TEMPORAL AND VERTICAL VARIABILITY OF THE SOIL- AND GROUND-WATER GEOCHEMISTRY OF THE ASHPORT SILT LOAM, PAYNE COUNTY, OKLAHOMA

By

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PREFACE

The soil-moisture content, soil- and ground-water quality of a site nestled in a suburban neighborhood were monitored intensively over a five month period, from late January to late June, 1987. Soil- and ground-water quality was found to be relatively consistent throughout most of the study. Near the end of May, more than five inches of rain fell on the study area, ending a five week dry period. In the days following this event, significant water quality changes were observed in several of the lysimeters, and later in a shallow well. Flow through macropores is invoked as one possible explanation for this occurrence.

During the course of these endeavors I came in contact with, and was assisted by many fine people. I wish to acknowledge and express my sincere gratitude to the many individuals who have helped shape, mold, enlighten, or otherwise enrich my stay at Oklahoma State University. This includes a diversity of faculty members, students, non-students and others too numerous to mention. However, there are several people to whom I owe a special thanks.

First, I thank the University Center for Water Research for the Presidential Fellowship which I recieved from September 1986 to September 1987.

I am especially indebted to my major adviser, Dr. Wayne A. Pettyjohn, School of Geology, for his consistent guidance, wit, motivation, and for allowing me to use his sunny backyard for study. I am also indebted to Dr. Brian J. Carter, School of Agriculture, for his guidance in and out of the field, for the long hours of helpful discussion in many areas which led to the "final product". I also thank Drs. Arthur W. Hounslow, School of Geology, for his helpful critique and guidance throughout my graduate studies, and Dr. Zuhair Al-Shaeib, School of Geology, for his unselfish assistance with the SEM and EDAX portions of this study. I am forever indebted to my mentor, Dr. Jack W. Keeley, one of the fathers of ground water research, for his inspiration and guidance throughout the years.

I must also express my appreciation to several graduate students who contributed to this study. I thank Dale Froneberger and Michael Nelson for their help in the field and laboratory, and for carrying on the tradition. I owe a special thanks to my field partner, Blythe Hoyle, who was always around for discussions and arguments. I must also thank Deb, Mark, Paul, and others for the welcomed distractions which helped keep life in perspective.

To my wonderful parents, Richard R. and Lois A. Ross, I give to you, above all others, my deepest thanks for providing never-ending support, guidance, warmth, understanding and love.

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CHAPTER I

INTRODUCTION

General Overview

Ground-water contamination is not a new phenomenon. It has affected man in one way or another for many decades. Attention has recently focussed on preventing the contamination of shallow unconfined aquifers, which are highly susceptible to contamination from pollutants migrating through the unsaturated zone. The diversity of contaminant sources is extreme, ranging from unintentional toxic chemical spills to intentional applications of useful pesticides and fertilizers.

This study was conducted in a suburban neighborhood of Stillwater, Oklahoma. Fertilizer is typically applied to suburban lawns three times yearly. Fertilization schemes are usually designed to maximize nutrient uptake by plants and minimize losses through leaching and other processes. Although this may be a major consideration for obvious financial reasons in large agricultural ventures, the average homeowner may not be as concerned with over use when trying to maintain a socially acceptable lawn. In such instances the adage "more is better" may not hold true in suburban areas.

Research Objectives

The primary objectives of this investigation are three-fold: 1) determine seasonal variations in soil-moisture content; 2) determine seasonal variations of inorganic geochemical parameters in the groundwater and soil water of the unsaturated zone, and 3) evaluate the effect of soil-moisture content on the movement of water and solutes through the unsaturated zone.

Literature Review

Previous Studies

Hagen (1986) initiated the first study of the site during the summer of 1985. Twenty groundwater monitoring wells were installed in four well clusters, five wells per cluster, completed at depths ranging from 8 to 14 feet below land surface. Hagen monitored water level fluctuations and various water quality parameters regularly through April 1986, concluding that water quality parameters varied spatially and temporally.

Acre (in prep) installed four neutron access tubes and monitored the soil moisture over the general study area from September 1985 to April 1986. Acre determined that the soil moisture content of the unsaturated zone varied temporally and spatially.

Hoyle (1987) measured water level fluctuations, monitored field parameters, chloride and bicarbonate concentrations on a regular basis from April 1986 through April 1987. Hoyle concluded that a significant portion of the diurnal water level fluctuations and certain changes in bicarbonate concentrations resulted from the effect of several large hackberry and pecan trees adjacent to the study area. Hoyle also determined various hydrologic parameters of the study area including transmissivity, storativity, hydraulic conductivity and gradient by various aquifer testing methods.

Groundwater Monitoring

Much of the literature concerning groundwater quality monitoring focusses on sampling and sample handling procedures. Barcelona and others (1985) reviewed the essential elements of groundwater sampling and suggest sampling protocols. Grisak and others (1978) discussed the technical difficulties involved in obtaining a representative groundwater sample. The principle sources of sample bias, including well-construction, sample collection and handling procedures were addressed by Gillham and others (1983). Ground-water monitoring well purging strategies are briefly discussed by Barcelona and others (1985). Nelson and Ward (1981) discussed various statistical considerations of ground-water monitoring. The sampling frequency for ground-water quality monitoring is addressed by Casey and others (1983). Saines (1981) discussed potential errors associated with the interpretation of ground-water level data.

Unsaturated Zone Monitoring

Monitoring soil water quality has received increasing attention in recent years as the concern over the migration of ground-water contaminants through the unsaturated zone has increased. Sampling soil water from the unsaturated zone was first reported by Briggs and McCall (1904) using a porous ceramic "artificial root". Everett and others (1983) provides a thorough evaluation of much of the available unsaturated zone monitoring equipment. The direct application of unsaturated zone monitoring equipment with hazardous waste land treatment facilities is discussed in detail by EPA (1986) and Everett and others (1983). Wood and Signor (1975) describe the use of suction lysimeters to examine the geochemical changes in water during flow through the unsaturated zone underlying recharge basins in Texas. The effects of negative pressure on water samples obtained with suction lysimetry is addressed by Hansen and Harris (1975) and Suarez (1986).

Measurement of soil-moisture content in the unsaturated zone by neutron activation and other methods is described by van Bavel (1963) and Hillel (1982).

Hillel (1982) provides an in depth discussion of the physical processes encountered in the unsaturated zone, including the flow of water in unsaturated soils. The infiltration and recharge of water in a soil with shrinkage cracks is discussed by Blake and others (1973). According to Thomas and others (1978), Lawes and others (1882) states that the drainage water from a soil may be of two kinds: it may consist (1) of rain-water which has passed with little alteration in composition, down the open channels of the soil; or (2) of the water discharged from the pores of a saturated soil. More recently, Thomas and Phillips (1979) describe the various avenues of macropores through which water movement in the unsaturated zone may occur. The effect of water moving via macropores through the unsaturated zone on ground-water geochemistry is also discussed by Pettyjohn (1982).

CHAPTER II

SITE DESCRIPTION

Site Location

The study area is located in Stillwater, Payne County, Oklahoma, NE 1/4 sec. 11, T 19 N, R 2 E (figure 1). The site is situated on a flood plain approximately 500 feet northeast of the confluence of Boomer Creek and an unnamed tributary.

General Geology

Lithology of the Stillwater area is dominated by interbedded sandstones, siltstones, and shales. Locally, outcrops of Upper Pennsylvanian and Lower Permian rocks can be found dipping west 40 to 50 feet per mile (Shelton and others, 1985). The study area is located on late Quaternary deposits infilling a steep walled canyon carved into the Upper Pennsylvanian Doyle Shale. Approximately 5000 feet of Paleozoic strata rest unconformably on the granitic basement rock of the stable Northern Oklahoma Platform.

Geography

The study area is located in the Central Redbed Plains physiographic province, characterized by rolling plains

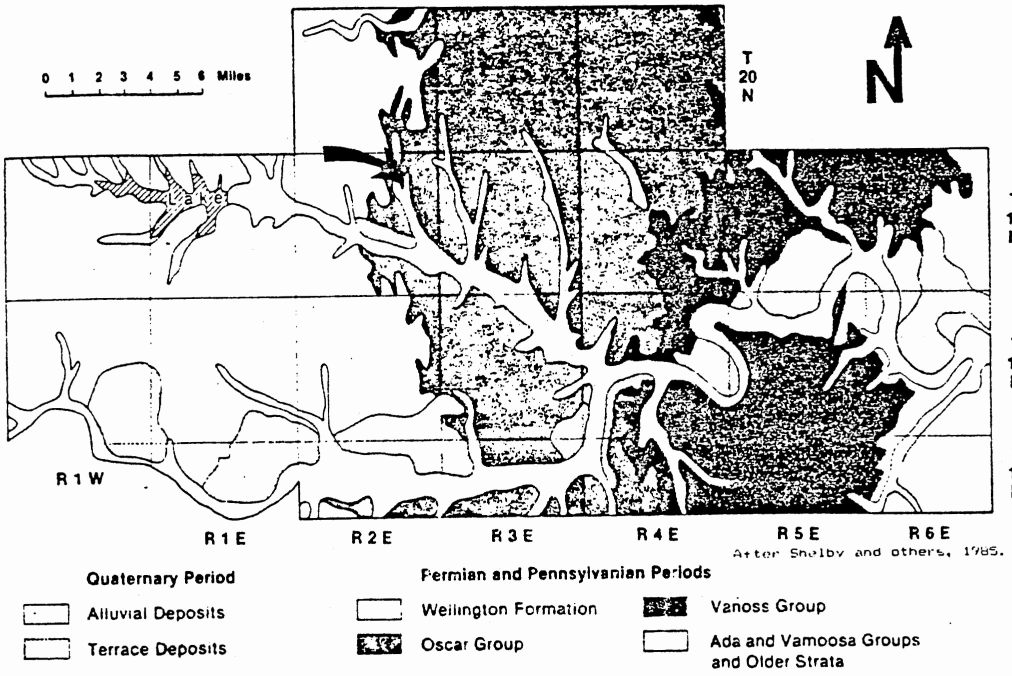

Figure 1. General geology and site location map. Arrow marks study area.

with valleys formed by the weathering of less resistant shale units. The relatively flat topography of the study area (less than 1% slope) allows little surface runoff. Pettyjohn and others (1983) report an average annual runoff of 4.5 inches for north central Oklahoma.

Climate

Mean daily temperatures for the winter and summer months are 39 and 80 degrees F, respectively (SCS,1987). Annual precipitation and evapotranspiration for the study area average approximately 34 inches and 30 inches, respectively (Pettyjohn and others, 1983). The research area received a total of 16.75 inches of precipitation during the five month study period, from 25 January to 23 June 1987. Effective regional ground-water recharge rates calculated by stream hydrograph separation for the north central portion of Oklahoma average about 1 inch per year (Pettyjohn and others, 1983).

Surface-water Hydrology

An unnamed tributary to Boomer Creek lies approximately 200 feet west of the investigative area. This ream is dammed near its confluence with Boomer Creek, resulting in a small pond that contains water throughout the year (figure 2). Total drainage area of this intermittent tributary is less than two square miles. Boomer Creek is dammed approximately one half mile northwest of

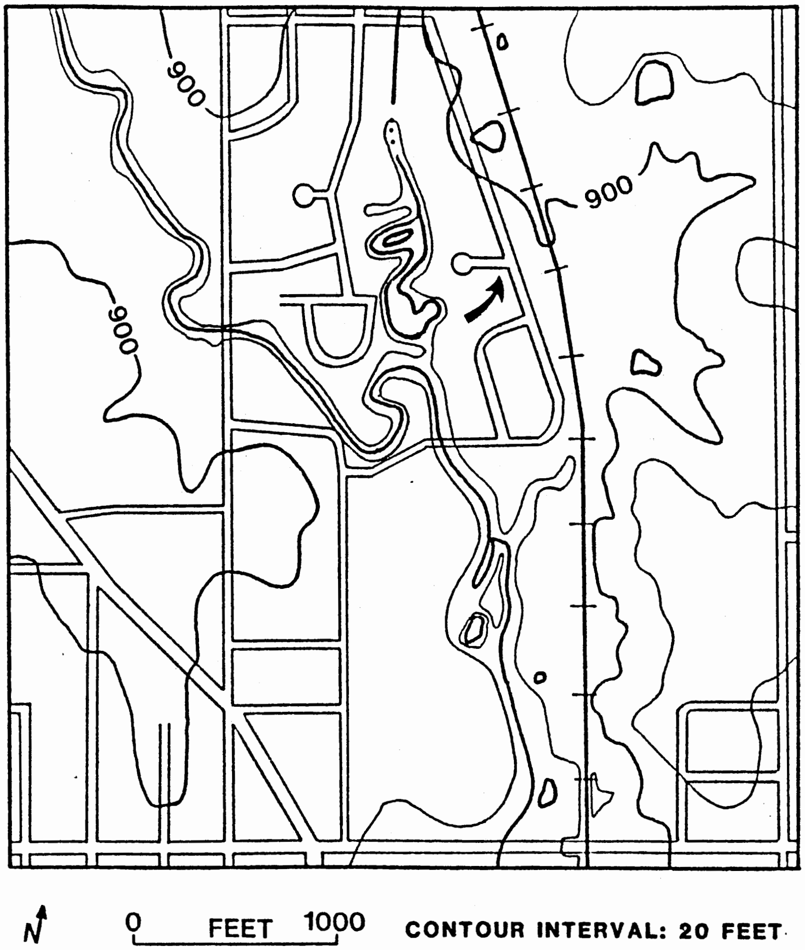

Figure 2. Topographic map of general study area.

the study area and flows most of the year.

Ground-water Hydrology

Interpretation of data obtained from several aquifer tests conducted at the study area indicates the average transmissivity is 2225 gpd/ft, the average hydraulic conductivity is 60 gpd/ft2 and the storativity is on the order of 0.01 (Hoyle, 1987). The ground-water gradient fluctuates from 0.003 to 0.008, and varies in direction from 145 to 225 degrees throughout the year. Hoyle (1987) and Hagen (1986) suggest that the seasonal shift in gradient may result from the evapotranspirative consumption of large trees located on the southern boundary of the study area. Ground-water velocities seasonally range from less than 0.4 to greater than 1.0 feet per day.

Historically, the water table fluctuates from 3 to 12 feet below land surface (Hagen, 1986; Hoyle, 1987). Water levels ranged from an average of 3.85 to 8.02 feet below land surface at site A from late January through late June 1987 (figure 3).

Site Instrumentation

General Instrumentation

The general study area is implemented with 27 ground-water monitoring wells distributed among six sites (A-F), eight soil-moisture suction lysimeters, and four soil-moisture neutron probe access tubes (figure 4). A contin-

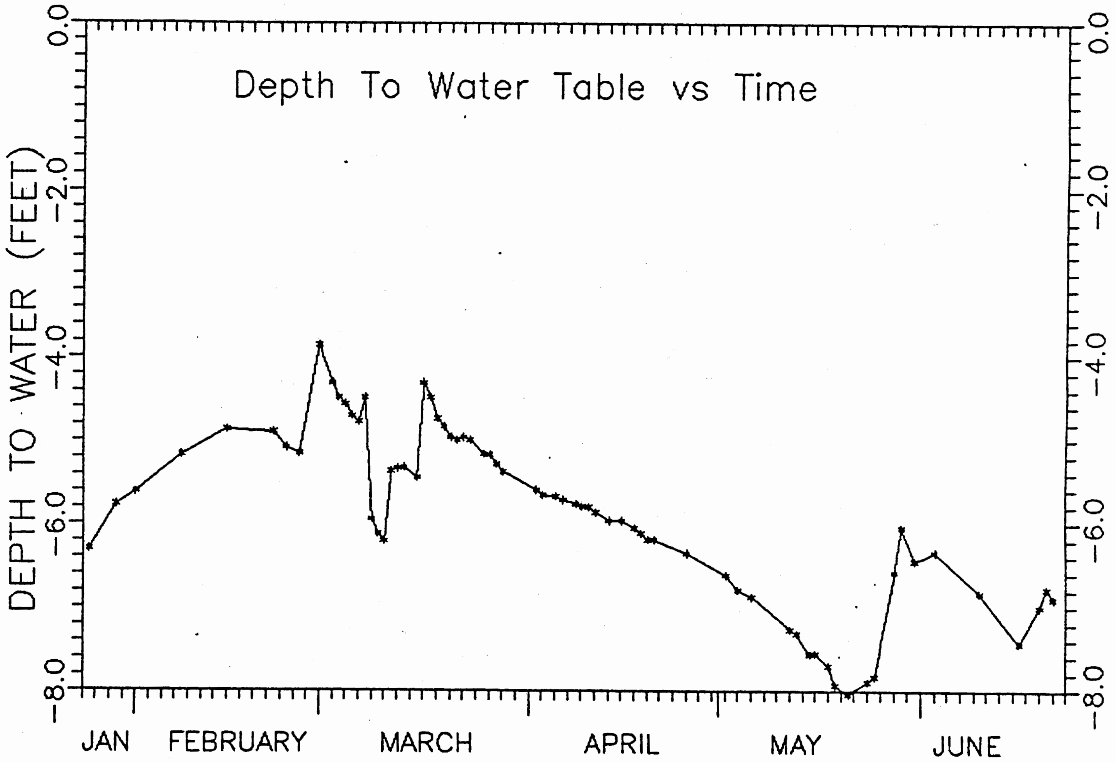

Figure 3. **Water table elevation fluctuations with time for well A4.**

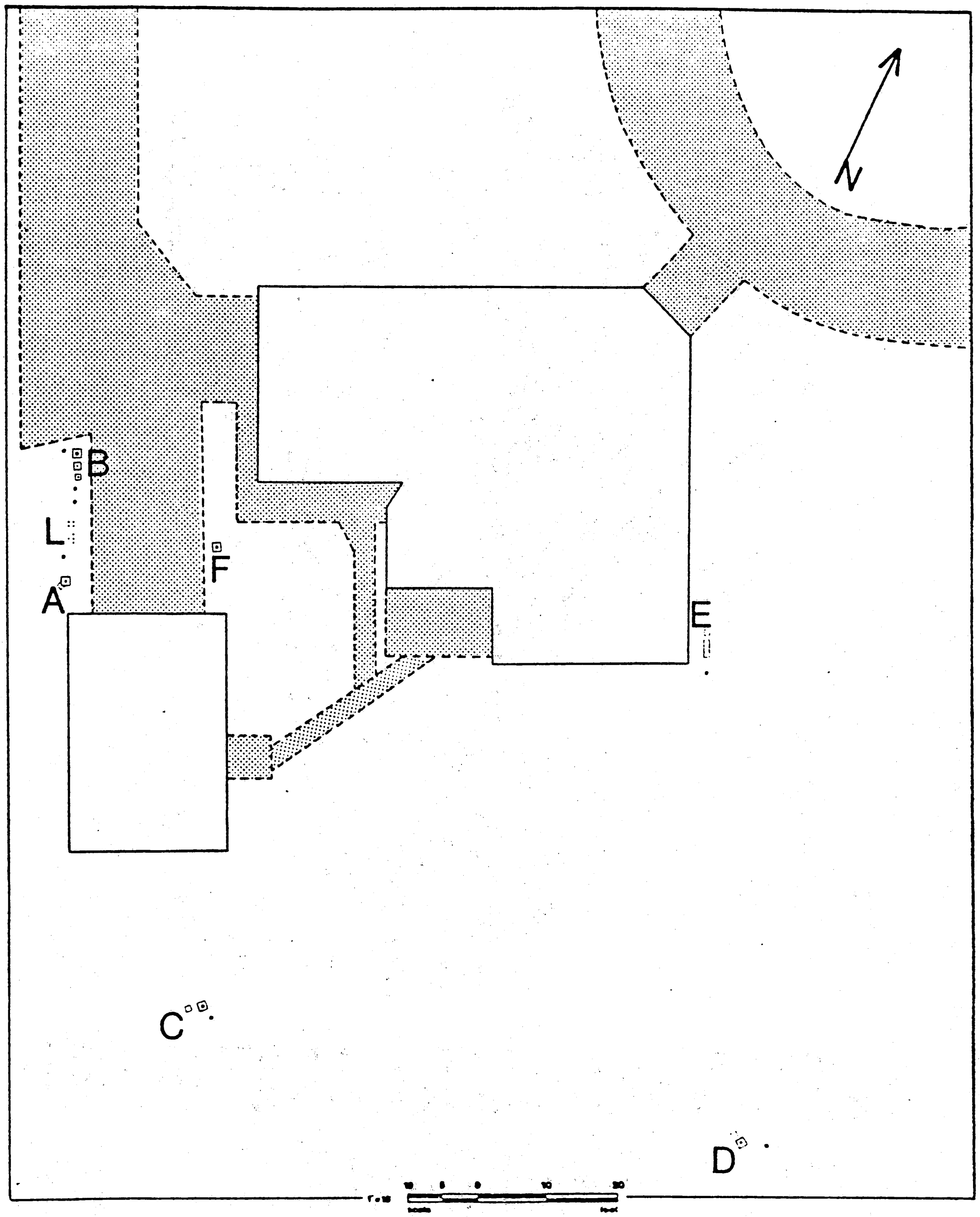

Figure 4. General instrumentation map of study area. Letters denoting well and lysimeter clusters.

uously recording tipping bucket rain gauge measures intensity and duration of precipitation events. Barometric pressure and solar intensity fluctuations are recorded on a barograph and photometer, respectively.

Ground-water Monitoring Wells

Four ground-water monitoring wells were used in this study (A1-A4). The monitoring wells are constructed of two inch diameter schedule 40 PVC tubing. The wells at site A are completed at 8.5, 9, 10, 13.8 and 14 feet below land surface, designated A1, A2, A3, A4 and A5, respectively (figure 5). Four of the five wells (A1 - A4) are slotted over a two to four inch interval. The composite well, A5 was not used in this study. A nylon mesh screen covers the slotted interval of each well.

The wells are completed in four inch diameter holes excavated by hand auger (Hagen, 1986). A medium-grained sand pack surrounds each screened interval. Bentonite slurry backfill and a concrete surface pad form seals above the sandpack, preventing downward migration of water from the surface (figure 5). The wells are located in an area 1.5 feet square.

Soil-water Suction Lysimeters

Water held at less than atmospheric pressure in a porous medium cannot be sampled by wells; negative pressure, or suction, must be applied to remove soil water.

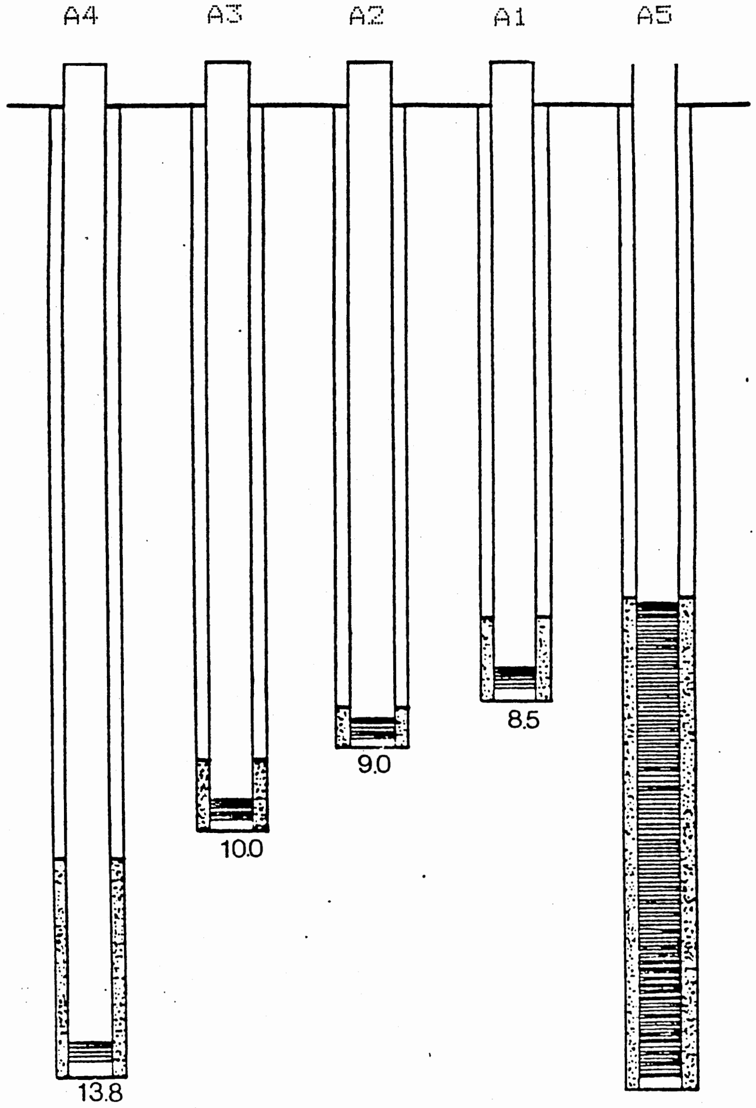

Figure 5. Cross-section through site A wells. Not to scale.

Suction lysimeters provide a means of effectively sampling soil water in the unsaturated zone.

One bar, high flow, porous ceramic sampling cups were bonded to PVC tubing (2 3/8 inch O.D., 9 1/2 inch long) with epoxy cement (figure 6). Each lysimeter has a sample volume of approximately 500 milliliters. Stainless steel and tygon tubing were used to sample and pressurize the suction lysimeters. The tygon tubing (5/8 inch O.D., 1/4 inch I.D.) is connected to the stainless steel tubing with hose clamps, extending from the top of the lysimeter to above the ground surface. Compressional O-rings form air tight seals at the top of the sample chamber and around the stainless steel access tubing.

Eight soil-water suction lysimeters were installed in holes excavated with a Giddings truck-mounted soil probe. The 2 1/2 inch O.D. split-spoon type core barrel produces "undisturbed" soil samples, necessary for the determination of bulk density and other soil properties in the laboratory. The lysimeters, designated L1, L2, L3, L4, L5, L6, L6B, and L7 are installed at depths of 1.5, 2, 3, 3.6, 5, 6.7, 6.9 and 8 feet below land surface, respectively (figure 7). The selected depths correspond with major soil horizons. The porous ceramic cups are firmly in contact with approximately two inches of 200 mesh silica flour placed in the bottom of each hole. The silica flour forms a continuum between the soil pores and the pores of the ceramic cup. Bentonite pellets and native backfill form a

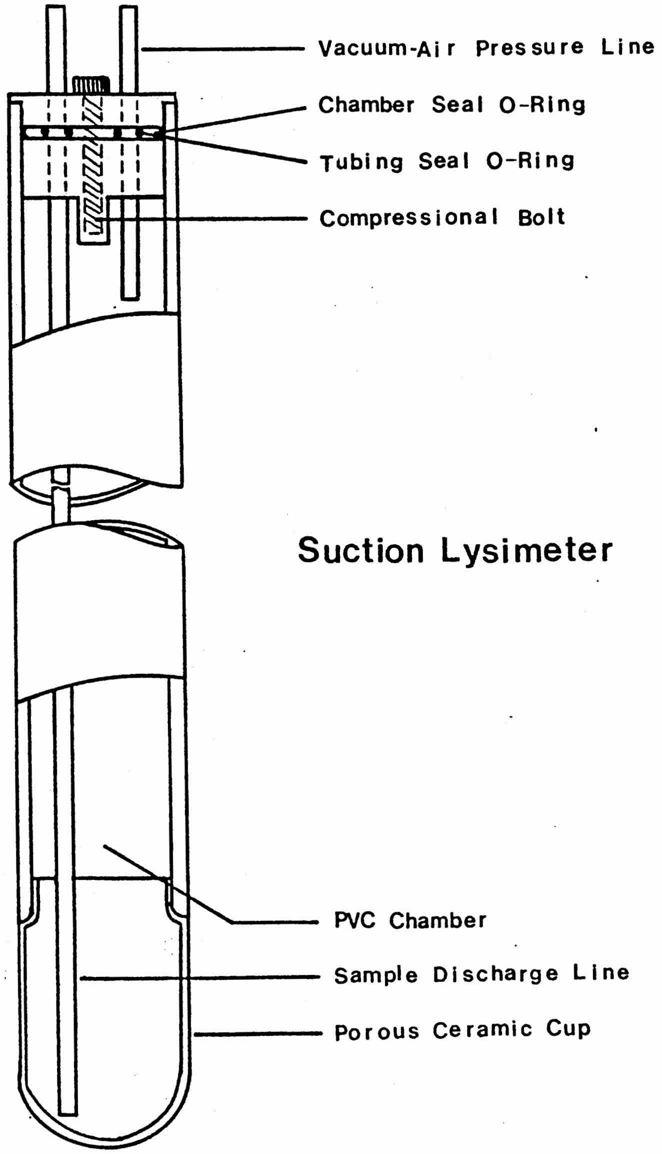

Figure 6. Schematic diagram of a suction lysimeter.

