Special Publication SJ96-SP14

INVESTIGATION OF LAKE AND SURFICIAL AQUIFER INTERACTION IN THE UPPER ETONIA CREEK BASIN: INTERIM REPORT

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Contract Number 93W296 (UF #4510 425 12)

August 1996

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The Upper Etonia Creek Basin (UECB) is located in north-central Florida and comprises parts of Alachua, Bradford, Clay, and Putnum counties. Over the last 5 to 10 years, many of the lakes in this basin have experienced significant declines in lake stage, adversely affecting both recreational use and surrounding property values.

To help identify factors causing lake stage reductions, the St. Johns River Water Management District (SJRWMD) authorized the University of Florida (UF) in January 1990 to investigate long-term hydrologic trends. This multi-phase investigation by Motz et al. (1993) cited rainfall, lake-bottom leakage, and the regional decline of water levels in the upper Floridan aquifer as factors contributing to low lake stages. To better define the leakage component, it was recommended that further analysis be done on the water budgets of the lakes to examine the interactions between the lakes and the surficial aquifer.

Following these recommendations, this project was authorized by SJRWMD in October 1993 to examine lake and surficial aquifer interactions for Lakes Sand Hill, Magnolia, Brooklyn, and Geneva and to refine previous water-budget calculations by Motz et al. (1993). This report details the initial investigations at Lakes Brooklyn and Geneva. This study has been continued for a second year to collect additional water-level data over a one-year period and to incorporate survey elevations on all wells installed.

To quantify the exchange of water between the lakes and the surficial aquifer, nineteen new surficial aquifer monitoring wells were installed around Lakes Brooklyn, Geneva, Halfmoon, Sand Hill, and Magnolia to measure water-table elevations. Hydraulic properties in the region were obtained from slug tests and two pumping tests. Flow net calculations were performed for Lakes Brooklyn and Geneva utilizing the newly obtained information for hydraulic properties and surficial aquifer potentiometric surface maps. An equation was developed that relates surficial aquifer inflow to lake stage based on the constructed potentiometric maps for February 5, 1994.

The calculations indicate that surficial aquifer inflow is a low percentage of the total water budget. Based on the calculations for Brooklyn Lake, the net surficial aquifer inflow accounted for 4.4 percent of the total long-term (1965-1994) water volume. Lake Geneva had a slightly higher net surficial aquifer inflow component of 5.6 percent.

Simplifications used in the flow net evaluations for both lakes tended to maximize the surficial aquifer inflow component. This was done to get a first approximation of this flux and to examine whether a more detailed investigation is warranted. It is believed that a more in-depth approach likely would result in a lower net surficial aquifer inflow component of each lake's total water budget.

1.0 INTRODUCTION

1.1 BACKGROUND

The Upper Etonia Creek Basin (UECB) is located in north-central Florida and comprises parts of Alachua, Bradford, Clay, and Putnum counties (Figure 1.1). This region is well-known for its numerous lakes, which provide multiple recreation uses and help bolster the local economy. Over the last 5 to 10 years, however, many of these lakes have experienced significant declines in lake stage, adversely affecting both recreational use and property values.

To help identify factors causing lake stage reductions, the St. Johns River Water Management District (SJRWMD) authorized the University of Florida (UF) in January 1990 to investigate long-term hydrologic trends. In Phase I of this investigation, below average rainfall was cited by UF as the primary factor influencing lake stage levels (Motz et al. 1991). A second phase of the project was authorized by SJRWMD in December 1990 to gather more information on the relation between ground water, surface water and lake stage. The Phase II report concluded that a regional decline in water levels in the Upper Floridan aquifer also had significantly affected Brooklyn Lake. It was found that Brooklyn Lake has a good hydraulic connection via vertical leakage with the upper Floridan aquifer, and that potentiometric head declines in the upper Floridan aquifer have had an adverse effect on the Brooklyn Lake stage levels.

To better define this leakage component, it was recommended that further analysis be done on the water budget of the lakes. Specifically, it was recommended that the interactions between the lakes and the surficial aquifer be examined in more detail.

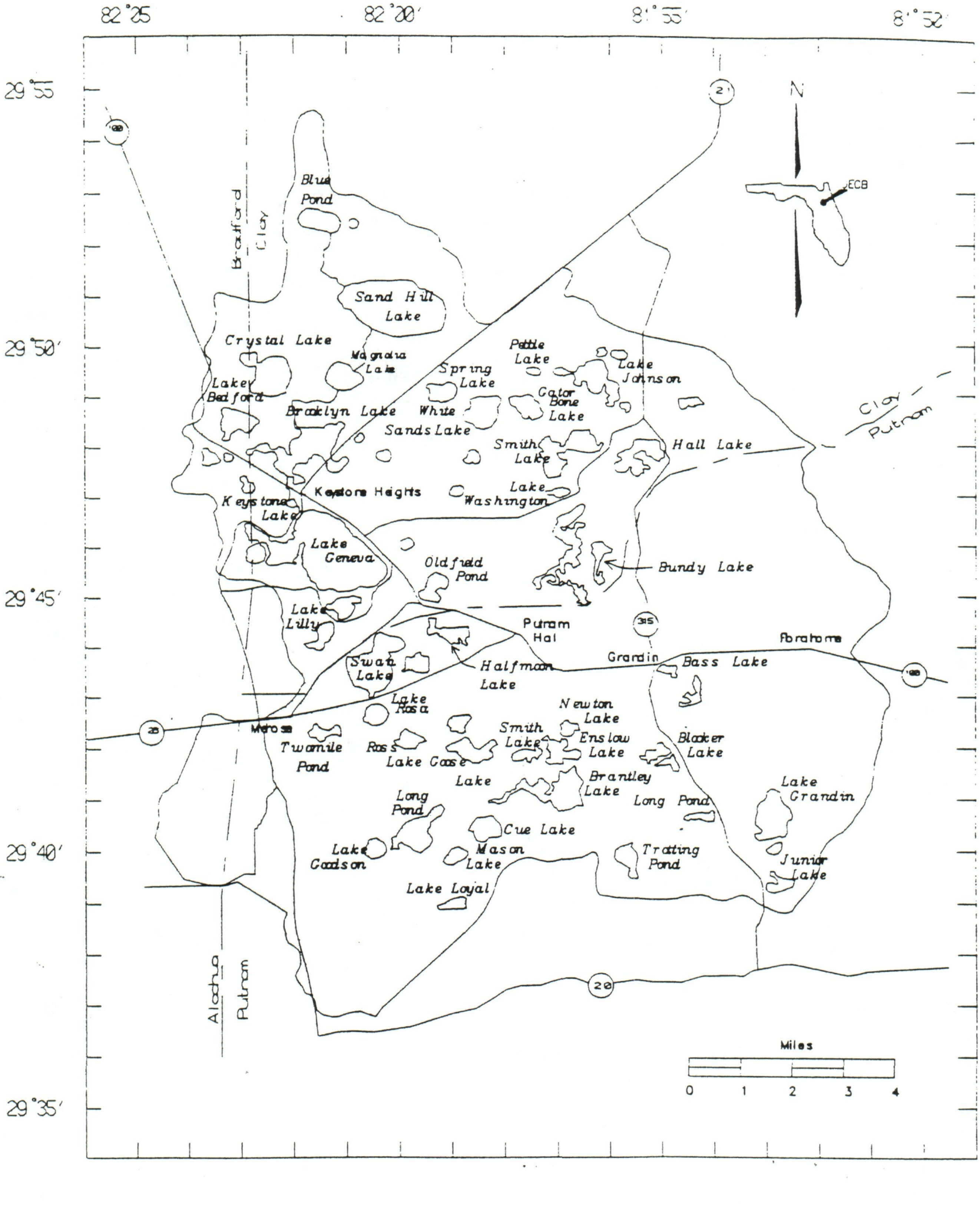


Figure 1.1 Upper Etonia Creek Basin (Motz et al. 1993)

1.2 PROJECT OBJECTIVES

Following the recommendation in the Phase II hydrologic study of the UECB, SJRWMD authorized UF to examine lake and surficial aquifer interactions in October 1993. The objective of this study was to determine the net surficial aquifer inflow components for Brooklyn Lake, Lake Geneva, Magnolia Lake, and Sand Hill Lake and to improve the accuracy of existing water-budget calculations. Additionally, this study was also to provide better quantification of the hydraulic properties of the surficial-aquifer and ground water contour maps around each of these lakes.

1.3 TASKS

To achieve this objective, the following five tasks were outlined:

- Task 1. Review data and select new monitoring well sites;
- Task 2. Conduct aquifer testing by means of slug tests and pump tests;
- Task 3. Evaluate tests and develop piezometric maps for area;
- Task 4. Revise lake water budgets; and
- Task 5. Prepare a technical report of findings.

The first task consisted of compiling and reviewing hydrological data for lakes, wells, climate, and geology in the UECB. Additionally, 40 well sites were selected around the four lakes, and all necessary permits were obtained for drilling and installing the wells. Site selection and permitting required production of numerous site maps and coordination with Bradford and Clay counties as well as the Camp Blanding military base.

Under Task 2, slug tests were performed in all the new surficial aquifer wells, and a pump test was also done at Halfmoon Lake. Task 3 included determining average values for the surficial aquifer hydraulic conductivity and storativity from the slug and pump tests. Additionally, ground penetrating radar (GPR) was used at Brooklyn Lake to help improve water-table mapping and define subsurface anomalies. This information was used in Task 4, which reevaluated the water budgets, which calculate a mass balance on all lake inflows and outflows for Brooklyn Lake and Lake Geneva using the new data obtained for the surficial aquifer. This report was prepared as part of Task 5.

1.4 PREVIOUS INVESTIGATIONS

Over the past 30 years, several hydrologic investigations have focused on lake and surficial aquifer interactions in north-central Florida. Clark et al. (1963) investigated the hydrology of Brooklyn Lake as part of a much larger study that examined the water resources of Alachua, Bradford, Clay and Union counties (Clark et al. 1964). The Brooklyn Lake investigation was prompted by a 20-ft decline in lake stage that was experienced from 1954 through 1958. By October 1959, though, the lake had refilled to capacity and was discharging to downstream lakes. More recently, Bentley (1977) looked at surface- and ground-water interactions in Clay County. In 1979, Yobbi and Chappell summarized the hydrology of the UECB. Motz et al. (1991 and 1993) prepared two comprehensive hydrologic studies in the UECB that quantified lake and aquifer interactions. It was concluded that low rainfall and a regional decline in water levels in the upper Floridan aquifer had adversely affected some of the area lakes. Subsequently, Motz et al. (1994)

developed a regional ground-water flow model of the Floridan aquifer system in north-central Florida to predict future impacts due to ground-water pumping.

Sacks et al. (1992) conducted a preliminary hydrologic budget of Lake Barco, a lake in a similar setting 3.5 miles south of the study area. Although this was done as part of an investigation focusing on the acid neutralizing capacity of the lake, a substantial effort went into the water-budget analysis. Sacks et al. (in press 1994) also looked at Lake Barco in an effort to compare energy-budget evaporation losses between morphometrically different Florida lakes. In this study, it was concluded that Lake Barco evaporation "could usually be estimated within 10 percent of the energy-budget evaporation method using a constant pan coefficient" (Sacks et al. in press 1994).

2.0 REGIONAL SETTING

2.1 LOCATION

Lakes Sand Hill, Magnolia, Brooklyn, and Geneva (listed in downstream order) all lie within the Upper Etonia Creek Basin (UECB) (see Figure 2.1). The UECB is a sub-basin within the St. Johns River Basin, and it lies adjacent to the Suwannee River Basin. It is located in north-central Florida and comprises parts of Alachua, Bradford, Clay, and Putnum counties. Lakes Sand Hill and Magnolia are located on the Camp Blanding Military Reservation, while Lakes Brooklyn and Geneva are south of the reservation near Keystone Heights.

2.2 CLIMATE

The climate in north-central Florida is subtropical, with the division between tropical and subtropical climates lying approximately 50 miles south of Gainesville. The area receives most of its rainfall during the summer months with winter normally considered to be fairly dry. The average annual temperature is approximately 72° F.

The nearest long-term rain gaging station, located in Gainesville, shows an average rainfall of 51.08 inches per year (in/yr). There are three trends in precipitation over approximately the last 100 years. Rainfall was below average from 1897 through 1943, above average from 1944 through 1972, and again below average from 1973 through 1992 (Motz et al. 1994). This is illustrated in the cumulative departure curve in Figure 2.2.

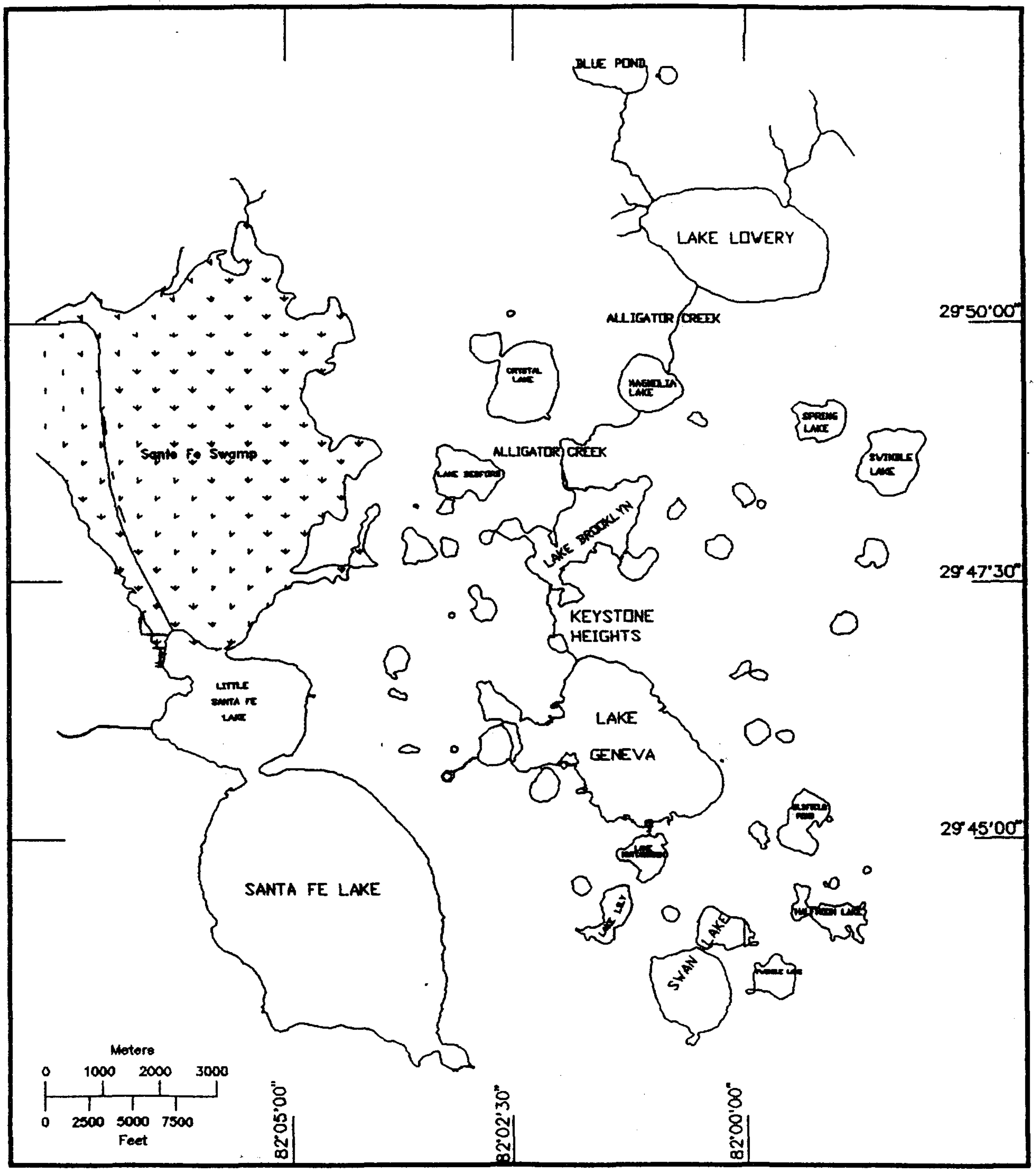


Figure 2.1 Lakes in study area

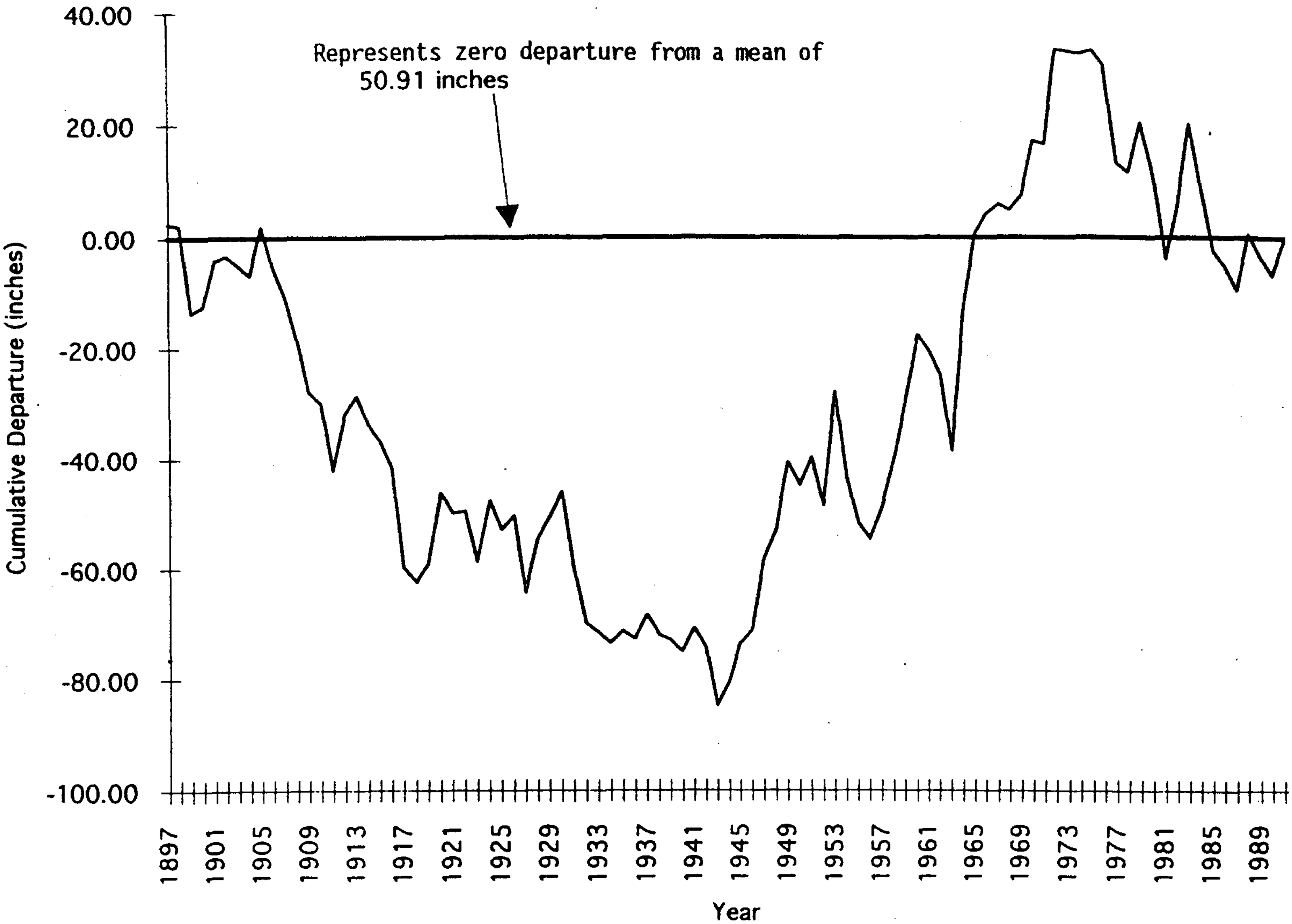


Figure 2.2 Cumulative departure from average rainfall measured at Gainesville for 1897-1992 (Motz et al. 1994)

Beginning in 1988, SJRWMD has collected some rainfall data from areas in and around the UECB. Unfortunately, unresolved gaps in some of the rainfall data precluded its use for this investigation. In a limited analysis of the partial record data, it appears that the short-term rainfall in the lake area is less than at Gainesville (see Figure 2.3).

Pan evaporation has been measured at Gainesville from 1954 to present, and it has averaged 61.72 in/yr from 1954 to 1989 (Motz et al. 1993).

2.3 PHYSIOGRAPHIC FEATURES

A major physiographic feature of the northern UECB is Trail Ridge, which is part of the Northern Highlands. Trail Ridge consists of a series of sand hills extending southward from southern Georgia, terminating near the lakes at Keystone Heights (Clark et al. 1964). Elevations on Trail Ridge can range above 200 feet, National Geodetic Vertical Datum (NGVD) (Pirkle et al. 1977). The northern part of the study area has elevations up to approximately 200 ft, NGVD, that are associated with Trail Ridge. Elevations drop off to the south at an average of 100 feet per mile (Clark et al. 1964). Gradients are much more pronounced near the boundaries of the solution formed lakes of the area. To the south of Trail Ridge, near Lake Geneva and Brooklyn Lake, is an area defined as the Interlachen Karstic Highland (Arrington 1985). This region has an abundance of lakes, higher sinkhole activity, and rather dramatic relief compared to adjacent areas.

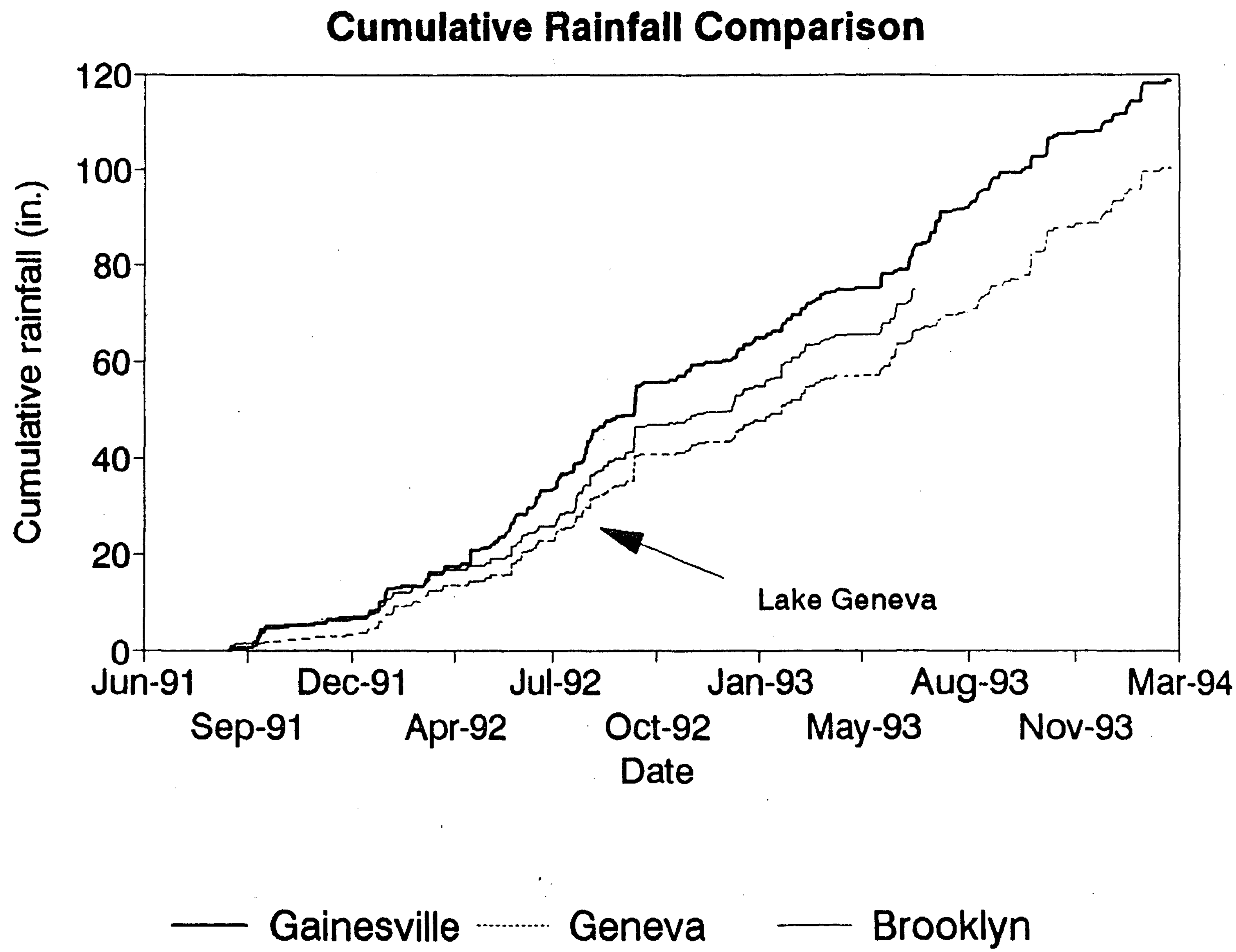


Figure 2.3 Short-term cumulative rainfall comparison between lake area and Gainesville

Numerous lakes are scattered throughout the UECB. Motz et al. (1991) reported that there are more than 100 named and unnamed lakes that lie within this basin. Most of these lakes have a surface area of less than 200 acres (Motz et al. 1991). Historically, eight interconnected lakes helped supplement the flow to Etonia Creek. From the northern end of the UECB, Blue Pond starts this intermittent chain, which ends at Putnum Prairie, just to the south of Halfmoon Lake. The chain of lakes is illustrated in Figure 2.4. Elevations decline from more than 170 ft, NGVD, at Blue Pond to near 90 ft, NGVD, at the Halfmoon Lake outfall (see Figure 2.5 Yobbi and Chappell 1979).

At present, the lakes in the UECB south of Magnolia Lake are experiencing extremely low stages. Over the last 20 years, there has not been any significant flow in Alligator Creek downstream from Brooklyn Lake.

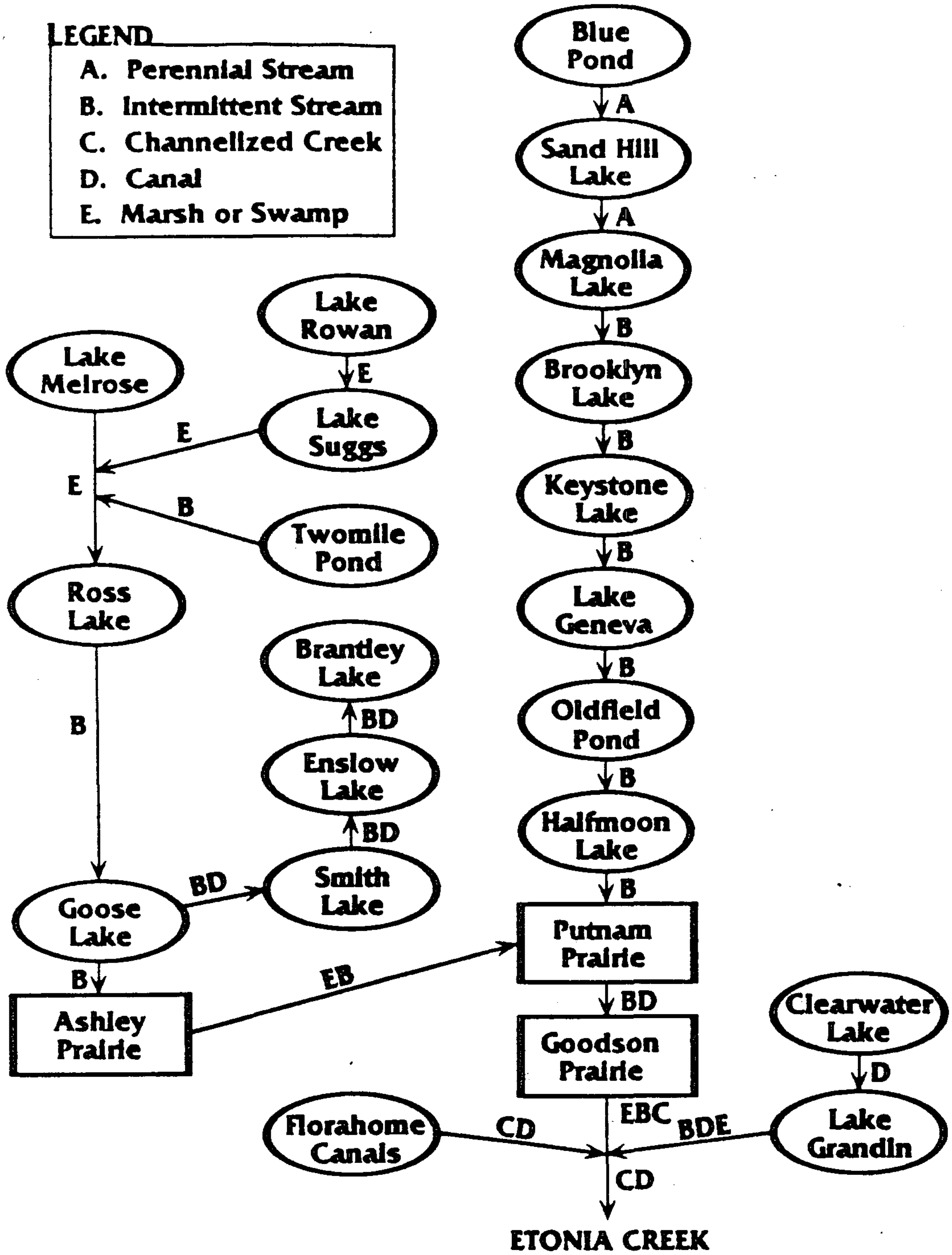


Figure 2.4 Lake chain in Upper Etonia Creek Basin

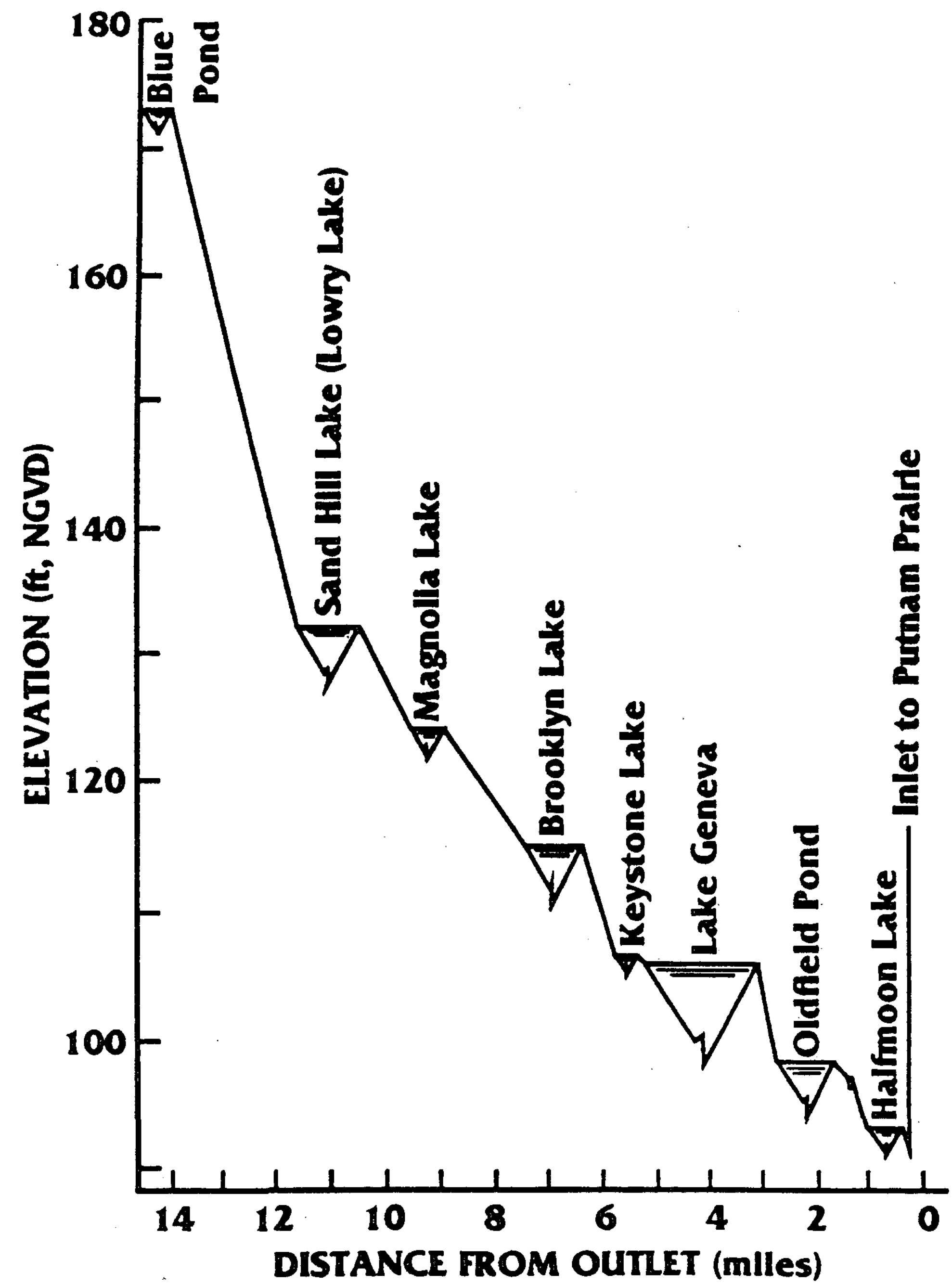


Figure 2.5 Lake and stream profile from Blue Pond to Halfmoon Lake (Yobbi and Chappell 1979)

3.0 GEOLOGY

3.1 INTRODUCTION

The surficial geologic deposits in the UECB consist of mostly unconsolidated to semi-consolidated sand, clayey sand, marl, and shell. The thickness of these sediments ranges from 10 to 100 ft, and they are associated with the Holocene, Pleistocene, and Pliocene periods. These deposits are underlain by the Hawthorn Formation, a marine deposit of Miocene age that consists of clay, quartz, sand, carbonate, and phosphate (Clark et al. 1964). Below the Hawthorn Formation lies the Ocala Limestone Formation of the Late Eocene period, which ranges in thickness from 200 to 400 ft. Table 3.1 summarizes the geologic units in the area of the UECB and Table 3.2 lists geologic ages.

3.2 PLEISTOCENE AND HOLOCENE DEPOSITS

Pleistocene and Holocene deposits are somewhat differentiated within the UECB (Boyes 1992). In the northern section, deposits associated with Trail Ridge consist mainly of coarse sands that are relatively uniform in size (Pirkle et al.1974). This is evidenced by the sand mining operations that are present throughout the region. South of Trail Ridge, the deposits are more likely to contain higher percentages of clay and sandy clay and may be partially stratified by semi-permeable clayey lenses.

Table 3.1 Geologic layers in the Upper Etonia Creek Basin (Motz et al. 1993)

Geologic Age	Stratigraphic Unit	Approximate Thickness (ft)	Lithology
Pleistocene and Recent	Post-Hawthorn Deposits	10-100	Discontinuous beds of loose sand, clayey sand, sandy clay, marl, and shell
Pliocene	Post-Hawthorn Deposits	10-100	Clay, clayey sand, sandy clay, shell, and limestone
Miocene	Hawthorn Group	100-400	Interbedded clay, quartz, sand, carbonate, phosphate
Late Eocene	Ocala Limestone	200-400	Porous limestone
Middle Eocene	Avon Park Formation	500-1,200	Interbedded limestone and dolomite
Early Eocene	Oldsmar Formation	300-800	Interbedded limestone and dolomite
Paleocene	Cedar Keys Formation	Unknown	Interbedded dolomite and anhydrite

Sources: Bermes et al. 1963; Clark et al. 1964; Fairchild 1972; Hoenstine and Lane 1991; Leve 1966; Miller 1986; and Scott 1988.

Table 3.2 Time before present of geologic ages (Batten 1987)

Geologic Epoch	Time Before Present (million years)
Pleistocene and Holocene	0.11 to 1.5
Pliocene	1.5 to 12
Miocene	12 to 20
Oligocene	20 to 35
Eocene	35 to 55
Paleocene	55 to 65

3.3 PLIOCENE DEPOSITS

The Pliocene deposits delineate a transition zone between the upper Pleistocene deposits and the Hawthorn Formation. These deposits contain interbedded clay, clayey sand, shell, and soft limestone (Motz et al. 1993). Clay content may vary considerably, ranging from 10 percent to 50 percent (Boyes 1992). This zone of transition is readily identifiable at the lower interface along the Hawthorn Formation, although the upper interface of the Pliocene is much less pronounced.

3.4 MIOCENE DEPOSITS

The Hawthorn Formation, a Miocene age marine deposit, is composed of clay, sand, and phosphate. This formation is semi-contiguous throughout the UECB region. Because of the relatively high radiation emitted from the phosphate, the top of the Hawthorn Formation is readily identifiable from gamma well logs. The Hawthorn Formation ranges in thickness from about 100 to 200 ft in most of the areas around the UECB (Clark et al. 1964).

3.5 EOCENE DEPOSITS

The deposits from the Eocene period are ubiquitous throughout the UECB. The period is generally classified in three sections: the Early Eocene, Middle Eocene, and Late Eocene. Stratigraphic units from the Eocene period include the Oldsmar Formation, Avon Park Formation, and Ocala Formation. The deposits consist of porous limestone, interbedded limestone, and dolomite. The total thickness of the Eocene layers ranges from approximately 1,500 to 2,500 ft.

4.0 GROUND WATER HYDROLOGY

4.1 INTRODUCTION

There are three major hydrologic units within the UECB: the surficial or water-table aquifer, the intermediate aquifer, and the Floridan aquifer. The surficial aquifer is the uppermost water bearing unit and is an integral part of the lakes and streams throughout the UECB. The intermediate aquifer lies within the permeable units in the Hawthorn Formation, and it is the primary source of self-supplied residential drinking water for the area. It is generally regarded as a confined aquifer, although there are many areas where the upper confining unit may have been breached. Below both the surficial and intermediate aquifers lies the Floridan aquifer. It is the principle source for public supply, agricultural, and commercial water use needs. Recharge to the Floridan aquifer is very high in the UECB, with the potentiometric surface generally lower in the Floridan than in either the surficial or the intermediate aquifer. Table 4.1 lists the hydrogeologic units within the UECB.

4.2 SURFICIAL AQUIFER

The surficial aquifer is composed of deposits from the Pliocene and Pleistocene periods. Mixtures of sand, clayey sand, and shell are the main components of the aquifer matrix, which ranges in thickness from 5 ft to more than 100 ft. The water table generally follows the local topography, but the saturated thickness can vary greatly. Local climatic

Table 4.1 Hydrogeologic units of the Upper Etonia Creek Basin (Motz et al. 1993)

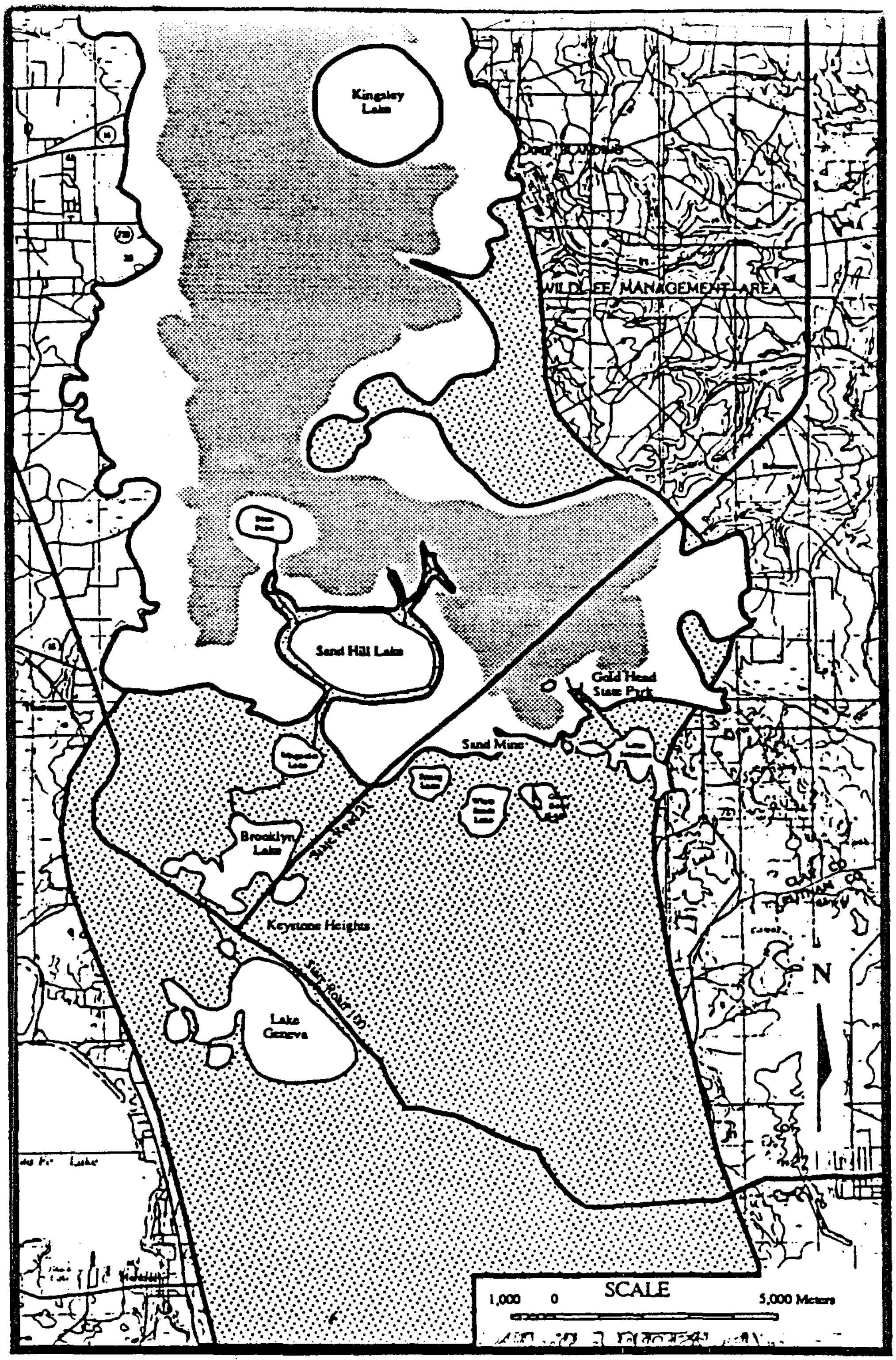
Geologic Age	Geologic Unit	Hydrologic Unit	Description
Pleistocene and Recent	Pleistocene and Recent deposits	Surficial Aquifer System	Consists of sands, clayey sand, and shell. Thickness ranges from 20 to more than 110 ft.
Pliocene	Pliocene deposits		
Miocene	Hawthorn Group	Upper Confining Unit	Consists of clay marl, and discontinuous beds of sand, shell, dolomite, and limestone. Thickness ranges from 150 to 450 ft.
		Intermediate Aquifer System	
		Lower Confining Unit	
Late Eocene	Ocala Limestone	Upper Floridan Aquifer	Consists mainly of limestone of high primary and secondary porosity. Thickness ranges from 300 to 700 ft.
Middle Eocene	Avon Park Formation	Middle Confining Unit	Consists of leaky, low permeability limestone and dolomite. Thickness ranges from 50 to 200 ft.
Early Eocene	Oldsmar Formation	Lower Floridan Aquifer	Consists primarily of interbedded limestone and dolomite. Thickness ranges from 1,100 to 1,500 ft.
Paleocene	Cedar Keys Formation	Lower Confining Unit	Consists of low permeability anhydrite beds.

Sources: Clark et al. 1964; Hoenstine and Lane 1991; Miller 1986; Scott 1988; and Southeastern Geological Society 1986.

conditions such as rainfall and evapotranspiration have a great effect on the saturated thickness.

Ground-water flow within the surficial aquifer is generally considered to be horizontal in the direction of decreasing gradients. This is true in the areas where the lower confining layer is continuous. However, breaches in the confining unit, higher permeability zones, or thin regions of the confining unit also can result in vertical flow of water. The magnitudes of these fluxes (vertically downward and horizontal) are controlled by the water gradient in the respective directions and by the horizontal and vertical hydraulic conductivities. Recharge to the surficial aquifer is primarily from the percolation of direct rainfall through soils at the ground surface. Other sources of recharge are the water exchange between lakes and streams.

Boyes (1992) reported that the surficial aquifer system in the UECB consists of two different hydrogeologic units. He reported that the surficial aquifer system in the northern section of the basin on Trail Ridge is characterized by "low transpiration, high recharge from rainfall, and relatively stable water tables that parallel local topography." In the southern section, on the Interlachen Karstic Highlands, Boyes (1992) states that the surficial aquifer "is an area of low transpiration, high recharge from rainfall and relatively unstable water tables . . . ". He indicates the division between these regions lies just north of Magnolia Lake (Figure 4.1) (Boyes 1992).



EXPLANATION

Trail Ridge Sands above 200 feet NGVD.

Trail Ridge Sands between 170 and 200 feet NGVD.

Cypresshead Formation

Figure 4.1 Locations of the division between Trail Ridge Sands and Cypresshead Formation (Boyes 1992)

4.3 INTERMEDIATE AQUIFER

The intermediate aquifer lies within the Hawthorn Formation, and it consists of discontinuous beds of limestone, sand, and shell (Motz et al. 1993). It is an artisian aquifer, semi-confined on the top and bottom by clay units of varying permeability. Many residential areas in the UECB rely on the intermediate aquifer for their supply of fresh water. The transmissivity of the intermediate aquifer is on the order of 10,000 square feet per day (ft^2/day) in the UECB (Motz et al. 1993).

The surficial aquifer recharges the intermediate aquifer through breaches or high conductivity areas in the upper confining unit. Recharge can also occur from lakes where a direct hydraulic connection exists between the intermediate aquifer and the lake (Motz et al. 1993). Similarly, vertical leakance from the bottom confining layer allows water movement out of the intermediate aquifer into the Floridan aquifer. Vertical flux rates are primarily controlled by the thickness, continuity, and conductivity of both the upper and lower confining layers.

4.4 UPPER FLORIDAN AQUIFER

The Floridan aquifer underlies both the surficial and intermediate aquifers throughout the study area (and throughout Florida). The Floridan aquifer is composed of limestone and dolomite. Reported values of transmissivity near Keystone Heights are as large as 497,000 ft^2/day (Motz et al. 1993).

Recharge to the Floridan aquifer in the UECB is from the intermediate aquifer and leakage from lakes in the region. Large recharge in this area is evidenced by the high potentiometric surface of the Floridan aquifer centered at Keystone Heights (see Figure 4.2).

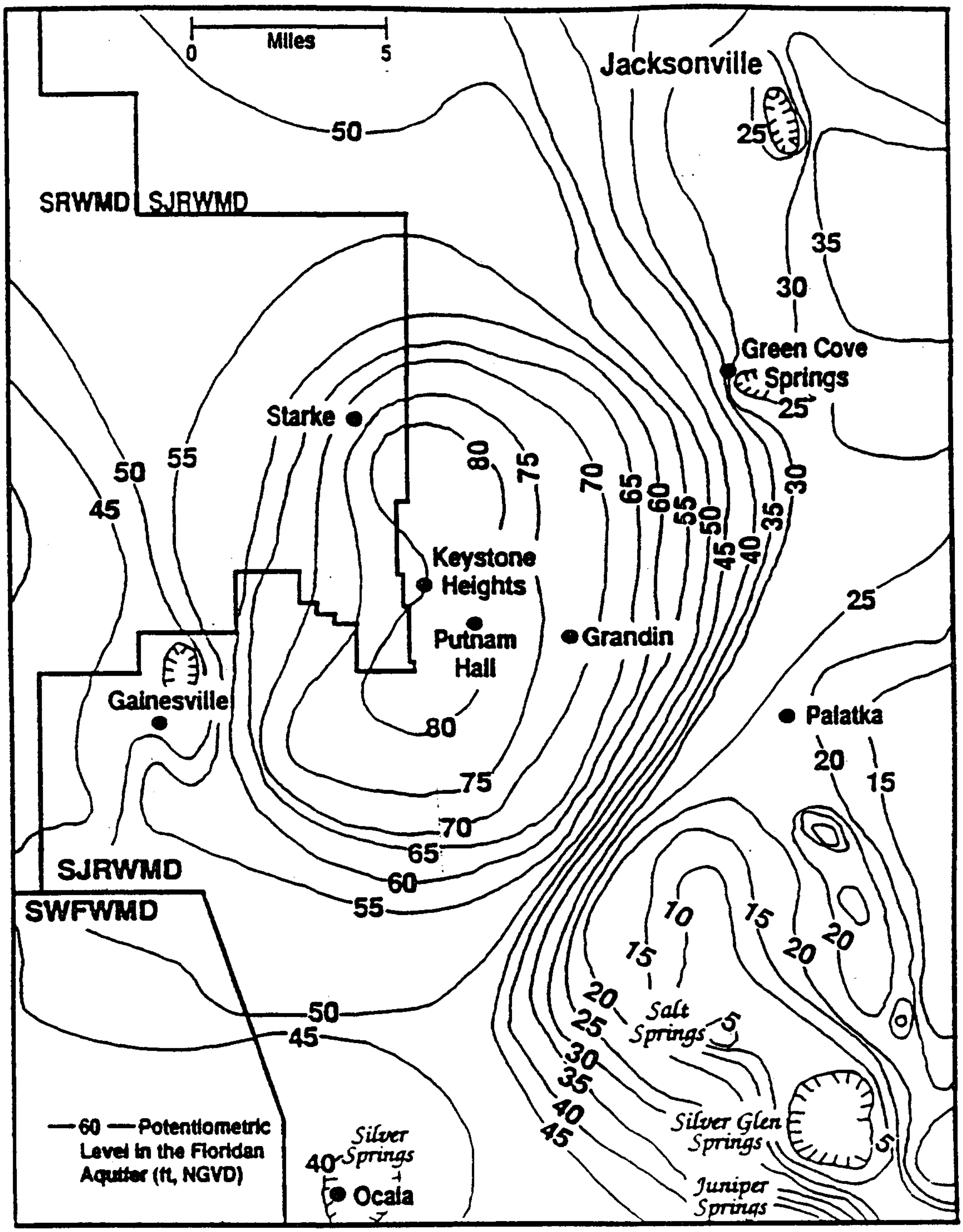


Figure 4.2 Potentiometric map of the Upper Floridan aquifer near Keystone Heights for September 1989 (Motz et al. 1993)

5.0 HYDROGEOLOGIC INVESTIGATIONS

5.1 NEW WELLS IN STUDY AREA

As part of this investigation, 40 new surficial aquifer monitoring wells were planned for the Keystone Heights area. At the time of this report, 19 wells have been drilled and the remaining wells are scheduled by SJRWMD to be completed by 1995. Figure 5.1 shows the location and status of these wells, and Table 5.1 lists the well elevations, screened interval, and total depths. Clay County well site location maps are shown in Appendix A.

Well locations were chosen to provide maximum coverage around Lakes Sand Hill, Magnolia, Brooklyn, and Geneva and to minimize cost. Existing wells were used for this study whenever possible. Most of the wells were placed on county road right-of-way or on Camp Blanding property. In some cases, narrow road right-of-way or high traffic areas necessitated placing the wells on private property.

The wells that were placed on Clay County right-of-way are mounted in monitoring well boxes so that the top of the well casing is flush with the existing grade. Each of the other wells has an exposed casing that extends from 0.5 to 2 ft above ground surface. Also, all of the wells on public land are equipped with locking caps to avoid tampering. The wells that are on county right-of-way are all located as far back on the right-of-way as possible to minimize damage to the wells and to facilitate road maintenance.

