GROUNDWATER EVALUATION IN THE CENTRAL COASTAL PLAIN OF NORTH CAROLINA

DEPARTMENT OF NATURAL RESOURCES AND COMMUNITY DEVELOPMENT

1980

GROUNDWATER EVALUATION
IN THE
CENTRAL COASTAL PLAIN OF NORTH CAROLINA

By

James Narkunas

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ABSTRACT

Groundwater is the principal source of water in the central Coastal Plain of North Carolina. The region's quality of life, its economy, and future growth are all linked to this important resource.

Sediments underlying the area consist of gravel, sand, silt, clay, limestone, and combinations of these lithologies. They are formed into layers or lenses varying in lithology, thickness, and texture. The sediments are subdivided into hydrogeologic units or aquifer systems on the basis of hydraulic conductivity and other hydrologic characteristics. The principal units are the unconfined Water Table Unit, and the confined Castle Hayne, and Cretaceous Upper Sand and Lower Sand Units.

The Cretaceous Lower Sand Unit is the principal water-bearing unit in the study area. The unit dips to the southeast and ranges from 200 feet to 700 feet in thickness. It is characterized by a mean transmissivity of 3,750 feet squared per day, a mean storage coefficient of 2.3×10^{-4}, a mean specific capacity of 4.50 gallons per minute per foot, and a mean recharge rate of 55,000 gallons per day per square mile.

Since the late 1960's, water levels in the Cretaceous aquifer system have declined significantly due to large-scale municipal and industrial withdrawals. These withdrawals have caused extensive cones of depression. The potentiometric surface in 35 percent of the study area is currently below sea level. Water levels near some pumping centers have declined 80 feet since 1965.

Water Quality in the Cretaceous lower sand unit is generally excellent. Groundwater in the overlying unit is of lesser quality, usually

requiring some degree of treatment.

Projections indicated that pumping rates will continue to increase causing water levels to maintain a downward trend. Increased water use and low recharge rates suggest that water management measures should be instituted.

INTRODUCTION

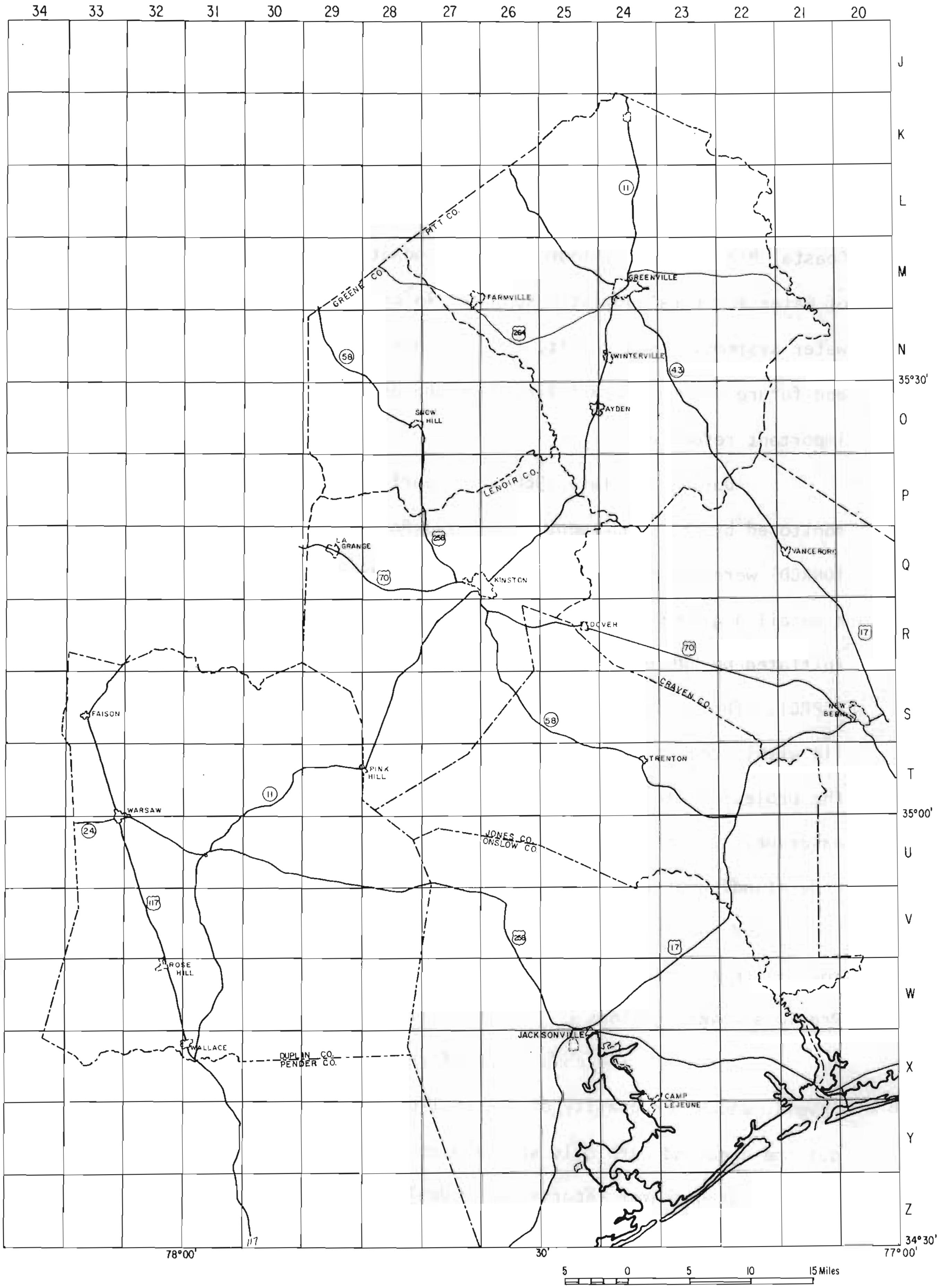
Purpose and Scope

Groundwater is the principal source of water for the majority of municipal and industrial water systems in North Carolina's central Coastal Plain region (Figure 1). Groundwater is also the major source of water for rural domestic supplies in areas which are not served by water systems. As a result, the region's quality of life, its economy, and future growth are all linked to the availability and quality of this important resource.

During the late 1960's and early 1970's, water levels in wells monitored by the Department of Natural Resources and Community Development (DNRCD) were found to be declining at a rate which indicated a need for a detailed groundwater investigation. In November, 1977, such a study was initiated by DNRCD under a grant from the Coastal Plains Regional Commission (CPRC). The study consisted of an evaluation of the aquifer systems that lie within the project area and a determination of their potential to meet the projected water needs of industrial and public supplies. This report describes the results of that study. Its intent is to provide a better understanding of the region's groundwater regime, so that the resource may be managed and developed in a manner that will insure maximum benefits to the region's inhabitants.

Previous Investigations

Prior to the completion of this study, the aquifer units, water levels, and water quality of the aquifer systems had not been mapped throughout the area and were only sparsely monitored. Therefore, there are no previous groundwater reports which deal with the entire area covered by the study.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10
15 Miles
PITT CO.
GREENE CO.
LENOIR CO.
CRAVEN CO.
JONES CO.
ONSLOW CO.
DUPLIN CO.
PENDER CO.
GREENVILLE
FARMVILLE
WINTERVILLE
AYDEN
SNOW HILL
LA GRANGE
KINSTON
VANCEBORO
DOVER
NEW BERN
TRENTON
PINK HILL
FAISON
WARSAW
ROSE HILL
WALLACE
JACKSONVILLE
CAMP LEJEUNE
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A number of reports released over the past 15 years have dealt with parts of the study area and have contributed to an increased understanding of the hydrogeology on a county or local level. These include sections of the United States Geological Survey Hydrologic Investigations Atlas entitled "Groundwater Resources of Craven County, North Carolina" by Floyd and "Summary of the Geology and Groundwater Resources of Pitt County, North Carolina" by Sumsion. In addition, Sumsion prepared a companion county report in cooperation with the North Carolina Department of Water and Air Resources entitled, "Geology and Groundwater Resources of Pitt County, North Carolina". A local report, "Groundwater Resources of the Kinston Area, North Carolina", by Nelson and Barksdale summarized the results of a groundwater investigation conducted by the North Carolina Department of Water Resources for the City of Kinston. Two other reports, Part Four and Part Five of "Public Water Supplies of North Carolina," by Robison and Mann describe the major public water systems in the Coastal Plain, and also provide brief water resources appraisals on an individual county basis.

Three earlier reconnaissance reports covered one or more counties included in the current study area. These reports, for the most part, have addressed the subject of groundwater from a geologic, rather than a hydrologic standpoint. The reports were prepared prior to 1960 and, as a result, do not reflect the current groundwater regime or the influence of large-scale withdrawals. These reports are "Geology and Groundwater Resources of Wilmington-New Bern Area" by LeGrand, "Geology and Groundwater Resources in the Greenville Area, North Carolina" by Brown, and "Progress Report on Groundwater in North Carolina" by Mundorff.

Well Location and Identification System

Wells referred to in this report are identified on the basis of their location within a state-wide grid system of latitude and longitude.

The State is divided into quadrangles of five-minutes latitude, identified by upper-case letters and five-minute longitude, identified by numbers. Each five-minute quadrangle is subdivided into 25 one-minute quadrangles and these are identified by lower-case letters. Wells located within a one-minute quadrangle are numbered serially.

Research Station and Monitor Wells

Figure 2 shows the location of the groundwater research stations and water-level monitor wells used for the collection of data during the course of this investigation.

A groundwater research station consists of a series of wells constructed at various depths and located on a single site. Each station was located at a site which provided optimum geologic correlation between the stations.

Eleven research stations are referred to in this report. Four of these stations were completed within or adjacent to the study area prior to the beginning of the project, while the remaining seven stations were constructed during the investigation period.

In addition to the water-level and water quality information collected from a station subsequent to its completion, much valuable information was obtained during its construction. The construction of a groundwater research station involved drilling an exploratory borehole to basement rock or to some other predetermined depth. The borehole was logged upon its completion to obtain electrical resistivity, spontaneous

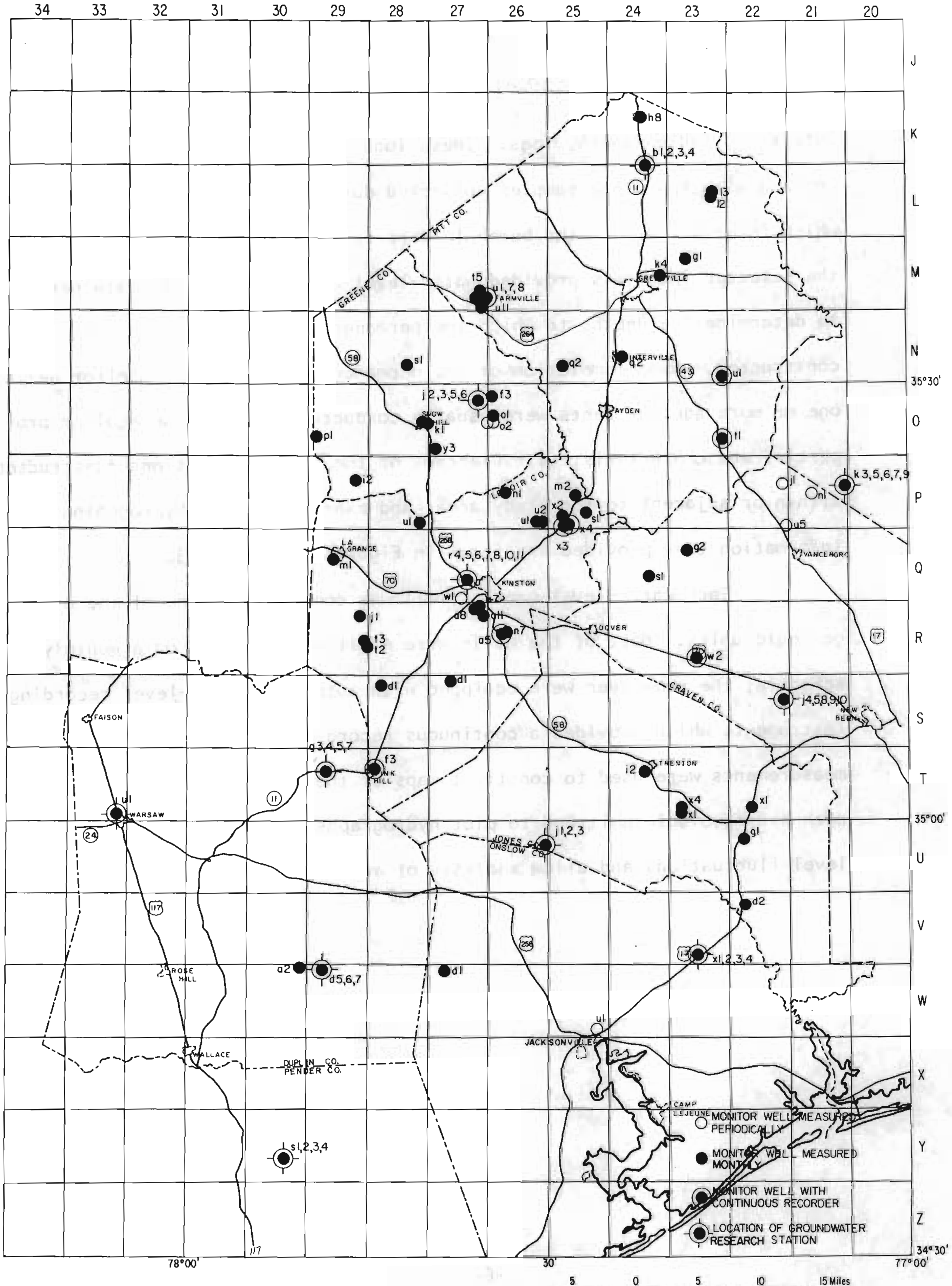
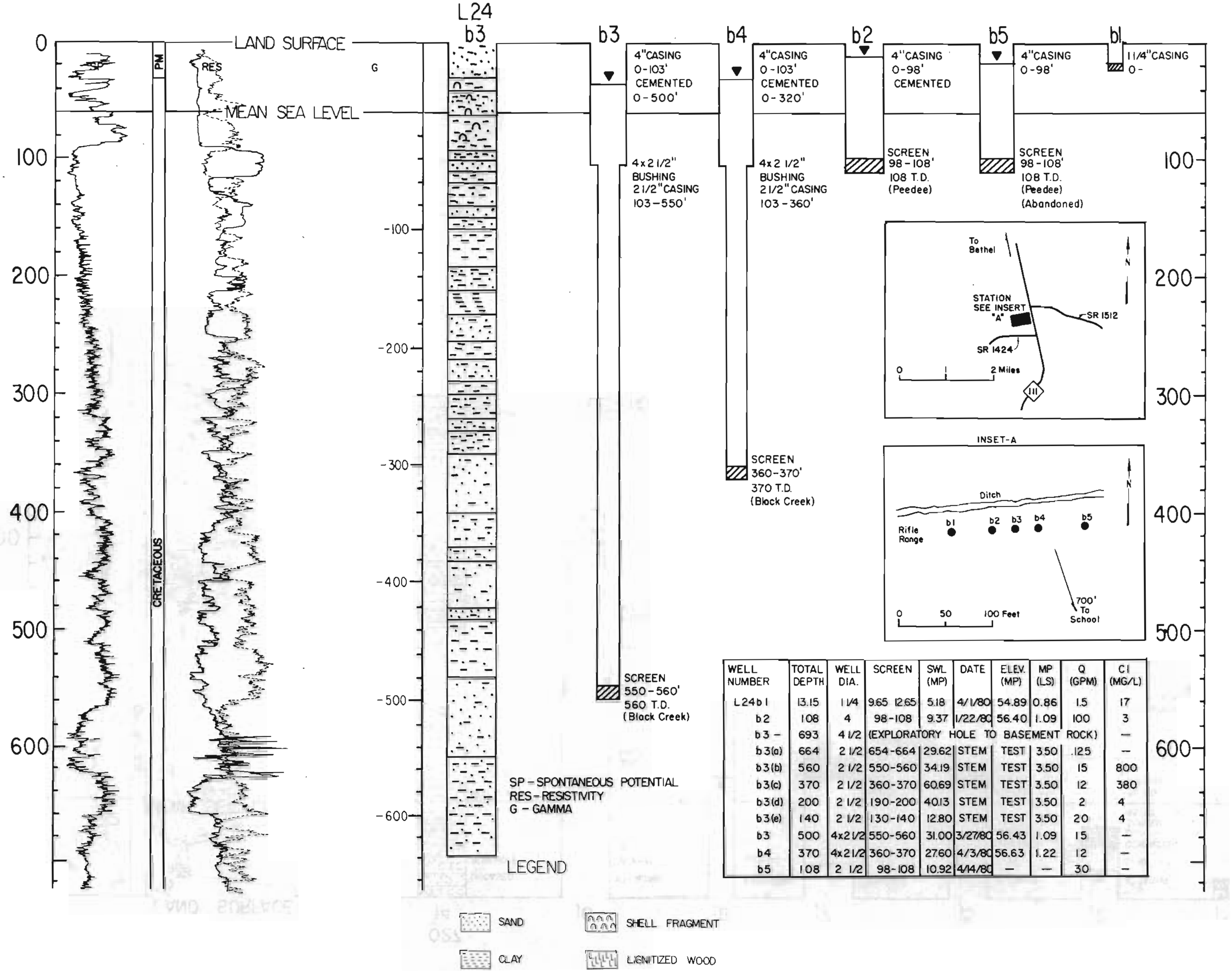


FIGURE 2 - MAP SHOWING LOCATION OF WATER-LEVEL MONITOR WELLS

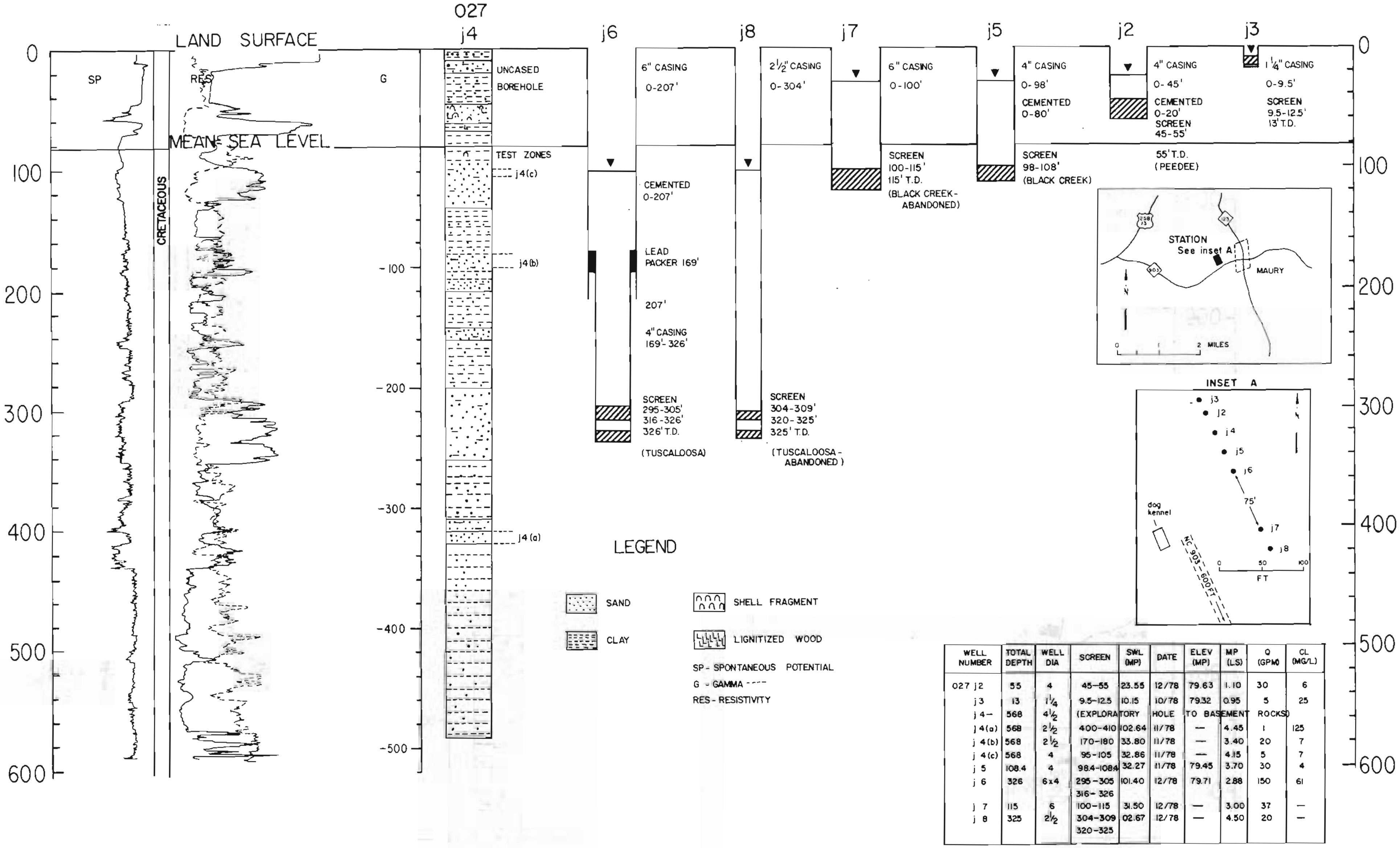
potential, and gamma-ray logs. These logs were compared with the driller's log and with formation samples collected during the drilling to determine which intervals within the borehole were to be tested. Stem-testing of the selected intervals provided water-level and water quality data necessary to determine the depths to which the permanent monitor wells were to be constructed. Upon completion of the permanent and temporary monitor wells, one or more aquifer tests were usually conducted to determine aquifer properties and characteristics. Diagrams of the research stations constructed within or adjacent to the study area, and examples of the hydrogeologic information they provided are shown in Figures 3 through 13.

Each water-level monitor well was completed in one of the hydrogeologic units. Most of the wells were monitored manually on a monthly schedule; the remainder were equipped with automatic water-level recording instruments which provided a continuous record of the water level. These measurements were used to construct maps of the potentiometric surface of each hydrogeologic unit and to plot hydrographs which illustrate water-level fluctuations and allow analysis of any existing trends.



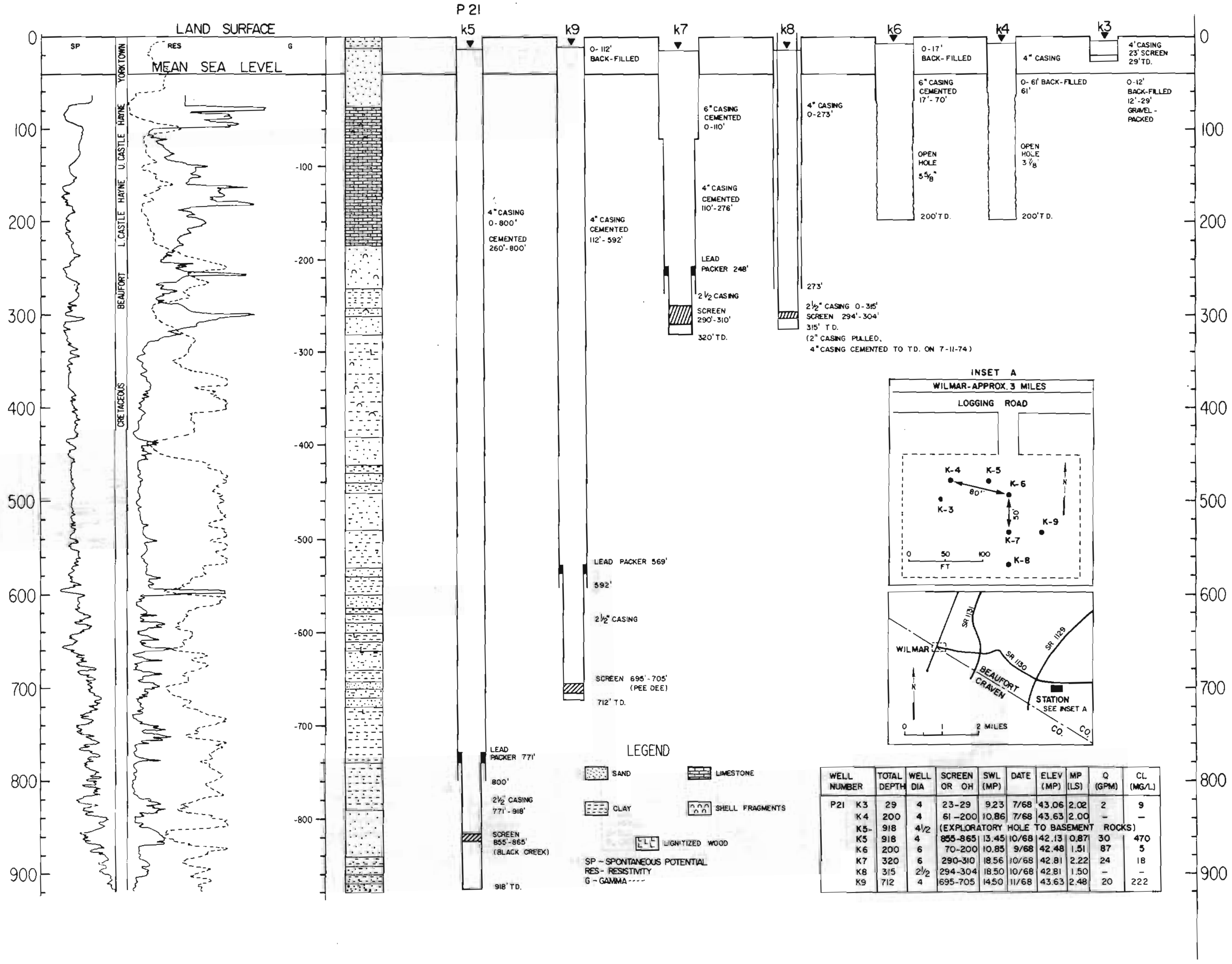
WELL NUMBER	TOTAL DEPTH	WELL DIA.	SCREEN	SWL (MP)	DATE	ELEV. (MP)	MP (LS)	Q (GPM)	Cl (MG/L)
L24b1	13.15	1 1/4	9.65 12.65	5.18	4/1/80	54.89	0.86	1.5	17
b2	108	4	98-108	9.37	1/22/80	56.40	1.09	100	3
b3 -	693	4 1/2	(EXPLORATORY HOLE TO BASEMENT ROCK)						—
b3(a)	664	2 1/2	654-664	29.62	STEM	TEST	3.50	.125	—
b3(b)	560	2 1/2	550-560	34.19	STEM	TEST	3.50	15	800
b3(c)	370	2 1/2	360-370	60.69	STEM	TEST	3.50	12	380
b3(d)	200	2 1/2	190-200	40.13	STEM	TEST	3.50	2	4
b3(e)	140	2 1/2	130-140	12.80	STEM	TEST	3.50	20	4
b3	500	4x2 1/2	550-560	31.00	3/27/80	56.43	1.09	15	—
b4	370	4x2 1/2	360-370	27.60	4/3/80	56.63	1.22	12	—
b5	108	2 1/2	98-108	10.92	4/14/80	—	—	30	—

FIGURE 3— DIAGRAM OF RESEARCH STATION AT BETHEL



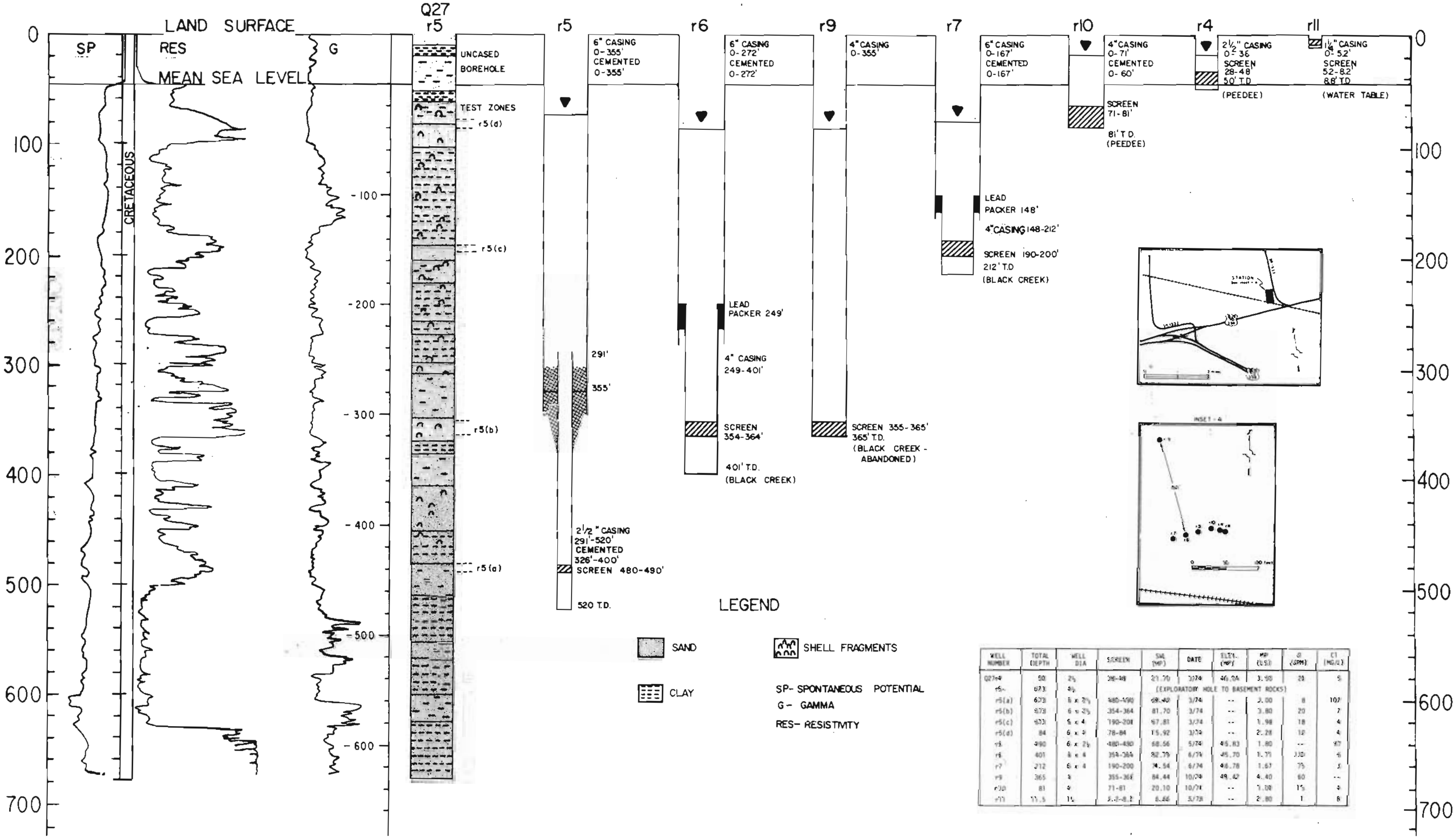
WELL NUMBER	TOTAL DEPTH	WELL DIA	SCREEN	SWL (MP)	DATE	ELEV (MP)	MP (LS)	Q (GPM)	CL (MG/L)
027 j2	55	4	45-55	23.55	12/78	79.63	1.10	30	6
j3	13	1¼	9.5-12.5	10.15	10/78	79.32	0.95	5	25
j4-	568	4½	(EXPLORATORY	HOLE	TO BASEMENT	ROCKS)			
j4(a)	568	2½	400-410	102.64	11/78	—	4.45	1	125
j4(b)	568	2½	170-180	33.80	11/78	—	3.40	20	7
j4(c)	568	4	95-105	32.86	11/78	—	4.15	5	7
j5	108.4	4	98.4-108.4	32.27	11/78	79.45	3.70	30	4
j6	326	6x4	295-305 316-326	101.40	12/78	79.71	2.88	150	61
j7	115	6	100-115	31.50	12/78	—	3.00	37	—
j8	325	2½	304-309 320-325	02.67	12/78	—	4.50	20	—