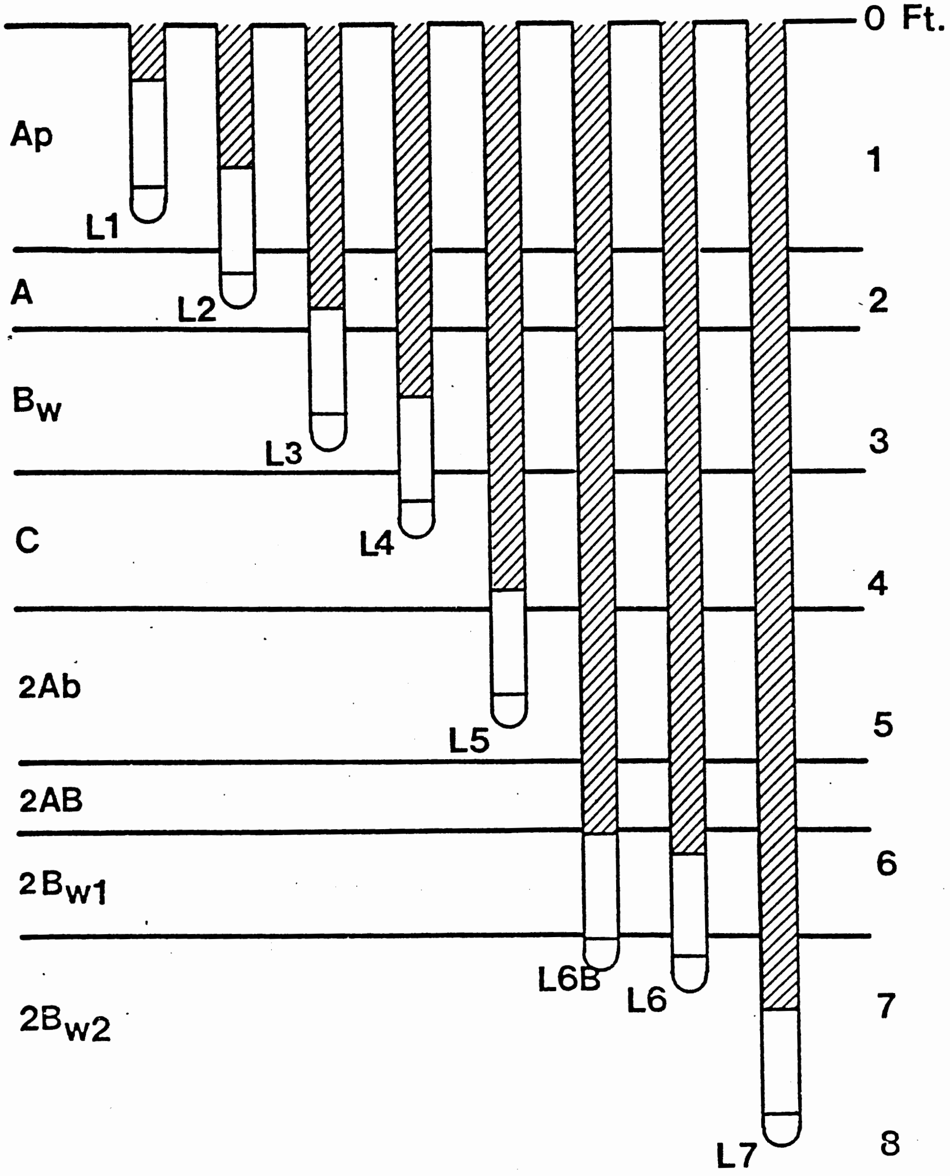

Figure 7. Cross-section through site A suction lysimeters.

seal preventing infiltration through the annulus.

Suction lysimeters were evacuated with a 42 liter displacement capacity vacuum pump. A vacuum of approximately -24 inches mercury was placed on each lysimeter to induce the flow of soil water into the sample chamber. Small clamps are used to seal the tygon tubing and maintain the vacuum pressure.

Removal of water samples from suction lysimeters is discussed later in detail.

Soil Moisture Neutron Probe

Soil moisture data were collected at the study area using a Troxler model 3330 depth moisture gauge (soil moisture neutron probe). The neutron probe access tube is located between the monitoring well cluster and the array of suction lysimeters (figure 8). The 1.7 inch diameter aluminum access tube extends seven feet below land surface (Acre, in prep.). The bottom of the access tube is open, and therefore subject to water entry allowing the determination of water levels. Care must be taken to prevent the submersion of the neutron probe. The main advantage to this method of soil moisture content determination is the capability of making repeatable, non-destructive in-situ measurements.

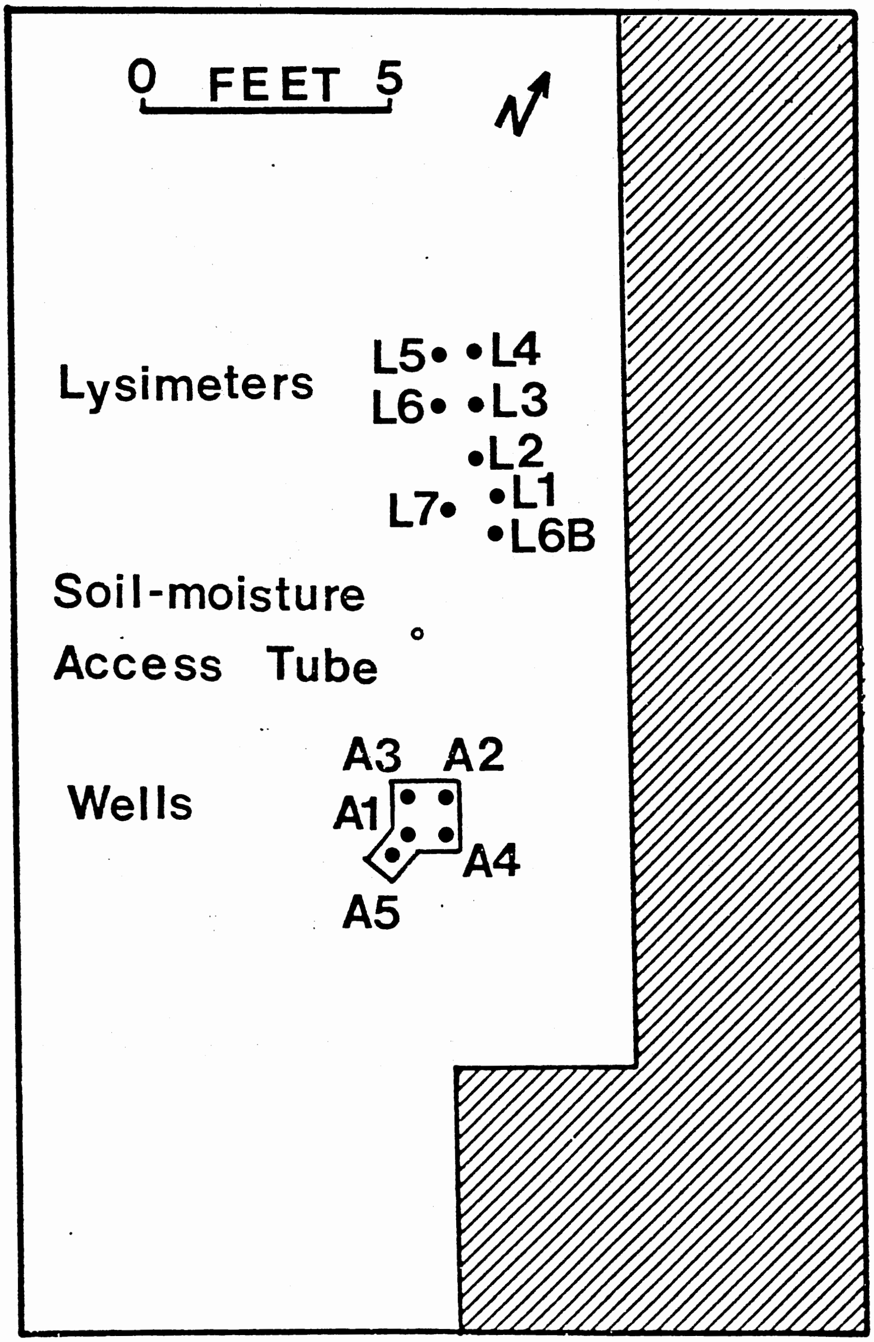

Figure 8. Site A instrumentation map.

CHAPTER III

SITE CHARACTERIZATION

Introduction

In late October 1986, six 8 inch diameter holes were drilled by personnel of the R. S. Kerr Environmental Research Laboratory using a continuous flight hollow stem auger. A composite core, 45 feet long was obtained by combining core material from the B and F sites. The core was logged and photographed in the field and later studied in detail in the laboratory.

Physical Characteristics

The lithologic section at the study site consists of 43 feet of unconsolidated sediments and soils overlying the Upper Pennsylvanian Doyle shale. Twenty-eight separate horizons have been delineated in the unconsolidated material (figure 9) on the basis of color, texture, structure, consistence and other characteristics (Soil Survey Staff, 1951).

Texture

Particle size analyses were conducted on 22 selected intervals from the composite core (appendix A). The Pipet

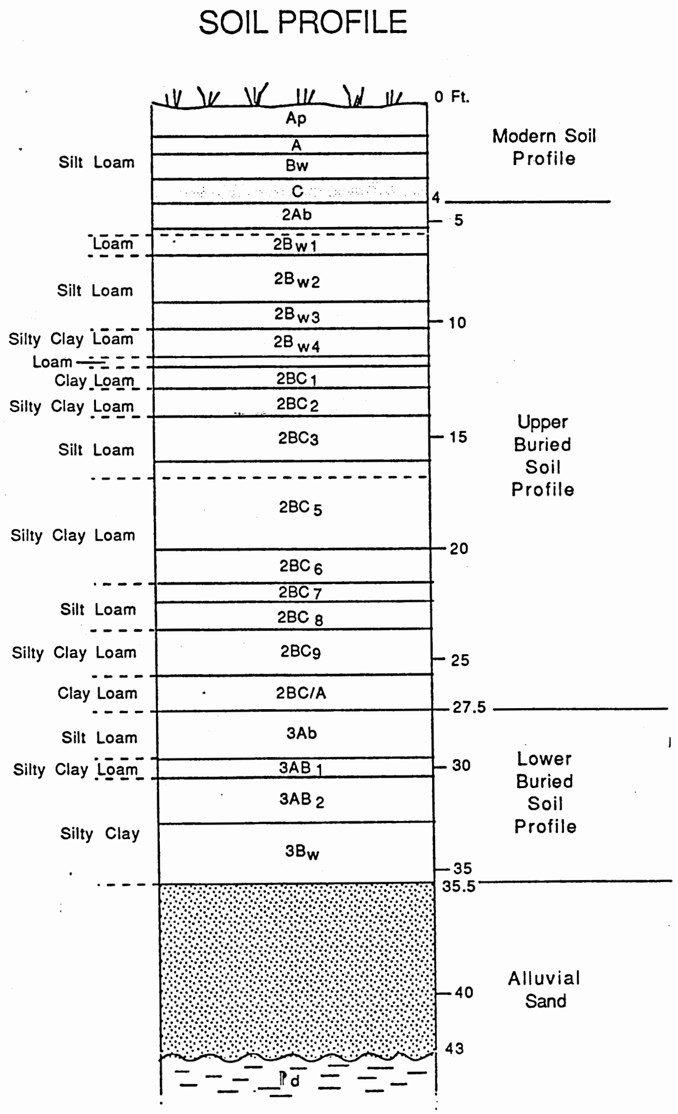

Figure 9. Soil profile with textures.

method was used to determine the clay fraction (Gee and Bauder, 1986). These analyses indicate the presence of several textural classes including loam, silt loam, silty clay loam, silty clay, and clay loam (figure 10).

Color

Soil color was described by hue, value, and chroma on dry soil material throughout the core, and on selected moist materials (Soil Survey Staff, 1975). Mottling, which is the color difference arising from the reduction of ferric iron (Fe^{+3}) to ferrous iron (Fe^{+2}), is described on the basis color, contrast (faint, distinct, and prominent), abundance (few, common, and many), and size of mottled area (fine, medium, and coarse). Mottling is characteristic of soils saturated during part of the year (Bohn and others, 1985).

Structure

Soil structure was described on the basis of grade, class, and type (Soil Survey Staff, 1975). The dominant soil structure throughout most of the core is weak to moderate, medium, subangular blocky. Fastovsky and McSweeney (1987) list processes relevant to the formation of soil structure including close juxtaposition of soil particles by the invasion of roots, shrinking and cracking associated with the removal of soil moisture by roots, animal activities, wetting and drying cycles, and freezing

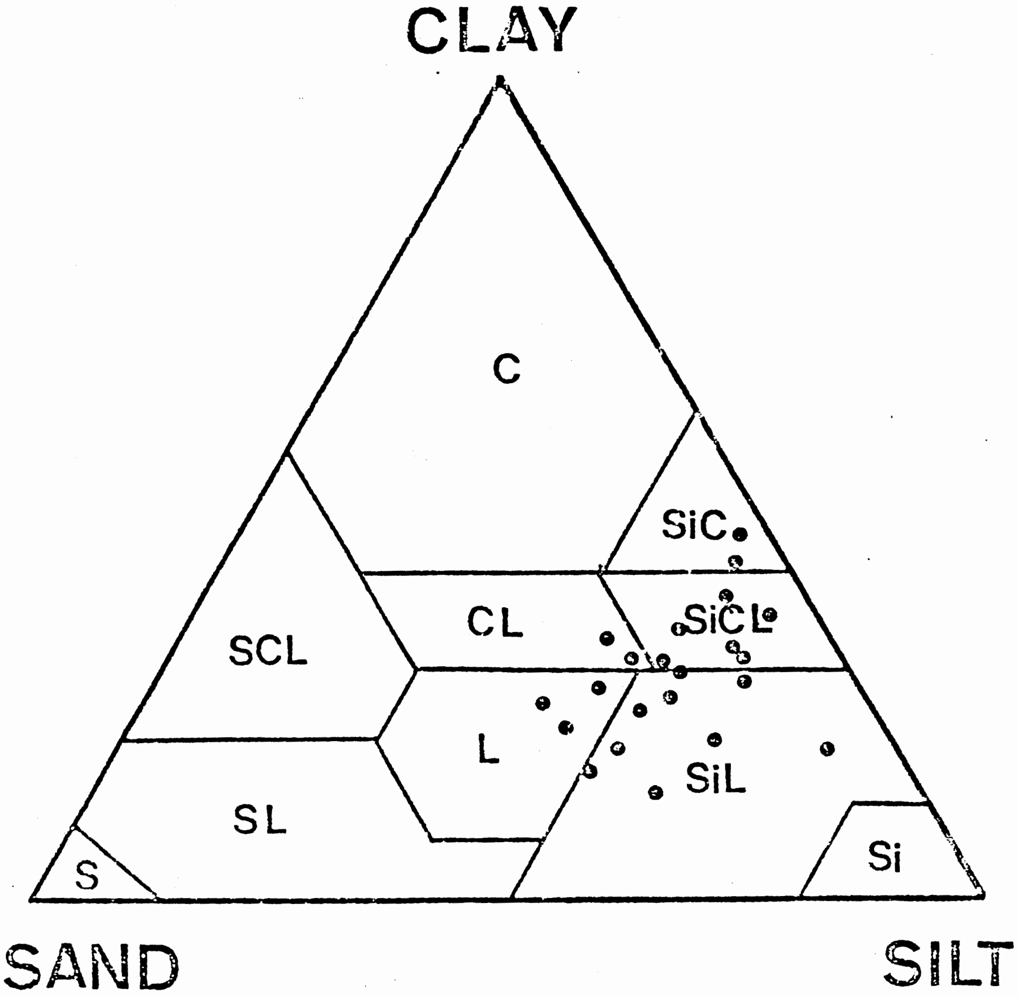

Figure 10. Distribution of soil textures throughout profile.

and thawing cycles.

Bulk Density

The bulk density of horizons within five feet of the surface was determined by collecting samples at six inch intervals with a Giddings probe and split spoon sampler (2 inch I.D.). The samples of known volume were wrapped in preweighed foil, weighed and oven dried (105 C) for 48 hours to ascertain bulk density and gravimetric water content. The bulk densities ranged from 1.50 to 1.75 gm soil/cm^3 within the upper five feet of the profile. These values are generally higher than would expected for typical soil profiles. Most fragipans have bulk densities of approximately 1.8 gm soil/cm^3, and greater.

Soil Description

Three soil profiles were delineated in the composite core. Radiocarbon dates were obtained for two buried soils (Beta Analytic Inc., 1987). A date of 1300 ± 70 years B.P. (Beta-21505) was determined for the upper buried soil found four feet below land surface. The deepest buried A horizon, extending from 27.5 to 29.5 feet below land surface, was dated at 10,600 ± 170 years B.P. (Beta-20144).

The contact between the Doyle shale and the overlying unconsolidated sediments lies 43 feet below land surface in well F1 (figure 11). Lying unconformably on the weathered shale is a sequence consisting of a poorly sorted friable gravel (3D2), composed of sandstone and shale fragments. This material grades upward into a well sorted, fine-grained, thinly laminated sand (3D1).

A gradual boundary separates the graded alluvial sands from the overlying buried soil profile. From 27.5 to 38 feet the buried profile is composed of four distinct horizons that are characterized by differences in color and texture (Appendix A). The principal structure is weak to moderate subangular blocky, parting to moderate medium platy structure in the 3Ab horizon. Root casts are common throughout the paleosol, ranging in size from less than one to five millimeters in diameter. Zones of mottling, ranging from grey to reddish grey surround most of the root casts. Small pieces of organic material, are dispersed through the soil matrix. Texturally, the profile becomes finer grained with depth, from silt loam in the 3Ab horizon (27.5 feet), to silty clay in the 3Bw horizon (38 feet). The presence of few fine distinct strong brown and pinkish gray mottles distinguishes the 3C horizon (35.5 to 38 feet) from the underlying, unaltered alluvial sediments, 3D1 and 3D2.

A diffuse boundary separates a two feet thick "mixing zone", 2BC/A, from the underlying 3Ab horizon. This horizon contains material characteristic of 3Ab and the overlying 2BC9 horizon. Small charcoal fragments are common with root casts becoming less common in this section of the profile. The intensity of mottling surrounding root casts diminishes upward through the profile.

The middle soil profile extends from approximately four to 25 feet below land surface (figure 9). The textures of this profile include loam, silt loam, silty clay loam, and clay loam. The lower two thirds of this soil profile are labeled 2BC1-9 (Appendix A). This notation indicates that the horizons have characteristics of both B and C horizons. Structure normally characteristic of B horizons is weak, but is usually present throughout the 2BC horizons.

The 2BC9 horizon, extending from 23.5 to 25.5, feet is characterized by a silty clay texture and a yellowish red matrix that contains few, faint reddish grey mottles. This horizon marks the lowest appearance of iron/manganese nodules, which appear as round to irregular black masses. Most of these nodules are soft, friable, and round, and range from less than 1 to more than 5 millimeters in diameter. Others nodules are hard although they are of the same size range. Root casts are common throughout this portion of the middle soil profile. Mottling decreases towards the top of the profile, nearly disappearing in the 2BC6 horizon at about 20 feet.

Horizons in the interval between 12 and 20 feet are differentiated on the basis of texture data. The material throughout this section is a fairly uniform reddish brown, and lacks significant mottling. Few irregular medium to fine iron/manganese nodules are interspersed throughout the matrix. A pocket of many fine round iron/manganese nodules is located in the 2BC3 horizon approximately 15 feet below land surface. The only horizon lacking notable structure in the middle soil profile is 2BC4, from 16 to 16.5 feet. There are very few root casts in this massive dense silt loam. The massive structure and the lack of significant root casts could restrict water flow through this horizon.

Structure becomes more noticeable above this rather uniform portion of the core. The 2Bw notation indicates the presence of characteristics usually associated with B horizons, namely better developed structure than in the 2BC1-9 horizons. Horizons 2Bw3, 2Bw4 and 2Bw5, which extend from 9 to 12 feet, are yellowish red and characterized by silt loam, silty clay loam, and loam textures, respectively. Iron reduction is most evident in the 2Bw3 horizon from 9 to 10.5 feet as evidenced by common, medium, distinct mottles. Mottling intensity decreases upward into the overlying reddish brown silt loam. Iron/manganese nodules are few to common throughout this portion of the buried soil profile.

Calcite nodules occur in the 2Bw2 and 2Bw3 horizons from 6.5 to 9 feet. The nodules are most prevalent in the 2Bw3 horizon and occur as fine to medium round masses. The size and number of nodules decrease upward into the 2Bw2 horizon.

The dominant structure present in the 2Bw1-5 horizons is fine to medium, moderate, subangular blocky, parting to moderate, medium prismatic. Moderate, coarse, platy structure is present in the 2Bw1 horizon. The 2AB horizon represents a zone of transition between the 1300 year old buried 2A and underlying 2Bw1 horizons.

The upper soil profile extends from 4.2 feet to land surface (Appendix A). The finely stratified silt loam of the C horizon is separated from the underlying buried soil by a clear boundary. This reddish brown horizon grades into the overlying red silt loam of the Bw horizon. The soil profile is topped by the A and Ap horizons. The Ap horizon represents a portion of the disturbed soil profile. Roots and root casts are common throughout the upper soil profile.

General Soil Mineralogy

Eight air dried soil clods selected from the profile were impregnated with an epoxy resin with optical properties similar to Canada balsam (1.54 refractive index). Samples were chosen from the Bw, C, 2Ab, 2Bw1, 2Bw2, 2Bw3, and 2Bw5 horizons. Following impregnation, the clods were slabbed and "chips" chosen for thin section preparation. The thin sections were polished to a thickness of 30 micrometers. The two by three inch thin sections were examined in plane-polarized, cross-polarized, and reflected light.

Five samples, including one manganese nodule, one carbonate nodule, one ped surface, and two broken ped interiors, were studied with a JEOL JSM 35-U scanning electron microscope (SEM). Specimens were glued to aluminum stubs with silver paint and coated with gold-palladium alloy.

Quartz grains dominate the sand and silt mineralogy throughout the profile. Feldspar comprises three to five percent of the grains present. Traces of zircon and other minerals are present in all thin sections. The matrix, or plasma (Brewer, 1976), consists of clay and silt, much of which exhibits reddish iron staining. Several quartz grains observed in thin section and with the SEM exhibited signs of corrosion.

Many of the skeletal grains are coated by cutans, which are coatings of different materials distinguished on the basis of function and composition (Brewer, 1976). The term argillan describes cutans composed of clays. Many of the argillans seen in thin section appear to consist of oriented clays, which are indicated by undulose extinction patterns. Mangans and sesquans are cutans composed of manganese oxides and hydroxides, and iron oxides and hydroxides, respectively. Argillans, mangans and sesquans are found throughout the thin sections, coating most grains, voids, channels and ped interfaces.

Black glaebules (nodules and concretions) appear in several thin sections. The glaebules range from less than 0.5 mm to 5mm in diameter. The concretions appear black, occasionally having a dark reddish tint, suggesting a composition of manganese and iron oxides and hydroxides.

Energy dispersive analyses of x-rays (EDAX), used in conjunction with SEM, provides qualitative to semi-quantitative elemental analyses on submicroscopic sample areas. EDAX analyses of the black nodules indicates the presence of silica, aluminum, iron and manganese. The aluminum and silica are indications of clays present in the matrix of the nodule.

Calcite concretions occur throughout a limited portion of the profile. Several generations of calcite may be delineated in the thin sections. Most of the nodules appear to be composed of a very fine-grained calcite. Several generations of larger calcite crystals fill voids within, and adjacent to the carbonate nodules. The boundary between the carbonate nodules and the surrounding matrix appears to be distinct in hand specimens, but under magnification the boundary appears irregular, and less abrupt. In several instances, calcite crystals coat internal voids of manganese concretions. EDAX analyses indicate magnesium is present in small quantities in portions of the $CaCO_3$ concretions.

Geopetal-like coatings occur in several thin sections. These features are found in root casts or channels. Several generations of iron and manganese oxide and hydroxide stains occur as concentric coatings on the pore walls and between layered argillans (figure 11). These features suggest cyclic deposition of clays and ferromangans.

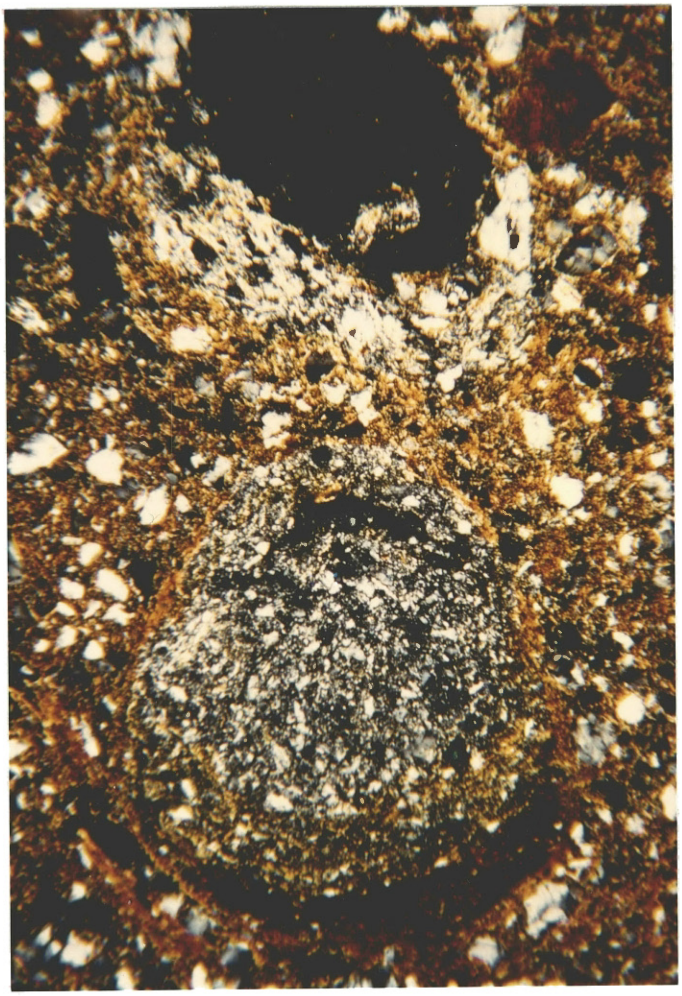

Figure 11. Photomicrograph of circular channels with clay coatings (x 63).

Clay Mineralogy

The clay fraction of the clay-silt slurry obtained during particle size analyses was extracted for x-ray diffraction (XRD) analyses. The slurry was brought to a volume of one liter, mixed thoroughly, and allowed to settle undisturbed for 18 hours. The top 250 milliliters of the dispersed clay-silt solution were decanted. The clays were filtered through porous ceramic plates coated with glass slivers. Several drops of 1 molar $CaCl_2$ were applied to the clay coating and allowed to air dry. Initially, the "natural" oriented clay mounts were analyzed. Two additional XRD runs were conducted for each sample following treatments of glycolation, and heating to approximately 550 degrees C.

Interpretation of the XRD analyses indicate the presence of kaolinite, smectite, and possibly illite and mixed-layer illite-smectite (Carrol, 1970).

Detrital clays appear throughout the matrix of most samples. Several of the pores examined by SEM exhibit the parallel alignment of clays as coatings, or argillans, as suggested by the undulose extinction present in thin section. The clay coated interior of several pores examined appears as a smooth surface. The accumulation of translocated detrital clays within the pores of the soil profile is a possible source for the coatings.

Wilson and Pittman (1977) distinguish authigenic clays from allogenic clays in sandstones on the basis of composition, morphology, structure, texture and distribution. SEM analyses indicated the presence of authigenic illite occurring as small patches coating grains. The distinct texture and structure is indicative of the authigenic illite (Al-Shaieb, 1987).

CHAPTER IV

SOIL WATER

The Unsaturated Zone

Classically, the water table has been considered the boundary between the unsaturated and saturated zones. The water table is defined as that surface at which the hydrostatic pressure within a porous medium is equal to atmospheric pressure (Freeze and Cherry, 1979). Intrinsically, the thickness of the unsaturated zone is dependant upon the depth to the water table. The thickness of the unsaturated zone varies considerably at the study site as the water table fluctuates seasonally from 3 to 12 feet below the land surface.

The Capillary Fringe

Gillham (1984) suggests that the top of the capillary fringe marks the boundary between the unsaturated and saturated zones. In certain fine-grained materials the very nearly saturated capillary fringe may extend several meters above the water table, occasionally up to land surface. The hydrostatic pressure of water held under tension in this zone is less than atmospheric. Under these conditions a curved surface develops balancing the pressure difference across the air-water interface. Large pores drain and fill with air as the negative pressure (suction) increases vertically away from the water table. The gradual increase in suction results progressively smaller pores draining, and a decrease in soil moisture farther away from the water table.

Expressing the pressure difference across the air-water interface in units of head, the capillary pressure head may be calculated from the capillary rise formula (Wagner, 1987),

$$hc = 2 \cos@/pgr \tag{2.1}$$

where c is the surface tension of water; @ is the contact angle between the meniscus and porous medium grain; p is the density of water; g is gravitational acceleration; and r is the radius of curvature of the meniscus. Equation (2.1) may be used to calculate the height of the capillary fringe above the free water surface of the water table.