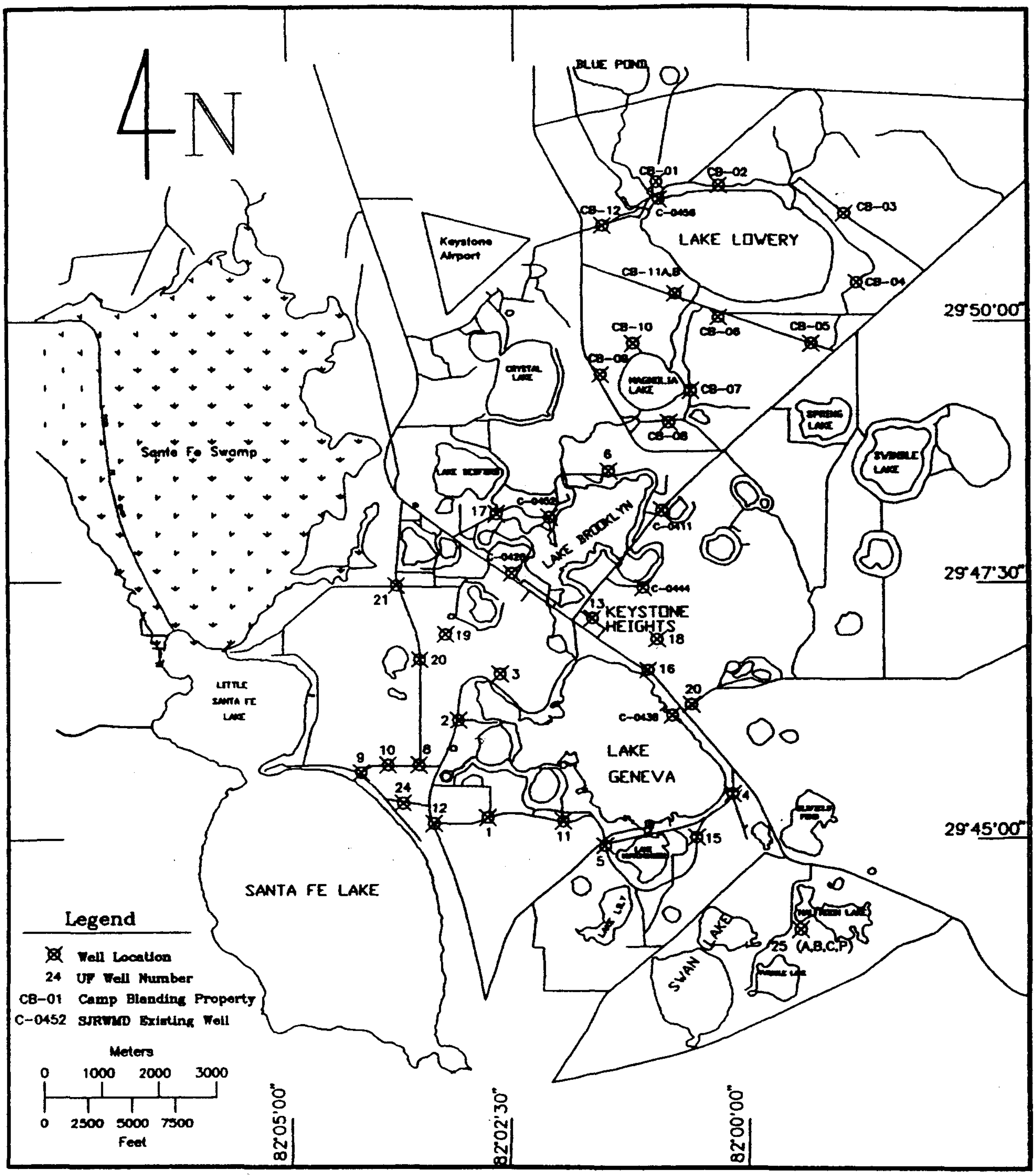


Figure 5.1 New surficial aquifer wells

Table 5.1 Data for new wells south of Camp Blanding

Well Number	Diameter (inches)	Elev. TOC* (ft, NGVD)	Total [1] Depth (ft)	Screen Length (ft)	Depth to Hawthorn (ft)	Date Drilled	Water-level Elevation 2/05/94
1	2	153.6	53	25	?	11/93	129.01
2	2	145.3	65	27	> 65	11/93	106.72
3	2	136.0	75	37	70	12/93	90.65
4	2	120.2	65	40	> 65	12/93	94.75
5	2	127.5	50	25	> 50	01/94	96.29
6	2	146.2	65	27	50	12/93	101.32
7	2	Not Yet Drilled					
8	2	148.0	48	22	43	12/93	120.72
9	2	153.7	48	32	48	12/93	128.80
10	2	148.6	48	22	?	12/93	125.49
11	2	139.5	55	20	> 55	01/94	109.61
12	2	153.5	51	32	> 51	12/93	127.22
13		Not Yet Drilled					
14		Not Yet Drilled					
15		Not Yet Drilled					
16		Not Yet Drilled					
17		Not Yet Drilled					
18		Not Yet Drilled					
19	2	166.1	55	12	> 55	12/93	118.32
20	2	166.6	60	25	> 60	01/94	122.84
21	2	153.3	59	22	> 59	01/94	118.3
22	2	Not Yet Drilled					
23	2	Not Yet Drilled					
24	2	155.4	55	20	46	11/93	124.44
25 (P)	4	-	50	25	-	11/93	No Survey

*Top of Casing

> Implies that Hawthorn formation was not encountered in well.

1 Total depth is depth to bottom of well below TOC.

5.2 SLUG TESTS

5.2.1 Methods for Determining Aquifer Properties

Information concerning important aquifer properties such as transmissivity and specific yield can be obtained by four different methods (Pandit and Miner 1986). These are grain-size analysis, laboratory column analysis, pump tests, and slug tests. Grain-size analysis is mostly empirical and has limited applicability in nonhomogeneous soils (Fetter 1986). Laboratory column analysis is typically used to obtain vertical hydraulic conductivity and specific yield but does not yield representative average horizontal transmissivity (Pandit and Miner 1986). Pump tests can be used to determine both transmissivity and specific yield, and for the most part they are considered to give the most accurate representation of the properties of the median. However, pump tests can be quite expensive and time consuming. Additionally, finding the space needed to place multiple wells in a populated area can be troublesome. Also, disposal of large volumes of water can be a major concern in a residential area.

A slug test consists of instantaneously raising or lowering the water level in a well or borehole and measuring the change in head with respect to time. From this information, the vertically averaged transmissivity of the medium and wellbore conditions may be obtained. The ability to obtain these important aquifer parameters quickly and inexpensively has made slug tests extremely popular (Chirlin 1989). However, the slug test has some shortcomings. The most predominant is that the slug test only measures aquifer properties local to the well.

5.2.2 Slug Tests

Slug tests were performed in all of the surficial wells drilled for this study. Head data were recorded by an *In-Situ Hermit 2000* data logger by means of a pressure transducer. After bailing 10 liters from each well and allowing the water level to stabilize, a solid PVC slug of known volume was introduced in the well, and initial and declining head levels were measured as a function of time. Additionally, measurements also were made when the PVC slug was withdrawn from the well.

The slug tests were analyzed using the Bower and Rice (1976) method for an unconfined aquifer. This method was chosen based on trials of slug test methodologies performed at Halfmoon Lake. In a comparison between Bower and Rice (1976), Dax (1987), and Hvorslev (1951), the Bower and Rice (1976) analysis proved to be superior. This method produced more precise (i.e., repeatable) aquifer parameters, which allowed for more accurate analysis of study area variability. Slug test calculations are presented in Appendix B.

The hydraulic conductivity values shown in Table 5.2 were obtained from the data representing the head value changes as the slug was withdrawn from the aquifer. For K_h, the arithmetic mean was 5.6 ft/day.

5.3 PUMP TESTS

5.3.1 Site Location

The first pump test was performed at Halfmoon Lake, which is at the lower end of the UECB, at the end of the lake chain. This site was chosen because of its proximity to

Table 5.2 Slug test results

Well Number	Date Performed	Saturated Thickness (ft)	Horizontal Hydraulic Conductivity (ft/day)
1	02/05/94	36.0	2.73
2	02/05/94	35.0	7.70
3	02/10/94	24.6	2.28
4	02/05/94	46.3	1.59
5	02/10/94	34.2	7.35
6	01/11/94	4.8	2.06
8	01/25/94	15.4	8.60
9	01/25/94	23.1	6.91
10	01/25/94	24.2	8.41
11	02/10/94	30.3	1.46
12	02/05/94	29.7	8.81
19	02/05/94	15.0	17.57
24	01/11/94	13.8	7.25
25 A	10/29/93	10.0	1.04
25 B	10/29/93	10.0	2.00
25 C	10/29/93	10.0	1.45
25 P	10/29/93	10.0	7.31
	Arithmetic mean:		5.55

Note: Saturated thickness for wells not intersecting the Hawthorn Formation was estimated from a Hawthorn Formation elevation map of the area.

Also note that most slug tests were conducted on dates that are different the date water levels were measured in Table 5.1.

the lakes of interest, accessibility, private landowner cooperation, and a shallow water table. Halfmoon Lake lies 2 miles southeast of Lake Geneva and is the lowest lake in the eight-lake Alligator Creek chain (see Figure 5.1). Over the last six years, this lake also has experienced a drastic decline in lake stage, and in May of 1994 it occupies approximately one fifth of its former high stage area. A second pump test was conducted north of Brooklyn Lake on Camp Blanding property. The preliminary calculations are presented in Appendix C but have not been used in this study.

5.3.2 Well Description and Placement

Four wells were used for the pump test at Halfmoon Lake, i.e., one 4-inch diameter pumping well and three 2-inch diameter monitoring wells. The three monitoring wells were placed 120 degrees apart at distances 20, 60, and 100 ft from the pumping well. All wells were drilled to a depth of 50 ft and fully screened throughout the aquifer thickness. The edge of Halfmoon Lake was approximately 400 ft from the closest well during the pump test operation (see Figure 5.2). A 220-volt, single-phase, 20 gallon per minute (gpm) Myers submersible pump was used for both the pumping tests.

5.3.3 Pump Test Discussion

Two separate pump tests and two recovery tests were conducted over a two-week period between December 15, 1993, to December 31, 1993, at Halfmoon Lake. The first test was run at a rate of 8.7 gallons per minute for a period of 2 days. Water from the test was discharged near the edge of the lake approximately 400 ft to the north of the pumping well. The pumping flow rate was measured throughout the test period and did not vary by more than 5 percent. Head-level data were recorded continuously during the tests by

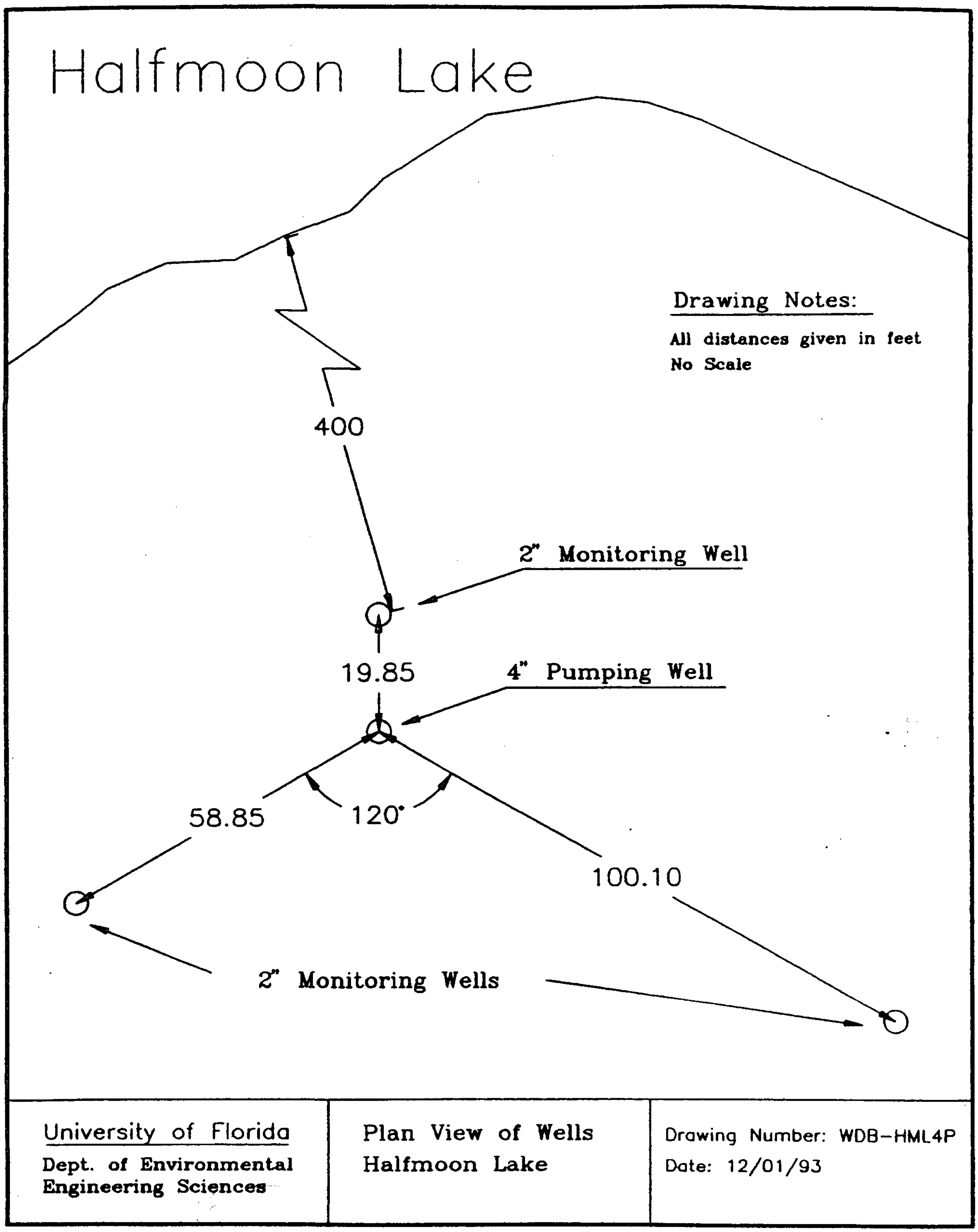


Figure 5.2 Well placement at Halfmoon Lake

an *In-Situ, Hermit 2000* data logger with four pressure transducers. Recovery tests followed each pump test and lasted for the same duration.

Excessive drawdowns in the pumping well during the end of the first test caused a slightly premature shutdown of that test. After the recovery test was over, another test was run at a flow rate of 5.0 gpm. The second pump test and recovery test were run for approximately 11 days. Drawdown during the pump test appeared to reach a quasi steady-state condition in about 2 days.

5.3.4 Pump Test Analysis

Data from the pump tests were analyzed by the Neuman (1975) method for unconfined aquifers. The drawdown curves and calculations are shown in Appendix C. Problems with the pressure transducer at well C prevented the collection of accurate sequential data for that well. Therefore, only the data obtained from the wells A and B were used to evaluate aquifer properties.

Additional difficulties in the pump test analysis were also encountered based on information obtained from the gamma log for the pumping well P. The gamma log indicates a high background radiation at depths from 20 to 30 ft. This may indicate that the top of the Hawthorn Formation could have been reached, and that pumping may have occurred from both the surficial aquifer and the Hawthorn Formation. Core samples that were taken for that well do indicate a high clay content, but they were not assumed to be associated with the Hawthorn Formation (Mike Huff, SJRWMD, personal communication, 10/93). Other Hawthorn control points close to the pump site also show that the Hawthorn Formation is much deeper than the gamma log indicates. Based on this information, the pump test was analyzed as an unconfined surficial aquifer, and the formation was assumed transmissive over the entire saturated thickness. Further evidence that supports this assumption is the shape of the drawdown response curves obtained from the pumping test. The shape of these curves is characteristic of an unconfined aquifer with a delayed drainage response. As a part of the second year of this study, additional borings are needed to verify the depth to Hawthorn at both pump test locations.

Transmissivity values obtained from drawdown curves for wells A and B ranged from 601 to 1,233 ft squared per day (ft^2/day) for the 8.70 gpm and 5.00 gpm pumping rates, respectively. The average was 784 ft^2/day. Table 5.3 shows all of the transmissivity and specific-yield values obtained from the four tests at Halfmoon Lake. The specific yield values ranged from 0.0098 to 0.032 with an average value of 0.018. Although these specific yield values are low, they are comparable to the values normally obtained from a pump test in an unconfined aquifer.

5.4 GROUND PENETRATING RADAR

5.4.1 Background

To overcome some of the problems associated with using a limited number of monitoring wells to represent a large area, ground penetrating radar (GPR) was used at Brooklyn Lake. The objective was to gain more information about the elevation and extent of the water table.

Since monitoring wells can only provide data at a point, it is necessary to make generalized assumptions about the water-table elevation at locations between the well

Table 5.3 Aquifer properties from pump tests at Halfmoon Lake

Test Number	Well Number	Transmissivity (ft^2/day)	Specific Yield
9 (Pump)	A	601	.0298
9 (Pump)	B	645	.0319
10 (Recovery)	A	971	N/A
10 (Recovery)	B	1233	N/A
11 (Pump)	A	798	.00260
11 (Pump)	B	1089	.00980
12 (Recovery)	A	458	N/A
12 (Recovery)	B	478	N/A
Arithmetic Mean:		784	.0185

sites. This can be especially difficult in areas with nonhomogeneous karst geology such as the UECB. The purpose of the GPR tests therefore were to determine if the water table could be located between well sites and to check for water-table depressions over buried sink holes.

The first test involved mapping the water table at strategic areas between existing monitoring wells. Use of GPR not only could reduce the number of monitoring wells needed, but also it could give a much more accurate picture of the water table. Another benefit would be to help locate anomalies in the subsurface terrain.

5.4.2 Ground Penetrating Radar Theory

Ground penetrating radar is based on the transmission of electromagnetic pulses that are emitted into the ground. These pulses are emitted with frequencies ranging from 10 to 1,000 megahertz (Mhz). When the pulses strike an interface between two different materials, some of the energy is reflected back to the receiving antenna. The portion of the energy reflected is a function of the difference in the dielectric constants of the materials. If this difference is large, as is the case between sand and water, this increases the reflectance, thereby allowing the depth to the interface to be calculated.

This energy is converted to a signal that is displayed on a graphic printer and resembles a sonar signal. The reflected pulse also may be stored in a digital format on magnetic tape. The unit is shown schematically in Figure 5.3.

5.4.3 GPR Field Work

The first trial site chosen for the GPR survey at Brooklyn Lake was based on its accessibility, ground truthing capabilities (in this case soil borings), and existing local

PROFILING RADAR

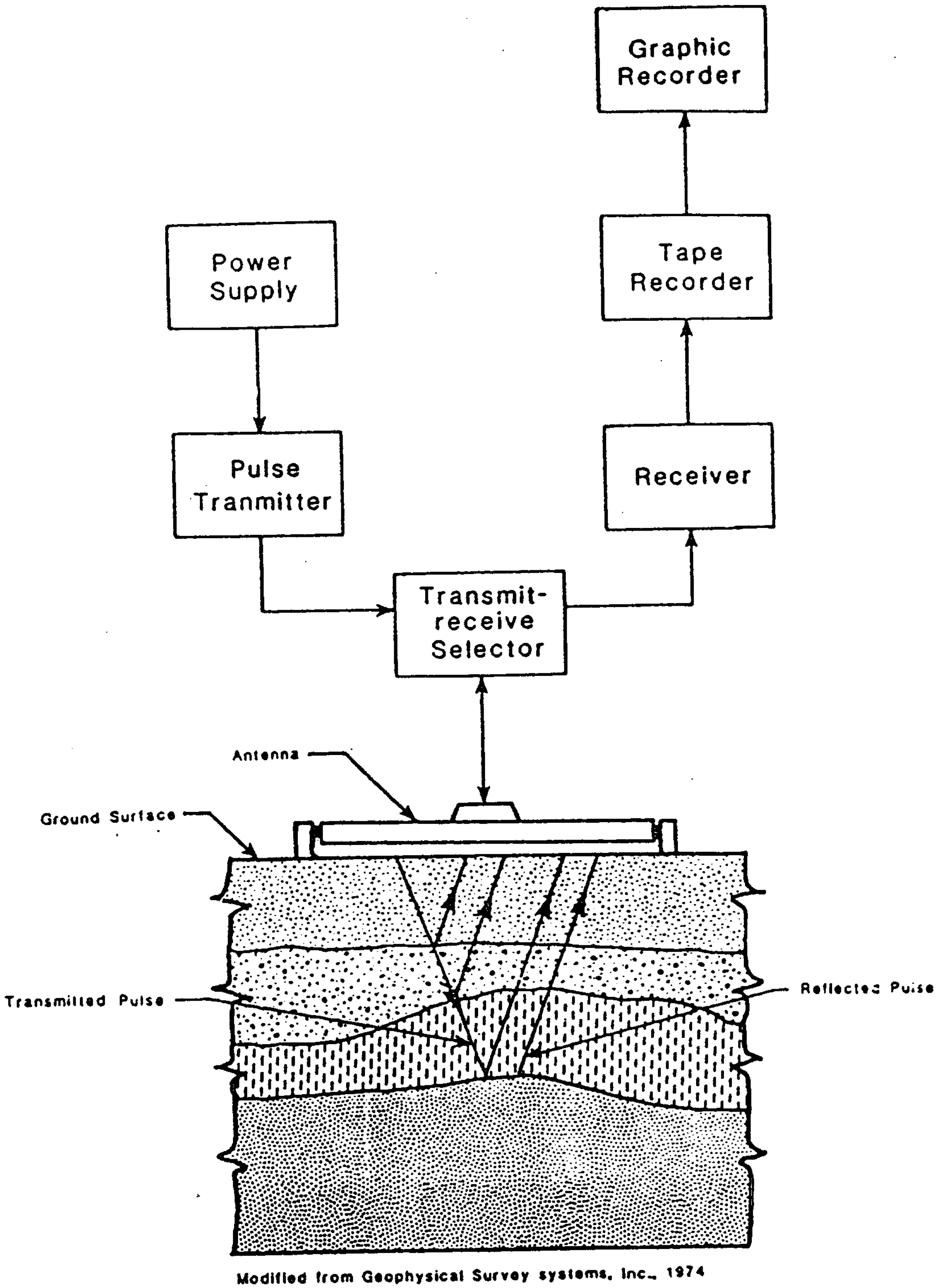


Figure 5.3 Schematic representation of profiling radar (Haeni et al. 1987)

survey points. The GPR unit used for this work was a Geophysical Survey Systems, Inc., model SIR-8, equipped with a 120 MHz antenna. This unit and its operator were on contract from the U.S. Department of Agriculture Soil Conservation Service. Because the area around Brooklyn Lake has very little public access, a local homeowner provided access to the lake from his property.

A site along the southern side of Brooklyn Bay was selected for the initial transect A-A' (see Figure 5.4). The transect extended from the lake surface southward, terminating at monitoring well C-0444. Elevations were surveyed by line level at 50-ft intervals from the lake surface to the monitoring well. Wooden stakes were placed at 50-ft intervals so that the GPR operator could mark the graph accordingly.

At this particular site, the ground slopes up very sharply from the lake surface at 88.73 ft, NGVD, to well C-0444 at 158.09 ft, NGVD. The transect distance was 600 ft. A piezometer was installed at station 1+00 to calibrate the GPR at shallow depths while the monitoring well C-0444 was used for the deep calibration (see Figure 5.5).

The radar contact on the water table (see Figures 5.5 and 5.6) was strong and distinct until slightly past Station 01+50. Shortly thereafter, at a depth of approximately 13 ft, other contacts on top of the water table are believed to have blocked the radar signal. The water table could not be located at any other points along the transect.

There are some questions as to whether or not the signal at station 01+50 is the true water table or just a perched high moisture zone. The gradient shown in the transect is uncharacteristically high compared to other monitoring well observations near Brooklyn Lake. Since only a piezometer rather than a fully screened monitoring well was used to

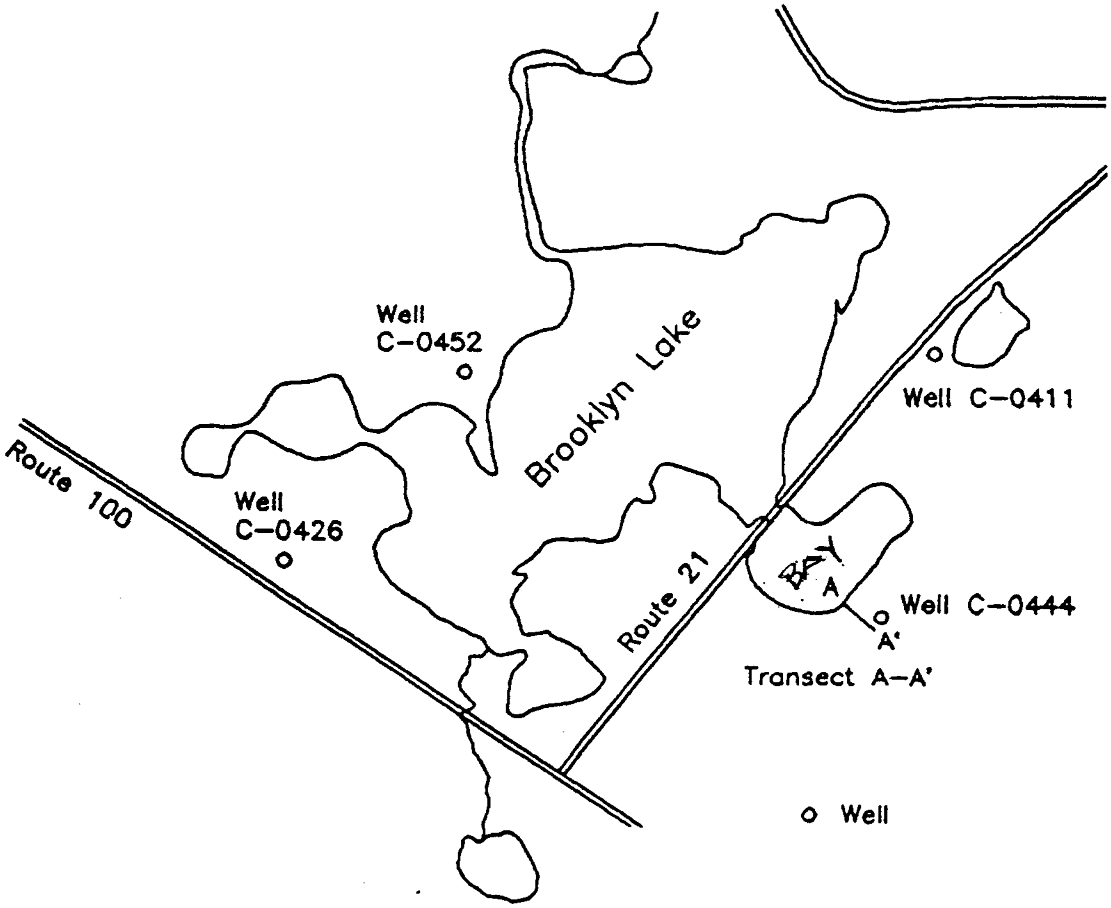


Figure 5.4 Location of GPR transect at Brooklyn Bay

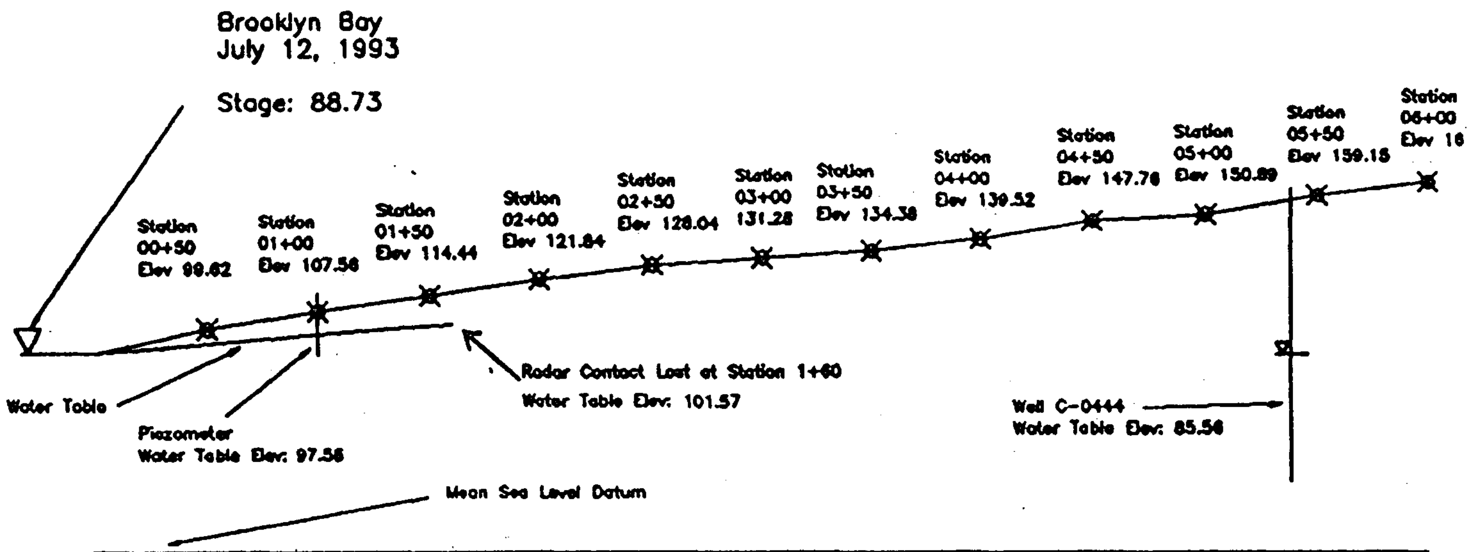


Figure 5.5 Water table and transect elevations at Brooklyn Bay

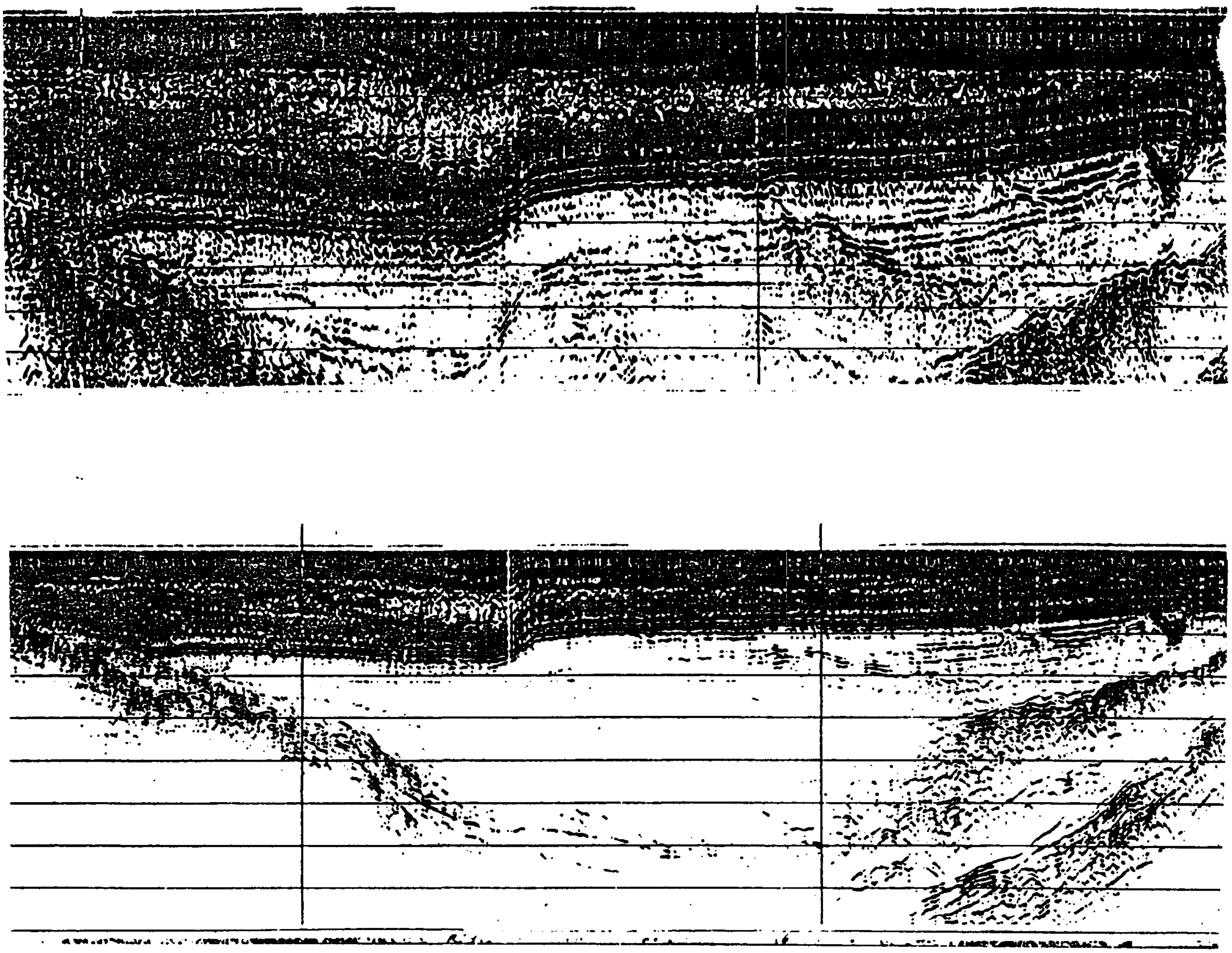


Figure 5.6 GPR transect along the bottom of Brooklyn Lake indicating downwarped beds

calibrate the depth to the water table (at the lake side), no specific conclusions can be made concerning the accuracy of the water-table gradient.

Soil borings along the transect showed layers of high clay content soil that ranged from within a few feet of the surface to 12 or more feet below land surface. Upon further investigation, it was concluded that the clay layers corresponded to the upper radar contacts and that the clay was responsible for the poor performance of the GPR for locating the water table.

Unfortunately, the GPR radar did not provide any additional information about the water-table elevations. A high clay content in the upper strata of the soil above the water table apparently prevented GPR from reaching the water table. Also, large water-table depths in this area, some in excess of 70 ft, limited the ability of GPR to locate the water table.

A second GPR experiment was conducted six months later on the dry lake bottom of Brooklyn Lake. The intent was to use GPR to quantify water-table gradients between some of the larger discontiguous pools that made up the lake at that time. It was reasoned that since the water table should be near the surface, and that there should be less clay than that found in the previous trial, GPR should work much better. Identifying large water-table gradients along the bottom of the dry lake sections would give clues as to the locations of high vertical conductivity regions.

The second experiment did locate the water table near the edge of the pools, although this could only be confirmed by piezometers. There was not any evidence of severe water table gradients, but there was evidence of downwarped confining beds along the bottom of the lake (see Figure 5.6). This seemed to indicate some type of subsurface collapse.

Because of difficulties in obtaining permits, no deep soil borings were drilled. However, it appears that a more in-depth investigation is warranted, provided permission for boring sites can be obtained. Additional information on the location and magnitude of the apparent collapse features under the lake would be extremely helpful in determining lake bottom leakage.

5.5 GAMMA WELL LOGS

Gamma logs were run by SJRWMD in all of the new wells in the study. The logs are shown in Appendix D. The large difference between background gamma radiation from the surficial aquifer and that from the top of the Hawthorn Formation is readily recognized.

The greatest emission of gamma radiation comes from the decay of radioactive phosphorus that has been concentrated in the clay layer. The elevation of the top of the Hawthorn formation was determined for the wells listed in Table 5.4. Wells that did not show a positive response were thought to be too shallow to intersect the Hawthorn Formation.

Table 5.4 Top of the Hawthorn Formation based on gamma logs

Well Number	Depth to Top of the Hawthorn Formation (ft)
1	?
2	> 65
3	70
4	> 65
5	> 50
6	50
8	43
9	48
10	43
11	> 55
12	> 51
19	> 55
20	> 60
21	> 59
24	46
25 A	?

> Indicates that the depth to the top of the Hawthorn Formation is greater than that number shown.

6.0 FLOW-NET ANALYSIS

6.1 INTRODUCTION

In this investigation, the net surficial aquifer inflow into Lakes Brooklyn and Geneva was quantified using Darcy's equation applied to a flow net analysis for each lake. The water flow between the surficial aquifer and the lake was calculated and used to update water-budget calculations originally presented by Motz et al. (1993). (More information about the water budgets and subsequent modifications are contained in Chapter 7.)

Darcy's equation can be expressed as

$$Q = K * A * I \tag{6.1}$$

where

	Q	=	volume of water per time [L^3/T]
	K	=	hydraulic conductivity [L/T]
	A	=	cross sectional area of flow [L^2]
	I	=	gradient [L/L]

This equation represents the volume of water per time flowing through a streamtube, where a streamtube is defined as a theoretical aquifer flow section that encompasses a volume between adjacent flow fields. These flow fields are designated by theoretical lines called streamlines that are tangent to the water velocity vectors within the aquifer matrix.

This application of Darcy's equation is a simplification that assumes a homogenous aquifer and only horizontal flow. However, this approach is appropriate to estimate the surficial component of the water budget of a lake. A sensitivity analysis of the variables was conducted to test the method. This analysis was used to determine if the magnitude of the surficial-aquifer component (determined as percentage of the lake's total water budget) would indicate the need for additional information or a more accurate modeling approach.

An average hydraulic conductivity of 40 ft/day was used for the flow-net analysis. This value is based on available data from the pump tests performed in the surficial aquifer at Half Moon Bay. This is approximately the same as the 30 ft/day that was obtained by Dupont in a surficial-aquifer pump test that was conducted in 1993 in the southern Trail Ridge area (report provided by Munch). The slug test data from this area support the use of a single value representative of the entire study region.

The cross-sectional area in Equation 6.1 was calculated by multiplying the water-table elevation minus the confining unit elevation by the average width of each streamtube. The hydraulic gradient applied was calculated by dividing the difference in head between the lake and the contour line on which the streamtube terminates by the length of that streamtube.

It was assumed that all of the water flowing through the streamtube entered the control volume that represents the lake. Without the use of multi-level piezometer clusters near the lake shore, the quantity, or fraction, of water entering the lake from the surficial-aquifer versus that flowing directly to the deeper formations cannot be determined. To evaluate the importance of the surficial aquifer on the water budget for each lake, distinguishing between water entering the lake and that flowing directly to the Floridan Aquifer is not required. Using water budgets to estimate leakance coefficients only requires that we estimate the volume of water flowing from the lake and surficial aquifer below the lake to the deeper aquifer. Additional cluster wells around the perimeter of the lakes are recommended if quantification of water entering the lake is needed.

The flow nets were developed using digitized USGS quadrangle maps. The maps are based on Universal Transverse Mercator (UTM) coordinates, zone 17, and contain most of the information found on the standard printed versions. These maps were then imported into an AutoCAD drawing file. The use of this computer aided drafting software greatly facilitated the task of getting measurements for the irregularly shaped streamtubes. Additionally, digitized lake bathymetry files, supplied by SJRWMD, were also imported into the USGS map files, and superimposed over the lake boundaries.

Based on information obtained from the monitoring wells around each of the lakes, a potentiometric map of the water table of the surficial-aquifer was constructed (see Figure 6.1). This was accomplished by using linear interpolation between heads observed at well locations and lake stage elevations along the edges of the lakes or control volume lines.

A flow-net was drawn for each of the lakes based on the individual water-table contours and the physiography of the lake. The streamtubes were drawn to subdivide the flow area into approximately 20 sections. The sections were chosen judiciously in an attempt to divide the flow area into subsections that were easily measurable and so that the areas between the streamlines were as geometric as possible. The flows from each streamtube were summed to give the net water flux.

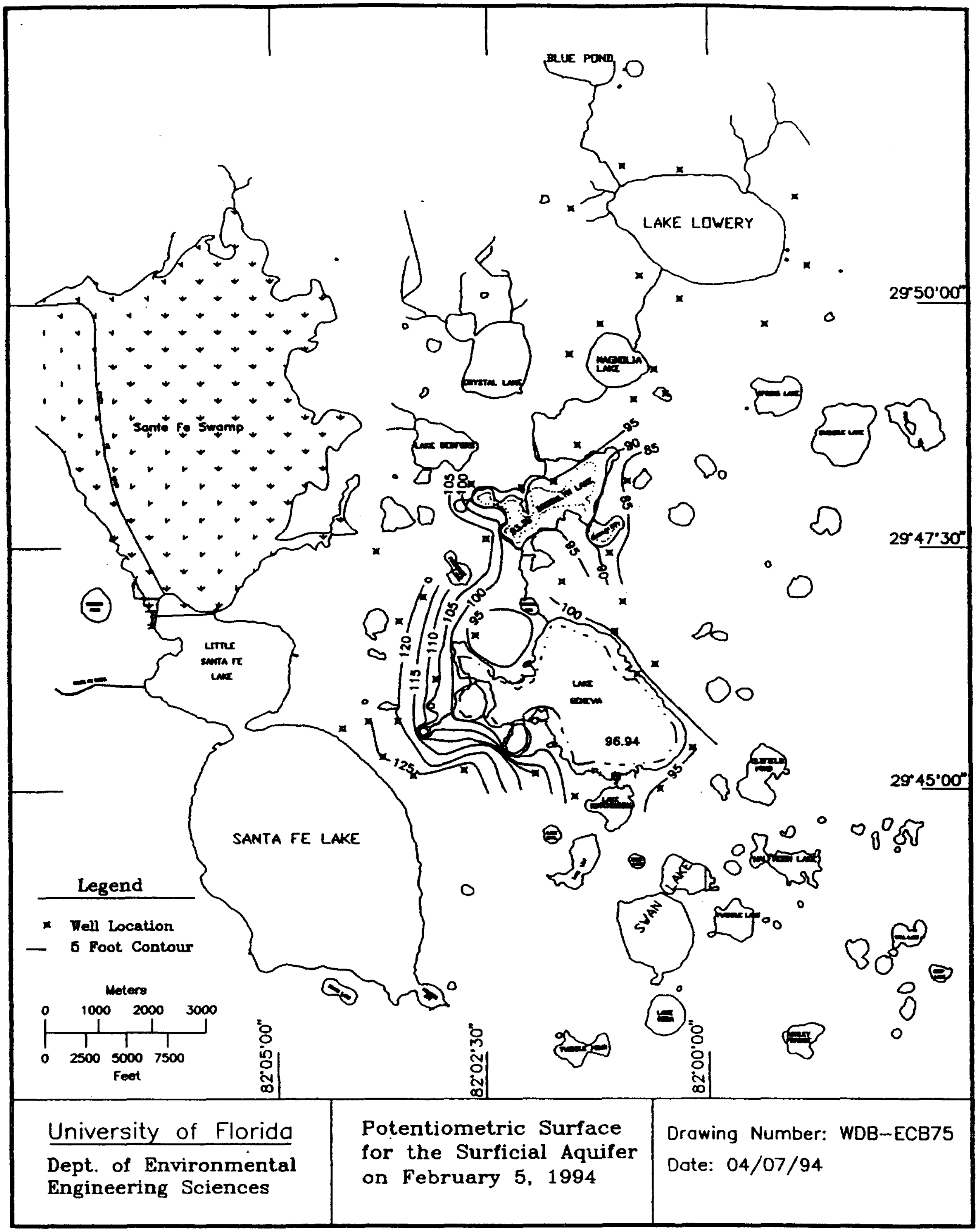


Figure 6.1 Water-table elevations around Lakes Brooklyn and Geneva

6.2 BROOKLYN LAKE FLOW NET

Water-table elevations for February 5, 1994, were used to construct the flow net for Brooklyn Lake. At this time, water-table elevations were higher than the lake elevation for much of the lake's perimeter, with the exception of the eastern edge. Figure 6.2 shows the water-table contours with the addition of the streamtube configuration for the flow net.

At low stages, Brooklyn Lake divides into eight or more pools. This complicated the water-budget calculations as well as the flow net analysis. In order to obtain estimates of the magnitude of surficial aquifer flow into Brooklyn Lake, some assumptions were made. These were as follows:

1) The water-table elevations within the aquifer between individual pool areas (within each main section, see Figure 6.2) are close to that of the adjacent pools;

2) There are no appreciable differences in elevations between the separate pools of each of the two main water bodies; and

3) All of the water flowing through each streamtube is going into the lake and not into a lower aquifer. The third assumption is applied to all the lakes and is critical if the goal is to calculate the exchange between the surficial aquifer and the lake. This assumption does not apply when the goal is to determine the magnitude of water moving vertically down and through the confining bed beneath the lake to deeper aquifers. With those assumptions made, an outline

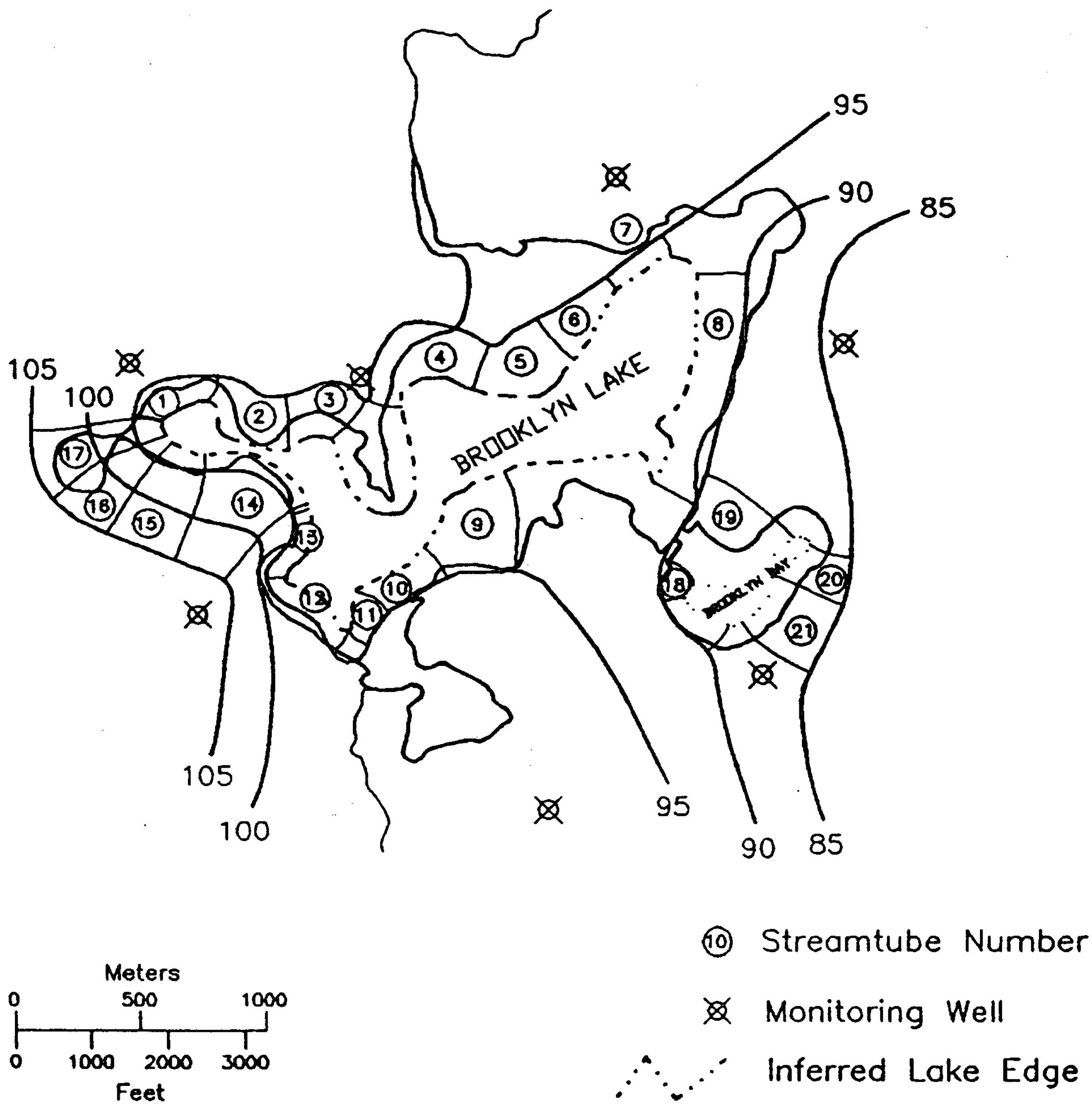


Figure 6.2 Flow net of Brooklyn Lake showing water-table elevations and streamtube sections

was drawn connecting the separate pools into two major units, i.e., the main lake area and Brooklyn Bay.

From information obtained from SJRWMD and USGS, the stage level in Brooklyn Bay was 89.00 ft, NGVD, and 93.38 ft, NGVD, for the main section, respectively, for February 5, 1994. (The value for the main section was interpolated from the nearest two measuring dates around February 5, 1994.) The water-table contours and streamtubes for that configuration are shown in Figure 6.2.

On February 5, 1994, approximately 55,000 ft^3/day (22.6 in/yr) more water entered the lake than left through the surficial aquifer (Table 6.1). This is approximately 9.7 percent of the short-term (1989-1991) average total daily water budget (sum of inflow and outflows -- see Chapter 7 for water-budget calculations). A sensitivity analysis is shown in Table 6.2 that illustrates the range of values in flux calculations, given an estimated error in each one of the measured variables. Note that at this low stage, a 1-ft error in water-table elevation will lead to a 76-percent error in flux volume calculation. Correspondingly, this changes the surficial aquifer's component of the total water budget from 9.7 percent to 16.5 percent. By comparison, a 5-ft error in the elevation of the confining unit would result in a 14 percent change in the flux volume.

6.3 LAKE GENEVA FLOW NET

Similarly, a flow-net evaluation was done for February 5, 1994, at Lake Geneva. The lake-stage elevation was 96.94 ft, NGVD. Water-table elevations were much higher on the west side of the lake, which is the side nearest Lake Sante Fe. Most of the lake

Table 6.1 Flow net calculations for Brooklyn Lake for February 5, 1994

Sect.	Average Length (ft)	Area (ft^2)	Calculated Width (ft)	Outer Water Table Elevation (ft)	Outer Hawthorn Elevation (ft)	Lake Elevation (ft)	Inner Hawthorn Elevation (ft)	X-Sect Area (ft^2)	Gradient	ft^3/day
1	463	379,762	821	95	90	93.38	60	15,754	0.00350	2,207
2	761	663,993	872	95	85	93.38	60	18,921	0.00213	1,611
3	725	577,645	797	95	65	93.38	60	25,247	0.00223	2,256
4	689	1,124,807	1,633	95	68	93.38	60	49,288	0.00235	4,636
5	738	859,122	1,164	95	60	93.38	60	39,791	0.00219	3,493
6	509	522,319	1,027	95	60	93.38	60	35,117	0.00319	4,475
7	246	223,104	907	95	65	93.38	65	26,466	0.00658	6,970
8	640	1,895,880	2,963	90	70	93.38	65	71,685	-0.00528	-15,149
9	1,001	1,218,098	1,217	95	60	93.38	60	41,619	0.00162	2,695
10	443	455,561	1,029	95	60	93.38	60	35,166	0.00366	5,145
11	410	233,771	570	95	60	93.38	60	19,489	0.00395	3,079
12	295	347,803	1,178	95	60	93.38	60	40,272	0.00549	8,838
13	230	248,356	1,081	95	60	93.38	60	36,973	0.00705	10,432
14	1,690	1,659,246	982	105	70	93.38	60	33,575	0.00688	9,236
15	1,460	1,155,075	791	105	80	93.38	80	15,182	0.00796	4,833
16	1,673	830,802	497	95	85	93.38	80	5,804	0.00097	225
17	1,772	970,732	548	95	90	93.38	80	5,035	0.00091	184
								Lake Total:		55,167

Table 6.1 Continued

Sect.	Average Length (ft)	Area (ft^2)	Calculated Width (ft)	Outer Water Table Elevation (ft)	Outer Hawthorn Elevation (ft)	Lake Elevation (ft)	Inner Hawthorn Elevation (ft)	X-Sect Area (ft^2)	Gradient	ft^3/day
18	394	172,395	438	90	80	89.00	80	4,160	0.00254	423
19	1,230	1,567,645	1,274	90	78	89.00	85	10,193	0.00081	331
20	735	460,695	627	85	85	89.00	80	2,821	-0.00544	-614
21	981	937,192	955	85	85	89.00	80	4,299	-0.00408	-701
22	361	293,909	814	90	83	89.00	80	6,515	0.00277	722
								Bay Total:		161
								Both Lake and Bay:		55,328
								Net Flow to Lake from Surficial Aquifer:		55,328

NOTE: Hydraulic conductivity = 40 ft/day.

NOTE: Columns 2 & 3 are measured in AutoCAD®
The third column is determined from (column 3)/(column 4)
(all values in the table are rounded up)
Column 9 (X-Sectional Area) is determined by ((Column 5- Column 6)+(Column 7 - Column 8))/2 * Column 4
Column10 (Gradient) is determined by (Column 5 - Column 7) / Column 2
Column 11 is determined by 40 ft/day * Column 10 * Column 9

53

Table 6.2 Sensitivity calculations for Brooklyn Lake

Error Type	Net Flow (ft^3/d)	Percent Change in Flow	Percent Change in Water Budget*
Base-line calculation	55,300	0	0
+ 1-foot error in well elevation	97,500	+ 76.3	+ 5.3
- 1-foot error in well elevation.	13,100	- 76.3	- 5.3
+ 5-foot error in water-table thickness	63,200	+ 14.3	+ 0.98
- 5-foot error in water-table thickness	47,400	- 14.3	- 0.98
Combined +1-foot well elevation and + 5-foot water-table thickness errors	113,400	+ 105.3	+ 6.8

* Percent change in water budget calculated for the short-term simulations from 1989-1991. Long-term water budgets showed much less sensitivity. (See Chapter 7 for more information on water budget percentages.)

receives water from the surrounding aquifer, with two exceptions. One is at the north-west section of the lake where a localized, low water-table elevation exists. This was unexpected, because it is in an area of higher land elevations, and it is also surrounded by higher water-table contours. However, this low region is based on only one well and may not be a true representation of the entire northeast section.

The other area where Lake Geneva loses water to the surficial aquifer is in the southeast region. This is anticipated because the regional ground-water table slopes to east (see Figure 6.1). A similar situation exists at Brooklyn Lake, where the water-table elevation declines in an eastward direction.

Lake Geneva has also divided into multiple pools, although the areas separating them are not nearly as great as they are in Brooklyn Lake. Because of limited data on the different pool configurations (elevation and size), and also because of the small distances separating them, the same assumptions made for Brooklyn Lake were also applied to Lake Geneva. An outline connecting the nearest water pools was drawn that represented the average water-table elevation between each pool. Streamtubes were drawn from the water-table contours to the edge of the pools or connecting line. Figure 6.3 shows the flow net for February 5, 1994.

