CAUSE AND EFFECT OF WATER-TABLE FLUCTUATIONS IN A SHALLOW AQUIFER SYSTEM, PAYNE COUNTY, OKLAHOMA

By

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TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

CHAPTER I

INTRODUCTION

Overview

Due to their proximity to surface features, shallow unconfined aquifer systems are highly susceptible to exterior influences. It is important, therefore, to determine how external factors may influence water-table stability. This can provide insight to the characteristics of an aquifer, and its vulnerability to external control.

Objectives

The primary concerns of this investigation are threefold: 1) to define those factors contributing to water-table fluctuations in a shallow aquifer system; 2) to determine what effect water-table fluctuations may have on ground-water flow; 3) to define the ground-water/surface-water relationship in a small drainage basin.

Previous Field Site Studies

Several studies have been conducted at this site since the summer of 1985. While each study at the site has a unique emphasis, a correlation of the studies has contributed greatly to the understanding of the hydrologic characteristics.

The first study was initiated by Hagen (1986) in August of 1985, with the installation of sixteen ground-water monitoring wells. The wells were used to monitor water-table fluctuations and ground-water quality. Electrical conductivity, pH, temperature and nitrate fluctuations were studied from August 1985 to April 1986. Hagen determined that ground-water quality may vary considerably in space and time.

Acre (in prep) contributed to the study by installing four soil-moisture neutron access tubes at the site. He measured soil-moisture content with a neutron probe from September 1985 to April 1986. His study demonstrated the variation in soil-moisture content through space and time.

Hoyle (1987) monitored ground-water quality and measured water-table fluctuations from April 1986 to April 1987. She noted that diurnal water-table fluctuations and changes in bicarbonate concentrations may be attributed to evapotranspirational processes. Hoyle used a variety of aquifer testing methods to determine the hydrologic parameters of transmissivity, storativity, and hydraulic conductivity.

Ross (1987) installed eight soil-water suction lysimeters at depths ranging from 1.5 to 8 feet below land surface. The lysimeters were used to sample water from the unsaturated zone. This study was conducted from January 1987 to June 1987. Ross found that nitrate concentrations are highly variable in both ground water and soil water through space and time.

Froneburger (in prep.) expanded the ground-water quality studies by installing fifteen additional monitoring wells and a series of tensiometers. He continued recording water-table fluctuations and monitoring ground-water quality through December 1988. In addition, tracer tests were performed to monitor migration through the subsurface. Froneberger found that migration does not follow uniform flow patterns.

Literature Review

A number of studies have been conducted on the various causes of water-table fluctuations, particularly with respect to atmospheric pressure, temperature waves, evapo-transpiration, and infiltration.

Although the effects of atmospheric pressure changes on the water levels of confined aquifer systems have been recognized for quite some time (King, 1899), the effects of atmospheric pressure changes on unconfined systems have only recently been addressed. Peck (1960) used laboratory results to confirm a theory suggesting that entrapped air contributes to the water table response to atmospheric pressure changes. Additional work by Stevenson and Van Schaik (1967) and Norum and Luthin (1968) confirmed Peck's theory. Turk (1975) also studied the effects of atmospheric pressure changes and determined that the texture of the aquifer materials could greatly effect the magnitude of the fluctuations. Turk discussed how atmospheric induced fluctuations may overshadow the influences that other variables have on the water table. As a means of isolating the effects of atmospheric pressure changes, Clark (1967) discussed two methods for determining the barometric efficiency of a well.

King (1899) not only recognized the influences of atmospheric pressure changes on the water table, but also attributed this effect to the presence of entrapped air below the water table. Peck (1960) supported this theory with his extensive study on the relationship of entrapped air and atmospheric pressure changes. This was followed by the study from Norum and Luthin (1968) that confirmed Peck's findings and further defined the influence of entrapped air on water table fluctuations. Additional field and laboratory tests were performed by Turk (1975), and were supportive of the previous work.

Studies were also conducted to determine the effect of entrapped air on permeability and recharge. Christiansen (1944) performed a laboratory study addressing the effect of entrapped air on permeability. He found that the presence of entrapped air greatly reduced the permeability of a soil. Bianchi and Haskell (1966) used a field study to observe the air movements between the water table and the wet front. They concluded that displaced air beneath the wet front produce an apparent water-table rise before actual recharge occurs.

Early work on the influence of a temperature gradient by Bouyoucos (1915) suggested that soil moisture moves from warmer to cooler soil, and from wet to dry soil. A number of authors (Meyer, 1960; Schneider, 1961; Benz et al., 1968; and Turk, 1975) have documented dramatic water table fluctuations on a seasonal basis. The seasonal fluctuations are a result of water moving from the saturated zone upward into the colder soils during the winter, thus dropping the water table. Others (Haise and Kelly, 1950) have studied the water table response to temperature changes on a smaller scale. They have found that there is a considerable time lag between changes in air temperature and changes in soil temperature. Turk (1975) conducted both laboratory and field studies and concluded that while daily temperature changes would not directly influence the water table, seasonal temperature changes could have a dramatic influence. He also concluded that temperature-induced atmospheric pressure changes could promote an instantaneous water table response.

There have been a variety of approaches to the study of the effects of precipitation on the water table. Field studies have frequently been used to observe the precipitation/water-table relationship. Horton (1933), addressed infiltration capacity, and Wenzel (1936) discussed soil-moisture deficits as a means of gaining a better understanding of this relationship. Gillham (1984) adds to the discussion, by addressing the effect of the capillary fringe. Additional field investigations were conducted by Stallman (1961), Zobeck and Ritchie (1984), and Bianchi and Haskell (1964).

A number of authors have taken a theoretical approach to defining this relationship, and as a means of predicting the influence of precipitation on the water table. Included are Werner and Noren (1951), Youngs (1957), and Venetis (1971). Jacob (1943, 1944) used a series of papers to present theories developed from field investigations.

CHAPTER II

SITE DESCRIPTION

Site Location

The study area lies in the NE 1/4, section 11, T19N-R2E, within the city limits of Stillwater, Payne County, Oklahoma (Figure 1). The site, situated in a residential area, lies on a broad flood plain just east of an unnamed tributary to Boomer Creek which is the primary stream in the area. The study site extends from this tributary eastward about 700 feet to a shale outcrop that forms the eastern boundary of the flood plain. The many urban structures within the study area consist primarily of houses and streets.

Topography

The majority of the study site is characterized by a nearly flat, gently sloping surface. However, there is distinct topographic relief at both east and west boundaries (Figure 2). The channels of Boomer Creek and it's tributary to the west, represent topographic lows while the shale outcrop on the eastern boundary represents the topographic high. The flood plain is about 886 feet above mean sea level, while the bed of Boomer Creek is

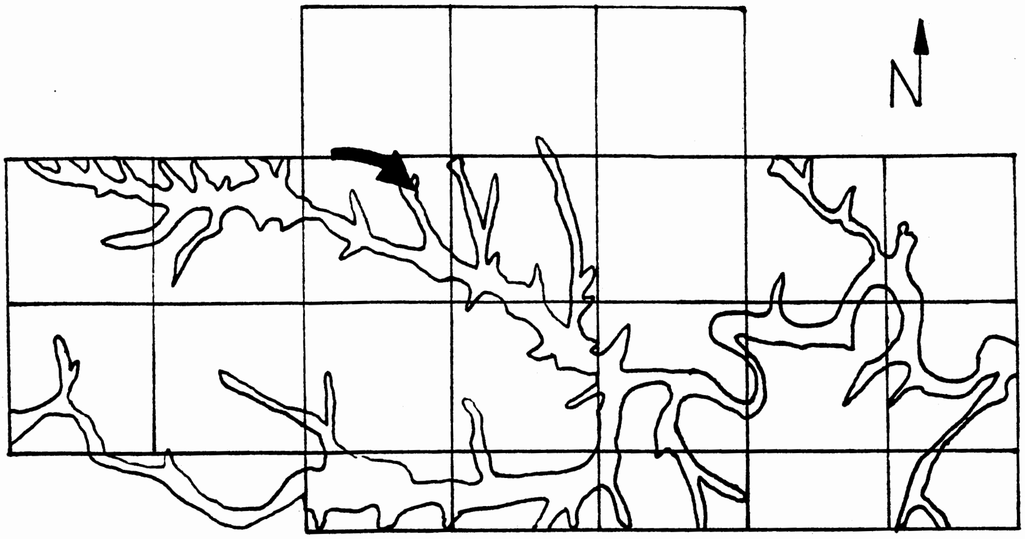


Figure 1. Location of Study Area (Soil Conservation Service, (1986).

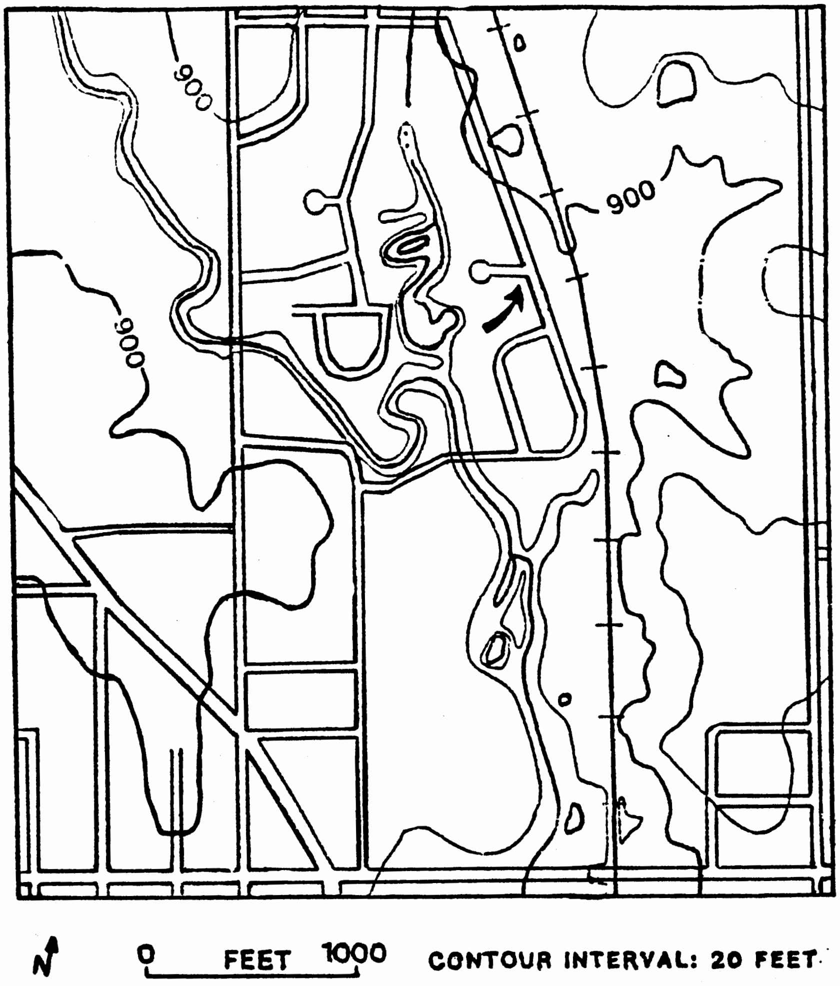


Figure 2. Topographic Relief (After Hagen, 1986).

about 869 feet. A dam at the mouth of the unnamed tributary forms a small pond. The pond, formally recognized as Chiquita Lake, has a spillway elevation of 880.6 feet. A berm, with an estimated elevation of about 888 feet, around Chiquita Lake.

Climate

Climatic conditions of major concern in this study include precipitation, temperature, and barometric pressure, all of which are monitored at the field site. The average annual precipitation and snowfall for this region are about 34 inches, and 6 inches, respectively (Pettyjohn and others, 1983). Although precipitation can be expected sporadically throughout the year, the majority tends to occur during the spring (May) and fall (September). Total precipitation for the years 1986 and 1987 as recorded by a tipping bucket rain gage at the site, was 39.57 inches and 30.47 inches, respectively.

Mean daily air temperatures range from 39 degrees F in the winter months to 80 degrees F in the summer months (SCS, 1987). It is not uncommon for air temperatures to exceed 100 degrees F in late July and August. Ground water maintains a nearly average temperature of 63 degrees F, and does not to fluctuate greatly from that average (Pettyjohn and others, 1983).

Vegetation

The study site was once a large pecan grove (Hoyle, 1987) and many property boundaries are delineated by tree lines. The tree lines generally consist of larger, older trees that pre-date residential development. that is, prior to 1970. Smaller, younger trees have recently been introduced as a means of supplementing these lines and as ornamentals. Many of the monitoring wells utilized in this study are situated near tree-lined boundaries (Figure 3).

The trees forming the southern edge of the study area are predominantly sugarberry and pecan, although other species are present. The western boundary contains several fruit and pecan trees. Other trees in the vicinity of the monitoring wells include: weeping willows, western soapberry, pecan, American elm, mulberry, and short leaf pine (Brown, personal communication, 1988). A great number of the trees, in the vicinity of the site predominantly sugarberry and American elm, are indigenous to the flood plain and most of these are near Boomer Creek and it's unnamed tributary. The composition of trees within the study area represent a wide range of ages and therefore exhibit a vast array of sizes. The trunk diameters range from 3 to 48 inches (Hoyle, 1987), while the dripline diameters range from 10 to 86 feet. The control that these large trees may have on ground-water flow patterns has been discussed previously by Hagen

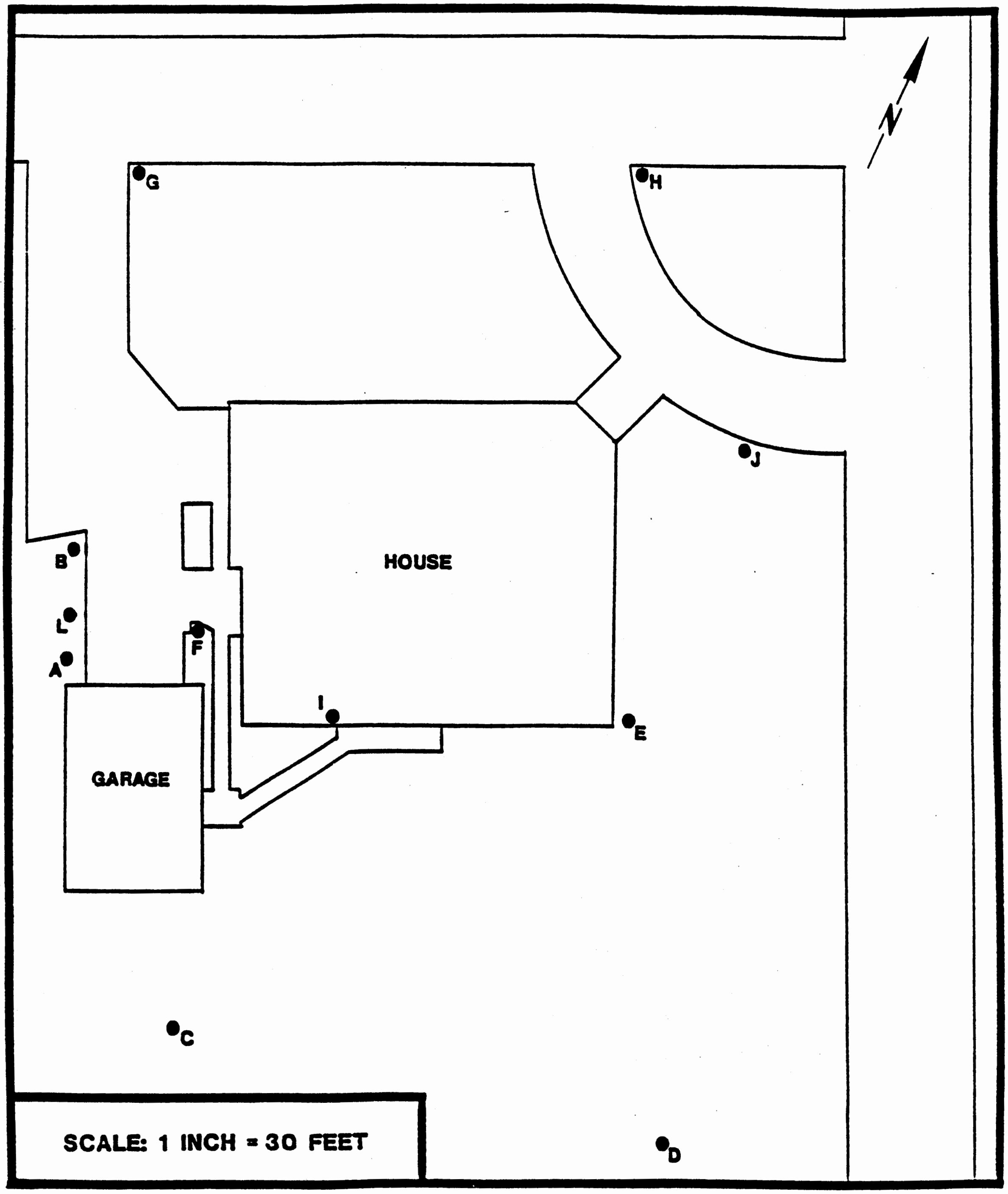


Figure 3. Ground-water Monitor Well Locations. (Froneberger, 1989).

(1986) and Hoyle (1987).

Other vegetation within the study area include grasses, predominantly, Bermuda, and shrubbery. Although the grasses may serve to inhibit erosion and facilitate infiltration, it is likely that they have no other major influence on the hydrogeology of the site.

Geology

Extensive geologic studies of the area have been conducted on both local and regional scales. Arbenz (1956) places Payne county as part of the Central Oklahoma Platform, corresponding to the southern portion of the Prairie Plains Homocline. This structure lends a gentle westerly dip of 40 to 50 feet per mile (Shelton and others, 1985). The stratigraphy of concern consists of rocks with associated Quaternary sediments (Shelton and others, 1985). Specifically, Ross (1987) described the study site as located on a flood plain comprised of Late Quaternary sediments that have infilled a canyon cut more than 70 feet into the Doyle Shale, which is Late Pennsylvanian in age. (Figure 4). The Doyle Shale is a red shale that contains lenticular sandstone and modular dolomite lenses (Shelton and others, 1985).

Alluvial Aquifer

The upper part of the Quaternary alluvium has been classified and mapped by the Soil Conservation Service

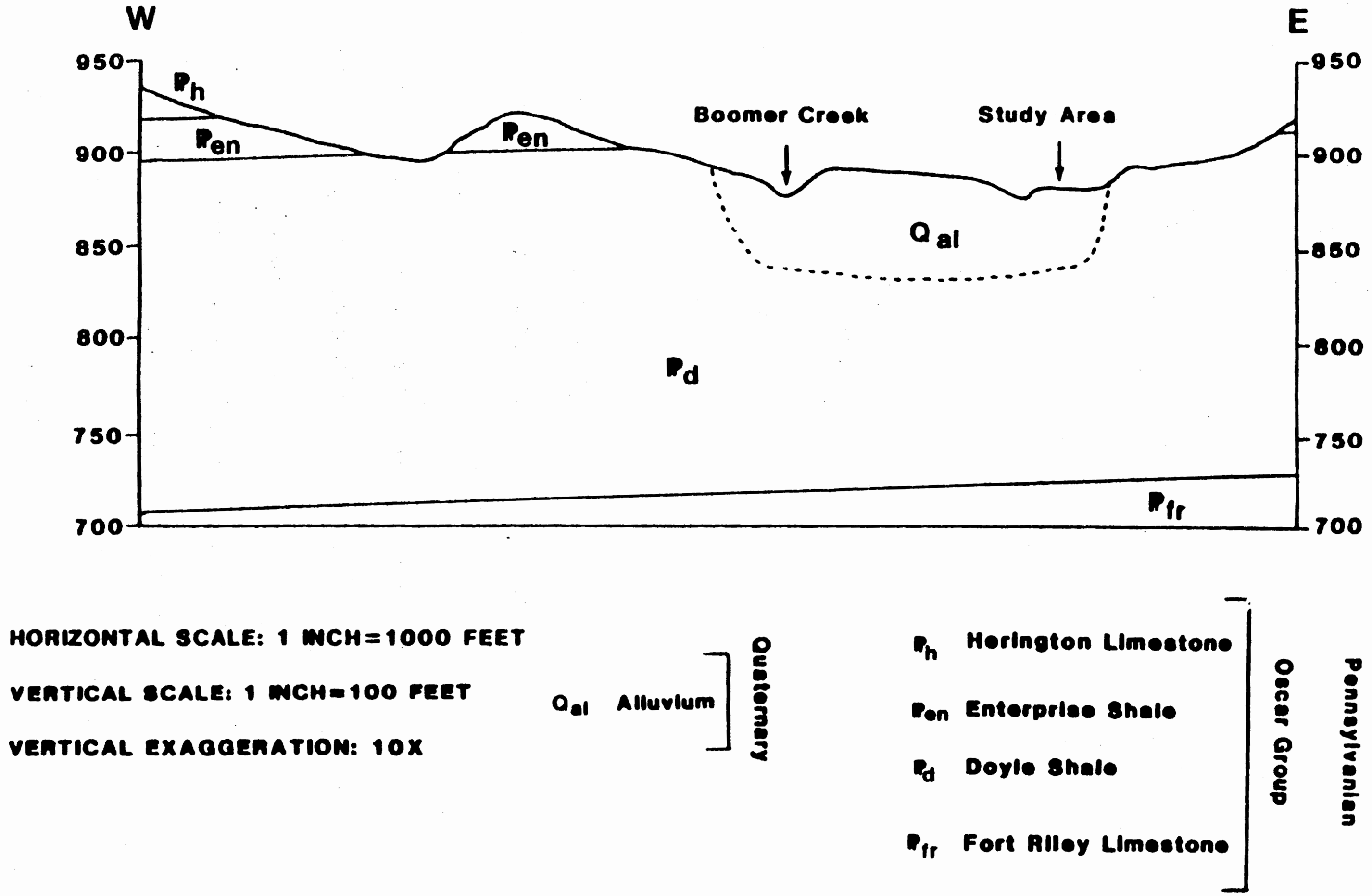


Figure 4. Geologic Cross-Section (After Hoyle, 1987).

(1986, Map 14) as the Ashport silty clay loam. In October, 1986 a 45 foot long composite core was obtained from two wells at the study site. Ross (1987) extensively studied this core and constructed a detailed description of the profile. He found that the alluvial fill consists of fine grained, unconsolidated sediments with soil characteristics, as well as two buried soil profiles. The fill at the site is 43 feet thick and lies on the Doyle shale. It thins abruptly eastward and terminates against the ancient valley wall, which is exposed about 200 feet east of the site. The lower seven feet or so of the alluvial fill consists of a sand lag gravel that lies directly on the weathered shale. The lag deposits increase in grain size as the contact is approached.

The primary interest of this study includes only the upper 14 feet of the alluvial fill, as water-table fluctuations have historically been limited to this zone. A particle size analysis was performed on materials obtained from this zone using the hydrometer method. Results show a preponderance of silt and clay with lessor quantities of very fine sand. Although there are slight variations throughout the profile, the aquifer system is considered to be homogeneous and isotropic.

The description by Ross (1986) includes the designation of 28 horizons within the total thicknesses of the alluvium and these are based on color, texture, structure, and consistence (Figure 5). Two buried soil

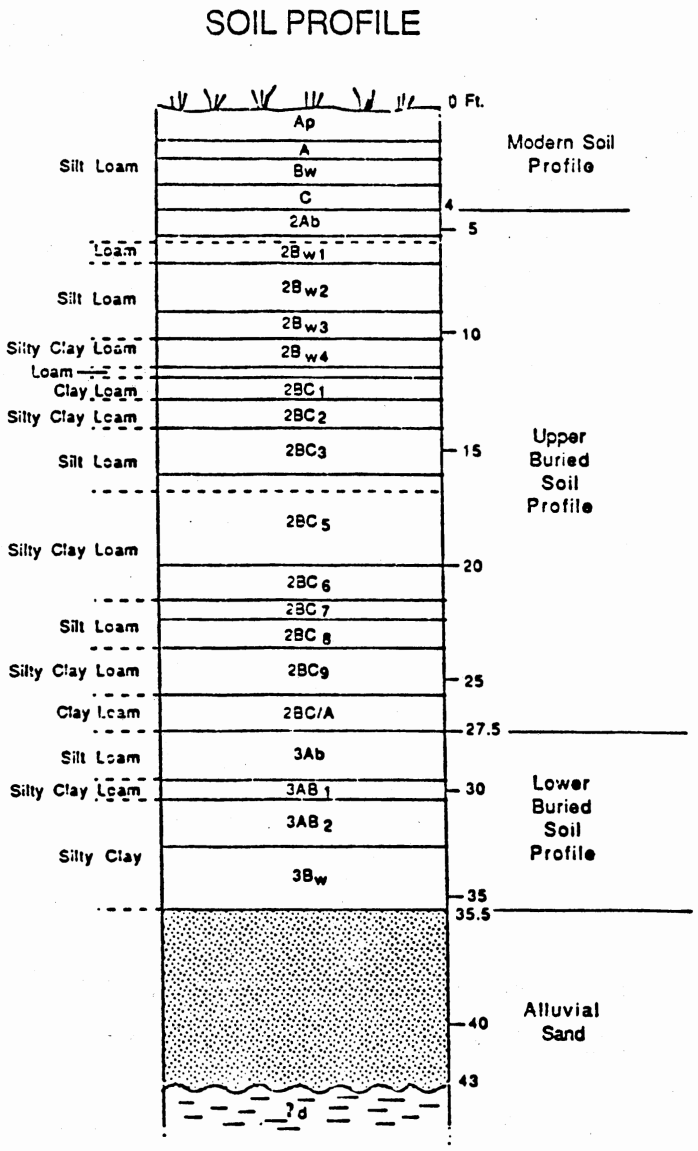


Figure 5. Soil Profile (After Ross, 1987).

horizons were identified and dated using radiocarbon methods. The oldest buried soil horizon, the top of which has a depth of 27.5 feet, is approximately 10,600 years old. The youngest soil horizon, which lies at a depth of 4 feet, is approximately 1300 years old (Ross, 1986). This suggests a net deposition rate of 325 to 385 years per foot of accumulation years/foot (Hoyle, 1986).

