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Floridan Aquifer Wellfield Study Data Collection and Evaluation Report

September 1990

FINAL REPORT

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ENGINEERS INC.
Jacksonville, Florida

FLORIDAN AQUIFER WELLFIELD STUDY
DATA COLLECTION AND EVALUATION REPORT

FINAL REPORT

SEPTEMBER 1990

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1.0 EXECUTIVE SUMMARY

This report sets forth and evaluates data generated by the drilling and testing of exploratory/monitor wells at Lake Washington, in Brevard County, Florida. It also includes the results of groundwater flow and solute transport models constructed for the study area. A data and evaluation report was presented to the City and approved by the St. Johns River Water Management District prior to constructing the models.

Nine wells were drilled at the site between May, 1989 and December, 1989 for the purpose of determining the geology, water quality, and aquifer characteristics of the Floridan Aquifer System in this area. Geological units penetrated include the Lake City Limestone, Avon Park Limestone, Ocala Group, Hawthorn Group, Tamiami Formation, Anastasia Formation, and undifferentiated terrace deposits. The major producing zones within the Floridan were present from 290 to 550 feet below land surface and from 680 to 864 feet below land surface. A 92-hour aquifer performance test was conducted on the upper zone (240 to 550 feet). The geometric mean calculated for the hydraulic values are: transmissivity (255,180 gpd/ft) and storage (1.18 X 10 -3). **Two aquifer performance tests were conducted on a combined upper/lower zone (240 to 864 feet). The first test ran for 31 days and the second, a verification test, for 10 hours.** The geometric mean of the transmissivity values for the combined zones was calculated to be 2,505,900 gpd/ft and the geometric mean for storage was 6.37 X 10 -4. Chlorides did not exceed 615 mg/l to a total depth of 1200 feet and were generally in the 400 to 500 mg/l range within the major producing intervals.

A groundwater flow model (MODFLOW) and a solute transport model (SUTRA) were constructed to simulate the Floridan Aquifer responses for a wellfield pumpage (8.133 MGD) scenario over a seven year period. The groundwater flow models showed only moderate drawdowns while producing the entire 8.133 MGD from the lower producing zone. Drawdowns were less than one foot at a distance of three miles from the wellfield and only three feet at the pumping node in the lower producing zone. The solute transport model indicated there would only be about a 6.4% change in TDS at the pumping node after a seven year period with TDS concentrations increasing from 1205 ppm to 1284 ppm.

2.0 INTRODUCTION

The purpose of this report is to gather the basic data needed to determine the availability of water from the Floridan Aquifer System near Lake Washington. The study includes an outline of the availability of geologic and hydrogeologic information in the area, gives the results of an aquifer testing program, and give the basic data needed to simulate the aquifer system under various withdrawal scenarios using groundwater flow and transport models. It also includes a discussion of the geology and hydrogeology of the area.

2.1 LOCATION

The study area is located within Townships 26, 27 and 28 South and Ranges 35, 36 and 37 east in the vicinity of latitude 28 degrees north and longitude 80 degrees West. Lake Washington is centered within the study area (Figure 1). It is the first major lake in the upstream portion of the St. Johns River Valley. The St. Johns River, one of a few rivers flowing northward in the United States, is slow moving and drains runoff from east central and north Florida flatlands. Lake Washington is about 15 miles west of the Atlantic Ocean. It is partly visible from Highway I-95 when looking west just north of the City of Melbourne.

2.2 RAINFALL, RUNOFF, EVAPOTRANSPIRATION

The yearly mean rainfall in the Melbourne area is approximately 48 inches. The rainfall in the six-month wet season, from May to October, accounts for about 70% of the total precipitation. Large amounts of rainfall occur over relatively short periods during hurricanes, tropical storms and thunderstorms. These rainfall events, depending on the antecedent soil moisture conditions, can produce major floods resulting in high volumes of runoff. The area is close to the ocean and the majority of the floods rush toward the Intracoastal Waterway and the St. Johns River. However, the sandy soil and negligible land slope (0.1 - 0.5 ft/mi) of the area present a high infiltration rate, thereby allowing a large amount of moisture to be absorbed in the soil horizons. With recorded yearly pan evaporation rates between 63 and 75 inches, most of the soil moisture returns to the atmosphere through evapotranspiration. Only a fraction of rainfall is recharging the local water table aquifer.

2.3 SURFACE WATER

The study area is within the head waters of the St. Johns River. The nearest stream flow station for the St. Johns River is located on Highway U.S. 192, about 2 miles south (upstream) of Lake

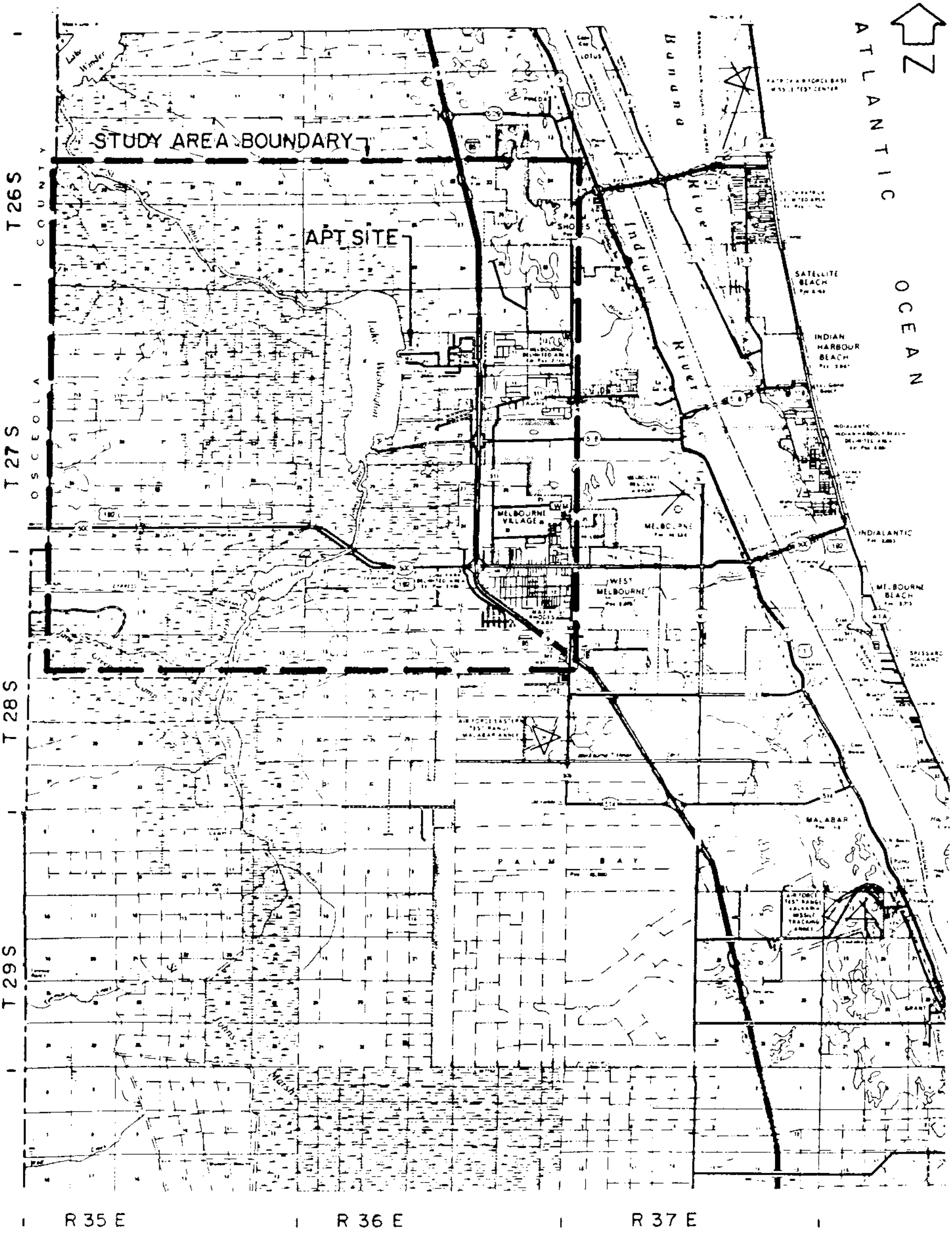

FIGURE 1: LOCATION OF STUDY AREA

Washington. The recorded mean low flow for 1943-1985 at this station for a 1-year duration was reported to be 671 cfs (Rao, 1987, Table 5-7). It has recorded a high discharge of over 5000 cfs and low of no flow at all. The river itself does not provide a reliable intake point for water supply upstream of Melbourne.

Lake Washington is the most important fresh water body in the area. The bottom elevation of the Lake is about 7 feet NGVD. At the stage of 13.5 feet NGVD., the Lake has a surface area of 2800 acres and a volume near 13500 acre-feet. It has a poorly defined shoreline with dense vegetation separating the marsh along most of its boundary. It is estimated that the lake holds water up to approximately 14.8 feet NGVD with no appreciable spill over its perimeter (Rao, 1987).

Lake Washington has been the primary source of the public drinking water for the City of Melbourne since 1959. To protect the water supplies of the lake, a semi-permanent dam was built in November 1961 across the narrow channel of the St. Johns River about 0.5 mile downstream from the lake outlet. The crest of the weir has varied through the years. More recently it is reported at 13.50 feet NGVD. However, when the lake is in high stages, the weir and the surrounding marshlands are fully submerged and the flow stretches across a width of 2 to 4 miles. Currently 14 MGD is withdrawn from the Lake for public water supply. Rao (1987) found that the ecologic/environmental requirements will not be violated by the consumptive use withdrawal from the lake of up to 25 mgd. The water quality in the lake, after filtration through the surrounding marsh, is generally suitable for potable use. In terms of chloride, the average concentration is at 150 mg/liter. However, the low flow conditions existing during extreme drought would considerably lower the lake levels and the secondary drinking water standards (250 mg/L chloride) might be exceeded.

2.4 GROUNDWATER (OVERVIEW)

Groundwater is currently the most important water resource for agriculture and domestic uses in the area. There are three aquifer systems in the area. The Surficial, Intermediate, and Floridan. The intermediate system is composed primarily of clays and low permeability silts. It is not a source of water in this area.

The Surficial Aquifer System is about 100 feet in thickness and is recharged directly by rainfall or baseflow from streams, canals or surface water bodies. Although there is plenty of good quality water, the surficial aquifer is fragmented. A fragmented aquifer may have a high volume of water per unit area in a localized area, but may not have a large total reservoir volume. Hence the surficial aquifer does not provide a reliable withdrawal point for municipal water supply.

The Intermediate Confining Beds lie below the Surficial Aquifer System separating it from the Floridan Aquifer System by approximately 100 feet of confining zone. Although this system does produce small quantities of water in other parts of central and south Florida, there is no evidence that it has that capability in this area.

The Floridan Aquifer System is a regional system present throughout Florida and Southern Georgia. Primary recharge for the system is in the structurally higher areas of west central Florida, where the aquifer system is exposed at land surface. The Floridan does, however, receive recharge locally through confining beds where hydrologic conditions are favorable. The base of the Floridan occurs in the low permeability sediments of the Cedar Keys Limestone at depths in excess of 2500 feet in the Brevard County area.

The Floridan Aquifer System in this area has been divided into three zones, an upper permeable zone, a middle less permeable zone, and a lower permeable zone (Tibbals, 1981 and Skipp, 1988). According to these reports the upper permeable zone occurs in the Ocala Group and upper part of the Avon Park Limestone and is about 200 to 400 feet in thickness. The top of the zone occurs at approximately 240 feet below land surface in the Lake Washington area. The piezometric head of this zone is 10 to 20 feet above land surface. The transmissivity is reported to be between 50,000 to 1,000,000 gpd/ft. Chloride concentrations are between 400 to 600 mg/L exceeding the secondary drinking water standards. This zone is the major water producer for Floridan wells in this area.

Regionally there is a less permeable zone reported at about 600 to 800 feet below land surface (Tibbals, 1981). This zone has been used to separate the upper permeable from the lower permeable zones of the Floridan Aquifer System. Since this confining layer is not very tight and is not thick, water may migrate from the lower permeable zone to the upper permeable zone when the pressure in the upper zone is reduced by pumpage. A leaky semi-confining zone was penetrated in this interval by exploratory wells at Lake Washington, but in this report it is not considered as the interval separating an upper and lower Floridan. Miller (1984) identifies the lower permeable zone (lower Floridan) as beginning in the lower portion of the Lake City Limestone with parts of the upper Lake City acting as confining beds separating the two. A zone of lower permeability was penetrated in the Lake City at the Lake Washington site from approximately 864 to 1204 feet below land surface (total depth of exploratory well). Information from deep injection wells in the area indicate that below this interval several zones of high transmissivity exist, and are separated from the wastewater injection zones (boulder zone) by an extremely low permeability zone from approximately 1500 to 2000 feet below land surface. Therefore the lower confining zone (864 feet to 1204 feet) is considered to be the zone separating the Upper Floridan from the Lower Floridan in the Lake Washington area.

2.5 TESTING PROGRAM METHODOLOGY

An exploratory/testing program was proposed for the area and approved by the City of Melbourne, the St. Johns River Water Management District, and the South Brevard Water Authority in January of 1989. A required U.S. Environmental Protection Agency permit (NPDS No. FL0041238) was granted a short time later to discharge Floridan waters into Lake Washington (surface water). The program consisted of well drilling, geophysical logging, water quality sampling, and aquifer testing. The testing program began in the month of May, 1989 after the successful well drilling contractor (Youngquist Bros.) mobilized to the site. An exploratory well was initially drilled to 1204 feet below land surface. Five (5) Floridan observation wells were then drilled to various depths by Youngquist Brothers and an additional three (3) shallow (Hawthorn and water table) observation wells drilled by the District. Three aquifer performance tests were conducted on the Floridan Aquifer System. Figure 2 shows the layout of the completed test wells at the site and Figure 3 the well construction details. The following table summarizes the casing and total depths of wells drilled at the site.

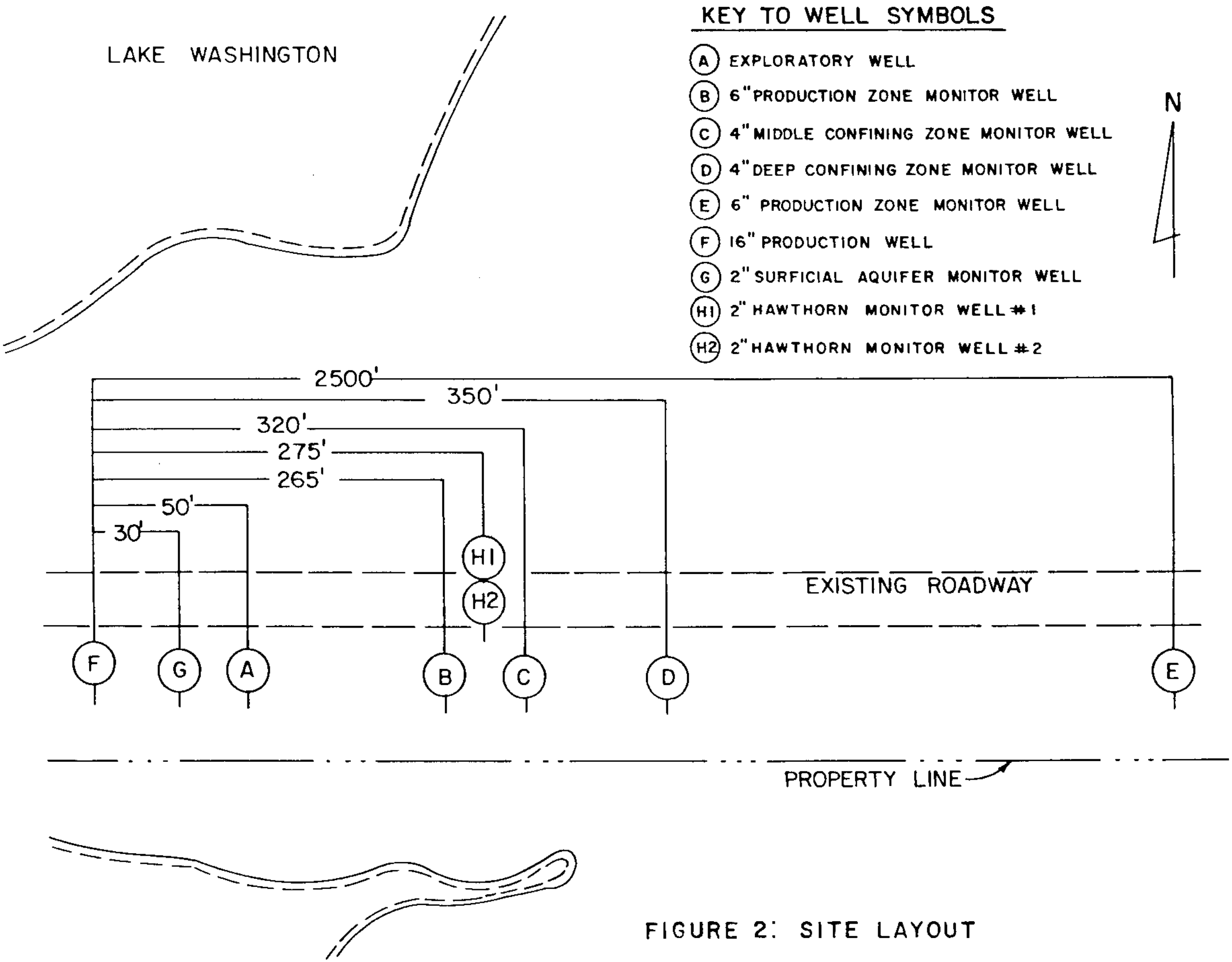

FIGURE 2: SITE LAYOUT

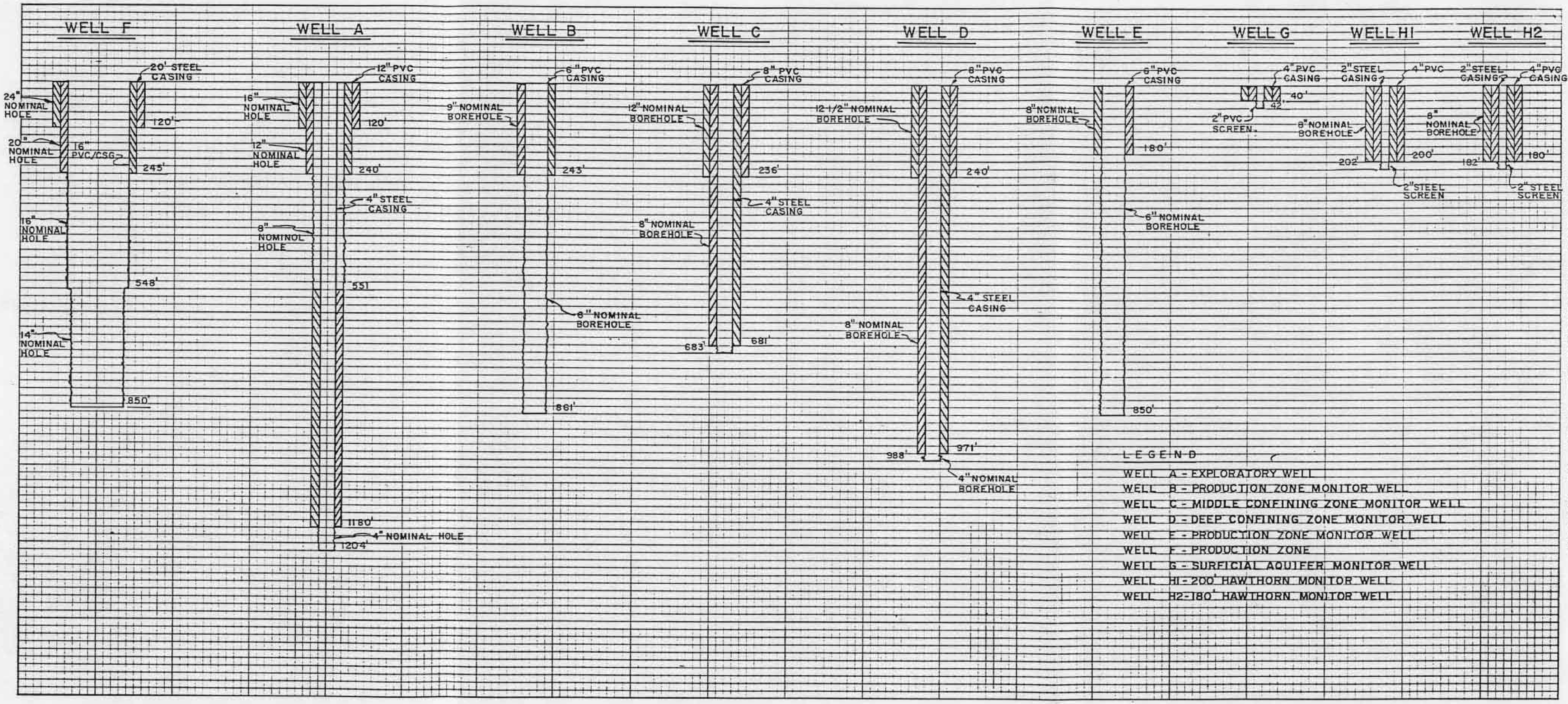

FIGURE 3: WELL CONSTRUCTION DETAILS

FIGURE 3: WELL CONSTRUCTION DETAILS

TABLE 2.1 - WELL DATA

SJRWMD WELL #	HD WELL #	CASING DIA.	CASING TYPE	CASING DEPTH	TOTAL DEPTH OF WELL	DIST. FROM PROD. WELL
BRO910&909	A	12"	PVC	0-120'		50'
BRO909	A(UPZMW)	8"	PVC	0-240'	551'	
BRO910	A(LCZMW)	4"	STEEL	0-1180'	1204'	
BRO912	B(UPZMW)	6"	PVC	0-243'	550'	265'
BRO916	B	6"	PVC	0-243'	861'	265'
BRO913	C'	8"	PVC	0-236'		
BRO913	C'	4"	STEEL	0-681'	683'	320'
BRO996	D	8"	PVC	0-240'		349'
BRO996	D	4"	STEEL	0-971'	988'	
BRO915	E	6"	PVC	0-180'	850'	2500'
BRO907	F	20"	STEEL	0-116'		
BRO907	F	16"	PVC	0-245'	850'	0'
BRO908	G	4"	PVC	0-40'		50'
BRO908	G	2"	STEEL	0-50'	50'	
BRO911	H1	4"	PVC	0-200'		300'
BRO911	H1	2"	STEEL	0-202'	202'	
BRO914	H2	4"	PVC	0-180'		305'
BRO914	H2	2"	STEEL	0-182'	182'	

SUMMARY OF CONSTRUCTION ACTIVITIES

The following is a brief summary of the construction and testing activities at the Lake Washington site. The reader is referred to Appendix 9.8 for a more detailed (daily) synopsis of construction activities.

EXPLORATORY WELL (WELL A)

The deep exploratory well was drilled to a depth of 1204 feet below land surface. Drilling was halted three times to conduct step drawdown tests on various zones. After drilling to the total depth of the well it was converted into a multi-zone monitor well with a monitor zone from 1180' to 1204' and another from 240' to 551'.

OBSERVATION AND PRODUCTION WELLS (WELLS B TO F)

Eight additional wells were drilled for the purpose of conducting two aquifer performance tests. Two of the wells (Well B and E) were drilled in phases to accommodate production zone monitoring during the two APT's.

LITHOLOGIC ANALYSIS AND GEOPHYSICAL LOGGING

All of the wells, with the exception of the shallow Hawthorn and water table wells, were geophysically logged. The exploratory well was initially drilled at the site to a depth of 1000 feet below land surface. The well was sampled at 10 foot intervals for lithology and 10 foot cores were taken at depths of 173 feet, 194 feet, 224 feet, 573 feet, 610 feet, 786 feet, 812 feet, and 873 feet. It was then decided to deepen the well to 1200 feet below land surface because no significant changes had occurred in water quality. Cores were also retrieved from Well C (675'), Well D (975'), Hawthorn #1 (202') and Hawthorn #2 (182'). Permeability and porosity measurements were made on all cores and available in Appendix 9.4. Lithologic and geophysical logs are available in Appendix 9.3 and Appendix 9.9, respectively. The following tables give the types of logs available on individual wells and core intervals sampled. Detailed lithologic descriptions of the cores and cuttings are available in Appendix 9.3.

TABLE 2.2 - GEOPHYSICAL LOGS

WELL #	DEPTH	LOGS CONDUCTED
A	575'	CALIPER, FLUID CONDUCTIVITY, FLOWMETER (STAT./FLOW.), GAMMA, SONIC, TEMP, 16-64
A	997'	CALIPER, FLUID CONDUCTIVITY, FLOWMETER (STAT./FLOW.), GAMMA, SONIC, TEMP, 16-64
A	1200'	CALIPER, FLUID RESISTIVITY, FLOWMETER (STAT./FLOW.), GAMMA, 16-64
B	850'	CALIPER
C	675'	CALIPER, FLUID CONDUCTIVITY, FLOWMETER (STAT./FLOW.), GAMMA, LONG NORMAL, TEMP.
D	985'	CALIPER, FLUID RESISTIVITY, FLOWMETER (STAT./FLOW.) GAMMA, TEMP, 16-64.
E	850'	CALIPER, GAMMA, 16-64.
F	850'	CALIPER, GAMMA, 16-64, FLOWMETER, TEMPERATURE, FLUID RESISTIVITY.

TABLE 2.3 - CORE SAMPLES RETRIEVED
(Vertical)

WELL #	CORED DEPTH	RECOV. (ft)	PERMEABLTY (cm/sec)	POROSITY	*Es (Kg/cm2)	*Es (lb/in2)	**Ss (ft-1)	SPL #
A	173'-183'	7'	1.3x10 -6	.49	100	1422	3.0 x10 -4	1
A	194'-204'	7'	2.0x10 -8	.51	860	12241	3.6 x10 -5	2
A	224'-234'	10'	9.1x10 -9	.62	1200	17068	2.6 x10 -5	3
A	575'-585'	8'	6.1x10 -7	.17	31111	442493	4.1 x10 -7	4
A	610'-620'	8'	2.9x10 -7	.13	82386	1171781	5.2 x10 -8	5
A	786'-796'	8'	2.5x10 -8	.12	55000	782265	2.0 x10 -7	6
A	812'-822'	7'	3.3x10 -8	.15	90000	1280000	4.7 x10 -8	7
A	873'-883'	8'	5.8x10 -6	.28	35294	501988	2.3 x10 -7	8
C	665'-675'	10'	2.6x10 -4	.47	3250	46224	5.2 x10 -6	9
D	975'-985'	5'	Lab Results Incomplete					
H1	200'-202'	2'	8.3X10 -9	.65				
H2	180'-182'	2'	2.2X10 -8	.61				

*Es = modulus of elasticity (calculated from stress-strain curves in Appendix 11.4 from compression tests on cores)

**Ss was calculated using equation 20 of Lohman (1972) for samples 1 to 3 and equation 21 of Lohman (1972) for samples 4 through 9.

WATER QUALITY SAMPLING

The conductivity and total dissolved solids were measured every drill rod (approximately 30 feet) in the exploratory (Well A), deep confining zone monitor (Well D) and middle confining zone monitor (Well C) wells. These wells were also point sampled at various intervals. Many samples were sent to a water quality laboratory for analysis of primary constituents. The other observation wells at the site were sampled as needed. The following table gives various field measurements and identifies horizons sampled for lab analysis for the exploratory well (Well A). The water quality data are discussed in another section of this report and lab analyses are available in Appendix 9.5. An additional sample was collected during the 31 day APT for acute toxicity. These data are also available in Appendix 9.5.

TABLE 2.4 - WATER QUALITY SAMPLING (EXPLORATORY WELL A)

SAMPLE NO.	DEPTH	DATE	TEMP. C	COND. UMHOS	TDS MG/L	FLOW GPM	CHLR MG/L	ADDITIONAL SAMPLES
1 (1)	260	5-29	27.0	2200	1100	15	545	PRIMARIES
2	293	5-29	26.8	2280	1140	50	(6)	PT.SPL.290'
3	314	5-29	26.4	2280	1140	250	(5)	WELL HD.
4	336	5-30	26.3	2270	1140	300		
5	358	5-30	26.3	2290	1140	300	511	
6 (2)	378	5-30	27.2	2300	1140	300		PRIMARIES
7	400	5-30	27.3	2290	1150	400	(7)	PT.SPL.400'
8	420	5-30	26.7	2250	1130	500		
9	443	5-30	26.7	2220	1130	500		
10 (3)	463	5-30	26.7	2080	1030	500		PRIMARIES
11	484	5-30	26.7	2080	1030	500		
12	506	5-30	26.8	2060	1030	500	475	
13 (4)	527	5-30	26.7	2220	1110	500		PRIMARIES
14	549	5-30	27.5	2250	1120	500		
15	570	5-30	27.0	2250	1120	500	(8)	PT.SPL.570'
16	591	6-03	27.0	2290	1140	500		
17	610	6-03	27.2	1750	880	500		PRIMARIES
18	WH	6-04	27.3	2230	1120	>500		
19	631	6-04	26.7	2230	1120	>500	534	PRIMARIES
20	655	6-05	26.8	2200	1100	>500		PT.SPL.625'
21	677	6-05	26.8	2280	1140	>600		
22	698	6-05	26.7	2270	1130	>600		
23	719	6-05	27.2	2260	1130	>600		
24	740	6-05	26.8	2260	1130	>600		
25	762	6-06	26.8	2260	1130	>600		
26	783	6-06	26.7	2260	1130	>600		PT.SPL.780'
27	805	6-08	27.0	2300	1150	>700	537	
28	825	6-11	26.9	2300	1150	>700		PRIMARIES
29	848	6-11	27.4	2310	1150	>800		
30	870	6-11	26.6	2290	1150	>800		
31	890	6-12	26.7	2290	1150	>800		
32	912	6-13	27.1	2300	1150	>800		
33	932	6-13	27.3	2270	1130	>800		
34	966	6-13	26.9	2280	1140	>800	550	
35	997	6-13	26.7	2220	1110	>800		PT.SPL.997'
36	1020	6-29	27.0	2200	1020	>800		PRIMARIES
37	1050	6-29	27.2	2230	1050	>800		
38	1080	6-29	26.7	2220	1110	>800		
39	1110	6-30	27.0	2200	1100	>800		PT.SPL.1120'
40	1140	7-01	27.1	2320	1160	>800		
41	1170	7-01	26.9	2400	1200	>800	512	PT.SPL.1200'
42	1200	7-01	27.3	2500	1250	>800	598	PRIMARIES

AQUIFER TESTING

Step drawdown, slug and long term aquifer performance tests were conducted at various stages of well construction and after the wells were completed. Data from these tests are available in Appendix 9.6 and discussed in the aquifer parameter section of this report. A-92 hour APT was conducted after the completion of the exploratory, production (550'), middle confining zone, and production zone monitor (550') wells were installed. The production and production zone monitor wells were subsequently deepened to 850' for a 31-day APT. Two additional Floridan wells were installed for the 31-day test. An additional APT was performed for 10 hours after completion of the 31-day test to verify drawdown data.