The amount of soil water retained at low suction (0 to 1 bar) is dependent on capillarity and pore size distribution, which is affected by soil texture and structure. Water retention at high suction is due to increasing adsorption, which is affected more by texture and less by soil structure (Hillel, 1971). Soil moisture retention curves (figure 12) illustrate the dependance of capillary head on water content. The capillary fringe, or zone of tension saturation, for the silt loam in Figure 12 extends

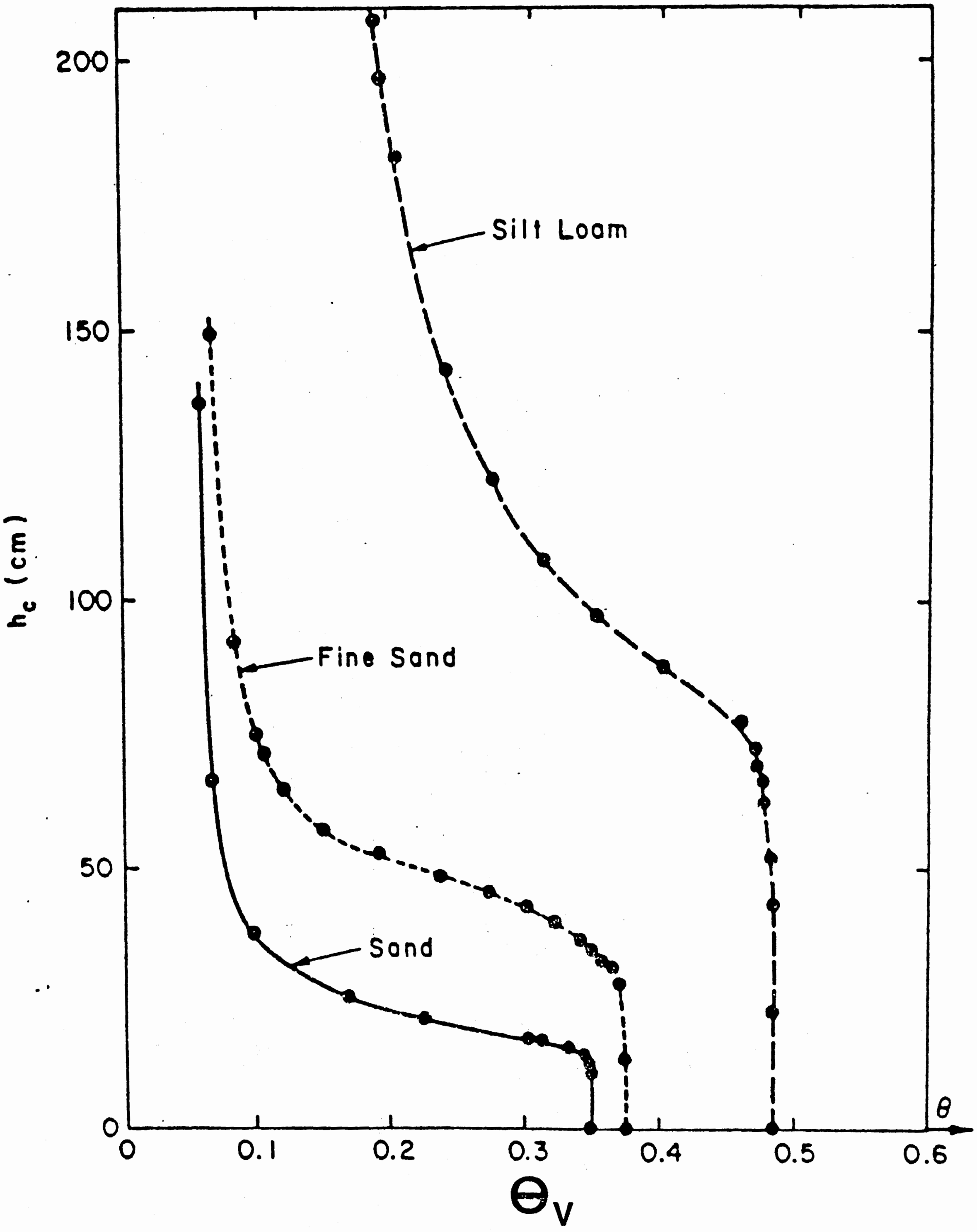

Figure 12. Soil-moisture retention curves for three soil textures.

approximately 75 cm, or about 2.5 feet above the water table.

Methods

Volumetric soil moisture measurements were made approximately every three days from the middle of January to 23 June 1987. The measurement frequency increased during periods of precipitation, and decreased during extended dry intervals. Soil moisture determinations were made at 0.5 foot intervals to a depth of 6.5 feet below land surface.

The soil moisture probe (Troxler model 3330) consists of a source of fast neutrons, a slow neutron detector, and a ratemeter to monitor the flux of neutrons scattered by the soil (Hillel, 1980). The neutron source consists of a 10 mCi Americium-241:Beryllium pellet, yielding 25000 neutrons per second (Troxler Manual, 1983). Fast neutrons are produced when beryllium is bombarded with alpha particles emitted from Americium (EPA, 1980). As the fast neutrons travel through the soil they collide with various atomic nuclei, and are thermalized, or slowed to a velocity characteristic for particles at the ambient temperature. Hydrogen thermalizes fast neutrons after only 18 collisions, far less than the number of collisions required with other elements (Hillel, 1980). The slow neutron detector consists of a Helium-3 tube, insensitive to fast neutrons. Slow neutrons are counted by a ratemeter and converted to volumetric water content by the following equation:

$$\Theta v = A + (B * R) \tag{2.2}$$

where R is equal to the measured count divided by the standard count. A and B are calibration constants determined in the laboratory for each probe.

The soil moisture probe was placed on the access tube and allowed to warm-up for 10 minutes prior to each use. Standard count measurements were made for four minutes within the protective shielding of the meter. Three 30 second "shield" counts were made after the standard count to verify that the meter was functioning properly. Three 30 second neutron counts were taken at each depth to reduce the possibilities of errors. The average of these three readings was converted to volumetric soil moisture content using a simple BASIC computer program employing equation (2.2).

Data Quality Assurance

Accuracy of the neutron moisture probe was determined by comparing the volumetric moisture content obtained by neutron probe with the gravimetric moisture content of soil from split-spoon samples taken simultaneously in the field. Volumetric soil moisture content (volume wetness) is related to gravimetric soil moisture (mass wetness) content by bulk density, shown in the following equation:

$$\Theta v = WPb/Pw \qquad (2.3)$$

where Θv is the volumetric moisture content, W is the mass wetness, Pb is the bulk density of the soil, and Pw is the density of water, assumed to be unity.

Bulk density effects the total pore volume as seen in the following equation:

$$Vn = 1 - Pb/Ps \qquad (2.4)$$

where Vn is porosity, Pb is the soil bulk density, and Ps is the mean particle density, assumed to be that of quartz (2.65 gm/cm^3).

The degree of saturation expresses the volume of water present in the soil relative to the total pore volume. This is expressed as

$$s = w/Vn \qquad (2.5)$$

where Vn is the total pore volume established in the equation (2.4). Hillel (1982) states that in practice, it is extremely difficult to saturate a soil without trapping some air in pore spaces.

The relationship between volume wetness and mass wetness for samples collected on March 03, 1987 is shown in Table I. Bulk density, porosity and degree of saturation are also included.

The volumetric moisture content in Table I, $\Theta*$, was calculated from equation (2.5). The soil moisture neutron probe was used to determine Θv. The percent difference

TABLE I

BULK DENSITY, MOISTURE CONTENT, POROSITY AND DEGREE OF SATURATION WITH DEPTH

Depth (in.)	Pb (gm/cm^3)	W (gm/gm)	θ* (cm^3/cm^3)	θv (cm^3/cm^3)	n	s
0-6	1.62	.210	.340	.312	.39	.80
6-12	1.75	.172	.301	.300	.34	.88
12-18	1.74	.175	.305	.305	.34	.90
24-30	1.63	.196	.319	.287	.39	.74
30-36	1.57	.197	.309	.295	.41	.74
36-42	1.50	.230	.345	.317	.43	.74
48-54*	1.50	.275	.410	-	.43	.95
54-60*	1.57	.236	.370	-	.41	.90
60-66*	1.67	.209	.349	-	.37	.94

between the two volumetric moisture measurements for any given depth ranged from -0.66 to 11.2, the average being less than 4 percent. The similarities in the moisture contents suggest that the moisture neutron probe is a reliable method for determining soil moisture content within the studied soil. The porosity and degree of saturation values for the 4.0 to 5.5 foot interval were calculated using Θ^*.

Variations in Moisture Profiles

Variations in soil moisture content occur with time and depth. The minimum and maximum measured volumetric soil moisture values range from approximately 0.15 to 0.35 cm^3 H_2O/cm^3 soil, respectively. The soil moisture profiles exhibit the same general undulating trend from January through most of March (figures 13a-d). Frequent rains and low evapotranspiration rates prevented drastic fluctuations in the moisture profile.

Increased evapotranspiration rates and less rainfall from the end of March through the middle of May resulted in a decline in the water table from 5.8 to 8.1 feet and a decrease in soil moisture content throughout the profile. The largest decrease in moisture content occurred in the upper two feet of the soil (figures 14a-b). The moisture content in the upper 0.5 foot decreased from 0.29 on March 23, to 0.15 cm^3 H_2O/cm^3 soil by May 20. Late May rainfall substantially increased the soil-moisture content through-

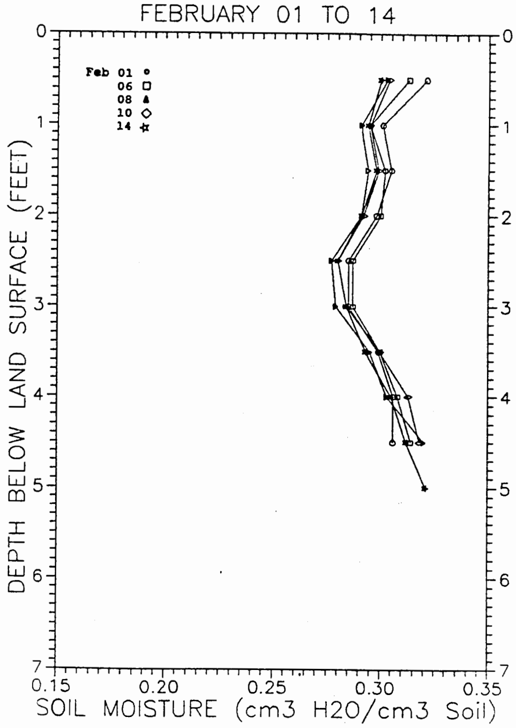

Figure 13a. Soil-moisture content for February 01 to 14.

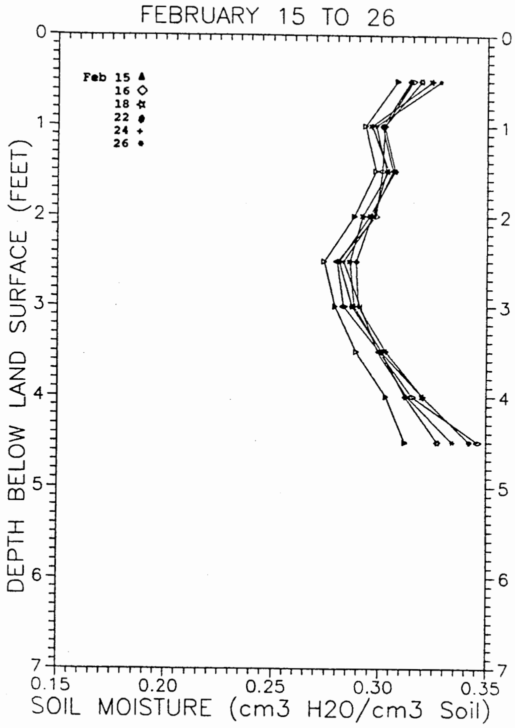

Figure 13b. Soil-moisture content for February 15 to 26.

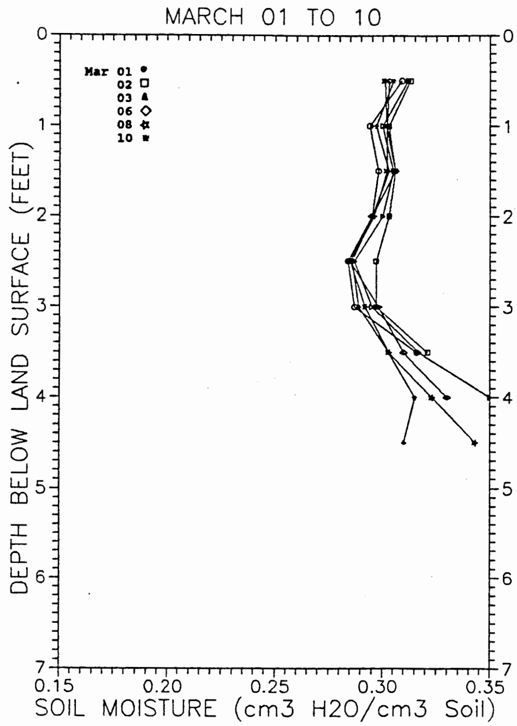

Figure 13c. Soil-moisture content for March 01 to 10.

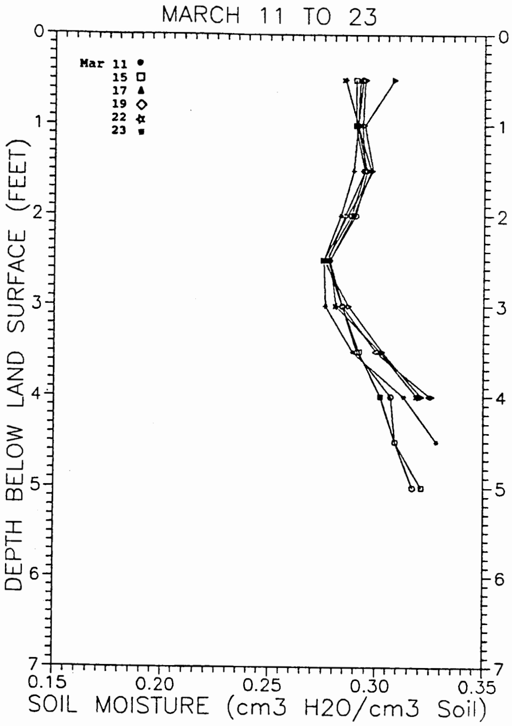

Figure 13d. Soil-moisture content for March 11 to 23.

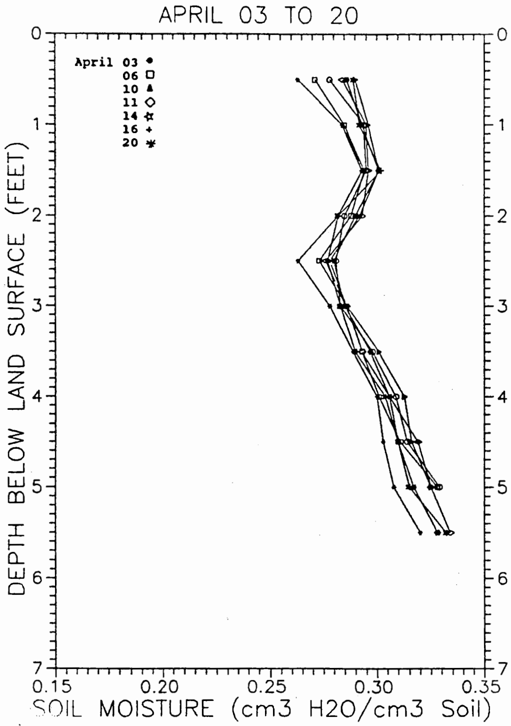

Figure 14a. **Soil-moisture content for April 03 to 20.**

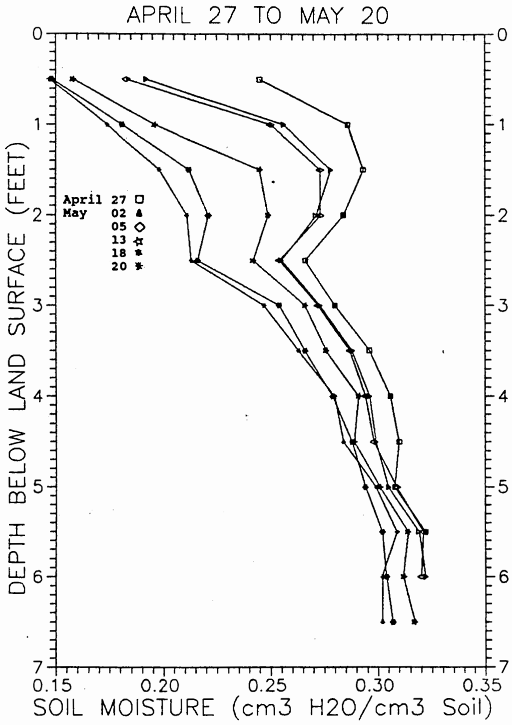

Figure 14b. **Soil-moisture content for April 27 to May 20.**

out the top 2 feet of the soil profile (figure 15). The moisture content of the soil below two feet deep increased only slightly as a result of the precipitation.

Effect of Rainfall on the Soil-moisture Content and the Water Table

Water table response to rainfall varies seasonally. Gillham (1987) states that an instantaneous response to rainfall will occur if the capillary fringe extends to land surface. Under such conditions, the addition of a small volume of water to the soil will result in a rapid disproportionately large rise in the water table, followed by an equally fast decline. This rapid rise and decline of the water table is referred to as the reversed Wieringermeer effect and Wieringermeer effect, respectively. Under such circumstances the effective specific yield, or fillable porosity (Bouwer, 1978), will be very small.

Meyboom (1967) described the rapid rise in water tables of sandy soils after light rains. Rain infiltrating evenly through the soil profile resulted in the entrapment and compression of air above the capillary fringe, resulting in an increase in the water table elevation. Hooghoudt (1947) referred to this phenomenon as the Lisse effect. The ratio of rainfall to water table rise, or the effective specific yield for the Lisse effect is on the order 1:18. The Lisse effect has been observed in areas having water tables less than four feet deep, lasting up to

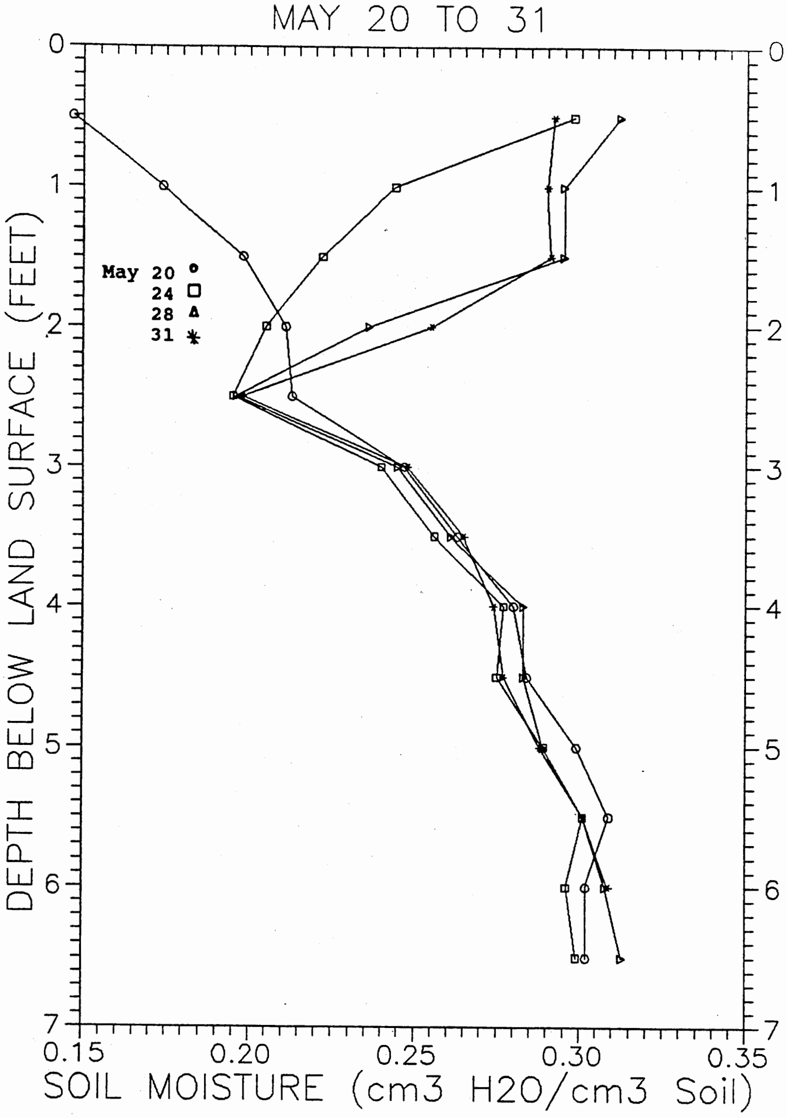

Figure 15. Soil-moisture content for May 20 to 31.

10 days after initial rainfall (Meyboom, 1967).

Two cases are presented to illustrate different responses of the water table to precipitation events. The first case describes the water table response to rainfall during the "wet" portion of this study, when the soil moisture content is high. The second case illustrates the effect of rainfall on the water table following a period of very little rainfall and low soil moisture content.

"Wet" Season Recharge - The March 17 Event

Soil moisture profiles for the months of January, February, and early March exhibit the same basic patterns. Seven inches of snow accumulated at the study area on January 17. The snow gradually melted over the next 10 days resulting in a slow, steady rise in the water table. The site received an additional 4.14 inches of rain through the end of February. The water table began to decline following a 1.72 inch rain on 28 February. Less than one tenth of an inch of rain was added to the system during the first half of March. Despite the slow decline in the water table and the lack of precipitation, the general trends of the moisture profiles remained similar through early March (Figure 13c).

The study area received 1.34 inches of rainfall from about 8:00 p.m. March 16 to 4:00 a.m. March 17. The water table began to rise approximately two hours after the rain started, and continued to rise for nine hours after the rain had ceased. The water table rose 14.5 inches in response to the 1.34 inch rain (figure 16). Therefore, the effective specific yield, or fillable porosity for this event is 0.092.

During this interval the soil moisture content increased from 0.28 to 0.31 in the upper six inches of the soil profile, and only slightly in the zone from 6 to 18 inches below land surface (figure 13d). Although the zone from 1.5 to 3 feet deep remained virtually unaffected by the rainfall, the moisture content increased noticeably at depths of three to four feet. The increase in moisture content in the lower portion of the profile is probably the direct result of the capillary effect accompanying the rise in water table. Low fillable porosity was indicated during this period of high soil- moisture content.

"Dry" Season Recharge - The May Event

Precipitation was minimal from the end of March through the first three weeks of May. During this time, the water table declined 0.08 feet per day, from five to eight feet below land surface. Figures 14a-b illustrate the significant decrease in soil moisture throughout the upper two feet of the profile during this time. A less pronounced decrease in soil moisture occurred throughout the lower 4.5 feet of the monitored profile.

The study area received 5.69 inches of rain between May 21 and 28. The steady water table decline was offset

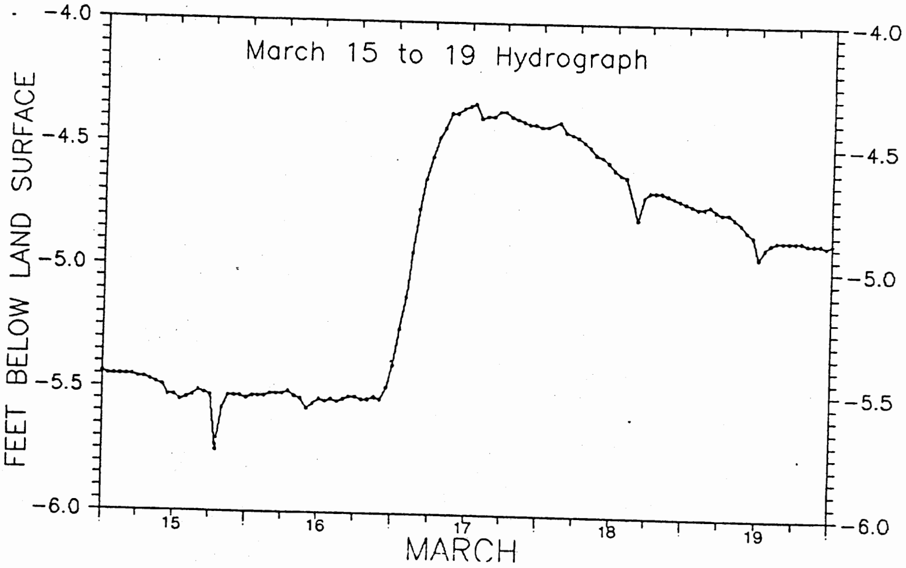

Figure 16. "Wet" season hydrograph from well A4 for March 15 to 19.

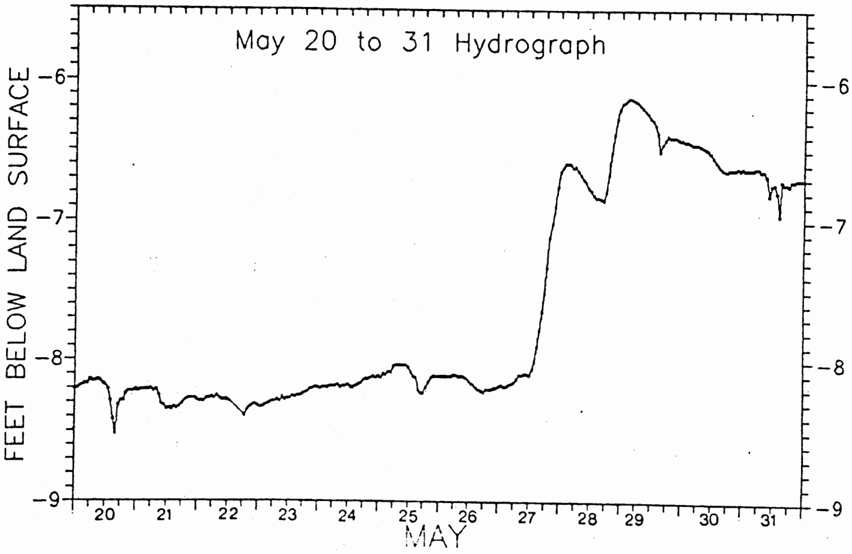

Figure 17. "Dry" season hydrograph from well A4 for May 20 to 31.

by 1.28 inches of rain that fell between May 21 and 25. Diurnal water-table fluctuations were masked by a gradual rise of 0.2 feet in water levels resulting from the rains (figure 17). Moisture profiles indicate the retention of the bulk of infiltrating rainfall in the top 1.5 feet of the soil (figure 15).

Two rain events produced 3.56 and 0.85 inches of rain at the site on May 27 and 28, respectively. The May 27 event consisted of 0.43 inches of rain followed approximately 6 hours later by an additional 3.13 inches resulting in an increase of the water table elevation by 19.1 inches (figure 17). The effective specific yield for this event was 0.19.

On May 28, 0.85 inches of rain resulted in a 8.8 inch rise in the water table (figure 17), and fillable porosity value of 0.097. The soil moisture content increased in the 0 to 2 feet zone, and in the zone below the three feet. However, the moisture content in the 2.5 feet zone remained unchanged. The anomalous low moisture content of the 2.5 feet depth persisted through June 23, despite the addition of almost 4 inches of rain during that period (figure 18).

These data suggest that fillable porosity, or effective specific yield is effected by the soil moisture content of the unsaturated zone. The moisture profile of a soil is related to the amount and intensity of precipitation and position of the water table. During the "wet" season the soil moisture measurements indicated the bulk of

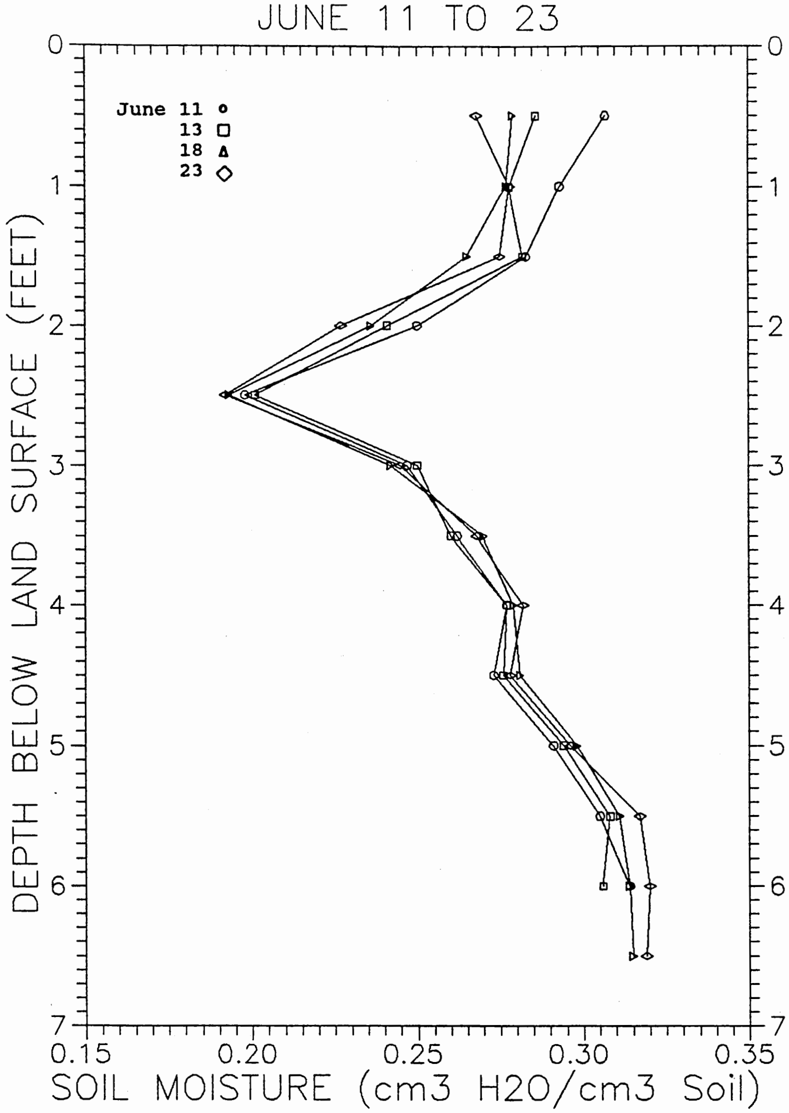

Figure 18. Soil-moisture content for June 11 to 23.

the soil proflile was at, or near saturation. The addition of a small volume of water was all that was necessary to raise the water table significantly. Conversely, during the "dry" season, approximately twice the volume of water would be required to raise the water table the same degree. Simple calculations indicate that the moisture deficient upper soil profile could absorb all the precipitation which occurred during the late May, "dry" season event. The increase in the water table elevation during that time indicates that at least a small volume of water arrived at the capillary fringe. The rapid water table rise to rain relationship suggests flow through macropores as a possible source of the recharge.

