SPATIAL AND TEMPORAL VARIABILITY OF GROUND-WATER QUALITY IN A SHALLOW AQUIFER IN NORTH-CENTRAL OKLAHOMA

By

DAVID J. HAGEN

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Baldwin-Wallace College

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Thesis Approved:

Wayne Pettyjohn
Thesis Adviser

A Hounslow

Cary T. Stewart

Norman N. Durham
Dean of the Graduate College

PREFACE

The spatial and temporal variability of the chemical quality of shallow ground water was determined by evaluating data obtained from several monitoring wells over a nine- month period. The investigated aquifer is located in Stillwater, Oklahoma. The 21 monitoring wells lie within an area of about 11,000 square feet and a vertical interval of 5.5 feet.

Nitrate was the main tracer used in the study and is applied to the land surface in the form of fertilizer three times annually and thus was routinely monitored. Nitrate has been found to vary temporally, particularly on the short-term during recharge events. Nitrate, and all other monitored parameters, have also shown rather large spatial variations.

I would like to express my thanks to my major advisor, Dr. Wayne A. Pettyjohn, for his support and encouragement. In one's life there are few persons that make a lasting and positve impact. In my case, Dr. Pettyjohn is one of those individuals.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

CHAPTER I

INTRODUCTION

General Overview of the Problem

Data that do not fit the expected or anticipated distributions are commonly discarded or ignored. This may be particularly true in ground-water quality studies and are in part due to the numerous sources of potential error. These sources include well construction, sampling, and chemical analysis to name a few. In addition, the complexity of the subsurface and our general ignorance of the ways in which it functions serves to compound the problem. Anomalous bits of data, however, may indicate far more than the anticipated bit, although it may not become apparent with the normal sampling frequency.

Ground-water quality often is decribed as being rather consistent in both space and time. This may be true for deeper, confined aquifers that are not stressed by pumping or construction. However, the chemical, and possibly even the biological quality, of shallow or surficial aquifers may change rather rapidly. These changes may be neither uniform nor anticipated, and may occur both horizontally and vertically. This appears to be especially true with respect to fine-grained systems, systems that are normally considered confining units, although they may be capable of producing a considerable volume of water to a well, stream, and plants.

Purpose and Scope

The purpose of this report is to describe the temporal and spatial variations in ground-water quality in a shallow aquifer over a nine month period. Additionally, quantification of several different sources of error in the water-quality data, other than variations in space and time, will be described. The data base was acquired by obtaining successive samples from several wells on a regular basis, which enabled the quantification of variations in quality within single wells at any defined instant in time.

Several sampling considerations were addressed during the study in order to achieve reliable results. Included is the affect of pumping on the chemistry of a sample and an assessment of well purging processes in low-permeability materials. Aquifer testing was undertaken in order to evaluate in-situ aquifer properties, while geophysical methods were used to better define geologic boundaries.

The objectives of the study are fourfold; (1) identify and quantify the variation in water quality expected in samples taken from a single well at an instant in time, (2) identify variations in water quality in both space and time, (3) characterize the site geology, geochemistry, and hydrology, at least on a preliminary basis, and (4) speculate on the causes of the variations of water quality in space and time. The main tracer used in the study is nitrate.

General Features of the Region

The investigative area is located in Stillwater, Payne County, Oklahoma, which lies in the north-central part of the state (Figure 1). Specifically the site is located in the SE 1/4, SW 1/4, NE 1/4, Section 11, T 19 N, R 2 E.

The region is characterized by low rolling hills formed on westward dipping strata consisting of alternating layers of sandstone and shale of Permian age. The region has about 34 inches of precipitation each year, most of which occurs as rain during the spring and fall. Evapotranspiration averages 31 inches per year and the average annual runoff is approximately 4.5 inches. Maximum relief in the region is about 100 feet.

The field site encompasses an area of no more than 22,000 square feet. The monitoring wells lie within an area of about 11,000 square feet. The site is located on private property, allowing for ready access and total control. Within the property boundary are two buildings and driveways. Most of the study area is covered by bermuda grass, but several large pecan trees and other woody plants are located along the southern boundary of the property (Figure 2).

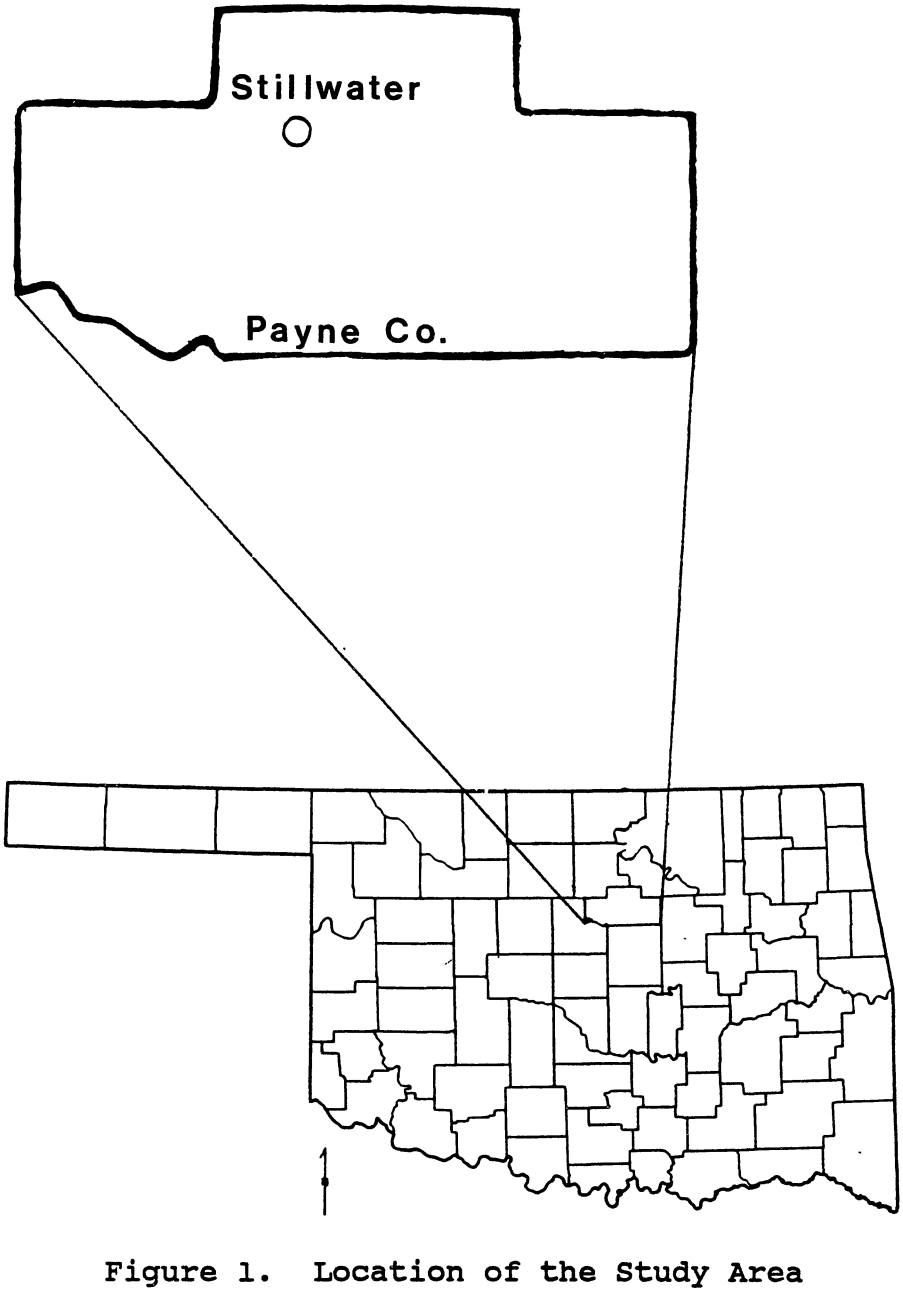


Figure 1. Location of the Study Area

Figure 2. Southern Boundary of the Study Area, Dominated by Large Pecan Trees and Other Woody Plants

General Methodology

In order to determine the variability of ground-water quality in space and time, several monitoring wells were installed at four separate sites over an area of about 11,000 square feet. The majority of the wells, which were constructed in four clusters of five wells each, are designed to sample discrete intervals of the aquifer and are screened accordingly. A fifth well at each site is designed to sample the entire saturated thickness of the aquifer.

Samples were taken from the monitoring wells on at least a weekly basis and nitrate concentration, specific conductance, temperature, and pH were routinely determined. Major ions, other than nitrate, were determined occasionally. Evaluation of the temporal variations in ground-water quality was based mainly upon nitrate and specific conductance. Spatial variations in ground-water quality were evaluated by utilizing the entire data base.

Source of Nitrogen: The Nitrogen Cycle

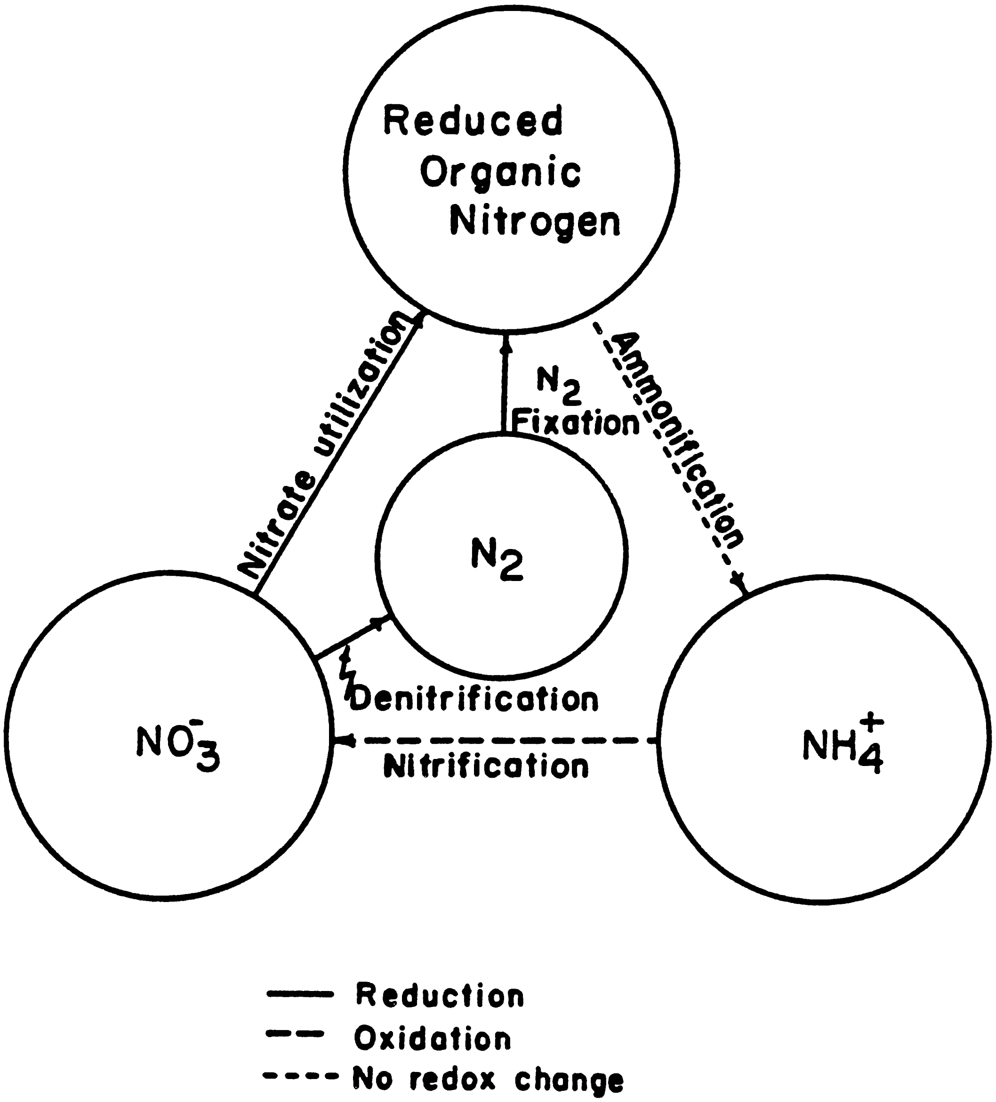
The fate of nitrogenous matter in the subsurface is influenced by many factors. In general, nitrogen enters the unsaturated zone in the form of nitrate from rain water, biologically fixed nitrogen, as a major component of fertilizers, and from decaying plant material. In this study, the latter two appear to contribute the bulk of the nitrogenous matter with fertilizer dominating. An abbreviated form of the nitrogen cycle is illustrated in Figure 3. The major processes are discussed below.

The primary control on the nitrogen cycle is microbes. Nitrogen fixation involves the assimilation of atmospheric nitrogen by bacteria and to a lesser extent by blue-green algae. The microbes attach electrons and hydrogen ions to atmospheric nitrogen through a series of reduction reactions forming ammonia (NH3) or ammonium (NH4+). When the microbes die, their nitrogenous compounds are released during decay. Soil bacteria use these nitrogenous compounds as energy sources in which the ammonia or ammonium is stripped of electrons producing the transient nitrite form (NO2-), which in turn is transformed into nitrate (NO3--) by continued microbial activity. The preceeding process is termed nitrification and nitrate becomes available for plant uptake (incorporated as organic compounds).

Upon the death and decomposition of plants, the organic nitrogen compounds are again used by soil microbes which release ammonia or ammonium. The above process is termed ammonification. Denitrification is the process by which nitrate (NO3) is converted to gaseous nitrogen (N2 or N2O) with the formation of nitrite as an intermediate and transient step. The process occurs in poorly drained, organic rich soils under anaerobic conditions.

Influences on the Nitrogen Cycle

The "natural" cycle of the foregoing discussion leads



Source: Hounslow, personal communication, (1981).

Figure 3. Nitrogen Cycle

one to believe a balance is easily achieved. In reality, stresses upon the natural nitrogen system are continuously being imposed, causing both nitrogen depletion and accumulation in different earth "spheres". Activities of man, which attempt to control or manage parts of the nitrogen cycle, often have adverse and unforeseen affects.

One particularly well known example of depletion and accumulation of nitrogenous matter is associated with agricultural activities. Demand for increased crop production has caused farmers to put more acres into production. Restoration of naturally occurring nitrogen within the soil does not take place, thus nitrogen compounds in the form of man-made fertilizers are added to the soils. Crop removal of the applied nitrogen has been estimated to be approximately 50 per cent (Committee on Nitrate Accummulation, 1972). The fate of the remaining 50 per cent is dependent upon many factors such as soil type, climate, and microbial activity. Thus, a significant amount of the nitrogen applied as fertilizer may reach the water table, adversely affecting water quality; numerous examples are found in the literature (see for example, Andersen and Kristiansen, 1983; Gustafson, 1983; Stewart, et al., 1967; Baier and Brykbost, 1976; Gray and Jones, 1980).

Although agricultural activities are not the source of nitrogenous matter in this study, fertilizer applied to a lawn is a major source. The fertilizers are applied three times a year (spring, summer and fall) to the lawn that forms the study area. As in the case of crops, turf-grass is unable to utilize all the nitrogen applied and leaching of the excess past the root zone occurs.

Literature Review

Emphasis on the detection and evaluation of ground-water contamination and adequate sampling methodology have brought about the publication of numerous reports on sampling and sampling protocol. Barcelona et al. (1983, 1985) gave excellent accounts of the considerations given prior to and during ground-water monitoring. Among the topics addressed are the effects of different drilling methods and fluids on ground-water quality, the influence different well construction materials have on the quality of a sample, quality assurance/quality control measures, sampling devices and their affects on the chemistry of the water withdrawn from a well, and well purging considerations. The authors found that peristaltic pumps and bailers are suitable for sampling shallow wells and will affect the chemistry of the sample as little as other devices. Also, PVC tubing is acceptable when inorganic constituents are being monitored and four to six well volumes adequately purges a well of casing storage water.

Nightingale and Bianchi (1980) specifically addressed the affects of pumping on nitrate concentrations and specific conductance. They reported that significant variations of the two monitored parameters occurred over the course of pumping in municipal wells of Fresno, California, although no explanation for the variations was given. Regular trends in the two monitored parameters with pumping time were not found, but they concluded that the chemical quality of pumped water from the municipal well field changed most drastically within the first five to ten minutes of pump startup. They also stated that the changes in quality in a well must be evaluated on an individual basis.

Schmidt (1977) found similar nitrate concentration fluctuations with pumping in several municipal wells of the San Joaquin Valley, California. In his study, nitrate concentrations were found to decrease with pumping time and the largest fluctuations occurred after the first few minutes of pumping. The noted variations were explained by "variability of pump operations". He concluded that seasonal changes in quality were related to variations in the magnitude of recharge and the amount and quality of the water reaching the water table from the unsaturated zone. Additionally, Schmidt (1977) stated that long-term trends are related to variations of recharge and water quality of pollution sources.

Considerable attention has been given to the methodology necessary for the collection of a sample representative of aquifer water. Schuller et al. (1981) discussed several such considerations including pumping mechanisms, well flushing, seasonal fluctuations, and sample preparation and storage, to name a few. The authors concluded that four to six well volumes removed prior to sampling will yield a sample representative of aquifer water, peristaltic pumps and bailers affect the chemistry of a sample relatively little, and measurements of pH and specific conductance should be made at the time of sample collection.

Everett (1981) addressed the need for the use of selected geophysical surveys prior to site selection of monitoring wells, methods for the determination of water levels, and sampling of geologic material. The author concluded that borehole geophysics in exploratory wells allows the delineation of subsurface stratigraphy as well as changes in chemical quality. He further stated that the steel tape method of water level measuring is quite reliable and cost effective. Nacht (1983) presented methods for determining sampling frequency, field filtering methods, and the style of collection bottles to be used in given sampling conditions. The author concluded that sampling frequency should be based on the toxicity of the material under observation, the suspected concentration, its mobility, and ground-water velocity to name a few. He also stated that filtering need be done only where called for by specific analytical procedures and then should be done immediately in the field.

Identification of fluctuations in ground-water quality in space and time has been the objective of several research efforts. Katz et al., (1978) documented the variations in chloride, sulfate, and nitrate concentrations in a shallow water-table aquifer at Long Island, New York. The authors attributed fertilizer as the source of these parameters and concluded that factors such as application rates of fertilizers and the concentration of dissolved constituents in storm runoff are responsible for the fluctuations. Growitz and Lloyd (1971), reported on the variations of specific conductance and nitrate in a shallow water-table aquifer in Pennsylvania. They found that increased nitrate concentrations and specific conductance values tended to correspond to rises in water level. The authors concluded that these increases resulted from the flushing of soluble minerals from the unsaturated zone by recharge water, while decreasing concentrations were due to dilution by water derived from underflow.

Pettyjohn (1971, 1972, 1982) presented findings of large variations of chloride concentrations in shallow ground water in the vicinity of abandoned brine pits in central Ohio. The variations were neither consistent nor uniform in space and time, although they appeared to fluctuate in a cyclic manner. Recharge, vertical flow, and leaching of salt from the unsaturated were assumed to be the causes of the variations. Short-term variations in ground-water quality were attributed to recharge through macropores.

An excellent article on the chemical variations in space and time was given by Keith et al., (1983). These authors discussed several causes of variation in water-quality data, such as chemical analysis, well construction, sampling technique and personnel, and pumping. They also discussed variations caused by short-term or seasonal recharge events and the impact of land use on water quality. In their study in southeastern Arizona, the authors concluded that the variations caused by sampling technique and personnel, pumping, chemical analysis, and well construction had to be dealt with at the onset of monitoring. Once the variations from these sources are known, variations caused by land use impact and recharge could be approached.

With recent emphasis on the quality of data retrieved during monitoring, statistical techniques have become important in both the planning and interpretation phases of ground-water quality studies. The practice of taking single "grab" samples from a well is often times considered undesirable. Nelson and Ward (1981) described several preliminary statistical considerations in the design of ground-water monitoring programs. Included is a procedure for determining the number samples and volume of each that should be taken in order to meet certain confidence limits. They also discussed the advantages and disadvantages of several sampling program designs.

Other authors have concentrated on the use of statistical methods in the detection of contamination or impact of a particular land use on ground-water quality. Rovers and McBean (1981) and McBean and Rovers (1984) discussed the use of the student's t-test and regression analysis, respectively, in the delineation of land use impact on ground-water quality. Additionally, McBean and Rovers (1985) described the use of analysis of variance in determining the effectiveness of split versus successive samples when evaluating sampling variance and error. The authors concluded that successive samples generally have a higher variance and more closely approximates sampling error than split samples.

References on contamination of ground water by nitrate number in the hundreds. Concern about high nitrate concentrations in ground water began with the first reported case of infant nitrate poisoning (methemaglobinemia) in 1944 (Comm. on Nitrate Accumulation, 1972). The case involved nitrate-contaminated ground water obtained from a rural well. Continued problems with high nitrate concentrations in shallow ground water and methemaglobinemia between 1945 and 1950 prompted the institution of federal limits of nitrate in public water supplies. The limit was set at 45 milligrams per liter when expressed as nitrate and 10 milligrams per liter when expressed as nitrogen (Comm. on Nitrate Accumulation, 1972). Since that time numerous journal articles concerning elevated nitrate concentrations in ground water have been published.

Among these articles are several on the spatial variations of nitrate in ground water. The vertical variability of nitrate in wells located in agricultural regions of Denmark was addressed by Anderson and Kristiansen (1980).

They found that nitrate concentrations generally decreased with depth and corresponded to increasing iron concentrations. A change in the oxidation-reduction potential was the concluded cause, with nitrite being stable at greater depths. Piskin (1973) studied the concentration of nitrate in shallow ground water of Hall County, Nebraska. The author noted sharp variations within relatively short distances and seasonal variations of nitrate concentrations. The high hydraulic conductivity of the unsaturated zone, dilution of ground water by the Platte River in some areas, and proximity of wells to feedlots were identified as the causes for these variations. Robertson (1979) conducted a regional study on the distribution of nitrate in Sussex County, Delaware. He concluded that high nitrate concentrations were associated with shallow water-tables, soils which possessed moderate to high permeability, and confined feeding operations.

It is often stated that recharge cannot occur until there is a soil moisture excess. That is, the soil moisture content must exceed field capacity for recharge to occur. Several authors have shown that this is not the case in many instances. For example, Ehlers (1975) found earthworm channels were able to conduct water to considerable depths of the unsaturated zone before field capacity was reached. He also stated that this occurrence is resticted to high intensity rainfall events. Aubertin (1971) found that macropores were able to transmit large quantities of water to depths of thirty feet or more in sloping forested land.

Dessication cracks have been known to transmit considerable quantities of water through the unsaturated zone. Blake et al., (1973) found this to be the case, as well as Pettyjohn (1982). In fact, Pettyjohn (1982), described an experiment at a field site located within a few miles of the study area of the enclosed report. Seven hundred ninety-two gallons of water were pumped into a dessication crack network over 132 minutes with no overflow of the fractures. In addition, water levels dropped dramatically in dessication cracks when pumping was discontinued. The transmission of water through the unsaturated zone was great even though the soil moisture content was small.

CHAPTER II

GENERAL FEATURES OF THE STUDY AREA

Topography and Climate

The study area lies on the flood plain of a small stream, Boomer Creek, which is located 600 feet to the west (Figure 4). The site is nearly flat, with a total relief of no more than a half foot. A few tens of feet to the east shale crops out to form a large area of rolling hills, with total relief exceeding 100 feet.

During the nine month period of investigation total rainfall was about 23 inches, the majority of which occurred in the spring and fall (Figure 5). Measured precipitation was 2.1 inches in August, 6.1 inches in September, 4.6 inches in October, 5.15 inches in November, 0.15 inches in December, 0.8 inches in February, 1.3 inches in March, and 3.1 inches in April. Generally the rainy periods were separated by several days of dry weather. December, January, and February were dry and it rained only five times from late February through March. Although the mean daily air temperature is 59 degrees Farenheit, summer temperatures generally range in the high 80's to low 90's, and commonly reach or exceed 100.

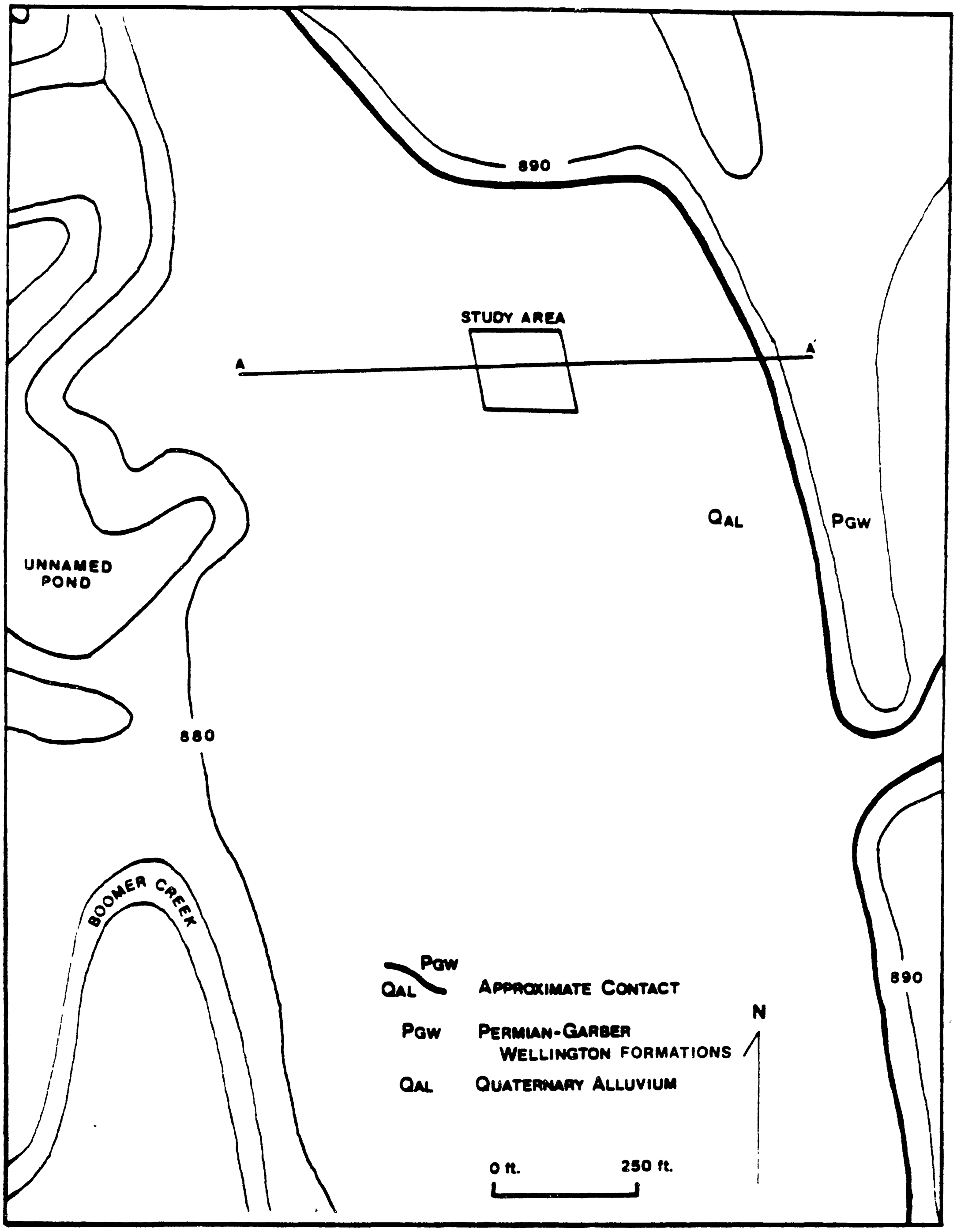


Figure 4. Topography and Surface Features of the Study Area

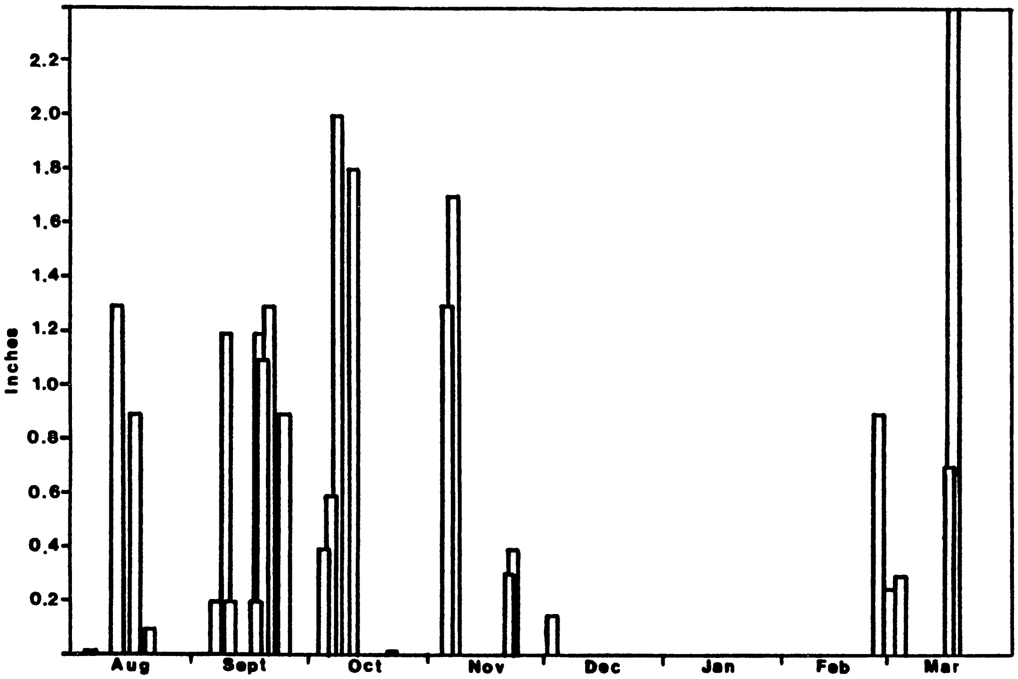


Figure 5. Graph of Precipitation Over the Period of Investigation

Soil and Pit Description

The soil of the study area belongs to the Ashport series, which is typical of low flood plains of large and small tributaries of the major rivers in the region. The soils of the Ashport series generally are well drained, possess moderate permeabilty, and have a silt-loam texture. Ashport soils are classified as Fluventic Haplustolls (SCS, Payne Co. Survey, 1985).

In order to describe the physical characteristics of the soil at the study area, a pit was excavated to a depth of approximately seven feet (Figure 6). Table I is a summary of the physical description of the pit. Of particular interest was the appearance of soil structure. Although described as a relatively immature soil, weak to moderate soil (ped) development was evident from the surface to the seven-foot interval. Some of the angular to blocky "peds" were filled with manganese nodules and, at depth, carbonate tubules. Distance between ped faces is on the order of 0.1 millimeters. The significance of soil development in relation to ground water quality fluctuations will be described in a later section of this report.

Geology

The geologic setting of the investigative area consists of two rock units-- a fine-grained Quaternary alluvium and a Permian shale, the upper part of which is extremely weathered. The weathered part of the shale and

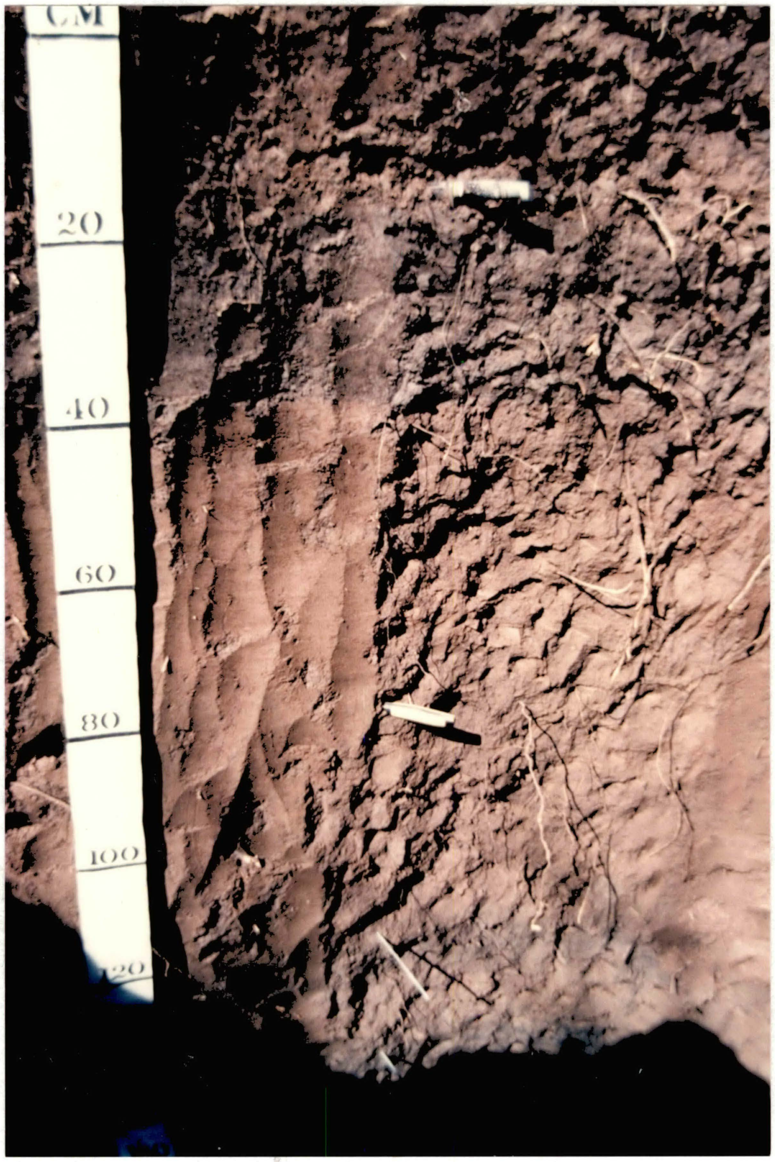


Figure 6. Wall of Pit Excavated in March, 1986

TABLE I

PIT DESCRIPTION

Horizon	Depth (cm.)	Description
A	0-10	Dark reddish brown (5yr3/3) silty-clay loam; weak, fine, subangular blocky structure; friable; gradual boundary.
Bw	10-27	Dark reddish brown to yellowish red (5yr4/4 to 5yr5/6) silty-clay loam; subangular blocky structure; friable; clear boundary.
2Ab	27-51	Dark reddish brown (5yr3/3) silty-clay loam; moderate, medium, angular blocky structure; friable; abrupt.
2Bwb	51-87	Dark red to reddish brown (5yr3/4 to 2.5yr3/4) silt loam; moderate, medium prismatic structure; parting subangular to blocky; friable; gradual boundary.
2BCb1	87-135	Dark reddish brown (5yr4/4) silt loam; weak coarse prismatic structure; friable; clear boundary.
2BCb2	135-161	Dark reddish brown (5yr3/4 to 5yr4/4) silty-clay loam; weak coarse prismatic structure; friable; clear boundary.
3Ab	161-184	Brown (7.5yr5/4) to dark reddish brown (5yr3/2) to dark brown (7.5yr3/2) silt loam; massive stratified structure; friable; abrupt contact.
3Bkb	184-210	Dark reddish brown (5yr3/4) silt loam; moderate, medium prismatic structure; few faint mottles; carbonate tubules; firm.

the alluvium appear to act as a single hydrologic unit.

The alluvium is characterized by a dominance of silt and clay, an overall red-brown color, and the presence of a few small sandstone and siltstone fragments near its base. The alluvium varies from about ten to thirteen feet in thickness at the study site. It thins to the north and east and abruptly pinches out against a bedrock high (Figure 7).

The weathered shale unit belongs to the Garber Sandstone and Wellington Formation of Early Permian age. In this area, the Garber-Wellington is fluvial in origin (Pettyjohn and Miller, 1982), and is characterized by alternating layers of red shale, siltstone, and sandstone, with the former dominating. They dip about 30 to 40 feet per mile to the west (Pettyjohn and Miller, 1982). At the investigated area, the weathered portion of the Garber-Wellington is all shale, that contains only a few very thin layers of silt and sandstone.

The boundary between the alluvium and weathered shale is quite subtle because the alluvial material is derived from the shale and is of similar color and texture. Most of the alluvium, however, is characterized by a fair proportion of brown silt, and contains small rock fragments. The absence of the above in the shale is the basis for boundary delineation between the two units. The boundary between weathered and unweathered bedrock has yet to be determined, but it lies below a depth of eighteen feet at Site A. Logs of auger drilled wells are contained in

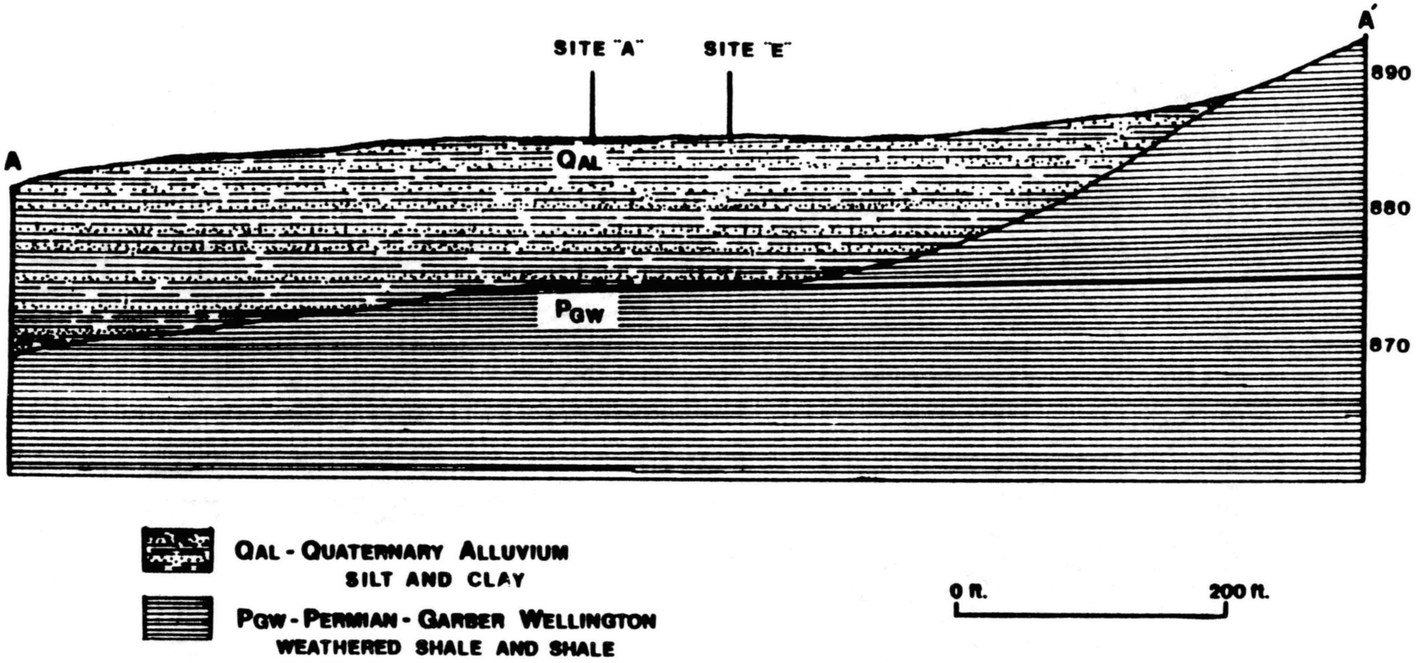


Figure 7. Geologic Cross-Section Along A-A' From Figure 4

Appendix A.

Geophysical Methods

Due to the difficulty in establishing accurately the contact between the weathered shale and alluvium, earth-resistivity and hammer-seismic surveys were carried out. Results of the earth resistivity survey indicate the presence of a boundary at approximately 10 feet and a second boundary at about 20 feet. The first boundary is probably the weathered shale-alluvium contact. The second boundary may represent the depth of largely unweathered shale. It was not possible to determine the position of the water-table by surface resistivity methods due to the inability of the method to distinguish the water table from the capillary fringe and the extension of the capillary fringe towards land surface at the site.

The hammer-seismic survey consisted of striking a metal plate with a sledge hammer and measuring the resultant seismic wave travel times with a sensing device. The metal plate was moved away from the sensing device, thus allowing the seismic waves to penetrate greater depths of the subsurface. The sensing device measures the travel times of the seismic waves to the instrument. The travel time of the seismic waves through the subsurface is dependent upon the density of the material, with more dense materials transmitting seismic waves more quickly. The seismic survey indicated a boundary at a depth of approximately 13 feet.

Both geophysical methods placed the weathered shale-alluvium boundary in the vicinity of 10 to 13 feet below land surface. This agrees well with the results of the auger cutting descriptions.

Surface-Water Hydrology

Due to the relatively flat surface topography dominating the study area, surface runoff is quite low. During large storms, considerable ponding on the land surface at the site has been observed. Nevertheless, Boomer Creek, which flows sluggishly from the northwest to the southeast, is the major drainage in the vicinity of the investigative area. The stream is dammed approximately a mile northwest of the study area. Several small tributary streams and ponds are also located nearby. These tributaries are generally dry by early summer. Average runoff in the region is about 4.5 inches annually (Pettyjohn et al., 1983).