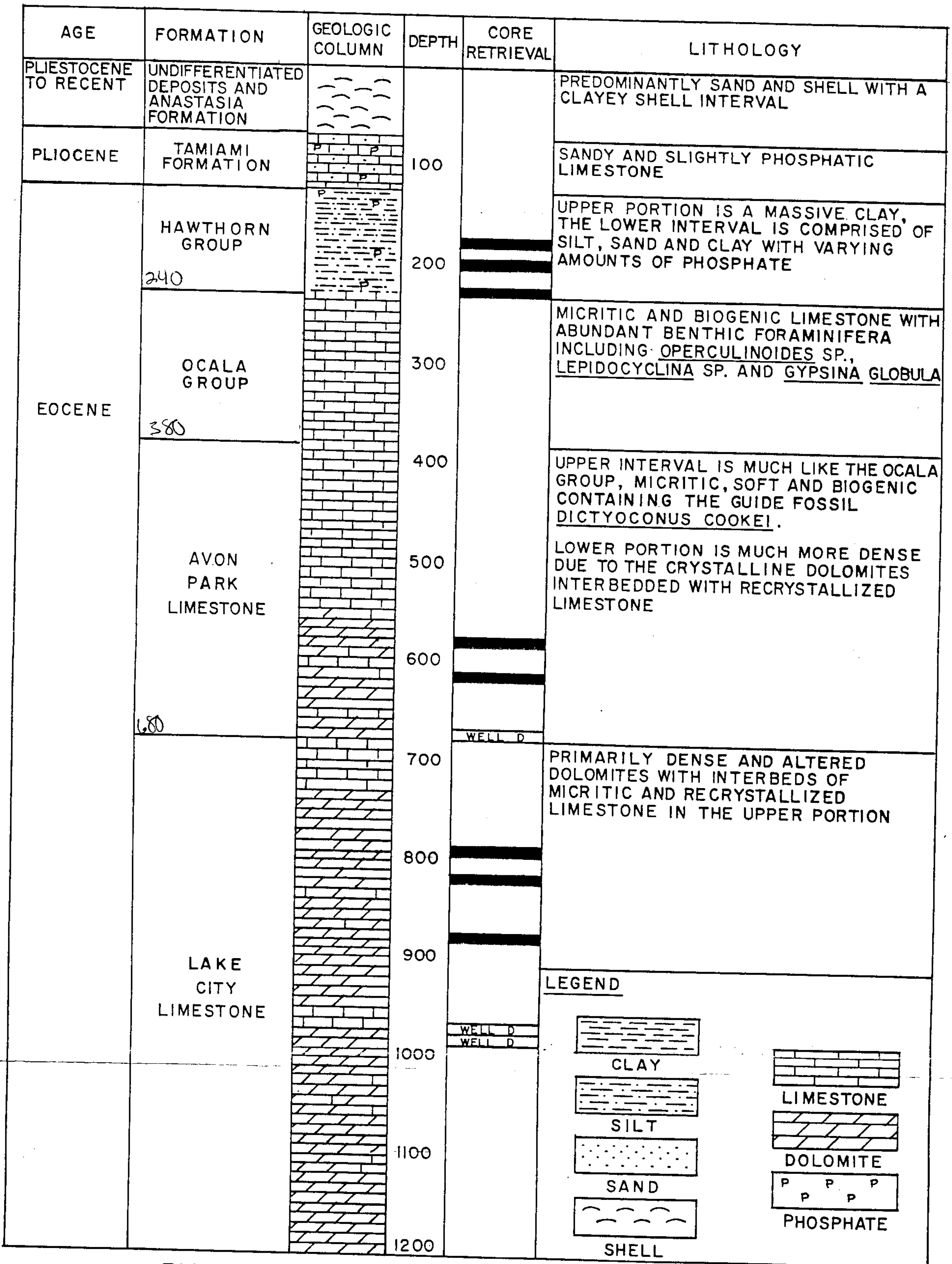

FIGURE 4 GEOLOGY OF EXPLORATORY WELL

FLORIDAN AQUIFER WELL FIELD STUDY
S & G PROJECT NO. 8407-56-01
APRIL 1990

3.0 GEOLOGY

The geologic units underlying Brevard County are summarized in Table 3.1. The anticipated position of the older formations (Oldsmar and Cedar Keys) in the test area are based primarily upon well logs from injection wells in the area. The stratigraphic position of the formations in the subsurface are depicted on the geologic column (Figure 4) and geologic cross section (Figure 5). Other information used to determine formation positions were derived from the Florida Geological Survey, St. Johns River Water Management District, and data developed from the deep exploratory and monitor wells at the Lake Washington test site.

TABLE 3.1 - APPROXIMATE DEPTHS OF FORMATIONS BELOW LAND SURFACE

Depth (ft)	Formation / Group
0 to 126	Undifferentiated Deposits, Anastasia Formation, & Tamiami Formation.
126 to 240	Hawthorn Group
240 to 380	Ocala Group
380 to 680	Avon Park Limestone
680 to 1670	Lake City Limestone
1670 to 2750	Oldsmar Limestone
2750 to ~3000	Cedar Keys Formation

3.1 PALEOCENE ERATHEM

Cedar Keys Formation

The Cedar Keys Formation is the deepest and oldest Tertiary limestone encountered in east-central Florida. The unit was originally proposed by Cole (1944) and described by Chen (1965) as a gray, micro-crystalline, slightly gypsiferous and rarely fossiliferous dolomite. Chen contoured the top of this unit at approximately -2300 to -2500 feet msl in the Brevard County area. The formation was penetrated in the South Beaches Test/Injection Well (Dames and Moore, 1985) from 2780 feet to the total depth of the well at 2915 feet below land surface. In this well the unit occurred as a low permeability gypsiferous dolomite interbedded with anhydrite.

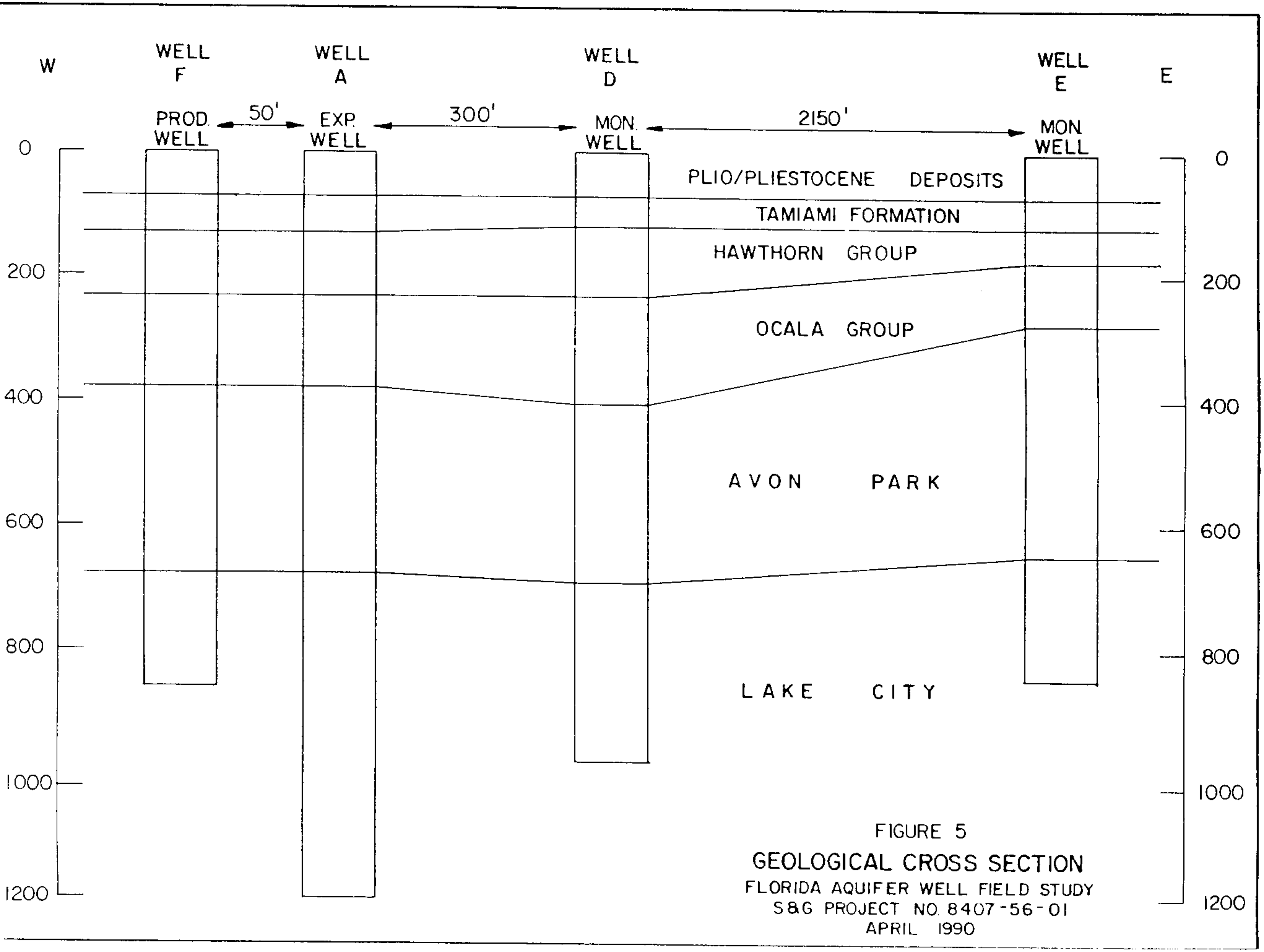

FIGURE 5

GEOLOGICAL CROSS SECTION
FLORIDA AQUIFER WELL FIELD STUDY
S&G PROJECT NO. 8407-56-01
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3.2 EOCENE ERATHEM

Oldsmar Limestone

Applin and Applin (1944) applied the name "Oldsmar Limestone" to a series of faunal zones overlying the Cedar Keys Formation. Chen (1965) described the unit in peninsular Florida as being predominantly dolomite and limestone with gypsum and anhydrite as minor components. In the Melbourne area he contoured the top of the unit between -1500 and -2000 feet msl and the thickness as approximately 900 feet. The Oldsmar was logged from 1800 to 2700 feet in the City of Melbourne Test/Injection Well at Grant Street. The upper portion of the unit in this well occurred as a cherty and glauconitic highly recrystallized limestone. Cavernous and possibly fractured dolomites were encountered from near 2040 feet below land surface to the base of the formation penetrated in the well.

Lake City Limestone / Avon Park Limestone

The Lake City Limestone and Avon Park Limestone were proposed by Applin and Applin (1944) for rocks of early middle Eocene and late middle Eocene age respectively in Florida. In the type area the Lake City Limestone is described as "a gray-brown, dense microcrystalline dolomite with occasional thin beds of limestone, chert, and carbonaceous material" (Ceryak, Knapp and Burnsen, 1982). The Avon Park Limestone is described as "a cream colored, chalky, limestone that contains a distinct fauna" from a type well located at the Avon Park bombing range in central Florida (Vernon, 1951). The two units are very similar lithologically and for the most part can only be separated by the guide fossils present within them. The Lake City, however, tends to be much more dolomitic than the Avon Park. A carbonaceous bed has been used to separate the two units in parts of western and southern Florida (Chen, 1965). This bed is not encountered in the Brevard County area and only subtle lithologic and paleontologic differences separate the units.

The top of the Avon Park was contoured at near -400 feet msl and the thickness of this unit combined with the underlying Lake City is between 1200 and 1400 feet in the Melbourne area by Chen (1965). At the Merritt Island injection well the Avon Park was present at 235 feet below land surface and the total thickness of it and the Lake City Limestone was 1445 feet. At the South Beaches injection well the top of the Avon Park was at 400 feet below land surface and the two units extended to 1663 feet below land surface for a total thickness of 1263 feet. In the Melbourne Well the top of the two units was encountered at 380 feet below land surface and the total thickness was 1400 feet.

At the Lake Washington test site, the top of the Avon Park Limestone occurred at a depth of 380 feet below land surface. The stratigraphic position of the unit in the Lake Washington wells is shown on Figure 5 (Geological Cross Section). The upper portion of the unit was primarily a fossiliferous limestone with interbeds of dolomite. The unit differed lithologically from the overlying Ocala Group primarily by the presence of dolomite and dolomitic limestone within its sequence. Lithologically the upper limestone beds within the unit were not distinctively different from the overlying Ocala. The major difference was the presence of the guide fossil Dictyoconus cookei.

The Lake City occurred at 680 feet below land surface. This unit was characterized by an overall dolomitic lithology, although the upper 40 feet was a fossiliferous limestone. Few interbeds of limestone were encountered and those interbeds that were present contained the diagnostic foram Dictyoconus americanus and Coskinolina, sp.

Ocala Group

Dall and Harris (1892) first used the term "Ocala Limestone" for limestones being quarried near the town of Ocala in Marion County, Florida. Puri (1957) raised the formation to the Ocala Group and subdivided it into three formations. Chen (1965) showed the top of the Ocala in the Melbourne area to be between -200 and -400 feet msl and the thickness near 100 to 150 feet. At the South Beaches injection well the Ocala occurred at 251 feet below land surface as a white micritic and coquinoid limestone with a large and diverse number of larger foraminifera. The unit was 149 feet thick at this site. At the City of Melbourne injection well the top of unit occurred at 272 feet below land surface in the coquinoid limestones.

At the Lake Washington test site the Ocala consistently occurred at 240 feet below land surface with the exception of the farthest easterly well (Well E) where the unit occurred at 180 feet below land surface. Lithologically it was a chalky (micritic) and fossiliferous coquinoid limestone with many of the characteristic Ocala fauna present (Lepidocyclina ocalana, Heterestegina sp., Gypsina globula, and Operculinoides sp.). The unit was more micritic and poorly indurated in the upper portion to a depth of 290 feet.

3.3 MIOCENE ERATHEM

Hawthorn Group

Dall and Harris first used the term "Hawthorn beds" for Miocene age phosphatic sediments being quarried near the town of Hawthorn in Alachua County, Florida. The Hawthorn normally consists of various mixtures of clay, quartz sand, carbonate (dolomite to limestone) and phosphates (Scott and Knapp, 1987). At the South Beaches injection well the Hawthorn was logged at 120 feet below land surface and was 131 feet thick. The unit occurred at 150 feet below land surface in the City of Melbourne injection well extending 123 feet down the hole to the top of the Ocala at 273 feet below land surface.

The Hawthorn Group was penetrated at 126 feet below land surface in the exploratory well at Lake Washington. The unit has an overall silty character (dolosilt) with phosphate, sand and some clay as accessory minerals. Massive clay beds are interbedded with the dolosilt to a depth of 173 feet below land surface. The Hawthorn unconformably overlies the Ocala Group.

3.4 PLIOCENE / PLEISTOCENE ERATHEM

Tamiami Formation

Mansfield (1939) proposed the term "Tamiami limestone" for a fossiliferous sandy limestone approximately 25 feet thick, which was penetrated in shallow ditches along the Tamiami Trail (U.S. Highway 41) in southern Florida. The formation was logged at 80 feet below land surface and was 40 feet thick in the South Beaches injection well. It was present in the City of Melbourne injection well from 100 feet below land surface to the top of the Hawthorn Group at 150 feet below land surface.

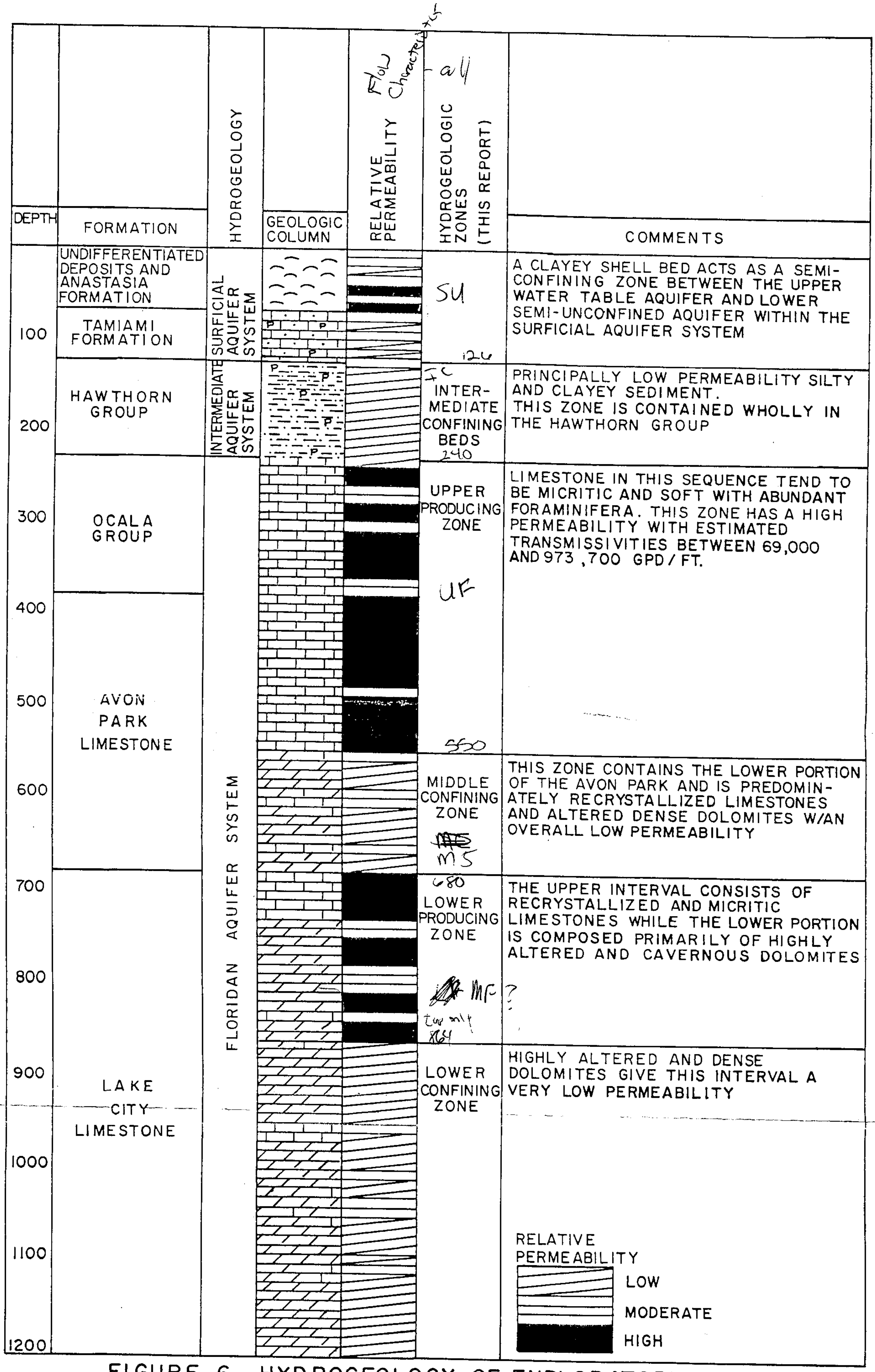
The exploratory well at Lake Washington penetrated the Tamiami Formation from 70 to 126 feet below land surface. The unit occurred as a sandy and slightly phosphatic fossilliferous limestone.

Anastasia Formation / Undifferentiated Deposits

These deposits vary in thickness throughout the Brevard

County area. The Anastasia Formation (Sellards, 1912) is normally composed of a sandy coquina of mollusk shells held loosely together by a calcareous cement. The unit can however be moderately to well indurated depending upon the quantity and composition of cementing material. Undifferentiated deposits blanket all of Florida resulting from sea level fluctuations and terracing during the Pleistocene Age. At the City of Melbourne injection well these two units extended from land surface to 100 feet.

The Anastasia Formation was logged from 10 to 70 feet below land surface in the exploratory well at Lake Washington. It was composed of loosely consolidated sandy limestone and shell beds. The Anastasia was overlain by 10 feet of very fine to coarse marine terrace sand, which is undifferentiated in the exploratory well.



A CLAYEY SHELL BED ACTS AS A SEMI-CONFINING ZONE BETWEEN THE UPPER WATER TABLE AQUIFER AND LOWER SEMI-UNCONFINED AQUIFER WITHIN THE SURFICIAL AQUIFER SYSTEM

PRINCIPALLY LOW PERMEABILITY SILTY AND CLAYEY SEDIMENT.
THIS ZONE IS CONTAINED WHOLLY IN THE HAWTHORN GROUP

LIMESTONE IN THIS SEQUENCE TEND TO BE MICRITIC AND SOFT WITH ABUNDANT FORAMINIFERA. THIS ZONE HAS A HIGH PERMEABILITY WITH ESTIMATED TRANSMISSIVITIES BETWEEN 69,000 AND 973,700 GPD/FT.

THIS ZONE CONTAINS THE LOWER PORTION OF THE AVON PARK AND IS PREDOMINATELY RECRYSTALLIZED LIMESTONES AND ALTERED DENSE DOLOMITES W/AN OVERALL LOW PERMEABILITY

THE UPPER INTERVAL CONSISTS OF RECRYSTALLIZED AND MICRITIC LIMESTONES WHILE THE LOWER PORTION IS COMPOSED PRIMARILY OF HIGHLY ALTERED AND CAVERNOUS DOLOMITES

HIGHLY ALTERED AND DENSE DOLOMITES GIVE THIS INTERVAL A VERY LOW PERMEABILITY

FIGURE 6 HYDROGEOLOGY OF EXPLORATORY WELL

FLORIDAN AQUIFER WELL FIELD STUDY
S & G PROJECT NO. 8407-56-01
APRIL 1990

4.0 HYDROGEOLOGY

There are four major hydrogeologic units that occur in peninsular Florida (Vechiolli et al, 1986). These are: the Surficial Aquifer System, the Intermediate Aquifer System or confining beds, the Floridan Aquifer System, and the sub-Floridan confining beds. The surficial aquifer system contains the water table and other semi-confined or semi-unconfined water bearing zones. The intermediate confining beds normally are restricted to the Hawthorn Group, but other beds may be included. The Floridan Aquifer System is the major regional artesian aquifer system in the southeastern United States. The top of the system normally occurs in the basal porous limestones of the Hawthorn or older Oligocene and Eocene beds. Its base is marked by the bedded anhydrites (sub-Floridan confining beds) associated with the Cedar Keys Formation (Miller, 1982).

4.1 SURFICIAL AQUIFER SYSTEM

The surficial aquifer system in Brevard County varies in thickness with the depth to the top of the Hawthorn Group. The system is composed of the sands, shell beds, and sandy limestones of the Pliocene and Pleistocene age sediments. The aquifer system is non-artesian and water levels are usually within 10 feet of land surface. Most wells completed into this unit are from 1 1/4" to 3" in diameter and are used domestically. Water quality ranges from good to poor depending on the location and wells generally produce between 5 and 10 gallons per minute (gpm). The SJRWMD has well records for 16 surficial aquifer wells within a 2 mile radius of the APT site.

The aquifer system was 120 feet thick at the South Beaches injection well and 150 feet thick at the City of Melbourne injection well. The system can be divided into two interconnected aquifers in this area based upon available shallow well log information. A silty sand occurs at approximately 40 feet below land surface that retards the vertical flow of water within the aquifer system. Underlying the silty sand the shell beds of the Anastasia Formation and sandy limestones of the Tamiami Formation form a semi-confined to semi-unconfined aquifer.

At the Lake Washington site the Surficial Aquifer System is 126 feet thick. A 10 foot thick clayey shell bed occurs at 20 feet below land surface and acts as a semi-confining zone between the upper water table aquifer and lower semi-unconfined aquifer within the Anastasia and Tamiami formations. The Hawthorn Group lies below the Surficial Aquifer System and is composed primarily of low permeability clays and silts.

The aquifer system is recharged primarily by local rainfall and surface water infiltration. Discharge occurs through well withdrawals, evapotranspiration, and losses by baseflow to the surface water network. The flow parallels the local topography towards the Indian River and St. John's River in the Brevard County area.

4.2 INTERMEDIATE AQUIFER SYSTEM OR CONFINING BEDS

The intermediate confining beds are associated with the Hawthorn Group in this area of Florida. The low permeability silty and clayey sediments within this sequence effectively retard the vertical flow of water between the Surficial Aquifer System and the Floridan. These confining beds were 131 feet thick at the South Beaches injection well and 123 feet thick at the City of Melbourne injection well. It is significant that the clays and dolosilts composing this unit are vertically continuous and massive enough that wells stay open without having to install casings through the confining bed.

At the Lake Washington site the Intermediate confining beds are 70 to 104 feet thick and wholly contained within the Hawthorn Group (Figure 6). The silts and clays within the Group are of very low permeability. Three core samples were taken from the confining zone (Table 2.3). Vertical permeabilities ranged between 1.3 X 10 -6 and 9.1 X 10 -9 cm/sec. Porosities ranged between .49 and .62.

4.3 FLORIDAN AQUIFER SYSTEM

The term "Floridan aquifer" was established by Parker (1955) for water bearing rocks associated with the Lake City Limestone, Avon Park Limestone, Ocala Limestone, Suwannee Limestone, Tampa Limestone, and the lower parts of the Hawthorn Group in hydrologic contact with underlying units. Miller (1982) referred to these beds as the Tertiary Limestone Aquifer System and showed the top of the system in the Melbourne area to be between -200 and -300 feet msl. He contoured the base at approximately -3000 feet msl in this area. The entire thickness of the Floridan was penetrated in the South Beaches injection well from 251 feet to 2760 feet below land surface. It was also fully penetrated in the Merritt Island injection well from 126 feet to 2670 feet below land surface. At the City of Melbourne injection well the top of the Floridan was penetrated at 273 feet below land surface, but the base was not encountered after total depth (2700 feet). Cavernous and possibly fractured zones occurred in the Merritt Island and South Beaches wells within the lower dolomite sequences of the Oldsmar Limestone. Waters in excess of 10,000 TDS were penetrated in the South Beaches well at a depth of 1253 feet below land surface, in the Merritt Island well at a depth of 950 feet below land surface, and in the City of Melbourne well at a depth of approximately 1250 feet below land surface.

Background hydrogeologic information for the Lake Washington study was obtained from previous investigations, primarily Toth 1988, Skipp 1988, and Brown et al 1962, and from drillers' logs provided by the SJRWMD. The previous investigations are regional in nature and are listed in the bibliography. They provided most of the initial data on the Floridan Aquifer System.

In the Lake Washington and Brevard County area the SJRWMD have well records for 53 Floridan wells within a 2 mile radius of the APT site. These wells are 2 to 3 inches in diameter and usually extend 80 feet or less into the Floridan aquifer. A list of the wells and their general uses are available in the Appendix. The well records indicate that the top of the Floridan is 180 to 240 feet below land surface in this area. The potentiometric head ranges from 10 feet to 20 feet above land surface. Chloride concentrations in the upper Ocala Group generally range from 300 to 600 mg/l around the study area.

Previous investigations suggest the possibility of a dense, low permeability zone within the Avon Park Limestone. Skipp 1988, uses this as a confining bed between an upper permeable zone and a lower permeable zone in his regional Floridan Aquifer groundwater-flow model. Data generated during this study indicates for the Lake Washington site a semi-confining bed within the lower portion of the Avon Park limestone. The hydrogeological units (producing and confining zones) within the portion of the Floridan Aquifer System penetrated by wells drilled during this study are discussed below. These zones are: an upper producing zone, a middle semi-confining zone, a lower producing zone, and a lower confining zone (Figure 6). The deepest well drilled (1204 feet - Well A) only penetrated into the top of the lower confining zone. This zone separated the upper Floridan from the lower Floridan in this area.

The hydrogeological characteristics of individual zones was determined by comparison of geophysical and geological logs from the deep exploratory well (Well A). Logs from the other wells at the site were used to verify the exploratory well logs. Using the method described by Kwader (1982) the estimation of flow percentages from individual zones was accomplished by comparing the caliper log to the flowmeter log on the exploratory well. The flow percentage was set at zero percent (0%) for the base of the flow log and at a hundred percent (100%) for the casing. Fluctuations on the flowmeter log were then corrected for borehole diameter. In general the smaller hole diameters caused major fluctuations on the flowmeter log because of increased velocity rather than an increase in flow volume. Major producing zones were identified by comparison of the flow and caliper logs to the acoustic and temperature logs. Major attenuations or fluctuations within the major zones were identified as producing intervals.

UPPER PRODUCING ZONE

The upper producing zone extends from 240 to 550 feet below land surface (Figure 6). The Ocala Group and part of the Avon Park Limestone are the geologic units present within the zone. Lithologically the zone is composed principally of coquinoid limestone. Electric logs (16" and 64" normal) show low resistivity through the interval verifying the presence of poor to moderately indurated limestone. The limestones in this zone have a tendency to washout during the drilling process and hole diameters (caliper logs on the APT wells were consistently in the 15 inch diameter size range with 5 7/8" to 7 7/8" pilot bits). The natural gamma ray logs show low radioactivity within the zone as compared to the very high radioactivity within the Hawthorn (phosphatic sediments) and moderate radioactivity within the underlying dolomites (probably from concentrations of uranium and thorium within the lattice structure of the dolomites). The caliper and flowmeter logs were used to estimate the percent contribution of flow to the wellbore from this zone. The zone collectively produced approximately 50% of the water into the well bore of the exploratory well when the well was 1000 feet deep. Based upon interpretation and correlation of the acoustic, caliper, electric, flowmeter, temperature, and geologic logs of the exploratory well the major individual flow zones within this interval are located at 290, 360, 470 and 550 feet below land surface. (estimate bottom from figure (6))

The conductivity and total dissolved solids (TDS) concentrations of samples taken during reverse air drilling were consistent through the upper producing zone. The conductivities were about 2250 umhos/cm and TDS around 1150 mg/l. Chlorides ranged between 430 mg/l to 615 mg/l and sulfates between 130 mg/l to 180 mg/l.

Step (3 steps) drawdown tests were conducted on several wells at the site when they had reached a depth of 550 feet. Estimates of transmissivity from these tests ranged between 166,000 and 356,400 gpd/ft. A 92 hour APT was performed in October at the site and transmissivity estimates (using HydroDesigns and SJRWMD data) from this APT range between 69,000 and 973,700 gpd/ft. Storage ranges between 7.98 X 10 -4 and 1.6 x 10 -3.