I FIGURE 4 — DIAGRAM OF RESEARCH STATION AT MAURY



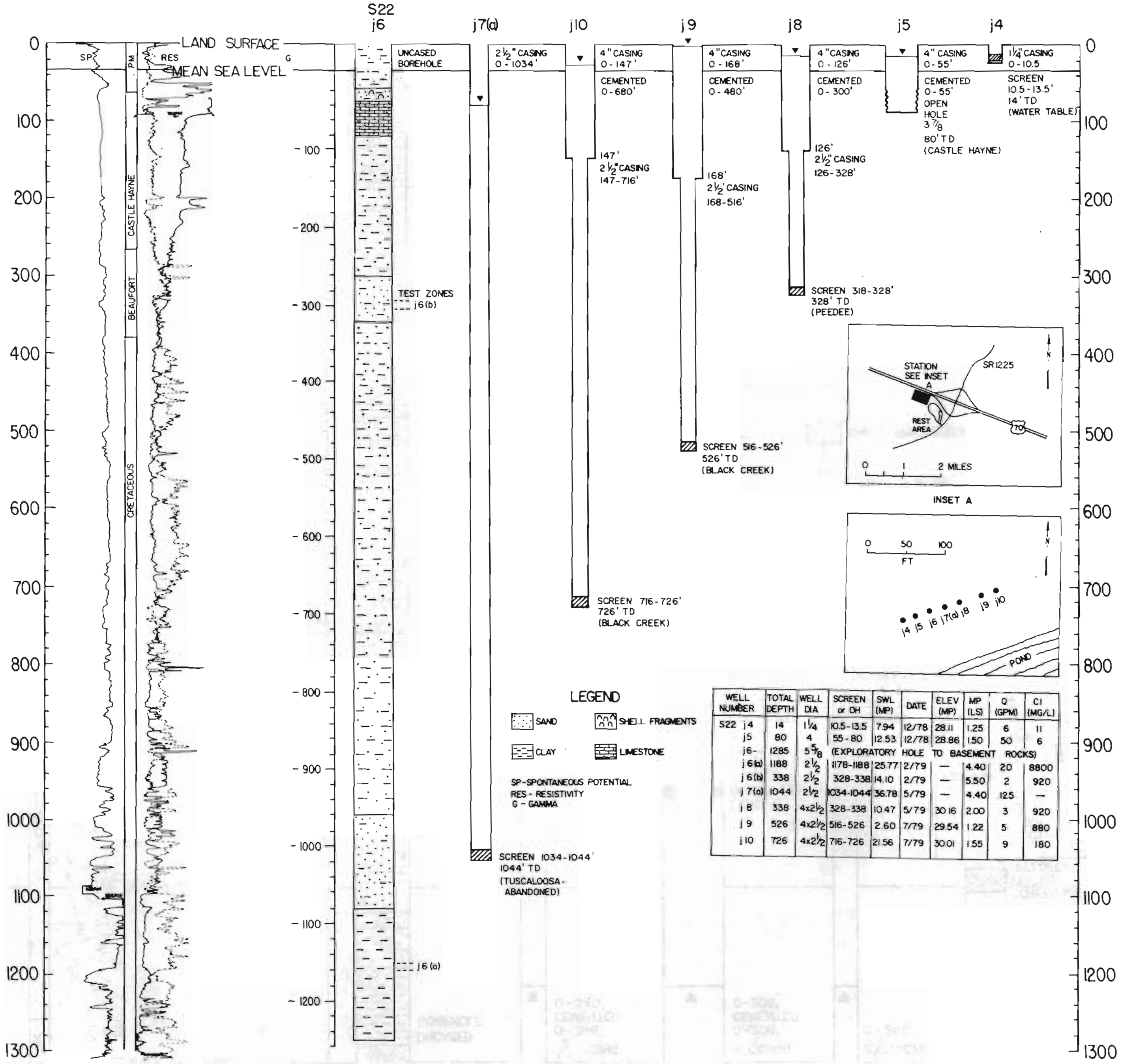
WELL NUMBER		TOTAL DEPTH	WELL DIA	SCREEN OR OH	SWL (MP)	DATE	ELEV (MP)	MP (LS)	Q (GPM)	CL (MG/L)
P21	K3	29	4	23-29	9.23	7/68	43.06	2.02	2	9
	K4	200	4	61-200	10.86	7/68	43.63	2.00	–	–
	K5-	918	4½	(EXPLORATORY HOLE TO BASEMENT ROCKS)						
	K5	918	4	855-865	13.45	10/68	42.13	0.87	30	470
	K6	200	6	70-200	10.85	9/68	42.48	1.51	87	5
	K7	320	6	290-310	18.56	10/68	42.81	2.22	24	18
	K8	315	2½	294-304	18.50	10/68	42.81	1.50	–	–
	K9	712	4	695-705	14.50	11/68	43.63	2.48	20	222

FIGURE 5—DIAGRAM OF RESEARCH STATION AT WILMAR



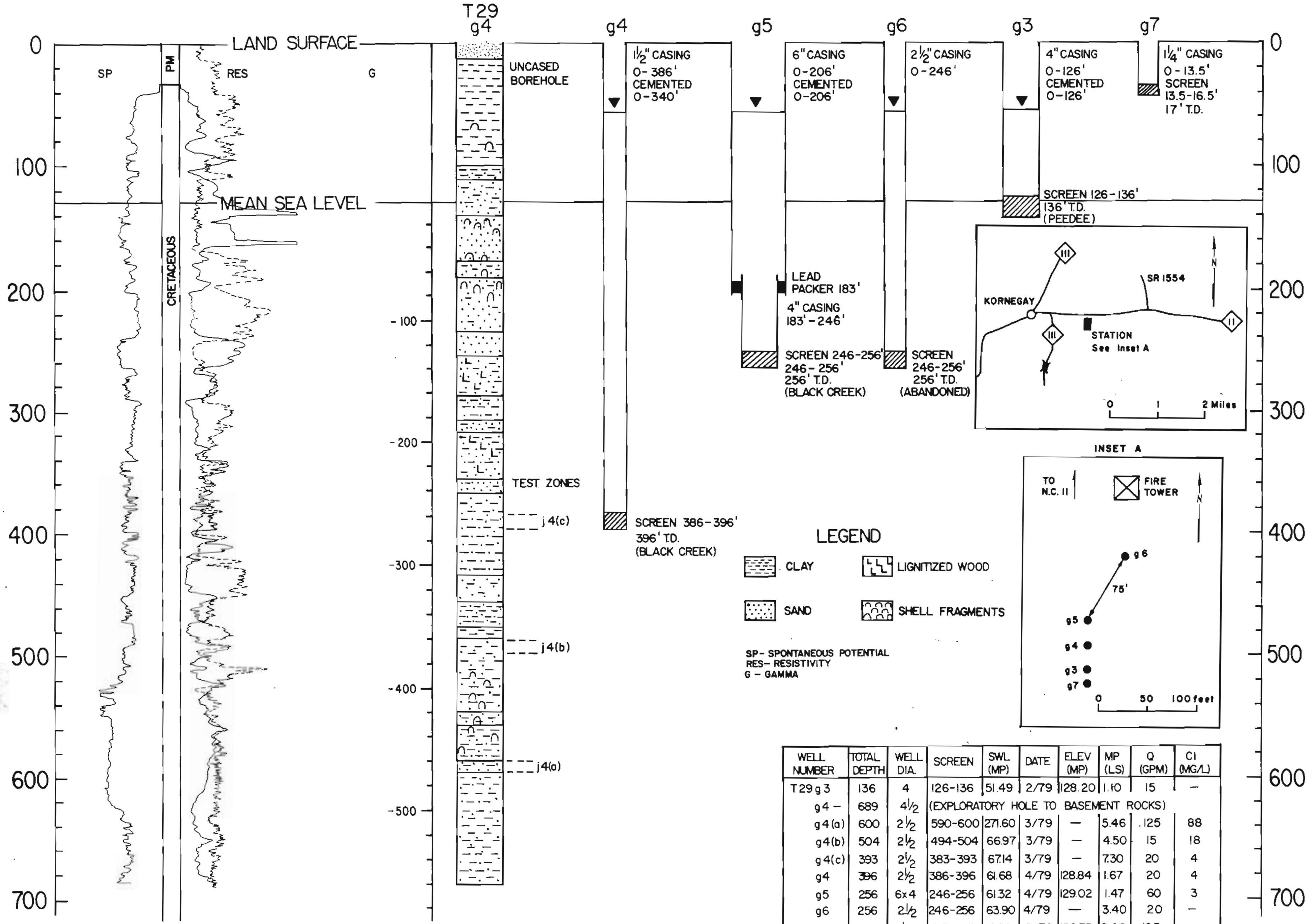
WELL NUMBER	TOTAL DEPTH	WELL DIA	SCREEN	SWL (MP)	DATE	ELEV. (MP)	MP (LS)	Q (GPM)	Cl (MG/L)
Q27r4	50	2½	28-48	21.70	3/74	46.04	3.50	20	5
r5	673	4½		(EXPLORATORY HOLE TO BASEMENT ROCKS)					
r5(a)	673	6 x 2½	480-490	69.40	3/74	--	3.00	8	107
r5(b)	673	6 x 2½	354-364	81.70	3/74	--	3.80	20	7
r5(c)	673	6 x 4	190-200	67.81	3/74	--	1.98	18	4
r5(d)	84	6 x 4	78-84	15.92	3/74	--	2.28	12	4
r5	490	6 x 2½	480-490	68.56	5/74	45.83	1.80	--	97
r6	401	6 x 4	354-364	82.79	6/74	45.70	1.71	330	6
r7	212	6 x 4	190-200	74.54	6/74	46.78	1.67	75	3
r9	365	4	355-365	84.44	10/74	49.42	4.40	60	--
r10	81	4	71-81	20.10	10/74	--	1.00	15	4
r11	11.5	1¼	5.2-8.2	6.66	5/78	--	2.80	1	8

FIGURE 6 — DIAGRAM OF RESEARCH STATION AT KINSTON



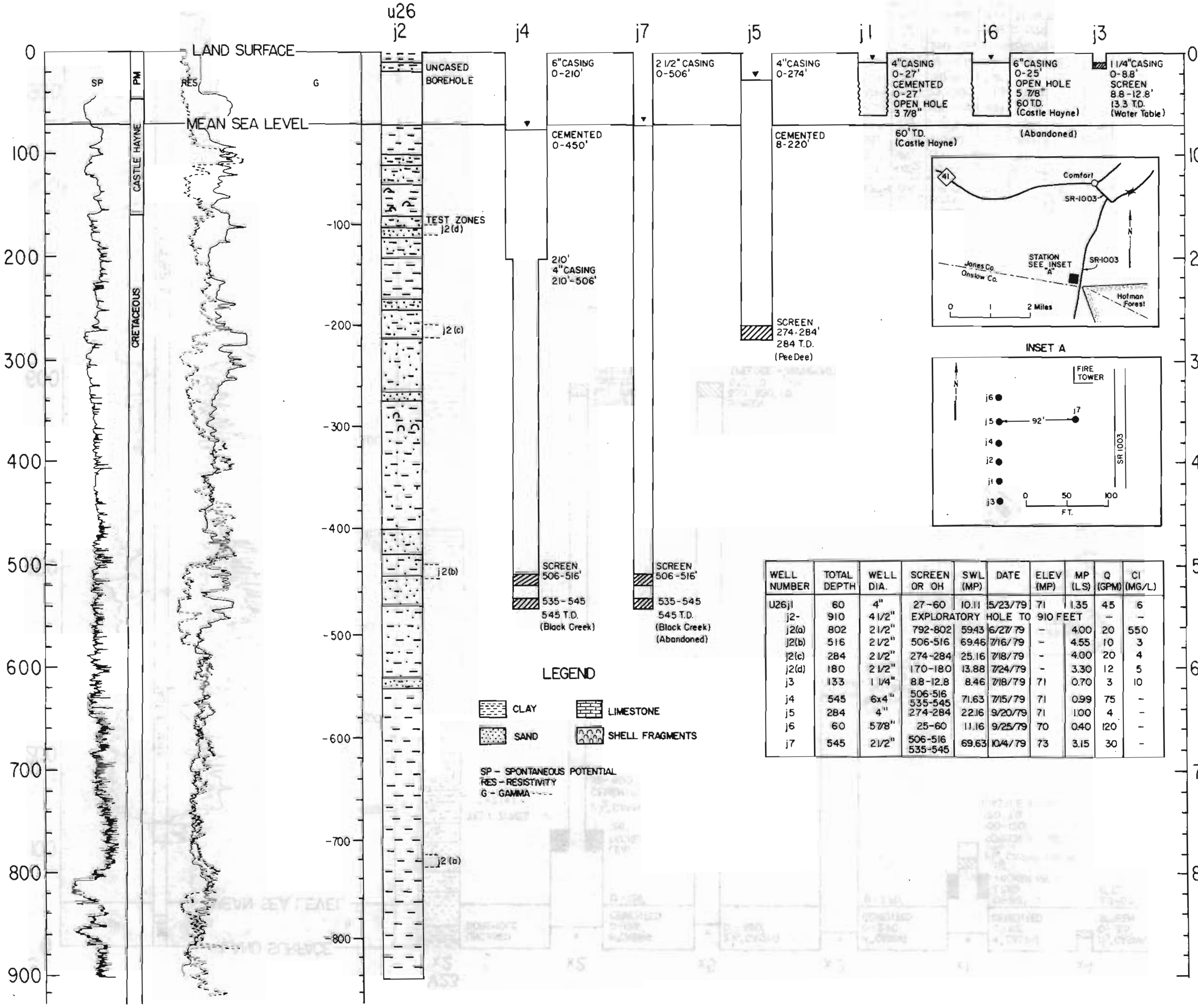
WELL NUMBER		TOTAL DEPTH	WELL DIA	SCREEN or OH	SWL (MP)	DATE	ELEV (MP)	MP (LS)	Q (GPM)	Cl (MG/L)
S22	j4	14	1¼	10.5-13.5	7.94	12/78	28.11	1.25	6	11
	j5	80	4	55 - 80	12.53	12/78	28.86	1.50	50	6
	j6-	1285	5⅝	(EXPLORATORY HOLE TO BASEMENT ROCKS)						
	j6(a)	1188	2½	1178-1188	25.77	2/79	—	4.40	20	8800
	j6(b)	338	2½	328-338	14.10	2/79	—	5.50	2	920
	j7(a)	1044	2½	1034-1044	36.78	5/79	—	4.40	125	—
	j8	338	4x2½	328-338	10.47	5/79	30.16	2.00	3	920
	j9	526	4x2½	516-526	2.60	7/79	29.54	1.22	5	880
	j10	726	4x2½	716-726	21.56	7/79	30.01	1.55	9	180

FIGURE 7— DIAGRAM OF RESEARCH STATION AT CLARKS



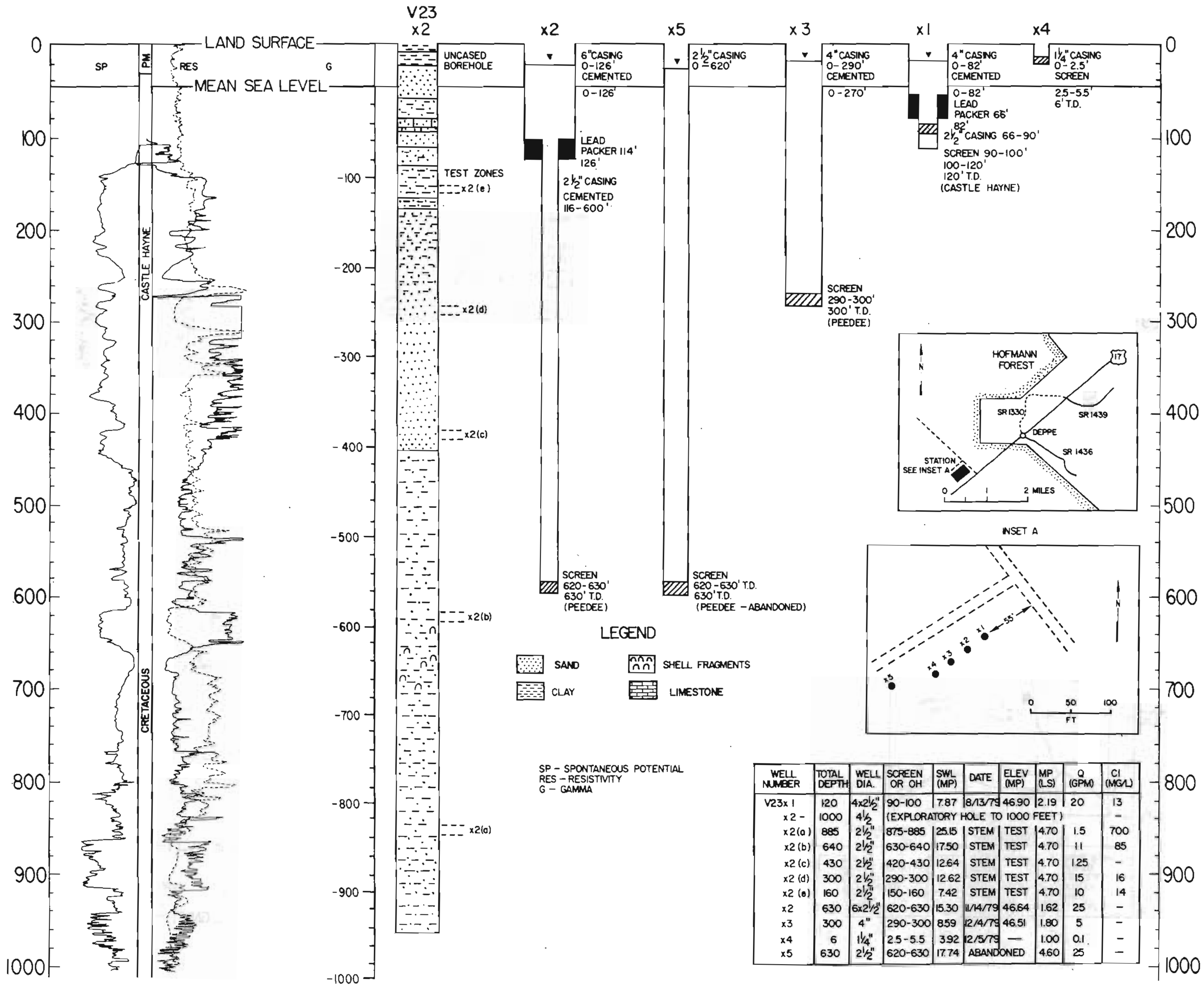
WELL NUMBER	TOTAL DEPTH	WELL DIA.	SCREEN	SWL (MP)	DATE	ELEV (MP)	MP (LS)	Q (GPM)	Cl (MG/L)
T29 g3	136	4	126-136	51.49	2/79	128.20	1.10	15	—
g4 -	689	4½	(EXPLORATORY HOLE TO BASEMENT ROCKS)						
g4(a)	600	2½	590-600	271.60	3/79	—	5.46	.125	88
g4(b)	504	2½	494-504	66.97	3/79	—	4.50	15	18
g4(c)	393	2½	383-393	67.14	3/79	—	7.30	20	4
g4	396	2½	386-396	61.68	4/79	128.84	1.67	20	4
g5	256	6x4	246-256	61.32	4/79	129.02	1.47	60	3
g6	256	2½	246-256	63.90	4/79	—	3.40	20	—
g7	17	1¼	13.5-16.5	5.29	2/79	130.35	3.00	.125	—

FIGURE 8—DIAGRAM OF RESEARCH STATION AT PINK HILL



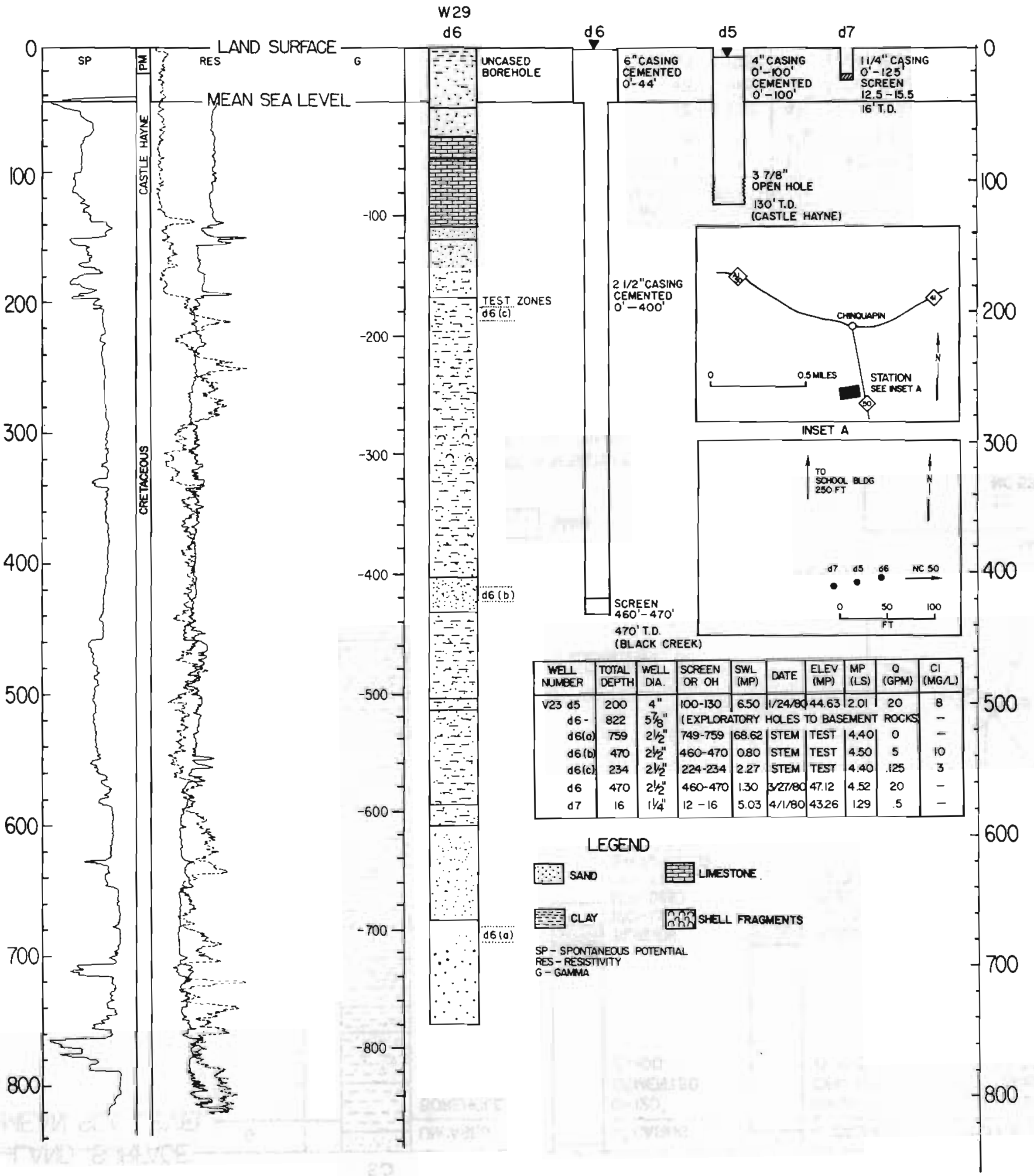
WELL NUMBER	TOTAL DEPTH	WELL DIA.	SCREEN OR OH	SWL (MP)	DATE	ELEV (MP)	MP (LS)	Q (GPM)	Cl (MG/L)
U26j1	60	4"	27-60	10.11	5/23/79	71	1.35	45	6
j2-	910	4 1/2"	EXPLORATORY HOLE TO 910 FEET					–	–
j2(a)	802	2 1/2"	792-802	59.43	6/27/79	–	4.00	20	550
j2(b)	516	2 1/2"	506-516	69.46	7/16/79	–	4.55	10	3
j2(c)	284	2 1/2"	274-284	25.16	7/18/79	-	4.00	20	4
j2(d)	180	2 1/2"	170-180	13.88	7/24/79	-	3.30	12	5
j3	133	1 1/4"	8.8-12.8	8.46	7/18/79	71	0.70	3	10
j4	545	6x4"	506-516 535-545	71.63	7/15/79	71	0.99	75	-
j5	284	4"	274-284	22.16	9/20/79	71	1.00	4	-
j6	60	5 7/8"	25-60	11.16	9/25/79	70	0.40	120	-
j7	545	2 1/2"	506-516 535-545	69.63	10/4/79	73	3.15	30	-

FIGURE 9—DIAGRAM OF RESEARCH STATION AT COMFORT



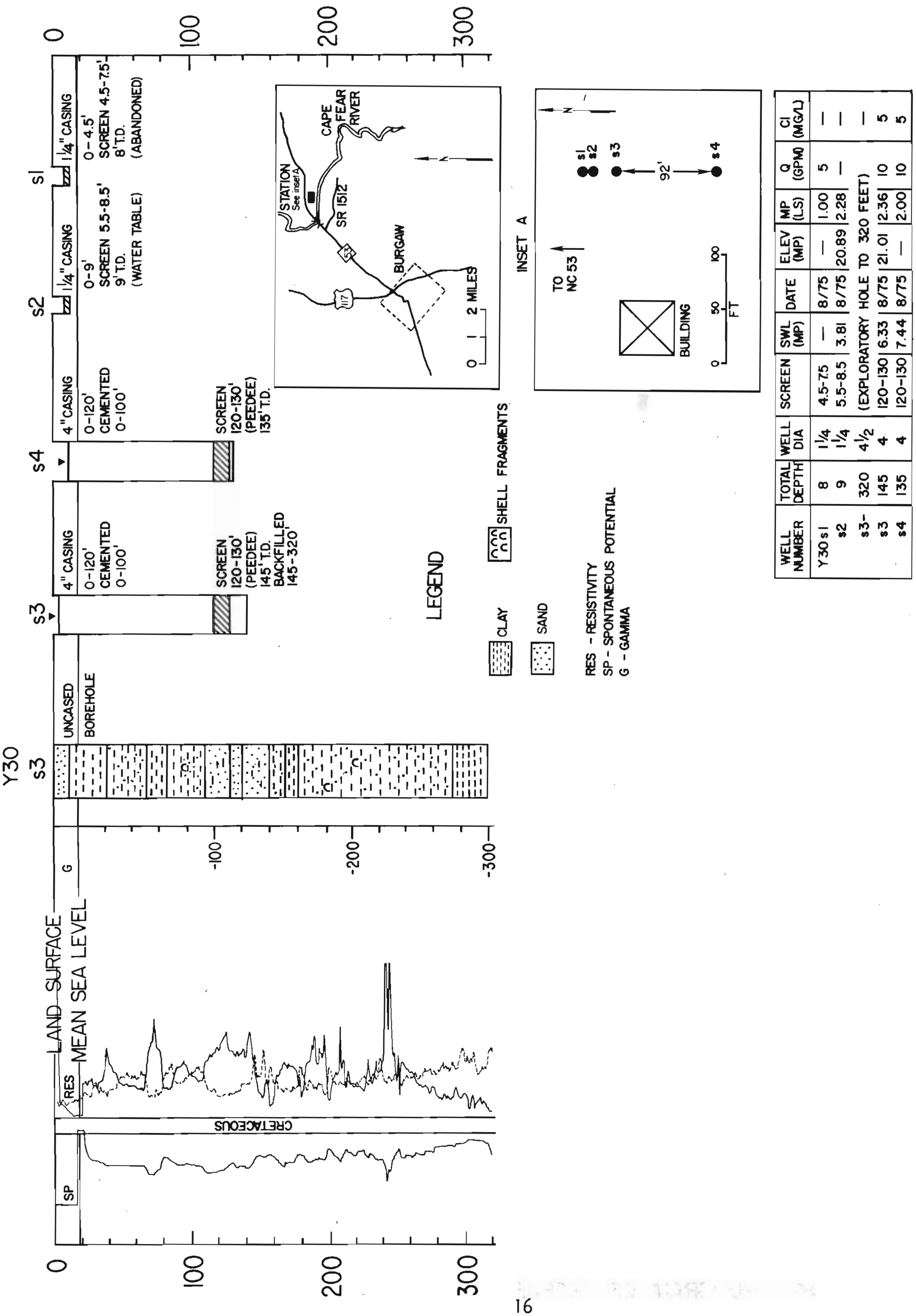
WELL NUMBER	TOTAL DEPTH	WELL DIA.	SCREEN OR OH	SWL (MP)	DATE	ELEV (MP)	MP (LS)	Q (GPM)	Cl (MG/L)
V23x 1	120	4x2½"	90-100	7.87	8/13/79	46.90	2.19	20	13
x 2 -	1000	4½	(EXPLORATORY HOLE TO 1000 FEET)						-
x 2 (a)	885	2½"	875-885	25.15	STEM	TEST	4.70	1.5	700
x2 (b)	640	2½"	630-640	17.50	STEM	TEST	4.70	11	85
x2 (c)	430	2½"	420-430	12.64	STEM	TEST	4.70	1.25	-
x2 (d)	300	2½"	290-300	12.62	STEM	TEST	4.70	15	16
x2 (e)	160	2½"	150-160	7.42	STEM	TEST	4.70	10	14
x2	630	6x2½"	620-630	15.30	11/14/79	46.64	1.62	25	-
x3	300	4"	290-300	8.59	12/4/79	46.51	1.80	5	-
x4	6	1¼"	2.5-5.5	3.92	12/5/79	—	1.00	0.1	-
x5	630	2½"	620-630	17.74	ABANDONED		4.60	25	-

FIGURE 10—DIAGRAM OF RESEARCH STATION AT DEPPE



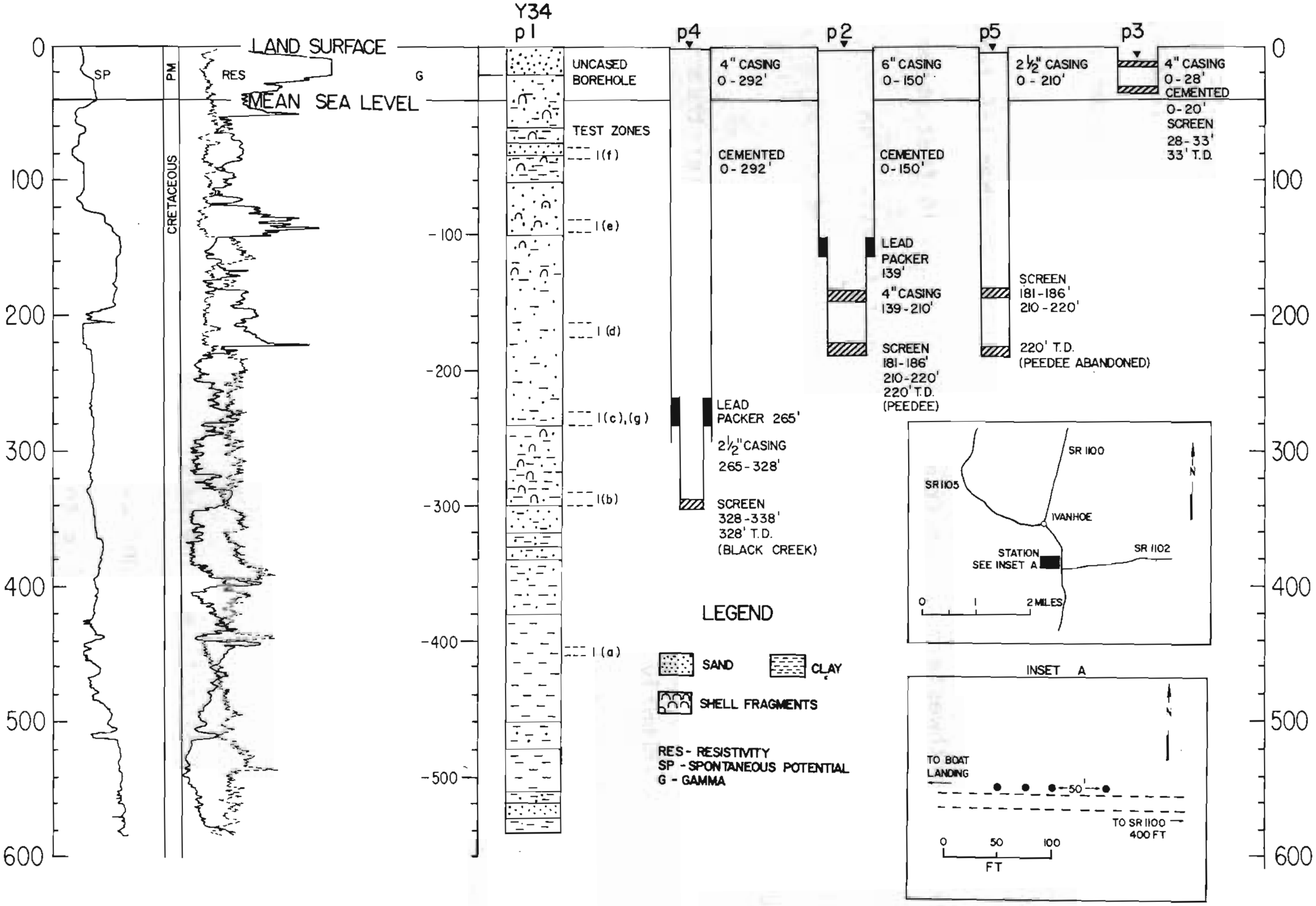
WELL NUMBER	TOTAL DEPTH	WELL DIA.	SCREEN OR OH	SWL (MP)	DATE	ELEV (MP)	MP (LS)	Q (GPM)	Cl (MG/L)
V23 d5	200	4"	100-130	6.50	1/24/80	44.63	2.01	20	8
d6 -	822	5⅞"	(EXPLORATORY HOLES TO BASEMENT ROCKS)						—
d6(a)	759	2½"	749-759	68.62	STEM	TEST	4.40	0	—
d6(b)	470	2½"	460-470	0.80	STEM	TEST	4.50	5	10
d6(c)	234	2½"	224-234	2.27	STEM	TEST	4.40	.125	3
d6	470	2½"	460-470	1.30	3/27/80	47.12	4.52	20	—
d7	16	1¼"	12 - 16	5.03	4/1/80	43.26	1.29	.5	—

FIGURE 11—DIAGRAM OF RESEARCH STATION AT CHINQUAPIN



WELL NUMBER	TOTAL DEPTH	WELL DIA	SCREEN	SWL (MP)	DATE	ELEV (MP)	MP (LS)	Q (GPM)	Cl (MG/L)
Y30 s1	8	1¼	4.5-7.5	—	8/75	—	1.00	5	—
s2	9	1¼	5.5-8.5	3.81	8/75	20.89	2.28	—	—
s3-	320	4½	(EXPLORATORY HOLE TO 320 FEET)						—
s3	145	4	120-130	6.33	8/75	21.01	2.36	10	5
s4	135	4	120-130	7.44	8/75	—	2.00	10	5

FIGURE 12 - DIAGRAM OF RESEARCH STATION AT BURGAW



WELL NUMBER	TOTAL DEPTH	WELL DIA	SCREEN	SWL (MP)	DATE	ELEV (MP)	MP (LS)	Q (GPM)	Cl (MG/L)
Y34p1-	581	4½	(EXPLORATORY HOLE TO BASEMENT ROCKS)						
p1 (a)	454	2½	444-454	16.14	12/77	—	23.60	1	690
p1 (b)	338	2½	328-338	16.75	12/77	—	24.20	30	94
p1 (c)	279	2½	269-279	14.40	1/78	—	27.21	20	70
p1 (d)	220	2½	210-220	18.37	1/78	—	24.30	18	18
p1 (e)	136	2½	126-136	1.32	1/78	—	4.29	11	14
p1 (f)	84	2½	74-84	5.45	1/78	—	4.30	10	5
p1 (g)	279	2½	269-279	19.80	1/78	—	27.39	12	64
p2	220	6x4	181-186 210-220	0.87	2/78	42.59	5.62	250	0
p3	33	4	28-33	14.09	2/78	35.72	1.68	5	—
p4	338	4x2½	328-338	0.69	2/78	41.79	7.48	150	94
p5	200	2½	181-186 210-220	2.55	3/78		9.10	30	—

FIGURE 13 - DIAGRAM OF RESEARCH STATION AT IVANHOE

GENERAL SETTING

Physiography

The central Coastal Plain is delineated by the shaded area in Figure 1. This area comprises 3,140 square miles within the Atlantic Coastal Plain Province and includes all of Duplin, Greene, Jones, Lenoir, and Pitt Counties, the western third of Craven County, and the northern half of Onslow County.

