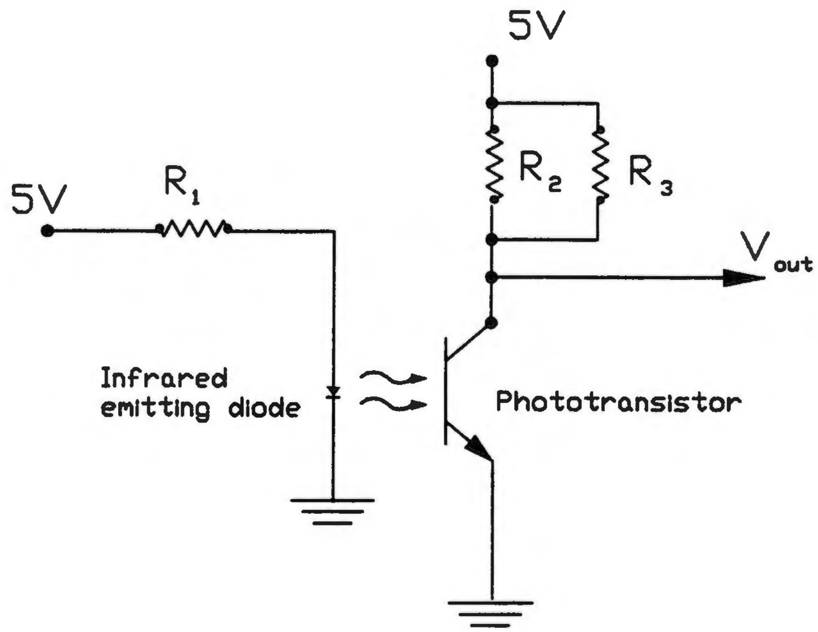


Figure 4.7. Modification used to repair defective flow sensors

Solenoid Valve

Isonic control valves by Mead Fluid Dynamics, Inc. are used to control the vacuum applied to the sample. Several of these valves can be attached to one manifold with a common air inlet. Eight 12-V isonic valves (V1B04-AY) and one manifold (M108-J0), are installed in each of three sampling systems. This will allow the addition of one shallow well in each system in the future. Technical specifications for the isonic valves are given in Appendix B5.

Datalogger/Controller

A Campbell Scientific CR10 datalogger/controller was tested with the prototype automatic sampler. The Campbell Scientific language does not lend itself to the type of control required for this application. It was difficult to program the delay required before checking the flow sensor. Depending on the vacuum in the vacuum tank, 4 to 15 seconds will pass before the water being sampled reaches the flow sensor. The datalogger/controller was successfully programmed to accomplish the delay by using the execution interval command. However, this also caused a delay prior to closing the isonic valve which resulted in a loss of vacuum. Alternative methods of programming the Campbell Scientific datalogger/controller for this application will be discussed in Chapter 5. The datalogger has 11 input/output ports including three excitation outputs. As designed, each well requires three input/output ports. This would require multiplexers, or several dataloggers, to include 21 shallow wells in the sampling system. Due to the complexity of the programming and the limited input/output capacity of the Campbell Scientific datalogger/controller, alternative datalogger/controllers were considered.

The Octagon 5081 microcontroller card by Octagon Systems Corporation is used in other projects in the Agricultural Engineering Department. The Octagon card is programmed with CAMBASIC IV programming language which is similar to BASIC programming language. This language is much more compatible with the type of control required in the automatic sampling system. The microcontroller card has three 8-bit ports. One 5081 card has the capacity to control the automatic sampling system for up to eight shallow wells. The 5081 card was programmed and tested in the laboratory and appeared to be compatible with the application. Schematic diagrams of the electronic components are shown in Figure 4.8. Schematic diagrams of the general arrangement of components for field servicing are included in Appendix D (Figures D.1, D.2, and D.3). The automatic sampling system is divided into three systems of seven shallow wells each (Figure 4.9). Each system has the capacity for an additional shallow well. Technical specifications for the Octagon 5081 microcontroller card are included in Appendix B6. The programming for the sampling system will be discussed in a later section.

Printed Circuit Board

The microcontroller card is not capable of direct control of the 12-V isonic valves. The high current output port of the microcontroller can sink 100 mA at 50 V; the initial current demand of an isonic valve is 1.6 W ÷ 12 V = 133 mA. Therefore, transistor control is installed between the microcontroller card and isonic valves. Printed circuit boards were fabricated in the electronics laboratory using double sided printed circuit board, transistors, diodes, and resistors (Figure 4.10). The high current output port (port B) of each microcontroller card is set for general purpose input/output by replacing the high current output driver chip with a dip shunt jumper, and is used to power the transistor control.

Batteries and Solar Panels

The sampling system was initially installed with 12-V lawn and garden tractor batteries and Campbell Scientific MSX 18R solar panels. The small batteries had inadequate storage capacity to power the system during the winter, especially when the systems were

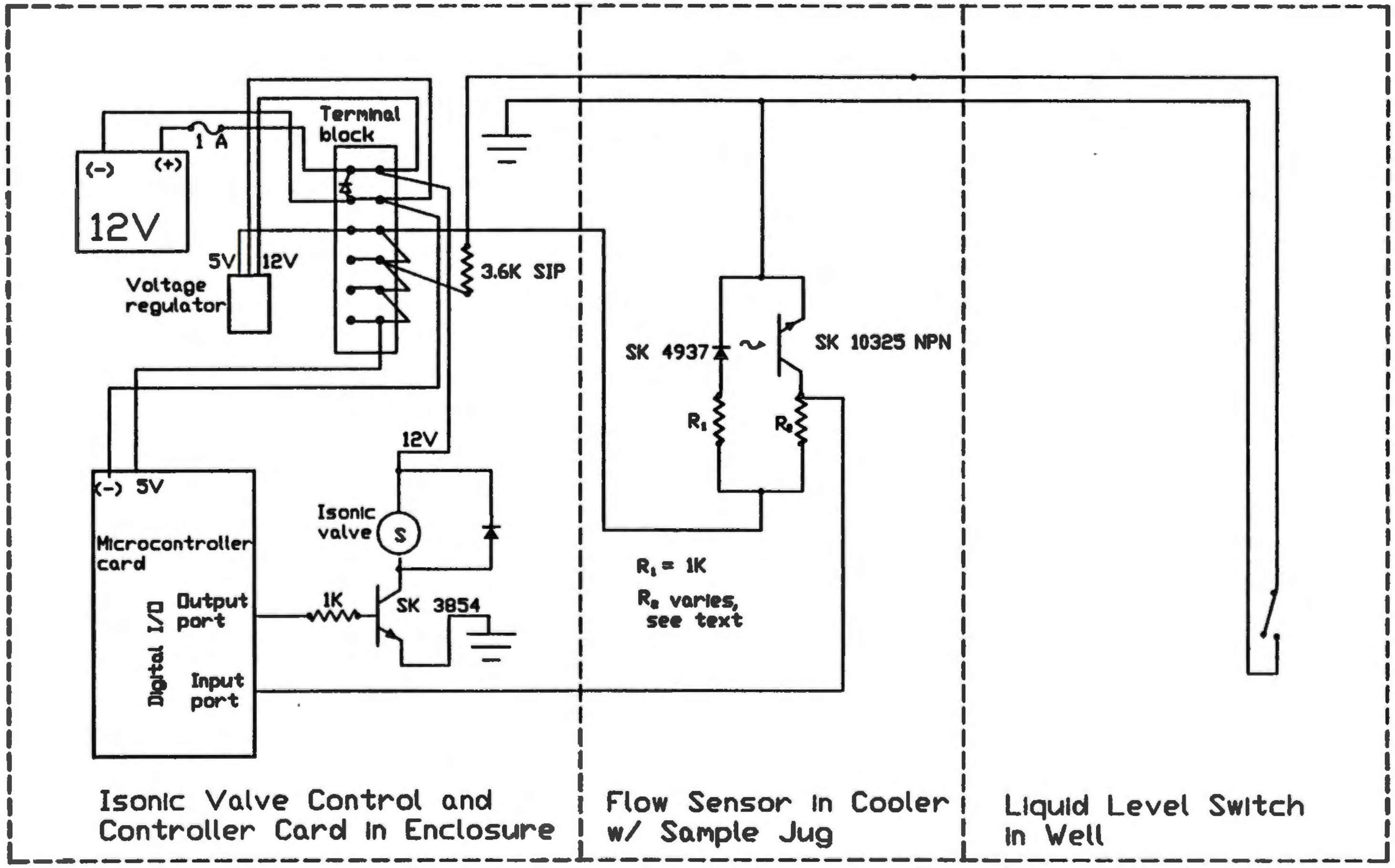


Figure 4.8. Schematic diagram of electronic controls used for one shallow well sampler.

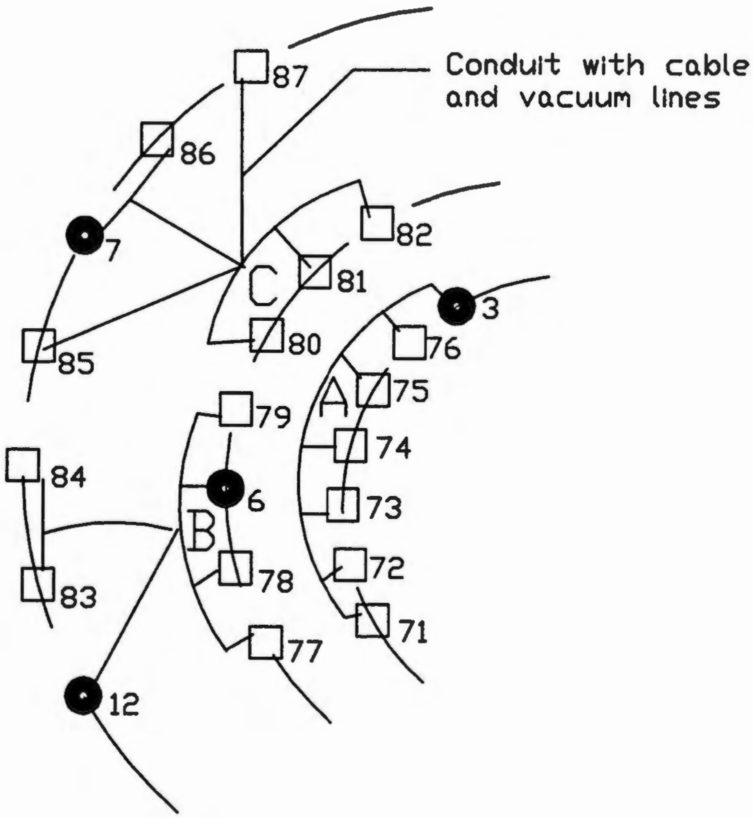


Figure 4.9. The automatic sampling system divided into three systems: A, B, and C. The letters indicate the central location of the vacuum tanks and electronic controls.

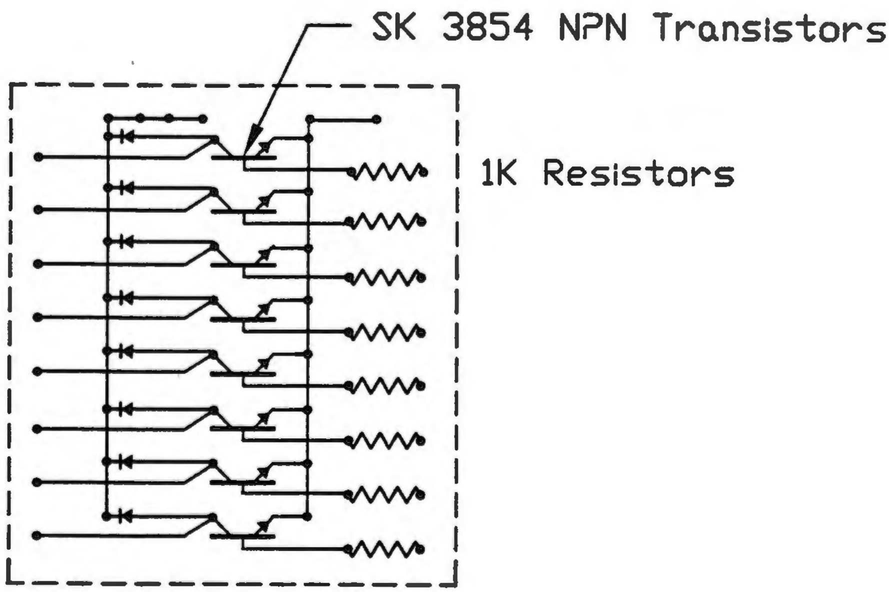


Figure 4.10. Printed circuit board used to provide transistor control of isonic valves.

malfunctioning. In February 1996, Delco Voyager deep cycle marine batteries were put on the systems in place of the utility batteries. The deep cycle batteries have a capacity of 105 ampere hours. Technical specifications for the MSX solar panels are included in Appendix B2.

Other Components

Rubbermaid 5-gallon (18.9-L) insulated coolers are modified to enclose the sample jug and flow sensor for each well. A 150-mm diameter hole is drilled in the bottom of each cooler and an aluminum plate is attached to the bottom of the cooler and sealed with silicone caulk. The sample jug sits on the aluminum plate and maintains the sample temperature equivalent to the soil temperature. The hollow lids of the coolers are filled with "Great Stuff" spray insulation foam. Each cooler is buried approximately 0.5 m from each of the 21 shallow wells in the sampling system. The top of each cooler extends approximately 150 mm above the ground surface. Conduit connections are sealed with polyurethane or silicone caulk. The coolers are anchored with a steel rod 0.5 m long hooked around a cooler handle.

A 2.4-L sample jug with a # 5 rubber stopper is placed in each cooler. As programmed, the system samples a maximum of once every four hours. If a well yields a 0.1-L sample every four hours, a 2.4-L jug will hold three days of composite samples. It is very unlikely that a shallow well will yield the maximum number of samples in a three-day period. The 2.4-L jugs should adequately contain water samples until the technician is able to remove the sample. However, in March 1996, a 4-L sample jug was placed at shallow well #85 after finding that it occasionally produces samples of 0.4 L.

Polyethylene tubing, 5/32 in. (4 mm) outside diameter, is placed between the vacuum tanks and the isonic valve manifold and from the manifold to the sample jugs. The isonic valve manifold is made to receive 5/32-in. (4-mm) tubing. Using larger tubing would have required more fittings, increasing the risk of vacuum leaks. The small tubing works well with the # 5 stopper in the sample jugs. Laboratory tests were performed to determine the vacuum loss in long lengths of the 5/32-in. (4-mm) tubing (Appendix C2, Table C3). The tests were performed with a vacuum gage at the vacuum tank and a vacuum gage near the end of a 31-m and 46-m length of vacuum line. Laboratory tests indicated that with a minimum vacuum of 14-in. (0.36-m) Hg at the vacuum tanks, vacuum lines of up to 46 m may be used. At longer lengths, vacuum loss and the time required to pull the sample could cause problems. Tubing connections are made with stainless steel collet ring fittings. The fittings are very secure and easy to use.

Polyethylene tubing, 1/4 in. (6.35 mm) outside diameter, is placed between the shallow well and sample jug. This size line works well with the # 5 stopper, results in laminar flow at the flow sensor, and purges well after the sample is pulled. The polyethylene tubing is placed 150 to 250 mm below the ground surface in ½-in. (13-mm), 3/4-in. (19-mm), or 1 ½-in. (38-mm) PVC pipe, depending on how many strands of cable and tubing are in the pipe.

The microcontroller cards, isonic valves, and printed circuit boards are enclosed in Nema IV fiberglass enclosures by Hammond Manufacturing (PJ12106L). All connections to the enclosure are sealed.

Laboratory tests indicated that one 10-gallon (37.8-L) vacuum tank would be adequate for one sampling system with seven shallow wells. However, loss from heat when exposed to sunlight was not considered during the tests. The field technician reported difficulty in maintaining adequate vacuum during the initial operation of the sampling systems. In October 1995, a second vacuum tank was added to each system and all fittings on the vacuum tanks were taken apart and resealed with pipe thread compound. Maintaining adequate vacuum has not been a problem since that time.

The enclosure, vacuum tanks, and battery for each system are placed in a small shelter enclosed on three sides. Polyethylene tubing between the vacuum tanks and between the tanks and enclosure are inside of ½-in. (13 -mm) vinyl tubing to protect the vacuum lines against damage.

Programming

The Octagon 5081 microcontroller cards store programs in the 32K EEPROM. The cards are configured to store four files of up to 8K each by using the CONFIG SSD 1 command (Octagon Systems Corporation, 1993). Each of the three systems (A, B, and C), have 4 programs stored in the EEPROM: (1) BOOTA, BOOTB, or BOOTC; (2) TESTA, TESTB, or TESTC; (3) ADATA, BDATA, or CDATA; and (4) IVTEST. As long as the boot program name begins with "boot," the card will automatically reboot running the boot program upon power up. The program flow of the boot programs is shown in Figure 4.11. The programs with explanatory comments, and procedures for using these programs, are included in Appendix D1 through D11.