Surface-Water Hydrology

Surface runoff is largely controlled by the drainage of Boomer Creek and it's tributary. Stream flow in the unnamed tributary is somewhat restricted by the dam that forms Chiquita Lake. Flow is sluggish and although the total drainage area for the tributary is less than two square miles, Chiquita Lake retains water throughout the year (Ross, 1987). The average annual lake evaporation rate for Central Oklahoma is 60 inches (Pettyjohn and others, 1983).

Pumps have been installed in Boomer Creek, where water is removed for irrigating lawns during the spring and summer. The pumps are located below the confluence of Boomer Creek and it's tributary and have no affect on the water table at the field site.

Pettyjohn and others (1983) also report an average annual surface runoff of five inches. For this area, surface runoff is very small owing to the nearly flat surface of the flood plain. On the other hand, residential development must be recognized for its contribution to surface runoff. Streets and driveways catch a considerable quantity of water, which is then directed to city drains.

Ground-water Hydrology

The effective regional ground-water recharge rate, based on stream hydrograph separations, has been reported to be one inch annually (Pettyjohn and others, 1983). On a local scale, however, Hagen (1986) determined recharge to be considerably higher, and at the study site, recharge amounted to approximately 14 inches during the period August 1986 to May 1987. This high rate of recharge may be attributed to the low relief of the study area, which allows for ponding of rainfall and the high hydraulic conductivity of the alluvial sediments. There is good correlation between precipitation and water-table rise (Figure 6).

Ground-water levels have been monitored extensively, and have shown that this area experiences dramatic fluctuations on both a diurnal and seasonal basis. Diurnal fluctuations of as much as 0.3 feet have been recorded, while the water table has been shown to fluctuate by as much as nine feet annually. These annual fluctuations tend to follow seasonal trends, with the lowest levels occurring July through September, and the highest levels occurring February through April.

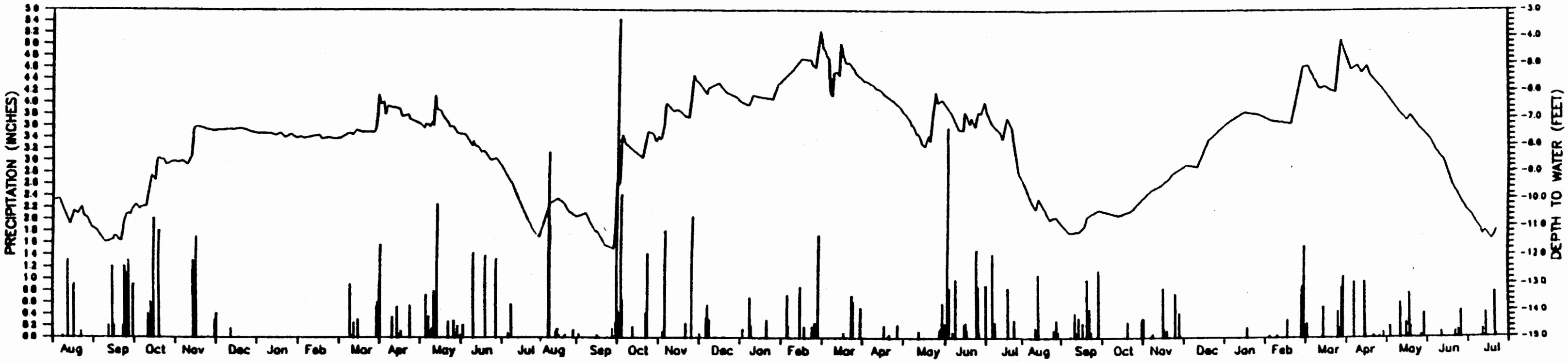


Figure 6. Ground-water Hydrograph--Well A4--With Precipitation August 1985 - July 1988.

A number of aquifer tests have been performed and analyzed. Data from these tests have been utilized in defining the aquifer parameters. The average transmissivity has been found to be 2225 gpd/ft, with the storativity and hydraulic conductivity being 0.01 and 60 gpd/ft2, respectively (Hoyle, 1987). Ross (1987) found that the range for ground-water velocities is from less than 0.4 feet per day to greater than 1.0 feet per day, and that the range for the ground-water gradient is from 0.003 ft/ft to 0.008 ft/ft. It has also been determined that the direction of ground-water flow shifts by as much as 100 degrees throughout the year (Hagen, 1986; Hoyle, 1987).

CHAPTER III

MATERIALS AND METHODS

Introduction

A variety of instruments have been employed in investigations at this site since August, 1985. Forty-three wells have been installed to monitor both water-table fluctuations and changes in ground-water quality. Instruments also have been used to oberve climatological and soil moisture conditions. Only those instruments specifically employed in the study of water-table fluctuations are included in this discussion.

Instrumentation

Climatological Recorders

Since some atmospheric conditions can be readily tied to water-table fluctuations, they were closely monitored. These conditions include precipitation, solar intensity, barometric pressure, and temperature.

Precipitation can have an almost immediate effect on the water table at the site. This may be attributed to the relativity thin (3 to 13 feet) unsaturated zone and the presence of macropores. A tipping bucket rain gauge records the intensity and duration of precipitation events. Precipitation records are available from February 1, 1986 to the present.

The effects of temperature on water-table fluctuations may be two-fold. Temperature must be studied first as it affects the expansion and contraction of entrapped air in an aquifer system, and secondly as it affects evapotranspiration. Temperature data, collected by means of a continuous recorder, are available from November 21, 1987 to the present.

Barometric pressure is of interest as it may have an effect on the expansion and contraction of entrapped air in unconfined aquifer systems. Continuous barometric pressure, measured in millibars, records are available from from August 1, 1986 to the present.

Solar intensity affects both evaporation and transpiration. Relative sunlight intensity data, collected with a photometer attached to a continuous strip-chart recorder, are available for the period April 1, 1986 to November 11, 1987.

Monitoring Wells

Monitoring wells, a major component of this study, were used to obtain water-table measurements throughout the investigation. An extensive ground-water monitoring system has been established since June, 1985. The wells are located along the periphery of a residential property (Figure 3).

The original ground-water monitoring system, installed by Hagen (1986), consisted of four well clusters. The clusters are identified as sites A, C, D, and E, with each cluster being comprised of four ground-water monitoring wells. The wells are designated by depth as 1, 2, 3, and 4, with each having a four-inch screened interval at respective depths of approximately 8, 9, 10, and 14 feet. An additional well designated as well 5 and screened from 7 to 14 feet, was later installed at each cluster (Hagen, 1986). The excavated holes, four inches in diameter, were hand-augered to the specified depth. The wells are cased with two-inch diameter schedule 40 PVC tubing. The screens were hand slotted and covered with a nylon mesh. The screened interval was sand packed with a medium-grained sand and the remainder of the annular space was filled with a bentonite slurry. The well was then encased with a cement pad at the surface. The bentonite and cement pad prevent surface water from flowing down the annulas (Hagen, 1986).

The ground-water monitoring system was expanded considerably with the installation of well sites B, F, G, H, I, and J (Froneberger, 1989). There is considerable variation in the design and installation of these wells, and, most were not employed in this investigation. Discussion will focus only on those wells pertinent to this investigation.

The I-3 well screened from 14.5 feet to 9.05 feet, has a total depth of 15 feet. It was constructed with a 5-foot long sand point attached to 2-inch diameter schedule 40 PVC tubing. The annular space was filled from 15.0 feet to 6.8 feet with sand, and from 6.8 feet to 3.3 feet with bentonite. The remainder of the annular space was filled with clay. The J well 14.4 feet deep is screened from 14.0 feet to 12.0 feet using a 2-foot long sand point attached to 2-inch diameter schedule 40 PVC tubing. A sandpack was applied from the bottom of the annulus to 7 feet below land surface. The remainder of the annular space was filled with bentonite and sealed with a cement cap.

Wells A5, C5, D5, E5, I-3, and J were used to obtain water levels in order to construct potentiometric surface maps. These wells were chosen on the basis of similarity in well design and depth.

The investigation focused on two of these wells for gathering continuous water-table data. The A5 and D5 wells were chosen for detailed study because of their distal locations and similarity in well design. They are situated so as to reflect water-table fluctuations with the greatest variation of contributing factors.

Soil-moisture Neutron Probe

Acre (1989), installed four neutron probe access tubes near well sites A, C, D, and E. The access tubes were installed in September, 1985, and are used in conjunction with the Troxler model 3330 depth moisture gauge to obtain soil moisture data (Ross, 1987; Froneberger, 1989.).

The tubes were installed by driving open-ended EMT thin-walled aluminum tubing, of 1.5-inch, in diameter, to approximately 7 feet below land surface. Soil was removed from within the tube with a hand auger.

The neutron probe emits alpha particles into the adjacent soils. The alpha particles collide with hydrogen ions in the soil and soil water which produce neutron emissions. The probe counts the emissions, which can then be converted to soil moisture using a calibration curve.

Soil moistures have been monitored periodically from September 1985 to the present (Acre, 1989.; Ross, 1987; and Froneberger, 1989.).

Surface-water Gaging Staffs

The scope of the study was expanded in June 1988 to include surface water monitoring within the study site. Two surface-water gaging staffs were installed to monitor fluctuations in both Chiquita Lake and Boomer Creek.

A gaging staff was installed in Chiquita Lake on June 9, 1988. Water-level measurements have been taken periodically since that time. The gaging staff was attached to bridge spanning the pond. It is situated in the deepest portion of the pond where water is held throughout the year. A gaging staff was installed in Boomer Creek on September 14, 1988. Water levels have been taken periodically since that time. The gaging staff was attached to a tree submersed in Boomer Creek.

Both gaging staffs were surveyed with the assistance of Jim Martell, formerly a civil engineering graduate student. Elevations for the top of the staffs in Chiquita Lake and Boomer Creek are 885.45 feet and 879 feet respectively.

Transducer Recorder

In order to obtain continuous water-table elevations, a pressure transducer system (In-Site, Inc. Model SE 1000) was installed in wells sites A5 and D5. There are three components in this system, consisting of a transducer, a remote recorder, and a connecting cable.

The transducer is submersed in a well, with the initial depth to water entered into the recorder. Pressure changes in the well, produced by water-table fluctuations, are detected by the transducer. The fluctuations are then recorded at specified time intervals. The fluctuations, measured to the nearest .01 of a foot, are recorded as depth to water. A minimal distance separating the transducer from the recorder is maintained so as to limit the amount of exposed cable, thus limiting outside electrical interference. A record of water-table fluctuations at Sites A and D are available from September 1986 to the present.

Methodology

As the object of this thesis is to study the cause and effect of water-table fluctuations, it is essential to develop an extensive data base of water-table elevations. This has been accomplished with the use of the monitoring wells and pressure transducers. The transducer recorders have been programed to record depth to water at 30-minute intervals. This allows for long-term observations of changes in the water table, as well as a detailed study of diurnal fluctuations.

The pressure transducers were installed in Wells A5 and D5. These wells are of identical design, but represent the greatest diversity in those conditions affecting water-table fluctuations. This determination was based on the presence of surface structures and vegetative cover. The A site is situated near several buildings and paved areas and there is only slight vegetative cover. The D site is situated in dense vegetation. The distal locations of the wells should best present the contrasts of factors contributing to water-table fluctuations.

The effect of evapotranspiration on the water-table was studied under a variety of conditions. The first approach was a study of water-table fluctuations under conditions of varying vegetation density. This was accomplished by the comparison of fluctuations at Sites A and D. It is important to note that since the initiation of the study, there has been considerable vegetative growth at the A site, and a loss of vegetation at the D site. This also allows for a comparison of water-table fluctuations under varying vegetation densities.

The next approach was to study the water-table fluctuations on a seasonal basis. Evapotranspirational effects should be greatest during the spring and summer months, as these months constitute the growing season. The magnitude of the fluctuations should decrease during the fall and winter months. The effect of the killing frost on the magnitude of water-table fluctuations must also be considered. Data has been collected during all seasons for comparison.

The final approach to determining the effects of evapotranspiration on the water-table, was to study the magnitude of diurnal fluctuations at varying depths to water. The effects of evapotranspiration should decrease with increasing depth to water.

Another contributing factor to water-table fluctuations is precipitation. The water table can be expected to show a highly variable response to precipitation owing to differences in intensity of precipitation, antecedent soil-moisture content, and the depth to water. Water-table response to precipitation has been recorded under a variety of conditions and, therefore, each of these factors can be isolated and studied independently.

Other studies have shown that barometric pressure changes also have a noted effect on the water table. Comparison of water-table fluctuations and barometric fluctuations under dry conditions and a constant temperature, should define this relationship. Temperature waves have also been isolated and studied for a possible contribution to water-table fluctuations at this site.

Once the contributing factors to water-table fluctuations have been identified and defined, one can investigate their resultant effects on the aquifer system. Of particular interest to this study are the resultant effects on ground-water flow dynamics.

As noted by Hagen (1986) and Hoyle (1987), the ground-water gradient may shift direction by as much as 100 degrees throughout the year. This suggests that the location of ground-water discharge is changing. There appear to be three possible explanations; removal of ground water by periodic pumping, the seasonal removal of ground water by evapotranspiration, or removal of ground water by natural discharge into the pond or creek.

In order to determine the possible influences of pumping on the gradient, a survey of the neighborhood was conducted to locate ground-water wells. Pumping schedules and rates were determined for those wells within the basin.

Determining the possible influence of evapotranspiration on the gradient is considerably more involved. One must first determine if the start of the growing season corresponds to the shift in the ground-water flow direction. One also can determine any possible correspondence between the killing frost and shift in flow direction. It is important to determine how a declining water table affects rates of evapotranspiration.

Determining the possible influence of natural ground-water discharge on the gradient also proved to be quite involved. It was first necessary to locate all areas of potential discharge, determine their elevations, and then define all factors that might influence natural discharge, such as proximity of the drains, topographic slope, water-table elevations, and the surface-water stages associated with both Boomer Creek and Chiquita Lake. Once the potential discharge areas have been located and surveyed, water-table elevations must be used to determine if ground-water and surface-water elevations correspond. This required examination of water-table elevations throughout the year since considerable fluctuations have been shown to occur on a seasonal basis. Since zones or areas of potential discharge are related to the elevation of the water table, studying the ground-water flow directions under varying water-table elevations was necessary. This helped to identify changes in the locations of ground-water discharge zones under fluctuating water table conditions. Surface-water stages also have been taken into consideration.

CHAPTER IV

FACTORS CONTRIBUTING TO WATER-TABLE FLUCTUATIONS

Introduction

When investigating the hydraulic controls of an unconfined aquifer system it is first necessary to identify all factors contributing to water-table fluctuations. Proper identification will allow for a greater understanding of the system, and eliminate potential error in interpretation. Water-table fluctuations are usually caused by changes in the quantity of ground water held in storage. This investigation is primarily concerned with precipitation and subsequent infiltration as a means of increasing ground-water storage, and ground-water discharge, pumping and evapotranspiration as a means of decreasing ground-water storage.

Water-table fluctuations may also be caused by factors that do not affect a change in storage. Such factors influence the water table by means of pressure changes, such as atmospheric, and loading-induced pressures and temperature. All of these factors may affect the position of the water table without changing the volume of ground water in storage.

Fluctuations Not Indicative Of A Change in Storage

Atmospheric Pressure

While atmospheric pressure has been demonstrated to influence certain water-table aquifer systems (Peck, 1960, and Turk, 1975), individual systems can be expected to show a highly varied response. This is due to variations in the texture of aquifer materials and the presence of air entraped in the capillary pores.

Studies of atmospheric pressure influences at this site were conducted under dry-weather conditions and with relatively little temperature variation. Water-table fluctuations were studied during different seasons and at various depths to the water table.

Water levels recorded at a depth of approximately 10 feet in November show little fluctuation in comparison to the atmospheric pressure (Figure 7). Atmospheric pressure increased over a 33 hour period at which time a marked decrease occurred. The water level remained relatively steady throughout the first 32 hours after which a slight decline in water level occurred and was followed almost immediately by a rise. There is no observable relationship between the atmospheric and water-level fluctuations at this depth.

Water-level fluctuations recorded at a depth of

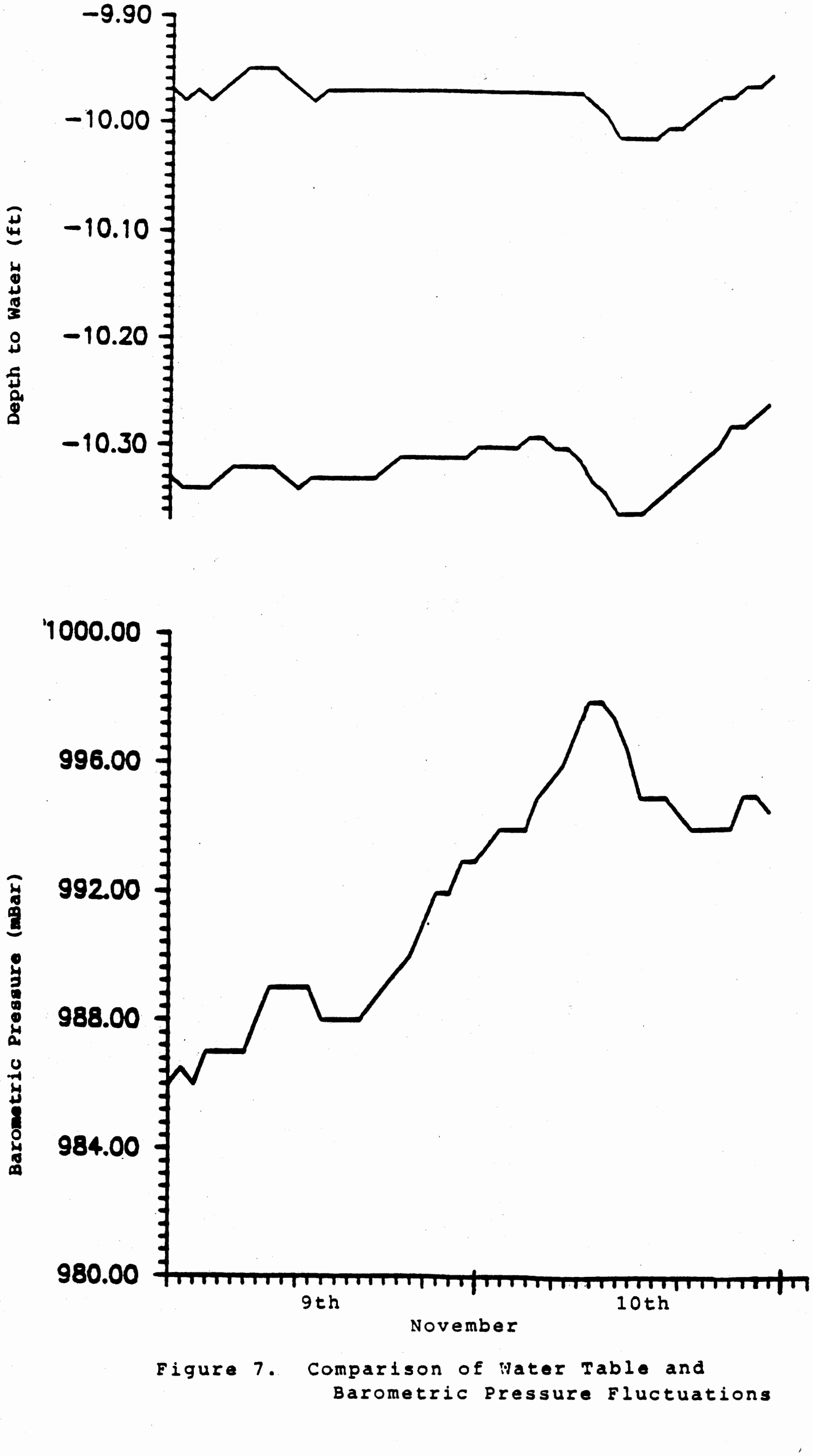


Figure 7. Comparison of Water Table and Barometric Pressure Fluctuations

approximately 8 feet in December also bear no relation with atmospheric pressure fluctuations (Figure 8). Atmospheric pressure decreased during the first 14 hours and then leveled off. From 24 hours to 48 hours, the atmospheric pressure increased dramatically. Water levels consistently declined for the 48 hour period, therefore no relationship can be defined at this depth.

Water-level fluctuations at approximately 6 feet again are inconsistent with atmospheric pressure changes (Figure 9). Although fluctuations in the water levels do occur during the 48 hour period, there is neither an increasing nor decreasing trend. Atmospheric pressure however, demonstrates an increasing trend for the 48 hour period. Even at shallow depths, a relationship cannot be defined for atmospheric pressure and water-level fluctuations.

Temperature

A number of authors (Meyer, 1960, Schneider, 1961, Benz and others, 1968, and Turk, 1975) documented seasonal water-table fluctuations in response to temperature waves. Haise and Kelly (1950) also studied water-table fluctuations in response to daily temperature changes. Although isolating temperature influences is extremely difficult in a field study, certain observations can be made and subsequent conclusions drawn.