The altitude of the land surface ranges from more than 165 feet above sea level in northwestern Duplin County to less than 10 feet above sea level along the banks of the Neuse River in Craven County. The terrain is flat to gently rolling and slopes eastward toward the Atlantic Ocean at about three feet per mile.

The land surface is dissected into gently sloping interstream areas and valleys by slightly entrenched streams which are present in a combination of parallel and dendritic drainage patterns. The headwaters of the New, Northeast Cape Fear, Trent, and White Oak Rivers occur within the boundaries of the study area, and many smaller tributaries originate in the large swampy upland flats known locally as pocosins. The Tar and Neuse Rivers, which flow through Pitt, and Lenoir and Craven Counties respectively, also contribute to the total drainage of the study area.

Climate

Climate has a significant influence on the groundwater resources because temperature, precipitation, and evapotranspiration all interact to determine the amount of water available to recharge the groundwater reservoir.

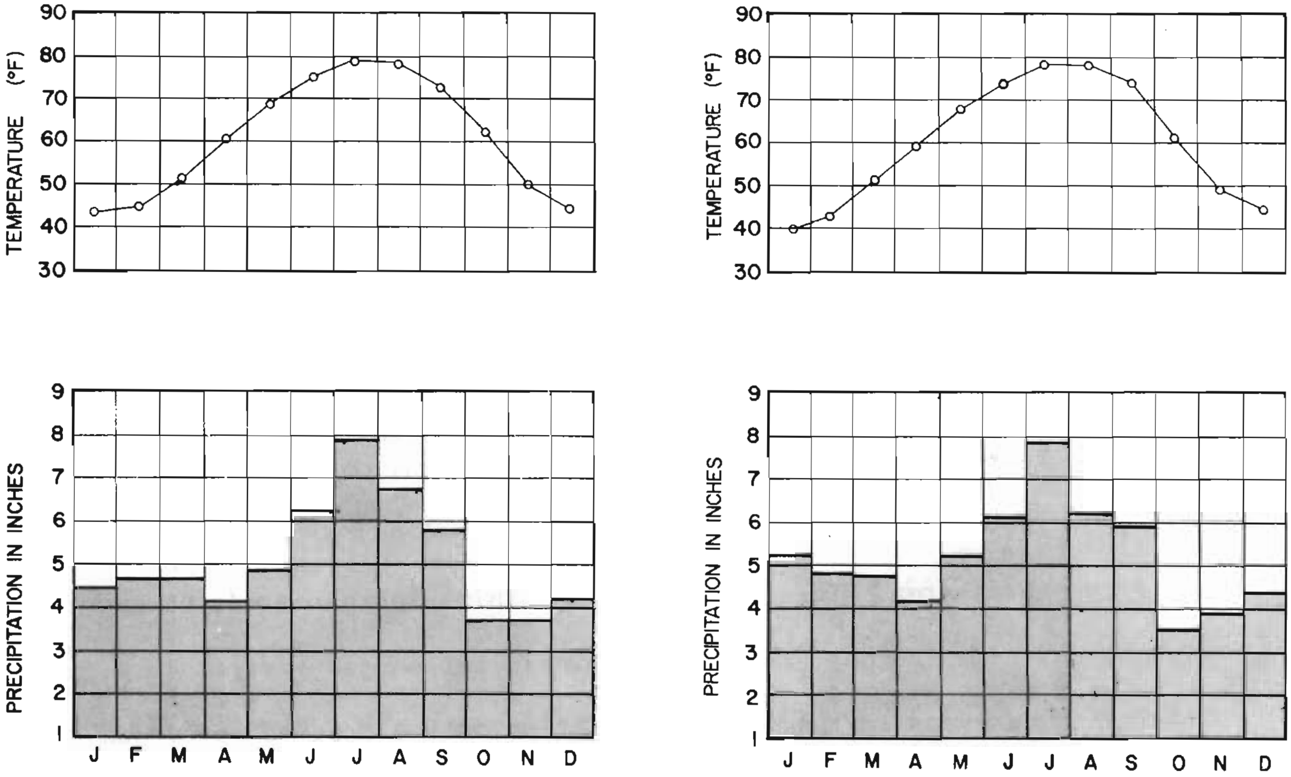
The climate of the study area is warm and humid, characterized by short, mild winters, and long, hot summers. The mean annual temperature is relatively consistent throughout the study area. It ranges from 60.0 degrees

Fahrenheit at Kenansville to 61.3 degrees Fahrenheit at Kinston and Greenville. Figure 14 shows the variations in mean monthly temperature measured at four selected observation stations.

Mean annual precipitation for the study area is 51.05 inches. This figure represents a volume of 887 million gallons per square mile per year (Mgal/mi^2)/yr. or almost 3 trillion gallons of water per year over the total area. The distribution of this precipitation, however, is not uniform. Rather, mean annual precipitation ranges from less than 48 inches per year in the northwest section of the area to more than 56 inches per year along the area's southeast boundary. Figure 15 shows this nonuniform distribution and also illustrates the fact that precipitation increases with proximity to the coast. This phenomenon is due to a persistent warm, moist air mass associated with the Atlantic Ocean.

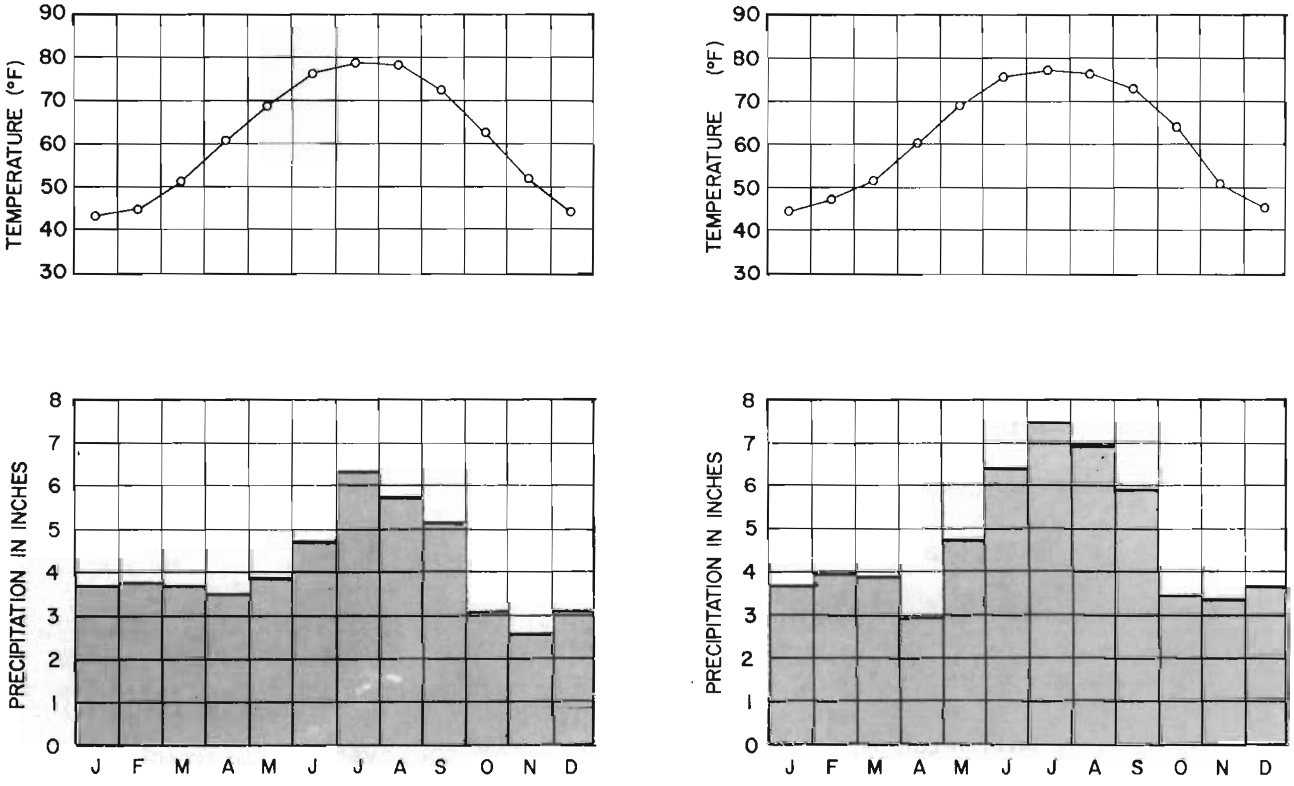
The distribution of mean monthly precipitation throughout the year at four selected observation stations is also shown in Figure 14. The distribution of precipitation is relatively uniform throughout the year except for a period from May through September. During these five months, the area receives more than 50 percent of the total annual precipitation. This increase is the result of convective air currents which form during the summer months.

Potential evapotranspiration (PET), as calculated by the Hamon Equation, ranges from 34 inches at Kenansville to 36 inches at Greenville. The concept of PET differs from actual evapotranspiration (ET) in that PET assumes an unlimited availability of water for the evapotranspiration process; nevertheless, PET values serve as reasonable approximations of ET in most instances. Figure 16 shows the variation of PET as calculated from data



MEAN MONTHLY PRECIPITATION AND TEMPERATURE AT KINSTON SSE

MEAN MONTHLY PRECIPITATION AND TEMPERATURE AT KENANSVILLE



MEAN MONTHLY PRECIPITATION AND TEMPERATURE AT GREENVILLE

MEAN MONTHLY PRECIPITATION AND TEMPERATURE AT MAYSVILLE 6SW

FIGURE 14 – MEAN MONTHLY PRECIPITATION AND TEMPERATURE AT FOUR SELECTED STATIONS.

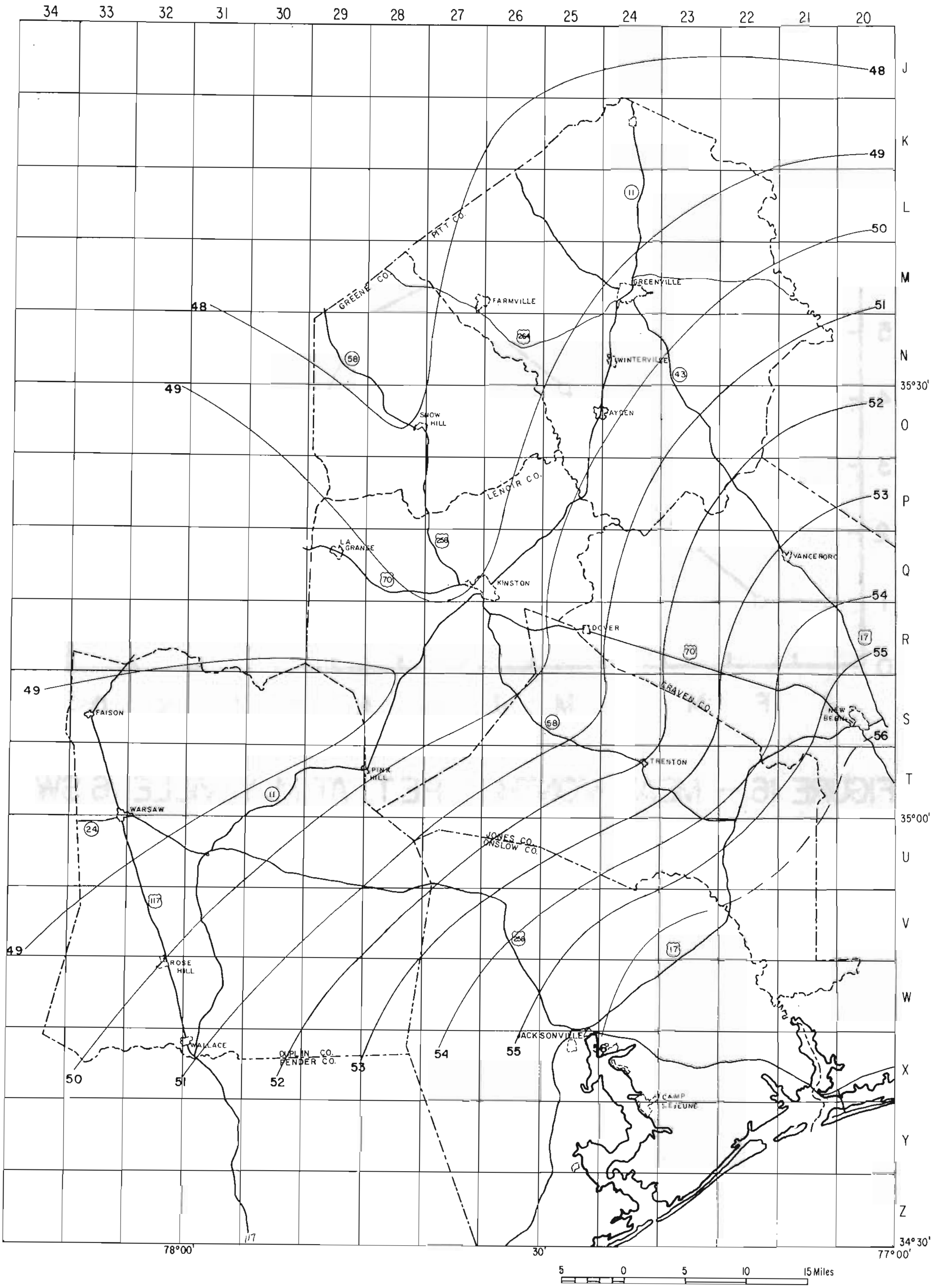


FIGURE 15 - MAP SHOWING DISTRIBUTION OF MEAN ANNUAL PRECIPITATION

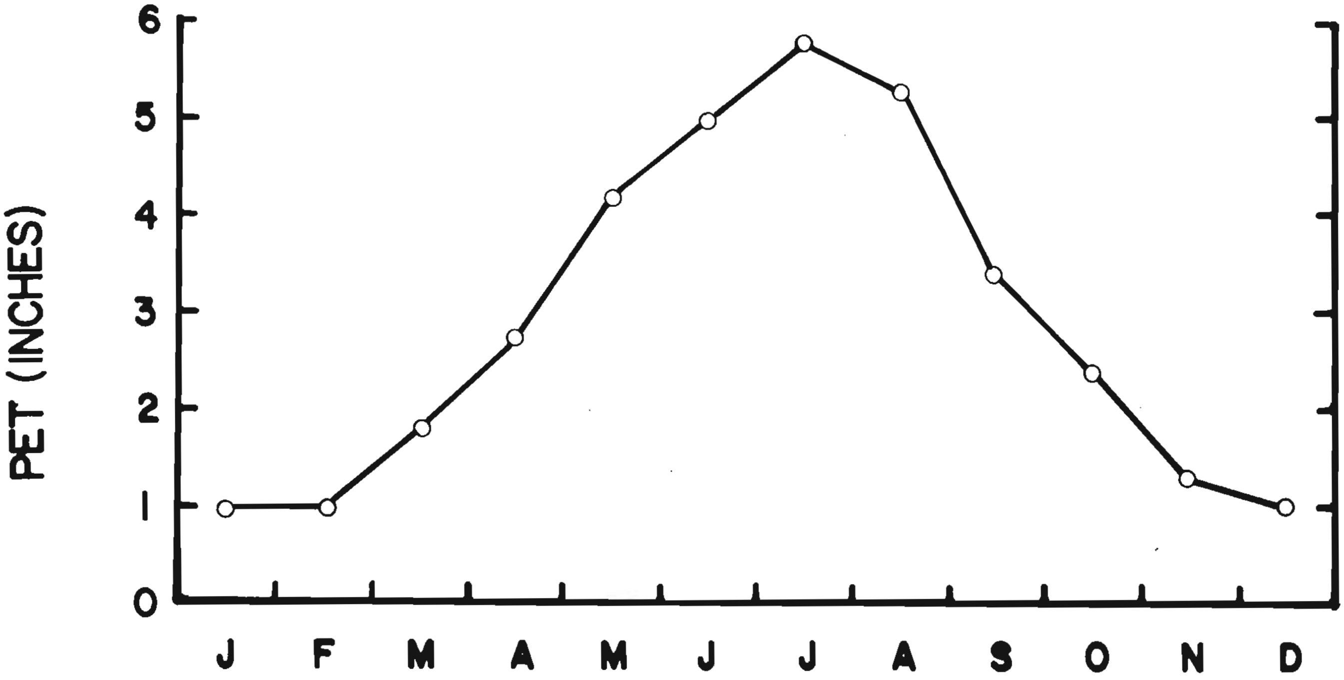


FIGURE 16 — MEAN MONTHLY PET AT MAYSVILLE 6 SW

collected at the Maysville Observation Station. This graph is representative of PET throughout the study area. Because PET is primarily a function of air temperature, the shape of the PET curve bears a close resemblance to the temperature graphs of Figure 14.

Over the period of record, PET, and therefore, presumably ET, has been more constant than precipitation. As a result, a large variation in annual precipitation is the principal factor in the occurrence of significant differences in the amount of water available for recharge.

Water Budget

The interaction of the various components operating within the hydrologic cycle may be summarized by a water budget of the study area. In the water budget, mean monthly PET and overland runoff are subtracted from mean monthly precipitation to obtain either a water surplus or water deficit value, and ultimately, a groundwater recharge estimate.

Figure 17 illustrates a water budget for a representative site in southeastern Pitt County. Examination of the bar graph reveals that a water surplus exists from January through April and groundwater recharge occurs. Later, during the warm summer and early autumn months, PET is high due to increased insolation and vegetative demands, and recharge ceases except in July and September when heavy precipitation offsets the effect of PET.

During the period of high PET, the moisture content of the soil drops below field capacity, creating a soil moisture deficit. Before recharge can occur following the summer deficit, the soil must be returned to its field capacity. Only when this condition has been met will surplus water be available as recharge.

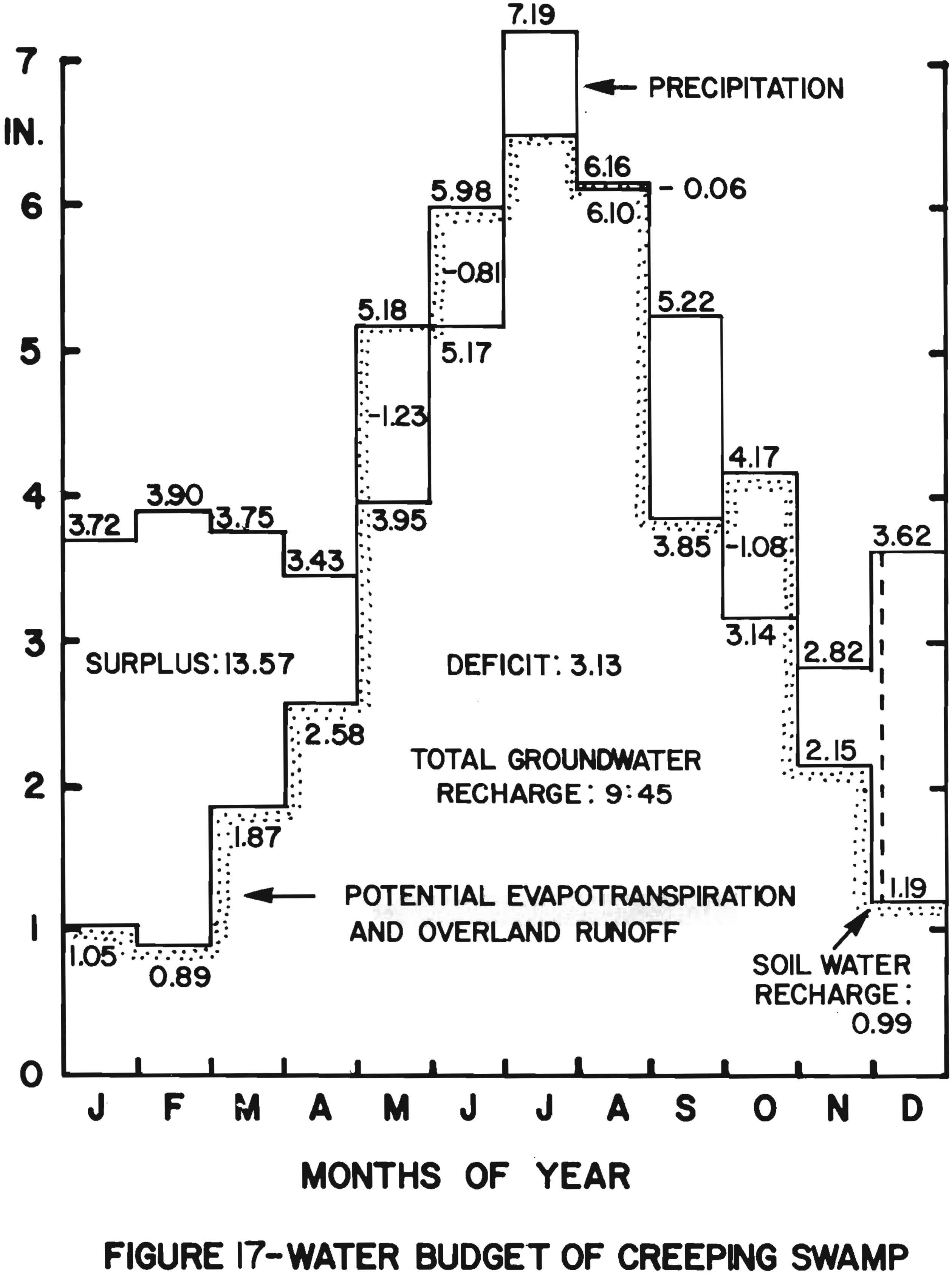


FIGURE 17-WATER BUDGET OF CREEPING SWAMP NEAR VANCEBORO

In this example, 52 inches of precipitation enter the hydrologic system annually while PET and overland runoff remove 41.5 inches during the same period. This results in an annual water surplus of 10.5 inches. The soil moisture deficit at this site was calculated to be 1 inch of water, and therefore, subtracting this value from the annual surplus leaves 9.5 inches of water available as annual groundwater recharge to the water table aquifer. This estimate of groundwater recharge represents 18 percent of the area's annual precipitation or about 165 $(\mathrm{Mgal/mi}^2)/\mathrm{yr}$.

GEOLOGY

Stratigraphic Units

The stratigraphy of the central Coastal Plain comprises a wedge-shaped sequence of stratified marine and non-marine sedimentary rocks deposited on the crystalline basement surface. The sedimentary rocks, ranging in age from Cretaceous to Recent, were deposited during successive periods of transgression and regression of the sea. The older sediments outcrop west of the study area and thicken in an eastward direction to almost 1300 feet at Clarks in Craven County.

The sediments vary in composition, consisting of gravel, sand, silt, clay, limestone and combinations of these lithologies. Most of the sediments were deposited on the underlying crystalline bedrock surface during the numberous advances and regressions of the sea, and represent various onshore, nearshore, and offshore environments. Depending upon the conditions prevailing at the time of deposition, the sediments were formed into layers or lenses varying in lithology, thickness, and texture.

The entire wedge of sediments comprising the Coastal Plain can be subdivided into separate and distinct stratigraphic units. Division of the sediments into stratigraphic units is based upon position in the sequence of sediments, lithologic composition, and faunal evidence, if any, contained in the sediments.

The stratigraphic units, which range in age from Recent to Lower Cretaceous, are also wedge-shaped. They originate as a thin veneer at their respective western boundaries and become progressively thicker and more deeply buried towards the east. The stratigraphic units exhibit an overlapping relationship to each other as older units outcrop or subcrop immediately west of the updip limit of the next younger unit. The strike of the stratigraphic units is to the northeast and the dip is to the southeast with a gradient between 10 and 30 feet per mile.

The third column in Table 1 illustrates those stratigraphic units present beneath the study area, and the sequence of their deposition.

Previously published reports by Brown (1959), LeGrand (1960), and Mundorff (1945) provide comprehensive discussions of the stratigraphic units or geologic formations underlying the study area. Therefore, a similar discussion will not be repeated here. Rather, the following sections are intended to provide only a brief description of each unit's lithology and areal extent.

Basement Complex

Although the basement complex is not a stratigraphic unit, it provides the surface upon which the sediments unconformably lie. The composition of the basement complex is similar or equivalent to the crystalline igneous or metamorphic rocks common to the Piedmont Province west of the Coastal Plain. A sample collected at a quarry at Fountain in western Pitt County was identified as calc-alkaline granite. Other samples collected during drilling operations in the area have been identified as highly metamorphosed schist and gneiss.

Figure 18 shows the elevations of the basement surface underlying the study area. Elevations range from 100 feet below sea level in northwestern Greene County to about 2100 feet below sea level in southeastern Jones County. The basement surface slopes toward the southeast at about 35 feet per mile.

Although the elevation contours suggest otherwise, the surface of the basement complex is irregular. This apparent discrepancy is due to

SYSTEM	SERIES	STRATIGRAPHIC UNIT	HYDROGEOLOGIC UNIT		HYDROGEOLOGIC PROPERTIES	DESCRIPTION AND EXTENT
QUATERNARY	RECENT	SURFICIAL		WATER TABLE	The deposits serve as an unconfined aquifer. The water table is shallow, ranging from land surface to within 20 feet of land surface even during dry periods. Water from this unit is soft and low in total dissolved solids. It is commonly corrosive and contains objectionable amounts of iron.	Surficial deposits consisting chiefly of sand, clay and gravel. Shell material is also present in the eastern part of the region. The relatively thin deposits overlie the entire area and range in thickness from a few feet to approximately 35 feet.
	PLEISTOCENE					
TERTIARY	MIOCENE	YORKTOWN		YORKTOWN	In the west, the Yorktown serves as a confining bed for those units below the water table aquifer. Small amounts of water are available from lenticular sand beds within the unit. In the east, the unit acts as a permeable semi-confined aquifer capable of yielding moderate amounts of good quality water.	In the western part of the study area, the Yorktown unit consists of a dark blue, massive clay matrix containing abundant shells. In the eastern part, the unit consists of loose shells and limestone in a sand matrix. Some amounts of yellow to gray clay are also present. The unit occurs as scattered remnants in the west, and as a continuous unit east of Greenville, New Bern, Pollocksville and Jacksonville. The thickness of the unit ranges from 0 to 15 feet in the west to about 60 feet in the eastern part.
	OLIGOCENE	UNNAMED	CASTLE HAYNE AQUIFER SYSTEM	CASTLE HAYNE	The Castle Hayne Unit is a highly permeable semi-confined aquifer capable of yielding large amounts of water. It is an important aquifer in the eastern part of the area, but remains relatively undeveloped in the western part where better quality water is available at slightly greater depth. The unit yields a hard, calcium bicarbonate - type water.	The Castle Hayne Unit varies in lithology and consolidation from shell limestone to sand with shell fragments. It occurs as a continuous unit throughout Craven, Jones and Onslow counties, and also in southeastern Duplin and eastern Pitt Counties. The unit thickens to the south and east from its western limit to more than 400 feet in the eastern part of the shady area.
	EOCENE	CASTLE HAYNE				
	PALEOCENE	BEAUFORT				
CRETACEOUS	UPPER CRETACEOUS	PEEDEE	CRETACEOUS AQUIFER SYSTEM	CRETACEOUS UPPER SAND	This unit is a semi-confined aquifer whose water-bearing sands yield moderate amounts of water to municipal, industrial or agricultural wells. The water is a soft, sodium bicarbonate-type except in those areas where indurated calcareous beds cause it to be moderately hard. Heavy withdrawals from the Cretaceous Lower Sand Unit are reflected in leakage from the Upper Sand Unit.	The Cretaceous Upper Sand Unit consists of dark green or gray glauconitic or clayey sands interbedded with massive dark gray clay beds. Indurated shell beds are present throughout. The unit outcrops or is near the surface in Duplin, Greene, Lenoir and Pitt counties. It thickens to the east from its origin to between 60 and 80 feet. The unit is overlain unconformably by the Surficial, Yorktown or Castle Hayne Units and separated from them by a massive clay layer 20 to 30 feet thick.
		BLACK CREEK		CRETACEOUS LOWER SAND	The Cretaceous Lower Sand Unit is the principal aquifer in the area. It is a semi-confined aquifer capable of supplying large amounts of excellent quality water. The water is a soft sodium bicarbonate-type except in those areas where indurated calcareous beds cause it to be moderately hard. Heavy withdrawals have resulted in declining water levels and expanding cones of depression.	The Cretaceous Lower Sand Unit consists of glauconitic sand and dark gray massive clays. Lenticular gravel deposits are also present. The unit outcrops in the extreme western parts of Lenoir, Greene and Pitt Counties. It dips and thickens to the east ranging from 140 feet in the west to more than 700 feet in the east. It is separated from the Cretacious Upper Sand Unit by a massive clay confining bed.
		TUSCALOOSA				

TABLE - Summary of Hydrogeologic Units underlying the Central Coastal Plain Area.

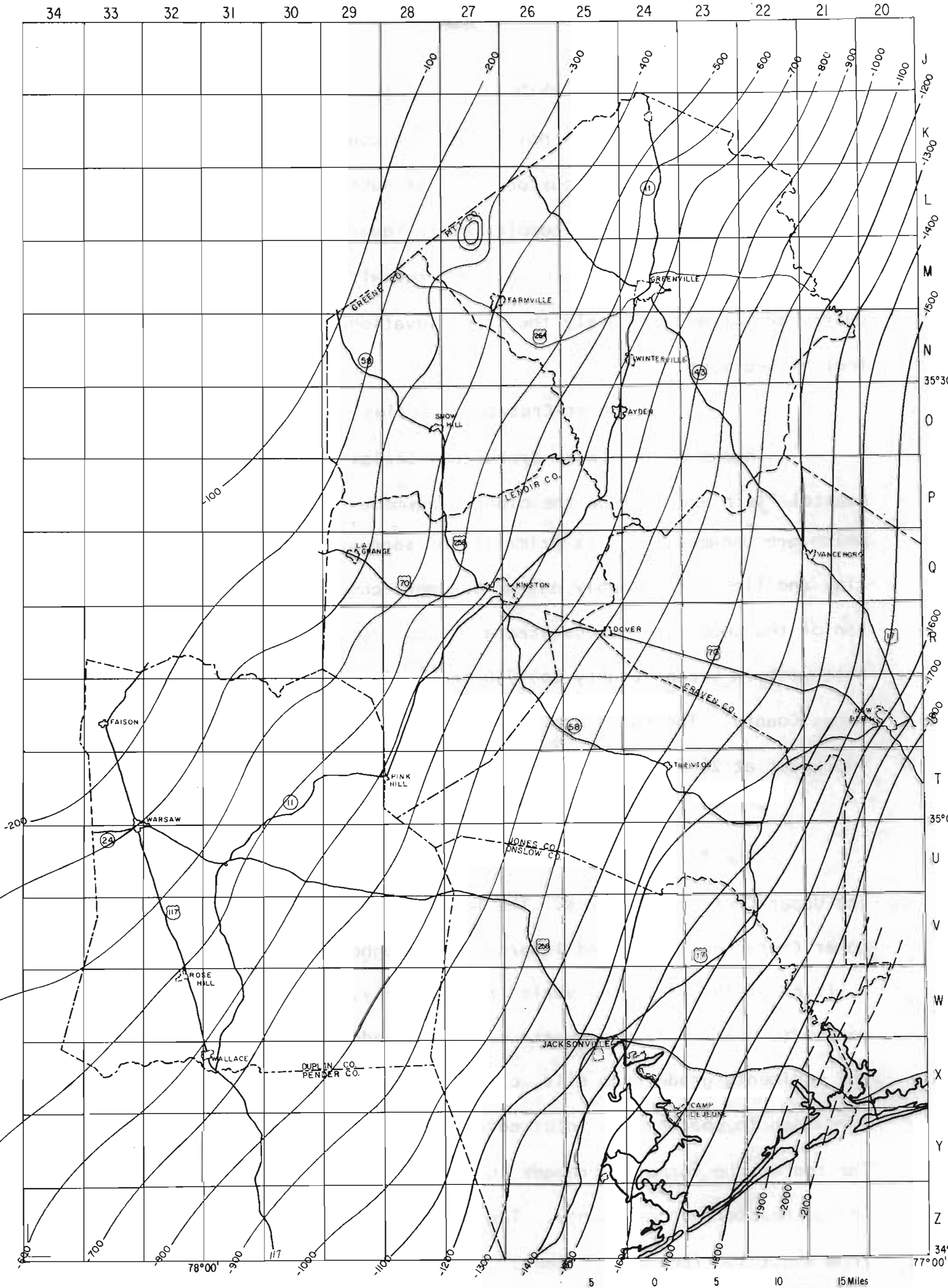


FIGURE 18 — ELEVATION OF THE TOP OF THE BASEMENT COMPLEX

the wide spacing of control points used in constructing the basement map. The case for an irregular surface is best substantiated in considering the fact that the basement complex at the quarry near Fountain is exposed at land surface, while a town well located within one-half mile of the quarry and at approximately the same elevation was drilled through 200 feet of sediment.

Lower Cretaceous Series

Rocks of the Lower Cretaceous Series underlie the entire central Coastal Plain and include the oldest sediments in the study area. The strata, which are unnamed, consist primarily of sand and silt interbedded with silty clay and lie unconformably on the basement complex. The elevation of the top of the Lower Cretaceous strata ranges from 100 feet below sea level in northwestern Greene County to 1750 feet below sea level in southeastern Jones County. The rocks are between 200 and 400 feet thick and dip to the southeast at 26 feet per mile.

Upper Cretaceous Series

The Tuscaloosa formation is the lowermost stratigraphic unit in the Upper Cretaceous Series. The formation unconformably overlies the Lower Cretaceous rocks and is present throughout the study area. The composition of the formation varies considerably. It generally consists of medium-to coarse-grained quartz sand interbedded with sandy or silty clay. The sediments grade from silt, clay, and fine sand in the lower part of the formation to coarse sand interbedded with silt and clay in the upper portion. The top of the formation ranges in elevation from slightly above sea level in southeastern Jones County. The formation thickens in a southeast direction from about 100 feet to 250 feet. The strata dip to the southeast at 25 feet per mile.

Black Creek Formation

The Black Creek formation underlies the entire study area except northwestern Pitt and Greene Counties. It unconformably overlies the Tuscaloosa formation and outcrops, or is near land surface, in central Greene County and northwestern Lenoir and Duplin Counties. The formation, which includes the upper Snow Hill member and an unnamed lower member, varies in composition, but generally consists of gray lenticular sand interbedded with dark gray to black micaceous clays. The unnamed member commonly contains lignitized wood fragments and some glauconite, and the Snow Hill member contains thin shell beds and glauconite. The Black Creek formation ranges in elevation from 50 feet above sea level in central Greene County to 1000 feet below sea level in southeastern Jones County. The unit thickens from a feather-edge along its updip limit to about 500 feet near the study area's eastern boundary in Jones County. The top of the unit slopes to the southeast at 22 feet per mile.