Ground-Water Hydrology

Well Construction

The study area is monitored by 21 wells, 20 of which are sampled regularly. With one exception, the wells are located in four clusters of five wells each (Figure 8). The maximal horizontal distance between wells in a cluster is about three feet, and most are closr than 1.5 feet

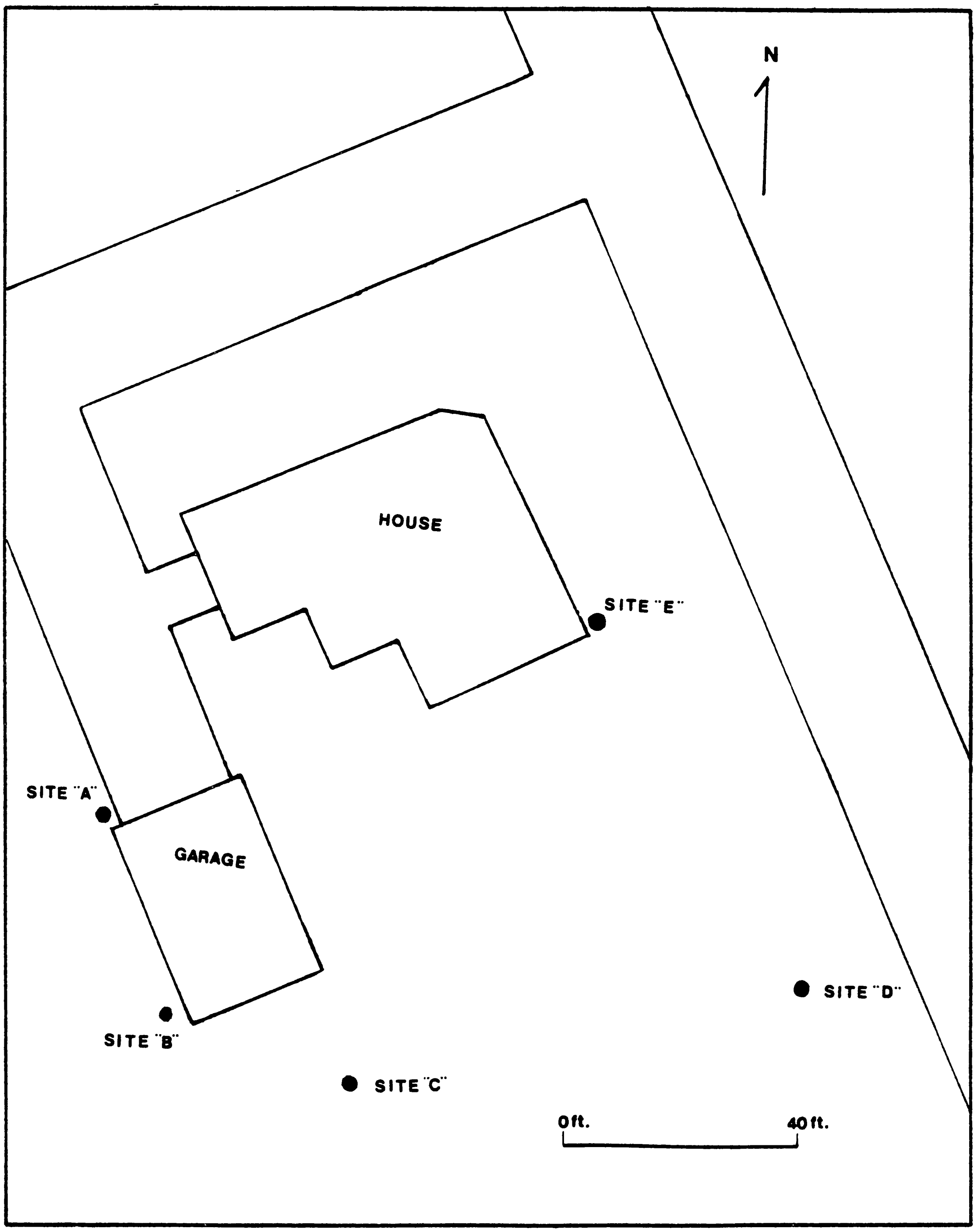


Figure 8. Locations of Well Sites

(Figure 9). The maximal distance between any two clusters is about 125 feet.

The wells, consisting of two-inch diameter PVC pipe, are completed to depths of 8.5, 9.5, 10.5, and 14 feet (2 wells). These wells are referred to as well number 1, 2, 3, 4, and 5 respectively. Four of the monitoring wells in each cluster are slotted along the lowermost four to six inches and are wrapped with nylon screen (Figure 10) . The slotted interval is sandpacked and the remainder of the annular space is filled with a bentonite slurry. The annulus is sealed at the surface with a concrete pad. The remaining well (5) in each cluster is slotted along the lowermost six feet, wrapped with a nylon screen, and sandpacked. The remainder of the annular space is filled with a bentonite slurry. The wells are installed in holes drilled by a hand auger. Specifications of individual wells are contained in Appendix B.

The wells were developed by surging and backwashing with water delivered to the bottom of the well by a half inch diameter hose. Well development proceeded until there was an absence of sediment being carried to the surface through the annulus. The development process was completed by pumping excess water from the well periodically for several days.

Recharge

Low relief at the site results in ponding of rainfall

Figure 9. Typical Configuration of Wells at a Cluster

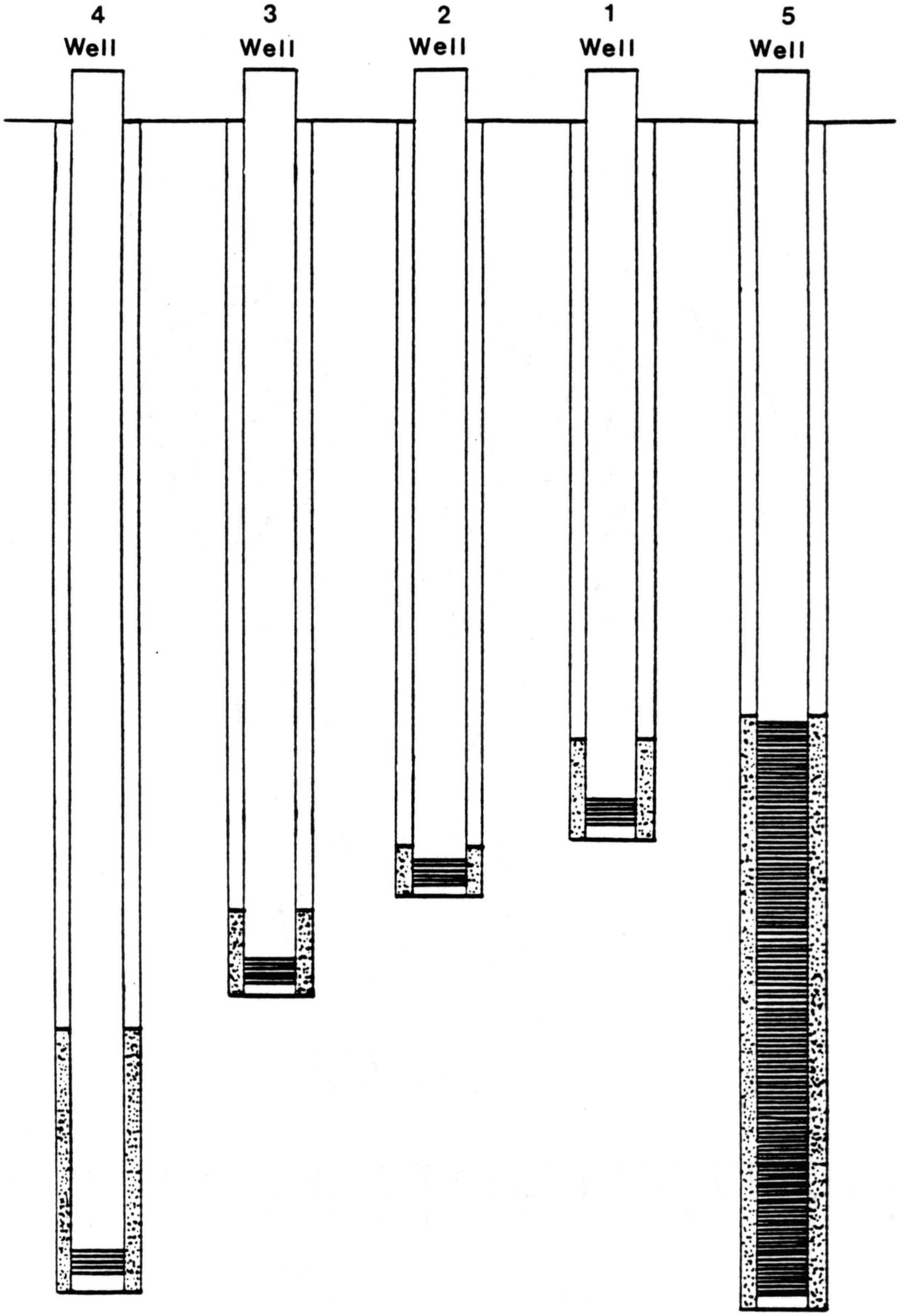


Figure 10. Generalized Construction Details of a Well Cluster

during periods of heavy rain. As a result, recharge to ground water in the study area has the potential to be relatively substantial. The hydrograph of a well 14 feet deep (well A4) illustrates the typical changes in water level during the period of investigation (Figure 11).

Recharge was calculated by projecting the trends of the declining water levels with time, thus creating a series of recession curves (Figure 12). These projected trends are used as a baseline for the calculation of the water-level rise during individual rain events. Using an assumed effective porosity of 0.10, and attributing all major water level rises to infiltration, calculation of recharge is accomplished by multiplying the porosity by the projected water level rise. Total recharge over the nine month period was derived by adding the calculated recharge values from each event. The total amount of recharge that took place was approximately 11 inches or 47 per cent of the total precipitation, a value that appears to be unusually large in view of the fine-grained nature of the alluvium.

The major period of recharge occurred from late September to mid-November, causing a rise in the water levels of some four feet. Precipitation during this period was about 13.1 inches or 54 per cent of the total measured over the investigative period. The early spring recharge interval took place over no more than a three day period. During this time, about 3.8 or 16% of the recorded precipi-

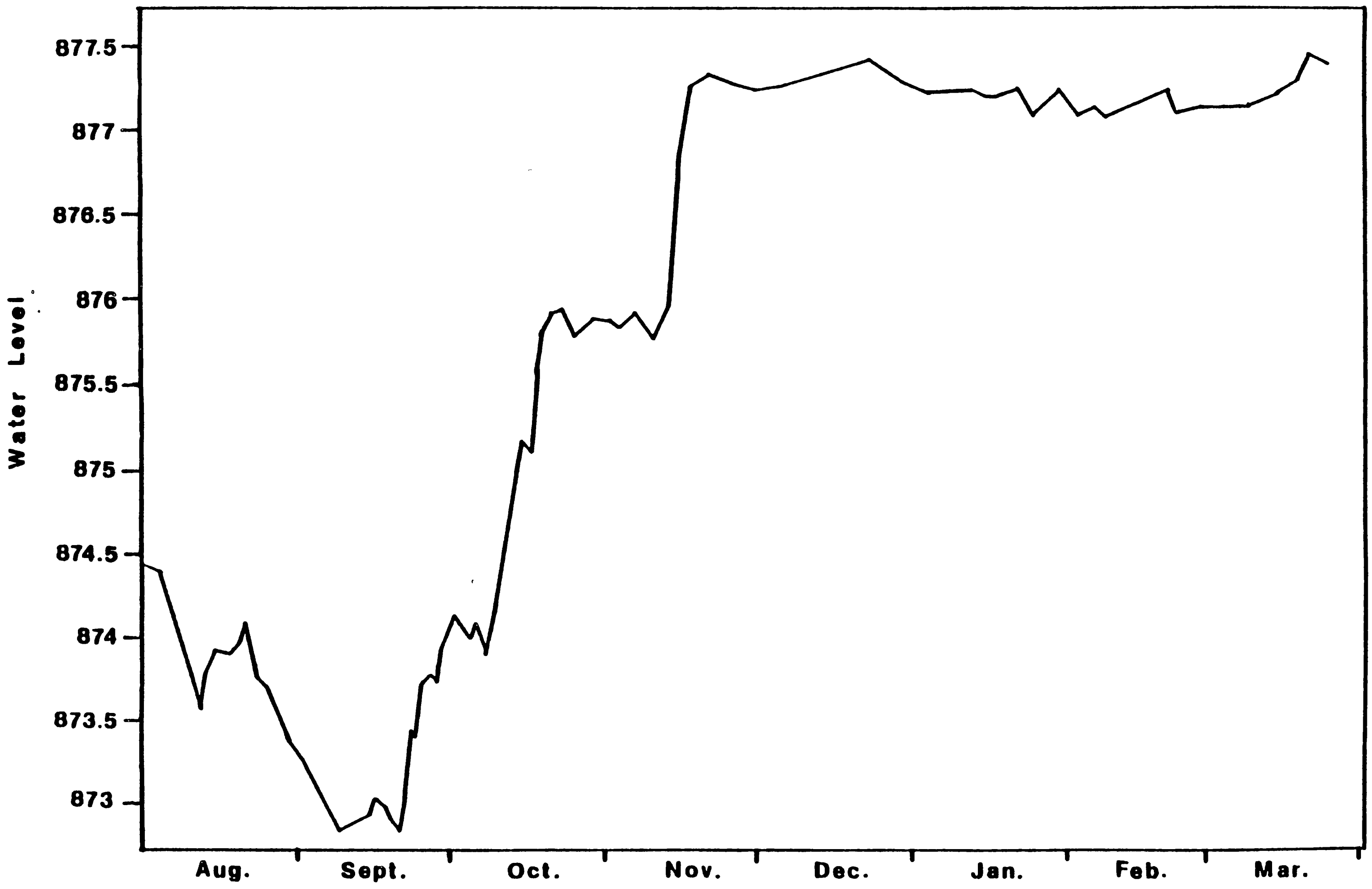


Figure 11. Hydrograph of Well A4 (14 Feet Deep)

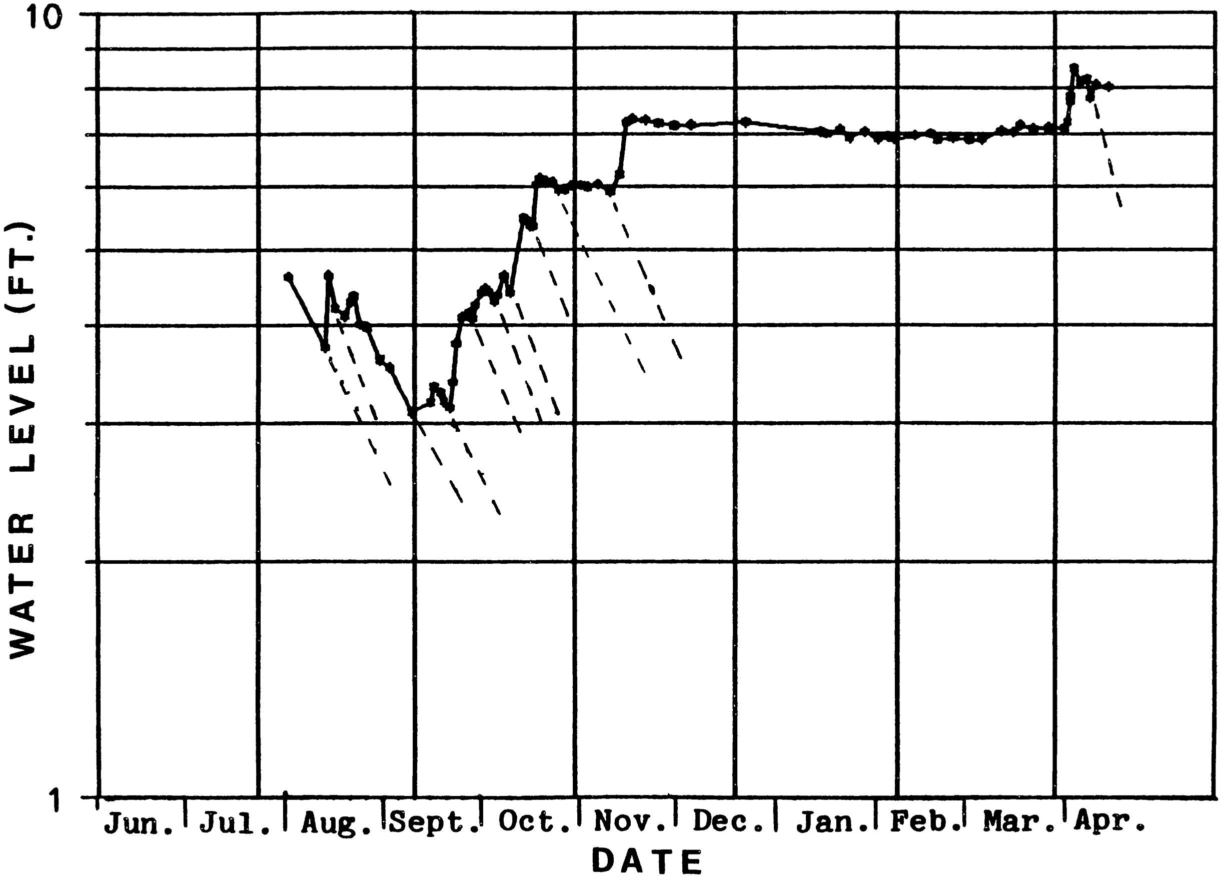


Figure 12. Semilogarithmic Plot of Water Level Versus Time, Well A4

tation fell, which resulted in a water level rise of more than a foot. The fall and spring recharge events accounted for about 81% of the recharge during the investigative period.

Several isolated periods of recharge occurred during August and early September, 1985. These events account for about 17% (four inches) of the total rainfall and about 19% of the recharge. The rains generally took place within 24 hour periods, were of short duration, and in some cases, quite high intensity. In all cases the events took place when there was a substantial soil moisture deficiency (Acre, 1986).

Pettyjohn and Miller (1982) estimated regional effective recharge in the area to be about two inches per year. Effective recharge is estimated by several methods. In the case of Pettyjohn and Miller (1982), the method was stream hydrograph seperation. Although the method calculates regional recharge, results should compare roughly with the values from the recession curve method. If they do not, local phenomena affecting recharge would account for the discrepencies.

Local recharge rates can be influenced by many factors including topography, soil type, presence of fractures, vegetation, and activities of man, to name a few. In this case, the rather large amount of recharge can be attributed to three phenomena: (1) lack of surface runoff, (2) abundance of vegetation, and (3) the presence of macropores/fractures. The determination of the first is based primarily on observations made by the author during rainfall events. The latter is based upon circumstantial evidence. Firstly, water levels were impacted by rainfall events that occcurred when the soil moisture content was far below field capacity. Flow through fractures would account for this occurrence. Also, as will be discussed later, geochemical evidence suggests rapid flow through macropores in the unsaturated zone during periods of rainfall, particularly when a soil moisture deficiency exists.

Water-Level Fluctuations

During the investigative period, water levels have shown rather large fluctuations and, despite the proximity of the wells, have rarely been the same from one well to the next. The maximal fluctuation of water levels has been about 6.5 feet and, consequently the saturated thickness has ranged from about two to eight feet.

The largest and most rapid changes in water levels have occurred during recharge events. During these periods, water levels in adjacent wells completed at different depths often have values which differ by as much as 0.1 feet. In general, during recharge the shallow wells have the higher head, indicating a downward component of flow. During prolonged periods of dry weather, water levels in adjacent wells are nearly equal, with head differences no greater than 0.05 feet per foot.

Water levels react to barometric pressure changes, implying the aquifer is semi-confined. These changes rarely exceed 0.1 feet, and are greater in the deeper wells than in the shallower wells. For example, on February 18 the barometric pressure was 963 millibars and the altitude of water levels in wells D1 (8.5 feet deep) and D4 (14 feet deep) were 877.01 and 877.04 feet respectively. On February 25 the barometric pressure was 979 millibars and the altitude of water levels in wells D1 and D4 were 876.92 and 876.91 feet, respectively. During this period, no rainfall was recorded, nor should there have been any significant evapotranspiration effects.

During the fall recharge period, water levels rose significantly and several of the shallow wells, which had been dry for months, began to fill with water. During this time heads in the deeper wells were much greater than those in the shallow wells. This indicates an upward component of flow, often times associated with discharge instead of recharge. For example, on October 18, 1985 wells D3 (10.5 feet deep) and D4 (14 feet deep) had water levels of 874.23 and 875.07 feet respectively. The head difference was 0.84 feet over a vertical distance of three feet or 0.28 feet per foot. Speculative causes for such a vertical gradient are pressure loading or upgradient recharge along the weathered shale-alluvium contact, which appears to be the most permeable zone of the aquifer.

Figure 13 illustrates an explanation that depends on recharge along a permeable zone, a zone which includes the upper few inches of the weathered shale and the lower few inches of the alluvium. Based on well yields, the contact between the weathered shale and alluvium is quite permeable. As water infiltrates at the pinchout to the east, significant head is generated because of the substantial amount of recharge. The water levels in the deeper wells (the "4" wells), which tap this boundary zone, rise more than wells not intersecting the boundary zone.

Water-Level Gradient

Unexpectedly, the ground-water flow direction and gradient have been found to be inconsistent over the course of the study. For example, Figure 14 shows that the ground-water gradient in August, 1985 was about 0.007 feet per foot to the southeast, directly towards a row of large trees. By February, 1986 (Figure 15) the gradient had decreased to about 0.003 feet per foot to the southwest. The change in flow direction is about 45 degrees, but the overall trend is toward Boomer Creek. Additionally, the soil-moisture content along the tree-dominated southern boundary is consistently less than elsewhere. This, in conjunction with the steeper summer gradient leads one to suspect that the change in flow direction from summer to winter is the result of evapo-transpiration.

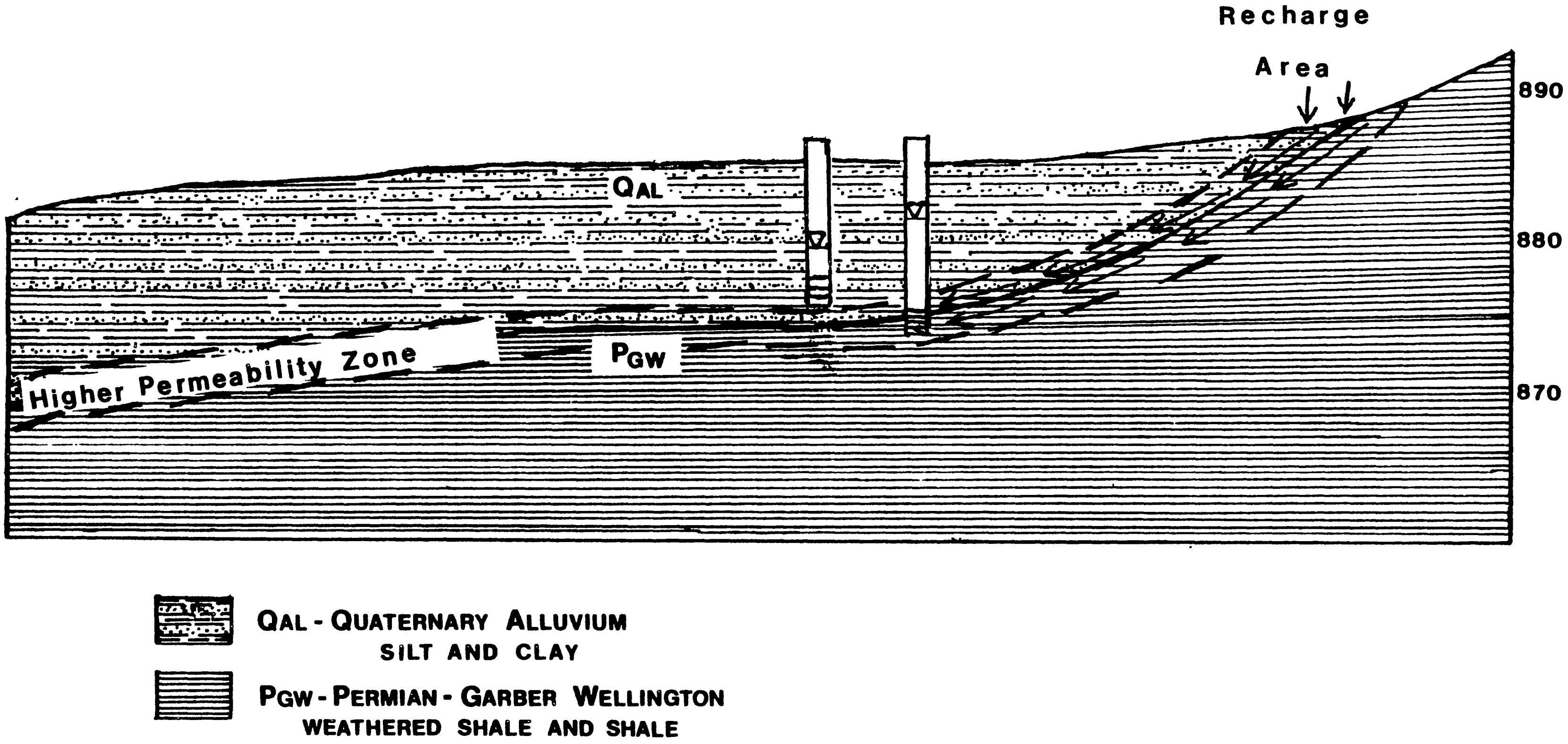


Figure 13. Illustration of Recharge Along the Permeable Weathered Shale-Alluvium Boundary

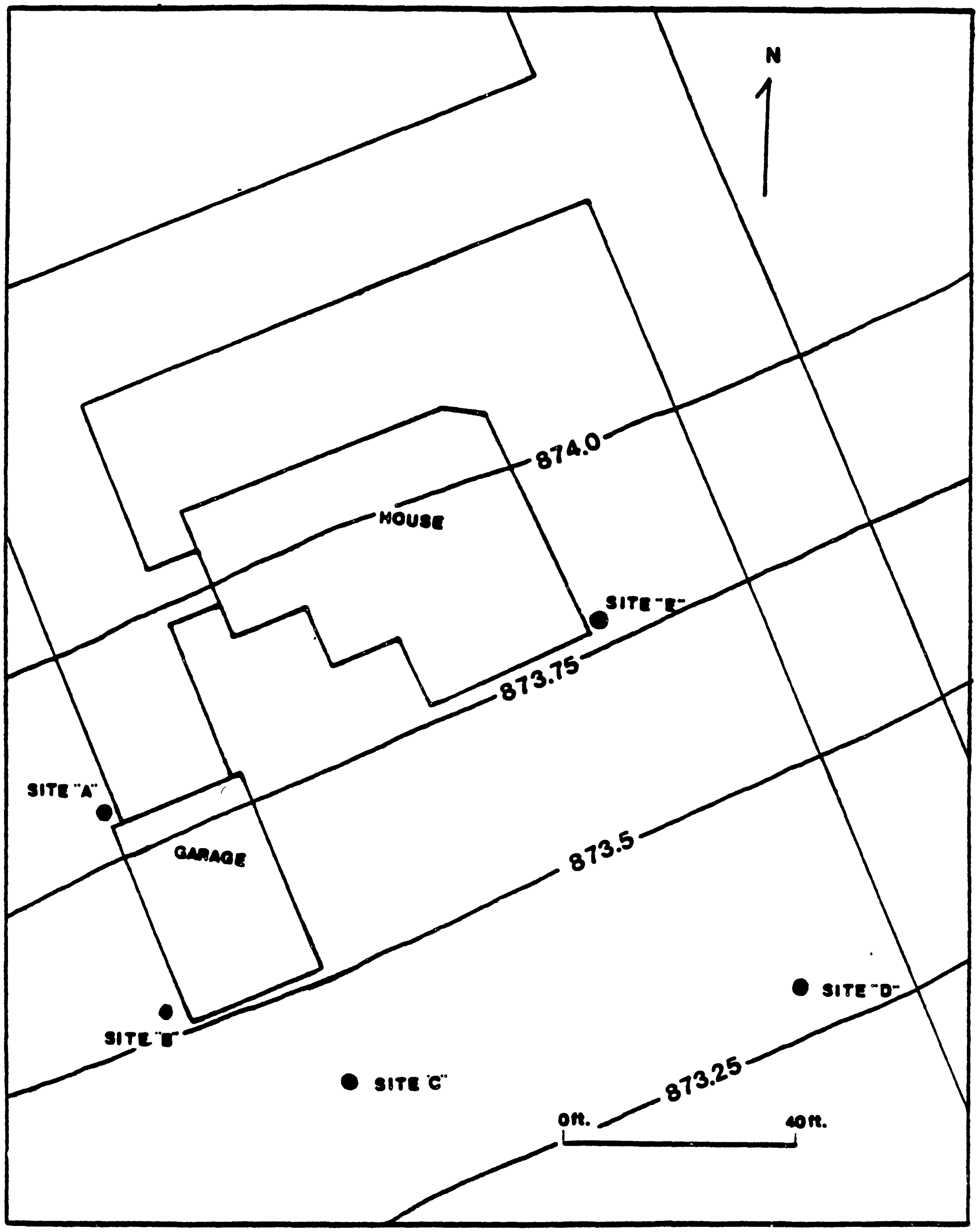


Figure 14. Water-Level Map, August, 1985
(Values in Feet)

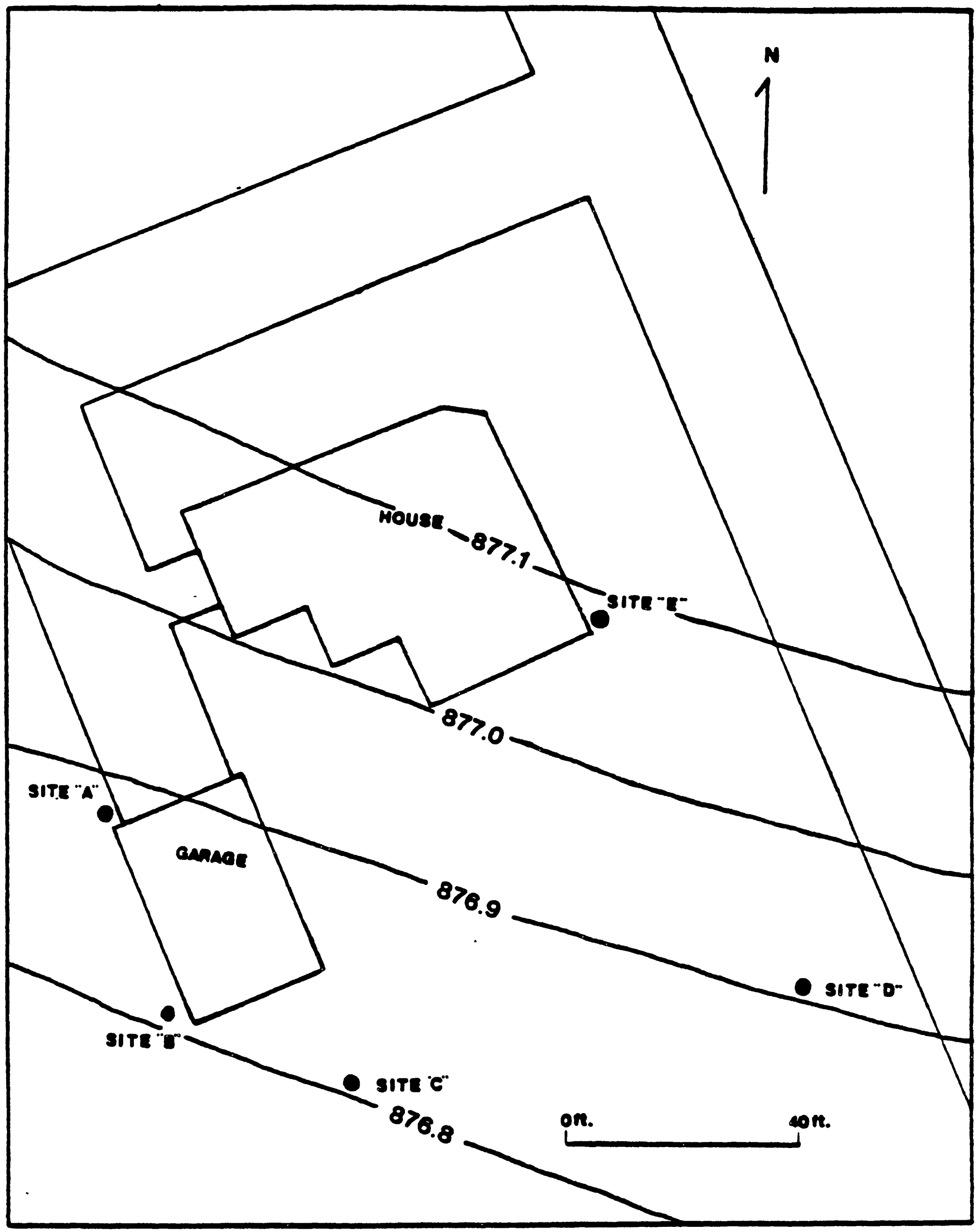


Figure 15. Water-Level Map, February, 1986
(Values in Feet)

Aquifer Testing

A series of aquifer tests were performed during the Spring of 1986 at the individual well sites. With one exception, the "5" wells were utilized as the pumping wells and the "4" wells as the observation wells. The test at site D used well D4 as the pumped well and well D5 as the observation well.

A peristaltic pump capable of producing 0.7 gpm from 14 feet was used as the pumping device. Pumping rates were held relatively constant over the course of each test. A steel tape and chalk were used to measure water levels in the observation wells.

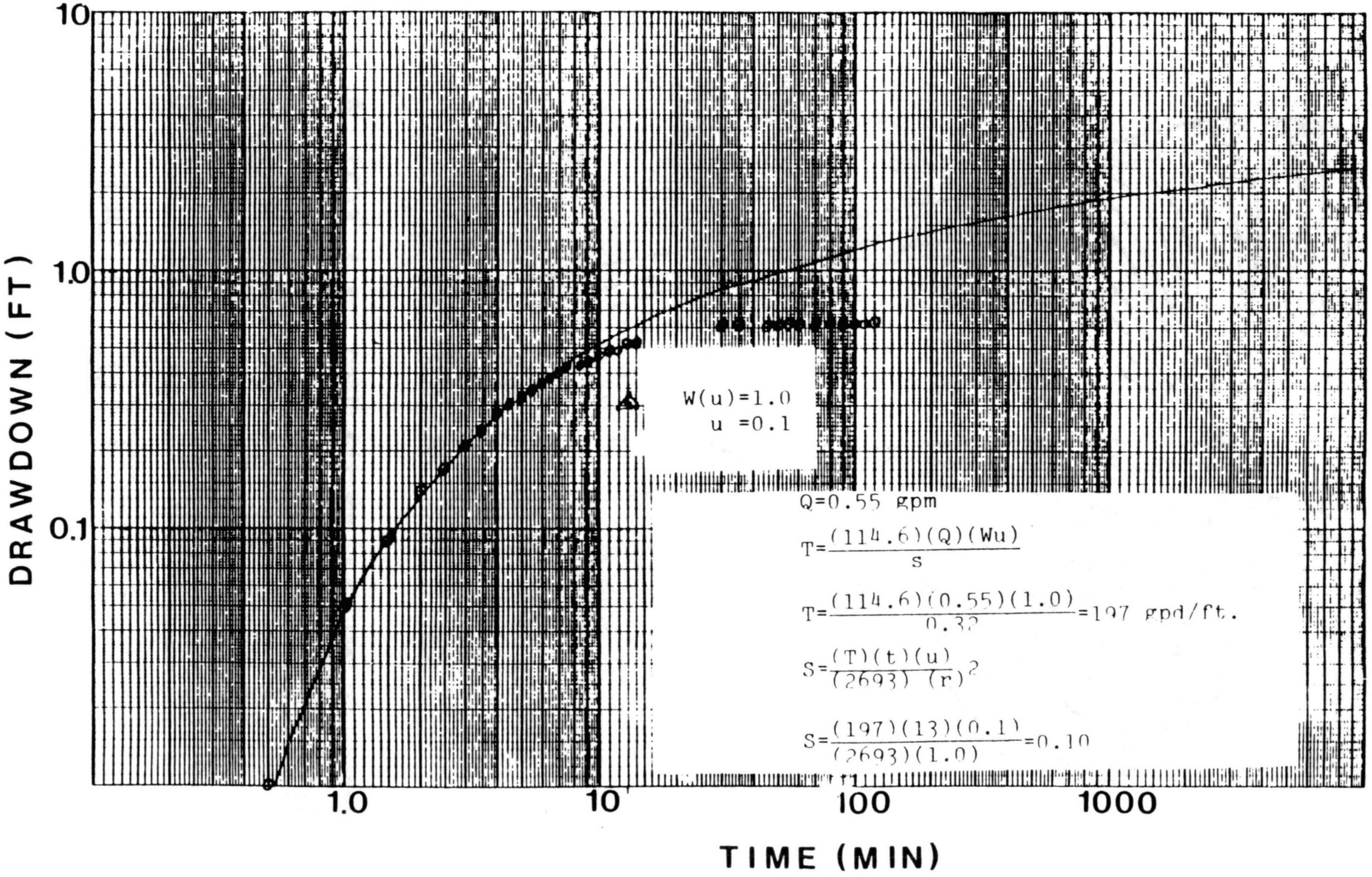
Drawdown data were analyzed by the Theis and Jacob methods (Figures 16 and 17). Due to the possibility that the aquifer behaves as a water-table aquifer, raw data were corrected for the change in saturated thickness with pumping. Partial penetration was not corrected for due to the small distance from the pumped well to the observation well. The water-table correction factor allows one to analyze water-table data with methods designed to evaluate drawdown data taken from artesian aquifers. The following formula was used to correct the data:

$$s' = s - s^2/2m \quad \text{(Jacob, 1944)} \qquad (2.1)$$

where: s = observed drawdown, in feet

m = initial saturated thickness, in feet

s' = drawdown that would have occurred



W(u)=1.0
u =0.1

Q=0.55 gpm

$$T=\frac{(114.6)(Q)(Wu)}{s}$$

$$T=\frac{(114.6)(0.55)(1.0)}{0.32}=197 \text{ gpd/ft.}$$

$$S=\frac{(T)(t)(u)}{(2693)\ (r)^2}$$

$$S=\frac{(197)(13)(0.1)}{(2693)(1.0)}=0.10$$

Figure 16. Time-Drawdown Plot, Well A4, Theis Method

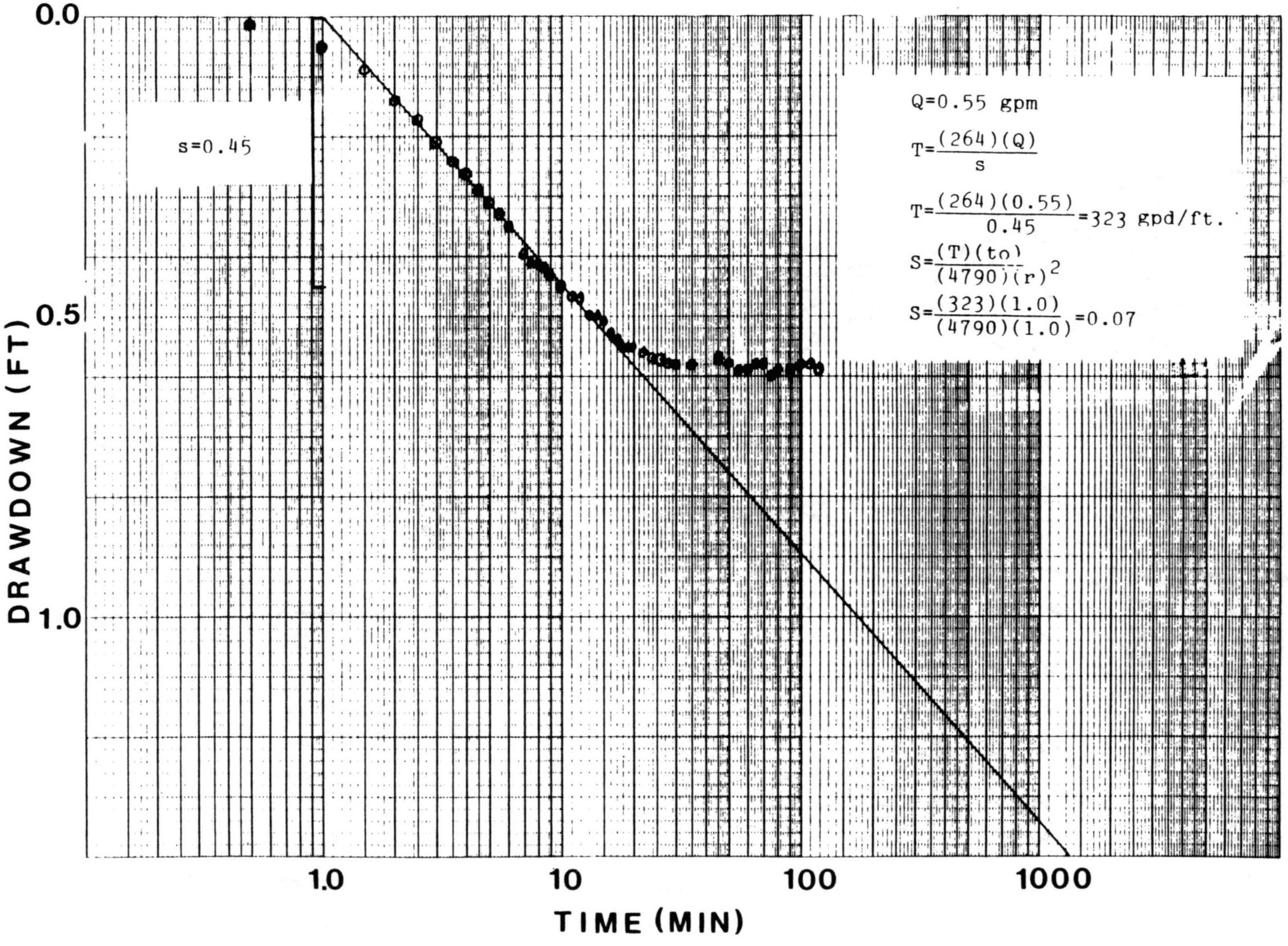


Figure 17. Time-Drawdown Plot, Well A4, Jacob Method

in an equivalent nonleaky
artesian aquifer, in feet

The results of the interpretation of the drawdown data are summarized in Table II. As one might expect, values of transmissivity estimated by either method differ from site to site. This is due to aquifer variability over the investigative area. The results derived from the two methods differ from one another, but the difference does not appear significant.

The storativity values are indicative of water-table conditions, although the values lie at the lower range of such aquifers. The deviation of the drawdown data from the ideal (i.e. the Theis type curve), results from gravity drainage. The correction factor does not alleviate this problem due to the small change in saturated thickness during pumping. Nevertheless, early drawdown data tend to conform to the ideal and gives a fair estimate of aquifer coefficients, at least at small time values.

The transmissivity and, thus, hydraulic conductivity values appear unusually large when considering the aquifer material. Freeze and Cherry (1979) estimate hydraulic conductivity for clay and silt to be from 0.001 to about 1.0 gpd/sq. ft. Fractures may play a major role in the flow of water through the aquifer under investigation.

The coefficients determined can be considered only as rough estimates, at best. Little work has been done on the development of aquifer test methods for low permeability aquifers. The application of the Theis and Jacob methods may be entirely inappropriate in cases such as these. In addition, the aquifer coefficients may vary seasonally due to changes in the saturated thickness, soil moisture content, and macropore development.

Well Yields and Specific Capacities

Although the wells are used primarily for monitoring purposes, well yield and specific capacity are important as an interpretative tools. These parameters may give an indication of the major producing intervals and provide indirect estimates of aquifer coefficients. Specific capacity may be related to transmissivity by the following general relationship:

$$T = Q/s * 2000 \qquad (2.2)$$

Results of the above equation on specific capacity data from the four aquifer tests are contained in Table II.

In general, the deepest wells ("4" and "5" wells) yield considerably more water than the shallower wells. In fact, several of the deeper wells are able to sustain pumping of 0.72 gallons per minute over prolonged periods of time (10 hours in one case), and reach what appears to be steady-state in no more than an hour. The shallow wells have less available head, but the difference in yields are greater than that expected by the difference in available head. Specific capacities range from 0.11 to 0.28 gallons per minute per foot of drawdown (Table II). Site E, which has the largest transmissivity value, also had the largest specific capacity value for the pumped well (E5).

The greater well yields of the deeper wells suggests that the zone of highest permeability lies in the vicinity of the base of the alluviumn and the upper part of the weathered sahle. Surprisingly, based on inspection of auger cuttings, this interval has the greatest amount of clay. The probability of fractures controlling groundwater flow in this interval is quite high.