Haise and Kelly (1950) found a considerable time lag

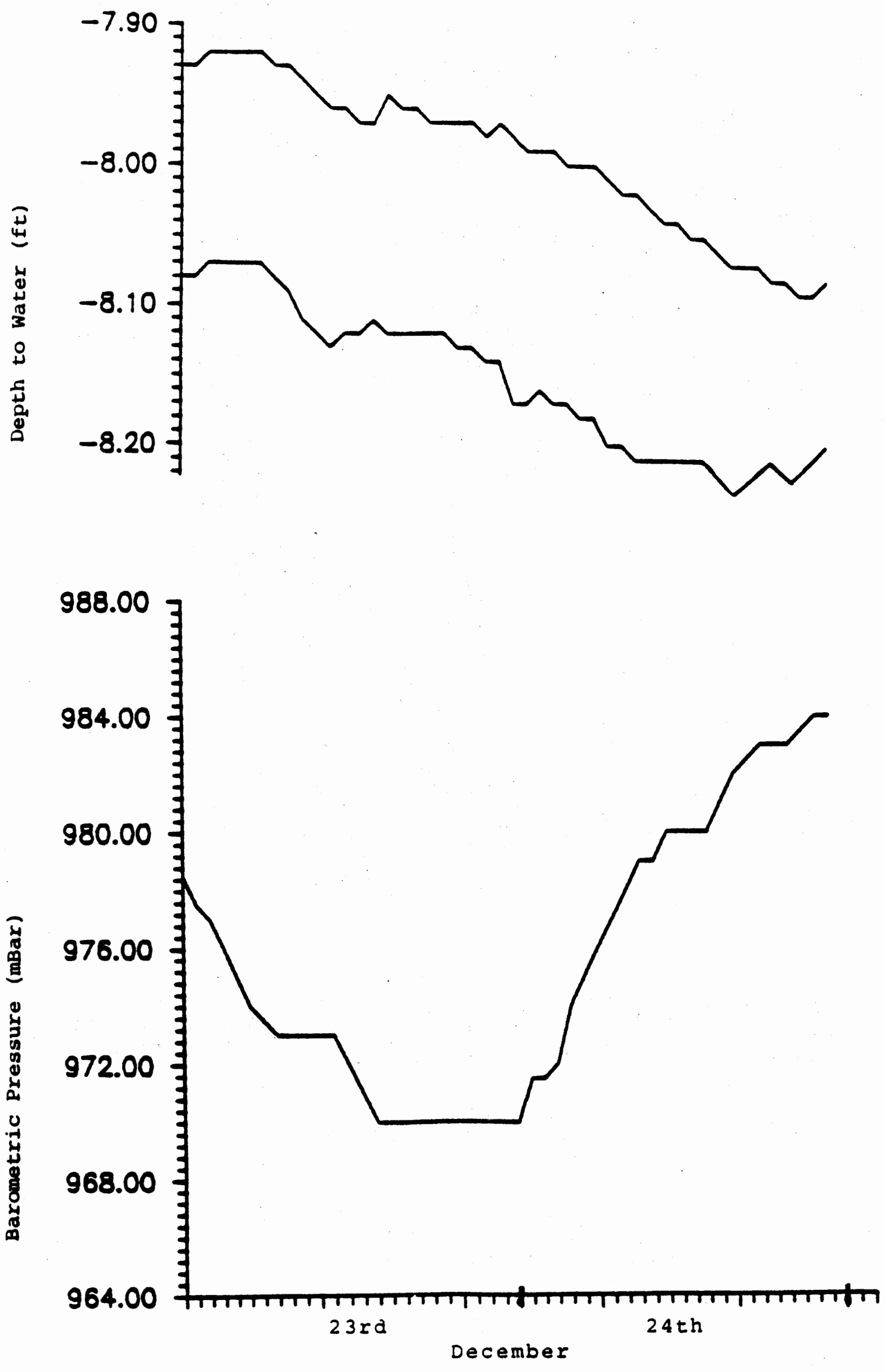


Figure 8. Comparison of Water Table and Barometric Pressure Fluctuations

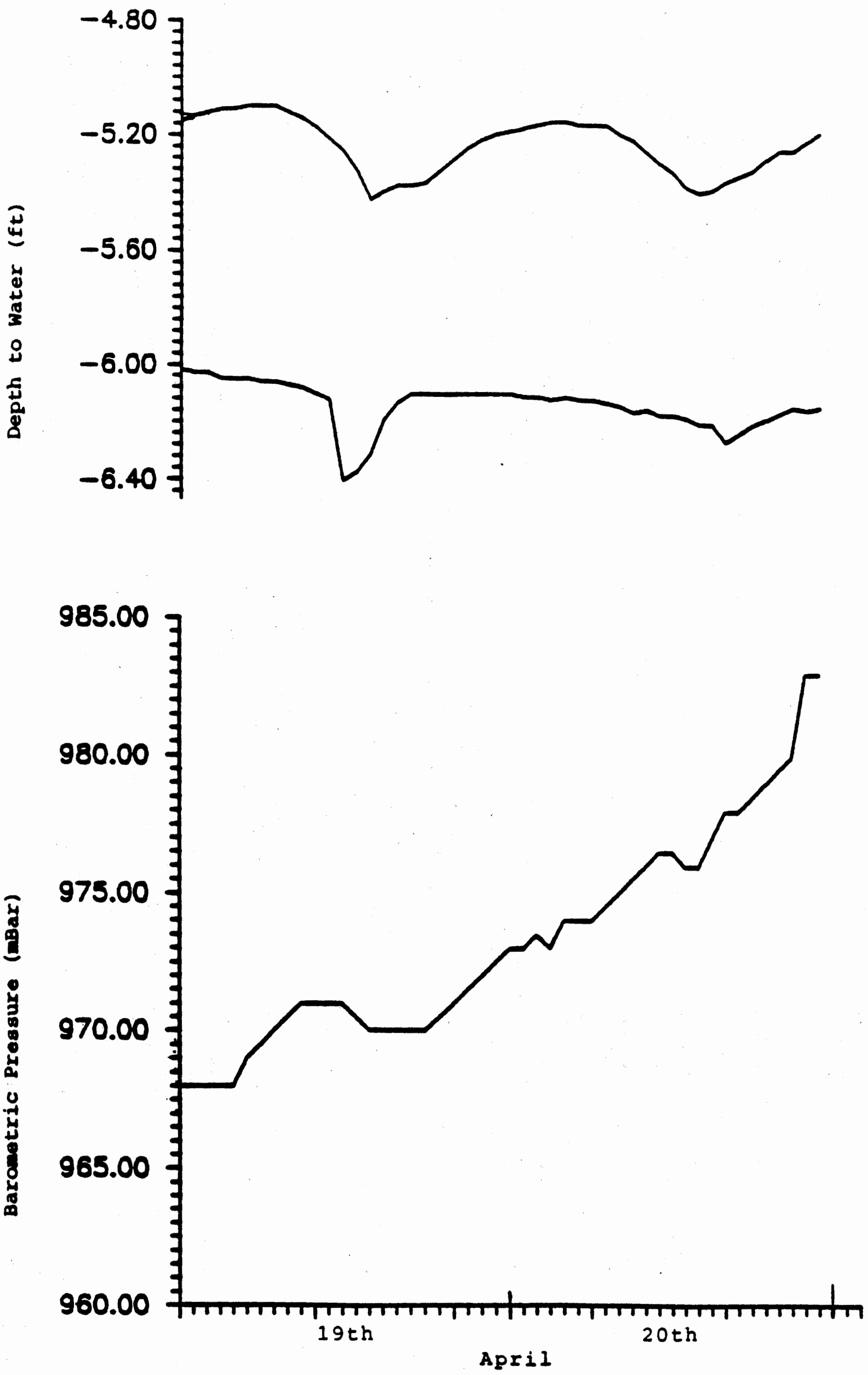


Figure 9. Comparison of Water Table and Barometric Pressure Fluctuations

between daily changes in air temperature and associated changes in soil temperature. Soil temperatures, therefore, may not assimilate to air temperatures that are highly variable.

Turk (1975) concluded that daily air temperature changes would not directly influence the water table due to the insulating effects of the soils. Turk suggested that temperature changes could, however, indirectly influence the water table. Water-table systems that are susceptible to barometric influences would respond instantaneously to temperature induced atmospheric pressure changes. Temperature also may have an indirect effect on water-table systems that are influenced by evapotranspiration. This aquifer system is not considered to be susceptible to atmospheric pressure influences, but is susceptible to the influences of evapotranspiration. A relationship between temperature changes and water-table fluctuations is suggested by figures 10 and 11. However, since daily temperature changes do not directly influence the water table, this is thought to be an evapotranspirational influence brought about by a change in temperature.

Seasonal responses are most commonly found in areas where the air temperature remains below freezing for extended periods of time. This allows for assimilation of soil and air temperatures. As Bouyoucos (1915) discussed, soil moisture moves from warmer to cooler soil, and from wet to dry soil. Therefore, frozen soil near the surface

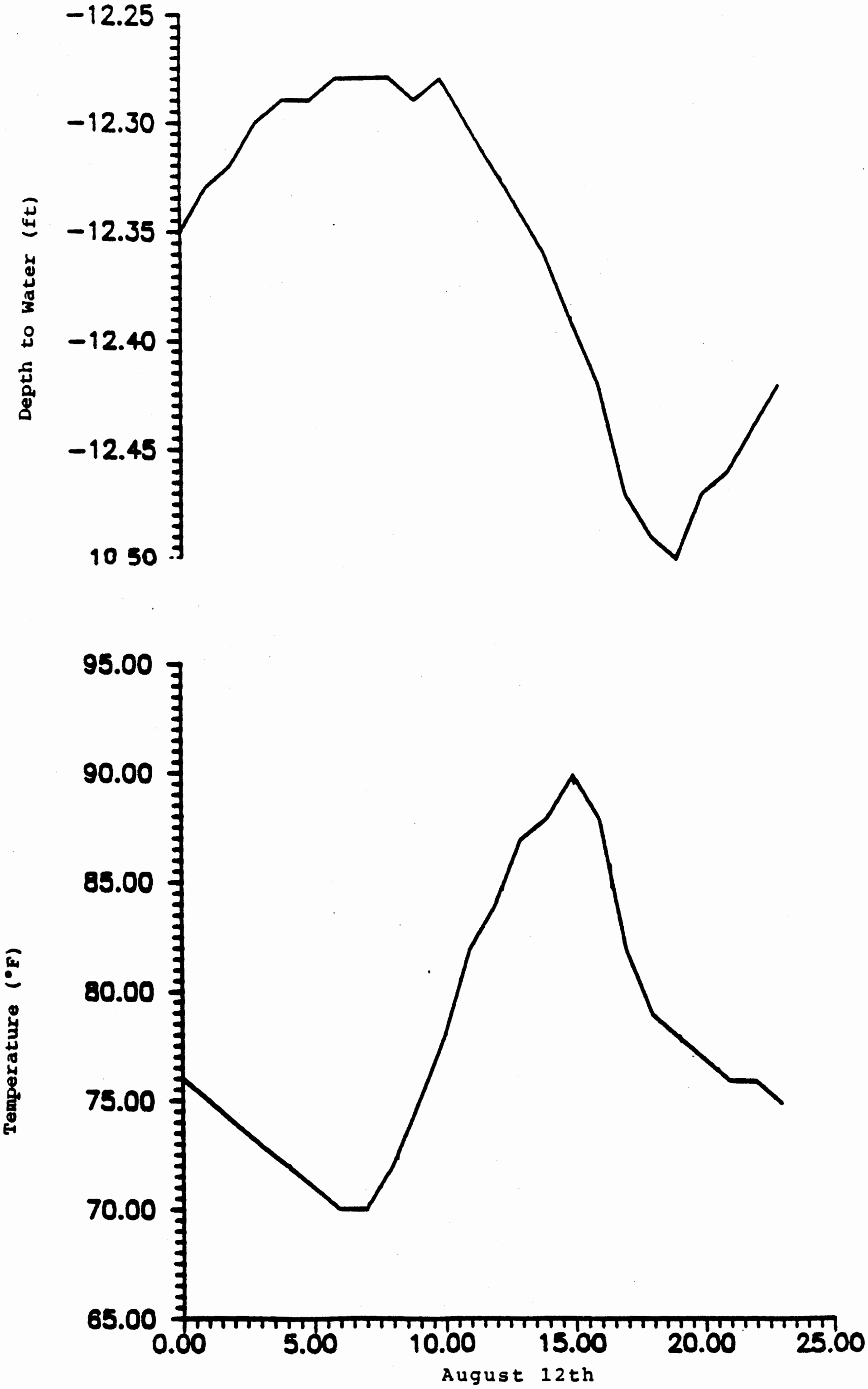


Figure 10. Comparison of Water Table and Temperature Fluctuations

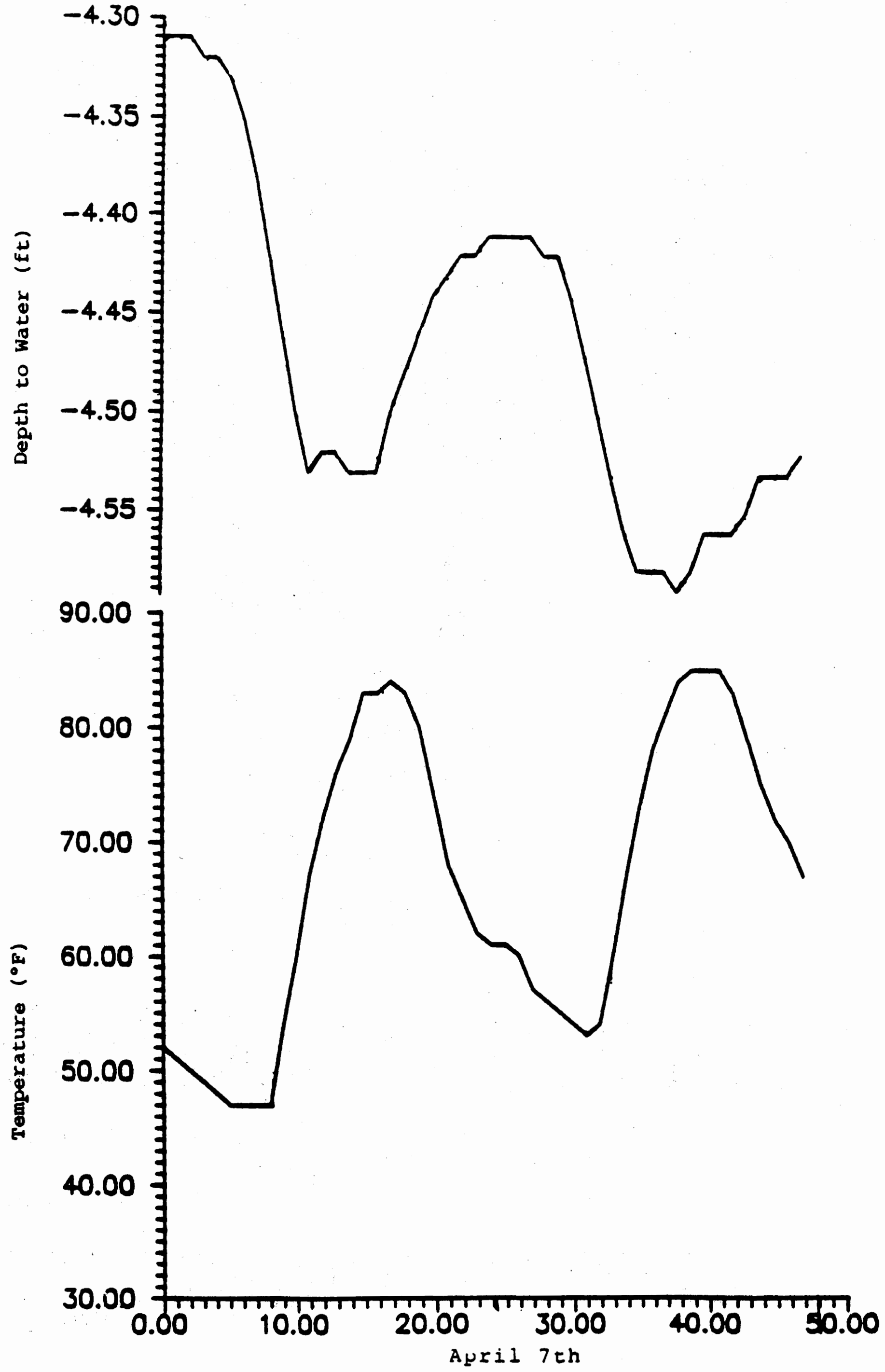


Figure 11. Comparison of Water Table and Temperature Fluctuation

will draw ground water upward, lowering the water table. Air temperatures at this site do not remain below freezing for periods long enough to influence the water table. During the winter of 1987-1988 air temperature fell below freezing on 53 days, however, the longest continuous freezing period was only four days.

Loading

While external loading has long been recognized as an influence on confined aquifer systems (Jacob, 1939; Parker and Stringfield, 1950), it has not been recognized as an influence on unconfined systems. Although these findings were supported by the initial observations of water-table fluctuations for this unconfined system, potential loading pressure generators were identified and studied.

As this site is situated in a residential area, there are limited potential sources of loading pressure. Sources identified include sporadic automobile traffic along the street near the D Site and in the driveway near the A Site, and trains passing along the tracks a few hundred feet east of the site. The train was immediately dismissed as a source since the tracks were found to be resting on the Doyle Shale, which underlies the shallow aquifer system. Studies were conducted, however, to determine if the automobile traffic had an influence on water-table elevations.

The study was conducted on 16 December 1988 under dry weather conditions. This time was chosen for the study, in order to reduce the possibility of influence from other factors such as evapotranspiration and precipitation. The test was conducted by passing several automobiles along the street and across the driveway while observing water levels at the D and A well sites, respectively. Water levels were recorded, by means of a transducer, at one second intervals during the test. The time at which automobiles were passing near the wells was also recorded. There were no measurable changes in the water-table elevation during these tests (Appendix D).

Fluctuations Indicating An Increase In Storage

Ground-water Recharge

Precipitation can produce a highly varied response in water-table fluctuations. This response is dependent upon many variables, including soil texture, depth to water, soil-moisture content, and the intensity of rainfall (Viswanathan, 1984). Viswanathan (1984) discussed the role of evapotranspiration on recharge, stating that precipitation would have little effect on the water table during periods of high evapotranspiration due to water uptake by plants and replenishment of soil moisture.

The role of the capillary fringe has been discussed by Gillham (1984), who found that in an aquifer system with fine-grained material, the capillary fringe could extend a considerable distance above the water table. He also found that when the capillary fringe extended to land surface, the water-table response to precipitation would be immediate and dramatic.

Horton (1933) showed that rainfall, when it reaches the ground surface, infiltrates the surface soils at a rate that decreases with time, reaching an approximately constant rate.

Two rainfall events were used by Ross (1987) to study the precipitation/water-table relationship at this site. One rainfall event occurred at a time when soil-moisture content was relatively low, while the other event occurred during a period of high soil-moisture content. He demonstrated that the effective specific yield, or fillable porosity, will be affected by the soil-moisture content of the unsaturated zone and that the soil-moisture content will be dependent upon the recent rainfall history.

To further develop this relationship, additional rainfall events will be discussed. These events represent variations in season, precipitation history, precipitation intensity, and depth to the water table.

An intense, rainfall event occurred 25 November 1986. Substantial precipitation occurred prior to this in September, October and early November (Figure 12). Recharge from these events brought the water table to

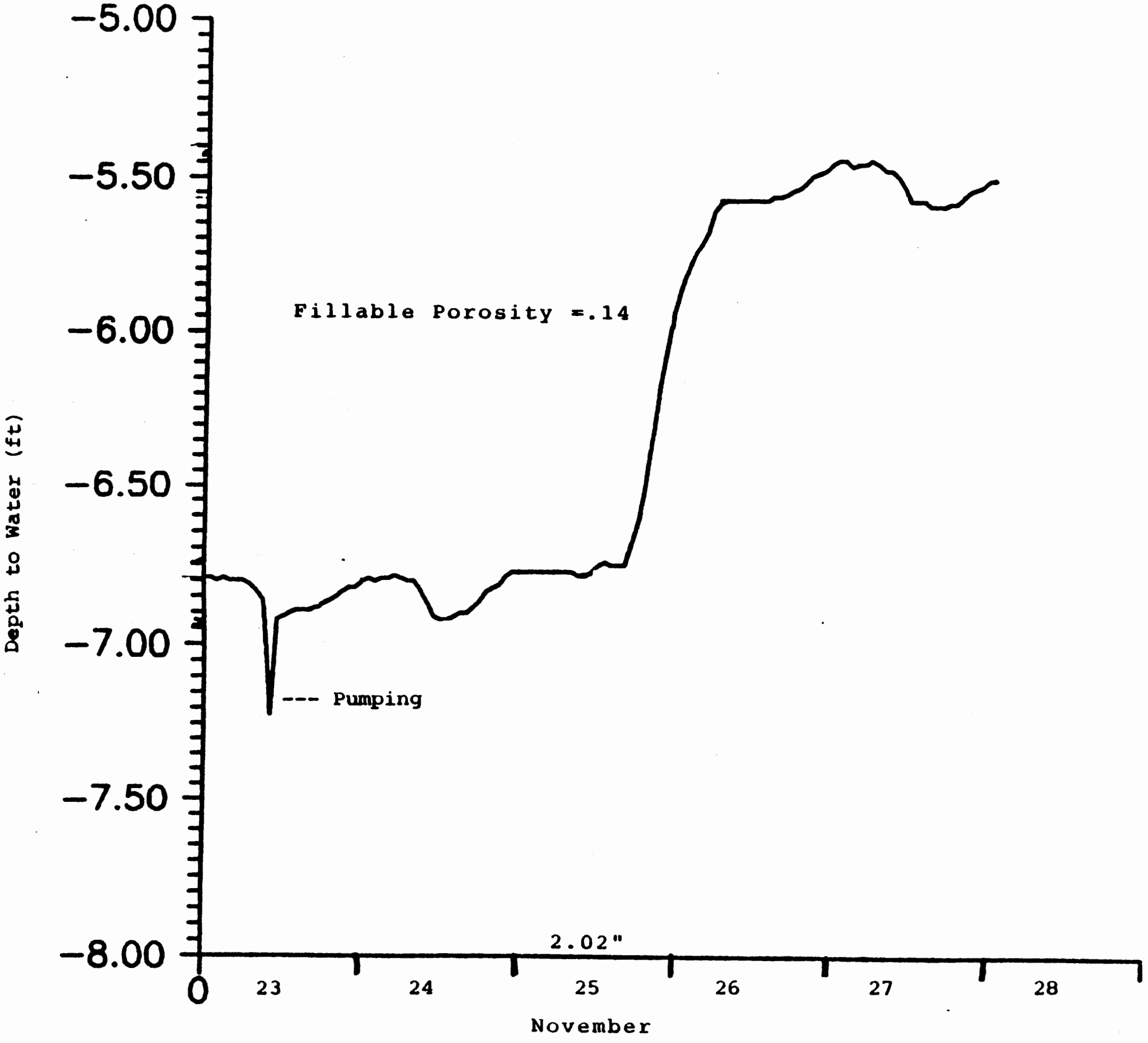


Figure 12. November Precipitation Event

within 7 feet of land surface, and produced high soil moisture conditions.

While there is evidence of diurnal fluctuations on 23 and 24 November, these fluctuations appear to have been attenuated prior to the rainfall event on 25 November (Figure 12). This event produced 2.02 inches of rain over a nine hour period and caused the water table to rise from 6.80 to 5.56 below land surface, a total rise of 1.24 feet. The water table continued to gradually rise until it reached a depth of 5.43 feet on 27 November, at which time diurnal fluctuations again become evident.

During this event the soil-moisture content increased slightly at depths of 1.5 to 3.5 feet, and just above the water table at 5.0 feet. The remainder of the soil profile above the water table remained unaffected. The 1.24 foot rise in the water table produced by 2.02 inches of rain represents a fillable porosity of 0.14. This relatively low fillable porosity can be attributed to high soil-moisture conditions prior to the recharge event, and a relatively shallow water table.

A series of rainfall events began in mid-May and continued into early June, 1987 (Figure 13). Prior to the rain, soil-moisture conditions were moderate and the depth to water was approximately 8 feet. The most recent rainfall event occurred on 5 May and, due to evapotranspirational losses, the water table had been declining since that time.

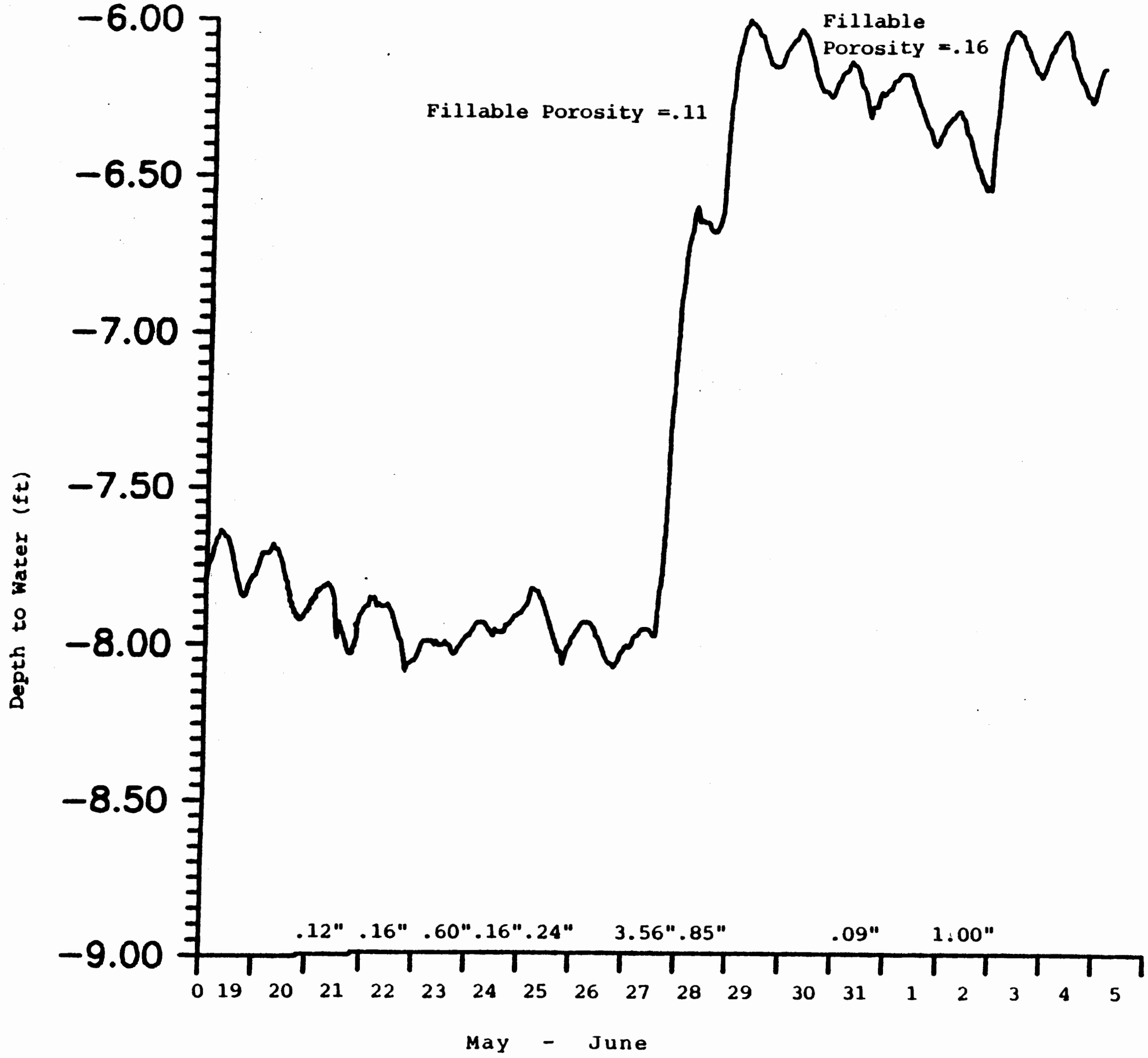


Figure 13. May and June Precipitation Events

Diurnal fluctuations are evident from 19 May to 22 May, and average 0.24 ft per day (Figure 13). A 0.12 inch rain, occurred on 21 May, but it had no measurable effect on the water table. Additional rains brought 0.16 inches on 22 May, 0.6 inches on 23 May, 0.16 inches on 24 May and 0.24 inches on 25 May. These events produced a gradual rise in water levels until 25 May, at which time diurnal fluctuations again become evident. Water levels began a gradual decline until 27 May when 3.56 inches of rain produced a significant and rapid rise in water levels. This event produced a 1.38 foot rise in water levels, representing a fillable porosity of 0.21. An additional 0.85 inches of rain fell on 28 May and produced a .65 foot rise in the water table. This represents a fillable porosity of 0.11 . Diurnal fluctuations averaging 0.22 feet are evident from 29 May to 2 June. And although a 0.09 inch rainfall event on 31 May generated a slight rise in the water table, it does not alter the diurnal fluctuation. On 2 June a 1.00 inch rain caused a .5 foot rise in the water table representing a fillable porosity of 0.16.