CHAPTER V

AQUEOUS GEOCHEMISTRY

Introduction

Ground-water and soil-water samples collected from January 25 to June 23, 1987 were analyzed for 15 physical and chemical parameters. Samples were obtained from four ground-water monitoring wells and eight soil-water suction lysimeters. On-site laboratory facilities allowed the immediate analyses of time sensitive parameters such as temperature, pH, and bicarbonate concentration.

Temporal variations in water quality may be viewed in two respects: long term and short term. Since both expressions are relative, in this study long term variations are defined as occurring over the period of weeks to months, or over the course of the entire study period. Short term variations occur within hours or days.

Water Analyses

Sampling Procedures

Sample bottles were prepared by washing with detergent, rinsing three times with tap water, rinsing three times with deionized distilled water, rinsing in dilute hydrochloric or dilute nitric acid, and finally rinsing again with deionized distilled water.

Three well volumes were purged from each monitoring well by peristaltic pump prior to sampling to ensure that representative samples of the ground-water were obtained (Barcelona, and others, 1985). Water purged from each well was discharged approximately 10 feet from the well locations to prevent immediate recharge to the ground water. Samples were collected from each monitoring well with the peristaltic pump, through tygon tubing. Approximately 200 milliliters of ground water were passed through the peristaltic pump and discharge tubing before sampling. This procedure ensured that all water from the previous sampling had flushed through the system.

Suction lysimeters sampled soil-water over two to seven day periods. Water was removed from the lysimeters through the stainless steel discharge tube and tygon tubing with a peristaltic pump. The sample volumes ranged from less than 10 to approximately 500 mls., depending on the soil moisture content and duration of the collection period. Approximately 50 mls. of deionized distilled water was passed through the peristaltic pump after each sample to prevent cross contamination between lysimeters.

Sample bottles were rinsed with water from each well or lysimeter as volume allowed before the sample was collected.

Field Parameters

Field parameters were measured in the field during sample collection, or immediately thereafter in the on-site laboratory, and included temperature, electrical conductivity (E.C.), pH and bicarbonate (HCO_3^-).

Water temperature was measured with a hand-held digital thermometer sensitive to 0.1 degrees celsius. Solution pH was measured with a hand-held digital pH meter sensitive to 0.01 pH units. The pH meter was calibrated regularly with standard pH solutions. The electrical conductivity was measured with a temperature compensating conductivity meter. Electrical conductivity values were adjusted by the meter to 25 degrees celsius and are reported in micromhos per centimeter (umhos/cm).

Bicarbonate concentrations were determined titrametrically with a Hach digital titrator to a 4.5 pH color end point with 2N HCl. The number of digits required to reach the end point were converted to HCO_3^- concentration with a simple BASIC computer program. Duplicate samples were analyzed for every fifth sample.

Sample Preparation

Samples were refrigerated immediately after field parameter determinations and stored at 4 degrees celsius. Samples collected on, or before 05 May were vacuum filtered through 0.45 micrometer Millipore acetate filters. Samples collected after 05 May were filtered through 0.2 micrometer Gelman acetate filters. An aliquot of each filtered sample was acidized to a pH of approximately 2 with 1N HCl and stored for cation analyses. The remaining volume of sample was refrigerated for anion analyses by ion chromatography.

Anion Analyses

Water samples were analyzed for chloride (Cl^-), nitrate (NO_3^-), sulfate (SO_4^{-2}) and bicarbonate (HCO_3^-) anions. Chloride, NO_3^- and SO_4^{-2} concentrations were determined by ion chromatography (Dionex 2000i) following EPA Standard Methods 300.0 (EPA, 1984). Standard solutions were prepared by diluting appropriate volumes of stock solutions containing 1000 ppm Cl^-, NO_3^-, and SO_4^{-2}.

Quality Assurance/Control

Three injections were made during calibration of the ion chromatograph, and for recalibration following the analyses of 20 samples. Duplicate samples and calibration standards were analyzed on a regular basis to ensure that the ion chromatograph was functioning properly.

The sample collected from well A1 on 01 March 1987 was used to determine if sample degradation over time was a problem. The sample was analyzed seven times between 02 April and 23 June 1987 for Cl^-, NO_3^- and SO_4^{-2} (Table II). The data indicate no noticeable degradation over three months, suggesting that samples may be refrigerated for an extended period without significant alteration of certain anionic concentrations. Variations between duplicate analyses ranged on the order of 0.1 mg/l, usually representing less than one percent difference between samples.

TABLE II

VARIATIONS IN CONCENTRATIONS WITH TIME

Analyses Date Designations

	4/02	4/14	5/18	5/24	5/26	6/10	6/23	$\bar{x}$
Cl^-	17.4	17.4	17.6	17.8	16.5	17.9	18.0	17.5
NO_3^-	29.7	29.9	29.7	30.0	29.8	30.2	30.2	29.9
SO_4^{-2}	24.7	24.6	24.1	24.4	24.5	24.5	24.4	24.6

Cation Analyses

Inductively coupled plasma atomic emission spectroscopy (ICP) was used for cation analyses. Water samples were analyzed for calcium (Ca^{+2}), magnesium (Mg^{+2}), sodium (Na^+), potassium (K^+), total iron (Fe), manganese (Mn), aluminum (Al) and silica (Si) on a regular basis. Decade standards were made for each element by diluting stock solutions prepared by diluting standard reagent solutions. Acidified laboratory blank samples were analyzed with acidified samples. Each sample was analyzed four times and reported as an average concentration.

Quality Assurance/Control

Samples of known cation concentration were used to determine the quality of laboratory analyses. E.P.A. Water, prepared and verified by analyses by personnel of the E.P.A., was analyzed on a regular basis with samples . Solutions of varying Ca^{+2} and Mg^{+2} concentrations were analyzed to detect possible matrix effects between the two cations. No apparent matrix effects were observed.

Overall Water Quality

Modified Piper diagrams were used to interpret chemical data from water analyses (Piper, 1944). Ionic concentrations were converted to milliequivalents per liter and plotted as percent cations and percent anions on Piper diagrams modified for use with NO_3^- data; nitrate concentrations were combined with sulfate concentrations. All water samples plotted in the general calcium-magnesium-bicarbonate area (Figure 21). Bicarbonate was the dominant ion in all water samples, commonly comprising more than half the total ionic content.

Temporal Variations of Selected Parameters

Electrical Conductivity

Electrical conductivity (EC) varied considerably with time and depth, ranging from a minimum of 408 to a maximum of 1445 umhos/cm. Electrical conductivity generally

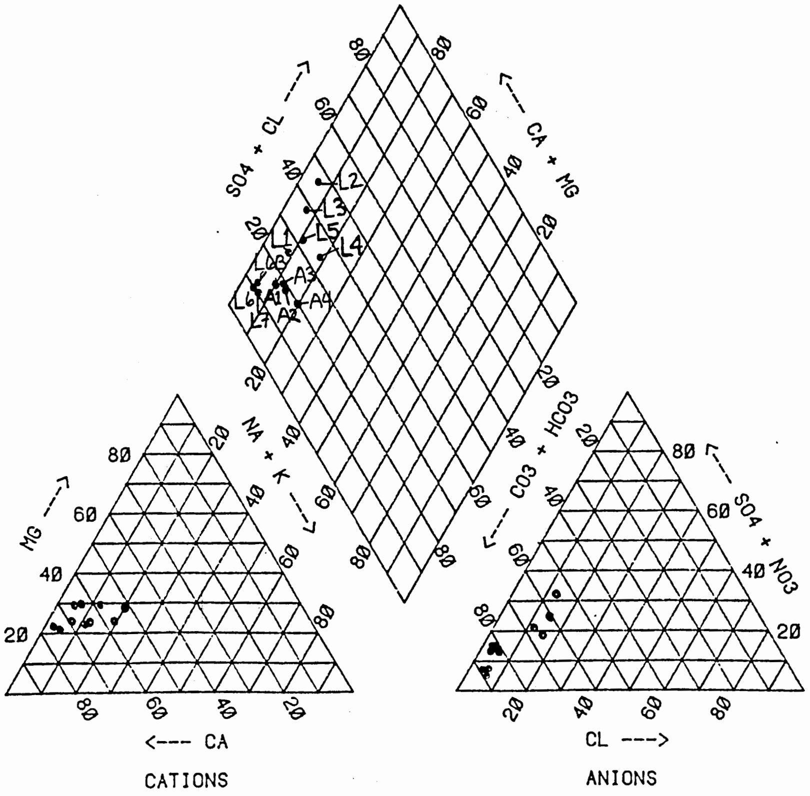

Figure 19. Modified Piper diagram.

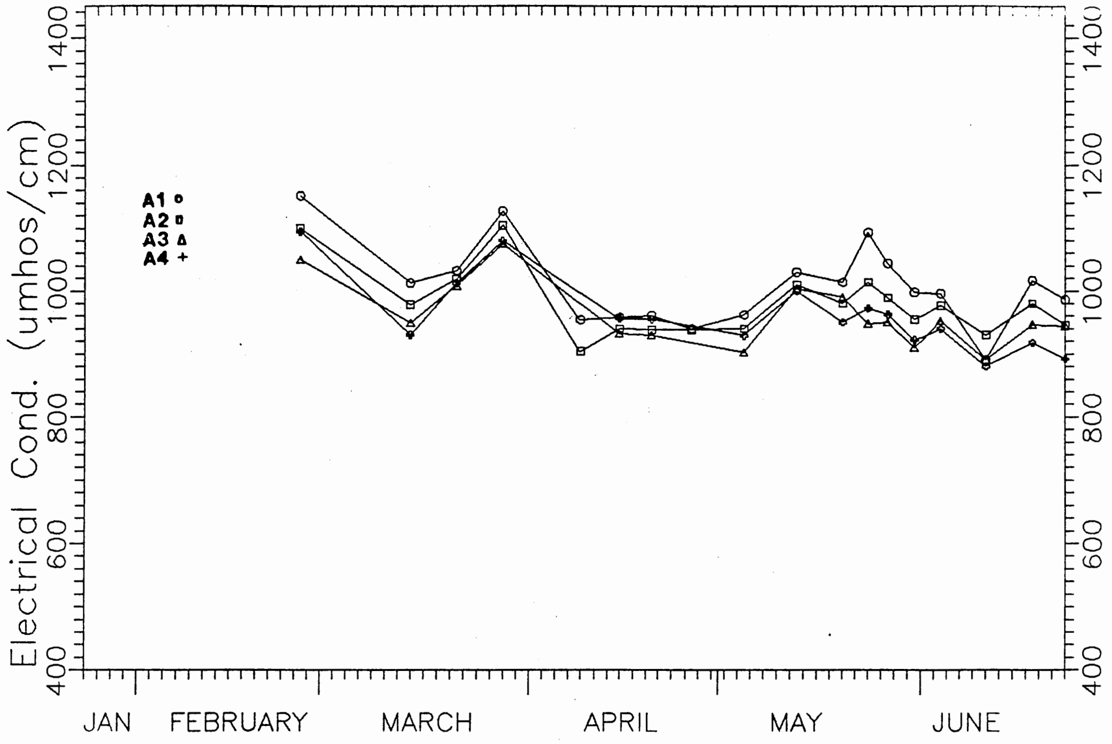

Figure 20a. Electrical conductivity versus time in A site wells.

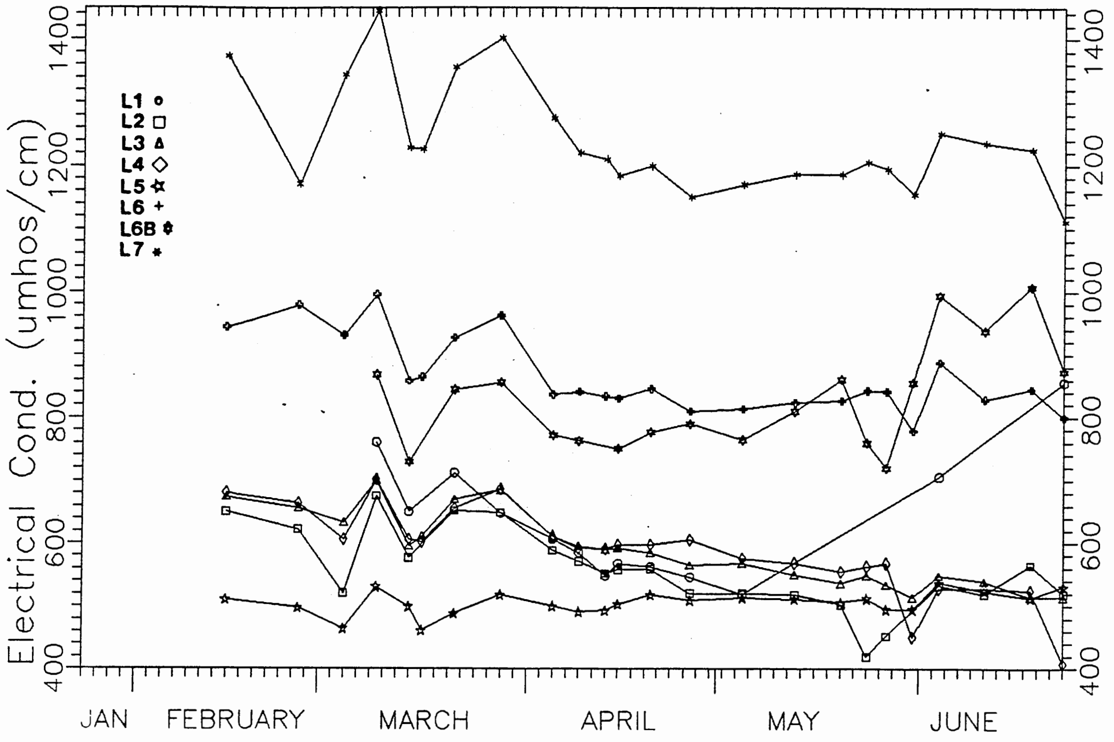

Figure 20b. Electrical conductivity versus time in suction lysimeters.

decreased with depth in the monitoring wells and increased with depth in the lysimeters (figures 20a-b). The notable exceptions being L1 and L5. Lysimeter L5 usually had the lowest electrical conductivity. During the last two months of the study the EC of L1 increased from 518 to 760 umhos/cm. Computer software was used to determine the mean, standard deviation, maximum and minimum values for electrical conductivity (appendix B) and other parameters from ground water and soil water samples. Electrical conductivities values were normally distributed at the 95% confidence level for all wells and most lysimeters, except for L2, L6 and L7.

Bicarbonate

Minimum and maximum bicarbonate (HCO_3^-) concentrations ranged from 125 to 871 mg/l. Throughout the study period, HCO_3^- concentrations decreased with depth in the ground water (figure 21a). The only exception being the February 22 and June 11 samples, when the HCO_3^- concentration of the A1 sample was less than that of the A2 sample. The general trends for HCO_3^- concentrations in the lysimeters remained relatively constant from late January through most of May (figure 21b). The HCO_3^- concentration of L5 began to increase slightly during April and continued gently rising through June. The same general rise was seen in L6B, with the exception of May 24 and 27 samples. Bicarbonate concentrations declined slowly in all other

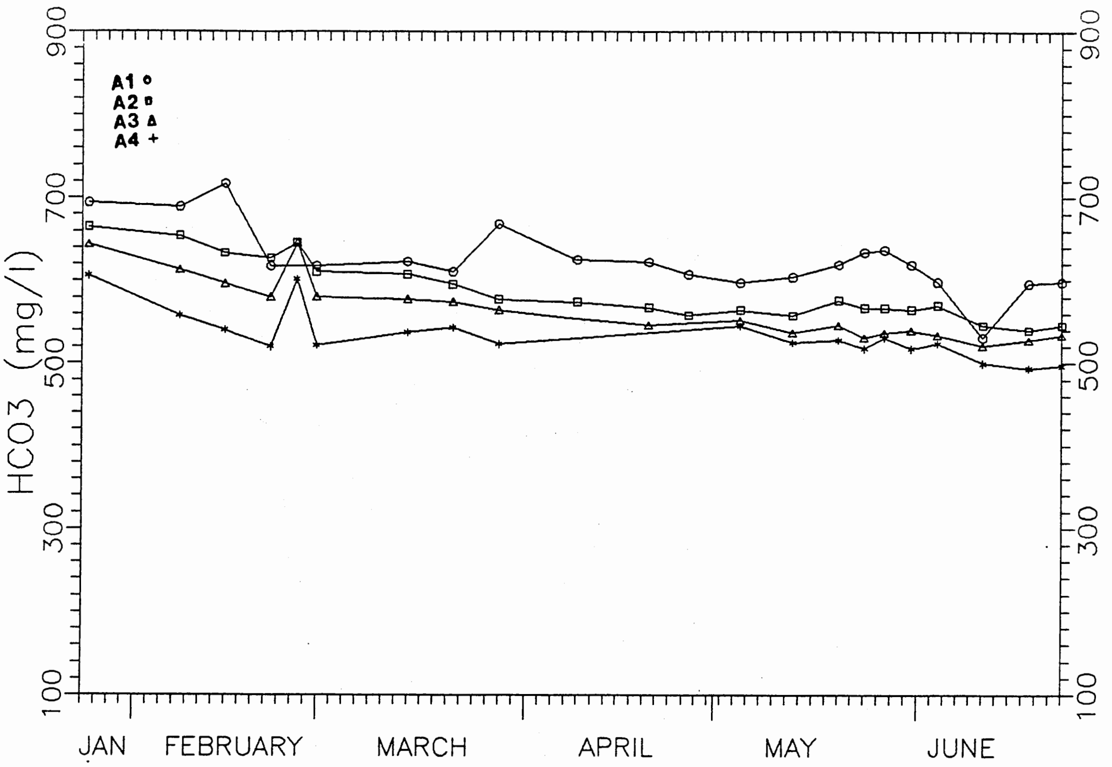

Figure 21a. Bicarbonate concentrations versus time. in A site wells.

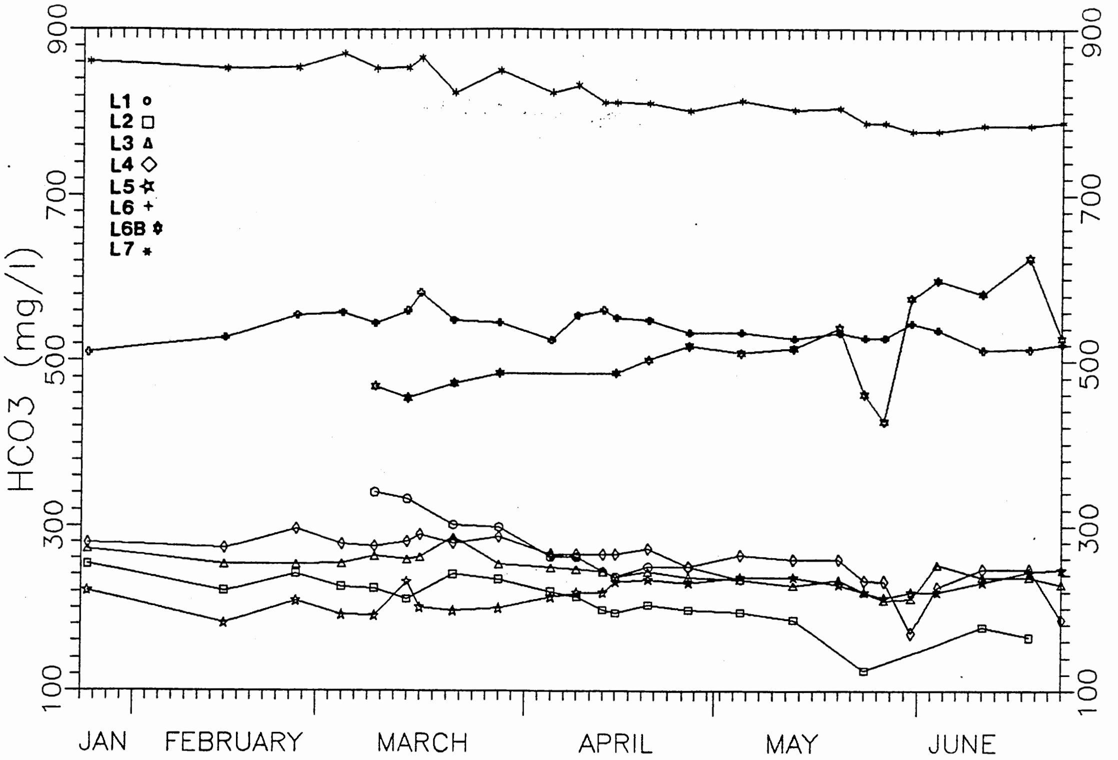

Figure 21b. Bicarbonate concentrations versus time. in suction lysimeters.

lysimeters and wells from January through June. Concentrations of HCO_3^- had a normal distribution in eight of the twelve lysimeters and wells at the 95% confidence level (Appendix B).

Chloride

Chloride concentrations ranged from 8.8 to 36.0 mg/l in samples collected from the monitoring wells and suction lysimeters. Concentrations of chloride from well samples decreased with depth from 23 January through 22 March (figure 22a). However, following the 22 March sampling chloride concentrations in the A1 well were usually lower than, or approximately equal to chloride concentration of the deeper wells. Wells A2, A3 and A4 exhibited a general increase in chloride concentrations from early February through early May. The gradual increase was followed by a steady decease in concentration through June.

Chloride concentrations varied considerably throughout intervals sampled by suction lysimeters. Highest concentrations were generally present in L3 and L4 samples (figure 22b). Lysimeters L2, L3 and L5 showed overall declines in chloride concentrations from late January through June. However, highest Cl^- concentrations in the 2 feet deep lysimeter occurred in the 18 June sample. The declining trend in Cl^- concentrations in L5 was reversed near the end of April by a slight rising trend. Samples from L7 were the only set exhibiting a consistent overall

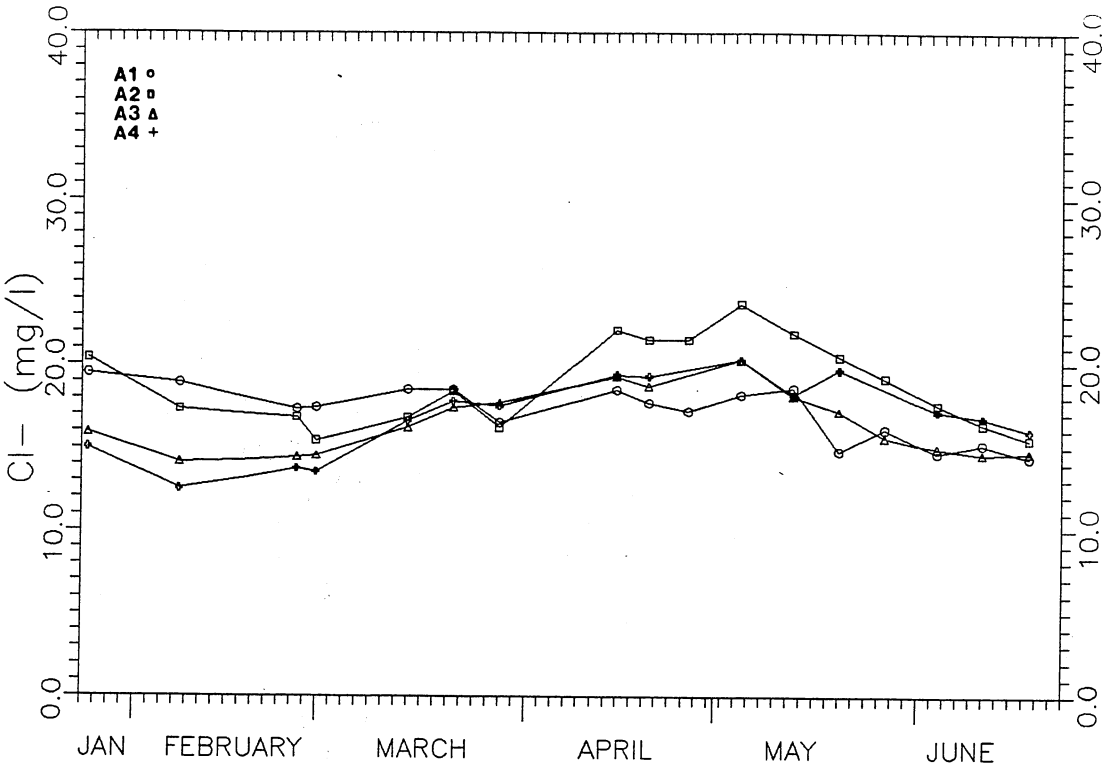

Figure 22a. Chloride concentrations versus time in A site wells.

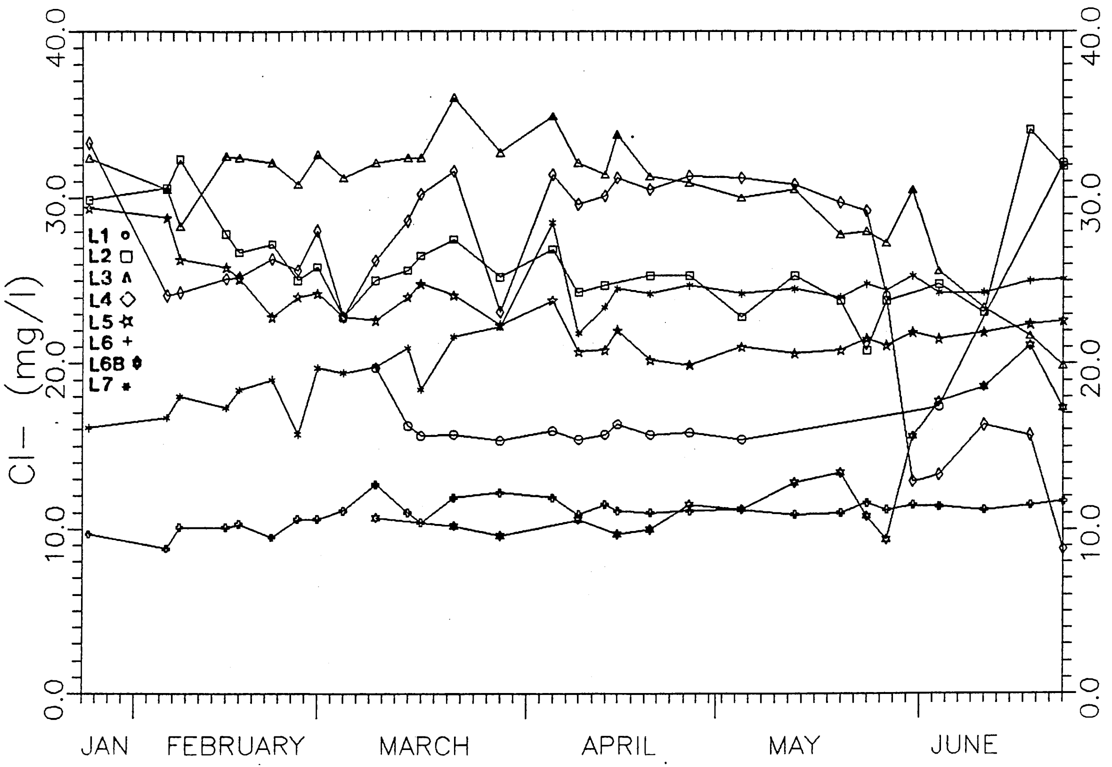

Figure 22b. Chloride concentrations versus time in suction lysimeters.

rise in Cl^- throughout the study. L1, L6B and L6 samples maintained consistent concentrations, increasing from late May through June in L1 and L6B. Chloride concentrations in L4 were the most variable of all the lysimeters. The largest decrease in concentration occurred between May 20 and 27.

Chloride concentrations in L2, L5, L6 and all the monitoring wells had normal distributions at the 95% confidence level (Appendix B).

Nitrate

Concentrations of nitrate as NO_3^- ranged from 16.0 to 65.6 mg/l. Nitrate in wells A1-4 increased with depth and time from late January through June (figure 23a). Well A1 appears to be the exception with concentrations decreasing in time from late January through late May, followed by a rapid increase and decline of NO_3^- in early June. Nitrate concentrations generally decreased with depth and increased with time in lysimeters samples from late January through mid May (figure 23b). NO_3^- concentrations in L1 decreased rapidly from late April through June. A similar decrease occurred in the L2 and L3 lysimeter samples beginning in mid May, and to a lesser extent in the L5 samples. Samples from the L6 and L6B lysimeters at 6.6 and 6.7 feet deep, respectively, contained less than one milligram per liter of nitrate throughout the study.