TABLE II

RESULTS OF AQUIFER TESTING FOR JACOB AND THEIS METHODS AT INDIVIDUAL WELL SITES

	Theis Method			Jacob Method				2000*Q/s
Site	T	S	K	T	S	K	Q/s	T
A	197	0.10	29	323	0.07	46	---	---
C	165	0.07	25	336	0.05	51	0.11	200
D	177	0.05	27	238	0.04	37	0.16	320
E	398	0.13	61	528	0.09	81	0.28	560

Units are:T=gpd/ft., K=gpd/sq.ft., and Q/s=gpm/ft.

CHAPTER III

SAMPLING AND ANALYTICAL METHODOLOGY AND SOURCES OF VARIATION IN GROUND-WATER QUALITY

Sampling and Analytical Methodology

Samples have generally been taken from the monitoring wells on a weekly basis. During periods of rainfall sampling frequency was increased, while during prolonged dry periods samples were taken less often. Prior to sample collection, the wells are flushed of water in casing storage. Where possible the wells are pumped dry and allowed to recover to the volume of sample required for analysis. In cases where this is not possible, at least three well volumes are withdrawn from the wells prior to sample collection. The process of well purging and changes of water quality with pumping are described further in a later section.

Several sampling devices have been utilized over the course of the study including vacuum, hand, and peristaltic pumps, as well as bailers. Due to ease of use and cleaning, and the shallow depths of the wells, the bailer and peristaltic pump have yielded the best results in collection procedures. Both methods appear to have a minor, if any, affect on the chemistry of a sample.

Samples are routinely analyzed for temperature, pH, specific conductance, and nitrate concentration. Periodically determined are several major ions, such as bicarbonate, chloride, sulfate, magnesium, sodium, calcium, and potassium. Samples are handled according to EPA procedures and analyzed within times suggested by EPA Report No. 600/4-79-020 (1983). Nitrate concentrations are determined by means of an Orion Ion Meter utilizing an nitrate ion selective electrode. The procedure for nitrate concentration determination is outlined in Orion Publication IM9307/3810 (1983). Calcium, magnesium, sodium, potassium, bicarbonate, chloride, and sulfate are determined by EPA methods 215.1, 242.1, 258.1, 273.1, 310.1, 325.3, and 375.4, respectively (EPA Report No. 600/4-79-020, 1983).

Preliminary Sampling Experiments and Variation with Pumping

Collection of a sample of ground water representative of water from the formation is dependent upon many factors. One such factor is the volume of water that must be withdrawn from the well prior to sample collection. Water within a well that lies above the screened interval is likely to be stagnant and does not adequately reflect the chemical nature of the ground water. The number of well volumes that must be withdrawn is dependent upon well contruction and the hydrogeology and geochemistry of the formation. Guidelines with respect to pumping must be established at the onset of monitoring in order to assure consistent and reliable data collection.

A sampling experiment was performed prior to routine monitoring in order to establish the number of well volumes that must be purged prior to sample collection. Samples were collected during the pumping wells A4 and D4. Well A4 is easily pumped dry (in this experiment, after 1.67 well volumes were withdrawn) and Well D4 could not be stressed enough with the equipment available to be pumped dry. Both wells are fourteen feet deep and are screened over the lowermost six inches.

During pumping, temperature, specific conductance, and pH were monitored on-site. Samples were collected and later analyzed for calcium, magnesium, sodium, and potassium. The response of these parameters to the number of well volumes withdrawn is summarized in Figures 18 through 22.

The figures suggest the following concerning the response of the monitored parameters to the number of well volumes withdrawn:

1) Temperature varied little with respect to the volume withdrawn.
2) Variation of pH occurred within the first well volume withdrawn, then appears to become stable. In both of wells, the total variation is less than 3 per cent.

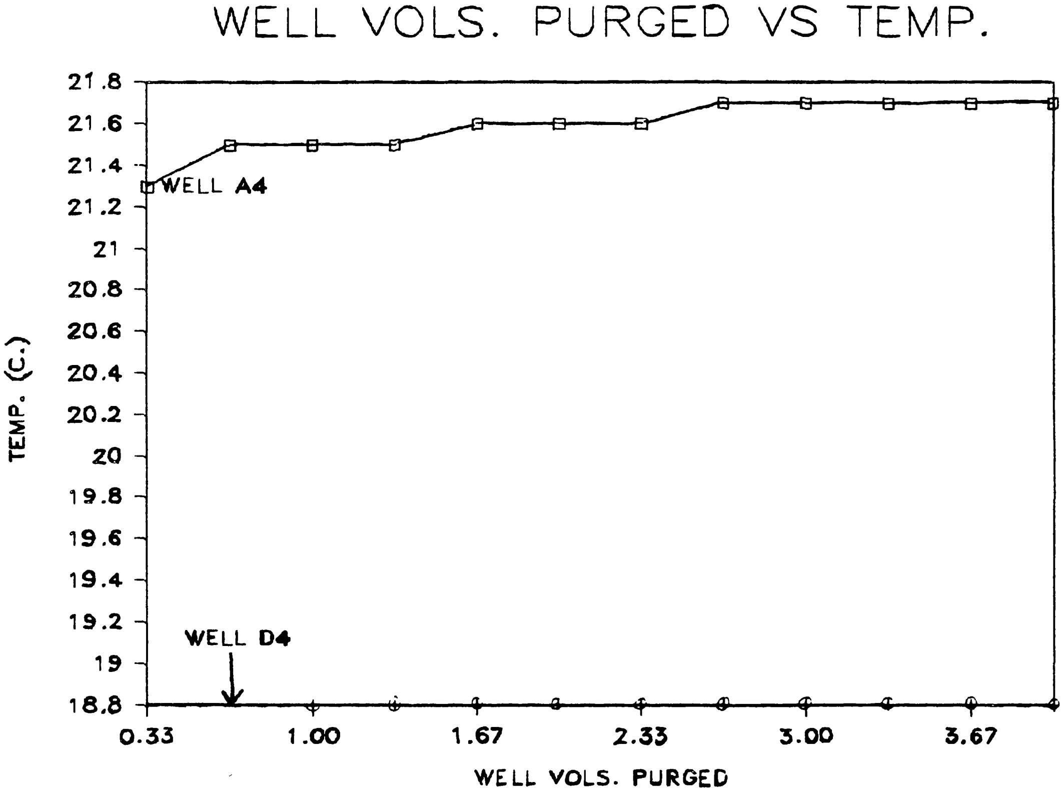


Figure 18. Temperature Versus Well Volumes Purged, Wells A4 and D4

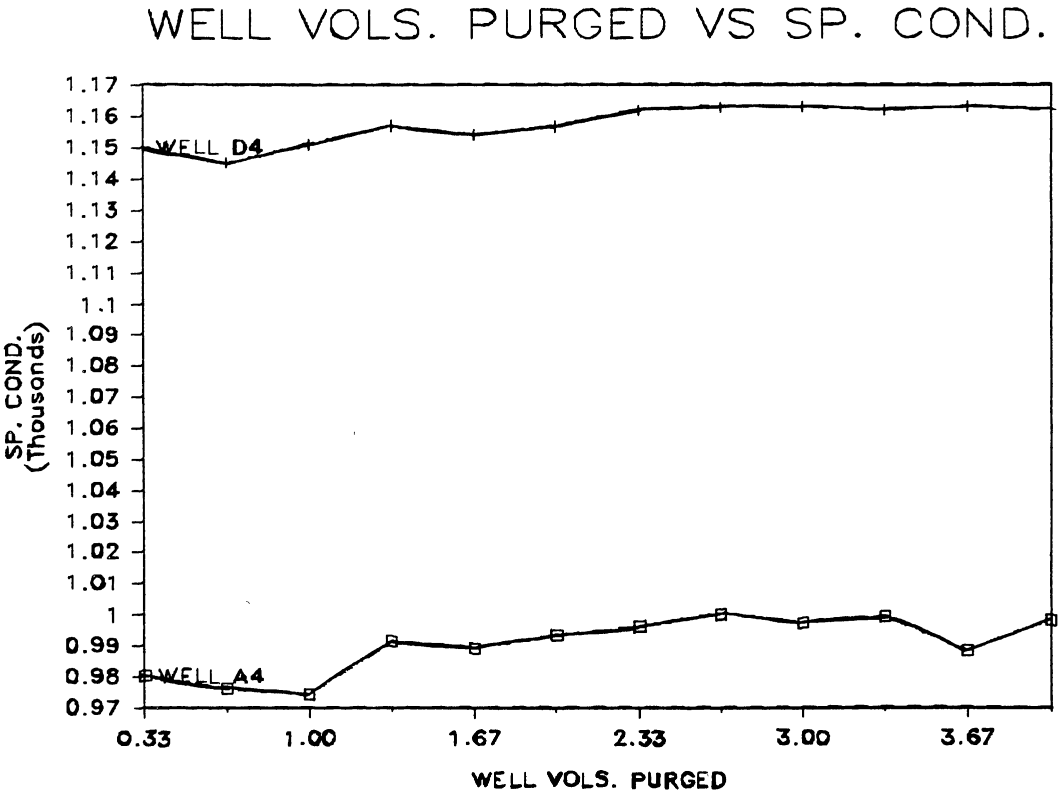


Figure 19. Specific Conductance Versus Well Volumes Purged, Wells A4 and D4

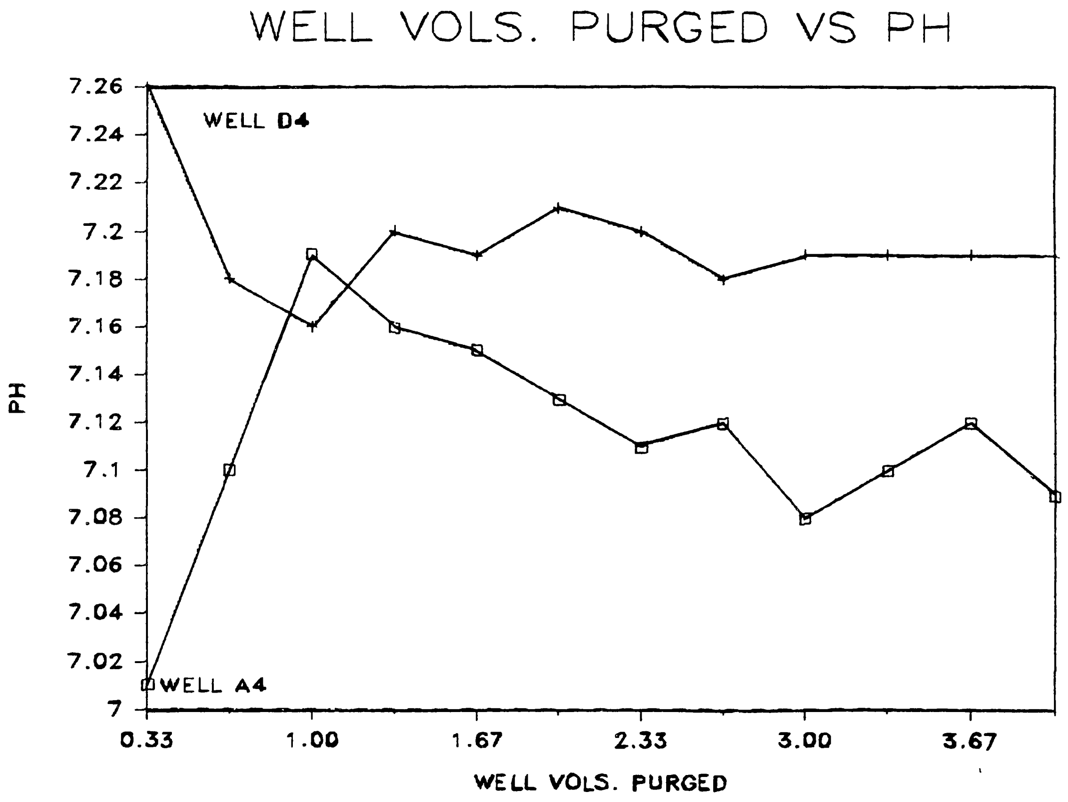


Figure 20. PH Versus Well Volumes Purged, Wells A4 and D4

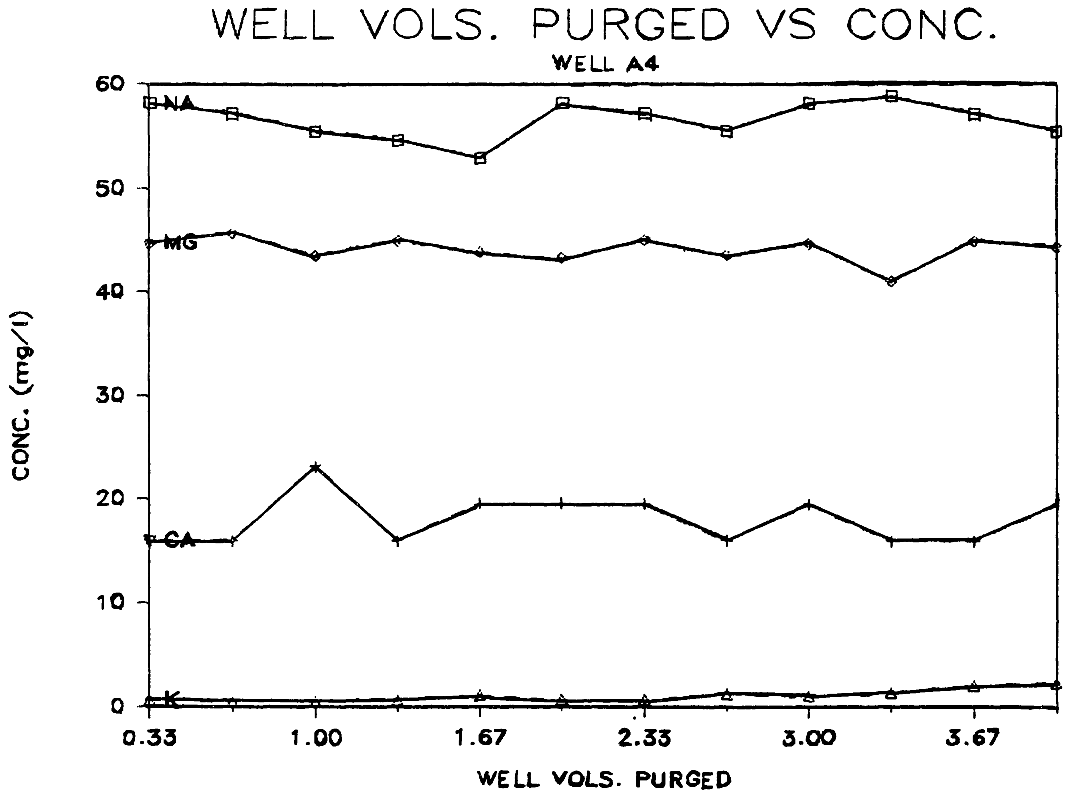


Figure 21. Concentration of Na, Mg, Ca, and K Versus Well Volumes Purged, Well A4

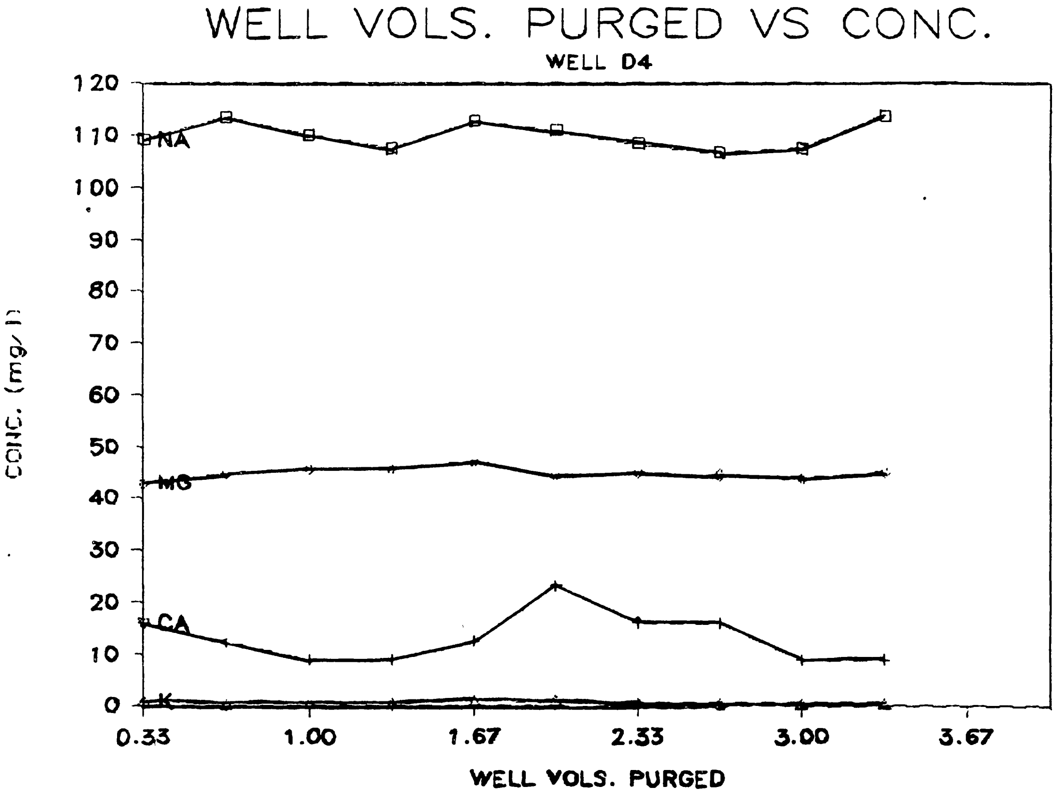


Figure 22. Concentration of Na, Mg, Ca, and K Versus Well Volumes Purged, Well D4

3) Variation of specific conductance occurred within about 1.3 well volumes withdrawn. In either case, total variation was less than 3 per cent.

4) No apparent trend between well volumes withdrawn and concentration of sodium, magnesium, calcium, and potassium is evident. The variation of the sodium and magnesium is relatively small (10 per cent or less) while the variation of calcium and potassium is relatively large (40 per cent or more). The large variation of calcium and potassium may be the result of analytical error.

The following conclusions are drawn based upon the sampling experiment:

1. A sample may be obtained from Well A4 by obtaining the sample immediately after the wells recover to the sample volume desired. Water in casing storage is not a factor after the well is pumped dry and additional purging is unnecessary.
2. Withdrawl of three well volumes from Well D4 sufficiently purges the well of casing storage water. A sample may be taken after three well volumes are removed.
3. Temperature, pH, and specific conductance are only fair indicators of the changes in ground-water chemistry with well volumes purged. Their

sensitivity is questionable. However, due to their application in the field and ease of use, these parameters are well suited for such experiments.

4. The use of sodium, magnesium, potassium, and calcium to detect trends in concentration versus well volumes purged proved insubstantial.

Due to routine analysis of nitrate concentrations, the determination of the effects of pumping on nitrate was necessary. Wells A4, C4, D4, and E4 were purged of three well volumes or until dry. Multiple samples, corresponding to the withdrawl of an additional three well volumes, were obtained from the wells and taken to the laboratory for analysis. In general, no substantial trends were apparent and little variation was noted (Figure 23).

An additional study on the effects of pumping on nitrate concentration was undertaken on well A3, which is designed to sample at an intermediate depth of the aquifer. In this case, samples were obtained from the start of pumping and taken until the well was pumped dry. Again, temperature, pH, and specific conductance were monitored on site and additional samples were collected for nitrate determination. The results of the aforementioned parameters with well volumes withdrawn are shown in Figures 24 through 27. As expected, substantial changes in specific conductance, pH, and nitrate occur within the first

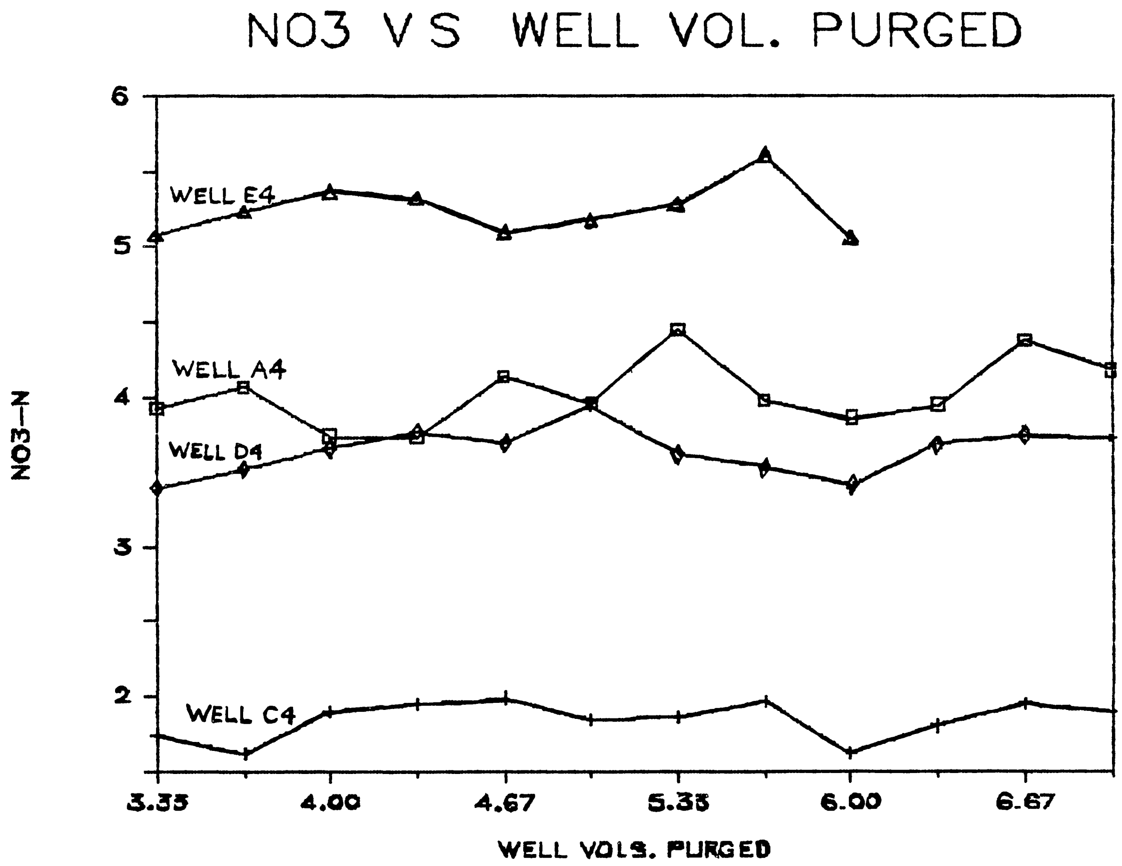


Figure 23. Nitrate Concentration Versus Well Volumes Purged, the "4" Wells

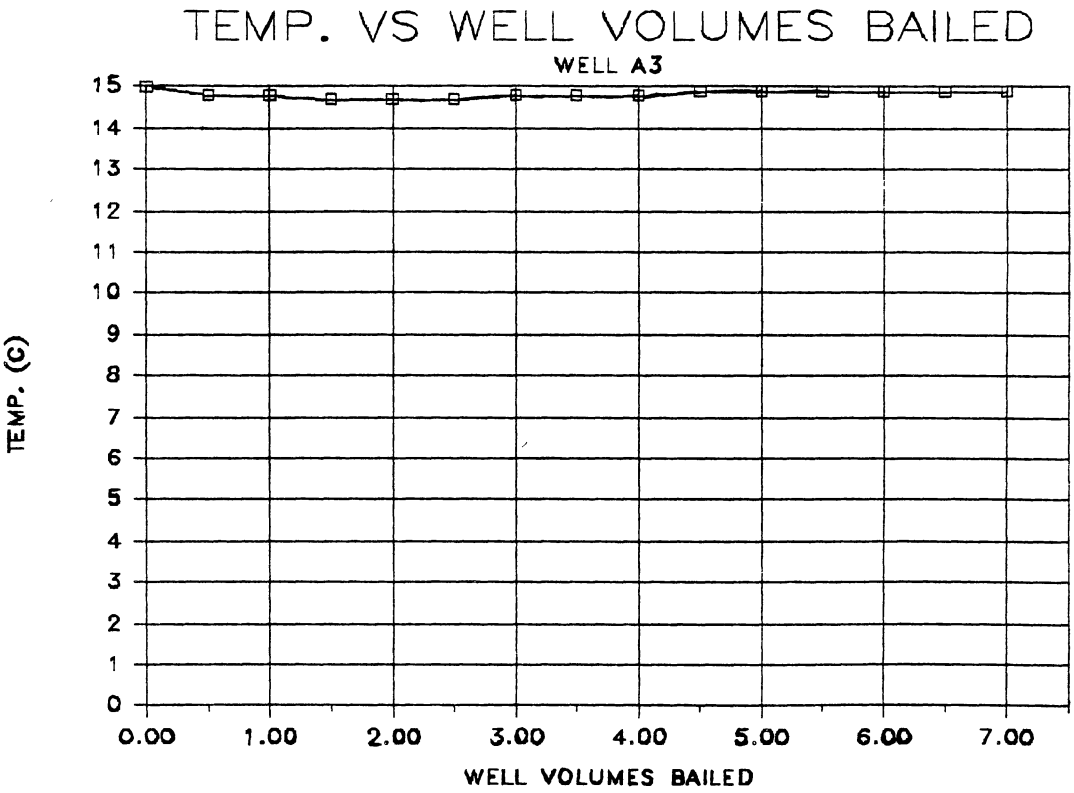


Figure 24. Temperature Versus Well Volumes Purged, Well A3

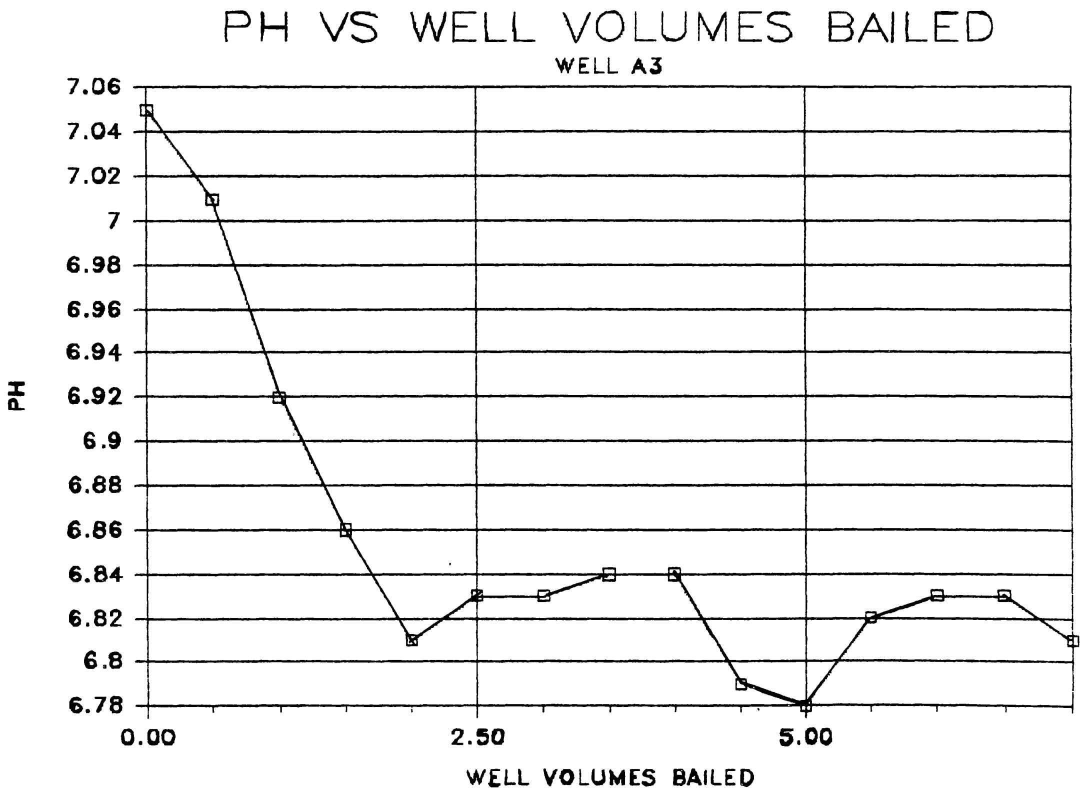


Figure 25. PH Versus Well Volumes Purged, Well A3

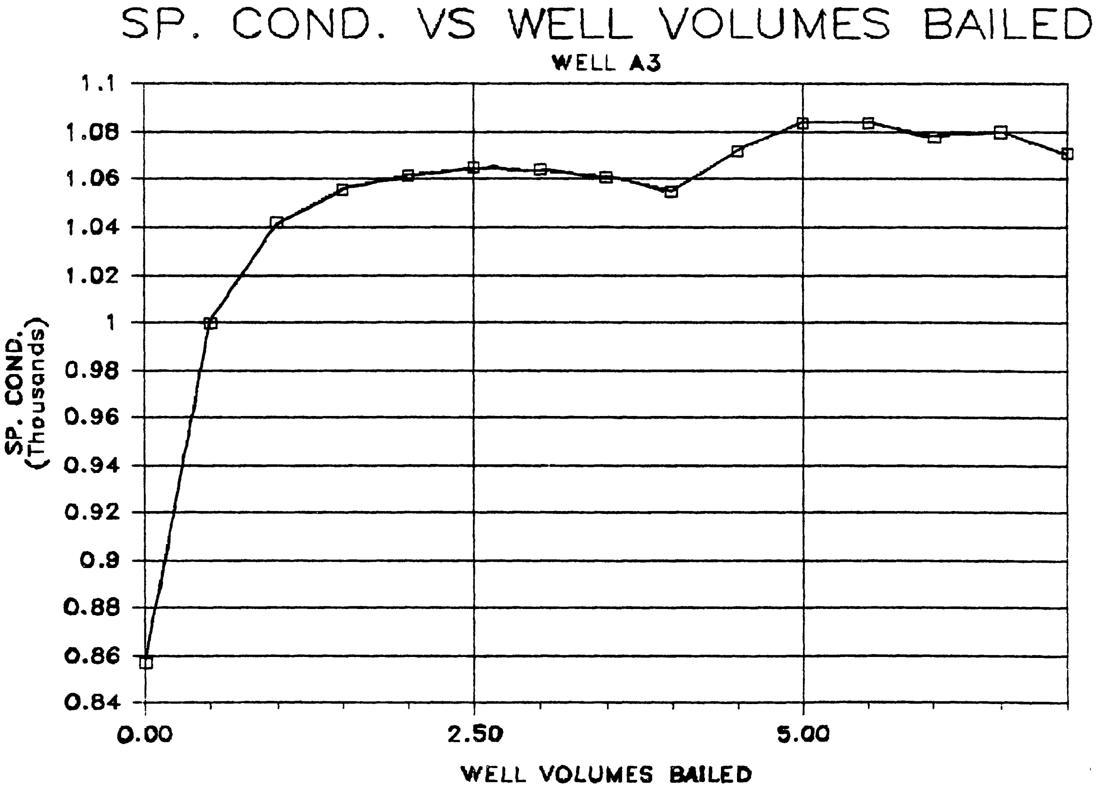


Figure 26. Specific Conductance Versus Well Volumes Purged, Well A3

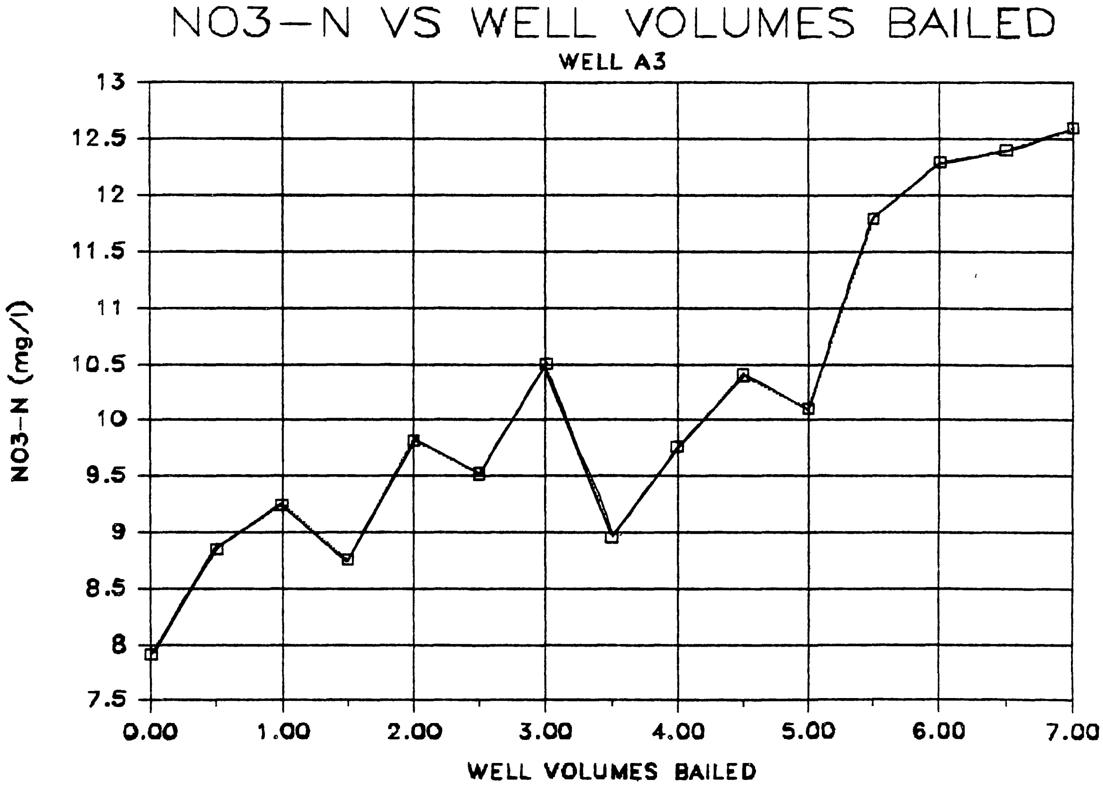


Figure 27. Nitrate Concentration Versus Well Volumes Purged, Well A3

well volume withdrawn (temperature remains relatively unchanged). Specific conductance and pH become relatively stable while nitrate appears to vary significantly (between 9 and 12 mg/l) through the remainder of the sampling experiment.

The day following the experiment, water was pumped from Well A3. After about one liter (approximately one well volume) was withdrawn from well A3, water level measurements in a well A2, which is a foot away and a foot shallower, indicated a drawdown of .03 feet. After approximately 2.5 liters were withdrawn from the pumped well, the water level measurements in well A2 had declined an additional 0.1 foot. Nitrate concentrations in Well A2, determined only days earlier, was about 12 mg/l and about half of that in well A3. During the purging of well A3 nitrate concentrations had increased from about eight to 12.5 milligrams per liter. Undoubtedly, water was being drawn into Well A3 from the upper interval during the purging process.

The data show that hard-and-fast rules on the purging of a well prior to obtaining a sample is not appropriate in all hydrogeologic and sampling situations. Many authors (for example see Barcelona, et al. 1983, Barcelona, et. al., 1985, and Schuller, et al., 1981) have stated the need for such hard-and-fast purging procedures regardless of the governing hydrogeology.

The purging experiments on the five wells yielded varying results. In several instances, the quality of the water withdrawn changed substantially within about two well volumes withdrawn and stabilized thereafter. The data also shows that removing additional amounts of water from a well may be more detrimental than desirable. It appears that not only should well purging procedures be based on a site-to-site basis, but on a well-to-well basis.

In light of the disposal problems of purged water from monitoring wells at hazordous waste sites, it may be better to remove less, instead of more, water from a well. This, along with problems of leakage, indicates the need for further research in the area of well purging procedures.

Variation Due to Analytical Error

The purpose of a quality assurance/quality control program is to limit the amount of error contributed to water-quality data by analytical techniques. During the course of the investigation the quantification of this source of variation was consistently undertaken and held to an amount deemed acceptable at the onset of monitoring. The two primary concerns in this effort were precision and accuracy.

Precision was determined by splitting approximately one third of the water samples into aliquots. The mean of the sample aliquot values are divided into the range, which is stated in terms of a per cent. In the case of nitrate concentration, the amount of acceptable error in precision was 10 per cent. With other, less monitored constituents, acceptable precision was determined as situations dictated, but in general were also limited to 10 per cent.

Accuracy is a comparison between the value of a known solution and the value obtained by a given analytical technique for the same solution. At the onset of monitoring, a 10 per cent error in accuracy was considered acceptable. Accuracy was determined for the nitrate method on a periodic basis and found to be within these limits. Lesser used methods for other chemical parameters were checked at least once during the course of the study in order satisfy accuracy criteria.

The variance caused by nitrate analytical techniques was quantified by the use of a pooled variance of aliquot values. Pooled variance is a measure of the average amount of variance of all observations within a particular data set. The number of observations in sample sets are weighted appropriately. In the case of nitrate, the pooled variance of the split samples over the course of the study was about 0.01. The mean of the precision data set was 6.04 milligrams per liter nitrate-nitrogen. Therefore, the variance of the nitrate data due to analytical error is quite small.

Variation Due to Sampling, Sample Handling, Pumping, and Analysis

In order to determine variations that result from land use impact and other processes, the amount of variation due to unwanted sources must be determined. If this step is omitted, false conclusions as to their true causes may be made.

Ground-water quality studies are particularly susceptible to numerous sources of unwanted variation in data. Fortunately there are methods to quantify at least the majority of the variations. Unfortunately, these sources of variation cannot be completely eliminated and in many cases only moderately controlled.

When a comparison of data from two or more different observation points is desired, whether they are space or time related, the amount of variation within a single observation point must be known. The variation of ground-water quality data within a single well at an instance in time must be known in order to make judgments concerning that well and other wells with respect to time.

The sources of variation within a single well at an instant in time begins when the pump is turned on and ends when the analysis is complete. Between these times, numerous influences on the sample are imposed, all of which have the potential to adversely affect the integrity of the sample and ultimately the data.

The actual act of taking a sample may be a major source of variation in ground-water quality data. Is a sample taken identically every time? If differences occur, how much variation will this cause in the data set? As was pointed out in a previously, pumping, particularly during the first well volume withdrawn, can have a significant affect on the quality of the sample withdrawn. Consistency in purging processes must be maintained in order to limit the variation caused by this source. Even with this assurance, is the third sample taken from a single well derived from the same statistical population as the first sample withdrawn, especially when leakage is occurring? What amount of variation would one expect in this situation, particularly in such a low-permeability formation?

As mentioned above, variation due to analytical techniques is often problematic and contributes to the overall variation in the data. Other sources of variation include well construction, changes in sampling personnel, the pumping device used, well materials, and sample handling, to name a few.

Although many of these unwanted sources of variation cannot be quantified, several of the dominant ones can. These sources include sampling, sample handling, pumping, and analytical error. The amount of variation caused by these factors can be obtained by gathering multiple samples from a single well at virtually an instant in time. If this procedure is followed in the sampling of several wells over the entire period of investigation, the amount of variation due to these sources may be adequately evaluated. Due to practical considerations, such as insufficient sample volume and time, multiple samples were taken only from a selected number of wells.

In order to determine if the variation due to sampling, sample handling, pumping, and analysis was a statistically significant source of variation in the overall study, a general linear model was used to calculate the variations due to the above, along with variations in time and space. This statistical method calculates the contribution of each parameter in the variance of the data set by utilizing F-ratios. In essence, the method calculates a within-group variance (variance due to sampling, etc.) and a between group variance (variance due to space or time). The F-ratio is derived by the following:

$$F = MSb/MSw \tag{3.1}$$

where MSb = mean squares between groups

MSw = mean squares within groups

$$MSb = SSb/dfb \tag{3.2}$$

where SSb = sum of squares between groups

dfb = degrees of freedom between multiple samples

$$MSw = SSw/dfw \tag{3.3}$$

where SSw = sum of squares within groups

dfw = degrees of freedom within groups

The F value calculated by the above method is compared to a table of F values at a given confidence interval. If the calculated F value is larger than the table F value, the hypothesis is rejected (or failed to be accepted), and if less than the table F value the hypothesis is accepted (or failed to be rejected), at that confidence limit.

In this case, the hypothesis is; the variance of nitrate concentration due to sampling, pumping, analysis and sample handling (i.e. multiple samples) does not contribute significantly to the overall variance of nitrate concentration in the data set. In other words, the variations of nitrate in space and time are much greater than the variations in multiple samples taken from a single well at an instant in time. The results of the general linear model simulation on the data of multiple samples is shown in Table III. The raw data are contained in Appendix C.

The extremely small F value for multiple samples indicates the hypothesis is not rejected at a confidence limit of 95. In other words, the variation due to sampling, etc. in single wells has contributed little to the overall variation in the data set. In addition, the results indicate that the majority of the variance in the data is due to space and time effects. It must be kept in mind that only four wells were consistently sampled in this manner and are the basis for this determination.

Variations over the Entire Study Area

From the foregoing discussion, it is apparent variations due to analytical error, sampling, pumping (after the well is purged), and sample handling are quite small. The variations of selected parameters over the entire study area have been substantial in both space and time. Prior

TABLE III

SUMMARY OF THE GENERAL LINEAR MODEL RESULTS ON MULTIPLE SAMPLES

	Degrees of Freedom	Sum of Squares	F Value
Multiple Samples	2	0.07	0.01
Space (well site)	3	2345.74	289.71
Time (days)	36	2493.18	25.66

to mid-October the range between the maximal and minimal values for these parameters was considerably less than after this date. During the fall recharge period water levels rose in excess of four feet which allowed the sampling of many shallower wells that had been dry for several months. By mid-November, all wells at the study area were being sampled. The ranges in the monitored parameters reflect this fact. That is, all the wells were sampled, rather than just four , as was the case during the summer.

The maximal and minimal specific conductance values for the investigative period are shown in Figure 28. As mentioned the range between the maximal and minimal increases after mid-October and is related to the water level rise brought about by the fall recharge period. The maximum and minimal nitrate concentrations throughtout the study area for the period of record is shown in Figure 29. Again the major trends are related to the fall recharge period and reflect the sampling of additional wells. The event in mid-September, which caused considerable short-term variation was a special case and will be discussed in a later section.