As expected, much of the early rain was absorbed by the unsaturated zone and did not produce a significant rise in the water table. This is due to moderate soil-moisture conditions prior to the rain, and to a reasonably thick unsaturated zone. Also, as expected, the fillable porosity decreased throughout a continuous series of rainfall events owing to an increase in the soil-moisture content and a decrease in the thickness of the unsaturated zone. However, since diurnal fluctuations represent processes that commonly generate declining water levels and a decreasing soil-moisture content, isolated rainfall events during a period of high evapotranspiration may not result in a decrease in fillable porosity. An example of this is the 3 May rainfall event in which the fillable porosity increased from 0.11 to 0.16 following four days of diurnal fluctuations.

Another series of rainfall events occurred in late September 1986. Prior to the rain, soil-moisture was low and the depth of the water table was approximately 12 feet. Limited rainfall had occurred prior to this series of events, and due to evapotranspiration, the water table was declining.

Diurnal fluctuations from 24 September to 28 September average 0.34 feet (Figure 14). These fluctuations were attenuated on 26 September by a 0.15 inch rainfall, but return to normal on 27 September. On 28 September a 0.25 inch rain produced only a slight increase in water levels. This was followed on 29 September by a 5.41 inch rain that produced a 1.65 foot rise in water levels. This represents a fillable porosity of 0.27. The water table continued to rise as additional rainfall events of 0.46 and 0.40 inches occurred on 30 September and 1 October respectively. A 2.39 inch rain on 2 October produced a 1.7 foot rise in water levels,

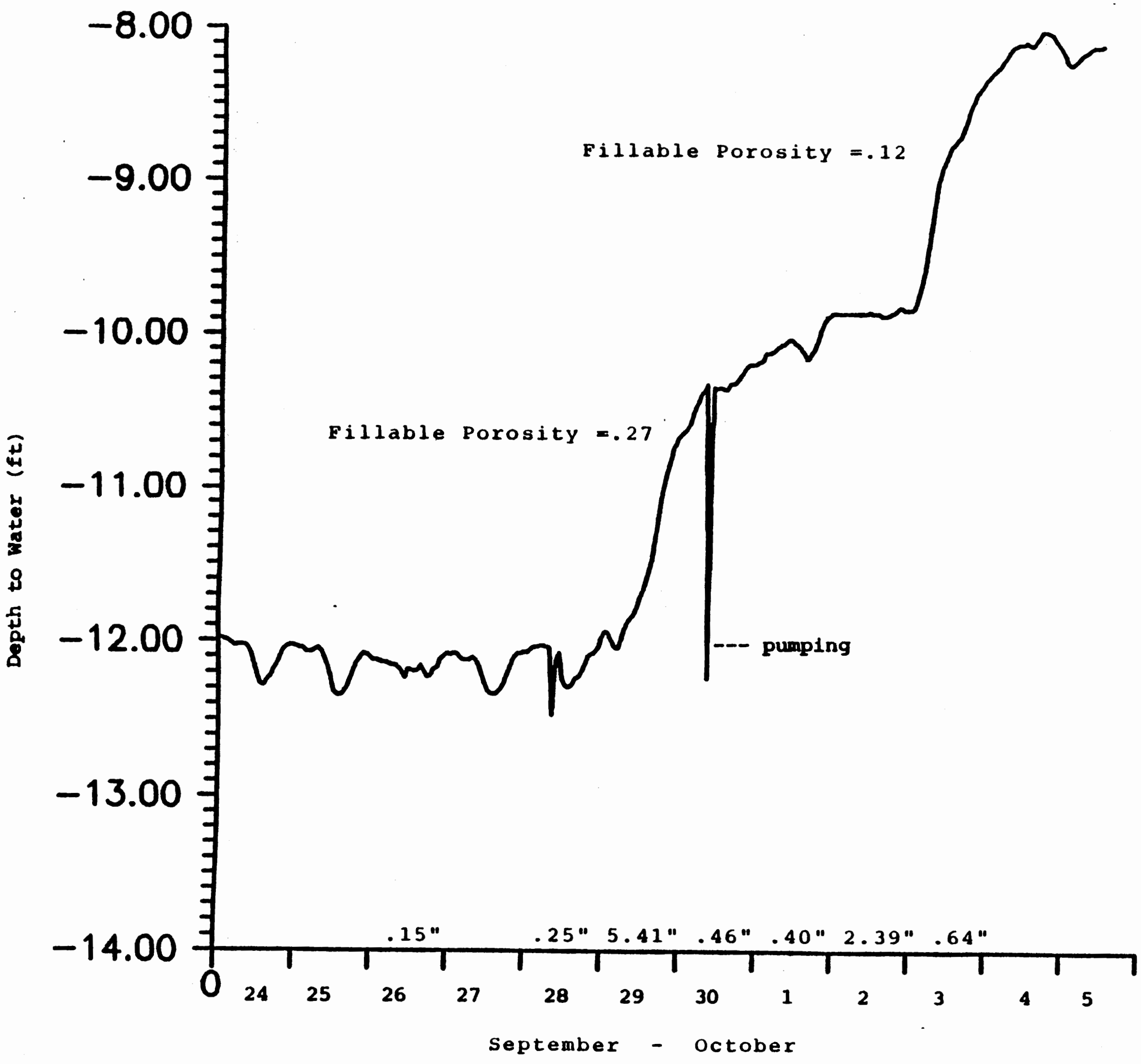


Figure 14. September and October Precipitation Events

representing a fillable porosity of 0.12. Although an additional 0.64 inches fell on 3 October, the associated rise in water level is not discernable.

This series of precipitation events during September, 1988, illustrate the effect of rain on water-table fluctuations. Initial rains occurred at a time when the soil-moisture content was relatively low and the depth to water was greater than 12 feet. The early rains did not make a measurable contribution to the water table because the moisture was absorbed by the unsaturated zone. The first major recharge event in September demonstrated an unusually high fillable porosity, that is, about 27 percent. Subsequent rains occurred, causing the water table to rise and increasing the soil-moisture content. This is evident in the second major recharge event (October 2) with a demonstrated fillable porosity considerably lower (.12) than the first.

Fluctuations Indicating a Decrease in Storage

Pumping

Pumping is a commonly recognized and easily identified cause of water-table fluctuations. Continuous pumping can significantly decrease the amount of ground water in storage and effectively alter the flow direction and gradient. It is important, therefore, to determine if substantial pumping occurs in the vicinity of the site, and if so, what effects it may have on the aquifer system.

A survey was conducted to determine the presence and use of water wells that tap the alluvial system within the general area. One such well is located approximately 800 feet south of the D site. This well produces from the shallow unconfined system, and is used for lawn irrigation during the summer months. Reportedly, the well is operated at low pumping rates and for only a few hours at a time. A distance drawdown plot was constructed to determine the radius of influence that would be expected if this well were pumped for eight hours at a rate of 2.7 gallons per minute (gpm). The radius of influence was found to be 400 feet, and therefore would not influence water levels in the observation wells (Figure 15).

Another pumping well is located approximately 30 feet to the southeast of the C site, and approximately 50 feet to the southwest of the D site. The well has reportedly been drilled to a depth of 76 feet, and is producing from a "sand rock". This probably represents a lenticular sand unit within the Doyle shale. There has been no indication that this well has influenced water levels at the study site.

The observation wells at the study site usually are pumped weekly for the purpose of obtaining ground-water samples, and, infrequently, for conducting aquifer performance tests. For the purpose of obtaining representative ground-water samples, no more than three

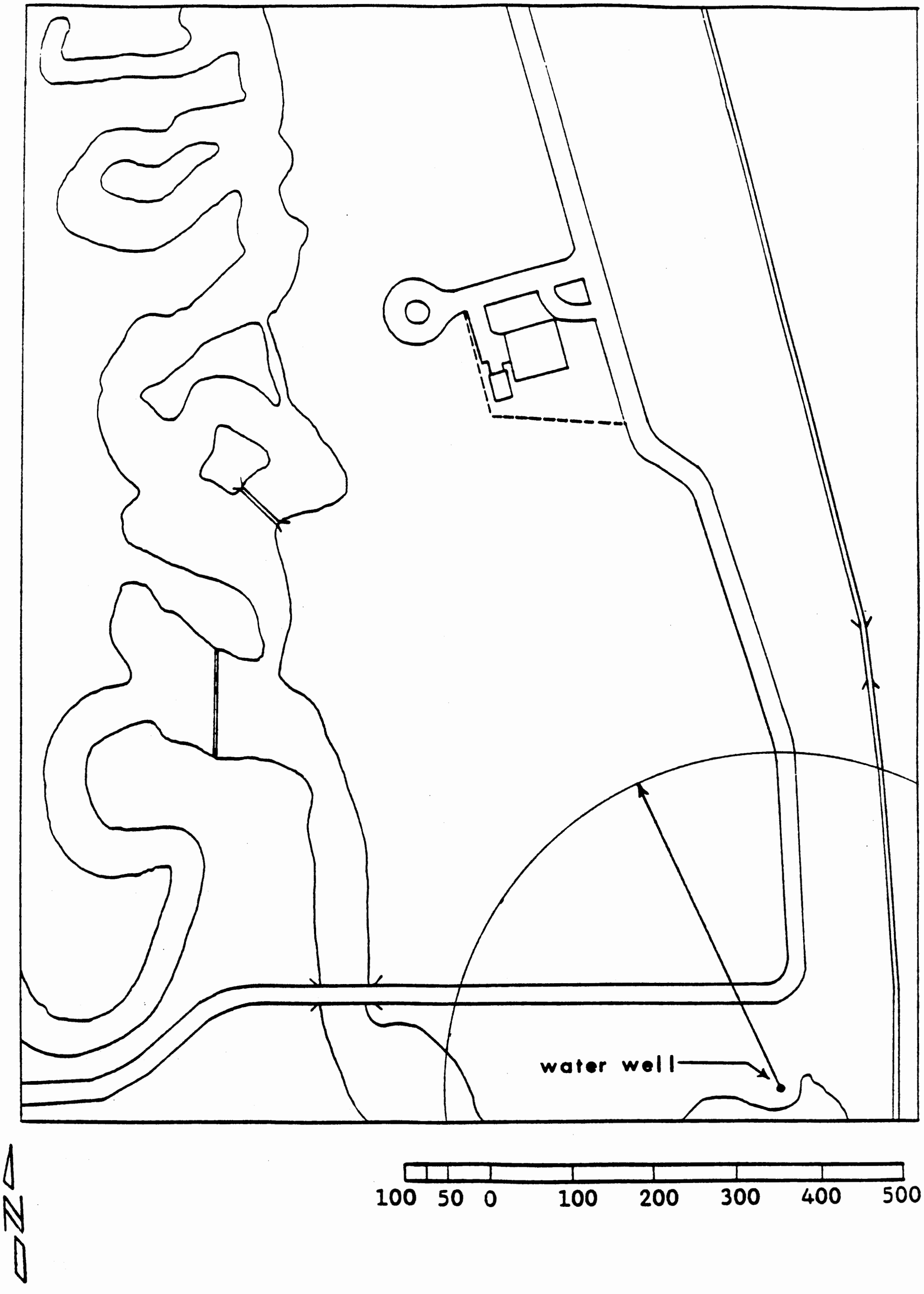


Figure 15. Water Well Location and Radius of Influence

well volumes are purged from each well prior to sampling. On 23 August 1987, water levels were recorded while purging at the D and A sites. The hydrograph in Figure 16 shows that a declining water level trend had been established at both sites, prior to purging, and although drawdown is pronounced during the purging event, water levels recover quickly. This demonstrates that purging has a dramatic, though short lived influence on the elevation of the water table in the vicinity of the wells being pumped.

A constant rate aquifer performance test was conducted by Melby (1989) on 14-17 August 1988. Well B12 was pumped at a rate of 2.7 gallons per minute (gpm) for 72 hours. During this period, water levels were recorded at wells A5, B7, B8, B9, C5, D5, E5, F1, G2, H2 and J1 (Appendix F). A maximum drawdown of 7.81 feet was observed in the pumping well, with a maximum drawdown of 0.45 feet being observed at well D5, which is 150 feet from B12. As can be demonstrated from this data, long term pumping can produce significant water table declines near the pumping well and measurable drawdown a considerable distance from the pumping well. However, since transmissivity and pumping rates are small, pumping must continue for an extended period before substantial declines occur in the distant wells.

As previously mentioned, the water wells in the area are used for irrigation purposes and operate for only

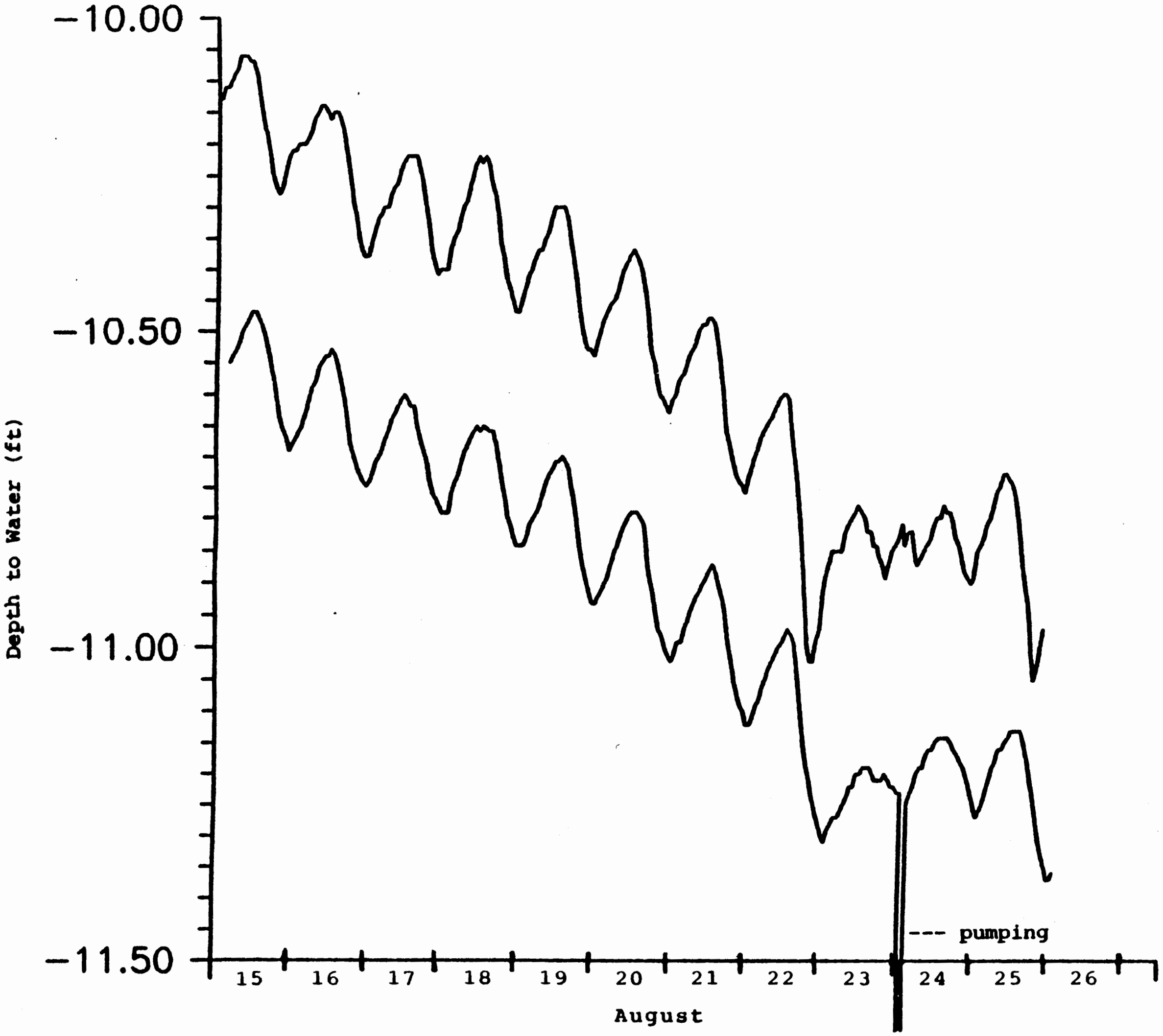


Figure 16. Effect of Pumping on Water Levels

short periods of time. Therefore, pumping may be expected to create localized, short lived cones of depression that are limited in areal extent. This may affect the water level in the vicinity of the pumping well, but not the water level throughout the system.

Evapotranspiration

Evapotranspiration can contribute significantly to ground-water losses in areas with shallow unconfined aquifer systems and dense vegetation. These evapotranspirational losses are attributed to consumptive use by phreatophytes, which have been defined as plants that habitually obtain their water supply from the zone of saturation, either directly or through the capillary fringe (Mayboom, 1967).

As discussed by Troxell (1936), diurnal fluctuations represent an accumulative curve of the rates of ground-water inflow (plus) and the ground-water loss by transpiration (minus). The hydrograph in Figure 17 shows that the daily drawdown begins at approximately 6:00 a.m., representing the time at which ground-water losses to evapotranspiration are greater than the ground-water inflow. Conversely, the water table begins to rise at approximately 7:00 p.m., representing the time at which the rate of ground-water inflow exceeds ground-water losses to evapotranspiration.

Evapotranspirational influences are controlled by

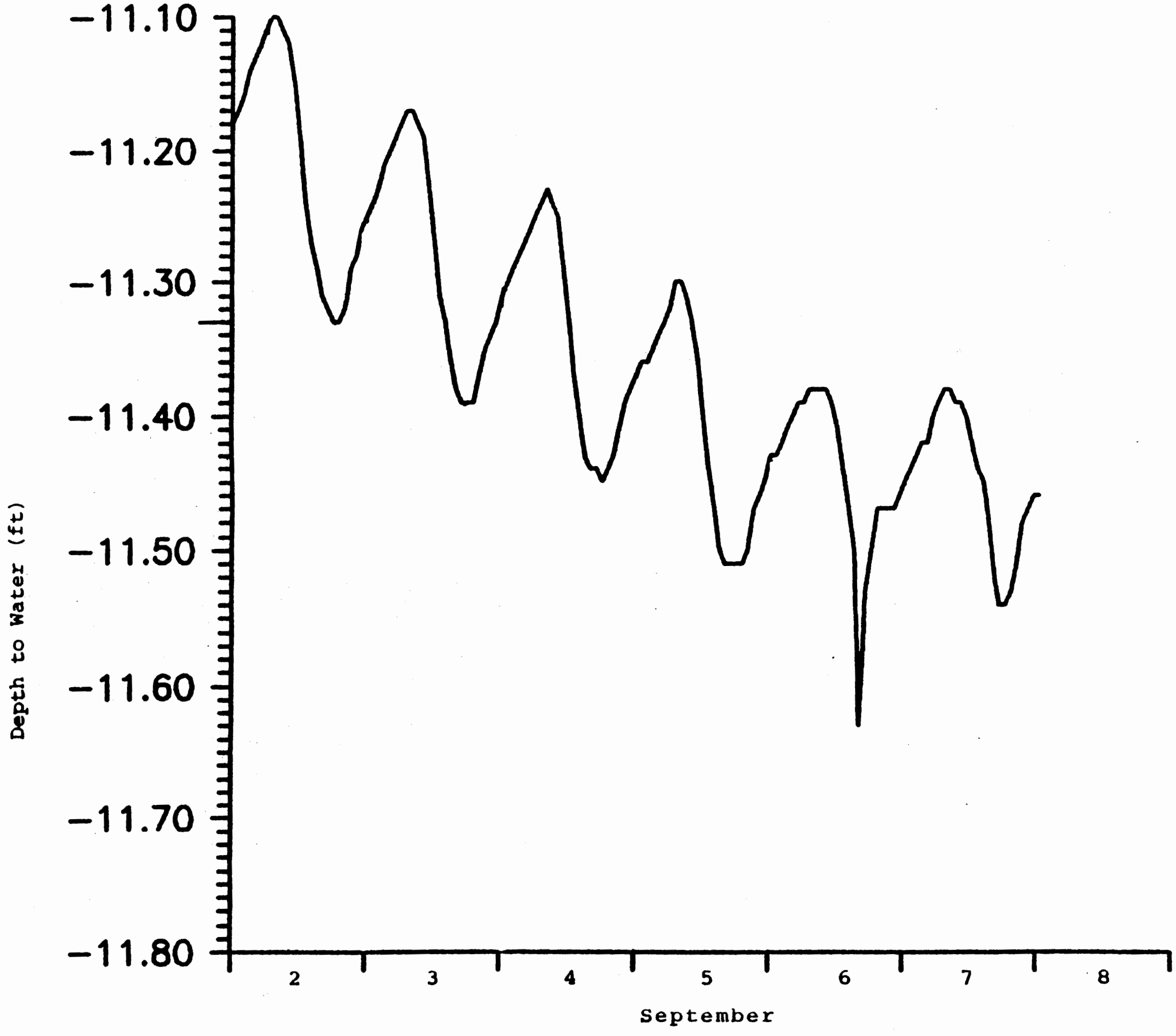


Figure 17. Diurnal Fluctuations

seasonal variations in climate and ambient air temperature, as well as depth to the water table and the density of vegetation (Mayboom, 1967). Any influence that these controlling factors have on evapotranspiration will be reflected as diurnal fluctuations of the water table.

It has been previously determined (Blaney, 1952) that temperature fluctuations control transpirational processes, thus influencing water-table fluctuations. Figure 10, as previously discussed in this text, demonstrates that rising temperatures are associated with declining water levels. This supports Blaney's work by showing that rising temperatures promote transpirational processes, which in turn, generate declining water levels.

Having established this relationship, it is then possible to address evapotranspirational influences on a seasonal basis. The magnitude of the diurnal fluctuations were calculated for those days with dry weather conditions. Monthly averages were then calculated. Figure 18 shows that the magnitude of the diurnal fluctuations is greatest March through August. This coincides with the leafing season, which should represent the period of greatest consumptive use by phreatophytes. Gardner (1960) states that large quantities of water will be drawn into the tree from the roots, prior to leafing.

The greatest fluctuations at the D site occur in April, and average 0.256 feet per day. The magnitude of these fluctuations begins to decline in June, and

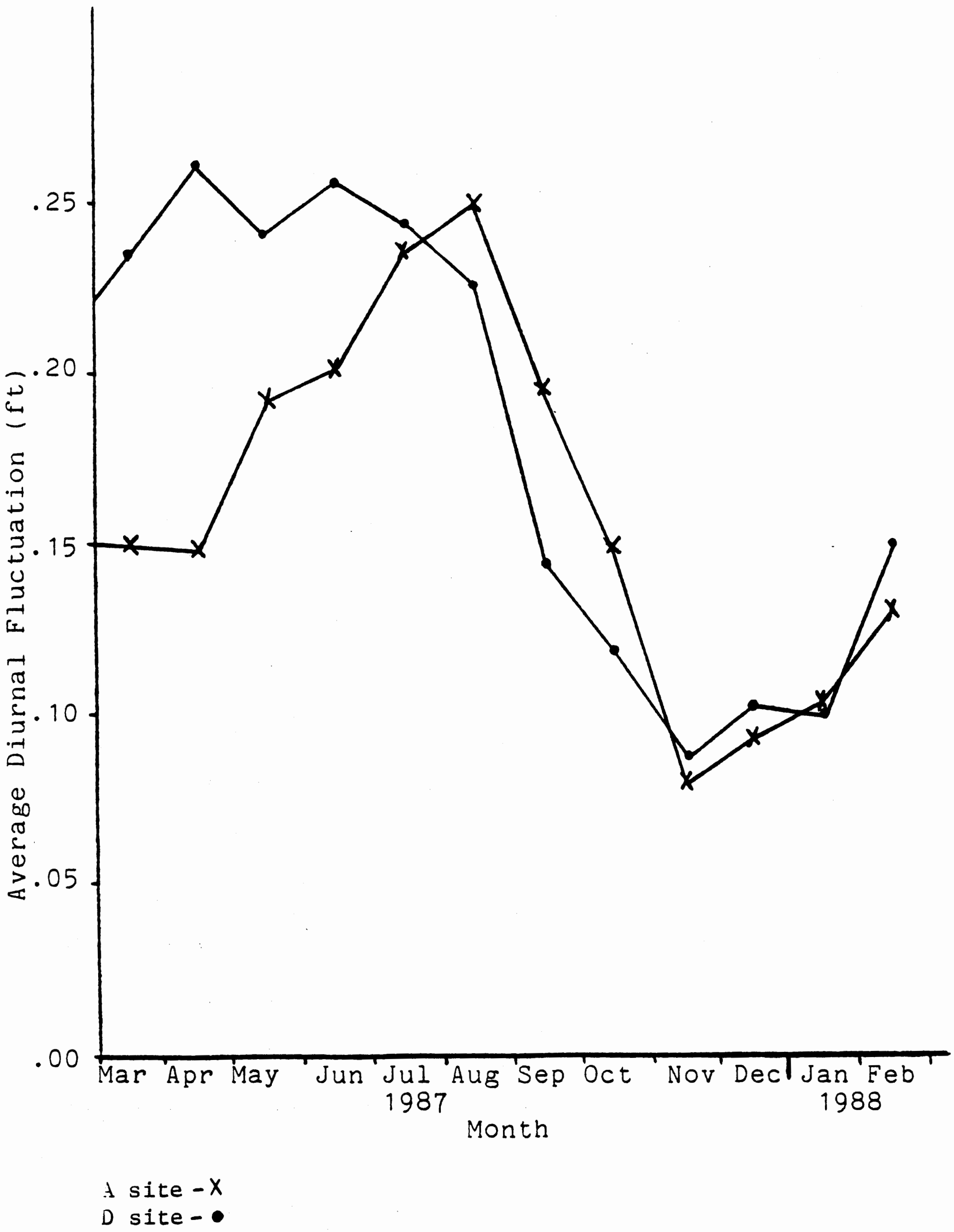


Figure 18. Seasonal Effect on the Average Diurnal Fluctuations.

continues to decline until the lowest monthly average of 0.085 feet per day occurs in November. The magnitude of the fluctuations begins to increase again in December.