For the configuration drawn for this date, approximately 84,000 ft^3/day (6.06 in/yr) more water entered Lake Geneva through the surficial aquifer than left the lake through the surficial aquifer (see Table 6.3). This volume corresponds to 6.17 percent of the total short-term water budget from 1989-1994. Because of the relatively high gradients between the water table and lake surface, the calculations were not as sensitive to

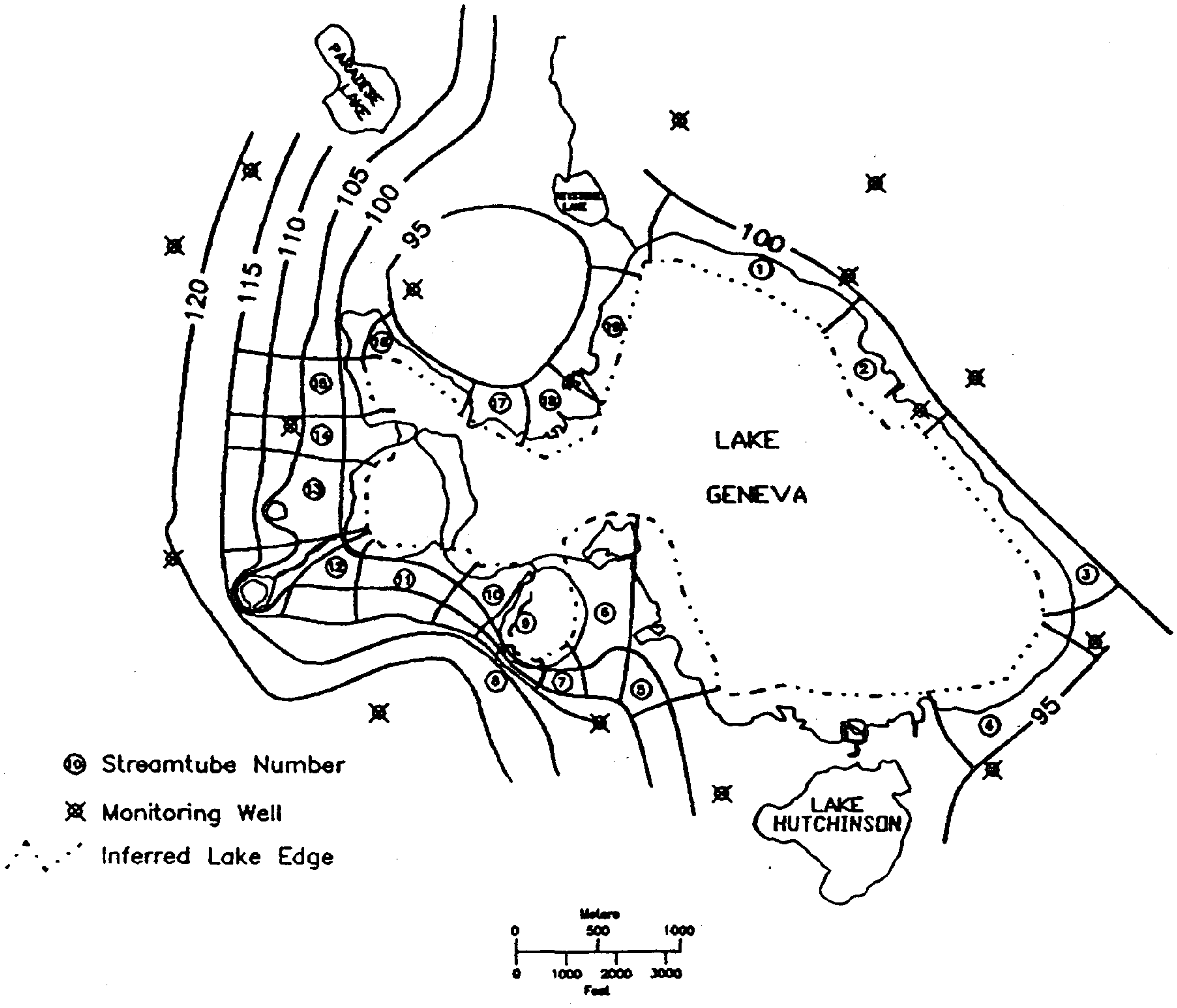


Figure 6.3 Flow net of Lake Geneva showing water-table elevations and streamtube sections

Table 6.3 Flow net calculations for Lake Geneva for February 5, 1994

Sect.	Average Length (ft)	Area (ft^2)	Calculated Width (ft)	Outer Water-Table Elevation (ft)	Outer Hawthorn Elevation (ft)	Lake Elevation (ft)	Inner Hawthorn Elevation (ft)	X-Sect Area (ft^2)	Gradient	ft^3/day
1	984	4,241,271	4,309	100	75	96.94	75	101,135	0.003109	12,577
2	1,362	3,300,226	2,424	100	90	96.94	86	25,378	0.002247	2,281
3	951	4,146,000	4,358	100	70	96.94	70	124,061	0.003216	15,960
4	869	3,865,503	4,446	95	50	96.94	60	182,155	-0.002231	-16,258
5	2,510	4,473,406	1,782	105	60	96.94	60	73,018	0.003211	9,379
6	3,281	4,161,188	1,268	105	75	96.94	75	32,939	0.002457	3,237
7	869	663,789	763	105	80	96.94	85	14,102	0.009271	5,229
8	410	394,670	962	110	85	96.94	85	17,775	0.031846	22,642
9	935	622,725	666	110	85	96.94	85	12,301	0.013967	6,872
10	1,575	1,492,201	948	110	85	96.94	85	17,501	0.008293	5,806
11	1,460	2,763,774	1,893	110	85	96.94	85	34,964	0.008945	12,511
12	2,165	1,740,546	804	110	90	96.94	90	10,827	0.006031	2,612
13	2,789	4,780,554	1,714	115	100	96.94	90	18,805	0.006476	4,871
14	3,215	2,393,162	744	115	90	96.94	80	15,608	0.005617	3,507
15	2,657	3,244,975	1,221	115	90	96.94	80	25,606	0.006796	6,961
16	558	1,325,942	2,377	95	70	96.94	80	49,853	-0.003478	-6,936
17	902	1,091,999	1,210	95	70	96.94	60	37,484	-0.002150	-3,224
18	1,444	1,883,523	1,305	95	80	96.94	80	20,837	-0.001344	-1,120
19	1,017	2,602,035	2,558	95	80	96.94	80	40,857	-0.001907	-3117
									Total:	83,789
									Net Flow to Lake from Surficial Aquifer:	83,789

NOTE: Hydraulic conductivity = 40 ft/day.

See page 53 for sample calculations

errors in water-table elevations as were the calculations for Brooklyn Lake. A sensitivity analysis (see Table 6.4) indicated a 1-ft error in water-table height would change the flow approximately 40 percent. This change would result in an increase in the total short-term water budget from 6.17 percent to 7.94 percent. A sensitivity to confining elevation showed that for a 5-ft error, the surficial aquifer component of the water budget changed only 0.98 percent.

From an examination of the water-table gradients between Lake Sante Fe and Lake Geneva, it appears that there is not a ground-water divide present. Although there is a surface-water divide, it evidently does not manifest itself (with current levels of surface recharge) into a true ground-water divide. This indicates that at present levels of precipitation, water from Lake Sante Fe is moving through the surficial aquifer to Lake Geneva.

Table 6.4 Sensitivity analysis for Lake Geneva

Error Type	Net Flow (ft^3/d)	Percent Change in Flow	Percent Change in Water Budget*
Base-line Calculation	83,700	0	0
+ 1-foot error in well elevation	116,600	+ 39.1	+ 1.8
- 1-foot error in well elevation	51,000	- 39.1	- 1.8
+ 5-foot error in water table thickness	106,700	+ 27.3	+ 1.3
- 5-foot error in water table thickness	60,900	- 27.3	- 1.3
Combined +1-foot well elevation and +5-foot water table thickness errors	146,000	+ 74.5	+ 3.7

* Percent change in water budget calculated for the short-term simulations from 1989-1994. Long-term water budgets showed much less sensitivity. (See Chapter 7 for more information on water budget percentages.)

7.0 LAKE WATER-BUDGET ANALYSIS

7.1 INTRODUCTION

Developing an accurate water budget for a lake requires an extensive data base on all the hydrologic factors that affect the lake. Many of these variables can be difficult to determine, such as vertical leakages and ground-water flux. Although some researchers such as Lee (1977) have used seepage measuring devices to measure these components, they often are computed as residual terms in the water-budget equation:

$$\Delta S = (P + Is + R + Ig) - (E + Os + Og + L) \tag{7.1}$$

where

ΔS	=	change in storage
P	=	precipitation
Is	=	surface-water inflow
R	=	overland flow (runoff)
Ig	=	ground-water flow from surficial aquifer
E	=	evaporation
Os	=	surface-water outflow
Og	=	ground-water outflow to surficial-aquifer
L	=	vertical leakage to lower aquifer

All terms have units of length per time.

Problems occur when there are more unknown variables than equations to solve them. Such is the case when doing a water budget on a lake with multiple components in the residuals.

In previous investigations by Motz et al. (1991 and 1993) of Lakes Sand Hill, Magnolia, Brooklyn and Geneva, the net surficial aquifer inflow was assumed small compared to the other components and subsequently dropped from the budget. This was necessary in order to reduce the residual terms in Equation 7.1 to one variable, i.e., leakage. The problem is that all the errors that are inherent in this analysis are lumped together with this residual leakage term.

The purpose of this investigation was to define better the water budgets of the lakes by estimating the net surficial aquifer inflow component for each lake. This was accomplished by using the flow-net analysis discussed in Chapter 6 and incorporating the surficial aquifer flux into Equation 7.1.

Water-budget calculations originally presented by Motz et al. (1993) were used in this investigation. These budgets were extended in time to include more recent data and modified to accept the newly estimated surficial aquifer net inflow component.

7.2 ORIGINAL WATER-BUDGET SIMULATIONS

The original water budgets used and developed by Motz et al. (1993) consisted of two main sections. The first section was a short-term, daily water budget for 1989-1991 that used data collected for rainfall, lake stage, surface runoff, surface-water inflows, and evaporation to find lake bottom leakage. The vertical leakage was calculated as the residual term assuming a zero net surficial-aquifer inflow component. When the leakage was known, it was then related to a leakance coefficient by another form of Darcy's equation (Motz and Fowler 1993):

$$L = AK'/b' * \Delta h \tag{7.2}$$

where	L	=	leakage per unit area determined from the residual term in the water budget;
	K'	=	vertical hydraulic conductivity of the confining unit;
	K'/b'	=	leakance; and
	Δh	=	difference in head between the lake stage and the upper Floridan aquifer.

Once leakance was computed, the second section of Motz et al. (1993) water budgets simulated the long-term (1965-1991) lake stages by using the calculated leakance and selecting the lake stage as the residual term. These simulated stages were compared to the observed stages over that same time period. The results were favorable for Lakes Sand Hill, Magnolia, and Brooklyn but did not compare well to the observed stage for Lake Geneva. However, since the leakance was computed as the residual term, any errors or unknown water fluxes would be included in this calculated leakance value. Even though most of the long-term water-budget simulations closely matched the observed values, questions still remained as to the accuracy of the leakance term. For example, if the net inflow from the surficial aquifer to the lake was a large percentage of the water budget, then the leakance term calculated from the short-term simulations would be lower than the actual leakance value.

7.3 MODIFICATIONS OF THE WATER BUDGETS

In an attempt to refine the leakance values calculated by Motz et al. (1993), a surficial aquifer inflow component was added to the previous water-budget calculations. Prior to the start of this investigation, only sparse data were available for the water-table elevations around the lakes. Therefore, estimates of the surficial aquifer flux as a function of lake stage had to be developed. For a first approximation, the surficial aquifer flux was assumed constant during the short-term and long-term simulations. In the next set of simulations, a linear function was used to relate surficial aquifer flux to lake stage.

To obtain a first estimate of the magnitude of water exchange between the surficial aquifer and the lake, a simulation was run using a constant value of surficial aquifer flux throughout the simulation. The constant value was chosen from the February 5, 1994, flow net analysis for each lake. This constant flux was input into the Motz et al. (1993) short-term simulation and a leakance value calculated for each lake. The new leakance value was then used for the long-term simulations and compared to the observed lake stage and the lake stage calculated by Motz et al. (1993).

7.4 BROOKLYN LAKE NEW WATER-BUDGET SIMULATIONS

The 55,000 cubic feet per day (ft^3/day) (22.6 in/yr) net surficial aquifer flux calculated for February 5, 1994, was added to the input term in the short-term water-budget calculations. This accounted for 9.68 percent of the total water-budget volume and changed the calculated leakance from 1.11×10^{-3}/day to 1.24×10^{-3}/day. The new leakance was then input into the long-term simulation (Figure 7.1) with constant surficial aquifer flux. In contrast to the short-term water budget, the net surficial aquifer inflow was 3.23 percent (see Figure 7.2) of the total long-term water-budget volume. The difference between the percentage of the surficial aquifer flow for the short-term budgets versus the percentage for the long-term budgets results from an increase in the surface-water inflow during the long-term simulations. The surface-water inflow was large compared to other components in the water budget and thus tended to minimize the percentages of the other constituents.

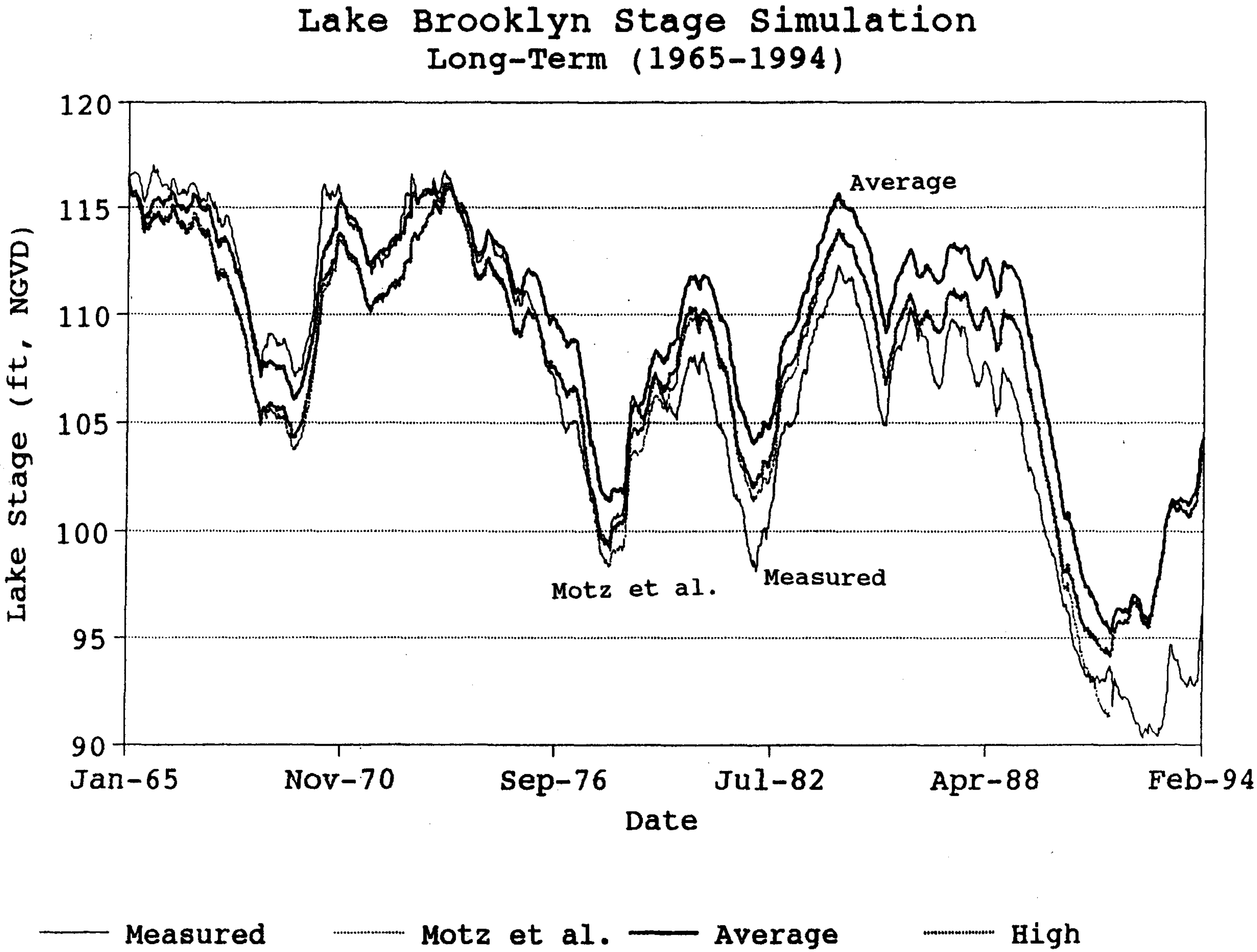


Figure 7.1 Brooklyn Lake long-term stage simulation with constant surficial flux

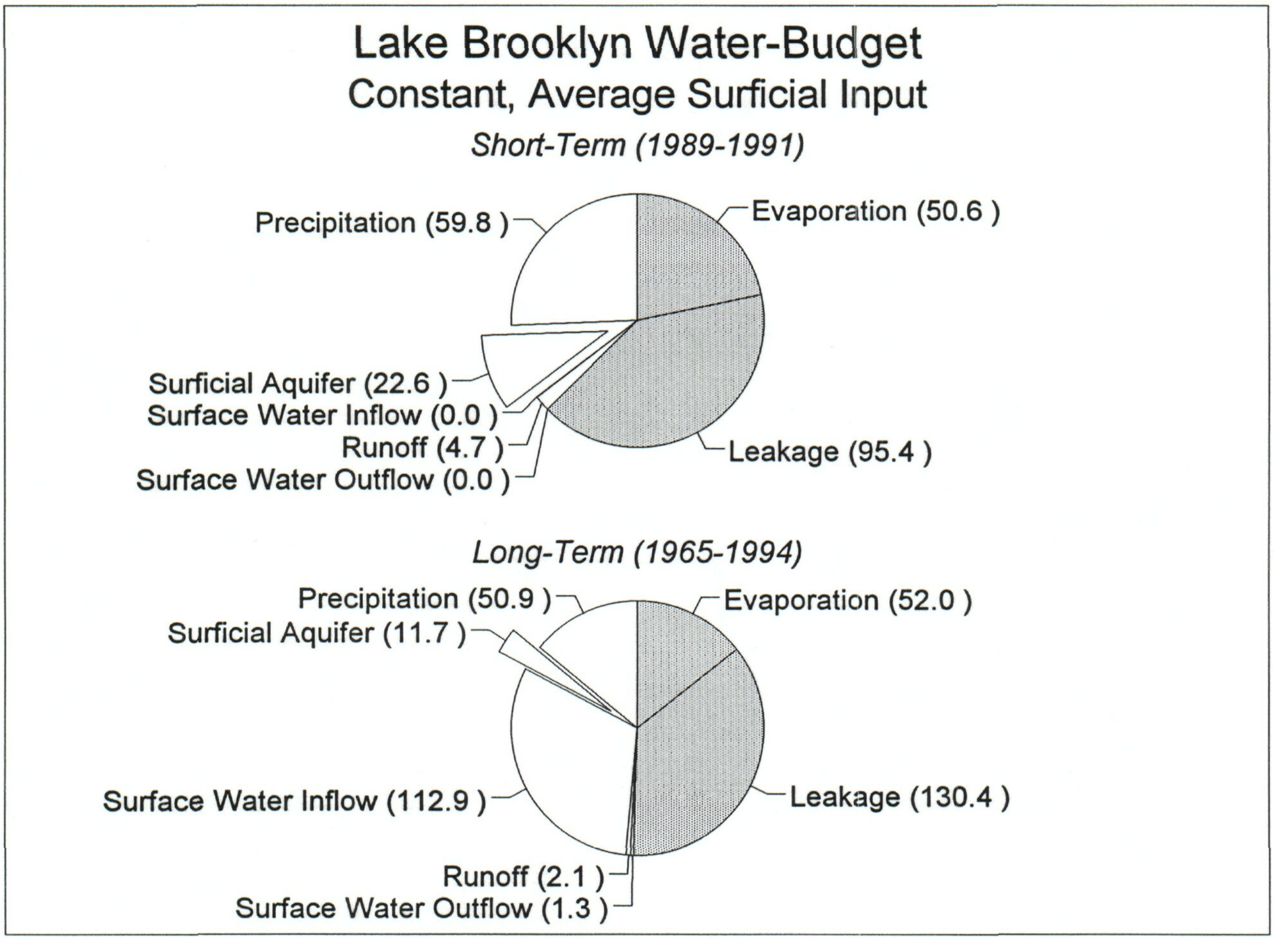


Figure 7.2 Water-budget component percentages for Brooklyn Lake
with constant average surficial input

This procedure was repeated using a higher value of net surficial aquifer flux of 121,000 ft^3/d (46.2 in/yr) based on the sensitivity analysis in Chapter 6. This increased the leakance to 1.46×10^{-3}/day and increased the component of the surficial aquifer's flow of the total short-term water budget to 16.5 percent (see Figure 7.3). The long-term simulation (Figure 7.3) had a surficial aquifer flow component of 6.26 percent. Brooklyn Lake long-term stage simulations are presented in Figure 7.4.

The simulations described above were also rerun using a function to relate surficial aquifer flow to lake stage. The approach used assumes that the water table rises uniformly with the lake stage. Based on the flow net developed in Chapter 6, it was assumed that the most significant variable that changes during lake stage variations is the thickness of the aquifer. It is recognized that this assumption is simplistic, and that there may very well be significant temporal gradient changes that overwhelm the thickness variable. However, due to the lack of long-term surficial data, this is believed to be a reasonable approximation.

Using the flow net of February 5, 1994 changing saturated thickness by the same amount that lake stage changes, but holding the gradients surrounding the lake constant, the net surficial flux can be linearly related to the lake stage by

$$\textit{Net Surficial Flux} = \textit{Lake Stage} * 1587.75 - 92937.16 \tag{7.3}$$

where the net surficial flux is in units of ft^3/d and the lake stage in ft, NGVD. Using this equation, a net surficial aquifer flux based on lake stage was input into the water-budget equations. The short-term budget produced a leakance of 1.25×10^{-3}/day, and the total surficial component was 10.31 percent. Similarly, the total surficial aquifer component of the long-term simulation was 4.37 percent (see Figure 7.5).

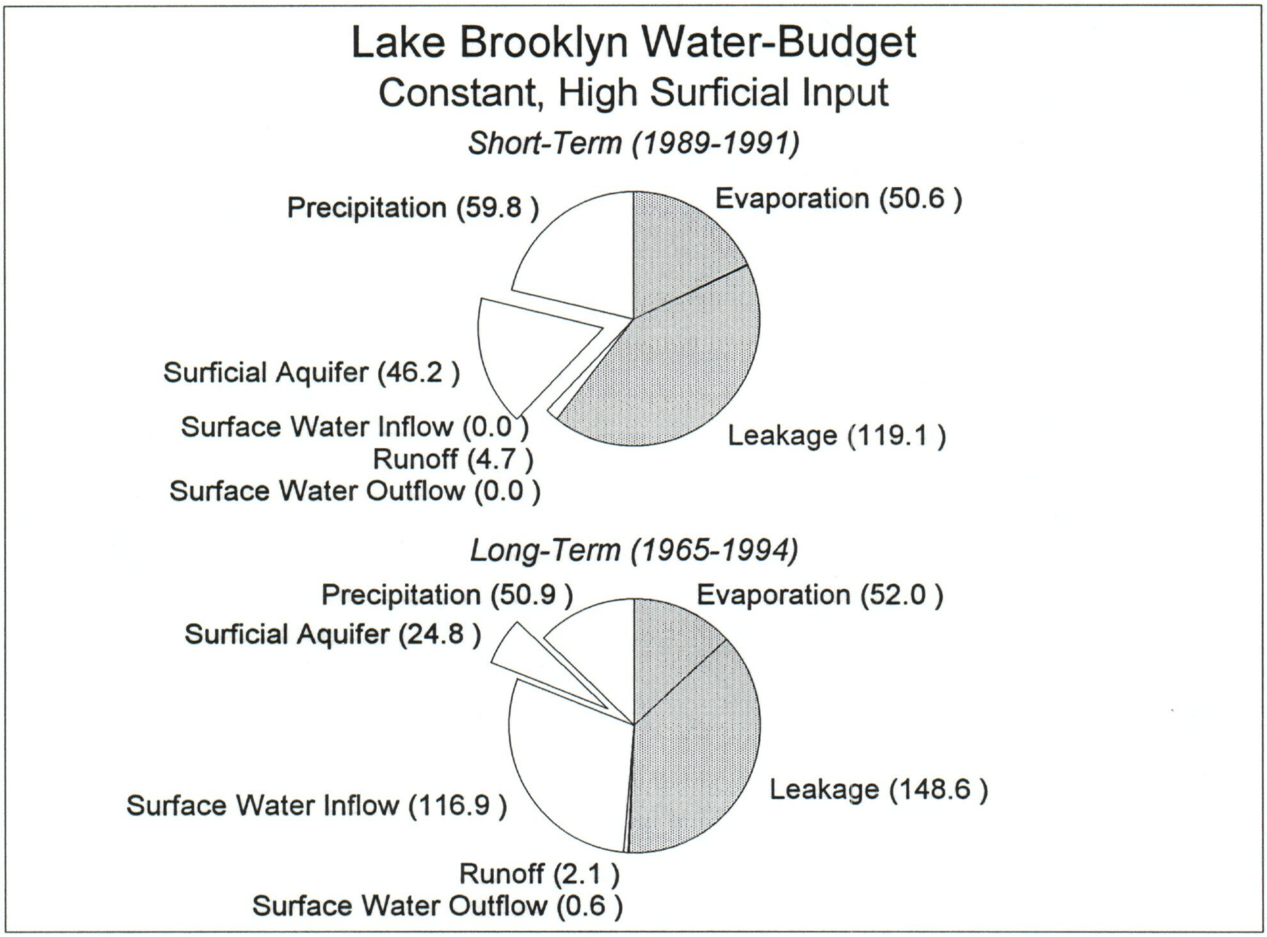


Figure 7.3 Water-budget component percentages for Brooklyn Lake with constant, high surficial input

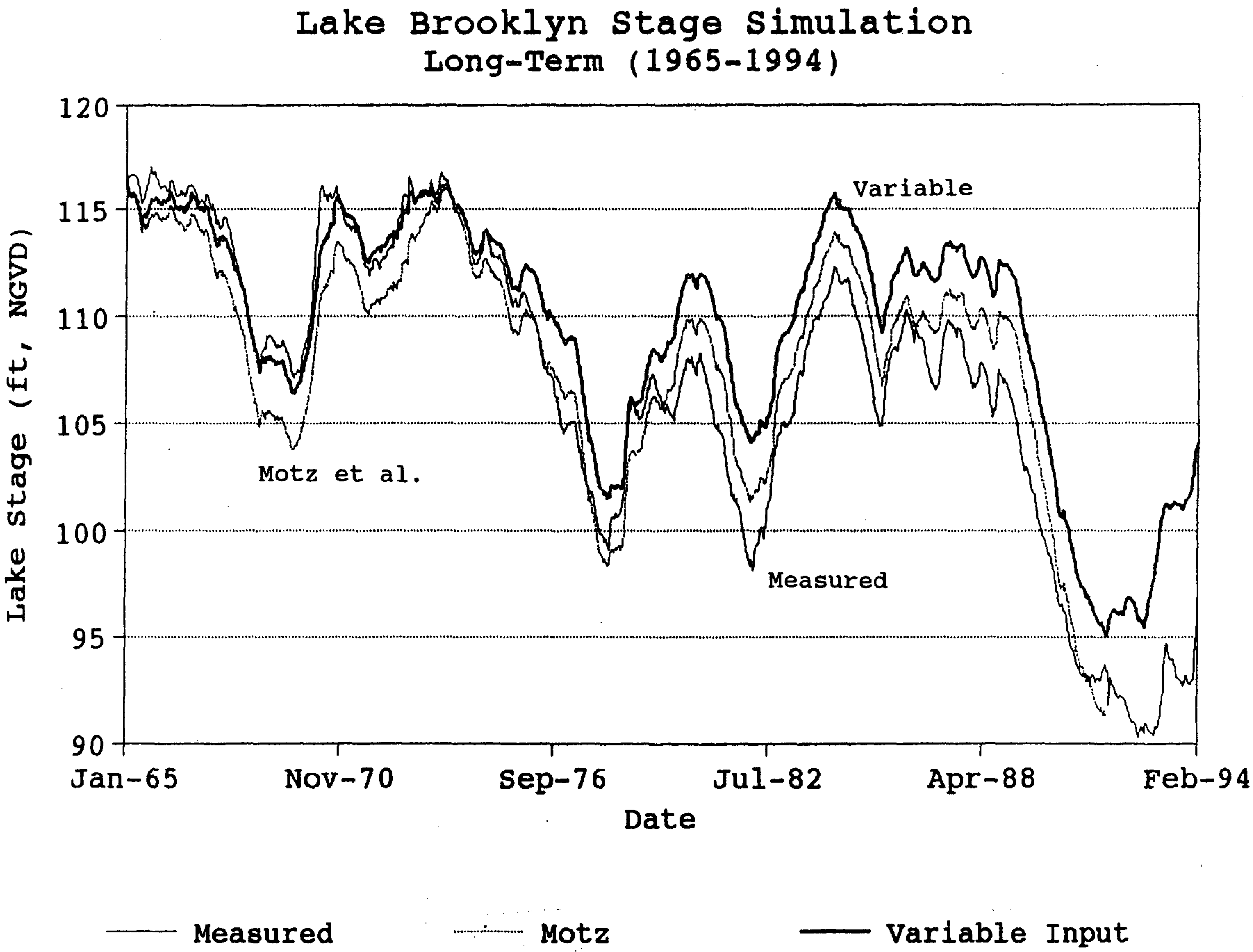


Figure 7.4 Brooklyn Lake long-term stage simulation with variable surficial flux

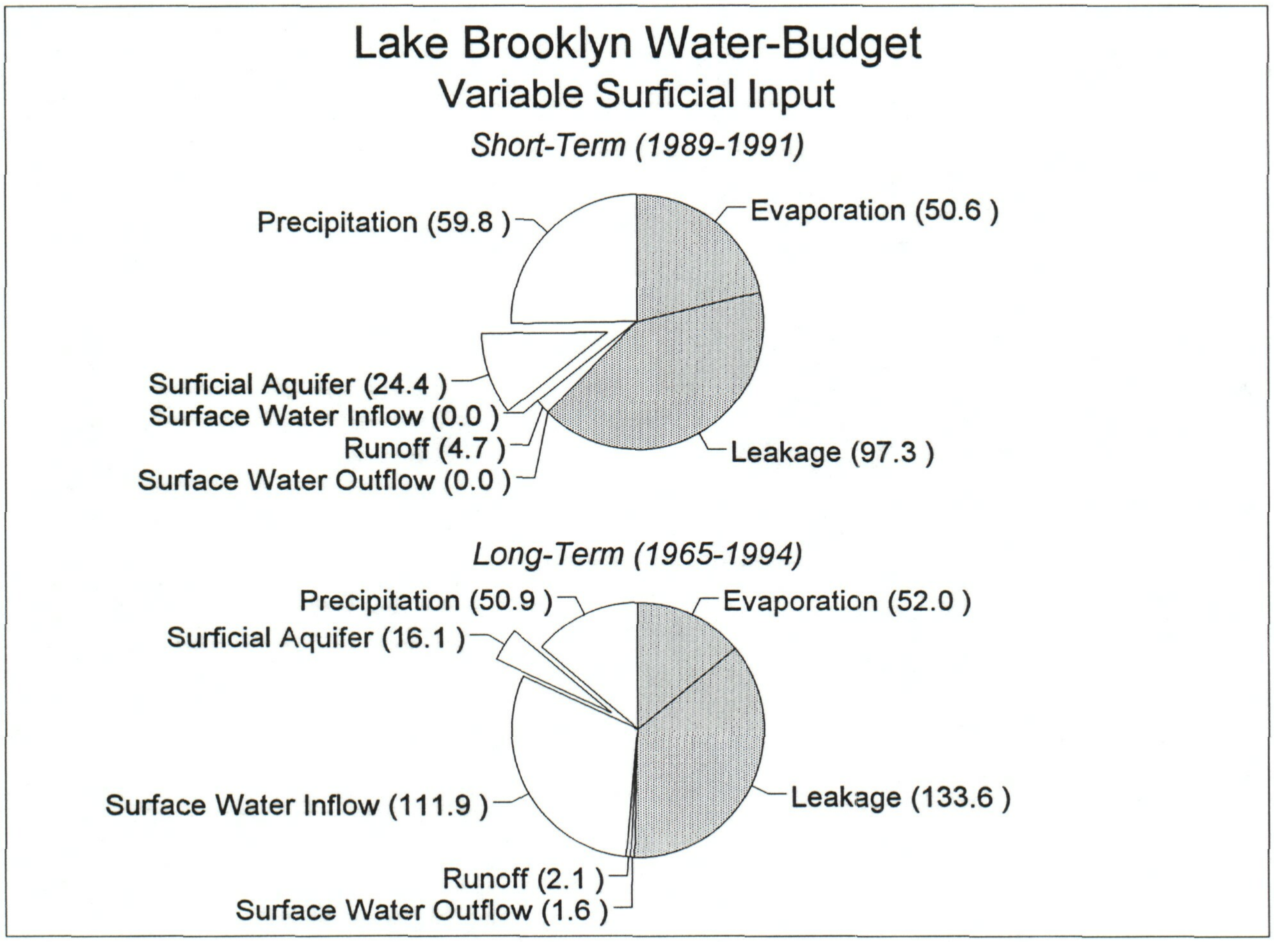


Figure 7.5 Water-budget component percentages for Brooklyn Lake with variable surficial input

The fraction of water that the surficial aquifer contributes (compared to the other water-budget components) to Brooklyn Lake during any of the long-term simulations is low (Figure 7.6). If it is assumed that the best method of simulating the surficial component is by the functional analysis between lake stage and input, then the surficial aquifer contributes less than 12 percent of the total water inflow plus outflow. However, when this number is converted to inches per year (found by dividing by the area corresponding to the average lake stage), it is noted that this value is equivalent to about 31 percent of the average yearly rainfall (see Figure 7.7).

7.5 LAKE GENEVA NEW WATER-BUDGET SIMULATIONS

Water-budget modification and calculations for Lake Geneva were performed identically to those for Brooklyn Lake. A constant surficial aquifer net flux of 84,000 ft^3/day (6.06 in/yr) calculated for February 5, 1994, changed the calculated leakance of the short-term budget from 5.55×10^{-4}/day to 5.97×10^{-4}/day. Figures 7.8 and 7.9 show the stage simulations for the various trials. The long-term constant simulation resulted in a change of surficial aquifer flow from 4.80 to 6.17 percent. The surficial aquifer component was 6.17 percent of the short-term water budget (see Figure 7.10).

Assuming a high constant net surficial aquifer flux of 146,000 ft^3/day (10.56 in/yr) (determined using the sensitivity analysis discussed in Chapter 6) increased the short-term leakance to 6.30×10^{-4}/day and resulted in an increase of the total surficial aquifer component to 9.85 percent of the water budget. The long-term simulation showed the percent-

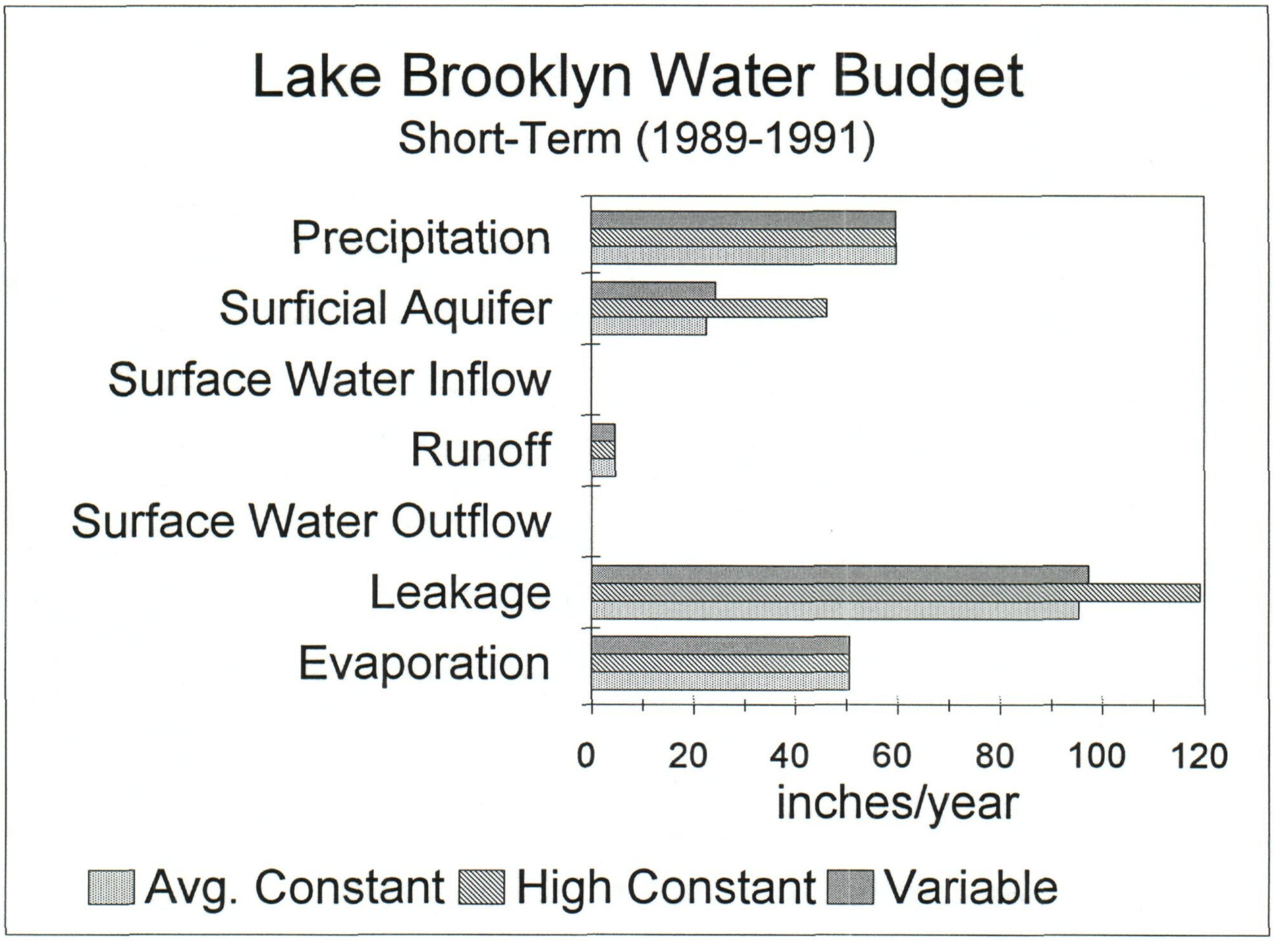


Figure 7.6 Water-budget components for Brooklyn Lake shown in in/yr for constant and variable surficial input for short-term simulation

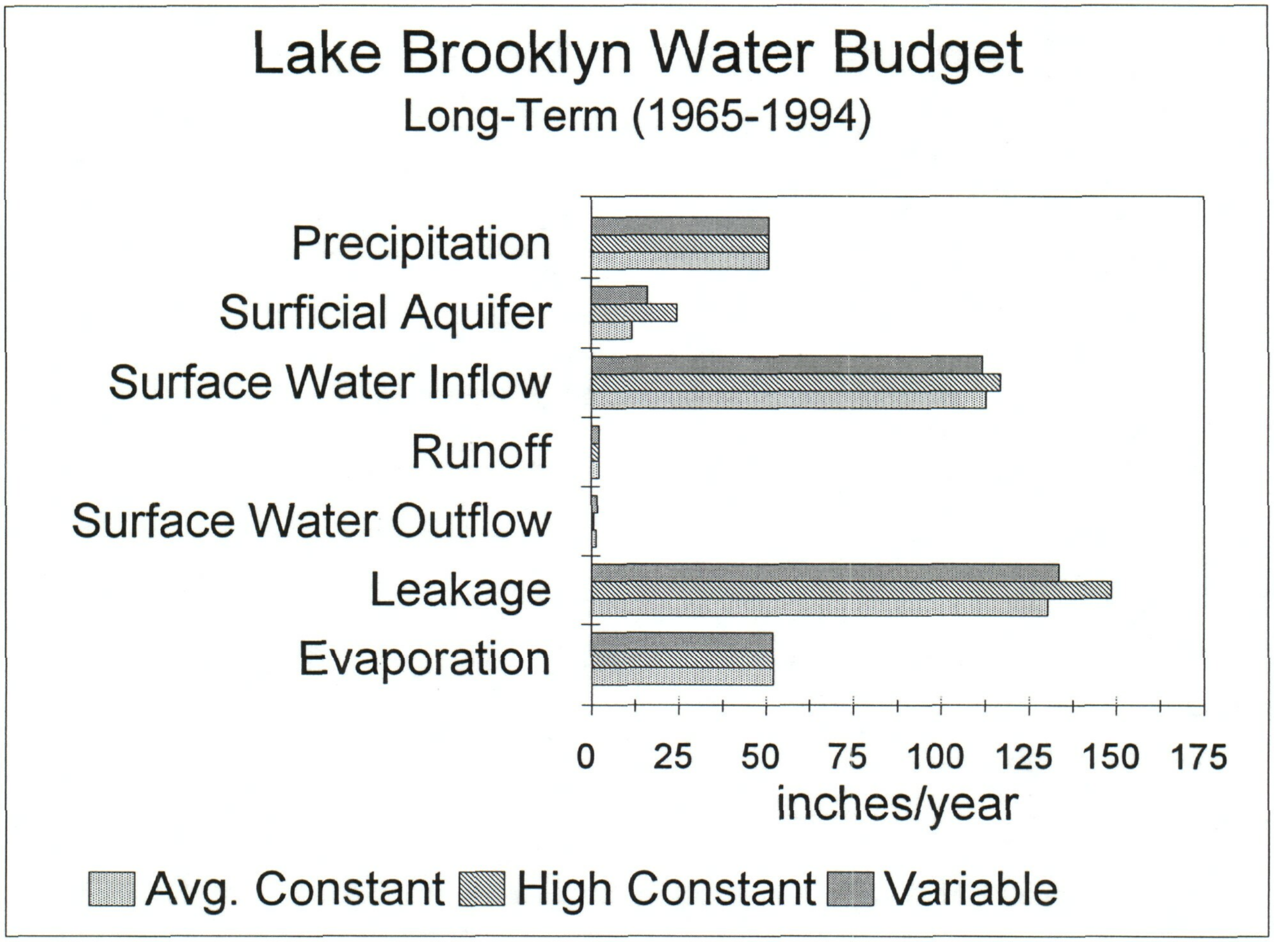


Figure 7.7 Water-budget components for Brooklyn Lake shown in in/yr for constant and variable surficial input for long-term simulation

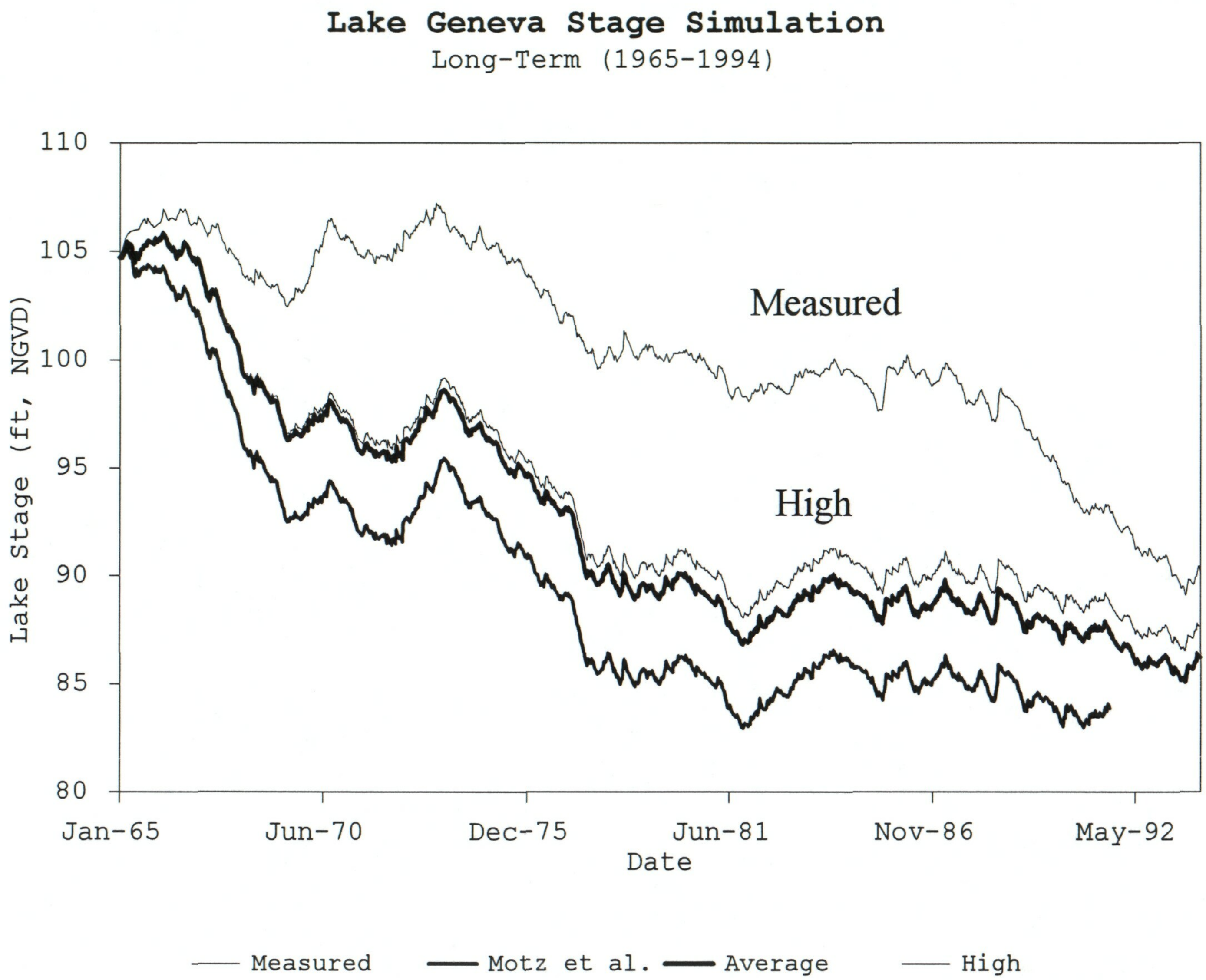


Figure 7.8 Lake Geneva long-term stage simulation using a constant net surficial aquifer flux

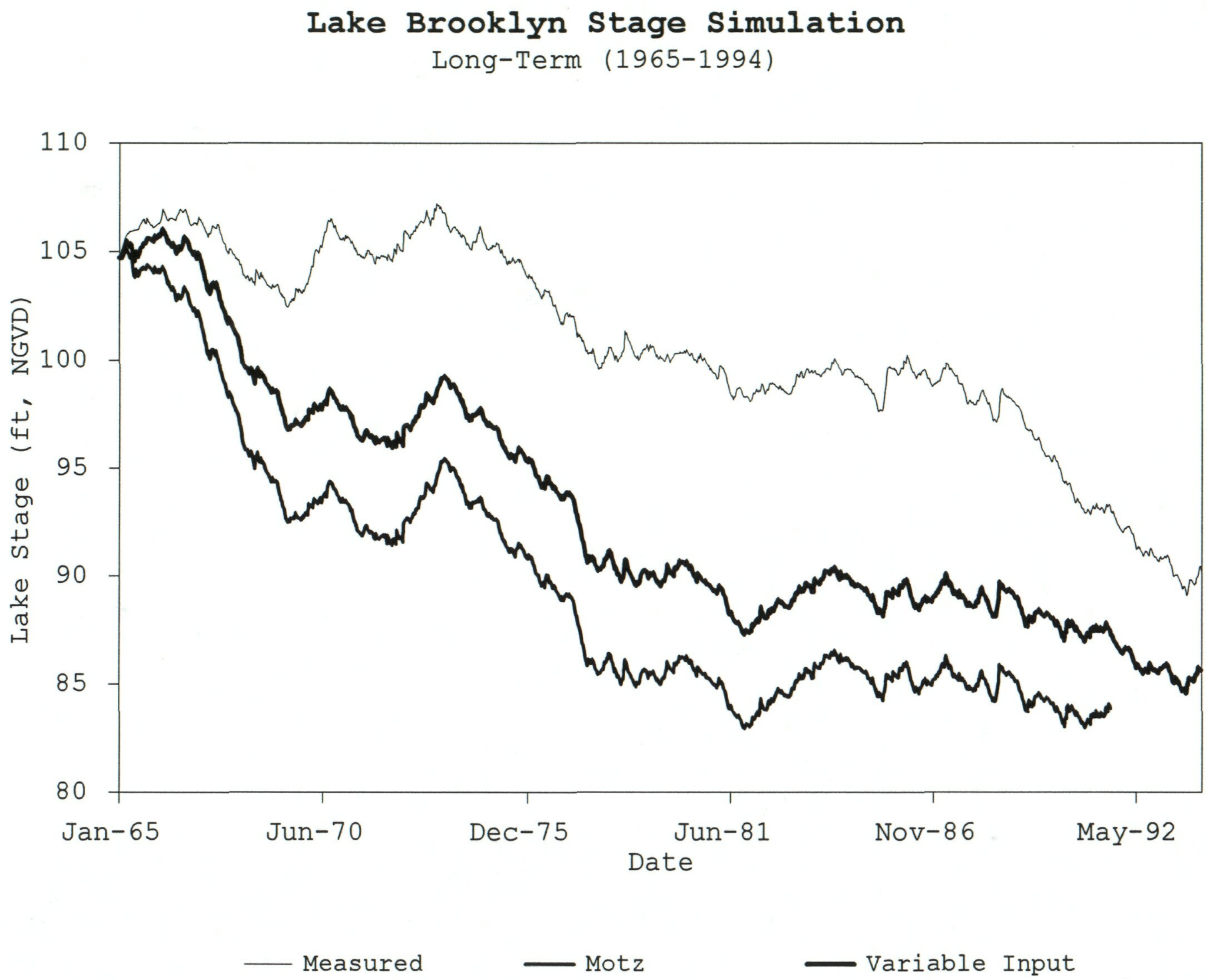


Figure 7.9 Lake Geneva long-term stage simulation using a variable net surficial aquifer flux

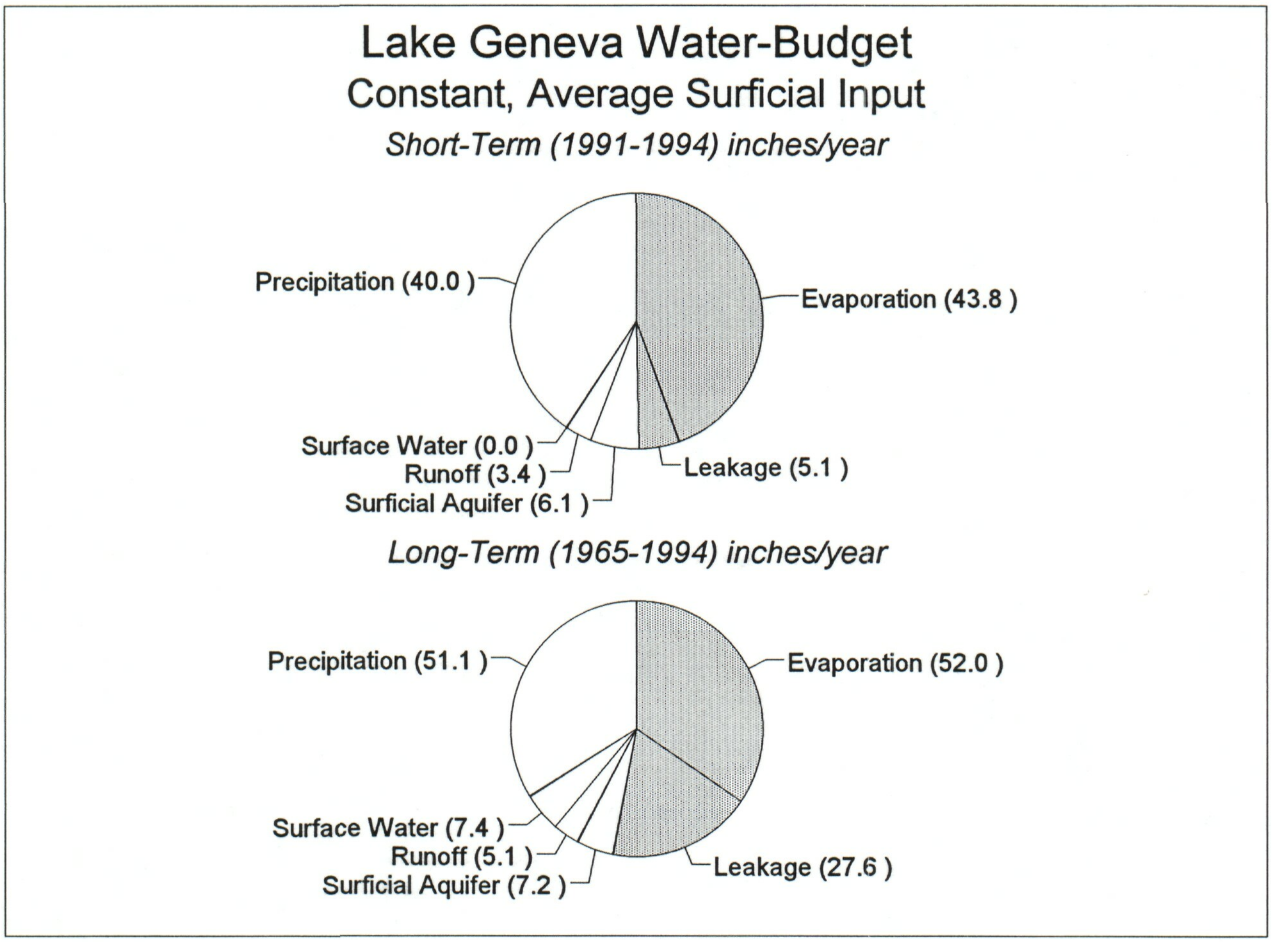


Figure 7.10 Water-budget component percentages for Lake Geneva with constant, average surficial input

age the surficial aquifer component increased to 7.57 percent of the total budget (Figure 7.11).