MIDDLE SEMI-CONFINING ZONE

The middle semi-confining zone extends from 550 feet to 680 feet below land surface. The zone is contained wholly within the lower sequence of the Avon Park Limestone. The Avon Park is composed of highly altered dolomites throughout this lowermost interval. The geophysical logs on the wells confirm the lithology in the middle confining zone. The electric (16" and 64" normal) logs show higher ohm/m readings through the dense dolomite sequence of the lower Avon Park. The natural gamma ray log also shows higher radioactivity to a depth of 680 feet indicative of dolomites. Correlation of the flowmeter and caliper logs indicate the zone gives a maximum estimated flow contribution of 4% to a well completed to 1000 feet. There is one small zone within the interval at 570 feet (temperature and acoustic logs) that may be contributing water.

LOWER PRODUCING ZONE

The lower producing zone is contained within the Lake City. It extends from the base of the middle confining zone at 680 feet to a depth of 864 feet below land surface. The upper portion of the zone (680 to 730 feet) is composed of recrystallized and micritic limestones. Below the limestones the zone is composed primarily of highly altered and cavernous dolomites. The electric (16" and 64" normal) and natural gamma ray logs respectively show the zone from 680 to 730 feet to have a lower resistivity and radioactivity indicative of limestones. The logs also show limestone interbeds in the lower dolomites from 752 to 764 feet and from 850 to 864 feet below land surface. The caliper log shows cavities in the lower dolomite sequence at 790, 810 and 850 feet. Analysis of the flowmeter and caliper logs indicates that the zone collectively contributed about 39% of the flow to the wellbore when the exploratory well was at a depth of 1000 feet. Major producing intervals in the zone are identified at 790, 810 and 850 feet below land surface. The production well (well F) shows an anomolous relationship to the flowmeter logs. When this well was tested at a depth of 550 feet at a pumping rate of over 2000 gpm, about 80 feet of drawdown occurred in the well. However, at the total depth (850 feet) of the well it would free flow at 2450 gpm with only about 9 feet of drawdown. It would appear just from the flow rates and resulting drawdowns that the lower producing zone contributes more than 39 percent of the inflow to the production well. The 80 feet of drawdown, however, is largely a result of poor well efficiency, because a turbine pump with about 85 feet of drop pipe was used on the initial test and the well was tested by free flow on the following longer test (APT #2). The observation wells at the site also showed minimal drawdown during the 92 hour test. In addition during the drilling of the exploratory well flow increased from 500 gpm at the top of this zone to only 800 gpm at the bottom (Table 2.4) and remained the same to the total depth of the well. It should be noted that as hole diameter increases, there is a percentage of flow increase (Driscoll, 1987 Table 13.15). This would indicate that the flowmeter interpretations are essentially within the correct range.

The conductivity of the water from this zone was consistently in the 2300 umhos/cm range.

LOWER CONFINING ZONE

The lower confining zone extends from 864 feet to at least 1204 feet below land surface. The zone is composed of highly altered and dense dolomites from the Lake City Formation. The exact depth of the base of the lower confining zone is not known in this area. However, a test/injection well for the City of West Melbourne (an area approximately the same distance west as Lake Washington) indicated the base of the dolomite and limestone (very confining) sequence occurred at 1450 feet below land surface. The exploratory well penetrated dense dolomites to its total depth of 1204 feet. The electric and natural gamma ray logs from this interval show highly resistive and radioactive signatures indicative of dolomites. The caliper log showed cavities to be present at 1080, 1090 and 1097 feet below land surface. The flowmeter through this section showed it collectively contributed not more than 7% of the water to the borehole when the exploratory well was at 1000 feet below land surface. The base of these confining beds is probably in the 1250 to 1450 feet below surface range. Normally (as is the case with the deep injection wells) the interface with waters in excess of 10,000 mg/l TDS (USDW) occurs just below this zone in porous rock.

LOWER FLORIDAN AQUIFER

The lower portion of the Floridan Aquifer System was not penetrated at the Lake Washington Site, but based upon injection well data in the Brevard County area, this unit is composed of multiple producing and confining zones. Generally, in the Brevard County area the zones within the lower Floridan can be delineated as: upper producing zone, lower confining zone and the Boulder Zone which extends to the top of the sub-Floridan confining beds (Cedar Keys).

The Lower Floridan is composed of alternating beds of limestone and dolomite with varying degrees of permeability. There is a regional confining bed (lower confining zone) that is usually about 300 feet thick and composed of glauconitic and cherty limestone from the upper portion of the Oldsmar Limestone. Below these confining beds are the cavernous and highly transmissive boulder zones.

5.0 WATER QUALITY

EXPLORATORY AND OBSERVATION WELLS

Water quality data were collected for the following five wells:

Well A - (BR0910)	Exploratory (1204')
Well B - (BR0916)	Production Zone Monitor (861')
Well C - (BR0913)	Middle Confining Zone Monitor (683')
Well D - (BR0996)	Deep Confining Zone Monitor (988')
Well F - (BR0907)	Production (850')

The wells were sampled continuously during drilling for field parameters. These parameters include specific conductance (conductivity), total dissolved solids (TDS), and temperature. There data are available in the Appendix of this report and outlined in Table 2.4.

The Floridan Aquifer System was encountered at approximately 240 feet below land surface in the sampled wells. Reverse air water samples were collected at approximately 30 foot intervals in wells A, B, C and F. At the end of each drill rod (30 feet) the drilling fluids were circulated and sampled after about 15 minutes. These samples were analyzed for chloride and sulfate. Reverse air samples were collected periodically in all 5 wells and analyzed for the Primary Drinking Water Standards (PDWS).

Point samples were also taken periodically and analyzed for the PDWS. The point samples were taken with a thief sampler from a geophysical logging unit. These samples are considered more representative of water quality with depth than the reverse air samples.

In a few samples, $CaCO_3$ precipitated out of solution prior to the sample being analyzed. When this occurred, the calcium values (and occasionally the magnesium values) were extremely high and considered unreliable for inclusion on the graphs.

The water quality within the Floridan stayed fairly constant to a depth of 1204 feet. In the exploratory well the conductivities range between 1750 umhos/cm and 2500 umhos/cm and total dissolved solids (TDS) between 880 and 1250 mg/l. A fluid resistivity log was performed on the exploratory well to the total depth and verified the field water analysis that showed little change in water quality. The chloride content of the waters to the total depth of the well was checked randomly with a HACH digital titrator. Chlorides ranged between 475 and 598 mg/l. The water samples from a depth of 1140 feet to 1200 feet were showing a slight increase in conductivity indicating an increase in salinity.

The following is a brief discussion of the individual water quality parameters analyzed during well drilling and point sampling.

Specific Conductance (Conductivity)

Conductivity ranges between 1750 umhos/cm and 2500 umhos/cm in Wells A, B, C and F (Figure 7). Values for Well D, however, are higher than in all other wells. Values in Well D range from 2360 umhos/cm to 2600 umhos/cm from a depth of 860 to 960 feet below land surface. Well D displayed the lowest conductivity value (1100 umhos/cm at a depth of 230 feet).

Conductivity in the exploratory well begins trending upward at 1110 feet below land surface. The concentration raises continuously from 2200 umhos/cm to 2500 umhos/cm at the bottom of the exploratory well (1204 feet below land surface).

Total Dissolved Solids (TDS)

The TDS was sampled as a field parameter and measured with conductivity on a digital HACH meter. As a result, the values are calculated by the meter and approximately one-half the conductivity values. Therefore, the TDS values measured in the field mirror the conductivity trends (Figure 7).

The TDS values that were measured in the field range between 550 mg/l and 1300 mg/l. The samples that were measured in the lab had somewhat higher TDS values and range from 888 mg/l to 1823 mg/l with most values falling between 1200 and 1600 mg/l.

Sulfates

In Wells A, B, and F, sulfate concentrations consistently range between 130 mg/l and 222 mg/l to a depth of 780 feet (Figure 8). At a depth of 740 feet the sulfates in Well A trend upward from 169 mg/l to 240 mg/l at 845 feet. From 845 feet to 1204 feet, sulfates trend down from 240 mg/l to 195 mg/l.

Sulfate values from the reverse air and point samples analyzed for sulfate are consistent with samples taken every 30 feet. Sulfate values in Well C are consistently higher then the other wells and range between 179 mg/l and 250 mg/l.

Chloride

Chloride concentrations range between 357 mg/l and 828 mg/l and are most consistent between 450 and 550 mg/l (figure 9). In Wells A and B there is an apparent decreasing trend in chloride values from 340 feet to 380 feet and from approximately 450 feet to 550 feet, where values drop to 420 mg/l. A high trend appears from 450 to 500 feet in Wells A, B, and C where values rise to 600 mg/l. There are a few other instances where single values either dip below 450 mg/l or rise above 550 mg/l. In Well A, from 1000 feet to 1200 feet, the chloride values trend upward from 470 mg/l to approximately 600 mg/l. In Well A, some chloride values rise or fall from 75 mg/l to 100 mg/l within 30 feet. The low value (357 mg/l) at 840 feet and the high value (828 mg/l) at 650 are isolated values. However, the values, 630 mg/l at 250 feet, 623 mg/l at 390 feet, 610 mg/l at 610 feet, 575 mg/l at 750 feet and 614 mg/l at 120 feet are substantiated by values in other wells.

Calcium

Calcium values range between 93.5 mg/l and 429 mg/l (Figure 10). Only four (4) samples in four (4) separate wells (A, B, C and D) displayed values above 200 mg/l. From approximately 650 feet to 1200 feet, calcium values for well A were between 100 mg/l and 126 mg/l.

Magnesium

Magnesium values range between 44.2 mg/l and 84.5 mg/l. The majority of values lie between 45 mg/l and 70 mg/l (Figure 10).

Alkalinity and Bicarbonate

As alkalinity and bicarbonate were both sampled as CaCO3 by the same laboratory method, the values are nearly identical. Accordingly, the values were plotted as the same (Figure 11). Values range between 87 mg/l and 231 mg/l. The majority of values lie between 125 mg/l and 160 mg/l with five (5) values from well D and one (1) value from Well A exceeding the average range. High values that exceed this range are: Well D - 203 mg/l at 350 feet, 231 mg/l at 450 feet, 182 mg/l at 650 feet, 209 mg/l at 750 feet and 192 mg/l at 840 feet. Well A - 169 mg/l at 1000 feet (A point sample at the same depth displayed a 125 mg/l value). Low values that fall below this range are Well A: 107 mg/l at 314 feet and Well C: 87 mg/l at 250 feet. Point samples in Well A consistently display values of 125 mg/l from 1000 feet to 1200 feet. In Well D, alkalinity and bicarbonate values plotted consistently higher than the other wells.

pH

The pH values in Figure 11 were measured in the lab. As samples were refrigerated and the shelf time for each sample was different, these values are unreliable. However, the majority of the reported values range between 7.55 and 8.05 pH units. Four point samples from Well D range from 7.2 to 7.3 pH units.

Potassium

Potassium values consistently range between 5 mg/l and 7 mg/l (Figure 12). Two samples from Well C exceed this range; 10.5 mg/l at 250 feet and 7.7 mg/l at 630 feet. Values in Well A trend slightly upward from 5.36 mg/l at 463 feet to 7.13 mg/l in the point sample at 1200 feet.

Strontium

Strontium values range from 7 mg/l to 15.7 mg/l (Figure 12). There is a slight upward trend in Well A, from 9 mg/l at 625 feet to 12.6 mg/l in the point sample at 1200 feet. The values for Well B are consistently higher than all the other wells extending to 15.7 mg/l at 310 feet.

Silica

Silica values range between 11.7 mg/l and 23.0 mg/l with most values falling between 13.0 mg/l and 16.5 mg/l (Figure 13). The majority of the values are within 1 mg/l (+ or -) of 15.0 mg/l. Values for well A begin at 15 mg/l (260 feet) and end at 14.5 mg/l (1200 feet). Well D plotted consistently higher than the other wells with one anomalous value of 41.6 mg/l recorded at 750 feet.

Sodium

Sodium values range between 180 mg/l and 286 mg/l with most values falling between 200 mg/l and 240 mg/l (Figure 13). The five (5) samples from Well D are all below 210 mg/l. Values for Well A trend slightly upward from 222 mg/l at 290 feet to 270 mg/l in a point sample at 1200 feet.

Iron

Iron is the most variable of all of the parameters analyzed. Values range from 0.05 mg/l to 7.5 mg/l (Figure 14). Values for Wells B and C are usually the highest and tend to be greater than 0.5 mg/l. Values for Well A are consistently between 0.05 mg/l and 0.45 mg/l with no trend evident.

92 HOUR AQUIFER PERFORMANCE TEST

A 92 hour aquifer performance test (APT) was run on the upper producing zone from October 16, 1989 at 5:17 pm through October 20, 1989 at 1:17 pm. The production well (Well F) was open from 240 feet to 550 feet and was pumped at an average rate of 2070 gpm throughout the 92 hour test. Water quality samples were collected from the production well (Well F) and the deep monitor zone of the exploratory well (Well A). Conductivity was monitored hourly in the production well (Well F). Conductivity was also monitored hourly in the deep monitor zone of the exploratory well (Well A) except during episodes when the small pump failed on that well. Conductivity values for both wells are plotted on Figure 15. The wells were also periodically sampled for chlorides and sulfates. These values are shown in Figure 16. Prior to the test, both wells were sampled for total metals and at the end of the test the wells were sampled for PDWS and total metals. All of the collected water quality parameters are listed in Appendix 9.5.

Conductivity

Conductivity in the production well ranges between 2020 umhos/cm and 2300 umhos/cm with most values falling between 2150 umhos/cm and 2290 umhos/cm (Figure 15). A one time high value occurred 23 hours into the test and was recorded at 2300 umhos/cm. Values dipped within the last 6 hours of the test. A low value of 2080 umhos/cm was recorded 3 hours before recovery. Values were trending upward at the end of the test, but stayed well below background.

Conductivity in the deep monitor zone of the exploratory well shows similar peaks and trends as those in the production well. Conductivity ranges between 2740 umhos/cm and 2300 umhos/cm. During the last 18 hours of the test, conductivity values trend downward with the lowest value of 2300 umhos/cm recorded 3 hours before recovery. Values in the exploratory well were also trending upward the last two hours of the test but never rose above 2420 umhos/cm.

Sulfate

Before the test, sulfate (SO4) was recorded at 163 mg/l in the production well (Figure 16). Sulfate values were consistently measured from 154 mg/l to 172 mg/l during the test. At the end of recovery, sulfate was recorded at 154 mg/l.

In the deep monitor zone, sulfate was recorded at 176 mg/l and were consistently recorded from 156 mg/l to 199 mg/l throughout the test. A post test value of 179 mg/l was measured at the end of recovery.

Chlorides

Chloride values in the production well ranged from 478 mg/l to 640 mg/l during the APT (Figure 16). Before the test, chlorides were measured at 502 mg/l and after the test they were measured at 526 mg/l.

In the deep monitor zone, chlorides were measured at 638 mg/l and varied from 633 mg/l to 723 mg/l during the test. A post test measurement of 614 mg/l was recorded after recovery.

31 DAY AQUIFER PERFORMANCE TEST

A 31-day aquifer performance test (APT) was conducted from 12/28/89 through 1/29/90. The production well free-flowed between 2320 gpm and 2390 gpm (Figure 17). Conductivity was monitored hourly in the production well (Well F) and the deep monitor zone in the exploratory well (Well A). Daily noontime values for conductivity are plotted on Figure 17. Both wells were periodically sampled for PDWS. These values are displayed in Figures 18, 19 and 20. The wells were also sampled before and at the end of the test for Secondary

Drinking Water Standards and Primary Inorganics. The values that apply are also displayed in Figures 18, 19 and 20 and the remainder of the values are in Appendix 9.5.

Conductivity

Conductivity in the production well ranges consistently between 2100 umhos/cm and 2300 umhos/cm with a one time value of 2100 umhos/cm recorded at 13 days. Values trend slightly downward from 2300 umhos/cm at day 20 to 2200 umhos/cm at the end of the test.

Conductivity values for the deep confining zone (Well A) are more variable, ranging from 1900 umhos/cm to 2700 umhos/cm. At the beginning of the test (the first 11 days) conductivity values were consistently ranging between 2550 umhos/cm to 2650 umhos/cm. Values trended downward with the lowest value recorded at 1900 umhos/cm on day 28 and 29, this value was followed by an abrupt rise the last three days of the test with a high value of 2700 umhos /cm recorded on day 31.

Each time the flow increased (6 times during the test) the conductivity in the 2 wells decreased.

Total Dissolved Solids

TDS values in the production well ranged from 1447 mg/l to 1712 mg/l (Figure 18). The value prior to the test was 1557 mg/l and the value at the end of the test was 1548 mg/l.

The value for Well A ranged from 2047 mg/l to 1548 mg/l. The low value was at the end of the test indicating a downward trend in total dissolved solids for this well.

Sulfate

Before the APT, the sulfate value in the production well was 212 mg/l (Figure 19). During the test the values ranged from 145 mg/l to 285 mg/l. The value at the end of the test was 200 mg/l.

The four values for Well A ranged from 204 mg/l to 252 mg/l.

Chloride

Before the APT, the chloride value was 254 mg/l in the production well (Figure 19). This value is considered unreliable and resulted from a sampling or measurement error. Chloride concentrations from previous samples on the exploratory and monitor wells show background levels to be in the 450 mg/l to 600 mg/l range. During the test, the values ranged from 560 mg/l to 670 mg/l. The last sample taken at the end of the test had a chloride value of 575 mg/l.

Chloride values in the four samples taken from Well A were consistently higher then Well F. These values ranged from 60 mg/l to 110 mg/l higher than the production well (F).

Calcium

During the APT, the calcium concentration in the production well ranged from 94.7 mg/l to 116 mg/l (Figure 20). The value at the end of the test was 113 mg/l.

Calcium values for the four samples taken from Well A were consistently higher than the values for Well F. They ranged from 117 mg/l to 132 mg/l.

Magnesium

Before the APT, the magnesium concentration in the production well was 46 mg/l (Figure 20). During the test the value ranged from 51.5 mg/l to 57.7 mg/l. The value at the end of the test was 56.6 mg/l.

Magnesium values for the four samples taken from Well A were consistently higher than the values for Well F. They ranged from 58.6 mg/l to 67.2 mg/l.

Alkalinity and Bicarbonate

These parameters were plotted as the same value as in the previous section. Values in both wells ranged from 100 mg/l to 180 mg/l (Figure 21). For the production well, the value near the beginning of the test was 135 mg/l and the value at the end of the test was 180 mg/l. For Well A the value near the beginning of the test was 145 mg/l and the value at the end of the test was 100 mg/l.

pH

The pH values in Figure 21 were measured in the lab. As samples were refrigerated and the shelf time for each sample was different, these values are unreliable. The values for the production well range from 6.85 to 8.16. Values for Well A ranged from 7.18 to 7.59 pH units.

Potassium

Potassium values for both wells varied little. The values for the production well ranged from 6.25 mg/l to 6.5 mg/l (Figure 22). Near the beginning of the test the value was 6.25 mg/l and at the end of the test the value was 6.35 mg/l.

The value in Well A was 7.45 mg/l at the beginning of the test and 7.5 mg/l at the end of the test. The range was from 7.28 mg/l to 7.5 mg/l.

Sodium

The values for sodium were very consistent throughout the test. In the production well, the value was 254 mg/l before the test and 261 mg/l at the end of the test. (Figure 22). The range was from 221 mg/l to 260 mg/l.

In Well A the sodium value ranged from 300 mg/l to 312 mg/l.

Silica

Silica values for both wells were very consistent and ranged between 14.5 mg/l and 16.0 mg/l (Figure 18).

Barium

Barium values were very consistent in both wells. In the production well the range was between 0.14 mg/l and 0.15 mg/l (Figure 23).

In Well A, the range was from 0.155 mg/l to 0.16 mg/l.

Strontium

Strontium values were consistent in both wells. In the production well the range was from 10.7 mg/l near the beginning of the test to 13.4 mg/l near the end of the test (Figure 23).