Laboratory and field tests were very important in developing the boot programs. The delay required before checking the flow sensor is a function of the vacuum, length of vacuum line to the sample jug, and depth of the shallow well. It is important to include protection against flow sensor failure in the program so that vacuum will not be lost if a sensor fails. The maximum amount of time to allow for pulling a sample is also a function of the vacuum, length of vacuum line to the sample jug, and depth of the shallow well. Laboratory tests were performed to determine the amount of time required for water to reach the flow sensor for 0.1 L of water to be sampled at various levels of vacuum and with 46 m of 5/32-in. (4-mm) tubing (Appendix C2). Different subroutines are included in the programs for the shallow wells within 29 m of the vacuum tanks and for those more than 29 m from the vacuum tanks.

The initial BOOT programs were based on laboratory tests and were adjusted as needed after running several field tests. The field tests were performed by pouring approximately 0.2 L of distilled water into each shallow well and monitoring the vacuum and the time required for the water to reach the flow sensor and to be completely sampled. The BOOT programs allow a maximum of one sample every four hours. This is to prevent an unnatural flow condition caused by drawing down the perched water table. If a well has not sampled in

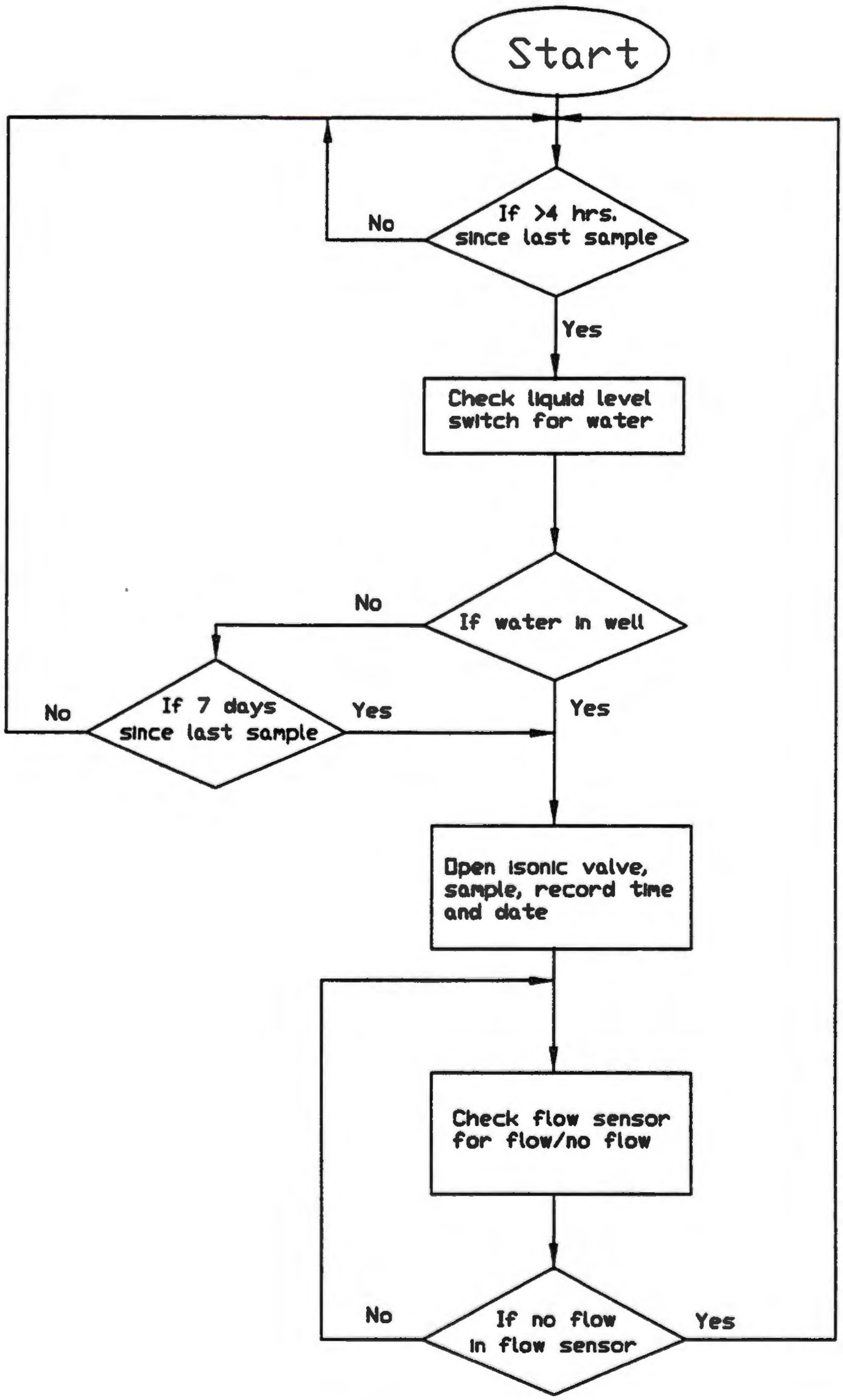


Figure 4.11. Program flow used for the BOOT programs.

seven days, the isonic valve is opened and any water in the well below the level switch is sampled. The TEST programs are revisions of the boot programs that omit the four-hour time limitation between samples. These programs allow efficient field testing of the sampling systems. The DATA programs are used to download data from the microcontroller cards. The IVTEST program is used to test the printed circuit board and the control and operation of the isonic valves.

CHAPTER 5

RESULTS AND CONCLUSIONS

The Automatic Shallow Well Sampling Systems

The automatic sampling systems were installed in August 1995. The three systems were thoroughly tested and the boot programs were adjusted as needed. Field testing was performed by pouring approximately 0.2 L of distilled water into the shallow well casing and monitoring the time required for the water to reach the flow sensor and the time required to sample the water at various levels of vacuum. The systems operated with some consistency through October. Unfortunately, a very dry period preceding and following the installation of the systems precluded extensive field testing. By the end of the year several technical problems had arisen and the systems continued to experience problems through the winter months. Most of the technical and programming problems were solved by May 1996. A summary of technical problems and maintenance procedures are included in Appendix E.

Since March 1995, when the new shallow wells were installed, nine of the shallow wells in the automatic sampling system have yielded water samples. Water samples were manually collected prior to the installation of the automatic samplers. Water sample data and automatic sampling system data are shown in Table 5.1. Saturated conditions seem to appear soon after infiltration at shallow well 85. The volumes of the January 29, 1996, samples from shallow wells 85, 86, and 7 indicate that the perched water table may reach depths greater than previously thought. When servicing system C in February, the depth of water in well 85 was 0.34 m (0.4 L), 0.24 m above the bottom of the screen. The program was designed to sample approximately 0.1 liters each sample. However, it is obvious that some wells are yielding larger

Table 5.1. Summary of data collected from the automatic sampling system, water samples, and precipitation.

I/O Address	MO	DAY	HR	MIN	WELL #	EVENT	COLLECTED	SAMPLED (ml)	EXCESS (ml)	BROMIDE (ppm)	CUMM. PRECIP (mm)
Auto sampler not in operation yet					75	8/5/95	8/7/95	100	0	ND	112
Malfunction, no useful auto sampler data					75	12/8/95	12/12/95	100	0	ND	16
Malfunction, no useful auto sampler data					75	1/2/96	1/4/96	325	0	0.56	11
Malfunction, no useful auto sampler data					75	1/26/96	1/29/96	500	540	ND	42
5	3	19	4	31	75	3/18/96					24
5	3	19	8	0	75		3/20/96	450	0	ND	
17	9	18	0	0	77	9/16/95					10
11	9	18	0	0	77		9/18/95	150	0	ND	
6	3	25	4	7	83	3/23/96					
6	3	25	8	0	83						
6	3	25	12	0	83		3/27/96	425	0	ND	
Malfunction, no useful data					84	1/26/96	1/29/96	300	0	ND	42
Auto sampler not in service yet					85	7/23/95	7/25/95	200	0	ND	45
Malfunction, no useful data					85	12/18/95	12/20/95	500	490	ND	35
Malfunction, no useful data					85	1/26/96	1/29/96	500	455	ND	9
Malfunction, no useful data					85	2/27/96	2/29/96	500	400	ND	16
Sampled while servicing system					85		3/18/96	550	0	ND	
0	3	18	18	0	85	3/18/96					24
0	3	18	22	24	85						
0	3	19	8	11	85						
0	3	19	12	0	85						
0	3	19	16	0	85						
0	3	19	20	0	85						
0	3	20	0	0	85						
0	3	20	4	0	85						
0	3	20	8	0	85						
0	3	20	12	0	85		3/20/96	500	3500	ND	
Auto sampler not in service yet					86	7/25/95	7/25/95	100	0	ND	45
Malfunction, no useful data					86	12/18/95	12/20/95	200	0	ND	35
Malfunction, no useful data					86	1/26/96	1/29/96	500	1435	ND	9
Malfunction, no useful data					87	12/18/95	12/20/95	225	0	ND	35
Malfunction, no useful data					87	1/26/96	1/29/96	500	0	ND	9
7	3	19	13	21	87	3/23/96	3/27/96	75	0	ND	40
Malfunction, no useful data					7	1/26/96	1/29/96	500	1950	ND	42

(See Appendix E for more detailed comments of malfunctions) volumes with each sample. When the antecedent soil moisture conditions are near field capacity, perched water will collect quickly with infiltration and will continue to increase in depth with prolonged precipitation. Revisions to the program to accommodate the larger volume will be discussed in Chapter 6. The most productive wells in the sampling system are located on the 90-m radius while most of the wells on the 45-m and 60-m radii remain dry. That continues to raise questions about the lateral movement of bromide to the outer shallow wells on the west side of the plot.

Water Sample Analysis

Shallow well 75 yielded a 0.325-L water sample with detectable bromide January 4, 1996 (Table 5.1). The spatial distribution of water and detectable bromide are discussed in the next section. No other water sample from the 21 shallow wells yielded bromide as of March 30, 1996. Operation of the automatic shallow well sampling system and water sample analysis will continue.

Topographic Features of the Loess-Paleosol Interface

Surface and Interface Plots

Surfer software by Golden Software Inc., was used to plot the loess-paleosol interface and surface topography. The loess-paleosol interface is plotted and compared to the surface topography using data from the original shallow well installation (wells 1 - 23, Figure 5.1). The interface elevation was calculated using the "pipe set at" and "bottom set at" data (Table 4.1 and Appendix A, Table A1), which indicate the depth to the well screen and the interface. The

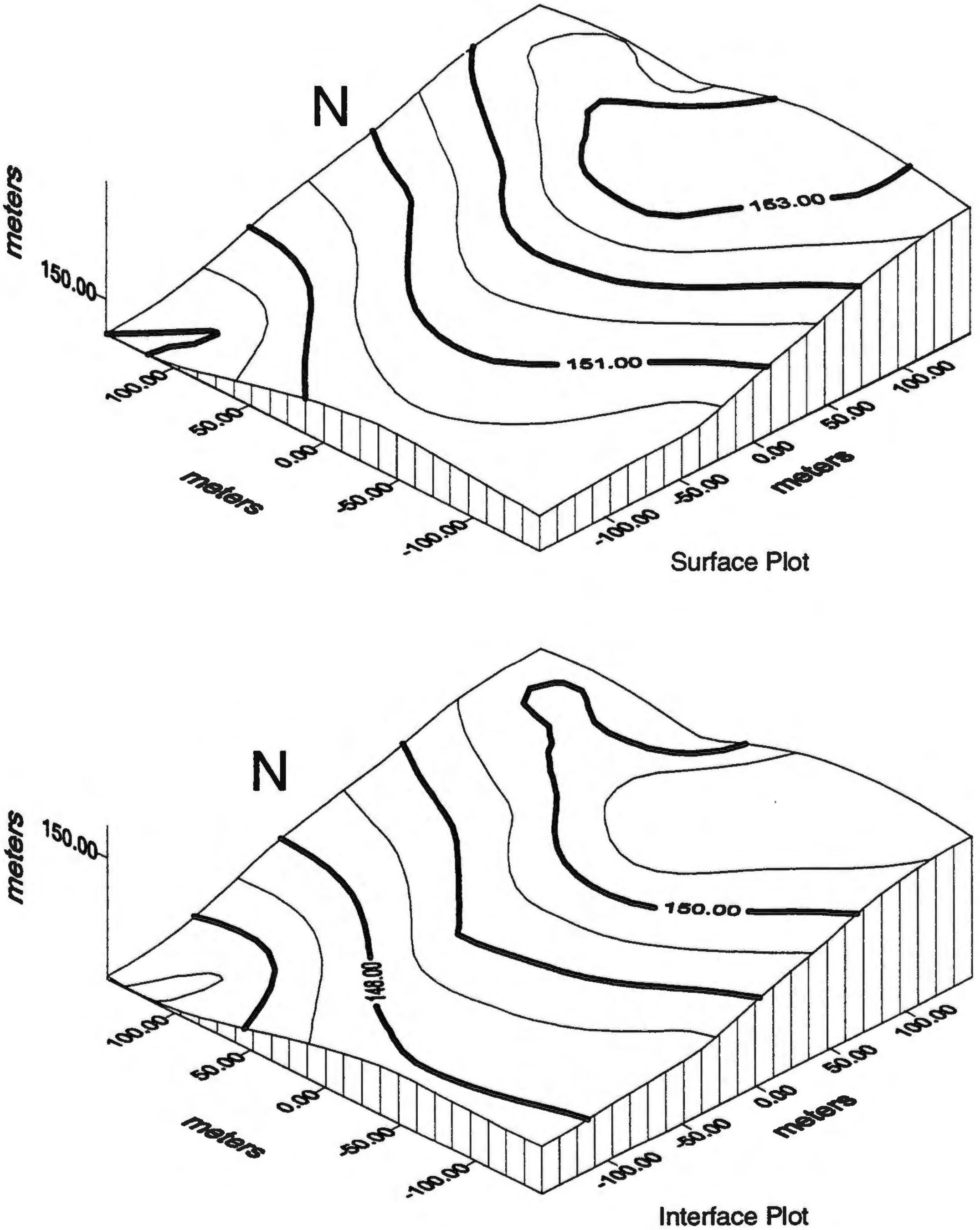
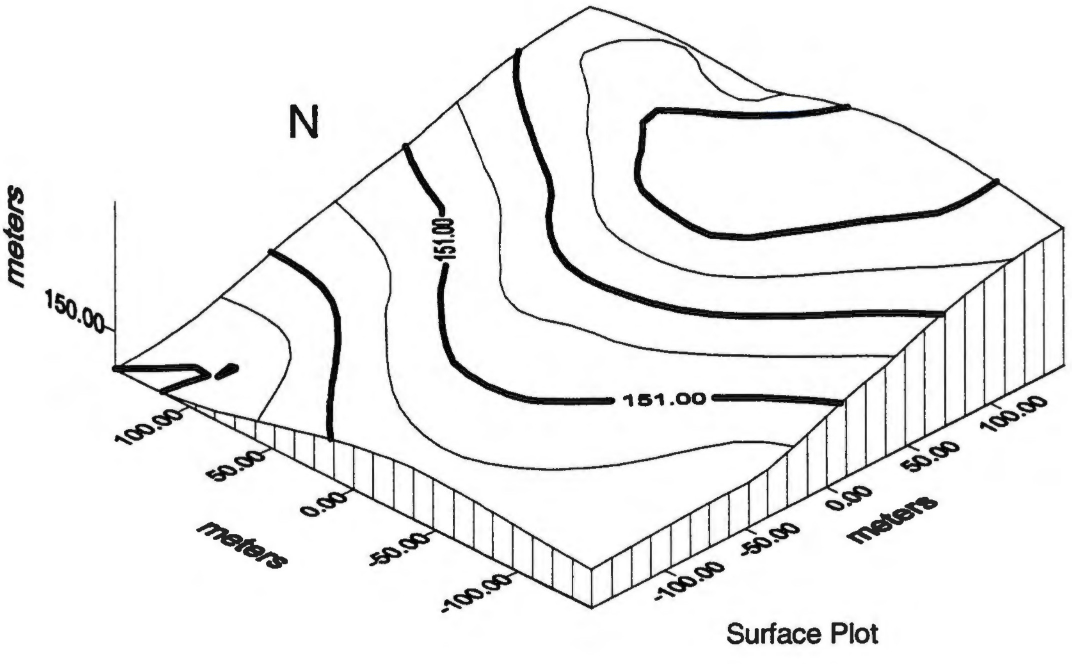


Figure 5.1. Plots using soil core data from shallow wells 1 - 23. Contour values are elevation above mean sea level.

plots show that the data points available from the original 23 shallow wells reveal no significant difference between the interface and surface topography. There are no obvious flow paths shown at the interface that cannot be inferred from the surface topography. When the data points from the new shallow wells (71 - 87) are included in the plot, a significant change is seen in the 148.5-m and 149-m contour lines (Figures 5.2 and 5.3). The most significant effect of the new data points occurs with shallow wells 71 - 76 which are above the 149-m contour line and are approximately 11 m apart.