The magnitude of the fluctuations increases more slowly at the A site, with the greatest magnitude of fluctuations occurring in August. These fluctuations average 0.242 feet per day. A more gradual increase and later peak in the magnitude of the diurnal fluctuations at this site would be expected, since nearby trees produce fruit late in the summer. Note that the diurnal fluctuations are greater at the A site from August to November. This could also be attributed to a later growing season.

The fluctuations at this site then decline from the highest monthly average in August, to the lowest monthly average of 0.078 feet per day in November. The magnitude of the fluctuations begins to increase again in December.

It is important to note that diurnal fluctuations are evident throughout the year. The magnitude of these fluctuations however, changes dramatically. As expected, the greatest fluctuations occur in the spring and summer, during the growing season. Lessor fluctuations occur during the winter months, and are thought to be highly dependent upon ambient air temperatures.

Robinson (1958) addressed the relationship between transpiration and water table depth, and concluded that transpiration would decrease with increasing depth to water. Landsberg and McMurtrie (1984) also addressed this topic and determined that the amount of water that can be removed from the soil by a tree, depends on the amount of the soil exploited by the roots of the tree. This work was conducted with the understanding that root density decreases away from the base of the tree.

The magnitudes of diurnal fluctuations were plotted as a function of the depth to water for the year beginning March 1987, and ending May 1988 (Figure 19).

Fluctuations at the D site in March, average about 0.21 feet per day at depths between four and five feet. The magnitude of these fluctuations increases with increasing depth until July, when the water table is at a depth of between eight and nine feet, and the average diurnal fluctuation is 0.29 feet per day. The water table declines to a maximum depth of 11.35 feet before in begins to rise again in September. The magnitude of the fluctuations however, declines through November, and exhibits the lowest average of the year at 0.09 feet per day. Fluctuations begins to increase again in December.

A similar response is seen at the A site, with the exception that the maximum average fluctuation of 0.27 feet per day, occurs in August, and at depths between nine and ten feet. Even at depths to water greater than 11 feet, fluctuations average greater than 0.20 feet per day. Water levels begin to rise in September, while the magnitude of the fluctuations continue to decline. The

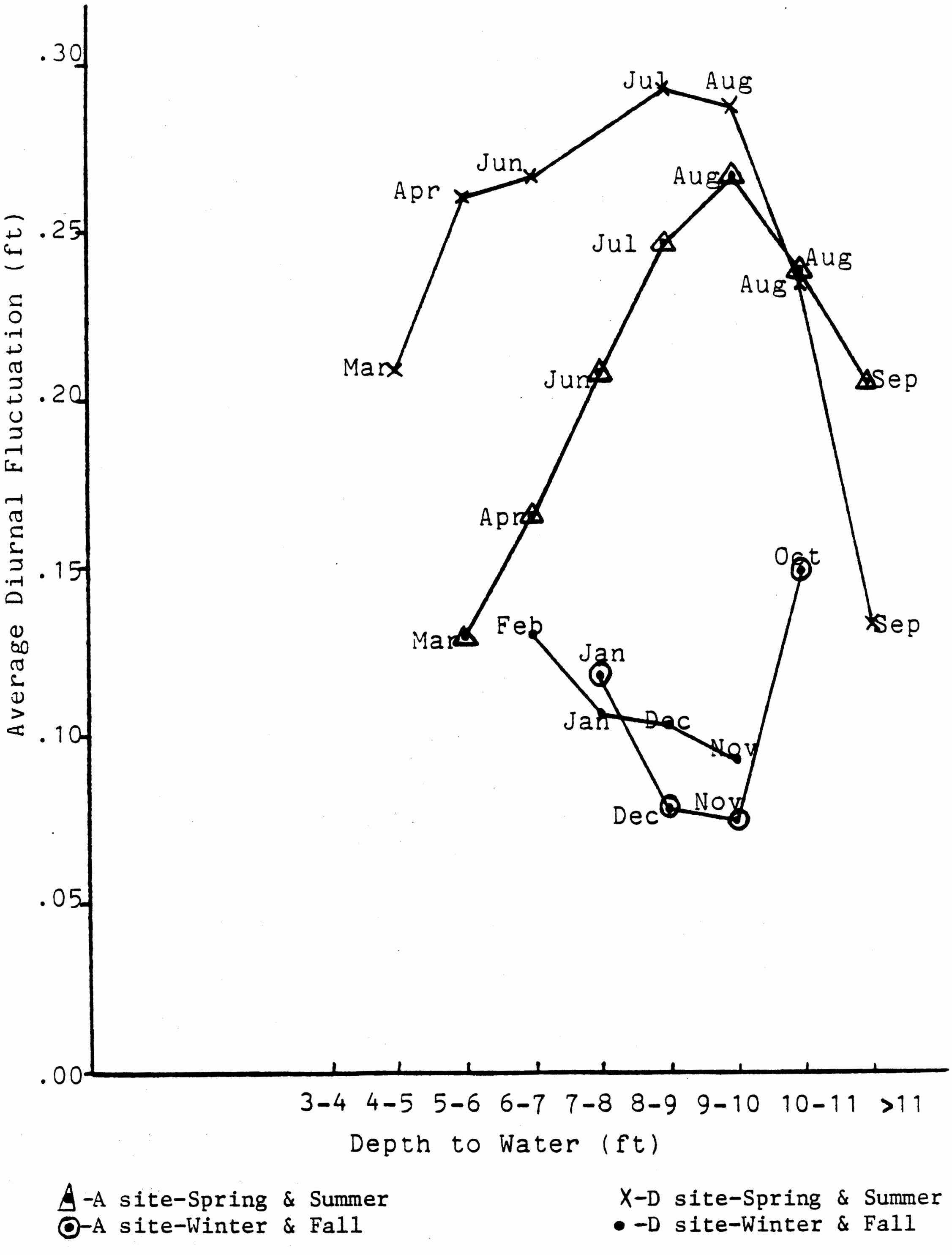


Figure 19. **Average Diurnal Flcutuations in Response to Changing Water-Table Depth.**

lowest average fluctuation of 0.07 feet per day occurs in November.

Both sites demonstrate a definable rise and fall in the magnitude of diurnal fluctuations during the Spring and Summer seasons (Figure 19). This increase is an expected response to increasing evapotranspiration during the leafing season. The dramatic decrease in fluctuations is thought to reflect declining vegetative development and subsequently, ground-water consumption.

The maximum depth to water at both sites, occurs in September. However, the diurnal fluctuations that occur during this time, do not represent the smallest average diurnal fluctuations that occur throughout the year. This would be expected if water levels dropped below the effective root structures for vegetation near these sites. At the A site for example, diurnal fluctuations occurring October through May, are less than those fluctuations occurring in September. This represents 67% of the year where higher water levels produce lower average diurnal fluctuations.

The magnitude of the fluctuations at both sites appears to follow a cyclic trend throughout the year. Therefore, it has been concluded that although water-table depths greater than nine feet may slightly inhibit diurnal fluctuations, the fluctuations appear to be more dependent upon seasonal climatic conditions than depth to water.

It has also been suggested that variations in porosity at depth could influence the diurnal fluctuations of a declining water table. Increasing clays might represent decreasing porosity, which would stimulate greater water-table fluctuations. Therefore, a significant decrease in silts and clays would be expected at depths of nine and ten feet for the D and A sites respectively. However, soil textures remain consistent throughout the zone where water table fluctuations have historically occurred (Figure 20). Variations in soil texture are not reflected in the diurnal fluctuations.

To determine the influence of vegetative density on evapotranspiration, it was necessary to first identify the vegetation at the study site, and then determine what vegetation was contributing to diurnal fluctuations. As discussed previously in this text, the vegetation has been identified and located by proximity to observation wells.

On 29 August 1987 dense schrubbry, located along the southern property boundary near the D site, was removed. Diurnal fluctuations occurring prior to the removal of the schrubbry have been compared to fluctuations occurring immediately following (Table I). There was no measurable change in the diurnal fluctuations as a result of the schrubbry removal. Therefore, it has been concluded that only trees with deep, well established root systems have been contributing to evapotranspiration at this site.

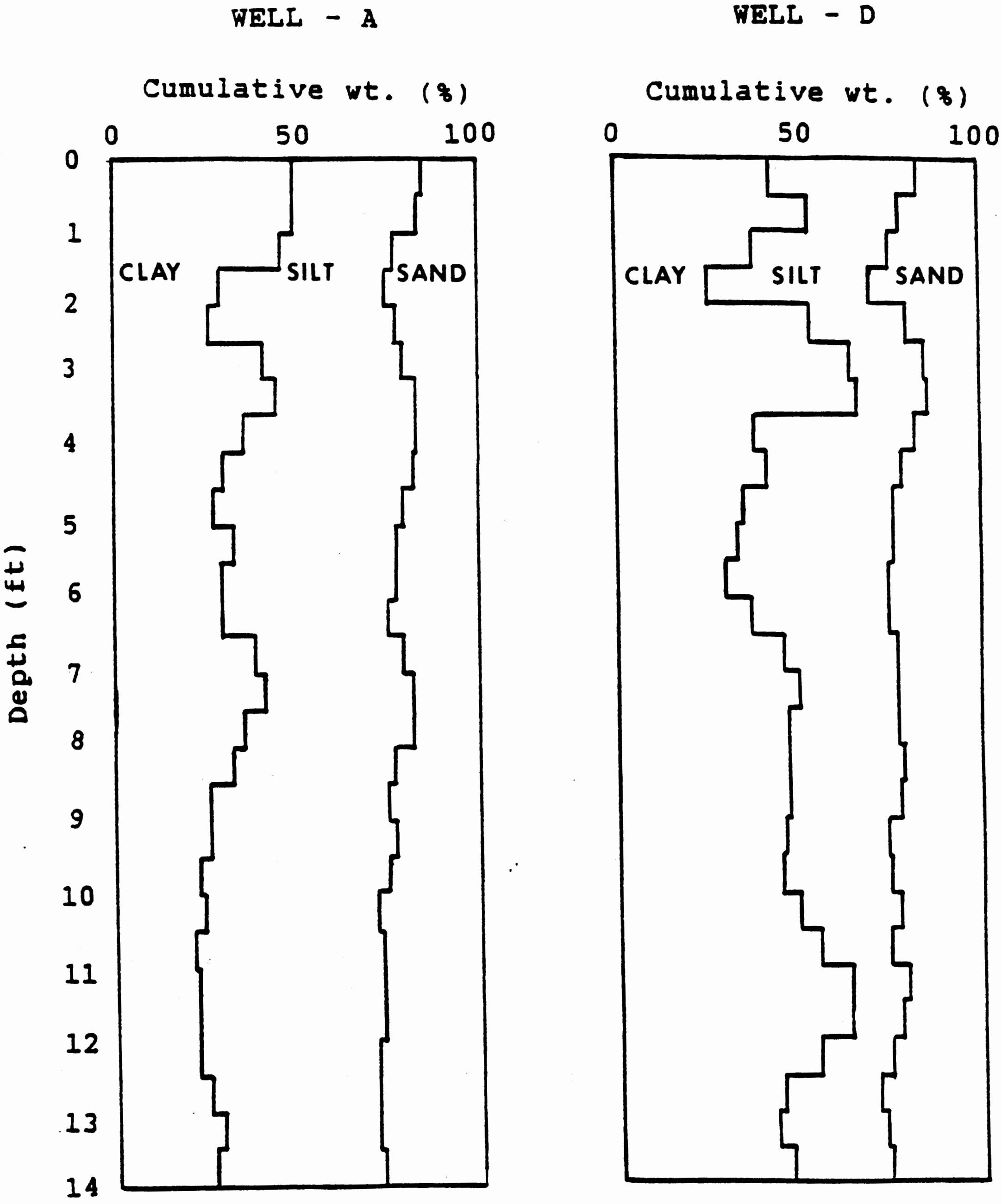


Figure 20. Particle Size Distribution With Depth

TABLE I

INFLUENCE OF SCHRUBBRY REMOVAL ON DIURNAL FLUCTUATIONS

Five Days Prior to Shrubbry Removal

Date	Aug 24	Aug 25	Aug 26	Aug 27	Aug 28
Diurnal Fluctuation (ft)	0.13	0.24	0.15	0.13	0.19

Average
0.17

Five Days Following Shrubbry Removal

Date	Aug 30	Aug 31	Sep 1	Sep 2	Sep 3
Diurnal Fluctuation (ft)	0.20	0.18	0.21	0.23	0.22

Average
0.20

CHAPTER V

EFFECTS OF WATER-LEVEL FLUCTUATIONS ON FLOW DIRECTION

Introduction

Early studies at this site have determined that the groundwater flow direction may shift considerably on a seasonal basis (Hagen, 1986; Hoyle, 1987). Hagen first noted that the groundwater flow direction was toward the southeast during winter and early spring, but shifted toward the south during summer and early fall. Additional studies by Hoyle produced similar results. Both Hagen and Hoyle suggested that the consumptive use of ground water by phreatophytes was effectively altering ground-water flow.

This investigation has also addressed the issue of ground-water flow, and will further define the ground-water flow system associated with this basin.

Toth (1963) defined a flow system as a set of flow lines in which any two flow lines adjacent at one point of the flow region remain adjacent through the whole region. Toth also discussed three types of flow systems that may occur in small drainage basins: local, intermediate, and regional. The ground-water flow system at this site is recognized as a local system.

Toth defined a local flow system as one in which the ground-water flow has its recharge area at a topographic high and its discharge area at a topographic low, and that these areas are located adjacent to each other. Toth further explained that the water table exhibits a hinge-like seasonal fluctuation, the hinge point being located halfway between divide and valley bottom. However, this holds true only if there is a mechanism for removing ground water from the downslope side of the mid-line. Davis (1963) determined that the configuration of the water table, and hence the potential field, is only affected by the topography, where it influences the recharge or discharge of ground water.

Norvatov (1961) contributed by defining three well pronounced vertical zones of groundwater flow: upper, medium and lower. The upper zone is of particular interest to this study. Norvatov describes this zone as one of active flow, whose geographical zonality coincides with climatic belts, and whose lower boundary coincides with the local base levels of rivers. It has already been determined that both precipitation and evapotranspiration greatly influence water levels at the study site. It is then reasonable to recognize that this shallow aquifer system represents the upper zone of ground-water flow, as defined by Norvatov. Therefore, it is also reasonable to expect Chiquita Pond and Boomer Creek, to influence ground-water flow.

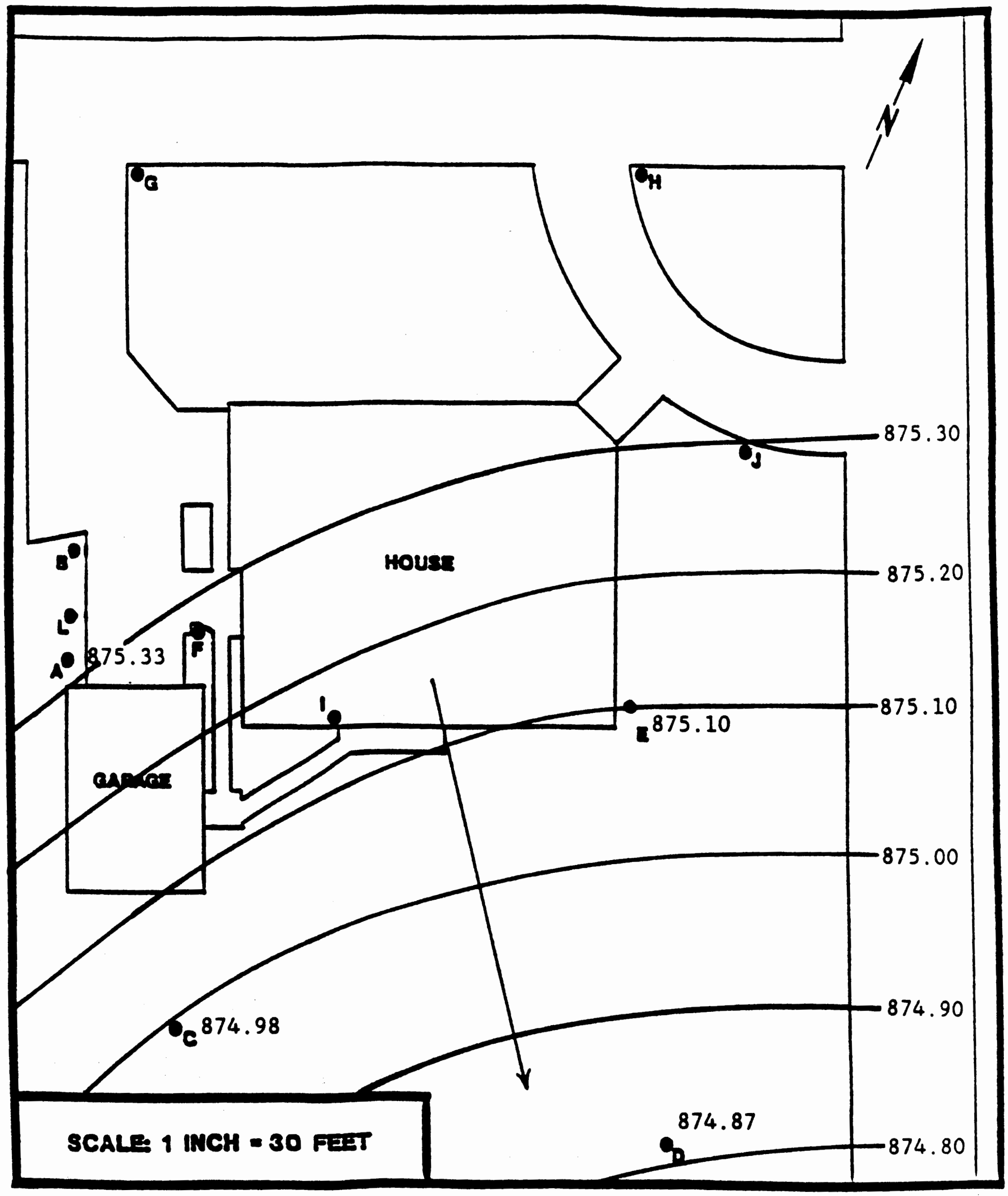
Ground-water Flow Direction

There are currently two hypothesis concerning the shift in ground-water flow direction. The first hypothesis suggests that seasonal evapotranspiration produces significant drawdown in the vicinity of dense vegetation, therefore altering ground-water flow. The second hypothesis suggests that flow direction is controlled by the surface-water/ground-water relationship, and the availability of ground-water discharge areas. Both hypothesis have been investigated, and will be discussed.

The influence of evapotranspiration is observed as diurnal fluctuations, and has been defined previously in this text. The rapid decline of the water table that occurs during the spring and summer months (Figure 6) can be attributed to ground-water losses by evapotranspiration. It has been noted (Hagen, 1986) that the gradual shift in flow direction from the west toward the south begins at approximately the same time as this dramatic decline in water levels. Hagen assumed that the process responsible for the declining water levels was also responsible for the shift in flow direction. This hypothesis was supported by evidence that flow directions during the summer months were toward the tree line marking the southern property boundry. Since summer was considered to be the time of greatest evapotranspiration, this suggested that the drawdown produced in the vicinity of these trees was significant enough to control ground water flow. Hoyle (1987) also noted that the ground-water shifts back toward the west during the winter, which is a time of limited evapotranspiration.

Hoyle attributed the shift in flow direction during the spring and summer months to evapotranspiration by the dense vegetation along the southern property boundary. Aerial photographs show, however that the areas of greatest vegetative density are along the unnamed tributary to Boomer Creek, which lies to the west and southwest of the study site.

Other inconsistencies in this hypothesis arise when comparing the flow direction to seasonal changes in evapotranspiration. Flow directions toward the south do not coincide with periods of greatest evapotranspirational influence. Figures 17 and 21 demonstrate that while the influence of evapotranspiration is lowest in October 1987, the ground-water flow direction remains toward the southeast. Figure 17 also shows that during the summer months when flow directions are shifting toward the south, evaptranspirational influences ar greatest at the A site. This would suggest that the drawdown produced by the fruit trees, along the western property boundary, should be controlling ground-water flow, rather than the trees along the souther property boundary. This does not appear to be the case.



Approximate Depth to Water - 10.5 feet 24 October 1987

Figure 21. Potentiometric Surface Map of Shallow Unconfined Aquifer System.

These inconsistencies implied that other factors could be controlling ground-water flow at the site. Therefore, an investigation of the surface-water/ground-water relationship and availability of drainage was initiated.

The second hypothesis is based on the assumption that surface water and available drainage control ground-water flow at this site. It has been determined that ground water flows from areas of recharge to areas of discharge, and that ground-water flow will be toward the most proximal area available for dishcarge. Boomer Creek and Chiquita Pond have been identified as areas of potential discharge, with Chiquita Pond being the most proximal.

Chiquita Pond may act as an area of discharge providing the water table is above both the base of the pond and the pond stage. As demonstrated in Figure 23, the elevation of the Chiquita Pond spillway is 880.6 feet msl. Note that Chiquita Pond holds water all year, but that the maximum stage will be controlled by the elevation of the spillway, which is 880.6 msl. The elevation of the base of the pond is approximately 878.0 feet msl, which corresponds to a depth of 7.5 feet at the D site. Therefore, the availability of Chiquita Pond for ground-water discharge will be determined by the pond stage for water-table depths of approximately 5 to 7.5 feet.

Once water levels have dropped below 7.5 feet or

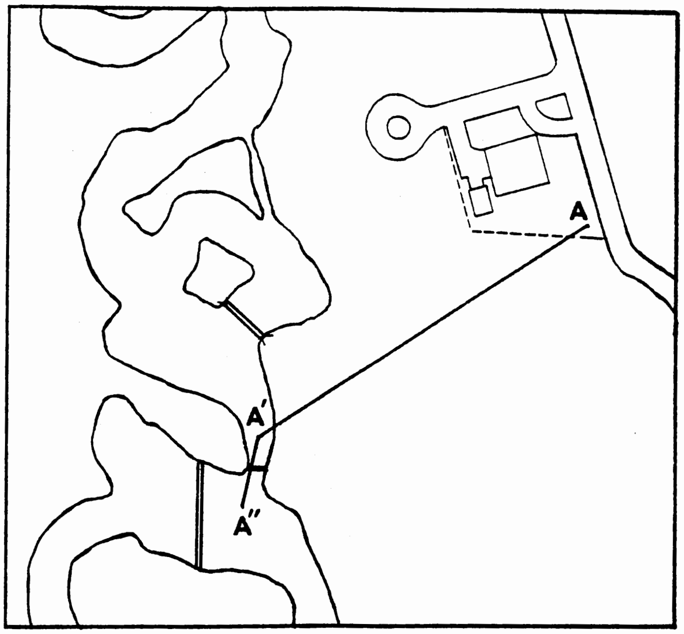


Figure 22. Area of Cross-Section.