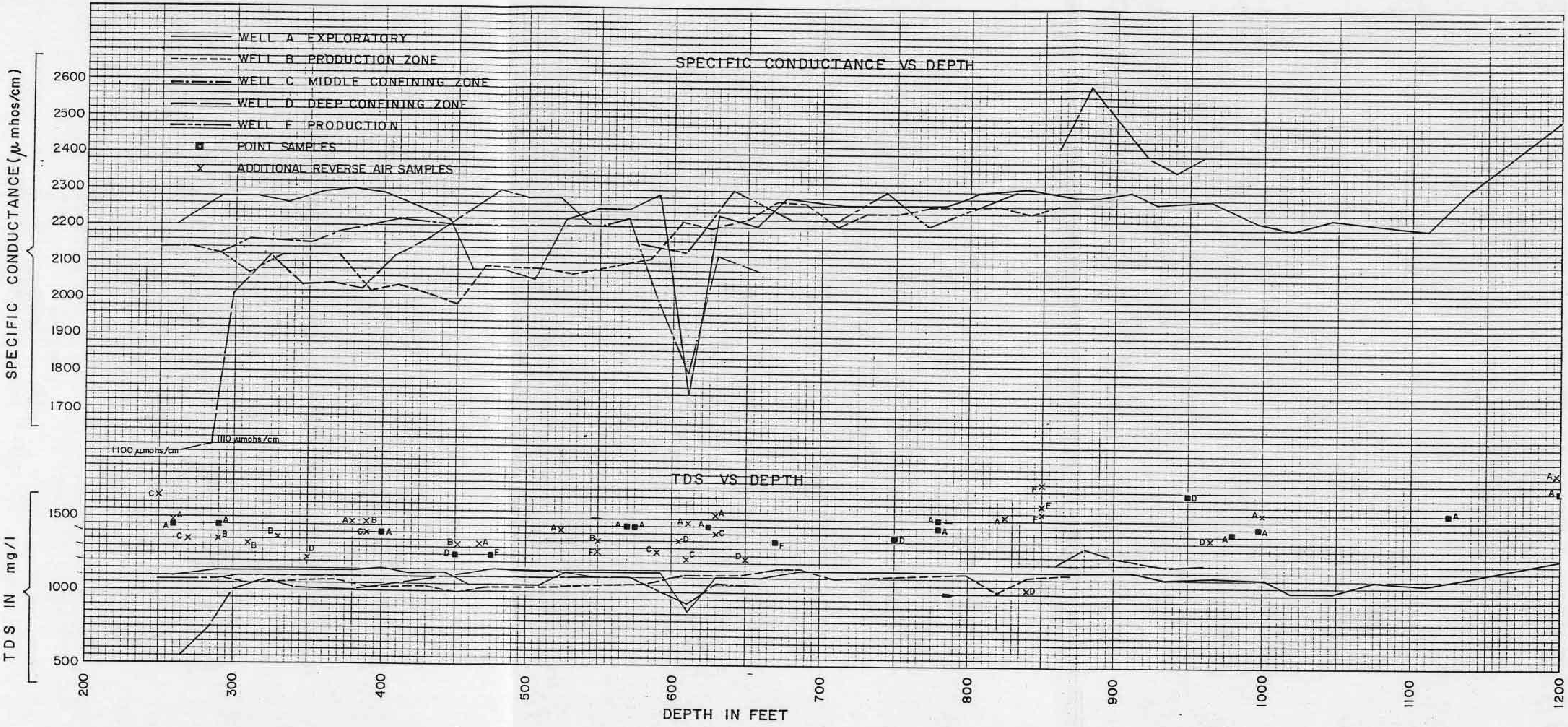


FIGURE 7: SPECIFIC CONDUCTANCE AND TDS VERSUS DEPTH

FIGURE 7: SPECIFIC CONDUCTANCE AND TDS VERSUS DEPTH

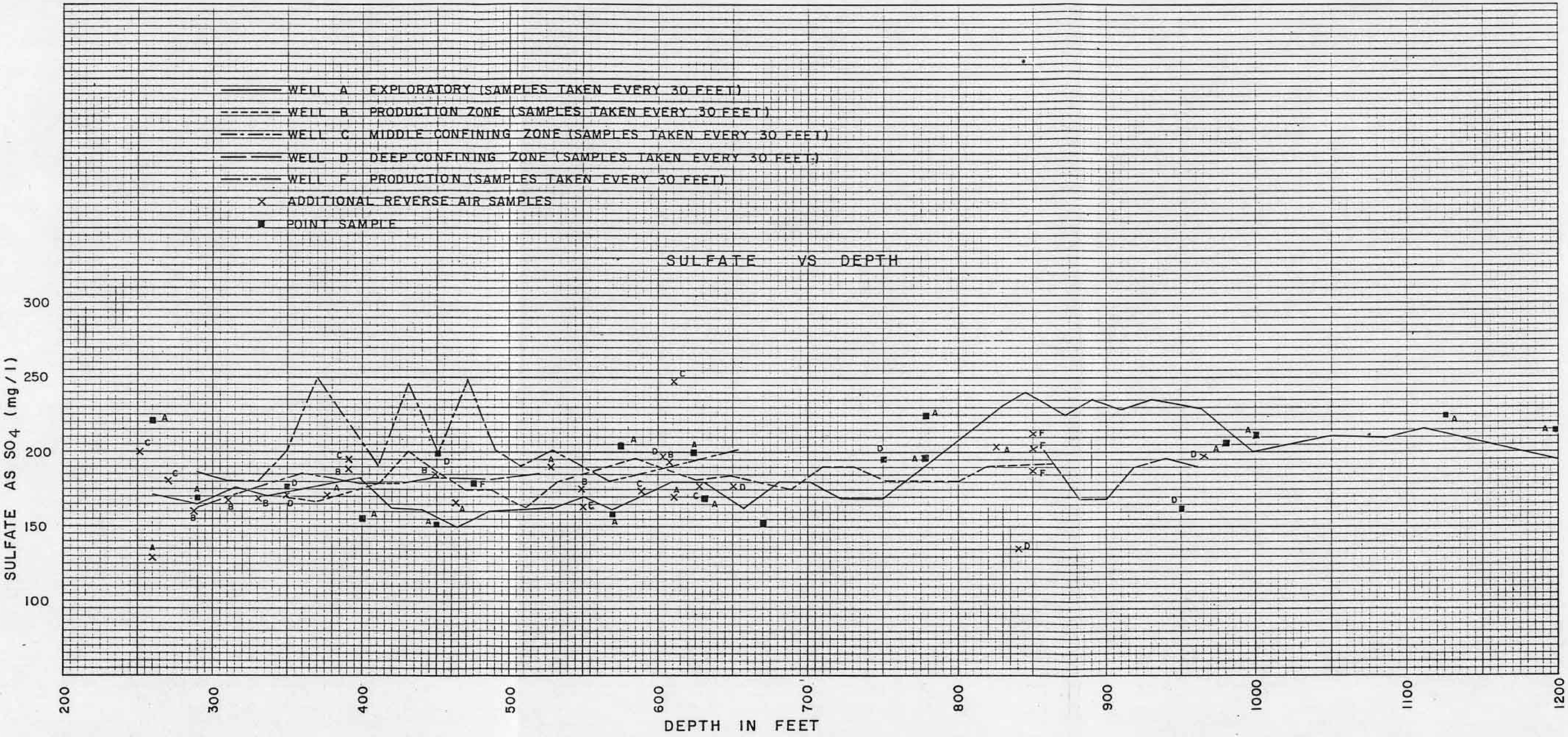


FIGURE 8: SULFATE VERSUS DEPTH

FIGURE 8: SULFATE VERSUS DEPTH

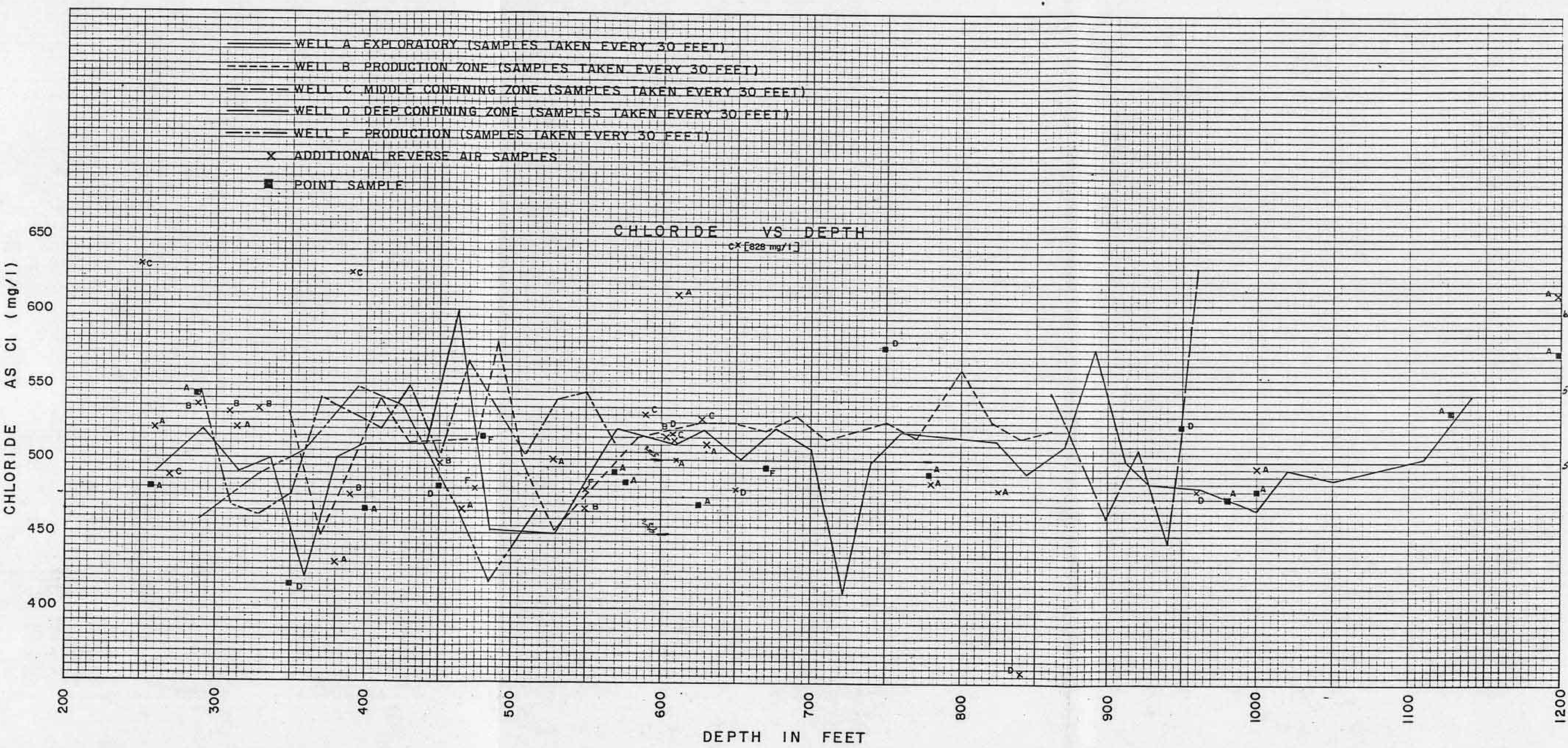


FIGURE 9: CHLORIDE VERSUS DEPTH

FIGURE 9: CHLORIDE VERSUS DEPTH

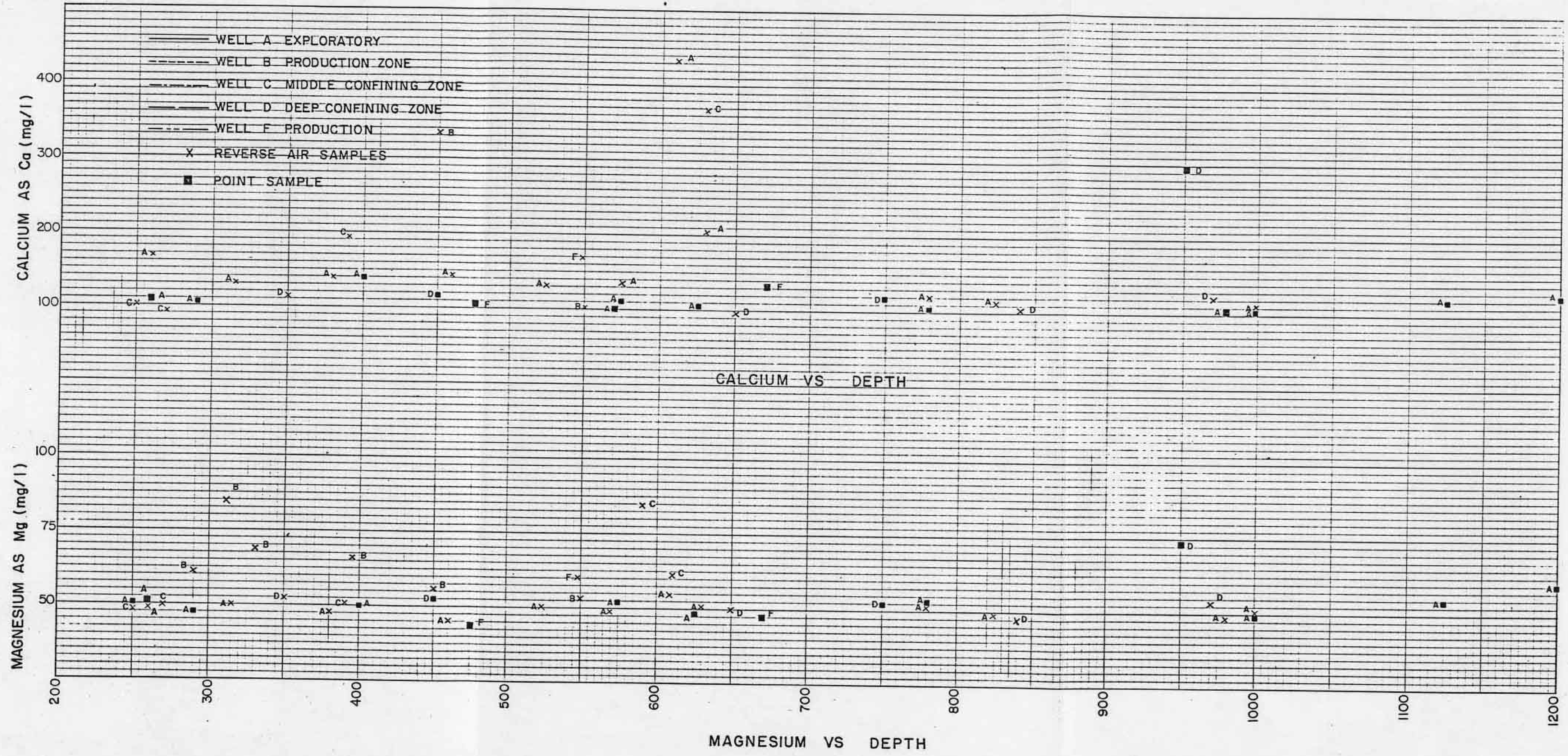


FIGURE 10: CALCIUM AND MAGNESIUM VERSUS DEPTH

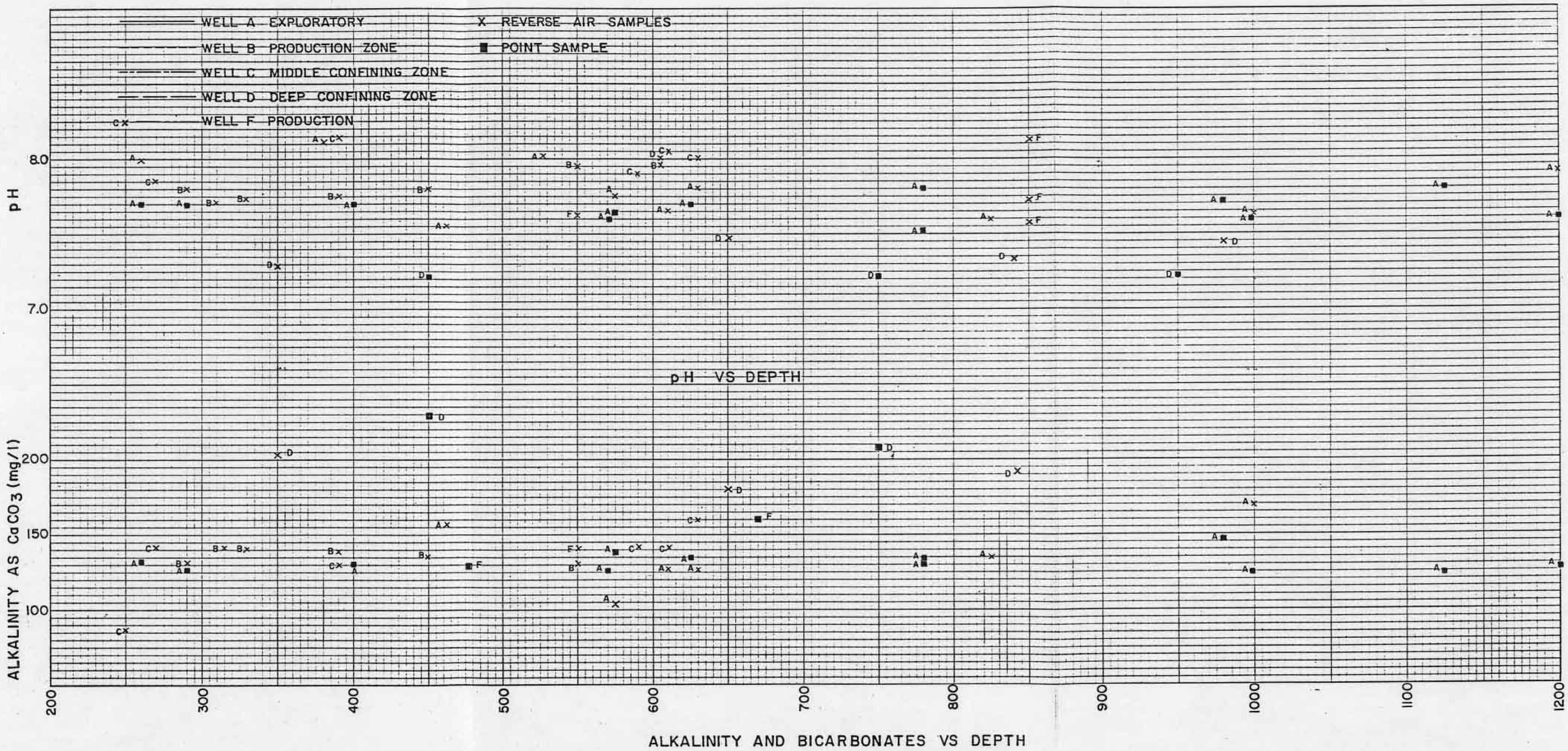


FIGURE 11: pH, ALKALINITY, AND BICARBONATE VERSUS DEPTH

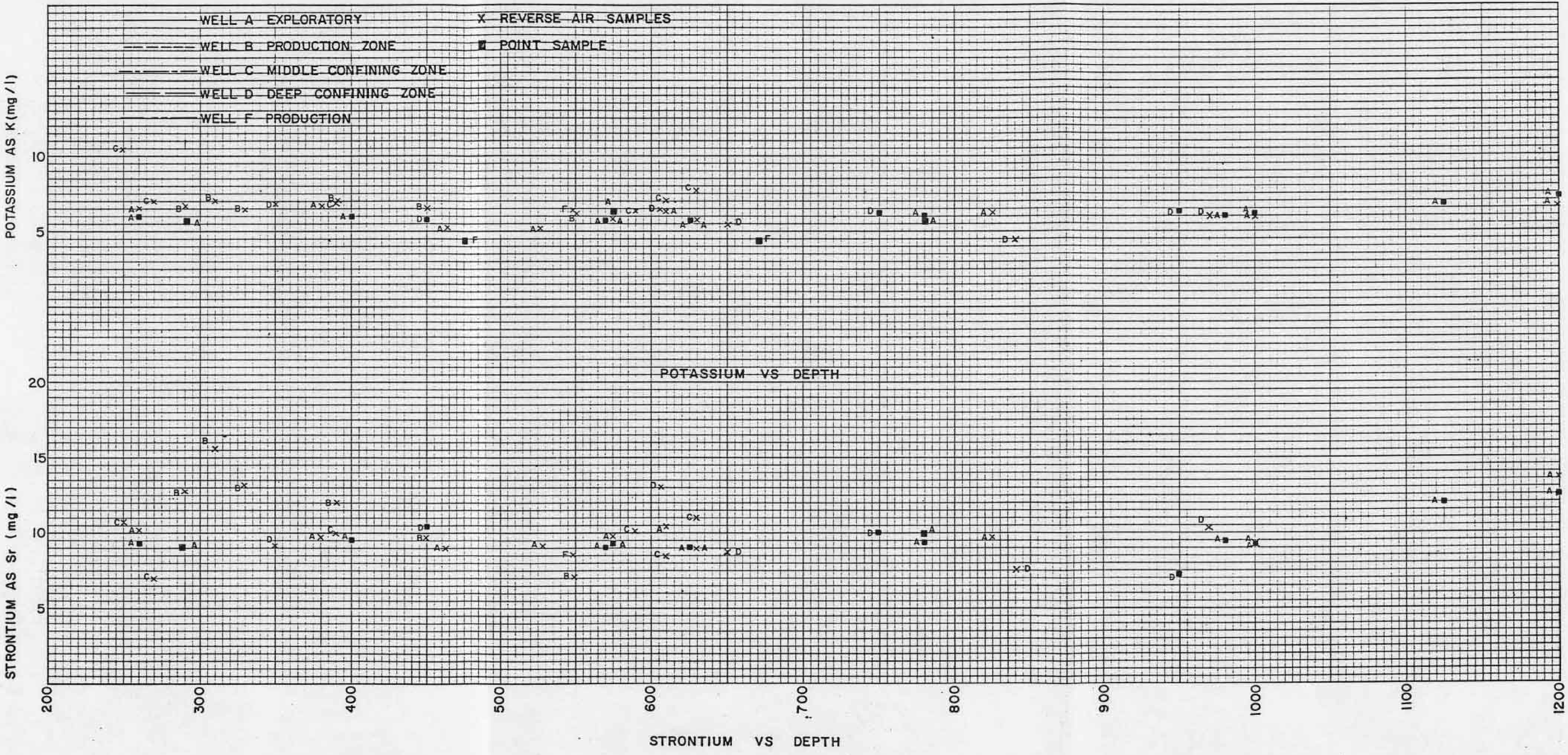


FIGURE 12: POTASSIUM AND STRONTIUM VERSUS DEPTH

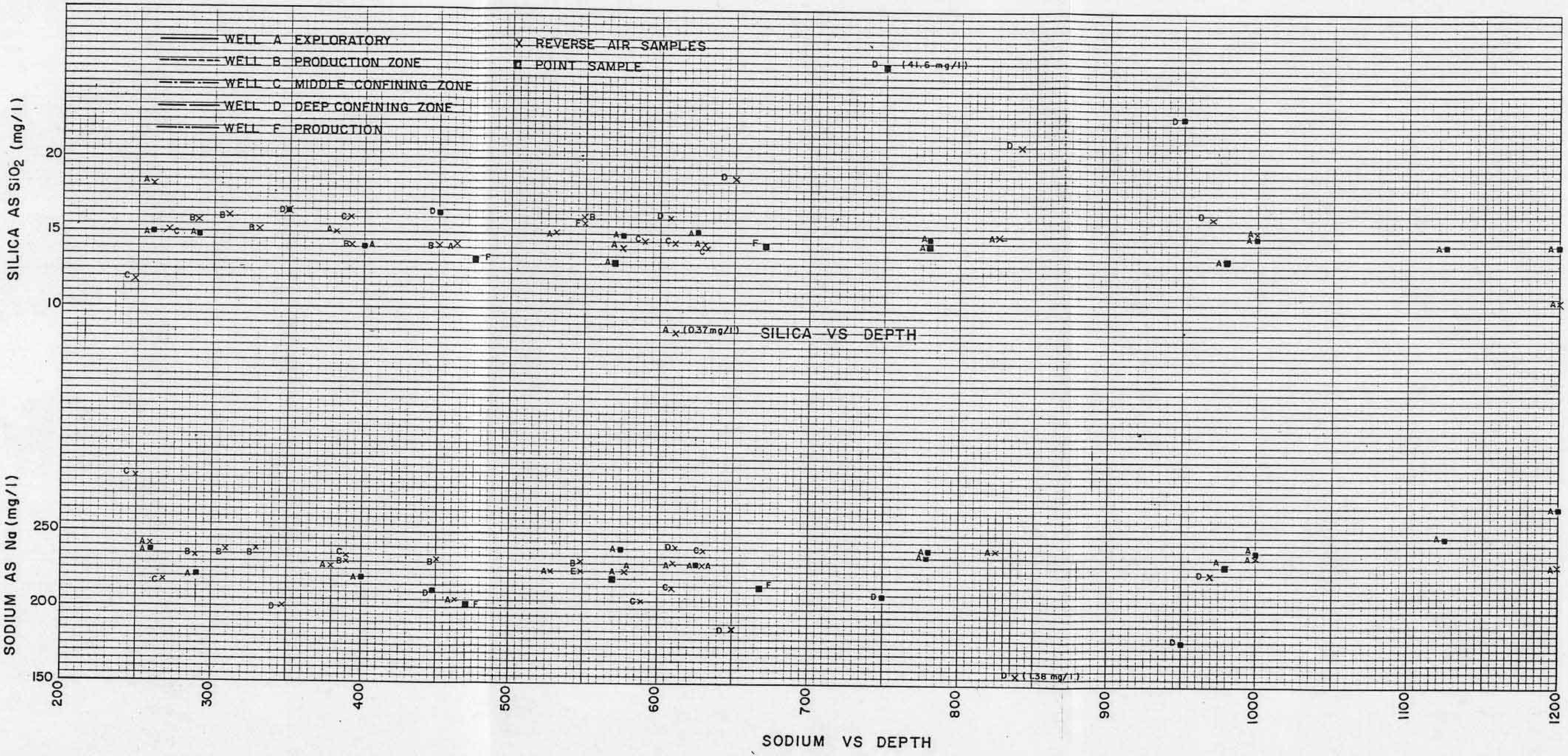


FIGURE 13: SILICA AND SODIUM VERSUS DEPTH

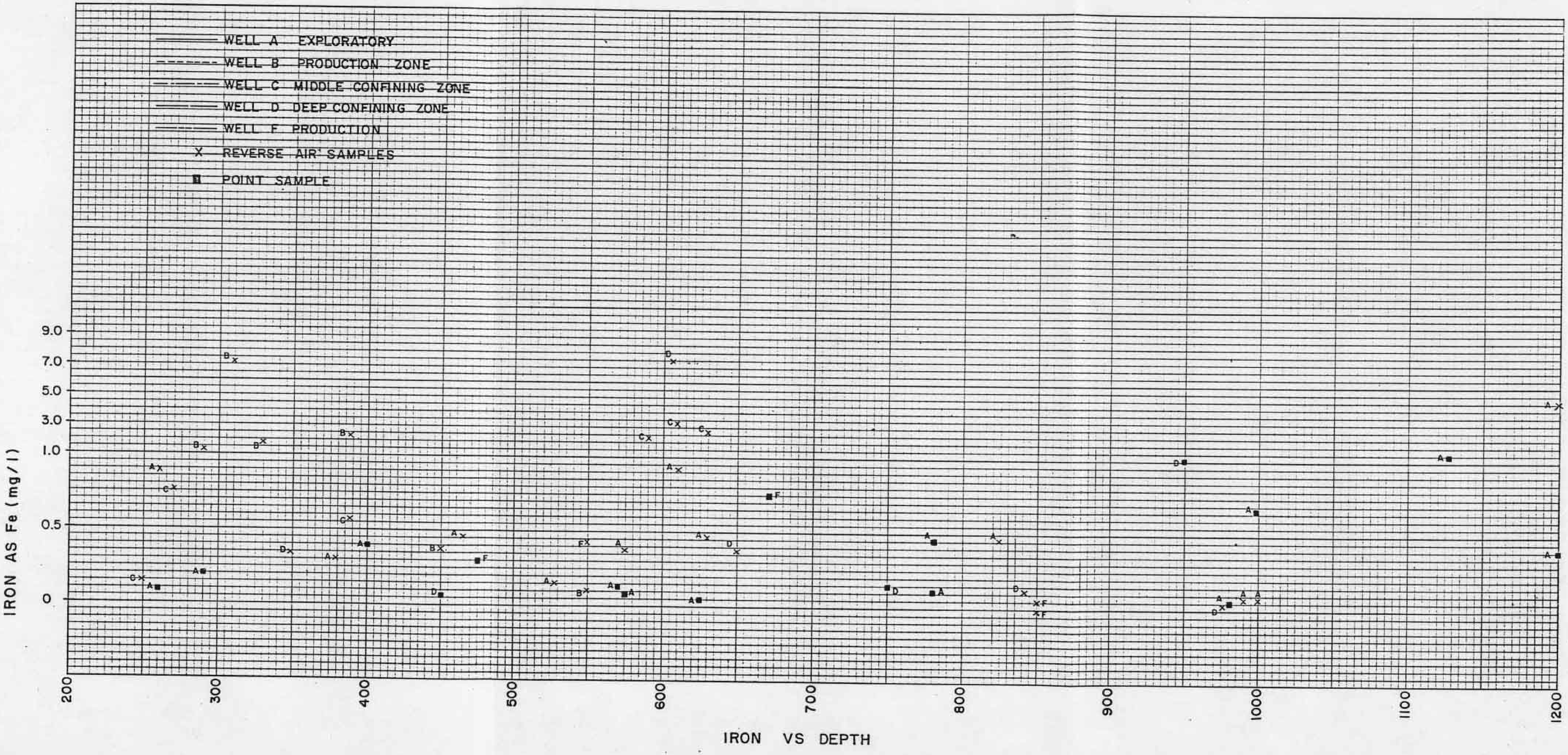


FIGURE 14: IRON VERSUS DEPTH

FIGURE 15: CONDUCTIVITY VERSUS TIME (APT # 1, 92 HOURS)

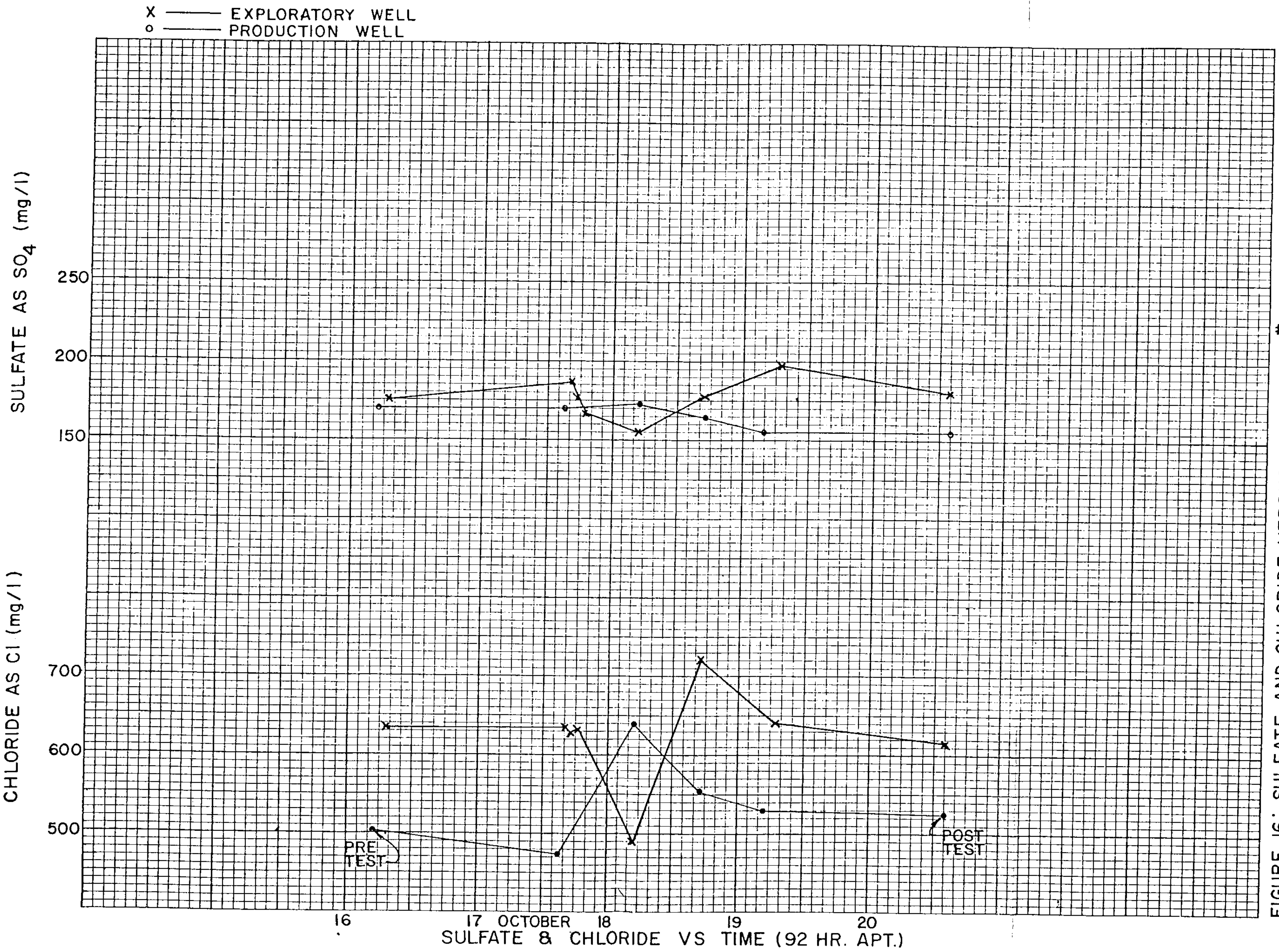


FIGURE 16: SULFATE AND CHLORIDE VERSUS TIME (APT # 1, 92 HOUR)

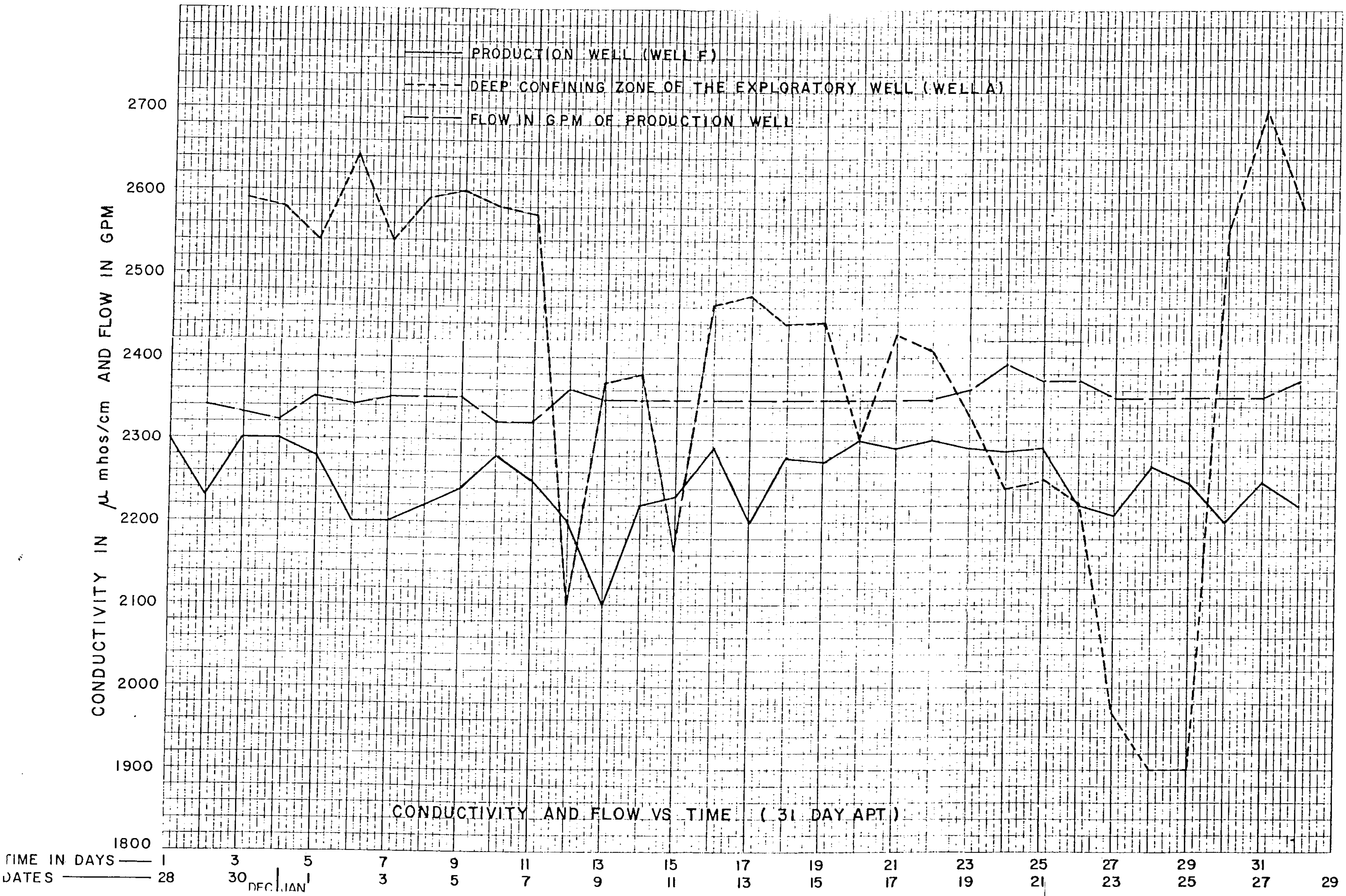


FIGURE 17: CONDUCTIVITY AND FLOW VERSUS TIME (APT # 2, 31 DAYS)

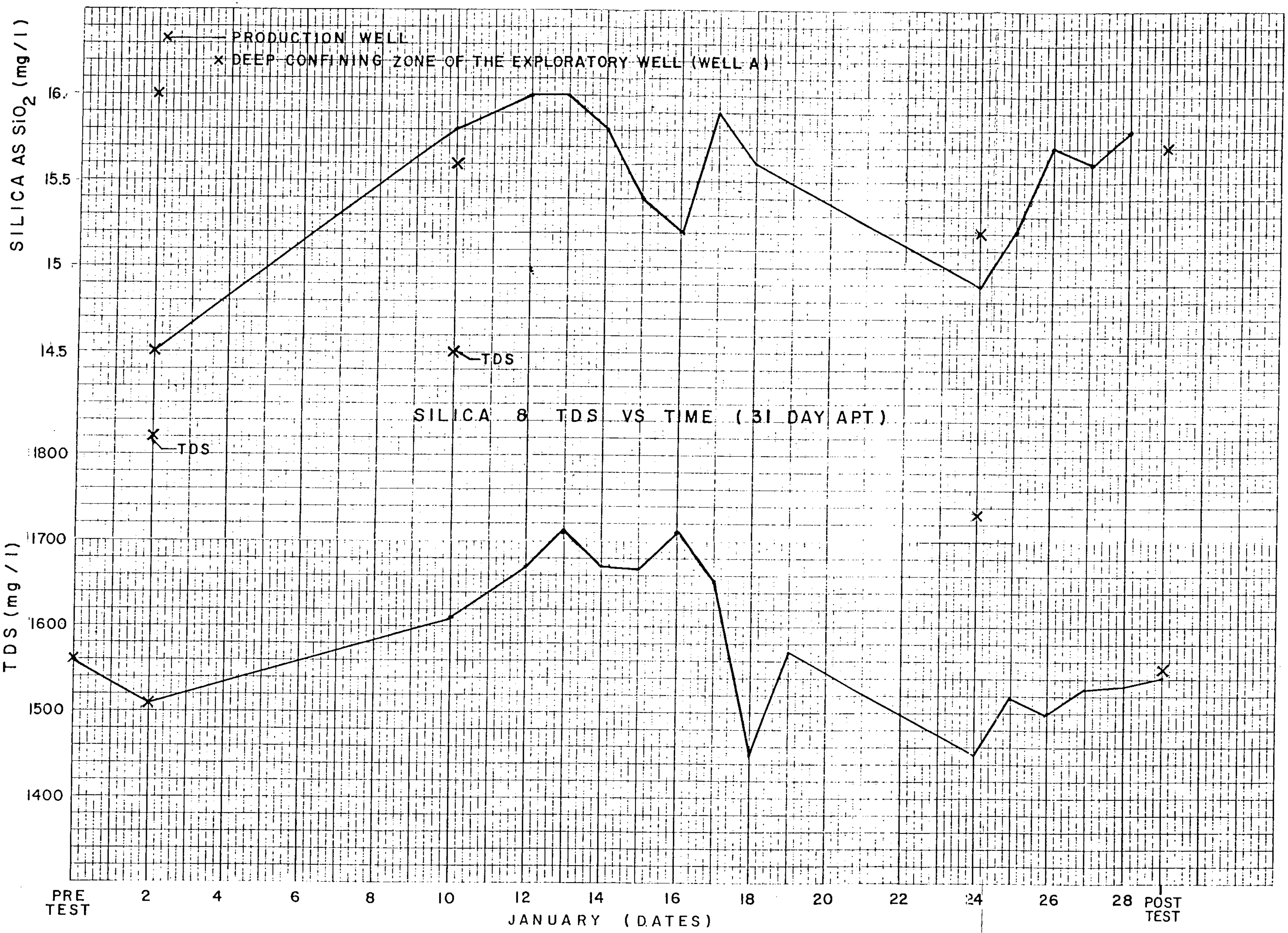


FIGURE 18: TDS AND SILICA VERSUS TIME (APT # 2, 31 DAYS)