Interface Flow Net

The topographic information of the interface was used to predict possible flow paths of the lateral movement of water at the interface using a two dimensional flow net (Figure 5.4). The flow net was developed by using the contour lines as equipotential lines of constant head and therefore, perpendicular to the flow lines. The flow net is qualitative and assumes lateral flow over the entire interface. This assumption will only be true if saturated conditions and uniform depths of saturation exist over the entire interface. The flow net model also assumes homogeneous and isotropic conditions. According to soil core and water sample data, none of these conditions are entirely true. However, they are adequate assumptions for making a quick comparison of predicted flow paths and actual data. After applying the flow net to the interface, water sample results from shallow wells 1 - 23 are applied to the interface plot and compared with flow net predictions (Figure 5.5). The flow net model constructed from the interface topography does not coincide with the data. It is apparent that well defined flow paths exist at the interface instead of a homogeneous perched water table across the entire interface. The northwest and west sides of the test area are where most of the activity is predicted by the flow net. Wells 13, 14, and 15, had water samples with detectable bromide. However, Table 2.1 and Figure 2.4 show that well 13 yielded 35 water samples in 27 months and 10 out of 32



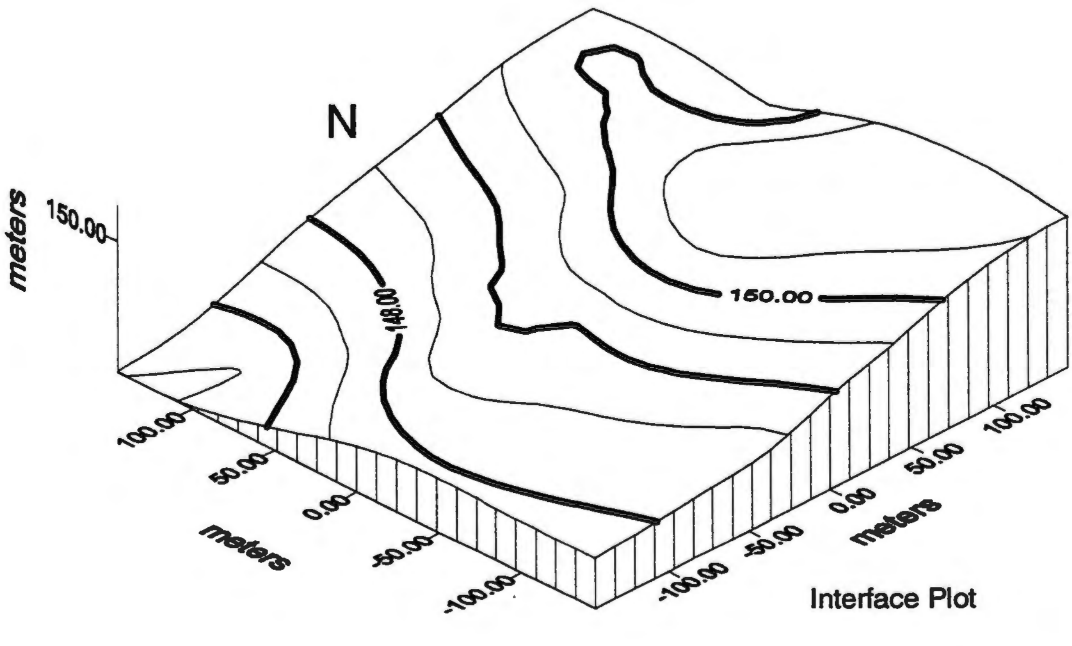


Figure 5.2. Plots including soil core data from shallow wells 1 - 23 and 71 - 87. Contour values are elevation above mean sea level.

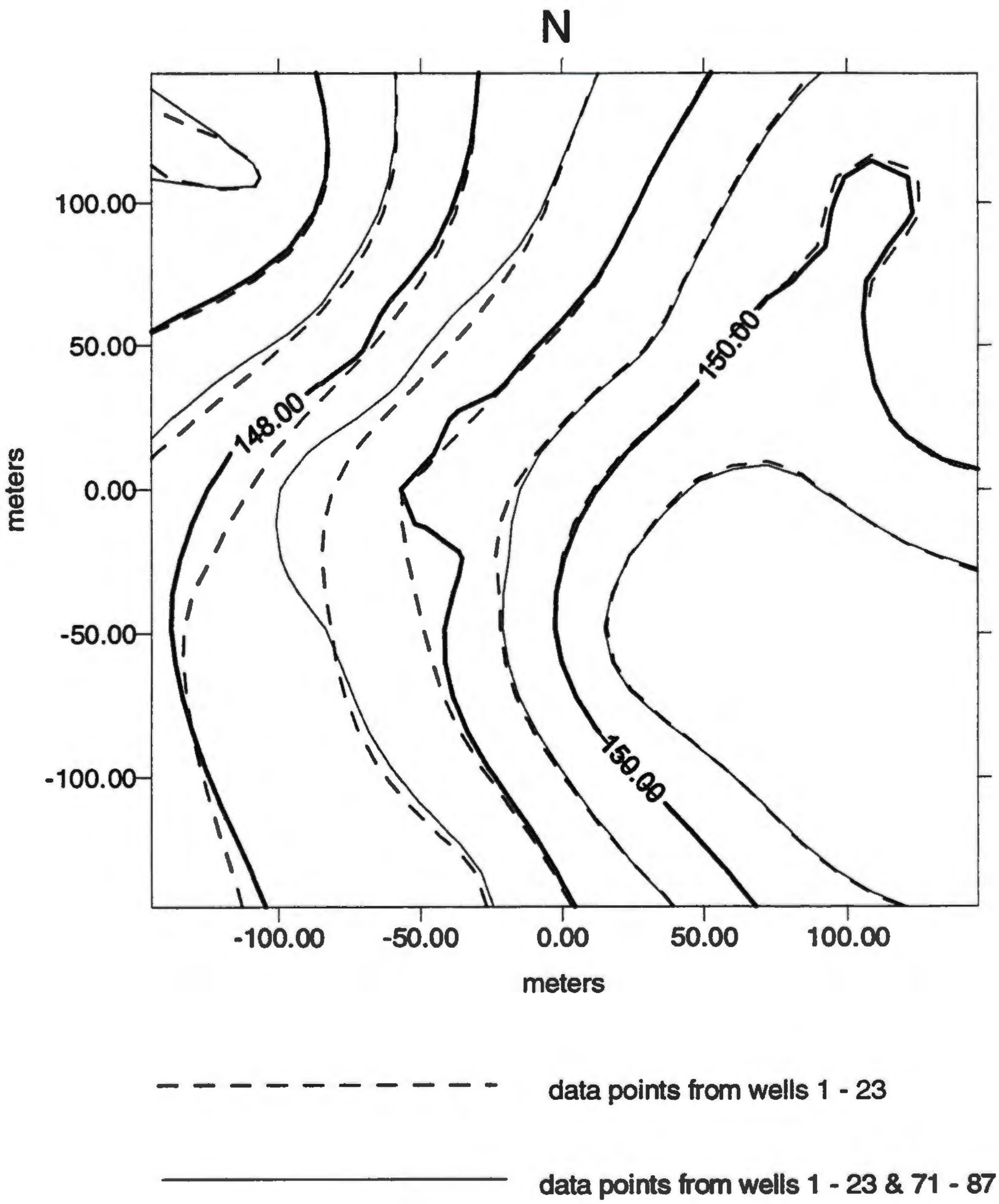


Figure 5.3. Contour plots comparing additional data points to original data points. Contour values are elevation above mean sea level.

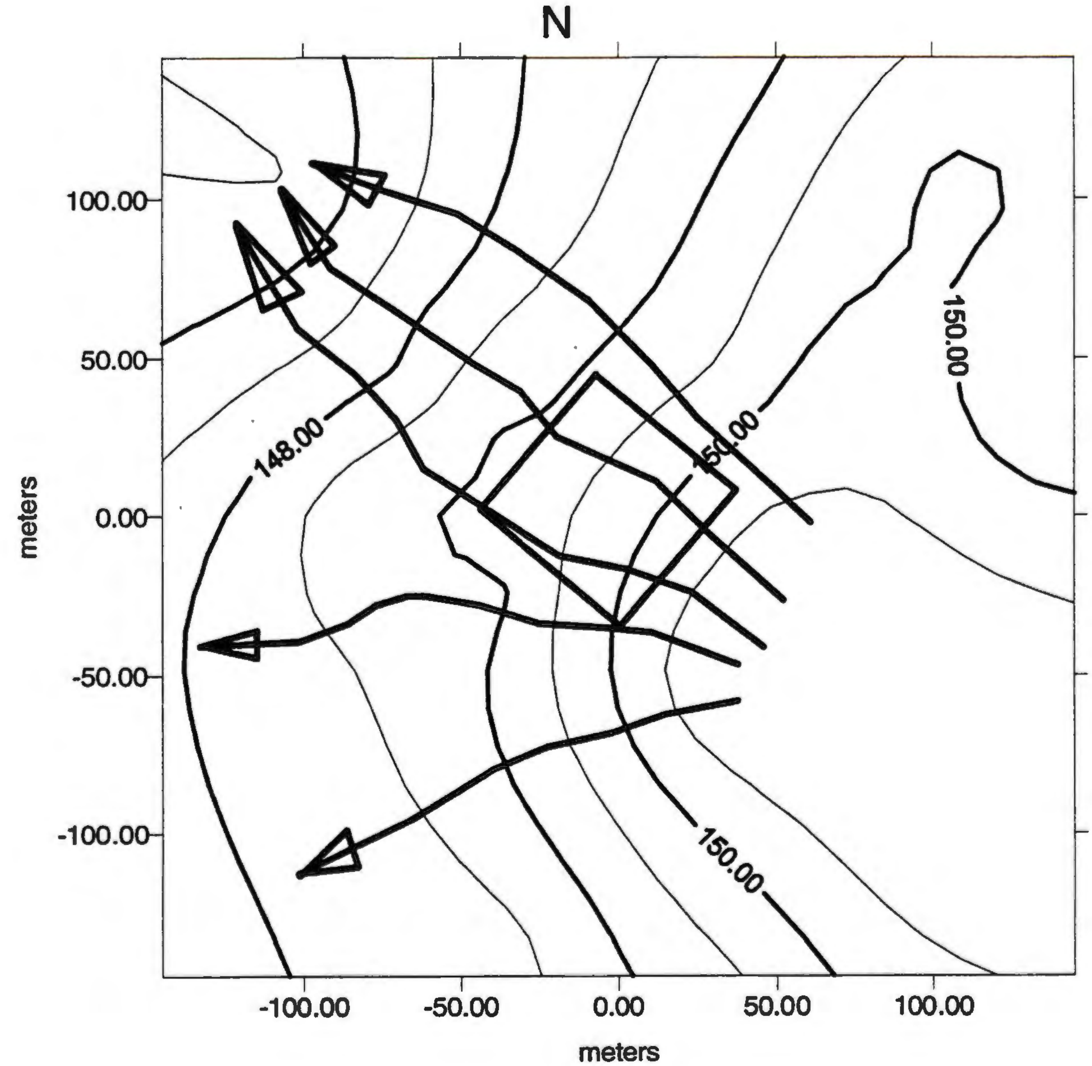


Figure 5.4. Two-dimensional flow net at the interface predicting possible flow paths of the lateral movement of subsurface flow. Contour values are elevation above mean sea level.

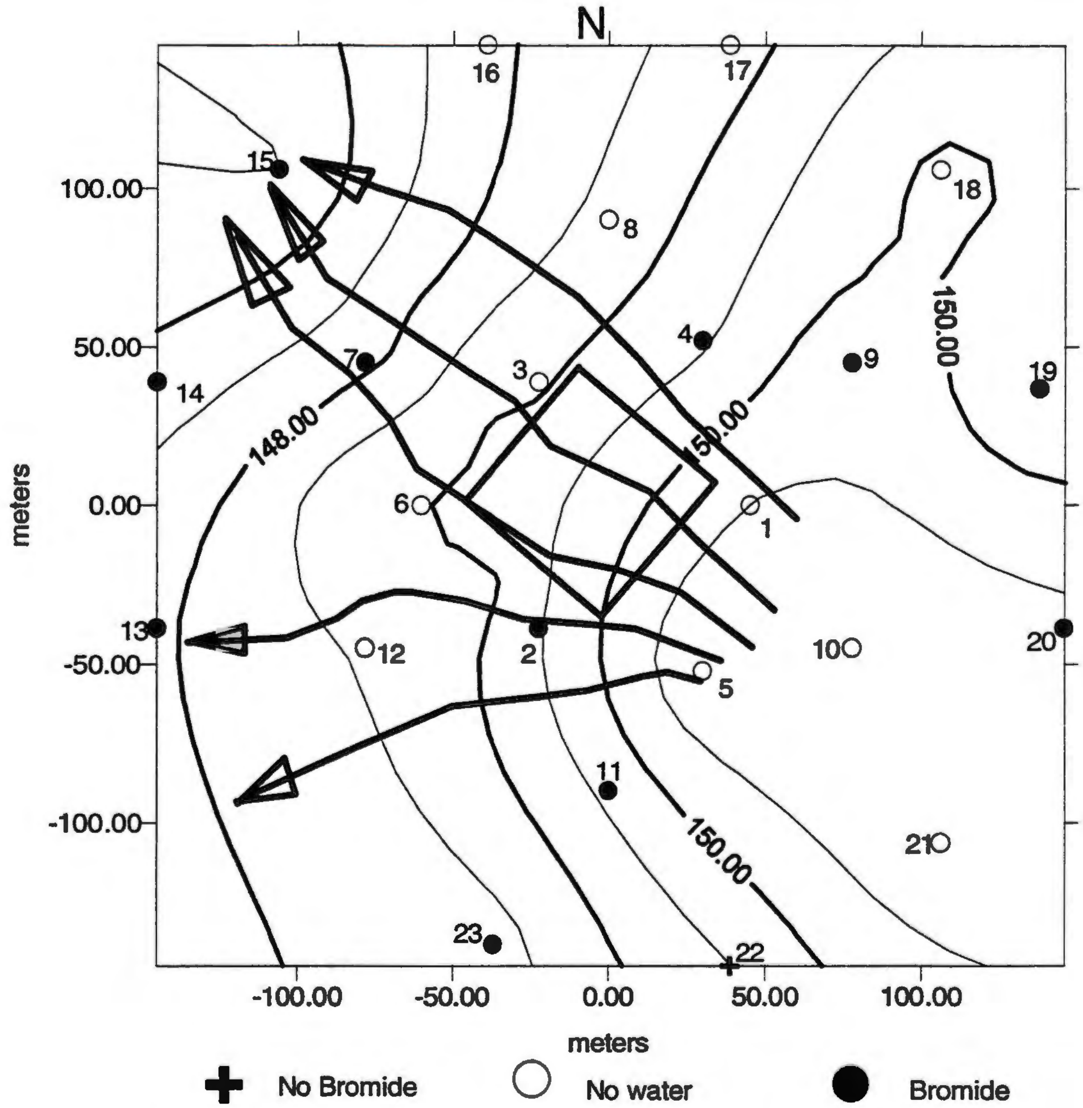


Figure 5.5. Two-dimensional flow net compared with the spatial distribution of bromide and water from shallow wells 1 - 23. Contour values are elevation above mean sea level.

water samples yielded detectable bromide in the 21 months following tracer application. It also yielded the first and highest bromide detection of the three wells. That well 13 would be the most productive well in bromide detection and water samples is not predictable from the flow net, interface topography, or soil core samples. Well 15, which is in the direct path of the predicted flow from the tracer application, would be expected to yield more bromide detections then well 13. Several other questions remain unanswered. How did the tracer arrive at wells 19 and 20? Why did wells 12, 6, 3, and 8 yield no water when the wells beyond them had water and tracer?

The spatial distribution of water and detectable bromide is graphically represented in Figure 5.6. The limited amount of new data may suggest a possible flow path from the 0.4-ha plot to shallow well 75 to shallow well 7. However, the interface topography plotted from the soil core data and the absence of water in shallow well 80 does not suggest this flow path. The soil core data and water sample analyses indicate that the spatial resolution of the new shallow wells on the 45-m radius are not adequate to define possible flow paths at the interface.