In a similar manner to the calculations that were performed on Brooklyn Lake, an equation was developed, based on the February 5, 1994, flow net of Lake Geneva. The equation relates the net surficial aquifer flux to the lake stage. This linear equation is based on the same assumptions that were used for Brooklyn Lake, and it only assumes changes in the surficial aquifer thickness equal to lake stage changes. The equation is

$$\textit{Net Surficial Flux} = \textit{Lake Stage} * 4580.78 - 360271.90 \tag{7.4}$$

where the net surficial flux is in units of ft^3/day and lake stage is in ft, NGVD. As was done for Brooklyn Lake, this equation was used to include in the water-budget equations a net surficial aquifer flux based on lake stage. The short-term budget produced a leakance of 5.94×10^{-4}/day, and the total surficial component was 5.83 percent. Similarly, the total surficial aquifer component of the long-term simulation (Figure 7.12) is 5.57 percent.

It is interesting to note that the surficial aquifer fraction of the total Lake Geneva water budget changed only slightly from the short-term to the long-term simulations. However, the reason for this change is essentially the same as it was for the surficial-aquifer component decrease for Brooklyn Lake. Since Brooklyn Lake is upstream from Lake Geneva, it receives more surface-water inflow. Also, since Brooklyn Lake has a higher leakance term, most of the water flowing into Brooklyn Lake from Alligator Creek often fails to reach Lake Geneva during periods of below normal rainfall. Hence, the surface-

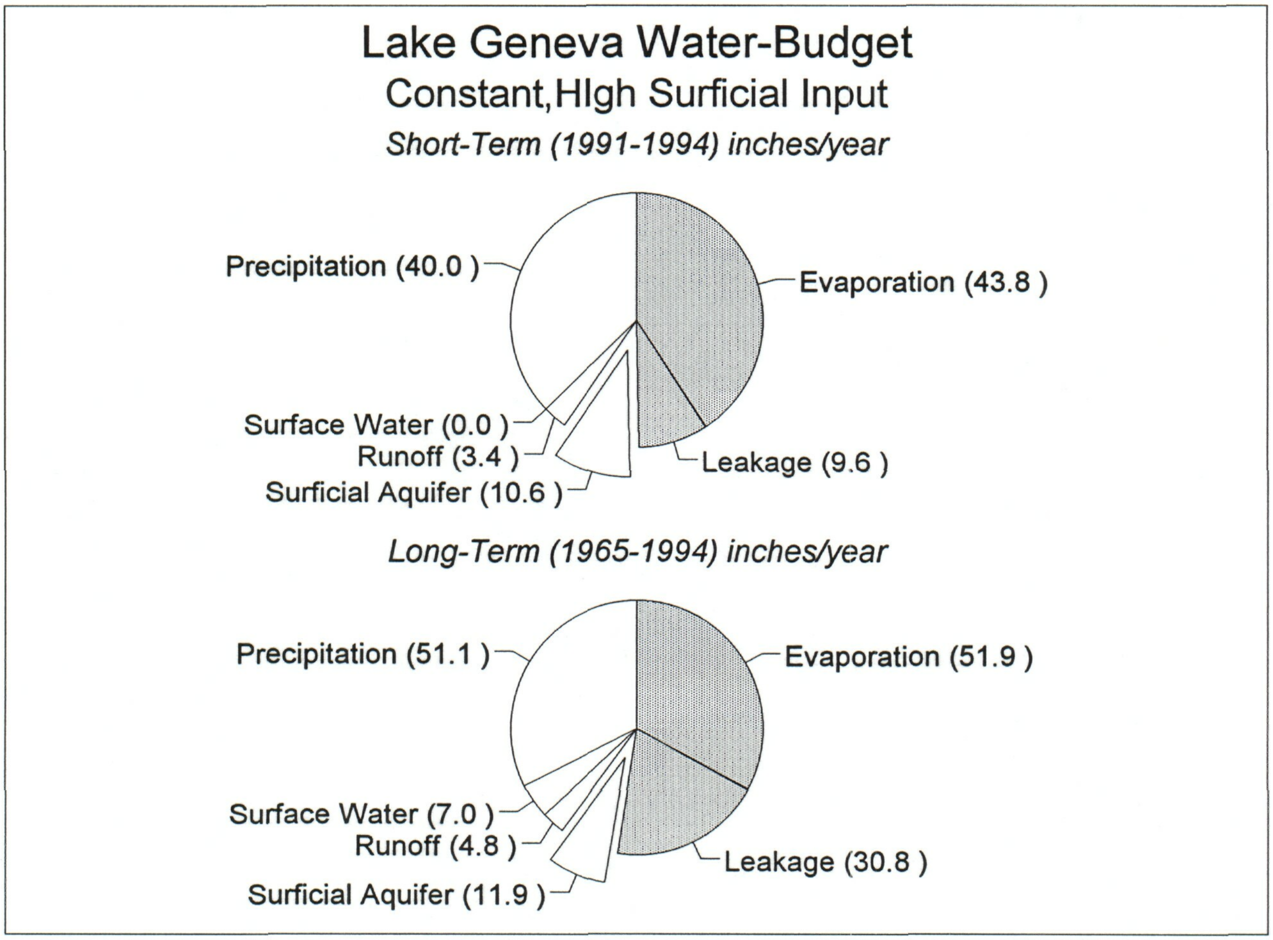


Figure 7.11 Water-budget component percentages for Lake Geneva with constant, high surficial input

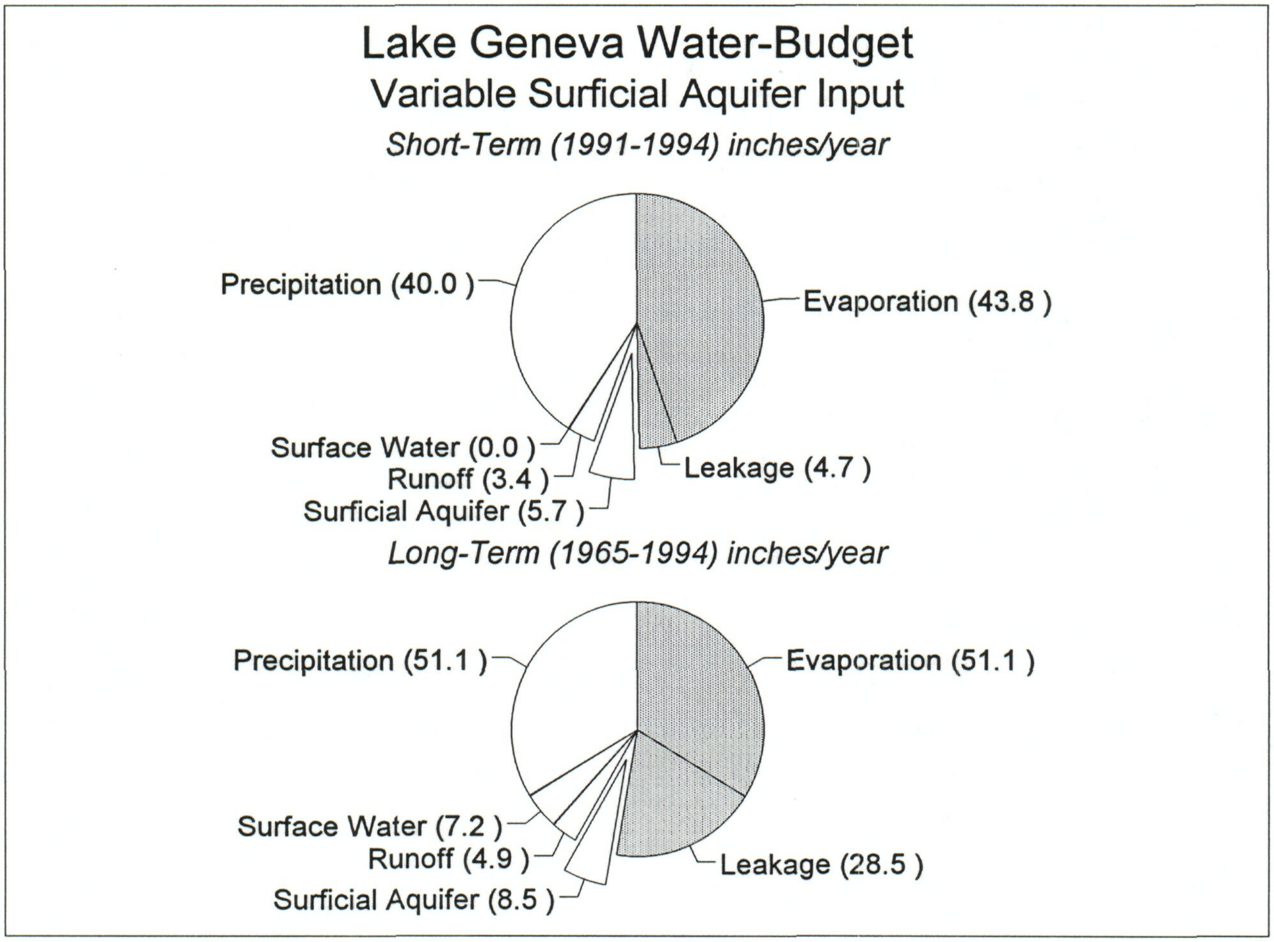


Figure 7.12 Water-budget component percentages for Lake Geneva with variable surficial input

water component of Lake Geneva does not increase dramatically and overwhelm the surficial-aquifer component during the long-term simulations as it does for Brooklyn Lake.

7.6 DISCREPANCIES IN THE LAKE GENEVA LAKE STAGE SIMULATION

The new leakance terms found in the new short-term analysis did not correct the deviation in the long-term simulation for the observed stage for Lake Geneva (see Figures 7.8 and 7.9). The difference in the calculated stage compared to the observed stage is immediately evident from the start of the simulation in 1965. It was originally speculated that a large volume of some type of inflow was missed, either during the start of the simulation or as a continuous source. Since the surficial-aquifer component is evidently not adequate to compensate for the discrepancy in the stage simulations, other alternative theories were examined.

If the stage simulations had only missed a large volume of water for a short time, i.e., between the period of 1965 to 1968, then restarting the simulations (correcting for initial conditions) at a later time would correct this. This was tried, and it did not alter the results significantly. The differences between observed stage and measured stage fol lowed a similar pattern of the original calculations. The new simulations immediately deviated to a much lower stage than what was observed.

Since the model seemed to be reaching steady-state, it was assumed that a constant flux was not accounted for in the water budget. This could be caused either by a very large inflow or a much smaller leakance term than previously calculated. Although

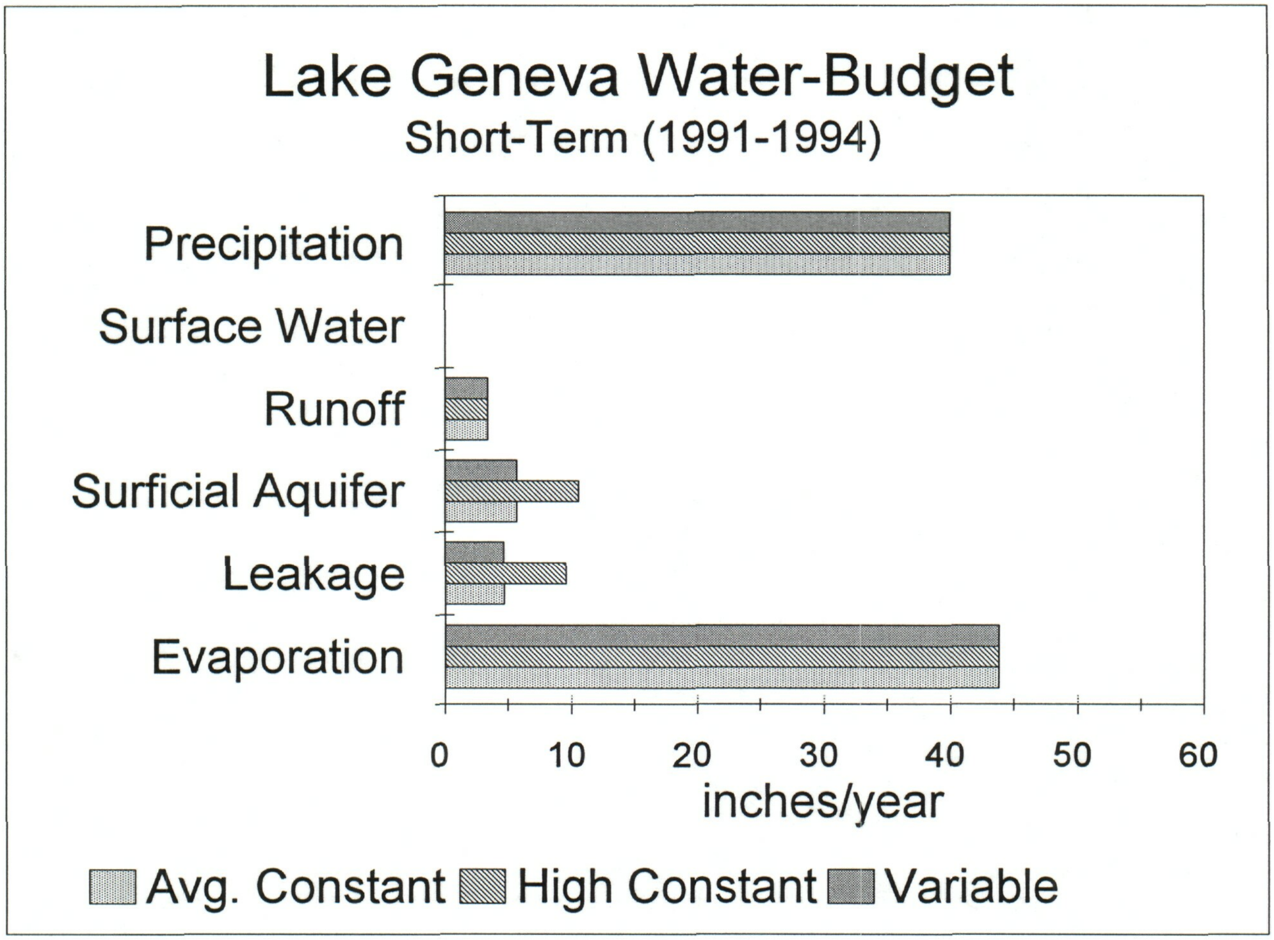


Figure 7.13 Water-budget components for Lake Geneva shown in in/yr for constant and variable surficial input for short-term simulation

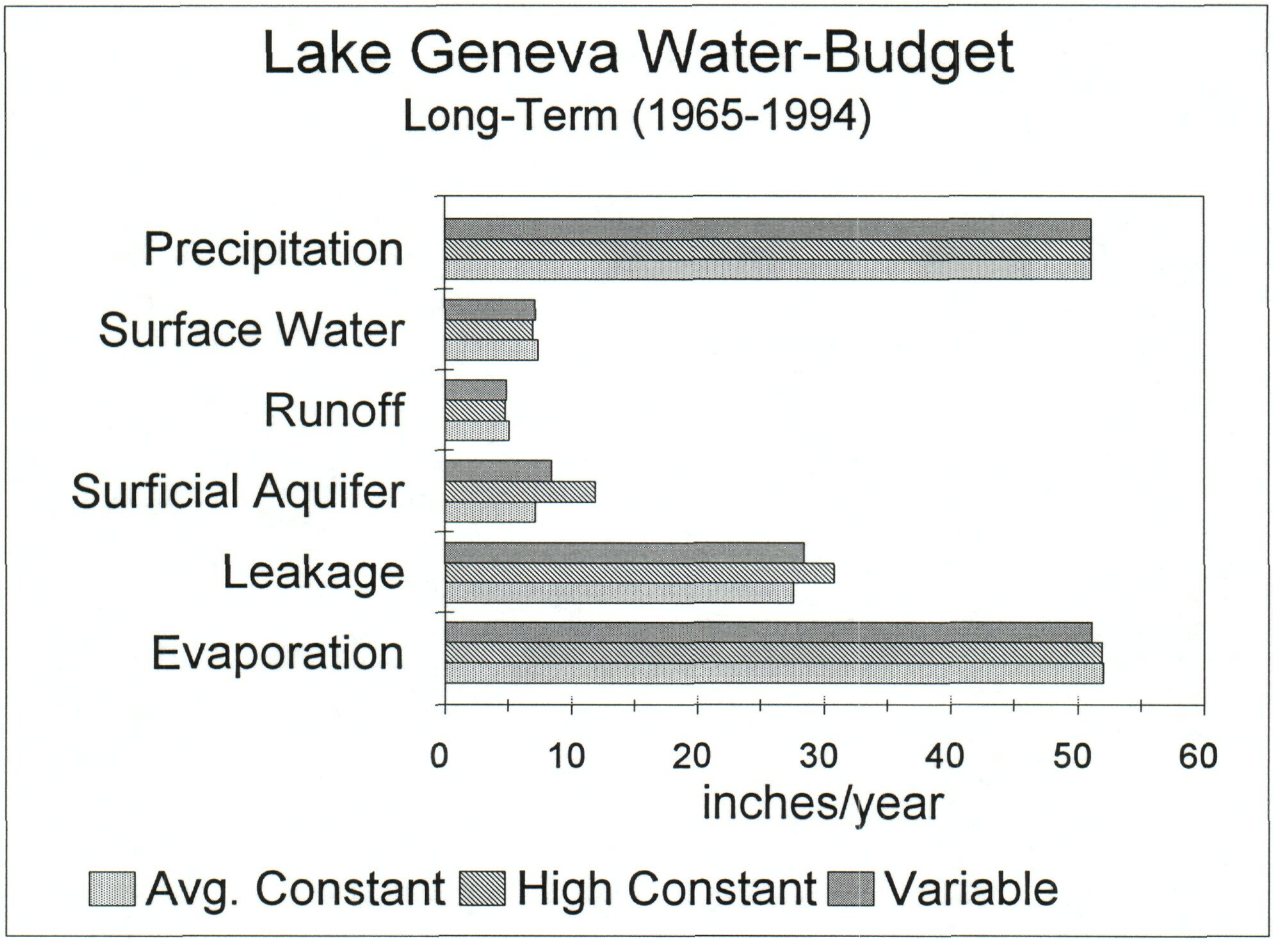


Figure 7.14 Water-budget components for Lake Geneva shown in in/yr for constant and variable surficial input for long-term simulation

the leakance is a coefficient and should not change unless the subsurface geology changes, the budgets were rerun with varied leakances to determine sensitivity. Figure 7.15 shows the long-term simulation with a leakance value of 2×10^{-4}/day and the variable surficial input. It would appear that a constant flux was missing in the simulations. The simulation with the new leakance value is a much closer match than any of the other simulations. This does not in anyway say that the correct leakance value is 2×10^{-4}/day. However, it does support the idea that there is still an unresolved constant flux.

7.7 CONCLUSIONS FROM WATER BUDGETS

Based on the three different surficial-aquifer flux simulations used on Lakes Brooklyn and Geneva, it appears that the surficial-aquifer flow component is a low percentage of the total overall water budget for each of the lakes. Assuming that the variable flux simulation best represents the overall surficial-aquifer input, then the long-term simulation showed a 4.37 and 5.57 percent surficial-aquifer flow component for Lakes Brooklyn and Geneva, respectively. Moreover, since the simplifying assumptions that were used for the calculations are believed to represent a maximum flux (i.e., all of the surficial flow goes into the lake, none into a lower aquifer) it is reasonable to assume that any additional refinement of the surficial aquifer flow components would further reduce the significance of this water source.

Although the long-term simulations indicated the surficial aquifer input was a low percentage of the overall water budget, it can nonetheless be a significant component

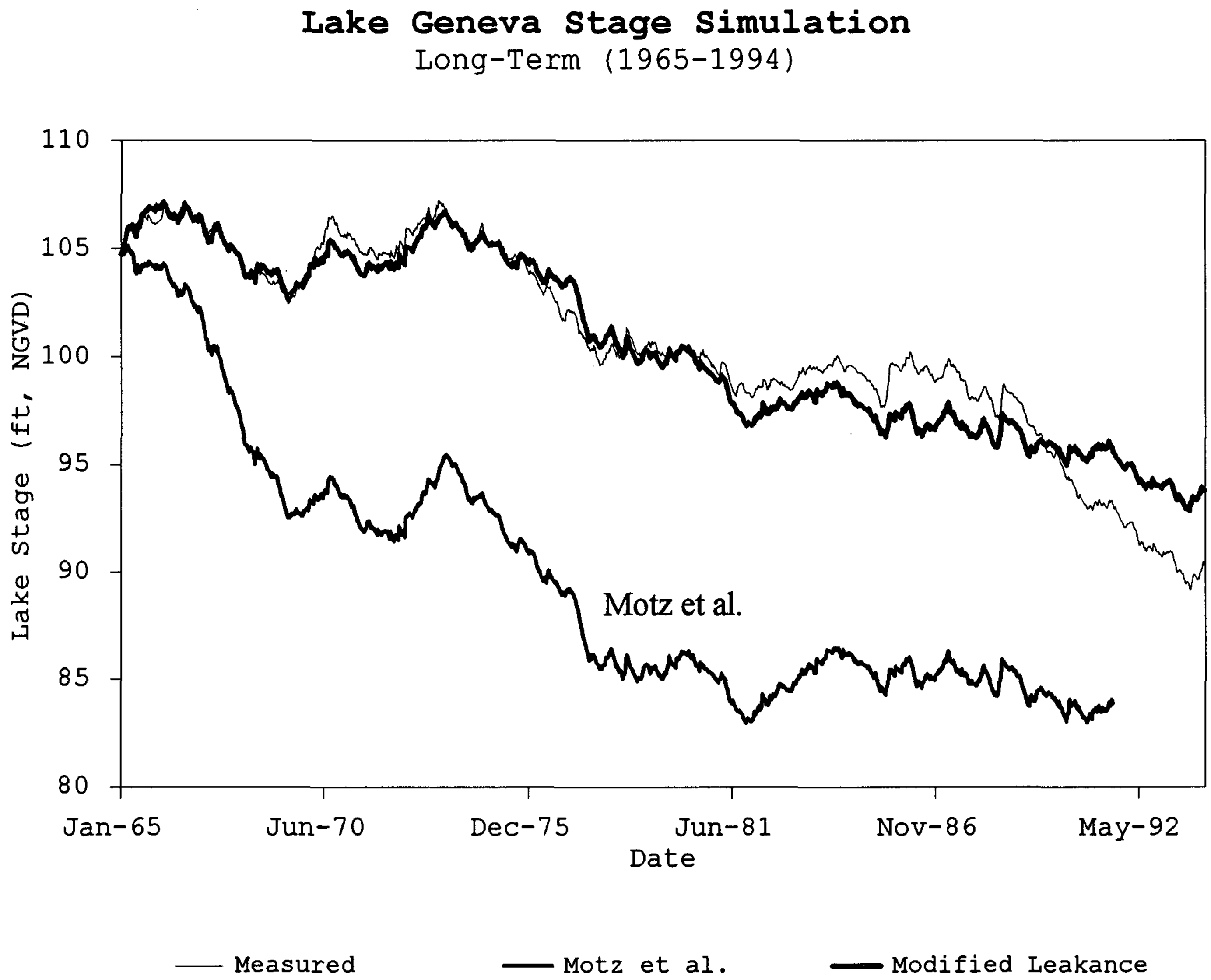


Figure 7.15 Lake Geneva long-term simulation with adjusted leakance and variable surficial aquifer input

during short time periods. This may be especially important during extremely low lake-stage events, such as are currently being experienced.

Lake leakance values calculated from the short-term simulations changed only slightly from Motz et al. (1993). The leakance value at Brooklyn Lake changed from 1.11×10^{-3}/day to 1.25×10^{-3}/day. This new leakance value (in addition to the surficial aquifer flux) did not appear to have a significant effect on the long-term lake simulations. The Lake Geneva leakance value changed from 5.55×10^{-4}/day to 5.95×10^{-4}/day but only slightly altered the long-term simulations. Based on a sensitivity analysis of leakance values for Lake Geneva, a decrease to 2.0×10^{-4}/day was required to alleviate the calculated stage discrepancies during the long-term simulation.

8.0 SUMMARY AND CONCLUSIONS

The Upper Etonia Creek Basin (UECB) is located in north-central Florida and comprises parts of Alachua, Bradford, Clay, and Putnum counties. Over the last 5 to 10 years, many of the lakes in this basin have experienced significant declines in lake stage, adversely affecting both recreational use and surrounding property values.

To help identify factors causing lake stage reductions, the St. Johns River Water Management District (SJRWMD) authorized the University of Florida (UF) in January 1990 to investigate long-term hydrologic trends. As part of this previous investigation, Motz et al. (1993) developed lake water budgets that were subsequently modified and used for this surficial aquifer investigation. Based on the Motz et al. (1993) multi-phase investigation, rainfall, lake-bottom leakage, and the regional decline of water levels in the Floridan aquifer were cited as factors contributing to low lake stages. To better define this leakage component, it was recommended that further analysis be done on the lake's water budgets. Specifically, it was recommended that the interactions between the lakes and the surficial aquifer be examined in more detail.

Given these recommendations, this project was authorized by SJRWMD in October 1993 to examine lake and surficial aquifer interactions. The goals were to determine the surficial aquifer flow components for Lakes Sand Hill, Magnolia, Brooklyn, and Geneva and to refine previous water-budget calculations by Motz et al. (1993). This report details the initial investigations at Lakes Brooklyn and Geneva.

Thirty-five new surficial monitoring wells were installed around Lakes Brooklyn, Geneva, Halfmoon, Sand Hill and Magnolia to measure water-table elevations to quantify the exchange of water between the lakes and the surficial aquifer. Based on the water-table elevations at the monitoring well locations, a potentiometric map of the surficial aquifer was prepared for February 5, 1994.

Hydraulic properties of the surficial aquifer were obtained from two pump tests, one at Halfmoon Lake near Lakes Brooklyn and Geneva, the other near Sand Hill Lake. Slug tests were performed at new wells installed by SJRWMD. Based on these tests, an average hydraulic conductivity of 40 ft/day was obtained. An experiment using ground penetrating radar (GPR) was performed at Brooklyn Lake in an attempt to obtain additional information on subsurface conditions. Due to unfavorable soil conditions, GPR was unable to provide water-table elevations, although it showed some promise in identifying subsurface anomalies.

Flow-net calculations were performed for Lakes Brooklyn and Geneva incorporating the newly obtained hydraulic properties and surficial aquifer potentiometric surface maps. An equation was developed that related surficial aquifer inflow to lake stage based on the February 5, 1994, potentiometric maps.

The volumetric fluxes that were obtained from the flow net analysis were then input into a modified version of the Motz et al. (1993) water-budget calculations done previously at UF, in which it had been assumed that the net surficial aquifer flux into the lakes was negligible.

The new calculations indicated that the long-term surficial aquifer inflow component was a low percentage of the total lake water budget. Based on the calculations for Brooklyn Lake, inflow from the surficial aquifer accounted for 4.4 percent of the total long-term (1965-1991) water budget. Lake Geneva had a higher surficial aquifer flow component of 5.57 percent.

Leakance values for both lakes changed slightly from the previous calculations done by Motz et al. (1993). The leakance for Brooklyn Lake changed from 1.11×10^{-3}/day to 1.25×10^{-3}/day. The leakance values for Lake Geneva changed from 5.55×10^{-4}/day to 5.95×10^{-4}/day. Deviations from observed lake stage verses calculated lake stage are still apparent in the new long-term (1965-1994) simulations for Lake Geneva. A sensitivity analysis performed on the leakance parameter found that a value of 2.0×10^{-4}/day forced the calculated stage simulation to match the observed lake stage. Based on these findings, it appears that a constant source flux and/or a change in leakance is still unaccounted for in the Lake Geneva water budgets.

Simplifications used in the flow net evaluations for both lakes tended to maximize the surficial aquifer net inflow component. This was done to get a first approximation of this flux and to examine whether a more detailed investigation is warranted. It is believed that a more in-depth approach would further minimize the surficial aquifer flow component of the lake's water budgets.