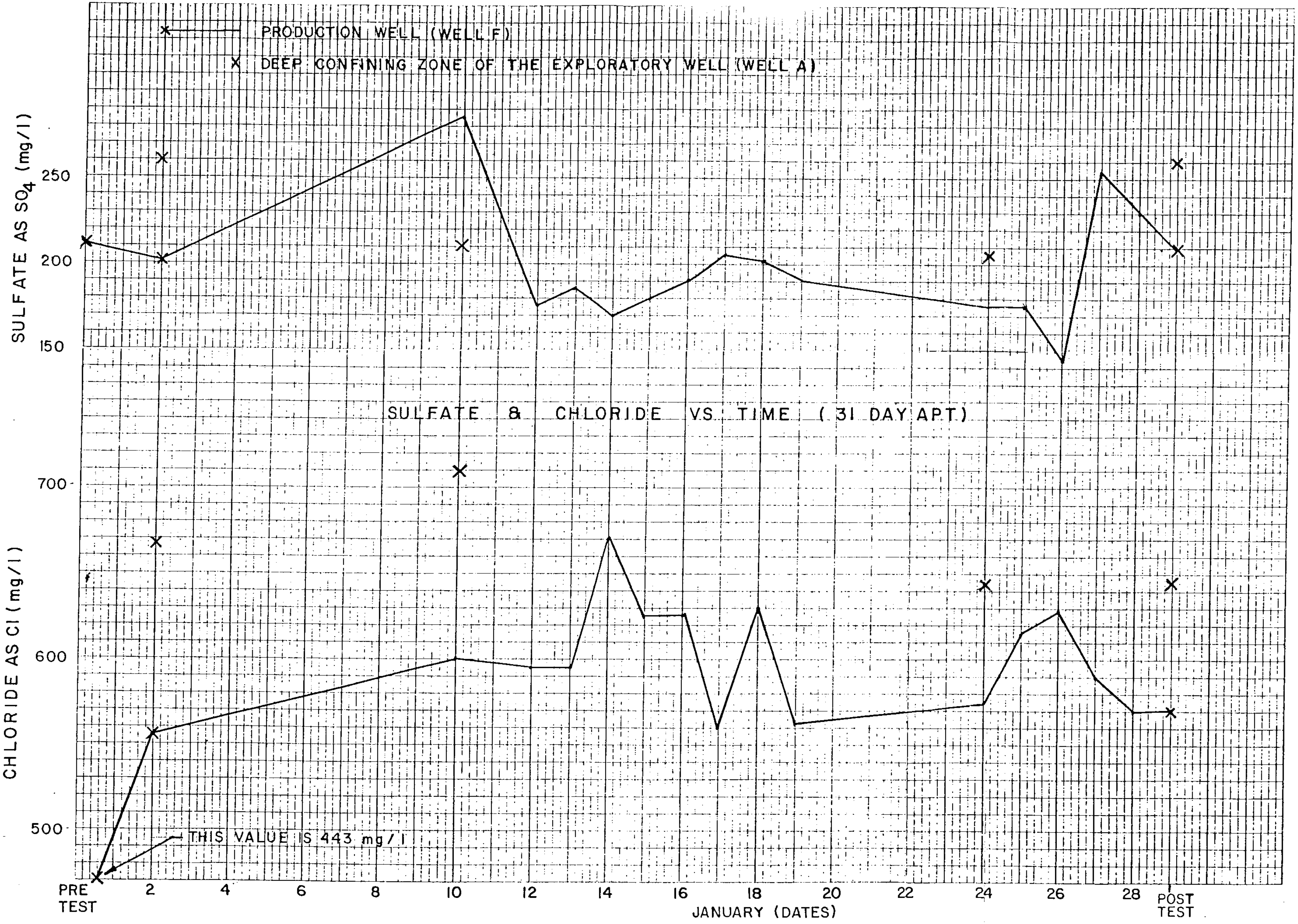


FIGURE 19: SULFATE AND CHLORIDE VERSUS TIME (APT # 2, 31 DAYS)

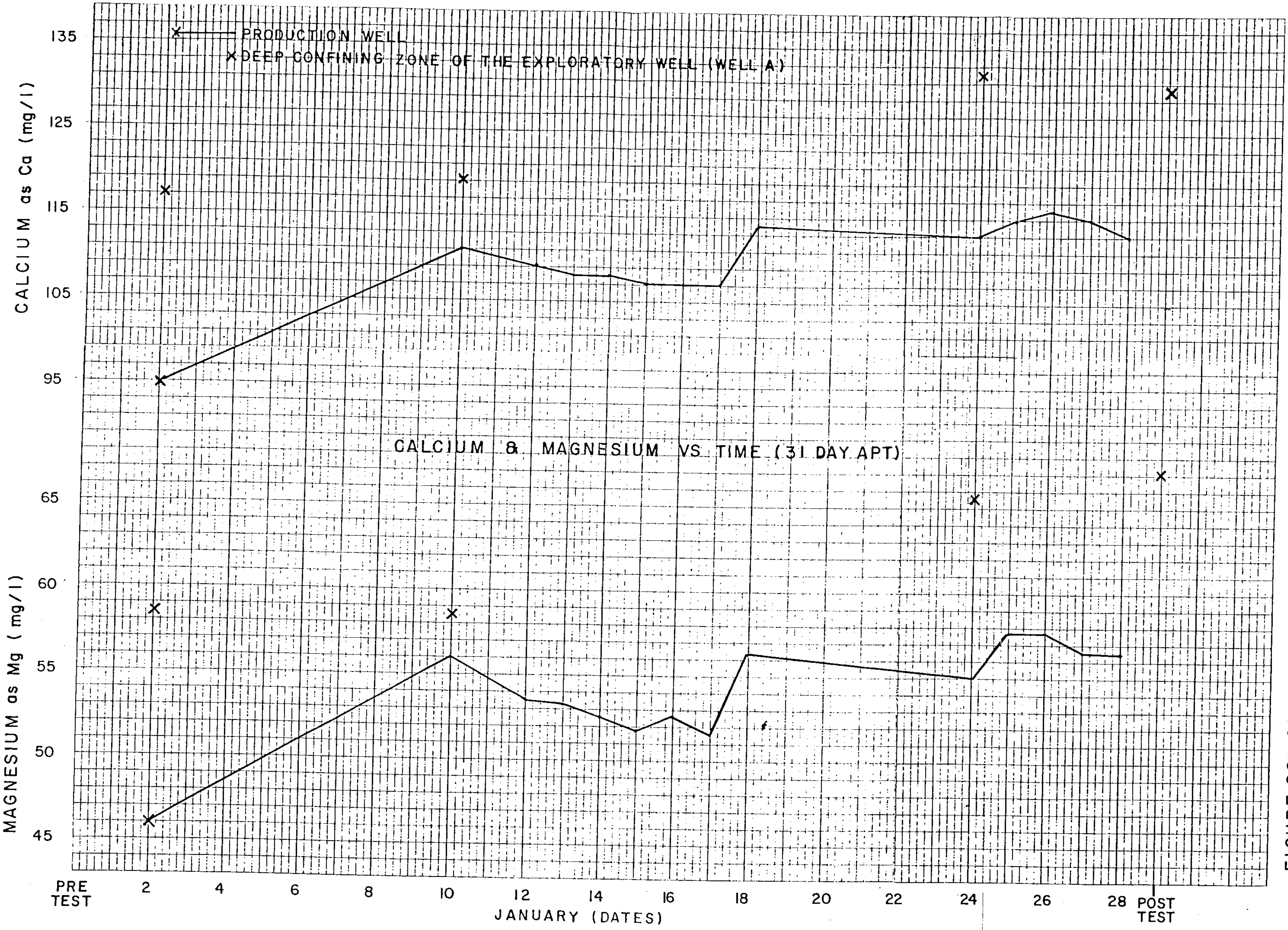
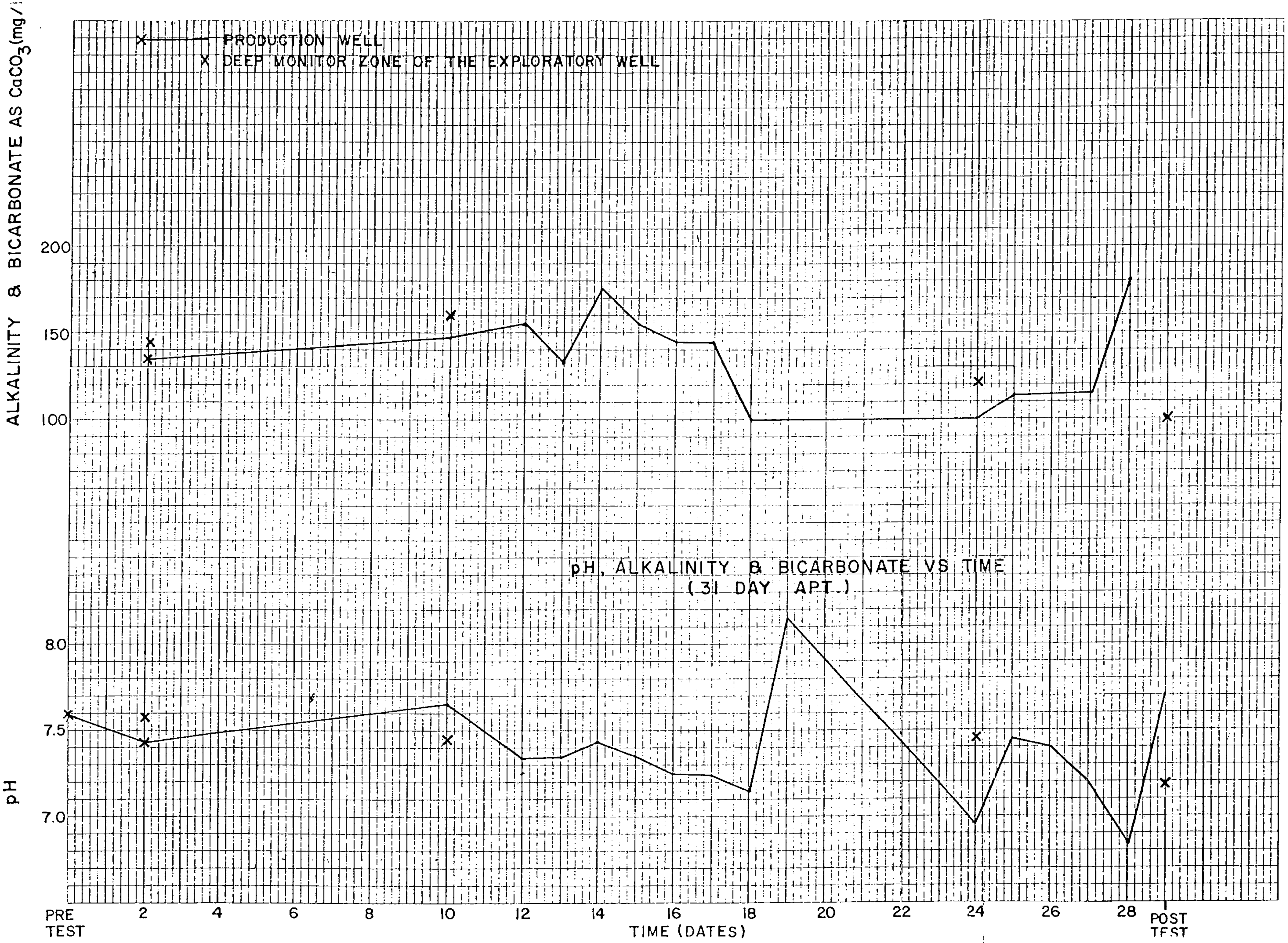


FIGURE 20: CALCIUM AND MAGNESIUM VERSUS TIME (APT # 2, 31 DAYS)



pH, ALKALINITY & BICARBONATE VS TIME
(31 DAY APT.)

FIGURE 21: pH, ALKALINITY AND BICARBONATE VERSUS TIME (APT # 2, 31 DAYS)

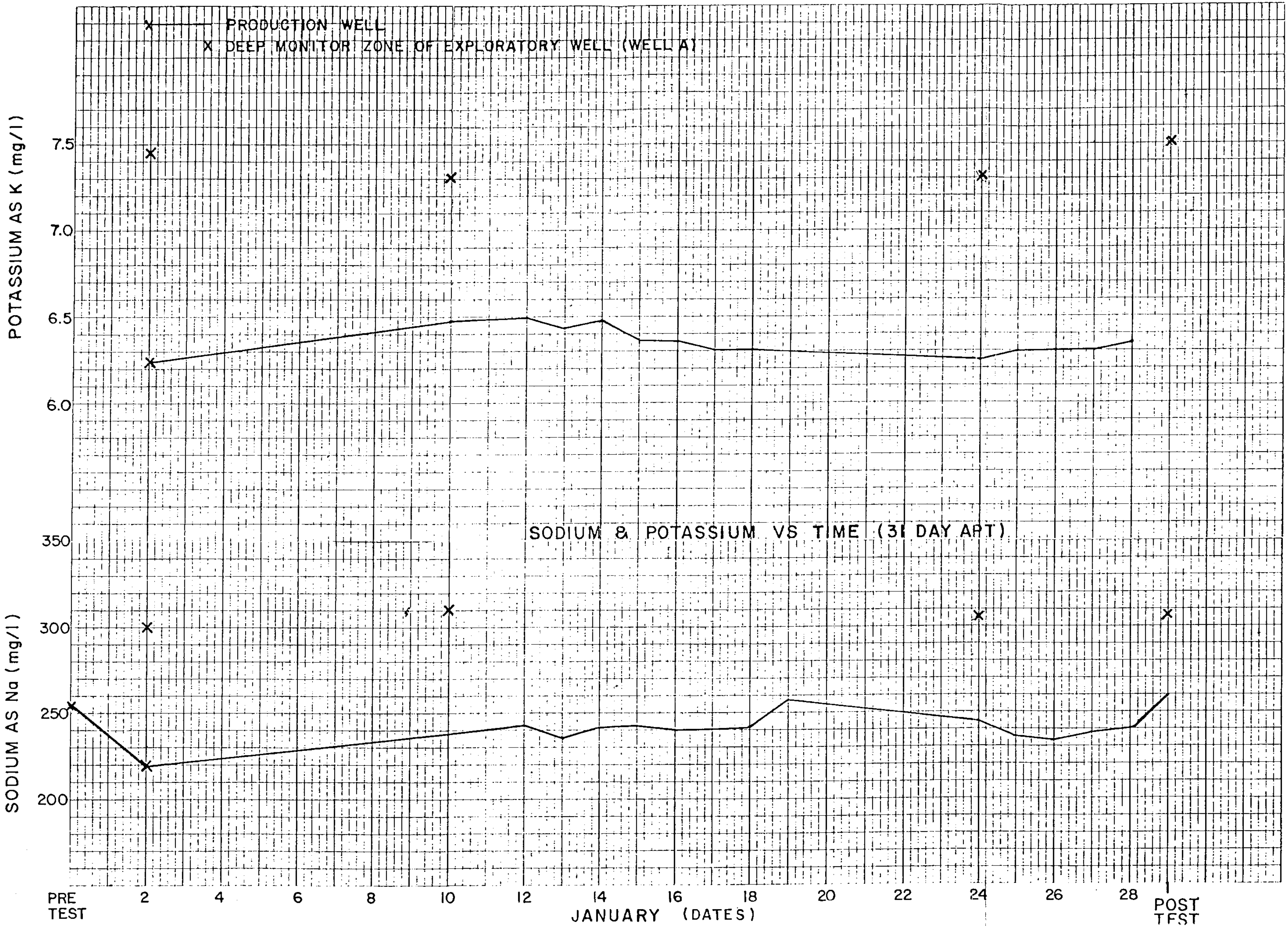


FIGURE 22: POTASSIUM AND SODIUM VERSUS TIME (APT # 2, 31 DAYS)

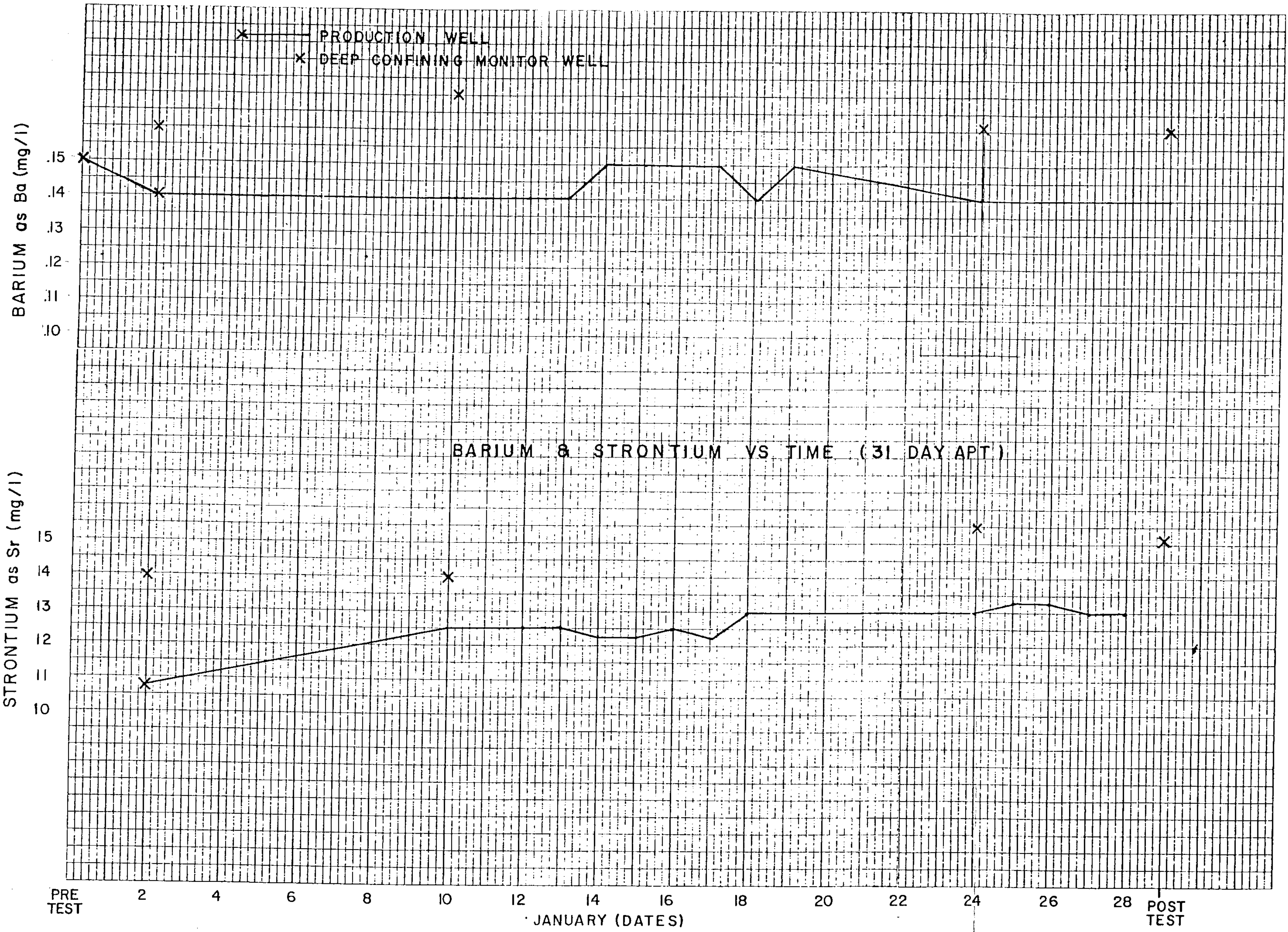


FIGURE 23: BARIUM AND STRONTIUM VERSUS TIME (APT # 2, 31 DAYS)

The values for Well A were slightly higher and ranged from 14 mg/l at the beginning of the APT to 15.6 mg/l near the end of the test.

Piper Trilinear Diagrams

Water quality data from the production well during the 31 day APT were plotted on a Piper trilinear diagram. Three samples were plotted; the start of the test (Figure 24, 1-2-90), the middle of the test (Figure 25, 1-15-90), and the end of the test (Figure 26, 1-28-90). For this type of analysis the cations and anions are plotted as percentages of milliequivalents (Table 5.1) on separate triangles. These points are then projected onto a diamond shaped diagram to classify the water type. The resultant plot shows percentages of milliequivalents, not concentrations.

The cations for these 3 samples plot coincidentally on Figure 27, with calcium percentages at either 26% or 27%, magnesium percentages at either 21% or 22%, and sodium and potassium percentages at 51% or 53% (Table 5.1).

The anions display a slight separation with chloride ranging from 67 to 74 percent, sulfate ranging from 16 to 20 percent, and alkalinity ranging from 10 to 12 percent (Table 5.1).

Sodium and chloride dominate this water type. The resultant plot onto the diamond (Figure 27) shows that the first sample (1-2-90) and the last sample (1-28-90) plot coincidentally. According to Walton (1970), "This water type is one where noncarbonate alkalinity ("primary salinity") exceeds 50%, chemical properties are dominated by alkalies and strong acids: ocean water and many brines plot in this area." This concludes that there was no variation in water type from the beginning to the end of the APT.

TABLE 5.1 - TRILINEAR CALCULATIONS (31 DAY APT)

SAMPLE #: 9098
DATE: 01/02/90
(START UP)

	Ca	Mg	Na	K	Cation Total	Cl	SO4	HCO3	Anion Total
mg/L	94.7	46	221	6.23	------	557	201	136	-----
me/L	4.73	3.78	9.6	0.16	18.28	15.71	4.18	2.23	22.12
%	26	21	53			71	19	10	

SAMPLE #: 90474
DATE: 01/15/90
(MIDDLE)

	Ca	Mg	Na	K	Cation Total	Cl	SO4	HCO3	Anion Total
mg/L	107	51.7	244	6.35	------	625	181	154	-----
me/L	5.34	4.25	10.44	0.16	20.36	17.63	3.77	2.52	23.92
%	26	21	53			74	16	11	

SAMPLE #: 90787
DATE: 01/28/90
(END)

	Ca	Mg	Na	K	Cation Total	Cl	SO4	HCO3	Anion Total
mg/L	113	56.6	240	6.35	------	625	181	154	-----
me/L	5.64	4.65	10.44	0.16	20.89	16.13	4.83	2.95	23.91
%	27	22	51			67	20	12	

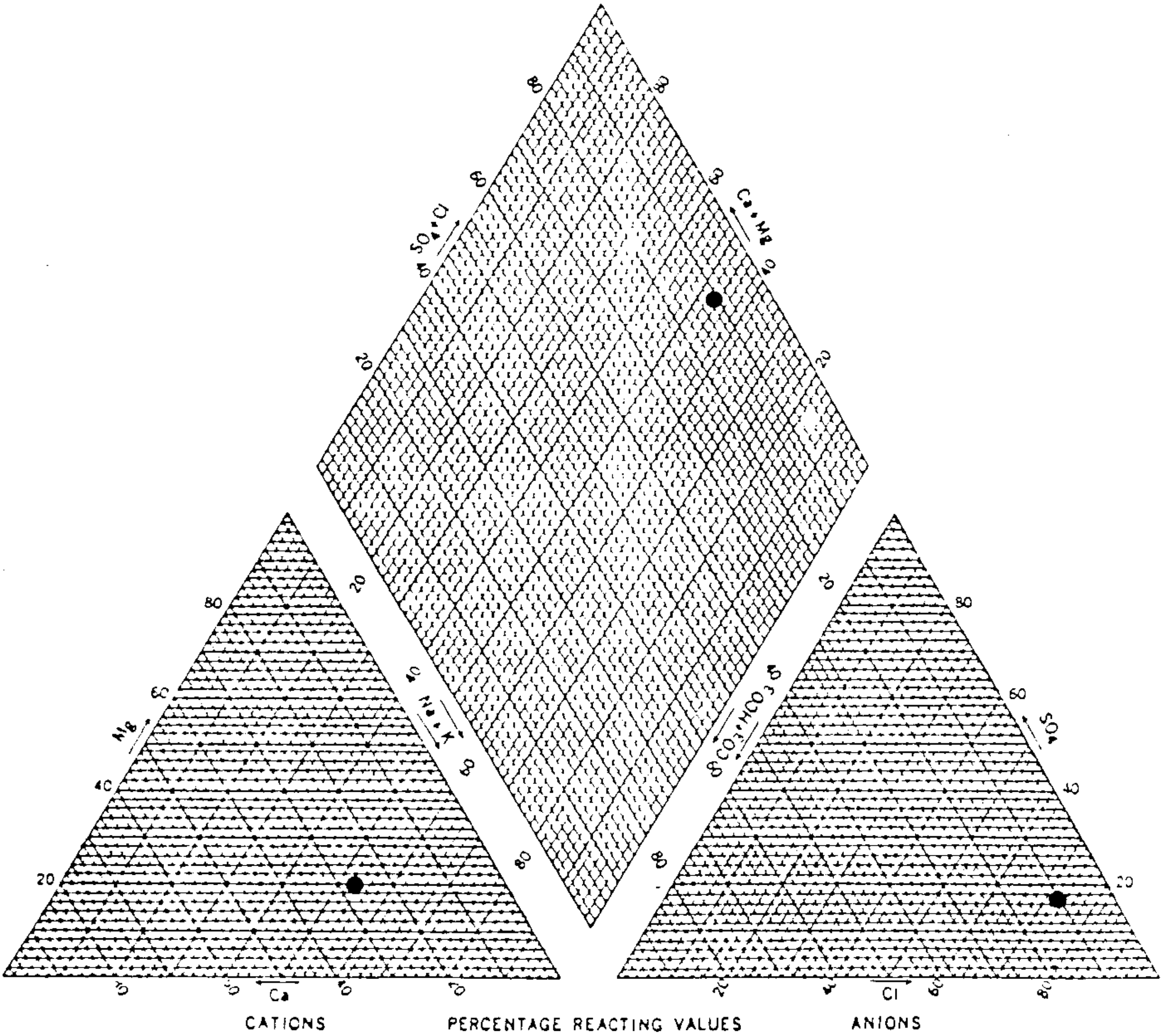


FIGURE: 24 PIPER TRILINEAR DIAGRAM OF WATER SAMPLE COLLECTED FROM THE PRODUCTION WELL AT THE BEGINNING (1/2/90) OF THE 31 DAY APT

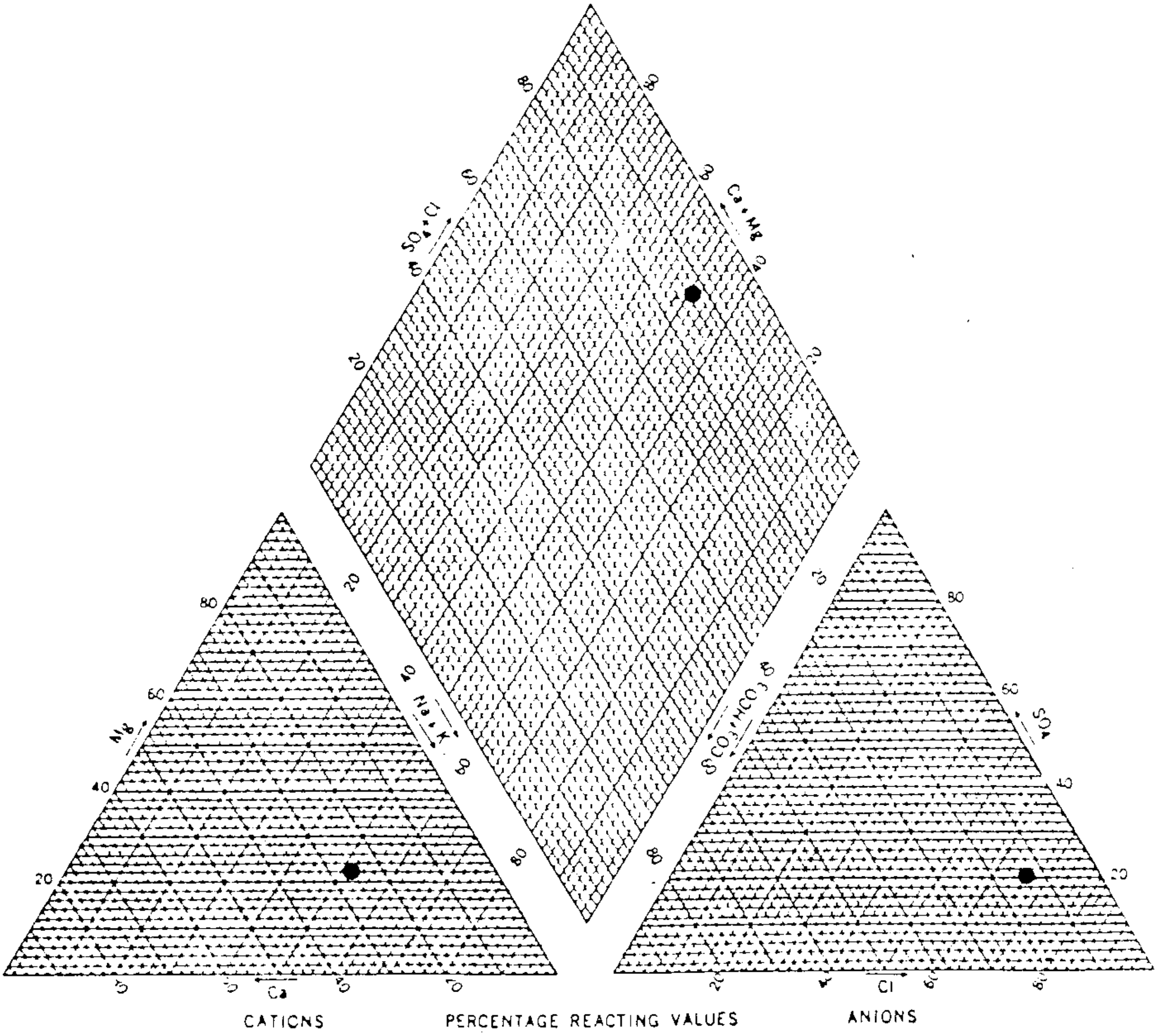


FIGURE: 25 PIPER TRILINEAR DIAGRAM OF WATER SAMPLE COLLECTED FROM THE PRODUCTION WELL DURING THE MIDDLE (1/15/90) OF THE 31 DAY APT