Conclusions

The automatic sampling system implemented at the Ames Plantation Water Quality Project has been a success. The instrumentation discussed in this thesis is a positive step forward in the continued development of vadose zone monitoring technology. The automatic sampling system results in better time resolution, more efficient utilization of field personnel, and better sample integrity than traditional methods of sampling from shallow wells. The automatic sampling technology has several potential applications. The technology could be improved to include discrete sampling to enhance the time resolution of tracer studies. The technology could be used to monitor the migration of hazardous chemicals since it is not

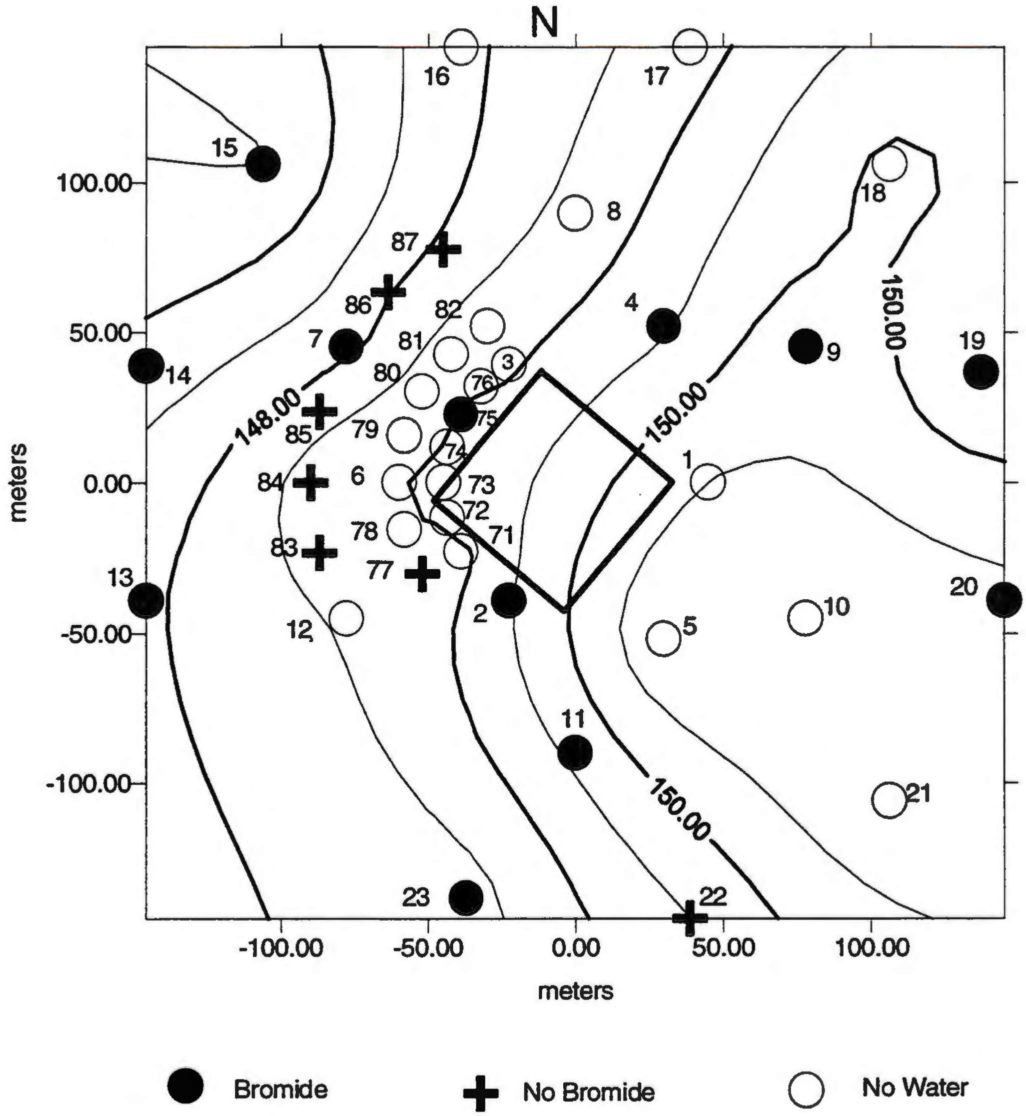


Figure 5.6. The interface topography compared with the spatial distribution of water and bromide from shallow wells 1 - 23 and 71 - 87. Contour values are elevation above mean sea level.

necessary for field personnel to stand over or handle the sample during the sampling process. The technology could be used to meet monitoring requirements for hazardous waste landfill sites where regulators are requiring more vadose zone monitoring. The technology could have several applications in the continued research of agrichemical fate. The flow sensor design could have application in several types of hydrologic instrumentation.

CHAPTER 6

RECOMMENDATIONS

The Automatic Shallow Well Sampling System

Datalogger/Controller

Use of the Campbell Scientific datalogger as the monitoring system controller should be reconsidered. The delays required in the program flow may be accomplished using the timer and "intermediate processing disable flag" (Campbell Scientific, Inc., 1991). If using the datalogger is feasible, one to three shallow wells should be put on a datalogger and compared with the operation of the Octagon microcontroller cards through at least one winter and spring. Using Campbell Scientific dataloggers could require as many as seven dataloggers or three dataloggers and three multiplexers.

Program

Several revisions for improving the programming are possible. The minimum amount of time allowed between samples should be raised to six hours to prevent over filling of sample jars. An alternative to this revision is to identify the most productive wells and replace the sample jars with 4-L sample jars. The maximum amount of time allowed for sampling should be raised by 100% to allow time to sample larger volumes. This revision will make flow sensor operation more critical. If a flow sensor fails and the sample volume is small, significant vacuum may be lost. The program should be revised to use the liquid level switches to record when 0.1 L of water has collected in the casing if less than four hours (six hours if revised) has passed since the last sample.

Flow Sensors

As flow sensors fail they should be replaced with an improved design. A light emitting diode and phototransister switch factory mounted approximately 1/4 in. (6.3 mm) apart may be sealed into a slit in the side of a small piece of tubing. This will eliminate the alignment problem experienced with the existing flow sensors. The existing design may be improved by using a rigid, thick wall, tubing instead of the flexible norprene. It may be necessary to fabricate the size of rigid tubing needed. Rigid tubing will make proper alignment of the light emitting diode and phototransistor easier to accomplish.

Tracer Application

The automatic sampling system may be of greatest value when a new tracer is applied. However, the problems with the system operation should be resolved before the application. The automatic sampling system has been a successful project. The literature review and results support it's continued development along with other vadose zone monitoring systems.

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APPENDICES

APPENDIX A

SOIL CHARACTERIZATION OF SOIL CORES

Table A1. Soil Characterization of Soil Cores at the No-Till (Hancock) Test Site

Well No.	Horizon	Depth (cm)	Color	Classification	Notes
1	Ap	0-17	10YR 4/4	sil	
	Bt1	22-80	10YR 5/4	sicl	
	2Bt2	80-220	10YR 4/4	l	mixing zone
	2BC	220-276	2.5YR 4/6	sl	not clayey paleosol pipe set at 276 cm
2	Ap	0-28	10YR 4/4	sil	
	Bt1	28-120	10YR 5/4	sicl	
	Bt2	120-180	10Yr 4/4 & 10YR 5/4	sicl	
	2Bt3	180-210	7.5 YR 4/6 w/ 10YR 6/3 faces	c	<10% sand
	2Bt4	210-230	2.5YR 4/6 w/ 7.5YR 5/6 mottles	c	<10 % sand pipe set at 230 cm
3	Ap	0-22	10YR 4/3	sil	
	Bt1	22-120	10YR 5/4	sicl	
	Bt2	120-180	10YR 4/4 & 10YR 5/4 ped faces	sil	
	2Bt3	180-213	5YR 4/6 w/ 7.5YR 6/4 mottles	l/cl	mixing zone 10% fragic
	2Bt4	213-250	2.5YR 3/6 w/ 5YR 6/4 mottles	cl/c	pipe set at 250 cm
4	Ap	0-17	10YR 4/3	sil	
	Bt1	17-105	10YR 5/6	sicl	
	Bt2	105-200	10YR 4/6	sicl	
	2Bt3	200-230	7.5YR 4/6	cl	mixing zone
	2Bt4	230-260	2.5YR 4/6	c	pipe set at 260 cm
5	Ap	0-14	10YR 4/3	sil	
	Bt1	14-110	10YR 5/4	sicl	
	Bt2	110-135	10YR 4/4 w/ 6/2 mottles	sicl	
	2Bt3	135-185	7.5YR 4/4 w/ 10 YR 5/6 mottles	l/cl	
	2Bt4	185-220	2.5 yr 4/6	c	pipe set at 220 cm

Well No.	Horizon	Depth (cm)	Color	Classification	Notes
6	Ap	0-20	10YR 4/3	sil	
	Bt1	20-120	10YR 4/4	sicl	
	Bt2	120-160	7.5YR 4/6	sicl	
	2Bt3	160-180	7.5YR 4/6	cl	mixing zone
	2Bt4	180-200	7.5YR 4/6 w/ 10YR 6/3 mottles	cl/l	20%-30% brittleness
	2Bt5	200-231	2.5 YR 4/6 w/ 7.5YR 5/6 mottles	sc/c	pipe set at 231 cm
7	Ap	0-16	10YR 4/3	sil	
	Bt1	16-65	10YR 4/4 w/ 10YR 6/3 ped faces	sicl	
	Bt2	65-200	10YR 3/4 & 10YR 4/4	sicl	20% brittlenes
	2Btx	200-230	7.5YR 4/6 w/ 10YR 6/2 E bodies	l/cl	
	2Bt	230-267	2.5YR 4/6 w/ 7.5YR 6/4 ped faces	c	very moist on faces pipe set at 267 cm
8	Ap	0-20	10YR 4/4	sil	
	Bt1	20-96	10YR 5/4 & 10YR 5/6	sil	
	Bt2	96-140	10YR 4/4 w/ 10YR 5/6 mottles	sicl	
	2Bt3	140-192	5YR 4/6	c/cl	c/cl
	2Bt4	192-231	2.5YR 3/6	c	pipe set at 231 cm
9	Ap	0-20	10YR 4/4	sil	
	Bt1	20-110	10YR 4/6	sicl	
	Bt2	110-155	10YR 4/4	sicl	
	2Bt3	155-230	10YR 4/3 & 10YR 5/4	l	mixing zone
	2Bt4	230-270	2.5YR w/ 10YR 4/4 mottles	sc/c	pipe set at 270 cm

Well No.	Horizon	Depth (cm)	Color	Classification	Notes
10	Ap	0-22	10YR 4/4	sil	
	Bt1	22-150	10YR 5/4	sil/sicl	
	Bt2	150-190	10YR 4/4 w/ 10YR 5/4 mottles	sicl	
	2Bt3	190-200	5YR 4/6 & 7.5YR 4/6	sicl/sil	
	2Bt4	200-253	5YR 4/6	c	<10% sand pipe set at 253 cm
11	Ap	0-25	10YR 4/4	sil	
	Bt1	25-70	10YR 4/4 & 10YR 4/6	sicl	
	Bt2	70-125	7.5YR 4/6 w/ 10YR 6/3 ped faces	sicl	20%-30% brittleness
	2Bt3	125-170	5YR 4/6 10YR 6/3 ped faces	sicl/l	mixing zone
	2Bt4	170-207	2.5YR 4/6 w/ 5YR 5/4 mottles	sc/scl	set pipe at 207 cm
12	Ap	0-70	10YR 4/4	sil	disturbed, edge of road
	Bt1	70-140	10YR 5/6	sil/sicl	
	Btx1	140-170	10YR 4/4 w/ 10YR 6/2 silt coatings	sicl	60% brittleness
	Btx2	170-200	10YR 4/4 w/ 10YR 6/2 silt coatings	sicl	30%-40% brittleness
	2B/E	200-217	5 YR 4/6 w/ 7.5YR 7/2 E bodies	cl-B & cl-E	
	2Bt	217-251	2.5YR 4/6 w/ 7.5YR 7/2 ped faces	c	pipe set at 251 cm

Well No.	Horizon	Depth (cm)	Color	Classification	Notes
13	O	10-0	-	-	leaves, twigs, roots
	Ap	0-8	10YR 3/4	sil	
	BE	8-20	10YR 5/4	sil	
	Bt1	20-90	10YR 5/6	sicl	
	Bt2	90-180	10YR 4/6 w/ 10YR 6/2 ped faces	sicl	mixing zone Loveland?
	2B/E	180-210	7.5YR 4/6 & 7.5YR 7/2 E bodies	l/cl	
	2Bt	210-242	2.5YR 4/6	c	about 30% sand pipe set at 242 cm
14	Ap	0-25	10YR 4/4	sil	
	Bt1	25-90	10YR 5/4	sicl/sil	
	Bt2	90-170	10YR 4/6	sicl	grey mottles in bottom some mixing in lower part between 150 and 170 cm
	2Bt3	170-210	7.5YR 4/6	cl	mixing zone
	2Bt4	210-254	2.5YR w/ 7.5YR 4/6 mottles	c	pipe set at 254 cm
15	Ap	0-33	10YR 4/3	sil	Ap is overthickened on edge of field
	Bt1	33-100	10YR 5/4	sicl	
	Bt2	100-170	10YR 4/4 w/ 10YR 5/6 mottles	sicl	
	2Bt3	170-210	5YR 4/6 w/ 7.5YR 5/4 mottles	cl/l	
	2Bt4	210-252	2.5YR 4/6	c	pipe set at 252 cm 94 cm of water in hole at time of pipe installation
16	Ap	0-22	10YR 4/3	sil	
	Bt1	22-110	10YR 4/6	sicl	
	Bt2	110-190	10YR 4/4	sicl	
	2Bt3	190-215	5YR 4/6 w/ 7.5YR 6/4 mottles	sicl/cl	10% brittleness mixing zone
	2Bt4	215-230	2.5YR 4/6 w/ 10YR 6/3 silt coatings	c	pipe set at 230 cm

Well No.	Horizon	Depth (cm)	Color	Classification	Notes
17	Ap	0-18	10YR 4/4	sil	
	Bt1	18-102	10YR 5/4	sil/sicl	
	Bt2	102-130	10YR 4/4 w/ 10YR 6/3 mottles	sicl	
	2Bt/E	130-197	5YR 4/6 w/ 10YR 6/2 E material	cl/l	
	2Bt	197-228	2.5YR 4/6 w/ 7.5YR 6/4 ped faces	c	pipe set at 228 cm
18	Ap	0-13	10YR 4/4	sil	
	Bt1	13-64	10YR 5/4	sil/sicl	
	Bt2	64-145	7.5YR 4/6 w/ 10YR 6/1 mottles	sicl	
	2Bt3	64-145	5YR 4/6 w/ 7.5YR 6/0 mottles	cl	mixing zone
	2Bt4	207-249	2.5YR 4/6	c	set pipe at 249 cm
19	Ap	0-22	10YR 4/3	sil	
	Bt1	22-140	10YR 5/4	sil/sicl	
	Bt2	140-195	10YR 4/4	sil	
	2Bt3	195-255	7.5YR 4/6	sicl/l	mixing zone
	2Bt4	255-285	5YR 4/6	c	<10% sand some free water in bottom of hole pipe set at 285 cm
20	Ap	0-18	10YR 4/4	sil	
	Bt1	18-115	10YR 5/4	sicl/sil	
	Bt2	115-165	10YR 4/4 w/ 10YR 5/4 mottles	sicl	
	2Bt3	165-220	5YR 4/6 w/ 7.5YR 6/4 mottles	cl/l	free water on ped faces
	2Bt4	220-257	2.5YR 4/6 w/ 5YR 6/4 mottles	c	pipe set at 257 cm
21	Ap	0-25	10YR 4/4	sil	
	Bt1	25-100	10YR 5/4	sicl	possibly 2 Bt's
	2Bt2	100-189	5YR 4/6	cl	mixing zone
	2Bt3	189-207	2.5YR 4/6 & 2.5YR 3/6	c	pipe set at 207 cm

Well No.	Horizon	Depth (cm)	Color	Classification	Notes
22	Ap	0-16	10YR 4/3	sil	
	BE	16-27	10YR 4/4	sil	
	Bt1	27-110	10YR 5/4	sicl	
	Bt2	110-160	10YR 4/4 w/ 10YR 5/4 mottles	sicl	
	2Bt3	160-180	5YR 4/6 w/ 7.5 YR 6/4 mottles	sicl/cl	mixing zone
	2Bt4	180-193	2.5YR 3/6 w/ 5YR 6/2 mottles	c	pipe set at 193 cm
23	Ap	0-10	10YR 4/3	sil	
	Bt1	10-50	10YR 4/4 & 10YR 5/4	sicl	
	Bt2	50-90	7.5YR4/4 w/ 10YR 6/2 mottles	sil	
	2Bt3	90-150	5YR 4/6 w/ 7.5YR 6/4 mottles	l/cl	mixing zone
	2Bt4	150-193	2.5YR 4/6 w/ 5YR 6/2 mottles	c	about 35% sand pipe set at 193 cm
24	Not installed, paleosol is exposed.				

APPENDIX B

TECHNICAL SPECIFICATIONS

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B1. Pumps considered for use in automatic sampler.