Of the major ions, bicarbonate has had the most obvious variability over the investigative period. Within the monitored area of 11,000 square feet, bicarbonate has ranged between 329.5 and 1165 milligrams per liter, with a mean concentration of 643. These values were obtained from samples taken on the same day. Other major ions, such as

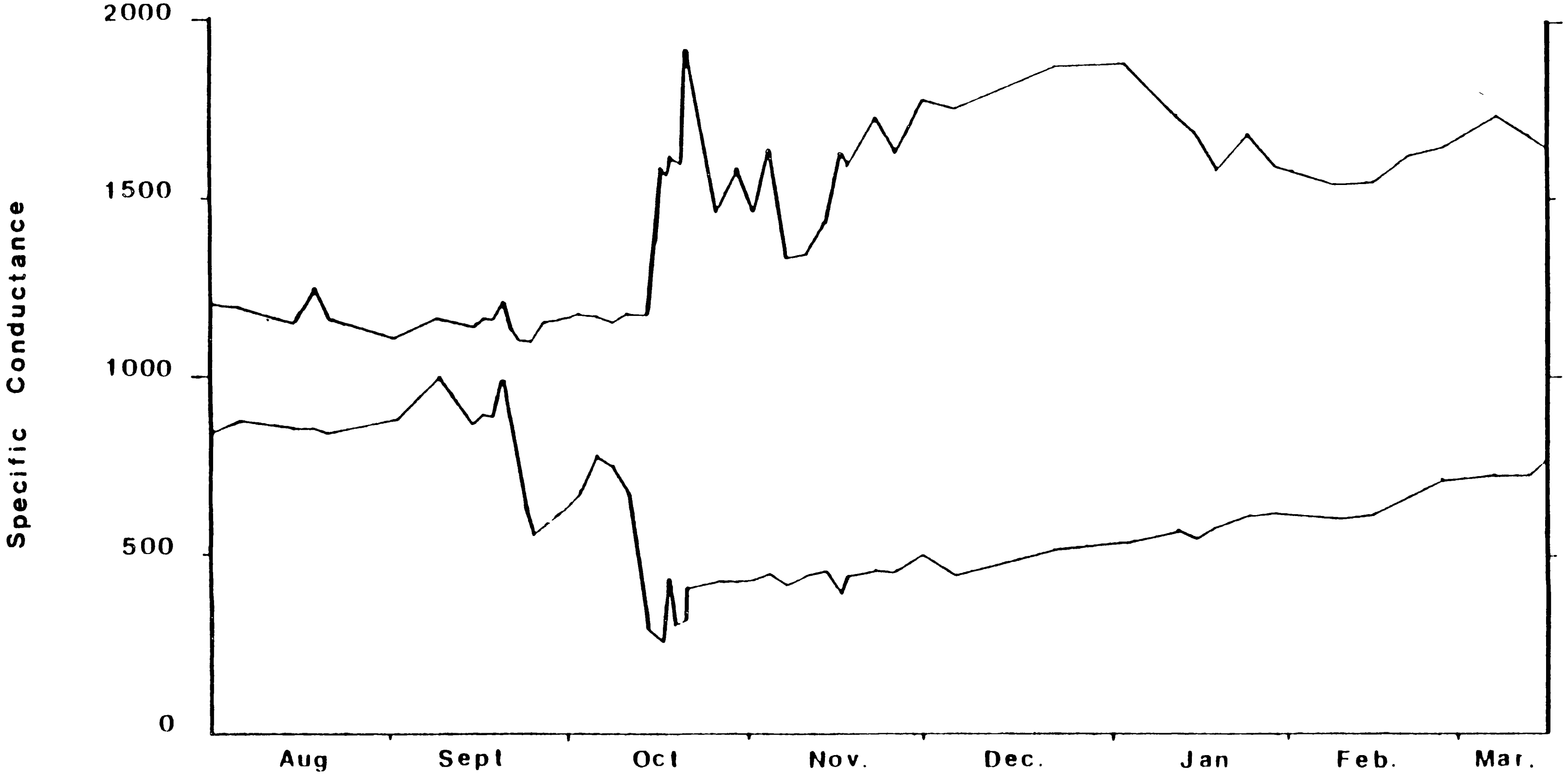


Figure 28. Maximum and Minimum Specific Conductance for All Monitoring Wells Over the Investigative Period

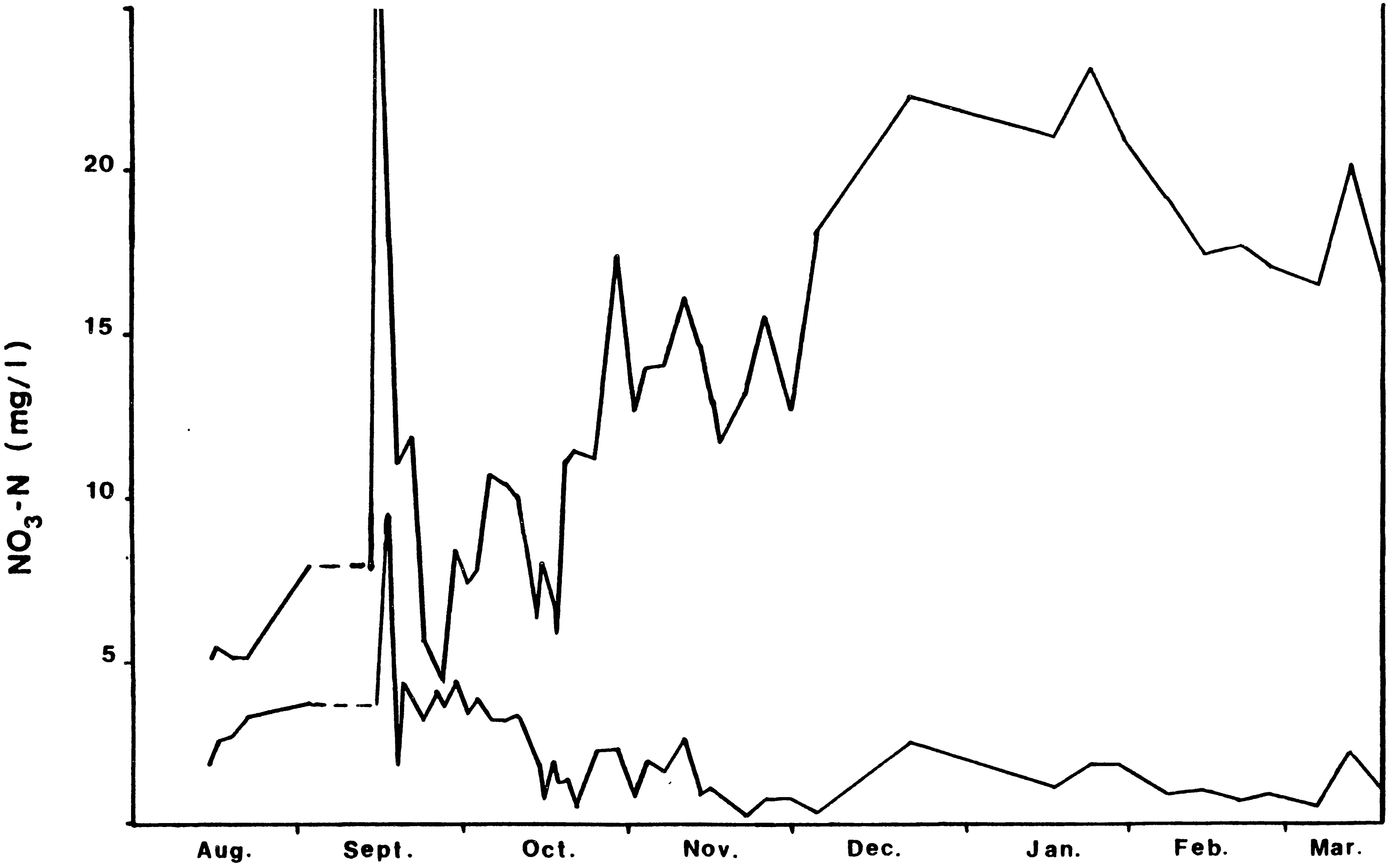


Figure 29. Maximum and Minimum Nitrate Concentrations for All Monitoring Wells Over Investigative Period

sodium and calcium have differed by as much as an order of magnitude over the study period. The maximal and minimal values for sodium and calcium are 179, 8.7 and 139.6, 13.2 milligrams per liter, respectively. Again these values were obtained from samples taken on the same day. The range of values of the other monitored parameters are not as extreme. Table IV summarizes the maximal, minimal, mean, and standard deviation of the monitored parameters over the course of the study.

Variations at Well Clusters

The variations with depth at individual well clusters, particularly in terms of nitrate and specific conductance, exceed variations expected by pumping, chemical analysis, and sampling. Additionally, the major ions show variations with depth one would not anticipate simply due to errors associated with sampling and analytical processes. Variations at each well cluster are discussed below (see Figure 8 for cluster locations). The "5" wells are omitted from the discussion and will be addressed separately.

Site A

Wells at Site A consistently have nitrate values that decrease with depth. The difference in nitrate concentration between 8.5 feet (well A1) and 14 feet (well A4) is at least an order of magnitude, despite their proximity (Figures 30, 31 ,and 32). Over the course of the investi-

TABLE IV

MAXIMUM, MINIMUM, AND MEAN OF THE MONITORED PARAMETERS OVER INVESTIGATIVE PERIOD

Parameter	Max.	Min.	Mean
Temp. (C.)	22.20	11.90	17.30
Spec. Cond.	1979.00	255.00	1089.00
pH	8.56	6.69	7.21
NO3-N	27.90	0.30	6.00
Cl	67.30	9.10	22.90
SO4	59.90	17.30	38.40
HCO3	1165.00	329.50	643.00
Na	179.80	8.70	67.20
Ca	139.60	13.20	80.40
Mg	96.30	19.60	51.10
K	1.54	0.36	0.48

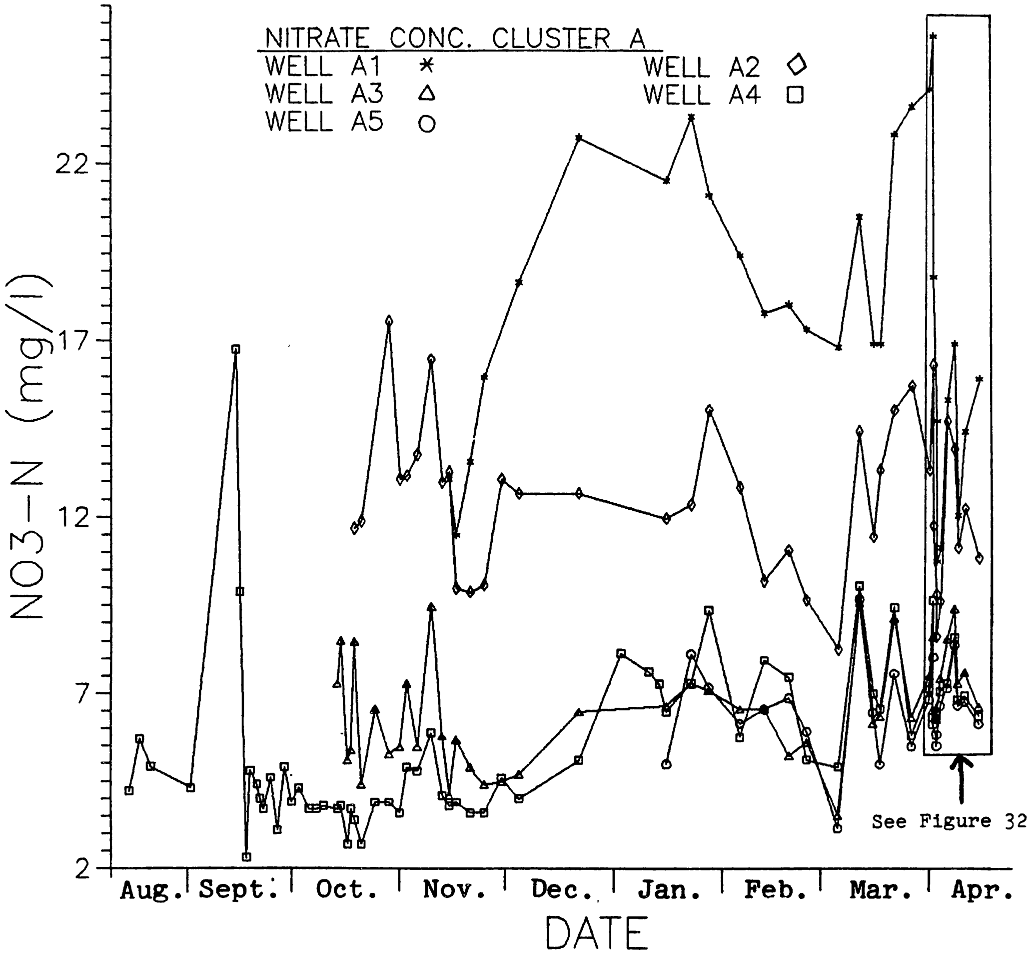


Figure 30. Nitrate Concentration, Cluster A

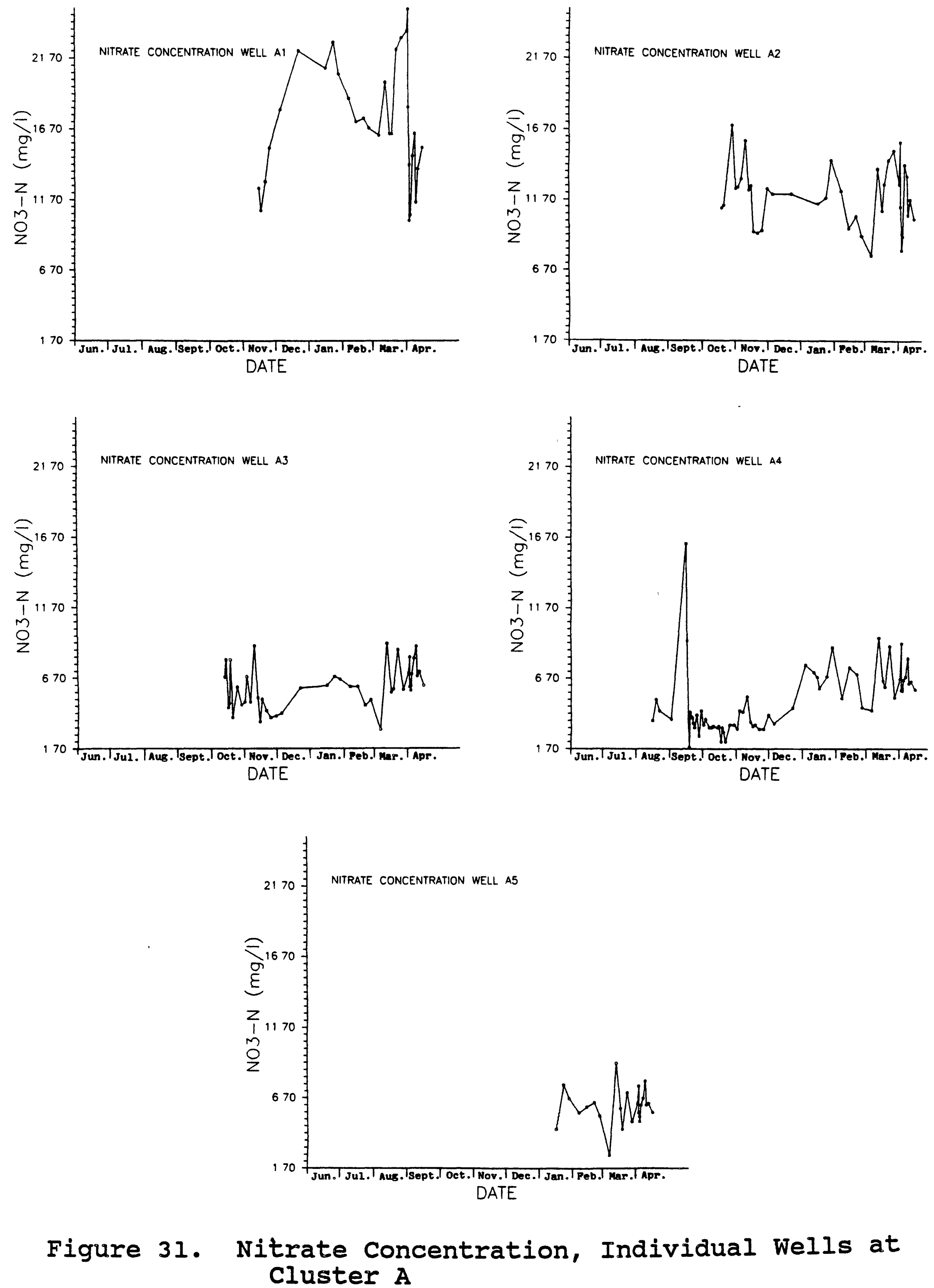


Figure 31. Nitrate Concentration, Individual Wells at Cluster A

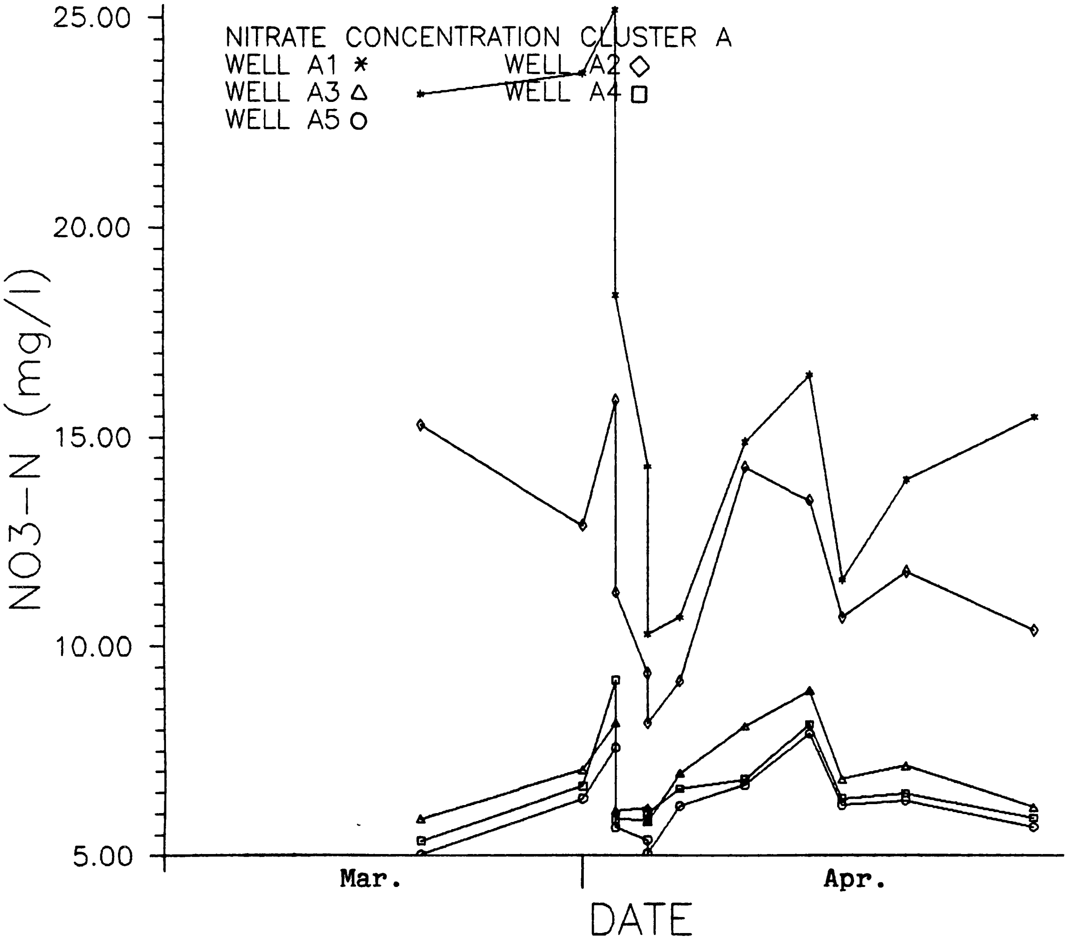


Figure 32. Nitrate Concentration, Cluster A, March 27-April 15, 1986

gation, the maximal concentration (25.2 mg/l) occurred in well A1 and the minimal (1.8 mg/l) occurred in well A4. Generally wells A2 and A3 exhibit intermediate nitrate concentrations, although well A3 had lower concentrations than well A4 on a few occasions. The variation of nitrate with depth at site "A" has consistently been the most pronounced over the study area.

Specific conductance at Site A have shown a slight decreasing trend with depth (Figure 33, 34, and 35). The values generally range between 850 and 1150 micromhos, with the maximal value being 1210 and the minimal value being 650 micromhos. Both the maximal and minimal values reflect well A1, but the minimum was determined shortly after the well was developed and probably reflects the specific conductance of the water used during the installation/development process. The variation of specific conductance at site "A" has been consistently less than elsewhere across the study area.

Sodium concentrations increases with depth, while the calcium decreases with depth, indicating the possibility of natural softening or cation exchange. Chloride decreases with depth, and bicarbonate, magnesium, and sulfate show no conclusive trends.

Site C

Unlike Site A, the nitrate concentrations in the "C" cluster generally increase with depth. During the investi-

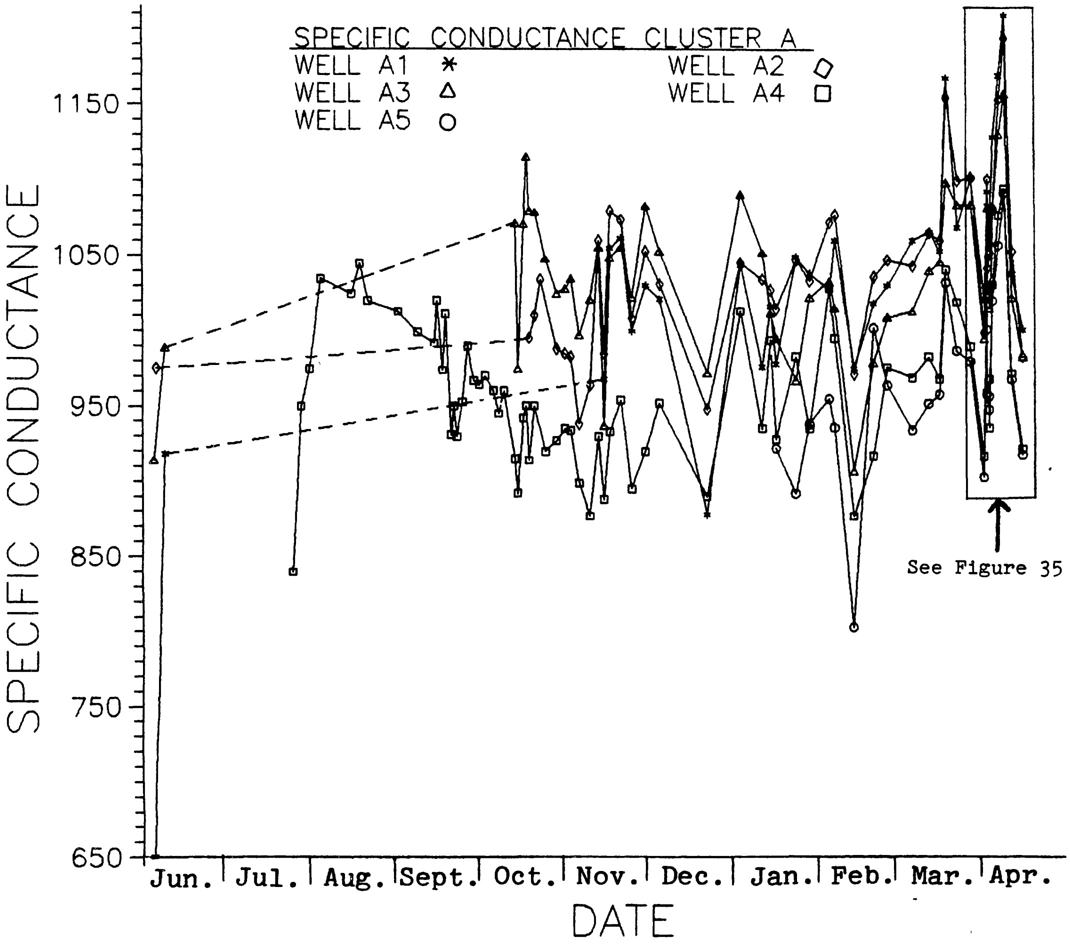


Figure 33. Specific Conductance, Cluster A

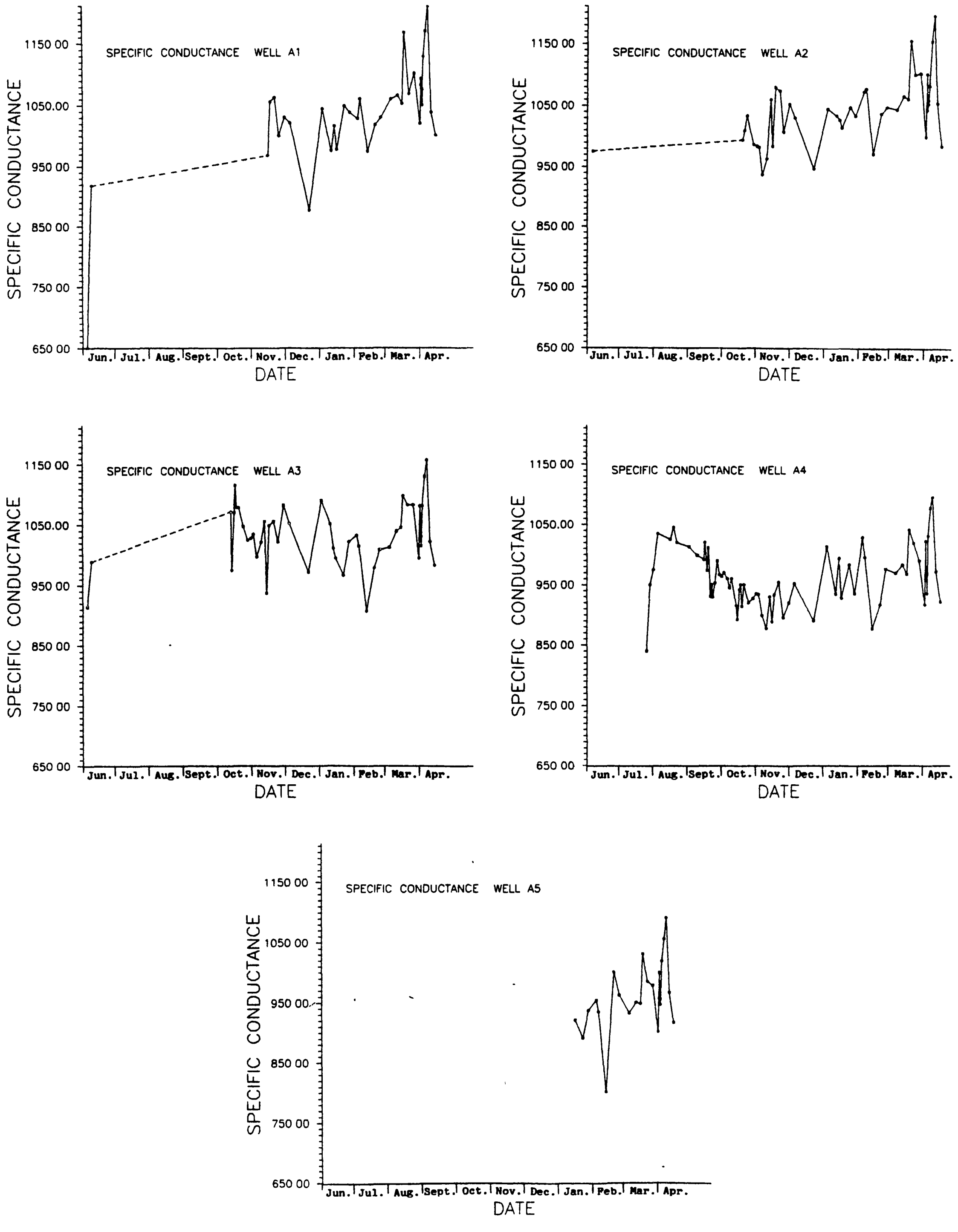


Figure 34. Specific Conductance, Individual Wells at Cluster A

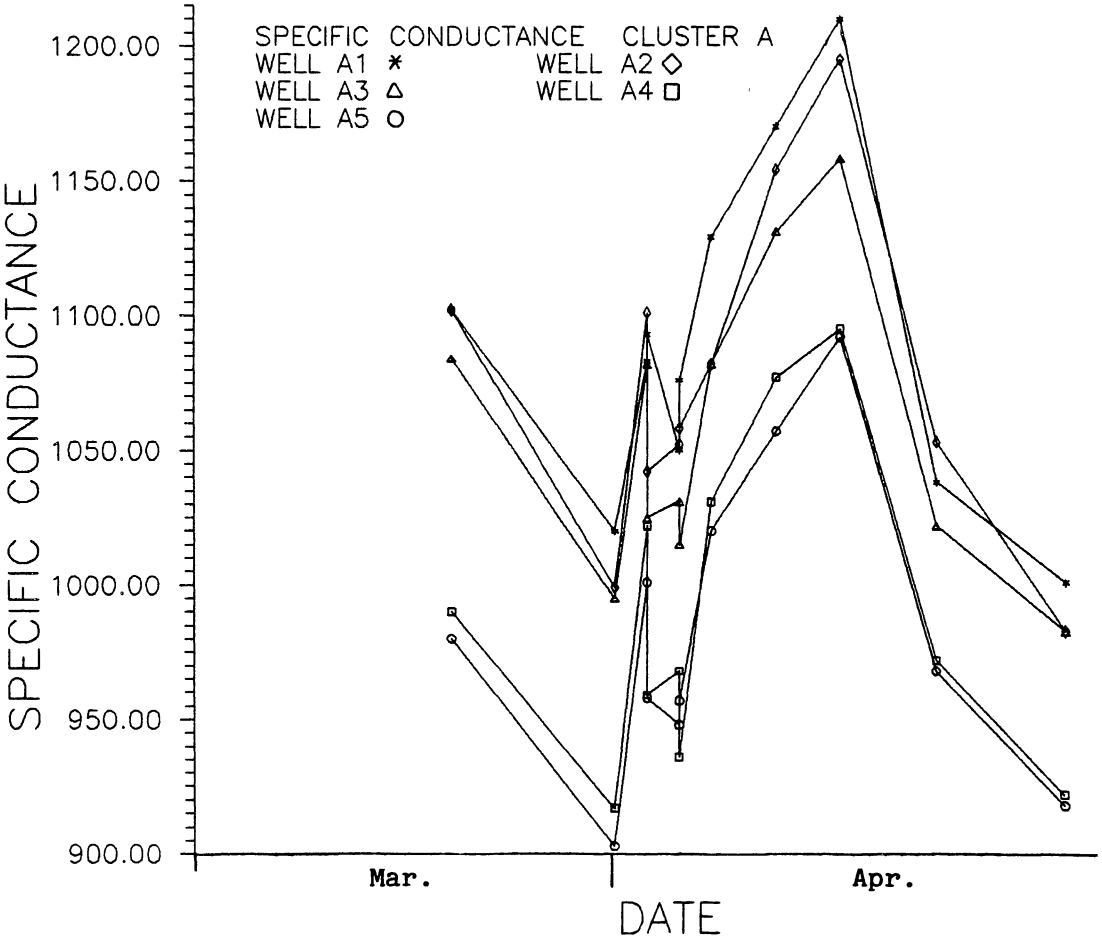


Figure 35. Specific Conductance, Cluster A, March 27-April 15, 1986

gative period, the nitrate concentration ranged between 0.95 and 10.8 milligrams per liter nitrate-nitrogen. The minimal value was taken from the interval tapped by well C1 and the maximal from well C4 (Figures 36, 37, and 38). Wells C2 and C3 have nitrate values which are intermediate between wells C1 and C4. The maximal value was obtained during a special event which will be discussed in a later section.

The maximal and minimal specific conductance values obtained from wells at Site C are 1979 and 862 micromhos respectively. Unlike nitrate concentrations, the specific conductance decreases with depth, with well C1 consistently yielding the largest values (Figure 39, 40, and 41). The difference between the maximum and minimum is about an order of magnitude, despite a distance of only 5.5 feet vertically and about one foot horizontally between sampled intervals.

Bicarbonate, magnesium, sodium, and sulfate decrease with depth, while calcium increases. In fact, within the 5.5 feet of vertical distance between wells C1 and C4, bicarbonate ranges between 1165 and 552 milligrams per liter. Chloride shows little variation in relation to depth.

Site D

Like Site C, the wells at Site D have consistently yielded nitrate concentrations which increase with depth