Nitrate concentrations in L4 samples remained rela-

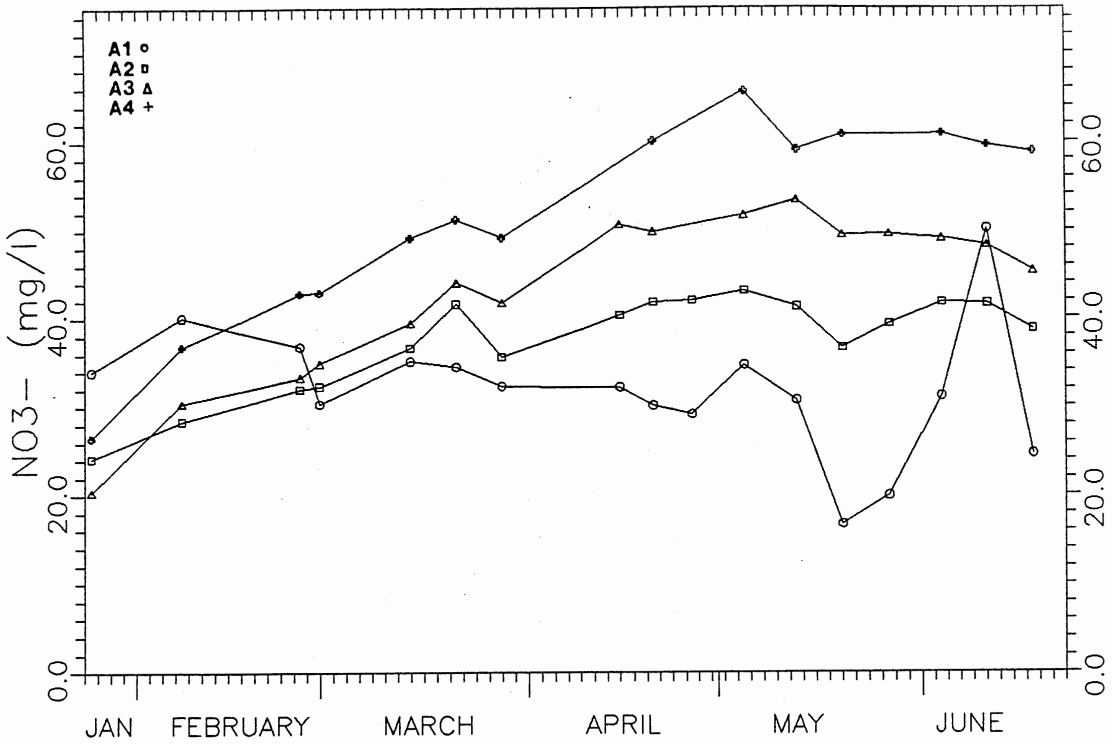

Figure 23a. Nitrate concentrations versus time in A site wells.

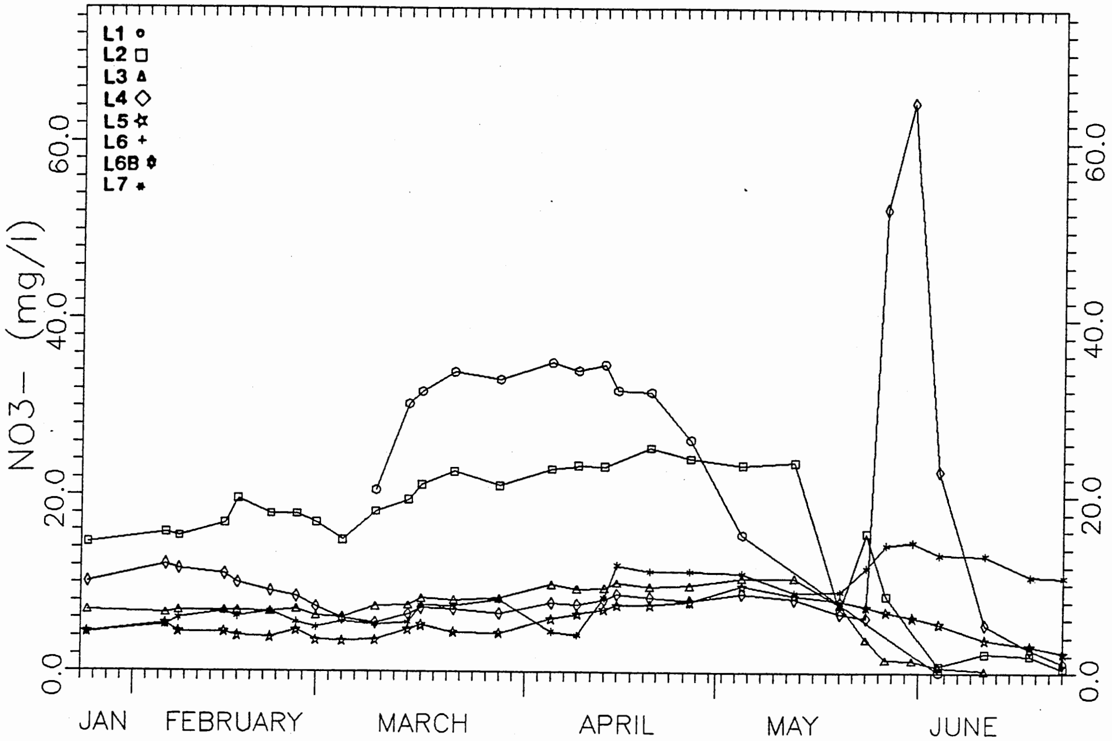

Figure 23b. Nitrate concentrations versus time in suction lysimeters.

tively consistent through the middle of May, but increased by an order of magnitude from 6.2 to 64.5 mg/l from May 24 to 27. This rapid increase was followed by a rapid decrease in NO_3^- concentrations through the end of June.

Nitrate concentrations in lysimeter samples do not appear normally distributed, except in L5. Wells A3 and A4 have normal distributions of NO_3^- at the 95% confidence level (Appendix B).

Sulfate

Sulfate concentrations ranged from 18.9 to 184 mg/l in water samples from monitoring wells and lysimeters during the study. With the exception of L1, sulfate concentrations from lysimeter samples decreased with depth from January through the mid May (figure 24a). L1 samples exhibited a steady increase in SO_4^{-2} concentration from March through June. However, caution must be taken when scrutinizing data from L1 due to several missing and suspect data points. Sulfate concentrations remained relatively constant at varying depths of the vadose zone, with a slight increasing trend in L5, L6, L6B and L7 samples. The largest concentration fluctuations occurred in L2 and L4 samples near the end of May.

Sulfate concentrations the monitoring wells remained relatively constant throughout the study period, ranging from 22.9 to 33.2 mg/l (figure 24b). There appears to be no specific trends in concentration versus depth. There is

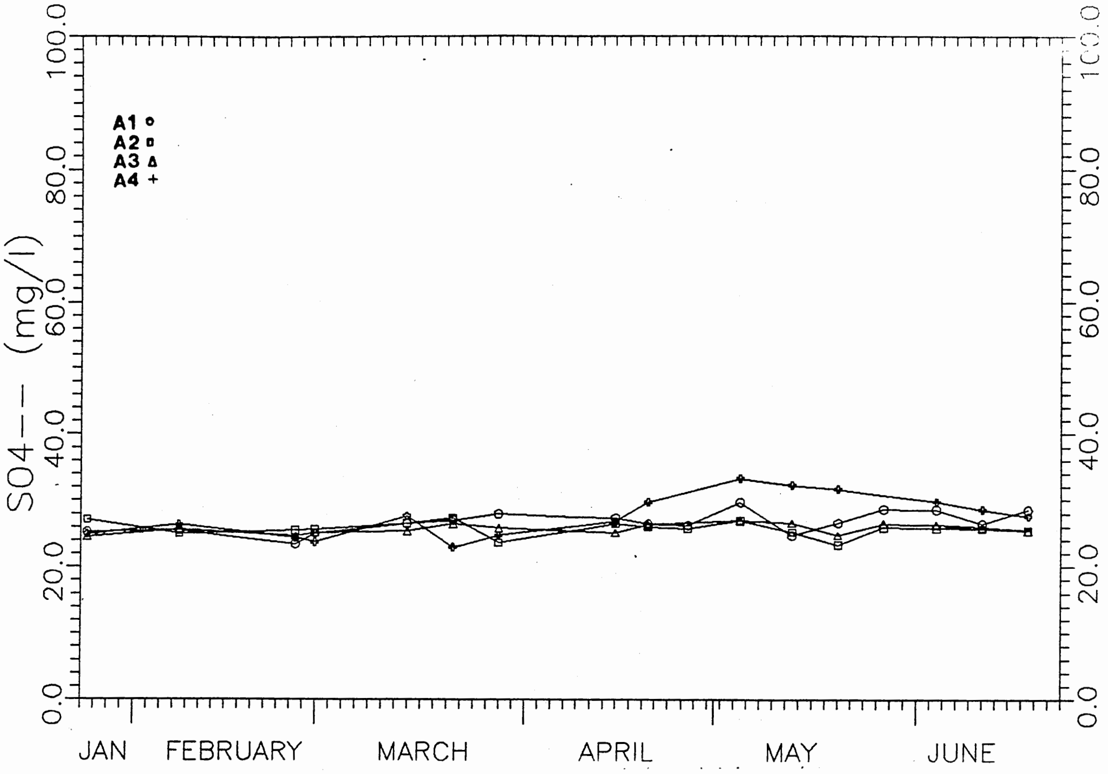

Figure 24a. Sulfate concentrations versus time in A site wells.

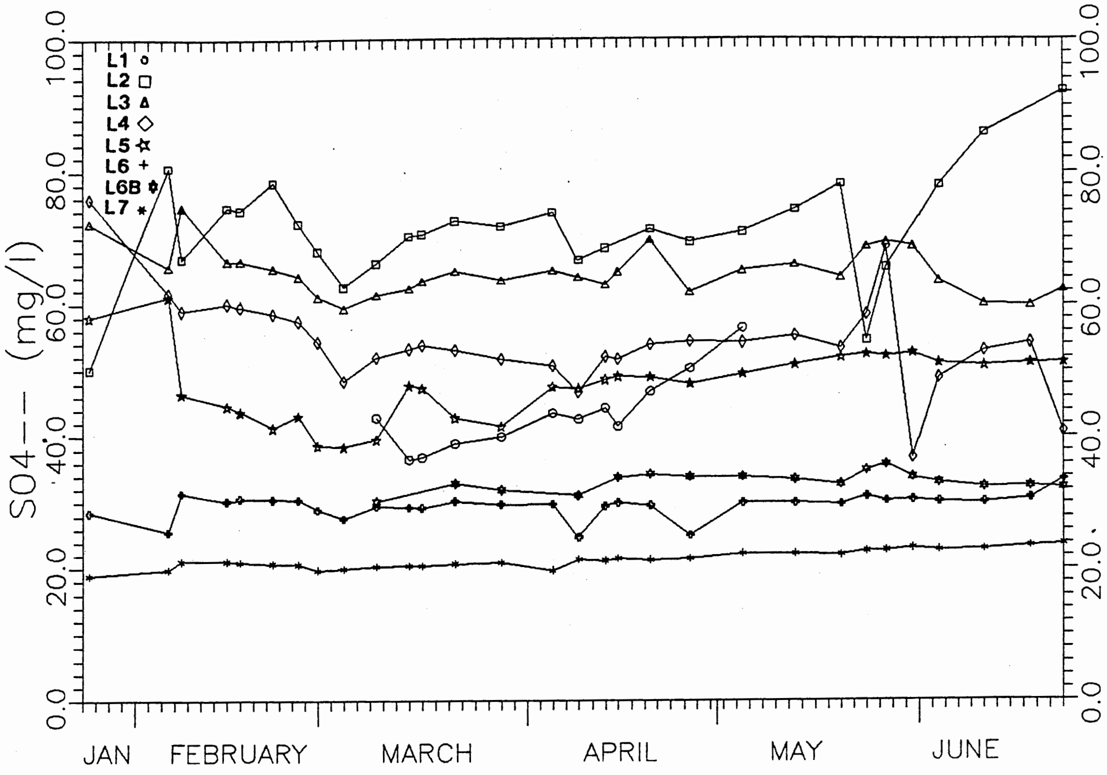

Figure 24b. Sulfate concentrations versus time in suction lysimeters.

a normal distribution of sulfate concentrations over time in all monitoring wells and all lysimeters except L1 and L6 (Appendix B).

Calcium

Water samples contained calcium concentrations ranging from 25.1 to 183.9 mg/l. Calcium proved to be the most difficult cation to analyze. Analysis of unacidized samples produced values equal to less than half the concentration of acidized samples. Samples collected during the first portion of the investigation were not acidized before analyses, resulting in abnormally low Ca^{+2} concentrations. Analyses of several of the unacidized samples after the addition of dilute HCl acid resulted in higher concentrations of Ca^{+2} in most cases. The low Ca^{+2} concentrations usually occurred in samples with high HCO_3^- concentrations, and were usually accompanied by large negative cation/anion balances. While it is not good practice to edit data, several unusually low Ca^{+2} values were removed from the graphs and statistical data base, but only if they were accompanied by large negative cation/anion balances.

Calcium concentrations generally decreased with depth in the upper five feet of the monitored profile (figure 25b). There appeared to be a slight decreasing trend in Ca^{+2} concentrations in L1-4 samples from February 06 through the end of May, and a slight increase in samples

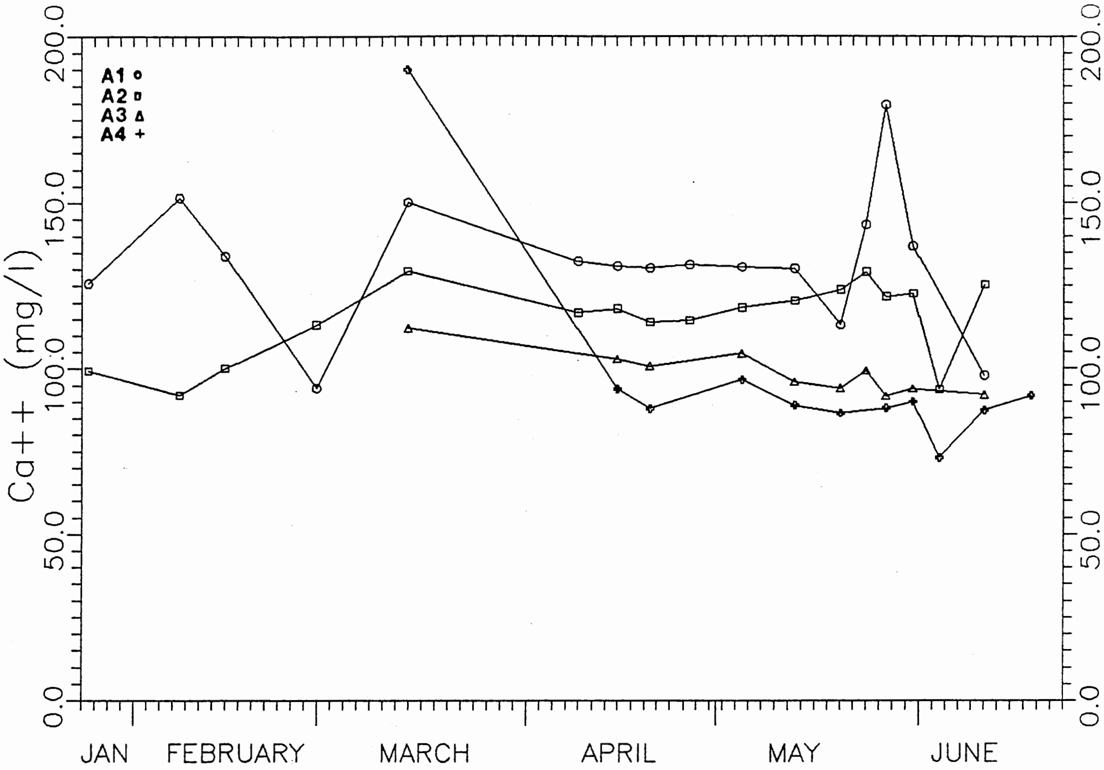

Figure 25a. Calcium concentrations versus time in A site wells.

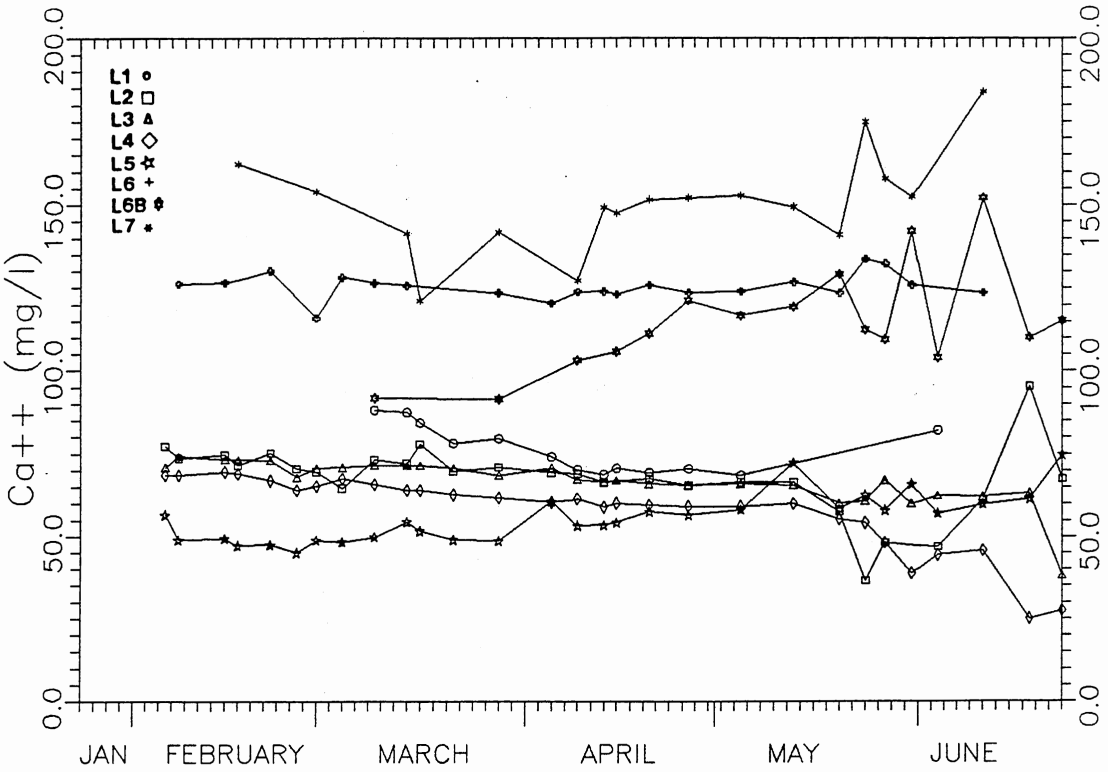

Figure 25b. Calcium concentrations versus time in suction lysimeters.

obtained from L5-7 of the same time period.

Concentrations of Ca^{+2} in ground-water sampled from January 25 through June 18 decreased with depth in most instances (figure 25a). Calcium was distributed normally at the 95% confidence level in three of the four well and only three of the eight lysimeters (Appendix B).

Magnesium

Magnesium concentrations ranged from 8.5 to 72.4 mg/l in water samples collected from lysimeters and wells throughout the duration of the study. Concentrations in lysimeter sampled zones vary considerably and generally increase with depth through most of the study (figure 26b). The most noticeable exception to this trend is L5 which maintains the lowest sample concentration through the first half of the investigation. Magnesium concentrations in L2, L3 and L4 were relatively unchanged from 08 February through 20 May. Concentrations decreased in L2 and L4 by May 24 and 27, respectively, followed by a decrease in L3 by 04 June. Magnesium concentrations in L7 were consistently higher than the wells, or other lysimeters.

Magnesium concentrations of samples collected from monitoring wells increased with depth to a minor extent from mid April through mid May (figure 26a). Prior to, and after this portion of the study period no specific trend in concentration with depth is evident. All wells and lysimeters except L3 and L4 had a normal distribution of Mg^{+2}

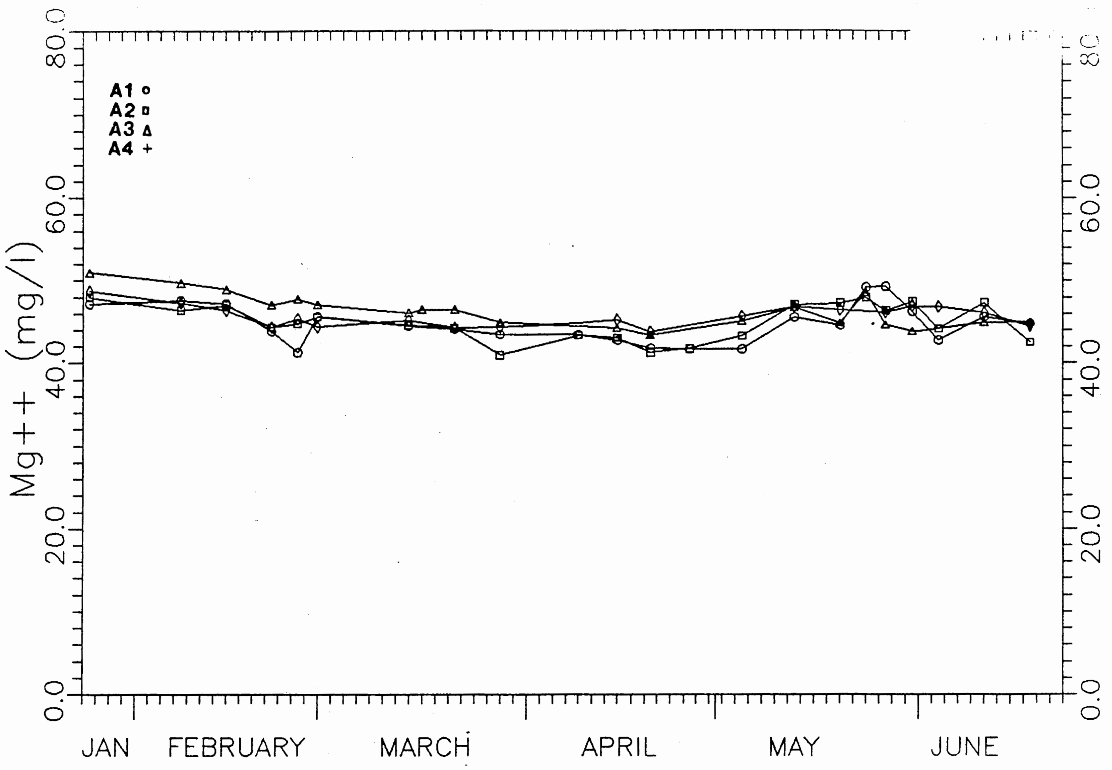

Figure 26a. Magnesium concentrations versus time in A site wells.

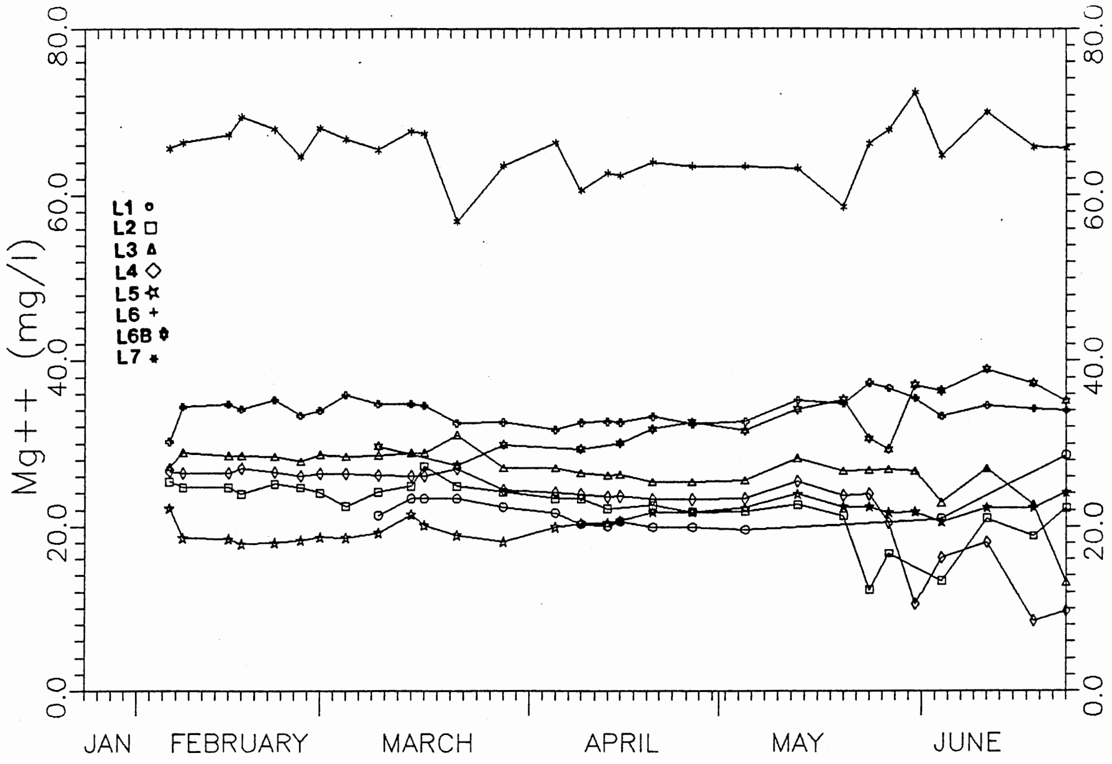

Figure 26b. Magnesium concentrations versus time in suction lysimeters.

concentrations from 06 February through June. All wells and lysimeters except L3 and L4 had normal distributions of sodium at the 95% confidence level (Appendix B).

Sodium

Sodium concentrations ranged from 6.3 to 53.5 mg/l from January 25 through June 23. Concentrations in most lysimeters remained relatively consistent during the study. There does not appear to be a general concentration trend with depth in the zones sampled by lysimeters. The largest variation in Na^+ concentrations occurred in L2, L3 and L4 after May 20 (figure 27b). Sodium concentrations in L2 and L4 increased from 6.4 and 29.0 to 25.8 and 50.1 by May 24 and 27, respectively. A four-fold increase in Na^+ occurred between June 18 and 23 in the three foot deep lysimeter.

The concentration of sodium in samples obtained from the monitoring wells usually increased with depth during the monitoring period (figure 27a). Well A1 had the greatest fluctuation in Na^+ from 26.8 to 51.7 mg/l between June 04 and 11. Sodium concentrations exhibit an overall slight increase during the study period. Wells A2-4 and lysimeters L6B and L7 had normal distributions of sodium at the 95% confidence level (Appendix B).

Potassium

Potassium concentrations ranged from 0.06 to 1.90 mg/l during the course of this investigation, generally de-

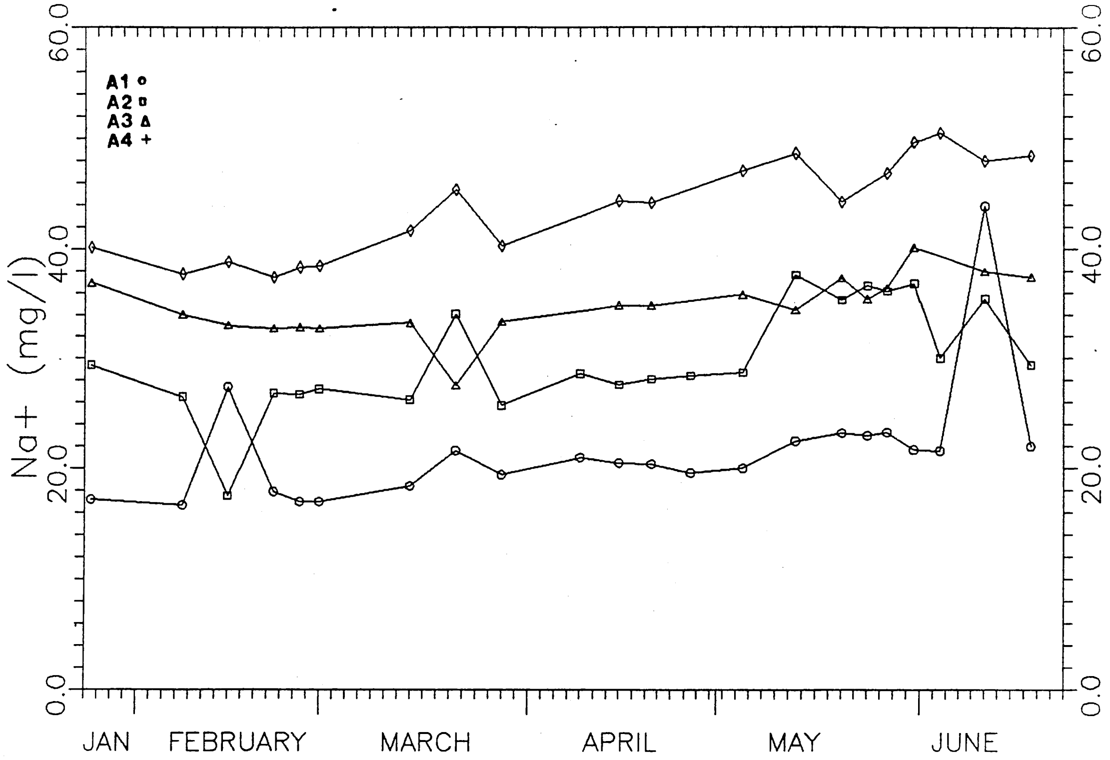

Figure 27a. Sodium concentrations versus time in A site wells.