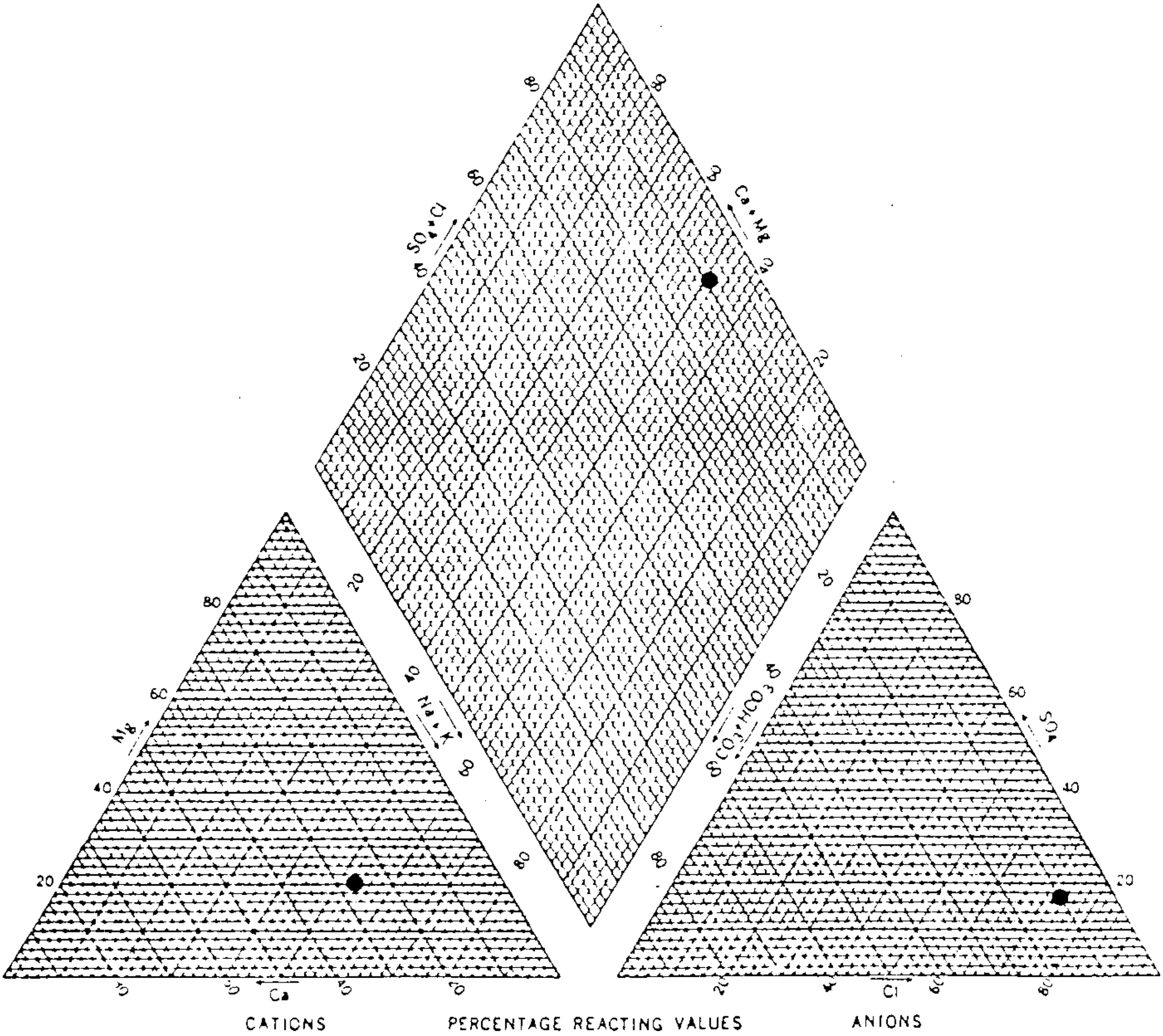


FIGURE: 26 PIPER TRILINEAR DIAGRAM OF WATER SAMPLE COLLECTED FROM THE PRODUCTION WELL AT THE END (1/28/90) OF THE 31 DAY APT

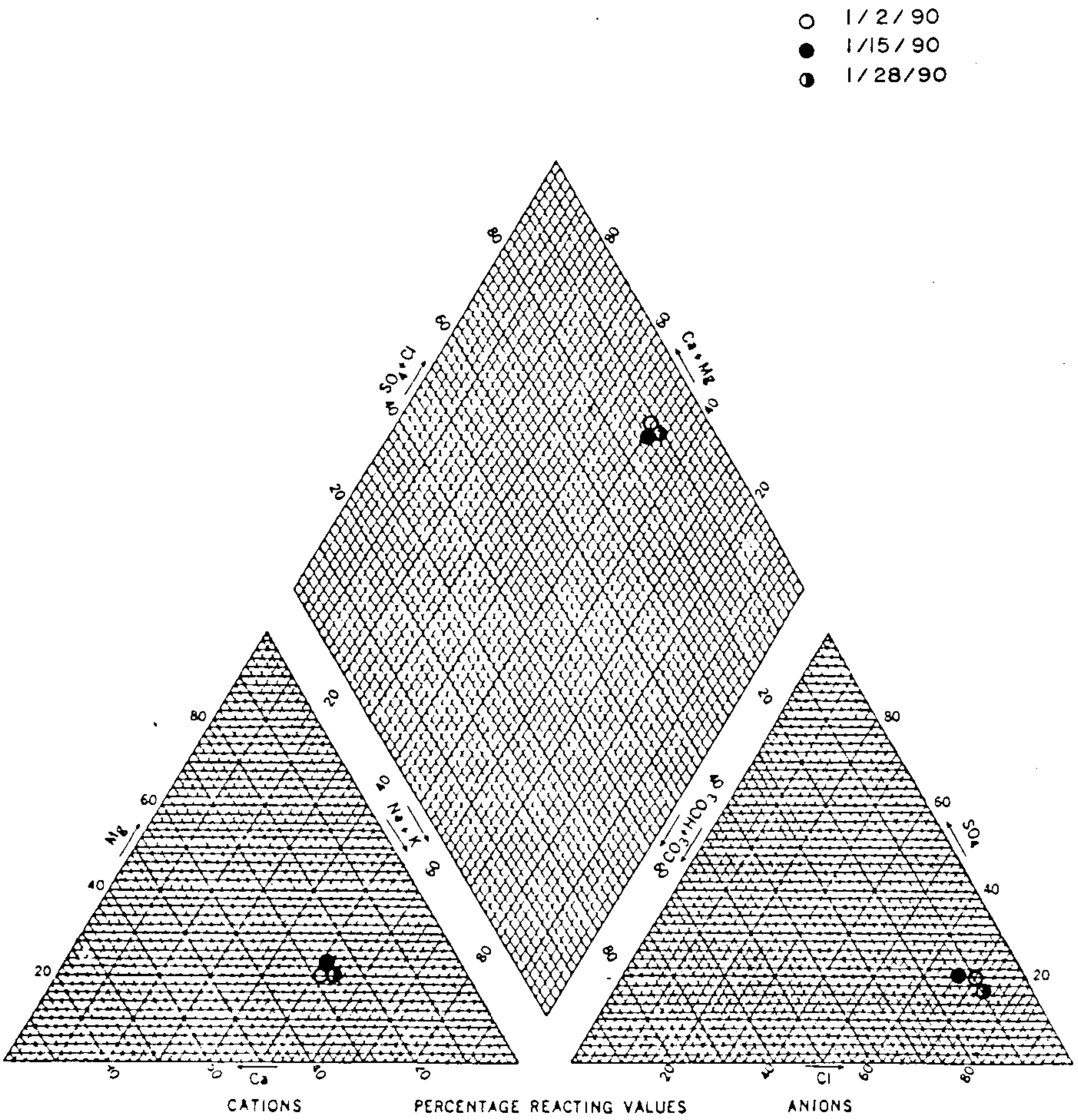


FIGURE: 27 PIPER TRILINEAR DIAGRAM OF THE THREE (3) WATER SAMPLES COLLECTED FROM THE PRODUCTION WELL DURING THE 31 DAY APT.

6.0 ANALYSIS OF AQUIFER PERFORMANCE TESTS

In a standard aquifer performance test (APT) the discharge is kept constant. If the discharge is purposely changed in several steps it is termed a step drawdown test. A total of ten step drawdown tests, two natural flow drawdown and recovery (APT) tests, and one pumped (92-hour) APT were conducted during the wellfield study. The background fluctuations of water levels in each well and the recorded data during the tests are attached in Appendix 9.6.

Background Fluctuation

The test site is less than 15 miles from the Atlantic Ocean and the 12-hour tidal cycle appears to affect the water levels of each well on the site. The barometric pressure changes coupled with the tidal cycles caused the observed background water levels to vary between one tenth and two tenths (0.1 to 0.2) of a foot in a 12-hour cycle. Consequently, a tenth of a foot fluctuation is considered to be the noise range in water-level readings. In many of the aquifer tests, when the total water level change in individual wells was approximately a tenth of a foot, the signal-to-noise ratio was so high that the data was difficult to analyze and is considered unreliable. Figure 28 depicts background water fluctuations for wells A, B, C, and F prior to the 92 hour APT.

Step Drawdown Tests

The step drawdown test is a method used to estimate the specific capacity of a well. Three steps were used on each of the step drawdown tests conducted on individual wells at the site. The discharge rate was kept at a constant in each step and each step lasted for up to two hours. The discharge was increased in each successive step. The step drawdown tests were normally completed within six hours of pumping onset and were followed by recording two hours of recovery data. The step tests are actually short duration aquifer performance tests, hence data from the tests can also be analyzed to estimate local transmissivity. In fact, as shown by the data of the long term APT's, the water levels in the wells reach steady state, or are fluctuating within the noise range within approximately one hour. Therefore, the data from some of the step drawdown tests are considered to be as reliable as the data from the longer APT's. The step drawdown tests were conducted

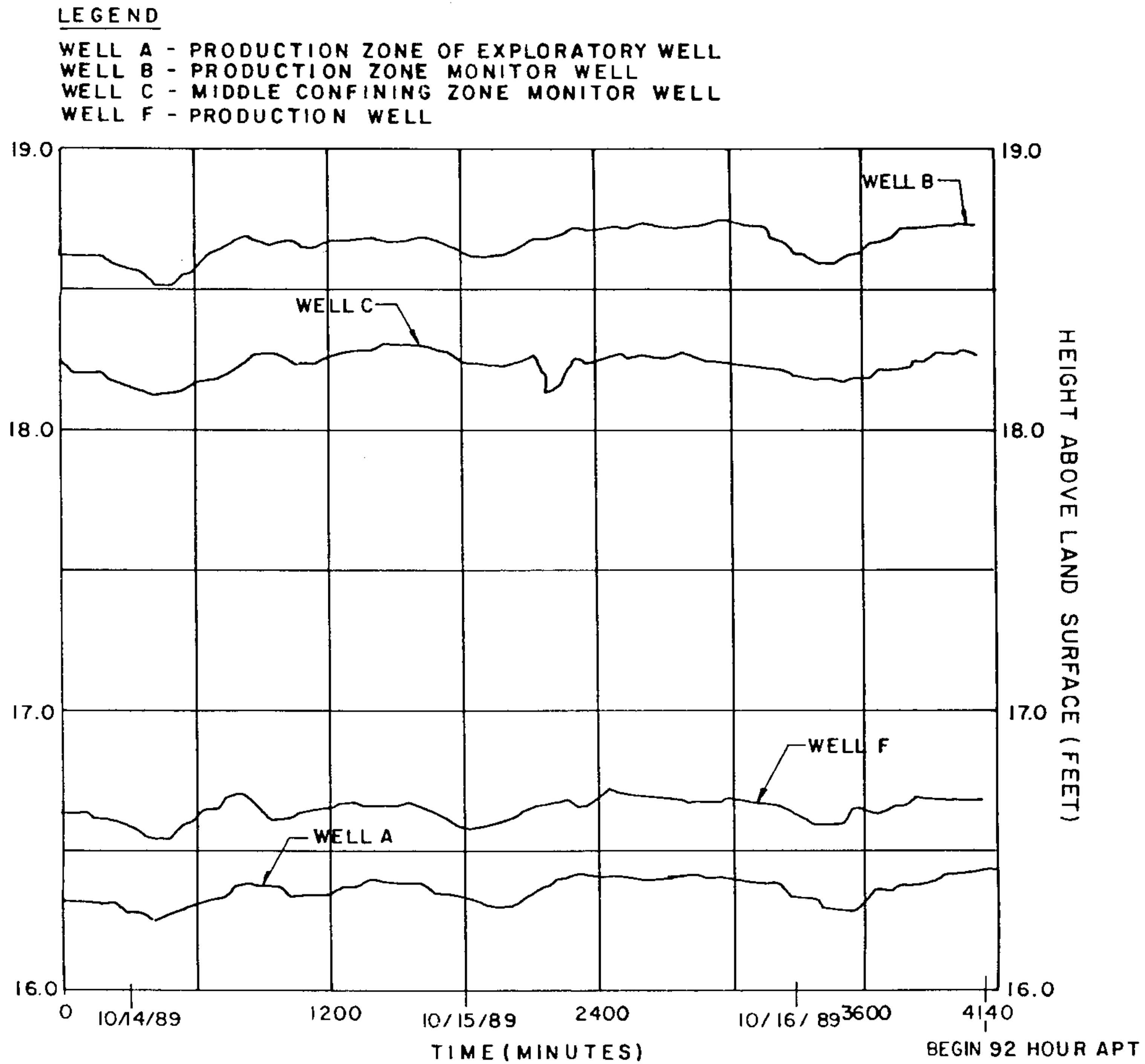


FIGURE 28: BACKGROUND FLUCTUATIONS BEFORE 92-HOUR APT

immediately after well construction or during well construction, and may involve higher well loss in the damaged zones (ref: Chapter 9, Aquifer Analysis. Class notes collected by Yilder Senay, published by National Water Well Association, Dublin, OH 43017. 1988), hence the computed transmissivity may tend to be lower than in the fully developed wells.

Only the water levels in the producing wells were recorded in the step drawdown tests, dictating the use of a time-drawdown curve in the analysis (ref: eq. (53) of Ground-Water Hydraulics. by W. Lohman, USGS Professional Paper 708, 1972). Computing a storage coefficient from this type of data is difficult.

From a total of 39 sets of step test data, only 5 sets showed meaningful drawdown useful for analysis. Each individual plot is attached in Appendix 9.6. The results are summarized in Table 6.1.

Aquifer Performance Test

Two long term aquifer performance tests and one short term test were conducted at the site. The configuration of the wells for these tests are shown on Figures 29 and 30. The well arrangement was dictated by the boundaries of the property owned by the City and drilling procedures. The first test was conducted on the upper producing zone (240 to 550 feet) and ran for 92 hours followed by a 24 hour recovery period. During this test there were two observation wells which penetrated the production zone and one well in the middle semi-confining zone (681' to 683'). Additionally there were two Hawthorn (upper confining bed) wells, a water table well and a deep confining zone monitor well at a depth of 1180 to 1200 feet. Most wells were equipped with continuous water level recorders supplied by the SJRWMD. The data plots and raw water level data from this test are available in Appendix 9.6 and 9.7, respectively. A 31-day APT was conducted at the site after deepening the production well and one of the monitor wells (B). Two additional wells were drilled to observe a deeper zone (971' to 978') and a combined upper and lower production zone at a distance of 2500' (Figure 29). A 10 hour verification test was conducted later on the final test site layout (Figure 29). The data from these tests are also available in Appendix 9.6.

The well arrangement was configured to collect good

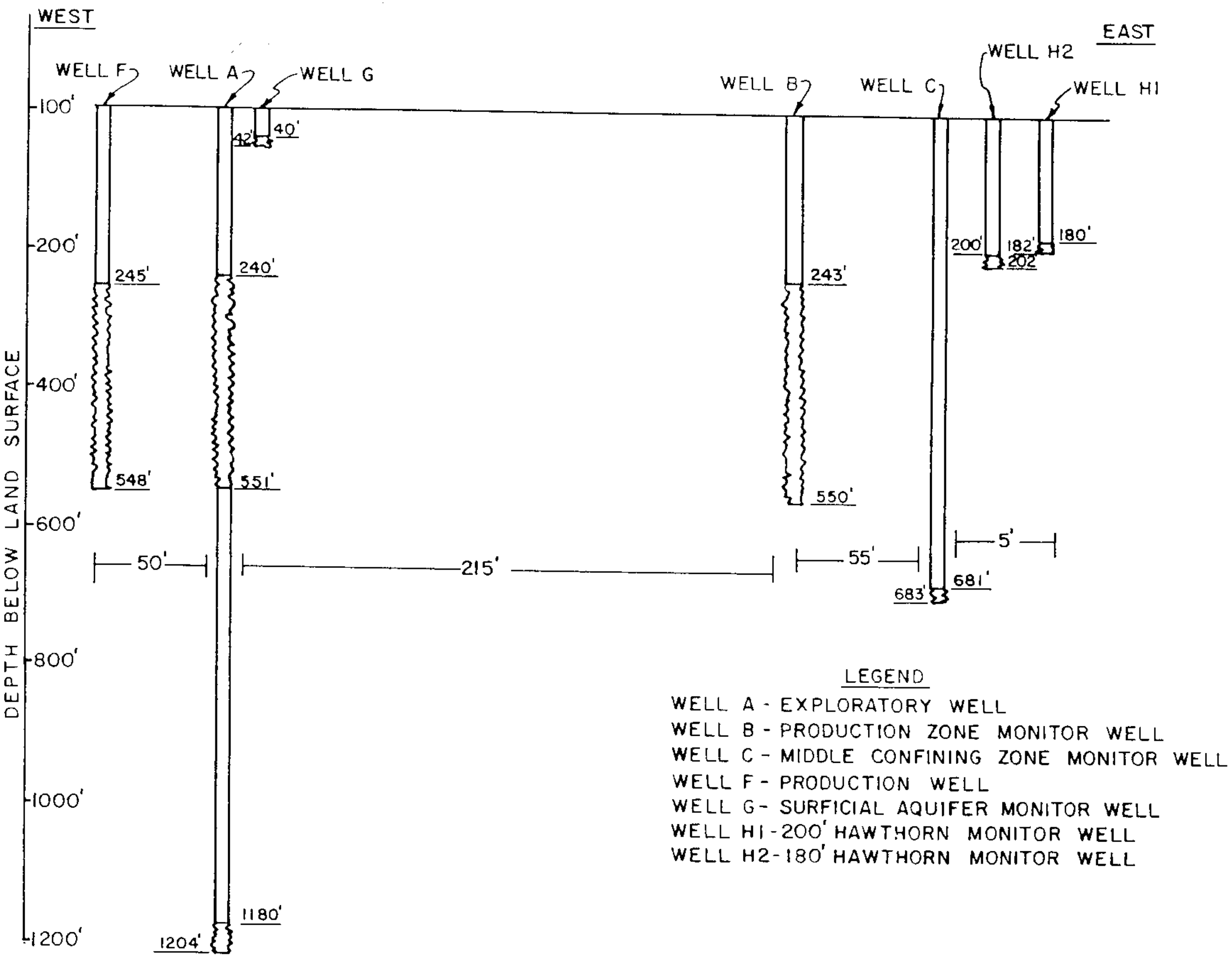
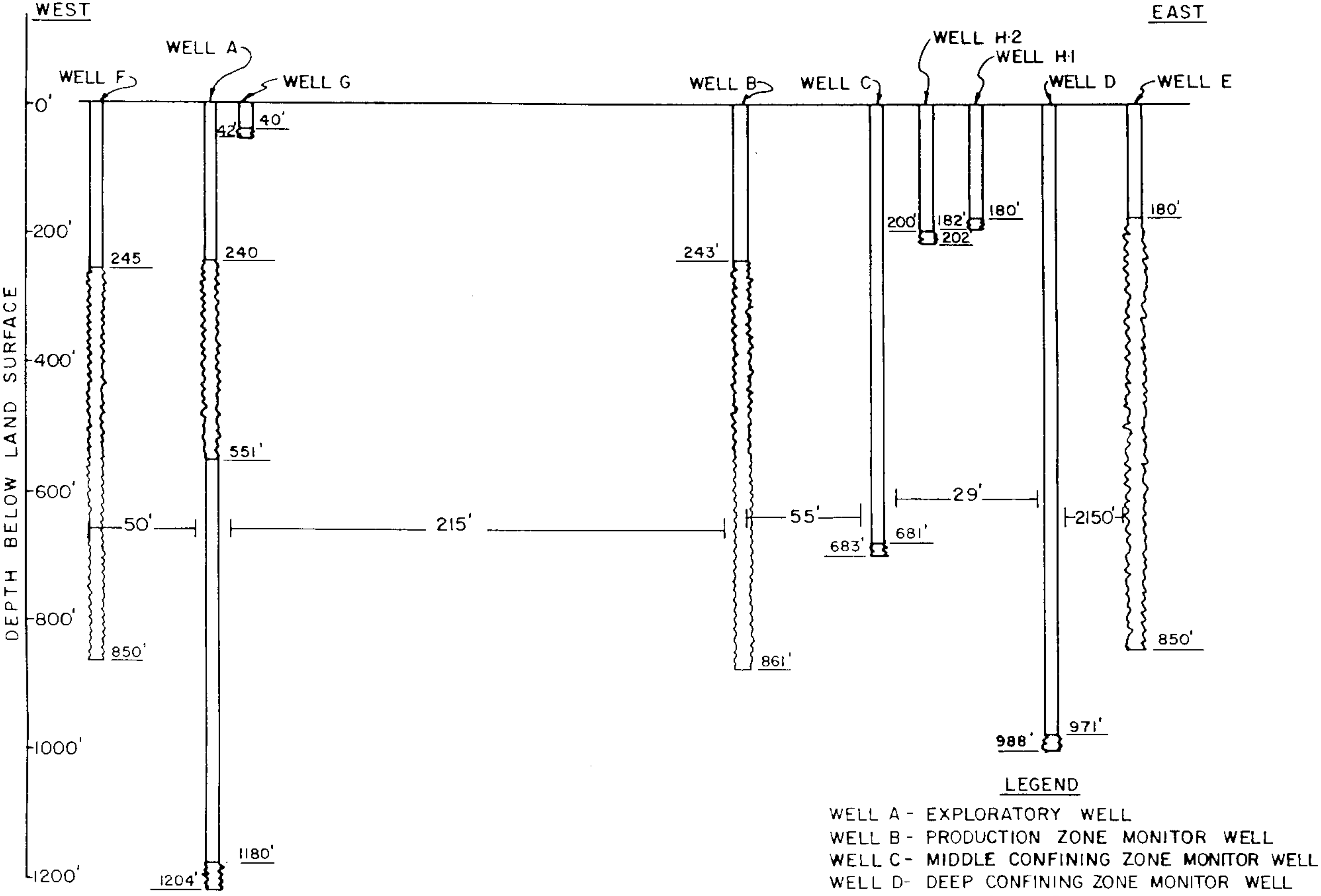


FIGURE 29· 92 HOUR APT. WELL CONFIGURATION.



LEGEND

WELL A - EXPLORATORY WELL
WELL B - PRODUCTION ZONE MONITOR WELL
WELL C - MIDDLE CONFINING ZONE MONITOR WELL
WELL D - DEEP CONFINING ZONE MONITOR WELL
WELL E - PRODUCTION ZONE MONITOR WELL
WELL F - PRODUCTION WELL
WELL G - SURFICIAL AQUIFER MONITOR
WELL H1 - 200' HAWTHORN MONITOR WELL
WELL H2 - 180' HAWTHORN MONITOR WELL

FIGURE 30: 31 DAY APT. WELL CONFIGURATION

quality data for the computation of:

1) leakance between the water table aquifer and the upper producing zone (ref: S. P. Neuman and P. A. Witherspoon, Field Determination of the Hydraulic Properties of Leaky Multiple Aquifer Systems. Water Resource Research, Vol 8:5 October, 1972 and, C. H. Tibbals and H. F. Grubb, Aquifer Test Results, Green Swamp Area, Florida, USGS Water-Resource Investigation 82-35, 1982),

2) transmissivity, storage coefficient and specific yield of the upper producing zone,

3) leakance between the upper and the lower producing zones,

4) transmissivity and storage coefficient of the lower producing zone and,

5) the transmissivity and the up-coning potential of the unpenetrated formation below the lower producing zone (Ref: I. Javandel and P. A. Witherspoon, Analytical Solution of a Partially Penetrating Well in a Two-layer Aquifer, Water Resource Research, Vol. 19:2, April, 1983). This is an extensive study and is primarily for academic interests. It is to fully realize the development potential of an aquifer system when only a few producing zones in the system are being pumped.

An examination of the recorded data for the observation wells during all of the tests reveal the following traits:

1) data sets approach steady-state in a short time, about 30 minutes,

2) the range of consistent data trends in both drawdown and recovery is very small, no more than a foot,

3) data fluctuation is large, more than 10% even in the best segment of the data.

These traits all point to the data quality having a high noise-to-signal ratio. The good news is that the hydrogeological condition that results in this kind of test data is very productive with high transmissivity. In this case, the aquifer parameters affected, namely transmissivity and storage coefficient in the producing zones are the dominating factors. Since the water transfer through the Hawthorn confining beds and lower Floridan confining beds (864' to 1204') is of minimal percentage, the vertical leakance and horizontal hydraulic diffusivity (transmissivity divided by storage coefficient) in the confining beds will have minimal effect on the water quantity and water quality of producing wells in the producing zones. Data collected at the test site during the 31 day test reflect these facts: the production well was flowing (artesian) near 2400 gallons per minute and the transmissivity of the producing zones combined is well over one million gallons per day per foot. The test data will first be used to estimate the transmissivity and storage coefficient of the two producing zones.

The data were first plotted in semi-log paper to observe the time versus drawdown (or recovery) of each well. It was quickly determined that not every data set was suitable for analysis. For the collected data displaying at least a log cycle of a straight line, Jacob's straight-line method (eq (53) of Lohman, 1972) was applied to compute the transmissivity, and then, when possible, the storage coefficient was estimated (eq. (61) of Lohman, 1972). For the pairs of observation wells that recorded reasonable steady-state data, the steady-state analysis (eq.(54) of Lohman 1972) was used. The storage coefficient (eq. (59) of Lohman, 1972) was used to estimate by extrapolation, the distance of zero drawdown at the time when the steady-state was achieved. The results of each analysis is summarized in Table 6.1. The change of drawdown was less than background fluctuation (0.1' to 0.2'). In one cycle such as Well F - APT #2 (delta S= 0.055'), the data were ignored.

Aquifer parameter estimation from aquifer performance tests is known to often vary several times in magnitude. In both the upper and lower production zones transmissivity changed from 6.0 X 10 5 gpd/ft to 10 X 10 6 gpd/ft or more than an order of magnitude difference (see Appendix). Complicated equations, which are more sensitive to data and judgement errors may be used when the collected data closely matches the theoretical conditions. Some of the more sophisticated methods, such as type curve matching, were attempted, but the high noise-to-signal ratio of the test data greatly reduced the credibility of those results. For practical purposes, only the estimations from the simple methods discussed above should be used to compute the final estimation of the transmissivities and storage coefficients of the upper and the lower producing zone. Type curve analyses were used on data from the APT test and the transmissivity results obtained listed in Table 6.1 (Also Appendix 10.0). In order to address the higher values from the type curve matching it was decided to use a geometric mean of all values for the final transmissivity storage estimations. The geometric mean is simply each value multiplied by the other values and then taking the nth root of the product.

Initially the aquifer tests were designed to derive parameters in the confining beds. However, the aquifer characteristics and the data collected in the tests make the computation of these parameters of low reliability. As an academic exercise, some filtering processes may be applied to enhance the signal-to-noise ratio by combining the hand collected data and the electronically recorded data. Perhaps realistic estimations of parameters in the confining beds at the test site can be obtained from the enhanced data set and methods by Neuman (1972,1983). The District applied the Neuman/Witherspoon method of analysis to data from the test site and this data is available in Appendix 10.0.