1. ANCO Universal Windshield Washer Pump 65-01.
   12 V
   Self-priming to 48 cm
   Pumps 275 cm head
   Requires >2.5 in (6.4 cm) diameter area.
   $16.00

2. Submersible Bilge Pump
   12 V, 2.5 A
   Max head: 381 cm
   Stock No. 3P996 (Grainger Cat. 384)
   3.5" x 2.37" x 2.37" (8.9 cm x 2.4 cm x 2.4 cm)
   0.75" (1.9 cm) outlet
   $15.43

3. Teel Marine & Camper Submersible Pump
   12 V, 1.0 A to 1.8 A
   not self-priming
   2" x 2" x 5.5" (5.1 cm x 5.1 cm x 14 cm)
   $24.53

4. Teel Compact Self-Priming Marine Utility Pump
   12 V, 6.5 A to 10 A
   Self-priming up to 214 cm
   6.62" x 3.5" x 4" (16.8 cm x 8.9 cm x 10.2 cm)

5. Miniature Gear Pump
   12 V, 2.0 A
   Self-priming to 214 cm
   4" x 1.75" x 2.62" (10.2 cm x 4.4 cm x 6.7 cm)
   $38.80

B2. MSX 18R Solar Panel

Nominal Voltage	15 V
Peak Power	18.6 W
Watt hrs/ week	469
Amp hrs/ week	26
Panel area	50.2 cm x 42.1 cm

1 KW/m^2 illumination, solar panel temperature at 25° C.

Up to 10% variation between individual panels.

Table B1. Climatological Data for the Memphis area.

Month	% of Possible Sunshine	MEAN NUMBER OF DAYS (Sunrise to Sunset)		
		Clear	Partly Cloudy	Cloudy
January	50	7.9	5.9	17.2
February	54	7.8	5.8	14.7
March	56	8.0	6.6	16.4
April	64	8.8	7.1	14.1
May	69	8.7	9.7	12.6
June	74	10.1	11.1	8.8
July	74	10.4	11.8	8.8
August	75	11.8	11.4	7.8
September	69	12.5	7.7	9.9
October	70	14.3	7.1	9.6
November	58	10.1	6.4	13.6
December	50	8.8	5.9	16.3

(Ref. The Weather Almanac. 1987. Gale Research Div.)

Solar illumination on a clear day in January in West Tennessee: 345 Cal/cm^2 = 167 W/m^2

B3. Liquid Level Switch

Omega Technologies Company
One Omega Drive, Box 4047
Stamford, Connecticut 06907-0047
1-800-826-6342 (sales)

Model: LV60

Stem/float material:	Polysulfone
Operating temperature:	-40 to 225° F (-40 to 107° C)
Switch actuation:	Halfway point of float travel
Float travel:	1 9/16" (3.97 cm)
Switch rating:	10VA
Lead wires:	22 awg. 24" (61 cm) PVC
Specific gravity of float:	0.5
Max. Resistive load at 0 - 50V:	0.13 A (dc)

B4. Miniature Vacuum Switches

1. Whitman Controls Corporation
   201 Dolphin Road
   P O Box 1478
   Bristol, CT 06010
   (203) 583-1847

   Model: P117V

Max. Vacuum:	29.9" (76 cm) Hg
Set point repeatability:	+/- 1.2" (3 cm) Hg
Set point range	
Decreasing:	1.6" - 27.0" (4.1 cm - 68.6 cm) Hg
Increasing:	2.7" - 28.2" (6.9 cm - 71.6 cm) Hg
Reset differential range, 1 A:	1.3" - 2.7" (3.3 cm - 6.9 cm) Hg
Vacuum range:	1.6" - 28.2" (4.1 cm - 71.6 cm) Hg
Temperature range:	-65° F to 225° F (-54° C to 107° C)
Cycling:	not to exceed 20 CPM
Materials:	Stainless steel, zinc alloy, et al.

2. Micro Pneumatic Logic, Inc.
   Miami, FL
   (305) 973-6166
   (305) 973-6339 fax

   Series MPL-500

Tolerance setting:	+/- 10% at 10" (25.4 cm) H2O
Operating temperature:	-40° C to 120° C (-40° F to 250° F)
Materials:	Glass-filled polyester et al.
Adjustment ranges:	C- 2 to 13 in H_2O (5.1 cm - 33.0 cm)
	D- 10 to 50 in H_2O (25.4 cm - 127.0 cm)
	E- 25 to 200 in H_2O (63.5 cm - 508 cm)
	F- 100 to 550 in H_2O (254 cm - 1397.0 cm)

B5. Isonic Valves

Mead Fluid Dynamics, Inc.
4114 North Knox Avenue
Chicago, IL 60641
(312) 685-6800
(312) 685-7002

Model: valve- V1B05-AY
manifold- M108-J0

Max. Vacuum:	28" (71.1 cm) Hg
Temperature range:	0° F to 120° F (-17.8° C to 49° C)
Tubing size:	5/32" or 4 mm
Voltage:	12V
Power consumption:	Initial power- 1.6 W Continuous on- 1.3 W

B6. Octagon 5081 Microcontroller Card

Octagon Systems
6510 West 91st Avenue
Westminister, CO 80030
(303) 426-4521 (technical support)

Memory:	32K, CAMBASIC IV ROM 32K, 128K, or 512K static RAM 32K nonvolatile memory (EEPROM)
Digital I/O:	24 digital I/O lines, all lines have 10K pull up resistors.
Drive current:	2.5 mA max. per line, sink or source (TTL compatible)
Output low voltage:	0.45 V max. at 2.5 mA, 1 V max. at 12 mA (opto rack compatible)
Output high voltage:	2.4 V min.
Power requirements:	5V +/- 5% @ 120 mA typical
Temperature range:	-25° C to 70° C
Operating humidity:	5% to 95% RH noncondensing

Table B2. Digital I/O Addresses

5081 Digital I/O			
I/O Line Address	Port A Pin #	Port B Pin #	Port C Pin #
0	19	10	13
1	21	8	16
2	23	4	15
3	25	6	17
4	24	1	14
5	22	3	11
6	20	5	12
7	18	7	9
+5V - Pin 2 Gnd - Pin 26			

APPENDIX C

LABORATORY TESTING RESULTS

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Table C4. Time to sample testing. 92

C1. Laboratory Tests to Determine Optimum Flow Sensor Design.

SK 4937 Infrared Emitting Diode

Maximum Ratings	
Total power dissipation	170 mW
Forward DC current	100 mA
Reverse voltage	3 V
Electro-Optical Characteristics	
Forward voltage drop	1.4 V
Peak emission wavelength	940 nm

The SK 10325 specifications are as follows:

Maximum Ratings	
Total power dissipation	150 mW
Collector current, continuous	50 mA
Breakdown Voltages	
Collector to base	50 V
Collector to emitter	40 V
Emitter to base	5 V
Electro-Optical Characteristics	
Maximum dark current	200 nA
Best condition collector to emitter voltage	0.25 V
Minimum light current	0.25 mA

Laboratory tests were conducted to determine the optimum size resistors for the flow sensor. Calculations were made to determine possible resistor sizes to begin laboratory testing.

$V_{in} = 5$ V
$V_f = 1.4$ V
$I_{max} = 100$ mA (use ½ of I_{max})
From $V = IR$, $R_1 = (5V - 1.4V) \div (.05A)$
$R_1 = 72\ \Omega$
From $P = IV$, $P = 0.05A(5V - 1.4V)$
$P = 0.18$ W
Begin tests with R_1 of approximately 72 Ω and 1/4 W
From $V = IR$, $R_2 = 5V \div 0.05A$
$R_2 = 100\ \Omega$ (min)
Use R_2 of 2 KΩ to 10 KΩ

Table C1. Laboratory test results to determine optimum size of R_1 and R_2 (refer to Figure 4.6).

R_1 Ω	Vin	R2 Ω	V_{out} w/air	V_{out} w/water	V_{out} purging
75	5V	10.28 K	4.98	4.97	4.98
190		10.28 K	0.9	0.14	-
330		10.28 K	0.22	0.19	-
500		10.28 K	0.9	1.56	-
750		10.28 K	0.94	2.99	0.2
830		10.28 K	0.63	3.27	0.2
910		10.28 K	0.72	3.39	0.2
900		10.28 K	0.22	3.47	0.2
1 K		10.28 K	0.57	3.58	0.22
1.2 K		10.28 K	1.10	3.90	3.4 (unstable)
1 K		7.5 K	1.03	3.95	1.16
1 K		4.7 K	3.70	4.27	2.79
1 K		12.35K	0.19	3.43	0.18
1 K		13.18 K	0.17	3.38	0.19
1 K		14.75 K	0.18	3.20	0.17
1 K		11.22 K	0.26	3.62	0.20
1 K		11.00 K	0.21	3.65	0.24
1 K		10.50 K	0.18	3.72	0.26
1 K		10.28 K	0.21	3.75	0.21
1 K		9.00 K	0.60	3.64	0.20
1 K		10.28 K	0.60	3.52	0.20
1 K		9.95 K	0.27	3.62	0.25

Optimum: R1 = 1 K, R2 = 10 K

Note: See chapter 4 for modification correcting defective sensors.

C2. Laboratory Tests of Vacuum Loss and Time to Sample.

Table C3. Vacuum loss testing.

Conditions	Vacuum (in. Hg) At Tank	At End of Line
31 m of 5/32" (4 mm) polyethelene tubing stretched across floor relatively straight	15.7 24.5	14.7 in 5 sec. 23.5 in < 10 sec.
Loosely rolled up in floor in approx. 10 m^2	24	15.0 in 5 sec. 22.0 in 10 sec.

Table C4. Time to sample testing. Test performed with 46 m of 5/32" (4 mm) polyethelene tubing loosely rolled up in the floor pulling a 100 ml sample approx. 300 cm negative head.

Vacuum at Tank (in. Hg)	Vacuum at Sample Jar at Time of Drawing Water (in. Hg)	Time Until Water Enters Jug (sec.)	Total Time to Sample (sec.) (100 ml)
20	9	18	-
19.5	9	15	28
16	9	22	38
14.5	9	21	35
25	9	12	23

APPENDIX D

COMPUTER PROGRAMS, PROCEDURES, AND FIELD SERVICE SCHEMATICS

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D1. BOOTA Program

	Comments
`5 CONFIG PIO 0,0,1,0,1,1`	Configures I/O
`10 P%=&5000`	Sets beginning memory pointer
`20 DIM T(7), D(7)`	
`30 FOR X=1 TO 7`	
`40 D(X) = VAL(MID$(DATE$(0),4,2))`	Lines 20 - 60 initializes time and date
`50 T(X) = VAL(LEFT$(TIME$(0),2))`	for each well.
`60 NEXT X`	
`90 FOR X=1 TO 7`	
`100 D=VAL(MID$(DATE$(0),4,2))`	Lines 90 - 170 checks for 4 hr.
minimum	
`110 T=VAL(LEFT$(TIME$(0),2))`	since last time reset (sample) and 7
days	
`130 IF T <T(X) GOTO 160`	max. since last sample.
`140 IF T(X)+4 >T THEN NEXT X ELSE GOTO 200`	
`150 GOTO 90`	
`160 IF T(X)-T>20 THEN NEXT X ELSE GOTO 200`	
`170 GOTO 90`	
`200 LLS=BIT(0,X)`	
`210 IF LLS=0 GOTO 499`	Lines 200 - 290 checks signal from
level	
`220 IF D<D(X) GOTO 270`	switch, only enters this loop if > 4 hrs
`240 IF D(X)+7 =D GOTO 490`	since last sample.
`250 GOTO 280`	
`270 IF D(X)-D=23 GOTO 490`	
`280 NEXT X`	
`290 GOTO 90`	
`490 A=X+10`	Stores as I/O add. + 10 if 7 day
sample.	
`491 IF P% = &5FFF GOTO 560`	Lines 491 & 499 limits data storage to
`495 POKE P%,A,1`	Prevent over writting program.
`496 GOTO 510`	
`499 IF P% = &5FFF GOTO 560`	
`500 POKE P%,X,1`	Stores I/O add. If normal sample
`510 POKE P%+1,VAL(LEFT$(DATE$(0),2)),1`	Month
`520 POKE P%+2,D,1`	Day
`530 POKE P%+3,T,1`	Hour
`540 POKE P%+4,VAL(MID$(TIME$(0),4,2)),1`	Minute
`550 P%=P%+5`	Moves pointer
`560 T(X)=VAL(LEFT$(TIME$(0),2))`	Resets time and date value for well
`570 D(X)=VAL(MID$(DATE$(0),4,2))`	sampled.
`600 IF X=1 THEN GOSUB 1000`	Sends to subroutine 1000 for wells
`610 IF X=2 THEN GOSUB 1000`	> 29 m from vacuum.
`630 IF X=7 THEN GOSUB 1000`	
`640 IF X=3 THEN GOSUB 2000`	
`641 IF X=4 THEN GOSUB 2000`	Sends to subroutine 2000 for wells
`642 IF X=5 THEN GOSUB 2000`	< 30 m from vacuum.
`643 IF X=6 THEN GOSUB 2000`	

```
650 NEXT X
660 GOTO 90
1000 CONFIG TIMER 1,1,X,0,60,1                          Sets line X port B high for 60 sec.
1010 START TIMER 1                                            (opens isonic valve)

1020 DELAY 30                                                 Delay 30 sec. before
checking
1030 FS=BIT(2,X)                                              flow sensor
1040 IV=BIT(1,X)
1050 IF FS=0 THENDELAY 1 ELSE GOTO 1070                       Two consecutive "low"
signals
1060 IF FS=0 THEN CLEAR TIMER 1                               from flow sensor sets bit low.
1070 IF IV=0 THEN CLEAR TIMER 1 ELSE GOTO 1030                Sets bit low after 60 sec. if
1080 RETURN                                                   flow sensor fails.
2000 CONFIG TIMER 1,1,X,0,45,1
2010 START TIMER 1
2020 DELAY 20
2030 FS=BIT(2,X)
2040 IV=BIT(1,X)
2050 IF FS=0 THEN DELAY 1 ELSE GOTO 2070
2060 IF FS=0 THEN CLEAR TIMER 1
2070 IF IV=0 THEN CLEAR TIMER 1 ELSE GOTO 2030
2080 RETURN
```

Note: The BOOT and TEST Programs may be revised in the future to power the flow sensors only while sampling. The revision will be made by adding a relay connected to bit 0 of port B and by adding the following lines to the programs.

```
7 BIT 1,0,ON
1025 BIT 1,0,OFF
1075 BIT 1,0,ON
2025 BIT 1,0,OFF
2075 BIT 1,0,ON
```

D2. BOOTB Program

```
5 CONFIG PIO 0,0,1,0,1,1
10 P%=&5000
20 DIM T(7), D(7)
30 FOR X=1 TO 7
40 D(X) = VAL(MID$(DATE$(0),4,2))
50 T(X) = VAL(LEFT$(TIME$(0),2))
60 NEXT X
90 FOR X=1 TO 7
100 D=VAL(MID$(DATE$(0),4,2))
110 T=VAL (LEFT$(TIME$(0),2))
130 IF T <T(X) GOTO 160
140 IF T(X)+4 >T THEN NEXT X ELSE GOTO 200
150 GOTO 90
160 IF T(X)-T>20 THEN NEXT X ELSE GOTO 200
170 GOTO 90
200 LLS=BIT(0,X)
210 IF LLS=0 GOTO 499
220 IF D<D(X) GOTO 270
240 IF D(X)+7 =D GOTO 490
250 GOTO 280
270 IF D(X)-D=23 GOTO 490
280 NEXT X
290 GOTO 90
490 A=X+10
491 IF P% = &5FFF GOTO 560
495 POKE P%,A,1
496 GOTO 510
499 IF P% = &5FFF GOTO 560
500 POKE P%,X,1
510 POKE P%+1,VAL(LEFT$(DATE$(0),2)),1
520 POKE P%+2,D,1
530 POKE P%+3,T,1
540 POKE P%+4,VAL(MID$(TIME$(0),4,2)),1
550 P%=P%+5
560 T(X)=VAL(LEFT$(TIME$(0),2))
570 D(X)=VAL(MID$(DATE$(0),4,2))
600 IF X=1 THEN GOSUB 1000
610 IF X=4 THEN GOSUB 1000
630 IF X=5 THEN GOSUB 1000
640 IF X=6 THEN GOSUB 1000
641 IF X=7 THEN GOSUB 1000
642 IF X=2 THEN GOSUB 2000
643 IF X=3 THEN GOSUB 2000
650 NEXT X
660 GOTO 90
1000 CONFIG TIMER 1,1,X,0,60,1
1010 START TIMER 1
1020 DELAY 30
1030 FS=BIT(2,X)
1040 IV=BIT(1,X)
```

```
1050 IF FS=0 THENDELAY 1 ELSE GOTO 1070
1060 IF FS=0 THEN CLEAR TIMER 1
1070 IF IV=0 THEN CLEAR TIMER 1 ELSE GOTO 1030
1080 RETURN
2000 CONFIG TIMER 1,1,X,0,45,1
2010 START TIMER 1
2020 DELAY 20
2030 FS=BIT(2,X)
2040 IV=BIT(1,X)
2050 IF FS=0 THEN DELAY 1 ELSE GOTO 2070
2060 IF FS=0 THEN CLEAR TIMER 1
2070 IF IV=0 THEN CLEAR TIMER 1 ELSE GOTO 2030
2080 RETURN
```