Peedee Formation

The Peedee formation underlies the southeastern two-thirds of the study area. It is absent in northwestern Pitt, Lenoir, and Duplin Counties, and in all but a small section of Greene County. The unit conformably overlies the Black Creek formation, and outcrops in a 10 to 25 mile-wide belt extending from southeastern Pitt County to central and southern Duplin County. The unit is comprised of lenticular beds of dark green or gray, medium-to coarse-grained quartz sand with thin layers of clay, dark gray silt, and indurated shell. The elevation of the Peedee surface ranges from 50 feet above sea level in northeastern Lenoir County to about 700 feet below sea level in southeastern Jones County. The unit thickens to the southeast from a feather-edge along its updip limit to about 300 feet in southeastern Jones County. The surface of the Peedee dips toward the southeast at 15 feet per mile.

Beaufort Formation

The Beaufort formation unconformably overlies the Peedee and occurs in the eastern third of the study area. There is no significant outcrop of the Beaufort in the central Coastal Plain. The unit consists primarily of fine glauconitic sand interbedded with thin layers of clay, silt, and marl. The elevation of the Beaufort surface ranges from slightly below sea level in western Craven County to about 650 feet below sea level in southeastern Jones County. The unit thickens to the east from a feather-edge along its updip limit to about 80 feet in southeastern Jones County. The top of the unit slopes generally to the east at about 15 feet per mile.

Castle Hayne Limestone

The Castle Hayne Limestone occurs in the southeastern two-fifths of the study area. It unconformably overlies the Beaufort formation, or where the Beaufort is absent, the Peedee formation. The formation outcrops in a belt 10 to 20 miles wide, extending through northwestern Craven, central Jones, and northwestern Onslow Counties. The composition of the Castle Hayne varies in lithology and consolidation. It consists of shell limestone, marl calcareous sand, and clay. The top of the unit ranges in elevation from 50 feet above sea level in central Jones County to 350 feet below sea level in the southeastern section. The Castle Hayne thickens to the southeast from a feather-edge along the unit's updip limit to more than 300 feet near the study area's southeastern boundary. The regional slope of the unit is towards the southeast at about 15 feet per mile.

Oligocene Series

Deposits of Oligocene Age comprise an unnamed stratigraphic unit in Onslow County and the southern two-thirds of Jones County. This unit unconformably overlies the Castle Hayne Limestone and is at or near the surface east of the Castle Hayne outcrop area. The unit, which is composed of shell limestone and calcareous sand, ranges in elevation from 40 feet above sea level in central Jones County to 60 feet below sea level in the southeastern part of the county. The unit thickens to the east from a feather-edge along its updip limit to more than 300 feet in southeastern Jones County. Its surface dips to the east at 12 feet per mile.

Miocene Series

The Yorktown formation occurs as a continuous unit east of Greenville, New Bern, Pollocksville, and Jacksonville, where it unconformably overlies the earlier stratigraphic units. It occurs only as scattered remnants throughout the remainder of the study area. The lithology of the Yorktown unit varies widely. Its updip section consists of a dark blue, massive clay matrix containing abundant shells. The eastern section is composed of loose shells and limestone in a sand matrix, with lesser amounts of yellow to gray clay. Elevations range from 70 feet above sea level in Greene County to 20 feet below sea level in southeastern Jones County. The unit thickens towards the east ranging from 0 to 15 feet in the updip section to about 60 feet in the eastern part. The surface of the unit dips to the east with a slope only slightly greater than that of the land surface.

Post Miocene Deposits

Undifferentiated deposits, ranging from Pleistocene to Recent, overlie most of the study area. These deposits include the youngest sediments in the central Coastal Plain and consist of sand, silt, clay, and gravel. The relatively thin deposits are generally thickest in the interstream areas in the southeastern part of the study area. The thickness of the Post Miocene Deposits typically range from a few feet to approximately 35 feet.

HYDROGEOLOGY

Hydrogeologic Units

Although the sediments below the water table are saturated with water, forming, in essence, one continuous groundwater reservoir, differences in their lithology and hydraulic properties suggest that sections of the sediments should be treated as separate entities. Since the stratigraphic units were differentiated on the basis of superposition, those units are not necessarily adequate in describing the groundwater regime. Therefore, units differentiated on the basis of other criteria are needed.

Sediments may be subdivided into separate hydrogeologic units on the basis of hydraulic conductivity and other hydrologic characteristics. Therefore, in most cases, the aquifers are separated from each other by semi-pervious clay layers. The subdivision of sediments into hydrogeologic units to differentiate between significant changes in hydraulic properties is necessarily oversimplified. The categorization of the sediments into several units does not suggest that the individual units are distinctly homogeneous. In reality, each unit is stratified and consists of complexly layered beds varying in lithology, texture, thickness and extent.

Table 1 shows the hydrogeologic units in the central Coastal Plain matched with their companion stratigraphic units. The hydrogeologic units generally coincide with the stratigraphic units, overlapping them in only two cases. Cross-sections of the hydrogeologic system underlying the study area are shown in Figures 19 through 23.

This report is primarily concerned with the hydrogeologic units of the Cretaceous aquifer system; however, the overlying hydrogeologic units will also be addressed due to the influence they have on the ground-

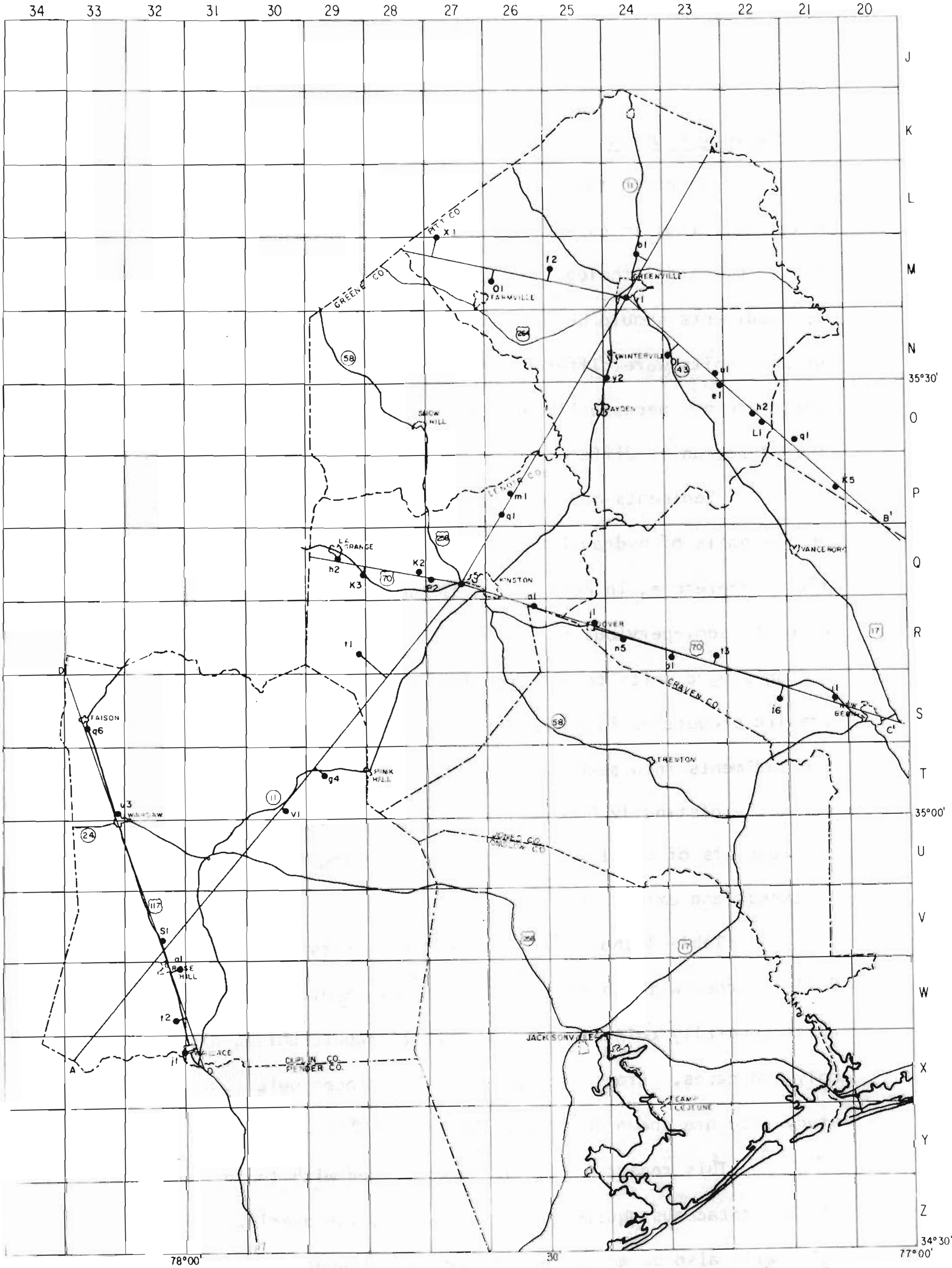


Figure 19 MAP SHOWING LOCATION OF CROSS-SECTIONS AND POINTS OF CONTROL

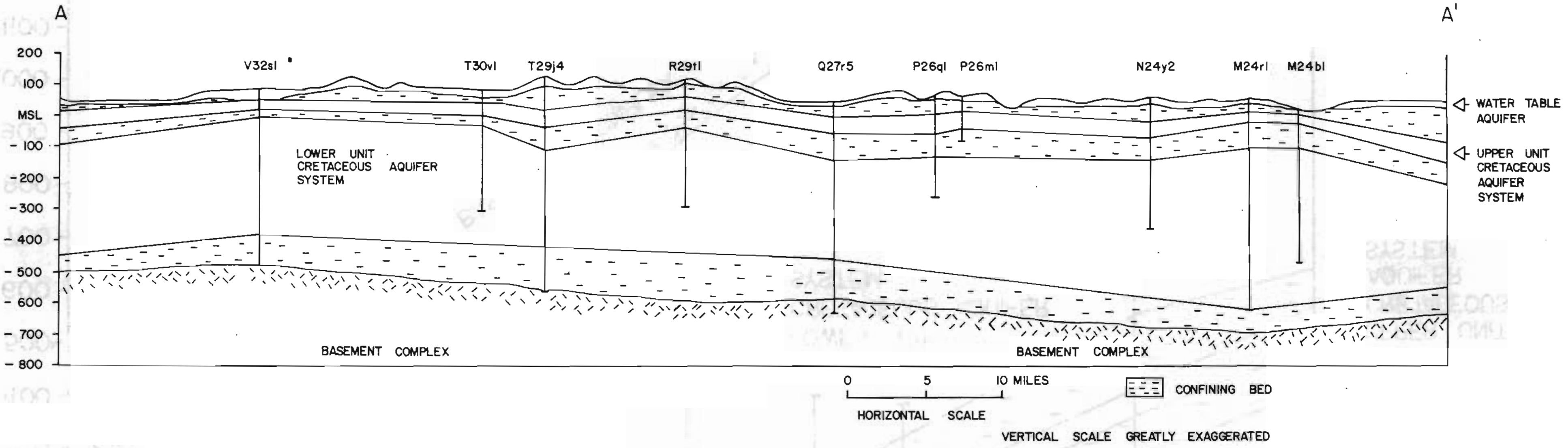


FIGURE 20 — HYDROGEOLOGIC CROSS-SECTION A-A'

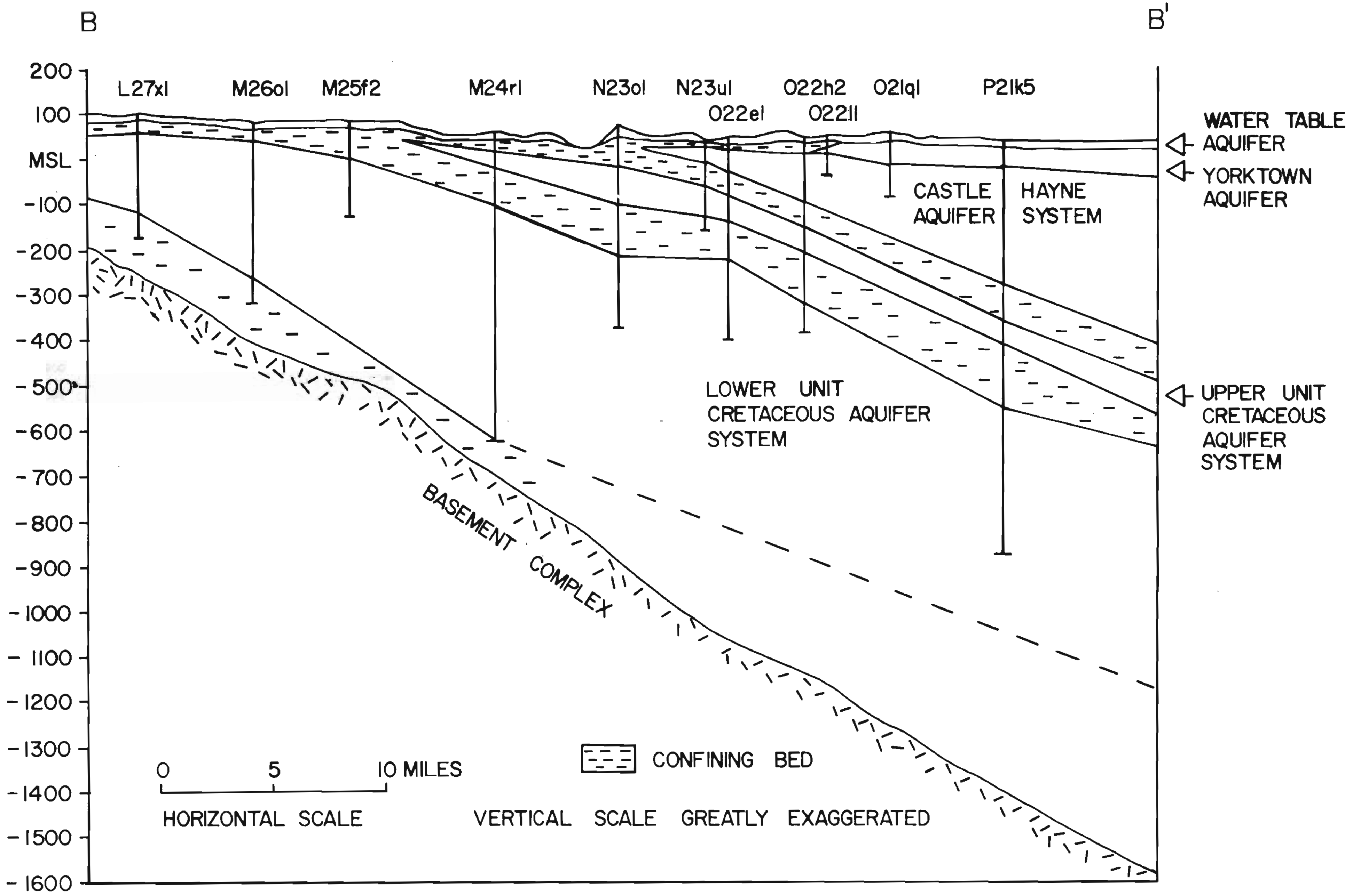


FIGURE 21 — HYDROGEOLOGIC CROSS-SECTION B-B'

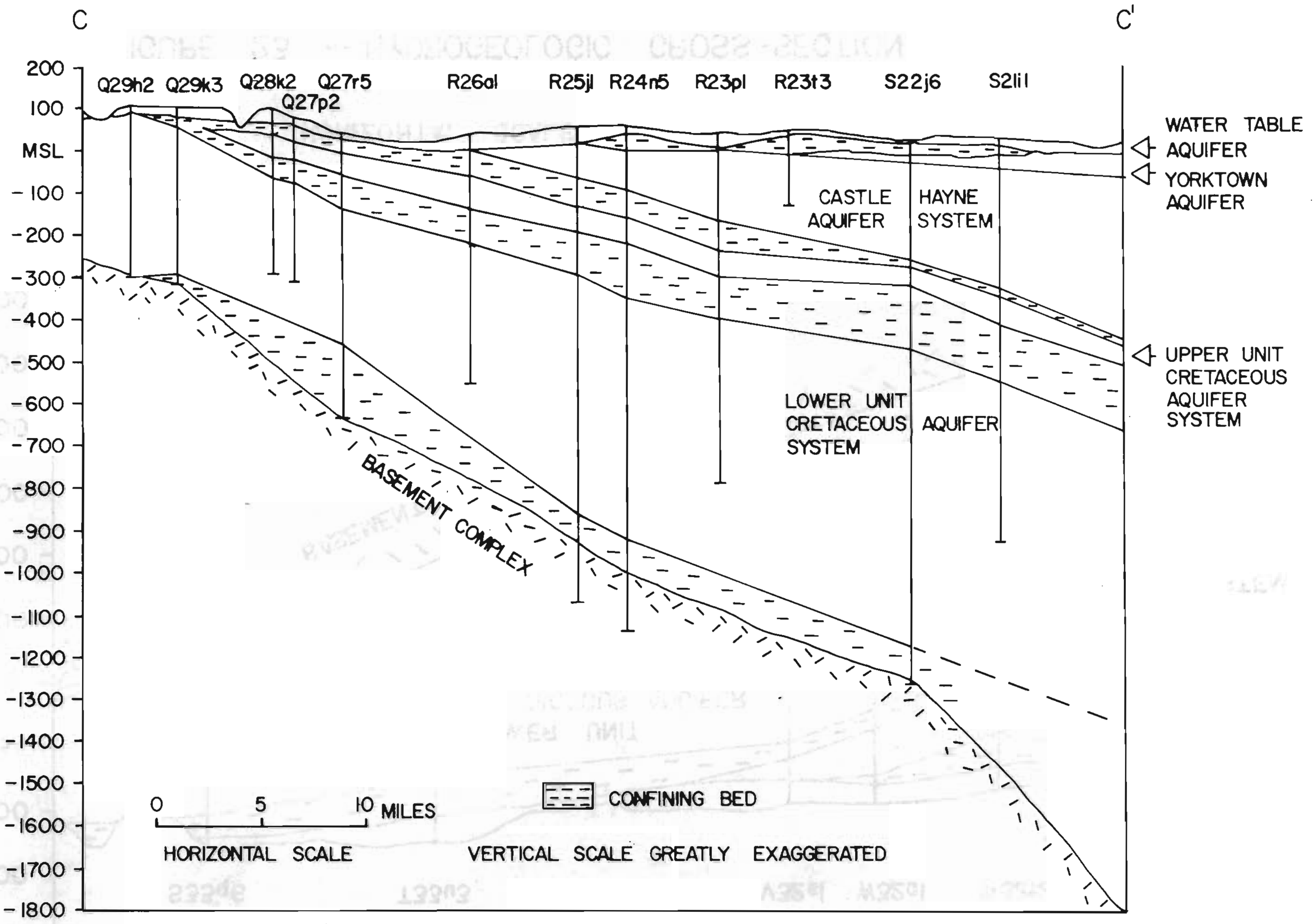


FIGURE 22 —HYROGEOLOGIC CROSS-SECTION C-C'

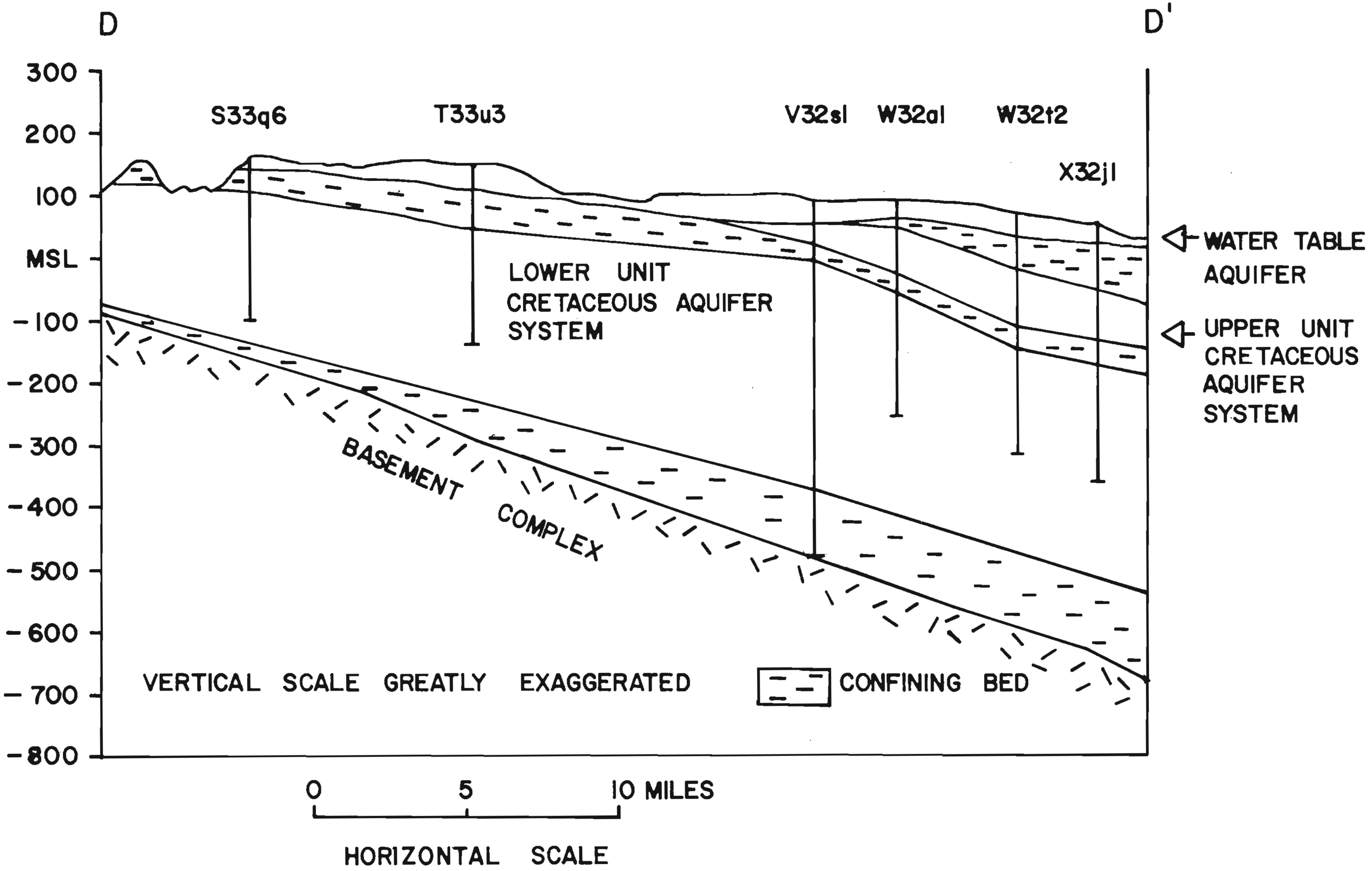


FIGURE 23 — HYDROGEOLOGIC CROSS-SECTION D-D'

water regime of the Cretaceous system. The following sections describe the principle hydrogeologic units in order of increasing depth.

Water Table Hydrogeologic Unit

The Water Table hydrogeologic unit is continuous over the entire study area. At many locations, it is comprised of the saturated section of the Post Miocene Deposits which overlie the first significant clay layer. In the remaining areas, where the Post Miocene Deposits are absent, the Water Table Unit occurs above the first significant clay layer in outcrops of the older formations. The top of the unit is defined by the water table. The thickness of the unit ranges from less than 10 feet to more than 60 feet, with an average thickness of about 25 feet.

All groundwater within the Water Table Unit is unconfined. Due to the unconfined nature of the unit, the water table is free to fluctuate with changes in groundwater storage. Figure 24 shows the hydrographs of three wells which monitor water levels in the Water Table Unit. Water levels in this unit range from within a few feet of the land surface to more than 20 feet below land surface. The fluctuation of the water table is a function of the various climatological factors discussed earlier. This fact is reflected in the hydrographs by a shallow water table during the months when ET is low and recharge is occurring, and by a deeper water table during the summer and early fall when ET rates are high.

Recharge to the Water Table hydrogeologic unit occurs on the interfluves throughout the study area. Analysis by the water budget method (Figure 17) indicates that the maximum potential recharge to the unit is about 9.5 inches annually, or about 18 percent of annual precipitation.

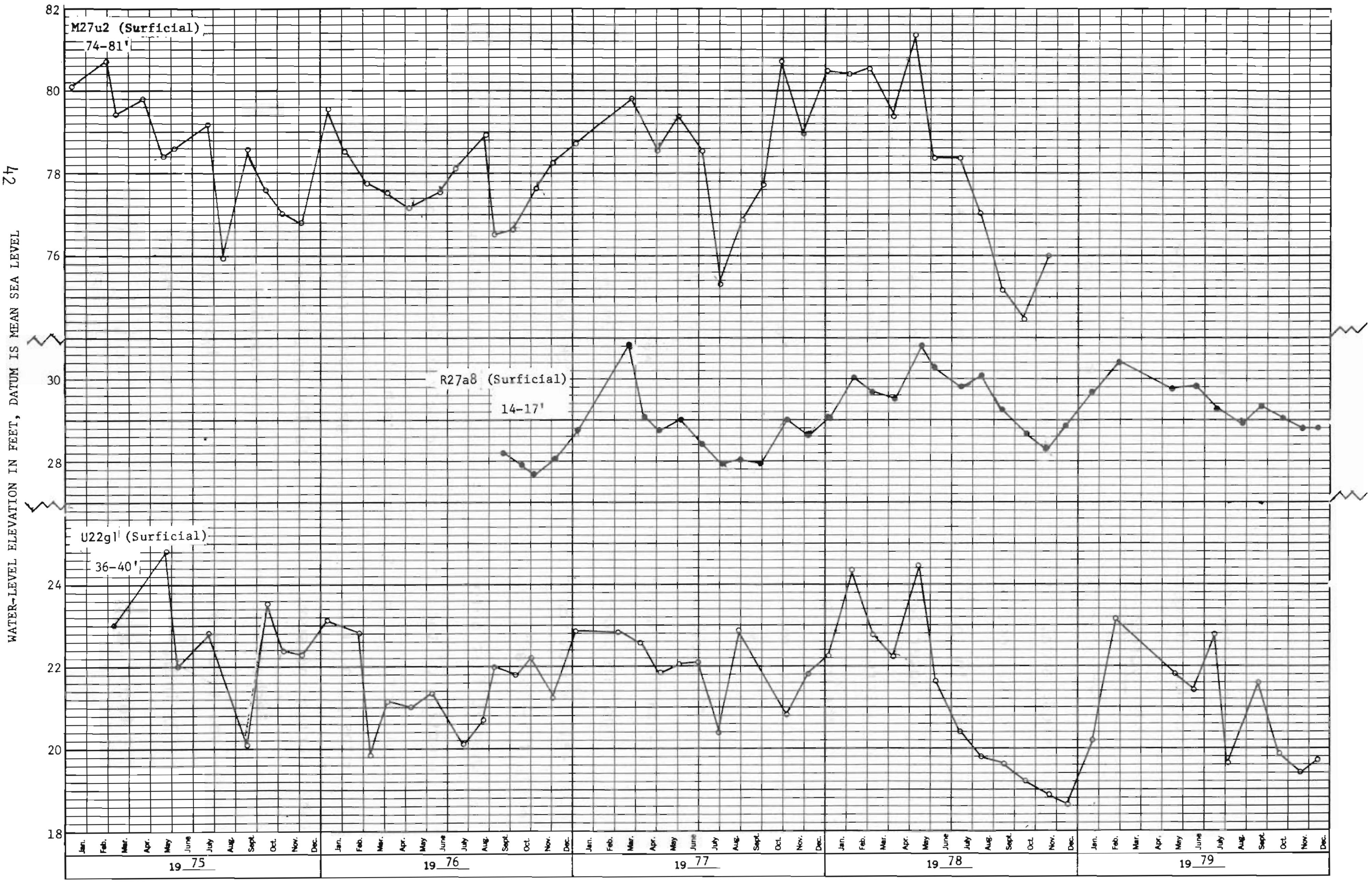


FIGURE 24 - HYDROGRAPHS OF SELECTED WELLS IN THE WATER TABLE UNIT

The Water Table Unit serves an important function as a groundwater reservoir in the study area by discharging a large percentage of stored water as baseflow to sustain streams during dry periods, and by recharging the underlying confined aquifer system. Based on the unit's average thickness and specific yield of eight percent, the amount of retrievable water in storage in the Water Table Unit is estimated to be about 417 $\mathrm{Mgal/mi^2}$. The Water Table Unit currently exhibits no evidence of stress from the large withdrawals occurring in the underlying confined aquifer systems.

The Water Table hydrogeologic unit is limited as a source of supply to a small number of domestic users. A thin zone of saturation and transmissivity values below 134 feet squared per day ($\mathrm{ft^2/day}$) preclude development of the unit into a major source of water. Wells completed in the Water Table Unit are usually of the screened, drive-point variety, and yield between five and ten gallons per minute (gpm).

Yorktown Hydrogeologic Unit

The Yorktonw hydrogeologic unit is equivalent in extent and composition to the Yorktown stratigraphic unit. Throughout most of its extent within the study area, the Yorktown consists primarily of stratified clay and silt deposits. Mixtures of clay and silt material similar to those which are found in the Yorktown formation have hydraulic conductivity values in the range of 10^{-3} to 10^{-4} feet per day (ft/day). As a result, this section of the unit functions as part of a semipervious confining bed for the underlying aquifer systems. The confining bed separates the Water Table Unit from the underlying aquifer systems and inhibits the percolation of water to the confined units.

The Yorktown grades eastward from predominately clay and silt deposits to lenticular sands interbedded with shells and clay. Due to the change in lithology, the water-bearing sand and shell beds of the hydrogeologic unit collectively serve as a confined aquifer. East of New Bern, the unit is capable of sustaining moderately high well yields. However, within the study area the Yorktown hydrogeologic unit has a lower hydraulic conductivity and attains a maximum thickness of only 60 feet resulting in correspondingly lower yield.

Recharge to the Yorktown is derived from the overlying Water Table Unit, or directly from precipitation where the Yorktown outcrops and forms part of the unconfined aquifer. The maximum amount of water available as recharge to the unit is equivalent to the amount of mobile water being stored in the Water Table Unit at any given time. The actual amount of recharge to the Yorktown depends on the vertical hydraulic conductivity and the magnitude of the hydraulic gradient.

Castle Hayne Hydrogeologic Unit

The Castle Hayne hydrogeologic unit includes all or parts of the Oligocene, Castle Hayne, and Beaufort stratigraphic units (Table 1). These three units are grouped together into a single aquifer system on the basis of gross similarities in their hydraulic conductivities and other hydrologic properties.

The unit occurs throughout the eastern half of the study area as delineated in Figure 25. The elevation of the top of the unit ranges from more than 40 feet above sea level along its updip limit to more than 40 feet below sea level just west of New Bern. The Castle Hayne strikes

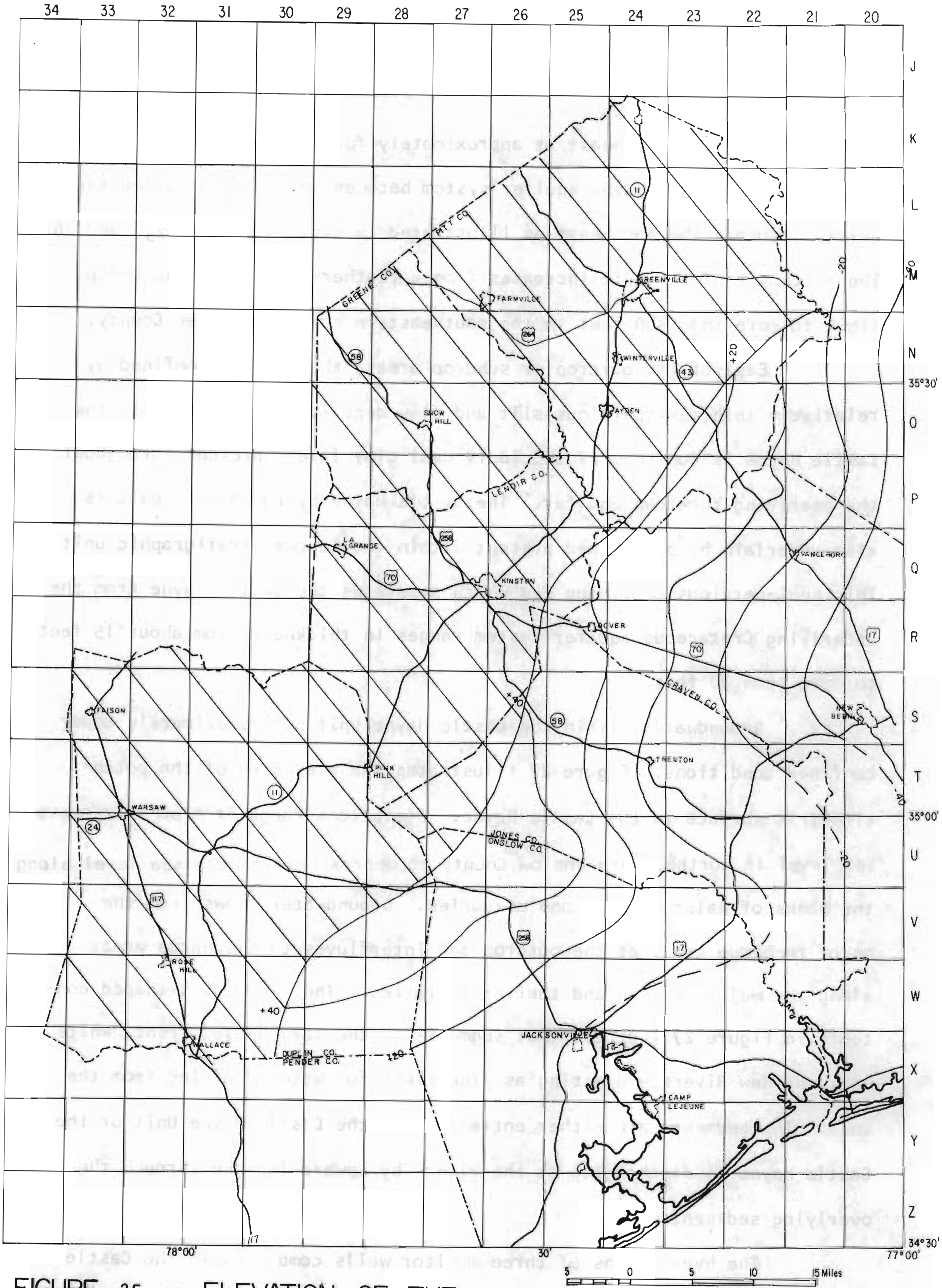


FIGURE 25 - ELEVATION OF THE TOP OF THE CASTLE HAYNE UNIT

northeast and dips southeast at approximately four feet per mile.