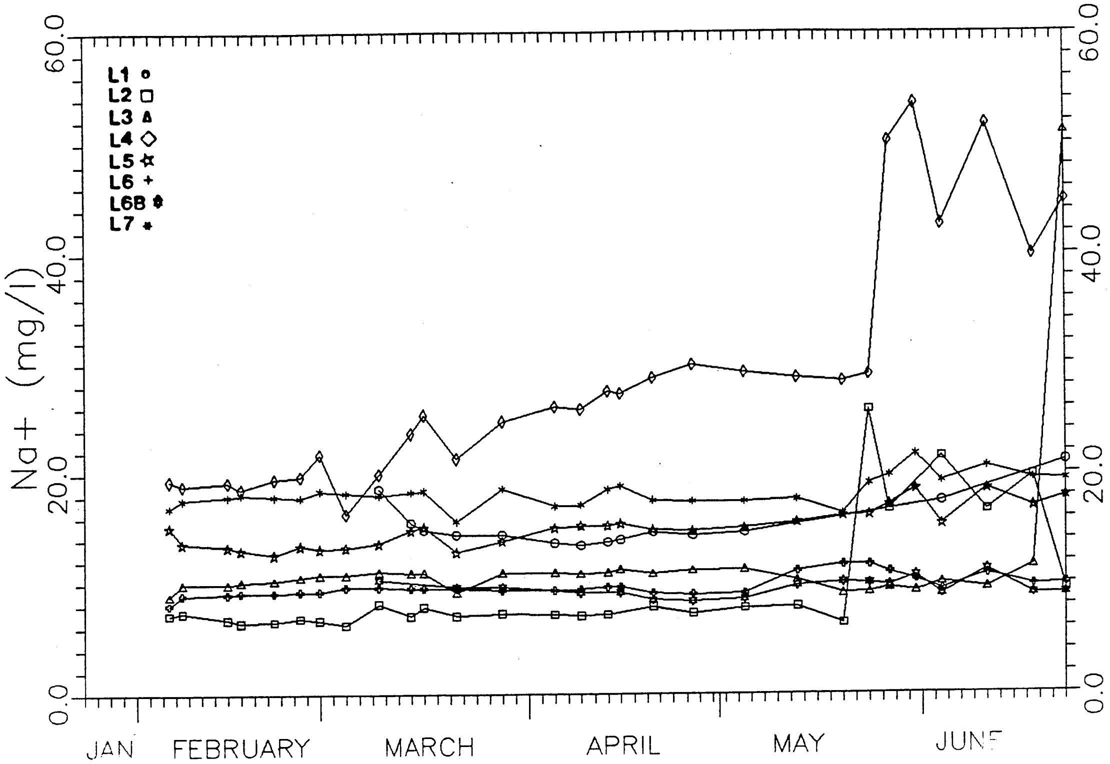

Figure 27b. Sodium concentrations versus time in suction lysimeters.

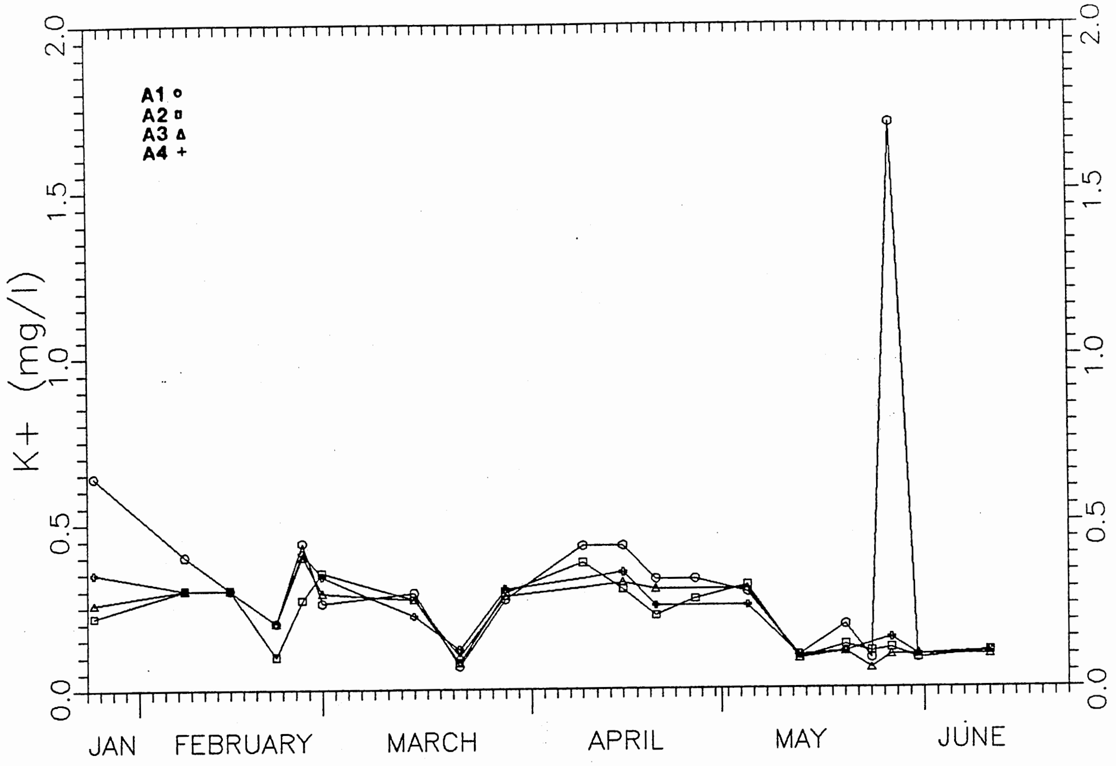

Figure 28a. Potassium concentrations versus time in A site wells.

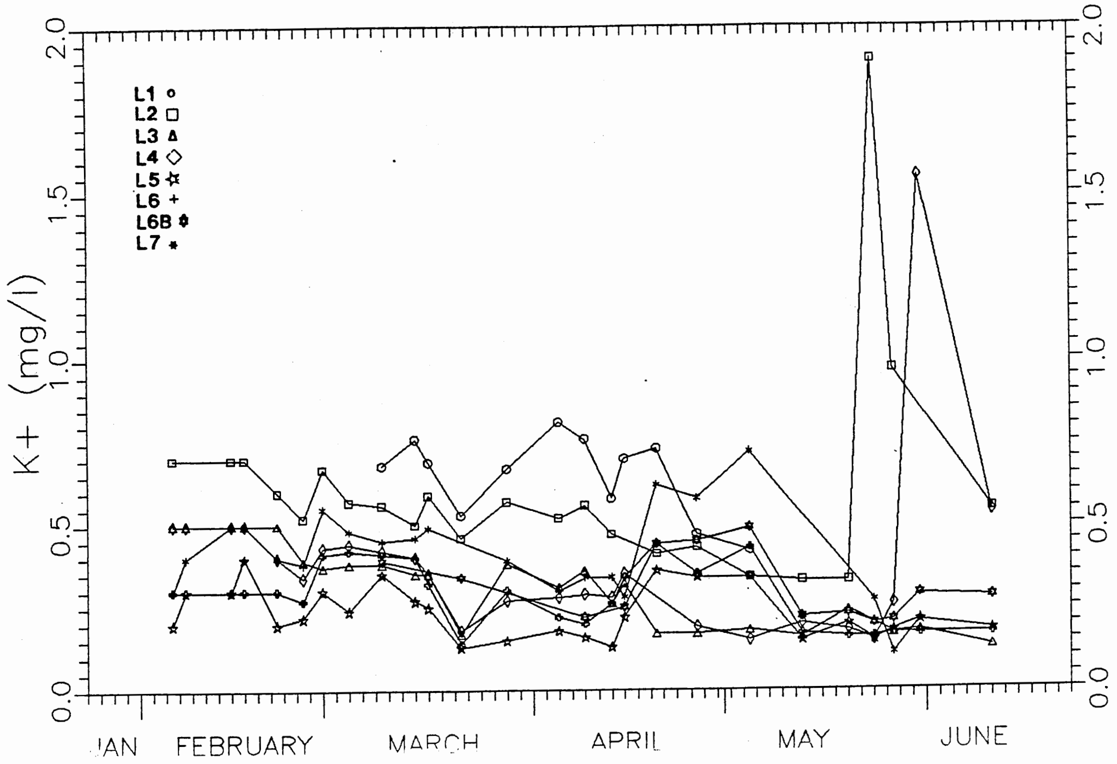

Figure 28b. Potassium concentrations versus time in suction lysimeters.

creasing with depth in lysimeter samples (figure 28b). No obvious trend of concentration with depth is apparent in monitoring well samples (figure 28a). The largest fluctuations in potassium concentrations occurs in L2 samples between May 20 and 24, and in A1 and L4 samples between May 24 and 27. This increase occurs after 5 inches of precipitation.

Normal distribution of potassium was found in samples L1, L5, L7, A2, and A4 (Appendix B).

Possible Sources of Parameter Variations

Carbonate Equilibria

Electrical conductivity is a function of the total dissolved solids (TDS) content of a solution. The dominate ion in water samples collected throughout the study was the bicarbonate anion. Bicarbonate concentration within a system is controlled by carbonate equilibria, described in the following equation (Krauskopf, 1979):

$$\begin{array}{c} CO_2 + H_2O \\ \| \\ CaCO_3 + H_2CO_3 = 2HCO_3^- + Ca^{+2} \end{array} \tag{6.1}$$

The main driving force in equation (6.1) is the partial pressure, and hence concentration of CO_2 in the system. As the CO_2 concentration increases, the carbonic acid (H_2CO_3) concentration increases, causing the dissolution of CaCO3 and an increase in HCO_3^- and Ca^{+2} concentrations. One bicarbonate ion is formed by the dissociation of H_2CO_3, and the other from the reaction of the H^+ with $CaCO_3$. Respiration by plant roots and microbial decay of organic material may result in the increase in CO_2 concentrations of the unsaturated zone one to two orders of magnitude greater than atmospheric concentrations (Bohn, and others, 1985). The CO_2 concentration of water may increase significantly during infiltration through the unsaturated zone to the water table, resulting in elevated HCO_3^- concentrations. However, the rapid movement of carbon dioxide poor rain water through a soil profile may result in the temporary dilution of HCO_3^- in the system. Evidence for this was seen with the decrease in HCO_3^- following the late May rains in the 2.0 and 3.6 feet deep lysimeters, L2 and L3, respectively; L6B demonstrates a similar trend.

Fertilization

Fertilizers and herbicides are applied to the study site three times yearly. The fertilizers are derived from monoammonium phosphate, urea, potassium chloride and sulfur. Urea constitutes the majority of the 20 to 34 percent total nitrogen content of the fertilizers.

Variations in sulfate concentration may result from the oxidation of sulfur by soil microbes of the genus *Thiobacillus*. The most rapid oxidation of sulfur to SO_4^{-2} occurs in aerated soils near field capacity (Tisdale and Nelson, 1975). The dramatic increase in SO_4^{-2} concentrations in the shallowest lysimeter (L1) after fertilization in late May is attributed to this process. The majority of the sulfate ions in the soil water and ground water may have originated from the weathering of sulfate-rich minerals (gypsum) present in the original parent material.

Urea readily hydrolyses to ammonium in the soil environment. Adsorption of ammonium ions by illite and other 2:1 clays prevents extensive leaching to the ground water. However, nitrate ions formed by the oxidation of ammonium may be readily leached through the soil profile to the water-table (Wild, 1981). The source of increase in NO_3^- concentrations in L2, L4, L7 and A1 following fertilizer application and rain in late May is hypothesized to be the degradation of urea to NO_3^- in the soil environment.

Chloride comprises three to six percent of the added fertilizer. The conservative nature of chloride allows it to move unhindered through soil/water systems. The majority of chloride anions in the water samples may originate from the dissolution of ancient evaporites and atmospheric precipitation.

The fertilizers contained 3% to 6% potassium. Adsorption of potassium by illite may reduce the potassium ion concentration in soil-water and ground-water samples. However, the significant increases in K^+ in L2, L4 and A1 in late May may result from the infiltration of potassium enriched water following fertilization and precipitation.

Exchangeable Cations

The relative replaceability, or ease of removal of cations from specific colloidal surfaces is referred to as the lyotropic series (Buol, and others, 1985). In order of decreasing replaceability, $Na^+ > K^+ > NH4^+ >> Mg^{+2} > Ca^{+2}$, or rather Na^+ may be replaced by any of the cations, while Ca^{+2} with its higher affinity for the colloidal surface is more likely to be retained. The hydrolysis of urea to ammonium and subsequent infiltration of ammonium and potassium enriched waters is hypothesized to increase the Na^+ concentration in L2, L4 and A1. The increase in Ca^{+2} concentrations during this same period could result from cation exchange if ammonium concentrations were sufficiently high.

Discussion

Movement of water and solutes through the unsaturated zone has been the topic of many recent investigations. Solute transport through the unsaturated zone is often responsible for man-made and natural pollutants contaminating ground water. Infiltration can occur as a discrete wetting front moving relatively evenly through the soil profile, as water movement through macropores, or as a combination of the two. Flow through macropores can have a significant impact on soil- and ground-water quality

1979).
ertilization on May 19, water quality
nd unsaturated zones was relatively
, soil- and ground-water constituents
he period May 20 through 31 following
all. Chemical parameters increasing in
this period included SO_4^{-2}, NO_3^-, Na^+,
$_3^-$, Cl^-, Ca^{+2}, and Mg^{+2} decreased in
most notable fluctuations were observed
L4 and monitoring well A1.
ite received about one inch of precip-
o months preceding fertilization, resul-
tion of soil moisture within approximately
the of the soil profile. Four days of dry weather followed the fertilizer application. The two month dry period ended on May 23 with 0.6 inches of rain, followed by 0.4 inches of precipitation over the next two days. Between May 27 and 28, 4.84 inches of rainfall resulted in a net water table rise of 2.06 feet.

I am so happy you are
by my side ♡
I love you to Pluto +
back!

The bulk of the infiltrating rainfall appears to have been retained in the upper two feet of the soil profile. Soil-moisture data indicate that a soil moisture deficiency existed in the 2.5 feet deep zone after the rainfall, and persisted throughout the duration of the study. The existence of this anomalously dry zone poses several questions. The most obvious question concerns flowing enough water through the 2.5 feet deep zone to cause over a two foot rise in the water table, without appearing to significantly increase the soil moisture content of that zone.

According to Gillham (1984), if the capillary fringe extends to land surface, application of a small volume of water to the surface will cause a disproportionate rise in the water table. If the capillary fringe does not extend to land surface, it would still be possible to produce the same effect if a sufficient volume of water were added to the capillary fringe. One means of quickly delivering the necessary volume of water to the capillary fringe would be through macropores. Macropores serve as conduits for water and solute movement under saturated flow conditions, which could exist after heavy rains. Water movement through macropores is dominated by the effects of gravity, rather than adsorption of the capillary effect. Under such conditions, a portion of the water flowing through macropores in the unsaturated zone would be adsorbed by the surrounding soil matrix. During unsaturated flow conditions, the air filled openings of macropores would obstruct the infiltration of water.

It is hypothesized that flow of a small volume of water through macropores was responsible for the rapid, disproportionate rise in the water table and certain fluctuations in the soil- and ground-water chemistry. The weak to moderate structure development and common rootcasts in the upper portion of the soil profile served as conduits for the transport of water through the unsaturated zone, without significantly altering the moisture content at the 2.5 feet depth. An increase in the sand fraction, and hence pore size could account for the low moisture values, but no such textural changes were noted in the core. The possibility exists that the soil in the area of the moisture neutron access tube has been disturbed, and a thin layer of sand could be present. The presence of a root from the near by pear tree could also effect soil-moisture content of the 2.5 feet deep zone. Further coring is necessary to determine the significance of the anomalous dry zone.

Lysimeter installation may indirectly bias the chemical content of samples. The lysimeter will sample water held in the larger pores at the lowest tension. As the soil moisture content decreases, the soil moisture becomes held by higher tensions in the smaller pores. Water moving through macropores would be readily sampled if it came in contact with the ceramic sampling cup, or the adjacent silica flour.

The distribution of macropores in the subsurface is not fully understood. The assumption that all lysimeter sampling cups are in contact with the same number of macropores is questionable. Conceivably, lysimeters completed at the same depth could sample different water in the same horizon, if one lysimeter intercepts a large macropore and the other does not. The samples would likely have different chemical signatures.

Solute transport through macropores is evidenced by the chemical data from L4, the 3.6 foot deep lysimeter (figure 31). The order of magnitude increase in NO_3^- is thought to be the indirect result of the May 19 fertilizer application. The lag between rainfall and the NO_3^- peaks is attributed to the time necessary for urea to be hydrolyzed to ammonium, and subsequently oxidized to NO_3^-. A portion of the ammonium produced from the degradation of urea is thought to have been exchanged for Na^+ on certain clay surfaces, resulting in the increased Na^+ concentrations noted in L2 and L4. The decrease in Ca^{+2}, Mg^{+2}, Cl^-, and HCO_3^- concentrations results from the dilution of the ions by the fertilizer enriched rainwater, which has a much lower TDS content.

The presence of the moisture deficient zone 2.5 feet deep throughout the latter part of the study indicates that movement of water as a discrete wetting front is unlikely. However, chemical fluctuations in L2, the two feet deep lysimeter, support both ideas of piston flow through the matrix and flow through macropores.

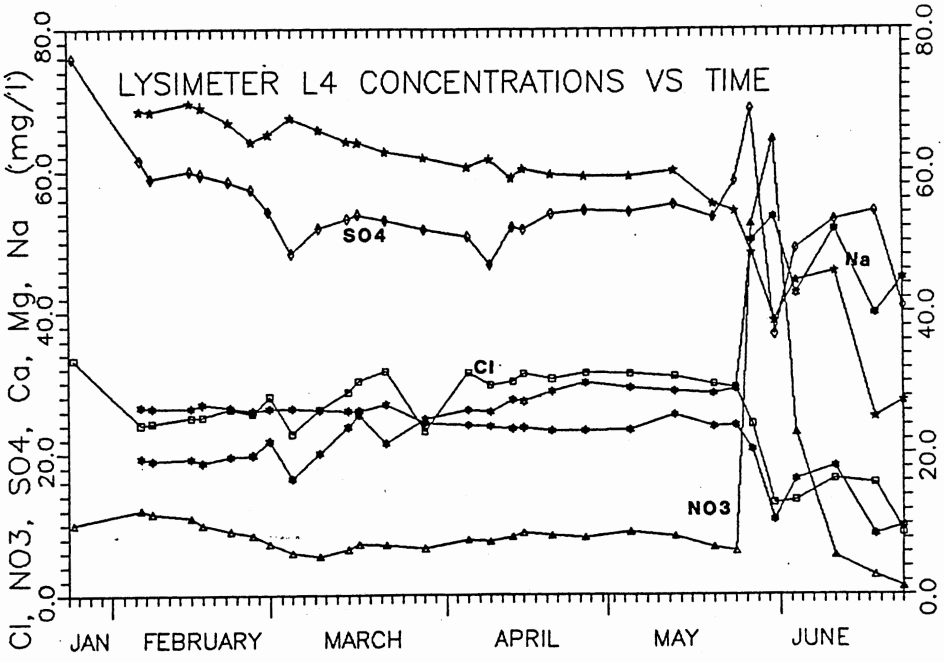

Figure 29. Concentrations versus time in L4.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Summary

Findings of this study suggest that water-table response to precipitation is directly related to the antecedent soil-moisture content prior to recharge events. The fillable porosity, or effective specific yield of an aquifer will be higher after prolonged dry periods than it will be during the "wet" seasons. Ground-water recharge to shallow water-table aquifers may occur during "wet", or "dry" soil-moisture conditions.

The geochemical character of the soil- and ground-water may be relatively consistent during portions of the year, but under certain soil-moisture regimes particular chemical parameters of the soil- and ground-water may change relatively rapidly following recharge events. Other geochemical changes appear to take place at slower rates.

Conclusions

Soil- and ground-water quality are often assumed to consistent through time. This investigation suggests that during portions of the year this may be true to an extent, but water and solute movement through macropores can effect soil- and ground-water quality. It is obvious that the soil-water quality, in particular may change significantly over a short period of time. The possible sources of the chemical fluctuations are numerous. The application of fertilizer had a significant, but relatively short lived effect on the soil-water chemistry.

The general increase in NO_3^- throughout the first four months of this study, followed by the slight decline in concentrations suggests some cyclical component to the fluctuations of nitrate concentrations in the ground water. However, further study is necessary to confirm these findings.

Suggestions For Further Research

Additional study on the effect of soil-moisture regimes on soil- and ground-water geochemistry is necessary to substantiate the findings of this study. In order to properly monitor the influence of infiltrating recharge water on the soil- and ground-water quality, the flux of water through the unsaturated zone must be known. The installation of tensiometers would allow water flux in the unsaturated zone to be monitored. Determining the flux of water in the unsaturated zone is necessary in any study of this nature.

Further study of the variations of the water-table response to recharge events is warranted.

Additional field work is necessary to elucidate the cause for the anomalous low soil-moisture content of the zone located 2.5 feet below land surface. Further coring in the area may discern any textural changes. The installation of an additional soil-moisture neutron access tube in the immediate vicinity of the existing access tube could verify the soil-moisture profile.

SELECTED BIBLIOGRAPHY

Acre, J.T., in prep. The influence of Macropores on water Movement in the Unsaturated Zone: Unpublished M.S. Thesis, Oklahoma State University.

Al-Shaieb, Z., 1987. Personal Communication.

Barcelona, M.J., Gibb, J.P., Helfrich, J.A. and Garske, E.E., 1985. Practical Guide for Ground-water Sampling: Illinois State Water Survey, Contract Report 374, 94p.

Barcelona, M.J., Gibb, J.P. and Miller, R.A., 1983. A Guide to the selection of Materials for Monitoring Well Construction and Ground-water Sampling: Illinois State Water Survey, Contract Report 327, EPA-600/52-84-024, 78p.

Beta Analytic, Inc., 1987. Beta Analytic, Inc., Report.

Blake, G.E., Schlichting, E., and Zimmerman, U., 1973. Water Recharge in a Soil With Shrinkage Cracks: Soil Sci. Soc. Amer. Proc., v. 37, pp. 669-672.

Bohn, H.L., McNeal, B.L. and O'Connor, G.A. 1985. Soil Chemistry: John Wiley and Sons, Inc., New York, 341p.

Bouwer, H. 1978. Groundwater Hydrology: McGraw-Hill book Company, New York, 480p.

Brewer, R., 1976. Fabric and Mineral Analysis of Soils: Robert Krieger Publishing Co., New York, 482p.

Brewer, R., Protz, R. and McKeague, J.A., 1973. Microscopy and Electron Microprobe Analyses of Some Iron-Manganese Pans from New Foundland: Can. J. Soil Sci., v.53, pp. 349-361.

Briggs, L.J., and McCall, B., 1904. An Artificial Root for Inducing Capillary Movement of Soil Moisture: Science, v.20, pp. 566-569.

Buol, S.W., Hole, F.D. and McCracken, R.J., 1980. Soil Genesis and Classification: Ames, Iowa, Iowa State University Press, 406p.

Carrol, D., 1970. Clay Minerals: A Guide to Their X-ray Identification: Geological Society of America, Boulder, CO., Special Paper 126, 80p.

Casey, D., Nemetz, P.N. and Uyeno, D.H., 1983. Sampling Frequency for Water Quality Monitoring: Measures of Effectiveness: Water Resources Research, v.19, no.5, pp. 1107-1110.

Childs, E.C. 1940. The Use of Soil Moisture Characteristics in Soil Studies: Soil Sci. (50), pp. 239-252.

Doner, H.E. and Lynn, W.C. 1977. Carbonate, Halide, Sulfate and Sulfide Minerals: in J.S. Dixon and S.B. Weed (eds.), Minerals in Soil Environments, SSSA, Madison, Wisconsin.

Everett, L.G., Hoylman, E.W. and Wilson, L.G., 1983. Vadose Zone Monitoring for Hazardous Waste Sites, U.S. Environmental Protection Agency.

Fastovsky, D.E. and McSweeney, K. 1987. Paleosols Spanning the Cretaceous-Paleogene Transition, Eastern Montana and Western North Dakota: Geol. Soc. Am. Bul., v.99, pp. 66-77.

Freeze, R.A. and Cherry, J.A., 1979. Groundwater: Prentice-Hall, Englewood Cliffs, New Jersey, 604p.

Gee, G.W. and Bauder J.W., 1986. Particle-size Analysis: in Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods - Agronomy Monograph no. 9, Second edition, ASA-SSSA, Madison, Wisconsin, pp. 383-411.

Gillham, R.W., 1984. The Capillary Fringe and its Effect on Water-table Response: Journal of Hydrology, v.67, pp. 307-324.

Gillham, R.W., Robin, M.J.L., Barker, J.F. and Cherry, J.A. 1983. Ground-water Monitoring and Sampling Bias: API Pub. 4367, 206p.

Grisak, G.E., Jackson, R.E., and Pickens, J.F., 1978. Monitoring Ground Water Quality, The Technical Difficulties: Water Resources Bulletin, San Francisco CA, pp. 210-232.

Hagen, D.J., 1986. Spatial and Temporal Variability of Ground-water Quality in a Shallow Aquifer in North-central Oklahoma: Unpublished M.S. Thesis, Oklahoma State University, 191p.

Hansen, E.A., and Harris, A.R., 1975. Validity of Soil-water Samples Collected with Porous Ceramic Cups: Soil Sci. Soc. Amer. Proc., v.39, pp. 528-536

Hem, J.D., 1985. Study and Interpretation of the Chemical Characteristics of Natural Water, 3rd Edition: U.S. Geological Survey Water-supply Paper 2254, 263p.

Hillel, D. 1982. Introduction to Soil Physics: Academic Press, Inc., Orlando, Florida 364p.

Hillel, D., 1971. Soil and Water, Physical Principles and Processes: Academic Press, New York, 288p.

Hoyle, B.L., 1987. Suburban Hydrogeology and Ground-water Geochemistry of the Ashport Silt Loam, Payne County, Oklahoma: Unpublished M.S. Thesis, Oklahoma State University, 187p.

Klute, A. 1973. Soil Water Flow Theory and its Application in Field Situations: in Field Soil Water Regime, Stelly, M., Dinauer, R.C. and Hach, J.M. (eds.), SSSA Publication Series No. 5, Soil Sci. Soc. Am., Inc. Madison, Wisconsin.

Krauskopf, K.B., 1979. Introduction to Geochemistry: McGraw-Hill Company, New York, 617p.

Lawes, J.B., Gilbert, J.H. and Warrington, R., 1882. On the Amount and Composition of the Rain and Drainage Waters Collected at Rothamsted: William Clowes and Sons, LTD, London.

McKenzie, R.M. 1977. Manganese Oxides and Hydroxides: in J.S. Dixon and S.B. Weed (eds.), Minerals in Soil Environments. SSSA Madison, Wisconsin, pp. 181-193.

Meyboom, P., 1967. Groundwater Studies in the Assiniboine River Drainage Basin: II. Hydrologic Characteristics of Phreatophytic vegetation in South-central Saskatchewan: Geological Survey of Canada Bulletin 139, 64p.

Nelson, J.D., and Ward, R.C., 1981. Statistical Considerations and Sampling Techniques for Ground-water Quality Monitoring: Ground Water, v.19, no. 6., pp. 617-625.

Pettyjohn, W.A., White, H. and Dunn, S., 1983. Water Atlas of Oklahoma: University center for Water Research, Oklahoma State University, Stillwater, 72p.

Pettyjohn, W.A., 1982. Cause and Effect of Cyclic Changes in Ground-water Quality: Ground Water Monitoring

Review, v.2, no.1, pp. 43-49.

Piper, A.M., 1944. A Graphic Procedure in the Geochemical Interpretation of Water Analyses: Transactions, American Geophysical Union, v. 25, pp. 914-923.

Saines, M., 1981. Errors in Interpretation of Ground-water Level Data: Ground Water Monitoring Review, v.1, no.1, pp. 56-61.

Schwertmann, U. and R.M. Taylor, 1977. Iron oxides: in J. S. Dixon and S.B. Weed (eds.), Minerals in Soil Environments. SSSA Madison, Wisconsin pp. 145-180.

Shelton, J.W., Ross, J.S., Garden, A.J. and Franks, J.L., 1985. Geology and Mineral Resources of Payne County, Oklahoma: Oklahoma Geological Survey Bulletin 137, 85p.

Soil Conservation Service, 1987. Soil Survey of Payne County, Oklahoma: U.S. Department of Agriculture, 268p.

Soil Survey Staff 1975. Soil Taxonomy. U.S. Dept. Agr. Handbook No. 436: U.S. Govt. Printing Office, Washington.

Soil Survey Staff, 1951. Soil Survey Manual, U.S. Dept. of Agric., Superintendent of Documents, Washington, D.C.

Suarez, D.L., 1986. A Soil Water Extractor That Minimizes CO2 Degassing and pH Errors: Water Resources Research, v.22, no.6, pp. 876-880.

Thomas, G.W. and Phillips, R. E., 1979. Consequences of Water Movement in Macropores: Journal of Environmental Quality, v. 8, no. 2, pp. 149-152

Thomas, G.W., Phillips, R.E., and Quisenberry, V.L., 1978. Characterization of Water Displacement in Soils Using Simple Chromatographic Theory. J. Soil Sci., v.29, pp. 32-37.

Troxler Company, 1987. Operating Manual for Troxler 3000 Model Soil-moisture Neutron Probes.

U.S. Environmental Protection Agency, 1986. Permit Guidance Manual on Unsaturated Zone Monitoring for Hazardous Waste Land Treatment Units: EPA/530-SW-86-040.

U.S. Environmental Protection Agency, 1984. EPA Standard Methods 300.0.