D3. BOOTC Program
(Revised to bypass bit 4 in port A due to malfunction)

```
5 CONFIG PIO 0,0,1,0,1,1
10 P%=&5000
20 DIM T(7), D(7)
30 FOR X=0 TO 7
35 IF X = 4 GOTO 60
40 D(X) = VAL(MID$(DATE$(0),4,2))
50 T(X) = VAL(LEFT$(TIME$(0),2))
60 NEXT X
90 FOR X=0 TO 7
95 IF X = 4 GOTO 280
100 D=VAL(MID$(DATE$(0),4,2))
110 T=VAL(LEFT$(TIME$(0),2))
130 IF T <T(X) GOTO 160
140 IF T(X)+4 >T THEN NEXT X ELSE GOTO 200
150 GOTO 90
160 IF T(X)-T>20 THEN NEXT X ELSE GOTO 200
170 GOTO 90
200 LLS=BIT(0,X)
210 IF LLS=0 GOTO 499
220 IF D<D(X) GOTO 270
240 IF D(X)+7 =D GOTO 490
250 GOTO 280
270 IF D(X)-D=23 GOTO 490
280 NEXT X
290 GOTO 90
490 A=X+10
491 IF P%=&5FFF GOTO 560
495 POKE P%,A,1
496 GOTO 510
499 IF P%=&5FFF GOTO 560
500 POKE P%,X,1
510 POKE P%+1,VAL(LEFT$(DATE$(0),2)),1
520 POKE P%+2,D,1
530 POKE P%+3,T,1
540 POKE P%+4,VAL(MID$(TIME$(0),4,2)),1
550 P%=P%+5
560 T(X)=VAL(LEFT$(TIME$(0),2))
570 D(X)=VAL(MID$(DATE$(0),4,2))
600 IF X=3 THEN GOSUB 1000
610 IF X=0 THEN GOSUB 1000
630 IF X=5 THEN GOSUB 1000
640 IF X=6 THEN GOSUB 1000
641 IF X=7 THEN GOSUB 1000
642 IF X=1 THEN GOSUB 2000
643 IF X=2 THEN GOSUB 2000
650 NEXT X
660 GOTO 90
1000 CONFIG TIMER 1,1,X,0,180,1
```

```
1010 START TIMER 1
1020 DELAY 30
1030 FS=BIT(2,X)
1040 IV=BIT(1,X)
1050 IF FS=0 THENDELAY 1 ELSE GOTO 1070
1060 IF FS=0 THEN CLEAR TIMER 1
1070 IF IV=0 THEN CLEAR TIMER 1 ELSE GOTO 1030
1080 RETURN
2000 CONFIG TIMER 1,1,X,0,45,1
2010 START TIMER 1
2020 DELAY 20
2030 FS=BIT(2,X)
2040 IV=BIT(1,X)
2050 IF FS=0 THEN DELAY 1 ELSE GOTO 2070
2060 IF FS=0 THEN CLEAR TIMER 1
2070 IF IV=0 THEN CLEAR TIMER 1 ELSE GOTO 2030
2080 RETURN
```

D4. TESTA Program
(omits four hour delay before sampling)

```
5 CONFIG PIO 0,0,1,0,1,1
10 P%=&5000
90 FOR X=1 TO 7
100 D=VAL(MID$(DATE$(0),4,2))
110 T=VAL(LEFT$(TIME$(0),2))
200 LLS=BIT(0,X)
210 IF LLS=0 GOTO 499
280 NEXT X
290 GOTO 90
499 IF P%=&5FFF GOTO 600
500 POKE P%,X,1
510 POKE P%+1,VAL(LEFT$(DATE$(0),2)),1
520 POKE P%+2,D,1
530 POKE P%+3,T,1
540 POKE P%+4,VAL(MID$(TIME$(0),4,2)),1
550 P%=P%+5
600 IF X=1 THEN GOSUB 1000
610 IF X=2 THEN GOSUB 1000
630 IF X=7 THEN GOSUB 1000
640 IF X=3 THEN GOSUB 2000
641 IF X=4 THEN GOSUB 2000
642 IF X=5 THEN GOSUB 2000
643 IF X=6 THEN GOSUB 2000
650 NEXT X
660 GOTO 90
1000 CONFIG TIMER 1,1,X,0,60,1
1010 START TIMER 1
1020 DELAY 30
1030 FS=BIT(2,X)
1040 IV=BIT(1,X)
1050 IF FS=0 THENDELAY 1 ELSE GOTO 1070
1060 IF FS=0 THEN CLEAR TIMER 1
1070 IF IV=0 THEN CLEAR TIMER 1 ELSE GOTO 1030
1080 RETURN
2000 CONFIG TIMER 1,1,X,0,45,1
2010 START TIMER 1
2020 DELAY 20
2030 FS=BIT(2,X)
2040 IV=BIT(1,X)
2050 IF FS=0 THEN DELAY 1 ELSE GOTO 2070
2060 IF FS=0 THEN CLEAR TIMER 1
2070 IF IV=0 THEN CLEAR TIMER 1 ELSE GOTO 2030
2080 RETURN
```

D5. TESTB Program

```
5 CONFIG PIO 0,0,1,0,1,1
10 P%=&5000
90 FOR X=1 TO 7
100 D=VAL(MID$(DATE$(0),4,2))
110 T=VAL(LEFT$(TIME$(0),2))
200 LLS=BIT(0,X)
210 IF LLS=0 GOTO 499
280 NEXT X
290 GOTO 90
499 IF P%=&5FFF GOTO 600
500 POKE P%,X,1
510 POKE P%+1,VAL(LEFT$(DATE$(0),2)),1
520 POKE P%+2,D,1
530 POKE P%+3,T,1
540 POKE P%+4,VAL(MID$(TIME$(0),4,2)),1
550 P%=P%+5
600 IF X=1 THEN GOSUB 1000
610 IF X=4 THEN GOSUB 1000
630 IF X=5 THEN GOSUB 1000
640 IF X=6 THEN GOSUB 1000
641 IF X=7 THEN GOSUB 1000
642 IF X=2 THEN GOSUB 2000
643 IF X=3 THEN GOSUB 2000
650 NEXT X
660 GOTO 90
1000 CONFIG TIMER 1,1,X,0,60,1
1010 START TIMER 1
1020 DELAY 30
1030 FS=BIT(2,X)
1040 IV=BIT(1,X)
1050 IF FS=0 THENDELAY 1 ELSE GOTO 1070
1060 IF FS=0 THEN CLEAR TIMER 1
1070 IF IV=0 THEN CLEAR TIMER 1 ELSE GOTO 1030
1080 RETURN
2000 CONFIG TIMER 1,1,X,0,45,1
2010 START TIMER 1
2020 DELAY 20
2030 FS=BIT(2,X)
2040 IV=BIT(1,X)
2050 IF FS=0 THEN DELAY 1 ELSE GOTO 2070
2060 IF FS=0 THEN CLEAR TIMER 1
2070 IF IV=0 THEN CLEAR TIMER 1 ELSE GOTO 2030
2080 RETURN
```

D6. TESTC Program
(without revision to bypass bit 4, port A)

```
5 CONFIG PIO 0,0,1,0,1,1
10 P%=&5000
20 DIM T(7), D(7)
90 FOR X=1 TO 7
100 D=VAL(MID$(DATE$(0),4,2))
110 T=VAL(LEFT$(TIME$(0),2))
200 LLS=BIT(0,X)
210 IF LLS=0 GOTO 499
280 NEXT X
290 GOTO 90
499 IF P%=&5FFF GOTO 600
500 POKE P%,X,1
510 POKE P%+1,VAL(LEFT$(DATE$(0),2)),1
520 POKE P%+2,D,1
530 POKE P%+3,T,1
540 POKE P%+4,VAL(MID$(TIME$(0),4,2)),1
550 P%=P%+5
600 IF X=3 THEN GOSUB 1000
610 IF X=4 THEN GOSUB 1000
630 IF X=5 THEN GOSUB 1000
640 IF X=6 THEN GOSUB 1000
641 IF X=7 THEN GOSUB 1000
642 IF X=1 THEN GOSUB 2000
643 IF X=2 THEN GOSUB 2000
650 NEXT X
660 GOTO 90
1000 CONFIG TIMER 1,1,X,0,180,1
1010 START TIMER 1
1020 DELAY 30
1030 FS=BIT(2,X)
1040 IV=BIT(1,X)
1050 IF FS=0 THENDELAY 1 ELSE GOTO 1070
1060 IF FS=0 THEN CLEAR TIMER 1
1070 IF IV=0 THEN CLEAR TIMER 1 ELSE GOTO 1030
1080 RETURN
2000 CONFIG TIMER 1,1,X,0,45,1
2010 START TIMER 1
2020 DELAY 20
2030 FS=BIT(2,X)
2040 IV=BIT(1,X)
2050 IF FS=0 THEN DELAY 1 ELSE GOTO 2070
2060 IF FS=0 THEN CLEAR TIMER 1
2070 IF IV=0 THEN CLEAR TIMER 1 ELSE GOTO 2030
2080 RETURN
```

D7. ADATA Program

```
10 P%=&5000
20 PRINT "ASW","MO","DAY","HR","MIN"
25 FOR X= 1 TO 300
30 PRINT PEEK(P%,1),PEEK(P%+1,1),PEEK(P%+2,1),PEEK(P%+3,1),PEEK(P%+4,1)
40 P%=P%+5
50 NEXT X
60 STOP
```

D8. IVTEST Program
(tests operation of isonic valves)

```
10 CONFIG PIO 0,0,1,0,1,1
20 FOR X=1 TO 7
30 BIT 1,X,ON
40 DELAY 5
50 BIT 1,X,OFF
60 DELAY 1
70 NEXT X
80 STOP
```

Note: This program can be revised to pull a sample from each well manually by increasing the delay in line 40.

D9. Download Procedure

Note: The following procedures assume the use of ProCom Communication software, procedures may vary some between versions and from other communications software like Terminal for Windows.

A. CONNECT RIBBON TO BACK OF LAPTOP AND TO SOCKET U10 ON COMPUTER BOARD. AT THE C PROMPT TYPE

CD\PCPLUS ↵

(or PROCOM)

PCPLUS ↵

WHEN SCREEN IS UP PUSH 'ESC' KEY, TYPE

NEW ↵

B. INSTALL DISK IN DRIVE A, TYPE

LOAD "ADATA" (OR "BDATA" OR "CDATA") ↵

C. PUSH '`' KEY, MENU WILL APPEAR AT TOP, SELECT 'FILE', THEN SELECT 'RECEIVE'. A SCREEN WILL APPEAR ASKING YOU TO MAKE A SELECTION, SELECT #4 (ASCII). A SCREEN WILL APPEAR ASKING FOR A FILE NAME, TYPE

A:XDATMMDD.TXT ↵ (X: SYSTEM LETTER - A, B, OR C)

RUN ↵ (DATA SHOULD PRINT ON SCREEN AND COPY ONTO DISK)

PUSH 'ESC' KEY, GO THROUGH STEP C WITH A SECOND DISK (YOU CAN CHECK FILES ON DISK A BY PUSHING 'ALT' & 'F' KEYS AT SAME TIME.)

PUSH 'ESC' KEY

D. TYPE

NEW ↵

MON ↵

F 5000 5FFF 00 1 ↵ (THIS CLEARS THE MEMORY WHERE DATA IS STORED)

Q ↵

NEW ↵

LOAD "BOOTA" ↵ **(or "BOOTB" or "BOOTC")**

RUN ↵

D10. Procedure for checking and setting calendar and clock.

<u>Clock</u>

type

PRINT TIME$(0) ↩

This should print out the time in *hours:minutes:seconds*
If time is incorrect wait a couple of minutes, then type again, If time reads the same then the clock is off. Do the following to turn clock on.

Type

CONFIG CLOCK ON ↩

If the clock is running but incorrect, proceed as follows:

Type

TIME$="HH:MM:SS" ↩ (military time) for the correct time

Type

PRINT TIME$(0) ↩ to check

<u>Calendar</u>

type

PRINT DATE$(0) ↩

This should print out the date in *month-day-year.*
If the date is incorrect, proceed as follows:

Type

DATE$="MO-DY-YR" ↩ (example: "04:26:96")

Type

PRINT DATE$(0) ↩ to check

D11a. Procedure for uploading files (programs) from a disk to the EEPROM of the Octagon board.

Note: This procedure may be used to upload files from a disk after reconfiguring the EEPROM. To reconfigure the EEPROM, type in the CONFIG SSD 1 command and enter. This will erase all programs stored in the EEPROM. Type FILES command and enter and the files (or programs) in the EEPROM will be listed.

Connect to board and establish link with communications software.

Push the 'ESC' key to break into program if it is running.

Push the '`' key to bring up the menu (or 'PAGE DOWN' key)

Select "FILE"

Select "SEND"

Select "ASCII"

Enter Filename: A:BOOTA.TXT (for example)

Type **SAVE "BOOTA"** or what ever name you wish to give the program and enter

Type **NEW** after each save or anytime a program is loaded and you wish to load another program. Otherwise the two programs will overwrite.

D11b. Procedure for copying a program from EEPROM to a disk using Procom.

Bring up menu.

Select "FILE"

Select "RECEIVE"

Select "ASCII"

Enter filename: A:BOOTC.TXT (for example)

Type **LIST** and enter

Press 'ESC' when copying is complete

D12. Trouble shooting procedure.

A. Check voltage at input of 5081 card (J7), should be 5V +/-0.25.

B. In terminal mode of ProComm, push <ESC>. If program was running should get a stop and line # message. You can verify communication by typing [files], this should list the files stored in EEPROM. If no response and cannot type any letters, then laptop is not communicating with the 5081 card. Push <ESC> about 5 times about 1 second apart. This enables the 5081 card to adjust to the baud rate etc of the communication software. If this does not work, push <ESC> 5 more times. If still no communication, RESET, go through pushing <ESC> routine. If still no communication change out the connector ribbon with one you know is good. <u>If still no communication, proceed as follows.</u>

Set Baud Rate in ProComm:

Bring up the menu at top of screen, select "Change", then select "Line Settings". This should put up a box with parameters. Set at **9600** baud, **8** data bits, **no parity**, and **1 stop bit.** Save and exit.

Go through pushing <ESC> routine as described above. If still no communication, RESET. <u>If still no communication, go home and try again another day.</u>

C. If communication link continues to be a problem, on a good day (communication established), proceed as follows (**use with caution!**).

Set Baud Rate of 5081 Card:

-type [config baud 1,6,5,0], check communication by pushing <ESC> routine and typing [files] as described earlier.

D13. Procedure for resetting auto reboot.

Note: This procedure was received from Octagon Systems Technical Support and did not work when performed on two boards that were not auto rebooting. It is included here for information.

Disable Autorun and Reenable:

-type [RENAME "BOOTB","ABOOTB"] or "BOOTC"

-type [files], this should list file names to verify if name -change was successful, if not do again.

-Power off (disconnect battery)

-Pull jumper on pin 1,2 of block W3.

-Power up

-Replace jumper

-RESET (should not autorun)

-type [RENAME "ABOOTB","BOOTB"

-type [files] to verify name change

-RESET, should autorun with boot program

-test by pushing <ESC>, should get a stop and line # message if successful. If not successful, call for help.