The Castle Hayne aquifer system becomes more deeply buried and thickens toward the southeast as illustrated in Figures 21, 22, 23, and 26. The thickness of the unit increases from a feather-edge along the updip limit to more than 400 feet in the southeastern corner of Jones County.

East of its outcrop or subcrop areas, the unit is confined by relatively thin,semi-pervious silt and clay deposits. Further east, the Castle Hayne is confined by the individual clay layers present throughout the overlying Yorktown aquifer. The Castle Hayne hydrogeologic unit is also underlain by a clay bed present within the Peedee stratigraphic unit. This semi-pervious confining bed which separates the Castle Hayne from the underlying Cretaceous aquifer system ranges in thickness from about 15 feet to more than 70 feet.

Groundwater within the Castle Hayne Unit occurs primarily under confined conditions. Figure 27 illustrates the elevation of the potentiometric surface in the Castle Hayne. Elevations range from 60 feet above sea level in northeastern Onslow County to approximately mean sea level along the banks of major streams and estuaries. Groundwater flows from the major recharge areas at the outcrop and interfluves to discharge areas along the major streams and their tributaries. The inverted V-shaped contours in Figure 27 indicate that segments of the Tar, Neuse, Trent, White Oak, and New Rivers are acting as line sinks for water draining from the unit. The segments are either entrenched in the Castle Hayne Unit or the Castle Hayne is discharging to the rivers by upward leakage through the overlying sediments.

The hydrographs of three monitor wells completed in the Castle

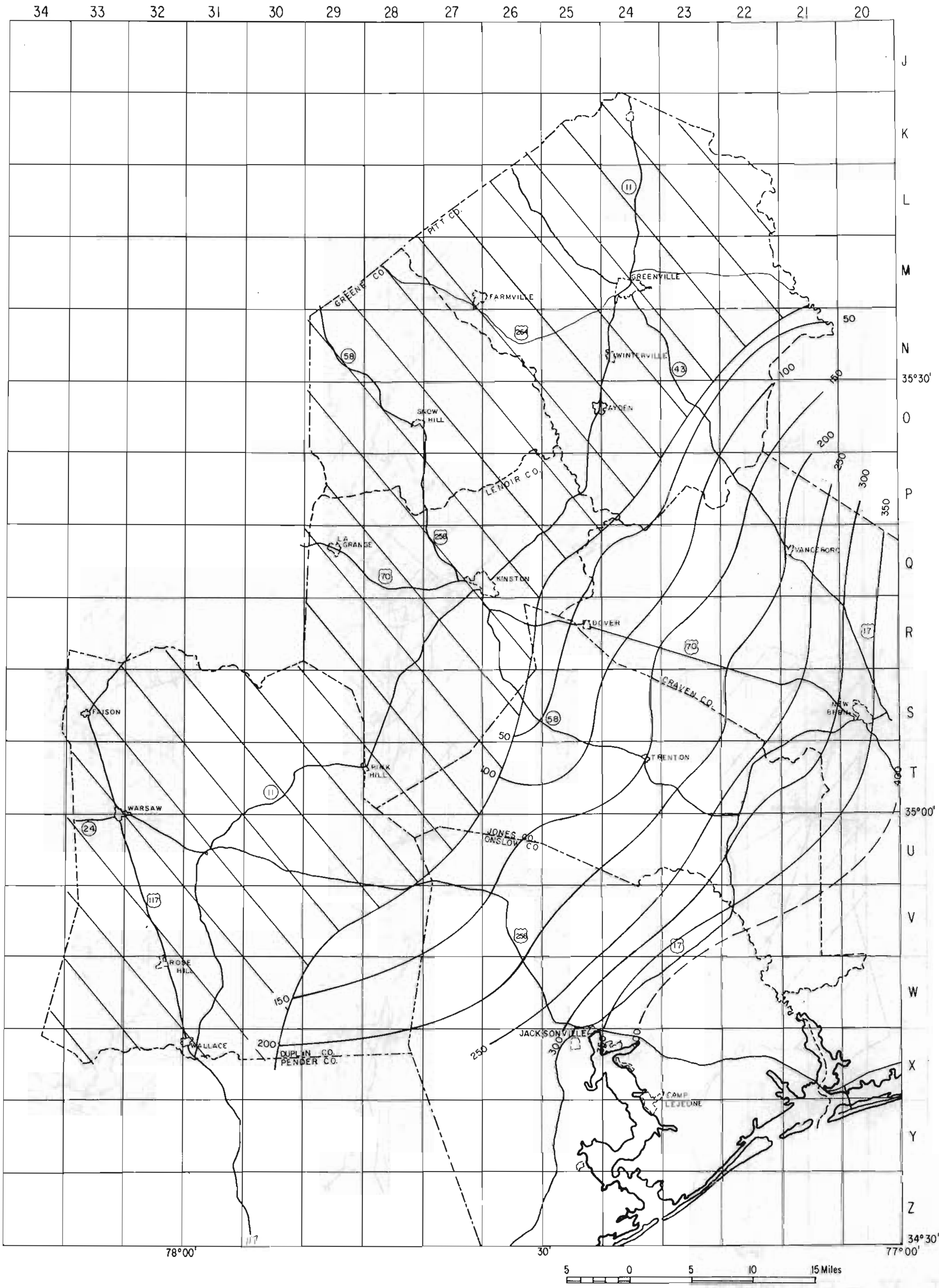


FIGURE 26 — THICKNESS OF THE CASTLE HAYNE UNIT

▨ AQUIFER ABSENT

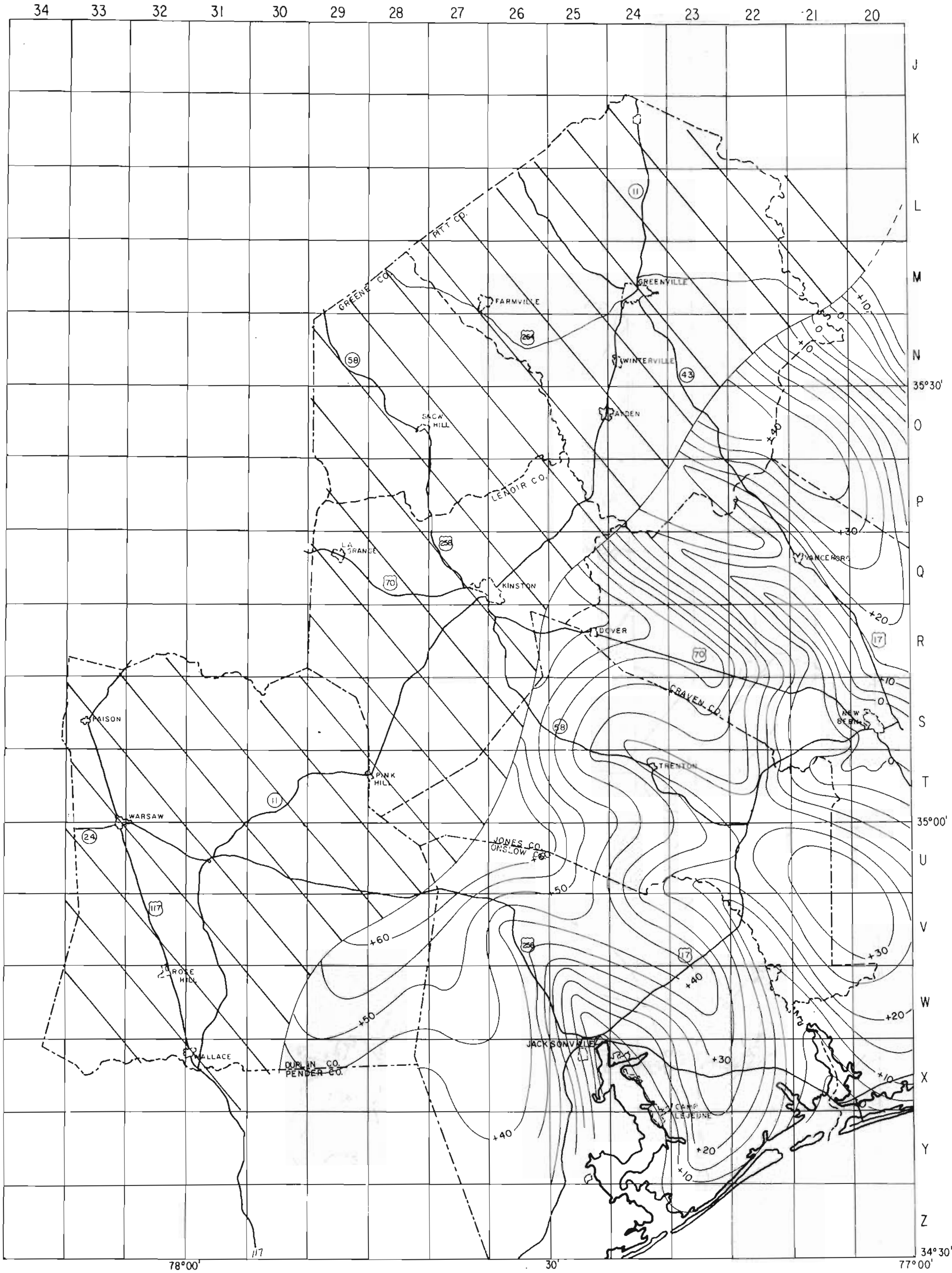


FIGURE 27 – ELEVATION OF THE POTENTIOMETRIC SURFACE IN THE CASTLE HAYNE UNIT IN 1979

Hayne Unit are shown in Figure 28. These hydrographs illustrate the seasonal fluctuations of the Castle Hayne potentiometric surface. As in the case of the Water Table Unit, the potentiometric surface exhibits a cycle of increasing water levels during the late fall, winter, and early spring, followed by decreasing water levels during the remainder of the year. Water levels in the Castle Hayne wells generally are within a few feet of the land surface to about 20 feet below land surface. The annual range of fluctuations in the potentiometric surface is usually between two and six feet. The absence of cones of depression in Figure 27 and of downward trends in the hydrographs indicates that the Castle Hayne is not being stressed by withdrawals from the Unit itself, or from the underlying Cretaceous aquifer system.

Except for that water which reaches the unit directly at the outcrop or subcrop areas, recharge to the Castle Hayne occurs in the form of leakage through the overlying confining bed. As a result, significant amounts of recharge, and ultimately, the long-term yield of the aquifer system, depend on those factors controlling the quantity of water that can leak through the confining bed from the overlying units. Leakage through the bed is governed by the thickness and vertical hydraulic conductivity of the confining bed, and the head difference between the Castle Hayne and the overlying source beds. Therefore, leakage to the Castle Hayne Unit varies with regional differences in the hydraulic properties of the aquifer system and its confining bed. Previous studies have calculated that recharge to the unit ranges from less than 200,000 gallons per day per square mile (gal/day/mi^2) (Floyd, 1969) to 382,000 gal/day/mi^2 (DeWiest and others, 1967, p.72). Recharge to the Castle Hayne Unit within the study area was estimated to average 240,000 gal/day/mi^2.

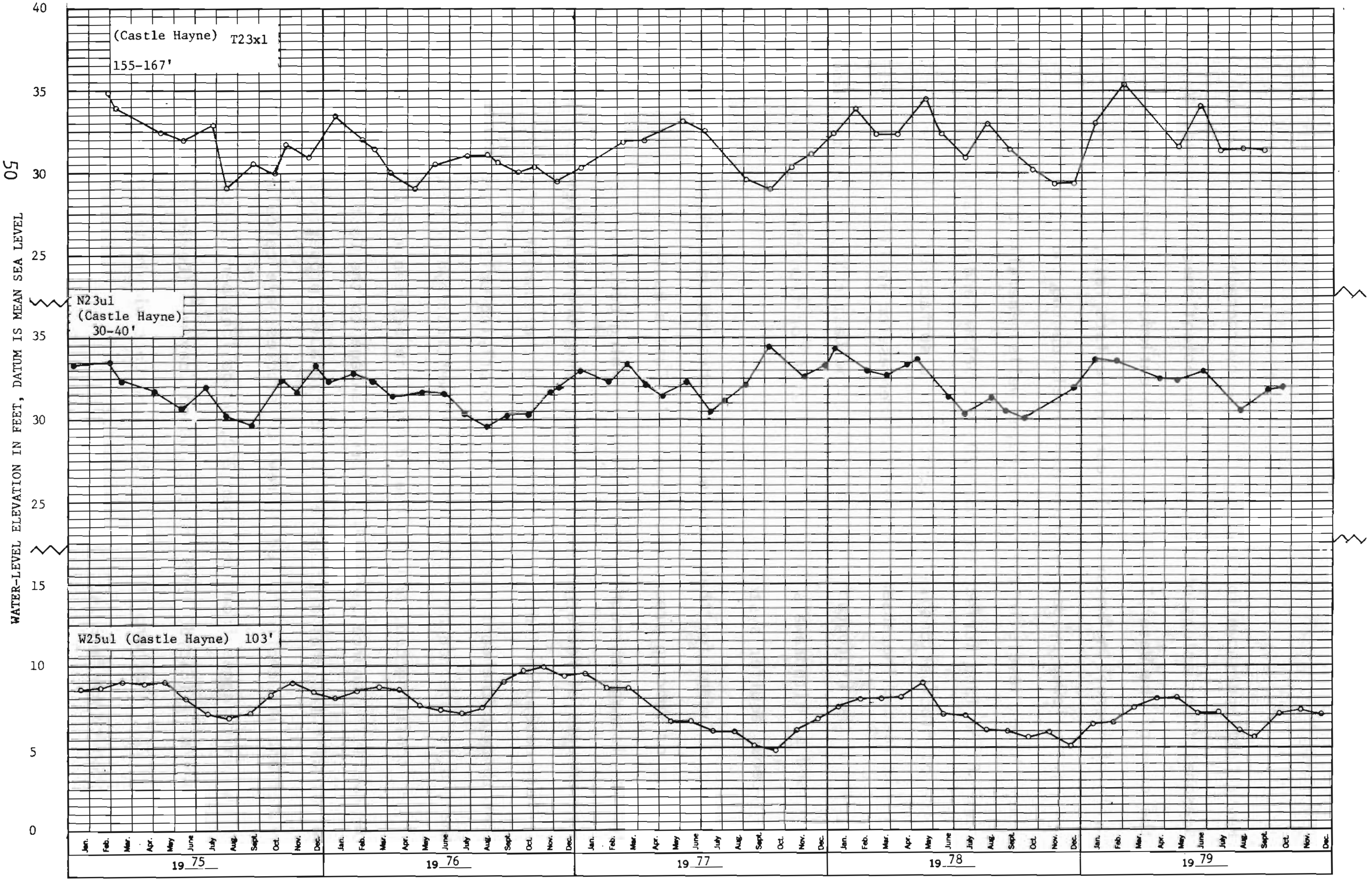


FIGURE 28 - HYDROGRAPH OF SELECTED WELLS IN THE CASTLE HAYNE UNIT

Table 2 shows typical values of transmissivity, storage coefficient, and specific capacity for the Castle Hayne aquifer system. Transmissivity was calcualted on the basis of data from eleven aquifer tests. The transmissivity of the unit ranges from 6,100 to 12,100 feet squared per day (ft^2/da) and averages 8,700 ft^2/da. These values represent the highest transmissivities of any hydrogeologic unit within the study area.

Sufficient data was available from two aquifer tests to estimate the storage coefficient of the aquifer system. The storage coefficient ranges from 2.6×10^{-3} to 7.4×10^{-5} and averages 1.3×10^{-3}.

The specific capacity after 24 hours of pumping was calculated using data from 20 six-inch wells. The values range from 0.61 gallons per minute per foot (gpm/ft) to 22.73 gpm/ft and average 9.54 gpm/ft.

The relatively high transmissivity values of the Castle Hayne Unit account for the fact that the yields of wells completed within this unit are among the highest in the study area. As a rule, well yields will increase towards the east and southeast as the unit becomes thicker and more deeply buried. Typically, the yields of municipal and industrial wells in the Castle Hayne Unit range from several hundred to 1000 gallons per minute (gpm).

Cretaceous Upper Sand Unit

The Cretaceous Upper Sand Unit and the Cretaceous Lower Sand Unit collectively form the Cretaceous aquifer system. The two units, which are separated by a semi-permeable confing bed, are treated as separate hydrogeologic units in this report, primarily on the basis of significant differences in the altitude of their respective potentiometric surfaces.

The Cretaceous Upper Sand Unit is comprised of the water-bearing

HYDROGEOLOGIC UNIT	TRANSMISSIVITY FT^2/ DAY		STORAGE COEFFICIENT (DIMENSION LESS)		SPECIFIC CAPACITY (6"WELL) GPM / FT	
	RANGE	MEAN	RANGE	MEAN	RANGE	MEAN
CASTLE HAYNE	6,100 to 12,100	8,750	7.4 X 10-5 to 2.6 X 10-3	1.3 X 10-3	0.61 to 22.73	9.54
UPPER CRETACEOUS SAND	400 to 1.950	1,050	1.0 X 10-4 to 1.7 X 10-4	1.3 X 10-4	0.61 to 3.93	1.89
LOWER CRETACEOUS SAND	1,400 to 5,750	2,750	2.5 X 10-5 to 6.7 X 10-4	2.3 X 10-4	0.61 to 12.50	4.50

TABLE 2 — TYPICAL HYDRAULIC PROPERTIES OF THE PRINCIPAL HYDROGEOLOGIC UNITS

sands which occur in the lower one-third to one-half of the Peedee stratigraphic unit. Individual sand layers, which are interbedded with clay, generally range from 5 to 20 feet in thickenss. The cumulative thickness of the sands in any section of the Cretaceous Upper Sand averages about 45 feet, or 55 to 60 percent of the total unit thickness. The maximum cumulative thickness encountered within the study area is about 85 feet.

The Cretaceous Upper Sand Unit occurs throughout the eastern three-fourths of the study area as shown in Figure 29. Elevation of the unit ranges from more than 50 feet above sea level along the updip limit to about 800 feet below sea level in southeastern Jones County. The unit strikes northeast and dips southeast at approximately 17 feet per mile.

Figures 21, 22, 23, and 30 show that the unit becomes thicker and more deeply buried towards the southeast. The thickness of the unit is irregular, but generally increases from a feather-edge along its updip limit to more than 100 feet in Onslow and Jones Counties.

East of its outcrop or subcrop, the Cretaceous Upper Sand is confined by overlying silt and clay deposits in the Peedee Unit. This confining bed, which is from 15 to 80 feet thick, separates the Cretaceous Upper Sand from the overlying Yorktown or Castle Hayne Units. The Cretaceous Upper Sand Unit is also underlain by a confining bed which occurs in the Black Creek stratigraphic unit. The lower confining bed separates the two sand units and ranges from about 30 feet to 150 feet in thickness.

Groundwater in the Cretaceous Upper Sand Unit occurs primarily under confined conditions. Figure 31 illustrates the elevation of the potentiometric surface in the Upper Sand Unit. Water-level elevations range from more than 100 feet above sea level in central Duplin County to about sea level near the Jacksonville well fields.

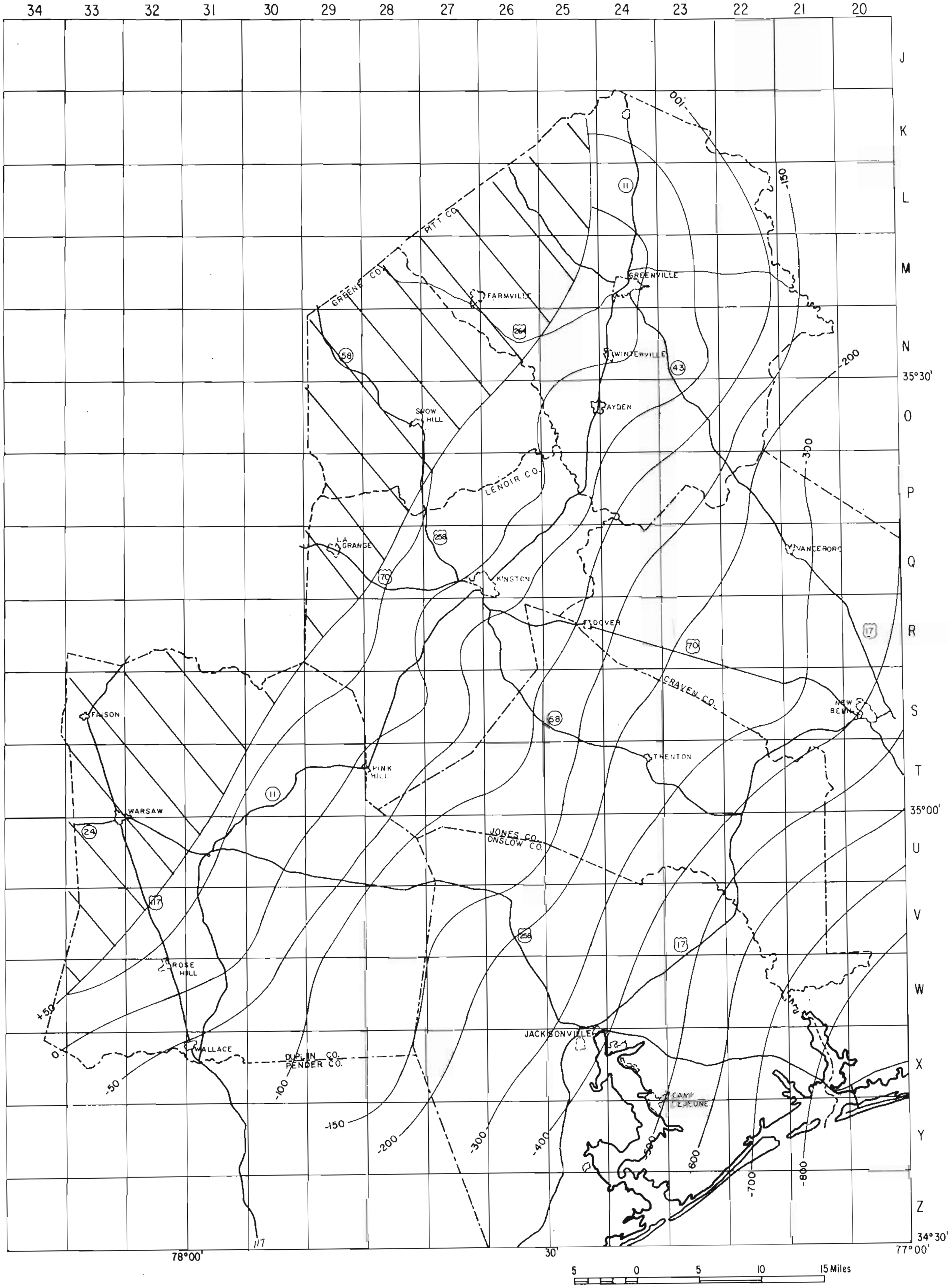


FIGURE 29 - ELEVATION OF THE TOP OF THE CRETACEOUS UPPER SAND UNIT

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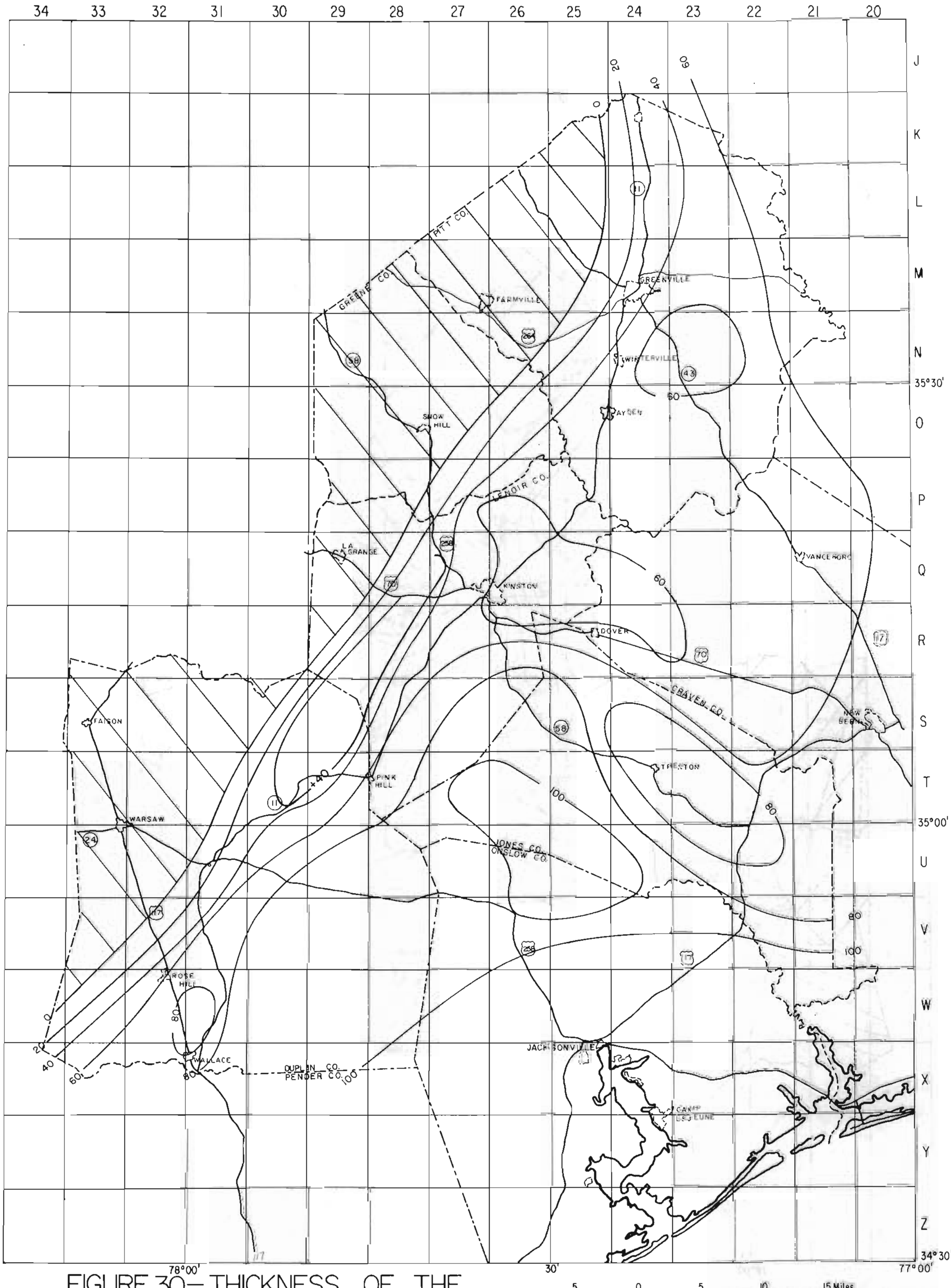


FIGURE 30—THICKNESS OF THE CRETACEOUS UPPER SAND UNIT

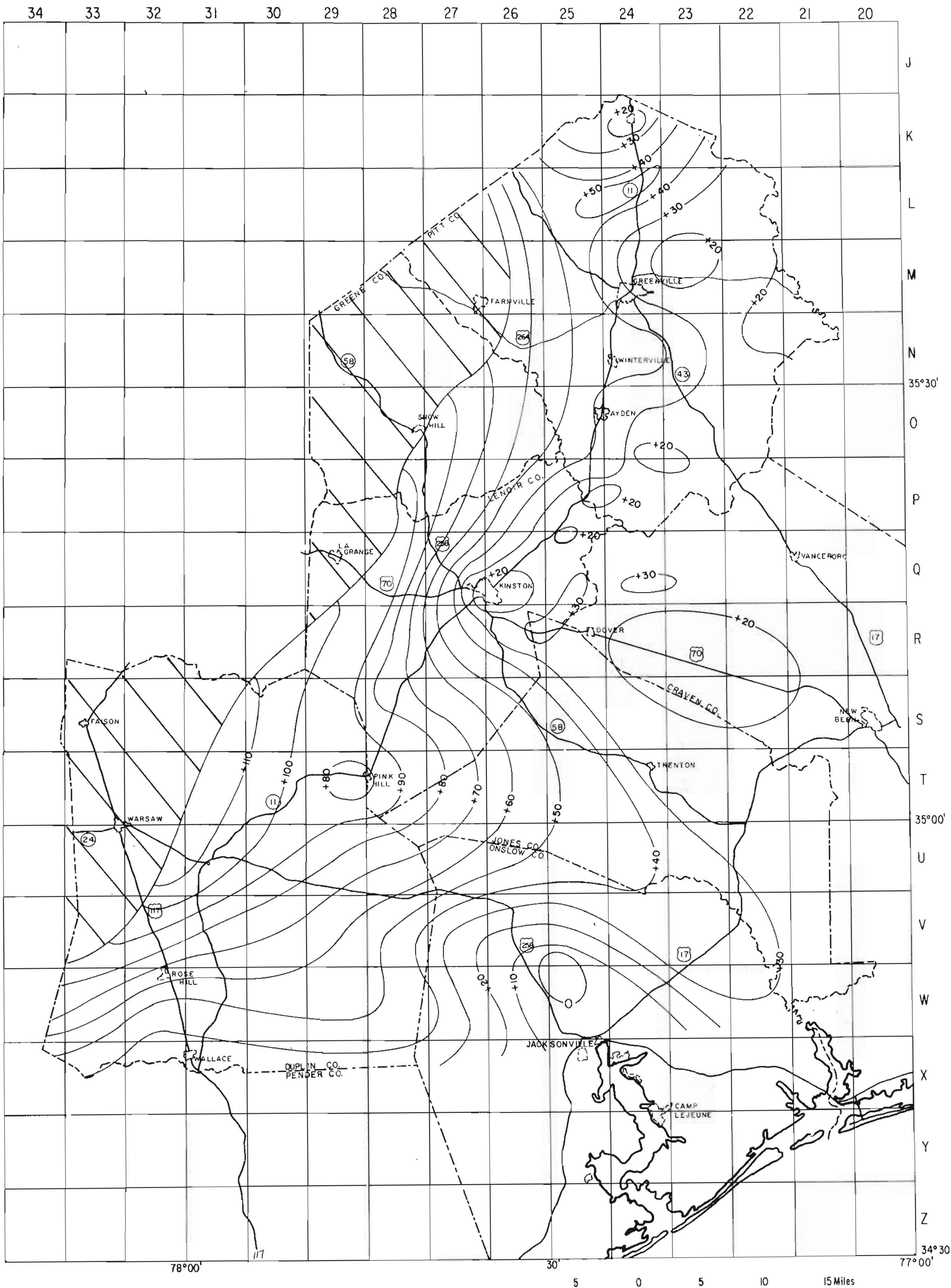


FIGURE 31— ELEVATION OF THE POTENTIOMETRIC SURFACE IN THE CRETACEOUS UPPER SAND UNIT IN 1979

Under natural discharge conditions, the general direction of groundwater flow in the Cretaceous Upper Sand would be toward the east and southeast, or in the same direction as the dip of the unit. However, in the study area, natural flow patterns do not exist, having been modified by heavy withdrawals from the underlying Cretaceous Lower Sand Unit. Since there are no major pumping centers in the study area withdrawing water from the Upper Sand Unit, the cones of depression in Figure 31 are evidence of induced leakage of water from the Cretaceous Upper Sand to the Cretaceous Lower Sand. Figure 31 shows that induced leakage is occurring at Greenville, Kinston, Cove City, Jacksonville, Bethel, Pink Hill, and southern Pitt County. Groundwater flow within the Cretaceous Upper Sand Unit is generally towards these areas.

The hydrographs of two monitor wells completed in the Cretaceous Upper Sand Unit are shown in Figures 32 through 34. Figure 32 illustrates the seasonal fluctuations of the unit's potentiometric surface. As in the case of the overlying hydrogeologic units, the potentiometric surface of the Cretaceous Upper Sand exhibits a cycle of increasing water levels during the late fall, winter and early spring, followed by decreasing water levels during the remainder of the year. The change in water level is generally small, usually on the order of one or two feet annually. Water levels in the Cretaceous Upper Sand Unit vary regionally, however, from near land surface to more than 60 feet below land surface.