U.S. Environmental Protection Agency, 1980. Monitoring in the Vadose Zone, A Review of Technical Elements and Methods: EPA-600/7-80-134

van Bavel, C.H.M., 1963. Neutron Scattering of Soil Moisture: Development and Current Status: Proceedings International Symposium Humidity and Moisture, Washington, D.C., pp. 171-184.

Wagner, J., 1987. Personal communication.

Wild, A., 1981. in The Chemistry of Soil Processes: Greenland, D.J. and Hayes, M.H.B., editors, John Wiley and Sons, New York, pp. 37-80.

Wilson, L.G., 1981. Monitoring in the Vadose Zone Part I: Storage Changes: Ground Water Monitoring Review, v.1, no.3, pp. 32-41.

Wilson, M.D. and Pittman, E.D., 1977. Authigenic Clays in Sandstones, Reconstruction and Influence on Reservoir Properties and Paleoenvironmental Analyses: J. Sed. Pet., 49(1), pp. 3-31.

Wood, W.W., and Signor, D.C., 1975. Geochemical Factors Affecting Artificial Recharge in the Unsaturated Zone: Trans. Am. Soc. of Agr. Eng., v.18, no.4, pp. 677-683.

Wood, W.W., 1973. A Technique Using Porous Cups for Water Sampling at Any Depth in the Unsaturated Zone: Water Res. Research, v.9, pp. 486-48.

APPENDIXES

APPENDIX A

SOIL PROFILE AND CORE DESCRIPTIONS

Soil Profile and Core Description
for the Pettyjohn Core
taken 11/86

Horizon	Depth (in.)	Description
Ap	0-19	Reddish brown (2.5YR 4/4, dry) to dusky red (2.5YR 3/2 moist) silt loam; moderate medium subangular blocky, parting to weak medium platy structure; friable; common roots and fine, continuous root cast; gradual boundary.
A	19-26	Dark reddish brown (2.5YR 3/4, dry) to dark red (2.5YR 3/6) silt loam; weak, coarse, prismatic structure; friable; common, fine, continuous root casts in peds; gradual boundary.
Bw	26-38	Red (2.5YR 4/6, dry) to dark reddish brown (2.5YR 3/4, moist) silt loam; weak, coarse, subangular structure; friable; common, fine continuous root casts; gradual boundary.
C	38-50	Reddish brown (5YR 4/4, dry) to dark reddish brown (2.5YR 3/4, moist) silt loam; finely laminated, stratified sands; friable; few, fine root casts; clear boundary.
2Ab	50-64	Dark reddish gray (5YR 4/2, dry) to dark reddish brown (5YR 3/3, moist) silt loam; moderate, fine subangular blocky structure; firm; roots; clear boundary.
2AB	64-68	Reddish brown (5YR 4/4, dry) to dark reddish brown (2.5YR 3/4, moist) silt loam; few, fine, faint yellowish red (5YR 5/6) mottles; medium fine subangular blocky, parting to moderate medium prismatic structure; firm; common, fine, round black (n 2/0) manganese nodules; few, fine root casts; gradual boundary.
2Bw1	68-78	Reddish brown (5YR 4/4, dry) loam; few, fine, faint yellowish red (5YR 5/6) mottles; moderate medium to fine subangular blocky, parting to moderate medium prismatic with moderate coarse platy structure; firm; common, fine to medium, black (n 2/0) manganese nodules; few, fine root casts; gradual boundary.

2Bw2	78-108	Reddish brown (5YR 4/4, dry) to dark red (2.5YR 3/6) silt loam; few, medium, faint yellowish red (5YR 5/6) and reddish brown (5YR 5/3) mottles; moderate medium to fine subangular blocky, parting to moderate medium prismatic structure; firm; common, medium black (n 2/0) manganese nodules; few, fine carbonate threads and fine concretions; few, fine root casts; gradual boundary.
2Bw3	108-124	Yellowish red (5YR 5/6, dry) silt loam; pinkish gray (5YR 7/2) mottles; moderate coarse to medium prismatic, parting to moderate medium prismatic structure; firm; few fine to medium black (n 2/0) manganese nodules; few, fine to medium carbonate concretions; few, fine root casts, surrounded by intense yellowish red (5YR 5/6) mottling; clear boundary.
2Bw4	124-138	Yellowish red (5YR 4/6, dry) silty clay loam; few, medium, faint reddish gray (5YR 5/2) mottles; moderate medium prismatic, parting to moderate medium subangular blocky structure; firm; few fine irregular black (n 2/0) manganese nodules; few, fine root casts; gradual boundary.
2Bw5	138-144	Yellowish red (5YR 4/6, dry) loam; few, fine, faint reddish gray (5YR 5/2) mottles; moderate to weak, medium subangular blocky, parting to moderate to weak, medium prismatic structure; firm; few, fine black (n 2/0) manganese nodules; few to common root casts; diffuse boundary.
2BC1	144-156	Reddish brown (5YR 4/4, dry) clay loam; weak medium prismatic, parting to moderate medium subangular blocky structure; few, medium black (n 2/0) manganese nodules; few, fine root casts; diffuse boundary.
2BC2	156-168	Reddish brown (5YR 4/4, dry) silty clay loam; weak medium prismatic, parting to weak medium subangular blocky structure; few, fine to medium black (n 2/0) manganese nodules; few, fine root casts; diffuse boundary.
2BC3	168-192	Reddish brown (5YR 4/4, dry) silt loam; weak, medium prismatic, parting to weak medium subangular blocky structure; firm; few, fine irregular, with patches of many fine round black (n 2/0) manganese nodules; few, fine root casts; clear boundary.

2BC4	192-198	Yellowish red (5YR 4/6, dry), silt loam; massive, breaking to weak medium subangular blocky structure; firm; few, medium irregular black (n 2/0) manganese nodules; very few, fine root casts; diffuse boundary.
2BC5	198-240	Reddish brown (5YR 4/4, dry) silty clay loam; weak medium prismatic, parting to weak, medium moderate platy structure; firm; few, medium irregular black (n 2/0) manganese nodules; few, fine root casts; diffuse boundary.
2BC6	240-255	Reddish brown (5YR 4/4, dry) silty clay loam; few very faint yellowish red (5YR 4/6) mottles; weak medium prismatic, parting to weak medium subangular blocky structure; friable; many continuous root casts and pores in peds; few, medium irregular black (n 2/0) manganese nodules; diffuse boundary.
2BC7	255-264	Reddish brown (5YR 4/4, dry) silt loam; few, medium, faint yellowish red (5YR 4/6) mottles; weak medium prismatic, parting to weak medium subangular blocky structure; firm; few, medium, irregular black (n 2/0) manganese nodules; diffuse boundary.
2BC8	264-282	Yellowish red (5YR 4/6, dry) silt loam; few, medium, distinct grayish brown (5YR 5/6) and yellowish brown (5YR 5/2) mottles; weak medium prismatic, parting to weak medium subangular blocky structure; firm; few, irregular, medium black (n 2/0) manganese nodules; diffuse boundary.
2BC9	282-306	Yellowish red (5YR 4/6, dry) silty clay loam; few, medium, faint pinkish gray (5YR 6/2) mottles; weak medium subangular blocky structure; firm; few to common continuous root casts; few, medium, round black (n 2/0) manganese nodules; diffuse boundary.
2BC/A	306-330	Dark reddish brown (5YR 3/4, dry) and yellowish red (5YR 4/6, dry) clay loam; few, fine, faint pinkish gray (5YR 6/2) mottles; weak medium subangular blocky structure; few, fine black (n 2/0) organic matter fragments (charcoal); firm; few, fine root casts; diffuse boundary.
3Ab	330-354	Dark reddish brown (5YR 3/3, dry) silt loam; few, fine, faint reddish gray (5YR 5/2) mottles; moderate medium subangular blocky structure, parting to weak medium platy structure; common, fine, continuous root casts; few, fine black (n 2/0) organic matter fragments; clear boundary.

3AB1	354-366	Reddish brown (5YR 4/4, dry) silty clay loam; few, fine, faint yellowish red (5YR 5/6) and reddish gray (5YR 5/2) mottles; moderate to weak medium subangular blocky, parting to moderate to weak medium prismatic structure; gradual boundary.
3AB2	366-390	Reddish brown (5YR 4/3, dry) silty clay; common fine distinct yellowish red (5YR 5/6), reddish gray (5YR 5/2) mottles; weak to moderate medium subangular blocky, parting to moderate to weak medium prismatic structure; firm; common, medium distinct, gray mottles (5Y 5/1) mottles surrounding common, medium root casts; gradual boundary.
3Bw	390-426	Reddish brown (5YR 4/6, dry) silty clay; common fine distinct gray (5Y 5/1) mottles; weak to moderate medium subangular blocky, parting to weak to moderate medium prismatic structure; firm; common medium root casts; gradual boundary.
3C1	426-456	Reddish brown (5YR 4/6, dry) silt loam; few, fine, distinct strong brown (7.5YR 5/8) and pinkish gray (5YR 6/2) mottles; stratified, massive structure; friable; gradual boundary.
3D1	456-468	Reddish brown (5YR 4/6, dry) sandy loam; stratified, massive structure; friable; gradual boundary.
3D2	468-516	Reddish brown (5YR 4/3, dry) gravelly sandy loam; massive; friable; abrupt boundary.
3R	516-540	Upper Pennsylvanian Doyle shale

APPENDIX B

DESCRIPTIVE STATISTICS FOR CONSTITUENTS

TABLE III

DESCRIPTIVE STATISTICS FOR ELECTRICAL CONDUCTIVITY

Sample ID	Number of Samples	Mean ----	Minimum (umhos/cm)	Maximum -----	Standard Deviation	Normal at 95%
L1	12	617	518	560	77	YES
L2	22	556	419	675	65	P=0.018
L3	24	588	514	700	56	YES
L4	24	585	408	701	68	YES
L5	24	505	461	537	18	YES
L6	24	864	779	995	59	P=0.002
L6B	19	828	720	1008	83	YES
L7	24	1237	1111	1445	86	P=0.003
A1	18	1009	890	1152	65	YES
A2	18	980	904	1104	54	YES
A3	16	961	891	1075	51	YES
A4	16	962	880	1095	60	YES

TABLE IV

DESCRIPTIVE STATISTICS FOR BICARBONATE

Sample ID	Number of Samples	Mean	Minimum	Maximum	Standard Deviation	Normal at 95% (p=n)
		---------(mg/l)	---------			
L1	11	274	235	341	38	0.042
L2	19	207	125	253	30	YES
L3	25	244	210	287	17	YES
L4	25	257	170	297	30	YES
L5	25	219	182	247	17	YES
L6	25	540	510	582	17	YES
L6B	17	514	427	625	55	YES
L7	25	820	777	871	31	YES
A1	21	624	531	717	40	0.044
A2	22	586	540	665	37	0.043
A3	19	565	521	645	37	YES
A4	18	535	494	606	29	0.016

TABLE V

DESCRIPTIVE STATISTICS FOR CHLORIDE

Sample ID	Number of Samples	Mean	Minimum	Maximum	Standard Deviation	Normal at 95% (p=n)
		--------(mg/l)--------				
L1	13	16.2	15.3	19.7	1.2	0.003
L2	28	26.2	20.8	34.1	3.1	YES
L3	30	30.2	19.9	36	3.7	4.6E-4
L4	30	25.7	8.8	33.3	6.4	0.0046
L5	30	23.0	19.9	29.4	2.4	YES
L6	30	11.0	8.8	12.7	0.82	YES
L6B	16	12.7	9.4	21.1	3.6	0.0068
L7	30	21.9	15.7	28.5	3.3	1.8E-4
A1	17	17.2	14.4	19.5	1.6	YES
A2	17	18.9	15.4	23.5	2.6	YES
A3	16	16.5	14.1	20.3	1.9	YES
A4	14	16.7	12.5	20.3	2.4	YES

TABLE VI

DESCRIPTIVE STATISTICS FOR NITRATE

Sample ID	Number of Samples	Mean	Minimum	Maximum	Standard Deviation	Normal at 95% (p=n)
		---------(mg/l)		--------		
L1	13	27.6	0.1	35	10.1	7.1E-3
L2	27	16.9	0.8	25.4	7.1	0.0296
L3	28	7.0	0.25	10.7	8.8	0.0175
L4	30	11.6	1.1	64.5	13.3	4.5E-7
L5	30	5.5	2.3	9.8	1.9	YES
L6	--	---	---	---	---	---
L6B	--	---	---	---	---	---
L7	30	8.6	4.2	14.8	3.3	0.0216
A1	16	32.0	16.0	50.0	7.6	0.0348
A2	16	37.4	24.2	43.1	5.6	4.5E-3
A3	15	43.0	20.4	53.4	9.6	YES
A4	13	51.1	26.5	65.6	11.4	YES

TABLE VII

DESCRIPTIVE STATISTICS FOR SULFATE

Sample ID	Number of Samples	Mean	Minimum	Maximum	Standard Deviation	Normal at 95% (p=n)
		--------(mg/l)--------				
L1	13	48.8	36.5	114	20.3	1.48E-3
L2	26	70.6	50.1	85.9	7.5	YES
L3	29	65.5	59.3	74.6	3.6	YES
L4	30	54.4	36.8	75.9	7.2	YES
L5	30	47.9	38.4	61.0	5.3	YES
L6	30	29.5	24.8	33.5	1.8	2.95E-2
L6B	16	33.2	30.2	35.8	1.4	YES
L7	30	21.4	18.9	23.8	1.3	YES
A1	16	26.6	23.4	29.7	1.6	YES
A2	16	25.7	23.3	27.3	1.1	YES
A3	15	25.7	24.5	27.0	0.8	YES
A4	14	27.6	22.9	33.2	3.3	YES

TABLE VIII

DESCRIPTIVE STATISTICS FOR CALCIUM

Sample ID	Number of Samples	Mean	Minimum	Maximum	Standard Deviation	Normal at 95% (p=n)
		--------(mg/l)--------				
L1	13	76.3	68.5	88.1	7.4	7.0E-3
L2	26	67.6	36.6	95.3	11.2	0.033
L3	28	67.8	60.2	74.2	4.1	YES
L4	29	57.8	25.1	69.6	11.6	2.7E-3
L5	29	55.5	45.0	74.7	7.3	0.033
L6	21	125.4	115.9	133.7	3.8	1.4E-3
L6B	15	114.7	91.5	152.1	16.7	YES
L7	17	150.6	121.1	183.9	15.0	YES
A1	16	131.9	94.0	179.0	20.2	0.034
A2	17	114.8	92.0	129.3	11.7	YES
A3	10	98.7	91.7	112.1	6.5	YES
A4	9	88.0	73.1	96.6	6.5	YES

TABLE IX

DESCRIPTIVE STATISTICS FOR MAGNESIUM

Sample ID	Number of Samples	Mean	Minimum (mg/l)	Maximum	Standard Deviation	Normal at 95% (p=n)
L1	14	21.8	19.6	28.6	2.4	YES
L2	27	22.3	12.3	27.2	3.5	YES
L3	29	26.7	13.2	31.0	3.1	5.5E-3
L4	29	22.8	8.5	27.0	5.2	5.7E-5
L5	29	20.6	17.9	24.1	1.8	YES
L6	29	33.9	30.2	37.3	2.4	YES
L6B	17	32.7	27.3	39.0	3.5	YES
L7	29	65.3	56.8	72.4	3.3	YES
A1	22	44.7	41.2	49.2	2.4	YES
A2	22	44.9	40.9	48.0	2.2	YES
A3	20	46.3	43.3	51.0	2.1	YES
A4	19	45.7	43.7	48.7	1.7	YES

TABLE X

DESCRIPTIVE STATISTICS FOR SODIUM

Sample ID	Number of Samples	Mean	Minimum	Maximum	Standard Deviation	Normal at 95% (p=n)
		(mg/l)				
L1	14	15.4	13.5	21.1	2.2	7.7E-3
L2	27	9.7	6.3	25.8	5.3	4.5E-7
L3	29	11.8	8.9	51.0	7.6	4.5E-7
L4	29	28.7	16.4	53.5	10.5	2.2E-3
L5	29	15.1	12.7	18.6	1.6	1.3E-3
L6	29	9.7	8.1	11.7	0.8	3.4E-3
L6B	17	9.5	8.4	11.2	0.8	YES
L7	29	18.3	15.7	21.7	1.2	YES
A1	22	21.6	16.7	43.8	5.6	5.4E-3
A2	22	29.9	17.5	37.6	4.9	YES
A3	19	34.8	27.5	40.1	2.7	YES
A4	19	43.6	37.4	50.4	4.4	YES

TABLE XI

DESCRIPTIVE STATISTICS FOR POTASSIUM

Sample ID	Number of Samples	Mean	Minimum	Maximum	Standard Deviation	Normal at 95% (p=n)
		--------(mg/l)--------				
L1	12	0.65	0.42	0.81	0.12	YES
L2	23	0.60	0.33	1.90	0.32	4.6E-5
L3	26	0.31	0.13	0.50	0.31	0.020
L4	25	0.39	0.15	1.55	0.27	0.017
L5	26	0.24	0.13	0.40	0.07	YES
L6	26	0.29	0.14	0.44	0.10	7.3E-3
L6B	13	0.31	0.20	0.49	0.10	0.032
L7	22	0.41	0.11	0.72	0.14	YES
A1	21	0.35	0.07	1.70	0.35	2.5E-3
A2	20	0.22	0.08	0.38	0.10	YES
A3	18	0.22	0.06	0.40	0.11	7.5E-3
A4	17	0.23	0.10	0.41	0.10	YES

APPENDIX C

SOIL- AND GROUND-WATER GEOCHEMICAL DATA

DATE: Jan. 25

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1															
L2	4.500	526.000	6.420	253.000	29.900	14.600	50.100								
L3	5.000	539.000	6.300	271.000	32.400	6.900	72.200								
L4	6.000	550.000	6.420	279.000	33.300	10.100	75.900								
L5	6.900	484.000	6.250	221.000	29.400	4.400	58.000								
L6	9.800	757.000	6.560	510.000	9.700	0.200	28.500								
L6B															
L7	11.500	1100.000	6.770	861.000	16.100	4.400	18.900								
A1		1088.000	6.600	694.000	19.500	34.000	25.200	125.700	47.200	17.200	0.640				
A2		1058.000	6.700	665.000	20.400	24.200	27.100	99.400	48.000	29.400	0.220				
A3		1053.000	6.750	644.000	15.900	20.400	24.500	73.200	51.000	36.900	0.260				
A4		1045.000	6.800	606.000	15.000	26.500	24.900	74.400	48.700	40.110	0.350				

DATE: Feb. 06

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1															
L2					30.600	15.700	80.600	77.200	25.400	7.200	0.700				
L3					30.500	6.600	65.500	70.800	27.200	8.900	0.500				
L4					24.100	12.100	61.500	68.500	26.600	19.400	0.500				
L5					28.800	5.400	61.000	56.600	22.200	15.200	0.200				
L6					8.800	0.000	25.600	101.400	30.200	8.100	0.300				
L6B															
L7					16.700	5.200	19.800	84.800	65.600	17.000	0.400				
A1															
A2															
A3															
A4															

DATE: Feb. 08

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1															
L2					32.300	15.300	66.800	73.500	24.700	7.400	0.700				
L3					28.300	6.900	74.600	74.200	28.900	10.000	0.500				
L4					24.300	11.600	58.900	68.400	26.400	19.000	0.500				
L5					26.300	4.500	46.400	48.900	18.600	13.700	0.300				
L6					10.100	0.200	31.400	126.100	34.400	9.000	0.300				
L6B															
L7					18.000	6.000	21.100	62.500	66.300	17.700	0.400				
A1	12.800	1125.000	6.300	689.000	18.900	40.100	25.400	151.600	47.600	16.700	0.400				
A2	13.200	1127.000	6.400	654.000	17.300	28.400	25.000	92.000	46.400	26.500	0.300				
A3	14.500	1106.000	6.560	613.000	14.100	30.400	25.600	92.500	49.700	34.000	0.300				
A4	15.200	1058.000	6.600	558.000	12.500	36.800	26.300	98.400	47.300	37.700	0.300				

DATE: Feb. 15

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1															
L2	8.100	650.000	6.000	221.000	27.800	16.800	74.500	74.700	24.700	6.800	0.700				
L3	8.100	674.000	6.000	253.000	32.500	6.900	66.400	73.200	28.500	10.000	0.500				
L4	8.500	680.000	6.000	273.000	25.100	11.000	60.000	69.600	26.400	19.300	0.500				
L5	9.000	510.000	6.900	182.000	25.800	4.500	44.600	49.300	18.500	13.400	0.300				
L6	10.500	943.000	6.300	528.000	10.100	0.400	30.200	126.600	34.700	9.100	0.300				
L6B															
L7	12.200	1373.000	6.600	854.000	17.300	6.800	21.100	94.500	67.200	18.000	0.500				
A1	11.700	1160.000	6.500	717.000				133.900	47.200	27.400	0.300				
A2	12.200	1134.000	6.600	633.000				100.100	47.000	17.500	0.300				
A3	13.200	1076.000	6.700	596.000				81.400	48.900	33.000	0.300				
A4	14.000	984.000	6.700	540.000				73.200	46.400	38.800	0.300				

DATE: Feb. 17

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1															
L2				230.000	26.700	19.600	74.100	71.400	23.900	6.500	0.700				
L3				253.000	32.400	6.900	66.400	73.100	28.500	10.200	0.500				
L4				283.000	25.200	10.000	59.500	69.000	27.000	18.700	0.500				
L5				200.000	25.100	4.100	43.700	47.200	17.900	13.100	0.400				
L6				535.000	10.300	0.000	30.600	62.400	34.100	9.200	0.300				
L6B															
L7				855.000	18.400	6.200	20.900	162.400	69.400	18.200	0.500				
A1															
A2															
A3															
A4															

DATE: Feb. 22 TIME: 1000.000

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1															
L2				230.000	27.200	17.900	78.300	75.100	25.100	6.600	0.600				
L3				253.000	32.100	6.770	65.300	72.900	28.400	10.300	0.500				
L4				283.000	26.300	9.100	58.500	66.900	26.500	19.600	0.400				
L5				200.000	22.800	3.900	41.300	47.500	18.000	12.700	0.200				
L6				535.000	9.500	0.200	30.500	130.100	35.200	9.200	0.300				
L6B															
L7				855.000	19.000	6.800	20.700	100.900	67.900	18.000	0.400				
A1	12.600	1069.000	6.350	617.000				38.900	43.800	17.900	0.230				12.900
A2	13.200	1056.000	6.390	627.000				22.100	44.300	26.800	0.140				13.200
A3	13.900	1020.000	6.480	580.000				44.400	47.000	32.700	0.210				13.600
A4	14.900	970.000	6.550	520.000				59.200	44.300	37.400	0.240				13.900

DATE: Feb. 26

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1															
L2	9.300	621.000	6.200	242.000	25.000	17.900	72.100	70.430	24.600	6.900	0.520	0.070	0.100	0.003	14.100
L3	9.100	656.000	5.940	253.000	30.800	7.100	64.100	67.900	27.800	10.600	0.390	0.070	0.100	0.005	7.990
L4	9.200	663.000	6.000	297.000	25.600	8.500	57.400	64.100	26.000	19.800	0.340	0.070	0.090	0.006	10.940
L5	9.700	497.000	5.900	209.000	24.000	4.700	43.100	45.000	18.300	13.500	0.220	0.060	0.070	0.003	15.800
L6	10.800	978.000	6.400	555.000	10.600	0.140	30.400	62.000	33.300	9.300	0.270	0.100	0.090	0.002	14.400
L6B															
L7	11.600	1430.000	6.600	855.000	15.700	5.600	20.600	55.400	64.600	17.900	0.380	0.100	0.100	0.003	19.900
A1	10.900	1170.000	6.600	0.000	17.300	36.800	23.400	62.500	41.200	17.000	0.440	0.080	0.160	0.005	11.900
A2	11.100	1152.000	6.600	645.000	16.800	32.000	25.400	63.000	44.700	26.700	0.270	0.060	0.140	0.004	13.200
A3	11.400	1100.000	6.700	645.000	14.400	33.300	24.600	94.800	47.700	32.800	0.400	0.100	0.200	0.010	13.500
A4	11.700	1050.000	6.800	601.000	13.700	42.800	24.300	85.500	45.300	38.300	0.410	0.100	0.190	0.008	14.100

DATE: March 01

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1															
L2	8.400	628.000	6.150	235.000	25.800	16.900	67.900	69.600	24.000	6.700	0.670				14.100
L3	8.700	660.000	5.900	254.000	32.600	6.300	61.000	70.600	28.600	10.800	0.370				8.100
L4	9.000	668.000	5.900	280.000	28.000	7.300	54.300	65.200	26.300	21.800	0.430				10.500
L5	9.300	502.000	5.700	200.000	24.200	3.600	38.600	48.800	18.700	13.200	0.300				16.100
L6	11.000	994.000	6.300	560.000	10.600	0.000	28.900	115.900	33.900	9.300	0.410				14.500
L6B															
L7	11.500	1448.000	6.500	855.000	19.700	5.000	19.700	154.000	67.980	18.500	0.550				19.800
A1	12.100	1055.000	6.370	617.000	17.400	30.300	25.000	94.000	45.580	17.000	0.260				13.000
A2	12.900	1067.000	6.550	610.000	15.400	32.300	25.600	113.100	45.450	27.200	0.350				13.100
A3	13.200	983.000	6.600	580.000	14.500	34.900	25.100	71.800	47.000	32.700	0.290				13.400
A4	14.200	925.000	6.780	521.000	13.600	42.500	23.700	61.100	44.300	38.400	0.340				14.100
															14.200

DATE: March 04

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1															
L2	10.900	520.000		226.000	22.800	14.900	62.500	64.600	22.400	6.300	0.570				13.200
L3	10.200	633.000	0.000	254.000	31.200	6.100	59.300	70.900	28.400	10.800	0.380				8.500
L4	9.800	605.000		278.000	22.800	6.000	48.300	67.500	26.300	16.400	0.440				12.800
L5	10.300	464.000		192.000	22.800	3.500	38.400	48.300	18.600	13.300	0.240				16.100
L6	11.800	930.000		558.000	11.100	0.000	27.600	128.200	35.800	9.700	0.420				14.900
L6B															
L7	12.500	1343.000	6.500	871.000	19.400	5.700	19.900	125.800	62.100	16.500	0.480				19.300
A1															
A2															
A3															
A4															

DATE: March 10

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1	7.400	760.000	6.300	341.000	19.700	20.600	42.800	88.100	21.300	18.700	0.680				15.300
L2	8.400	675.000	6.100	224.000	25.000	18.200	66.100	73.200	24.100	8.200	0.560				15.100
L3	9.300	700.000	6.000	263.000	32.100	7.400	61.300	71.400	28.500	11.100	0.380				8.500
L4	9.800	701.000	6.000	275.000	26.200	5.500	51.900	65.800	26.100	20.000	0.420				11.400
L5	9.900	530.000	5.900	191.000	22.600	3.600	39.500	49.800	19.200	13.700	0.350				16.000
L6	10.800	995.000	6.400	545.000	12.700	0.300	29.400	126.500	34.700	9.700	0.410				14.800
L6B	10.800	867.000	6.500	469.000	10.700	0.300	30.200	91.700	39.600	10.400	0.390				13.400
L7	11.000	1445.000	6.600	853.000	19.800	5.300	20.300	145.100	62.300	16.700	0.450				18.900
A1															
A2															
A3															
A4															

DATE: March 15 TIME: 1300.000

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1	12.300	650.000		333.000	16.200	30.300	36.500	87.400	23.300	15.600	0.760				16.200
L2	12.400	576.000		211.000	25.600	19.500	70.200	72.000	24.800	7.100	0.500				15.400
L3	12.000	597.000		259.000	32.400	7.500	62.300	71.400	28.800	11.000	0.350				8.600
L4	11.900	605.000		281.000	28.600	6.500	53.200	64.100	26.000	23.700	0.400				10.700
L5	12.100	499.000		332.000	24.000	4.800	47.700	54.500	21.400	14.900	0.270				17.600
L6	13.000	858.000		530.000	11.000	0.170	29.300	125.700	34.700	9.600	0.400				14.800
L6B	13.600	729.000		455.000											
L7	13.900	1228.000		854.000	20.900	5.600	20.400	141.100	66.000	17.500	0.090				19.900
A1		1012.000		622.000	18.500	35.100	26.400	150.000	47.900	20.500	0.108				13.000
A2		978.000		607.000	16.800	34.600	26.500	129.300	46.500	32.200	0.120				13.000
A3		949.000		577.000	16.200	39.400	25.300	112.100	48.200	30.800	0.180				13.200
A4		930.000		537.000	16.600	49.100	27.600	190.100	55.000	49.600	0.230				14.400

DATE: March 17 TIME: 1400.000

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1	14.800			320.000	15.600	31.700	36.800	84.300	23.300	14.900	0.690				17.200
L2	13.900			240.000	26.500	21.200	70.500	77.900	27.200	7.900	0.590				16.200
L3	13.400	611.000	5.900	262.000	32.400	8.300	63.400	71.400	28.800	11.000	0.350				8.600
L4	12.900	601.000	6.000	290.000	30.200	7.200	53.800	64.000	26.000	25.400	0.350				10.400
L5	13.000	451.000	5.900	201.000	24.800	5.300	47.300	51.700	20.100	15.200	0.250				17.700
L6	15.100	864.000	6.400	582.000	10.400	0.220	29.200	101.100	34.500	9.600	0.320				14.800
L6B															
L7	15.500	1225.000	6.600	866.000	18.200	7.500	20.400	121.100	60.200	16.100	0.490				20.100
A1															
A2															
A3															
A4															