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Appendix A

Well Site Maps for Clay County

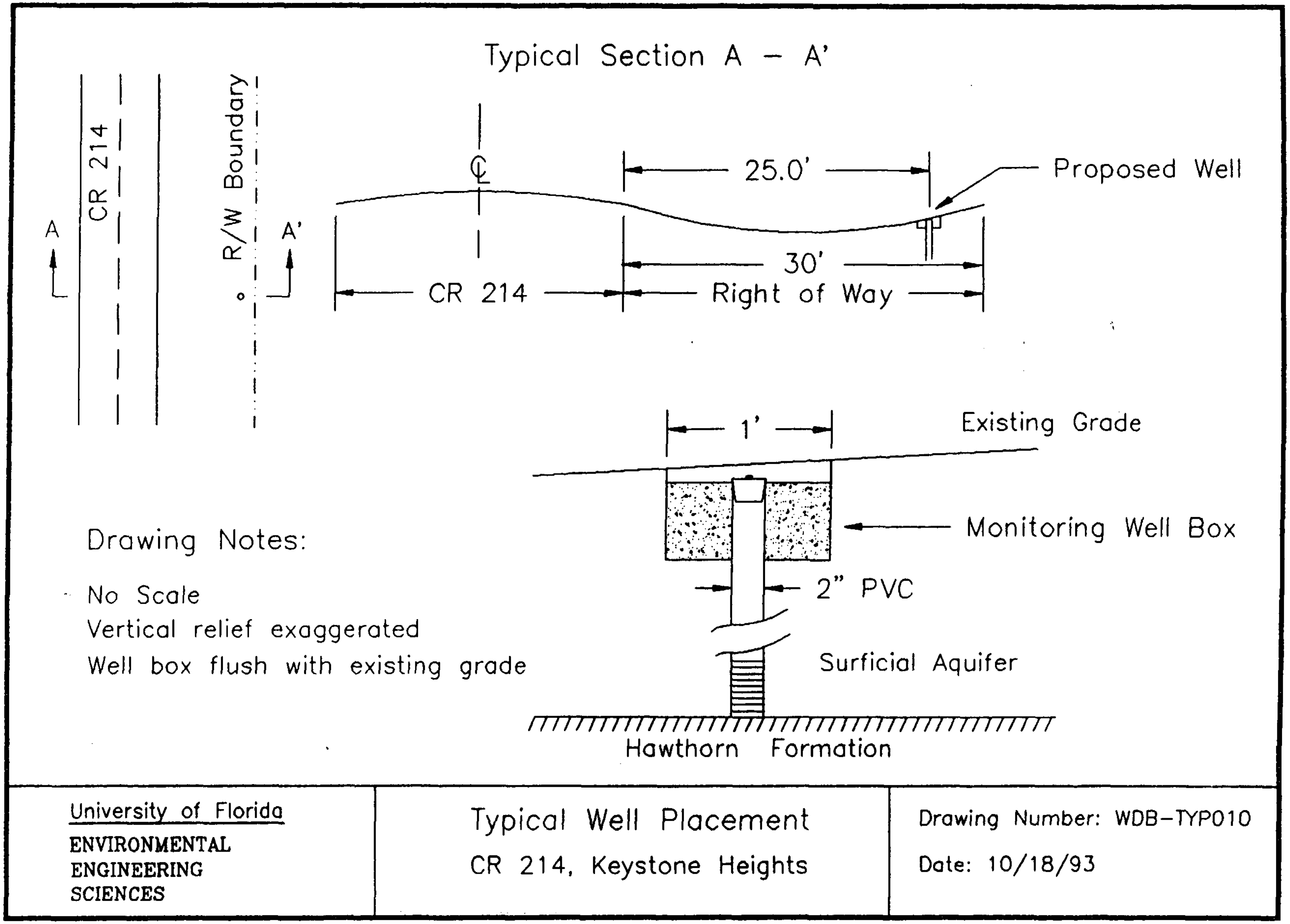


Figure A.1 Typical well placement on Clay County right of way

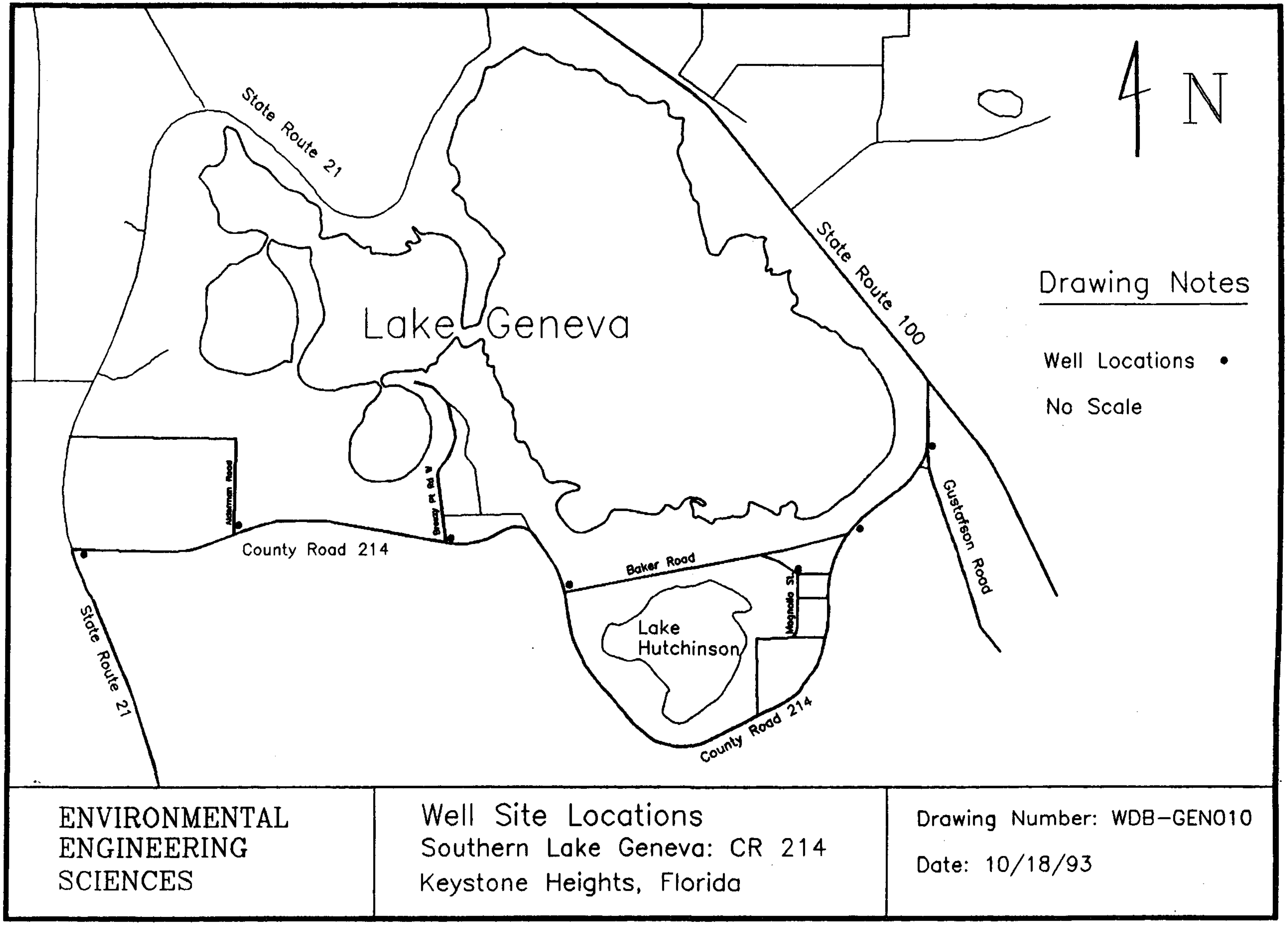


Figure A.2 Overview of wells along CR-214, south of Lake Geneva

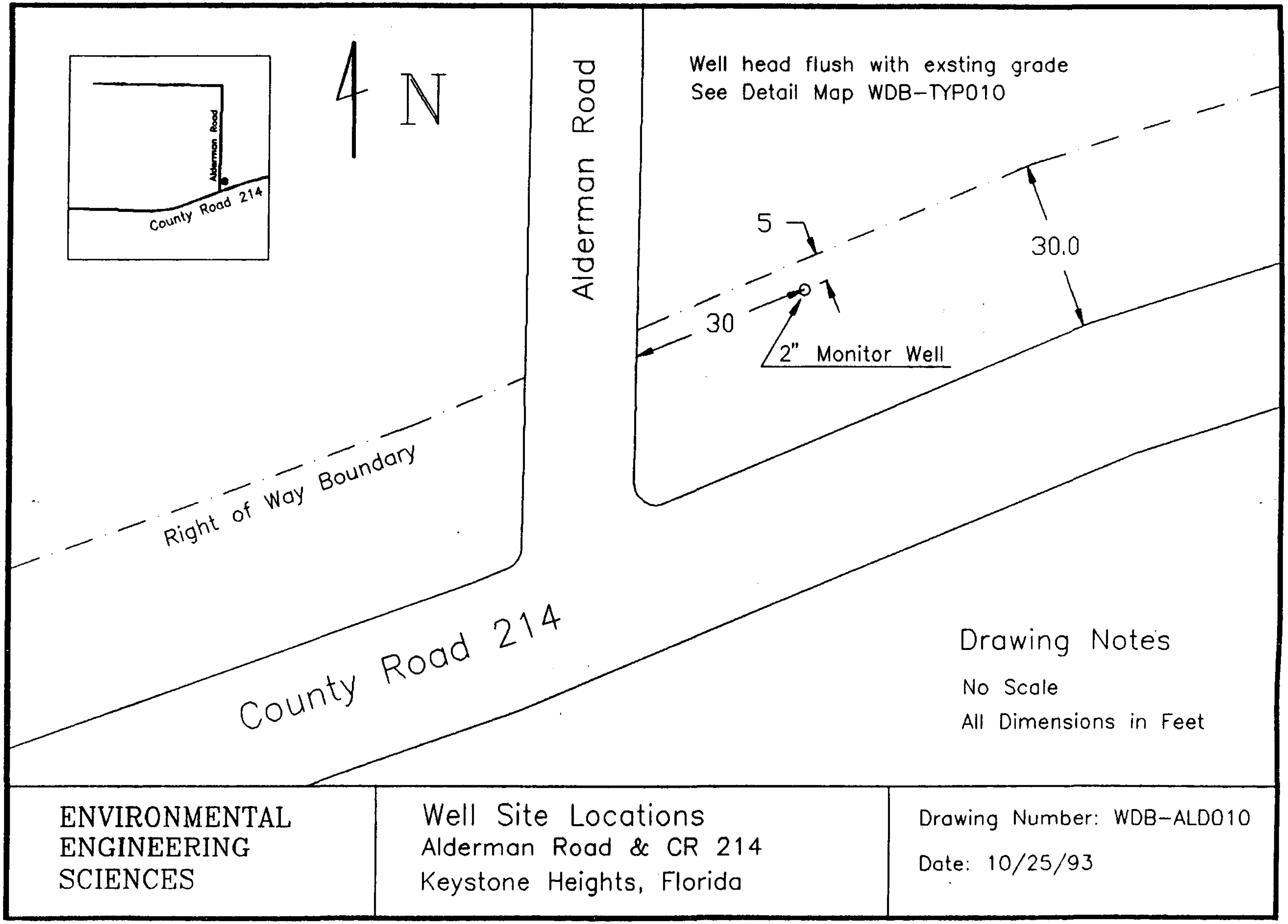


Figure A.3 Location of Well 1: CR-214 and Alderman Road

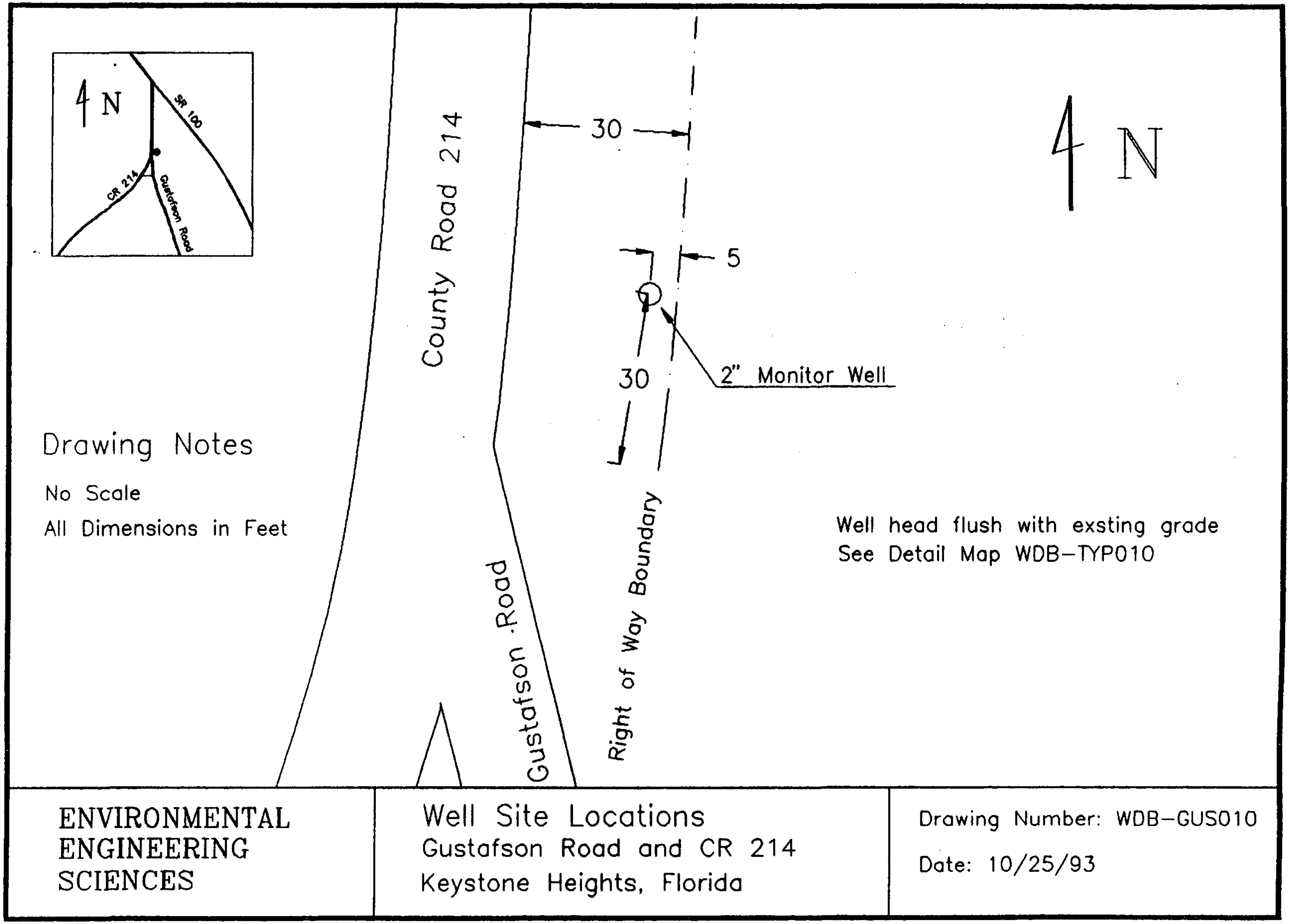


Figure A.4 Location of Well 4: CR-214 and Gustafson Road

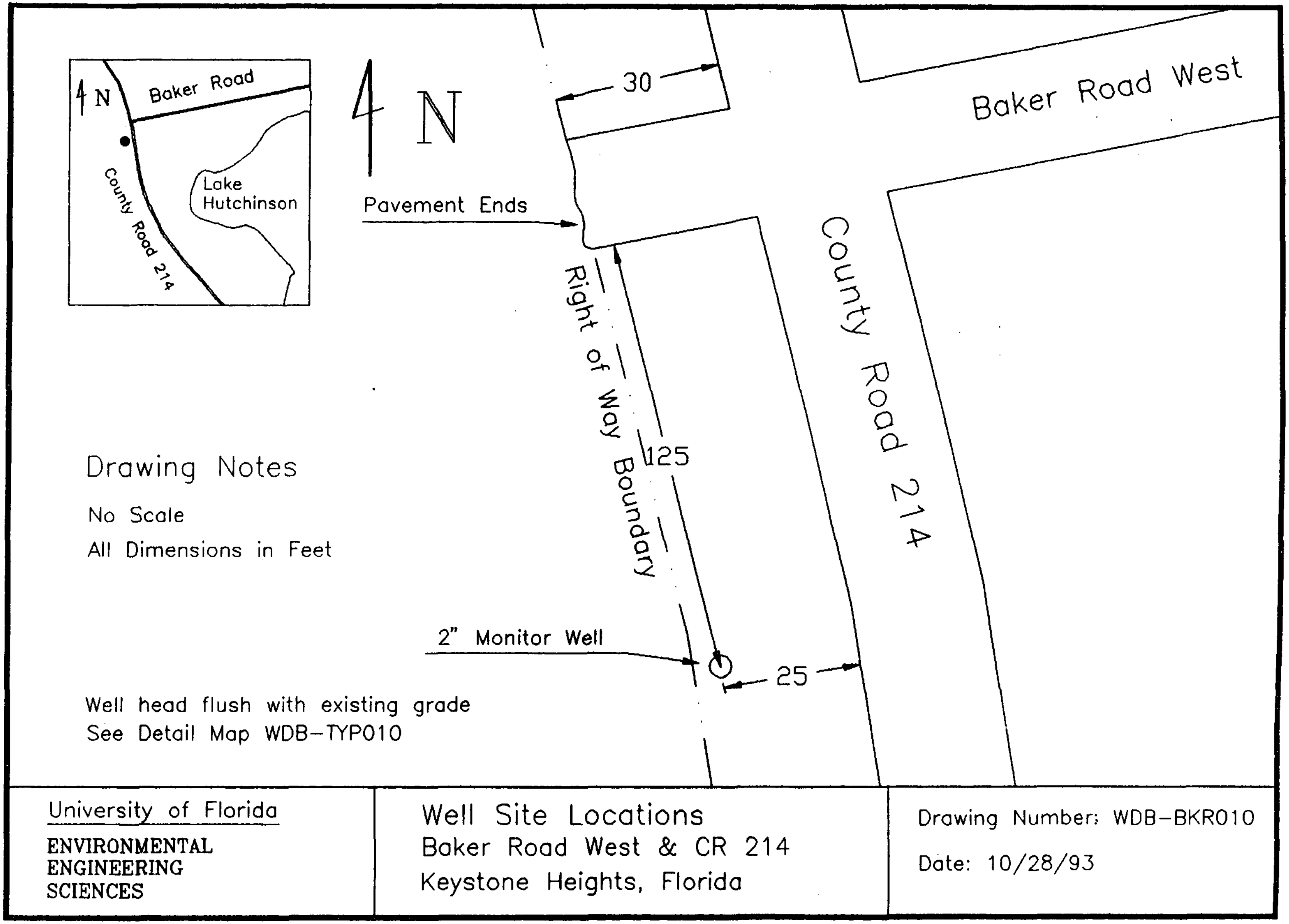


Figure A.5 Location of Well 5: CR-214 and Baker Road West

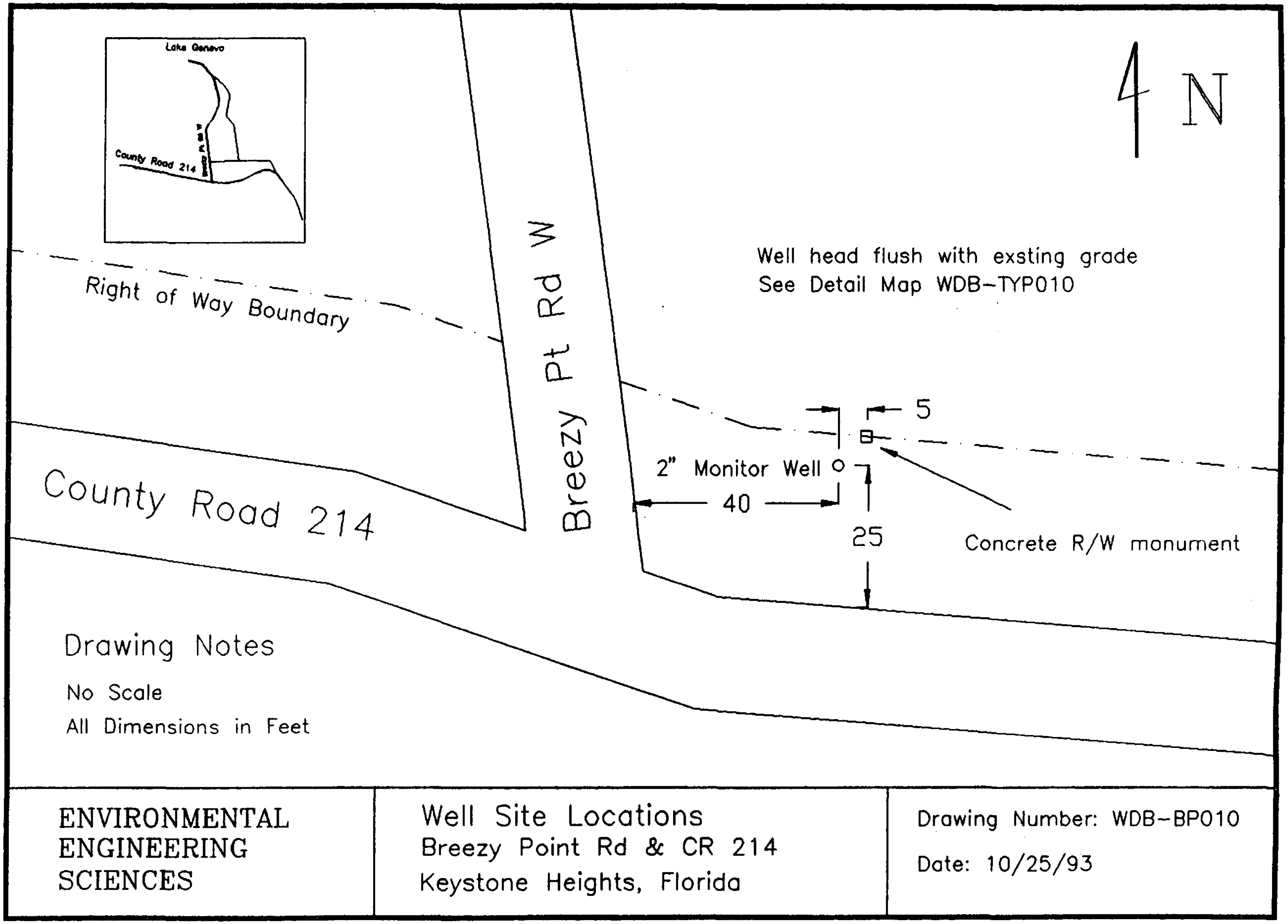


Figure A.6 Location of Well 11: CR-214 and Breezy Point Road

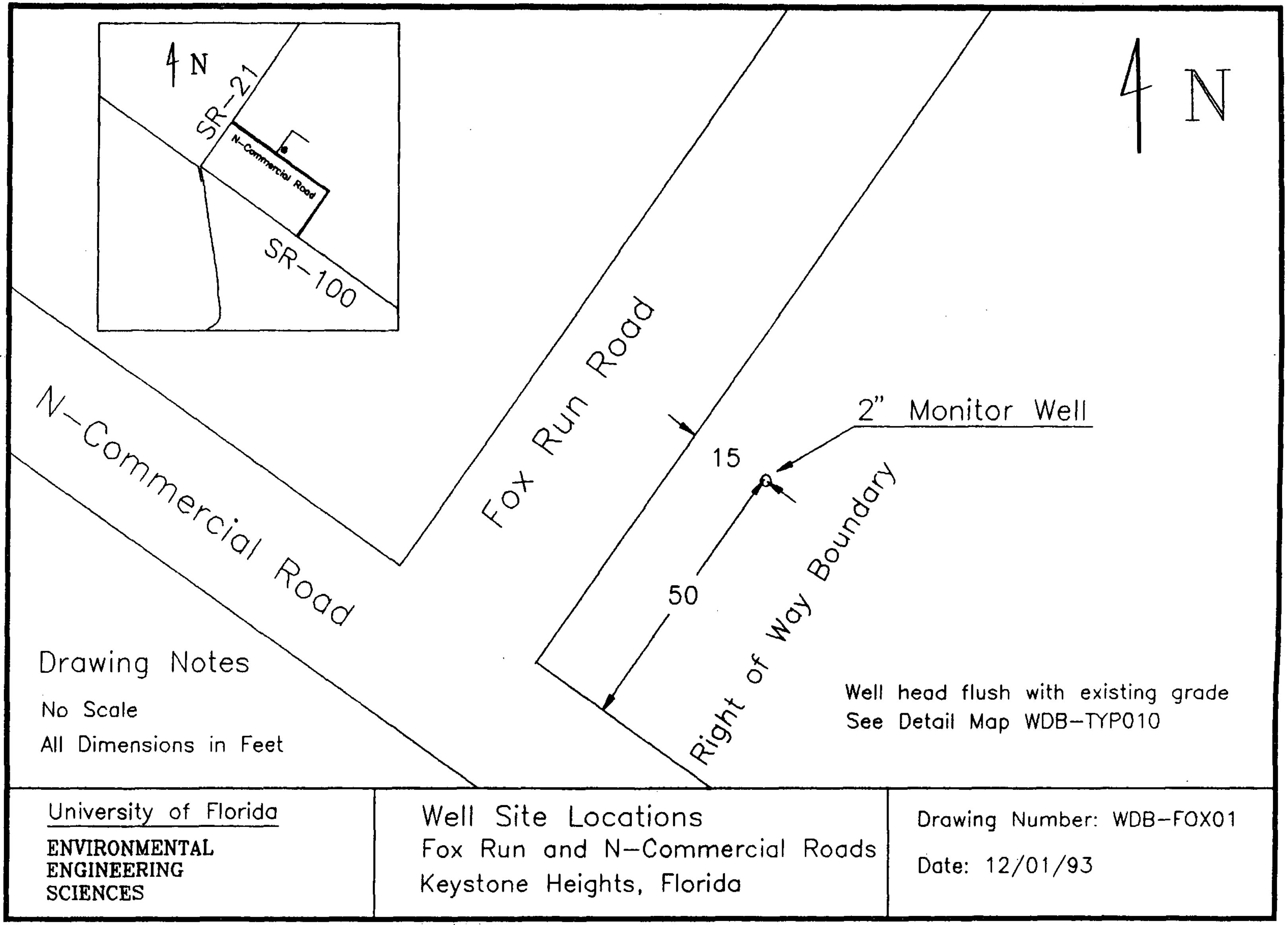


Figure A.7 Location of Well 13: N.Commercial and Fox Run Road

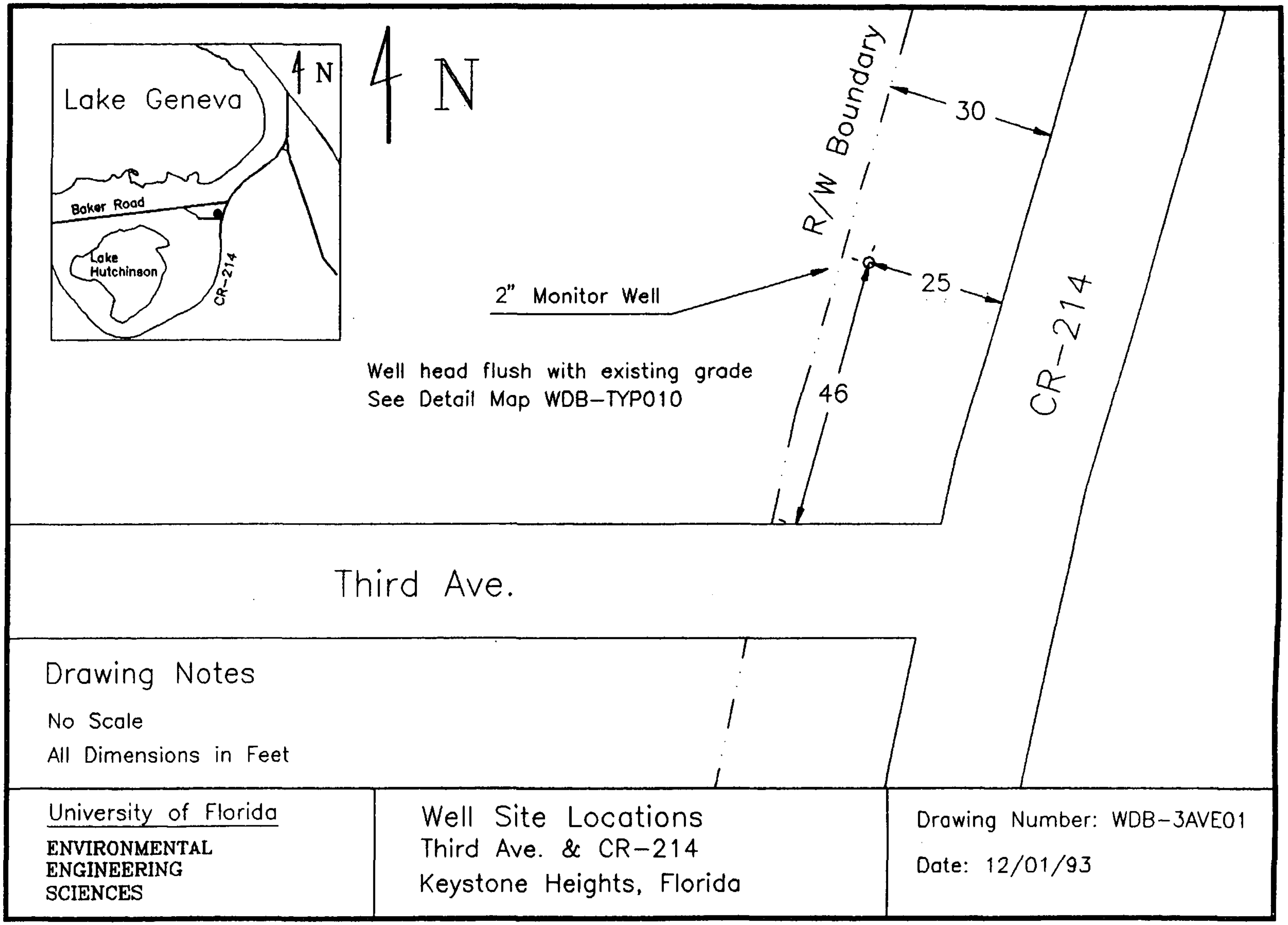


Figure A.8 Location of Well 15: CR-214 and Third Avenue

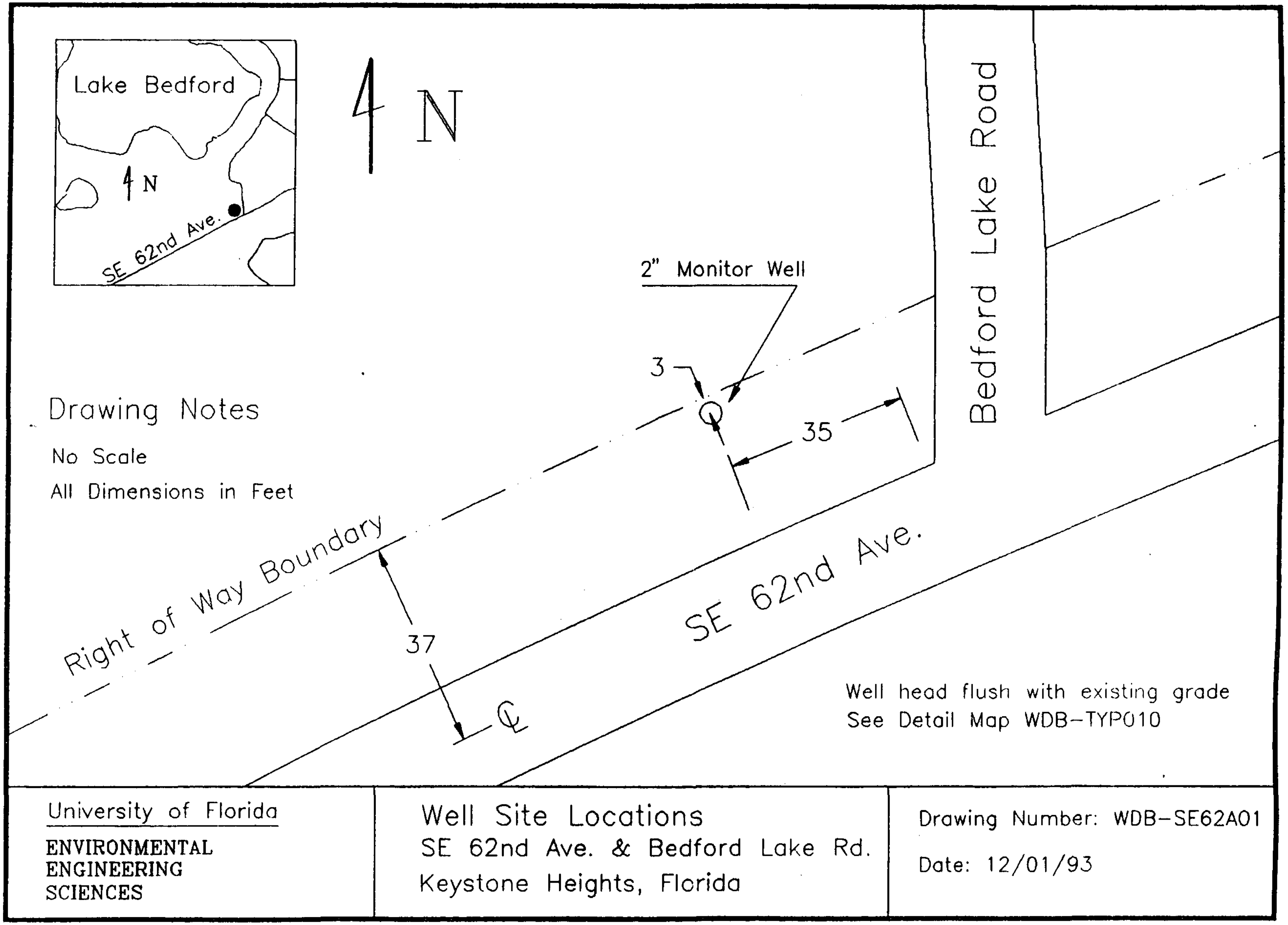


Figure A.9 Location of Well 17: Bedford Lake Road and SE 62 Avenue

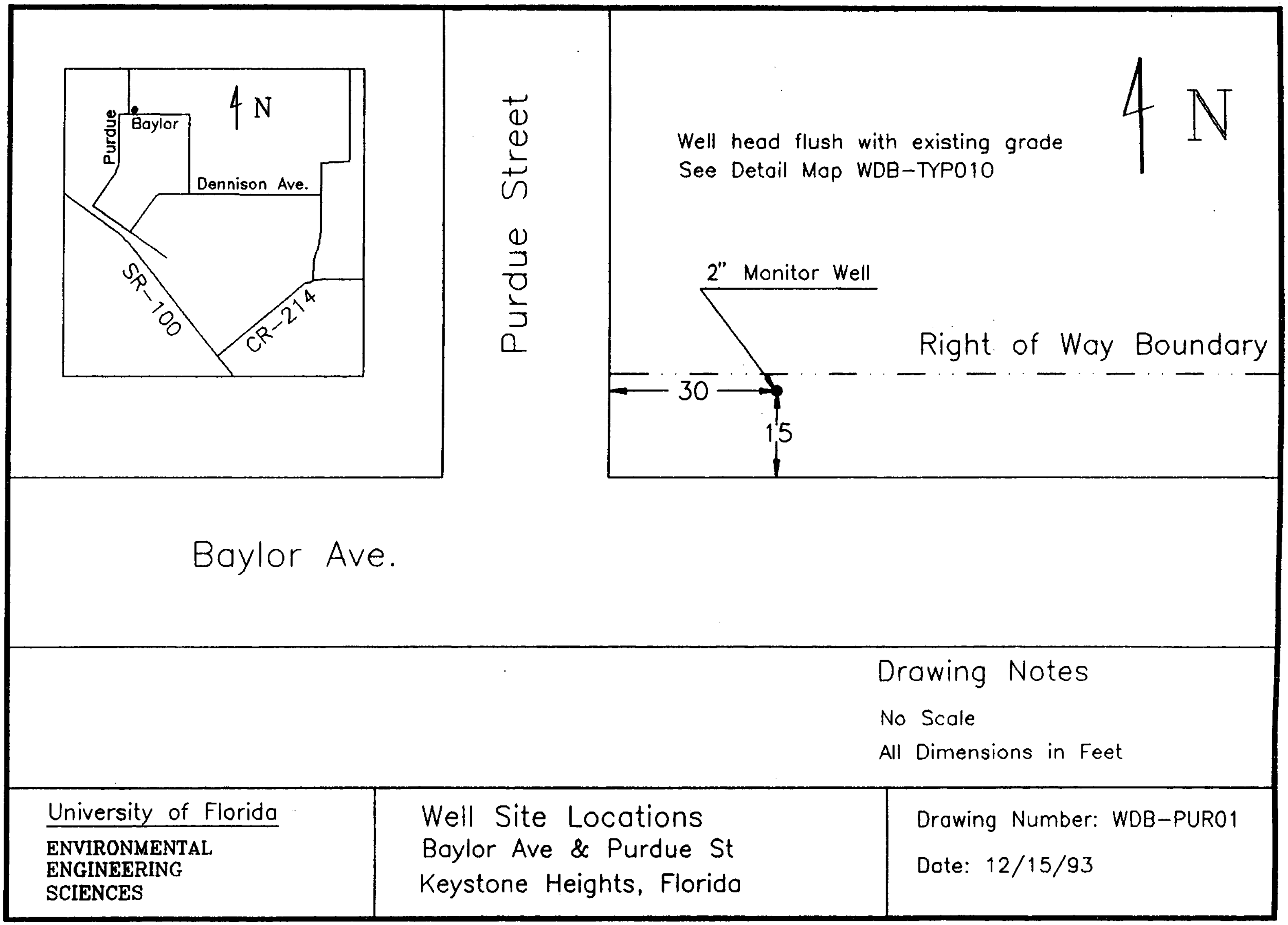


Figure A.10 Location of Well 18: Baylor Avenue and Purdue Street

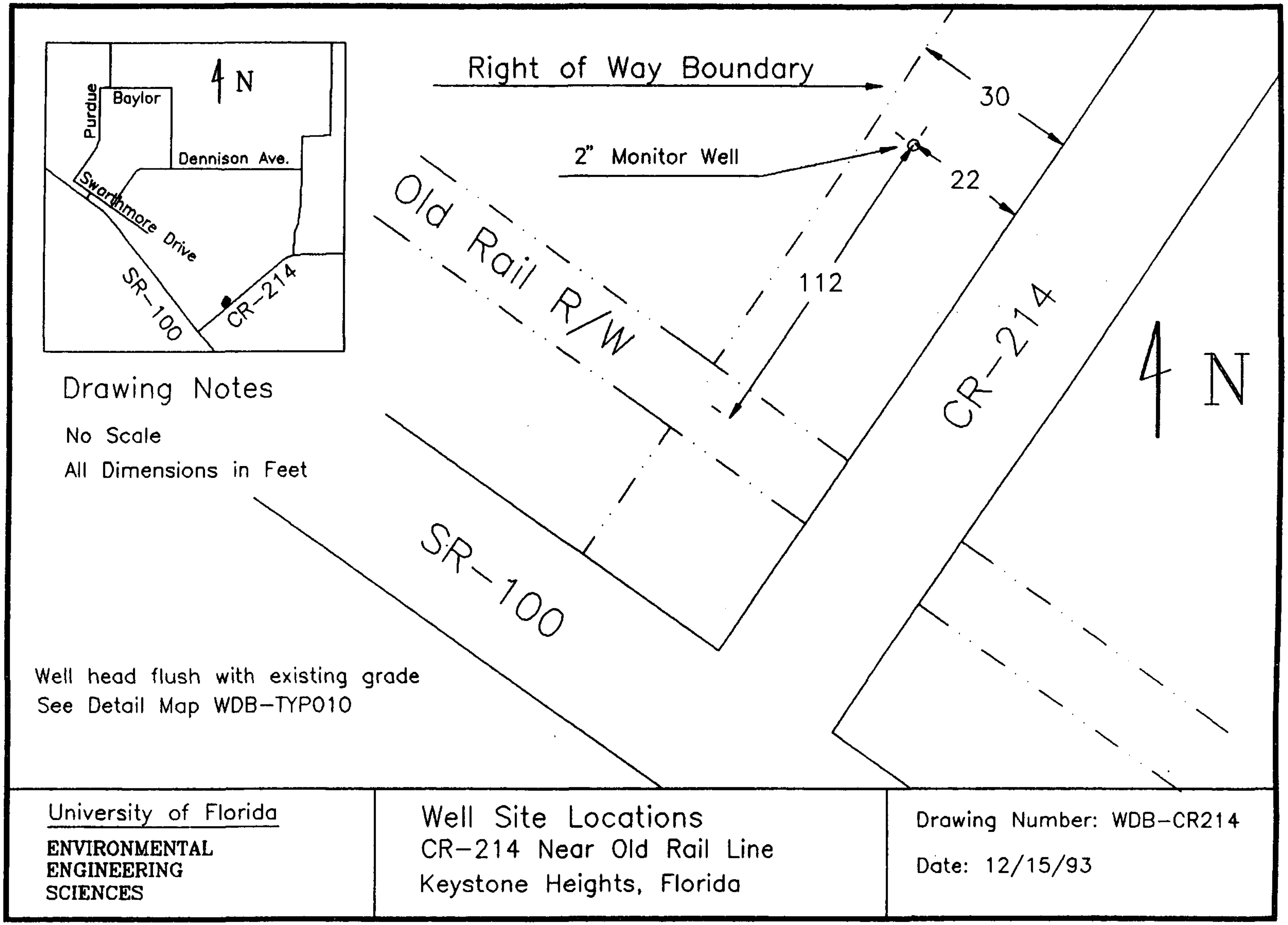


Figure A.11 Location of Well 20: CR-214 and SR-100

Appendix B

Slug Test Calculations

Slug Test Calculations for Well 1

Bouwer and Rice (1976) Method

Slug Test Date: 02/05/94

Data:

Well Inner Diameter :	0.1667	Ft
Casing Radius (rc)	0.0833	Ft
Effective Radius (rw):	0.2500	Ft
Total Well Depth:	53.00	Ft
Well Screen Length (L)	25.00	Ft
Dist. from TOWT to BOW (H):	28.40	Ft
Saturated Thickness (D):	36.00	Ft
Slug Volume:	0.0444	Ft^3

TOWT = Top of Water-Table BOW = Bottom of Well

Calculate: Expected Initial Drawdown : 2.035 Ft (Approximated)

From Bouwer and Rice: L/rw = 100 dimensionless

From Bouwer & Rice Graph: A = 4
B = 0.75
C = N/A

Eqn A Ln(Re/Rw) = (1.1/ln((D/rw) + C/(L/rw))^-1 For Partially Penetrating Well

Eqn B Ln(Re/Rw) = (1.1/ln((D/rw) + A+(B*ln((D-H)/rw)/(L/rw) For Fully Penetrating Well

Check if : Ln((D-H)/rw) > 6 ; then Ln((D-H)/rw) = 6 is used in Eqn A

Ln((D-H)/rw) = 3.414443 Ok

Solving for Ln(Re/rw) : Ln(Re/rw) 3.355315 dimensionless

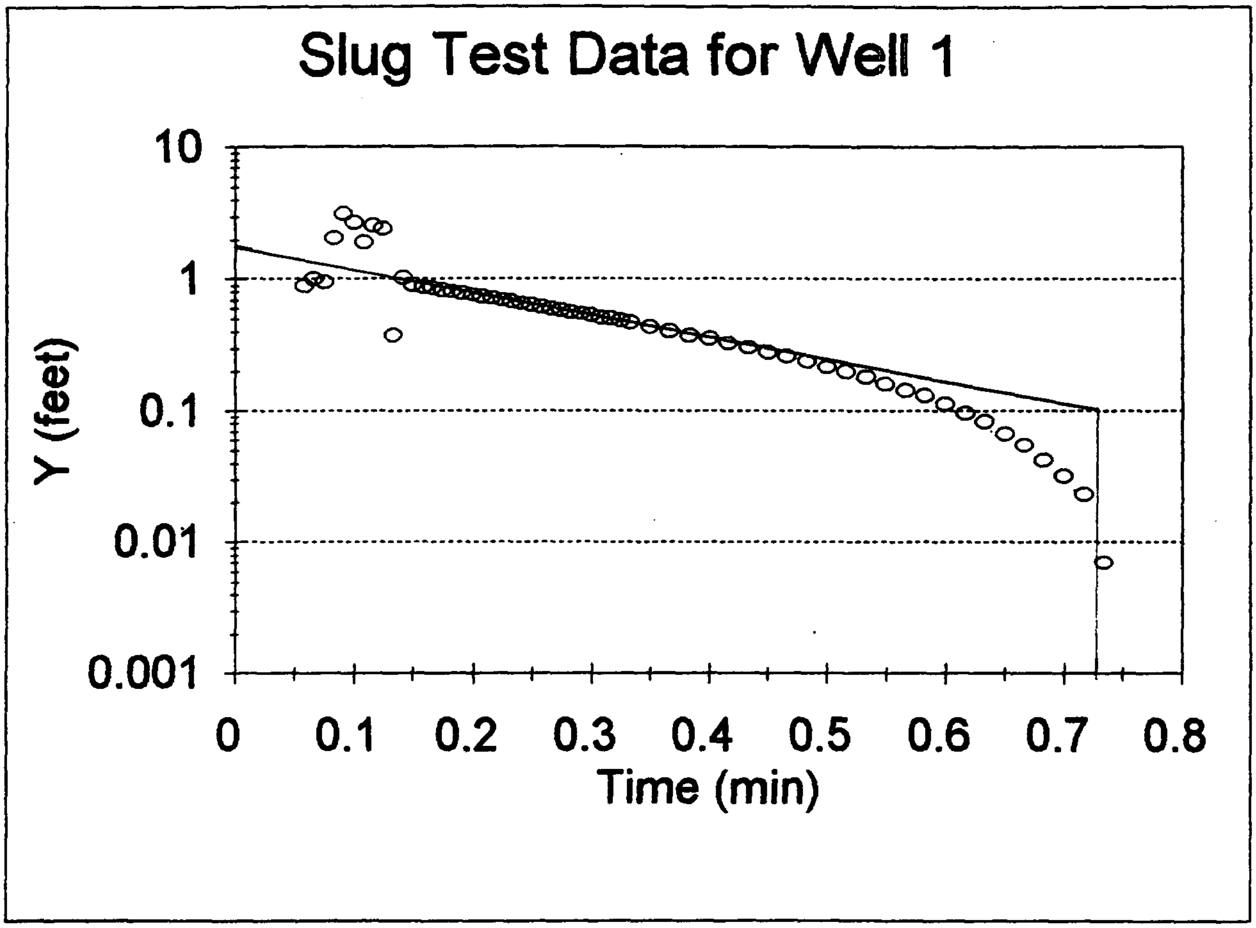
From Plot of Data: Yo = 1.9 (Observed)
Yt = 0.1
t = 0.725 min

Solve for Hydraulic Conductivity (K):

K = rc^2*ln(re/rw)/(2*L)*t^-1*ln(Yo/Yt)

K = 0.001893 ft/min

Change Units: $\boxed{\text{K = 2.73 ft/d}}$



Slug Test Data for Well 1
10
1
0.1
0.01
0.001
Y (feet)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Time (min)

Slug Test Calculations for Well 2

Bouwer and Rice (1976) Method

Slug Test Date: 02/10/94

Data:

Well Inner Diameter :	0.1667	Ft	
Casing Radius (rc)	0.0833	Ft	
Effective Radius (rw):	0.2500	Ft	
Total Well Depth:	65.00	Ft	
Well Screen Length (L)	27.00	Ft	
Dist. from TOWT to BOW (H):	26.50	Ft	
Saturated Thickness (D):	35.00	Ft	(Approximated)
Slug Volume:	0.0444	Ft^3	

TOWT = Top of Water-Table BOW = Bottom of Well

Calculate: Expected Initial Drawdown : 2.035 Ft (Approximated)

From Bouwer and Rice: L/rw = 108 dimensionless

From Bouwer & Rice Graph: A = 4
B = 0.75
C = N/A

Eqn A Ln(Re/Rw) = (1.1/ln((D/rw) + C/(L/rw))^-1 For Partially Penetrating Well

Eqn B Ln(Re/Rw) = (1.1/ln((D/rw) + A+(B*ln((D-H)/rw)/(L/rw): For Fully Penetrating Well

Check if : Ln((D-H)/rw) > 6 ; then Ln((D-H)/rw) = 6 is used in Eqn A

Ln((D-H)/rw) = 3.526361 Ok

Solving for Ln(Re/rw) : Ln(Re/rw) 3.36244 dimensionless

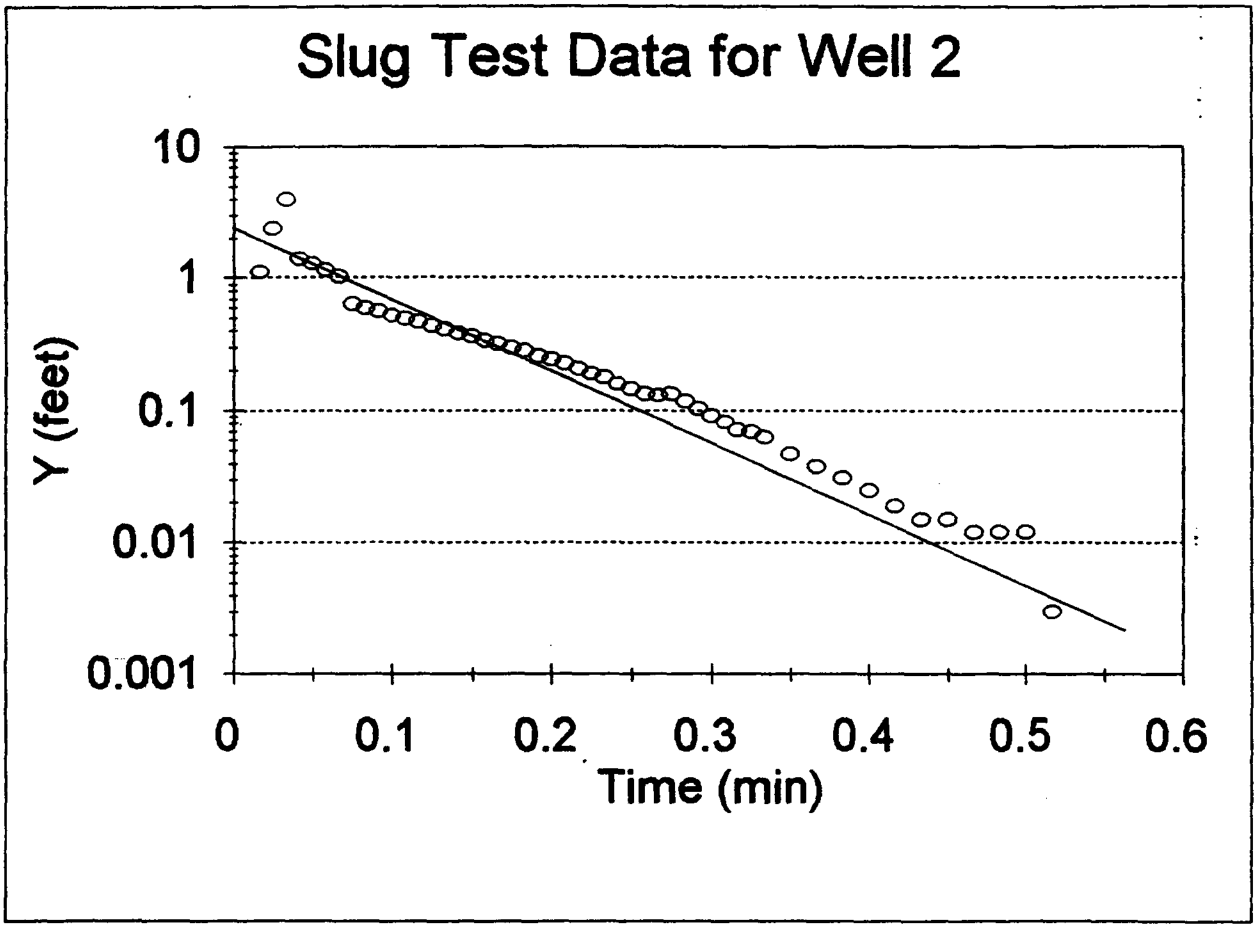
From Plot of Data: Yo = 2.2 (Observed)
Yt = 0.1
t = 0.25 min

Solve for Hydraulic Conductivity (K):

K = rc^2*ln(re/rw)/(2*L)*t^-1*ln(Yo/Yt)

K = 0.005346 ft/min

Change Units: **K = 7.70 ft/d**



Slug Test Data for Well 2
10
1
0.1
0.01
0.001
Y (feet)
0
0.1
0.2
0.3
0.4
0.5
0.6
Time (min)

Slug Test Calculations for Well 3

Bouwer and Rice (1976) Method

Slug Test Date: 02/10/94

Data:

Well Inner Diameter :	0.1667	Ft
Casing Radius (rc)	0.0833	Ft
Effective Radius (rw):	0.2500	Ft
Total Well Depth:	75.00	Ft
Well Screen Length (L)	37.00	Ft
Dist. from TOWT to BOW (H):	24.60	Ft
Saturated Thickness (D):	24.60	Ft
Slug Volume:	0.0444	Ft^3

TOWT = Top of Water-Table BOW = Bottom of Well

Calculate: Expected Initial Drawdown : 2.035 Ft (Approximated)

From Bouwer and Rice: L/rw = 148 dimensionless

From Bouwer & Rice Graph:
A = N/A
B = N/A
C = 3.8

Eqn A Ln(Re/Rw) = (1.1/ln((D/rw) + C/(L/rw))^-1 For Partially Penetrating Well

Eqn B Ln(Re/Rw) = (1.1/ln((D/rw) + A+(B*ln((D-H)/rw)/(L/rw) For Fully Penetrating Well

Check if : Ln((D-H)/rw) > 6 ; then Ln((D-H)/rw) = 6 is used in Eqn A

Solving for Ln(Re/rw) : Ln(Re/rw) 3.768221 dimensionless

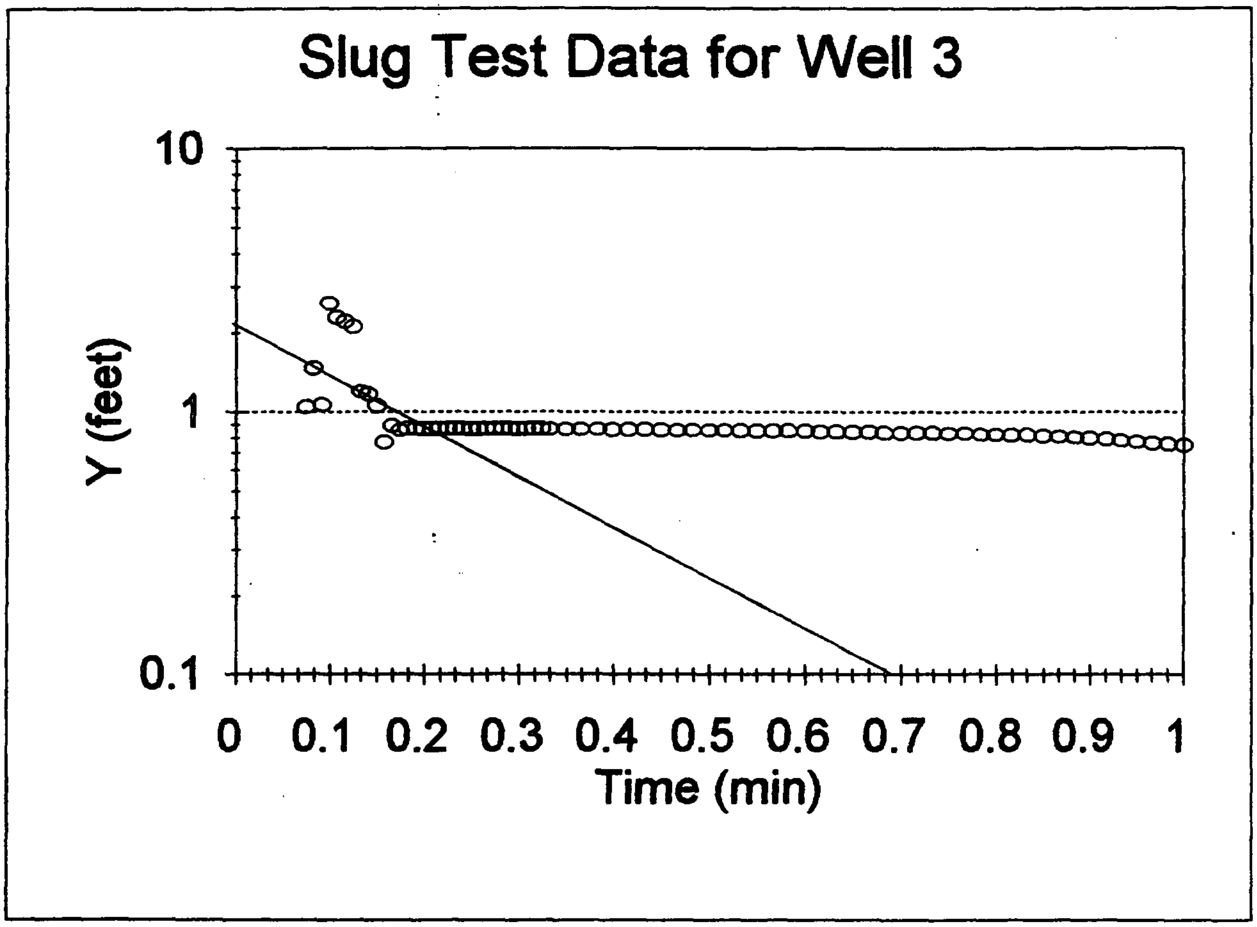
From Plot of Data:
Yo = 2.1 (Observed)
Yt = 0.1
t = 0.68 min

Solve for Hydraulic Conductivity (K):

K = rc^2*ln(re/rw)/(2*L)*t^-1*ln(Yo/Yt)

K = 0.001583 ft/min

Change Units: $\boxed{\text{K = 2.28 ft/d}}$


Slug Test Data for Well 3
10
1
0.1
Y (feet)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Time (min)

Slug Test Calculations for Well 4

Bouwer and Rice (1976) Method

Slug Test Date: 02/05/94

Data:

Well Inner Diameter :	0.1667	Ft
Casing Radius (rc)	0.0833	Ft
Effective Radius (rw):	0.2500	Ft
Total Well Depth:	50.00	Ft
Well Screen Length (L)	25.00	Ft
Dist. from TOWT to BOW (H):	18.79	Ft
Saturated Thickness (D):	46.29	Ft
Slug Volume:	0.0444	Ft^3

TOWT = Top of Water-Table BOW = Bottom of Well

Calculate: Expected Initial Drawdown : 2.035 Ft (Approximated)

From Bouwer and Rice: L/rw = 100 dimensionless

From Bouwer & Rice Graph: A = 4
B = 0.75
C = N/A

Eqn A Ln(Re/Rw) = (1.1/ln((D/rw) + C/(L/rw))^-1 For Partially Penetrating Well

Eqn B Ln(Re/Rw) = (1.1/ln((D/rw) + A+(B*ln((D-H)/rw)/(L/rw) For Fully Penetrating Well

Check if : Ln((D-H)/rw) > 6 ; then Ln((D-H)/rw) = 6 is used in Eqn A

Ln((D-H)/rw) = 4.70048 Ok

Solving for Ln(Re/rw) : Ln(Re/rw) 3.031169 dimensionless

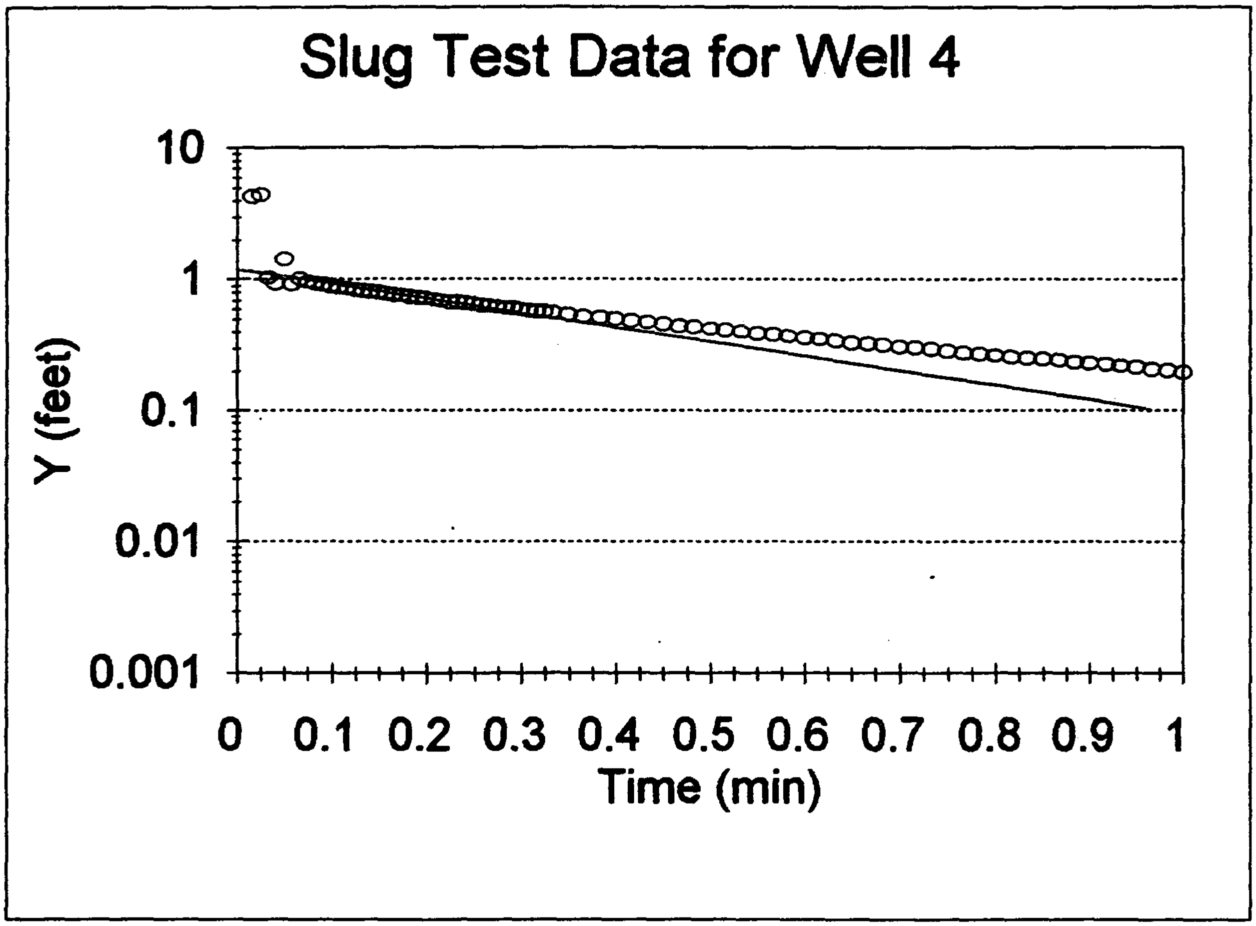
From Plot of Data: Yo = 1.2 (Observed)
Yt = 0.1
t = 0.95 min

Solve for Hydraulic Conductivity (K):

K = rc^2*ln(re/rw)/(2*L)*t^-1*ln(Yo/Yt)

K = 0.001101 ft/min

Change Units: **K = 1.59 ft/d**



Slug Test Data for Well 4
10
1
0.1
0.01
0.001
Y (feet)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Time (min)

Slug Test Calculations for Well 5

Bouwer and Rice (1976) Method

Slug Test Date: 02/10/94

Data:

Well Inner Diameter :	0.1667	Ft
Casing Radius (rc)	0.0833	Ft
Effective Radius (rw):	0.2500	Ft
Total Well Depth:	50.00	Ft
Well Screen Length (L)	25.00	Ft
Dist. from TOWT to BOW (H):	19.44	Ft
Saturated Thickness (D):	34.22	Ft
Slug Volume:	0.0444	Ft^3

TOWT = Top of Water-Table BOW = Bottom of Well

Calculate: Expected Initial Drawdown : 2.035 Ft (Approximated)

From Bouwer and Rice: L/rw = 100 dimensionless

From Bouwer & Rice Graph: A = 4
B = 0.75
C = N/A

Eqn A Ln(Re/Rw) = (1.1/ln((D/rw) + C/(L/rw))^-1 For Partially Penetrating Well

Eqn B Ln(Re/Rw) = (1.1/ln((D/rw) + A+(B*ln((D-H)/rw)/(L/rw) For Fully Penetrating Well

Check if : Ln((D-H)/rw) > 6 ; then Ln((D-H)/rw) = 6 is used in Eqn A

Ln((D-H)/rw) = 4.079569 Ok

Solving for Ln(Re/rw) : Ln(Re/rw) 3.093488 dimensionless

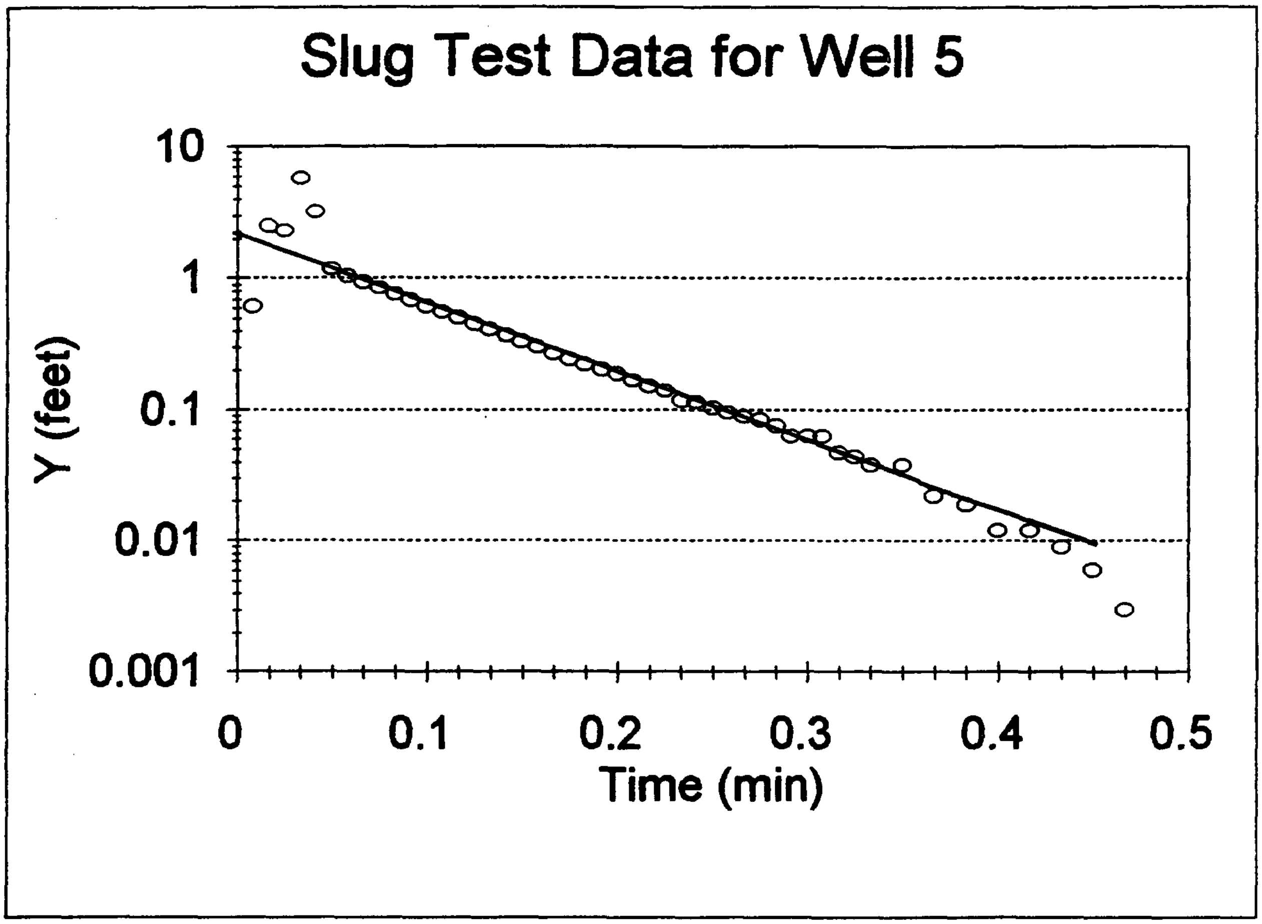
From Plot of Data: Yo = 2.1 (Observed)
Yt = 0.01
t = 0.45 min

Solve for Hydraulic Conductivity (K):

K = rc^2*ln(Re/rw)/(2*L)*t^-1*ln(Yo/Yt)

K = 0.005105 ft/min

Change Units: $\boxed{\text{K = 7.35 ft/d}}$


Slug Test Data for Well 5
10
1
0.1
0.01
0.001
Y (feet)
0
0.1
0.2
0.3
0.4
0.5
Time (min)

Slug Test Calculations for Well 6

Bouwer and Rice (1976) Method

Slug Test Date: 01/11/94

Data:

Well Inner Diameter :	0.1667	Ft
Casing Radius (rc)	0.0833	Ft
Effective Radius (rw):	0.2500	Ft
Total Well Depth:	65.00	Ft
Well Screen Length (L)	27.00	Ft
Dist. from TOWT to BOW (H):	4.82	Ft
Saturated Thickness (D):	4.82	Ft
Slug Volume:	0.0444	Ft^3

TOWT = Top of Water-Table BOW = Bottom of Well

Calculate: Expected Initial Drawdown : 2.035 Ft (Approximated)

From Bouwer and Rice: L/rw = 108 dimensionless

From Bouwer & Rice Graph: A = N/A
B = N/A
C = 4.5

Eqn A Ln(Re/Rw) = (1.1/ln((D/rw) + C/(L/rw))^-1 For Partially Penetrating Well

Eqn B Ln(Re/Rw) = (1.1/ln((D/rw) + A+(B*ln((D-H)/rw)/(L/rw) For Fully Penetrating Well

Check if : Ln((D-H)/rw) > 6 ; then Ln((D-H)/rw) = 6 is used in Eqn A

Solving for Ln(Re/rw) : Ln(Re/rw) 2.418934 dimensionless

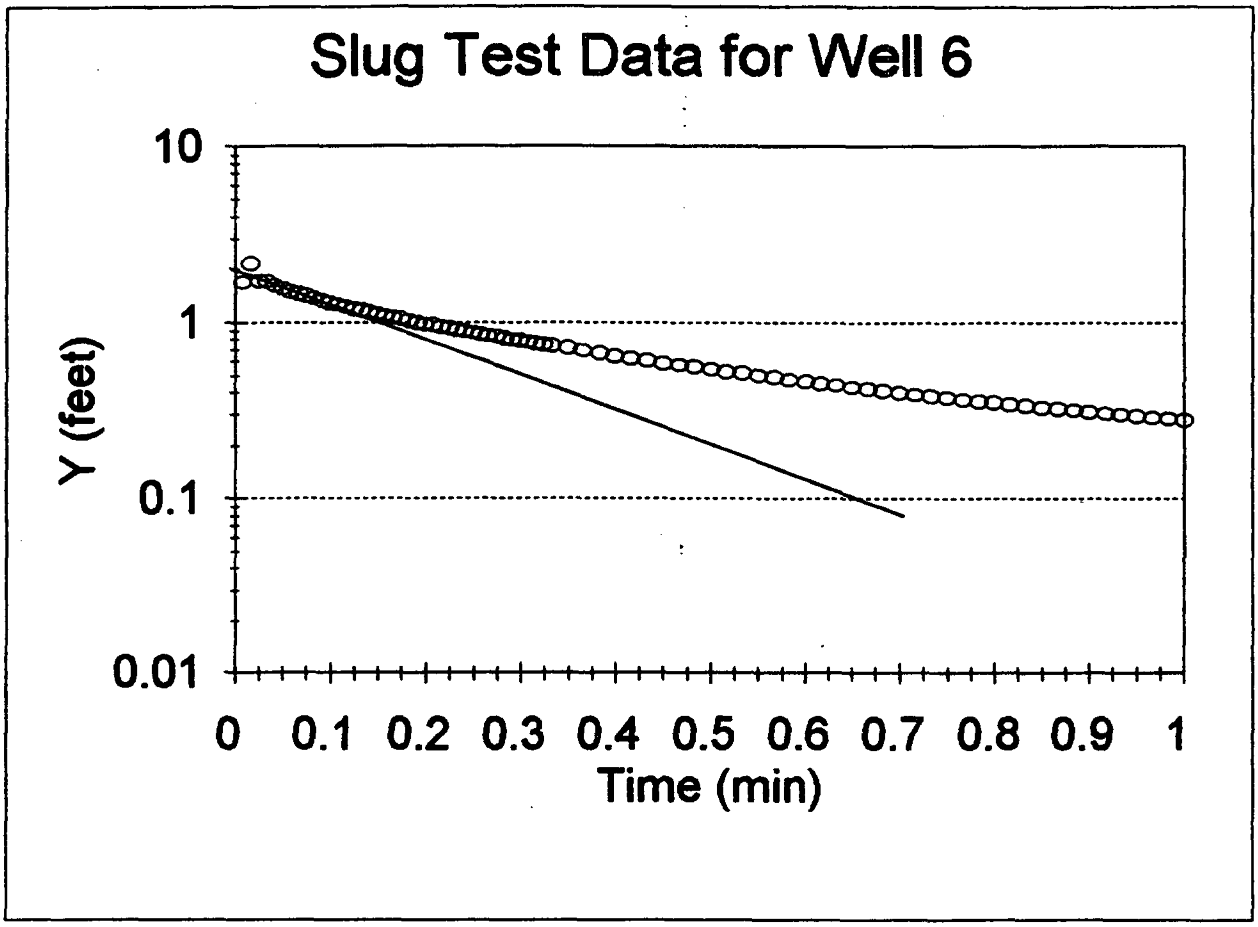
From Plot of Data: Yo = 2.0 (Observed)
Yt = 0.1
t = 0.65 min

Solve for Hydraulic Conductivity (K):

K = rc^2*ln(Re/rw)/(2*L)*t^-1*ln(Yo/Yt)

K = 0.001434 ft/min

Change Units: $\boxed{K = 2.06 \text{ ft/d}}$



Slug Test Data for Well 6
10
1
0.1
0.01
Y (feet)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Time (min)

Slug Test Calculations for Well 8

Bouwer and Rice (1976) Method

Slug Test Date: 01/25/94

Data:

Well Inner Diameter :	0.1667	Ft
Casing Radius (rc)	0.0833	Ft
Effective Radius (rw):	0.2500	Ft
Total Well Depth:	48.00	Ft
Well Screen Length (L)	22.00	Ft
Dist. from TOWT to BOW (H):	15.36	Ft
Saturated Thickness (D):	15.36	Ft
Slug Volume:	0.0444	Ft^3

TOWT = Top of Water-Table BOW = Bottom of Well

Calculate: Expected Initial Drawdown : 2.035 Ft (Approximated)

From Bouwer and Rice: L/rw = 88 dimensionless

From Bouwer & Rice Graph: A = N/A
B = 1.8
C = 3.9

Eqn A Ln(Re/Rw) = (1.1/ln((D/rw) + C/(L/rw))^-1 For Partially Penetrating Well

Eqn B Ln(Re/Rw) = (1.1/ln((D/rw) + A+(B*ln((D-H)/rw)/(L/rw) For Fully Penetrating Well

Check if : Ln((D-H)/rw) > 6 ; then Ln((D-H)/rw) = 6 is used in Eqn A

Solving for Ln(Re/rw) : Ln(Re/rw) 3.210951 dimensionless

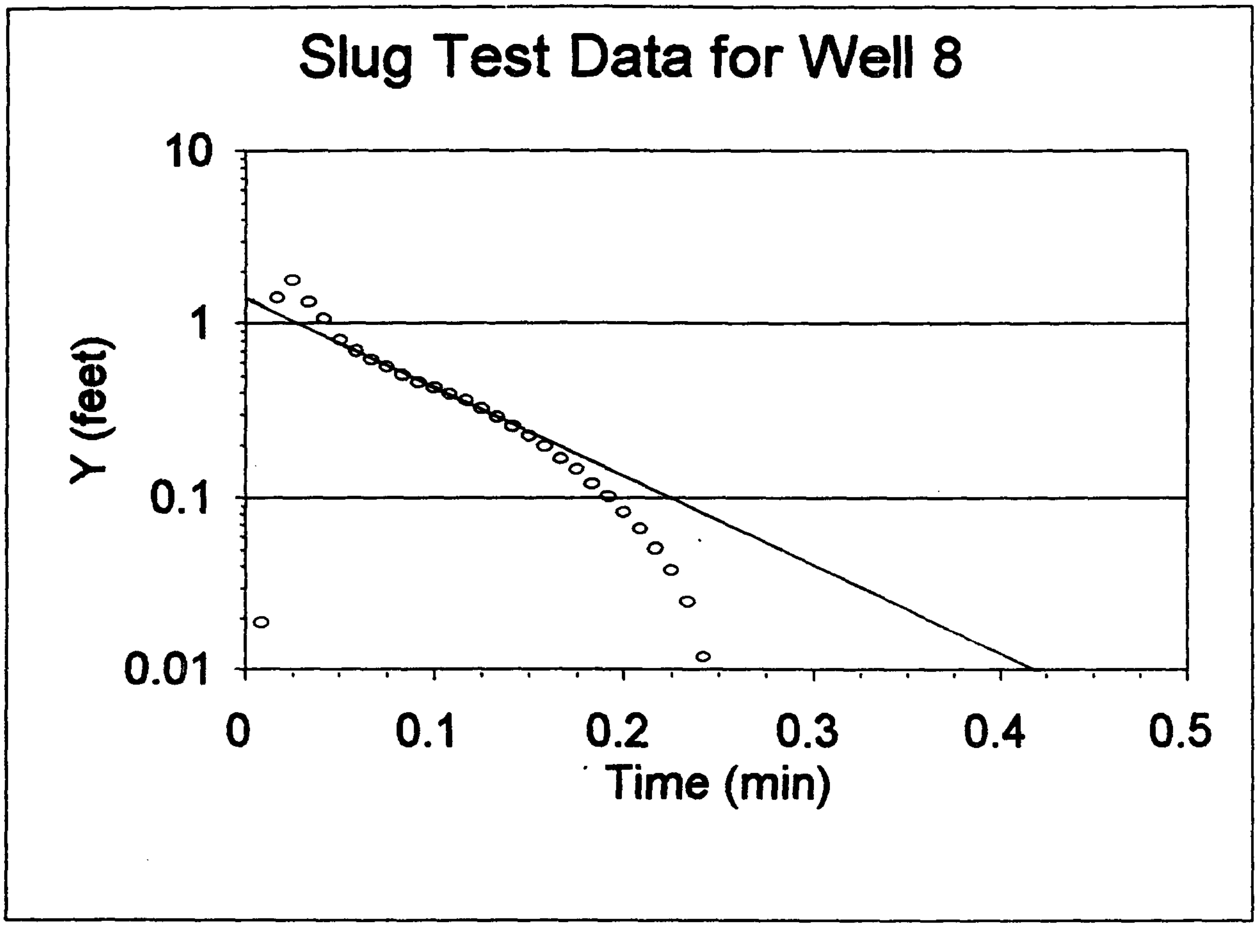
From Plot of Data: Yo = 1.5 (Observed)
Yt = 0.01
t = 0.425 min