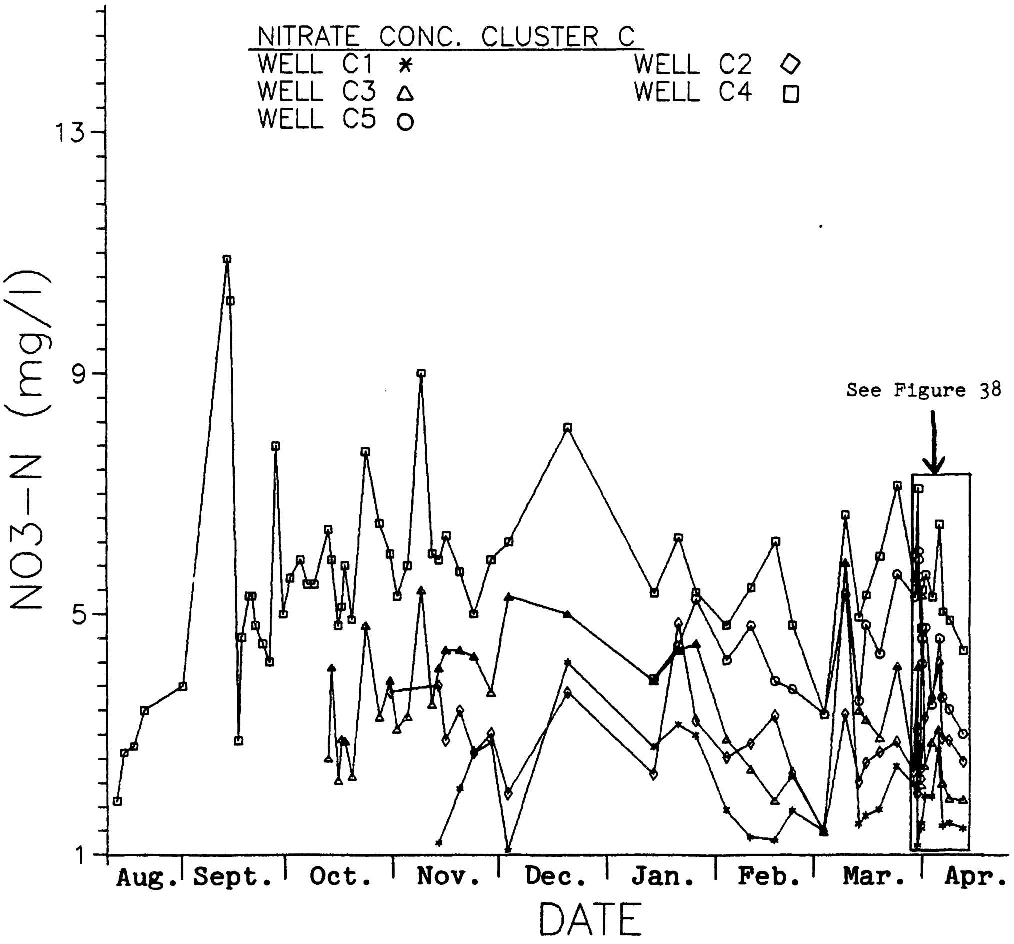


Figure 36. Nitrate Concentration, Cluster C

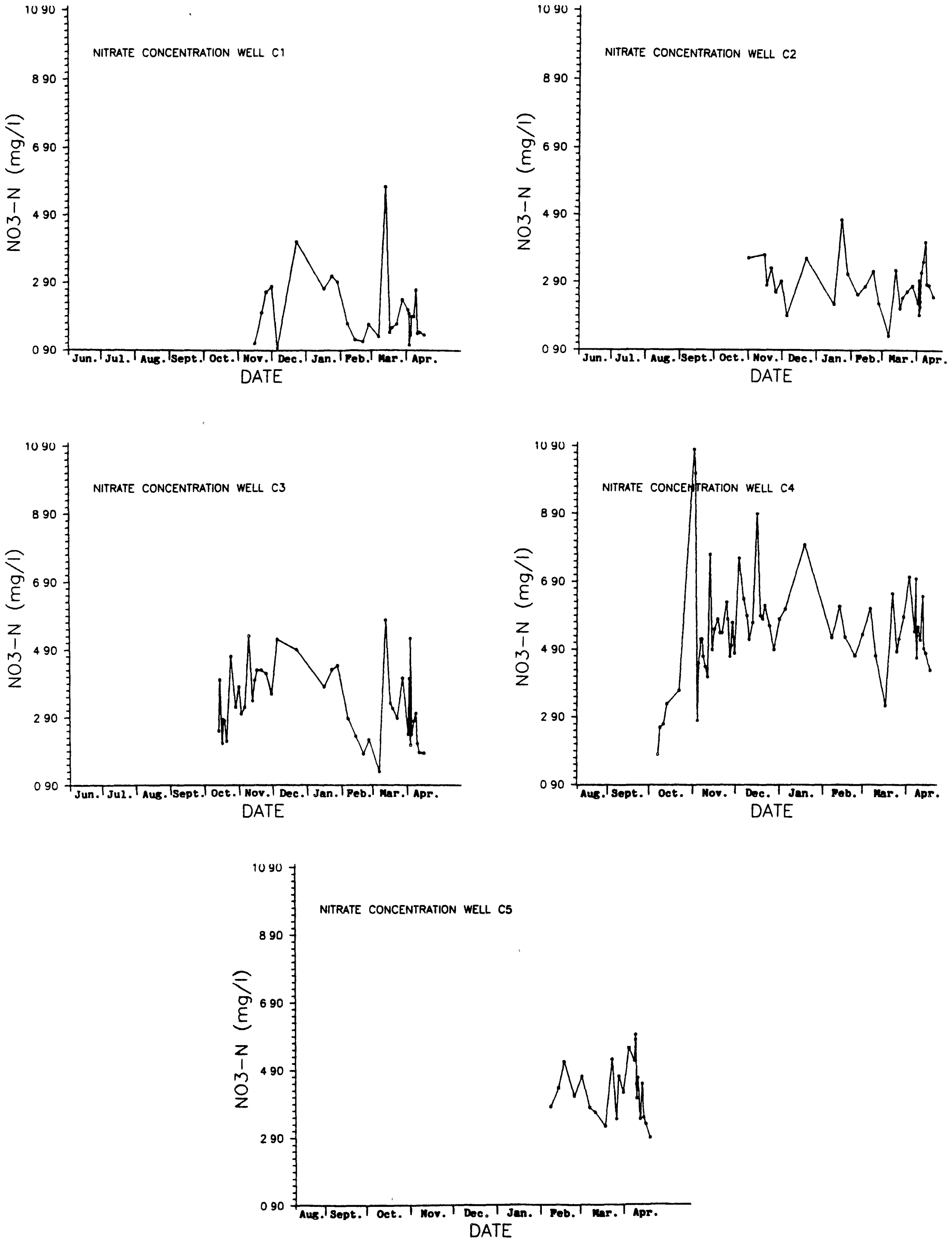


Figure 37. Nitrate Concentration, Individual Wells at Cluster C

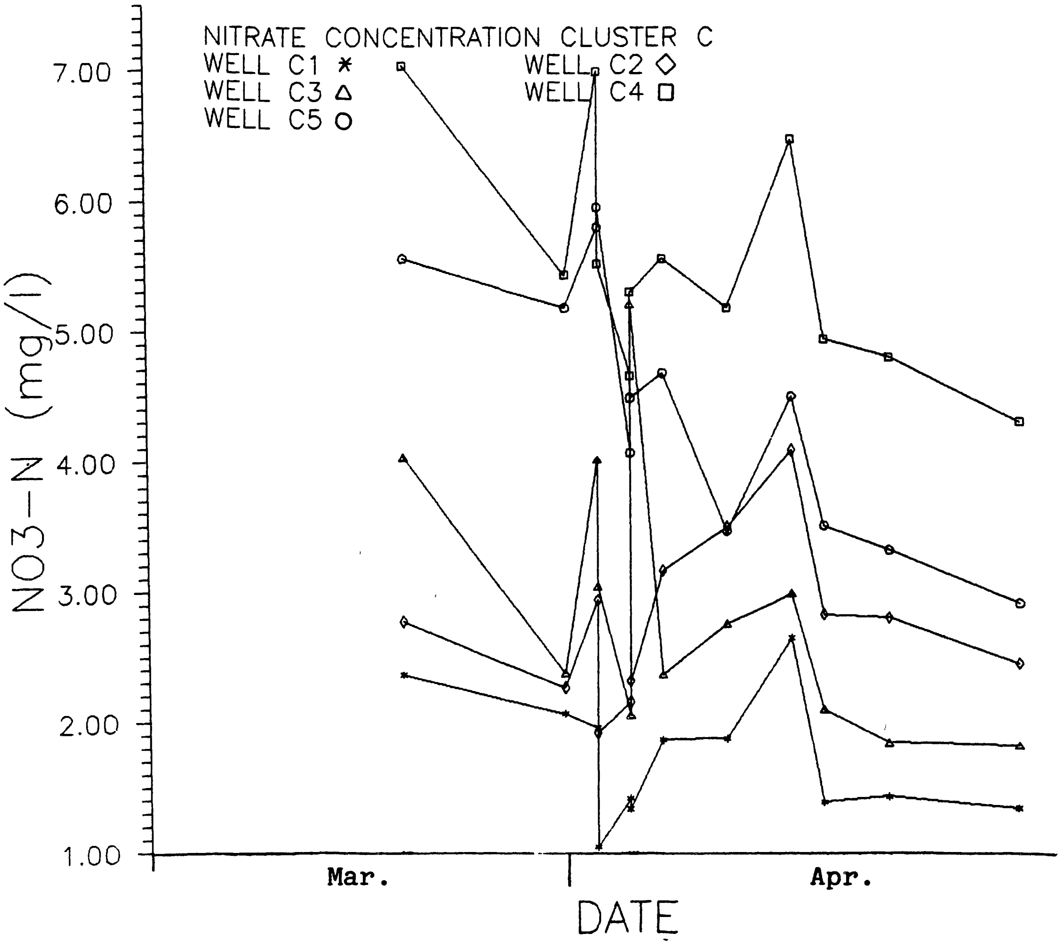


Figure 38. Nitrate Concentration, Cluster C, March 27-April 15, 1986

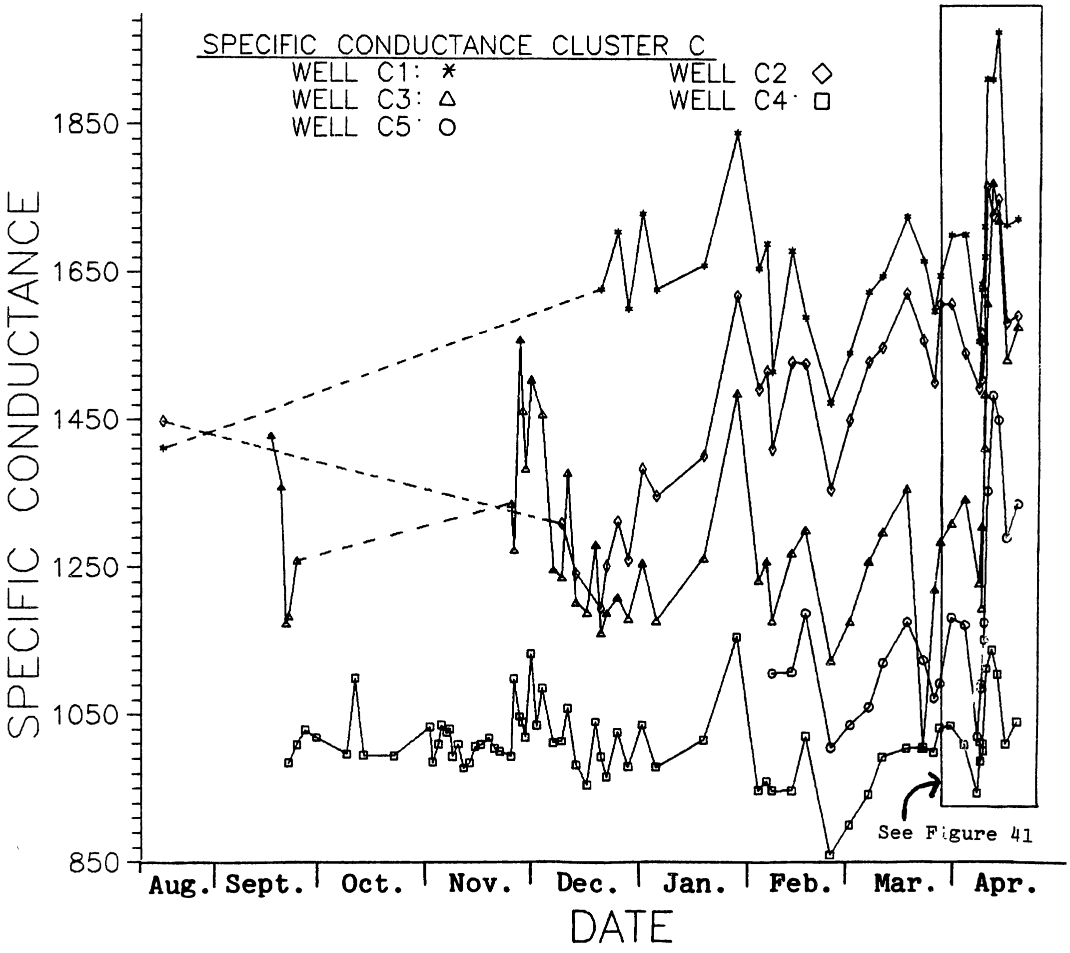


Figure 39. Specific Conductance, Cluster C

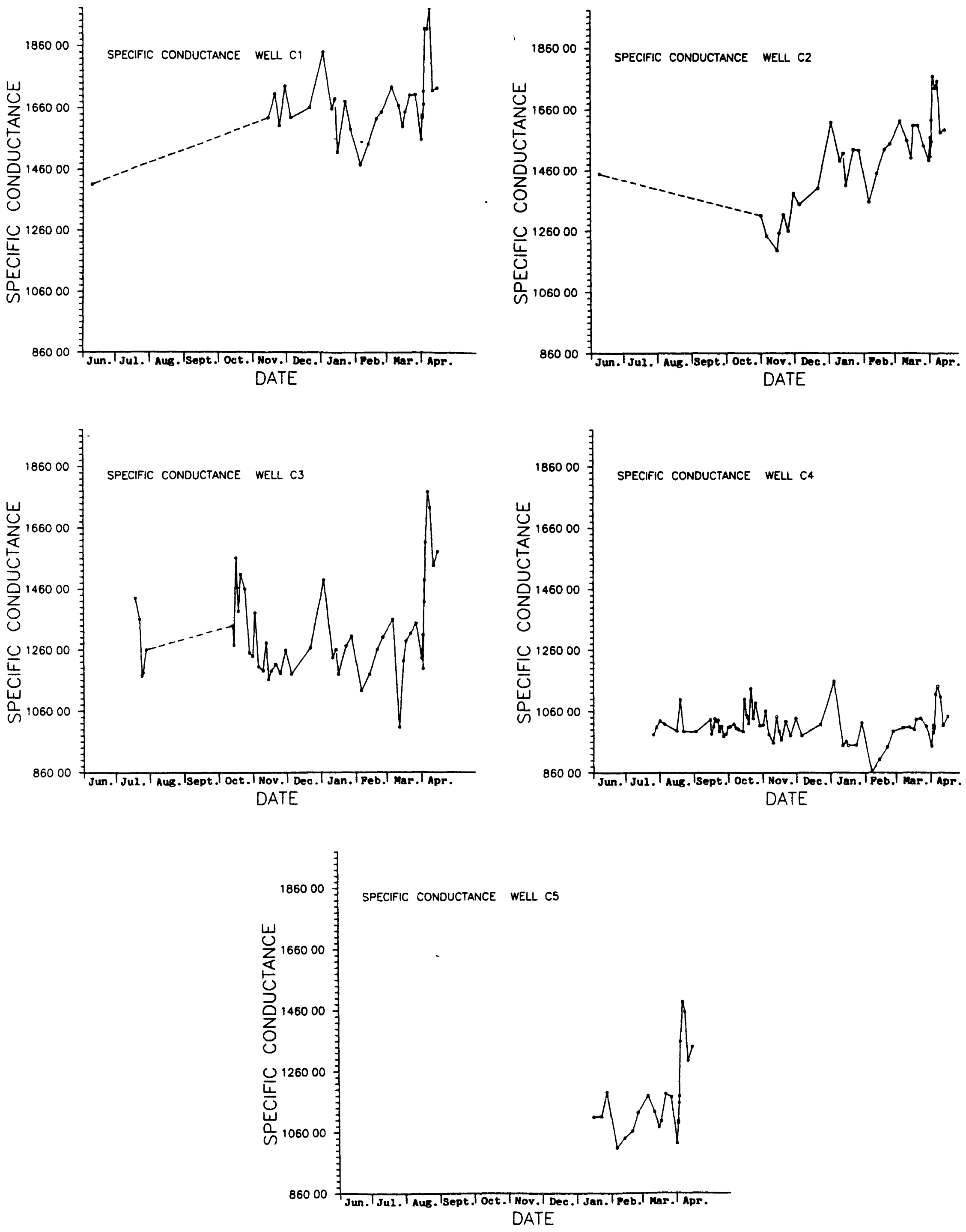


Figure 40. Specific Conductance, Individual Wells at Cluster C

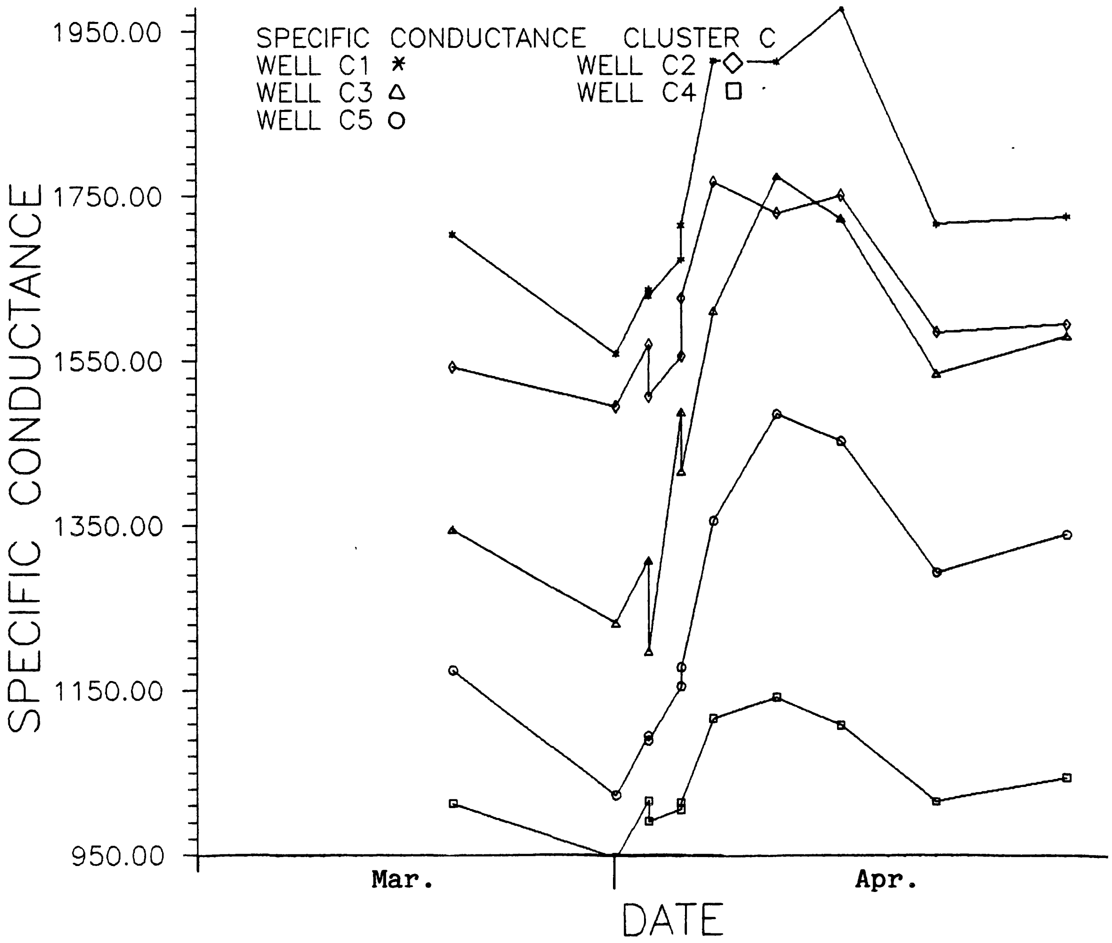


Figure 41. **Specific Conductance, Cluster C, March 27-April 15, 1986**

(Figures 42, 43, and 44). The maximal and minimal values, 12.1 and 0.3 milligrams per liter nitrate-nitrogen, occurred at wells D4 and D1 respectively. Wells D1, D2, and D3 have nitrate values that are generally one or less, while well D4 has a mean concentration of 6.5 milligrams per liter nitrate-nitrogen. Again, the difference between nitrate concentrations over the 5.5 depth interval monitored has been approximately an order of magnitude, and often times occurs over a vertical distance of only three feet (between intervals sampled by wells D3 and D4).

The specific conductance at Site D has consistently shown a decrease with depth, although intervals sampled by wells D1 and D2 are similar. The maximal and minimal values are 1904 and 1018 micromhos, which occurred in wells D1 and D4 respectively. Figures 45, 46, and 47 illustrate the specific conductance trends at Site "D". Preliminary sampling and analysis have shown that bicarbonate, sodium, calcium, chloride, sulfate, and magnesium decrease with depth.

Site E

Nitrate concentrations at Site E generally increase with depth. Wells E1, E2, and E3 do not consistently follow this pattern, but well E4 has invariably yielded samples with the largest nitrate concentrations. Over the course of investigation, the maximal and minimal nitrate concentrations were 27.9 and 0.7 milligrams per liter,

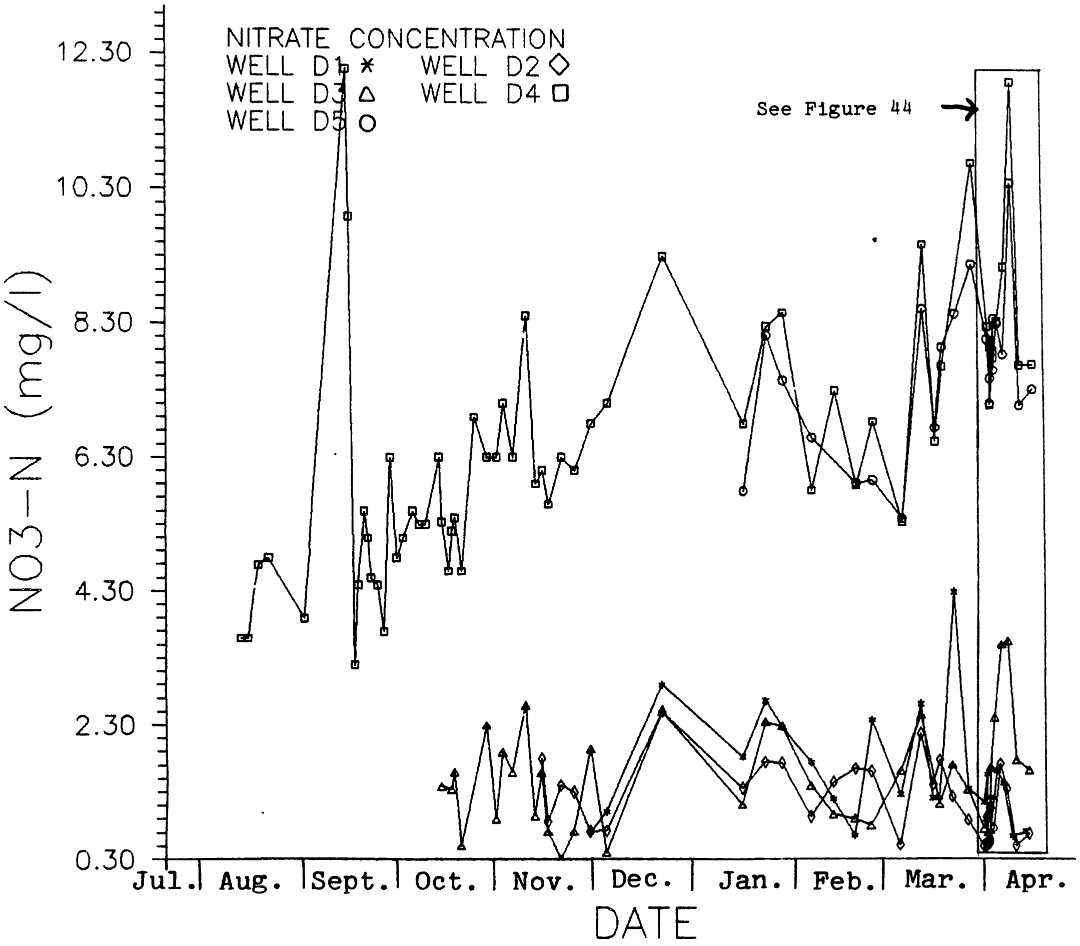


Figure 42. Nitrate Concentration, Cluster D

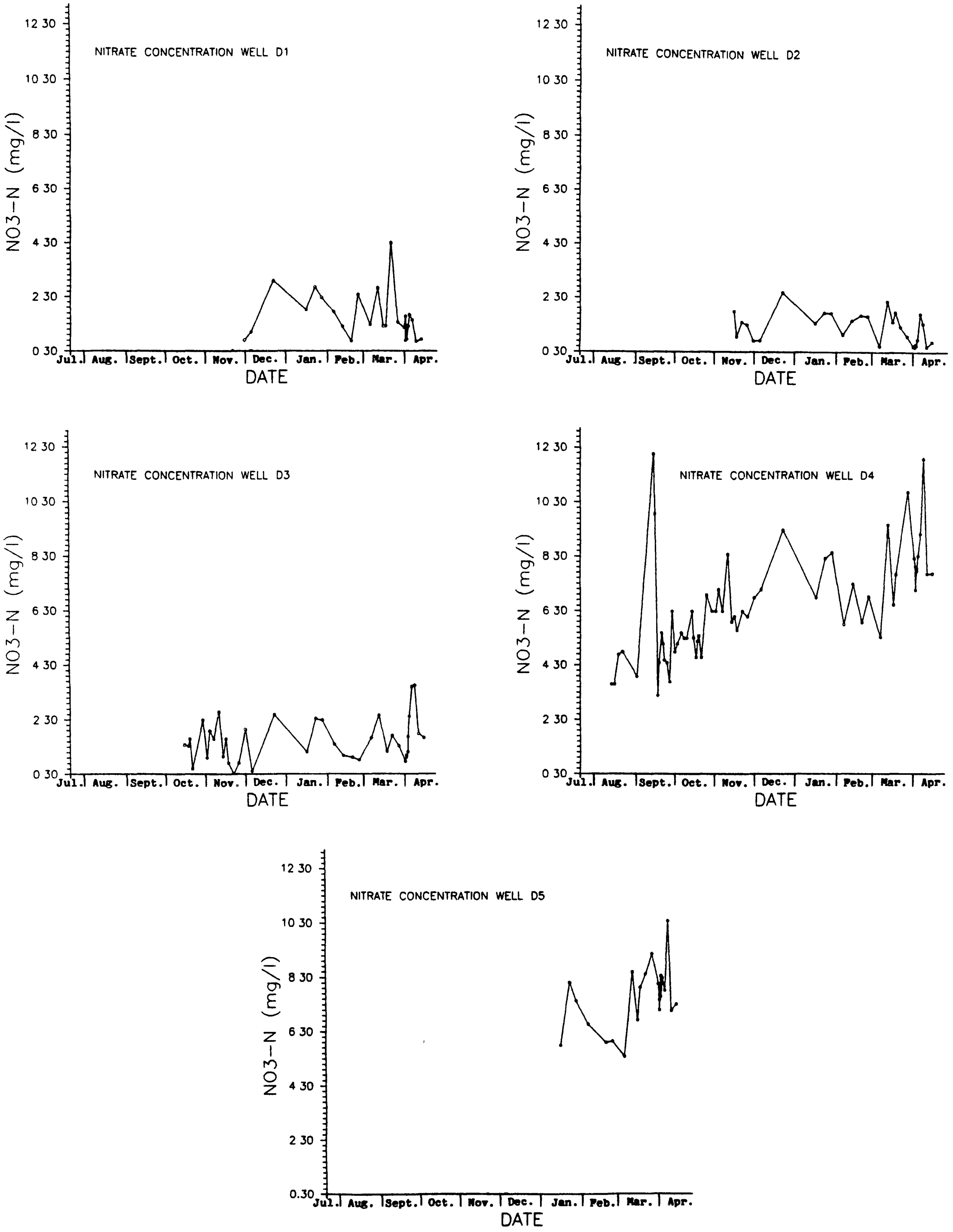


Figure 43. Nitrate Concentration, Individual Wells at Cluster D

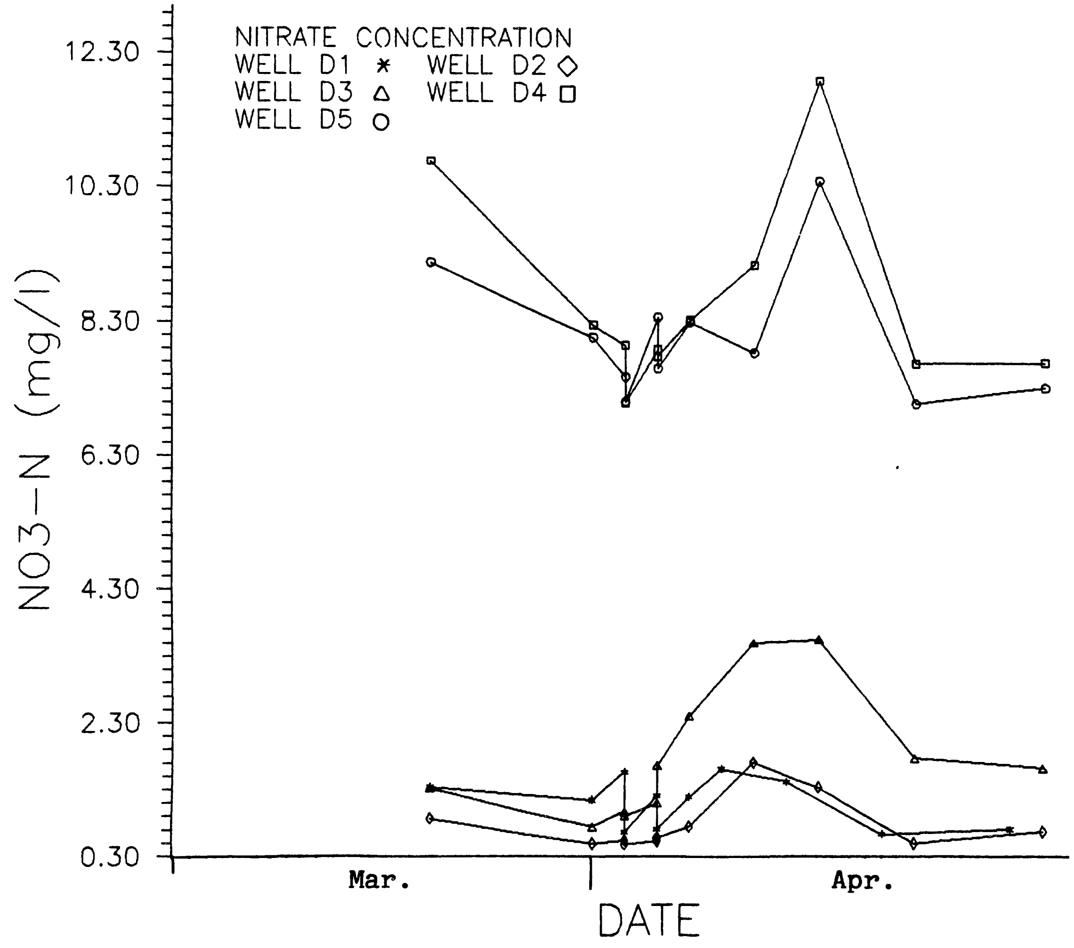


Figure 44. Nitrate Concentration, Cluster D, March 27-April 15, 1986

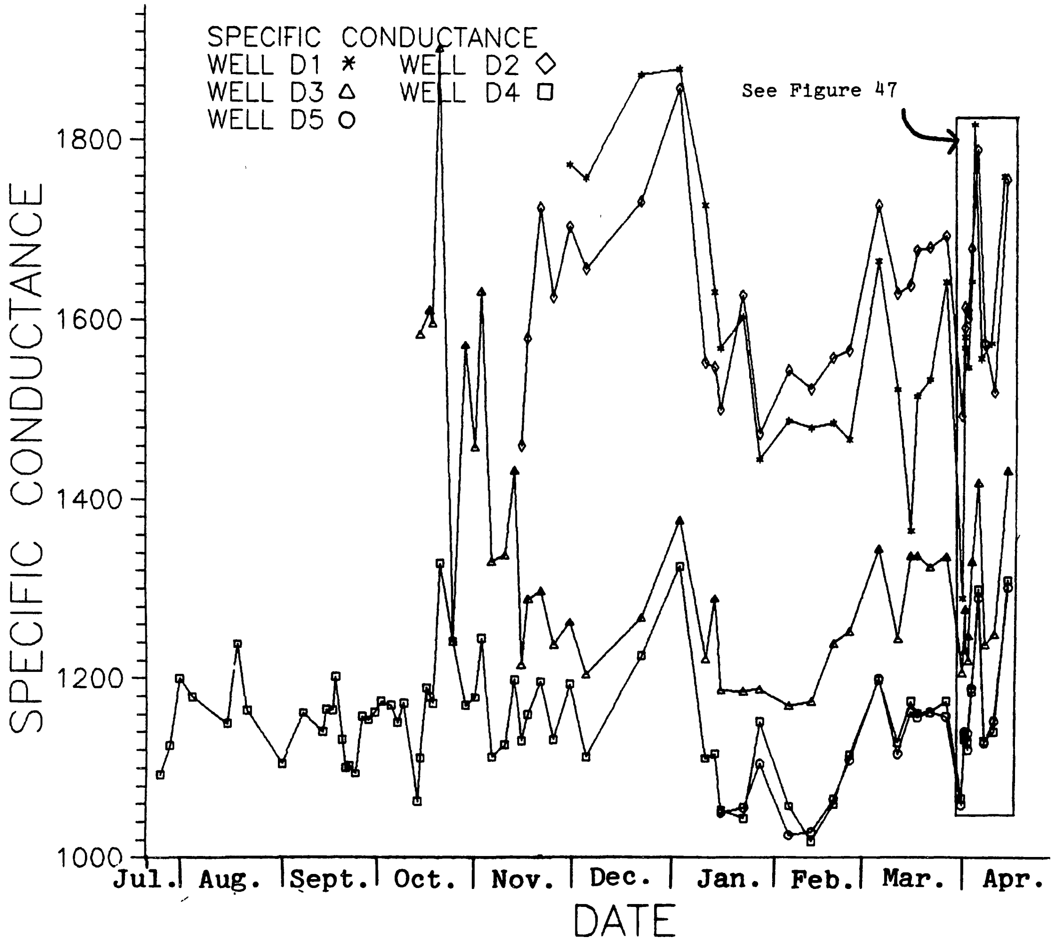


Figure 45. Specific Conductance, Cluster D

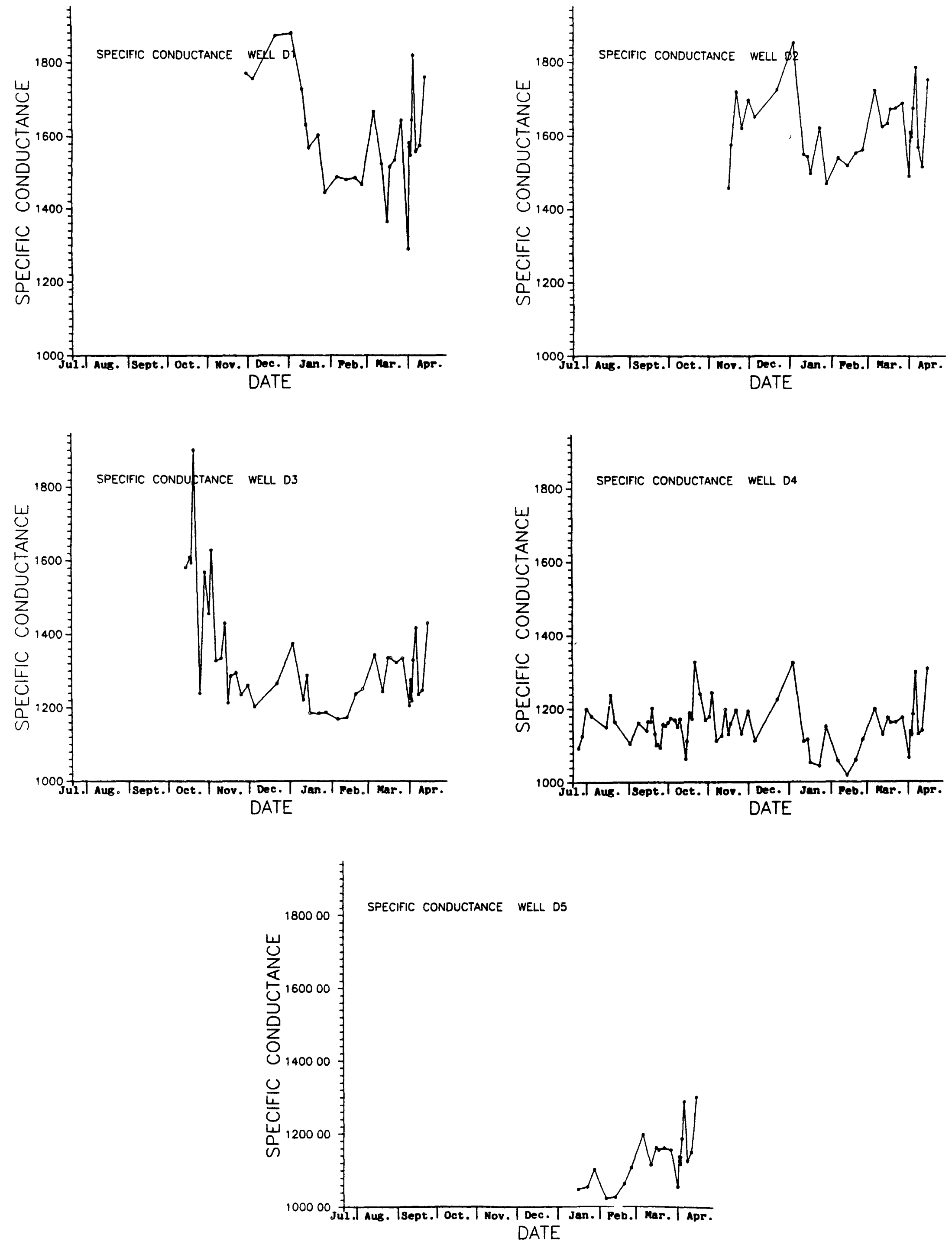


Figure 46. Specific Conductance, Individual Wells at Cluster D

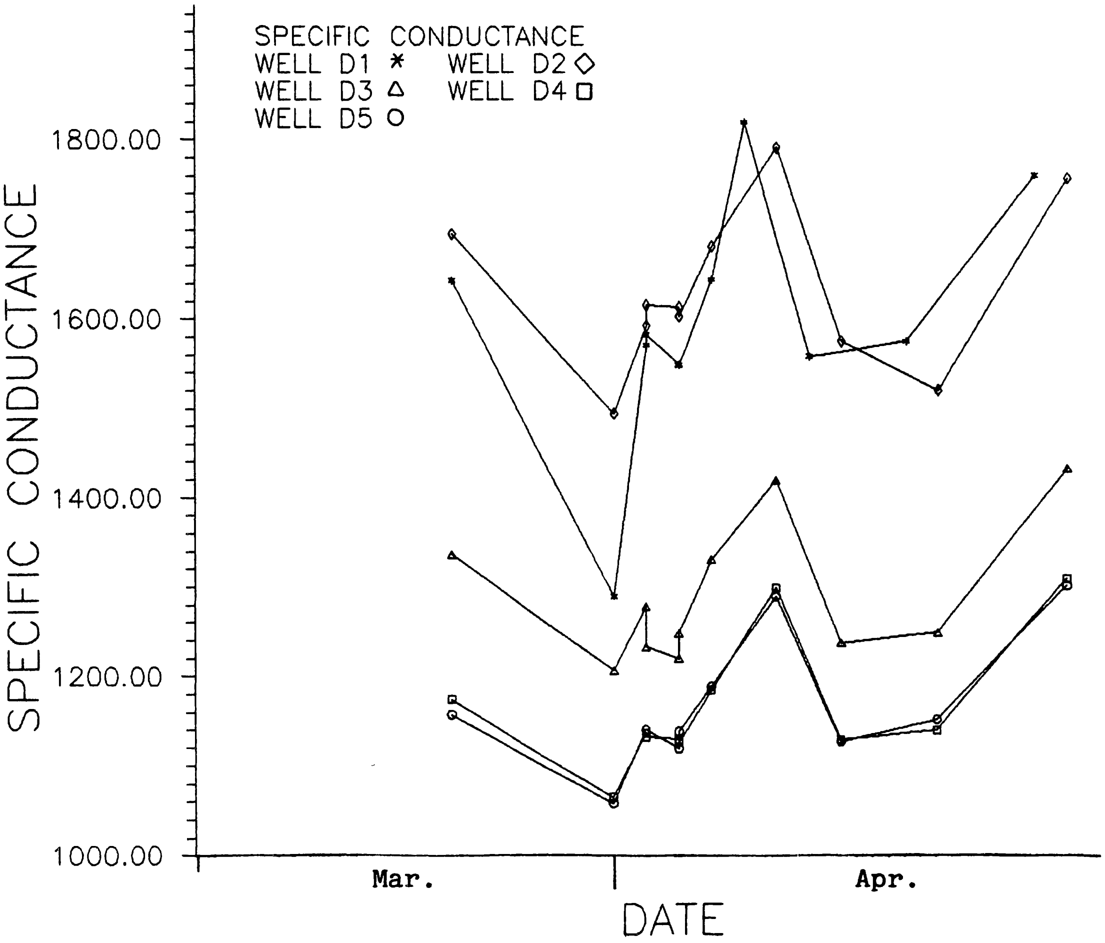


Figure 47. Specific Conductance, Cluster D, March 27-April 15, 1986

which occurred in wells E4 and E3 respectively. Figures 48, 49, and 50 illustrate the vertical distribution of nitrate over the course of investigation at Site E.

The vertical variability of specific conductance has been substantial in the wells at site "E". The maximal and minimal values are 1433 and 255 micromhos, which occurred in wells E4 and E2 respectively. In general, there was an increase in specific conductance in all of the E wells from about mid-November to the end of the study period. Figure 51, 52, and 53 illustrate the vertical distribution of specific conductance over the investigative period for Site "E".

Preliminary results of the major ion concentrations at Site "E" show bicarbonate, sodium, chloride, magnesium, and calcium increase with depth. No apparent trends with respect to sulfate and depth are evident.

Variations in Individual Wells Over Time

Due to the number of wells that monitor the study area, a discussion of each well is not practical. Instead, the discussion that follows is based on general trends observed throughout the site, although exceptions to these trends do occur. Specific examples illustrating important concepts are included.

Both small and large variations of nitrate and specific conductance occur in all of the wells over time. The greatest amount of variation over the study area has been