DATE: March 22 TIME: 1300.000

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1	16.000	712.000	6.400	302.000	15.700	33.900	38.900	78.200	23.320	14.500	0.530				15.200
L2	15.700	652.000	6.200	241.000	27.500	22.700	72.500	69.800	24.800	7.100	0.460				15.100
L3	14.300	670.000	5.900	287.000	36.000	8.100	64.900	70.700	31.000	9.200	0.170				7.000
L4	14.200	656.000	6.000	279.000	31.600	7.100	53.000	62.700	26.900	21.400	0.180				9.000
L5	14.800	488.000	5.800	197.000	24.100	4.500	42.300	49.000	18.900	12.900	0.130				16.700
L6	14.500	927.000	6.300	549.000	11.900	0.140	30.200	39.100	32.400	9.600	0.140				15.400
L6B		844.000	6.600	473.000	10.200	0.200	32.900	26.700	27.300	9.700	0.340				14.100
L7	16.100	1355.000	6.500	824.000	21.600	7.400	20.700	27.600	56.800	15.700					
A1	15.000	1032.000	6.400	610.000	18.500	34.500	27.000	48.000	44.000	21.600	0.070				13.100
A2	15.700	1019.000	6.500	595.000	18.400	41.600	27.300	27.900	44.200	34.000	0.080				13.700
A3	16.300	1008.000	6.600	574.000	17.400	44.000	26.400	58.500	46.400	27.500	0.100				10.300
A4	17.800	1012.000	6.600	543.000	17.800	51.200	22.900	29.500	44.200	45.300	0.120				12.600

DATE: March 29

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1		684.000	5.900	299.000	15.300	33.100	39.900	79.600	22.300	14.500	0.670	0.002	0.143	0.026	17.500
L2		649.000	5.900	235.000	25.200	21.100	71.700	71.000	24.100	7.300	0.570	0.002	0.132	0.013	16.900
L3		685.000	5.800	253.000	32.700	8.300	63.500	68.600	27.000	11.000	0.380	0.002	0.123	0.006	8.600
L4		687.000	5.800	287.000	23.100	6.600	51.700	61.800	24.300	24.800	0.270	0.002	0.107	0.005	10.700
L5		518.000	5.800	200.000	22.300	4.400	41.500	48.600	18.100	13.900	0.150	0.001	0.860	0.003	16.900
L6		963.000	6.000	546.000	12.200	0.300	29.700	123.400	32.500	9.400	0.300	0.002	0.150	0.120	15.100
L6B		856.000	6.300	485.000	9.600	0.200	31.900	91.500	29.800	9.700	0.070	0.002	0.083	0.638	14.500
L7		1402.000	6.400	850.000	22.200	8.200	20.900	141.900	6305.000	18.500	0.390	0.002	0.160	0.082	19.700
A1		1127.000	6.500	668.000	16.500	32.300	27.900	45.100	44.300	19.400	0.270	0.004	0.140	0.004	13.100
A2		1104.000	6.600	577.000	16.200	35.600	23.600	54.600	42.300	45.700	0.290	0.003	0.133	0.003	12.300
A3		1075.000	6.700	564.000	17.700	41.700	25.800	45.700	46.400	33.300	0.290	0.002	0.135	0.003	13.300
A4		1080.000	6.700	523.000	17.500	49.100	24.700	62.500	47.500	40.200	0.300	0.003	0.157	0.004	14.000

DATE: April 06

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1	12.900	606.000	6.200	262.000	15.900	35.000	43.500	74.100	21.600	13.700	0.810	0.002	0.157	0.020	17.600
L2	12.700	588.000	6.000	220.000	26.900	23.000	73.800	69.400	23.300	7.200	0.520	0.002	0.157	0.010	16.600
L3	12.600	610.000	5.700	249.000	34.900	9.900	65.000	70.800	27.000	11.000	0.310	0.002	0.115	0.007	9.400
L4	12.800	611.000	5.800	265.000	31.400	7.800	50.700	60.500	24.000	26.100	0.280	0.001	0.100	0.010	10.300
L5	13.100	560.000	5.800	214.000	23.800	6.000	47.500	60.600	19.900	15.100	0.180	0.002	0.093	0.007	18.000
L6	13.900	837.000	6.300	525.000	11.900	0.000	29.800	120.400	31.600	9.400	0.220	0.002	0.144	0.006	14.900
L6B	13.700	772.000													
L7	14.400	1275.000	6.700	824.000	28.500	4.600	19.700	79.900	59.600	17.100	0.300	0.001	0.093	0.004	22.000
A1															
A2															
A3															
A4															

DATE: April 10 TIME: 1600.000

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1	17.600	585.000	6.500	262.000	15.400	34.100	42.600	70.300	20.300	13.500	0.760	0.003	0.159	0.032	17.200
L2	17.000	571.000	6.400	214.000	24.300	23.400	66.600	69.000	23.300	7.100	0.560	0.002	0.154	0.011	17.000
L3	15.000	575.000	6.100	247.000	32.100	9.400	64.000	67.300	26.400	10.900	0.360	0.002	0.114	0.006	8.700
L4	14.500	592.000	6.100	265.000	29.600	7.600	46.700	61.600	23.800	25.900	0.290	0.001	0.106	0.005	10.100
L5		491.000	6.000	219.000	20.700	6.600	47.200	53.400	20.400	15.300	0.160	0.001	0.075	0.004	17.900
L6		841.000	6.400	555.000	10.900	0.000	24.800	123.900	32.500	9.500	0.200	0.001	0.137	0.005	15.200
L6B		763.000	7.100	435.000	10.600	0.630	31.100	103.200	29.300	9.220	0.220	0.002	0.107	0.790	14.800
L7		1220.000	7.100	833.000	21.800	4.200	21.400	127.300	60.500	17.200	0.340	0.002	0.157	0.049	22.900
A1		954.000	6.800	625.000	18.700	31.400	26.800	132.300	43.400	21.000	0.430	0.002	0.209	0.008	13.000
A2		904.000	6.900	574.000	19.700	41.000	26.100	116.800	43.300	28.600	0.380	0.002	0.187	0.005	12.900
A3															
A4															

DATE: April 14 TIME: 1430.000

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1	13.500	548.000		244.000	15.700	34.800	44.300	68.800	20.000	13.800	0.580	0.002	0.158	0.015	18.500
L2	14.600	552.000		198.000	24.700	23.300	68.400	66.400	22.100	7.200	0.470	0.002	0.170	0.010	16.800
L3	15.400	590.000		244.000	31.400	9.500	62.900	66.500	26.100	11.000	0.260	0.001	0.107	0.004	8.900
L4	15.500	591.000		265.000	30.100	8.200	52.000	59.000	23.500	27.500	0.280	0.002	0.120	0.004	9.800
L5	15.100	493.000		219.000	20.800	7.100	48.600	53.600	20.400	15.300	0.130	0.002	0.099	0.004	17.900
L6	15.000	834.000		561.000	11.500	0.300	29.500	124.000	32.600	9.700	0.260	0.001	0.155	0.004	15.200
L6B															
L7	14.600	1210.000		812.000	23.400	8.400	21.200	149.300	62.600	18.600	0.340	0.002	0.166	0.092	20.700
A1															
A2															
A3															
A4															

DATE: April 16, 1987 TIME 1115.000

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1	18.400	568.000	6.500	238.000	16.300	31.900	41.500	70.600	20.600	14.000	0.700	0.003	0.155	0.016	18.300
L2	18.100	558.000	6.500												
L3	16.200	592.000	6.200	238.000	33.800	10.100	64.800	67.000	26.200	11.300	0.320	0.002	0.124	0.005	8.900
L4	15.700	597.000	6.200	265.000	31.200	8.800	51.700	60.200	23.600	27.300	0.350	0.001	0.093	0.004	11.000
L5	16.200	503.000	6.400	232.000	22.000	7.600	49.100	54.300	20.700	15.500	0.220	0.002	0.087	0.004	17.600
L6	16.100	831.000	6.600	552.000	11.100	0.000	30.000	123.100	32.500	9.700	0.340	0.002	0.149	0.005	15.400
L6B	15.600	751.000	6.600	485.000	9.700	0.200	33.800	105.800	30.000	9.200	0.250	0.002	0.099	1.250	14.100
L7	16.300	1184.000	6.800	812.000	24.500	12.100	21.500	147.600	62.300	18.900	0.280	0.002	0.147	0.062	19.000
A1	15.100	958.000	6.700	601.000	18.500	32.200	27.300	130.800	42.700	20.500	0.430	0.002	0.203	0.018	12.900
A2	15.300	940.000	6.800	568.000	22.100	40.300	26.500	118.000	43.000	27.600	0.300	0.002	0.186	0.006	12.700
A3	15.800	932.000	6.800	546.000	19.300	50.600	25.100	102.800	44.200	34.800	0.320	0.002	0.180	0.015	13.000
A4	16.800	956.000	6.900	531.000	19.400	60.200	26.800	93.800	45.200	44.300	0.350	0.002	0.165	0.014	14.000

DATE: April 21, 1997 TIME: 1100.000

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1	19.700	563.000	6.300	250.000	15.700	31.700	46.800	69.300	19.900	14.700	0.730	0.002	0.138	0.014	18.700
L2	19.400	559.000	6.200	204.000	25.300	25.400	71.300	67.500	22.500	7.900	0.410	0.001	0.120	0.010	17.700
L3	18.100	585.000	6.000	244.000	31.300	9.700	69.700	65.900	25.300	10.900	0.170	0.003	0.090	0.005	8.200
L4	17.300	597.000	6.100	272.000	30.500	8.400	53.900	59.500	23.200	28.700	0.098	0.001	0.080	0.003	9.500
L5	16.200	518.000	6.100	235.000	20.200	7.600	49.000	57.600	21.700	14.900	0.360	0.002	0.160	0.005	18.200
L6	16.100	846.000	6.400	549.000	11.000	0.300	29.600	125.800	33.200	9.100	0.440	0.002	0.210	0.007	15.500
L6B	16.100	777.000	6.500	501.000	10.000	0.200	34.300	111.200	31.700	8.500	0.440	0.002	0.190	1.310	14.100
L7	16.200	1199.000	6.600	811.000	24.200	11.400	21.300	151.600	63.900	17.600	0.620	0.003	0.240	0.064	19.100
A1	15.200	961.000	6.700	622.000	17.700	30.100	26.400	130.200	41.700	20.400	0.330	0.002	0.168	0.007	12.400
A2	15.400	938.000	6.800	567.000	21.500	41.800	26.000	114.000	41.200	28.100	0.220	0.002	0.158	0.006	12.030
A3	15.700	930.000	6.900	546.000	18.700	49.800	26.300	100.700	43.270	34.800	0.300	0.002	0.155	0.014	12.460
A4	16.600	955.000	6.800		19.300	60.000	29.700	87.900	43.700	44.100	0.250	0.002	0.155	0.011	13.400

DATE: April 27, 1987 TIME: 1400.000

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1	23.100	546.000	6.400	250.000	15.800	26.300	50.300	70.400	19.900	14.400	0.470	0.002	0.120	0.014	19.400
L2	21.300	520.000	6.200	198.000	25.300	24.200	69.400	65.400	21.700	7.300	0.430	0.002	0.113	0.011	18.600
L3	20.500	565.000	6.200	228.000	30.900	9.800	61.800	65.600	25.300	11.200	0.170	0.004	0.099	0.005	9.300
L4	20.000	605.000	6.200	215.000	31.300	8.100	54.400	59.200	23.200	29.900	0.190	0.001	0.091	0.003	9.500
L5	18.700	509.000	6.100	231.000	19.900	8.000	48.000	56.600	21.700	14.800	0.340	0.001	0.132	0.004	18.500
L6	17.800	810.000	6.400	534.000	11.100	0.300	25.100	123.500	32.300	9.000	0.350	0.002	0.177	0.008	15.400
L6B	17.500	790.000	6.400	518.000	11.500	0.200	33.900	121.200	32.500	8.400	0.450	0.002	0.194	1.030	14.200
L7	17.700	1150.000	6.500	802.000	24.700	11.400	21.500	152.100	63.400	17.500	0.580	0.003	0.240	0.051	19.800
A1	17.600	940.000	6.600	607.000	17.200	29.100	26.200	131.200	41.600	19.600	0.330	0.002	0.180	0.018	12.440
A2	17.200	938.000	6.600	558.000	21.500	42.000	25.700	114.400	41.700	28.400	0.270	0.002	0.161	0.006	12.200
A3															
A4															

DATE: May 05, 1987 TIME: 1000.000

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1	23.800	518.000	6.400	235.000	15.400	15.600	56.400	68.500	19.600	14.700	0.420	0.002	0.122	0.014	20.900
L2	23.500	519.000	6.100	195.000	22.800	23.500	70.900	66.400	21.800	7.800	0.340	0.001	0.098	0.012	20.600
L3	22.200	568.000	6.100	235.000	30.000	10.700	65.100	65.900	25.500	11.300	0.180	0.001	0.085	0.005	10.300
L4	21.400	575.000	6.100	264.000	31.200	8.900	54.200	59.200	23.300	29.200	0.150	0.001	0.095	0.005	10.100
L5	20.000	513.000	6.100	238.000	21.000	9.800	49.500	58.200	22.200	15.100	0.340	0.001	0.134	0.004	19.200
L6	18.400	814.000	6.400	534.000	11.200	0.000	30.000	123.900	32.600	9.130	0.430	0.002	0.214	0.012	15.900
L6B	18.400	765.000	6.400	509.000	11.200	0.000	33.900	116.600	31.500	8.600	0.490	0.002	0.199	0.948	14.800
L7	17.700	1170.000	6.600	814.000	24.200	11.200	22.300	152.700	63.400	17.500	0.720	0.003	0.272	0.048	20.500
A1	18.300	962.000	6.600	597.000	18.200	34.700	29.700	130.500	41.600	20.000	0.290	0.002	0.171	0.025	12.900
A2	17.800	940.000	6.700	564.000	23.700	43.100	26.900	118.300	43.200	28.700	0.310	0.002	0.182	0.008	12.700
A3	17.100	902.000	6.800	552.000	20.300	51.700	27.000	104.500	45.000	35.800	0.300	0.002	0.157	0.014	12.800
A4	17.900	929.000	6.800	545.000	20.300	65.600	33.300	96.600	45.600	47.000	0.250	0.002	0.151	0.017	13.900

DATE: May 13, 1987 TIME: 1500.000

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1															
L2	26.500	518.000		186.000	25.300	23.800	74.300	66.500	22.600	7.900	0.330	0.003	0.048	0.059	20.300
L3	23.500	550.000		228.000	30.500	10.700	66.000	65.600	28.200	10.300	0.160	0.002		0.011	10.300
L4	23.400	568.000		259.000	30.800	8.300	55.200	60.000	25.400	28.700	0.200	0.002		0.011	9.700
L5	21.900	511.000		238.000	20.600	8.700	50.900	72.300	23.900	15.600	0.150	0.003	0.085	0.080	19.300
L6	20.200	824.000		527.000	10.900	0.000	30.000	126.700	35.200	11.100	0.170	0.003	0.140	0.016	15.700
L6B	20.100	810.000		515.000	12.800	0.000	33.500	119.300	34.100	9.800	0.220	0.003	0.150	0.760	14.400
L7	19.700	1186.000		803.000	24.500	9.100	22.300	149.400	63.200	17.700				0.011	19.100
A1	18.200	1030.000		604.000	18.600	30.700	24.700	130.100	45.500	22.500	0.100	0.003	0.100	0.022	12.800
A2	17.700	1010.000		558.000	21.900	41.300	25.200	120.400	47.000	37.600	0.085	0.002	0.119	0.006	12.900
A3	18.600	1004.000		537.000	18.100	53.400	26.600	95.900	46.700	34.400	0.088	0.003	0.032	0.014	10.200
A4	18.000	1000.000		525.000	18.200	59.000	32.200	88.800	46.810	48.600	0.104	0.003	0.041	0.007	11.200

DATE: May 20, 1987

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1															
L2	28.000	502.000		225.000	23.800	7.100	78.100	57.600	21.300	6.400	0.330	0.004	0.005	0.014	20.600
L3	25.800	536.000		259.000	27.800	7.700	64.100	60.300	26.700	9.100	0.240	0.003	0.000	0.013	11.300
L4	25.200	555.000		229.000	29.700	6.700	53.400	55.300	23.700	28.400	0.190	0.001	0.005	0.002	10.000
L5	23.200	506.000		534.000	20.800	8.200	52.000	58.500	22.400	16.200	0.200	0.003	0.090	0.011	20.600
L6	20.800	827.000		540.000	11.000	0.000	29.800	123.500	34.800	11.700	0.160	0.002	0.150	0.009	16.000
L6B	21.700	861.000		805.000	13.400	0.000	32.800	129.200	35.300	10.100	0.230	0.003	0.135	0.740	14.900
L7	20.300	1186.000		619.000	24.000	9.200	22.100	141.000	58.600	16.400				0.030	19.100
A1	21.200	1014.000		576.000	14.800	16.700	26.600	113.100	44.500	23.200	0.190	0.005	0.104	0.040	13.000
A2	19.500	980.000		546.000	20.500	36.600	23.300	123.700	47.200	35.300	0.130	0.003	0.120	0.010	13.100
A3	21.100	990.000		528.000	17.200	49.400	24.700	94.000	44.800	37.200	0.110	0.002	0.060	0.005	10.400
A4	19.000	950.000		552.000	19.700	60.700	31.700	86.500	46.400	44.200	0.110	0.003	0.020	0.009	10.800

DATE: May 24, 1987 TIME: 1330.000

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L2	24.100	419.000		119.000	20.800	15.800	54.600	36.600	12.300	25.800	1.900	0.003	0.020	0.010	11.800
L3	24.000	548.000		220.000	28.100	3.900	68.700	60.800	26.800	9.200	0.200	0.003		0.011	11.600
L4	23.800	563.000		234.000	29.200	6.200	58.500	54.300	23.900	29.000	0.150	0.002		0.002	9.700
L5	27.900	512.000		220.000	21.500	7.500	52.600	62.600	22.400	16.300	0.150	0.003	0.110	0.160	20.600
L6	20.500	843.000		528.000	11.600	0.000	31.000	133.700	37.300	11.700	0.160	0.003	0.130	0.014	16.800
L6B	20.900	760.000		460.000	10.900	0.300	34.900	112.400	30.600	10.000	0.200	0.002	0.130	0.410	16.400
L7	19.600	1206.000		787.000	24.800	11.900	22.700	174.900	66.200	19.100	0.270	0.003	0.140	0.070	21.000
A1	20.200	1093.000		634.000	15.500	19.500	29.000	143.400	49.100	23.000	0.090	0.003	0.108	0.002	14.000
A2	18.700	1014.000		567.000	19.800	38.400	25.600	129.100	47.900	36.600	0.110	0.003	0.140	0.104	13.900
A3	18.000	948.000		531.000	15.100	47.200	24.700	99.400	48.500	35.400	0.060	0.003	0.050	0.010	10.800
A4	19.000	972.000		518.000	16.700	47.000	29.500								

DATE: May 27, 1987 TIME: 1245.000

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1															
L2	22.900	452.000	6.200		23.800	8.700	65.600	48.200	16.700	16.800	0.970	0.003		0.010	3.200
L3	23.200	534.000	6.000	210.000	27.300	1.500	69.500	67.200	26.900	9.600	0.170	0.003		0.016	11.500
L4	22.900	568.000	6.100	233.000	24.100	51.100	66.400	48.300	20.500	50.100	0.260	0.002	0.014	0.005	9.400
L5	21.800	495.000	6.200	213.000	21.100	6.900	52.200	58.100	21.700	17.200	0.180	0.002	0.116	0.011	21.400
L6	20.100	842.000	6.300	528.000	11.200	0.200	30.300	132.300	36.700	11.000	0.170	0.004	0.130	0.020	16.700
L6B	20.000	720.000	6.500	427.000	9.400	0.000	35.800	109.500	29.300	9.800	0.210	0.003	0.140	0.140	17.100
L7	19.200	1195.000	6.500	787.000	24.400	14.500	22.800	157.900	67.800	19.800	0.110	0.002	0.140	0.023	21.300
A1	18.800	1044.000	6.700	637.000	16.100	19.900	28.700	179.400	49.200	23.300	1.700	0.004	0.120	0.009	13.700
A2	18.600	989.000	6.700	567.000	19.200	39.300	25.900	121.700	46.300	36.100	0.120	0.003	0.119	0.006	13.000
A3	17.800	950.000	6.800	537.000	15.600	49.500	26.500	91.700	44.600	36.400	0.100	0.003	0.054	0.003	10.400
A4	17.900	963.000	6.800	531.000				88.100	46.100	46.800	0.150	0.003	0.040	0.007	11.100

DATE: May 31, 1987

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1															
L2															
L3	23.600	514.000	6.060	212.000	28.000	1.300	67.200	60.200	26.700	9.300	0.180	0.003		0.013	10.600
L4	23.600	451.000	6.320	170.000	12.100	62.700	36.100	38.800	10.600	53.500	1.350	0.003	0.020	0.014	13.300
L5	23.800	495.000	6.200	220.000	21.900	6.300	52.700	66.000	21.800	18.600	0.210	0.002	0.130	0.033	21.500
L6	21.200	779.000	6.350	546.000	11.500	0.470	30.500	126.000	35.500	10.300	0.170	0.004	0.110	0.018	16.100
L6B	21.200	856.000	6.400	576.000	15.600	0.960	33.900	142.200	37.100	10.710	0.290	0.004	0.140	0.060	15.700
L7	20.300	1155.000	6.560	777.000	25.300	14.800	23.200	152.500	72.400	21.700	0.210	0.003	0.174	0.011	22.500
A1	20.000	998.000	6.530	619.000	14.900	25.100	28.000	136.800	46.200	21.700	0.090	0.003	0.093	0.001	13.500
A2	19.600	955.000	6.620	565.000	19.400	40.900	25.900	122.600	47.400	36.800	0.090	0.003	0.113	0.001	13.400
A3	19.500	910.000	6.700	540.000	16.000	50.000	26.900	93.900	43.800	40.100	0.100	0.002	0.071	0.003	10.900
A4	19.300	922.000	6.710	518.000	17.700	61.200	30.800	90.000	46.900	49.600	0.100	0.003	0.058	0.014	11.700

DATE: June 04, 1987 TIME: 1545.000

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1	26.400	706.000	6.900		17.400	0.100	114.000	82.200	21.000	17.500	0.990	0.017	0.040	0.135	15.100
L2	26.400	532.000	7.040		24.900	0.800	78.000	47.000	13.400	21.500	0.270			0.021	14.200
L3	24.500	548.000	6.040	253.000	25.600	0.700	63.600	62.600	22.900	10.100				0.030	11.800
L4	23.900	527.000	6.200	226.000	13.300	22.900	48.900	44.400	16.200	42.600					9.230
L5	23.300	537.000	6.130	220.000	21.500	5.600	51.200	57.200	20.600	15.400		0.001		0.001	19.600
L6	21.200	888.000	6.320	538.000	11.400	0.500	30.200	56.000	33.300	9.400	0.052	0.002	0.092	0.001	16.600
L6B	21.300	994.000	6.340	598.000	17.700	1.000	33.100	104.100	36.400	9.000					15.600
L7	20.900	1251.000	6.630	777.000	24.300	13.400	22.900	55.660	64.770	19.300		0.000			21.800
A1	19.100	995.000	6.530	598.000	14.700	31.100	28.600	57.900	42.700	21.600					13.300
A2	19.100	977.000	6.690	570.000	17.600	41.700	25.800	93.700	44.100	30.000		0.000			12.500
A3	18.700	953.000	6.700	534.000	15.000	49.000	26.300								
A4	19.100	940.000	6.830	524.000	17.200	60.800	29.800	73.100	46.800	50.400		0.001	0.020		13.600

DATE: June 11, 1987 TIME: 1410.000

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1	29.100														
L2	27.200	518.000	6.520	177.000	23.100	2.200	85.900	61.300	21.000	16.700	0.550	0.004		0.040	18.800
L3	25.700	529.000	6.300	238.000	23.400	0.250	60.100	62.200	27.000	9.600	0.130	0.050		0.240	11.900
L4	25.000	529.000	6.300	247.000	16.300	5.500	53.000	45.700	18.100	51.700	0.540	0.001	0.070	0.014	11.000
L5	24.000	524.000	6.260	232.000	21.900	3.800	50.800	59.900	22.300	18.600	0.180	0.002	0.110	0.011	22.600
L6	22.400	829.000	6.380	514.000	11.200	0.610	30.100	123.600	34.600	10.800	0.170	0.003	0.120	0.004	16.200
L6B	22.600	938.000	6.430	522.000	18.600	1.000	32.400	152.100	39.000	11.200	0.280	0.003	0.160	0.170	16.100
L7	21.400	1226.000	6.600	784.000	24.300	13.300	23.000	183.900	70.000	20.600			0.180	0.060	23.900
A1	21.700	990.000		531.000	15.200	50.100	26.400	98.000	45.600	43.800	0.080	0.002	0.080		13.100
A2	21.800	930.000		546.000	16.400	41.600	25.700	125.300	47.300	35.400	0.110	0.003	0.110	0.001	13.900
A3	21.300	891.000		521.000	14.600	48.200	25.900	92.100	44.900	37.900	0.100	0.003	0.040	0.003	10.900
A4	20.800	880.000		500.000	16.800	59.500	28.600	87.400	46.100	47.900	0.110	0.003	0.034	0.009	11.900

DATE: June 18, 1987 TIME: 1500.000

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1															
L2	29.800	565.000	6.240	165.000	34.400	2.000	101.200	95.300	18.900	19.800	0.790	0.000	0.099	0.774	21.900
L3	27.900	515.000		238.000	21.700	0.000	59.900	63.400	22.700	11.600				0.011	13.200
L4	27.100	525.000		247.000	15.700	2.700	54.200	25.100	8.500	39.800				0.007	8.700
L5	25.200	513.000		244.000	22.400	3.100	51.200	61.600	22.300	17.000	0.260		0.061	0.006	20.900
L6	22.800	845.000		515.000	11.500	0.500	30.700	85.400	34.200	9.800					17.300
L6B	23.200	1008.000		625.000	21.100	1.100	32.500	110.100	37.300	9.000					16.000
L7	21.800	1225.000		784.000	25.000	10.900	23.500	63.500	65.800	19.500				0.000	23.600
A1	20.100	1017.000		596.000	14.400	24.600	28.500	75.800	44.800	22.000					14.000
A2	20.200	980.000		540.000	15.500	38.700	25.400	83.300	42.500	29.400					12.700
A3	19.800	947.000		528.000	14.700	45.300	25.400	70.000	45.000	37.500					12.600
A4	19.300	918.000		494.000	16.000	58.800	27.600	91.800	44.500	48.400					13.100

DATE: June 23, 1987

TIME: 1600.000

	TEMP C	EC	pH	HCO3	Cl	NO3	SO4	Ca	Mg	Na	K	Fe	Al	Mn	Si
L1	31.900	856.000	7.300		32.100	0.000	184.800	120.800	28.600	21.100	0.800			0.130	15.700
L2	31.400	519.000	7.300		31.900	0.500	92.200	67.500	22.200	9.400	0.030			0.086	10.100
L3	30.400	514.000	6.030	229.000	19.900	0.000	62.300	38.100	13.200	51.000				0.044	11.400
L4	27.400	408.000	6.190	185.000	8.800	1.100	40.800	27.400	9.700	44.800				0.012	10.000
L5	26.200	531.000	6.140	247.000	22.600	2.300	51.300	74.700	24.100	17.900	0.240		0.180	0.011	22.400
L6	23.700	800.000	6.330	521.000	11.700	0.000	33.500	62.700	34.000	9.900					17.500
L6B	24.000	873.000	6.400	592.000	17.300	0.000	32.300	115.200	35.100	9.000				0.016	16.400
L7	22.700	1111.000	6.530	788.000	25.100	10.800	23.800	102.300	65.600	19.400			0.009	0.002	23.700
A1	21.500	986.000	6.690	598.000											
A2	21.200	946.000	6.760	564.000											
A3	20.600	944.000	6.850	534.000											
A4	20.000	892.000	6.880	497.000											

VITA 2

Randall Royce Ross

Candidate for the Degree of

Master of Science

Thesis: TEMPORAL AND VERTICAL VARIABILITY OF THE SOIL- AND GROUND-WATER GEOCHEMISTRY OF THE ASHPORT SILT LOAM, PAYNE COUNTY, OKLAHOMA

Major Field: Geology

Biographical:

Personal Data: Born in Douglas, Wyoming, 27 February 1962, the son of Richard R. and Lois A. Ross.

Education: Graduated from Ada High School, Ada, Oklahoma, in May 1980; received Bachelor of Science Degree in Geology from Oklahoma State University in May 1985; completed requirements for the Master of Science Degree at Oklahoma State University in May 1988.

Professional Experience: Hydrologist (temporary), Oklahoma Water Resources, Stream Water division, June 1985 to August 1985; Teaching Assistant, School of Geology, Oklahoma State University, August 1985 to June 1986; Hydrologist, Engineering Enterprises, Inc., Norman, Oklahoma, June 1986 to September 1986; Presidential Fellow, Oklahoma State University, August 1986 to December 1987. Hydrologist, U.S. EPA, Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma, September 1987 to present.

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