Solve for Hydraulic Conductivity (K):

K = rc^2*ln(Re/rw)/(2*L)*t^-1*ln(Yo/Yt)

K = 0.005975 ft/min

Change Units: **K = 8.60 ft/d**


Slug Test Data for Well 8
10
1
0.1
0.01
Y (feet)
0
0.1
0.2
0.3
0.4
0.5
Time (min)

Slug Test Calculations for Well 9

Bouwer and Rice (1976) Method

Slug Test Date: 01/25/94

Data:

Well Inner Diameter :	0.1667	Ft
Casing Radius (rc)	0.0833	Ft
Effective Radius (rw):	0.2500	Ft
Total Well Depth:	48.00	Ft
Well Screen Length (L)	32.00	Ft
Dist. from TOWT to BOW (H):	23.10	Ft
Saturated Thickness (D):	23.10	Ft
Slug Volume:	0.0444	Ft^3

TOWT = Top of Water-Table BOW = Bottom of Well

Calculate: Expected Initial Drawdown : 2.035 Ft (Approximated)

From Bouwer and Rice: L/rw = 128 dimensionless

From Bouwer & Rice Graph: A = N/A
B = N/A
C = 4.4

Eqn A Ln(Re/Rw) = (1.1/ln((D/rw) + C/(L/rw))^-1 For Partially Penetrating Well

Eqn B Ln(Re/Rw) = (1.1/ln((D/rw) + A+(B*ln((D-H)/rw)/(L/rw)) For Fully Penetrating Well

Check if : Ln((D-H)/rw) > 6 ; then Ln((D-H)/rw) = 6 is used in Eqn A

Solving for Ln(Re/rw) : Ln(Re/rw) 3.604794 dimensionless

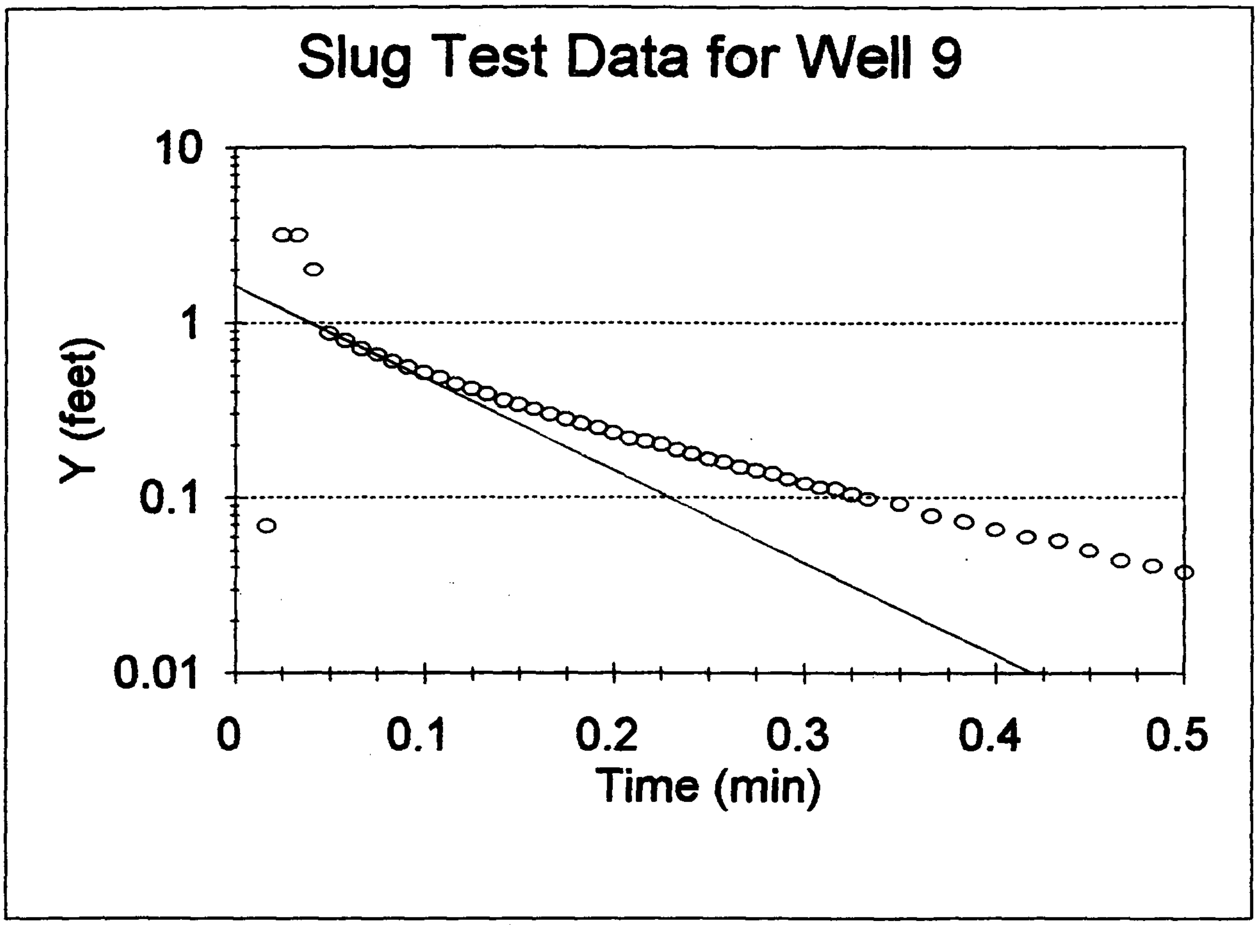
From Plot of Data: Yo = 1.8 (Observed)
Yt = 0.01
t = 0.423 min

Solve for Hydraulic Conductivity (K):

K = rc^2*ln(re/rw)/(2*L)*t^-1*ln(Yo/Yt)

K = 0.004802 ft/min

Change Units: $\boxed{\text{K = 6.91 ft/d}}$


Slug Test Data for Well 9
10
1
0.1
0.01
Y (feet)
0
0.1
0.2
0.3
0.4
0.5
Time (min)

Slug Test Calculations for Well 10

Bouwer and Rice (1976) Method

Slug Test Date: 01/25/94

Data:

Well Inner Diameter :	0.1667	Ft
Casing Radius (rc)	0.0833	Ft
Effective Radius (rw):	0.2500	Ft
Total Well Depth:	48.00	Ft
Well Screen Length (L)	22.00	Ft
Dist. from TOWT to BOW (H):	24.15	Ft
Saturated Thickness (D):	24.15	Ft
Slug Volume:	0.0444	Ft^3

TOWT = Top of Water-Table BOW = Bottom of Well

Calculate: Expected Initial Drawdown : 2.035 Ft (Approximated)

From Bouwer and Rice: L/rw = 88 dimensionless

From Bouwer & Rice Graph: A = N/A
B = N/A
C = 3.9

Eqn A Ln(Re/Rw) = (1.1/ln((D/rw) + C/(L/rw))^-1 For Partially Penetrating Well

Eqn B Ln(Re/Rw) = (1.1/ln((D/rw) + A+(B*ln((D-H)/rw)/(L/rw)) For Fully Penetrating Well

Check if : Ln((D-H)/rw) > 6 ; then Ln((D-H)/rw) = 6 is used in Eqn A

Solving for Ln(Re/rw) : Ln(Re/rw) 3.508921 dimensionless

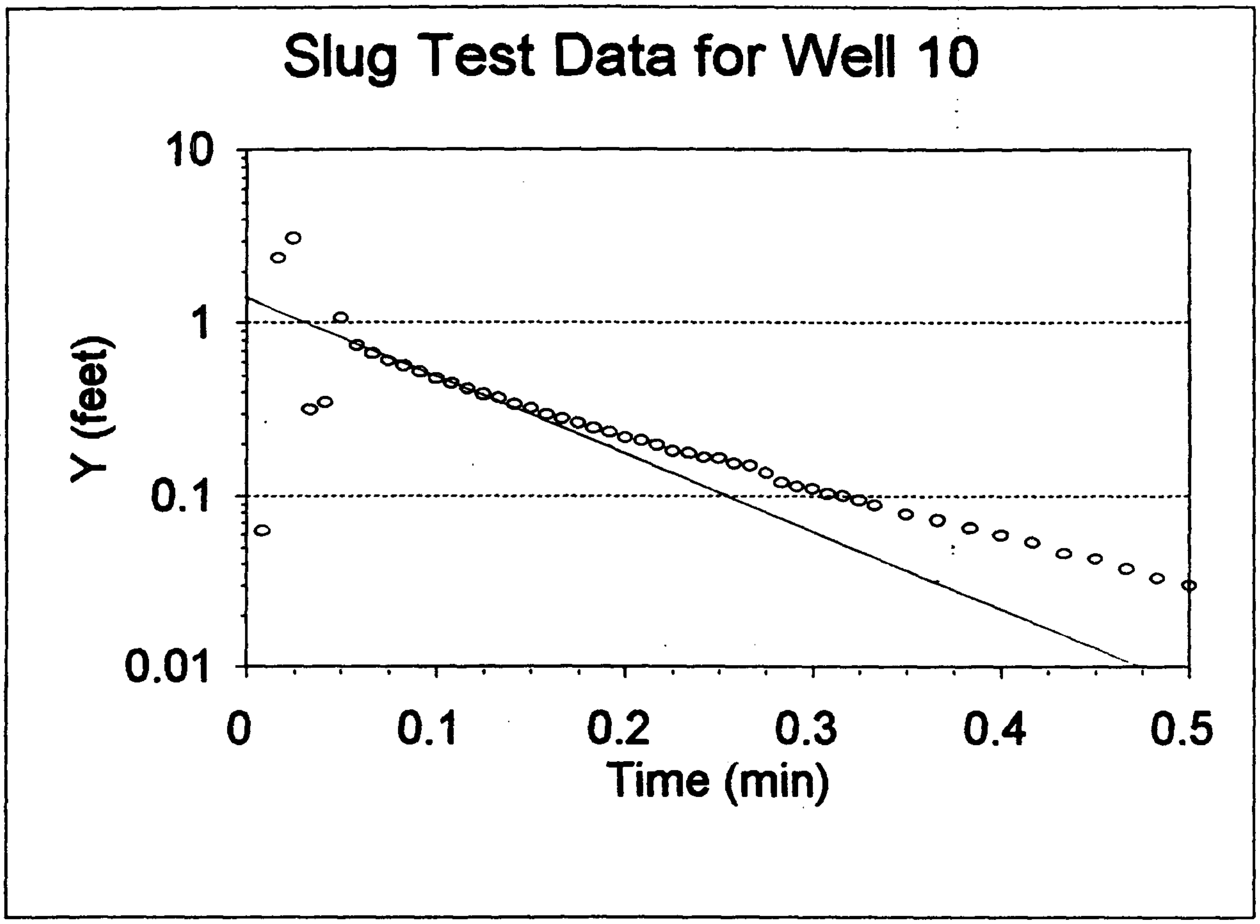
From Plot of Data: Yo = 1.5 (Observed)
Yt = 0.01
t = 0.475 min

Solve for Hydraulic Conductivity (K):

K = rc^2*ln(re/rw)/(2*L)*t^-1*ln(Yo/Yt)

K = 0.005842 ft/min

Change Units: **K = 8.41 ft/d**



Slug Test Data for Well 10
10
1
0.1
0.01
Y (feet)
0
0.1
0.2
0.3
0.4
0.5
Time (min)

Slug Test Calculations for Well 11

Bouwer and Rice (1976) Method

Slug Test Date: 02/10/94

Data:

Well Inner Diameter :	0.1667	Ft
Casing Radius (rc)	0.0833	Ft
Effective Radius (rw):	0.2500	Ft
Total Well Depth:	55.00	Ft
Well Screen Length (L)	20.00	Ft
Dist. from TOWT to BOW (H):	25.31	Ft
Saturated Thickness (D):	30.31	Ft
Slug Volume:	0.0444	Ft^3

TOWT = Top of Water-Table BOW = Bottom of Well

Calculate: Expected Initial Drawdown : 2.035 Ft (Approximated)

From Bouwer and Rice: L/rw = 80 dimensionless

From Bouwer & Rice Graph: A = 3.7
B = 0.65
C = N/A

Eqn A Ln(Re/Rw) = (1.1/ln((D/rw) + C/(L/rw))^-1 For Partially Penetrating Well

Eqn B Ln(Re/Rw) = (1.1/ln((D/rw) + A+(B*ln((D-H)/rw)/(L/rw); For Fully Penetrating Well

Check if : Ln((D-H)/rw) > 6 ; then Ln((D-H)/rw) = 6 is used in Eqn A

Ln((D-H)/rw) = 2.995732 Ok

Solving for Ln(Re/rw) : Ln(Re/rw) 3.238187 dimensionless

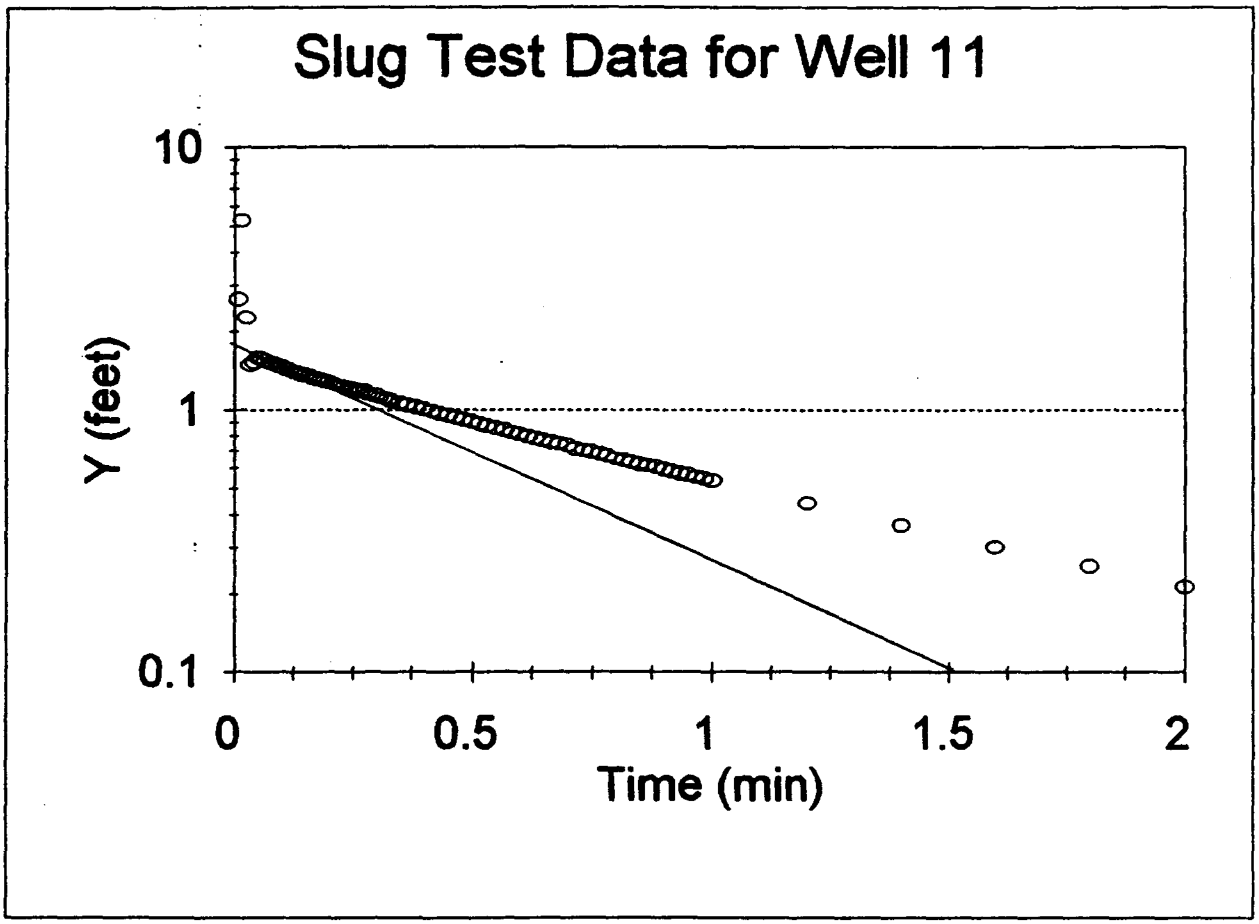
From Plot of Data: Yo = 1.5 (Observed)
Yt = 0.1
t = 1.5 min

Solve for Hydraulic Conductivity (K):

K = rc^2*ln(re/rw)/(2*L)*t^-1*ln(Yo/Yt)

K = 0.001015 ft/min

Change Units: $\boxed{\text{K = 1.46 ft/d}}$


Slug Test Data for Well 11
10
1
0.1
Y (feet)
0
0.5
1
1.5
2
Time (min)

Slug Test Calculations for Well 12

Bouwer and Rice (1976) Method

Slug Test Date: 02/05/94

Data:

Well Inner Diameter :	0.1667	Ft
Casing Radius (rc)	0.0833	Ft
Effective Radius (rw):	0.2500	Ft
Total Well Depth:	51.00	Ft
Well Screen Length (L)	32.00	Ft
Dist. from TOWT to BOW (H):	24.92	Ft
Saturated Thickness (D):	29.72	Ft
Slug Volume:	0.0444	Ft^3

TOWT = Top of Water-Table BOW = Bottom of Well

Calculate: Expected Initial Drawdown : 2.035 Ft (Approximated)

From Bouwer and Rice: L/rw = 128 dimensionless

From Bouwer & Rice Graph:
A = 3.7
B = 0.45
C = N/A

Eqn A Ln(Re/Rw) = (1.1/ln((D/rw) + C/(L/rw))^-1 For Partially Penetrating Well

Eqn B Ln(Re/Rw) = (1.1/ln((D/rw) + A+(B*ln((D-H)/rw)/(L/rw)) For Fully Penetrating Well

Check if : Ln((D-H)/rw) > 6 ; then Ln((D-H)/rw) = 6 is used in Eqn A

Ln((D-H)/rw) = 2.95491 Ok

Solving for Ln(Re/rw) : Ln(Re/rw) 3.592949 dimensionless

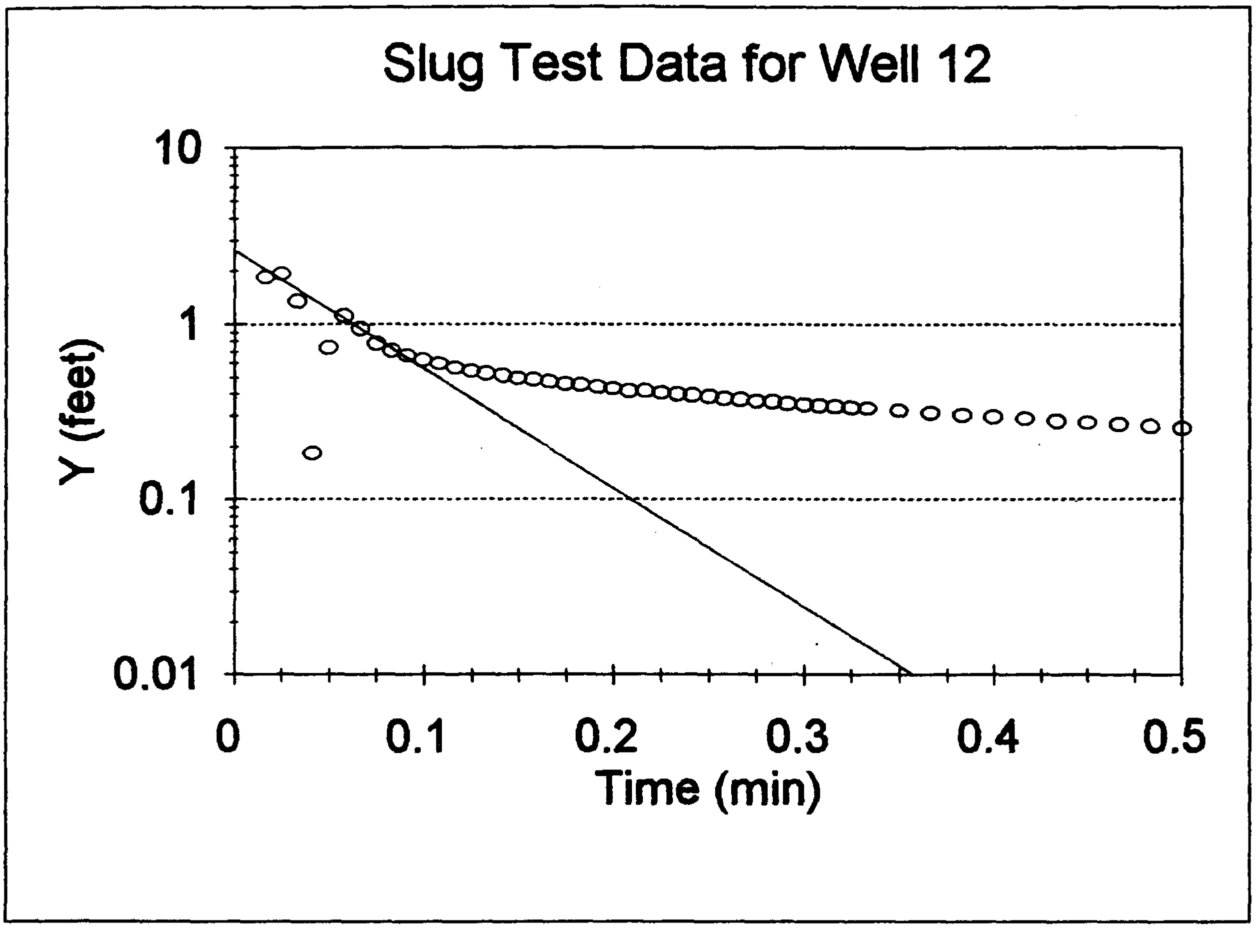
From Plot of Data:
Yo = 2.5 (Observed)
Yt = 0.01
t = 0.352 min

Solve for Hydraulic Conductivity (K):

K = rc^2*ln(Re/rw)/(2*L)*t^-1*ln(Yo/Yt)

K = 0.006115 ft/min

Change Units: **K = 8.81 ft/d**


Slug Test Data for Well 12
10
1
0.1
0.01
Y (feet)
0
0.1
0.2
0.3
0.4
0.5
Time (min)

Slug Test Calculations for Well 19

Bouwer and Rice (1976) Method

Slug Test Date: 02/05/94

Data:

Well Inner Diameter :	0.1667	Ft	
Casing Radius (rc)	0.0833	Ft	
Effective Radius (rw):	0.2500	Ft	
Total Well Depth:	55.00	Ft	
Well Screen Length (L)	12.00	Ft	
Dist. from TOWT to BOW (H):	7.22	Ft	
Saturated Thickness (D):	15.00	Ft	(Approximated)
Slug Volume:	0.0444	Ft^3	

TOWT = Top of Water-Table BOW = Bottom of Well

Calculate: Expected Initial Drawdown : 2.035 Ft (Approximated)

From Bouwer and Rice: L/rw = 48 dimensionless

From Bouwer & Rice Graph: A = 2.5
B = 0.45
C = N/A

Eqn A Ln(Re/Rw) = (1.1/ln((D/rw) + C/(L/rw))^-1 For Partially Penetrating Well

Eqn B Ln(Re/Rw) = (1.1/ln((D/rw) + A+(B*ln((D-H)/rw)/(L/rw); For Fully Penetrating Well

Check if : Ln((D-H)/rw) > 6 ; then Ln((D-H)/rw) = 6 is used in Eqn A

Ln((D-H)/rw) = 3.437851 Ok

Solving for Ln(Re/rw) : Ln(Re/rw) 2.430798 dimensionless

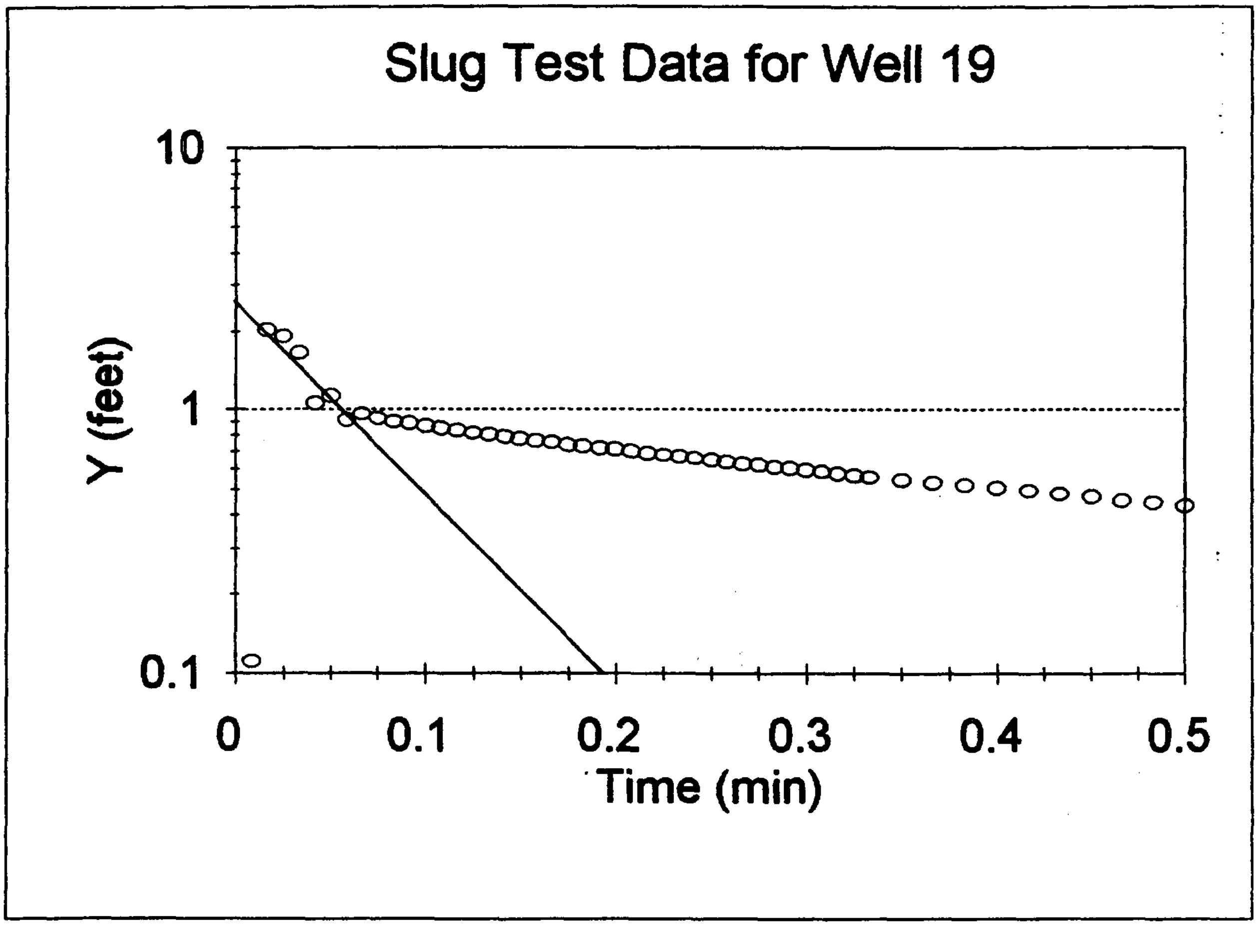
From Plot of Data: Yo = 2.7 (Observed)
Yt = 0.1
t = 0.19 min

Solve for Hydraulic Conductivity (K):

K = rc^2*ln(re/rw)/(2*L)*t^-1*ln(Yo/Yt)

K = 0.012201 ft/min

Change Units: $\boxed{K = 17.57 \text{ ft/d}}$



Slug Test Data for Well 19
10
1
0.1
Y (feet)
0
0.1
0.2
0.3
0.4
0.5
Time (min)

Slug Test Calculations for Well A, Halfmoon Lake

Bouwer and Rice (1976) Method

Slug Test Date: 10/29/93

Data:

Well Inner Diameter :	0.1667 Ft	
Casing Radius (rc)	0.0833 Ft	
Effective Radius (rw):	0.2500 Ft	
Total Well Depth:	50.00 Ft	
Well Screen Length (L)	25.00 Ft	
Dist. from TOWT to BOW (H):	10.00 Ft	
Saturated Thickness (D):	10.00 Ft	(Approximated)
Slug Volume:	0.0444 Ft^3	

TOWT = Top of Water-Table BOW = Bottom of Well

Calculate: Expected Initial Drawdown : 2.035 Ft (Approximated)

From Bouwer and Rice: L/rw = 100 dimensionless

From Bouwer & Rice Graph: A = N/A
B = N/A
C = 4

Eqn A Ln(Re/Rw) = (1.1/ln((D/rw) + C/(L/rw))^-1 For Partially Penetrating Well

Eqn B Ln(Re/Rw) = (1.1/ln((D/rw) + A+(B*ln((D-H)/rw)/(L/rw); For Fully Penetrating Well

Check if : Ln((D-H)/rw) > 6 ; then Ln((D-H)/rw) = 6 is used in Eqn A

Ln((D-H)/rw) = N/A Ok

Solving for Ln(Re/rw) : Ln(Re/rw) 2.956887 dimensionless

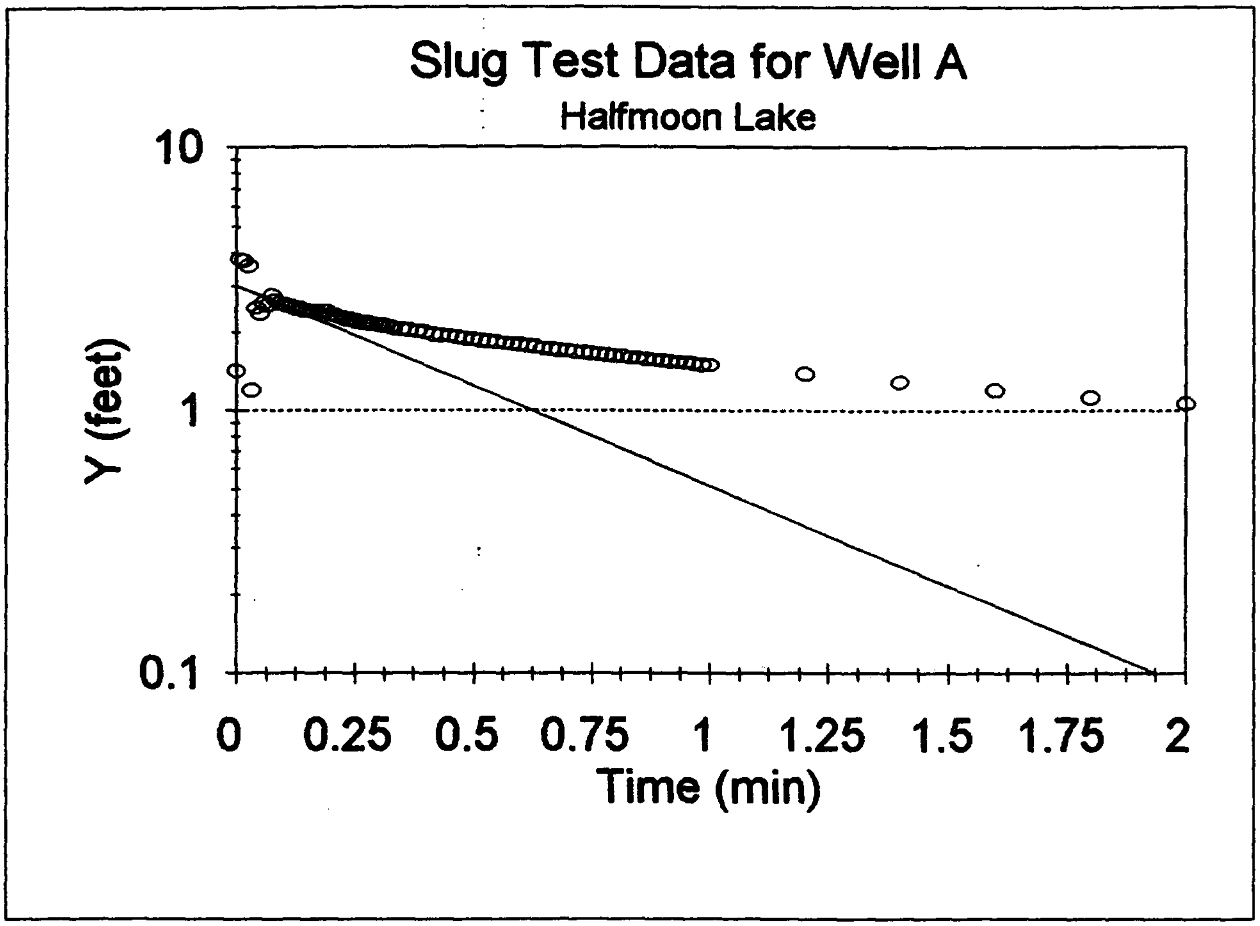
From Plot of Data: Yo = 3 (Observed)
Yt = 0.1
t = 1.94 min

Solve for Hydraulic Conductivity (K):

K = rc^2*ln(Re/rw)/(2*L)*t^-1*ln(Yo/Yt)

K = 0.00072 ft/min

Change Units: **K = 1.04 ft/d**


Slug Test Data for Well A
Halfmoon Lake
10
1
0.1
Y (feet)
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
Time (min)

Slug Test Calculations for Well B, Halfmoon Lake

Bouwer and Rice (1976) Method

Slug Test Date: 10/29/93

Data:

Well Inner Diameter :	0.1667	Ft	
Casing Radius (rc)	0.0833	Ft	
Effective Radius (rw):	0.2500	Ft	
Total Well Depth:	50.00	Ft	
Well Screen Length (L)	25.00	Ft	
Dist. from TOWT to BOW (H):	10.00	Ft	
Saturated Thickness (D):	10.00	Ft	(Approximated)
Slug Volume:	0.0444	Ft^3	

TOWT = Top of Water-Table BOW = Bottom of Well

Calculate: Expected Initial Drawdown : 2.035 Ft (Approximated)

From Bouwer and Rice: L/rw = 100 dimensionless

From Bouwer & Rice Graph: A = N/A
B = N/A
C = 4

Eqn A Ln(Re/Rw) = (1.1/ln((D/rw) + C/(L/rw))^-1 For Partially Penetrating Well

Eqn B Ln(Re/Rw) = (1.1/ln((D/rw) + A+(B*ln((D-H)/rw)/(L/rw); For Fully Penetrating Well

Check if : Ln((D-H)/rw) > 6 ; then Ln((D-H)/rw) = 6 is used in Eqn A

Ln((D-H)/rw) = N/A Ok

Solving for Ln(Re/rw) : Ln(Re/rw) 2.956887 dimensionless

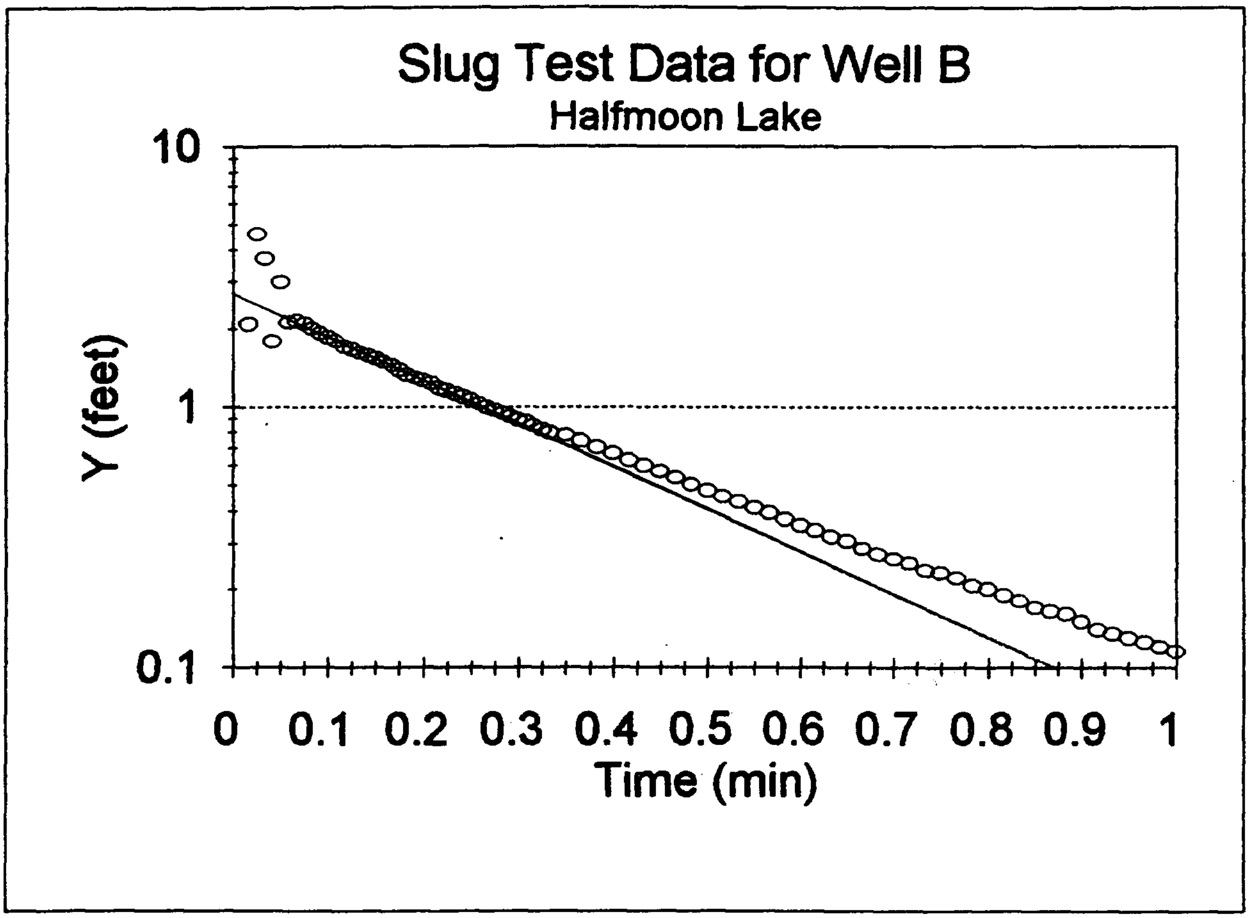
From Plot of Data: Yo = 1.94 (Observed)
Yt = 0.1
t = 0.875 min

Solve for Hydraulic Conductivity (K):

K = rc^2*ln(re/rw)/(2*L)*t^-1*ln(Yo/Yt)

K = 0.001392 ft/min

Change Units: **K = 2.00 ft/d**


Slug Test Data for Well B
Halfmoon Lake
10
1
0.1
Y (feet)
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Time (min)

Slug Test Calculations for Well C, Halfmoon Lake

Bouwer and Rice (1976) Method

Slug Test Date: 10/29/93

Data:

Well Inner Diameter :	0.1667	Ft	
Casing Radius (rc)	0.0833	Ft	
Effective Radius (rw):	0.2500	Ft	
Total Well Depth:	50.00	Ft	
Well Screen Length (L)	25.00	Ft	
Dist. from TOWT to BOW (H):	10.00	Ft	
Saturated Thickness (D):	10.00	Ft	(Approximated)
Slug Volume:	0.0444	Ft^3	

TOWT = Top of Water-Table BOW = Bottom of Well

Calculate: Expected Initial Drawdown : 2.035 Ft (Approximated)

From Bouwer and Rice: L/rw = 100 dimensionless

From Bouwer & Rice Graph:
A = N/A
B = N/A
C = 4

Eqn A Ln(Re/Rw) = (1.1/ln((D/rw) + C/(L/rw))^-1 For Partially Penetrating Well

Eqn B Ln(Re/Rw) = (1.1/ln((D/rw) + A+(B*ln((D-H)/rw)/(L/rw) For Fully Penetrating Well

Check if : Ln((D-H)/rw) > 6 ; then Ln((D-H)/rw) = 6 is used in Eqn A

Ln((D-H)/rw) = N/A Ok

Solving for Ln(Re/rw) : Ln(Re/rw) 2.956887 dimensionless

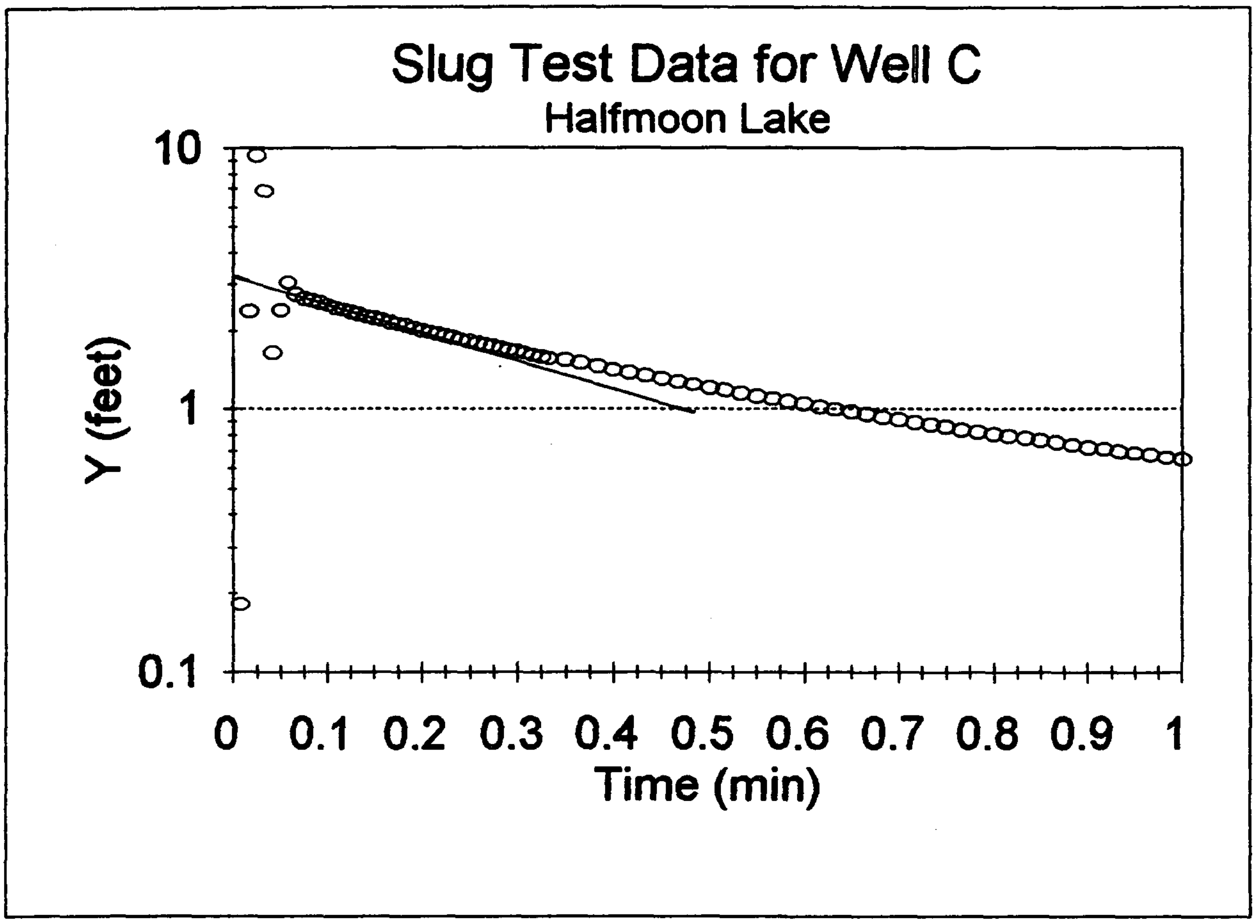
From Plot of Data:
Yo = 3.2 (Observed)
Yt = .1
t = 0.475 min

Solve for Hydraulic Conductivity (K):

K = rc^2*ln(re/rw)/(2*L)*t^-1*ln(Yo/Yt)

K = 0.001006 ft/min

Change Units: **K = 1.45 ft/d**


Slug Test Data for Well C
Halfmoon Lake
10
1
0.1
Y (feet)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Time (min)

Slug Test Calculations for Well P, Halfmoon Lake

Bouwer and Rice (1976) Method

Slug Test Date: 10/29/93

Data:

Well Inner Diameter :	0.3333	Ft	
Casing Radius (rc)	0.1667	Ft	
Effective Radius (rw):	0.3333	Ft	
Total Well Depth:	50.00	Ft	
Well Screen Length (L)	25.00	Ft	
Dist. from TOWT to BOW (H):	10.00	Ft	
Saturated Thickness (D):	10.00	Ft	(Approximated)
Slug Volume:	0.0444	Ft^3	

TOWT = Top of Water-Table BOW = Bottom of Well

Calculate: Expected Initial Drawdown : 0.509 Ft (Approximated)

From Bouwer and Rice: L/rw = 75 dimensionless

From Bouwer & Rice Graph: A = N/A
B = N/A
C = 3.75

Eqn A Ln(Re/Rw) = (1.1/ln((D/rw) + C/(L/rw))^-1 For Partially Penetrating Well

Eqn B Ln(Re/Rw) = (1.1/ln((D/rw) + A+(B*ln((D-H)/rw)/(L/rw); For Fully Penetrating Well

Check if : Ln((D-H)/rw) > 6 ; then Ln((D-H)/rw) = 6 is used in Eqn A

Ln((D-H)/rw) = N/A Ok

Solving for Ln(Re/rw) : Ln(Re/rw) 2.677982 dimensionless

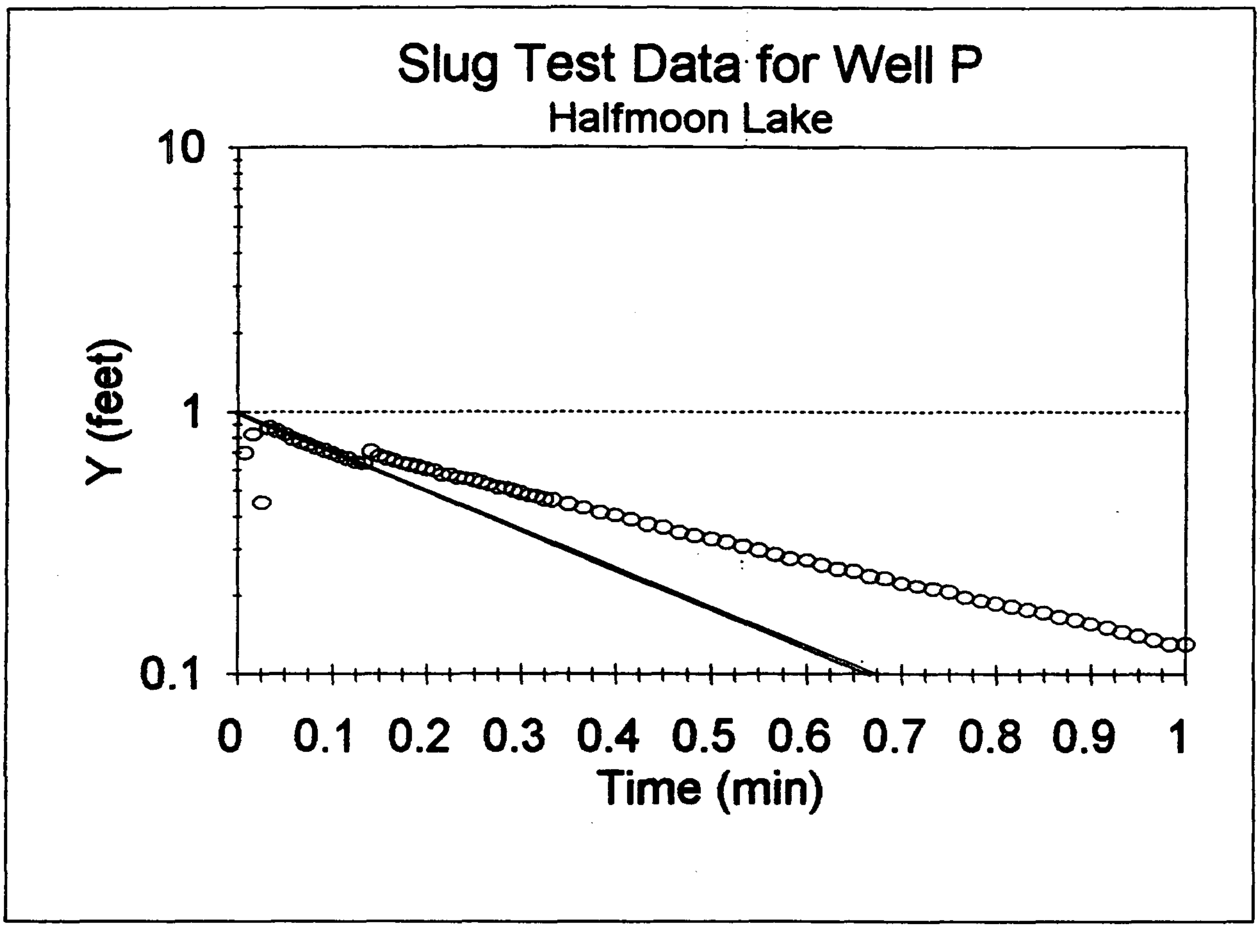
From Plot of Data: Yo = 1 (Observed)
Yt = 0.1
t = 0.675 min

Solve for Hydraulic Conductivity (K):

K = rc^2*ln(re/rw)/(2*L)*t^-1*ln(Yo/Yt)

K = 0.005075 ft/min

Change Units: **K = 7.31 ft/d**



Slug Test Data for Well P
Halfmoon Lake
10
1
0.1
Y (feet)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Time (min)

Appendix C

Pump Test Calculations

Pump Test Analysis Calculations, Neuman 1975 Method
Halfmoon Lake, Test # 9 Well A

Pump Data:
Average Pumping Rate: Q = 8.70 gpm

Well Data:
Distance from Pumping Well: r = 19.85 ft
Total Aquifer Thickness: b = 20 ft

Slope Data:
Late drawdown slope: dSL = 0.530 ft
Early drawdown slope: dSE = 0.492 ft

Time Data
Time at late slope intercept (tL) 13 min
Time at early slope intercept (tE) 0.8 min
Time at intersection Horiz and Late data (tBeta) 190 min

Convert Flow to consistent units: Calc: Q = 1674.75 Ft^3/d

Calculate Transmissivity:
T = C3*(Q/dSL) C3 = 2.303/(4*@PI) C3 = 0.183267

Calculate Transmissivity w/late slope: TL = 579 Ft^2/d

Calculate Transmissivity w/early slope: TE= 624 Ft^2/d

Average Transmissivity: T = 601 Ft^2/d

Calculate Specific Yeild:

Sy = C4*(T*tL/r^2) C4 = 2.246
Change tL to days: tL = 0.009028 days

Specific Yeild: Sy = 0.0298 unitless

Calculate Dimensionless time parameter, tyBeta
change tBeta days: tBeta = 0.131944 days tyBeta = 6.758593 unitless

For : 4.0 < tyBeta <100.0 ;
Beta = 0.195/(tyBeta^1.1053) Beta = 0.023594 unitless

Calculate Storage from early data: S = C4*(T*tE/r^2)

Change tE to days: tL = 0.000556 days S = 0.0020 unitless

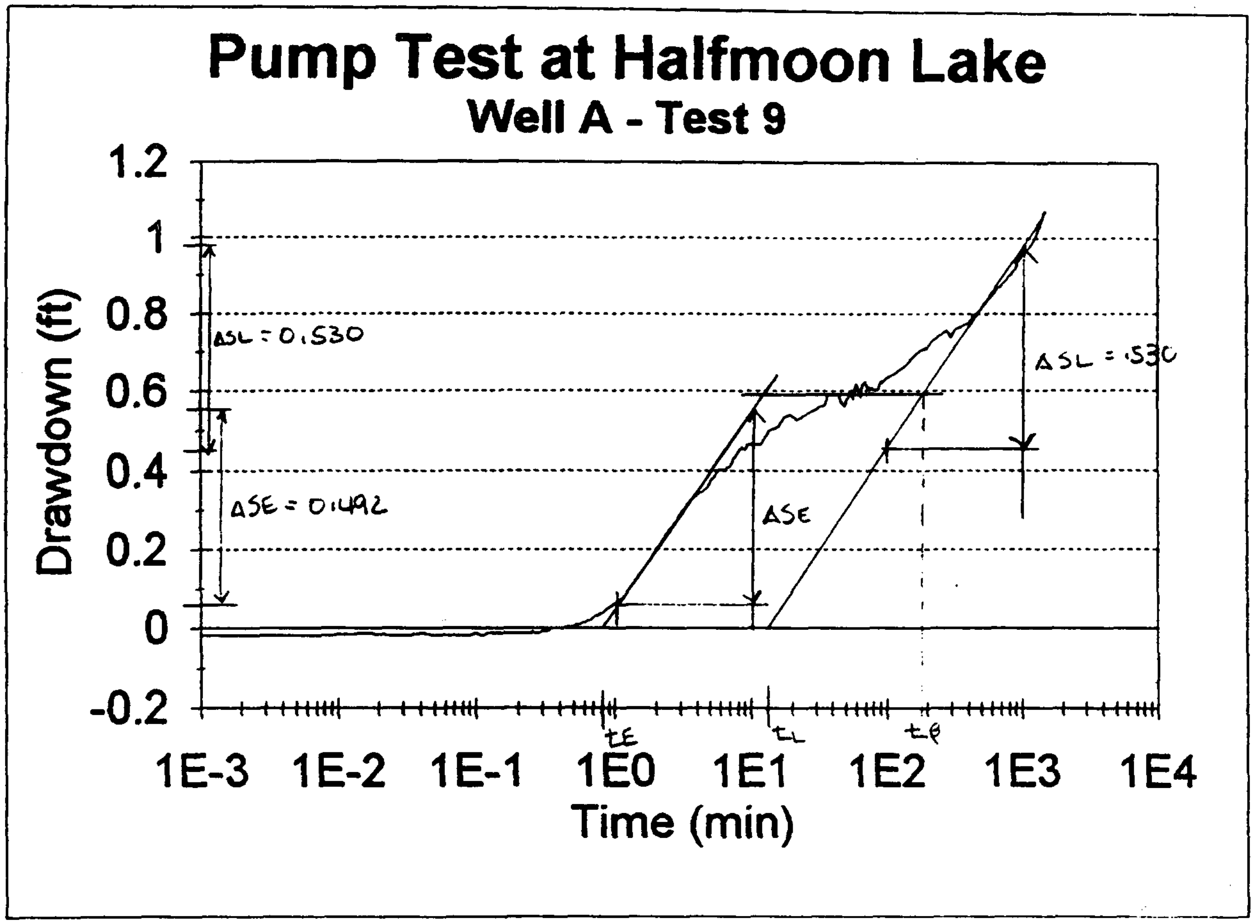
Calculate Specific Storage: Ss = S/b Ss = 9.9E-05 unitless