Long-term downward trends evident in both hydrographs are the result of induced leakage to the Cretaceous Lower Sand Unit. The stress created by pumping water from the lower unit has caused water levels in well T28f3 to decline about two feet in seven years. More dramatically, water levels in

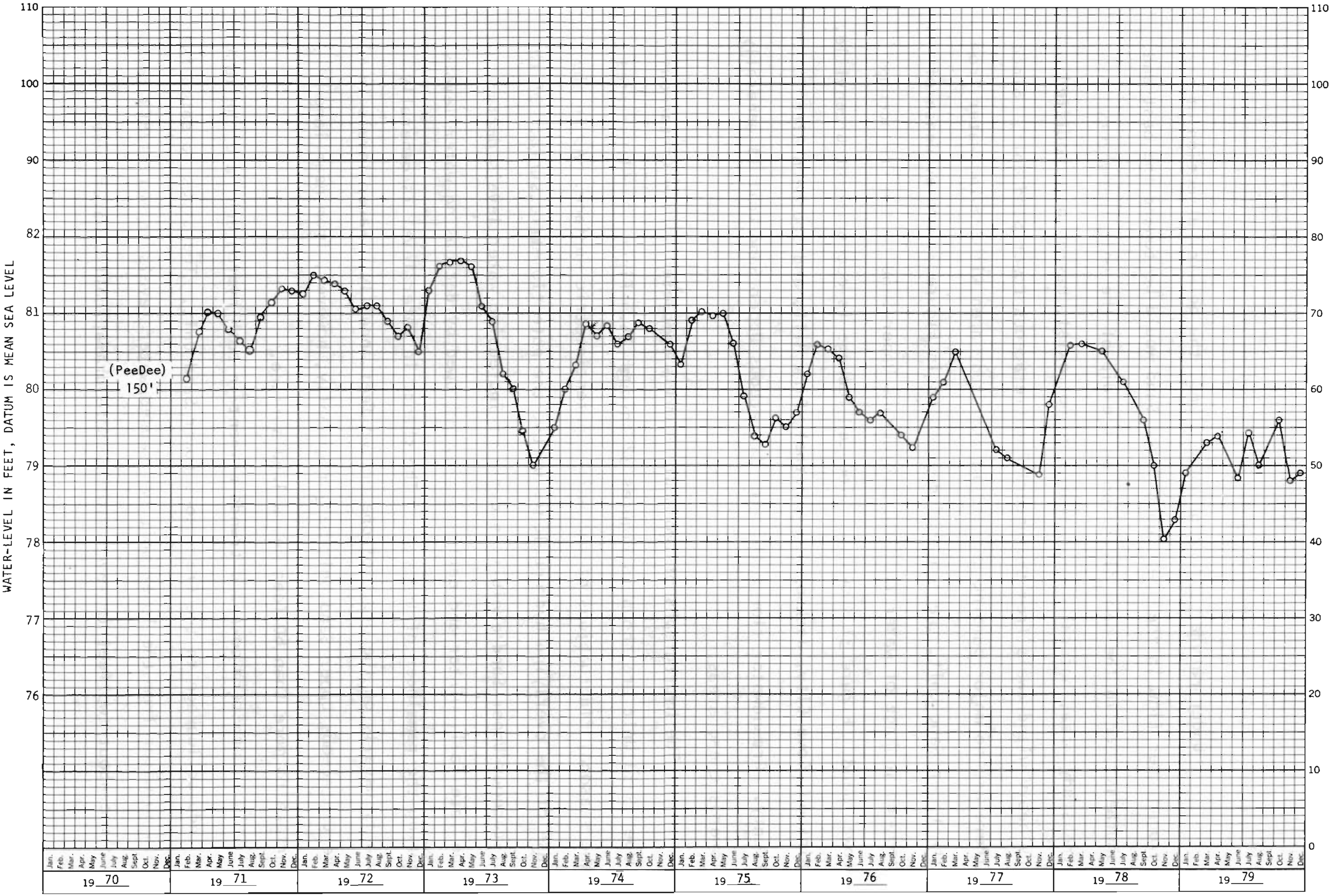


FIGURE 32 - HYDROGRAPH OF WELL T28f3 AT PINK HILL, LENOIR COUNTY

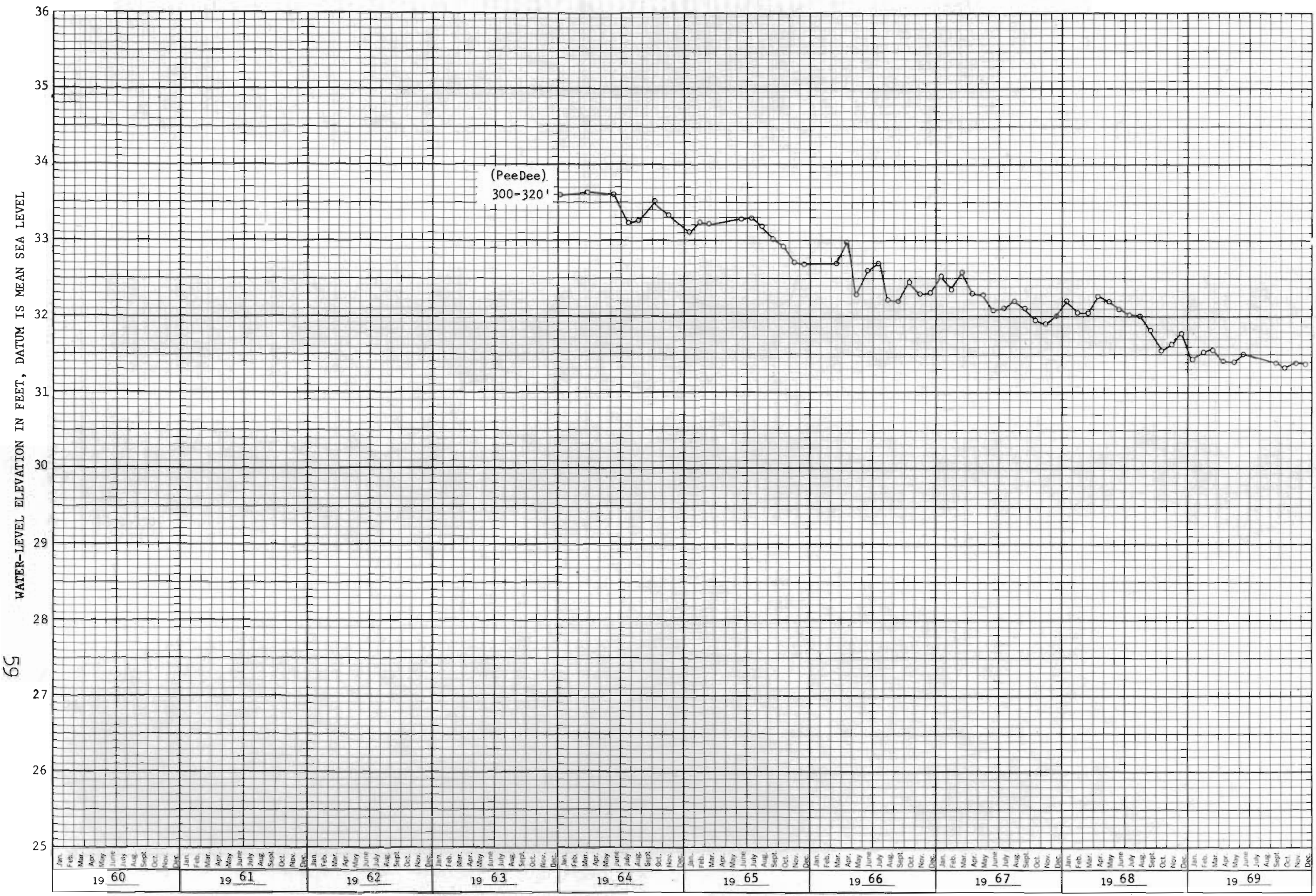


FIGURE 33 - HYDROGRAPH OF WELL P22j1 AT WILMAR, CRAVEN COUNTY

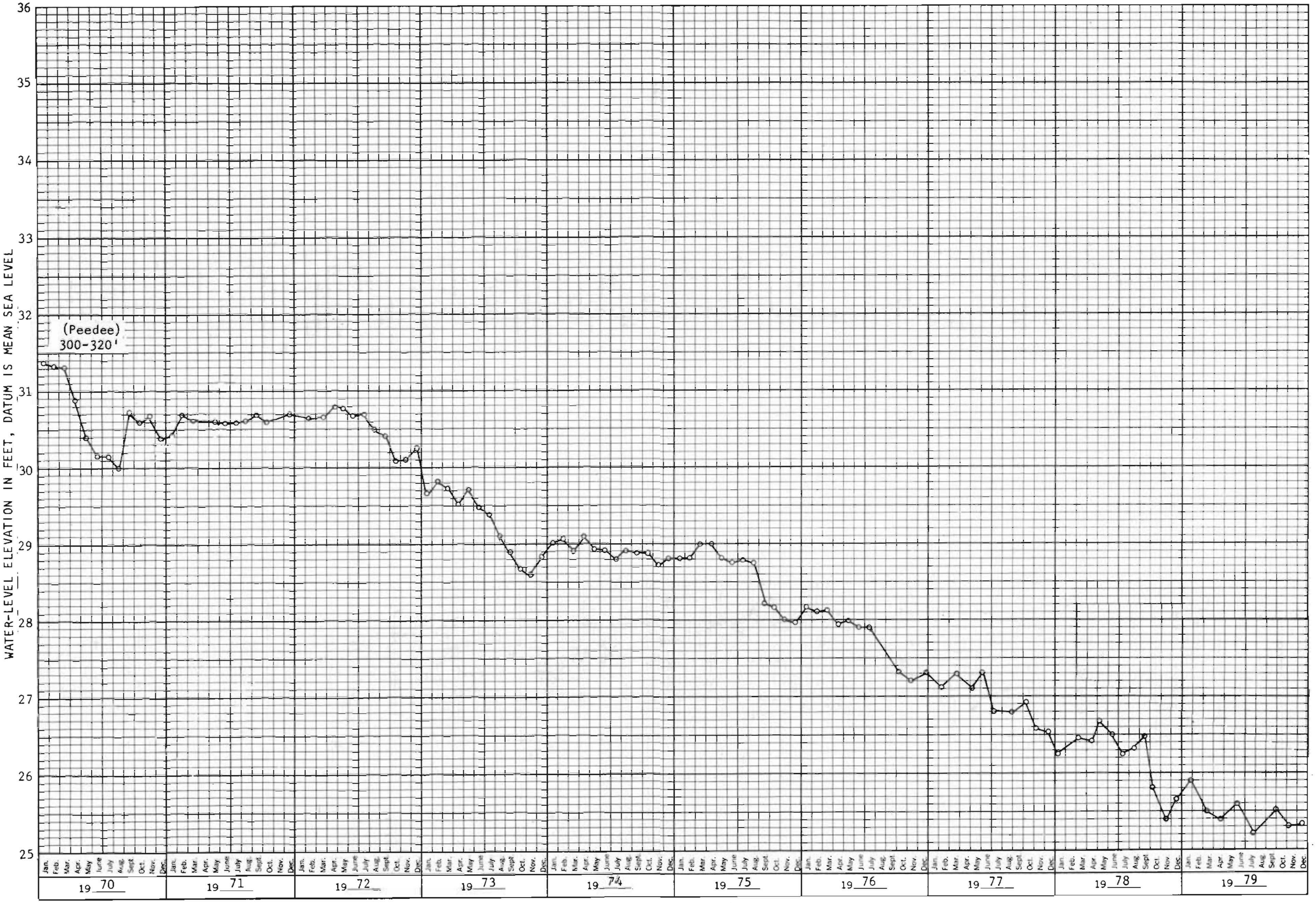


FIGURE 34-CONTINUATION OF HYDROGRAPH OF WELL P22j1 AT WILMAR, CRAVEN COUNTY

well P22j1 have declined eight feet over a 16-year period in response to withdrawals at Greenville, Kinston, and Cove City.

Except for direct recharge to the unit on its outcrop and subcrop areas, most water reaches the Cretaceous Upper Sand Unit in the form of leakage through the overlying confining bed. As in the case of the Castle Hayne Unit, the amount of recharge and the long-term yield of the Cretaceous aquifer system depends on those factors controlling the quantity of water that can leak through the confining bed from the source beds. Regional differences in the hydraulic properties of the aquifer system and the confining bed result in different recharge values throughout the study area. The relatively small seasonal water-level fluctuations in the Cretaceous Upper Sand Unit suggest a low recharge rate. Previous studies have calculated that recharge to the unit ranges from 50,000 to 60,000 gal/da/mi^2 (Robison and Mann, 1977). Recharge to the Cretaceous Upper Sand Unit within the study area was estimated to average 56,000 gal/da/mi^2.

Table 2 shows typical values of transmissivity, storage coefficient, and specific capacity for the unit. Transmissivity was calculated on the basis of data from four aquifer tests. The transmissivity of the unit ranges from 400 ft^2/da to 1,950 ft^2/da and averages 1,050 ft^2/da. These values represent the lowest transmissivities in Table 2 and reflect the limited thickness of the Cretaceous Upper Sand Unit.

Sufficient data was available from three aquifer tests to estimate the storage coefficient of the unit. The storage coefficient ranges from 1.0×10^{-4} to 1.7×10^{-4} and average 1.3×10^{-4}.

The specific capacity after 24 hours of pumping was calculated using data from 19 wells. The values range from 0.61 gpm/ft to 3.93 gpm/ft and average 1.89 gpm/ft.

Withdrawal of water from the Cretaceous Upper Sand Unit is limited to a small number of domestic and irrigation wells. Most wells within the study are usually completed in either the overlying Castle Hayne unit or the deeper Cretaceous Lower Sand Unit. Typically, the yields of wells in the Cretaceous Upper Sand are between 20 and 100 gpm.

Cretaceous Lower Sand Unit

The Cretaceous Lower Sand Unit comprises the lower part of the Cretaceous aquifer system and includes the water-bearing sands and clays of the Black Creek and Tuscaloosa stratigraphic units. Individual sand layers within the unit generally range from 5 to 20 feet in thickness, and the cumulative thickness of the sands in any section of the Cretaceous Lower Sand Unit averages 185 feet, or about 45 percent of the total unit thickness. The maximum cumulative thickness encountered in the study area is about 230 feet.

The unit underlies the entire study as shown in Figure 35. Elevations of the top of the unit range from more than 100 feet above sea level in northwestern Duplin County to more than 900 feet below sea level in southeastern Jones County. The unit strikes northeast and dips to the southeast at approximately 21 feet per mile.

Figures 21, 22, and 36 shows that the Cretaceous Lower Sand Unit becomes thicker and more deeply buried towards the southeast. The thickness of the unit increases from 200 feet along the western boundary of the study area to more than 700 feet in southeastern Jones County.

East of its outcrop and subcrop, the Cretaceous Lower Sand Unit is confined by overlying silt and clay deposits in the Black Creek stratigraphic unit, and by numerous clay beds occurring within the hydrogeologic unit itself.

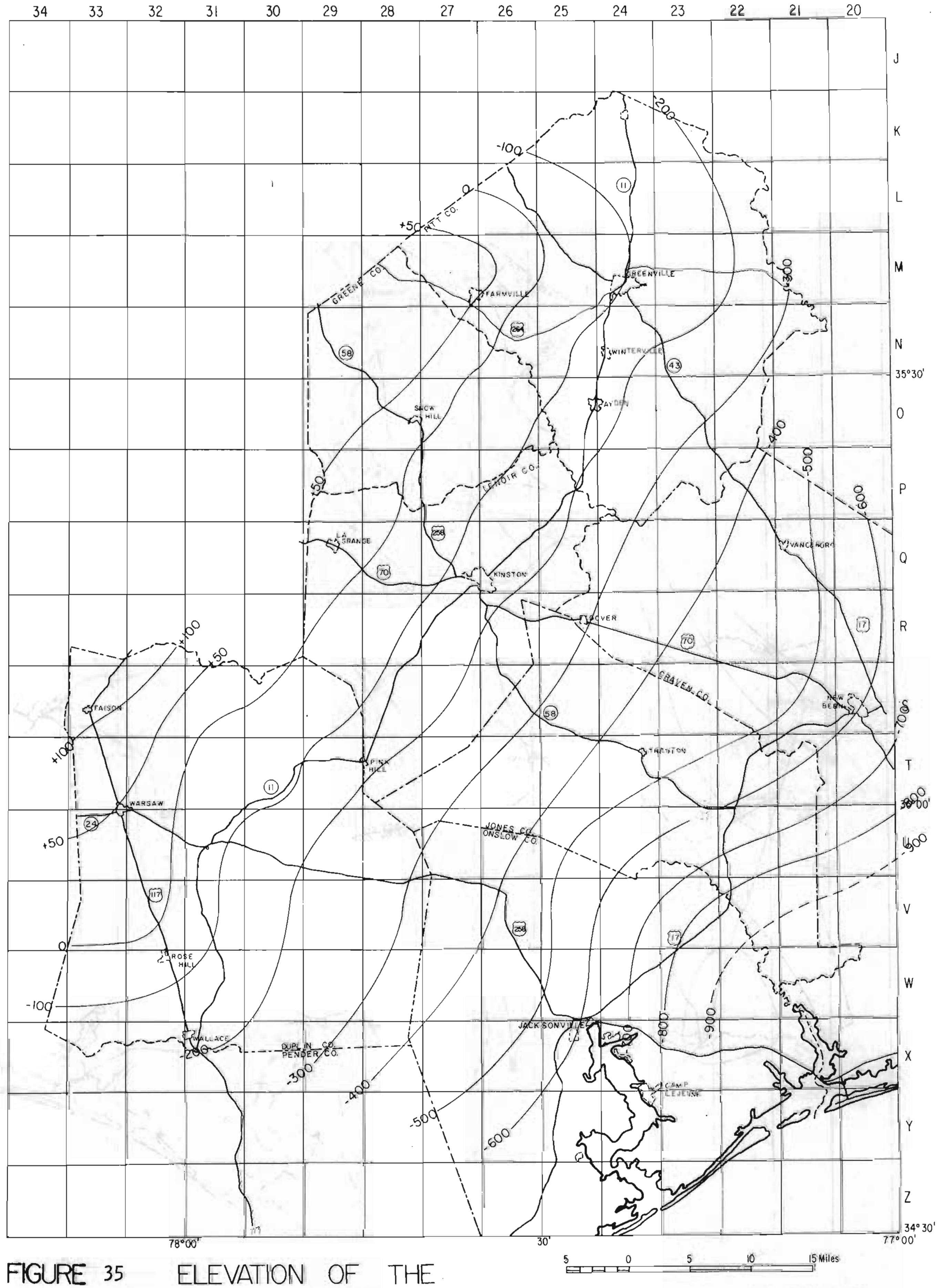


FIGURE 35 ELEVATION OF THE TOP OF THE CRETACEOUS LOWER SAND UNIT

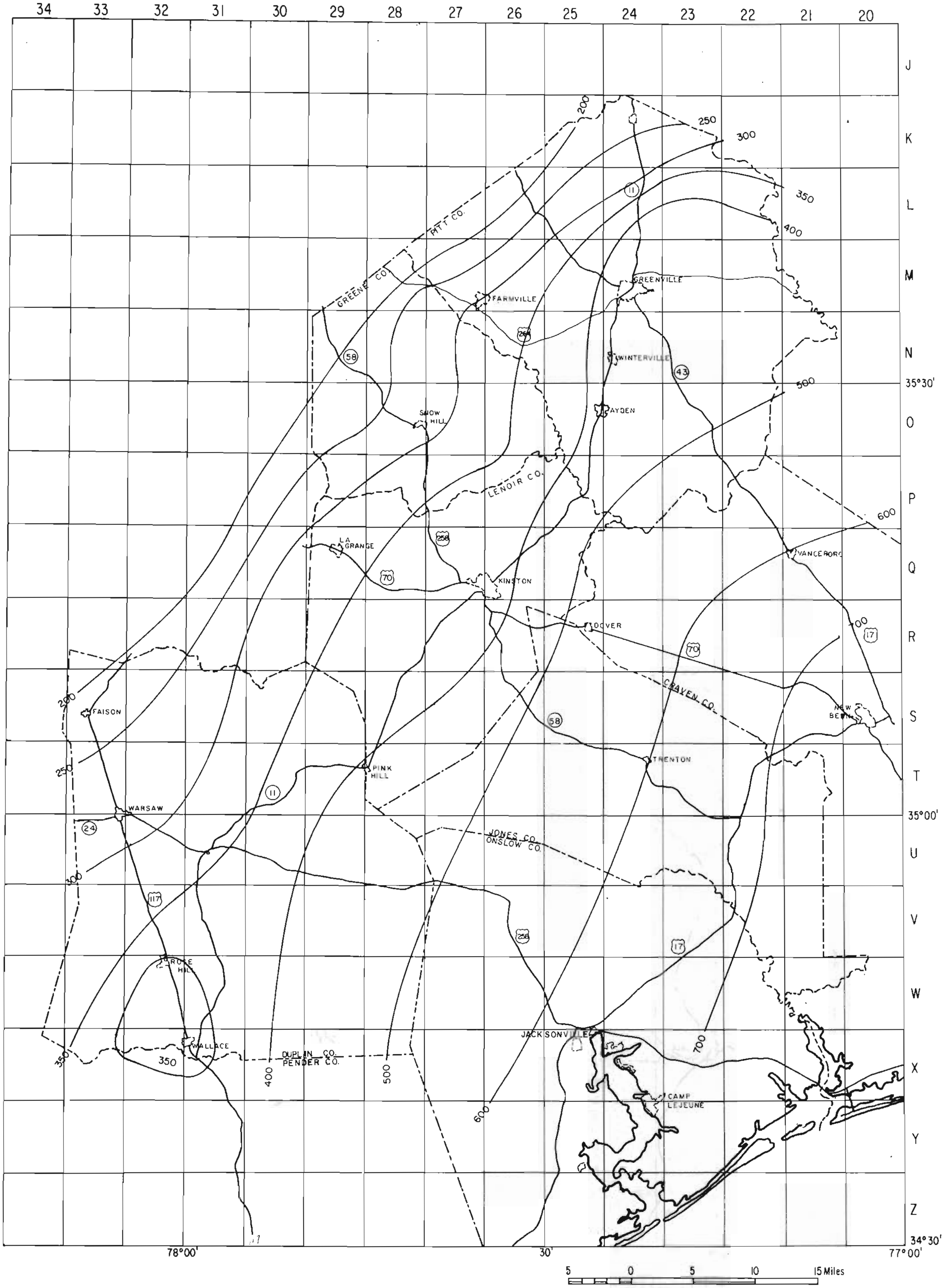


FIGURE 36 — THICKNESS OF THE CRETACEOUS LOWER SAND UNIT

The overlying confining bed is between 30 and 150 feet thick and separates the Cretaceous Lower Sand Unit from the Cretaceous Upper Sand Unit. The hydrogeologic unit is also underlain by a confining bed which occurs in the Tuscaloosa and Lower Cretaceous stratigraphic units.

Groundwater in the Cretaceous Lower Sand Unit occurs primarily under confined conditions. Figure 37 illustrates that elevations range from more than 210 feet above sea level to more than 70 feet below sea level near the pumping centers of Kinston and Greenville.

Under natural discharge conditions, the general direction of groundwater flow in the Cretaceous Lower Sand Unit would be toward the east and southeast, or in the same direction as the dip of the unit. However, in the study area, natural flow patterns do not exist, having been greatly modified by the large-scale withdrawal of water from this unit. In no part of the study area is the Cretaceous Lower Sand Unit unstressed by municipal or industrial pumping. Figure 37 shows deep and extensive cones of depression in the potentiometric surface of the unit. In about thirty-five percent, or about 1100 square miles of the study area, the potentiometric surface is below sea level. Large cones of depression exist in the vicinity of major pumping centers such as the communities of Kinston, Greenville, Jacksonville, and Cove City which supplies water to New Bern. Individual cones surrounding Kinston, Greenville, and Cove City have expanded to the point where they have coalesced to form a large, regional cone of depression. Continued expansion of the regional cone will ultimately result in its coalescing with the cone of depression formed by pumping at the Jacksonville well fields. Less extensive cones of depression have developed at the towns of Bethel, Farmville, Ayden, Walstonburg, LaGrange, Wallace, Rose Hill, and

FIGURE 37—ELEVATION OF THE POTENTIOMETRIC SURFACE IN THE CRETACEOUS LOWER SAND UNIT IN 1979

Warsaw. Throughout most of the study area, the direction of groundwater flow has been altered towards the cones of depression.

Figures 38 through 44 illustrate the hydrographs of wells completed in the Cretaceous Lower Sand Unit. Figures 45, 46, 47 show the hydrographs of wells located at the Wilmar and Kinston Research Stations. For comparative purposes, the latter figures also include the hydrographs of well completed in overlying hydrogeologic units.

The hydrograph of well T33ul in Warsaw shows the least influence of pumping, and therefore, best illustrates the seasonal fluctuation of water levels in the Cretaceous Lower Sand Unit. The cycle of fluctuation which was evident in the overlying units, also occurs in some parts of the Cretaceous Lower Sand. Water levels rise through the late fall, winter, and early spring, and decline throughout the remainder of the year. The annual water level fluctuation in T33ul ranges from two to six feet and averages almost four feet per year. Since T33ul is near the unit's outcrop, water levels in wells further downdip from the outcrop should exhibit correspondingly less seasonal fluctuations.

Major fluctuations in the potentiometric surface of the Cretaceous Lower Sand Unit are due primarily to local and regional pumping. Long-term downward trends are evident in the hydrographs of all wells completed in the Cretaceous Lower Sand Unit. For comparative purposes, the average decline in water level for the period of 1975 to 1979 was computed for each well. The average water level change in each well and the community nearest the well are listed below.

T33ul	-0.5 ft/yr	Warsaw
R29jl	-0.8 ft/yr	La Grange
O26o2	-1.6 ft/yr	Maury
P21k9	-2.0 ft/yr	Wilmar

Q27r10	-2.4 ft/yr	Kinston
Q27w1	-2.5 ft/yr	Kinston
P25s1	-3.0 ft/yr	Grifton
R23w2	-3.5 ft/yr	Cove City

Water levels declined from 0.5 feet per year (ft/yr) in Duplin County where pumping centers are relatively small to 3.5 ft/yr near the major pumping center at Cove City. The five-year averages, when compared to averages computed over the entire period of record, indicate that, in most cases, the rate of water-level decline is remaining essentially the same or decreasing slightly. The most significant decreases in the rate of decline are evident in Figures 41 and 43. Water levels in well Q27w1 at Kinston fell 4.5 ft/yr during the five years from 1970 to 1974, and 2.5 ft/yr from 1975 to 1979. Similarly, water levels in well R23w2 at Cove City declined 7.5 ft/yr from 1968 to 1974, and 3.5 ft/yr from 1975 to 1979. This decrease in the rate of water-level decline is attributed to the capture of greater amounts of recharge as the cones of depression expand from the pumping centers. A similar decrease in the rate of decline would occur if the amount of water being withdrawn were significantly decreased. Conversely, increasing the amount of water pumped, as it likely to occur with the addition of another well to a system, would increase the rate of water-level decline.

Figure 48, which illustrates the potentiometric surface of the Cretaceous Lower Sand Unit as it existed in 1965, was prepared from information previously available in reports by Sumsion (1970, p.28) and Nelson and Barksdale (1965, p.19). In comparing the potentiometric surface of 1965 with that of 1979, it becomes apparent that the gross shape, position, and orientation of the major cones of depression have remained the same. They have, however, become considerably deeper and more extensive.