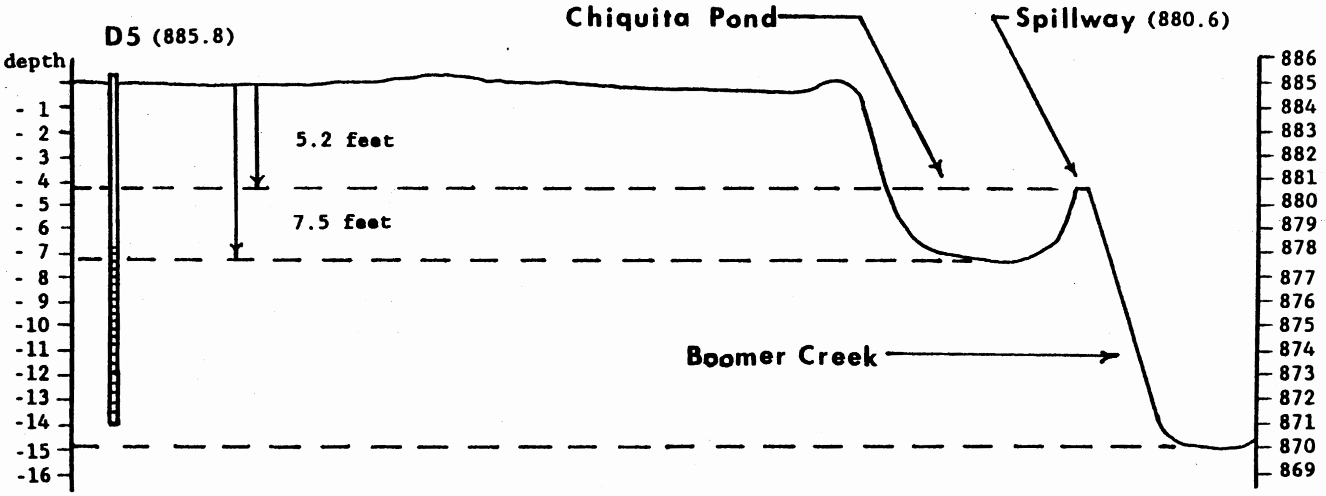
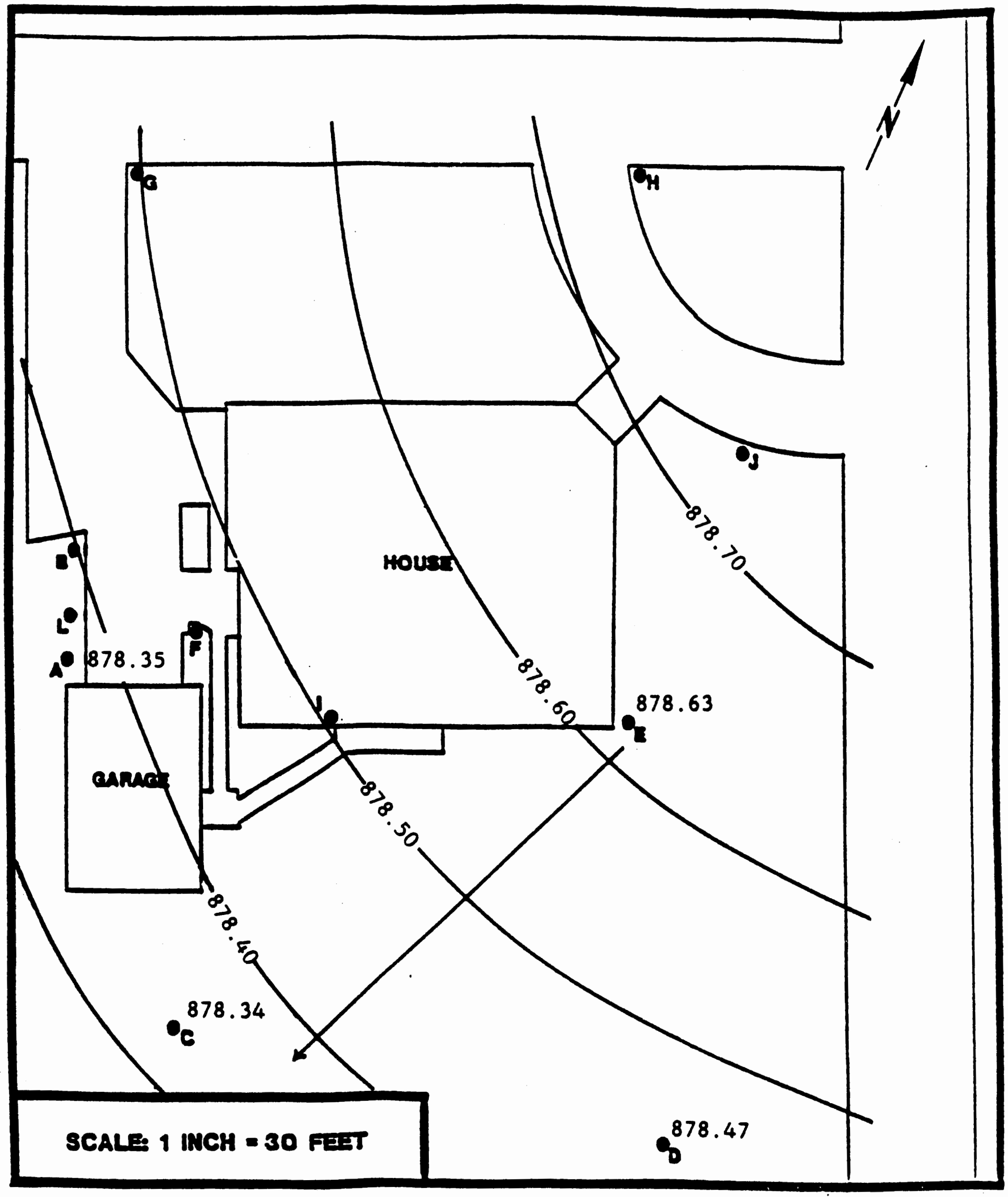


Figure 23. Cross-Section of well D5, Chiquita Pond, and Boomer Creek.

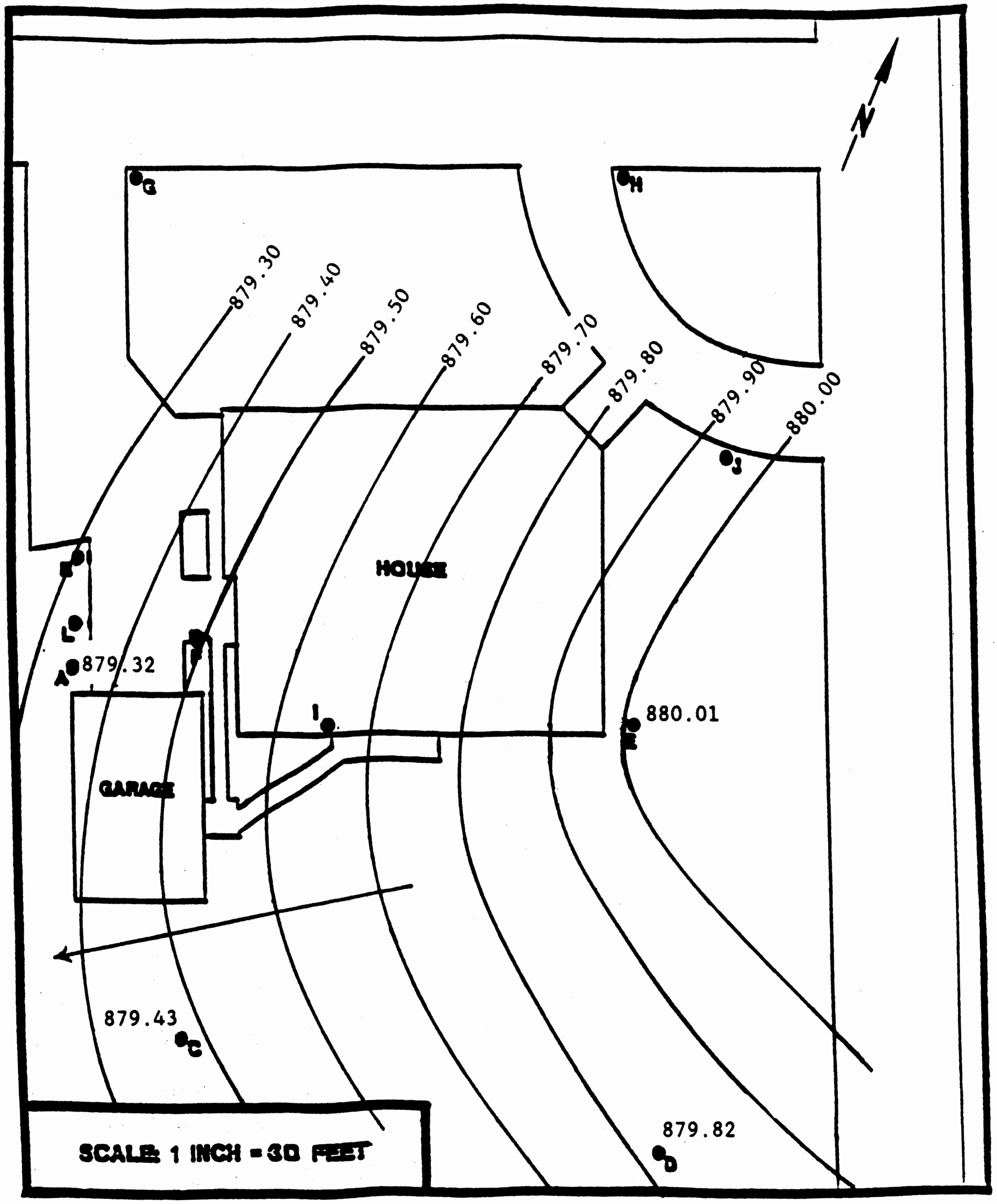
below the pond stage, the nearest available ground-water discharge area becomes Boomer Creek to the southwest. The base of Boomer Creek is estimated to be about 870 feet msl, which correlates to about 16 feet below land surface at the D site. Boomer Creek holds water all year, with a minimum stage of about 873 feet msl. This corresponds closely to the elevation of 873.24 feet msl (-12.5 feet below land surface), which is the lowest recorded depth to water at the D site. It is assumed that for water-table depths between 7.5 feet and 16 feet below land surface, the creek stage will govern ground water discharge and subsiquent flow direction. It may be appropriate therefore, to investigate ground-water flow with respect to water table depth. It is assumed that as the declining water table reaches equalibrium with the creek stage, the ground-water flow direction will shift down-stream/down-gradient seaking an area of discharge.

The water table generally reaches its highest point of four to five feet below land surface in March, during which time ground-water flow directions are toward the southwest (Chiquita Pond). Figures 24 and 25 illustrate the shift in ground-water flow direction as water levels rese from 7.16 feet to 6.0 feet below land surface at the D site. As ground-water levels decline, the flow direction shifts toward the south. This is generally a gradual shift that proceeds through the spring and summer (Figures 26 and 27).



Approximate Depth to Water - 7.0 feet 2 April 1988

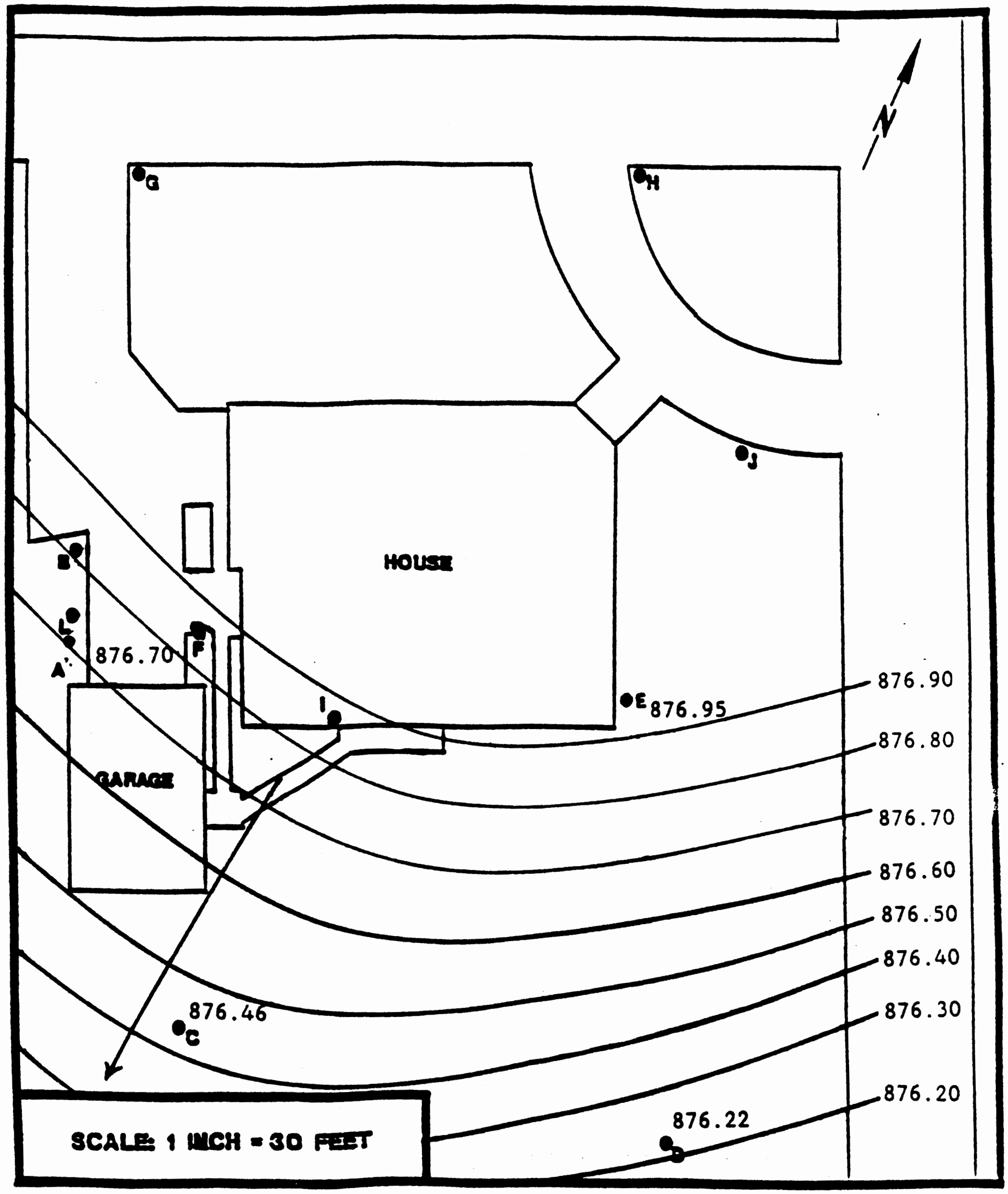
Figure 24. Potentiometric Surface Map of Shallow Unconfined Aquifer System.



Approximate Depth to Water - 6.0 feet

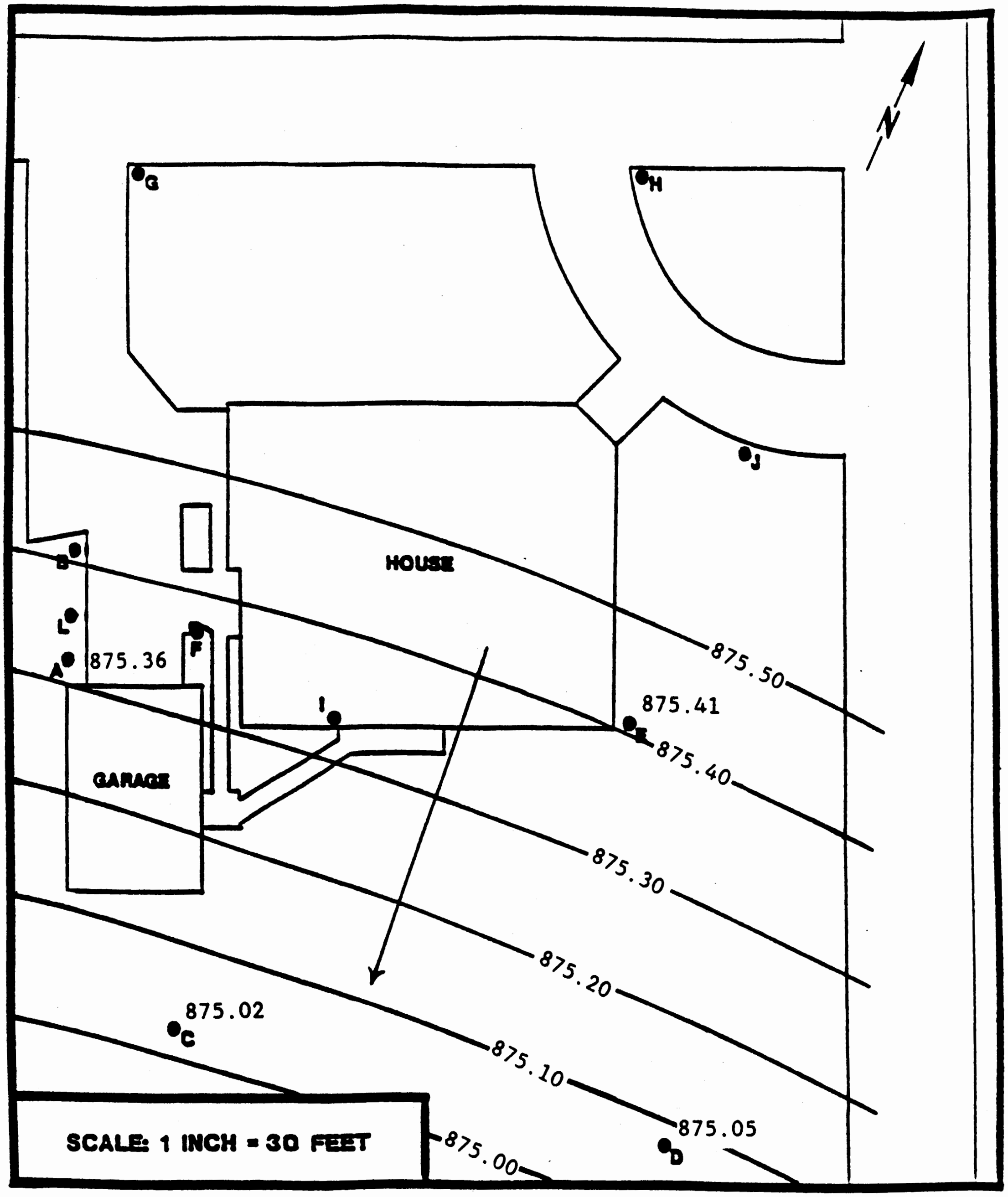
8 April 1986

Figure 25. Potentiometric Surfa



Approximate Depth to Water - 9.5 feet 21 June 1988

Figure 26. Potentiometric Surface Map of Shallow Unconfined Aquifer System.



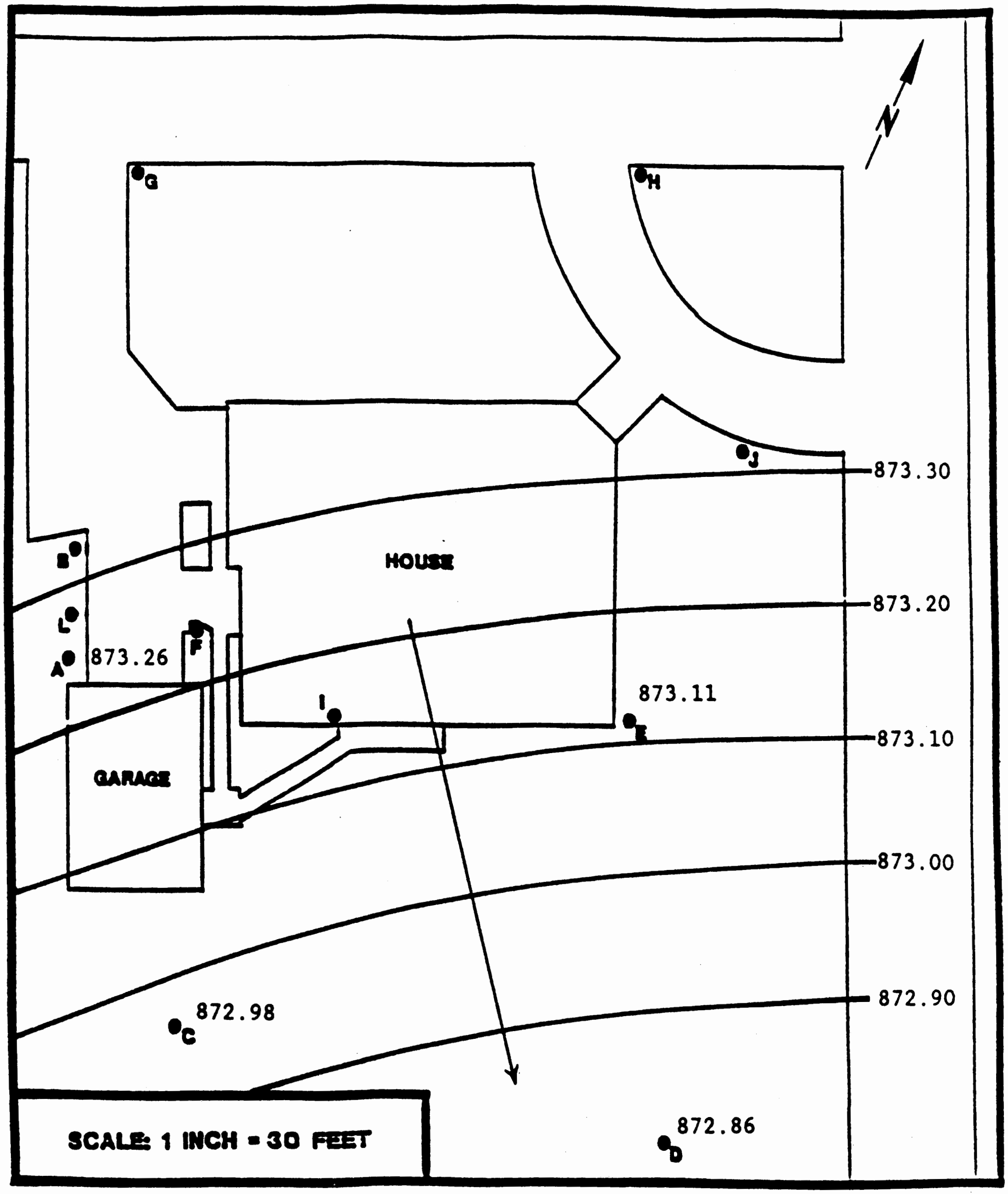
Approximate Depth to Water - 10.5 feet 6 July 1988

Figure 27. Potentiometric Surface Map of Shallow Unconfined Aquifer System.

As the water table reaches its maximum depth of the season, the flow direction is observed to have shifted toward the southeast (Figure 28). Although rising water levels usually begin in the fall, the ground-water flow direction remains in the southeasterly direction until water levels have risen to within eight feet of land surface (Figures 29 and 30). As water levels rise above eight feet, the flow direction shifts toward the south (Figure 31). The flow direction remains to the south until water levels have risen to within seven feet of land surface. When water levels have risen above seven feet the flow direction will shift to the southwest (Figure 32).

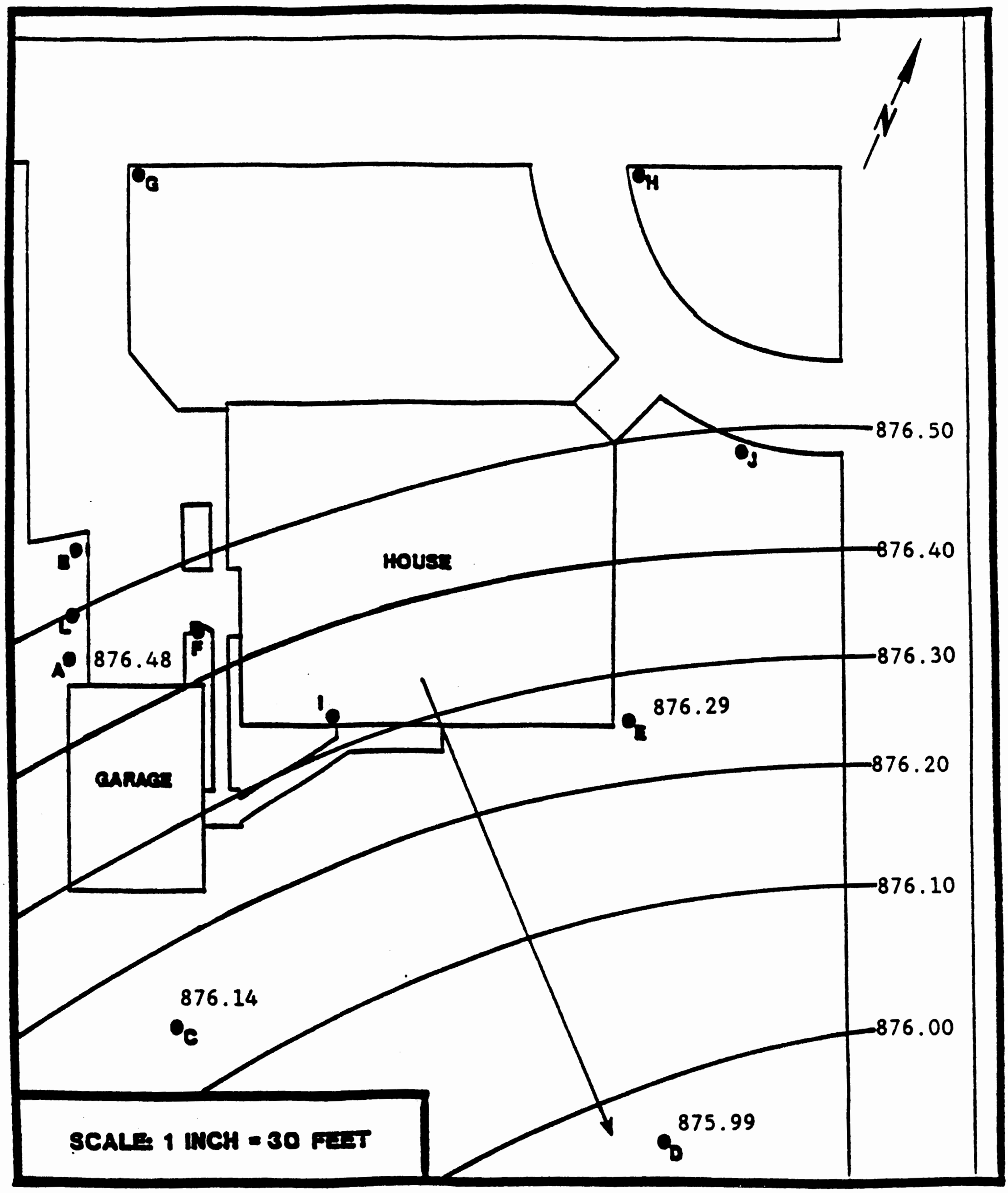
It is suggested that from these observations, a correlation between ground-water flow direction and water-table elevations can be determined, and that ground-water flow directions at this site are dependent upon water-table elevations, and subsiquent available areas of discharge.