Calculate Horiz. Permeability: Kr = T/b Kr = 30 Ft/d

Calculate Degree of Anisotropy: KD = Beta*b^2/r^2 KD = 0.0240

Calculate Vertical Permeability: KZ = KD*Kr 128 KZ = 0.72 Ft/d

Calculate Sigma: Sigma = S/Sy Sigma = 0.066


Pump Test at Halfmoon Lake
Well A - Test 9
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
Drawdown (ft)
ΔSL = 0.530
ΔSE = 0.492
ΔSE
ΔSL = .530
tE
tL
tθ
1E-3
1E-2
1E-1
1E0
1E1
1E2
1E3
1E4
Time (min)

Pump Test Analysis Calculations, Neuman 1975 Method
Halfmoon Lake, Test # 9 Well B

Pump Data:
Average Pumping Rate: Q = 8.70 gpm

Well Data:
Distance from Pumping Well: r = 58.85 ft
Total Aquifer Thickness: b = 20 ft

Slope Data:
Late drawdown slope: dSL = 0.476 ft
Early drawdown slope: dSE = 0 ft

Time Data
Time at late slope intercept (tL) 110 min
Time at early slope intercept (tE) 0 min
Time at intersection Horiz and Late data (tBeta) 0 min

Convert Flow to consistent units: Calc: | Q = 1674.75 Ft^3/d |

Calculate Transmissivity:
T = C3*(Q/dSL) C3 = 2.303/(4*@PI) C3 = 0.183267

Calculate Transmissivity w/late slope: | TL = 645 Ft^2/d |

Calculate Transmissivity w/early slope: | TE= Ft^2/d |

Average Transmissivity: | T = 645 Ft^2/d |

Calculate Specific Yeild:

Sy = C4*(T*tL/r^2) C4 = 2.246
Change tL to days: tL = 0.076389 days

Specific Yeild: | Sy = 0.0319 unitless |

Calculate Dimensionless time parameter, tyBeta
change tBeta days: tBeta = 0 days | tyBeta = 0 unitless |

For: 4.0 < tyBeta <100.0 ;
Beta = 0.195/(tyBeta^1.1053) | Beta = unitless |

Calculate Storage from early data: S = C4*(T*tE/r^2)

Change tE to days: tL = 0 days | S = unitless |

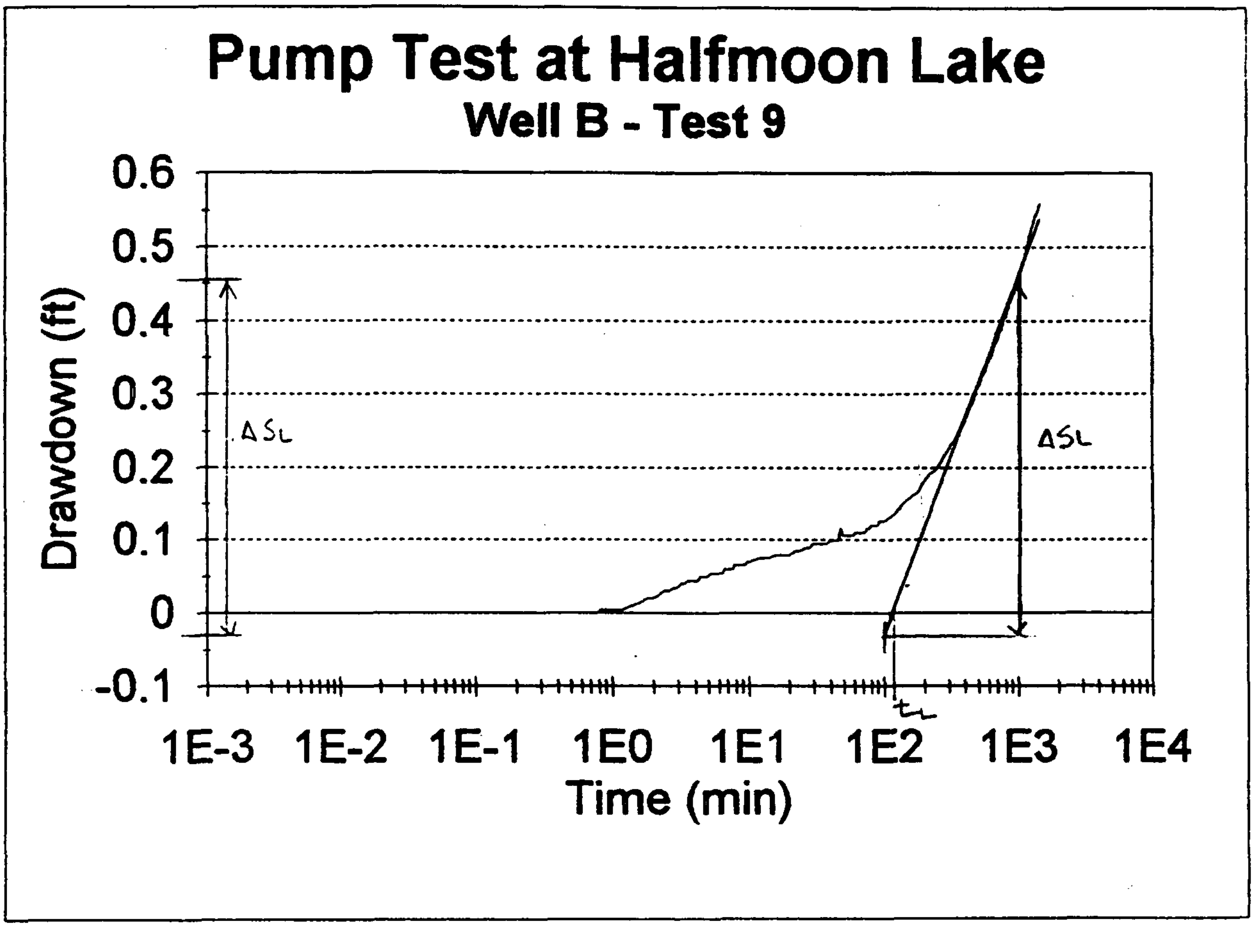
Calculate Specific Storage: Ss = S/b | Ss = unitless |

Calculate Horiz. Permeability: Kr = T/b | Kr = 32 Ft/d |

Calculate Degree of Anisotropy: KD = Beta*b^2/r^2 | KD = |

Calculate Vertical Permeability: KZ = KD*Kr | KZ = Ft/d |

Calculate Sigma: Sigma = S/Sy | Sigma = |



Pump Test at Halfmoon Lake
Well B - Test 9
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
Drawdown (ft)
ΔSL
ΔSL
tL
1E-3
1E-2
1E-1
1E0
1E1
1E2
1E3
1E4
Time (min)

Recovery Test Analysis Calculations, Neuman 1975 Method
Halfmoon Lake, Test # 10 Well A

Pump Data:
Average Pumping Rate: Q = 8.70 gpm

Well Data:
Distance from Pumping Well: r = 19.85 ft
Total Aquifer Thickness: b = 20 ft

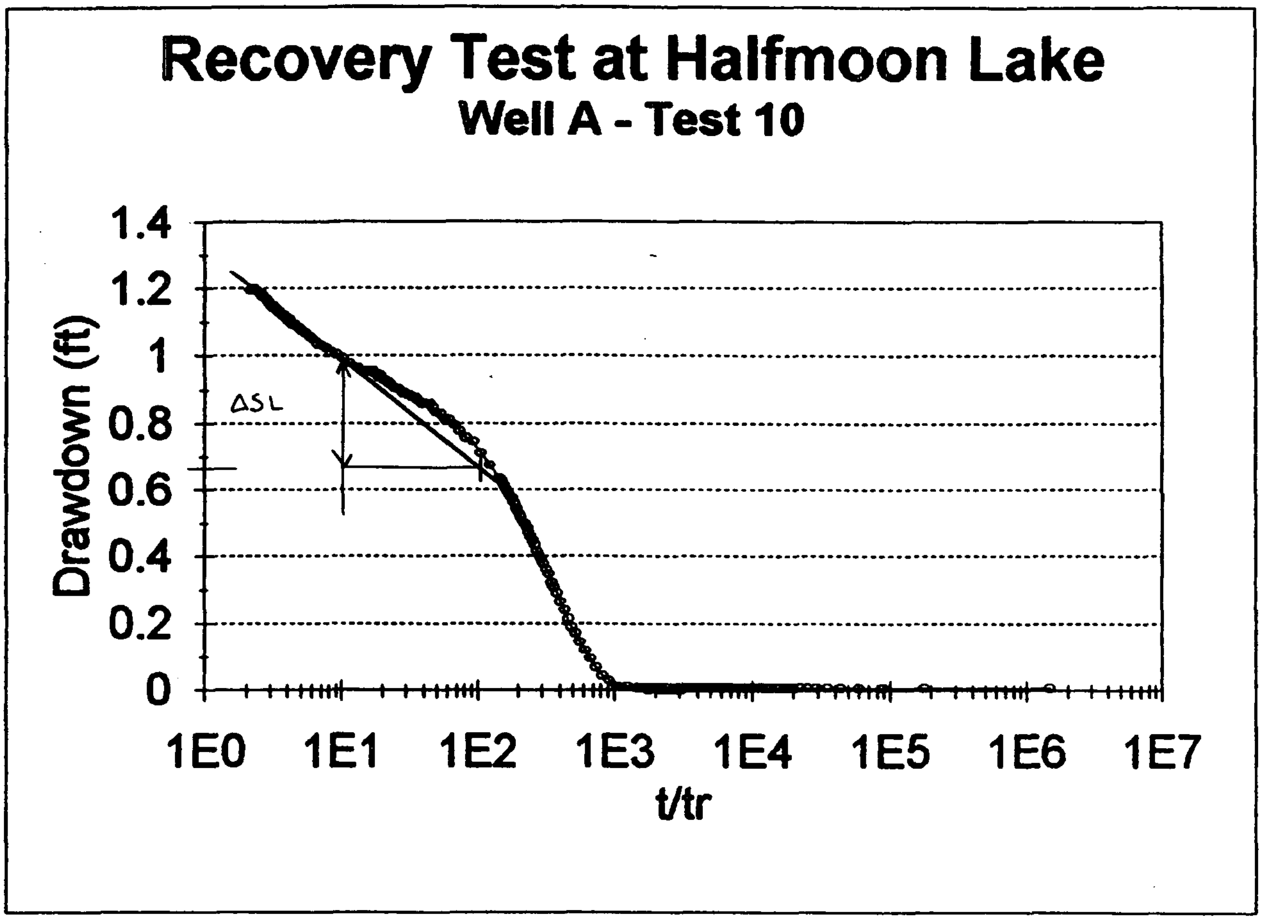
Slope Data:
Late drawdown slope: dSL = 0.316 ft

Convert Flow to consistent units: Calc: **Q = 1674.75 Ft^3/d**

Calculate Transmissivity:
T = C3*(Q/dSL) C3 = 2.303/(4*@PI) C3 = 0.183267

Calculate Transmissivity w/late slope: **TL = 971 Ft^2/d**

Calculate Horiz. Permeability: Kr = T/b **Kr = 49 Ft/d**



Recovery Test at Halfmoon Lake
Well A - Test 10
Drawdown (ft)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
ΔSL
1E0
1E1
1E2
1E3
1E4
1E5
1E6
1E7
t/tr

Recovery Test Analysis Calculations, Neuman 1975 Method
Halfmoon Lake, Test # 10 Well B

Pump Data:

Average Pumping Rate:	Q =	8.70 gpm

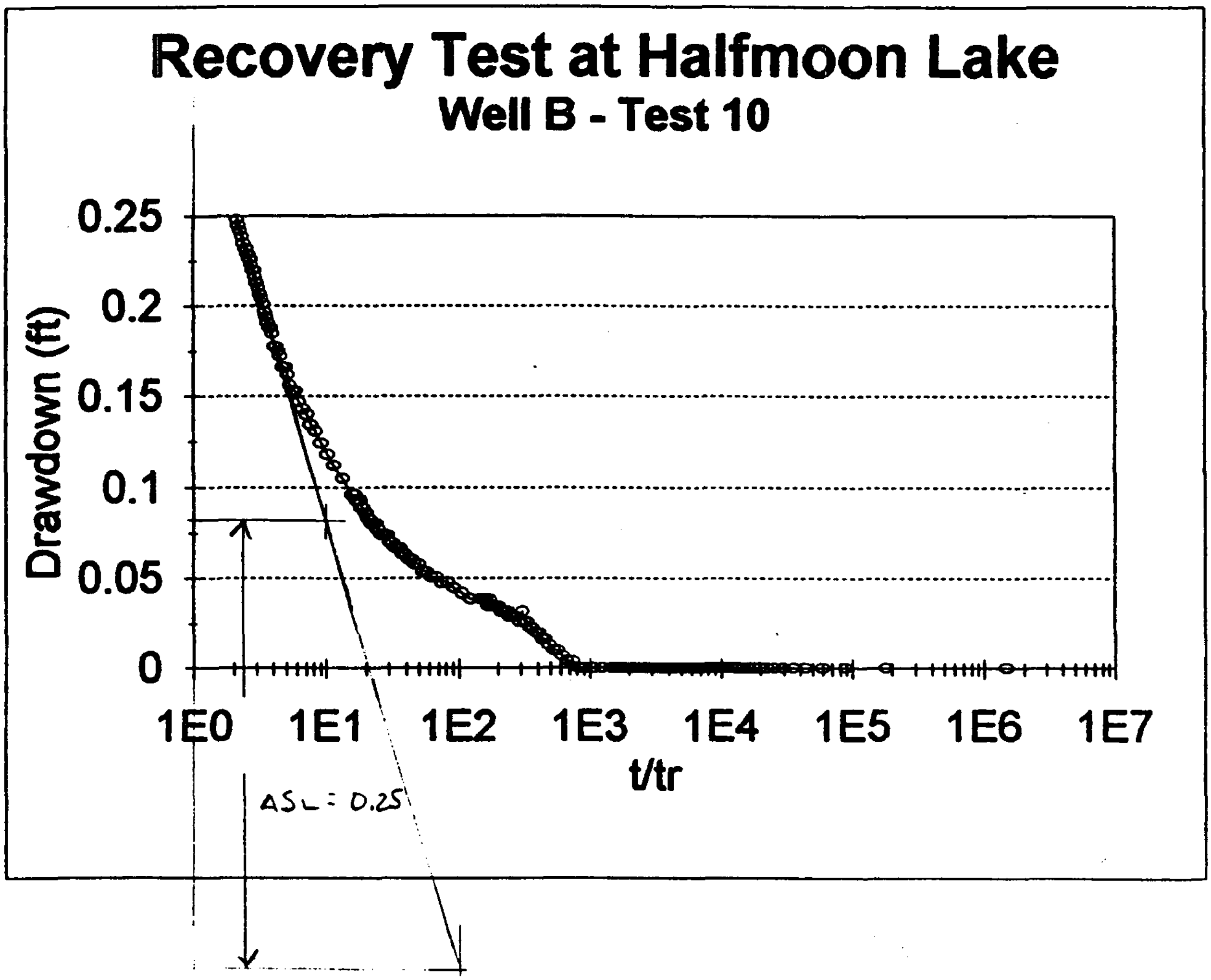
Well Data:

Distance from Pumping Well:	r =	58.85 ft
Total Aquifer Thickness:	b =	20 ft

Slope Data:

Late drawdown slope:	dSL =	0.249 ft

Convert Flow to consistent units:		Calc:	Q =	1674.75 Ft^3/d
Calculate Transmissivity:				
T = C3*(Q/dSL)	C3 = 2.303/(4*@PI)		C3 =	0.183267
Calculate Transmissivity w/late slope:			TL =	1233 Ft^2/d
Calculate Horiz. Permeability:	Kr = T/b		Kr =	62 Ft/d



Recovery Test at Halfmoon Lake
Well B - Test 10
Drawdown (ft)
0.25
0.2
0.15
0.1
0.05
0
1E0
1E1
1E2
1E3
1E4
1E5
1E6
1E7
t/tr
ΔSL = 0.25

Pump Test Analysis Calculations, Neuman 1975 Method
Halfmoon Lake, Test # 11 Well A

Pump Data:
Average Pumping Rate: Q = 5.00 gpm

Well Data:
Distance from Pumping Well: r = 19.85 ft
Total Aquifer Thickness: b = 20 ft

Slope Data:
Late drawdown slope: dSL = 0.221 ft
Early drawdown slope: dSE = 0 ft

Time Data
Time at late slope intercept (tL) 0.81 min
Time at early slope intercept (tE) 0 min
Time at intersection Horiz and Late data (tBeta) 0 min

Convert Flow to consistent units: Calc: | Q = 962.50 Ft^3/d |

Calculate Transmissivity:
T = C3*(Q/dSL) C3 = 2.303/(4*@PI) C3 = 0.183267

Calculate Transmissivity w/late slope: | TL = 798 Ft^2/d |

Calculate Transmissivity w/early slope: | TE= Ft^2/d |

Average Transmissivity: | T = 798 Ft^2/d |

Calculate Specific Yeild:

Sy = C4*(T*tL/r^2) C4 = 2.246
Change tL to days: tL = 0.000563 days

Specific Yeild: | Sy = 0.0026 unitless |

Calculate Dimensionless time parameter, tyBeta
change tBeta days: tBeta = 0 days | tyBeta = 0 unitless |

For : 4.0 < tyBeta <100.0 ;
Beta = 0.195/(tyBeta^1.1053) | Beta = unitless |

Calculate Storage from early data: S = C4*(T*tE/r^2)

Change tE to days: tL = 0 days | S = unitless |

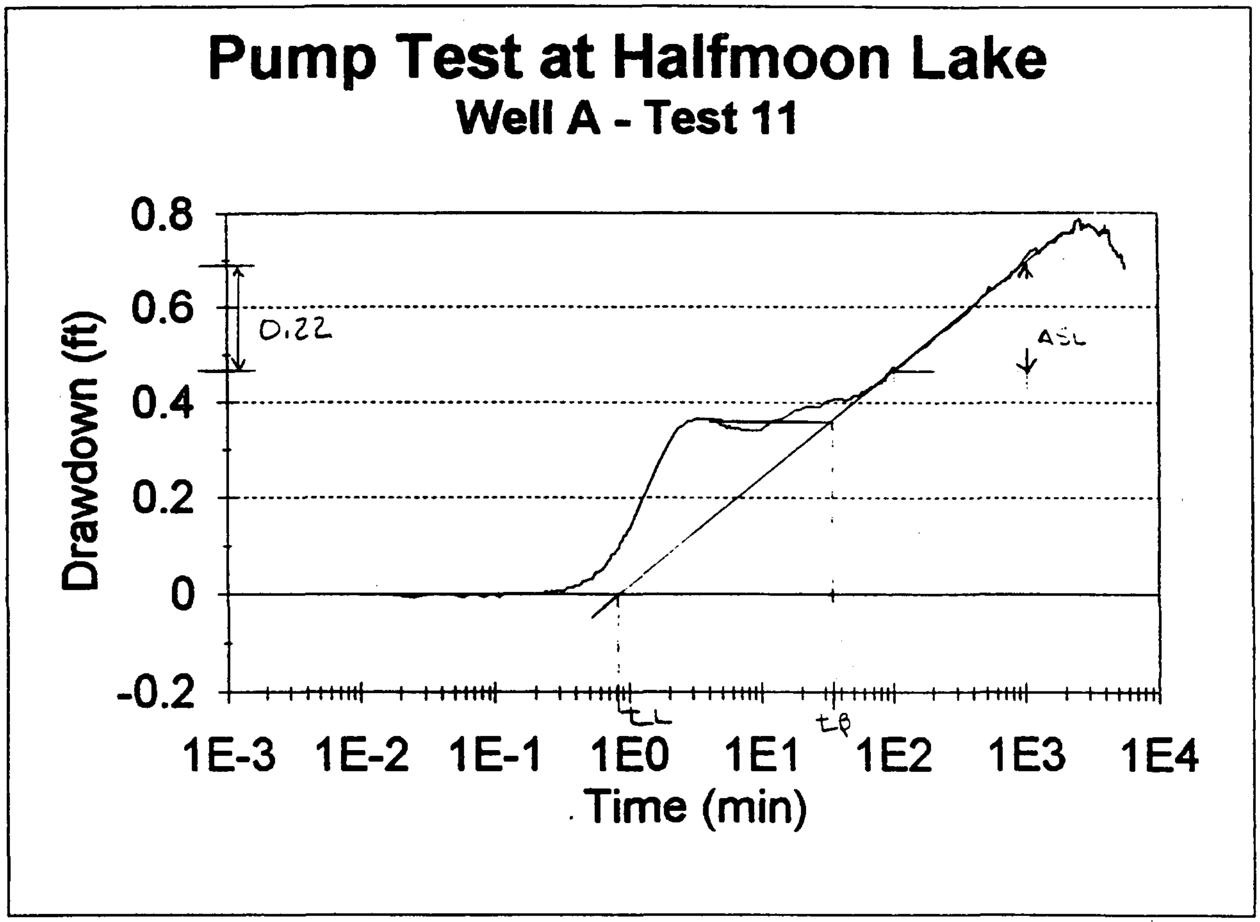
Calculate Specific Storage: Ss = S/b | Ss = unitless |

Calculate Horiz. Permeability: Kr = T/b | Kr = 40 Ft/d |

Calculate Degree of Anisotropy: KD = Beta*b^2/r^2 | KD = |

Calculate Vertical Permeability: KZ = KD*Kr | KZ = Ft/d |

Calculate Sigma: Sigma = S/Sy | Sigma = |



Pump Test at Halfmoon Lake
Well A - Test 11
0.8
0.6
0.4
0.2
0
-0.2
Drawdown (ft)
0.22
ASL
tL
tβ
1E-3 1E-2 1E-1 1E0 1E1 1E2 1E3 1E4
Time (min)

Pump Test Analysis Calculations, Neuman 1975 Method
Halfmoon Lake, Test # 11 Well B

Pump Data:		
Average Pumping Rate:	Q =	5.00 gpm
Well Data:		
Distance from Pumping Well:	r =	58.85 ft
Total Aquifer Thickness:	b =	20 ft
Slope Data:		
Late drawdown slope:	dSL =	0.162 ft
Early drawdown slope:	dSE =	0 ft

Time Data

Time at late slope intercept (tL)	20 min
Time at early slope intercept (tE)	0 min
Time at intersection Horiz and Late data (tBeta)	63 min

Convert Flow to consistent units: Calc: **Q = 962.50 Ft^3/d**

Calculate Transmissivity:
T = C3*(Q/dSL) C3 = 2.303/(4*@PI) C3 = 0.183267

Calculate Transmissivity w/late slope: **TL = 1089 Ft^2/d**

Calculate Transmissivity w/early slope: **TE= Ft^2/d**

Average Transmissivity: **T = 1089 Ft^2/d**

Calculate Specific Yeild:

Sy = C4*(T*tL/r^2) C4 = 2.246
Change tL to days: tL = 0.013889 days

Specific Yeild: **Sy = 0.0098 unitless**

Calculate Dimensionless time parameter, tyBeta
change tBeta days: tBeta = 0.04375 days **tyBeta = 1.402681 unitless**

For : 4.0 < tyBeta <100.0 ;
Beta = 0.195/(tyBeta^1.1053) **Beta = unitless**

Calculate Storage from early data: S = C4*(T*tE/r^2)

Change tE to days: tL = 0 days **S = unitless**

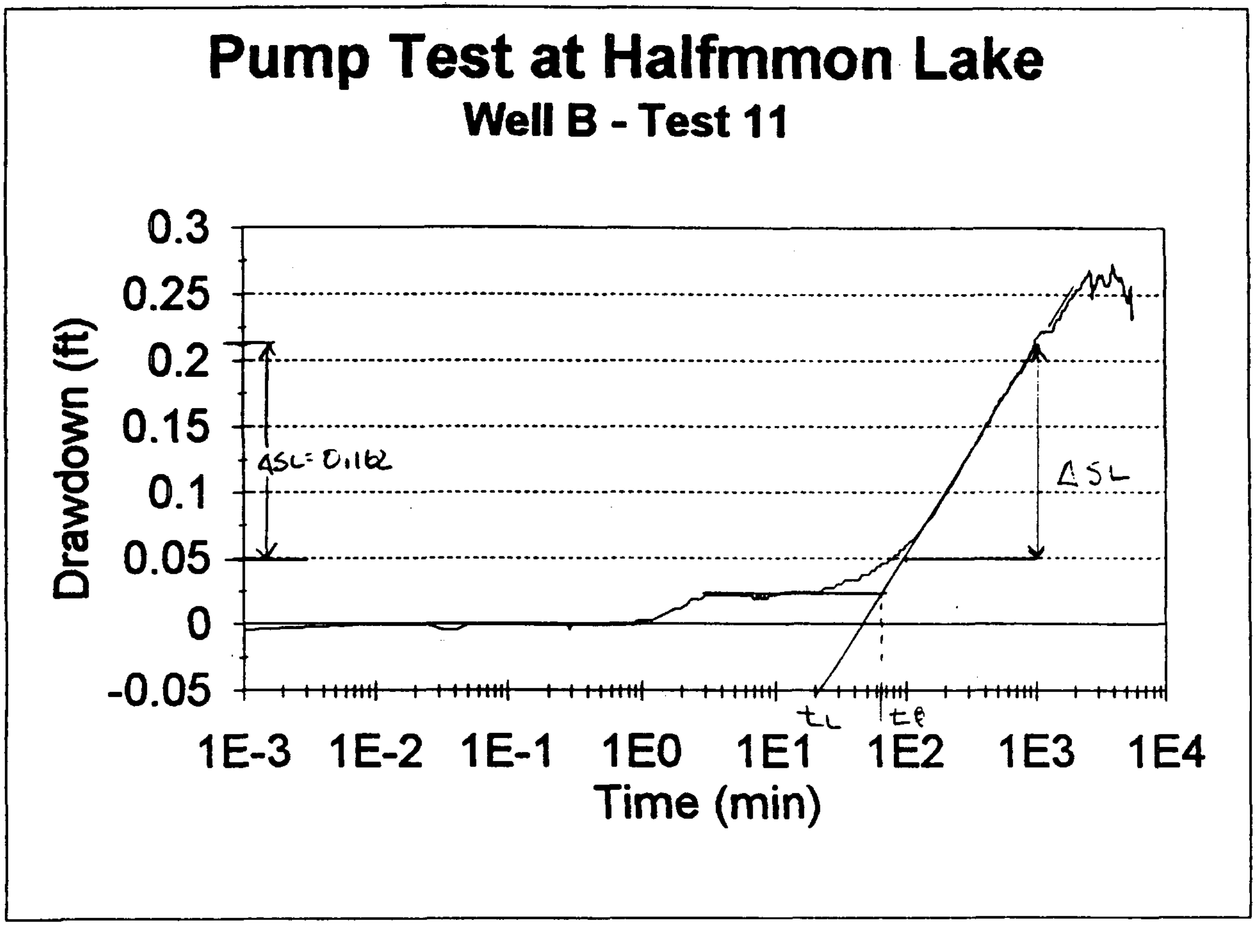
Calculate Specific Storage: Ss = S/b **Ss = unitless**

Calculate Horiz. Permeability: Kr = T/b **Kr = 54 Ft/d**

Calculate Degree of Anisotropy: KD = Beta*b^2/r^2 **KD =**

Calculate Vertical Permeability: KZ = KD*Kr **KZ = Ft/d**

Calculate Sigma: Sigma = S/Sy **Sigma =**


Pump Test at Halfmmon Lake
Well B - Test 11
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
Drawdown (ft)
ΔSL= 0.162
ΔSL
tL
te
1E-3
1E-2
1E-1
1E0
1E1
1E2
1E3
1E4
Time (min)

Recovery Test Analysis Calculations, Neuman 1975 Method
Halfmoon Lake, Test # 12 Well A

Pump Data:

Average Pumping Rate:	Q =	5.00 gpm

Well Data:

Distance from Pumping Well:	r =	19.85 ft
Total Aquifer Thickness:	b =	20 ft

Slope Data:

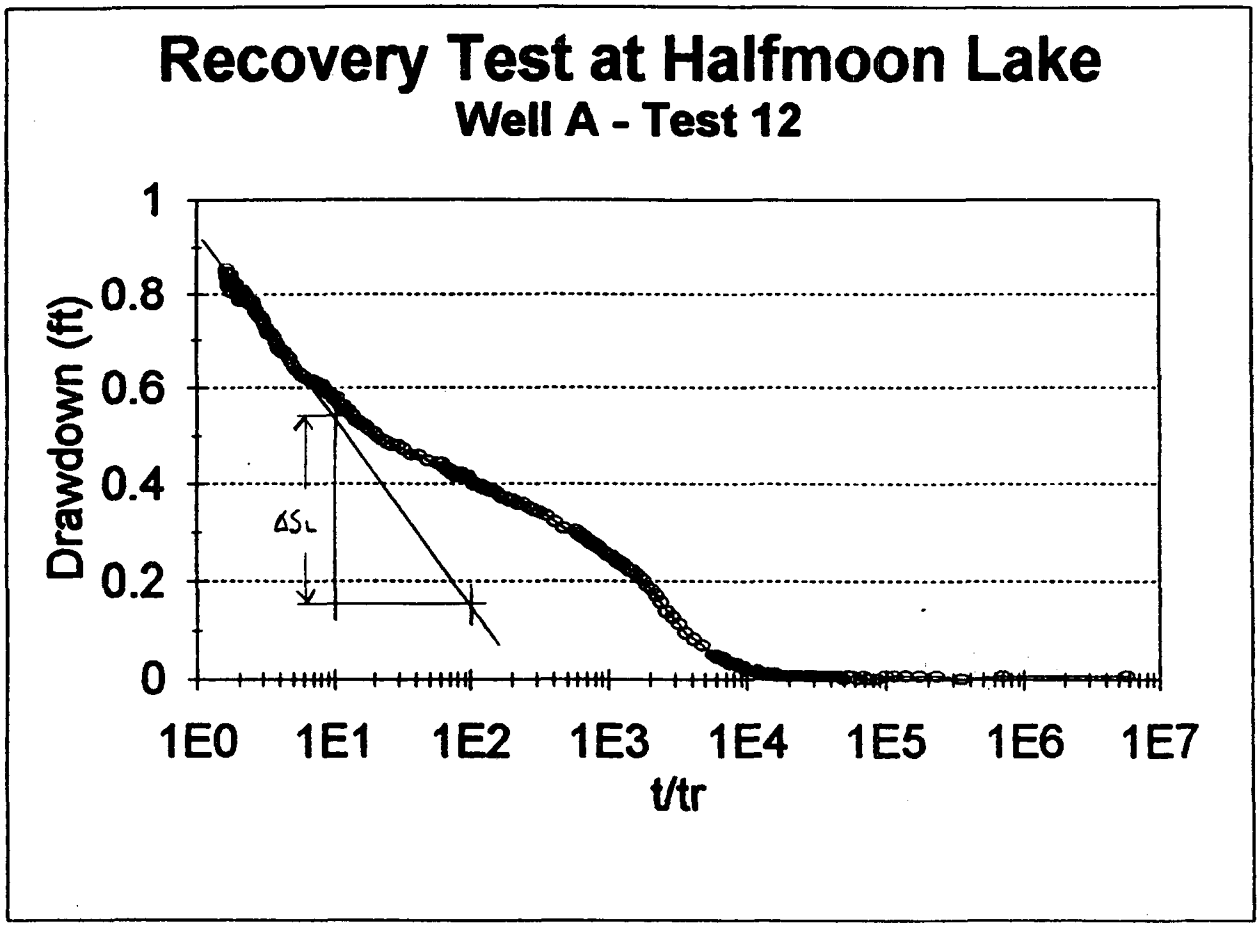
Late drawdown slope:	dSL =	0.385 ft

Convert Flow to consistent units: Calc: **Q = 962.50 Ft^3/d**

Calculate Transmissivity:
T = C3*(Q/dSL) C3 = 2.303/(4*@PI) C3 = 0.183267

Calculate Transmissivity w/late slope: **TL = 458 Ft^2/d**

Calculate Horiz. Permeability: Kr = T/b **Kr = 23 Ft/d**



Recovery Test at Halfmoon Lake
Well A - Test 12
Drawdown (ft)
1
0.8
0.6
0.4
0.2
0
ΔSL
1E0
1E1
1E2
1E3
1E4
1E5
1E6
1E7
t/tr

Recovery Test Analysis Calculations, Neuman 1975 Method
Halfmoon Lake, Test # 12 Well B

Pump Data:

Average Pumping Rate:	Q =	5.00 gpm

Well Data:

Distance from Pumping Well:	r =	58.85 ft
Total Aquifer Thickness:	b =	20 ft

Slope Data:

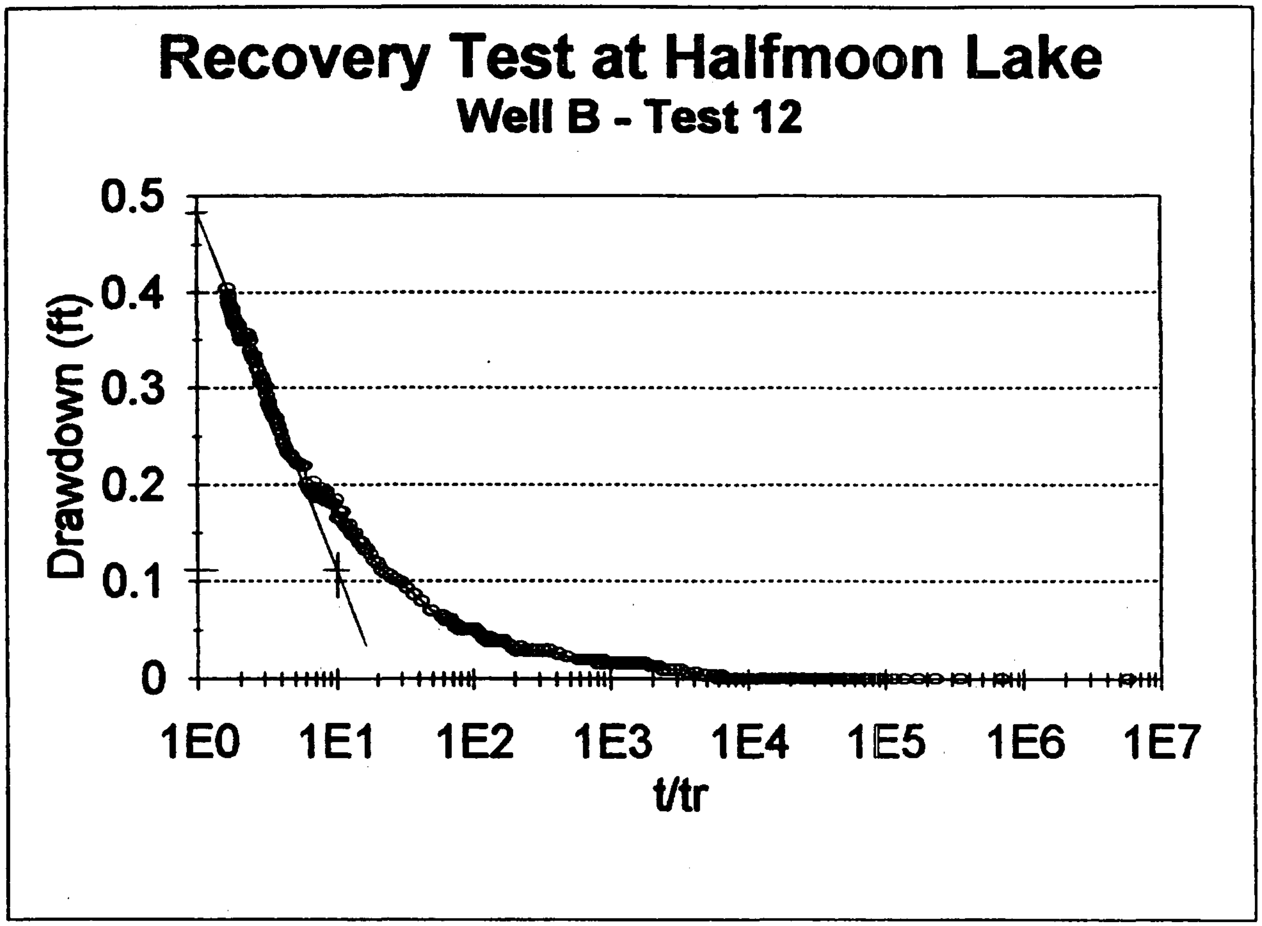
Late drawdown slope:	dSL =	0.369 ft

Convert Flow to consistent units: Calc: | Q = 962.50 Ft^3/d |

Calculate Transmissivity:
T = C3*(Q/dSL) C3 = 2.303/(4*@PI) C3 = 0.183267

Calculate Transmissivity w/late slope: | TL = 478 Ft^2/d |

Calculate Horiz. Permeability: Kr = T/b | Kr = 24 Ft/d |



Recovery Test at Halfmoon Lake
Well B - Test 12
Drawdown (ft)
0.5
0.4
0.3
0.2
0.1
0
1E0
1E1
1E2
1E3
1E4
1E5
1E6
1E7
t/tr

Pump Test Analysis Calculations, Neuman 1975 Method
Camp Blanding , Test # 0 Well A

Pump Data:
Average Pumping Rate: Q = 9.12 gpm

Well Data:
Distance from Pumping Well: r = 82.5 ft
Total Aquifer Thickness: b = 58.01 ft

Slope Data:
Late drawdown slope: dSL = 0.530 ft
Early drawdown slope: dSE = 0.64 ft

Time Data
Time at late slope intercept (tL) 11 min
Time at early slope intercept (tE) 2.5 min
Time at intersection Horiz and Late data (tBeta) 190 min

Convert Flow to consistent units: Calc: | Q = 1755.60 Ft^3/d |

Calculate Transmissivity:
T = C3*(Q/dSL) C3 = 2.303/(4*@PI) C3 = 0.183267

Calculate Transmissivity w/late slope: | TL = 607 Ft^2/d |

Ft

Calculate Transmissivity w/early slope: | TE= 503 Ft^2/d |

Average Transmissivity: | T = 555 Ft^2/d |

Calculate Specific Yeild:

Sy = C4*(T*tL/r^2) C4 = 2.246
Change tL to days: tL = 0.007639 days

Specific Yeild: | Sy = 0.0015 unitless |

Calculate Dimensionless time parameter, tyBeta
change tBeta days: tBeta = 0.131944 days | tyBeta = 7.029542 unitless |

For : 4.0 < tyBeta <100.0 ;
Beta = 0.195/(tyBeta^1.1053) | Beta = 0.022591 unitless |

Calculate Storage from early data: S = C4*(T*tE/r^2)

Change tE to days: tL = 0.001736 days | S = 0.0003 unitless |

Calculate Specific Storage: Ss = S/b | Ss = 4.96E-06 unitless |

Calculate Horiz. Permeability: Kr = T/b | Kr = 10 Ft/d |

Calculate Degree of Anisotropy: KD = Beta*b^2/r^2 | KD = 0.0112 |

Calculate Vertical Permeability: KZ = KD*Kr | KZ = 0.11 Ft/d |

Calculate Sigma: Sigma = S/Sy | Sigma = 0.188 |

Recovery Test Analysis Calculations, Neuman 1975 Method
Camp Blanding, Test # 1

Pump Data:

Average Pumping Rate:	Q =	9.12	gpm

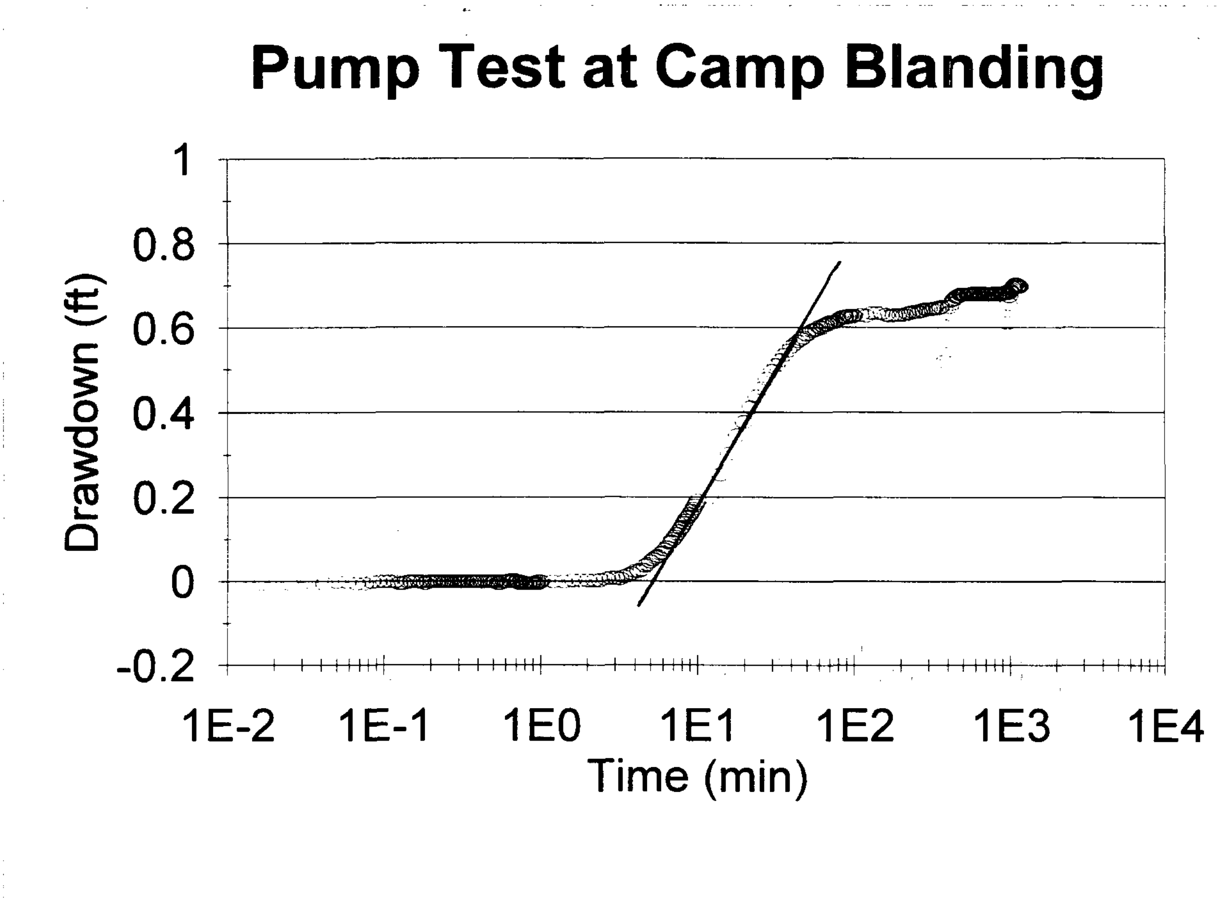
Well Data:

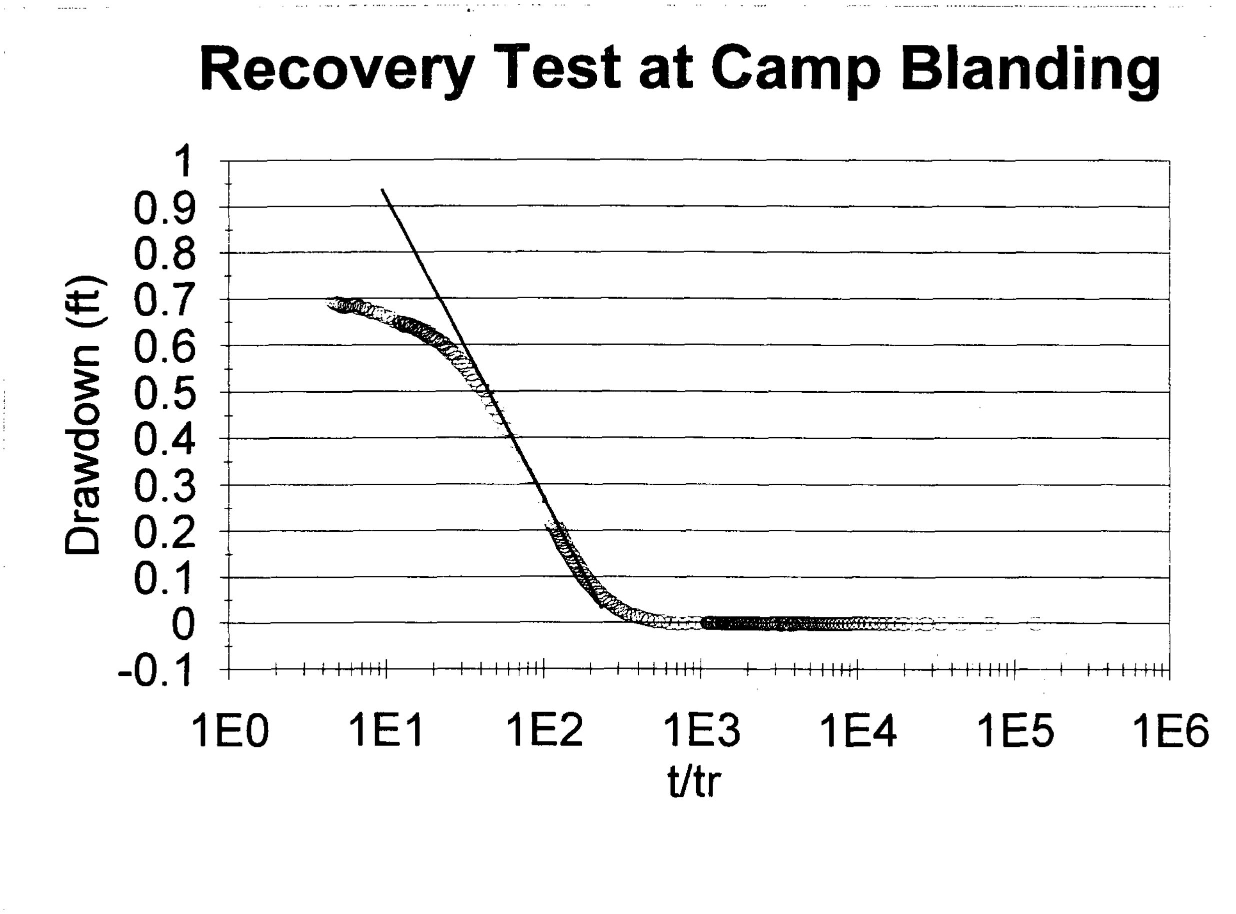
Distance from Pumping Well:	r =	82.5	ft
Total Aquifer Thickness:	b =	58.01	ft

Slope Data:

Late drawdown slope:	dSL =	0.660	ft

Convert Flow to consistent units:		Calc:	**Q =**	**1755.60 Ft^3/d**
Calculate Transmissivity:				
T = C3*(Q/dSL)	C3 =	2.303/(4*@PI)	C3 =	0.183267
Calculate Transmissivity w/late slope:			**TL =**	**487 Ft^2/d**
Calculate Horiz. Permeability:	Kr = T/b		**Kr =**	**8 Ft/d**


Pump Test at Camp Blanding
Drawdown (ft)
1
0.8
0.6
0.4
0.2
0
-0.2
1E-2
1E-1
1E0
1E1
1E2
1E3
1E4
Time (min)


Recovery Test at Camp Blanding
Drawdown (ft)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
1E0
1E1
1E2
1E3
1E4
1E5
1E6
t/tr