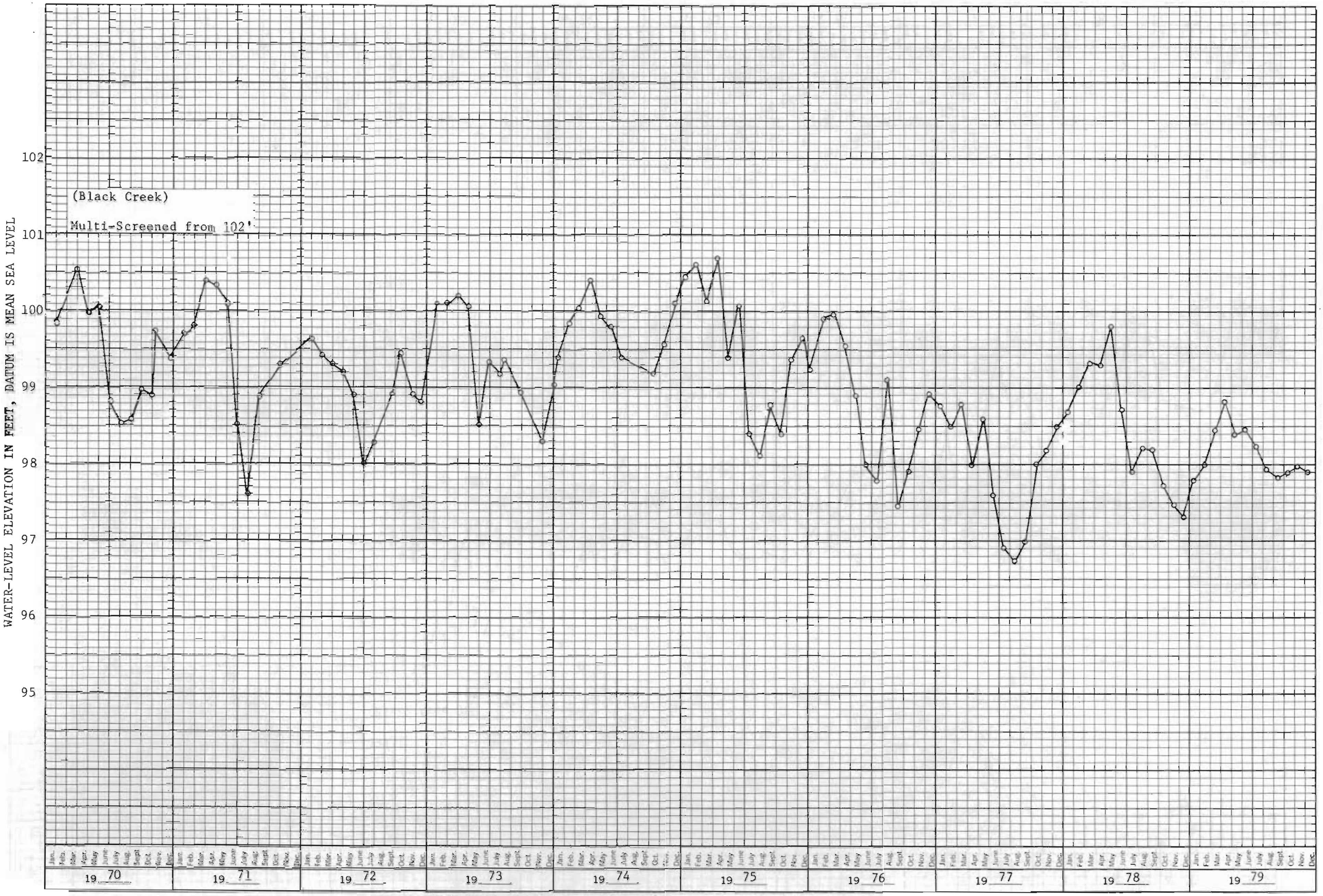


FIGURE 38 - HYDROGRAPH OF WELL T33u1 AT WARSAW, DUPLIN COUNTY

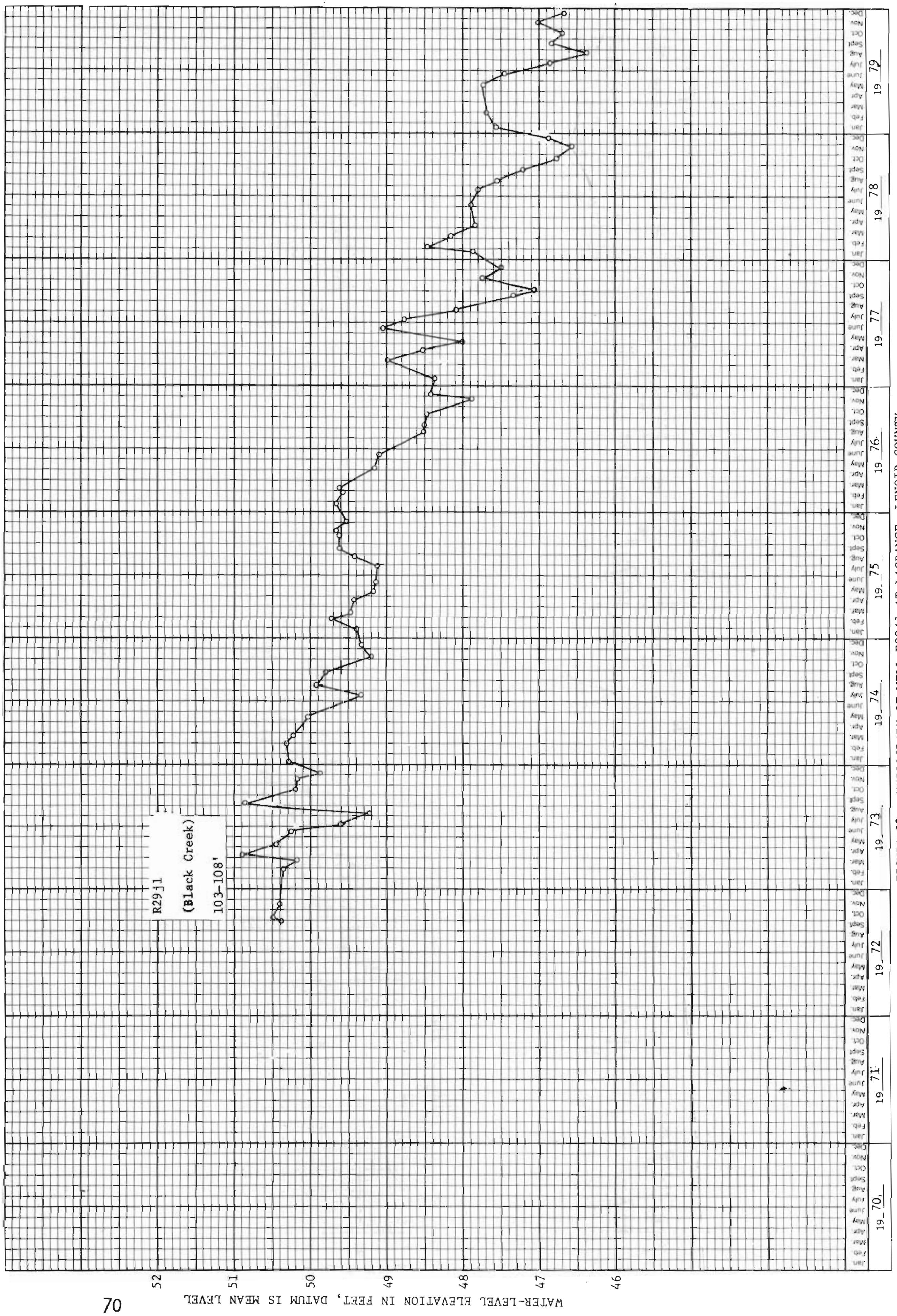


FIGURE 39 - HYDROGRAPH OF WELL R29j1 AT LAGRANGE, LENOIR COUNTY

FIGURE 40 - HYDROGRAPH OF WELL 026o2 AT MAURY, GREENE COUNTY

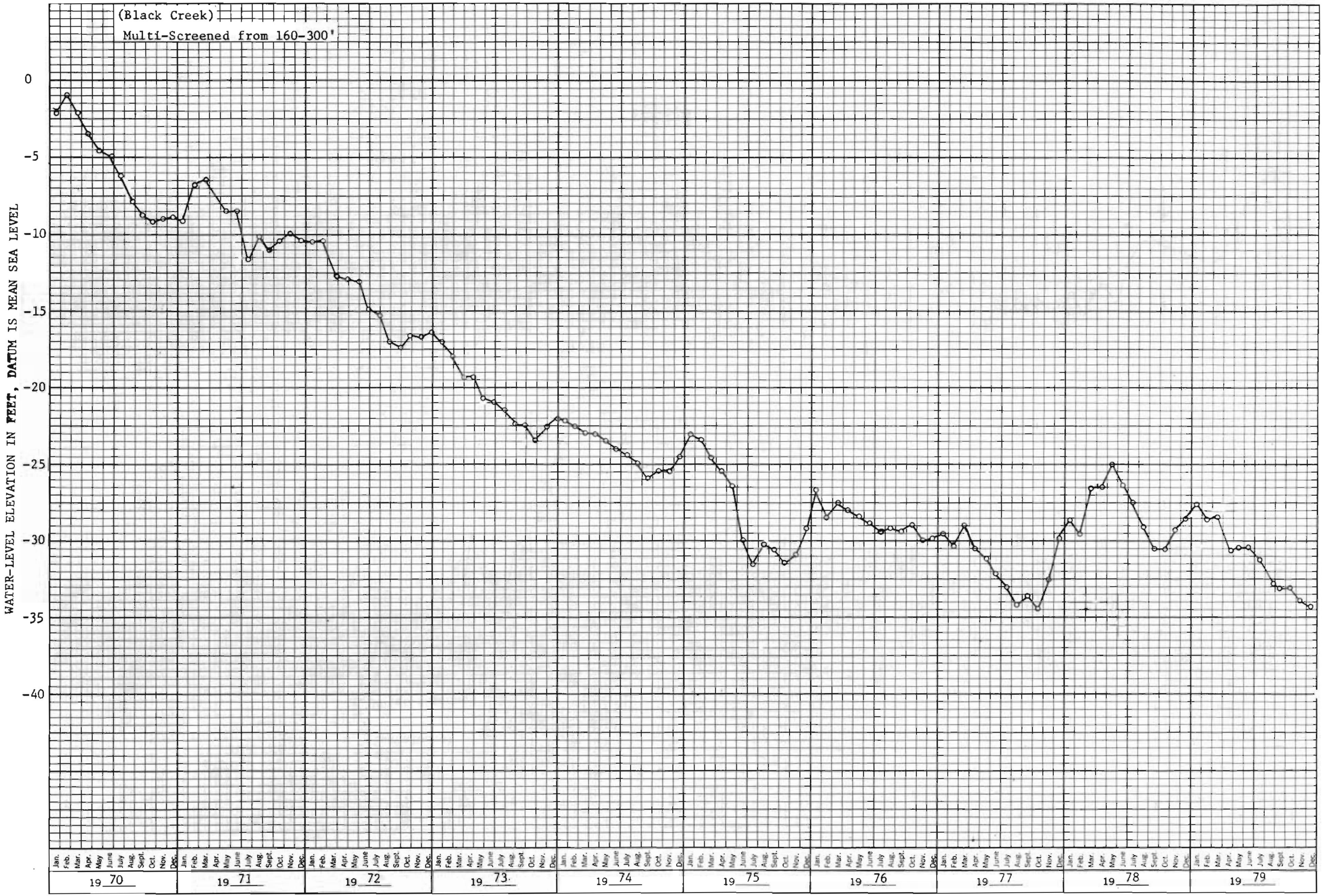


FIGURE 41.- HYDROGRAPH OF WELL Q27w1 AT KINSTON, LENOIR COUNTY

FIGURE 42 - HYDROGRAPH OF WELL P25s1 AT GRIFTON, LENOIR COUNTY

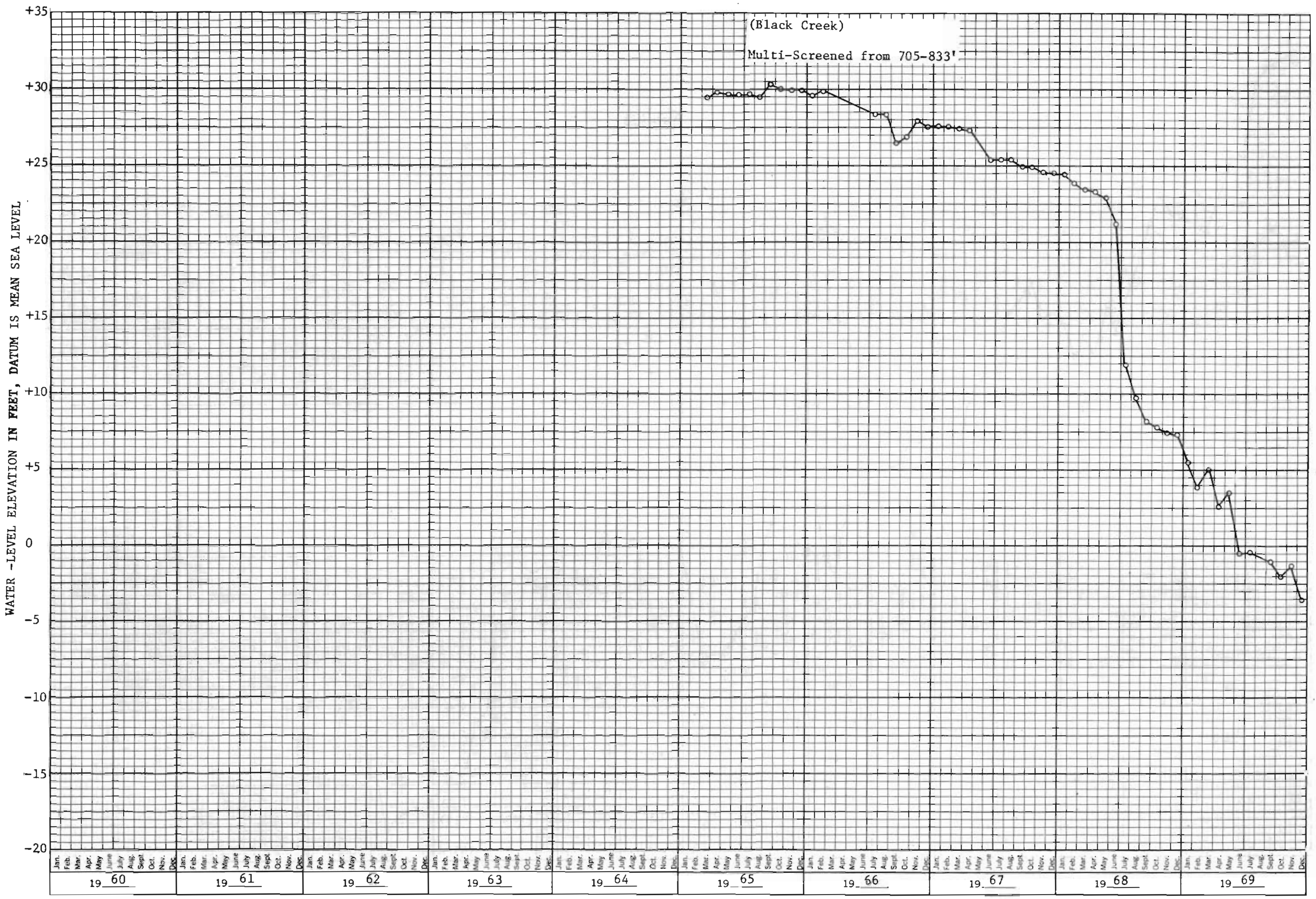


FIGURE 43 - HYDROGRAPH OF WELL R23w2 AT COVE CITY, CRAVEN COUNTY

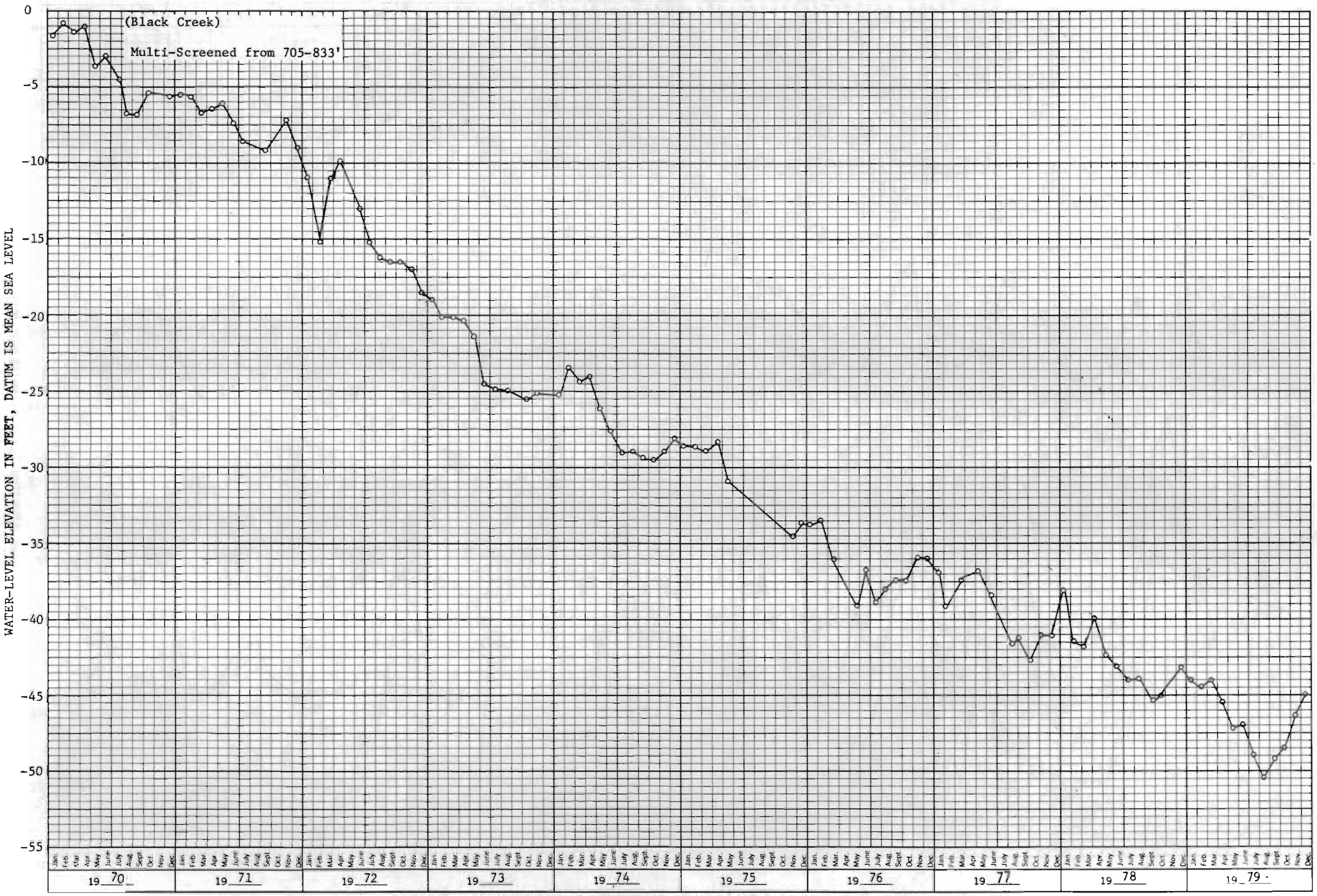


FIGURE 44 - CONTINUATION OF HYDROGRAPH OF WELL R23w2 AT COVE CITY, CRAVEN COUNTY

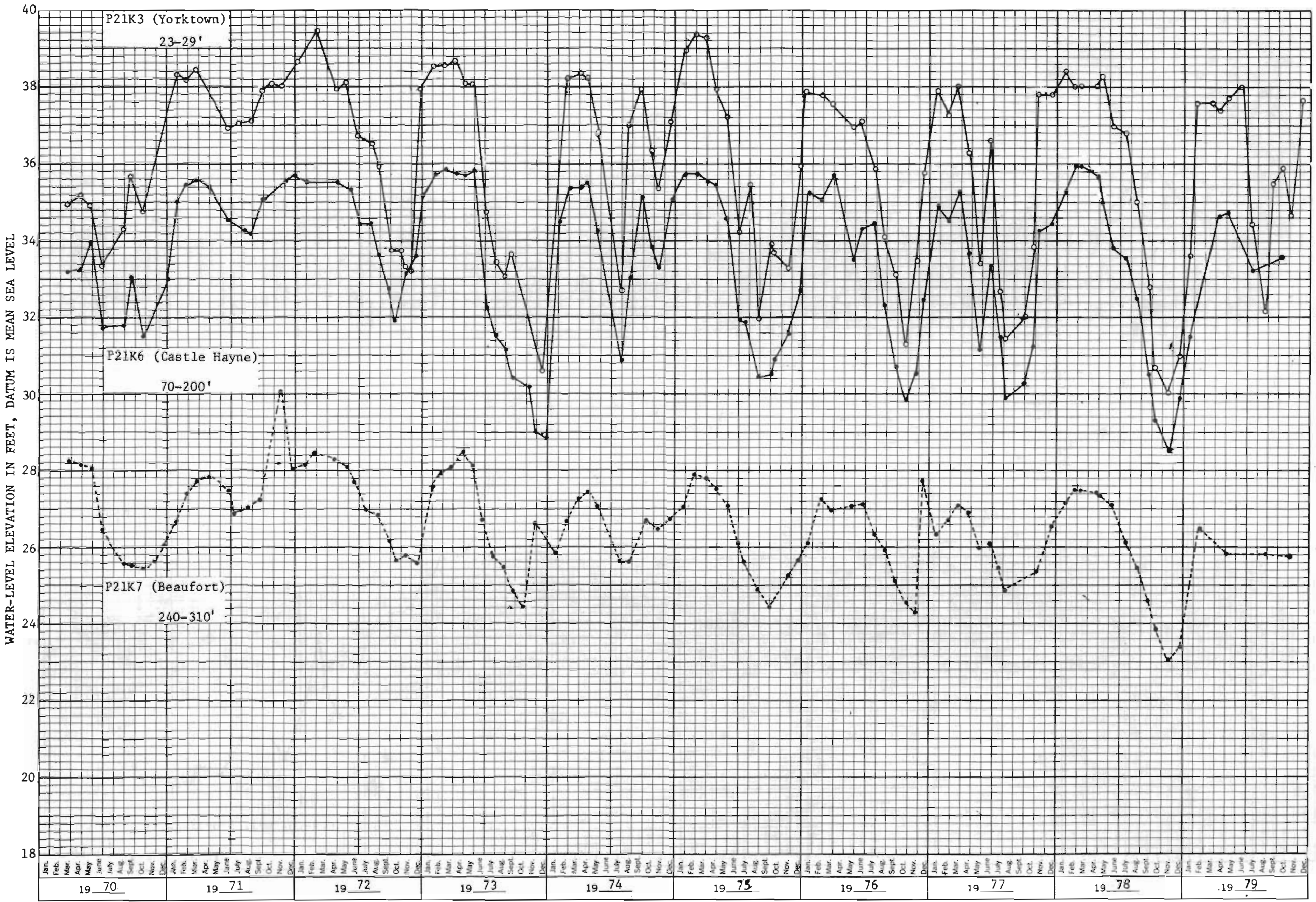


FIGURE 45 - HYDROGRAPHS OF SELECTED WELLS AT THE WILMAR RESEARCH STATION

FIGURE 46 - HYDROGRAPHS OF SELECTED WELLS AT THE WILMAR RESEARCH STATION

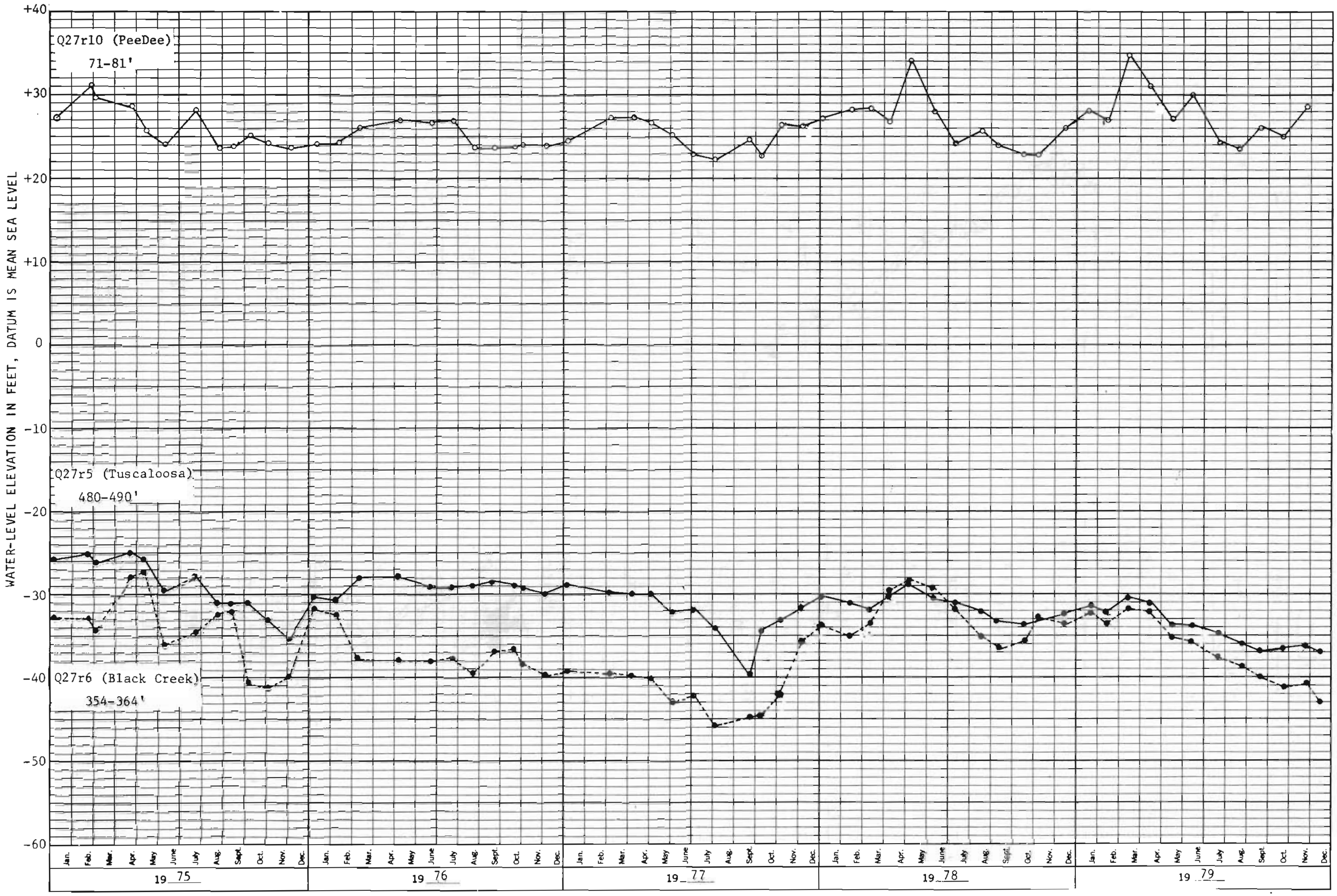


FIGURE 47 - HYDROGRAPHS OF SELECTED WELLS AT THE KINSTON RESEARCH STATION

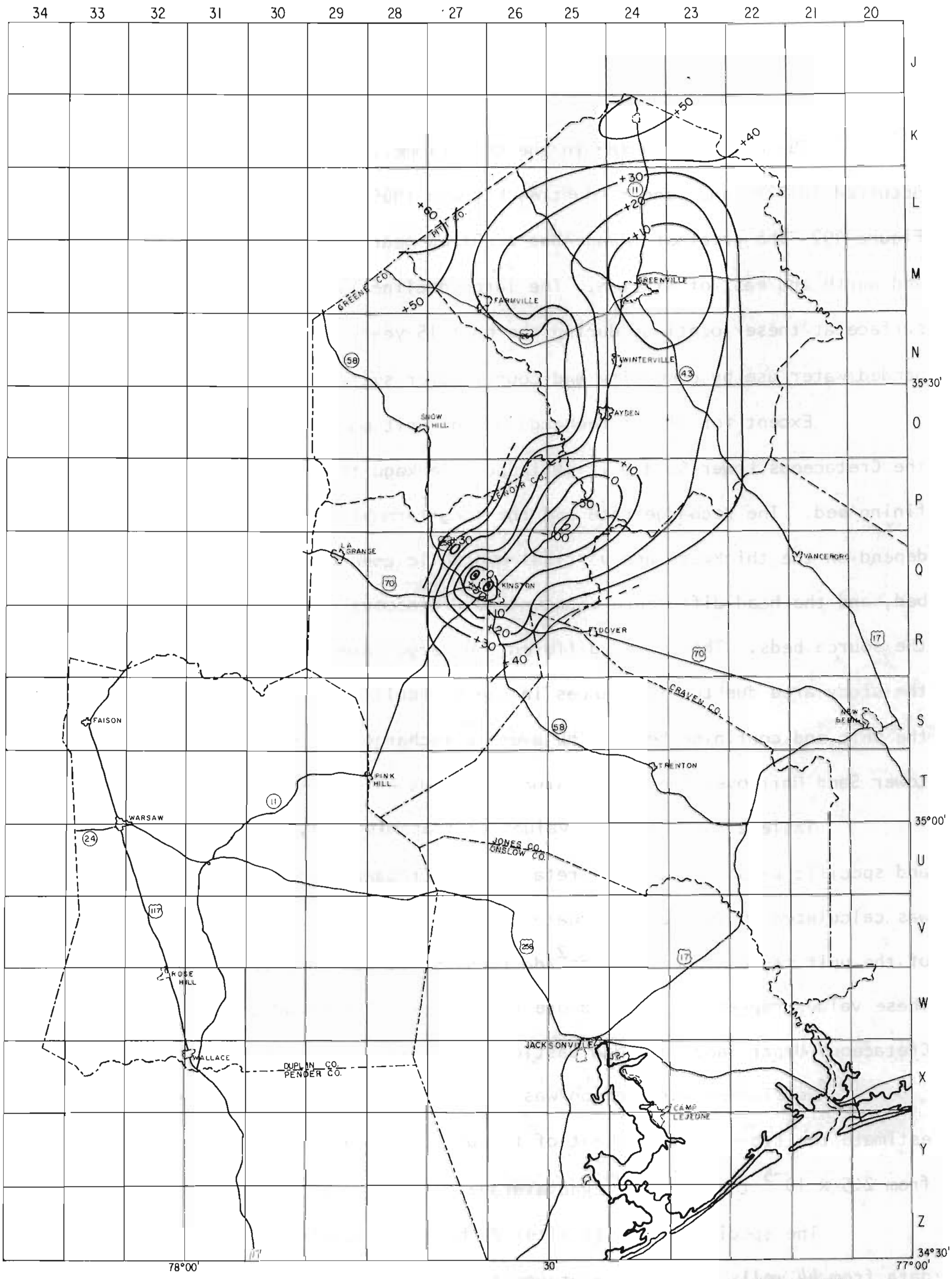


FIGURE 48 - ELEVATION OF THE POTENTIOMETRIC SURFACE IN THE CRETACEOUS LOWER SAND UNIT IN 1965

The overall decline in the potentiometric surface which has occurred in Pitt and Lenoir Counties between 1965 and 1979 is shown in Figure 49. The greatest change has occurred near Greenville and Farmville and north and east of Kinston. The large decline in the potentiometric surface at these locations during the past 15 years is the result of expanded water use by community and county water systems in the area.

Except for direct recharge on the unit outcrop, most water reaches the Cretaceous Lower Sand Unit as induced leakage through the overlying confining bed. The recharge rate and the long-term yield of the aquifer system depend on the thickness and vertical hydraulic conductivity of the confining bed, and the head difference between the Cretaceous Lower Sand Unit and the source beds. Therefore, different recharge rates will exist throughout the study area due to differences in the hydraulic properties throughout the unit and confining beds. The average recharge rate to the Cretaceous Lower Sand Unit over the entire study area was estimated to be 55,000 gpd/ft^2.

Table 2 shows typical values of transmissivity, storage coefficient, and specific capacity for the Cretaceous Lower Sand Unit. Transmissivity was calculated on the basis of data from 29 aquifer tests. The transmissivity of the unit ranges from 1,400 ft^2/da to 5,750 ft^2/da and averages 2,750 ft^2/da. These values represent intermediate transmissivities between those of the Cretaceous Upper Sand Unit and Castle Hayne Unit.

Sufficient information was available from five aquifer tests to estimate the storage coefficient of the unit. The storage coefficient ranges from 2.5×10^{-5} to 6.7×10^{-4} and averages 2.3×10^{-4}.

The specific capacity after 24 hours of pumping was calculated using data from 44 wells. The values range from 0.61 gpm/ft to 12.50 gpm/ft and

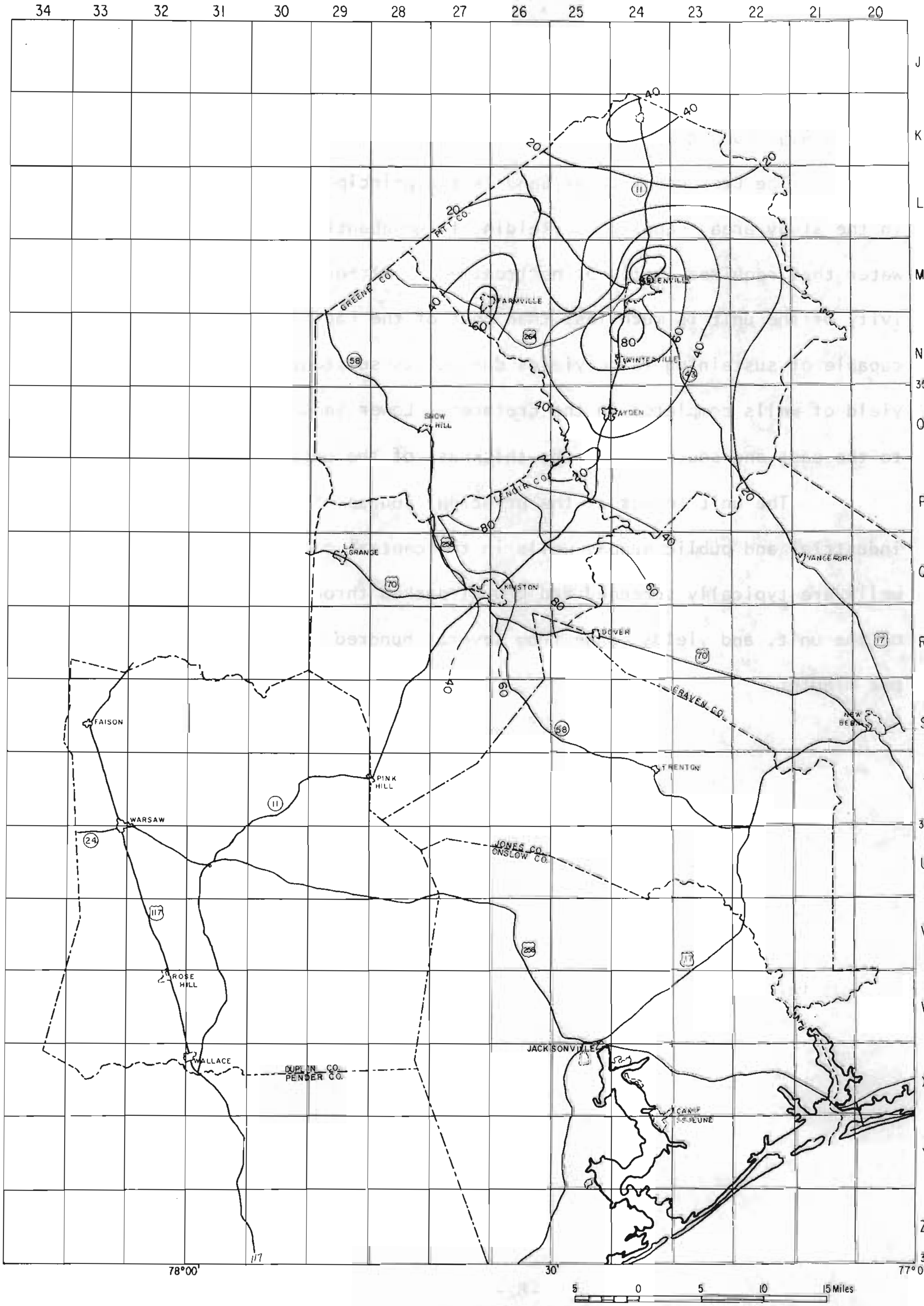


FIGURE 49 - DECLINE IN THE POTENTIOMETRIC SURFACE IN THE CRETACEOUS LOWER SAND UNIT BETWEEN 1965 AND 1979

average 4.50 gpm/ft.

The Cretaceous Lower Sand is the principal hydrogeologic unit in the study area, capable of yielding large quantities of excellent quality water that requires little or no treatment. Although the hydraulic conductivity of the unit is much less than that of the Castle Hayne Unit, it is capable of sustaining large yields due to its substantial thickness. The yield of wells completed in the Cretaceous Lower Sand Unit generally increase to the east and southeast as the thickness of the unit increases.

The unit serves as the principal source of water for the major industrial and public supply wells in the central coastal plain. The wells are typically screened and gravel-packed throughout a major portion of the unit, and yields range from several hundred to a thousand gallons per minute.

WATER QUALITY

Hydrochemistry

Although water quality is not a major consideration of this report, a brief discussion of the subject will explain why the Cretaceous aquifer system, and the Cretaceous Lower Sand Unit specifically, is favored as a source of water over the other hydrogeologic units.

Water quality is a function of the mineral composition of the sediments, the chemical and physical characteristics of the water, and the residence time of the water. As a result, the water quality of the different hydrogeologic units in the study area varies significantly. Table 3 summarizes the range and median of water quality parameters in the four major hydrogeologic units and Figure 50 uses Stiff diagrams to illustrate typical water-types in the various units. The following discussion addresses the geochemical changes which take place as water moves through a hypothetical section of the four hydrogeologic units.

In the Water Table Unit, water is typically soft, low in total dissolved solids, and corrosive as a result of its combination with carbon dioxide from the atmosphere. It also commonly contains excessive concentrations of dissolved iron. Water in this unit may be classified as a sodium-chloride-sulfate type (Figure 50).

As water moves downward into the Castle Hayne Unit, it reacts with calcium and magnesium ions in the marl and shell beds, becoming typically hard and highly alkaline. Iron, after combining with bicarbonate, precipitates out and does not normally present a problem except at those locations where the water has a short residence time as in areas of direct recharge. The Stiff diagram indicates that water from this unit is a calcium bicarbonate-type.

Hard, alkaline water enters the Cretaceous aquifer system from the Castle Hayne Unit and undergoes cation exchange, losing calcium and magnesium

Hydrogeologic Unit	Water Table Unit			Castle Hayne Aquifer System			Cretaceous Upper Sand Unit			Cretaceous Lower Sand Unit		
Concentration, mg/l	Low	High	Med	Low	High	Med	Low	High	Med	Low	High	Med
Silica (SiO_2)	1.0	5.7	2.6	1.6	39.0	16.0	5.0	38.0	15.0	.0	36.0	11.0
Aluminum (Al)	.1	1.0	.1	.0	.3	.1	.0	.5	.1	.0	.5	.1
Iron (Fe)	.40	4.00	.70	.00	8.00	.50	.00	1.60	.10	.00	4.90	.10
Manganese (Mn)	.05	.12	.05	.00	.12	.05	.00	.05	.02	.00	.30	.10
Calcium (Ca)	.3	16.0	1.2	7.1	120.0	62.0	3.7	76.0	37.0	.4	74.0	4.8
Magnesium (Mg)	.2	2.6	.8	.2	36.0	4.2	.6	41.0	6.4	.0	22.0	2.0
Sodium (Na)	2.6	24.0	8.0	3.0	25.0	6.4	4.0	270.0	26.5	12.0	640.0	78.0
Potassium (K)	.3	4.5	1.2	.8	30.5	2.0	.8	31.0	18.2	.6	18.0	7.0
Lithium (Li)	.05	.05	.05	.00	.05	.05	.05	.80	.05	.00	0.80	.05
Carbonate (CO_3)	1.0	1.0	1.0	.0	1.0	.0	.0	1.0	.0	.0	35.0	.0
Bicarbonate (HCO_3)	2.0	68.0	8.0	119.0	460.0	260.0	52.0	658.2	195.3	8.0	821.0	164.0
Sulfate (SO_4)	5.0	23.0	5.0	.0	42.0	4.0	.0	29.0	5.0	.0	80.0	5.0
Chloride (Cl)	6.0	110.0	10.0	4.8	240.0	7.4	3.0	85.0	6.5	1.0	160.0	7.7
Fluoride (F)	0.1	0.2	.1	.0	.7	.3	.0	5.3	.3	.0	160.0	.7
Nitrate (NO_3)	.05	2.00	.05	.00	1.50	.09	.00	2.70	.08	.00	230.00	.10
Phosphate (PO_4)	.05	.11	.05	.00	.90	.05	.00	.60	.05	.10	4.50	.70
Dissolved Solids	26.	265.	69.	140.	1000.	287.	73.	717.	189.	40.	1058.	193.
Hardness	4.	50.	10.	89.	475.	187.	1.	324.	117.	.0	206.	25.
pH	4.8	7.3	5.3	6.7	8.3	7.6	5.8	8.9	7.7	6.7	9.2	8.0
Specific Conductance	40.	180.	70.	212.	675.	357.	85.	1200.	329.	52.	1630.	335.
Temperature (°C)	12.	26.	18.	15.	24.	18.	16.	20.	18.	16.	20.	18.