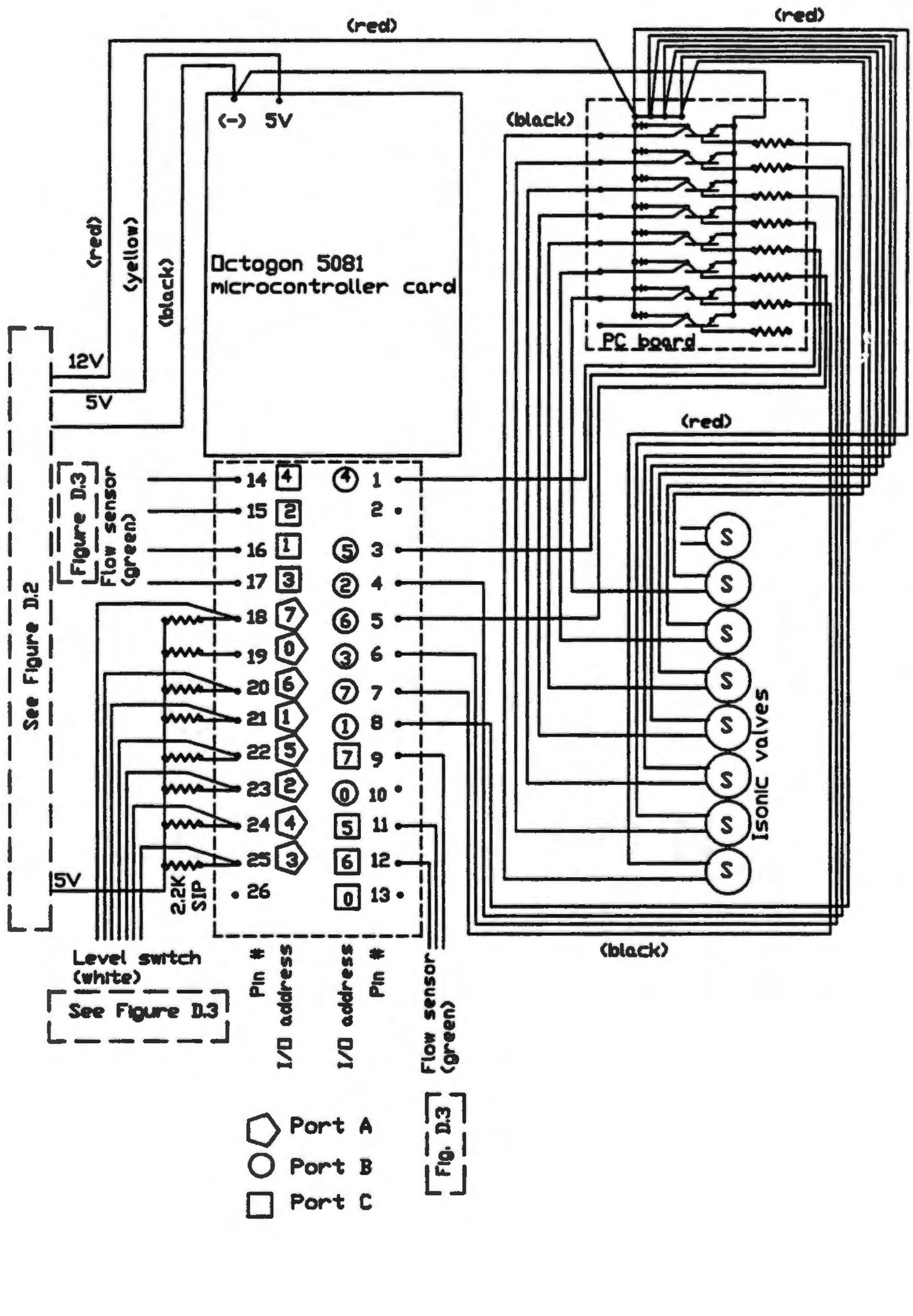

Figure D.1. Schematic of general arrangement of electronic components in the enclosure.

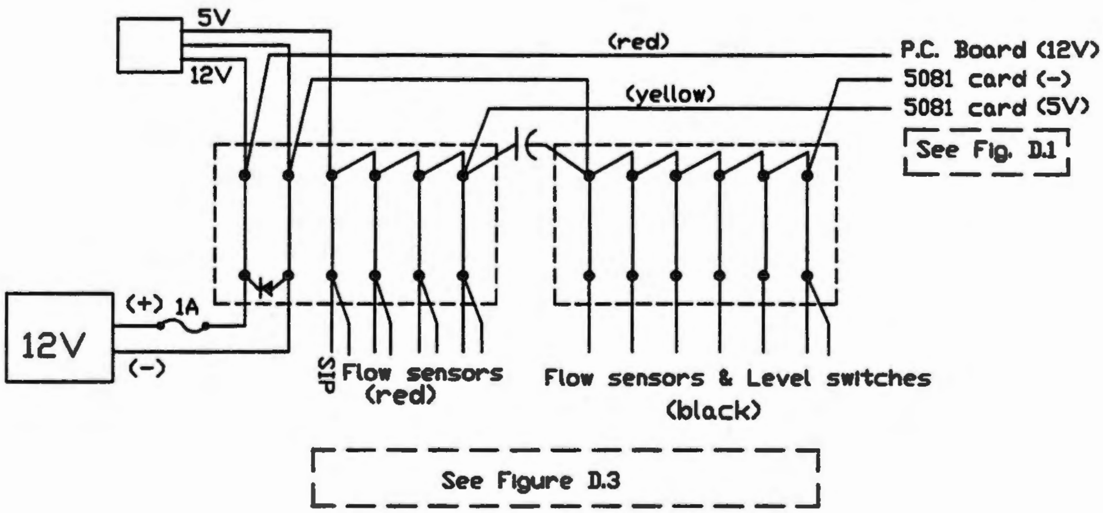

Figure D.2. Schematic of terminal block in enclosure.

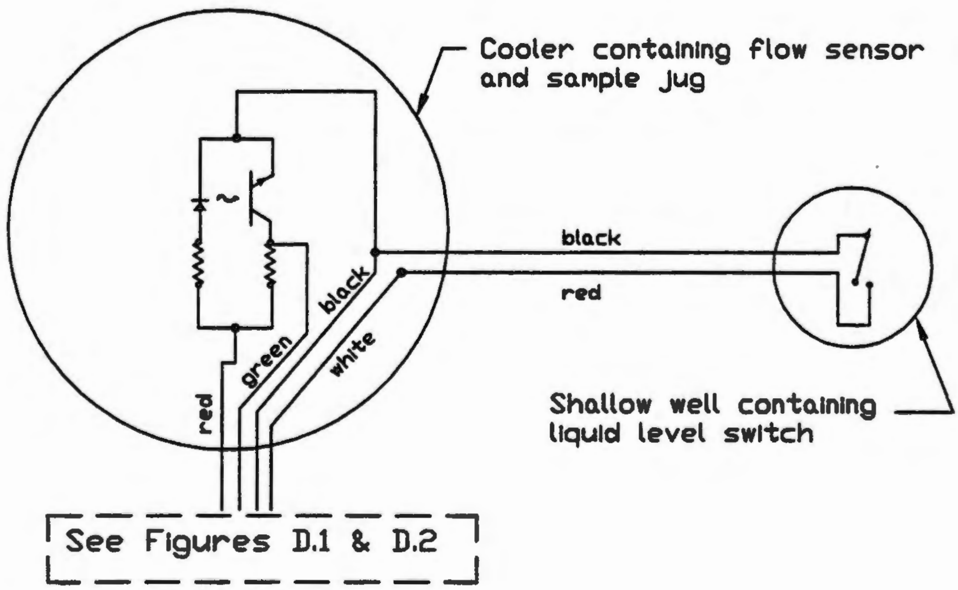

Figure D.3. Schematic of flow sensor and level switch.

APPENDIX E

SUMMARY OF TECHNICAL AND PROGRAM PROBLEMS

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Table E3. System C Downloads With Log Notes 123

E1. Summary of Technical and Programing Problems Encountered.

Although the Octagon 5081 microcontroller cards have internal batteries, the memory is volatile. Some data was lost when 12-V batteries were taken off for charging, or when the reset button was pushed. The technician reported difficulty maintaining adequate vacuum in the vacuum tanks. A second vacuum tank was added to each system and all connections were taken apart and put back together with thread compound in October. In September and October the download disks were infected with a virus and some of the data was lost. In November a download disk was defective and the files were not readable. In December an error was discovered in line 1070 of the boot programs. There was an "o" were there should have been a "0." Line 1070 is an override command that bypasses the flow sensor if it has not signaled the board to set the isonic valve bit low after a specific amount of time has passed. As early as October 16, the technician reported problems in the operation and downloading of system C. In December and January, the technician reported difficulty maintaining adequate charge in the batteries. In late December, systems B and C were not operating. The light emitting diodes on the valves were dimly lit each time the technician checked them. When servicing the systems, it was found that the boards were not auto rebooting. When the program was not running a small current would run to the valves turning the light emitting diodes on. It is possible that the boards were shutting off when the battery voltage dropped below an adequate charge. Also, the technician had been instructed to push the reset button after installing a charged battery, but systems B and C were not rebooting with this procedure. The EEPROM was reconfigured using the CONFIG SSD 1 command and the programs were reloaded. The boards appeared to operate properly but would not automatically reboot.

In January, deep cycle marine batteries were installed with each system. Due to mismatched connector plugs, systems A and B were connected with reverse polarity blowing the transistorized valve controls and the voltage regulators. Although system C was connected properly, the technician reported that the system did not appear to be operating properly. Systems A and B were repaired and put back into service February 28,1996. An automatic reboot reset procedure from Octagon Technical Services was unsuccessfully performed on systems B and C. Shallow well 85 (system C) had approximately 0.4 L of water in it. The BOOT program was not allowing enough time for the vacuum to pull a 0.4-L sample. A third subroutine was added to the boot program that would allow enough time to sample this amount of water.

On March 5 the technician reported the light emitting diodes were dimly lit on all three systems and the boot program did not appear to be running on any of the systems. Systems A and C were giving a CONFIG MISMATCH ERROR 44 message. The only explanation given in the Octagon manual for this error message is "reserved" (Octagon, 1993). Air temperatures had been as low as -14 ° C. The systems were disconnected from the batteries. On March 15, all three systems were reconfigured using the CONFIG SSD 1 command and the programs were reinstalled. The systems automatically rebooted and systems A and B appeared to operate properly. System C experienced several problems.

The microcontroller card in system C was not executing the program properly. The program loops and IF conditions were not being executed. The last subroutine, specific to I/O address 4 (well 85), appeared to be all that was being executed. The valve for well 85 repeatedly opened and closed. Debugging procedures were carried out using the STOP command. The STOP commands were ignored and the last subroutine would be executed. The third subroutine was deleted and one of the existing subroutines was revised to handle the large sample volume of well 85. The program appeared to be properly executed but bit 4 in port A (liquid level switch for well 85) was not being read correctly. Bit 4 in port A was bypassed in the program and bit 0 was used in it's place. The wiring was modified to accommodate the revised program. System C appeared to work correctly until April 8 when the technician reported that it was giving the CONFIG MISMATCH ERROR 44 message again. The enclosure and electronics were removed and examined in the electronics laboratory. During the malfunction, data had been written over part of

the program and the chip reading the I/O addresses of port A was defective. The program is being revised to prevent data overwriting the programs and a new chip is on order. Successful downloads and condensed log notes of problems and maintenance are included in Appendix E (Tables E1, E2, and E3).

Table E1. System A Downloads With Log Notes

SYSTEM A I/O Address	MO	DAY	HR	MIN	Well No.	Log Notes:
	(Aug. & Sept. downloads)					8/15/95 - 8/18/95 installed systems, tested, and adjusted programs.
14	8	24	0	0	74	I/O address + 10 indicate weekly sample if > 7
15	8	24	0	0	75	days since previous sample.
16	8	24	0	0	76	
17	8	24	0	1	3	No samples
11	8	24	0	1	71	
12	8	24	0	2	72	
13	8	24	0	2	73	
5	8	25	6	0	75	
5	8	25	12	0	75	No sample, level switch is stuck, repaired
5	8	25	18	0	75	early Oct. after looking at data.
5	8	26	0	0	75	
5	8	26	6	0	75	
5	8	26	12	0	75	
5	8	26	18	0	75	
5	8	27	0	0	75	
5	8	27	6	0	75	
5	8	27	12	0	75	
5	8	27	18	0	75	
5	8	28	0	0	75	
5	8	28	6	0	75	
5	8	28	12	0	75	
5	8	28	18	0	75	
5	8	29	0	0	75	
5	8	29	6	0	75	
5	8	29	12	0	75	
5	8	29	18	0	75	
5	8	30	0	0	75	
5	8	30	6	0	75	
5	8	30	12	0	75	
5	8	30	18	0	75	
5	8	31	0	0	75	
5	8	31	6	0	75	
						Technician reportd problems establishing link with board in early Sept.
5	9	8	13	0	75	
5	9	8	19	0	75	
5	9	9	1	0	75	
5	9	9	7	0	75	
5	9	9	13	0	75	
5	9	9	19	0	75	
5	9	10	1	0	75	
5	9	10	7	0	75	
5	9	10	13	0	75	
5	9	10	19	0	75	
5	9	11	1	0	75	
5	9	11	7	0	75	
5	9	11	13	0	75	
5	9	11	19	0	75	
5	9	12	1	0	75	
5	9	12	7	0	75	
5	9	12	13	0	75	
5	9	12	19	0	75	
5	9	13	1	0	75	
5	9	13	7	0	75	
5	9	13	13	0	75	
5	9	13	19	0	75	
5	9	14	1	0	75	
5	9	14	7	0	75	
5	9	14	13	0	75	
5	9	14	19	0	75	
5	9	15	1	0	75	
5	9	15	7	0	75	
5	9	15	13	0	75	
5	9	15	19	0	75	
5	9	16	1	0	75	
5	9	16	7	0	75	
5	9	16	13	0	75	

Table E1. System A Downloads With Log Notes

5	9	16	19	0	75	
5	9	17	1	0	75	
5	9	17	7	0	75	
5	9	17	13	0	75	
5	9	17	19	0	75	
13	9	18	0	0	73	
14	9	18	0	0	74	
16	9	18	0	0	76	No weekly sample.
17	9	18	0	1	3	
11	9	18	0	1	71	
12	9	18	0	2	72	
5	9	18	1	0	75	
5	9	18	7	0	75	
5	9	18	13	0	75	
5	9	18	19	0	75	
5	9	19	1	0	75	
5	9	19	7	0	75	
5	9	19	13	0	75	
5	9	19	19	0	75	
5	9	20	1	0	75	
5	9	20	7	0	75	
5	9	20	16	0	75	
5	9	20	22	0	75	
5	9	21	4	0	75	
5	9	21	10	0	75	
5	9	21	16	0	75	
5	9	21	22	0	75	
5	9	22	4	0	75	
5	9				75	
	(10/1x/95 download)					Download disks were infected with virus "form," not all of files copied to new disks, lost data from late Sept. & early Oct. downloads.
5	10	12	13	0	75	
						10/11/95 added 2nd vacuum tank to each system & repaired leaks.
						10/12/95 revised boot program to sample every 4 hrs instead of 6.
						Part of file name being lost, to many characters.
	(10/3x/95 download)					
14	10	25	0	0	74	
15	10	25	0	0	75	
16	10	25	0	0	76	No weekly samples.
17	10	25	0	1	3	
11	10	25	0	1	71	
12	10	25	0	2	72	
13	10	25	0	2	73	
	(early Nov. downloads)					Nonsense data caused by memory loss during battery change or power loss . Corrected by downloading first.
118	50	127	182	222		
195	245	228	206	126		
etc.						
	11/2x/95 download					
14	0	22	0	0	74	
15	0	22	0	0	75	
16	0	22	0	0	76	No weekly samples.
17	0	22	0	1	3	
11	0	22	0	1	71	
12	0	22	0	2	72	
13	0	22	0	2	72	
						Problems reading disk.
	(11/3x/95 download, only 0's)					
0	0	0	0	0		
						Problems reading disk.
	(12/0x/95 download, only 0's)					
0	0	0	0	0		12/12/95 # 75 yielded ......ml sample.
						12/20/95 corrected line 1070 of boot program, replaced o with 0. Line 1070 is for flow sensor override in case of sensor failure.
	(12/21/95 download)					
255	255	255	0	0		
etc.						