Appendix D

Gamma Logs

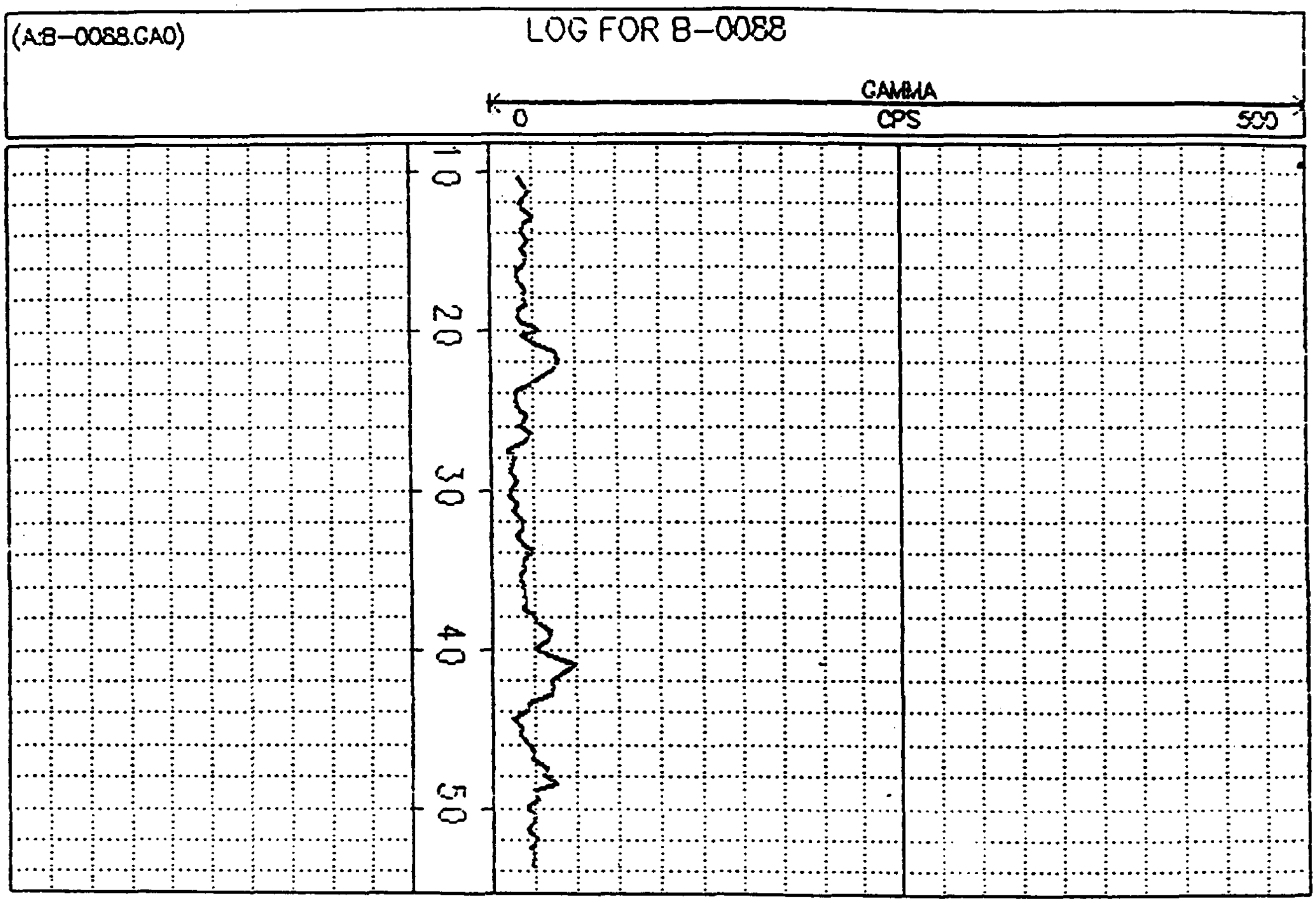


Figure D.1 Gamma log for well number 1

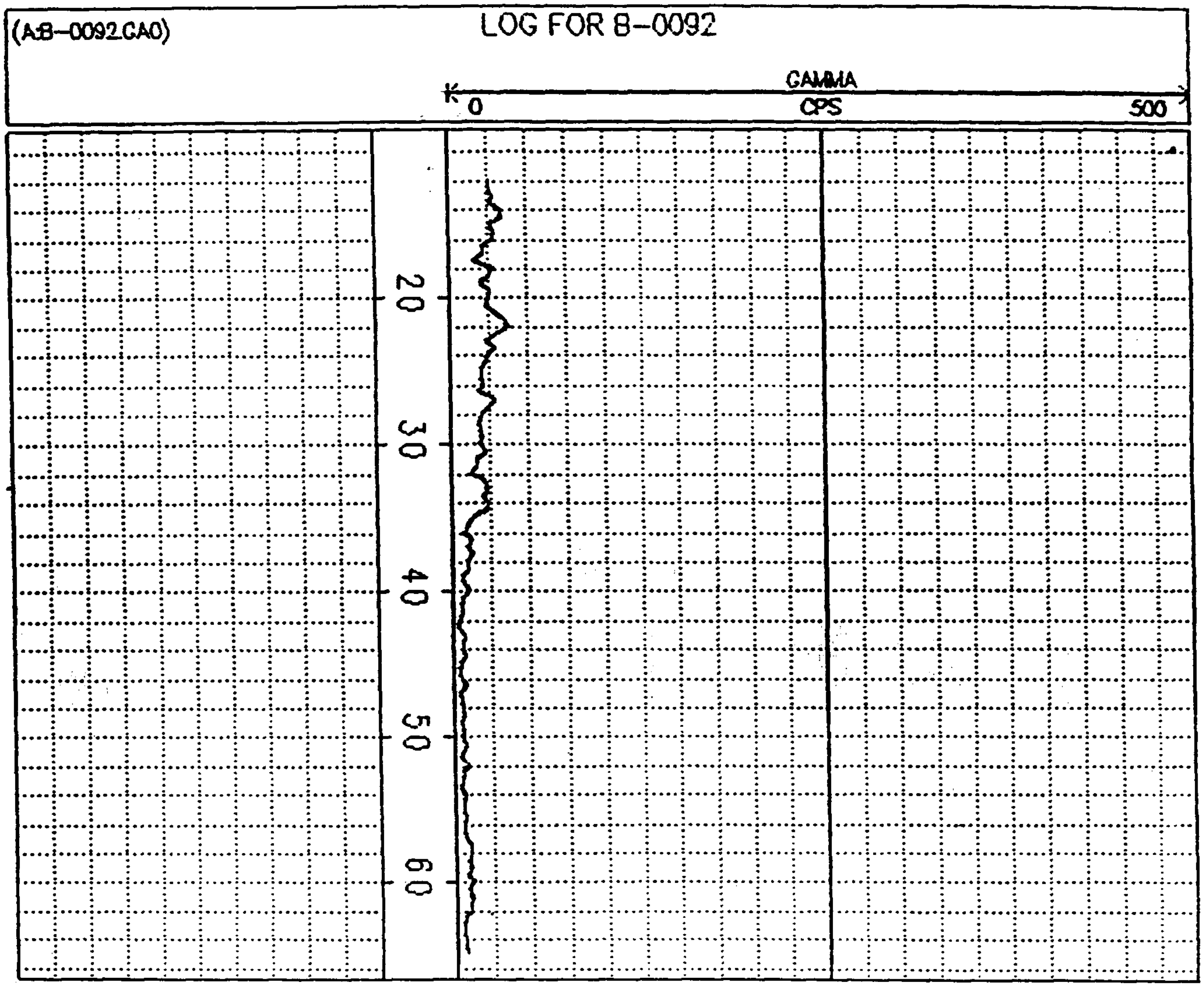


Figure D.2 Gamma log for well number 2

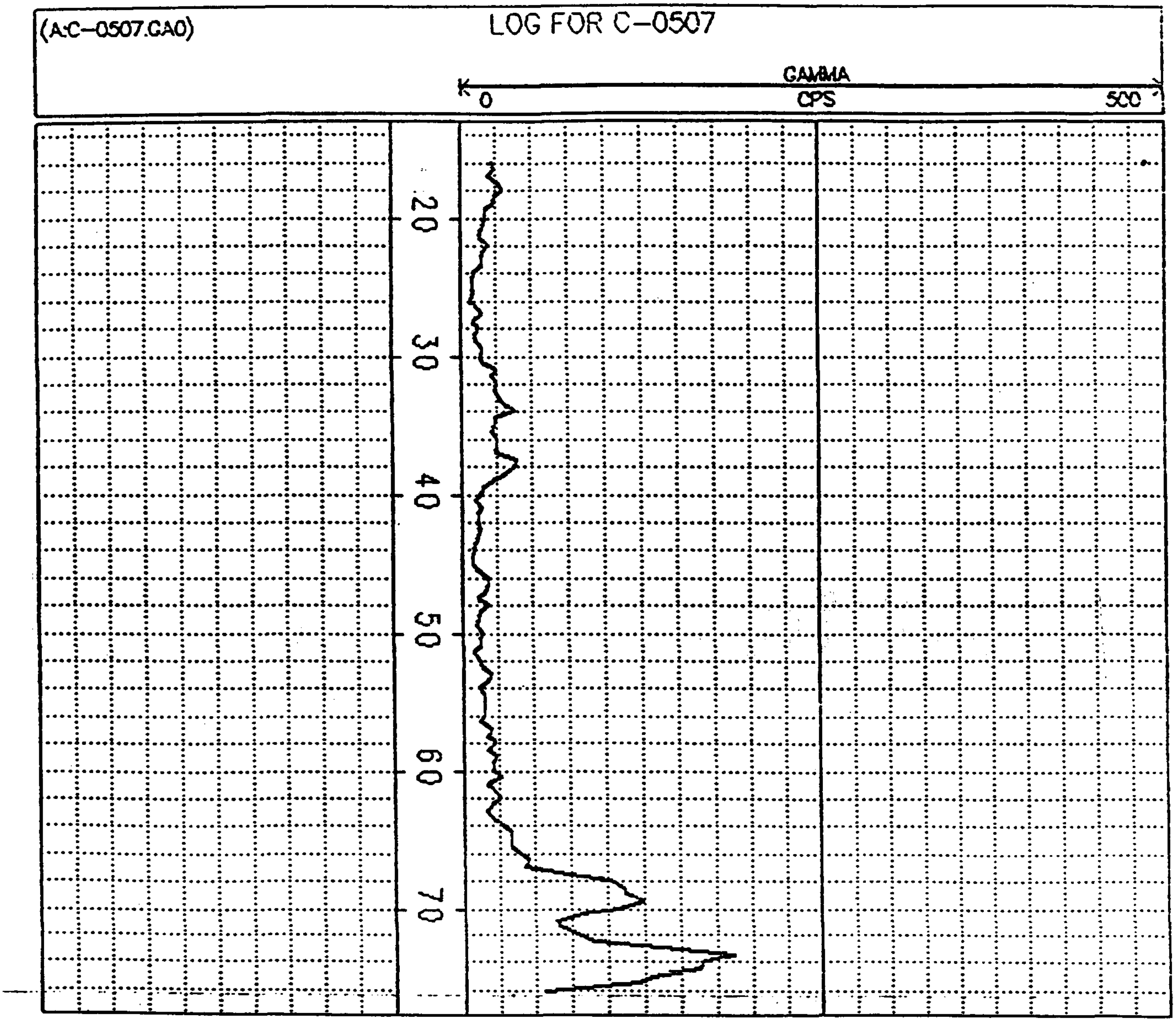


Figure D.3 Gamma log for well number 3

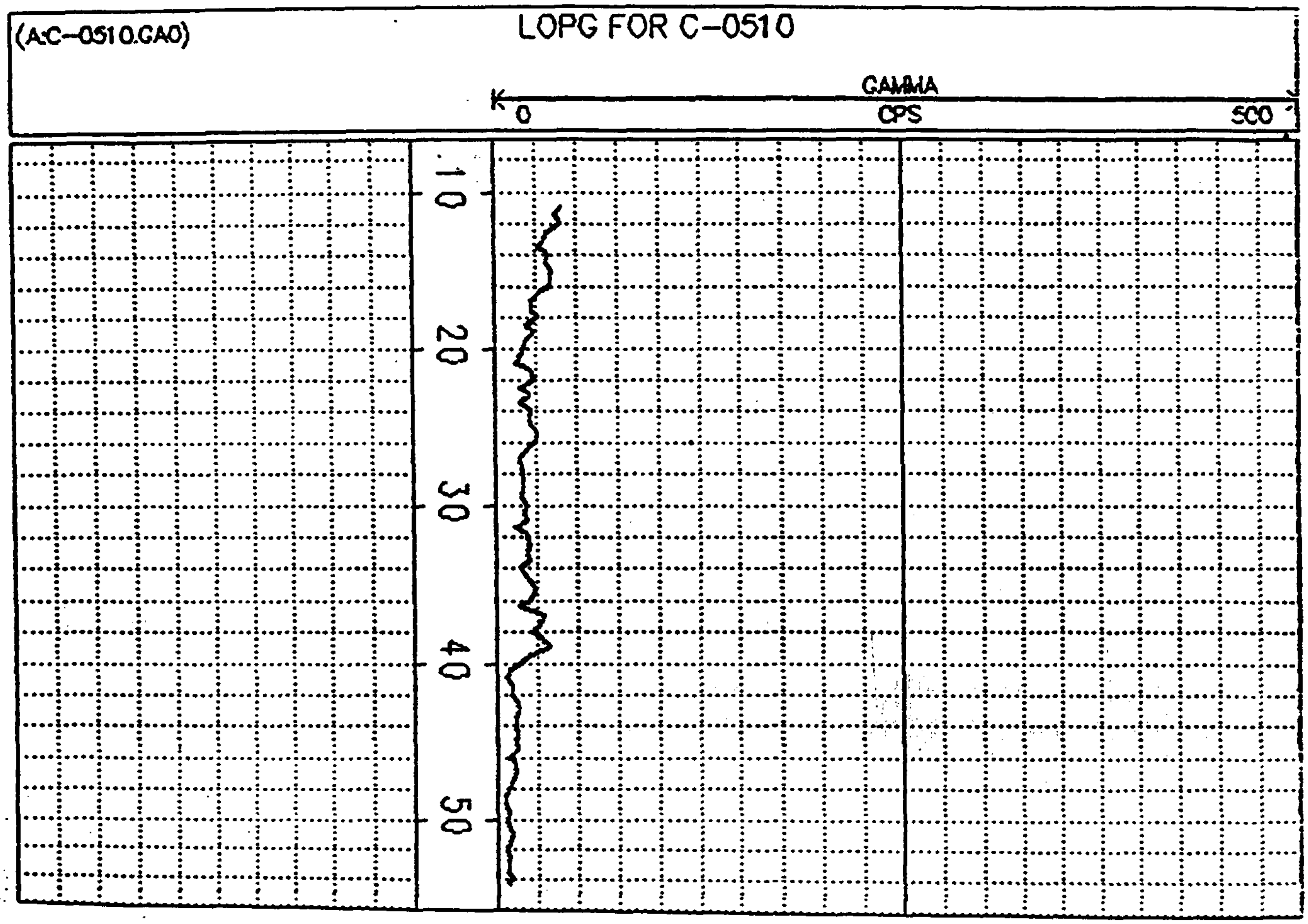


Figure D.4 Gamma log for well number 4

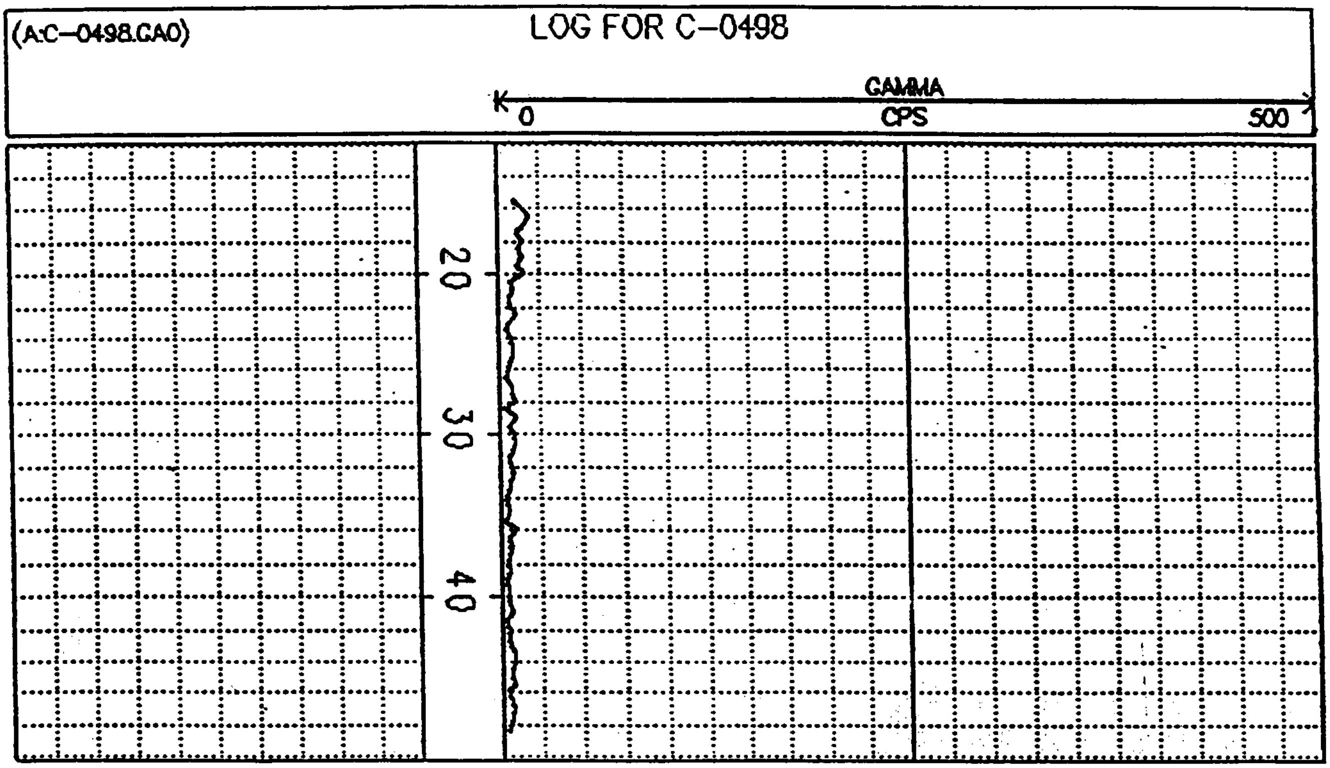


Figure D.5 Gamma log for well number 5

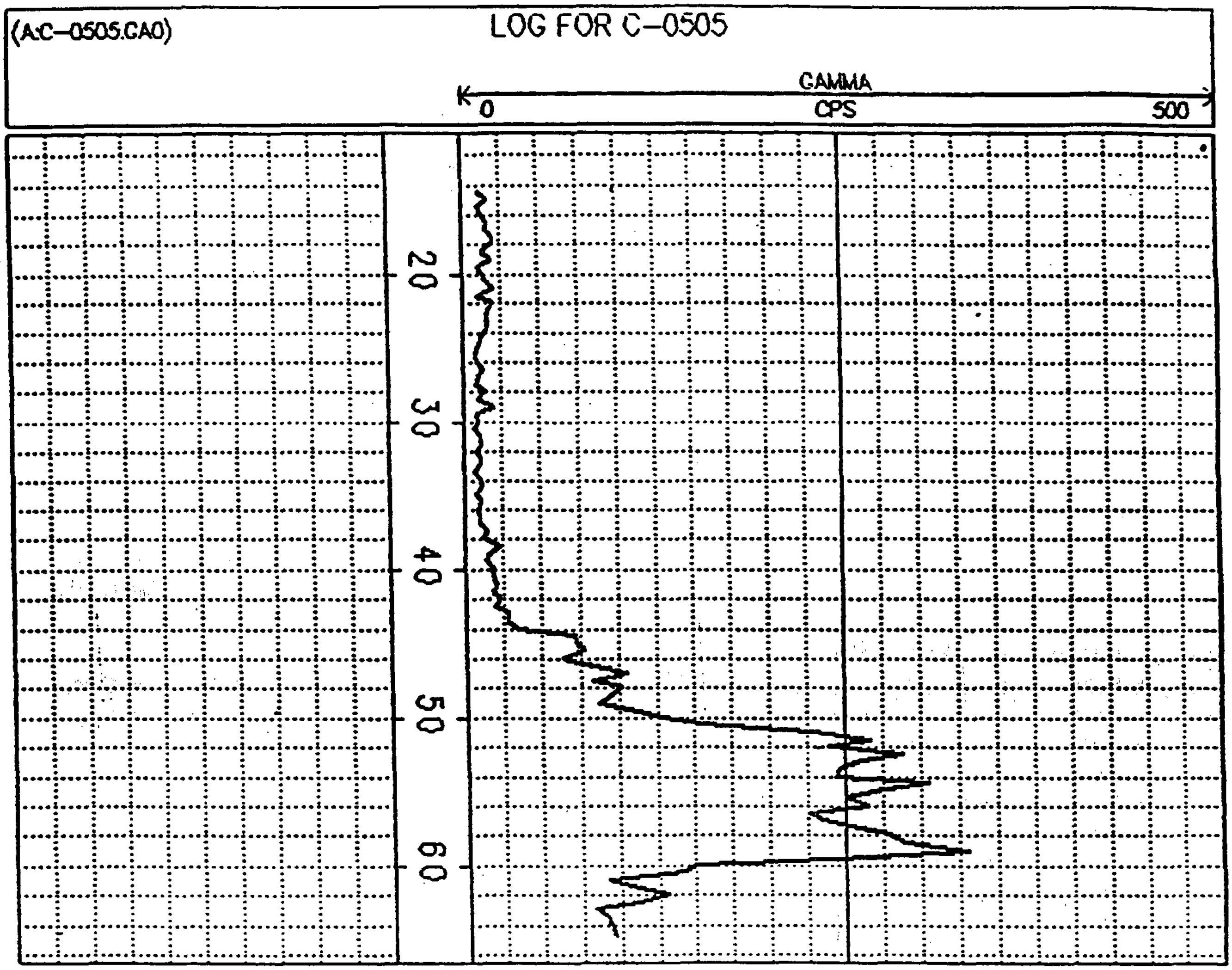


Figure D.6 Gamma log for well number 6

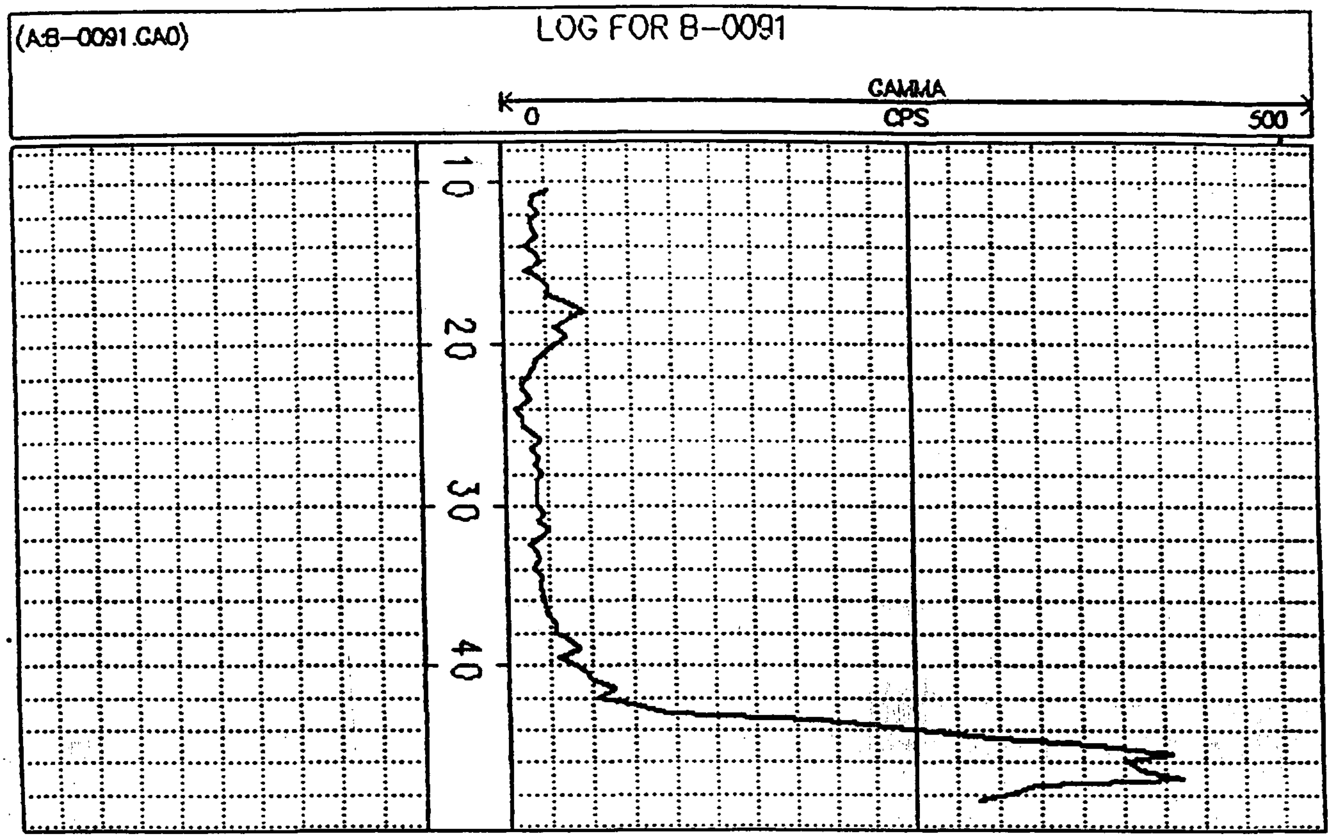


Figure D.7 Gamma log for well number 8

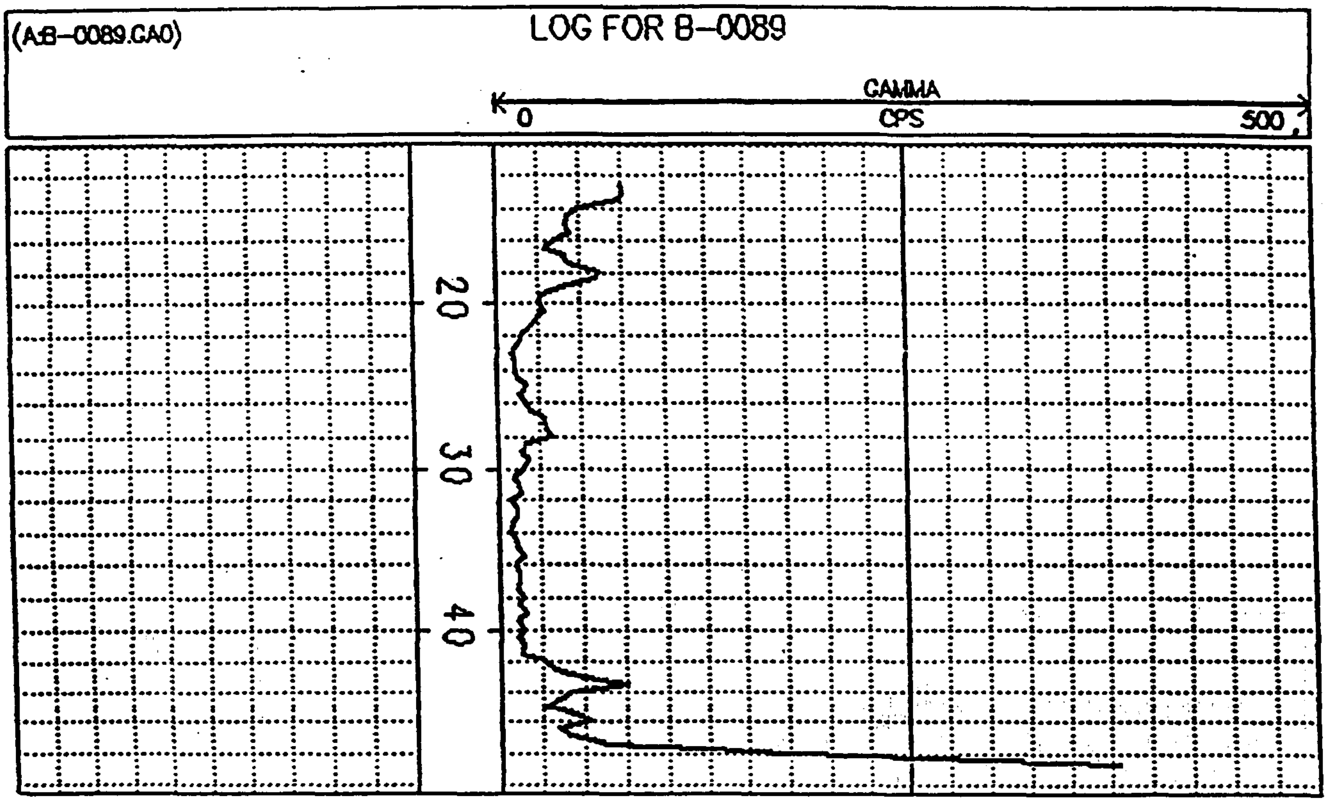


Figure D.8 Gamma log for well number 9

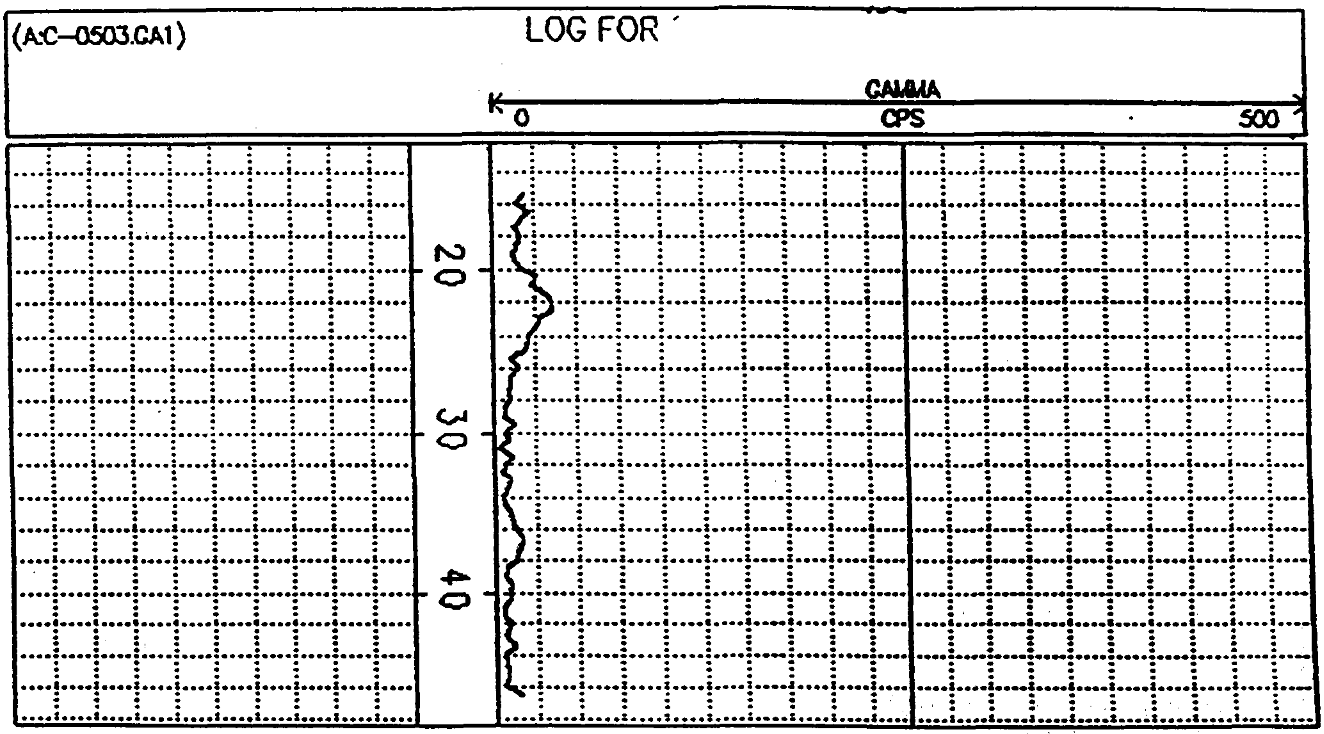


Figure D.9 Gamma log for well number 10

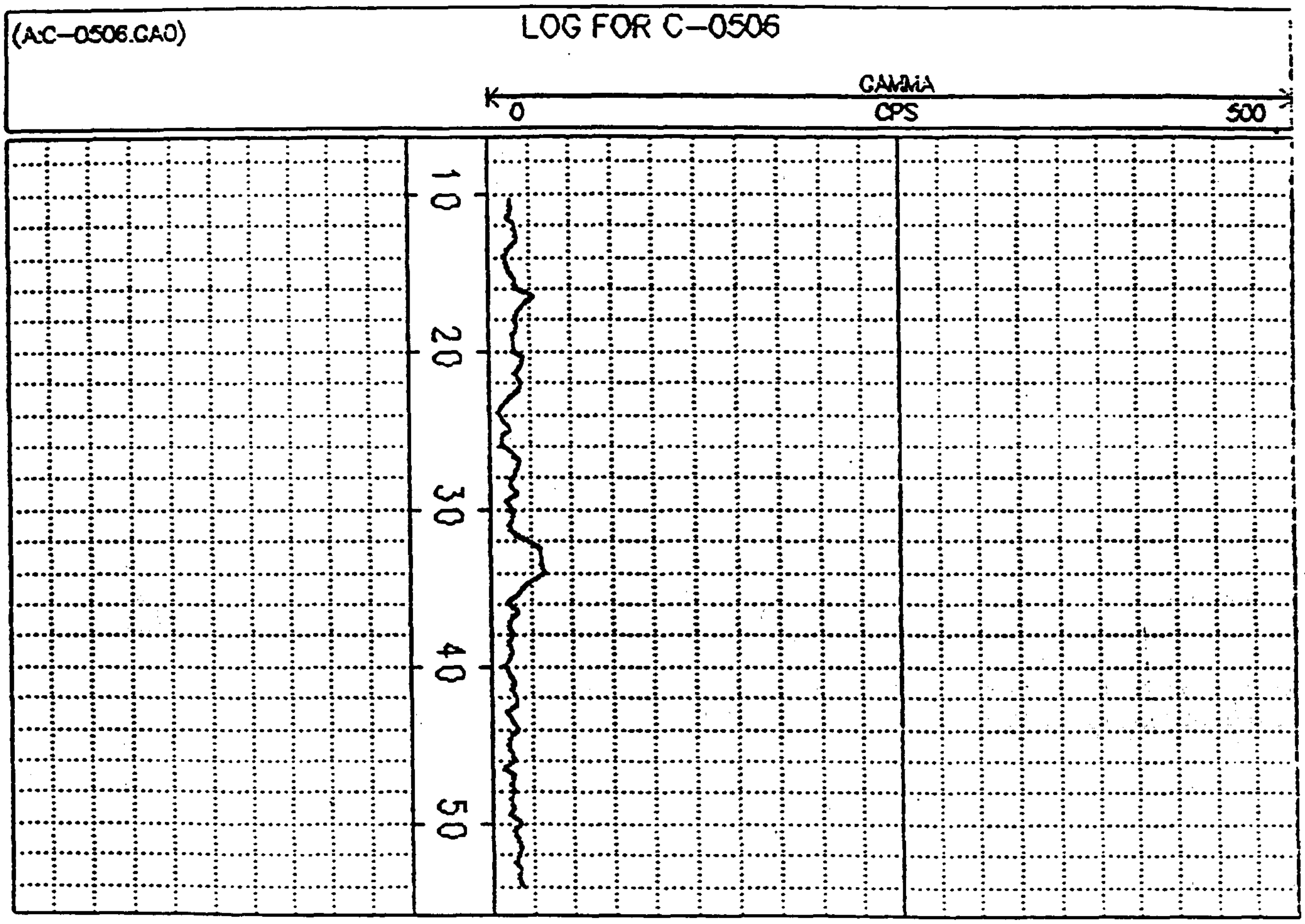


Figure D.10 Gamma log for well number 11

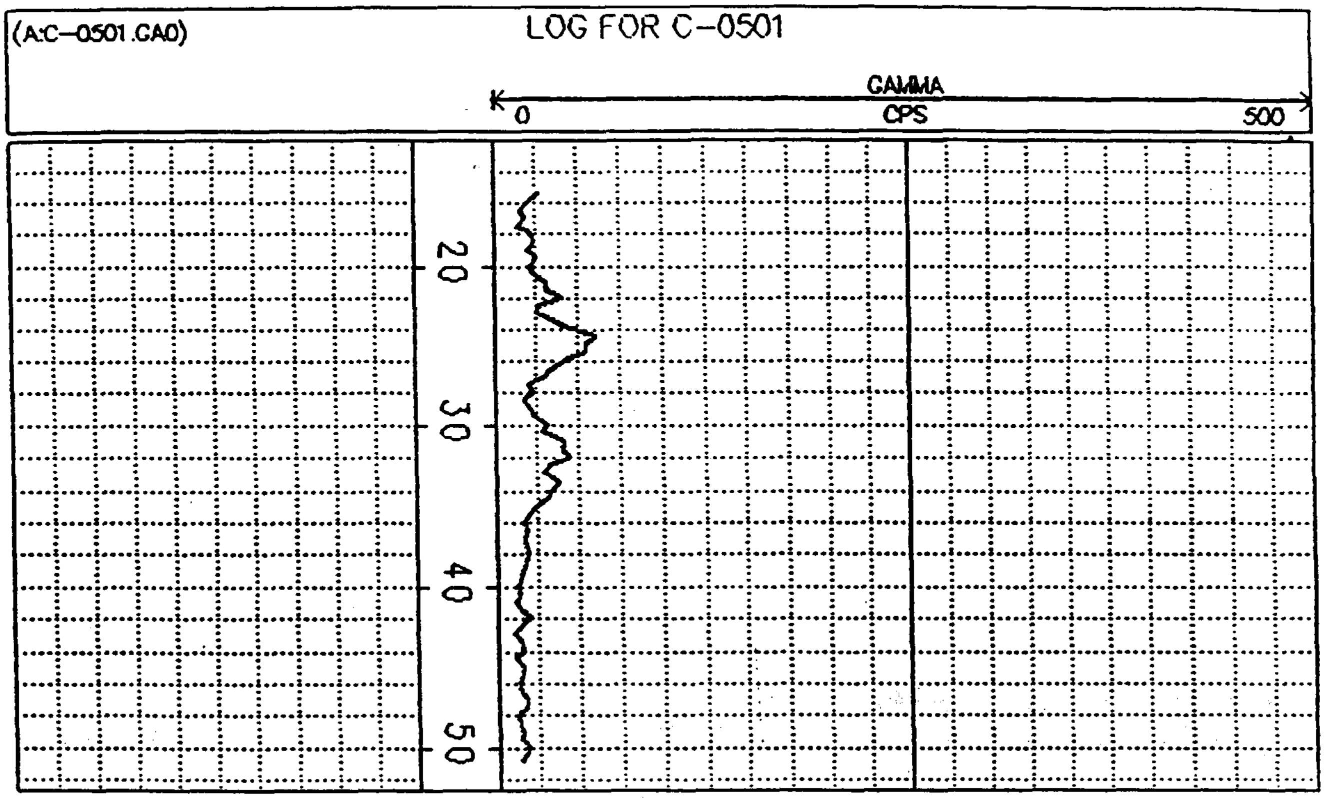


Figure D.11 Gamma log for well number 12

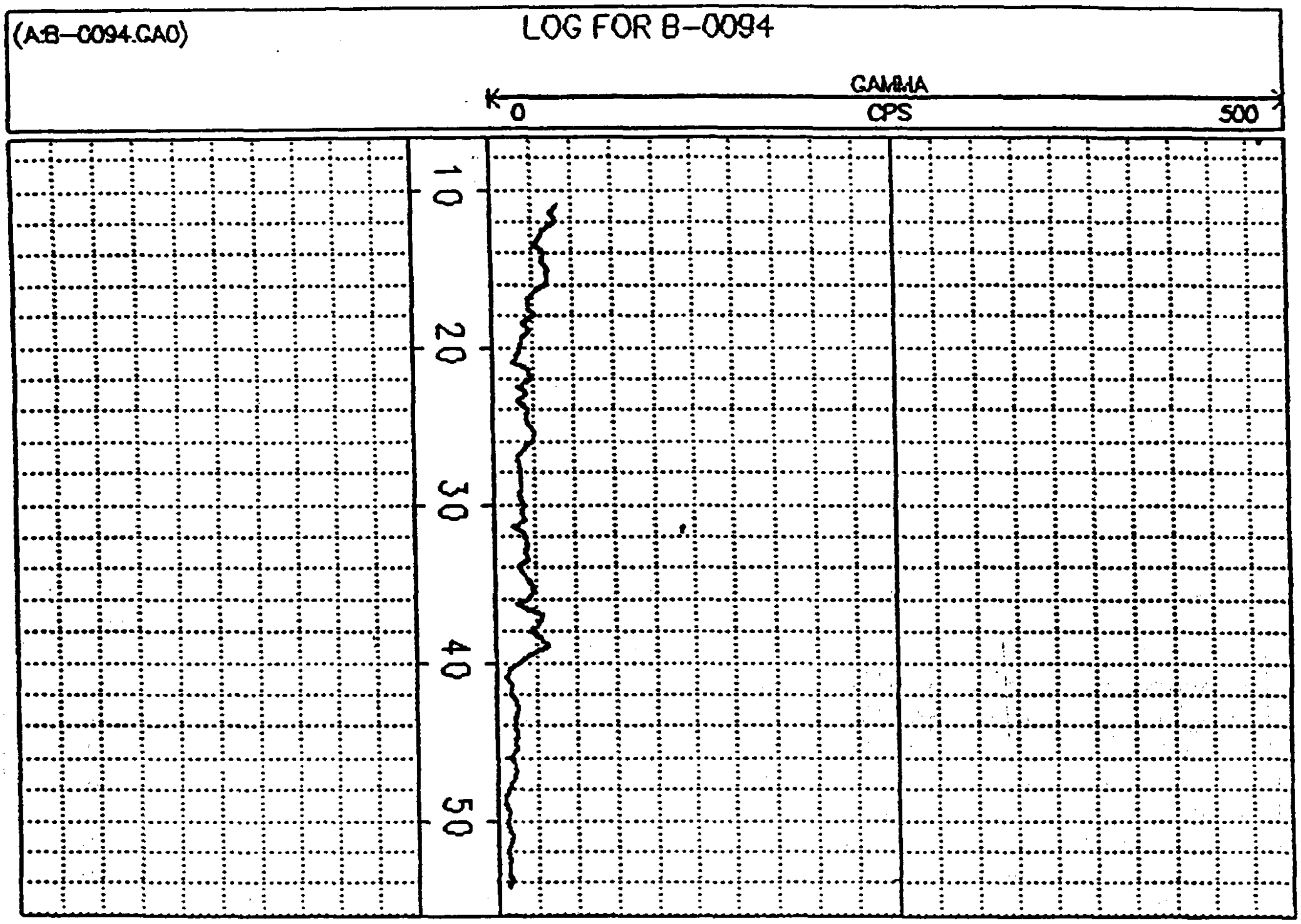


Figure D.12 Gamma log for well number 19

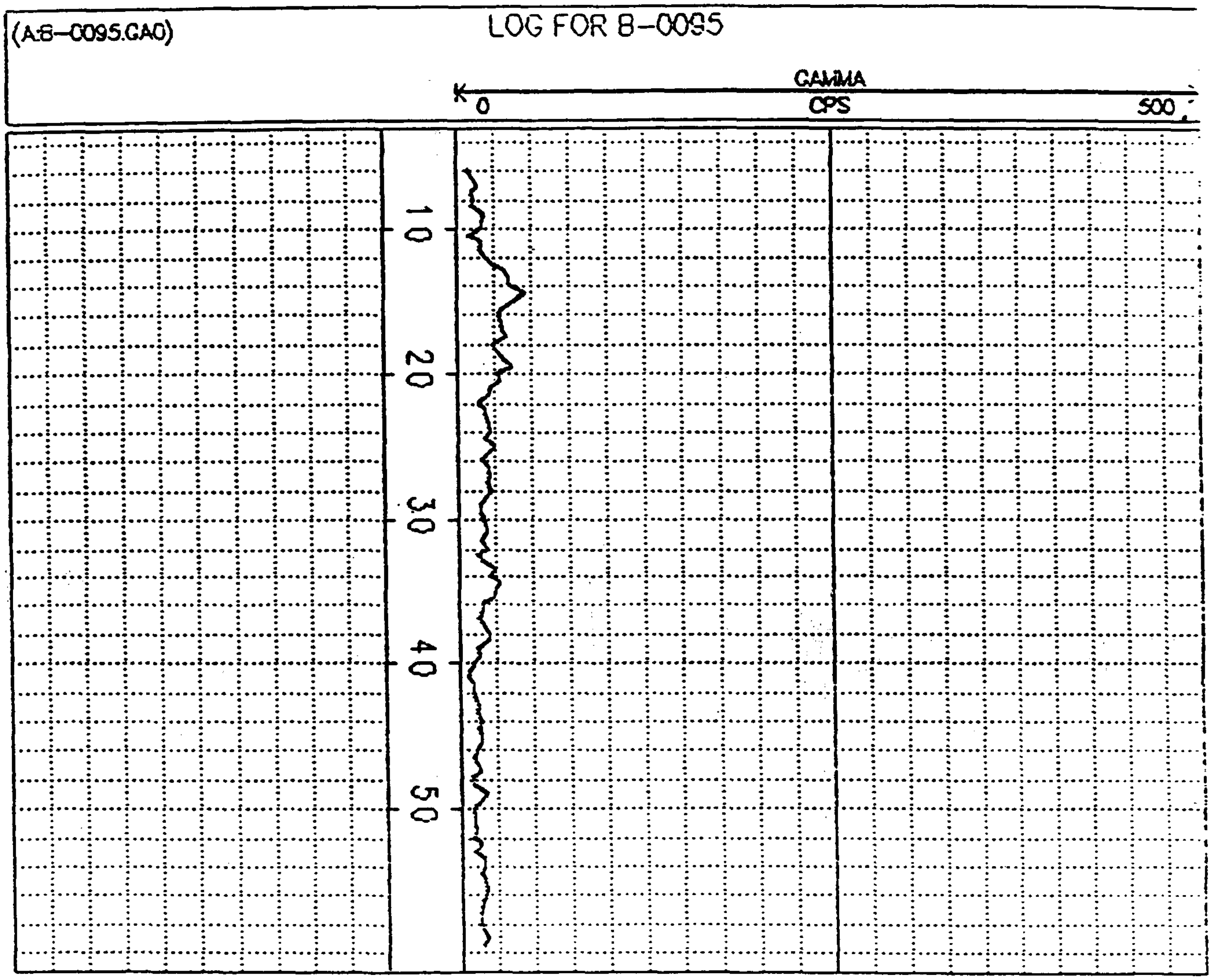


Figure D.13 Gamma log for well number 20

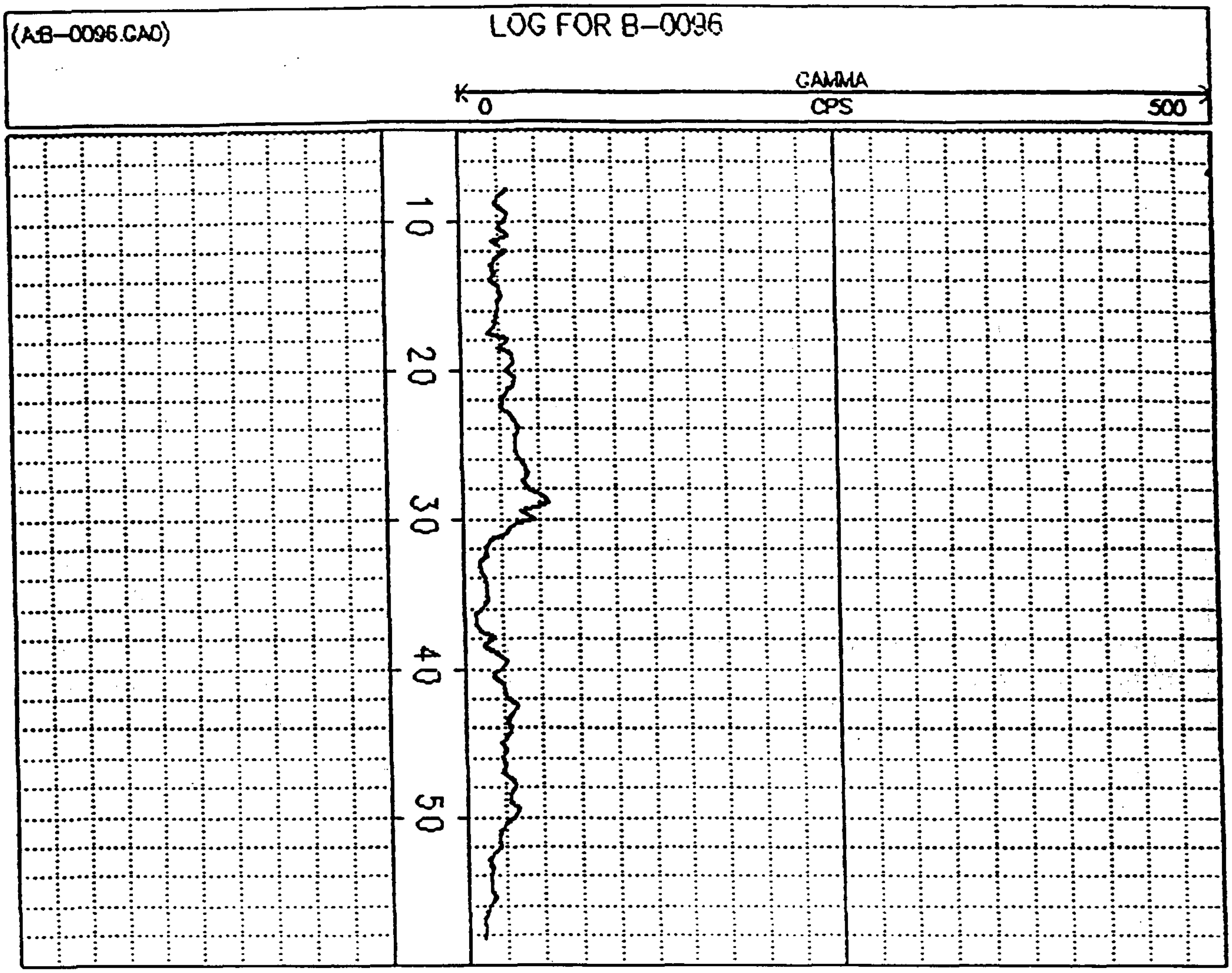


Figure D.14 Gamma log for well number 21

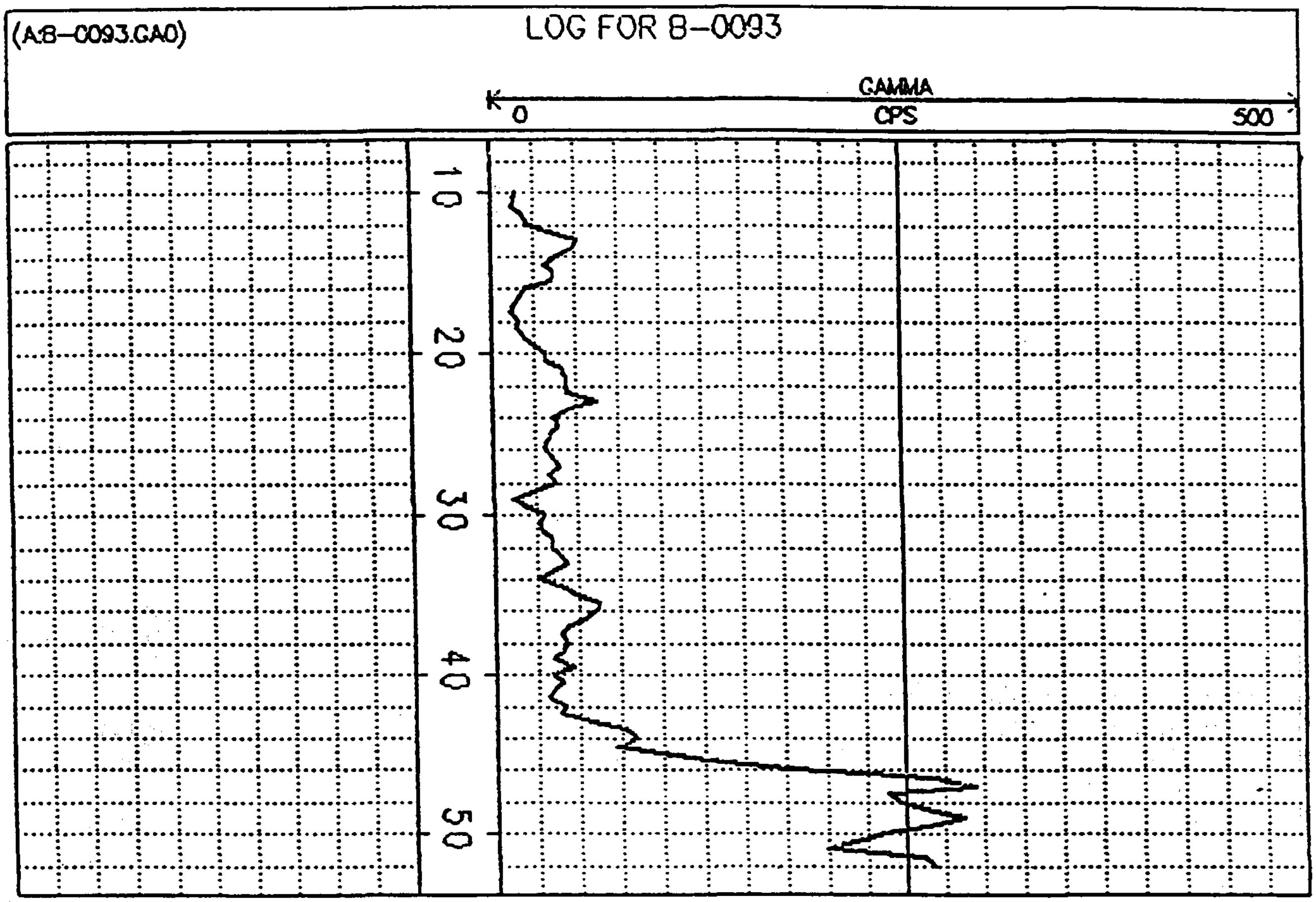


Figure D.15 Gamma log for well number 24

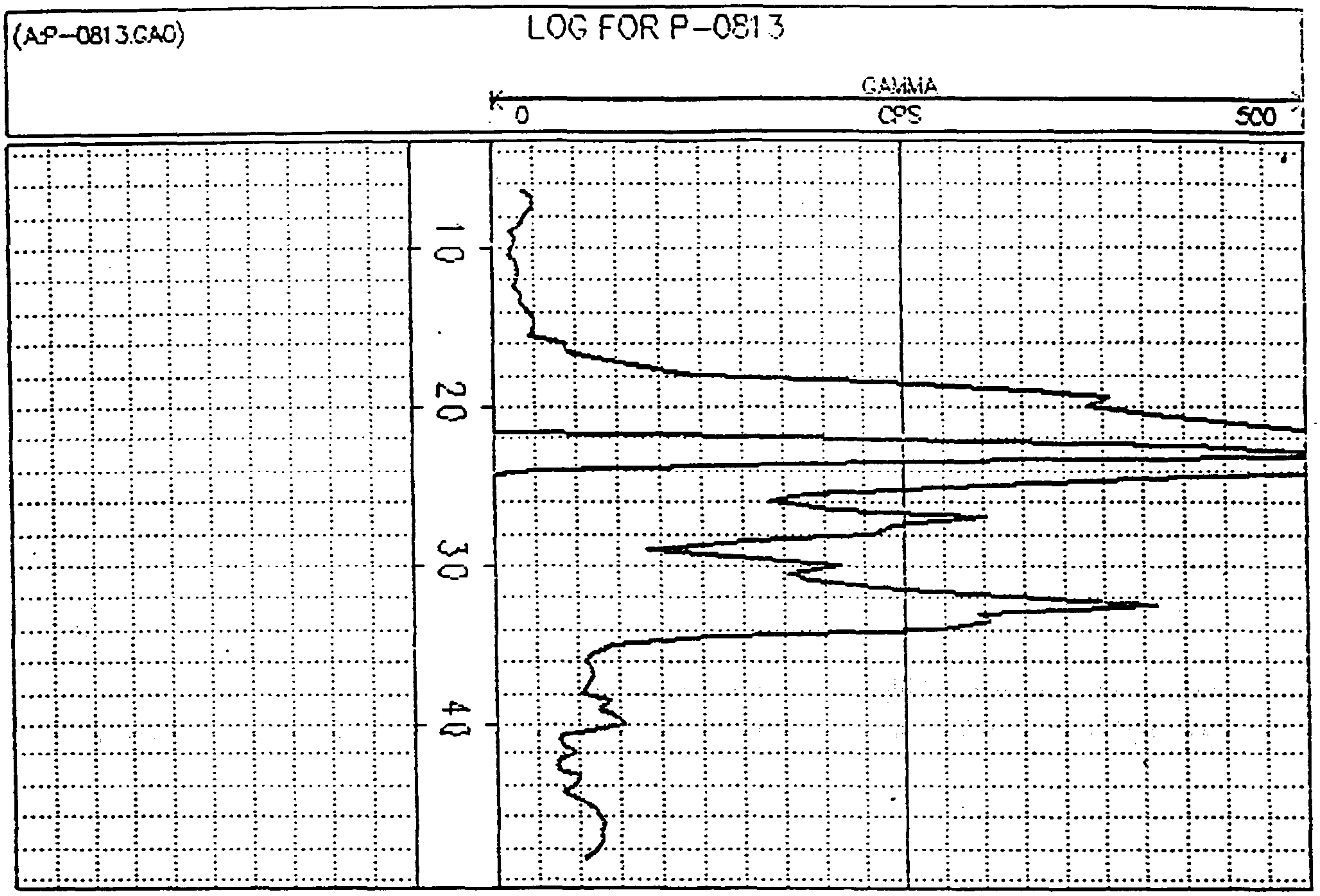


Figure D.16 Gamma log for well number 25A