UPPER PRODUCING ZONE

TYPE DATA	WELL IDENTIFICATION H.D.	SJRWMD	TYPE OF TEST	TRANSMISSIVITY IN GPD/FT	STORAGE	AQUIFER METHOD*	COMMENTS ANALYSIS*	U VALUE
HYDRO DESIGNS	B	BR0912	STEP	356,400		1	TEST 4 STEP 3	3.6X10 -6
	A	BR0909	DRAWDOWN	295,700		1	TEST 1 STEP 2	4.4X10 -5
	F	BR0907	TEST	166,100		1	TEST 5 STEP 3	1.6X10 -6
	A	BR0909		409,500+	2.9X10 -3+	1	DRAWDOWN	0.016+
	F	BR0907	APT #1	390,300		1	DRAWDOWN	1.7X10 -7
	F	BR0907	(92 HOUR)	853,800		1	RECOVERY	3.0X10 -6
	B	BR0912		316,700+	9.4X10 -3+	1	DRAWDOWN	0.7+
	A	BR0910		202,600	4.1X10 -3	3	B	--
	B	BR0912						
		GEOMETRIC MEAN:		325,100	4.1X10 -3			
SJRWMD	A	BR0909		195,000+	1.6X10 -3+	1	A	0.055+
	A	BR0909		546,000	5.0X10 -4	1	A, RECOVERY	0.006
	B	BR0912		563,000+	5.8X10 -4+	1	A	0.2+
	B	BR0912		197,000 to 394,000	7.98X10 -4	2	A, GEOMETRIC MEAN 278,600 r/B RANGE FROM 0.3 TO 0.8	--
	F	BR0907						
	A	BR0909		69,000		3	B, NOT GOOD STRAIGHT LINE FIT	--
	B	BR0912						
	A	BR0909	APT #1					
	B	BR0912	(92 HOUR)	270,000		3	B	--
	F	BR0907						
	A	BR0909		81,700		1	B, POOR MATCH	--
	B	BR0912						
		GEOMETRIC MEAN:		200,300	6.3X10 -4			
		TOTAL GEOMETRIC MEAN: (COMBINING ALL DATA)		255,180	1.18X10 -3			

TABLE 6.1: SUMMARY OF ANALYSIS OF AQUIFER TEST (PART 1)

+ NOT USED IN COMPUTATION OF GEOMETRIC MEAN

BOTH PRODUCING ZONES

TYPE DATA	WELL IDENTIFICATION H.D.	SJRWMD	TYPE OF TEST	TRANSMISSIVITY IN GPD/FT	STORAGE	AQUIFER METHOD*	COMMENTS ANALYSIS*	U VALUE
HYDRO DESIGNS	A	BR0909	STEP DRAWDOWN TEST	1,467,800		1	TEST 2 STEP 2	9.8X10 -7
	F	BR0907		606,900		1	TEST 9 STEP 2	2.4X10 -6
	A	BR0909		2,026,500	2.4X10 -3	1		0.0088
	B	BR0916	APT #3 (10 HOUR)	3,134,800+	0.93X10 -3+	1		0.055
	C	BR0913		3,777,700+	7.7X10 -3+	1		0.11+
	A	BR0909	APT #2 (31 DAY)	1,383,700	3.1X10 -3	3	DRAWDOWN, B	--
	B	BR0916						
	A	BR0909		2,988,000	2.5X10 -3	1		0.001
		GEOMETRIC MEAN:		1,494,800	2.65X10 -3			
SJRWMD	A	BR0909		4,500,000	1.0X10 -4	1	A, RECOVERY	0.000015
	B	BR0916		6,330,000	2.4X10 -4	1	A	0.0078
	B	BR0916		7,040,000	1.5X10 -4	1	A, RECOVERY	0.004
	E	BR0915		10,000,000+	2.3X10 -3+	1	A, RECOVERY	0.39+
	F	BR0907						
	B	BR0916		1,780,000		3	B, NOT GOOD STRAIGHT LINE FIT	--
	E	BR0915						
	B	BR0916	APT #2 (31 DAY)	4,700,000		3	B	--
	E	BR0915						
	B	BR0916		1,400,000		3	B	--
	F	BR0907						
	F	BR0907						
	B	BR0916		3,500,000		1	B, GOOD MATCH WITH 2 WELLS ONLY	--
	E	BR0915						
		GEOMETRIC MEAN:		3,624,700	1.53X10 -4			
		TOTAL GEOMETRIC MEAN: (COMBINING ALL DATA)		2,505,900	6.37X10 -4			

TABLE 6.1: SUMMARY OF ANALYSIS OF AQUIFER TEST (PART 2)

+ NOT USED IN COMPUTATION OF GEOMETRIC MEAN

7.0 GROUNDWATER FLOW MODEL (MODFLOW)

The aquifer performance tests conducted at the Lake Washington site established that a large quantity of water is available in the upper and lower producing zones in the upper portion of the Floridan Aquifer System. These producing zones are to be developed at a proposed rate of up to 8.133 million gallons per day. The purpose of the groundwater flow simulation is to decipher the area of impact due to the groundwater withdrawal from the potential wellfield. The basic model used here to simulate this system is commonly called Modflow, the McDonald model, (A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model, by M. G. McDonald and A. W. Harbaugh, USGS, Reston, Virginia, 1984). The study area is treated as an in-set of previous modeling work by Tibbals (Computer Simulation of the Steady-State Flow System of the Tertiary Limestone (Floridan) Aquifer System in East-Central Florida, USGS Water Resource Investigations, Open-file Report 81-681, C.H. Tibbals, 1981) and Skipp (Ground-Water Flow Model of Brevard, Indian River, Orange, Osceola, and Seminole Counties, Florida, Technical Publication SJ 88-2, St. Johns River Water Management District, Palatka, FL. by David Skipp, January, 1988).

Model Structures and Scale

The hydrogeologic units in Brevard, Indian River, Orange, Osceola, and Seminole counties (BIOS area) have been identified as:

1) The Surficial Aquifer (System) which extends from land surface to about 180 feet below mean sea level (msl).
2) The upper confining bed (Intermediate Confining Beds) that extend from -180 ft. msl to -240 ft. msl.
3) The upper producing zone (first zone within the Floridan Aquifer System) from -240 ft. msl to -550 ft. msl.
4) The middle confining zone (-550 feet to -690 feet msl.). This is a leaky confining layer separating the upper and the lower producing zones.
5) The lower producing zone (starts at about -690 ft. msl. and ends between -850 to -900 ft. msl.).
6) The lower confining bed (the dense dolomite that separates the Upper Floridan and the Lower Floridan).
7) The Lower Floridan Aquifer generally occurs about 1200 feet below mean sea level and is a source of higher TDS water at dephts in excess of 1400 feet below land surface in the Lake Washington area.

The possible area of influence by the development of a wellfield at Lake Washington is estimated to be less than a 16-mile radius circle. The extent of the area of influence is based on the fact that, at the withdrawal rate of 8.133 MGD, the total amount of water to be pumped from the aquifer system is estimated as 21 billion gallons in 7 years. At the combined storage coefficient of the upper and the lower producing zones of 9.81E-4 and the total producing thickness of 490 feet, the water required can be supplied from an area with a radius of 8.4 miles. Additionally, substantial amounts of water are also contained in the 134 feet of leaky confining zone between the upper and the lower producing zones. To include this area, the scale model (Figure 31) for MODFLOW is a 32-mile by 40-mile in-set of the BIOS area with the center located at Lake Washington. There are 64 by 80 blocks in the small scale model. The block size of this model is 0.5 mile by 0.5 mile, or a quarter of a square mile. There are 5120 blocks in each layer of aquifer in the small scale model.

Aquifer Parameters

Aquifer parameters are assumed to be time invariants. Tibbals (1981) and Skipp (1988), used the USGS 3-dimensional model (a similar model before the McDonald model), to study the steady-state and transient groundwater flows respectively. They compiled and model-calibrated most of the aquifer parameters in the BIOS area. This study uses the results of Tibbals (1981) and Skipp (1988) supplemented and modified by aquifer parameters computed from the data collected from the drilling and aquifer testing program described in this report. Table 7.1 is a detailed source of aquifer parameters. The aquifer parameters utilized in the modeling computed from the Lake Washington data are as follows:

Upper producing zone

Transmissivity:	255,180 gpd/ft
Storage:	1.18×10^{-3}

Middle confining beds

Leakance:	0.5×10^{-4}

Lower producing zone

Transmissivity:	2,505,900 gpd/ft
Storage:	6.37×10^{-4}

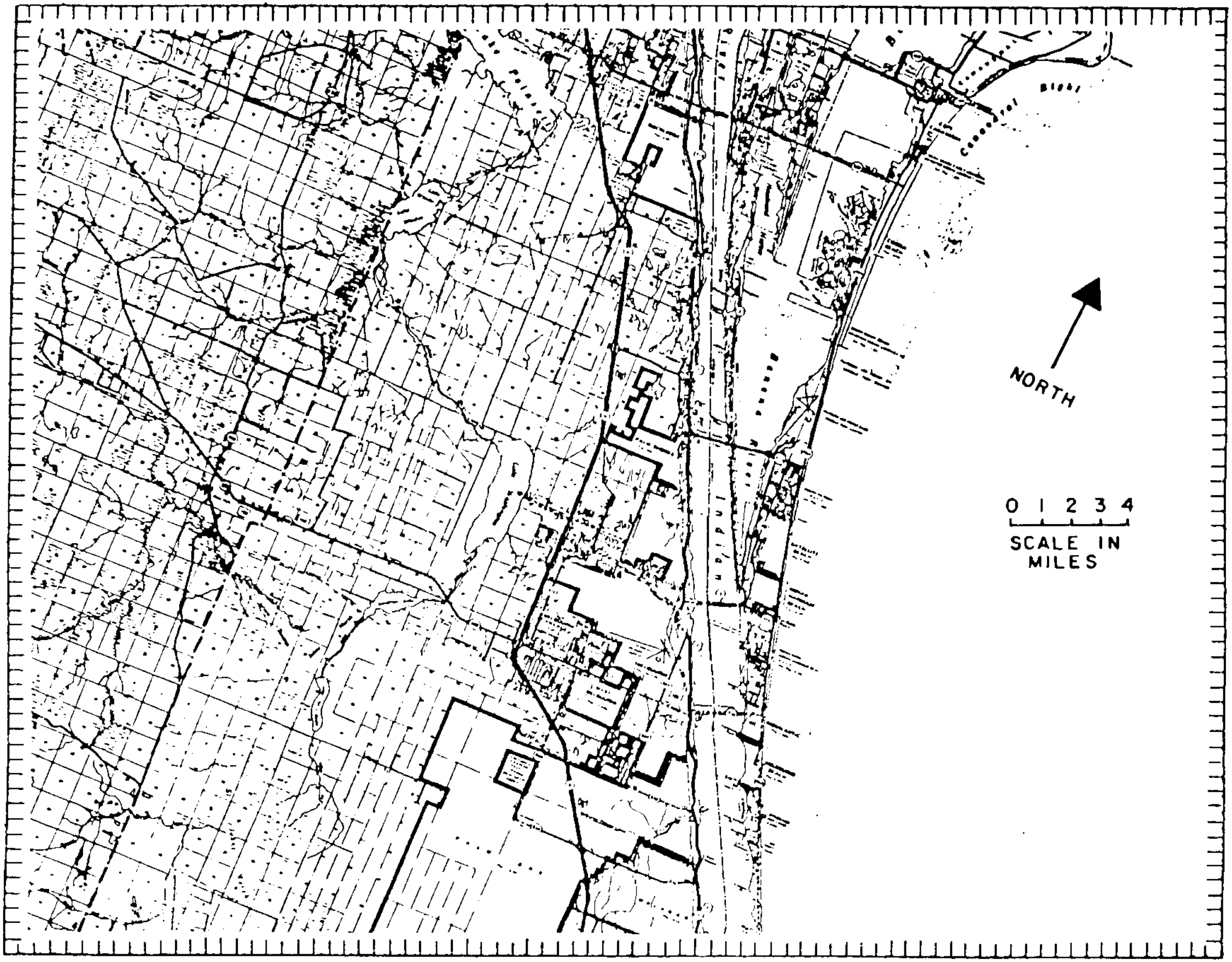


FIGURE 31: MODEL AREA FOR MODFLOW SIMULATIONS.

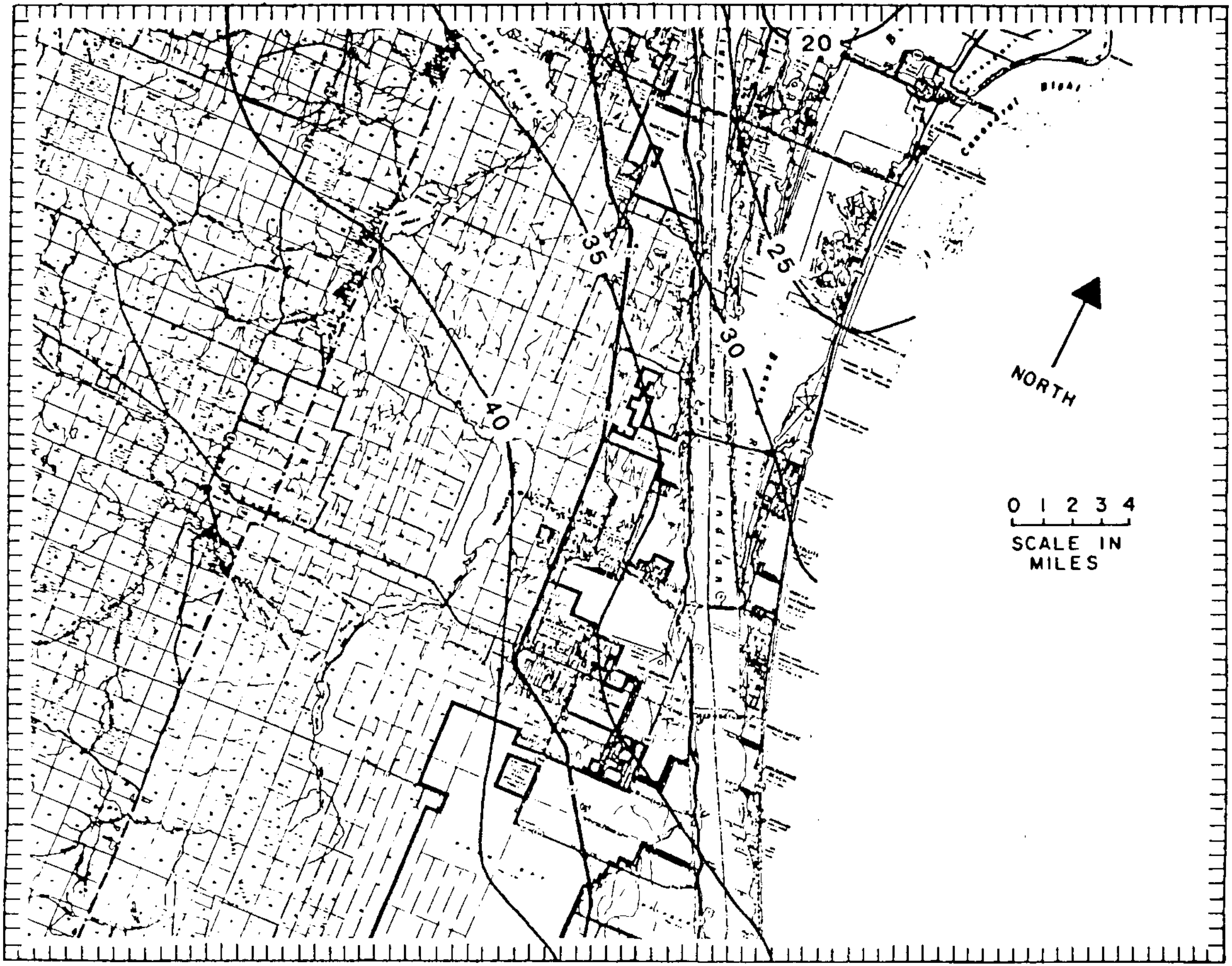


FIGURE 32: ESTIMATED POTENTIOMETRIC SURFACE OF THE FLORIDAN AQUIFER PRIOR TO DEVELOPING THE LAKE WASHINGTON WELLFIELD.

TABLE 7.1: AQUIFER PARAMETER SOURCES USED FOR MODELS

AQUIFER	MODEL LAYER	PARAMETER SOURCE	COMMENTS
Surficial Aquifer System	1	Transmissivity Storage	Irrelevant Irrelevant
Upper Confining Bed	Leakance	Tibbals	Figure 8
Upper Producing Zone	2	Transmissivity Storage	Lake Washington Lake Washington
Middle Confining Bed	Leakance	Tibbals	p14, uniform
Lower Producing Zone	3	Transmissivity Storage	Lake Washington Lake Washington
Lower Confining Bed	Leakance	Tibbals	Assumed for Testing
Lower Floridan Aquifer	4	Transmissivity Storage	Assumed to be the same as Layer 3

Initial Heads

To accurately depict the absolute water level responses after groundwater withdrawal, the initial heads are assumed to be the actual water levels at the beginning of pumpage. However, it is uncertain in which year the wellfield will begin operation; and, the water levels in the BIOS area may be subject to changes since more than one groundwater project is being considered in the modeled area. Rather than attempt to forecast the real water levels, this study depicts the impacts of wellfield development by additional drawdown caused solely by the new wellfield. In this case, the water levels at the beginning of pumpage can be referenced to any water level that actually prevails in the area at any point of time. In fact, when drawdown is the only variable of interest, the initial head in the model can be assumed to any convenient head value. Since the aquifer system is near equilibrium now, the initial heads for all confined aquifer layers are assumed to be 40 feet above mean sea level. The initial head in the surficial aquifer, even though not directly stressed, is assumed to be near the land elevation of 20 feet above mean sea level.

Boundary Conditions

The only boundary condition assumed for the simulation to find the additional drawdown is the constant head on the four sides of the modeled area in each aquifer layer. The constant head boundary is considered realistic since the model area is four times the size of the estimated influence area. All blocks in aquifer layers are active blocks with their heads subject to change due to pumpage. This type of specification limited the drawdown near the model boundaries, hence the model area has to be large enough to avoid the boundary effect.

Pumping Period and Pumping Rates

Pumping periods and pumping rates at the wellfield were dictated by the City of Melbourne. The pumping period was seven years and the withdrawal at Lake Washington was 8.133 MGD. Additional withdrawals from existing users were inputted exclusively from the upper producing zone land in an aggregate amount of 0.6 MGD.

Results

The groundwater flow simulations attempt to depict the probable aquifer drawdown when it is subjected to a pumping stress period. Table 7.2, which follows, summarizes model simulation results at the wellfield area (area of the largest drawdown) at the end of 7 years utilizing the previously introduced aquifer parameters. The value for leakance between layers 3 and 4 is assumed for testing to be equal to that of the leaky middle confining beds between layers 2 and 3. Simulations A through C are based on the total flow of 8.133 MGD being withdrawn from layers 2 and 3 at varying rates. Simulation D is based on the entire flow being withdrawn from layer 3.

TABLE 7.2: SIMULATIONS AT VARIOUS PUMPING SCENARIOS AT THE END OF SEVEN (7) YEARS

Simulation	Modeling Zone Aquifer /	Modeling Zone Layer	Pumping Volume MGD	Wellfield Area Draw down (ft)	Leakance Conductivity Value between Layers 3 & 4
A	Upper Producing Zone	2	5.39	14.6	.5E-4
	Lower Producing Zone	3	2.74	1.3	
	Lower Floridan Aquifer	4	0	0.1	
B	Upper Producing Zone	2	4.06	11.2	.5E-4
	Lower Producing Zone	3	4.06	1.6	
	Lower Floridan Aquifer	4	0	0.2	
C	Upper Producing Zone	2	1.62	5.2	.5E-4
	Lower Producing Zone	3	6.51	2.3	
	Lower Floridan Aquifer	4	0	0.5	
D	Upper Producing Zone	2	0	1.5	.5E-4
	Lower Producing Zone	3	8.133	2.7	
	Lower Floridan Aquifer	4	0	0.7	

Discussion of Flow Simulation Results

The results of the modeling effort summarized above in Table 7.2 emphasize the opportunity to manage the wellfield to reduce the area of the cone of influence. The upper producing zone is 310 feet thick with a computed storage coefficient of 1.18E-3, which is approximately 3 times greater than the lower producing zone, but with a computed transmissivity of only 255,180 GPD/FT, about one tenth that of the lower producing zone. It follows, therefore, that in order to have minimal effects on the Upper Floridan and with the water quality about the same in both producing zones, it is prudent to withdraw more water from the lower producing zone than from the upper producing zone.

Another factor which reinforces the desirability of pumping from the lower producing zone is the protection of the Surficial Aquifer. Most of the land surface in the modeled area is wetland. Since it is important that ground water development does not impact this environmentally sensitive area, it follows, as above, that pumpage take place from within a layer which would have the least impact on the Surficial Aquifer. Pumpage notwithstanding, it is felt that the impact on the surficial aquifer would be minimal under any modeled scenario. Fortunately, the land surface elevation is approximately 20 feet msl, while the pressure head in the Floridan Aquifer is about 40 feet msl. At the dictated pumping rate, the drawdown in the producing zone never exceeds 20 feet. This is reassured from the zero drawdown map of the Surifical Aquifer from the simulation results. Hence the wellfield will not include surficial recharge, and alter the hydro-period of the area.

Sensitivity Analysis

It can be reasonably expected that increased pumpage from the lower producing zone (layer 3), will induce more drawdown in, and upward leakance of water from layer 4, through the 386-foot thick lower confining beds. In order to test the sensitivity of this parameter, several simulations were performed assuming all pumpage exclusively from layer 3 while using varying leakance rates for the lower confining beds. Two additional simulations, identified as E and F, were performed using leakance values one order of magnitude (ten times) higher or lower than those for simulation D. Table 7.3 below summarizes the results and illustrates the effect of the different leakance rates on the amount of upconing through the lower confining beds.

TABLE 7.3: SIMULATIONS TESTING SENSITIVITY OF LEAKANCE PARAMETER

Simulation	Modeling Zone Aquifer /	Modeling Zone Layer	Pumping Volume MGD	Wellfield Area Draw down (ft)	Leakance Conductivity Value between Layers 3 & 4
E	Upper Producing Zone	2	0	1.2	.5E-3
	Lower Producing Zone	3	8.133	2.4	
	Lower Floridan Aquifer	4	0	1.1	
D	Upper Producing Zone	2	0	1.5	.5E-4
	Lower Producing Zone	3	8.133	2.7	
	Lower Floridan Aquifer	4	0	0.7	
F	Upper Producing Zone	2	0	1.6	.5E-5
	Lower Producing Zone	3	8.133	3.0	
	Lower Floridan Aquifer	4	0	0.2	

Discussion of Sensitivity Analysis Results

The applicability of the sensitivity analysis procedure is justified due to the difficulty in determining the change in water quality caused by leakance across the lower confining beds into the upper and lower producing zones. The factors affecting a more direct determination include the following:

1) there is little amount of data in this area on the water quality of the lower Floridan Aquifer,
2) there is little information on the transport characteristics of the lower confining bed, and
3) it may require a true three-dimensional (not layered) transport model.

A review of the model results for each of the simulations in Table 7.3 generates the following observations:

1) If the leakance of the lower confining beds is one tenth that of the middle confining bed (the most likely value), there would be almost no up-coning.
2) If the leakance of the lower confining beds is about the same as the middle confining zone, there might be seven tenths of a foot of drawdown (resulting in 7/10 foot of up-coning) from the Lower Floridan Aquifer at the wellfield after 7 years of pumpage.
3) If the leakance of the lower confining beds is ten times that of the middle confining zone, the predicted drawdown in the Lower Floridan would be 1.1 feet. Considering the respective drawdown in the upper producing zone (1.2 ft) and in the lower producing zone (2.4 ft), most of the withdrawn water will be coming from the Upper Floridan with some contributions from the Lower Floridan through upconing.

Formulation of Final Simulation Parameters and Final Model Outputs

After having established: (1) the desirability of withdrawing solely from the lower producing zone, and (2) the anticipated conditions assuming varying leakance rates, Simulation F in Table 7.3 was selected as the one which most closely simulates actual conditions in the Lake Washington area. This simulation is based on the withdrawal of 8.133 MGD from the lower producing zone while assuming a leakance rate value for the lower confining beds of

.5E-5. The results of this final simulation are illustrated by Figures 33 and 34.

Figure 33 illustrates drawdowns in the lower producing zone while pumping solely from this layer. A maximum drawdown of three (3.0) feet is located at the wellfield. The illustrated one and one half (1 1/2) foot drawdown contour is centered around the wellfield and extends radially 1 1/4 miles from the site. The one-foot drawdown contour occurs three (3) miles in all directions from the wellfield.

Figure 34 illustrates drawdown in the upper producing zone while pumping solely from the lower producing zone. The upper producing zone has a drawdown of 1.4 feet at the wellfield. However, the maximum drawdown of 1.6 feet is located approximately three (3) miles south-southwest of the wellfield. This displacement of the location of the point of maximum drawdown demonstrates that the upper producing zone is stressed more by local well users (producing 0.6 MGD) rather than pumping the lower producing zone at the Lake Washington wellfield. The illustrated one and one half (1.5) foot of drawdown contour occurs south of the wellfield. The center is located two (2) miles south of the wellfield with the contour extending radially one and three quarter (1 3/4) miles. The northernmost boundary of the contour lies less than one (1) mile from the wellfield. The one-foot drawdown contour extends radially with its center located one half (1/2) mile east of the wellfield. The contour extends seven miles to the east and west and eight miles to the north and south.

Summary of Analysis of Upper Floridan Aquifer

A major concern in the development of groundwater resources is the water quality changes which may occur in the life term of the project (wellfield). The groundwater flow model addresses this question indirectly. The expected water quality changes are inferred by combining data from the aquifer performance tests, the drawdown maps, and the water quality information. At the Lake Washington test site the water quality profile is relatively uniform throughout the interval (240' to 850') containing the two major producing zones. The water quality was also stable in the discharges from the production and monitor wells after development. Even during the 31 day APT, when flow was continually registered at around 2400 gpm, the water quality changes were minimal and did not show any upward trends in major cations or anions. This indicates that the aquifer is extensive, with good continuity from the test site. However, as the aquifer is subjected to larger scale withdrawals during wellfield development the cone of influence will expand as shown on the simulations and some gradual changes in water quality will result

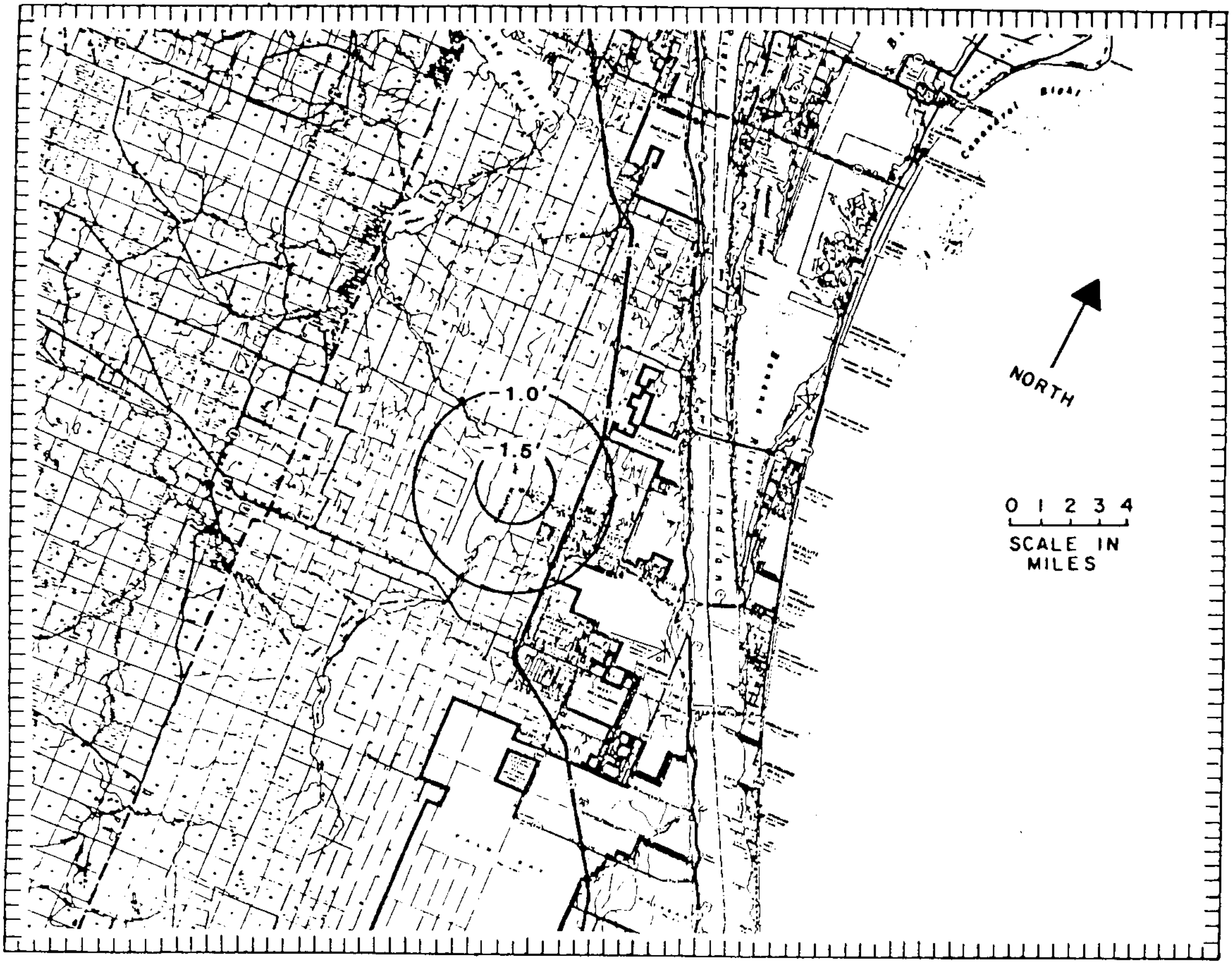


FIGURE 33: SIMULATED DRAWDOWN IN THE LOWER PRODUCING ZONE WHILE DEVELOPING 8.133 MILLION GALLONS PER DAY SOLELY FROM THE LOWER PRODUCING ZONE AT THE END OF SEVEN (7) YEARS.

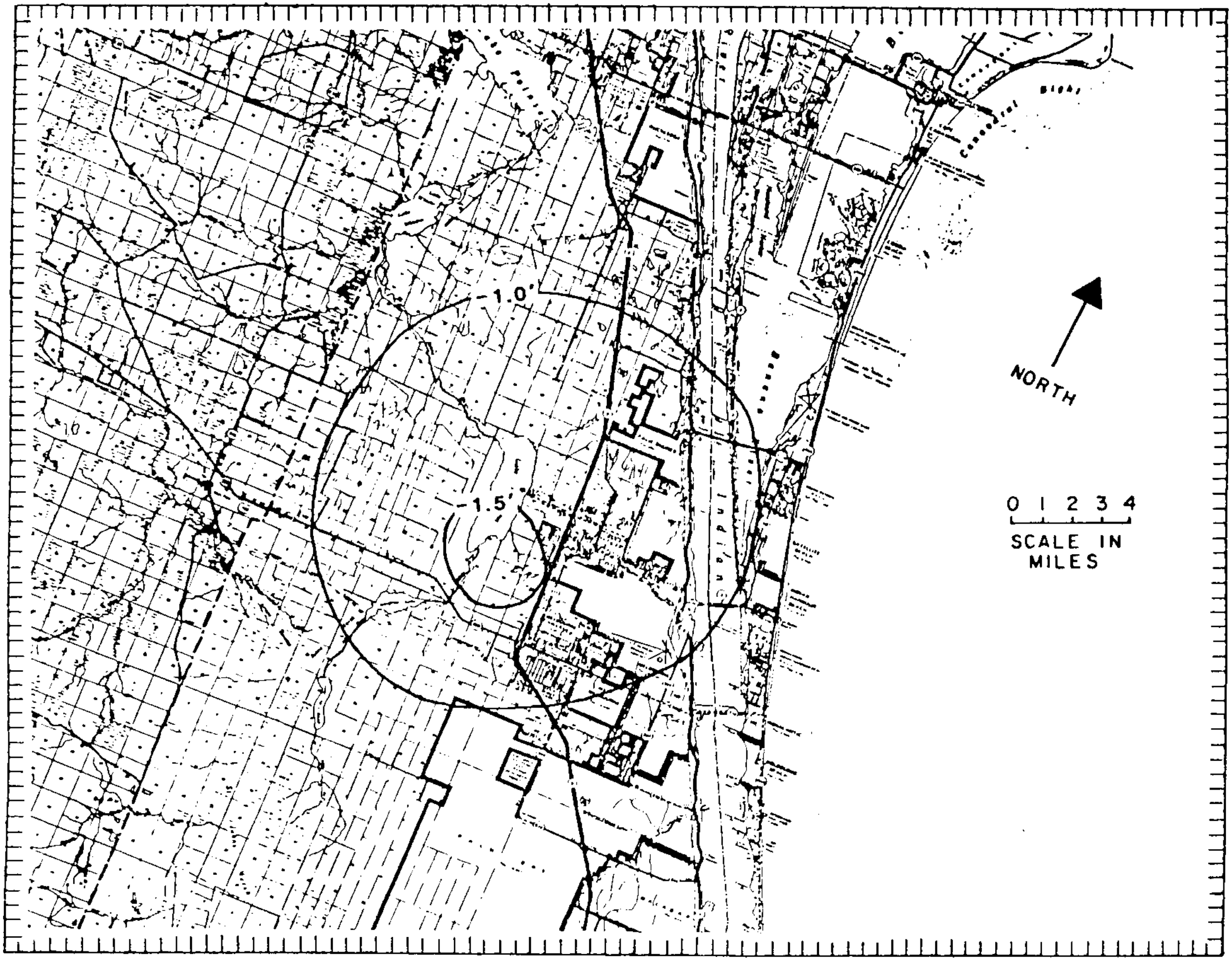


FIGURE 34: SIMULATED DRAWDOWN IN THE UPPER PRODUCING ZONE WHILE DEVELOPING 8.133 MILLION GALLONS PER DAY SOLELY FROM THE LOWER PRODUCING ZONE AT THE END OF SEVEN (7) YEARS.

in some areas. The changes in water quality at the wellfield due to transport of water with different qualities in the same producing zone to the wellpoint will be addressed by the solute transport model.