As mentioned however, confirmation of this hypothesis depends highly on the correlation of water-table and surface-water elevations. Therefore, gaging staffs were placed in both Chiquita Pond (in June) and Bommer Creek (in September). Water levels were recorded through November. However, during this time the water table fluctuated from approximately 10 to 12.5 feet below land surface, and no fluctuation in ground-water flow direction was observed. Therefore, limiting correlations



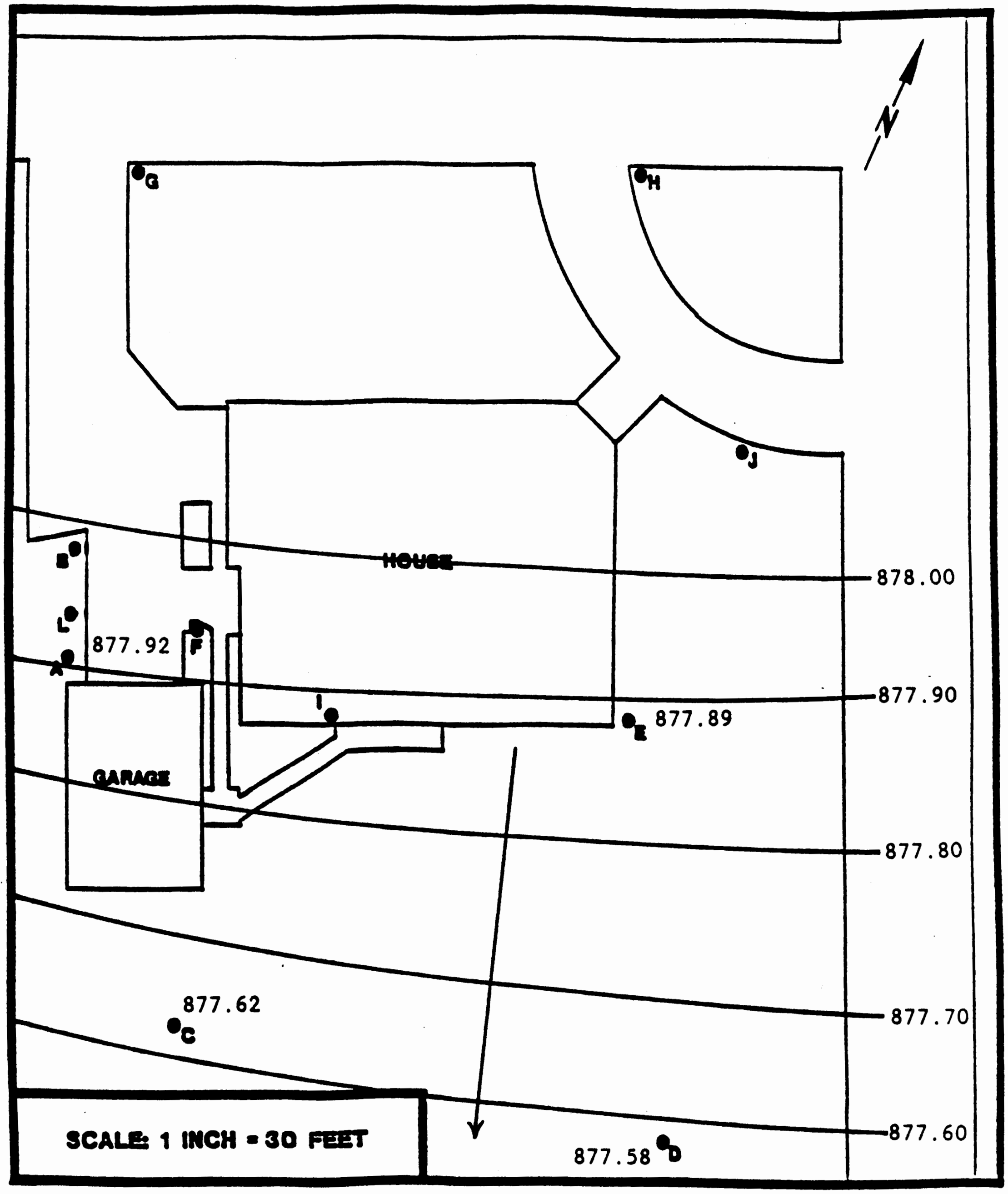
Approximate Depth to Water - 12.5 feet 10 September 1988

Figure 28. Potentiometric Surface Map of Shallow Unconfined Aquifer System.



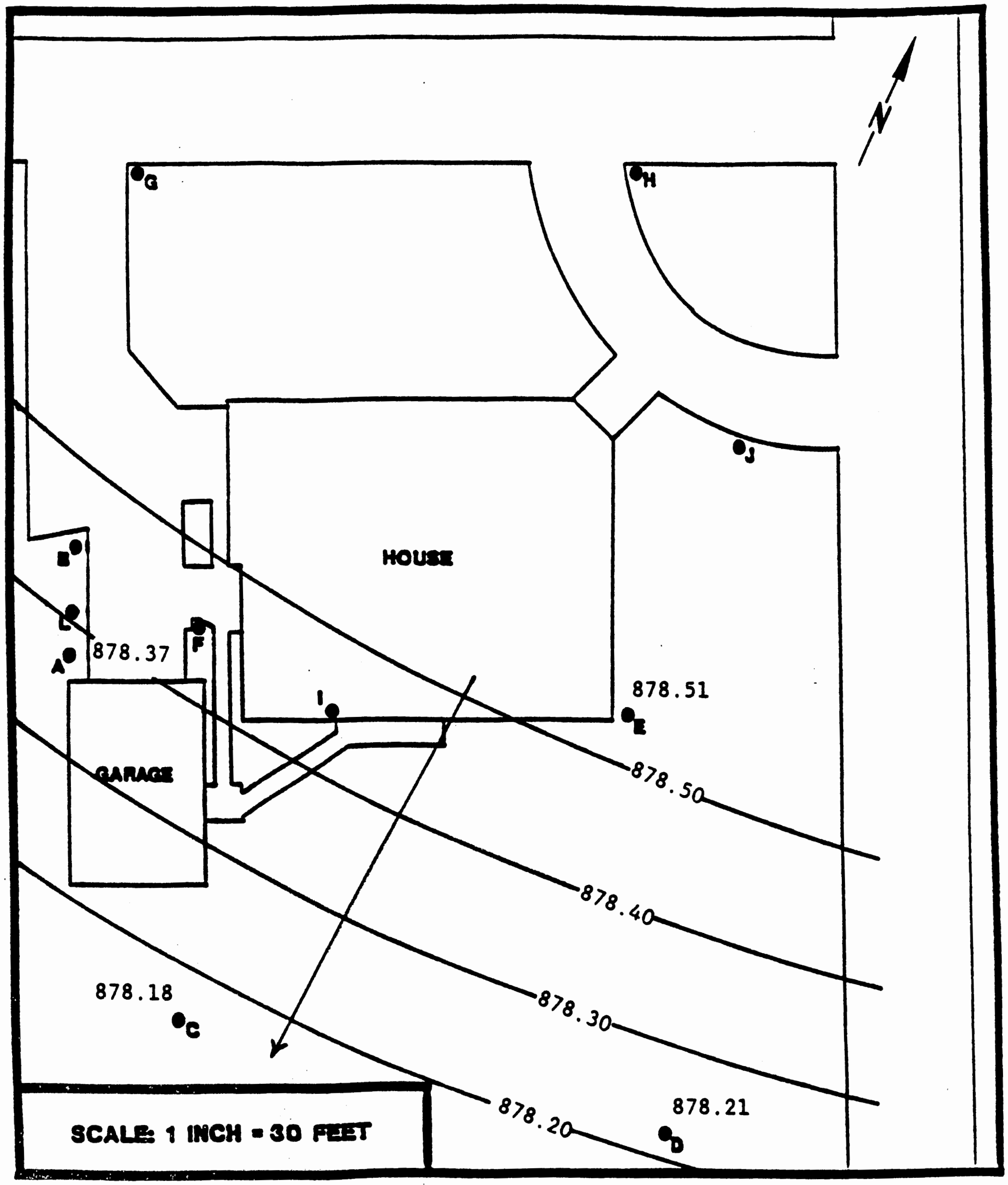
Approximate Depth to Water - 9.5 feet 23 November 1987

Figure 29. Potentiometric Surface Map of Shallow Unconfined Aquifer System.



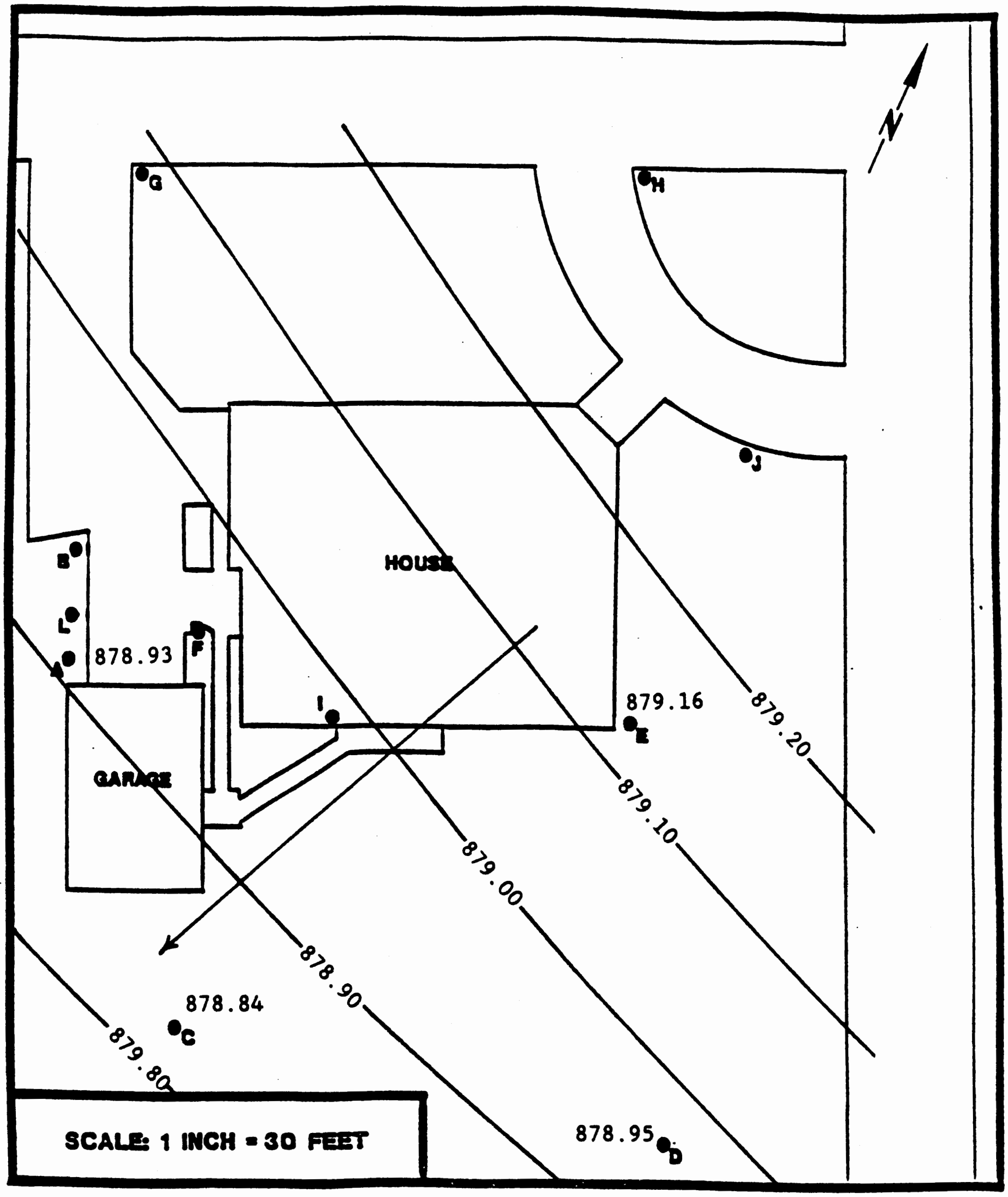
Approximate Depth to Water - 8.0 feet 22 December 1987

Figure 30. Potentiometric Surface Map of Shallow Unconfined Aquifer System.



Approximate Depth to Water - 7.6 feet 4 January 1988

Figure 31. Potentiometric Surface Map of Shallow Unconfined Aquifer System.



Approximate Depth to Water - 7.0 feet 18 January 1988

Figure 32. Potentiometric Surface Map of Shallow Unconfined Aquifer System.

between surface-water and ground-water elevations under fluctuating conditions are available.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The purpose of this study was to identify the factors that contribute to ground-water fluctuations at this site, and to determine the effect that these fluctuations have on groundwater flow.

This was accomplished by studying climatic and anthropogenic conditions at this site with respect to fluctuations in water-table elevations. Once the influencing factors had been identified and defined, water-table fluctuations were studied to determine their effect on ground-water flow directions and surface-water interaction.

Several factors could induce water-table fluctuations without effectively changing the volume of water held in storage. Atmospheric pressure, temperature, and loading are included in this category. It was concluded that neither atmospheric pressure nor loading pressures contributed to water-table fluctuations. It was also concluded that although temperature fluctuations did not directly influence water levels, temperature could indirectly influence water-table fluctuations by influencing evapotranspiration.

Ground-water Recharge was studied as a means of increasing the volume of water held in storage. It was determined that this shallow unconfined system displayed a highly varied response to precipitation, and that this response was dependent upon soil-moisture content and depth to water. The water-table is expected to show the greastest response to precipitation when the water-table is shallow and soil-moisture content is high.

Pumping was studied as a means of decreasing the volume of water held in storage. It was determined that pumping could produce a decline in water levels that is limited in extent and short lived. Therefore, pumping does not significantly influence water-table elevations.

Evapotranspiration was also studied as a means of decreasing the volume of ground water held in storage. It was determined the evapotranspiration produces diurnal fluctuations throughout the year. It was also determined that ground-water losses to evapotranspiration are greatest in the spring and early summer. These losses contribute to the dramatic decline in water levels observed in the spring and summer.

The final aspect of this study was to determine what effect water-table fluctuations have on ground-water flow directions and the surface-water interaction. It has been concluded that seasonal declines in the water table, due to evapotranspiration, could affect the availability of ground-water discharge areas. It is therefore suggested that declining water levels promote the seasonal shift in ground-water flow direction by limiting the available ground-water discharge areas. The ground-water/surface-water relationship could not be adequately defined with the available data and would therefore require additional study.

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APPENDIX A

GROUND-WATER LEVELS

Well A5

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-12.02 "Sept. 23, 1986"
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-8.75    "Oct. 20, 1986"
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-12.33	"Aug. 12, 1988"
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APPENDIX B

BAROMETRIC PRESSURE

986
986.5 "Nov. 9, 1987"
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993.5 "Nov. 10, 1987"
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977.5 "Dec. 23, 1987"
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971.5 "Dec. 24, 1987"
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968   "Apr. 19, 1987"
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973   "Apr. 20, 1987"
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APPENDIX C

TEMPERATURE

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51    "Apr. 7, 1988"
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61    "Apr. 8, 1988"
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73    "Jun. 8, 1988"
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80    "Jun. 9, 1988"
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75   "Aug. 12, 1988"
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APPENDIX D

LOADING RESPONSE

	SITE "D"	SITE "A"
0	9.16	8.95
1	0.16	0.94
2	0.16	0.94
3	0.16	0.94
4	0.16	0.94
5	0.16	0.94
6	0.16	0.94
7	0.16	0.94
8	0.16	0.95
9	0.16	0.94
10	0.16	0.94
11	0.16	0.95
12	0.16	0.95
13	0.16	0.95
14	0.16	0.95
15	0.16	0.95
16	0.16	0.95
17	0.16	0.95
18	0.16	0.95
19	0.16	0.95
20	0.16	0.95
21	0.16	0.95
22	0.16	0.95
23	0.16	0.95
24	0.16	0.95
25	0.16	0.95
26	0.16	0.95
27	0.16	0.94
28	0.16	0.94
29	0.16	0.94
30	0.16	0.94
31	0.16	0.94
32	0.16	0.94
33	0.16	0.94
34	0.16	0.94
35	0.16	0.94
36	0.16	0.94
37	0.16	0.94
38	0.16	0.94
39	0.16	0.94
40	0.16	0.94
41	0.16	0.94
42	0.16	0.94
43	0.16	0.94
44	0.16	0.94
45	0.16	0.94
46	0.16	0.94
47	0.16	0.94
48	0.16	0.94

APPENDIX E

SOIL MOISTURE

23 NOVEMBER 1986

DEPTH	%
0.50	0.31
1.00	0.29
1.50	0.29
2.00	0.27
2.50	0.26
3.00	0.26
3.50	0.26
4.00	0.22
4.50	0.17
5.00	0.19
5.50	0.27
6.00	0.30

4 OCTOBER 1986

DEPTH	%
0.50	0.32
1.00	0.28
1.50	0.30
2.00	0.26
2.50	0.13
3.00	0.11
3.50	0.12
4.00	0.14
4.50	0.17
5.00	0.21
5.50	0.24
6.00	0.26
6.50	0.28

26 NOVEMBER 1986

DEPTH	%
0.50	0.31
1.00	0.29
1.50	0.30
2.00	0.29
2.50	0.29
3.00	0.28
3.50	0.28
4.00	0.22
4.50	0.17
5.00	0.20

4 JUNE 1986

DEPTH	%
0.50	0.29
1.00	0.29
1.50	0.29
2.00	0.28
2.50	0.20
3.00	0.25
3.50	0.27
4.00	0.28
4.50	0.28
5.00	0.29
5.50	0.31
6.00	0.32

18 MAY 1986

DEPTH	%
0.50	0.15
1.00	0.18
1.50	0.21
2.00	0.22
2.50	0.22
3.00	0.25
3.50	0.27
4.00	0.28
4.50	0.29
5.00	0.29
5.50	0.30
6.00	0.30
6.50	0.31

24 MAY 1986

DEPTH	%
0.50	0.30
1.00	0.24
1.50	0.22
2.00	0.20
2.50	0.19
3.00	0.24
3.50	0.26
4.00	0.28
4.50	0.28
5.00	0.29
5.50	0.30
6.00	0.30
6.50	0.30

20 MAY 1986

DEPTH	%
0.50	0.15
1.00	0.17
1.50	0.20
2.00	0.21
2.50	0.21
3.00	0.25
3.50	0.26
4.00	0.28
4.50	0.28
5.00	0.30
5.50	0.31
6.00	0.30
6.50	0.30

28 MAY 1986

DEPTH	%
0.50	0.31
1.00	0.29
1.50	0.29
2.00	0.24
2.50	0.20
3.00	0.25
3.50	0.26
4.00	0.28
4.50	0.28
5.00	0.29
5.50	0.30
6.00	0.31
6.50	0.31

31 MAY 1986

DEPTH	%
0.50	0.29
1.00	0.29
1.50	0.29
2.00	0.25
2.50	0.20
3.00	0.25
3.50	0.26
4.00	0.27
4.50	0.28
5.00	0.29
5.50	0.30
6.00	0.31

APPENDIX F

AQUIFER TEST

Well A5 Drawdown
Distance to pumped well = 18.3 feet
Pumped well B12 at 2.7 gpm
8/14/88 (1:00 PM) - 8/17/88 (1:00 PM)

Time (Min.)	Depth to Water (D.T.W.) (Feet)	Decline-Adjusted D.T.W. (Feet)	Drawdown s (Feet)	Adjusted Drawdown s' (Feet)
0	12.10	12.10	0.00	0.00
38.3	12.55	12.55	0.45	0.45
47	12.59	12.59	0.49	0.48
72	12.66	12.66	0.56	0.55
93.3	12.71	12.71	0.61	0.60
104	12.72	12.72	0.62	0.61
142.3	12.78	12.78	0.68	0.67
167	12.81	12.81	0.71	0.70
224	12.85	12.84	0.74	0.73
318	12.90	12.89	0.79	0.78
408	12.99	12.98	0.88	0.87
523	13.00	12.99	0.89	0.87
650	13.10	13.08	0.98	0.97
1106	13.21	13.18	1.08	1.06
1288	13.24	13.21	1.11	1.09
1582	13.27	13.23	1.13	1.11
1702	13.30	13.26	1.16	1.14
1825	13.30	13.26	1.16	1.13
1936	13.33	13.28	1.18	1.16
2088	13.36	13.31	1.21	1.18
2557	13.37	13.31	1.21	1.18
2890	13.39	13.32	1.22	1.19
3021	13.40	13.33	1.23	1.20
3271	13.46	13.38	1.28	1.25
3500	13.49	13.41	1.31	1.28
4075	13.55	13.45	1.35	1.32
4286	13.48	13.38	1.28	1.25

Well B7 Drawdown
Distance to pumped well = 2.3 feet
Pumped well B12 at 2.7 gpm
8/14/88 (1:00 PM) - 8/17/88 (1:00 PM)

Time (Min.)	Depth to Water (D.T.W.) (Feet)	Decline-Adjusted D.T.W. (Feet)	Drawdown s (Feet)	Adjusted Drawdown s' (Feet)
0	11.90	11.90	0.00	0.00
23	13.18	13.18	1.28	1.25
31	13.31	13.31	1.41	1.37
41.5	13.40	13.40	1.50	1.46
66	13.51	13.51	1.61	1.56
86	13.59	13.59	1.69	1.64
97	13.62	13.62	1.72	1.67
106.5	13.64	13.64	1.74	1.68
143.5	13.67	13.67	1.77	1.71
201	13.74	13.74	1.84	1.78
264	13.78	13.77	1.87	1.81
297	13.83	13.82	1.92	1.86
399	13.88	13.87	1.97	1.90
455	13.93	13.92	2.02	1.95
510	13.97	13.96	2.06	1.98
571	13.98	13.97	2.07	1.99
636	Well Dry			

Well B8 Drawdown
Distance to pumped well = 2.3 feet
Pumped well B12 at 2.7 gpm
8/14/88 (1:00 PM) - 8/17/88 (1:00 PM)

Time (Min.)	Depth to Water (D.T.W.) (Feet)	Decline-Adjusted D.T.W. (Feet)	Drawdown s (Feet)	Adjusted Drawdown s' (Feet)
0	11.87	11.87	0.00	0.00
21	12.91	12.91	1.04	1.02
31.7	13.24	13.24	1.37	1.34
42.5	13.40	13.40	1.53	1.49
67	13.56	13.56	1.69	1.64
87	13.65	13.65	1.78	1.72
98	13.66	13.66	1.79	1.73
107.5	13.69	13.69	1.82	1.76
144.5	13.73	13.73	1.86	1.80
203	13.79	13.79	1.92	1.85
265	13.85	13.84	1.97	1.90
308	13.87	13.86	1.99	1.92
400	13.94	13.93	2.06	1.98
459	14.00	13.99	2.12	2.04
512	14.04	14.03	2.16	2.07
575	14.08	14.07	2.20	2.11
637	14.09	14.07	2.20	2.12
741	14.14	14.12	2.25	2.16
854	14.18	14.16	2.29	2.20
977	14.22	14.20	2.33	2.23
1098	14.25	14.22	2.35	2.25
1224	14.26	14.23	2.36	2.26
1338	14.28	14.25	2.38	2.28
1458	14.30	14.27	2.40	2.29
1574	14.31	14.27	2.40	2.30
1695	14.33	14.29	2.42	2.32
1817	14.34	14.30	2.43	2.32
1930	14.36	14.31	2.44	2.34
2058	14.38	14.33	2.46	2.35
2547	14.38	14.32	2.45	2.34
2885	14.43	14.36	2.49	2.38
3015	14.45	14.38	2.51	2.40
3260	14.55	14.47	2.60	2.48
3495	14.59	14.51	2.64	2.51
4079	14.56	14.46	2.59	2.47
4288	14.56	14.46	2.59	2.47

Well B9 Drawdown
Distance to pumped well = 1.8 feet
Pumped well B12 at 2.7 gpm
8/14/88 (1:00 PM) - 8/17/88 (1:00 PM)

Time (Min.)	Depth to Water (D.T.W.) (Feet)	Decline-Adjusted D.T.W. (Feet)	Drawdown s (Feet)	Adjusted Drawdown s' (Feet)
0	11.92	11.92	0.00	0.00
17	13.66	13.66	1.74	1.69
32.5	13.76	13.76	1.84	1.78
43.5	13.82	13.82	1.90	1.83
68	13.90	13.90	1.98	1.91
88	13.97	13.97	2.05	1.97
99	13.98	13.98	2.06	1.98
108	13.99	13.99	2.07	1.99
145.5	14.02	14.02	2.10	2.02
205	14.08	14.08	2.16	2.07
266	14.14	14.13	2.21	2.13
310	14.16	14.15	2.23	2.14
402	14.26	14.25	2.33	2.23
461	14.30	14.29	2.37	2.27
514	14.33	14.32	2.40	2.30
577	14.36	14.35	2.43	2.32
639	14.38	14.36	2.44	2.34
742	14.45	14.43	2.51	2.40
855	14.48	14.46	2.54	2.42
979	14.51	14.49	2.57	2.45
1099	14.53	14.50	2.58	2.46
1225	14.55	14.52	2.60	2.48
1340	14.57	14.54	2.62	2.50
1465	14.63	14.60	2.68	2.55
1576	14.60	14.56	2.64	2.52
1697	14.63	14.59	2.67	2.54
1819	14.64	14.60	2.68	2.55
1931	14.66	14.61	2.69	2.56
2059	14.68	14.63	2.71	2.58
2550	14.66	14.60	2.68	2.55
2880	14.76	14.69	2.77	2.63
3016	14.76	14.69	2.77	2.63
3265	14.88	14.80	2.88	2.73
3496	14.91	14.83	2.91	2.76
4080	14.87	14.77	2.85	2.71
4289	14.87	14.77	2.85	2.70