Table E1. System A Downloads With Log Notes

(12/29/95 download)						
16	0	27	0	0	76	On 12/19/95 battery was < 4V, clock probably shut off during low power or whille battery was unhooked and being charged.
17	0	27	0	0	3	
11	0	27	0	0	71	No weekly samples.
12	0	27	0	1	72	
13	0	27	0	1	73	
14	0	27	0	2	74	
15	0	27	0	2	75	
(1/5/96 download)						1/4/96 # 75 yielded ....ml sample.
5	0	30	13	0	75	
5	0	30	17	0	75	Clock is off.
5	0	30	21	0	75	
5	14	1	1	0	75	
5	14	1	5	0	75	
5	14	1	9	0	75	
5	14	1	13	0	75	
1/12/96 download						Dec. & Jan. batteries not staying charged. Memory loss due to power drain or battery change.
118	50	127	150	222		
etc.						
1/19/96 download						No sample, level switch is stuck.
5	14	18	15	51	75	
5	14	18	19	0	75	
5	14	18	23	0	75	Installed marine deep cycle battery late Jan. 1/29/96 # 75 yielded ......ml sample.
						System A was down from late Jan. to 2/28/96 due to power reversal. Electronics repaired and fuse protection installed in all 3 systems.
						Malfunction during early March, gave 'config mismatch error 44' message,LED's dimly lit, battery dead. Temperature as low as 6 deg. F. 3/15/96 reconfigured EEPROM (config ssd 1) and reloaded programs.
(3/18/96 download)						
112	132	0	0	112		
132	0	0	112	132		
etc.						
(3/22/96 download)						
5	3	19	4	31	75	Yeilded 450 ml sample.
5	3	19	8	0	75	
(3/29/96 download)						
17	3	29	0	0	3	No weekly sample.
11	3	29	0	0	71	Clock may have shut off during battery change.
12	3	29	0	1	72	
13	3	29	0	1	73	
(4/5/96 download, only 0's)						
0	0	0	0	0		
(4/12/96 download)						
11	15	23	2	0	71	
12	15	23	2	0	72	No weekly samples.
13	15	23	2	1	73	
14	15	23	2	1	74	
15	15	23	2	1	75	
16	15	23	2	2	76	
17	15	23	2	2	3	

Table E2. System B Downloads With Log Notes

SYSTEM B I/O Address	MO	DAY	HR	MIN	Well No.	Log Notes:
						8/15/95 - 8/18/95 installed systems, tested, and adjusted programs.
	(8/25/95 download)					
15	8	24	0	0	12	I/O address + 10 indicate weekly sample if > 7
16	8	24	0	0	83	days since previous sample.
17	8	24	0	1	84	
11	8	24	0	1	77	No weekly samples.
12	8	24	0	2	78	
13	8	24	0	2	6	
14	8	24	0	2	79	
						Technician reportd problems establishing link with board in early Sept.
	(9/11/95 download)					
8	0	0	0	255		Memory loss due to power drain or battery
255	255	255	8	0		change.
etc.						
	(9/20 /95 - 10/30/95 downloads)					
17	9	18	0	0	84	
11	9	18	0	0	77	Weekly sample of ......ml 19/18/95.
12	9	18	0	1	78	
13	9	18	0	1	6	No other weekly samples.
14	9	18	0	1	79	
15	9	18	0	2	12	
16	9	18	0	2	83	
17	9	27	0	0	84	
11	9	27	0	0	77	
12	9	27	0	1	78	
13	9	27	0	1	6	No weekly samples
14	9	27	0	1	79	
15	9	27	0	2	12	
16	9	27	0	2	83	
17	10	4	0	0	84	
11	10	4	0	0	77	
12	10	4	0	1	78	
13	10	4	0	1	6	No weekly samples
14	10	4	0	1	79	
15	10	4	0	2	12	10/11/95 added 2nd vacuum tank to each system
16	10	4	0	2	83	& repaired leaks.
11	10	12	0	0	77	10/12/95 revised boot program to sample
12	10	12	0	0	78	every 4 hrs instead of 6.
13	10	12	0	0	6	
14	10	12	0	1	79	No weekly samples
15	10	12	0	1	12	
16	10	12	0	2	83	10/12/95 discovered broken vacuum line to
17	10	12	0	2	84	# 83 sample jug, repaired.
11	10	25	0	1	77	
12	10	25	0	1	78	
13	10	25	0	2	6	No weekly samples
14	10	25	0	2	79	
15	10	25	0	2	12	
4	10	26	23	38	79	
	(11/8/95 download)					
0	106	87	124	89		
etc.						
	(11/30/95 download)					
111	89	158	253	254		
etc.						
	(12/7/95 download, only 0's)					
0	0	0	0	8		12/12/95 technician reported problems establishing link with board, LED's on valves dimly lit. 12/20/95 serviced system and found that board was not auto rebooting on power up. When program is not running a small current runs to valves turning LED on. Reconfigured EEPROM (config ssd 1) and reloaded programs. Still not auto rebooting. 12/20/95 corrected line 1070 of boot program, replaced o with 0. Line 1070 is for flow sensor override in case of sensor failure.

Table E2. System B Downloads With Log Notes

	(1/19/96 download)					
7	1	19	13	0		Dec. & Jan. batteries not staying charged.
255	255	255	0	0		
etc.						Technician reported problems establishing link with board in early Jan.
						1/29/96 # 84 yielded .....ml sample.
						1/29/96 installed marine deep cycle battery. System A was down from late Jan. to 2/28/96 due to power reversal Electronics repaired and fuse protection installed in all 3 systems.
						Feb. performed auto reboot reset procedure as instructed by Octogon tech. support, unsuccessful.
	(3/5/96 download)					
						Malfunction in early March, LED's dimely lit,
8	0	0	0	255		dead battery. Temperature as low as 6 deg. F.
etc.						3/15/96 reconfigured EEPROM (config ssd 1)
	(3/22/96 download)					and reloaded programs, board reboots now.
0	0	0	0	0		
0	112	132	0	0		Clock is off.
etc.						
	(3/29/96 download)					
6	3	25	4	7	83	No sample available for # 83, malfunction or
6	3	25	8	0	83	sample was lost.
6	3	25	12	0	83	
7	3	25	13	3	84	
7	3	25	17	0	84	
7	3	25	21	0	84	
7	3	26	1	0	84	
7	3	26	5	0	84	
7	3	26	9	0	84	
7	3	26	13	0	84	
7	3	26	17	0	84	
7	3	26	21	0	84	
7	3	27	1	0	84	
7	3	27	5	0	84	
7	3	27	9	0	84	
7	3	27	13	0	84	3/27/96 yielded 425 ml sample
7	3	27	17	0	84	
7	3	27	21	0	84	
7	3	28	1	0	84	
7	3	28	5	0	84	
7	3	28	9	0	84	
7	3	28	13	0	84	
7	3	28	17	0	84	
7	3	28	21	0	84	
11	3	29	0	0	77	
12	3	29	0	0	78	
13	3	29	0	1	6	
14	3	29	0	1	79	
15	3	29	0	1	12	
7	3	29	1	0	84	
7	3	29	5	0	84	
7	3	29	9	0	84	
7	3	29	13	0	84	Level switch is stuck.
	(4/5/96 download)					
7	3	29	18	0	84	
7	3	29	22	0	84	
7	3	30	2	0	84	
7	3	30	6	0	84	
7	3	30	10	0	84	
7	3	30	14	0	84	
7	3	30	18	0	84	
7	3	30	22	0	84	
7	3	31	2	0	84	Level switch is stuck.
	(4/12/96 download)					
16	4	12	0	0	83	No weekly sample
						Apparently some data lost in this download.

Table E3. System C Downloads With Log Notes

SYSTEM C I/O Address	MO	DAY	HR	MIN	Well No.	Log Notes:
						8/15/95 - 8/18/95 installed systems, tested, and adjusted programs.
	(8/25/95 - 10/13/95 downloads)					I/O address + 10 indicate weekly sample if > 7
12	8	24	0	0	81	days since previous sample.
13	8	24	0	0	82	
14	8	24	0	0	85	
15	8	24	0	1	7	No weekly samples.
16	8	24	0	1	86	
17	8	24	0	2	87	
11	8	24	0	3	80	
						Technician reported some problems in
12						downloading and establishing link with board
13	9	19	0	0	81	late Aug. & early Sept.
14	9	19	0	0	82	
15	9	19	0	0	85	No weekly samples.
16	9	19	0	1	7	
17	9	19	0	1	86	
11	9	19	0	2	87	
14	9	19	0	3	80	
15	9	28	0	0	85	No weekly samples.
16	9	28	0	0	7	
17	9	28	0	1	86	
11	9	28	0	1	87	
12	9	28	0	2	80	
13	9	28	0	2	81	
	9	28	0	2	82	
15	10	5	0	0	85	
16	10	5	0	0	7	
17	10	5	0	1	86	
11	10	5	0	1	87	No weekly samples.
12	10	5	0	2	80	
13	10	5	0	2	81	
14	10	5	0	2	82	
15	10	13	0	0	85	10/11/95 added 2nd vacuum tank to each system
16	10	13	0	1	7	& repaired leaks.
17	10	13	0	1	86	10/12/95 revised boot program to sample
11	10	13	0	2	87	every 4 hrs instead of 6.
12	10	13	0	2	80	
13	10	13	0	2	81	No weekly samples.
	10	13	0	3	82	
						From 10/16/95 into Dec. technician reported frequent problems attempting to download, LED's dimly lit. 12/20/95 serviced board and found it was not auto rebooting on power up. Thus, when technician attempted to break into program, it appeared that there was no link. When program is not running a small current runs to valves. Reconfigured EEPROM (config ssd 1) and reloaded programs. Still not auto rebooting. 12/20/95 corrected line 1070 of boot program, replaced o with 0. Line 1070 is for flow sensor override in case of sensor failure.
						Manually sampled these wells while servicing: 12/20/95 # 85 yielded ....ml sample. 12/20/95 # 86 yielded ....ml sample. 12/20/95 # 87 yielded ....ml sample.
	(12/21/95 download)					
0	0	0	0	255		Dec. & Jan. batteries not staying charged.
etc.						
						Technician reported problems establishing link with board in early Jan.
	(1/19/96 download)					
52	137	52	137	52		
etc.						

Table E3. System C Downloads With Log Notes

						1/29/96 installed marine deep cycle battery. 1/29/96 # 85 yielded ....ml sample. 1/29/96 # 86 yielded ....ml sample. 1/29/96 # 87 yielded ...ml sample.
						Feb. performed auto reboot reset procedure as instructed by Octogon tech. support, unsuccessful.
						2/27/96 battery < 5V. # 85 ha 34 cm of water, program not allowing enough time to sample all of water, level switch staying closed and drawing more current.
(2/28/96 download)						Added subroutine to program for well 85 allowing
4	2	27	19	0	85	up to 180 sec. to sample.
4	2	27	23	0	85	
4	2	28	3	0	85	
4	2	28	7	0	85	
4	2	28	11	0	85	
4	2	28	15	0	85	Yielded 900 ml sample 2/29/96.
						Malfunction during early March, gave 'config mismatch error 44' message, LED's dimly lit, battery dead. Temperature as low as 6 deg. F.
						3/15/96 reconfigured EEPROM (config ssd 1) and reloaded programs. Board is not reading program correctly, ignores loops and stop commands, goes to last line and stays there. Removed last subroutine and adjusted 2nd subroutine to handle volume of # 85. Board reads program correctly but is not reading I/O address 4 (port A) properly. Bypassed
3/22/96 download						I/O address 4 and used I/O address 0, modified wiring. Appears to work. Board is auto rebooting.
0	3	18	18	0	85	
0	3	18	22	24	85	Yielded 550 ml sample 3/18/96.
0	3	19	8	11	85	
0	3	19	12	0	85	
7	3	19	13	21	87	Yielded 75 ml sample 3/27/96.
0	3	19	16	0	85	
0	3	19	20	0	85	
0	3	20	0	0	85	
0	3	20	4	0	85	
0	3	20	8	0	85	
0	3	20	12	0	85	
0	3	20	16	0	85	Yielded 4000 ml sample 3/20/96.
0	3	20	20	0	85	
0	3	21	0	0	85	
0	3	21	4	0	85	
0	3	21	8	0	85	
0	3	21	12	0	85	
0	3	21	16	0	85	
0	3	21	20	0	85	
0	3	22	0	0	85	
0	3	22	4	0	85	
0	3	22	8	0	85	
0	3	22	12	0	85	No sample available.
0	3	22	16	0	85	
3/29/96 download						3/29/96 technician reported that board is giving 'config mismatch error 44' message
225	138	225	138	225		at first but eventually downloaded.
138	225	138	225	138		
etc.						4/8/96 technician reported that board is giving 'config mismatch error 44' message and will not do anything else.
						4/18/96 removed enclosure with board and electronics. Examined in electronics lab, config PIO statement was corrupted and will not read I/O address 4 (port A) properly, will replace chip.

APPENDIX F

DATA FILES FOR SURFER PLOTS

CONTENTS--APPENDIX F

Table F1. Surfer Data File for Wells 1 - 23 127

Table F2. Surfer Data File for Wells 1 - 23 & 71 - 87 128

Table F3. Surfer Data File for 0.4-ha Test Plot 129

Table F1. Surfer Data File for Wells 1 - 23

A	B	C	D	E	F	G
x meters	y meters	ground meters	paleosol meters	well name number	label angle	symbol
44.99726	2.5E-05	153.3	150.54	1		11
-22.4986	-38.9688	151.77	149.47	2		12
-22.4987	38.96872	151.41	148.91	3		11
29.99816	51.95836	152.01	149.41	4		12
29.99822	-51.9583	153.15	150.95	5		11
-59.9963	-0.0001	151.29	148.98	6		11
-77.9376	44.99711	150.52	147.85	7		12
0	89.99451	150.95	148.64	8		11
77.93752	44.99729	153.04	150.34	9		12
77.93757	-44.9972	153.44	150.91	10		11
0.000101	-89.9945	151.69	149.62	11		12
-77.9375	-44.9974	151.06	148.55	12		11
-144.88	38.82023	149.73	147.19	14		12
-106.06	106.0593	148.98	146.46	15		12
-38.8208	144.88	150.17	147.87	16		11
38.82048	144.88	151.08	148.8	17		11
106.0595	106.0596	152.61	150.12	18		11
137.1531	36.75013	152.31	149.46	19		12
144.8801	-38.8204	153.21	150.64	20		12
106.0596	-106.059	153.01	150.94	21		11
38.82064	-144.88	151.39	149.46	22		2
-37.0087	-138.119	150.23	148.3	23		12
-144.88	-38.8207	150.34	147.92	13		12

Table F2. Surfer Data File for Wells 1 - 23 & 71 - 87

A	B	C	D	E	F	G	
x meters	y meters	ground meters	paleosol meters	well name number	label angle	symbol	
44.99726	2.5E-05	153.3	150.54	1		11	
-22.4986	-38.9688	151.77	149.47	2		12	
-22.4987	38.96872	151.41	148.91	3		11	
29.99816	51.95836	152.01	149.41	4		12	
29.99822	-51.9583	153.15	150.95	5		11	
-59.9963	-0.0001	151.29	148.98	6		11	
-77.9376	44.99711	150.52	147.85	7		12	
0	89.99451	150.95	148.64	8		11	
77.93752	44.99729	153.04	150.34	9		12	
77.93757	-44.9972	153.44	150.91	10		11	
0.000101	-89.9945	151.69	149.62	11		12	
-77.9375	-44.9974	151.06	148.55	12		11	
-144.88	38.82023	149.73	147.19	14		12	
-106.06	106.0593	148.98	146.46	15		12	
-38.8208	144.88	150.17	147.87	16		11	
38.82048	144.88	151.08	148.8	17		11	
106.0595	106.0596	152.61	150.12	18		11	
137.1531	36.75013	152.31	149.46	19		12	
144.8801	-38.8204	153.21	150.64	20		12	
106.0596	-106.059	153.01	150.94	21		11	
38.82064	-144.88	151.39	149.46	22		2	
-37.0087	-138.119	150.23	148.3	23		12	
-144.88	-38.8207	150.34	147.92	13		12	
-38.9	-22.5	151.53	148.88	71		11	
-43.5	-11.6	151.51	149.11	72		11	on berm, interpolated
-45	0	151.49	149.15	73		11	surface elev.
-43.5	11.6	151.47	148.98	74		11	
-38.9	22.5	151.44	149.06	75		12	
-31.8	31.8	151.38	148.95	76		11	
-52	-30	151.31	148.66	77		2	
-58	-15.5	151.34	148.95	78		11	
-58	15.5	151.27	148.89	79		11	
-52	30	151.14	148.69	80		11	
-42.4	42.4	151.11	148.71	81		11	
-30	52	151.12	148.79	82		11	
-86.9	-23.3	151	148.66	83		2	
-90	0	150.93	148.69	84		2	
-86.9	23.3	150.7	148.32	85		2	
-63.6	63.6	150.46	147.99	86		2	
-45	77.9	150.47	148.07	87		2	

Table F3. Surfer Data File for the 0.4-ha Test Plot

A	B	C	
X (m)	Y(m)	symbol	notes
-4.84	52.57	4	NW corner
21.55	37.33	14	
52.57	4.84	4	E corner
37.38	-21.55	14	
4.84	-52.57	4	SE corner
-21.55	-37.33	14	
-52.57	-4.84	4	W corner
-37.38	21.55	14	

VITA

N. Randy Rainwater was born in Maryville, Tennessee on November 15, 1955. He attended schools in Anderson County and graduated from Clinton High School in June 1974. He entered The University of Tennessee where he received a Bachelor of Science degree in Agricultural Engineering in June, 1979. He was in the Engineering Cooperative Education program and was employed by the USDA Forest Service as a Student Trainee Civil Engineer. After graduation he was employed by The Cherokee National Forest as a Civil Engineer until October, 1982. In 1982 he resigned from the Forest Service and entered The New Orleans Baptist Theological Seminary where he received a Master of Divinity degree in Biblical Studies in December, 1985. While living in New Orleans he was involved in inner-city ministries. In 1986 he moved to Taos Missouri where he became the Mission Pastor of the Liberty Road Baptist Mission and participated in various prison ministries and in flood relief ministry. In 1994 it was clear to Randy that he no longer belonged in full-time ministry. He returned to The University of Tennessee to pursue a Master of Science in Agricultural Engineering. Randy continues to be involved in ministry as a volunteer.