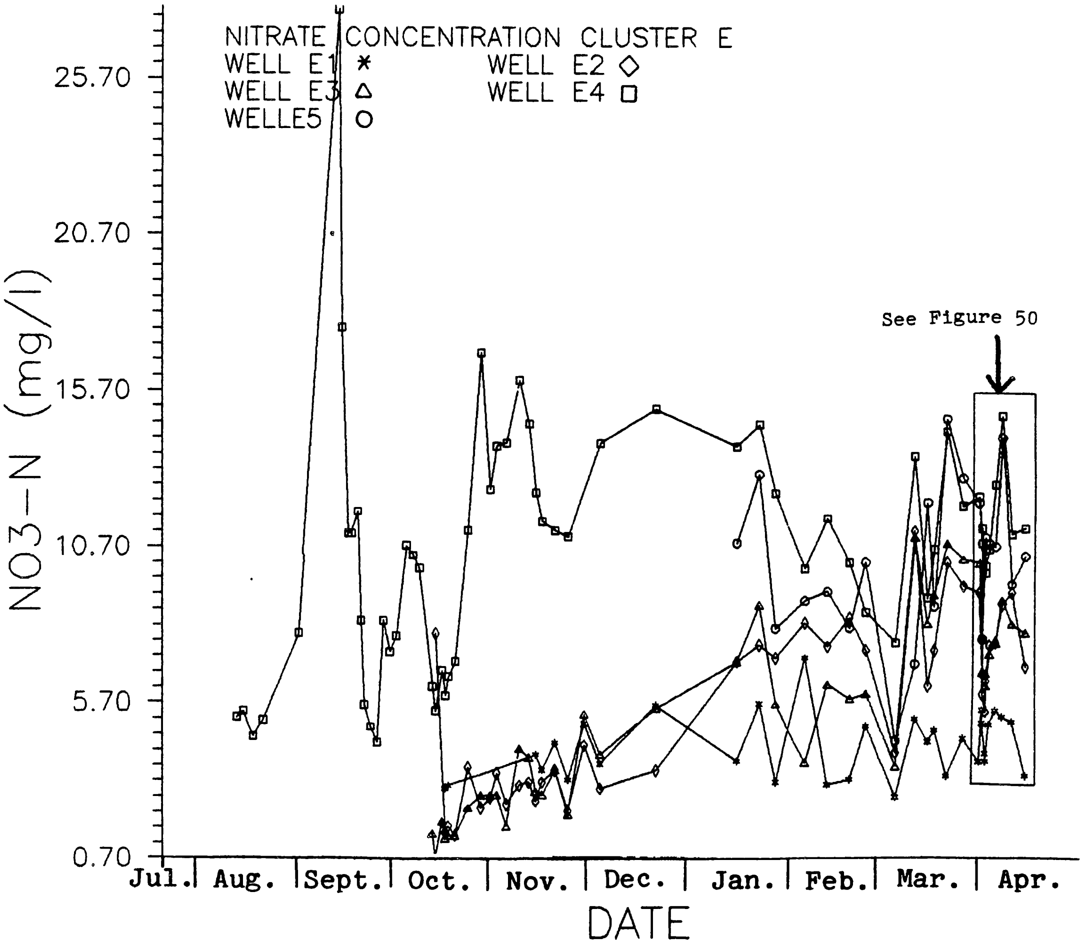


Figure 48. Nitrate Concentration, Cluster E

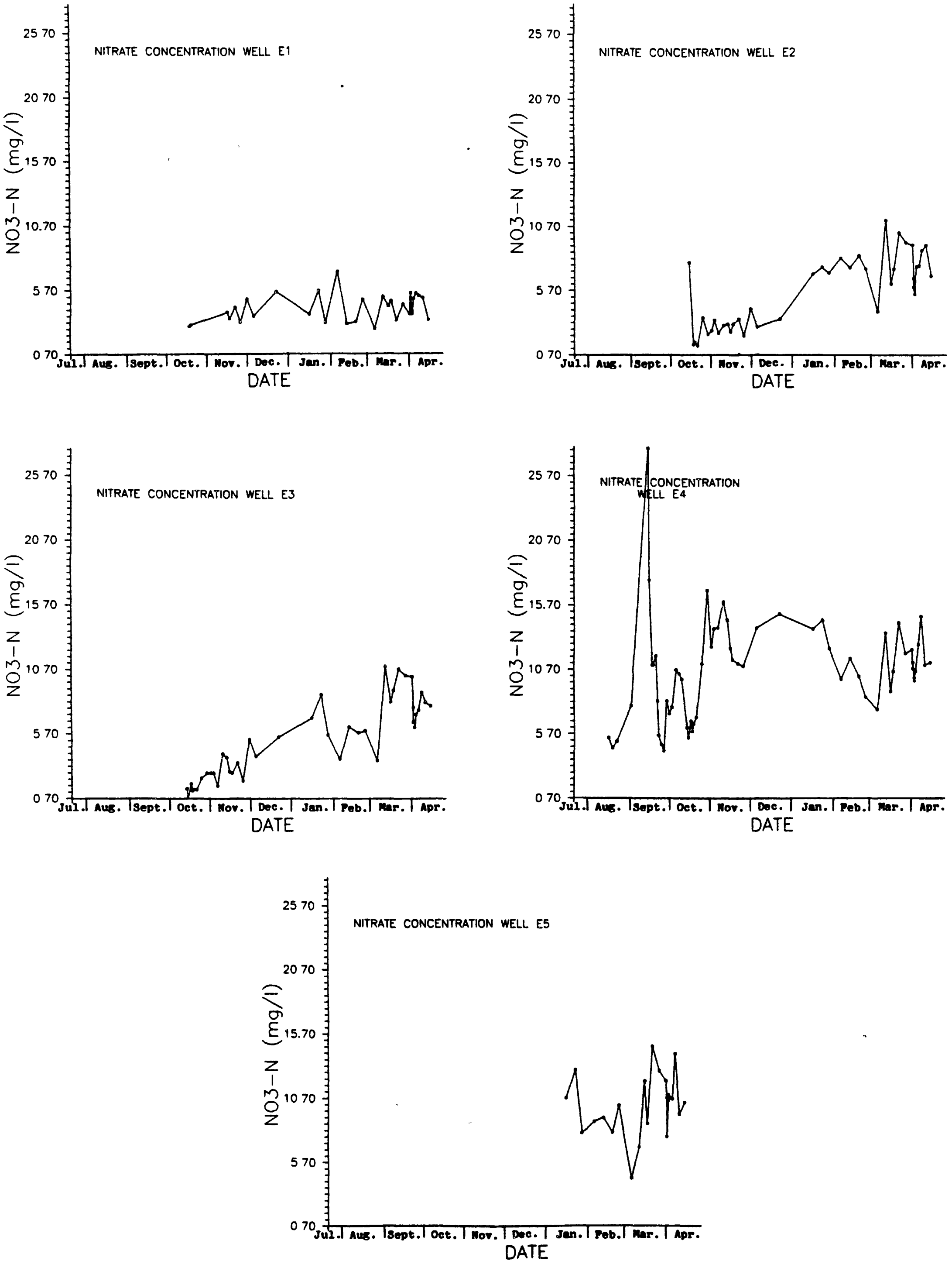


Figure 49. Nitrate Concentration, Individual Wells at Cluster E

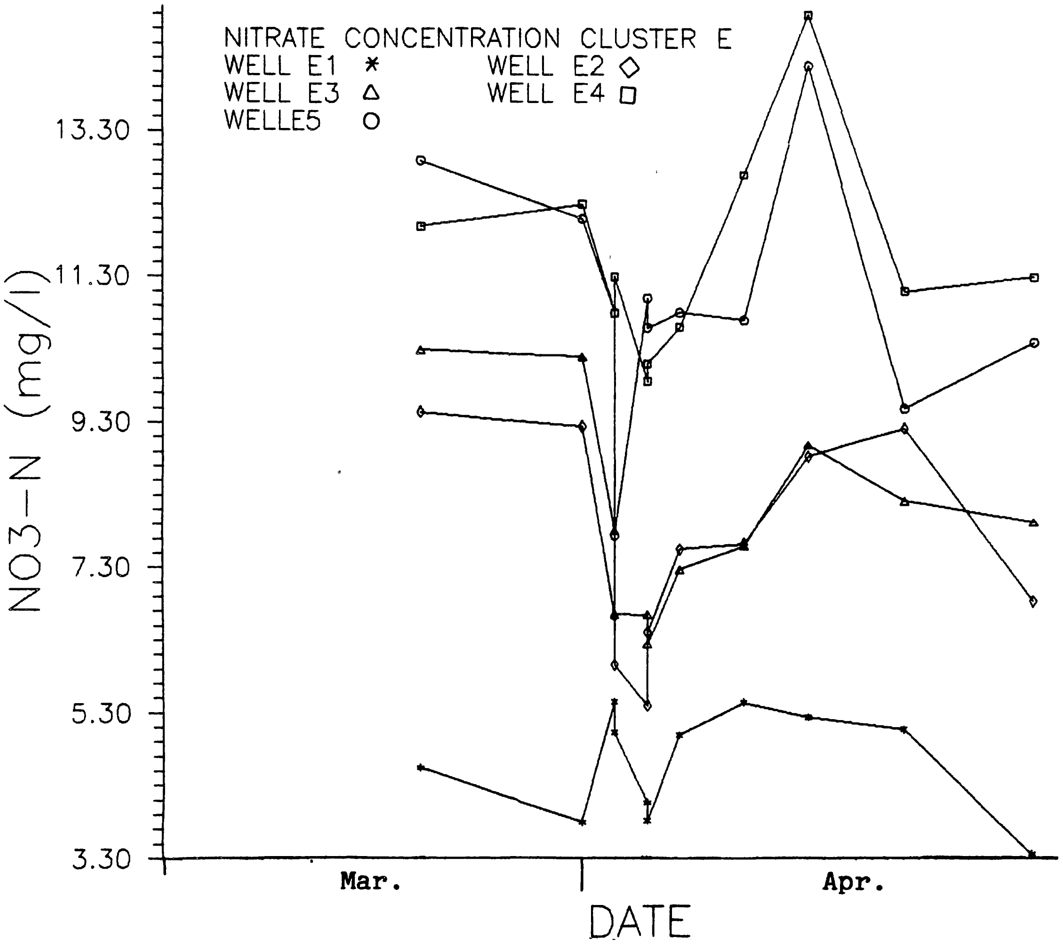


Figure 50. Nitrate Concentration, Cluster E, March 27-April 15, 1986

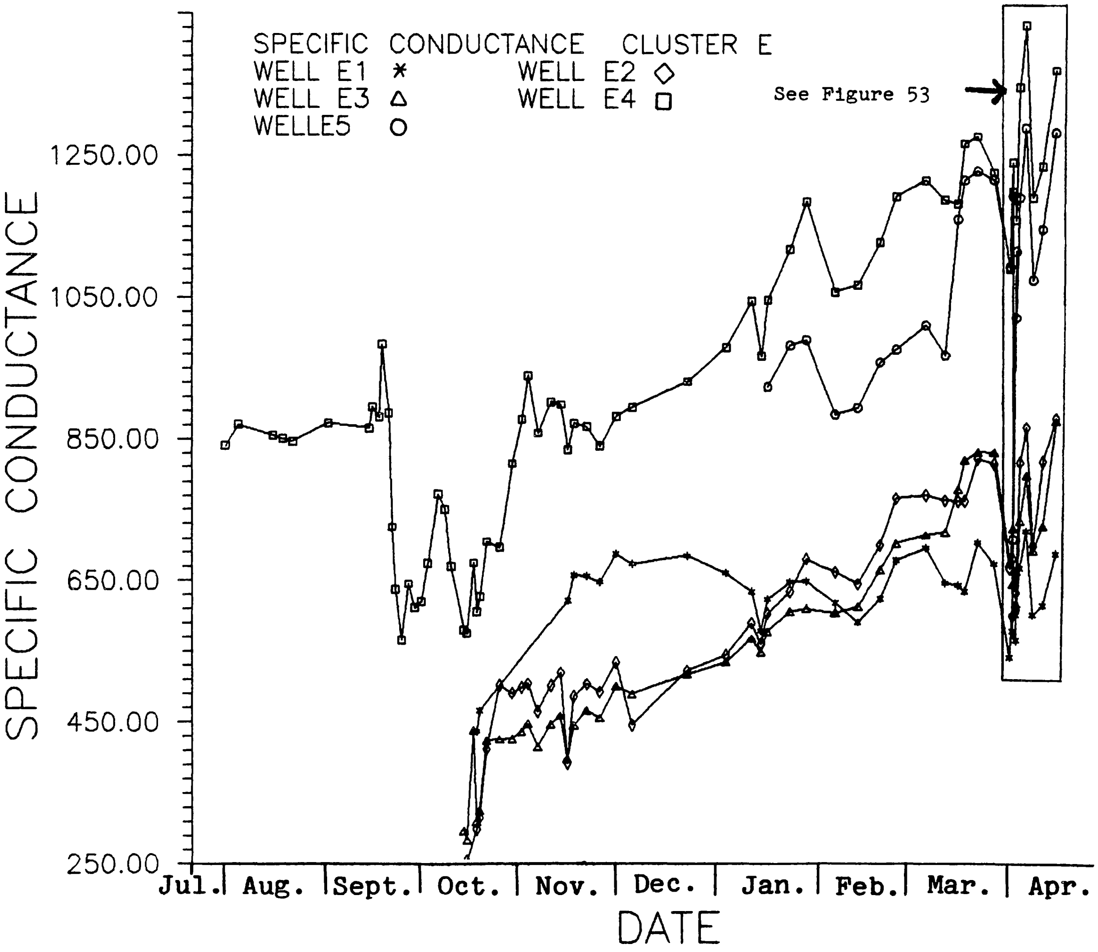


Figure 51. Specific Conductance, Cluster E

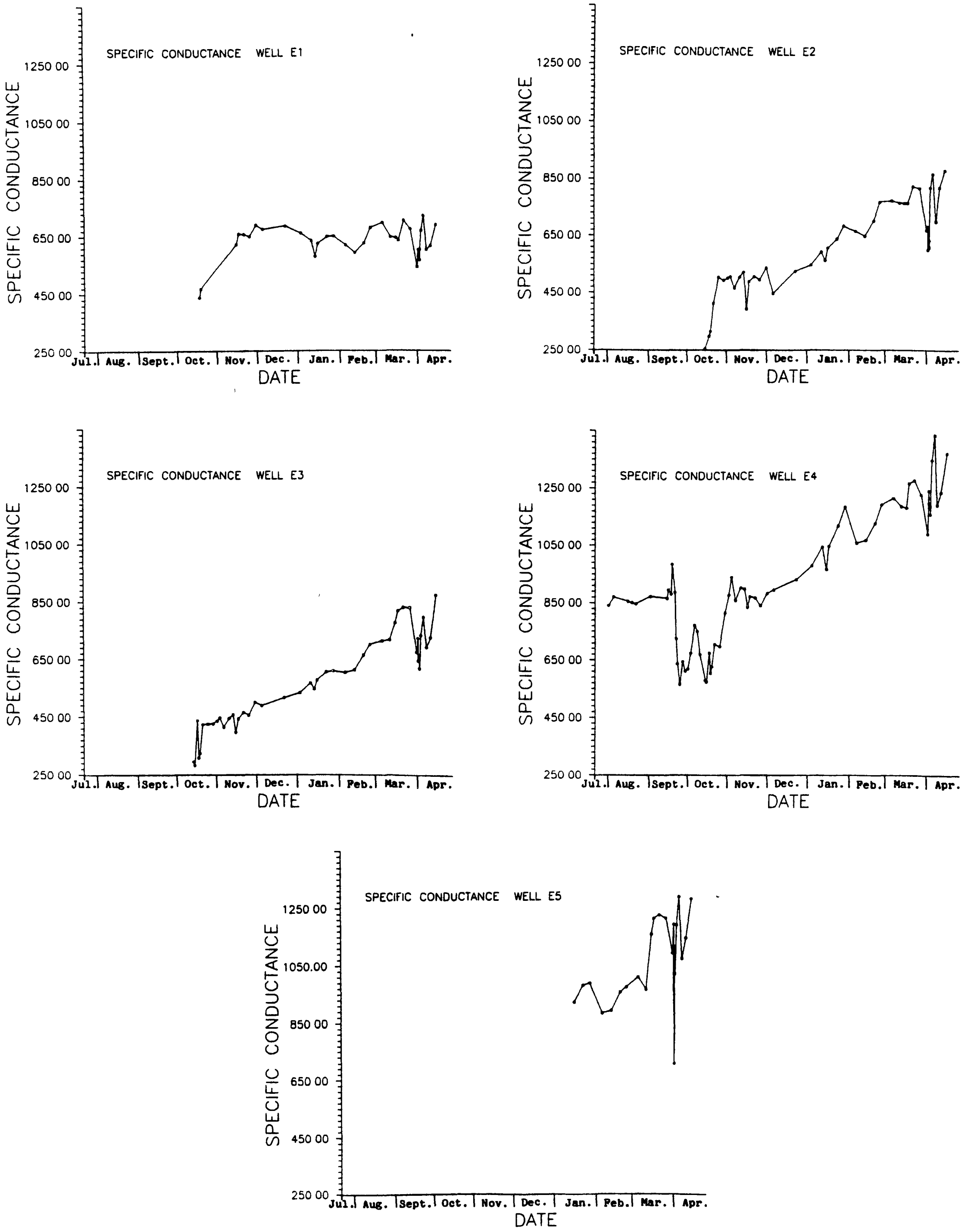


Figure 52. Specific Conductance, Individual Wells at Cluster E

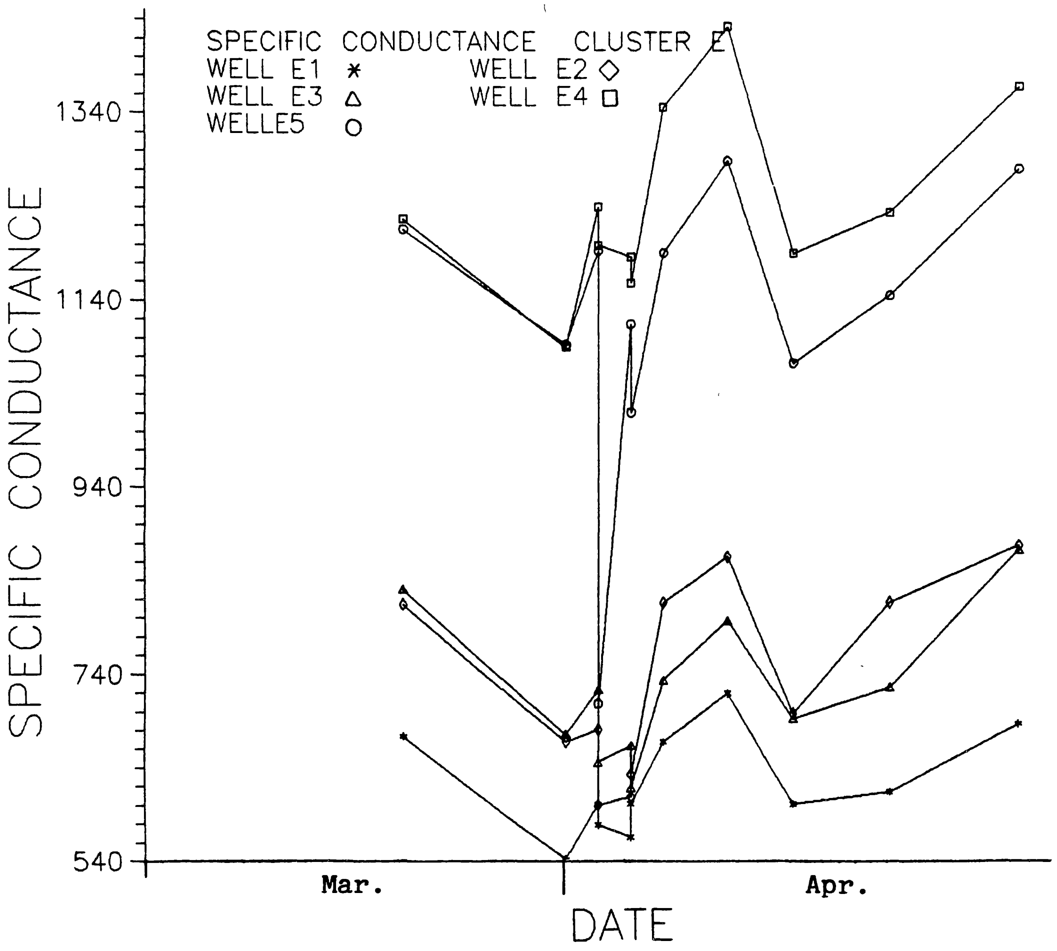


Figure 53. Specific Conductance, Cluster E, March 27-April 15, 1986

observed after recharge events. Two specific examples are are noteworthy and are discussed in the following section. The least variation with respect to time appears to occur during periods characterized by an absence of precipitation, such as the winter of 1986. The variations observed during periods of no rainfall may be related to the accuracy limits of the techniques used to determine nitrate and specific conductance, or underflow phenomena.

Rather large variations in nitrate and specific conductance have been observed in several of the wells which sample intermediate intervals. As mentioned earlier, these variations are probably related to leakage from more or less mineralized zones located above or below the sampled interval.

Several wells exhibited a good correlation between nitrate concentration and specific conductance during the fall recharge period (Figure 54). By mid-November this correlation began to deteriorate, and by mid-winter, the specific conductance was increasing while the nitrate concentration was decreasing. There are several exceptions to this pattern.

Temporal Variation: A Study of Three Individual Cases

In addition to the spatial variations over the study area, several changes in ground-water quality have occurred with time. These fluctuations in quality have been asso-

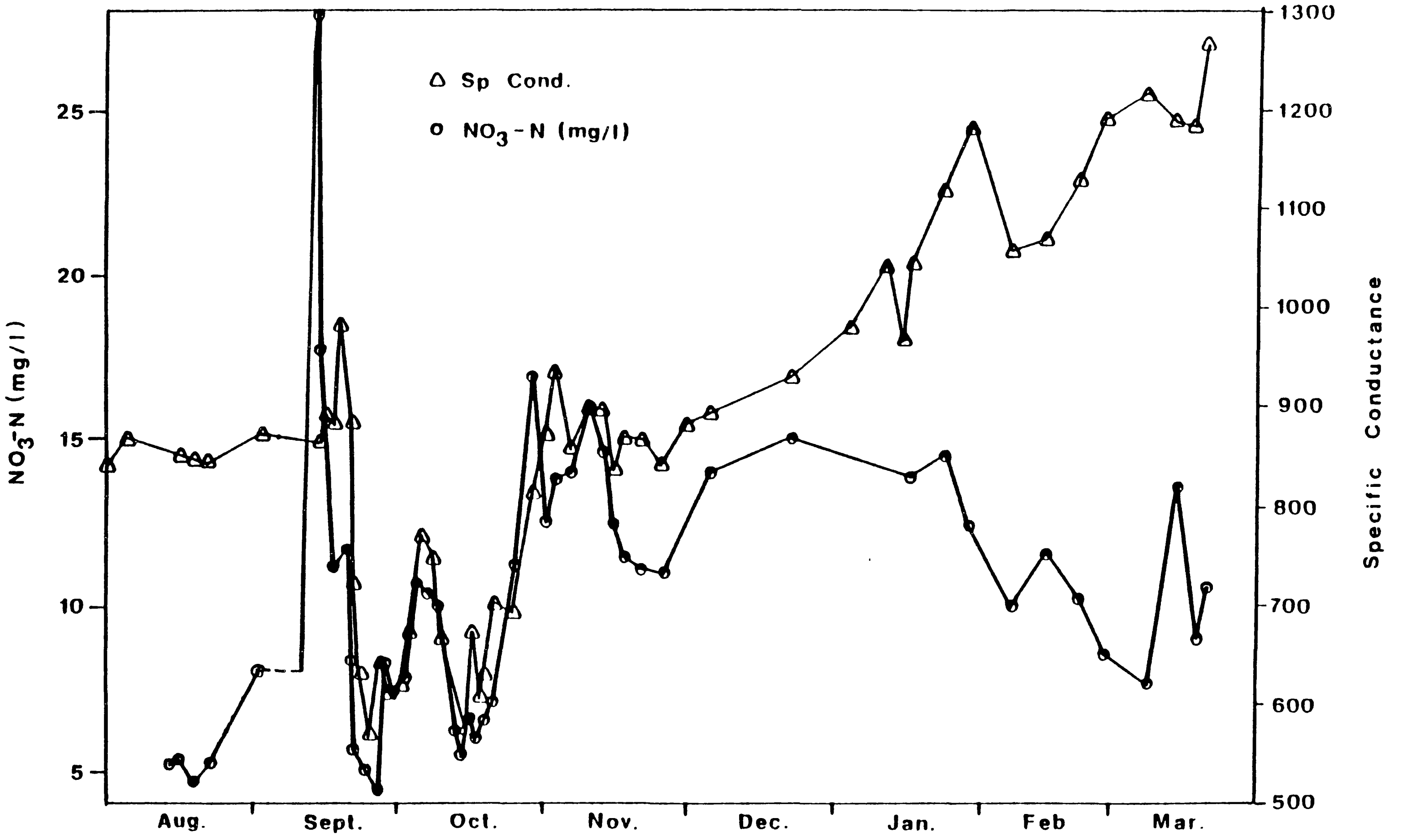


Figure 54. Nitrate and Specific Conductance Trends With Time, Well E4

ciated with both short-term and long-term recharge events. In isolated cases, changes in quality have occurred in deeper wells, while the shallower wells appear to change little. Three individual events are discussed in detail below.

Mid-September, 1985 Event

In early September, water levels across the study area had fallen to about 11.25 feet below land surface, permitting the sampling of only the four deepest wells (A4, C4, D4, and E4). The nitrate concentrations on September 2 ranged from 3.7 to 7.9 milligrams per liter nitrate-nitrogen. The week prior to and two weeks following this sampling, no precipitation was recorded and the maximal daily air temperature was consistently near 100 degrees. During this time, several large dessication cracks formed. These cracks had openings at the surface nearly a half inch wide.

On July 31 and September 13, a total of 300 pounds of dry fertilizer was applied over the study area. The fertilizer was composed of 16 per cent nitrogen, which is equivalent to 48 pounds (Chemlawn, personal comm.). Several rainfall events in August caused very little change in ground-water quality with respect to nitrate.

On the night of September 13 and part of the following morning, a series of large thunderstorms produced 1.4 inches of rainfall. It was noted on September 14 that there was a lack of surface ponding of the precipitation. Samples collected on September 15 indicated nitrate-nitrogen concentrations had increased about fourfold and ranged between 10.8 and 27.9 milligrams per liter. By September 16, the nitrate concentrations across the site had decreased and ranged from 9.4 to 17.7 milligrams per liter nitrate-nitrogen. Samples collected through September 25 indicated a general decrease in concentration, with nitrate concentrations on this date being between 4.1 and 4.9 milligrams per liter.

Water levels rose about two tenths of a foot by September 16 and fell to the lowest level recorded over the period of investigation (approximately 11.8 feet below land surface) by September 21. It appears the volume of water infiltrating to the water table was quite small, but the concentration in terms of nitrate was large. In addition, it is evident that flow through the unsaturated zone during this event was at least five feet per day. During this time, the soil moisture content was exceedingly low and undoubtedly well below field capacity. This implies that flow through the unsaturated zone was controlled by macropores. At depth the control on flow may have been the extension of dessication cracks to the water table and/or pathways between ped faces, which are known to exist to at least seven feet.

Early April, 1986 Event

By early April, 1986, water levels ranged from 7.3 to

7.5 feet below land surface and all 20 monitoring wells were routinely being sampled. The concentrations of nitrate ranged from 23.7 to 0.5 milligrams per liter nitrate-nitrogen throughout the site, with the maximal concentration being obtained from the interval tapped by well A1.

From April 1 to April 4 there was approximately 3.1 inches of precipitation. In this respect, the event was quite similar to the September 13, 1986 event. During the four days, water levels rose approximately 1.5 feet in all wells, with the shallower wells being impacted to a greater degree. On April 1, the concentration of nitrate in well A1 was 23.7 milligrams per liter. On April 1 and 2, 0.8 inches of precipitation fell and samples taken from well A1 indicated nitrate concentrations had increased to 25.2 milligrams per liter. By the afternoon of April 2, the concentration of nitrate in well A1 had decreased to 18.4 milligrams per liter nitrate-nitrogen. The following day an additional 1.3 inches of rainfall was recorded and samples taken from well A1 indicated the nitrate concentrations had decreased to 14.3 milligrams per liter and by the afternoon of the same day had declined to 10.3 milligrams per liter. By the April 15 the nitrate concentration in well A1 was still only about 65 per cent of the concentration prior to the recharge event.

Other shallow wells at the site showed similar, although not as pronounced, trends in nitrate concentration. The exception was well E1, which exhibited no apparent trend during this interval. The deeper wells were also affected in terms of nitrate concentration, but they did not follow the pattern of the shallowest wells.

Variations in Well D4

On several occasions the nitrate concentration in well D4 has varied considerably while the concentration in the shallower wells at that site remained relatively unchanged. Surface influences, such as direct infiltration of nitrate-enriched percolate would undoubtedly impact the shallower wells prior to influencing well D4. Occurrences such as this were not observed. Therefore, it appears the cause of this phenomenon is related to underflow which transporting nitrate-enriched ground water into the study area from outside sources. Similar occurrences have been noted at well E4, but are they not as pronounced at the other "4" wells.

During the early spring recharge period, well D4 had nitrate concentrations that ranged from 7.9 to 11.9 milligrams per liter nitrate-nitrogen. Figures 42 and 44 illustrate the distribution of nitrate at Site D. On April 2 and April 8, the nitrate concentration in well D4 was 7.09 and 11.9 respectively. On the same days, the nitrate concentrations in well D1 were 0.67 and 1.43, respectively. Although both wells show an increase of the same order of magnitude, the actual increase was much greater in well D4. The causes for such changes are discussed further in the following chapter.

The Composite Well: A Special Case

The "5" wells at each well cluster are designed to collect a composite sample over the interval monitored by the other four wells. The quality of the samples collected from these wells should reflect the quality of the entire interval and should most closely resemble the zone with the greatest permeability.

In most cases, the nitrate concentrations and specific conductance values from the composite wells lie between the maximal and minimal values found in the other four wells. In all cases, the values most closely resemble the interval sampled by the "4" wells, that is, the deepest interval. This interval corresponds closely to the alluvium-weathered shale boundary zone, indicating increased permeability in the vicinity of this boundary.

On several occasions, samples collected from the composite wells have yielded nitrate and/or specific conductance values that fall outside the maximal or minimal values collected from the other four wells in the same cluster (Figures 30, 33, and 45, for examples). The reason for this is the placement of the screened interval in the "1" through "4" wells. These wells sample intervals no greater than about four to six inches. Between the sampled intervals are areas in the aquifer that are essentially unsampled by these wells. The composite well samples the entire interval, including that part not sampled by the other wells. It is very likely the composite wells are reflecting either more highly mineralized or less mineralized intervals not sampled by the other wells, even though the composite wells are still most strongly influenced by the interval tapped by the "4" wells.

CHAPTER IV

POSSIBLE CAUSES OF VARIATIONS IN GROUND-WATER QUALITY

The data show that large ranges in the concentration of many constituents exists over the small study area. For example, nitrate concentrations have ranged from 0.30 to 27.9 milligrams per liter and bicarbonate has ranged between 329.5 and 1165 milligrams per liter. The range between the minimal and maximal of most of the monitored parameters is at least an order of magnitude in space and time. These variations occur within vertical distances of only 5.5 feet and a maximal horizontal distance between well sites of about 125 feet. In terms of time, nitrate concentrations have increased fourfold and alternatively decreased twofold in a matter of days.

The possible causes for these large scale variations in such short distances and small time intervals are numerous and include proximity to large, deep-rooted trees, dilution, cation exchange, recharge through macropores, surface sources of nitrogen, and dentrification. These processes and their relationship to the recorded variations are discussed on the following pages.

Temporal Variations

Short-Term Variations

The short-term variations in nitrate concentration appear to be controlled by recharge and a surface source of nitrogen. Large fluctuations of nitrate concentrations have occurred during some, but not all, recharge events. These variations have been neither consistent nor uniform. One recharge event caused a fourfold increase in nitrate concentration, while a similar event caused a more than twofold decrease. The mid-September and early April events are discussed below.

The mid-September event was responsible for the largest short-term nitrate increases. Several facts are known about the event. First, a nitrate source, in the form of fertilizer, was present. Secondly, relatively large surface fractures dominated the study area and a soil moisture deficiency existed (Acre, 1986). Finally, the rainfall event was of extremely high intensity, and short duration; surface ponding was absent.

The recorded variations (Figures 30 and 32, for example) in nitrate concentration were probably controlled by flow through macropores and a substantial amount of nitrogen at the surface. Two days following the storm, the nitrate concentrations had increased about fourfold over the monitored area. During this time, water levels rose but slightly. Therefore, the volume of water reaching the water table was small, while the nitrate concentration was large. Based on the chemical data, flow through the unsaturated zone was at least five feet per day. Due to the soil moisture deficiency which existed at the time, there is a strong implication that flow through the unsaturated zone was macropore-controlled.

Four days following the event, samples taken from many of the wells had nitrate concentrations that were less than the pre-storm conditions. These anomalously low concentrations can be attributed to dilution and/or microbial activity. Flow of percolating water depleted in nitrates through the unsaturated zone following the initial nitrate "slug" would sufficiently dilute the ground water in terms of nitrate. Also, increased nutrients (nitrate) reaching the water table during the first two days may have caused an increase in the microbial population and activity which would cause nitrate depletion.

The early April recharge event was in some respects quite similar to the mid-September event, except the unsaturated zone contained substantially more moisture. During this time, the area received heavy rainfall from a series of several large thunderstorms of high intensity. Unlike the the fall event, macropores were not visible and the soil moisture content was greater (Acre, 1986). During the precipitation periods surface ponding was common and remained for several days. A large nitrate source at the surface was absent.

Dilution appears to be the controlling factor on nitrate concentrations during the early April event. The water levels were impacted to a large extent, indicating that a relatively large volume of water had infiltrated through the unsaturated zone and reached the ground water. With initial precipitation, nitrate concentrations in many wells increased slightly. With further rainfall, nitrate concentrations decreased, most dramatically in well A1. An initial "slug" of a solution with slightly higher nitrate concentrations impacted the water table. This was followed by percolating water through the unsaturated zone which was low in nitrate, causing dilution. Again, microbial activity could have played a role in the decreasing nitrate concentrations, although is questionable. Prior to the recharge event, the nitrate concentrations in well A1 were consistently high and did not appear to be affected by denitrification processes. Data do not suggest that conditions had changed enough to support denitrification processes.

Underflow phenomena appear to contribute to the variations of nitrate, particularly in wells D4 and E4. At times the nitrate concentration may increase in these wells while adjacent wells are impacted little. An upgradient nitrate source would account for this occurrence, and it is not unlikely. The area is residential, and undoubtedly heavily fertilized. These wells appear to tap the zone of greatest permeability and thus would be affected to the greatest degree from these upgradient sources.

Nitrogen Mass Balance

The amount of nitrogen available at the surface is a controlling factor in the short-term variations noted at the study area. The mass of nitrogen reaching the water table during recharge events is controlled by the surface nitrogen content. Over the course of a year, the investigative area received three applications of fertilizer equivalent to 72 pounds of nitrogen (Chemlawn, personal comm.). The amount of nitrate-nitrogen in rain water may vary from season to season, but on two occasions was found to be 0.3 mg/l. Calculations for the following discussion are contained in Appendix D.

The following assumptions must be made in order to calculate the mass of nitrogen which reaches the ground water:

1. An average value of 0.10 for the porosity of the aquifer over the entire area is reasonable.
2. The composite wells reasonably reflect the mass of nitrogen reaching the ground water during a given event (i.e. the concentration of composite wells should beused in the calculations).
3. All water level changes during the two discussed events are due to recharge.
4. Underflow does not significantly contribute to the nitrate concentrations of the composite wells on a

short-term basis.

The mid-September event resulted in an estimated 4.1 pounds of nitrate-nitrogen entering the ground-water system, most likely from the surface. The amount of nitrogen entering the area dominated by grasses (monitored by wells A4 and E4) was about 2.8 pounds or 7.7 per cent of the total nitrogen applied at the surface prior to the event. The wells monitoring the tree-dominated southern boundary (wells C4 and D4) showed that only about 1.3 pounds of nitrate-nitrogen entered the system (about 3.7 per cent of the total applied).

The early April event differed from the September event in that it was not preceeded by substantial additions of nitrogen at the surface. Nitrate concentrations during the April event appear to be controlled by dilution. A larger volume of water migrated through the unsaturated zone during the mid-April event due to the increased precipitation. During this four day time a total of about 1.1 pounds of nitrogen entered the ground-water system, with about 0.66 pounds entering in the grass-dominated areas and about 0.44 entering from the tree-dominated area. This is equivalent to 1.8 and 1.2 per cent respectively of the total nitrogen applied the prior year. During this time, the concentration of nitrate-nitrogen in the composite wells decreased even though nitrogen was added to the system. Dilution from the large volume of water reaching the ground water accounts for this occurrence.

The mass of nitrogen entering the system during the two events was controlled by surface availability of nitrogen and the volume of water reaching the ground water. Despite the lesser precipitation and severe soil moisture deficiency of the mid-September event, the mass of nitrogen entering the ground-water system was almost four times that of the early-April event. In both cases, the deep-rooted trees appear to influence significantly the amount of nitrogen reaching the ground water when compared to grasses.

Long-Term Variations

The data shows that from mid-September to mid-November of 1985, rather large variations of many monitored parameters occurred over the study area. The possible cause for this occurrence is due to the number of wells and corresponding aquifer intervals being sampled. During fall recharge, the water levels rose four to five feet and allowed the sampling of wells that had been dry for several months. These wells tap different aquifer intervals. Prior to this, only four wells (one at each site) were monitoring the area. These wells sampled only one depth at each site. The noted variations are a function of the increased number of intervals and wells sampled.

Spatial Variations

The possible causes for the noted spatial variations include dilution, cation exchange, proximity to large, deep-rooted trees, and denitrification. Sharp vertical and horizontal changes in geochemical and microbiological parameters may play a large role in the variations of certain ionic species. Oxidation-reduction potential and denitrifying bacteria are two examples. Statistical and empirical methods were used as interpretive tools to aid in the delineation of the causes of the spatial variations. Possible causes for these variations are discussed below.

Dilution

The chemical quality over the study area is quite variable, but the ground water is essentially of the same character (see Appendix E). In general the water is of the calcium-sodium-bicarbonate and calcium-magnesium-bicarbonate type.

In general, the concentration of the major ions decrease with depth and it appears dilution is occurring. Although no regular trends with depth hold true over the entire area, some general statements may be made. As one would expect specific conductance, bicarbonate, and other ions decrease with depth. In fact, specific conductance appears to be controlled primarily by the dominant, bicarbonate ion (strongly supported by a correlation coefficient of 0.99).

Based on specific conductance, an empirical relationship resulting in a dilution factor may be derived. The mean specific conductance for the entire data set is about

1000 micromhos. Based upon that value, a dilution factor for individual wells may be calculated by the following:

$$\text{Dilution Factor} = 1000/\ \text{specific conductance} \qquad (4.1)$$

When the concentration of the monitored ionic species are multiplied by the dilution factor, stabilization of those ions controlled solely by dilution will occur. Table V summarizes the results of the application of this method on the data set.

Based upon the changes in and stabilization of the standard deviations, it appears dilution accounts for the variation of bicarbonate and possibly magnesium and chloride. Variations in sulfate and potassium may be the result of lower concentrations and decreased precision. Calcium, sodium, and nitrate concentrations do not stabilize after they have been corrected for dilution. Therefore, additional geochemical processes are affecting the variations in their concentrations.

Cation Exchange

Calcium and sodium concentrations are quite possibly being controlled by ion exchange as well as dilution. When one looks at the analysis of January 23, 1986 (Appendix E) it appears this is the case and is possibly related to changes in clay type with depth. After dilution is taken into account, the trend of these parameters with depth is certainly not consistent. For example, in well

TABLE V

MEAN AND STANDARD DEVIATION OF IONIC CONSTITUENTS (MG/L) PRIOR TO AND FOLLOWING MULTIPLICATION BY THE DILUTION FACTOR (1000/S.C.)

	Prior		Following	
	Mean	Std. Dev.	Mean	Std. Dev.
NO3-N	6.02	4.25	6.23	4.49
Cl	22.30	13.80	20.80	10.50
SO4	38.40	10.90	37.00	10.10
HCO3	643.00	199.00	613.00	70.00
Na	67.20	46.90	57.90	29.80
Ca	80.40	30.60	78.70	26.70
Mg	51.10	14.70	48.90	7.30
K	0.48	0.36	0.48	0.38

cluster A the sodium concentration increases with depth while the calcium concentration decreases. In well cluster C, the opposite is true and in well clusters D and E there is no clear trend with depth.

Mass balance techniques enable one to measure the amount of cation exchange occurring at each site and depth. The technique involves balancing equivalent weights of the major ions. Although several weaknesses in the assumptions are apparent, they must be made in order to evaluate the data. They are as follows:

1. All chloride is derived by solution of halite and is subtracted from the milliequivalents of sodium. The remaining sodium is assumed to be derived from ion exchange.
2. All sulfate is derived from the solution of gypsum and is subtracted from the calcium milliequivalents. The remaining calcium is assumed to be derived from carbonate weathering.
3. Magnesium is derived from a carbonate source and is thus subtracted from bicarbonate milliequivalents. The remaining bicarbonate is assumed to be derived from weathering of calcite.

The remaining calcium and sodium values may then be added and compared with the remaining bicarbonate value. These values should essentially balance. An ion exchange factor may then be derived. The purpose of the ion exchange factor calculation is to measure the amount of ion exchange occurring at the sampled interval. It is calculated by dividing the remaining sodium milliequivalents by the sum of the remaining calcium and sodium milliequivalents. Larger values are indicative of increased sodium for calcium ion exchange. Table VI summarizes the results of this methodology on the January 23, 1986 analyses. Cation exchange of sodium for calcium increases with depth at site A, decreases with depth at site C, is relatively consistent with depth at site D, and increases with depth at site E.

The causes for the variation of ion exchange factors is probably related to a change in clay mineralogy with depth. Mineral coatings on quartz grains may also play a role in the ion exchange of the sampled intervals. Further research in the area of subsurface characterization is necessary before any definite conclusions regarding these variations may be made.

Proximity to Deep-Rooted Trees

A possible cause for the spatial variations of nitrate concentration is the proximity of some well sites to large, deep-rooted trees. Spatial variations of nitrate concentrations follow few trends, with each well cluster having individual patterns. The two well sites along the tree-dominated southern boundary show an inverse correlation between specific conductance and normalized nitrate values (-0.82 for site C and -0.74 for site D) with nitrate decreasing with depth. It was noticed during the pit

TABLE VI

ION EXCHANGE FACTORS FOR INDIVIDUAL WELLS AFTER DILUTION HAS BEEN TAKEN INTO ACCOUNT

Well	Ion Exchange Factor (adjusted Na/Na+Ca)	Balance (%)
A2	0.06	1.2
A3	0.15	1.8
A4	0.24	5.1
A5	0.26	3.5
C1	0.73	8.5
C2	0.69	14.0
C3	0.70	6.0
C4	0.25	3.1
C5	0.41	1.8
D1	0.45	2.5
D2	0.41	3.6
D3	0.40	5.5
D4	0.55	2.3
D5	0.55	8.2
E1	0.19	15.6
E2	0.01	6.4
E3	0.28	5.7
E4	0.41	1.5
E5	0.28	5.7

excavation that the roots from trees along this boundary extended beyond seven feet. The withdrawl of nutrients (nitrate) from ground water by these trees and woody plants is quite possible. The other two sites, which do not have close proximity to deep-rooted trees, have failed to show similar trends in nitrate concentration with depth. In fact data from site E shows a strong direct correlation (0.75) between nitrate concentration and specific conductance. Site A has nitrate concentration which decrease with depth, probably resulting from fall recharge influences and distance from trees and woody plants. These observations are strongly supported by the nitrogen mass balance results of the preceding section.

Oxidation-Reduction and Microbial Activity

The dominant nitrogen species existing at a given time is controlled by a series of oxidation-reduction reactions and accompanied microbial activity. Under reducing conditions, denitrification occurs with nitrate being converted to nitrite and finally to atmospheric nitrogen. This is primarily a biochemical process with denitrifying bacteria being responsible for the transformations.

The low nitrate concentration of several wells may be explained by changing redox potential and the prescence of denitrifying bacteria. Evidence for varying redox potential with depth and at well sites is not conclusive, but the possibility of such a condition does exists. Oxidation-reduction reactions and microbial activity may be the cause for the variations in nitrate as well as other constituents. Nitrate concentrations in several shallow wells, particularly at site D, are quite low. Microbial activity (denitrification) under reducing conditions would account for these anomalies.

Cluster E: The Exception

The above discussion has stated there are several exceptions to the general cases. In most instances, the exceptions are found in well cluster E. Examples include; (1) all major ions concentrations increase with depth, (2) nitrate concentrations increase with depth and all are high, and (3) specific conductance values increase with depth. It appears dilution is occurring at the shallow depths.

Cluster E is located at the corner of one of the buildings at the study area. The causes for the anomalies at cluster E could be related to its proximity to this structure. Increased runoff from the building causing an increased volume of infiltrating water through the unsaturated zone would account for the dilution trend present at site E.

CHAPTER V

CONCLUSIONS, IMPLICATIONS, AND SUGGESTIONS FOR FURTHER RESEARCH

Ground-water quality is often thought of as being consistent and uniform in time and space. When anomalies in the data occur, many researchers tend to discount those data as being erroneous. This may be especially true when the data do not fit preconceived ideas. The fact that ground-water quality may change quickly horizontally, vertically, and temporally is not well documented, and the mechanisms for such occurrences certainly are poorly understood.

Sources of error that contribute to variations in water-quality data include chemical analyses, sampling, sample handling, and inadequate purging processes to name a few. These unwanted sources of variation must be controlled and limited if variations due to sources such as land use and recharge are to be detected.

Changes in ground-water quality may be greatest in fine-grained systems, which are often thought of as confining units. Additionally, these changes may be neither consistent nor uniform in time and space. The temporal variations of ground-water quality depend on a number of content, the presence of macropores, and a surface source of a contaminant. Spatial variations depend on physical and geochemical processes such as aquifer stratigraphy, underflow phenomena, dilution, redox potential, and rock-water interactions, to name a few.

Conclusions

Based on the results of the study, the following conclusions may be made:

1. Variations in the nitrate data due to analytical error, sampling, sample handling, and pumping after the well is adequately purged do not contribute significantly to the overall variation of the data.
2. Short-term variations of nitrate concentration are related to recharge events, although not all recharge events produced large variations.
3. Short-term increases in nitrate concentrations are controlled by the presence of a surface nitrogen source such as fertilizer and open pathways through the unsaturated zone. Short-term decreases in nitrate concentration are related to the lack of a surface source of nitrogen, a large volume of water reaching the water table, and the lack of macropore development (absence of open pathways).
4. The single greatest increase in nitrate concentration occurred when the soil moisture content was at its lowest. This event was

responsible for a fourfold increase in the nitrate concentration in no more than two days.

5. Spatial variation of many monitored parameters ranged by at least an order of magnitude. This is despite vertical distances of no more than 5.5 feet and a maximal horizontal distance between any sampling point of about 125 feet.
6. Spatial variations, with respect to bicarbonate and possibly chloride and magnesium, are due to the process of dilution. Calcium and sodium concentrations are controlled by cation exchange processes. Spatial variations of nitrate are controlled by the proximity to deep-rooted trees and possibly denitrification.
7. Flow through the unsaturated and saturated zones appears to be fracture controlled, at least in part. Macropores in the unsaturated zone are responsible for recharge when the soil moisture content is below field capacity, and in turn, are responsible for large variations in nitrate over short time periods. Vertical flow velocities may exceed 5.5 feet per day during these times. Fractures in the saturated zone, particularly in the vicinity of the alluvium- weathered shale contact accounts for elevated hydraulic conductivity values and underflow phenomena, which appear to influence ground-water quality.

8. The greatest spatial variations have occurred during the late fall and winter. This is a function of the increased number of wells and intervals being sampled, which was brought about by a water level rise of several feet due to recharge.
9. The event which caused the fourfold increase in nitrate resulted in only a two-tenth of a foot rise in water levels. This implies that a small, highly concentrated volume of water reached the water-table during the event.
10. Convective thunderstorms of high intensity, short duration, and small areal extent have the potential to affect ground-water quality as much as or more than cyclonic systems of long duration, low intensity, and large areal extent.
11. Fluctuating ground-water flow direction and gradient are controlled by evapotranspiration from large,deep-rooted trees.

Implications

The conclusions bring to light a number of questions concerning ground-water monitoring. Since the parameters monitored over the investigative period had a range of values, what are their background concentrations? Wouldn't their background concentrations be expressed more appropriately as a range rather than a finite number? Is such a range of values typical of shallow, low-permeabilty formations or an anomaly? Would one expect to find such ranges in an aquifer with higher permeability? What effect do the above questions have on the accepted schemes and practices of sampling and monitoring?

Should one sample a well following a large convective storm, or sample after a prolonged dry period? If a well is sampled following a storm, will the concentration be anomalously high, low, or not affected? How would one predict the concentration expected in situations such as these?

The data base suggests that purging even a small volume of water from a well may cause leakage of more highly mineralized or less mineralized water from overlying or underlying zones. Should generally accepted well purging practices be re-evaluated? Would such sampling considerations need to be evaluated on a site-specific or well-specific basis?

The data base has shown a great deal of variation of all ionic species. In this study, these parameters were measured in the parts per million range. What is the significance of the variation caused by unwanted sources, such as sampling, pumping, and sample handling, when constituents are measured in the parts per billion range? Might this have a major impact on aquifer restoration schemes and legal action?

Suggestions for Further Research

In most projects as many questions as answers are generated. The exploratory nature of this research makes it no exception. Areas that are suggested for further work include:

1. Quantification of the redox potential of the various intervals being sampled.
2. Subsurface characterization including texture analysis, x-ray diffraction, petrography, soil organic matter and cation exchange capacity determinations, and soil microbiological characterization.
3. Aquifer testing for longer durations in order to gain a better understanding of the water-bearing properties of the aquifer.
4. Expansion of the monitored parameters to include pesticides and herbicides that are applied at the surface periodically.
5. Monitor the unsaturated zone in order to understand better the movement of contaminants from land surface to the ground water.