It is concluded from the information above that water quality change, if any, would be due to the transport of different quality water laterally within the same producing zones.

8.0 SOLUTE TRANSPORT MODEL (SUTRA)

Model Selection

The SUTRA model (Saturated-Unsaturated Transport, A Finite-Element Simulation Model for Saturated-Unsaturated, Fluid Density-Dependent Ground-water Flow with Energy Transport or Chemically-Reactive Single-Species Solute Transport by Clifford I. Voss, U.S. Geological Survey, Water Resources Investigations Report 84-4369, Prepared in Cooperation with U.S. Air Force Engineering and Services Center, Tyndall A F B, Florida, 1984) is selected for this study.

The selection of SUTRA was based on many factors:

1) Initially, it was listed as an acceptable model by St. John's to predict regional water quality impacts as well as site specific water quality impacts.

2) It is a public domain model developed and maintained by a government agency. Anyone can have access to the source code and a modeler can have the exact knowledge of how each part of the model works.

3) It contains all the basic components involved in groundwater modeling.

4) The SUTRA model can address unsaturated flow. Even though this study does not consider unsaturated flow, in the real world, unsaturated flow is occurring in the surficial unit of any hydrologic system receiving rainfall recharge.

5) SUTRA is also capable of determining chemical reactions as a result of solute transport. Solute transport in this investigation is limited to only conservative material; however, chemical reactions may be occurring when the aquifer is subject to a large scale withdrawal.

6) The complexity of SUTRA appears to be cumbersome for this study, but it will provide good continuity for follow-up studies.

7) SUTRA, a two-dimensional model, is an appropriate model to run. Results of drilling and testing support the following:

   a) Water quality parameters measured during the field investigation stayed fairly stable for all wells and APT's.

   b) The water quality, as indicated by the total dissolved solid (TDS) concentrations, stayed between 1150 to 1200 ppm for both the upper and lower producing zones during the entire period of field testing.

c) There is a connection between the upper and lower producing zones through the middle confining zone.

Hypothetically, with SUTRA, if the upper and lower producing zones were not connected and were layered, the modeler would have to provide a connection mechanism between the layers. Alternatively, if the layers are really connected (such as the Upper Floridan Aquifer in this study) these layers can be combined as one layer or analyzed individually.

8) As compared to a three-dimensional model, SUTRA is more appropriate for this study. A true three-dimensional model is not only inappropriate but it is not needed. A three-dimensional model is not needed because of the water quality of the study area (item #7 above). It is inappropriate because it would require additional field data and at this time there is not sufficient reliable data to estimate parameters addressed in a 3-D model. In short, there would be too many assumptions and not enough actual data at this point to run an accurate true three-dimensional model.

Discussion on Model Selection

The SUTRA model is not a 'canned' package. Its document gives clear instructions to which part of the model should be specifically programmed by the modeler. While the finite element method is elegant and efficient, it employs complicated mathematical concepts and its data input requires careful bookkeeping. In short, to work with SUTRA, some basic programming and mathematical skills are required.

There is limited areal information available for TDS concentration over 1200 ppm in the Upper Floridan aquifer in the Brevard County area. For water resource protection, transport modeling provides a general idea as to the movement of (TDS) contour lines due to the groundwater development.

There is a high degree of uncertainty in each of the required data input parameters for the transport modeling. Hence the results of the model is better interpreted qualitatively (relatively) rather than quantitatively (absolutely). Before starting a complex simulation with uncertain data, a simple mass balance computation will help to establish a framework of reference.

Model Layout

In the previous flow model using MODFLOW, 0.5-mile by 0.5-mile square blocks were used for the finite difference discretization. Each block is represented by the center point in the mathematical computation. With SUTRA, using the finite element method, the basic operation is integration over an element which is defined by nodal points (vertices of the element). For the best continuation from MODFLOW, the SUTRA nodal points should coincide with the block centers of MODFLOW in this study as much as possible. However, SUTRA is a much more complex program and demands a lot more computer capacity. To reduce the computation requirements, the node spacing in SUTRA is increased to 1 mile, and each element is 1 square mile.

To minimize the effects of specified boundary conditions, which are at most 'guestimations', the stress point, Lake Washington, is placed at the center of the model area. The transport model covered most of the MODFLOW area. The model area is 32 miles by 32 miles and has a total 1024 nodes, with 32 nodes each in X and Y directions. There are 961 elements, with 31 elements in both row and column directions; each element is a square area. Lake Washington is represented at coordinates (x,y)=(17,16), or at node point 528. In other words, the transport model area deletes the 8-mile easternmost portion of the MODFLOW model area (Figure 35).

Input Parameters

The basic aquifer parameters required by SUTRA are permeabilities, porosities, dispersivities and thicknesses. The aquifer was assumed to be isotropic, requiring the aquifer parameters in the major and the minor axes to be equal. In confirmation with the flow model, the aquifer thickness was assumed to be uniform. For relationship of aquifer parameters between SUTRA and MODFLOW, permeabilities are assumed to be a function of transmissivities; porosities are proportional to storage coefficients. Dispersivities are derived from the literature.

Boundary Conditions

There was not enough information to define the initial concentration distribution eastward beyond Lake Washington area. However, the concentration on the eastern boundary, which can be considered constant, is most crucial in the final distribution of the salinity. Even though other high eastern boundary TDS concentrations have been tried and observed, only the results from the most probable eastern concentration of TDS at about 1800 ppm are reported.

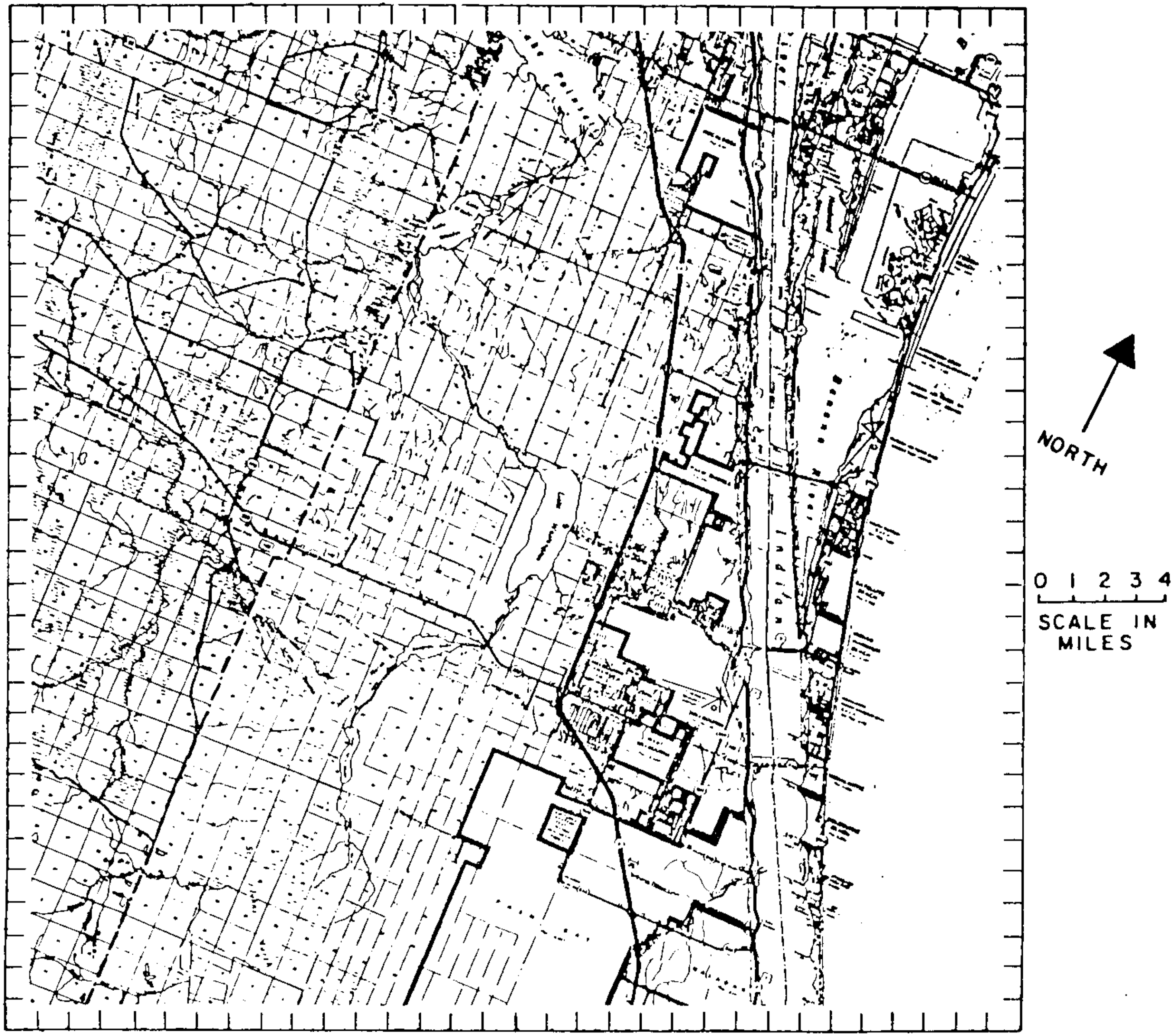


FIGURE 35: MODEL AREA FOR SUTRA SIMULATIONS.

Unit Conversions

The time unit in SUTRA is always in seconds. Usually the model requires MKS (meter-kilogram-second) system. In case that gravitational force is not important, such as in this simulation, the conventional units used in the MODFLOW can be employed.

Model Calibrations

Pressure heads are the only variable that change with the rate and the duration of groundwater withdrawal, since no water quality change was observed during the field investigations. Again, in MODFLOW, the drawdown due to the proposed wellfield was related to a reference contour map of pressure heads. Consequently, the model calibration for SUTRA was achieved by adjusting the multiplication factors of permeability (PMAXFA, PMINFA) so that the progression of drawdowns are similar to that of MODFLOW. That is not difficult, because, for pressure head computations, both models are based on the same equation; and both models are well-behaved. In fact, direct conversion between related parameters verifies satisfactorily.

Dispersivities control the dispersion transport in the model. Dispersivities, however, varied widely, and there was no local data. Walton (1984, Walton, W. C., Practical Aspects of Groundwater Modeling, National Water Well Association) cited longitudinal dispersivity for alluvial sediment and limestone-dolomite in the range of 7 to 61 meters, and transverse dispersivity in the range of 1 to 20 meters for areal model. Konikow (1977, Konikow, L. F., Modeling chloride movement in the alluvial aquifer at the Rocky Mountain Arsenal, Colorado. U.S. Geological Survey Water Supply Paper 2044, 43p), however, in alluvial sediment, for longitudinal and transverse dispersivities used 500 feet and 100 feet (153 m and 30.5 m) respectively. While the uniform value of this parameter can be varied easily by the multiplication factor, this report centers the results with the most probable longitudinal dispersivity of 500 feet and transverse dispersivity of 50 feet.

Results

It has been established that water within the study area in both the upper and lower producing zones is stable and virtually of the same quality. This is indicative of the nature of the Upper Floridan Aquifer System. Consequently, a change in water quality, if any, should be gradual and predictable. Transport modelling has provided an approximate rate of water quality change for a given pumping scenario. However, the actual rate of water quality change may also depend on the percentage of up-coning contribution. A true 3-dimensional transport simulation model would be useful in addressing up-coning if sufficient data were available. Also, the field investigation and results of MODFLOW show upconing to only have a negligible effect. However, once the wellfield is put into operation, the water quality changes at the wellpoint can be best projected from real time data.

Estimated TDS concentrations in the upper Floridan Aquifer prior to pumping the Lake Washington wellfield have been illustrated on Figure 36 (taken from TDS map of Gee and Jenson, Osceola-Brevard Interdistrict Water Supply Preliminary Engineering and Feasibility Report. Prepared for the South Florida Water Management District, December 1987). With the total withdrawal of 21 billion gallons in seven (7) years from the Upper Floridan aquifer, considering the aquifer thickness (490 feet of producing zone, plus 134 feet of leaky confining zone) and the combined storage coefficient of the producing zones only at 9.8E-4 the water within an eight mile radius of the wellfield currently in the aquifer will eventually be replaced. The implication to the water quality is that at the end of the pumping period, the water quality at the wellfield can not be worse than the worst water quality currently existing within the eight mile radius of influence around the wellfield. In other words, it is expected that the TDS contour line of 1200 ppm will move further west (inland) when water is withdrawn near the test site. While the exact progression of contour lines is difficult to verify, modeling results indicate that a TDS of 1300 ppm will approach near the wellfield after a seven (7) year pumpage at 8.133 MGD (Figure 36).

Additionally, simulations were conducted pumping the Lake Washington wellfield (8.133 MGD) and noting water quality changes in TDS (ppm) at the end of each year up to seven (7) years. This is summarized in Table 8.1 below.

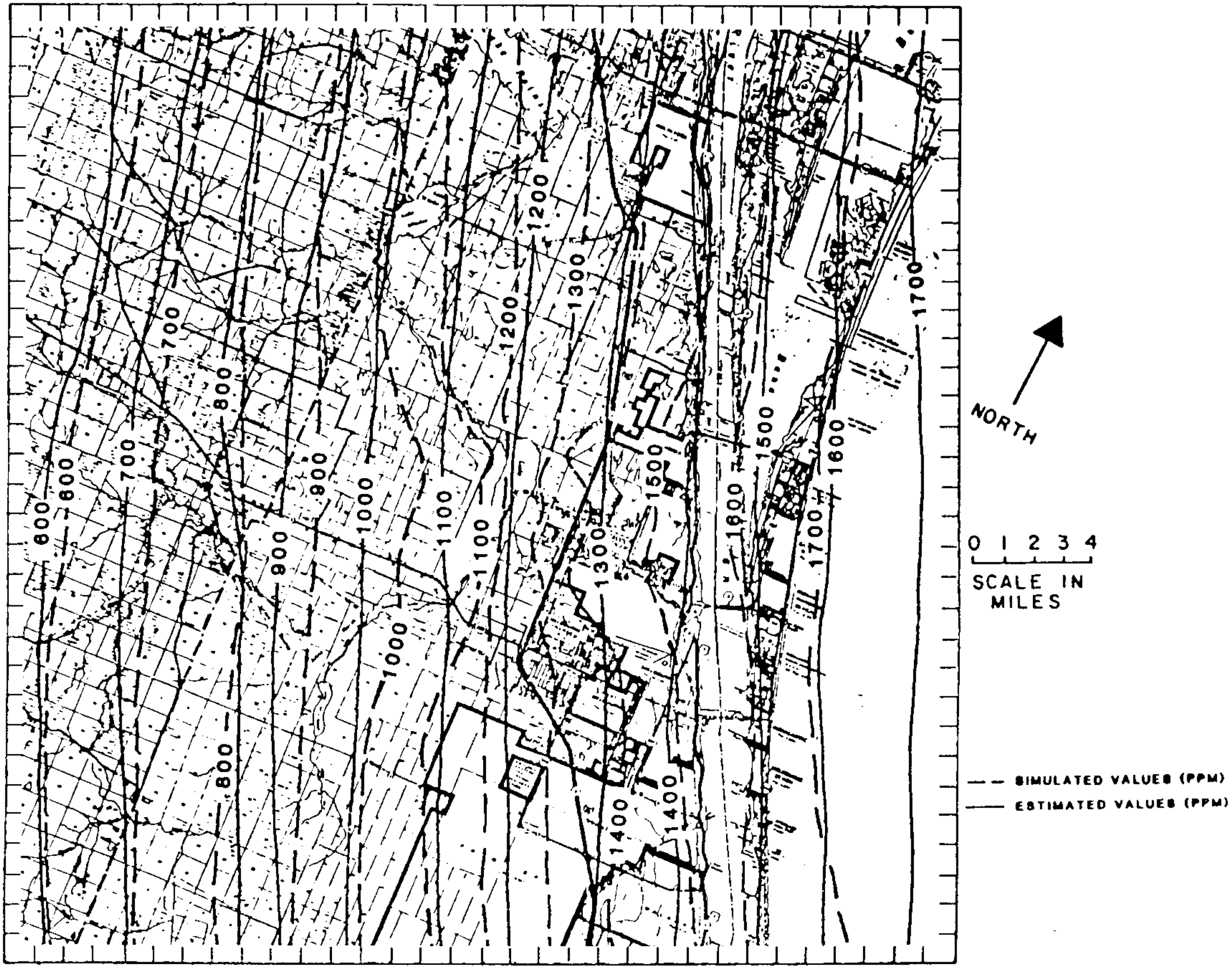


FIGURE 36: ESTIMATED VALUES OF TOTAL DISSOLVED SOLIDS IN UPPER FLORIDAN AQUIFER PRIOR TO PUMPING THE LAKE WASHINGTON WELLFIELD AND SIMULATED EFFECTS AFTER PUMPING 8.133 MGD AT THE END OF SEVEN (7) YEARS

TABLE 8.1: TOTAL DISSOLVED SOLIDS CONCENTRATIONS VERSUS TIME

YEAR	TDS AT PUMPING NODE (ppm)	PERCENTAGE INCREASE FROM YEAR 0 (%)	HIGHEST PERCENTAGE INCREASE FROM YEAR 0 (%)	CORRESPONDING TDS CONCENTRATION (PPM)
0	1205	-	-	- 1280
1	1216	0.9	2.4	1316
2	1227	1.7	4.4	1344
3	1239	2.7	6.6	1376
4	1249	3.5	8.8	1409
5	1261	4.4	9.1	1370
6	1272	5.2	13.3	1482
7	1284	6.6	15.4 18.2	1518 233

As anticipated, the largest water quality changes were found to be in the eastern vicinity of the wellfield but not at the wellfield. This is due to the fact that the wellfield is taking in higher TDS water from the east (coast) but at the same time it is taking in lower TDS water from the west (inland), thus the largest changes in TDS concentrations are less than two miles to the east of the intake point or wellfield. These increases are listed in Table 8.1 as 'highest percentage increase in model area'.

As illustrated in Figure 36, the TDS values in the upper Floridan prior to developing the Lake Washington wellfield (Gee and Jenson, 1987) and results of pumping at the end of seven (7) years indicate a 6.6% increase at the wellfield.

The actual concentration changes (increases and decreases) are illustrated on Figure 37. This figure depicts the lower TDS water approaching the wellfield from the west and the higher TDS water approaching from the east. Concentration increases of 150 ppm are noted to the northeast. The 150 ppm increased-concentration contour is approximately five (5) miles in diameter and is centrally located 2.5 miles to the northeast of the wellfield. A simulated increase of 100 ppm TDS would extend to the east of the wellfield and have an oblong shape stretching northwest-southeast. This 100 ppm increased-concentration contour would stretch a minimum of 15.5 miles to the northwest, slightly past the modeled area and would extend 13.5 miles to the southeast of the wellfield. The eastern boundary would stretch 12.5 miles from the wellfield which is approximately 3 miles into the Atlantic Ocean. Simulated changes of -50 ppm TDS are located to the southwest of the wellfield with a diameter of five (5) miles. The center is approximately located two and one half (2.5) miles from the wellfield. The concentrations from this scenario have been extrapolated onto Figure 36 to show water quality changes in the Upper Floridan.

Discussions on SUTRA Model Results

The reliability of the simulation depends mostly on the extrapolation of initial concentration distributions and the constant concentration boundaries on the east. The eastern boundary was extended into the ocean and assumed the TDS in the confined aquifer was 1800 ppm on the coast. If these concentration estimations on the eastern boundary (1800 ppm) are reasonable, then TDS concentration distributions presented here are believed to be on the conservative side, e.g. the actual TDS concentration due to horizontal movement will probably be less than that depicted in the maps from simulations. The actual TDS concentration of the withdrawn water will also be slightly

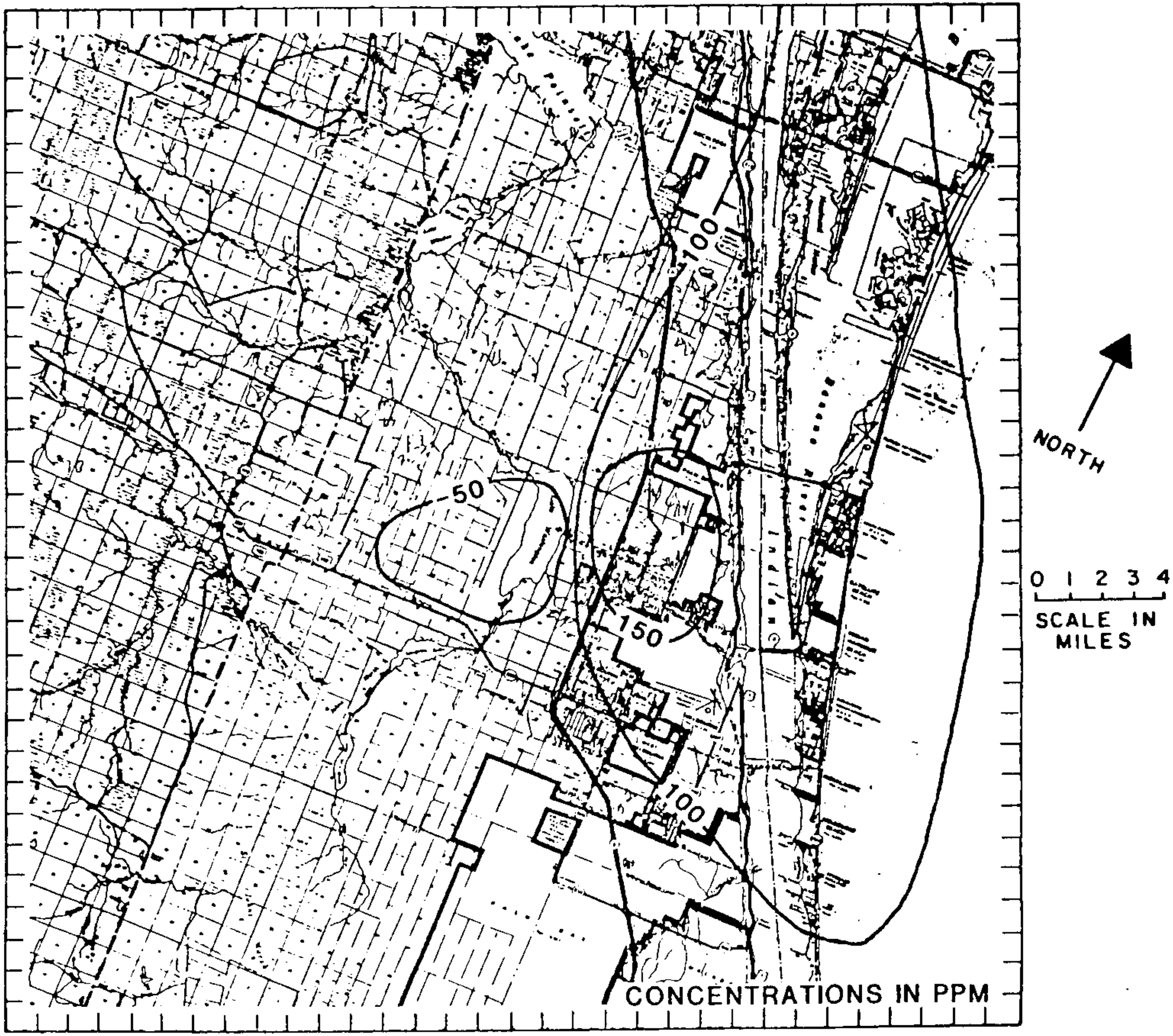


FIGURE 37: SIMULATED CHANGES IN TOTAL DISSOLVED SOLIDS CONCENTRATIONS AFTER PUMPING THE LAKE WASHINGTON WELLFIELD AT THE END OF SEVEN (7) YEARS AT A RATE OF 8.133 MGD.

affected by up-coning. To guard against estimation and simulation errors, a monitoring program should be established to collect the real time data for resource protection.

9.0 FINDINGS

1) There are three aquifer systems present in the Lake Washington area; the surficial, the intermediate, and the Floridan.

2) The intermediate aquifer system is wholly contained within the Hawthorn Group. The vertical permeabilities of cores taken from the strata were very low and ranged between 1.3 X 10-6 cm/sec and 9.1 X 10-9 cm/sec. The unit is considered a confining bed that effectively retards the vertical transfer of water from the Surficial into the underlying Floridan system.

3) The upper section of the Floridan Aquifer System can be divided into 5 major zones based upon the geology and hydrogeology at the site. These are:

   a) upper producing zone (240 to 550 feet)
   b) middle (semi) confining zone (550 to 680 feet)
   c) lower producing zone (680 to 850 feet)
   d) lower confining zone (850 to +1200 feet)
   e) Lower Floridan Aquifer (below 1200 feet)

4) The transmissivity of the upper producing zone (using a geometric mean of all reliable calculated values) is 255,180 gpd/ft and the storage coefficient is 1.18 x 10 -3.

5) The middle (semi) confining zone is a very leaky unit composed primarily of dolomites with limestone in the lower sequence. Water levels during all of the aquifer tests responded rapidly in these beds. The vertical permeability from core data varied from 2.6 X 10 -4 cm/sec to 6.1 X 10 -7 cm/sec.

6) The lower producing zone was tested in combination with the upper producing zone and yielded a transmissivity value of 2,505,900 gpd/ft and storage of 6.37 X 10 -4. Geophysical logs indicate that a major portion of flow to the production well is entering in this zone.

7) The lower confining zone is composed of dense dolomites to at least 1204 feet below land surface (total depth of exploration well). The vertical permeability of a core sample from this zone was 5.8 X 10 -6, although the actual permeability is probably much lower for the total thickness of the zone. A monitor well in this zone did not record water level changes above background during the 31-day aquifer performance test.

There is little evidence that water would move across this zone under the proposed (8.133 MGD) wellfield pumpage rates.

8) The water quality parameters measured during the field investigation stayed fairly stable for all wells and APT's. The water quality as indicated by the TDS concentrations stayed consistently between 1150 to 1200 ppm for both the upper and lower producing zones for the entire period of field testing.

9) The layers and thickness of the various zones to be used in the flow model (MODFLOW) are listed below. The thickness of the lower Floridan Aquifer is inferred from injection well data in the area.

   1) SURFICIAL AQUIFER SYSTEM (120 FEET) (LAYER 1)
   2) INTERMEDIATE AQUIFER/CONFINING SYSTEM (104 FEET)
   3) UPPER PRODUCING ZONE (UPPER FLORIDAN) (310 FEET) (LAYER 2)
   4) MIDDLE CONFINING ZONE (UPPER FLORIDAN) (134 FEET)
   5) LOWER PRODUCING ZONE (UPPER FLORIDAN) (180 FEET) (LAYER 3)
   6) LOWER CONFINING ZONE (386 FEET)
   7) LOWER FLORIDAN AQUIFER (LAYER 4)

10) The groundwater flow model (MODFLOW) simulated a withdrawal of 8.133 MGD at the end of seven years. The model depicted 3.0 feet of drawdown at the pumping node and a 1.0 foot cone of influence extending radially 2.5 miles from the wellfield. The model also showed no effect on the surficial aquifer from the simulated withdrawal.

11) The solute transport model (SUTRA) also simulated a withdrawal of 8.133 MGD for seven years. At the end of seven years a 6.6% increase in TDS concentration (from 1205 ppm to 1284 ppm) was noted at the wellfield.

10.0 CONCLUSIONS

The development of a wellfield at Lake Washington will have a minimal affect on the water resources of Brevard County at the proposed rate of 8.133 MGD. The analysis of data from the exploratory drilling and aquifer performance tests show good quality water (treatable) to a depth of at least 1200 feet below land surface. During the 31 day APT there was no indication of water quality degradation. It appears from the test data around the area that confining beds exist from about 860 feet to at least 1400 feet below land surface, which should effectively retard the movement of higher TDS water across these beds. In fact, the groundwater models showed that even with unrealistic leakage rates through these beds that there would be minimal effect. The major concern is lateral movement of water and, because the wellfield will be drawing from a radius of at least eight (8) miles, the quality of the water should not be severely affected. As with any withdrawal from the Floridan, there will be some effects on adjacent users. However, the groundwater flow model showed only about 1.5 feet of drawdown one and a half miles from the site while withdrawing solely from the lower producing zone.

During the second APT at a pumpage rate of 3.448 MGD no drawdown was detected at a monitor well 2500 feet from the production well and less than a foot of drawdown only 300 feet from the production well. The existing users of water from the Floridan in the area withdraw primarily from the upper producing zone (240 to 550 feet) and if the wellfield is designed to withdraw from the lower producing zone (680 to 860 feet) the flow model shows only approximately 1 foot of drawdown within an eight mile radius in the upper producing zone. Actually the existing users affect water levels more under this scenario. The only other concern is the effect the withdrawals will have in the easterly areas, because the westerly areas should actually freshen as water is drawn in. The solute transport model indicates that the total dissolved solids content of water in the easterly areas (in the Floridan) can be expected to only be moderately affected.

In summary, it appears that the City can safely withdraw the proposed 8.133 MGD of water from a wellfield in the Lake Washington area with minimal affect on the water resources of the region. The wellfield should be designed to withdraw from multiple wells constructed into the lower producing zone (680' to 860' below land surface). Water quality degradation from up coning should not be a factor unless much larger withdrawals are made.

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