Well C5 Drawdown
Distance to pumped well = 85 feet
Pumped well B12 at 2.7 gpm
8/14/88 (1:00 PM) - 8/17/88 (1:00 PM)

Time (Min.)	Depth to Water (D.T.W.) (Feet)	Decline-Adjusted D.T.W. (Feet)	Drawdown s (Feet)	Adjusted Drawdown s' (Feet)
0	12.18	12.18	0.00	0.00
74	12.36	12.36	0.18	0.18
128	12.47	12.47	0.29	0.29
235	12.56	12.55	0.37	0.37
326	12.58	12.57	0.39	0.39
470	12.68	12.67	0.49	0.48
598	12.70	12.69	0.51	0.50
1292	12.79	12.76	0.58	0.57
1706	12.83	12.79	0.61	0.60
1898	12.85	12.80	0.62	0.62
2563	12.89	12.83	0.65	0.64
3024	12.90	12.83	0.65	0.64
4085	12.96	12.86	0.68	0.67
4299	12.95	12.85	0.67	0.66

Well D5 Drawdown
Distance to pumped well = 150 feet
Pumped well B12 at 2.7 gpm
8/14/88 (1:00 PM) - 8/17/88 (1:00 PM)

Time (Min.)	Depth to Water (D.T.W.) (Feet)	Decline-Adjusted D.T.W. (Feet)	Drawdown s (Feet)	Adjusted Drawdown s' (Feet)
0	12.40	12.40	0.00	0.00
76.5	12.42	12.42	0.02	0.02
125	12.48	12.48	0.08	0.08
238.5	12.54	12.53	0.13	0.13
349	12.58	12.57	0.17	0.17
354	12.62	12.61	0.21	0.21
618	12.65	12.64	0.24	0.23
1299	12.73	12.70	0.30	0.30
1710	12.78	12.74	0.34	0.34
1902	12.80	12.75	0.35	0.35
2566	12.84	12.78	0.38	0.38
3027	12.87	12.80	0.40	0.40
4090	12.95	12.85	0.45	0.45
4302	12.91	12.81	0.41	0.40

Well E5 Drawdown
Distance to pumped well = 105 feet
Pumped well B12 at 2.7 gpm
8/14/88 (1:00 PM) - 8/17/88 (1:00 PM)

Time (Min.)	Depth to Water (D.T.W.) (Feet)	Decline-Adjusted D.T.W. (Feet)	Drawdown s (Feet)	Adjusted Drawdown s' (Feet)
0	12.30	12.30	0.00	0.00
79.5	12.34	12.34	0.04	0.04
123	12.38	12.38	0.08	0.08
252	12.44	12.43	0.13	0.13
353	12.48	12.47	0.17	0.17
478	12.53	12.52	0.22	0.22
622	12.56	12.55	0.25	0.24
1302	12.69	12.66	0.36	0.36
1713	12.74	12.70	0.40	0.40
1906	12.77	12.72	0.42	0.42
2630	12.83	12.77	0.47	0.46
3030	12.85	12.78	0.48	0.47
4093	12.93	12.83	0.53	0.53
4307	12.92	12.82	0.52	0.51

Well F1
Distance to pumped well = 25 feet
Pumped well B12 at 2.7 gpm
8/14/88 (1:00 PM) - 8/17/88 (1:00 PM)

Time (Min.)	Depth to Water (D.T.W.) (Feet)	Adjusted D.T.W. (Feet)	Drawdown s (Feet)	Adjusted Drawdown s' (Feet)
0.00	12.40	12.40	0.00	0.00
0.50	12.40	12.40	0.00	0.00
1.00	12.40	12.40	0.00	0.00
2.50	12.44	12.44	0.04	0.04
3.00	12.46	12.46	0.06	0.06
3.50	12.46	12.46	0.06	0.06
4.00	12.48	12.48	0.08	0.08
4.50	12.49	12.49	0.09	0.09
5.00	12.50	12.50	0.10	0.10
7.00	12.53	12.53	0.13	0.13
8.00	12.55	12.55	0.15	0.15
9.00	12.57	12.57	0.17	0.17
10.00	12.58	12.58	0.18	0.18
12.00	12.60	12.60	0.20	0.20
14.00	12.61	12.61	0.21	0.21
16.00	12.63	12.63	0.23	0.23
18.00	12.65	12.65	0.25	0.25
20.00	12.66	12.66	0.26	0.26
22.00	12.68	12.68	0.28	0.28
24.00	12.69	12.69	0.29	0.29
26.00	12.70	12.70	0.30	0.30
28.00	12.71	12.71	0.31	0.31
30.00	12.72	12.72	0.32	0.32
35.00	12.73	12.73	0.33	0.33
40.00	12.77	12.77	0.37	0.37
45.00	12.78	12.78	0.38	0.38
50.00	12.81	12.81	0.41	0.41
55.00	12.81	12.81	0.41	0.41
60.00	12.82	12.82	0.42	0.42
70.00	12.85	12.85	0.45	0.44
80.00	12.87	12.87	0.47	0.46
90.00	12.88	12.88	0.48	0.47
100.00	12.90	12.90	0.50	0.49
111.00	12.92	12.92	0.52	0.51
120.00	12.94	12.94	0.54	0.53
140.00	12.95	12.95	0.55	0.54
180.00	12.99	12.99	0.59	0.58
216.00	13.03	13.02	0.62	0.62
241.00	13.04	13.03	0.63	0.63
271.00	13.07	13.06	0.66	0.66

Well F1 Drawdown (Continued)

Time (Min.)	Depth to Water (D.T.W.) (Feet)	Adjusted D.T.W. (Feet)	Drawdown (Feet)	Adjusted Drawdown s' (Feet)
301.00	13.08	13.07	0.67	0.66
331.00	13.09	13.08	0.68	0.67
361.00	13.11	13.10	0.70	0.69
420.00	13.16	13.15	0.75	0.74
482.00	13.19	13.18	0.78	0.77
542.00	13.21	13.20	0.80	0.79
602.00	13.23	13.22	0.82	0.80
661.00	13.27	13.25	0.85	0.84
725.00	13.29	13.27	0.87	0.86
842.00	13.33	13.31	0.91	0.90
963.00	13.35	13.33	0.93	0.91
1083.00	13.38	13.35	0.95	0.94
1200.00	13.39	13.36	0.96	0.94
1320.00	13.40	13.37	0.97	0.95
1440.00	13.41	13.38	0.98	0.96
1560.00	13.42	13.38	0.98	0.97
1680.00	13.46	13.42	1.02	1.00
1800.00	13.46	13.42	1.02	1.00
1920.00	13.49	13.44	1.04	1.02
2040.00	13.50	13.45	1.05	1.03
2520.00	13.54	13.48	1.08	1.06
2880.00	13.56	13.49	1.09	1.07
3000.00	13.56	13.49	1.09	1.07
3240.00	13.62	13.54	1.14	1.12
3480.00	13.65	13.57	1.17	1.14
4052.00	13.66	13.56	1.16	1.14
4319.00	13.64	13.54	1.14	1.11

Well G2 Drawdown
Distance to pumped well = 70 feet
Pumped well B12 at 2.7 gpm
8/14/88 (1:00 PM) - 8/17/88 (1:00 PM)

Time (Min.)	Depth to Water (D.T.W.) (Feet)	Decline-Adjusted D.T.W. (Feet)	Drawdown s (Feet)	Adjusted Drawdown s' (Feet)
0	10.30	10.30	0.00	0.00
113	10.34	10.34	0.04	0.04
260	10.42	10.41	0.11	0.11
357	10.46	10.45	0.15	0.15
500	10.50	10.49	0.19	0.19
634	10.53	10.51	0.21	0.21
1317	10.70	10.67	0.37	0.37
1722	10.77	10.73	0.43	0.43
1735	10.78	10.74	0.44	0.44
2577	10.86	10.80	0.50	0.49
3038	10.92	10.85	0.55	0.54
4100	11.01	10.91	0.61	0.61
4312	11.01	10.91	0.61	0.60

Well H2 Drawdown
Distance to pumped well = 130 feet
Pumped well B12 at 2.7 gpm
8/14/88 (1:00 PM) - 8/17/88 (1:00 PM)

Time (Min.)	Depth to Water (D.T.W.) (Feet)	Decline-Adjusted D.T.W. (Feet)	Drawdown s (Feet)	Adjusted Drawdown s' (Feet)
0	10.92	10.92	0.00	0.00
114	10.94	10.94	0.02	0.02
257	10.98	10.97	0.05	0.05
355	10.99	10.98	0.06	0.06
503	10.98	10.97	0.05	0.05
631	11.00	10.98	0.06	0.06
1312	11.13	11.10	0.18	0.18
1718	11.19	11.15	0.23	0.23
1912	11.20	11.15	0.23	0.23
2635	11.28	11.22	0.30	0.30
3035	11.33	11.26	0.34	0.34
4098	11.42	11.32	0.40	0.40
4310	11.42	11.32	0.40	0.39

Well J1 Drawdown
Distance to pumped well = 125 feet
Pumped well B12 at 2.7 gpm
8/14/88 (1:00 PM) - 8/17/88 (1:00 PM)

Time (Min.)	Depth to Water (D.T.W.) (Feet)	Decline-Adjusted D.T.W. (Feet)	Drawdown s (Feet)	Adjusted Drawdown s' (Feet)
0	11.68	11.68	0.00	0.00
505	11.81	11.80	0.12	0.12
629	11.90	11.89	0.21	0.20
1307	11.94	11.91	0.23	0.23
1716	12.00	11.96	0.28	0.28
1908	12.03	11.98	0.30	0.30
2633	12.11	12.05	0.37	0.36
3032	12.18	12.11	0.43	0.42
4095	12.22	12.12	0.44	0.44
4308	12.21	12.11	0.43	0.42

APPENDIX G

PRECIPITATION

Date	Precipitation (in)
Apr. 14, 1987	0.05
Apr. 20, 1987	0.22
May 5, 1987	0.11
May 21, 1987	0.12
May 22, 1987	0.16
May 23, 1987	0.60
May 24, 1987	0.16
May 25, 1987	0.24
May 27, 1987	3.56
May 28, 1987	0.85
May 31, 1987	0.09
Jun. 2, 1987	1.00
Jun. 9, 1987	0.22
Jun. 10, 1987	0.25
Jun. 11, 1987	0.12
Jun. 18, 1987	1.48
Jun. 19, 1987	0.88
Jun. 20, 1987	0.10
Jun. 25, 1987	0.90
Jun. 30, 1987	1.42
Jul. 2, 1987	0.26
Jul. 12, 1987	0.85
Jul. 17, 1987	0.30
Aug. 10, 1987	0.16
Aug. 12, 1987	1.08
Aug. 24, 1987	0.12
Aug. 25, 1987	0.01
Aug. 26, 1987	0.29
Aug. 27, 1987	0.10
Sep. 6, 1987	0.02
Sep. 9, 1987	0.42
Sep. 10, 1987	0.08
Sep. 12, 1987	0.34
Sep. 15, 1987	0.25
Sep. 18, 1987	1.00
Sep. 20, 1987	0.49
Sep. 21, 1987	0.09
Sep. 26, 1987	0.03
Sep. 27, 1987	1.15
Oct. 19, 1987	0.27
Oct. 30, 1987	0.31
Oct. 31, 1987	0.33
Nov. 6, 1987	0.02
Nov. 7, 1987	0.06
Nov. 15, 1987	0.85

Date	Precipitation (in)
Nov. 16, 1987	0.14
Nov. 18, 1987	0.12
Nov. 20, 1987	0.01
Nov. 24, 1987	0.75
Nov. 27, 1987	0.42
Nov. 28, 1987	0.03
Jan. 18, 1988	0.16
Feb. 4, 1988	0.02
Feb. 10, 1988	0.02
Feb. 18, 1988	0.30
Mar. 1, 1988	0.89
Mar. 2, 1988	1.54
Mar. 4, 1988	0.23
Mar. 5, 1988	0.24
Mar. 16, 1988	0.01
Mar. 17, 1988	0.53
Mar. 28, 1988	0.45
Mar. 29, 1988	0.17
Mar. 31, 1988	0.87
Apr. 1, 1988	1.05
Apr. 9, 1988	0.96
Apr. 17, 1988	0.97
Apr. 18, 1988	0.04
Apr. 24, 1988	0.03
Apr. 25, 1988	0.03
Apr. 29, 1988	0.02
May 2, 1988	0.09
May 7, 1988	0.19
May 15, 1988	0.60
May 20, 1988	0.26
May 21, 1988	0.04
May 22, 1988	0.77
May 23, 1988	0.19
May 31, 1988	0.04
Jun. 1, 1988	0.04
Jun. 2, 1988	0.42
Jun. 15, 1988	0.10
Jun. 26, 1988	0.10
Jun. 27, 1988	0.01
Jun. 28, 1988	0.13
Jun. 30, 1988	0.46
Jul. 17, 1988	0.14
Jul. 19, 1988	0.42
Jul. 26, 1988	0.78
Jul. 27, 1988	0.04

Date	Precipitation (in)
Aug. 6, 1985	0.02
Aug. 10, 1985	1.30
Aug. 15, 1985	0.90
Aug. 20, 1985	0.10
Sep. 10, 1985	0.20
Sep. 13, 1985	1.20
Sep. 14, 1985	0.20
Sep. 21, 1985	0.20
Sep. 22, 1985	1.20
Sep. 23, 1985	1.10
Sep. 25, 1985	1.30
Sep. 29, 1985	0.90
Oct. 10, 1985	0.40
Oct. 12, 1985	0.60
Oct. 14, 1985	2.00
Oct. 18, 1985	1.80
Nov. 13, 1985	1.30
Nov. 15, 1985	1.70
Nov. 30, 1985	0.30
Dec. 1, 1985	0.40
Dec. 12, 1985	0.15
Mar. 12, 1986	0.90
Mar. 15, 1986	0.25
Mar. 18, 1986	0.30
Apr. 1, 1986	0.53
Apr. 2, 1986	0.60
Apr. 3, 1986	0.94
Apr. 4, 1986	1.57
Apr. 13, 1986	0.35
Apr. 17, 1986	0.52
Apr. 20, 1986	0.11
Apr. 27, 1986	0.54
May 9, 1986	0.72
May 10, 1986	0.30
May 11, 1986	0.36
May 14, 1986	0.15
May 15, 1986	0.79
May 17, 1986	2.24
May 26, 1986	0.27
May 30, 1986	0.28
Jun. 2, 1986	0.19
Jun. 4, 1986	0.04
Jun. 6, 1986	0.21
Jun. 14, 1986	1.43
Jun. 23, 1986	1.38
Jul. 1, 1986	1.33

Date	Precipitation (in)
Jul. 10, 1986	0.07
Jul. 12, 1986	0.56
Aug. 8, 1986	3.12
Aug. 9, 1986	1.86
Aug. 14, 1986	0.09
Aug. 15, 1986	0.14
Aug. 16, 1986	0.04
Aug. 21, 1986	0.04
Aug. 27, 1986	0.12
Aug. 31, 1986	0.06
Sep. 14, 1986	0.04
Sep. 26, 1986	0.15
Sep. 28, 1986	0.25
Sep. 29, 1986	5.41
Sep. 30, 1986	0.46
Oct. 1, 1986	0.40
Oct. 2, 1986	2.39
Oct. 3, 1986	0.64
Oct. 11, 1986	0.18
Oct. 21, 1986	0.42
Oct. 22, 1986	1.42
Nov. 3, 1986	0.10
Nov. 4, 1986	1.79
Nov. 20, 1986	0.24
Nov. 25, 1986	2.02
Dec. 1, 1986	0.06
Dec. 6, 1986	0.34
Dec. 7, 1986	0.56
Dec. 8, 1986	0.30
Jan. 3, 1987	0.14
Jan. 8, 1987	0.68
Jan. 9, 1987	0.20
Jan. 21, 1987	0.31
Feb. 5, 1987	0.73
Feb. 6, 1987	0.20
Feb. 15, 1987	0.87
Feb. 18, 1987	0.18
Feb. 24, 1987	0.19
Feb. 26, 1987	0.25
Feb. 28, 1987	1.72
Mar. 10, 1987	0.08
Mar. 16, 1987	0.72
Mar. 17, 1987	0.62
Mar. 23, 1987	0.51
Apr. 10, 1987	0.21
Apr. 13, 1987	0.02

APPENDIX H

DIURNAL FLUCTUATIONS

SITE "A"

	1987									1988	
DAY	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB
1	---	0.06	0.18	0.25	---	0.28	---	0.16	0.08	0.06	0.05	0.07
2	---	0.07	0.16	0.34	---	0.29	0.23	0.20	0.10	0.06	0.08	0.03
3	---	0.12	0.12	0.21	---	0.27	0.22	---	0.15	0.08	0.06	0.06
4	---	0.15	0.13	0.23	---	0.22	0.22	0.23	0.06	0.09	0.19	0.18
5	---	0.07	0.07	0.12	---	0.21	0.21	0.22	0.06	---	0.04	0.17
6	---	0.07	0.05	0.20	---	0.28	0.15	0.20	0.11	0.05	0.06	0.08
7	0.17	0.08	---	0.20	---	0.26	0.16	0.16	0.06	0.05	0.05	0.23
8	---	0.07	---	0.19	0.19	0.23	0.19	0.15	0.05	0.08	0.11	0.07
9	0.23	0.12	---	0.11	0.19	0.32	0.15	0.15	0.03	0.08	0.05	0.09
10	0.15	0.17	---	0.06	0.25	0.19	0.18	0.05	0.06	0.08	0.21	0.11
11	0.39	---	0.29	0.21	0.21	0.22	0.17	0.11	0.08	0.10	0.10	---
12	0.09	---	0.26	0.15	0.21	0.25	0.18	0.16	0.06	0.06	0.20	0.15
13	0.09	---	0.39	0.22	0.23	0.31	0.19	0.23	0.06	0.10	0.09	0.26
14	0.08	---	0.14	0.22	0.19	---	0.23	0.22	---	0.15	0.09	0.18
15	0.10	---	0.19	0.21	0.29	0.22	0.14	0.14	---	0.06	0.10	0.07
16	0.12	---	0.20	0.22	0.22	0.25	0.22	0.11	0.08	0.05	---	0.09
17	---	---	0.13	---	0.13	0.20	0.21	0.14	0.05	0.08	0.09	0.08
18	0.29	0.36	---	---	0.20	0.25	0.33	0.15	0.07	---	0.14	0.12
19	0.22	0.38	0.15	---	0.22	0.23	---	0.13	0.08	---	0.05	0.03
20	0.10	0.16	0.28	---	0.21	0.26	0.25	0.10	0.07	0.17	0.07	0.09
21	0.12	0.24	0.17	---	0.22	0.28	0.16	0.08	0.14	0.05	0.15	0.10
22	0.18	0.06	---	---	0.27	0.43	0.14	0.11	0.05	0.12	0.06	0.16
23	0.10	0.11	0.14	---	0.23	0.11	0.16	---	0.13	0.06	0.11	0.07
24	0.14	0.10	0.12	---	0.23	0.12	0.18	---	0.26	0.11	---	0.12
25	0.11	0.11	0.22	---	---	0.32	0.23	0.14	0.04	0.08	0.06	---
26	---	0.19	0.12	---	0.33	0.16	0.18	0.05	0.04	0.20	0.17	0.32
27	---	0.34	---	---	0.22	0.19	0.09	0.14	---	0.17	0.20	0.13
28	0.09	0.12	0.27	---	0.25	0.22	0.37	0.18	0.06	0.09	0.15	0.29
29	0.16	0.12	0.33	---	0.25	0.23	0.14	0.11	0.06	0.10	0.16	0.13
30	0.10	0.12	0.21	---	0.26	0.24	0.14	0.08	0.03	0.14	0.11	
31	0.09		0.19		0.30	0.22		0.18		0.08	0.09	
COUNT	21	23	24	16	23	30	28	28	27	28	29	27
AVG	0.149	0.147	0.188	0.196	0.230	0.242	0.194	0.146	0.079	0.093	0.107	0.129

SITE "D"

					1987						1988	
DAY	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB
1	0.03	0.33	0.25	0.24	0.13	0.30	---	0.13	---	0.08	0.08	0.09
2	0.36	0.12	0.25	0.25	0.14	0.32	0.23	0.14	0.12	0.11	0.05	0.05
3	0.41	0.26	0.18	0.15	0.17	0.30	0.22	---	---	0.12	0.08	0.09
4	0.36	0.28	0.21	0.24	---	0.19	0.21	0.14	0.10	0.12	0.08	0.08
5	0.36	0.25	0.16	---	---	0.25	0.19	0.19	0.13	---	0.06	0.08
6	0.32	0.15	0.11	0.29	0.22	0.30	0.10	0.14	0.11	0.02	---	0.12
7	0.31	0.24	0.26	0.32	0.24	0.28	0.12	0.13	0.05	0.08	0.08	0.18
8	0.35	0.29	---	0.26	0.24	0.28	0.18	0.16	0.07	0.11	0.17	0.12
9	0.16	0.31	---	0.19	0.22	0.29	0.13	0.11	0.04	0.10	0.04	---
10	0.20	0.16	---	---	0.28	0.18	0.14	0.04	0.10	0.10	0.05	0.14
11	---	0.34	---	0.19	0.24	0.22	0.14	---	0.12	0.14	0.10	0.09
12	0.25	0.24	0.26	0.21	0.24	0.25	---	0.12	0.16	0.05	0.22	---
13	0.26	0.09	0.30	0.29	0.16	0.18	0.15	0.18	0.13	0.06	0.15	0.20
14	0.19	0.17	0.26	0.29	0.21	---	0.14	0.14	---	0.10	0.11	0.15
15	0.16	0.15	0.25	0.28	0.26	0.22	0.10	0.14	---	0.13	0.12	0.16
16	0.12	0.31	0.38	0.31	0.25	0.22	0.19	0.10	0.06	0.09	---	0.21
17	---	0.33	0.24	0.32	0.05	0.19	0.16	0.13	0.06	0.07	0.10	0.10
18	0.11	---	0.44	---	0.21	0.19	---	0.12	0.10	0.21	0.06	0.08
19	0.31	0.32	0.21	0.29	0.24	0.23	---	---	0.09	---	0.08	0.10
20	0.19	0.24	0.24	0.18	0.25	0.23	---	0.08	0.10	0.06	0.07	0.17
21	0.17	0.20	0.22	0.21	0.25	0.25	0.07	0.09	0.09	0.05	0.08	0.25
22	0.25	0.26	---	0.23	0.28	0.34	0.09	0.10	0.05	0.11	0.12	0.16
23	0.11	0.30	0.07	0.30	0.28	0.07	0.12	---	0.10	0.09	0.17	0.15
24	0.13	0.31	0.06	0.19	0.26	0.13	0.14	---	0.14	0.07	0.08	0.20
25	0.21	0.31	0.21	0.18	---	0.24	0.19	0.09	0.04	0.15	0.09	0.24
26	0.12	0.34	0.14	0.26	0.34	0.15	0.14	0.04	0.05	0.15	---	---
27	0.24	0.28	---	0.29	0.27	0.13	0.09	0.09	---	0.20	---	0.18
28	0.12	0.29	0.70	0.39	0.31	0.19	0.16	0.12	0.04	0.08	0.14	0.27
29	0.24	0.29	0.15	0.19	0.29	0.21	0.09	0.11	0.05	0.14	0.06	0.17
30	0.20	0.28	0.22	---	0.30	0.20	0.11	0.10	0.04	0.10	0.05	
31	0.29		0.15		0.34	0.18		0.09		0.05	0.13	
COUNT	29	29	25	26	28	30	25	26	25	29	27	26
AVG	0.225	0.257	0.237	0.252	0.238	0.224	0.144	0.116	0.086	0.101	0.097	0.147

APPENDIX I

POND SURFACE ELEVATIONS

Date	Pond Surface Elevation
6-09-88	880.95
6-10-88	0.90
6-11-88	0.85
6-12-88	0.80
6-13-88	0.75
6-14-88	0.71
6-15-88	0.66
6-16-88	0.64
6-17-88	0.62
6-18-88	0.55
6-20-88	0.47
6-21-88	0.42
6-22-88	0.38
6-23-88	0.31
6-24-88	0.27
6-25-88	0.23
6-26-88	0.20
6-27-88	0.17
6-28-88	0.13
6-29-88	0.12
6-30-88	0.10
7-04-88	0.25
7-05-88	0.22
7-06-88	0.17
7-07-88	0.13
7-08-88	0.11
7-09-88	0.07
7-12-88	879.97
7-14-88	0.90
7-17-88	0.82
7-19-88	0.82
7-20-88	0.92
7-27-88	880.55
7-28-88	0.75
7-29-88	0.77
8-01-88	0.57
8-02-88	0.50
8-03-88	0.42
8-05-88	0.30
8-06-88	0.23

VITA

Michael Jess Nelson

Candidate for the Degree of

Master of Science

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