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APPENDIXES

APPENDIX A

LOGS OF AUGER DRILLED WELLS

Site A

0-4 ft........brown silt and clay with fine sand lenses
4-6 ft........dark brown, organic-rich clay and silt
6-8 ft........red-brown clay with silt, manganese nodules
8-10 ft.......red clay and silt, red shale fragments
10-18 ft......red weathered shale, shale and sandstone fragments, few fine sand lenses present

Site C

0-2.5 ft......brown silt and clay
2.5-4.5 ft....dark brown silt, clay and fine sand
4.5-6ft.......light brown clay with silt, few red fine sand stringers, manganese nodules
6-8 ft........red-brown clay and silt with few fine sand stringers and manganese nodules
8-10 ft.......red clay and silt, shale frags.
10-14 ft......red weathered shale, shale and sandstone fragments

Site D

0-3 ft........red-brown silt and clay
3-4 ft........red-brown silt and fine sand, little clay
4-5.5 ft......brown silt and clay with few fine sand lenses,from 4.8 to 5.5 ft well sorted medium quartz sand (probably fill material)
5.5-12 ft.....red silt, increasing clay content with depth, few fine sand lenses and manganese nodules
12-13 ft......red fine sand
13-14 ft......weathered shale, shale and sandstone fragments

Site E

0-3.5 ft...... silt with small amount of clay
3.5-5 ft...... dark brown silt, clay content increasing but still low compared to other sites
5-6 ft........ light brown clay with silt
6-7 ft........ red clay and silt, sandstone frags.
7-11 ft....... red clay and silt, sandstone frags. extremely difficult to auger (drilling time much slower), real tight
11-14 ft...... weathered shale

APPENDIX B

WELL SPECIFICATIONS

Well Specifications Measured in Feet from Concrete Pad

Well	Tot. Depth	Screened Interval	Gravel Pack
A1	8.48	8.01-8.19	7.29
A2	9.16	8.72-8.89	8.56
A3	10.31	9.95-10.12	9.29
A4	13.76	13.65-13.40	10.65
A5	14.00	7.00-14.00	7.00
C1	8.26	7.93-8.10	7.98
C2	9.19	8.93-9.10	9.00
C3	10.58	9.90-10.40	
C4	14.62	14.23-14.40	11.07
C5	14.00	7.00-14.00	7.00
D1	8.24	8.00-8.16	7.50
D2	9.33	9.04-9.21	8.77
D3	10.76	9.91-10.41	9.35
D4	14.16	13.59-13.92	11.17
D5	14.00	7.00-14.00	7.00
E1	8.67	8.33-8.50	8.17
E2	9.71	9.35-9.52	9.10
E3	10.54	10.10-10.35	9.93
E4	14.10	13.61-13.90	10.90
E5	14.00	7.00-14.00	7.00

PAD ELEVATIONS

Site	Pad Elev.
A	884.63
C	884.37
D	884.47
E	884.71

APPENDIX C

NITRATE MULTIPLE SAMPLES FROM "4" WELLS

Well	Day	Obs. #	Value (NO3-N mg/l)
A4	1.0 (Aug. 14, 1985)	1	3.93
		2	4.06
		3	3.74
		4	3.73
		5	4.14
		6	3.96
		7	4.45
		8	3.98
		9	3.87
		10	3.95
		11	4.38
		12	4.18
C4	1.0	1	1.73
		2	1.62
		3	1.90
		4	1.95
		5	1.99
		6	1.84
		7	1.86
		8	1.97
		9	1.62
		10	1.80
		11	1.95
		12	1.90
D4	1.0	1	3.40
		2	3.53
		3	3.67
		4	3.77
		5	3.69
		6	3.94
		7	3.63
		8	3.54
		9	3.69
		10	3.41
		11	3.75
		12	3.73
E4	1.0	1	5.08
		2	5.24
		3	5.37
		4	5.33
		5	5.10
		6	5.18
		7	5.29
		8	5.61
		9	5.06
A4	6.0	1	5.24
		2	5.16
		3	5.08
C4	6.0	1	2.76
		2	2.65
		3	2.77
D4	6.0	1	4.96
		2	4.50
		3	4.78
E4	6.0	1	4.25
		2	4.40
		3	5.24
A4	12.0	1	4.30

		2	4.45
C4	12.0	1	3.12
		2	3.23
		3	3.43
D4	12.0	1	4.41
		2	5.15
E4	12.0	1	5.94
		2	5.53
A4	22.0	1	3.73
		2	3.61
		3	3.92
C4	22.0	1	3.90
		2	4.14
		3	3.72
D4	22.0	1	4.38
		2	4.32
		3	3.91
E4	22.0	1	8.11
		2	7.97
		3	7.39
A4	35.0	1	16.45
		2	16.30
		3	16.20
C4	35.0	1	10.70
		2	10.70
		3	11.20
D4	35.0	1	11.85
		2	12.30
		3	12.30
E4	35.0	1	27.35
		2	28.50
		3	27.70
A4	36.0	1	9.58
		2	9.08
		3	9.41
C4	36.0	1	10.15
		2	9.98
		3	10.10
D4	36.0	1	9.81
		2	9.98
		3	9.78
E4	36.0	1	17.05
		2	17.50
		3	18.50
A4	38.0	1	1.88
		2	1.71
		3	1.76
C4	38.0	1	2.86
		2	2.78
		3	2.68
D4	38.0	1	3.35
		2	3.22
		3	2.99
E4	38.0	1	10.45
		2	11.40
		3	11.50
A4	39.0	1	4.60
		2	4.19
		3	4.15
C4	39.0	1	4.91

		2	4.50
		3	4.00
D4	39.0	1	4.64
		2	4.30
		3	4.28
E4	39.0	1	10.90
		2	11.20
		3	11.10
A4	45.0	1	4.12
		2	4.24
		3	3.96
E4	45.0	1	5.26
		2	4.72
		3	4.59
D4	45.0	1	4.34
		2	4.36
		3	4.47
C4	45.0	1	4.40
		2	4.28
		3	4.40
A4	47.0	1	2.31
		2	2.68
		3	2.79
C4	47.0	1	4.09
		2	4.01
		3	4.01
D4	47.0	1	3.98
		2	3.61
		3	3.59
E4	47.0	1	4.43
		2	4.36
A4	51.0	1	3.44
		2	3.47
		3	3.33
C4	51.0	1	5.05
		2	4.88
		3	4.81
D4	51.0	1	4.80
		2	4.74
		3	4.97
E4	51.0	1	7.41
		2	7.37
		3	7.00
A4	53.0	1	3.90
		2	3.76
		3	3.72
C4	53.0	1	5.55
		2	5.39
		3	5.53
D4	53.0	1	5.12
		2	5.12
		3	5.05
E4	53.0	1	7.60
		2	7.85
		3	7.82
A4	58.0	1	3.30
		2	3.17
		3	3.13
C4	58.0	1	5.44
		2	5.44

		3	5.30
D4	58.0	1	5.31
		2	5.13
		3	5.25
E4	58.0	1	10.25
		2	10.40
		3	10.40
A4	60.0	1	3.45
		2	3.17
		3	3.16
C4	60.0	1	5.38
		2	5.36
		3	5.35
D4	60.0	1	5.19
		2	5.35
		3	5.46
E4	60.0	1	10.20
		2	9.95
		3	10.00
A4	67.0	1	2.32
		2	2.13
		3	2.16
C4	67.0	1	4.61
		2	4.85
		3	4.73
D4	67.0	1	4.60
		2	4.57
		3	4.65
E4	67.0	1	6.78
		2	6.69
		3	6.70
A4	79.0	1	3.50
		2	3.48
		3	3.31
C4	79.0	1	6.35
		2	6.50
		3	6.25
D4	79.0	1	6.25
		2	6.28
		3	6.49
E4	79.0	1	17.00
		2	16.50
		3	17.20
A4	82.0	1	3.11
		2	3.08
		3	3.17
C4	82.0	1	6.01
		2	5.90
		3	5.98
D4	82.0	1	6.16
		2	6.38
		3	6.36
E4	82.0	1	12.20
		2	12.60
		3	12.70
A4	84.0	1	4.50
		2	4.36
		3	4.41
C4	84.0	1	5.13
		2	5.19

D4	84.0	1	7.10
		2	7.09
E4	84.0	1	14.00
		2	14.00
		3	13.80
A4	87.0	1	4.30
		2	4.36
C4	87.0	1	5.50
		2	5.96
		3	5.65
D4	87.0	1	6.21
		2	6.18
		3	6.41
E4	87.0	1	14.00
		2	13.90
A4	96.0	1	3.50
		2	3.41
		3	3.30
C4	96.0	1	5.53
		2	5.96
		3	5.82
D4	96.0	1	6.18
		2	6.10
		3	6.26
E4	96.0	1	12.40
		2	12.40
		3	12.30
A4	160.0	1	6.83
		2	7.16
		3	6.53
C4	160.0	1	6.19
		2	5.96
		3	6.40
D4	160.0	1	7.61
		2	8.42
		3	8.71
E4	160.0	1	13.10
		2	14.60
A4	164.0	1	8.77
		2	8.60
		3	9.35
C4	164.0	1	4.83
		2	4.90
		3	6.08
D4	164.0	1	8.37
		2	9.13
		3	7.83
E4	164.0	1	12.20
		2	12.10
		3	12.90
A4	180.0	1	7.95
		2	7.59
		3	6.94
C4	180.0	1	5.07
		2	5.42
		3	5.57
D4	180.0	1	6.42
		2	7.77
		3	7.70
E4	180.0	1	11.50

		2	11.60
		3	11.70
A4	189.0	1	7.50
		2	6.17
		3	7.50
C4	189.0	1	6.13
		2	6.10
E4	189.0	1	10.20
		2	9.91
		3	10.50
C4	194.0	1	4.43
		2	4.82
		3	4.94
D4	194.0	1	6.46
		2	6.98
		3	7.07
E4	194.0	1	8.51
		2	10.20
		3	8.39
A4	203.0	1	3.82
		2	5.04
		3	4.42
C4	203.0	1	2.71
		2	3.79
D4	203.0	1	5.53
		2	5.84
		3	4.68
E4	203.0	1	7.58
		2	8.94
		3	6.37
A4	213.0	1	6.90
		2	6.93
		3	5.83
C4	213.0	1	4.60
		2	4.35
		3	5.61
D4	213.0	1	6.59
		2	6.52
		3	6.55
E4	213.0	1	9.15
		2	9.95
		3	8.02
A4	215.0	1	6.51
		2	5.14
		3	6.67
C4	215.0	1	5.59
		2	5.24
		3	4.84
D4	215.0	1	7.35
		2	7.76
		3	7.86
E4	215.0	1	10.70
		2	10.20
		3	10.75
A4	219.0	1	8.29
		2	9.71
C4	219.0	1	6.47
		2	5.92
		3	5.23
E4	219.0	1	15.00

		2	13.80
		3	13.90
A4	224.0	1	5.22
		2	5.33
		3	5.50
C4	224.0	1	7.05
		2	7.24
		3	6.86
D4	224.0	1	10.40
		2	10.50
		3	11.20
E4	224.0	1	11.60
		2	12.40
A4	229.0	1	6.74
		2	6.60
		3	6.68
C4	229.0	1	5.74
		2	5.16
		3	5.42
D4	229.0	1	12.40
		2	11.50
		3	13.00
E4	229.0	1	12.40
		2	11.50
		3	13.00
A4	230.0	1	10.30
		2	8.50
		3	8.76
C4	230.0	1	7.48
		2	6.64
		3	6.87
D4	230.0	1	7.48
		2	8.37
		3	7.81
E4	230.0	1	10.60
		2	11.00
		3	10.70
A4	230.0	1	5.67
		2	6.07
C4	230.0	1	5.50
		2	5.53
D4	230.0	1	7.14
		2	7.11
		3	7.01
E4	230.0	1	11.30
		2	9.75
		3	12.80
A4	231.0	1	5.72
		2	5.79
		3	6.00
C4	231.0	1	4.62
		2	4.68
		3	4.70
D4	231.0	1	7.98
		2	7.87
		3	7.83
E4	231.0	1	9.74
		2	10.10
		3	9.74
A4	231.0	1	5.76

		2	6.01
		3	6.09
C4	231.0	1	5.34
		2	5.36
		3	5.22
D4	231.0	1	7.58
		2	7.94
		3	7.84
E4	231.0	1	9.14
		2	10.40
		3	10.70
A4	232.0	1	6.72
		2	6.53
		3	6.55
C4	232.0	1	5.62
		2	5.46
		3	5.62
D4	232.0	1	8.47
		2	8.37
		3	8.16
E4	232.0	1	10.80
		2	10.70
		3	10.30
A4	234.0	1	6.69
		2	6.81
		3	6.95
C4	234.0	1	5.22
		2	5.16
		3	5.09
E4	234.0	1	12.60
		2	12.50
		3	13.10
A4	236.0	1	8.33
		2	8.18
		3	7.93
C4	236.0	1	6.41
		2	6.49
		3	6.55
D4	236.0	1	11.40
		2	12.30
		3	11.90
E4	236.0	1	15.10
		2	14.90
		3	14.70
A4	239.0	1	6.54
		2	6.57
		3	6.32
C4	239.0	1	4.78
		2	4.88
		3	4.76
D4	239.0	1	7.76
		2	7.69
		3	7.58
E4	239.0	1	11.50
		2	10.70
A4	243.0	1	5.93
		2	5.88
		3	5.70
C4	243.0	1	4.25
		2	4.28

		3	4.38
D4	243.0	1	8.04
		2	7.82
		3	7.93
E4	243.0	1	11.80
		2	11.10
		3	10.90

APPENDIX D

NITROGEN MASS BALANCE CALCULATIONS

NITROGEN BALANCE CALCULATIONS

Conversions: 1 pound = 457 grams
1 cubic ft. = 28.32 liters

General Equation: lbs. N = 28.32 * mg/l N * sat. thickness * effective porosity * area of aquifer

Methodology: Calculate pounds of N prior to and after individual events, and subtract the prior amount to obtain the amount leached to ground water system. Compare that value to the amount added at the surface for that year to obtain the per cent leached to the ground water.

September 13, 1985 Event
Sites A and E
Prior N
28.32 * 5.85 mg/l * 2.1 ft. * 0.1 * 11,000 = 0.83 lb
After N
28.32 * 22.1 mg/l * 2.4 ft. * 0.1 * 11,000 = 3.6 lbs
Amount Leached
2.77 lbs N

Sites C and D
Prior N
28.32 * 3.8 mg/l * 2.1 ft. * 0.1 * 11,000 = 0.55 lb
After N
28.32 * 11.5 mg/l * 2.4 ft. * 0.1 * 11,000 = 1.88 lbs
Amount Leached
1.33 lbs N

April 1-4, 1986 Event
Sites A and E
Prior N
28.32 * 9.0 mg/l * 6.7 ft. * 0.1 * 11,000 = 4.16 lbs
After N
28.32 * 8.5 mg/l * 8.4 ft. * 0.1 * 11,000 = 4.82 lbs
Amount Leached
0.66 lbs N
Sites C and D
Prior N
28.32 * 7.4 mg/l * 6.7 ft. * 0.1 * 11,000 = 3.28 lbs
After N
28.32 * 6.5 mg/l * 8.4 ft. * 0.1 * 11,000 = 3.72 lbs
Amount Leached
0.44 lbs.

APPENDIX E

CHEMICAL DATA, JAN. 26, 1986

```
JAN. 23, 1986        WELL A1
                      mg/l       mM        meg/l
TEMP (C)              13.60
SP. COND.           1049.00
  PH                   6.95
 NO3-N                22.90
  Cl                  31.70     0.89       0.89
  SO4                 38.50     0.40       0.80
 HCO3                572.10     9.38       9.38
  NA                  10.80     0.47       0.47
  CA                 141.90     3.54       7.08
  MG                  44.20     1.82       3.63
   K                   0.23     0.01       0.01


SUM OF ANIONS:        11.07
SUM OF CATIONS:       11.19
BALANCE:              -0.54
```

```
JAN. 23, 1986        WELL A2
                      mg/l       mM        meg/l
TEMP (C)              14.10
SP. COND.           1047.00
  PH                   6.90
 NO3-N                11.90
  Cl                  28.70     0.81       0.81
  SO4                 41.90     0.44       0.87
 HCO3                608.70     9.98       9.98
  NA                  26.70     1.16       1.16
  CA                 137.70     3.44       6.87
  MG                  45.80     1.88       3.77
   K                   0.26     0.01       0.01


SUM OF ANIONS:        11.66
SUM OF CATIONS:       11.81
BALANCE:              -0.63
```

```
JAN. 23, 1986        WELL A3
                      mg/l       mM        meg/l
TEMP (C)              14.80
SP. COND.            967.00
  PH                   6.95
 NO3-N                 6.81
  Cl                  16.50     0.47       0.47
  SO4                 28.70     0.30       0.60
 HCO3                649.90    10.65      10.65
  NA                  31.90     1.39       1.39
  CA                 114.30     2.85       5.70
  MG                  58.80     2.42       4.84
   K                   0.28     0.01       0.01


SUM OF ANIONS:        11.71
SUM OF CATIONS:       11.93
BALANCE:              -0.93
```

```
JAN. 23, 1986         WELL A4
                       mg/l         mM        meg/l
TEMP (C)               16.80
SP. COND.             983.00
   PH                   7.00
  NO3-N                 6.84
   Cl                  17.20       0.49        0.49
    SO4                24.20       0.25        0.50
  HCO3                611.70      10.02       10.02
   NA                  42.70       1.86        1.86
   CA                  95.20       2.38        4.75
   MG                  46.20       1.90        3.80
    K                   0.18        .00         .00


SUM OF ANIONS:         11.01
SUM OF CATIONS:        10.41
BALANCE:                2.81
```

```
JAN. 23, 1986         WELL A5
                       mg/l         mM        meg/l
TEMP (C)               16.40
SP. COND.             892.00
   PH                   7.01
  NO3-N                 7.66
   Cl                  15.60       0.44        0.44
    SO4                24.90       0.26        0.52
  HCO3                585.80       9.60        9.60
   NA                  43.50       1.89        1.89
   CA                  93.10       2.32        4.65
   MG                  43.80       1.80        3.60
    K                   0.23       0.01        0.01


SUM OF ANIONS:         10.56
SUM OF CATIONS:        10.15
BALANCE:                1.99
```

```
JAN. 23, 1986        WELL C1
                      mg/l        mM         meg/l
TEMP (C)              13.00
SP. COND.           1681.00
   PH                  7.00
  NO3-N                3.07
   Cl                 30.00      0.85        0.85
   SO4                48.40      0.50        1.01
  HCO3              1113.60     18.25       18.25
   NA                166.10      7.22        7.22
   CA                 67.60      1.69        3.37
   MG                 96.30      3.96        7.92
    K                  0.30      0.01        0.01


SUM OF ANIONS:        20.10
SUM OF CATIONS:       18.52
BALANCE:               4.09
```

```
JAN. 23, 1986        WELL C2
                      mg/l        mM         meg/l
TEMP (C)              13.20
SP. COND.           1530.00
   PH                  6.78
  NO3-N                4.75
   Cl                 30.00      0.85        0.85
   SO4                48.00      0.50        1.00
  HCO3              1165.50     19.10       19.10
   NA                179.80      7.82        7.82
   CA                 80.30      2.00        4.01
   MG                 70.00      2.88        5.76
    K                  0.28      0.01        0.01


SUM OF ANIONS:        20.95
SUM OF CATIONS:       17.59
BALANCE:               8.71
```

```
JAN. 23, 1986        WELL C3
                      mg/l        mM         meg/l
TEMP (C)              13.80
SP. COND.           1271.00
   PH                  6.96
  NO3-N                4.30
   Cl                 29.10      0.82        0.82
   SO4                45.10      0.47        0.94
  HCO3               836.00     13.70       13.70
   NA                153.40      6.67        6.67
   CA                 69.70      1.74        3.48
   MG                 51.70      2.13        4.25
    K                  0.15       .00         .00


SUM OF ANIONS:        15.46
SUM OF CATIONS:       14.41
BALANCE:               3.53
```

JAN. 23, 1986	WELL C4 mg/l	mM	meg/l
TEMP (C)	15.30		
SP. COND.	950.00		
PH	6.96		
NO3-N	6.18		
Cl	28.90	0.82	0.82
SO4	31.50	0.33	0.66
HCO3	612.70	10.04	10.04
NA	47.40	2.06	2.06
CA	89.20	2.23	4.45
MG	52.50	2.16	4.32
K	0.24	0.01	0.01
SUM OF ANIONS:	11.51		
SUM OF CATIONS:	10.84		
BALANCE:	3.02		

JAN. 23, 1986	WELL C5 mg/l	mM	meg/l
TEMP (C)	14.80		
SP. COND.	1110.00		
PH	6.94		
NO3-N	4.38		
Cl	26.90	0.76	0.76
SO4	30.10	0.31	0.63
HCO3	715.50	11.73	11.73
NA	81.60	3.55	3.55
CA	93.10	2.32	4.65
MG	56.70	2.33	4.66
K	0.18	.00	.00
SUM OF ANIONS:	13.11		
SUM OF CATIONS:	12.86		
BALANCE:	0.96		

```
JAN. 23, 1986          WELL D1
                        mg/l       mM        meg/l
TEMP (C)                13.00
SP. COND.             1604.00
   PH                    7.18
  NO3-N                  2.66
   Cl                   67.30     1.90       1.90
   SO4                  59.90     0.62       1.25
  HCO3                 942.80    15.45      15.45
   NA                  139.70     6.08       6.08
   CA                  127.00     3.17       6.34
   MG                   69.20     2.85       5.69
    K                    0.34     0.01       0.01


SUM OF ANIONS:          18.60
SUM OF CATIONS:         18.11
BALANCE:                 1.32


JAN. 23, 1986          WELL D2
                        mg/l       mM        meg/l
TEMP (C)                13.40
SP. COND.             1628.00
   PH                    7.19
  NO3-N                  1.75
   Cl                   53.80     1.52       1.52
   SO4                  52.70     0.55       1.10
  HCO3                1016.00    16.65      16.65
   NA                  125.90     5.48       5.48
   CA                  137.70     3.44       6.87
   MG                   75.40     3.10       6.20
    K                    0.15      .00        .00


SUM OF ANIONS:          19.27
SUM OF CATIONS:         18.55
BALANCE:                 1.89


JAN. 23, 1986          WELL D3
                        mg/l       mM        meg/l
TEMP (C)                13.80
SP. COND.             1186.00
   PH                    6.95
  NO3-N                  2.35
   Cl                   45.60     1.29       1.29
   SO4                  35.70     0.37       0.74
  HCO3                 771.90    12.65      12.65
   NA                   93.20     4.05       4.05
   CA                   97.30     2.43       4.86
   MG                   60.40     2.48       4.97
    K                    0.07      .00        .00


SUM OF ANIONS:          14.68
SUM OF CATIONS:         13.88
BALANCE:                 2.81
```

```
JAN. 23, 1986         WELL D4
                        mg/l        mM        meg/l
TEMP (C)               15.00
SP. COND.            1044.00
   PH                   7.12
  NO3-N                 8.25
   Cl                  26.70       0.75       0.75
   SO4                 50.10       0.52       1.04
  HCO3                672.70      11.02      11.02
   NA                 103.40       4.50       4.50
   CA                  81.70       2.04       4.08
   MG                  47.70       1.96       3.92
    K                   0.08        .00        .00


SUM OF ANIONS:         12.82
SUM OF CATIONS:        12.50
BALANCE:                1.27
```

```
JAN. 23, 1986         WELL D5
                        mg/l        mM        meg/l
TEMP (C)               14.70
SP. COND.            1056.00
   PH                   7.17
  NO3-N                 8.12
   Cl                  31.70       0.89       0.89
   SO4                 48.20       0.50       1.00
  HCO3                685.00      11.23      11.23
   NA                  97.40       4.24       4.24
   CA                  76.10       1.90       3.80
   MG                  48.30       1.99       3.97
    K                              0.00       0.00


SUM OF ANIONS:         13.12
SUM OF CATIONS:        12.01
BALANCE:                4.45
```

```
JAN. 23, 1986        WELL E1
                      mg/l        mM        meg/l
TEMP (C)              14.90
SP. COND.            648.00
   PH                  7.37
  NO3-N                5.65
   Cl                 11.70      0.33       0.33
   SO4                41.30      0.43       0.86
  HCO3               382.90      6.28       6.28
   NA                 20.30      0.88       0.88
   CA                 63.30      1.58       3.16
   MG                 28.80      1.18       2.37
    K                            0.00       0.00


SUM OF ANIONS:         7.46
SUM OF CATIONS:        6.41
BALANCE:               7.60



JAN. 23, 1986        WELL E2
                      mg/l        mM        meg/l
TEMP (C)              15.20
SP. COND.            635.00
   PH                  7.36
  NO3-N                7.54
   Cl                 14.30      0.40       0.40
   SO4                41.00      0.43       0.85
  HCO3               358.50      5.88       5.88
   NA                  9.70      0.42       0.42
   CA                 67.60      1.69       3.37
   MG                 36.30      1.49       2.99
    K                            0.00       0.00


SUM OF ANIONS:         7.13
SUM OF CATIONS:        6.78
BALANCE:               2.53



JAN. 23, 1986        WELL E3
                      mg/l        mM        meg/l
TEMP (C)              15.50
SP. COND.            607.00
   PH                  7.32
  NO3-N                8.82
   Cl                 17.80      0.50       0.50
   SO4                25.70      0.27       0.54
  HCO3               329.50      5.40       5.40
   NA                  8.70      0.38       0.38
   CA                 59.10      1.47       2.95
   MG                 32.10      1.32       2.64
    K                            0.00       0.00


SUM OF ANIONS:         6.44
SUM OF CATIONS:        5.97
BALANCE:               3.79
```

```
JAN. 23, 1986        WELL E4
                      mg/l        mM         meq/l
TEMP (C)              16.70
SP. COND.           1118.00
   PH                  7.10
  NO3-N               14.60
   Cl                 31.50      0.89        0.89
   SO4                58.30      0.61        1.21
  HCO3               611.00     10.01       10.01
   NA                 63.40      2.76        2.76
   CA                 77.70      1.94        3.88
   MG                 64.80      2.66        5.33
    K                            0.00        0.00

SUM OF ANIONS:        12.12
SUM OF CATIONS:       11.96
BALANCE:               0.63


JAN. 23, 1986        WELL E5
                      mg/l        mM         meq/l
TEMP (C)              16.80
SP. COND.            982.00
   PH                  7.18
  NO3-N               13.00
   Cl                 28.20      0.80        0.80
   SO4                47.90      0.50        1.00
  HCO3               549.20      9.00        9.00
   NA                 41.40      1.80        1.80
   CA                 71.90      1.79        3.59
   MG                 60.40      2.48        4.97
    K                            0.00        0.00

SUM OF ANIONS:        10.79
SUM OF CATIONS:       10.36
BALANCE:               2.07
```

APPENDIX F

RAW DATA, ALL WELLS

WELL A1

DATE	WATER L.	TEMP	SC	PH	NO3
07-Jun	6.11				
10-Jun	6.48	19.10	918.00	6.95	
15-Nov	7.75	19.60	968.00	7.17	12.60
17-Nov	7.29	19.40	1055.00	7.16	11.00
21-Nov	7.33	19.00	1062.00	7.20	13.10
25-Nov	7.41	18.70	1000.00	7.17	15.50
30-Nov	7.50	18.00	1030.00	7.36	
05-Dec	7.51	17.60	1021.00	7.39	18.20
22-Dec	7.42	16.50	878.00	7.35	22.30
29-Dec	7.58				
03-Jan	7.62	14.00	1044.00	7.59	
11-Jan	7.65	14.10	976.00	7.15	
14-Jan	7.67	13.50	1016.00	6.72	
16-Jan	7.70	15.10	978.00	6.75	21.10
20-Jan	7.68				
23-Jan	7.79	13.60	1049.00	6.95	22.90
28-Jan	7.66	13.30	1038.00	6.77	20.70
01-Feb	7.80				
04-Feb	7.73		1028.00	6.95	
06-Feb	7.79	13.60	1060.00	6.81	19.00
13-Feb	7.74	12.80	975.00	6.86	17.35
18-Feb	7.67				
20-Feb	7.79	12.80	1018.00	6.87	17.60
25-Feb	7.76	14.90	1030.00	6.96	16.90
02-Mar	7.79				
06-Mar	7.78	13.50	1060.00	6.93	16.40
12-Mar	7.65		1066.00	6.76	20.10
16-Mar	7.61		1053.00	6.73	16.50
18-Mar	7.44	13.80	1168.00	6.87	16.50
22-Mar	7.54	14.70	1069.00	6.72	22.40
27-Mar	7.53	14.20	1102.00	6.72	23.20
01-Apr	7.47		1020.00	6.88	23.70
02-Apr	7.40		1083.00	6.85	25.20
02-Apr	6.55		1093.00	6.87	18.40
03-Apr	6.49		1050.00	6.80	14.30
03-Apr			1076.00	6.95	10.30
04-Apr			1129.00	6.74	10.70
06-Apr	6.14		1170.00	6.81	14.90
08-Apr	6.33		1210.00	6.75	16.50
09-Apr	6.44				11.60
11-Apr	7.81		1038.00	6.76	14.00
15-Apr	6.65	12.10	1001.00	6.85	13.50

WELL A2

DATE	WATER L.		TEMP	SC	PH	NO3
07-Jun	5.95	878.68	18.60	975.00	7.05	
10-Jun	6.47	878.16				
19-Oct	8.48	876.15	21.90	995.00	6.75	11.20
21-Oct	8.52	876.11	21.20	1010.00	6.96	11.40
23-Oct	8.53	876.10	21.60	1034.00	7.05	
25-Oct	8.70	875.93				
27-Oct	8.66	875.97				
29-Oct	8.59	876.04	20.80	988.00	7.39	17.10
01-Nov	8.59	876.04	20.50	985.00	7.31	12.60
03-Nov	8.65	875.98	20.00	983.00	7.40	12.70
06-Nov	8.55	876.08	20.50	938.00	7.39	13.30
10-Nov	8.70	875.93	20.00	964.00	7.38	16.00
13-Nov	8.50	876.13	20.00	1060.00	7.43	12.50
15-Nov	7.50	877.13	20.00	985.00	7.33	12.80
17-Nov	7.31	877.32	19.60	1080.00	7.23	9.50
21-Nov	7.33	877.30	19.40	1074.00	7.22	9.40
25-Nov	7.39	877.24	19.00	1008.00	7.31	9.60
30-Nov	7.44	877.19	18.30	1053.00	7.34	12.60
05-Dec	7.46	877.17	18.00	1031.00	7.49	12.20
22-Dec	7.37	877.26	16.50	948.00	7.18	12.20
29-Dec	7.52	877.11				
03-Jan	7.56	877.07	14.60	1045.00	7.56	
11-Jan	7.58	877.05	14.80	1034.00	6.96	
14-Jan	7.60	877.03	14.70	1027.00	6.73	
16-Jan	7.64	876.99	15.60	1014.00	6.75	11.50
20-Jan	7.54	877.09				
23-Jan	7.70	876.93	14.10	1047.00	6.90	11.90
28-Jan	7.56	877.07	14.10	1033.00	6.82	14.60
01-Feb	7.73	876.90				
04-Feb	7.66	876.97		1072.00	6.91	
06-Feb	7.75	876.88	14.10	1077.00	6.75	12.40
13-Feb	7.70	876.93	13.80	971.00	6.87	9.74
18-Feb	7.63	877.00				
20-Feb	7.74	876.89	13.70	1036.00	6.83	10.60
25-Feb	7.71	876.92	15.90	1047.00	6.92	9.20
02-Mar	7.74	876.89				
06-Mar	7.73	876.90	13.90	1043.00	6.93	7.81
12-Mar	7.55	877.08		1065.00	6.80	14.00
16-Mar	7.56	877.07		1060.00	6.77	11.00
18-Mar	7.41	877.22	14.40	1155.00	6.78	12.90
22-Mar	7.49	877.14	15.10	1100.00	6.94	14.60
27-Mar	7.48	877.15	14.20	1102.00	6.81	15.30
01-Apr	7.46	877.17		999.00	7.04	12.90
02-Apr	7.35	877.28		1101.00	6.89	15.90
02-Apr		884.63		1042.00	6.88	11.30
03-Apr	6.57	878.06		1052.00	6.84	9.36
03-Apr	6.34	878.29		1058.00	7.04	8.18
04-Apr	5.78	878.85		1082.00	6.72	9.17
06-Apr	6.15	878.48		1154.00	6.90	14.30
08-Apr	6.35	878.28		1195.00	6.77	13.50
09-Apr	6.45	878.18				10.70
11-Apr	6.49	878.14		1053.00	6.76	11.80
15-Apr	6.61	878.02	12.40	983.00	6.94	10.40

WELL H3 DATE	WATER L.	TEMP	SC	PH	NO3
07-Jun	6.07				
10-Jun	6.50	18.40	989.00	7.05	
10-Oct	9.05				
14-Oct	9.55	21.00	1072.00	6.97	6.79
15-Oct	9.14	18.00	975.00	7.05	8.03
16-Oct	9.24				
17-Oct	9.24	22.10	1071.00	7.03	4.60
18-Oct	8.96	22.00	1116.00	6.92	4.90
19-Oct	8.53	21.90	1080.00	6.95	8.00
21-Oct	8.52	21.60	1079.00	7.03	3.90
23-Oct	8.53				
25-Oct	8.67	21.20	1048.00	7.16	6.08
27-Oct	8.64				
29-Oct	8.58	21.30	1025.00	7.26	4.80
01-Nov	8.58	21.20	1028.00	7.20	5.00
03-Nov	8.63	21.30	1035.00	7.20	6.80
06-Nov	8.56	21.00	997.00	7.21	5.00
10-Nov	8.69	20.40	1021.00	7.24	9.00
13-Nov	8.48	20.80	1056.00	7.20	5.30
15-Nov	7.53	21.00	937.00	7.33	3.60
17-Nov	7.29	20.10	1049.00	7.24	5.20
21-Nov	7.34	19.80	1056.00	7.43	4.40
25-Nov	7.43	19.40	1022.00	7.24	3.90
30-Nov	7.44	18.80	1083.00	7.36	4.00
05-Dec	7.42	18.60	1053.00	7.32	4.20
22-Dec	7.43	16.70	972.00	7.29	6.00
29-Dec	7.52				
03-Jan	7.57	15.80	1091.00	7.51	
11-Jan	7.58	15.20	1052.00	7.02	
14-Jan	7.62	15.20	1012.00	6.85	
16-Jan	7.65	16.10	995.00	6.83	6.17
20-Jan	7.55				
23-Jan	7.73	14.80	967.00	6.95	6.81
28-Jan	7.44	14.50	1022.00	6.86	6.62
01-Feb	7.76				
04-Feb	7.68		1033.00	6.93	
06-Feb	7.75	15.50	1015.00	6.85	6.09
13-Feb	7.69	14.40	907.00	6.86	6.10
18-Feb	7.63				
20-Feb	7.75	14.20	979.00	6.91	4.75
25-Feb	7.73		1009.00	6.99	5.14
02-Mar	7.74				
06-Mar	7.75	14.30	1013.00	7.00	3.04
12-Mar	7.59		1040.00	6.86	9.15
16-Mar	7.58		1046.00	6.87	5.69
18-Mar	7.44	14.70	1099.00	6.84	5.91
22-Mar	7.51	15.50	1084.00	6.93	8.71
27-Mar	7.51	15.20	1084.00	6.94	5.88

01-Apr	7.47		995.00	6.97	7.05
02-Apr	7.37		1082.00	6.97	8.18
02-Apr			1025.00	6.90	6.07
03-Apr	6.40		1031.00	6.70	6.14
03-Apr	6.26		1015.00	6.95	5.81
04-Apr	5.65		1082.00	6.82	6.97
06-Apr	5.94		1131.00	6.95	8.1[illegible]
08-Apr	6.15		1158.00	6.82	8.95
09-Apr	6.34				6.83
11-Apr	6.36		1022.00	6.81	7.15
15-Apr	6.65	12.60	983.00	7.09	[illegible]

WELL A4

DATE	WATER L.	TEMP	SC	PH	NO3
5-Jul	9.91	20.20	840.00	7.05	
19-Jul	9.81	20.30	950.00	7.09	
02-Aug	10.02	20.70	975.00	7.14	
05-Aug	10.00	20.60	1035.00	7.14	
13-Aug	10.68				
14-Aug					4.00
16-Aug	10.42	21.10	1025.00	7.10	3.70
19-Aug	10.51	20.00	1045.00	7.09	5.20
21-Aug	10.34				
22-Aug	10.27	22.10	1020.00	7.17	4.40
24-Aug	10.62				
26-Aug	10.65				
30-Aug	11.02				
02-Sep	11.10	21.70	1013.00	7.14	3.80
09-Sep	11.53	21.70	999.00	7.10	
15-Sep	11.44	21.60	992.00	7.10	16.30
16-Sep	11.29	21.70	1020.00	7.10	9.10
18-Sep	11.35	21.30	974.00	7.15	1.80
19-Sep	11.43	22.20	1011.00	7.17	4.30
21-Sep	11.49	20.80	921.00	7.22	3.70
22-Sep	11.25	21.70	950.00	7.19	3.50
23-Sep	10.84	20.50	930.00	7.17	3.20
25-Sep	10.53	20.60	953.00	7.16	4.10
27-Sep	10.48	20.20	990.00	7.17	2.60
28-Sep	10.55				
29-Sep	10.38	19.60	967.00	7.14	4.40
01-Oct	10.23	20.00	964.00	7.15	3.40
02-Oct	10.18				
03-Oct	10.21	20.30	970.0	7.21	3.80
05-Oct	10.34				
06-Oct	10.26	20.80	960.00	6.99	2.[illegible]
08-Oct		21.30	945.00	6.9[illegible]	3.20
10-Oct	10.23	19.60	960.00	7.08	3.30
14-Oct	9.15	20.10	915.00	7.14	3.2[illegible]
15-Oct	9.18	19.00	892.00	7.09	3.30
16-Oct	9.27				
17-Oct	9.28	21.70	942.00	7.03	2.20
18-Oct	8.59	21.50	950.00	7.08	3.20
19-Oct	8.48	21.60	914.00	7.04	2.90
21-Oct	8.53	21.50	950.00	7.1[illegible]	2.20
23-Oct	8.54				
25-Oct	8.70	21.50	9[illegible].00	7.15	3.40
27-Oct	8.63				
29-Oct	8.61	21.30	927.00	7.25	1.40
01-Nov	8.60	21.2[illegible]	935.00	7.20	3.10
03-Nov	8.64	21.50	934.00	7.21	4.40
05-Nov	8.39	21.10	899.00	7.26	4.30
10-Nov	8.72	20.60	877.00	7.42	5.40
13-Nov	8.40	21.00	93[illegible].[illegible]	7.29	3.60
15-Nov	7.59	20.90	888.00	7.31	3.30
17-Nov	7.32	20.60	933.00	7.37	3.40
21-Nov	7.34	20.50	954.00	7.37	3.10
25-Nov	7.40	20.20	895.00	7.38	3.[illegible]

30-Nov	7.45	20.00	920.00	7.46	4.10
05-Dec	7.44	19.90	952.00	7.47	3.50
22-Dec	7.38	18.60	890.00	7.44	4.60
29-Dec	7.52				
03-Jan	7.57	16.90	1013.00	7.67	
11-Jan	7.57	17.00	935.00	7.15	
14-Jan	7.58	17.50	994.00	6.80	
16-Jan	7.63	18.50	928.00	6.85	6.00
20-Jan	7.54				
23-Jan	7.71	16.80	983.00	7.00	6.84
28-Jan	7.59	16.10	935.00	6.93	8.90
01-Feb	7.74				
04-Feb	7.69		1028.00	6.95	
06-Feb	7.74	16.00	995.00	6.90	5.19
13-Feb	7.67	16.00	877.00	6.90	7.49
18-Feb	7.63				
20-Feb	7.75	15.80	917.00	6.92	7.00
25-Feb	7.71		976.00	6.96	4.61
02-Mar	7.75				
06-Mar	7.74	15.70	969.00	7.02	4.47
12-Mar	7.56		983.00	6.39	9.60
16-Mar	7.59		968.00	6.85	5.55
18-Mar	7.44	16.10	1041.00	6.83	6.11
22-Mar	7.51	16.50	1019.00	6.90	[illegible]
27-Mar	7.50	16.50	970.00	6.84	5.75
01-Apr	7.50	16.00	917.00	6.99	6.67
02-Apr	7.38		1022.00	6.93	[illegible]
02-Apr			959.00	[illegible]	[illegible]
03-Apr	6.73		968.00	6.38	5.34
03-Apr	6.80		936.00	5.09	[illegible]
04-Apr	6.15		1031.00	6.82	6.60
06-Apr	6.49		1077.00	6.96	6.82
08-Apr	6.41		1095.00	6.35	8.15
09-Apr	6.85				6.36
11-Apr	6.55		972.00	6.87	6.48
15-Apr	6.60	12.50	922.00	7.18	[illegible]

WELL A5

DATE	WATER L.	TEMP	SC	PH	NO3
22-Dec	7.39				
29-Dec	7.50				
03-Jan	7.57				
11-Jan	7.61				
14-Jan	7.64	18.50	922.00	6.91	4.50
16-Jan	7.54				
20-Jan	7.72	16.40	892.00	7.01	7.06
23-Jan	7.57	16.10	938.00	6.92	6.70
28-Jan	7.75				
01-Feb	7.67		955.00	6.91	
04-Feb	7.75	16.00	936.00	6.81	5.68
06-Feb	7.68	16.00	803.00	6.89	6.09
13-Feb	7.63				
18-Feb	7.81	15.60	1002.00	6.89	6.40
20-Feb	7.76		964.00	6.99	5.45
25-Feb	7.73				
02-Mar	7.76	15.70	934.00	6.99	2.66
06-Mar	7.58		952.00	6.93	9.22
12-Mar	7.59		958.00	6.89	6.00
16-Mar	7.45	15.70	1032.00	6.85	4.01
18-Mar	7.52	16.40	987.00	6.92	7.[illegible]
22-Mar	7.60	16.50	980.00	6.93	5.03
27-Mar	7.60		703.00	7.00	6.37
01-Apr	7.41		1001.00	6.94	7.38
02-Apr			958.00	6.98	5.67
02-Apr	6.71		948.00	6.88	5.37
03-Apr	6.59		757.00	6.88	5.05
03-Apr	5.80		1020.00	6.80	6.19
04-Apr	6.24		1057.00	6.97	6.67
06-Apr	6.21		1092.00	6.84	7.[illegible]
08-Apr	6.50				
09-Apr	6.36		968.00	6.35	6.32
11-Apr	6.63	12.50	918.00	7.14	7.68
15-Apr					

WELL C1

DATE	WATER L.	TEMP	SC	PH	NO3
10-Jun	7.05	18.30	1411.00		
15-Nov	7.53	17.60	1628.00	7.34	[illegible]
21-Nov	7.49	17.50	1706.00	7.53	2.00
25-Nov	7.45	17.80	1602.00	7.50	2.60
30-Nov	7.44	16.80	1731.00	7.74	2.77
05-Dec	7.46	16.40	1628.00	7.76	0.95
22-Dec	7.29	14.60	1661.00	7.56	4.10
29-Dec	7.40				
03-Jan	7.44	14.20	1940.00	7.98	
11-Jan	7.45	13.40	1657.00	7.12	
14-Jan	7.48	13.00	1690.00	6.99	
16-Jan	7.50	15.20	1517.00	7.14	[illegible]
20-Jan	7.42				
23-Jan	7.60	13.00	1681.00	7.00	3.07
28-Jan	7.41	12.80	1591.00	7.11	2.96
01-Feb	7.59				
04-Feb	7.53				
06-Feb	7.60	15.80	1475.00	7.21	1.60
13-Feb	7.54	13.00	1543.00	7.16	1.20
18-Feb	7.47				
20-Feb	7.38	12.80	1625.00	7.26	[illegible]
25-Feb	7.56	16.20	1647.00	7.28	1.65
02-Mar	7.56				
06-Mar	7.58	12.70	1728.00	7.24	1.3
12-Mar	7.40		1668.00	7.18	[illegible]
16-Mar	7.39	18.40	1600.00	7.21	[illegible]
18-Mar	7.23	12.90	1648.00	7.14	[illegible]
22-Mar	7.32	13.30	1707.00	7.32	[illegible]
27-Mar	7.33	13.60	1704.00	7.05	[illegible]
01-Apr	7.42		1559.00	7.15	[illegible]
02-Apr	7.18		1677.00	7.10	[illegible]
[illegible]-Apr			1629.00	7.02	[illegible]
03-Apr	5.93		1674.00	7.10	[illegible]
03-Apr	[illegible]		1715.00	7.04	1.35
04-Apr	5.14		1915.00	7.04	1.88
06-Apr	5.74		1914.00	6.79	[illegible]
08-Apr	5.83		1979.00	6.94	[illegible]
09-Apr	5.97				1.40
11-Apr	5.95		1717.00	6.93	1.44
15-Apr	6.31	11.90	[illegible]	[illegible]	[illegible]

WELL C2

DATE	WATER L.	TEMP	SC	PH	NO3
10-Jun	7.05	17.30	1448.00	7.10	
29-Oct	8.79				
01-Nov	8.76	18.60	1311.00	7.57	3.60
03-Nov	8.78				
06-Nov	8.75	18.50	1243.00	8.01	
13-Nov	8.56				
15-Nov	7.83	18.00	1196.00	7.58	3.70
17-Nov	7.42	17.90	1253.00	7.39	2.80
21-Nov	7.41	17.90	1314.00	7.55	3.30
25-Nov	7.40	17.70	1261.00	7.40	2.60
30-Nov	7.42	16.90	1385.00	7.60	2.92
05-Dec	7.43	16.80	1348.00	7.61	1.71
22-Dec	7.26	14.80	1403.00	7.56	3.61
29-Dec	7.38				
03-Jan	7.42	14.60	1620.00	7.83	
11-Jan	7.42	13.30	1493.00	6.96	
14-Jan	7.45	13.70	1518.00	6.94	
16-Jan	7.48	16.00	1412.00	6.91	2.25
20-Jan	7.38				
23-Jan	7.58	13.20	1530.00	6.73	1.75
28-Jan	7.40	13.20	1528.00	6.89	3.14
01-Feb	7.57				
04-Feb	7.51				
06-Feb	7.63	16.40	1357.00	7.02	2.91
13-Feb	7.51	13.20	1452.00	6.99	2.70
18-Feb	7.44				
20-Feb	7.53	13.00	1531.00	6.93	3.2[illegible]
25-Feb	7.34	16.40	1550.00	7.05	[illegible]
02-Mar	7.54				
05-Mar	7.54	12.70	1624.00	7.07	1.31
12-Mar	7.41		1560.00	7.00	3.25
16-Mar	7.37	18.50	1503.00	7.[illegible]	[illegible]
18-Mar	7.21	13.00	1609.00	6.9[illegible]	2.44
22-Mar	7.27	13.60	1610.00	7.02	2.52
27-Mar	7.31	13.[illegible]0	1547.00	6.74	2.72
01-Apr	7.31		1495.00	7.10	2.38
02-Apr	7.14		1570.00	7.03	2.95
02-Apr			15[illegible].00	[illegible]4	1.73
03-Apr	6.13		1536.00	7.04	[illegible]
03-Apr	5.85		1626.00	7.00	[illegible]
04-Apr	5.38		1768.00	6.98	3.18
06-Apr	5.80		1770.00	6.97	3.01
08-Apr	6.04		1752.00	6.95	4.10
09-Apr	5.20				2.64
11-Apr	6.17		1585.00	6.81	2.81
15-Apr	6.42	12.20	1594.00	7.13	1.40

WELL C3

DATE	WATER L.	TEMP	SC	PH	NO3
19-Jul		19.80	1430.00	7.11	
23-Jul		19.30	1360.00	7.16	
25-Jul		20.60	1175.00	7.20	
26-Jul		19.60	1185.00	7.20	
29-Jul		20.30	1260.00	7.15	
14-Oct	10.10	18.40	1338.00	7.02	1.50
15-Oct	9.61		1275.00	7.14	4.01
16-Oct	9.62				
17-Oct	9.70	19.30	1560.00	6.98	2.14
18-Oct	9.50	19.10	1463.00	7.04	2.63
19-Oct	8.90	19.20	1385.00	7.12	2.80
21-Oct	8.34	19.10	1506.00	7.11	2.20
23-Oct	8.32				
25-Oct	8.93	19.00	1459.00	7.26	4.70
27-Oct	8.89				
29-Oct	8.81	18.70	1249.00	7.16	3.20
01-Nov	8.78	18.70	1238.00	7.31	3.80
03-Nov	8.80	18.90	1380.00		3.00
06-Nov	8.72	18.30	1204.00	7.25	3.10
10-Nov	8.83	18.20	1191.00	7.29	5.30
13-Nov	8.55	18.60	1282.00	7.25	3.40
15-Nov	7.79	18.40	1163.00	7.47	4.00
17-Nov	7.44	18.30	1190.00	7.34	4.30
21-Nov	7.43	18.00	1211.00	7.41	4.30
25-Nov	7.40	18.20	1187.00	7.26	4.20
30-Nov	7.44	17.40	1258.00	7.46	3.20
05-Dec	7.45	17.60	1180.00	7.43	3.20
22-Dec	7.30	15.50	1265.00	7.47	4.00
29-Dec	7.41				
03-Jan	7.45	15.60	1488.00	7.52	
11-Jan	7.44	14.20	1234.00	6.96	
14-Jan	7.48	14.50	1260.00	6.72	
16-Jan	7.51	16.70	1180.00	6.93	3.60
20-Jan	7.41				
23-Jan	7.59	13.80	1271.00	6.96	4.30
28-Jan	7.43	13.70	1303.00	6.92	4.41
01-Feb	7.59				
04-Feb	7.52				
06-Feb	7.59	16.50	1126.00	7.02	2.85
13-Feb	7.51	13.80	1180.00	7.05	2.34
18-Feb	7.44				
20-Feb	7.60	13.70	1260.00	7.05	.61
25-Feb	7.55	15.70	1300.00	7.02	2.33
02-Mar	7.58				
06-Mar	7.58	13.10	1359.00	7.08	1.29
12-Mar	7.39		1007.90	6.98	5.76
16-Mar	7.40	17.70	1223.00	7.01	3.31
18-Mar	7.24	13.30	1268.00	6.95	3.16
22-Mar	7.29	13.90	1313.00	7.13	1.85
27-Mar	7.25	14.00	1746.00	6.98	4.05

01-Apr	7.22		1232.00	7.08	2.39
02-Apr	7.18		1308.00	7.06	4.03
02-Apr			1198.00	7.03	3.06
03-Apr	6.33		1488.00	7.06	2.07
03-Apr	6.14		1416.00	6.97	5.22
04-Apr	5.43		1611.00	6.99	2.38
06-Apr	5.91		1775.00	6.95	2.77
08-Apr	6.18		1724.00	6.92	3.0
09-Apr	6.31				2.11
11-Apr	6.15		1535.00	6.80	1.85
15-Apr	6.48	12.40	1580.00	7.09	1.8

WELL C4

DATE	WATER L.	TEMP	SC	PH	NO3
26-Jul	10.22	18.90	985.00	7.17	
29-Jul	10.21	18.60	1010.00	7.17	
01-Aug	10.42	18.80	1030.00	7.17	
05-Aug	10.45	18.70	1022.00	7.21	
13-Aug	11.33				
14-Aug	11.17				1.80
16-Aug	10.91	19.30	998.00	7.21	2.50
19-Aug	10.95	19.40	1100.00	7.30	[illegible]
21-Aug	10.94				
22-Aug	10.80	19.60	996.00	7.17	3.70
24-Aug	11.13				
26-Aug	11.17				
30-Aug	11.53				
02-Sep	11.65	19.50	995.00	7.27	[illegible]
09-Sep	12.06				
15-Sep	11.91	17.30	1034.00	7.12	10.30
16-Sep	11.83	19.10	986.00	7.13	10.10
18-Sep	11.87	19.10	1011.00	7.23	2.80
19-Sep	11.94	20.00	1037.00	7.17	4.50
21-Sep	11.98	18.60	1028.00	7.27	5.20
22-Sep	11.76	19.20	1032.00	7.29	5.20
23-Sep	11.34	17.80	995.00	7.54	4.70
25-Sep	11.32	18.00	1012.00	7.17	4.40
27-Sep	11.10	17.60	979.00	7.17	4.10
28-Sep	10.78				
29-Sep	10.55	17.40	986.00	7.16	7.70
01-Oct	10.43	17.10	1008.00	7.14	4.90
02-Oct	10.41				
04-Oct	10.41	17.60	1011.00	7.17	5.00
05-Oct	10.54				
06-Oct	10.45	18.50	1020.00	7.05	[illegible]
08-Oct	10.50	19.00	1006.00	7.07	5.40
10-Oct	10.34	17.30	1002.00	7.11	[illegible]
14-Oct	9.57	18.20	994.00	7.18	6.30
15-Oct	9.47	18.10	1100.00	7.15	5.30
16-Oct	9.47				
17-Oct	9.47	19.00	1047.00	7.07	4.40
18-Oct	9.02	18.90	1041.00	7.11	[illegible]
19-Oct	8.75	17.00	1021.00	7.09	[illegible]
21-Oct	8.77	18.90	1114.00	7.08	[illegible]
22-Oct	8.71	19.00	1037.00	7.06	
23-Oct	8.83	19.00	1088.00	7.15	[illegible]
27-Oct	8.80				
29-Oct	[illegible]	18.80	1014.00	7.16	5.40
01-Nov	8.70	18.80	1016.00	7.22	5.90
03-Nov	8.73	18.80	1061.00		[illegible]
06-Nov	8.66	18.60	934.00	7.15	5.70
10-Nov	8.79	18.50	957.00	7.22	6.90
13-Nov	8.48	18.60	1042.00	7.29	5.90
15-Nov	7.54	19.60	995.00	7.31	5.60

17-Nov	7.37	18.50	967.00	7.33	6.20
21-Nov	7.35	18.50	1028.00	7.28	5.60
25-Nov	7.38	18.70	981.00	7.23	4.90
30-Nov	7.43	18.30	1038.00	7.28	5.80
05-Dec	7.37	18.10	981.00	7.39	6.10
22-Dec	7.29	17.00	1018.00	7.40	8.00
29-Dec	7.40				
03-Jan	7.44	17.50	1158.00	7.62	
11-Jan	7.43	15.90	949.00	6.88	
14-Jan	7.46	15.90	962.00	6.69	
16-Jan	7.49	17.20	949.00	6.92	5.26
20-Jan	7.38				
23-Jan	7.54	15.30	950.00	6.96	6.18
28-Jan	7.43	15.00	1023.00	6.97	5.27
01-Feb	7.58				
04-Feb	7.52				
06-Feb	7.57	19.00	862.00	7.04	4.[illegible]2
13-Feb	7.48	15.30	903.00	7.00	5.35
18-Feb	7.42				
20-Feb	7.56	15.20	944.00	6.99	6.12
25-Feb	7.52	16.40	995.00	6.78	4.73
02-Mar	7.54				
06-Mar	7.54	14.00	1007.00	7.09	3.2[illegible]
12-Mar	7.36		1009.00	6.98	6.05
16-Mar	7.36	19.20	1002.00	6.97	4.85
18-Mar	7.21	14.10	1034.00	6.90	5.22
22-Mar	7.27	14.50	1038.00	7.01	5.87
27-Mar	7.29	15.20	1013.00	7.03	7.05
01-Apr	7.29		947.00	7.02	5.44
02-Apr	7.13		1016.00	6.95	[illegible].00
02-Apr			991.00	6.94	5.57
03-Apr	6.53		1005.00	6.97	4.67
03-Apr	6.42		1014.00	6.95	5.71
04-Apr	5.47		1116.00	6.96	5.37
06-Apr	6.02		1142.00	6.93	5.10
08-Apr	6.04		1108.00	6.70	6.43
09-Apr	6.45				4.95
11-Apr	5.97		1014.00	6.80	4.81
15-Apr	6.61	11.70	1044.00	7.10	4.[illegible]1

WELL D1

DATE	WATER L.	TEMP	SC	PH	NO3
15-Nov	7.80				
21-Nov	7.74	17.00	1774.00	7.60	0.70
25-Nov	7.69	16.90	1759.00	7.63	1.01
30-Nov	7.38	14.60	1875.00	7.90	2.90
05-Dec	7.48				
22-Dec	7.52		1881.00	8.07	
29-Dec	7.48	13.50	1729.00	7.18	
03-Jan	7.46	13.60	1632.00	7.06	
11-Jan	7.51	15.50	1569.00	7.05	1.83
14-Jan	7.43				
16-Jan	7.62	13.00	1604.00	7.18	2.66
20-Jan	7.44	13.30	1446.00	7.11	2.28
23-Jan	7.59				
28-Jan	7.56				
01-Feb	7.60	15.80	1489.00	7.24	1.75
04-Feb	7.56	13.00	1481.00	7.22	1.20
06-Feb	7.46				
13-Feb	7.53	12.70	1486.00	7.29	0.66
18-Feb	7.55	15.20	1468.00	7.33	2.38
20-Feb	7.54				
25-Feb	7.58	12.90	1667.00	7.29	1.27
02-Mar	7.55		1524.00	7.16	2.62
06-Mar	7.38	14.40	1366.00	7.32	1.21
12-Mar	7.22	13.40	1516.00	7.23	1.22
16-Mar	7.28	14.30	1535.00	7.29	4.30
18-Mar	7.22				
22-Mar	7.32	13.40	1643.00	7.25	1.35
27-Mar	7.37		1290.00	7.38	1.15
01-Apr	7.37		1570.00	7.53	1.57
02-Apr			1582.00	7.20	0.67
02-Apr	6.56		1549.00	7.24	1.22
03-Apr	6.60		1548.00	7.19	0.72
03-Apr	5.83		1644.00	7.10	1.20
04-Apr	5.57		1819.00	7.17	1.52
06-Apr	5.76		1558.00	7.14	1.47
08-Apr	5.86				
09-Apr	5.81		1575.00	7.15	0.64
11-Apr	6.13		1761.00	7.30	0.71
15-Apr					

WELL D2 DATE	WATER L.	TEMP	SC	PH	NO3
06-Nov	8.66	17.80	1461.00	7.77	1.80
13-Nov	7.93	17.90	1580.00	7.63	0.86
15-Nov	7.80	17.70	1726.00	7.38	1.40
17-Nov	7.75	17.50	1626.00	7.45	1.30
21-Nov	7.71	17.00	1705.00	7.55	0.71
25-Nov	7.69	17.00	1658.00	7.56	0.72
30-Nov	7.37	15.00	1733.00	7.75	2.50
05-Dec	7.46				
22-Dec	7.50	15.10	1859.00	7.79	
29-Dec	7.46	14.10	1554.00	7.07	
03-Jan	7.45	14.20	1548.00	6.86	
11-Jan	7.49	16.20	1501.00	6.94	1.36
14-Jan	7.40				
16-Jan	7.59	13.40	1628.00	7.19	1.75
20-Jan	7.44	13.70	1474.00	6.95	1.74
23-Jan	7.57				
28-Jan	7.49				
01-Feb	7.56	15.70	1545.00	7.14	0.94
04-Feb	7.50	13.40	1524.00	7 09	1.46
06-Feb	7.41				
13-Feb	7.50	13.10	1559.00	7.03	1.66
18-Feb	7.50	15.10	1567.00	7.12	1.62
20-Feb	7.50				
25-Feb	7.57	13.10	1729.00	7.16	0.62
02-Mar	7.46		1631.00	7.05	2.18
06-Mar	7.36	14.70	1640.00	7.14	1.41
12-Mar	7.20	13.70	1679.00	7.05	1.78
16-Mar	7.25	14.40	1682.00	7.16	1.27
18-Mar	7.19				
22-Mar	7.28	17.50	1695.00	7.03	0.85
27-Mar	7.26		1494.00	7.14	0.50
01-Apr	7.14		1592.00	7.17	0.55
02-Apr			1615.00	7.12	0.49
02-Apr	6.51		1617.00	7.09	0.54
03-Apr	6.46		1603.00	7.07	0.59
03-Apr	5.70		.681.00	7.05	0.76
04-Apr	5.62		1791.00	7.08	1.72
06-Apr	5.74		1575.00	7.04	1.35
08-Apr	5.84				
09-Apr	6.94		1520.00	6.99	0.30
11-Apr	6.11		1758.00	7.39	0.68
15-Apr					

WELL D3

DATE	WATER L.	TEMP	SC	PH	NO3
14-Oct					
15-Oct	10.36				
16-Oct	10.24	18.80	1612.00	7.36	1.34
17-Oct	10.22	18.90	1597.00	7.29	1.60
18-Oct	9.76	18.70	1904.00	7.33	0.50
19-Oct	9.74				
21-Oct	9.57	18.50	1242.00	7.31	
23-Oct	9.27				
25-Oct	9.12	18.60	1573.00	7.41	2.[illegible]
27-Oct	9.02	18.50	1459.00	7.35	0.9[illegible]
29-Oct	9.05	18.80	1632.00	7.37	1.90
01-Nov	8.95	18.40	1331.00	7.38	1.60
03-Nov	9.00	17.80	1338.00	7.43	2.60
06-Nov	8.82	18.30	1433.00	7.43	0.95
10-Nov	8.35	18.00	1216.00	7.55	1.60
13-Nov	7.71	17.90	1289.00	7.45	0.71
15-Nov	7.63	17.90	1298.00	7.22	0.30
17-Nov	7.61	17.70	1238.00	7.39	0.71
21-Nov	7.59	17.30	1264.00	7.55	1.[illegible]
25-Nov	7.36	17.20	1205.00	7.51	0.40
30-Nov	7.32	15.70	1269.00	7.78	1.50
05-Dec	7.42				
22-Dec	7.46	15.10	1378.00	7.92	
29-Dec	7.43	14.60	1223.00	6.98	
03-Jan	7.43	14.70	1290.00	6.77	
11-Jan	7.48	16.70	1187.00	6.81	1.12
14-Jan	7.39				
16-Jan	7.59	13.80	1186.00	6.95	1.75
20-Jan	7.37	14.20	1189.00	6.84	2.29
23-Jan	7.57				
28-Jan	7.50				
01-Feb	7.50	15.80	1170.00	7.03	1.40
04-Feb	7.57	13.80	1175.00	7.03	0.76
06-Feb	7.44				
13-Feb	7.51	13.70	1240.00	7.02	0.91
18-Feb	7.52	14.30	1253.00	7.09	0.81
20-Feb	7.53				
25-Feb	7.56	13.40	1346.00	7.03	1.6[illegible]
02-Mar	7.4[illegible]		1245.00	6.90	2.46
06-Mar	7.75	14.5[illegible]	1378.[illegible]	7.04	
12-Mar	7.1[illegible]	17.80	13[illegible]8.[illegible]	6.7[illegible]	[illegible]
16-Mar	7.24	14.50	1[illegible]5.00	[illegible]	[illegible]
18-Mar	7.16				
22-Mar	7.24	17.[illegible]	1337.0[illegible]	6.9[illegible]	[illegible].33
27-Mar	7.2[illegible]		1207.00	7.04	0.7[illegible]
01-Apr	7.12		1278.00	6.96	0.98
02-Apr			1233.00	[illegible].03	0.71
02-Apr	6.47		1220.00	7.03	1.1[illegible]
03-Apr	6.42		1249.00	7.[illegible]0	[illegible]
03-Apr	5.70		1331.00	6.98	[illegible].41
04-Apr	5.58		1420.00	7.05	3.5[illegible]
06-Apr	5.7[illegible]		1238.00	6.99	[illegible]
08-Apr	5.83				
09-Apr	[illegible].[illegible]5		1[illegible]50.[illegible]	6.[illegible]	1.[illegible]
11-Apr	5.[illegible]3		14[illegible]	[illegible].33	1.[illegible]3
15-Apr					

WELL D4

DATE	WATER L.	TEMP	SC	PH	NO3
26-Jul	10.21	18.30	1125.00	7.30	
29-Jul	10.42	19.50	1200.00	7.38	
01-Aug	10.45	19.80	1180.00	7.36	
05-Aug	11.33				
13-Aug	11.17				3.60
14-Aug	10.91	18.90	1150.00	7.22	3.60
16-Aug	10.95	18.90	1239.00	7.29	4.70
19-Aug	10.94				
21-Aug	10.80	19.80	1165.00	7.25	4.80
22-Aug	11.13				
24-Aug	11.17				
26-Aug	11.53				
30-Aug	11.65	19.00	1105.00	7.30	3.90
02-Sep	12.06	18.80	1162.00	7.19	
09-Sep	11.91	18.80	1141.00	7.20	12.10
15-Sep	11.82	18.80	1166.00	7.19	9.90
16-Sep	11.87	19.00	1165.00	7.26	3.20
18-Sep	11.94	19.70	1202.00	7.30	4.40
19-Sep	11.98	18.60	1132.00	7.28	5.50
21-Sep	11.76	18.90	1100.00	7.33	5.10
22-Sep	11.54	17.50	1103.00	7.53	4.50
23-Sep	11.32	17.80	1094.00	7.22	4.40
25-Sep	11.10	17.00	1158.00	7.30	3.70
27-Sep	11.15				
28-Sep	10.92	17.00	1154.00	7.23	6.30
29-Sep	10.81	16.50	1163.00	7.24	4.80
01-Oct	10.77				
02-Oct	10.75	17.20	1175.00	7.27	5.10
03-Oct	10.88				
05-Oct	10.79	18.30	1170.00	7.17	5.60
06-Oct	10.96	18.70	1151.00	7.17	5.30
08-Oct	10.74	17.20	1173.00	7.21	5.40
10-Oct	10.07	17.80	1063.00	7.13	6.30
14-Oct	9.82	17.70	1112.00	7.23	5.30
15-Oct	9.81				
16-Oct	9.79	16.50	1190.00	7.17	4.60
17-Oct	9.40	18.50	1190.00	7.21	5.20
18-Oct	9.13	18.50	1173.00	7.18	5.40
19-Oct	9.01	18.50	1329.00	7.19	4.60
21-Oct	8.93				
23-Oct	9.11	18.30	1242.00	7.31	[illegible]
25-Oct	9.04				
27-Oct	8.96	18.40	1170.00	7.31	6.30
29-Oct	8.93	18.40	1179.00	7.30	6.30
01-Nov	8.96	18.40	1245.00	7.26	7.10
03-Nov	8.89	18.40	1113.00	7.26	6.30
06-Nov	9.24	18.20	1126.00	7.36	8.40
10-Nov	8.68	18.30	1199.00	7.41	3.90
13-Nov	7.89	18.30	1131.00	7.46	6.10

15-Nov	7.55	18.20	1160.00	7.45	5.60
17-Nov	6.98	18.20	1197.00	7.34	6.30
21-Nov	7.49	18.30	1132.00	7.33	6.10
25-Nov	7.49	18.30	1194.00	7.46	6.80
30-Nov	7.46	17.90	1113.00	7.45	7.10
05-Dec	7.31	17.00	1226.00	7.53	9.31
22-Dec	7.42				
29-Dec	7.47	16.60	1326.00	7.75	
03-Jan	7.42	15.90	1111.00	7.08	
11-Jan	7.47	16.20	1116.00	6.86	
14-Jan	7.49	18.00	1053.00	7.00	6.80
16-Jan	7.37				
20-Jan	7.57	15.00	1044.00	7.12	8.25
23-Jan	7.41	15.10	1152.00	6.98	8.45
28-Jan	7.57				
01-Feb	7.47				
04-Feb	7.57	17.50	1058.00	7.14	5.8
06-Feb	7.50	15.00	1018.00	7.13	7.30
13-Feb	7.43				
18-Feb	7.56	15.00	1060.00	7.08	5.89
20-Feb	7.51	15.40	1115.00	7.17	6.04
25-Feb	7.55				
02-Mar	7.54	14.00	1199.00	7.23	5.15
06-Mar	7.37		1129.00	7.10	9.47
12-Mar	7.34	15.40	1175.00	7.16	6.53
16-Mar	7.16	14.50	1162.00	7.06	7.66
18-Mar	7.24	15.00	1163.00	7.11	
22-Mar	7.18				
27-Mar	7.29	14.60	1175.00	7.22	[illegible]
01-Apr	7.27		1065.00	7.17	8.23
02-Apr	7.10		1137.00	7.17	7.75
02-Apr			1172.00	7.15	[illegible]
03-Apr	6.67		1130.00	7.24	7.89
03-Apr	6.15		1127.00	7.11	7.79
04-Apr	5.56		1185.00	7.08	8.33
06-Apr	5.56		1200.00	7.19	9.15
08-Apr	5.75		1130.00	7.06	[illegible]
09-Apr	5.76				
11-Apr	5.77		1140.00	7.05	[illegible]
15-Apr	6.10		1310.00	7.16	[illegible]

WELL 05

DATE	WATER L.	TEMP	SC	PH	NO3
03-Jan	6.86				
11-Jan	7.54				
14-Jan	7.56	17.50	1050.00	7.02	5.80
16-Jan	7.45				
20-Jan	7.65	14.70	1056.00	7.17	8.12
23-Jan	7.49	15.00	1115.00	6.91	7.45
28-Jan	7.67				
01-Feb	7.57				
04-Feb	7.66	17.50	1025.00	7.10	6.60
06-Feb	7.54	14.70	1028.00	7.09	7.10
13-Feb	7.50				
18-Feb	7.64	14.60	1065.00	7.03	5.92
20-Feb	7.59	15.20	1109.00	7.11	5.97
25-Feb	7.56				
02-Mar	7.61	14.00	1200.00	7.12	3.40
06-Mar	7.44		1116.00	7.13	3.52
12-Mar	7.42	15.40	1163.00	7.12	5.75
16-Mar	7.24	14.40	1157.00	7.04	7.95
18-Mar	7.30	14.80	1163.00	7.17	8.45
22-Mar	7.26				
27-Mar	7.35	14.20	1158.00	7.14	9.17
01-Apr	7.34		1058.00	7.16	8.07
02-Apr	7.17		1140.00	7.12	7.48
02-Apr			1140.00	7.12	7.11
03-Apr	6.47		1120.00	7.13	8.37
03-Apr	6.40		1139.00	7.10	7.61
04-Apr	5.68		1189.00	7.07	8.30
06-Apr	5.43		1290.00	7.12	7.24
08-Apr	5.79		1128.00	7.06	10.40
09-Apr	5.87				
11-Apr	5.84		1152.00	7.03	7.08
15-Apr	6.18		1302.00	7.49	7.22

WELL E1

DATE	WATER L.	TEMP	SC	PH	NO3
01-Nov	7.27	19.70	437.00	7.75	2.90
03-Nov	8.07	20.50	466.00	7.86	3.00
06-Nov	8.23				
13-Nov	7.48	18.20	622.00	8.20	4.00
15-Nov	7.45	18.60	658.00	8.09	3.50
17-Nov	7.47	18.50	657.00	8.23	4.40
21-Nov	7.44	18.40	648.00	8.27	3.20
25-Nov		17.70	688.00	8.30	5.00
30-Nov	7.52	17.50	674.00	8.18	3.70
05-Dec	7.32	16.20	686.00	8.39	5.60
22-Dec	7.48				
29-Dec	7.54	15.50	661.00	8.56	
03-Jan	7.53	15.20	635.00	7.44	
11-Jan	7.51	15.10	580.00	7.54	
14-Jan	7.54	16.90	624.00	7.37	3.82
16-Jan	7.54				
20-Jan	7.69	14.90	648.00	7.37	5.65
23-Jan	7.49	14.90	650.00	7.33	3.14
28-Jan	7.64				
01-Feb	7.59				
04-Feb	7.67	16.80	619.00	7.33	7.17
06-Feb	7.60	14.50	592.00	7.44	3.95
13-Feb	7.51				
18-Feb	7.57	14.20	625.00	7.42	3.22
20-Feb	7.59	15.70	679.00	7.54	4.76
25-Feb	7.60				
02-Mar	7.61	14.50	697.00	7.61	[illegible]
06-Mar	7.57		647.00	7.50	5.12
12-Mar	7.45	15.70	644.00	7.68	[illegible]
16-Mar	7.30	14.90	635.00	7.65	[illegible]
18-Mar	7.35	15.20	704.00	[illegible]	[illegible]
22-Mar	7.30				
27-Mar	7.36	14.80	574.00	7.43	[illegible]
01-Apr	7.23		542.00	7.84	[illegible]
02-Apr	7.23		601.00	7.59	5.45
02-Apr			579.00	7.47	5.03
03-Apr	6.36		566.00	7.54	1.06
03-Apr	6.20		602.00	7.37	3.82
04-Apr	5.48		668.00	7.34	4.59
06-Apr	5.55		720.00	7.33	5.44
08-Apr	5.73		602.00	7.44	5.24
09-Apr	5.86				
11-Apr	5.83		615.00	7.61	5.07
15-Apr	6.18		688.00	7.55	[illegible]

WELL E2

DATE	WATER L.	TEMP	SC	PH	NO3
14-Oct	8.68	19.20	255.00	7.90	1.60
15-Oct	9.29				
16-Oct					
17-Oct	7.55	19.70	299.00	7.41	1.50
18-Oct	8.39	20.00	315.00	7.71	1.70
19-Oct	8.74	20.50	412.00	7.73	1.40
21-Oct	8.74				
23-Oct	8.94	20.20	502.00	7.81	3.60
25-Oct	8.92				
27-Oct	8.86	19.70	491.00	8.02	2.30
29-Oct	8.80	19.60	499.00	8.03	2.00
01-Nov	8.89	20.10	504.00	7.91	3.40
03-Nov	8.78	19.90	465.00	8.15	2.40
06-Nov	8.92	19.40	502.00	7.89	3.00
10-Nov	8.34	19.40	520.00	8.02	3.10
13-Nov	7.56	18.50	392.00	7.96	2.50
15-Nov	7.46	18.90	486.00	7.89	3.10
17-Nov	7.44	18.70	504.00	7.97	3.50
21-Nov	7.45	18.70	493.00	7.95	2.20
25-Nov	7.58	17.90	535.00	8.06	4.10
30-Nov	7.52	17.80	446.00	7.95	1.90
05-Dec	7.36	17.20	523.00	8.11	3.50
22-Dec	7.48				
29-Dec	7.53	16.30	545.00	8.23	
03-Jan	7.51	15.70	591.00	7.25	
11-Jan	7.53	15.80	561.00	7.31	
14-Jan	7.56	17.60	604.00	7.11	7.00
16-Jan	7.49				
20-Jan	7.67	15.20	635.00	7.36	7.54
23-Jan	7.48	15.20	681.00	7.21	7.11
28-Jan	7.66				
01-Feb	7.60				
04-Feb	7.67	17.50	663.00	7.24	8.25
06-Feb	7.61	15.00	646.00	7.24	7.49
13-Feb	7.50				
18-Feb	7.61	14.60	700.00	7.28	8.43
20-Feb	7.61	16.60	756.00	7.24	7.39
25-Feb	7.62				
02-Mar	7.60	14.70	771.00	7.40	4.08
06-Mar	7.54		763.00	7.23	11.20
12-Mar	7.46	16.10	762.00	[illegible]	6.23
16-Mar	7.29	15.20	762.00	7.43	7.37
18-Mar	7.36	15.30	822.00	[illegible]	[illegible]
22-Mar	7.30				
27-Mar	7.38	15.00	815.00	7.23	7.44
01-Apr	7.27		658.00	7.37	9.24
02-Apr	7.22		681.00	7.35	6.04
02-Apr			600.00	7.37	5.96
03-Apr	6.45		609.00	7.37	3.40
03-Apr	5.92		533.00	7.35	6.41
04-Apr	5.52		817.00	7.24	[illegible]
06-Apr	5.58		866.00	7.23	[illegible]
08-Apr	5.77		697.00	7.26	8.3
09-Apr	5.89				
11-Apr	5.87		818.00	7.31	7.22
15-Apr	6.19		879.00	7.38	[illegible]

WELL E3

DATE	WATER L.	TEMP	SC	PH	NO3
10-Oct	8.87	19.40	297.00	7.53	1.48
14-Oct	9.47	19.50	284.00	7.74	0.70
15-Oct	9.57				
16-Oct	9.57	20.30	438.00	8.01	1.85
17-Oct	7.85	20.00	310.00	7.57	1.30
18-Oct	8.56	20.10	325.00	.63	1.40
19-Oct	8.81	20.00	424.00	7.67	1.40
21-Oct	8.77				
23-Oct	8.94	20.20	426.00	7.79	2.30
25-Oct	8.92				
27-Oct	8.34	19.80	427.00	7.92	2.70
29-Oct	8.82	19.90	437.00	8.00	2.70
01-Nov	8.87	19.90	448.00	7.74	2.70
03-Nov	8.78	19.90	416.00	7.87	1.70
06-Nov	8.94	19.40	447.00	7.97	4.20
10-Nov	8.49	19.40	459.00	7.88	2.90
13-Nov	7.60	18.70	398.00	7.89	2.80
15-Nov	7.44	19.00	445.00	7.89	2.70
17-Nov	7.38	18.80	467.00	7.87	3.50
21-Nov	7.42	18.90	456.00	7.84	[illegible]
25-Nov	7.51	18.50	501.00	7.76	5.70
30-Nov	7.45	18.00	490.00	7.94	4.00
05-Dec	7.34	18.20	518.00	7.97	5.50
22-Dec	7.45				
29-Dec	7.49	16.90	535.00	8.07	
03-Jan	7.47	16.40	569.00	7.22	
11-Jan	7.52	16.30	547.00	7.27	
14-Jan	7.32	18.20	579.00	[illegible]	7.00
16-Jan	7.45				
20-Jan	7.64	15.50	607.00	7.32	6.82
23-Jan	7.61	15.90	611.00	7.30	5.63
28-Jan	7.64				
01-Feb	7.58				
04-Feb	7.64	18.00	603.00	7.76	[illegible]
06-Feb	7.58	15.20	614.00	7.26	6.29
13-Feb	7.48				
18-Feb	7.64	14.80	665.00	7.25	5.82
20-Feb	7.59	17.10	703.00	7.30	5.97
25-Feb	7.61				
02-Mar	7.57	[illegible]	715.00	7.35	[illegible]
06-Mar	7.45		719.00	7.31	11.00
12-Mar	7.44	[illegible]	778.00	7.32	[illegible]
16-Mar	7.26	15.60	820.00	7.32	9.15
18-Mar	7.33	15.50	832.00	7.29	10.80
22-Mar	7.28				
27-Mar	7.35	15.40	[illegible]	7.29	[illegible]
01-Apr	7.20		676.00	7.39	[illegible]
02-Apr	7.17		724.00	.30	7.81
02-Apr			646.00	7.31	6.66
03-Apr	6.44		664.00	7.72	6.65
03-Apr	6.11		619.00	7.40	6.25
04-Apr	5.55		734.00	7.25	[illegible]
06-Apr	5.58		798.00	7.25	[illegible]
08-Apr	5.78		693.00	7.72	[illegible]
09-Apr	5.62				
11-Apr	5.35		727.00	[illegible]	[illegible]
15-Apr	6.18		875.00	[illegible]	[illegible]

WELL E4

DATE	WATER L.	TEMP	SC	PH	NO3
26-Jul	10.27	21.90	840.00	7.33	
29-Jul	10.33	20.10	870.00	7.51	
01-Aug	11.14				
05-Aug	10.93				5.20
13-Aug	10.79	20.90	855.00	7.31	5.40
14-Aug	10.82	20.50	850.00	7.28	4.60
16-Aug	10.75				
19-Aug	10.64	21.70	846.00	7.41	5.10
21-Aug	10.95				
22-Aug	11.02				
24-Aug	11.33				
26-Aug	11.45	20.70	872.00	7.36	7.90
30-Aug	11.88				
02-Sep	11.78	20.80	865.00	7.29	27.90
09-Sep	11.68	20.30	895.00	7.18	17.70
15-Sep	11.74	20.10	980.00	7.30	11.10
16-Sep	11.81	21.00	983.00	7.20	11.10
18-Sep	11.89	19.60	886.00	7.33	11.30
19-Sep	11.67	20.30	723.00	7.42	8.30
21-Sep	11.28	19.70	637.00	7.75	7.60
22-Sep	11.32				
23-Sep	11.01	19.30	566.00	7.40	4.70
25-Sep	10.94	19.30	645.00	7.46	4.40
27-Sep	10.99				
28-Sep	10.31	18.50	611.00	7.42	8.10
29-Sep	10.65	19.00	620.00	7.44	7.20
01-Oct	10.59				
02-Oct	10.60	19.70	674.00	7.43	7.80
03-Oct	10.73				
05-Oct	10.64	20.70	771.00	7.29	10.[illegible]
06-Oct	10.82	20.70	750.00	7.23	10.40
08-Oct	10.53	18.00	670.00	7.35	10.00
10-Oct	9.71	19.40	580.00	7.43	6.70
14-Oct	9.56	19.30	575.00	7.48	5.40
15-Oct	9.62				
16-Oct	9.62	20.00	675.00	7.31	6.70
17-Oct	9.15	20.00	605.00	7.53	5.90
18-Oct	8.92	20.00	527.00	7.36	6.50
19-Oct	8.81	20.00	705.00	7.22	7.00
21-Oct	8.79				
23-Oct	8.94	20.00	697.00	7.44	11.20
25-Oct	8.92				
27-Oct	8.64	19.80	515.00	7.52	16.90
29-Oct	8.35	19.90	877.00	7.53	12.50
01-Nov	8.90	19.80	739.00	7.42	13.90
03-Nov	8.91	20.00	859.00	7.48	14.00
06-Nov	8.97	19.40	902.00	7.55	16.00
10-Nov	9.73	19.60	898.00	7.72	14.00
13-Nov	.90	19.50	635.00	7.47	13.40

15-Nov	7.47	19.40	872.00	7.64	11.50
17-Nov	7.39	19.40	867.00	7.55	11.20
21-Nov	7.45	19.40	840.00	7.57	11.00
25-Nov	7.49	19.50	882.00	7.63	
30-Nov	7.46	18.80	895.00	7.66	14.00
05-Dec	7.30	19.10	931.00	7.80	15.10
22-Dec	7.44				
29-Dec	7.50	17.60	979.00	7.98	
03-Jan	7.48	17.40	1045.00	7.07	
11-Jan	7.52	17.20	967.00	7.11	
14-Jan	7.53	19.90	1046.00	6.97	13.90
16-Jan	7.47				
20-Jan	7.64	16.70	1118.00	7.10	14.60
23-Jan	7.48	16.90	1185.00	7.07	12.40
28-Jan	7.64				
01-Feb	7.59				
04-Feb	7.65	20.00	1058.00	7.08	10.00
06-Feb	7.56	16.00	1068.00	7.08	11.60
13-Feb	7.48				
18-Feb	7.63	15.90	1127.00	7.13	10.20
20-Feb	7.59	18.00	1192.00	7.07	8.60
25-Feb	7.59				
02-Mar	7.59	16.00	1215.00	7.17	7.63
06-Mar	7.50		1187.00	7.18	13.60
12-Mar	7.42	18.30	1182.00	7.12	9.04
16-Mar	7.27	16.30	1267.00	7.16	10.60
18-Mar	7.33	16.00	1277.00	7.17	14.40
22-Mar	7.27				
27-Mar	7.35	15.40	1227.00	7.17	12.00
01-Apr	7.33		1090.00	7.16	12.30
02-Apr	7.16		1240.00	7.18	10.80
02-Apr			1199.00	7.17	11.30
03-Apr	6.54		1187.00	7.19	9.86
03-Apr	6.30		1159.00	7.17	10.10
04-Apr	5.63		1346.00	7.12	10.60
06-Apr	5.69		1433.00	7.20	12.70
08-Apr	5.78		1191.00	7.16	14.70
09-Apr	5.87				
11-Apr	5.85		1235.00	7.16	11.10
15-Apr	6.16		1370.00	7.54	11.30

WELL E5

DATE	WATER L.	TEMP	SC	PH	NO3
03-Jan	7.47				
11-Jan	7.49				
14-Jan	7.51	19.70	923.00	7.03	10.80
16-Jan	7.44				
20-Jan	7.62	16.80	982.00	7.18	13.00
23-Jan	7.46	16.80	990.00	7.10	8.07
28-Jan	7.63				
01-Feb	7.57				
04-Feb	7.65	19.00	885.00	7.17	8.96
06-Feb	7.54	16.00	894.00	7.15	9.25
13-Feb	7.47				
18-Feb	7.63	15.90	958.00	7.17	8.09
20-Feb	7.58	18.20	976.00	7.16	10.20
25-Feb	7.59				
02-Mar	7.56	16.10	1011.00	7.25	4.47
06-Mar	7.44		968.00	7.24	6.93
12-Mar	7.42	18.10	1160.00	7.18	12.10
16-Mar	7.25	16.30	1215.00	7.19	8.79
18-Mar	7.31	16.20	1228.00	7.17	14.30
22-Mar	7.25				
27-Mar	7.35	16.20	1216.00	7.15	12.90
01-Apr	7.33		1093.00	7.21	12.10
02-Apr	7.16		1193.00	7.14	10.80
02-Apr			709.00	7.22	7.74
03-Apr	6.41		1115.00	7.18	11.00
03-Apr	6.03		1021.00	7.23	10.60
04-Apr	5.47		1191.00	7.12	10.80
06-Apr	5.57		1289.00	7.15	10.70
08-Apr	5.77		1074.00	7.10	14.20
09-Apr	5.84				
11-Apr	5.83		1146.00	7.13	9.45
15-Apr	6.15		1282.00	7.21	10.40

APPENDIX G

AQUIFER TEST DATA

Aquifer Test Site A, April 12, 1986

Pumped Well- A5 Q = .55 gpm b = 7.00 ft
Obs. Well A4 r = 1 foot

t (min)	s (ft.)	Corr. s	t (min)	s (ft.)	Corr. s
0.50	0.01	0.01	18.00	0.57	0.55
1.00	0.05	0.05	19.00	0.57	0.55
1.50	0.09	0.09	20.00	0.57	0.55
2.00	0.14	0.14	22.00	0.58	0.56
2.50	0.17	0.17	24.00	0.60	0.57
3.00	0.21	0.21	26.00	0.59	0.57
3.50	0.24	0.24	28.00	0.61	0.58
4.00	0.27	0.26	30.00	0.61	0.58
4.50	0.30	0.29	35.00	0.61	0.58
5.00	0.32	0.31	40.00		0.00
5.50	0.34	0.33	45.00	0.60	0.57
6.00	0.36	0.35	50.00	0.61	0.58
7.00	0.41	0.40	55.00	0.62	0.59
7.50	0.42	0.41	60.00	0.62	0.59
8.00	0.42	0.41	65.00	0.61	0.58
8.50	0.43	0.42	70.00	0.61	0.58
9.00	0.44	0.43	75.00	0.63	0.60
9.50	0.45	0.44	80.00	0.62	0.59
10.00	0.47	0.45	90.00	0.62	0.59
11.00	0.49	0.47	100.00	0.61	0.58
12.00	0.49	0.47	110.00	0.61	0.58
13.00	0.52	0.50	120.00	0.62	0.59
14.00	0.52	0.50			0.00
15.00	0.53	0.51			0.00
16.00	0.55	0.53			0.00
17.00	0.56	0.54			0.00

VITA

David J. Hagen

Candidate for the Degree of

Master of Science

Thesis: SPATIAL AND TEMPORAL VARIABILITY OF GROUND-WATER QUALITY IN A SHALLOW AQUIFER IN NORTH-CENTRAL OKLAHOMA

Major Field: Geology

Biographical:

Personal Data: Born in Cleveland, Ohio, April 12, 1958, the son of Donald E. and Ruth B. Hagen. Married to Martha J. Leene on November 26, 1983.

Education: Graduated from Columbia High School, Columbia Station, Ohio, in June, 1976; received Bachelor of Science Degree in Biology from Baldwin-Wallace College in June 1981; completed requirements for the Master of Science degree at Oklahoma State University in December, 1986.

Professional Experience: Teaching Assistant, School of Geology, Oklahoma State University, August, 1984, to May, 1985; Research Assistant, School of Geology, Oklahoma State University, July, 1985, to August, 1985; Teaching Assistant, School of Geology, Oklahoma State University, August, 1985, to May, 1986.