TABLE 3 - Range and median concentrations of water quality parameters in the major hydrogeologic units

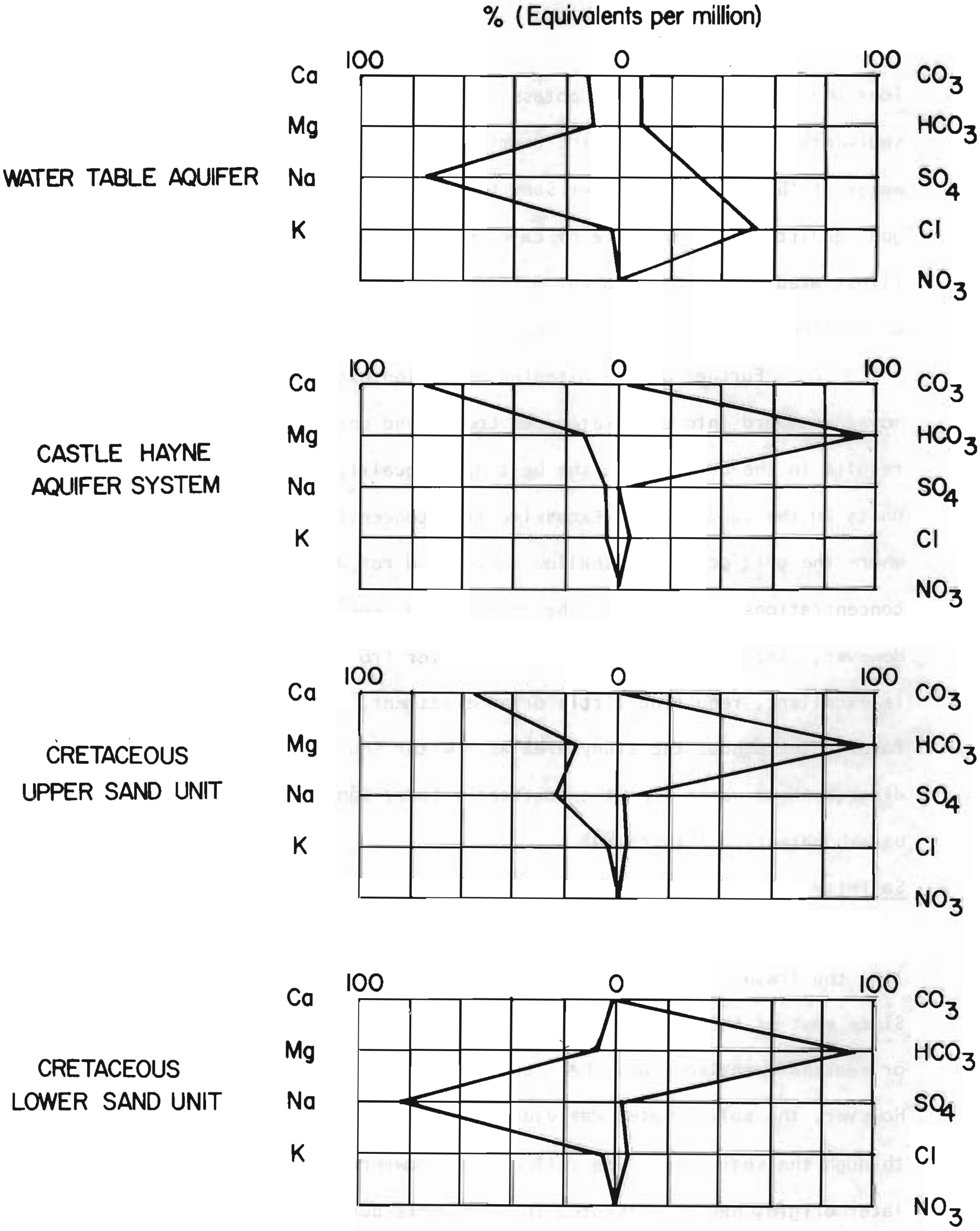


FIGURE 50 — STIFF DIAGRAMS ILLUSTRATING WATER TYPES IN SELECTED HYDROGEOLOGIC UNITS.

ions and gaining sodium and potassium ions that remained in the Cretaceous sediments following the last transgression of the sea. As a result, the water of the Cretaceous Upper Sand Unit becomes softer and of relatively good quality. The presence of calcium is still evident, however, as illustrated by the Stiff diagram (Figure 50). The water from this unit is classified as a calcium-sodium-bicarbonate type.

Further water softening by cation exchange occurs as the water moves downward into the Cretaceous Lower Sand Unit. This additional conditioning results in the unit having the best water quality of the major hydrogeologic units in the study area. Excessive iron concentrations can be a local problem where the unit occurs at shallow depths and residence time is short. Fluoride concentrations in excess of the recommended levels may also be a local problem. However, since the overall quality of water from the Cretaceous Lower Sand is excellent, requiring little or no treatment, the unit has become widely favored throughout the study area as a water source. Examination of the Stiff diagram shows water from the Cretaceous Lower Sand Unit is typically a sodium-bicarbonate-type (Figure 50).

Salinity

In the extreme eastern part of the study area, saline water underlies the freshwater within the lower sections of the Cretaceous aquifer system. Since most of the sediments in the study area were deposited in an offshore or nearshore environment, the deposits originally contained saline water. However, the saline water was eventually flushed out by fresh water circulating through the sediments. The saline water now present in the sediments is of later origin, having saturated the sediments during the last transgression of the sea. Following the lowering of sea level, flushing of this saline water began. As a result, the saline water in the aquifer system today represents residual sea water that has not been completely flushed out of the system and, therefore, water in the system becomes progressively more saline toward the coast and with depth. Figure 51 shows the locations in the study area where the chloride concentration in all or part of the Cretaceous Lower Sand Unit exceeds 250 milligrams per liter (mg/l).

The modification of groundwater flow patterns by large-scale withdrawals from the Cretaceous aquifer system could conceivably affect the distribution of the saline water within the system. Chloride concentrations near eastern pumping centers may increase in the future due to the vertical or lateral movement of water towards the wells in response to changing hydraulic gradients. At this time, however, data from water quality monitoring wells do not indicate any significant change in the salinity of the water at sites near the eastern boundary of the study area.

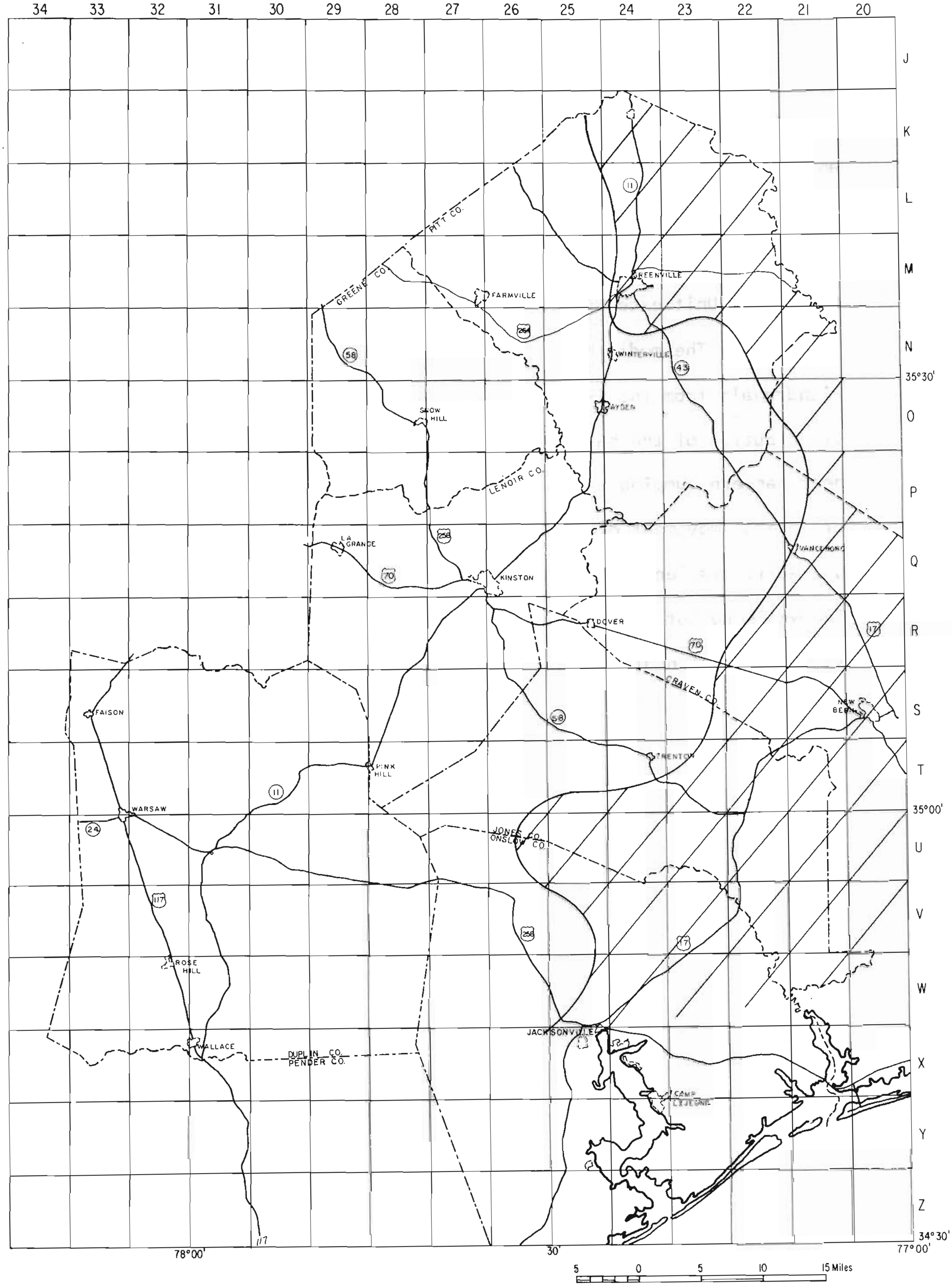


FIGURE 51 - MAP SHOWING CHLORIDE DISTRIBUTION IN THE CRETACEOUS LOWER SAND UNIT

▨ AREA WHERE CHLORIDE CONCENTRATION EXCEEDS 250 MG/L IN ALL OR PART OF UNIT

WATER USE

Withdrawal Rates

Water used by most industrial and public water supply systems in the study area is obtained from the Cretaceous Lower Sand Unit. Figure 52 shows the locations of water systems withdrawing more than 100,000 gallons of water per day from the Cretaceous aquifer system. The area of the shaded circles represents the magnitude of withdrawals at that location. Withdrawal rates range from 100,000 gallons per day (gpd) for the Jones County Water System to almost 5 million gallons per day (mgd) for the Kinston municipal system. Industries also withdraw significant quantities of water as evidenced by Dupont's water use of 3 mgd at their plant near Graingers.

Further inspection of Figure 52 reveals that the largest water users are concentrated in the northern and central sections of the study area. Nearly 18 million gallons, or almost two-thirds of the 27 million gallons of water used daily by the major water systems, is withdrawn from the northern half of the study area. Not surprisingly, this is the same area which is experiencing the greatest decline in the potentiometric surface of the Cretaceous aquifer system.

Figures 53 through 58 show the average withdrawal rates during the last ten years of six selected water systems in the study area. Figure 53 shows that the withdrawal rate at Kinston, the major water user in the central Coastal Plain, has increased by more than 40 percent in the past 10 years. New Bern (Figure 54) has increased its withdrawals at Cove City by 50 percent since 1971, and has recently added another well to the system. Withdrawal rates at the Jacksonville water system (Figure 55) were relatively constant until 1976 when the municipal system began supplying water to parts of Onslow County. Since that time, water use has increased by 25 percent.

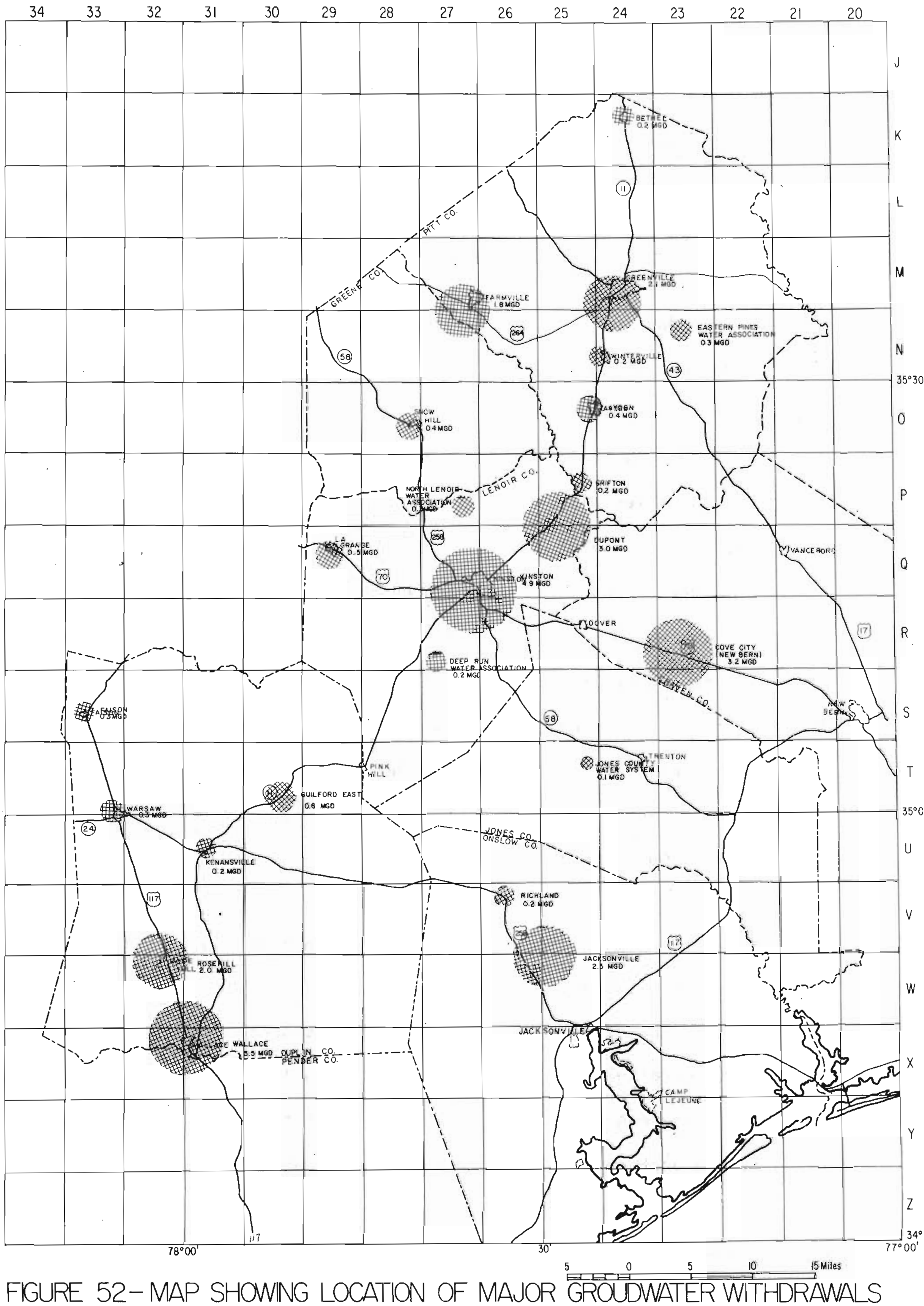


FIGURE 52 – MAP SHOWING LOCATION OF MAJOR GROUDWATER WITHDRAWALS FROM THE CRETACEOUS AQUIFER SYSTEM

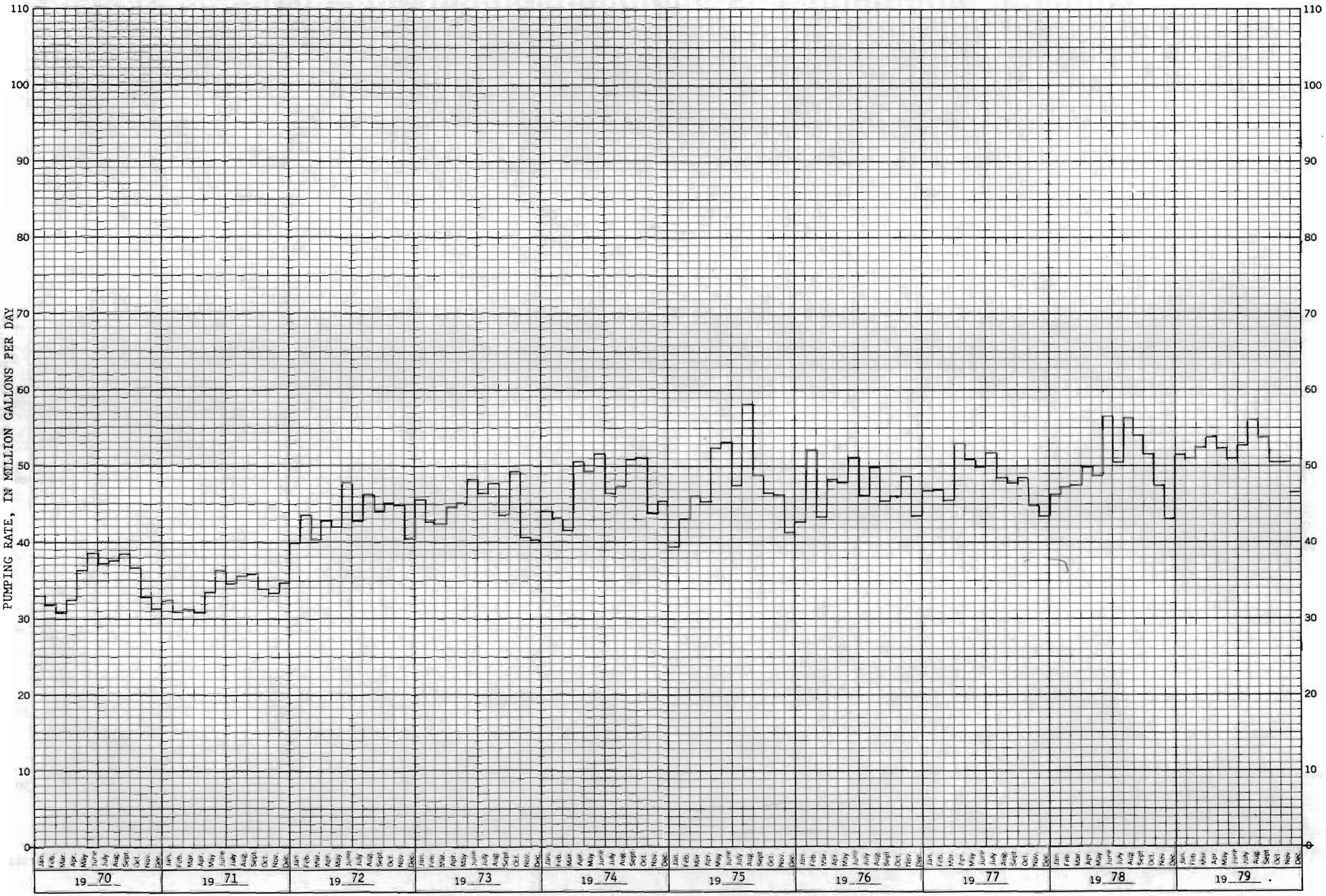


FIGURE 53 - GRAPH OF WITHDRAWALS FROM KINSTON MUNICIPAL WELLS

FIGURE 54 - GRAPH OF WITHDRAWALS FROM NEW BERN MUNICIPAL WELLS

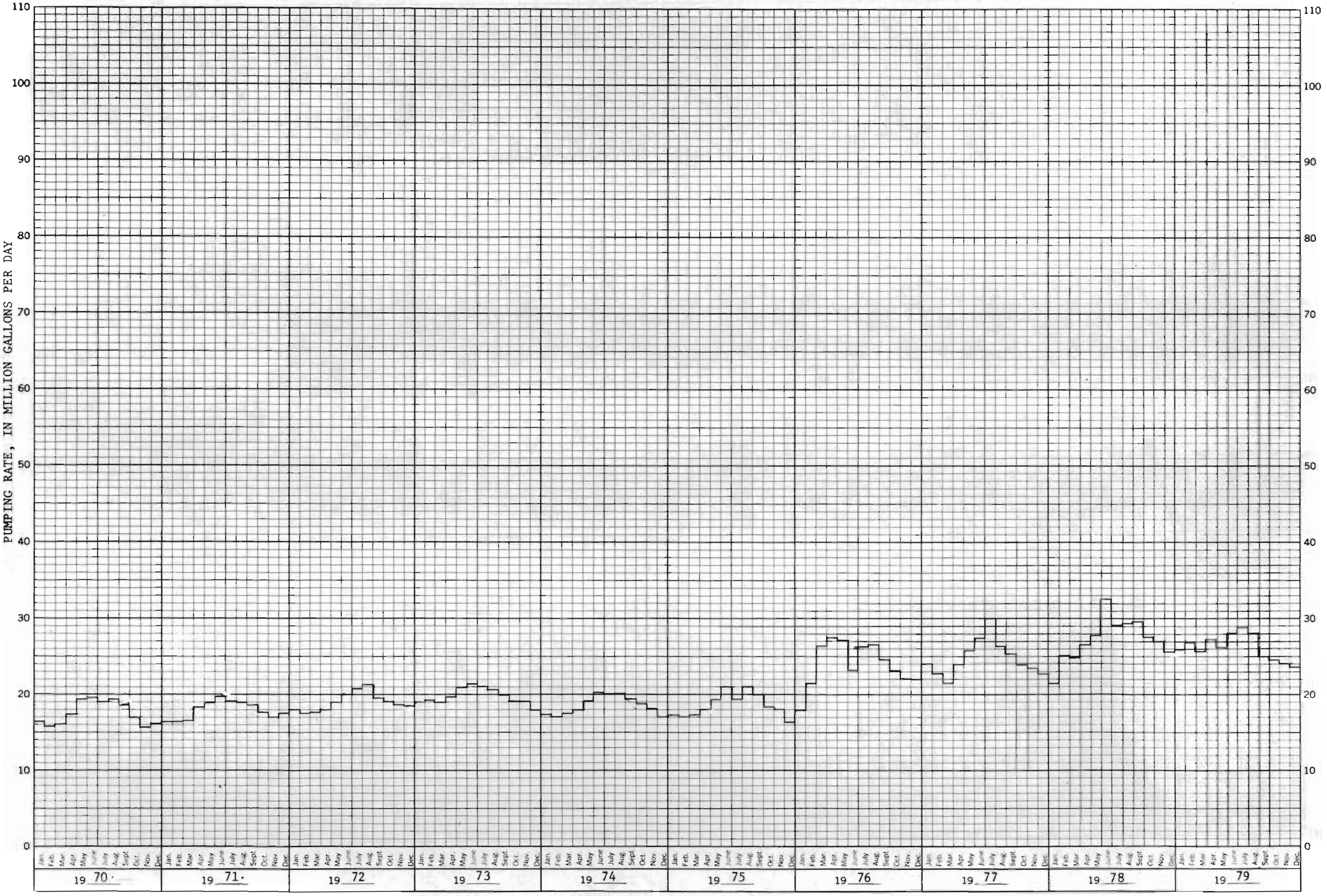


FIGURE 55 - GRAPH OF WITHDRAWALS FROM JACKSONVILLE MUNICIPAL WELLS

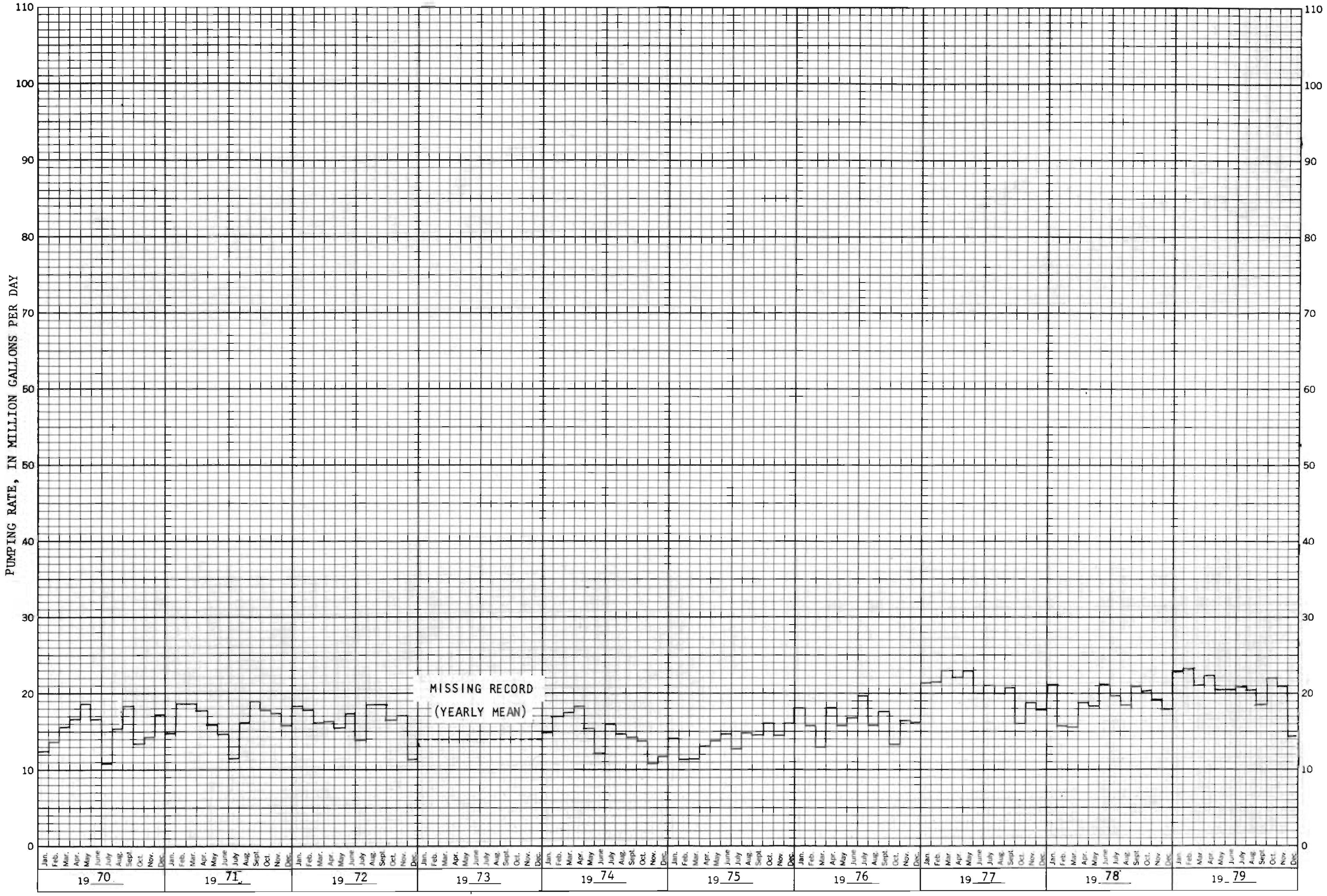


FIGURE 56 - GRAPH OF WITHDRAWALS FROM GREENVILLE MUNICIPAL WELLS

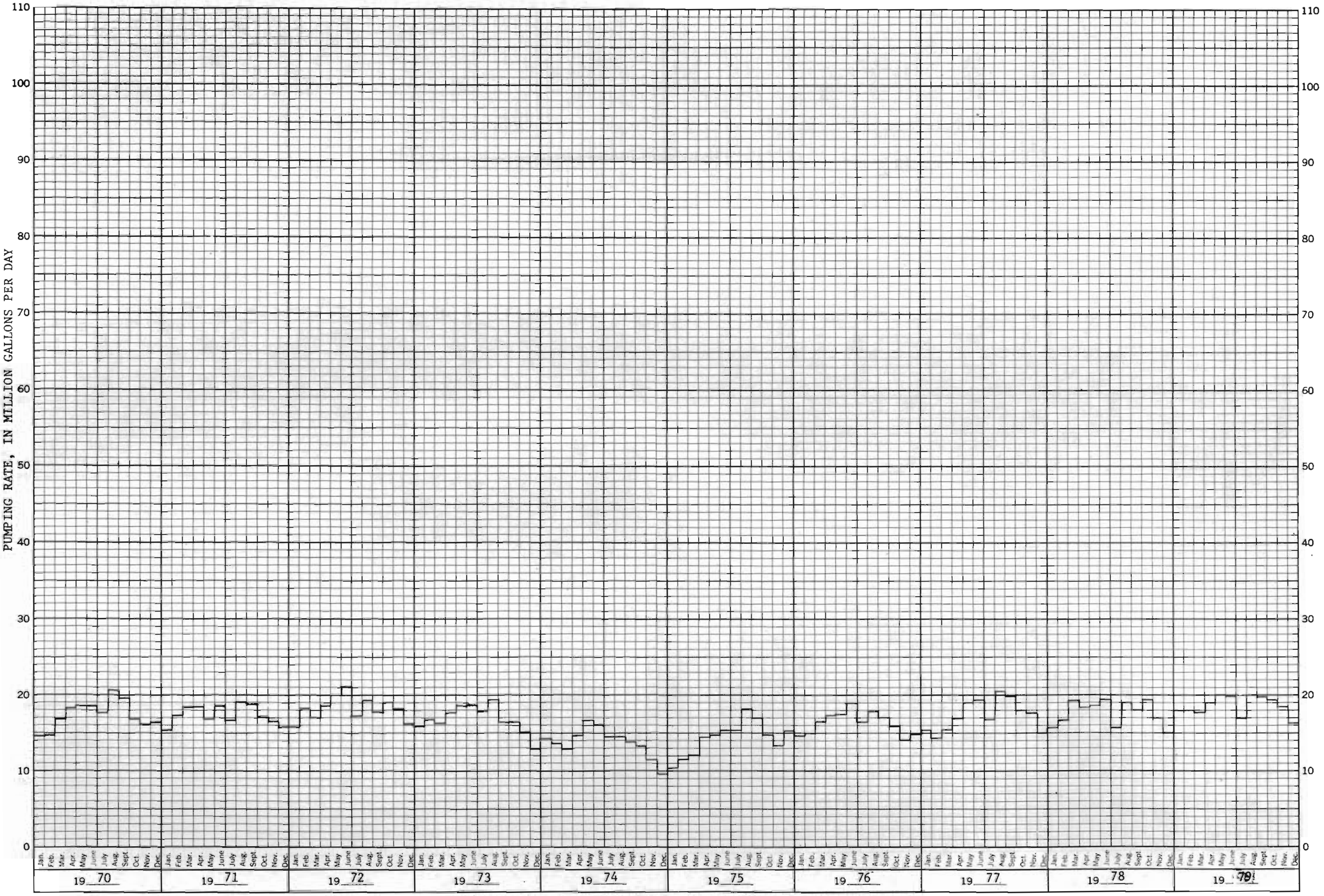


FIGURE 57 - GRAPH OF WITHDRAWALS FROM FARMVILLE MUNICIPAL WELLS

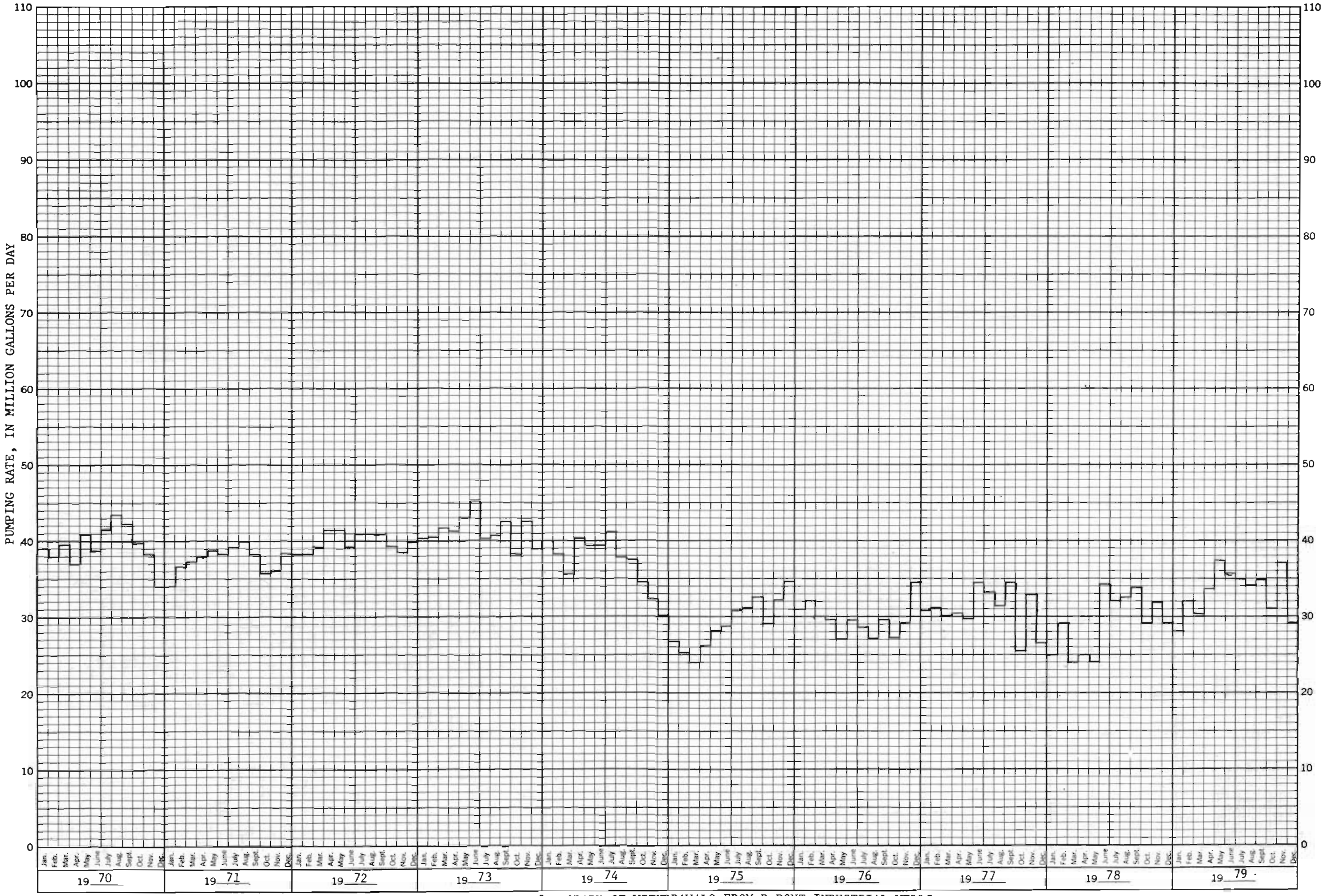


FIGURE 58 - GRAPH OF WITHDRAWALS FROM DuPONT INDUSTRIAL WELLS

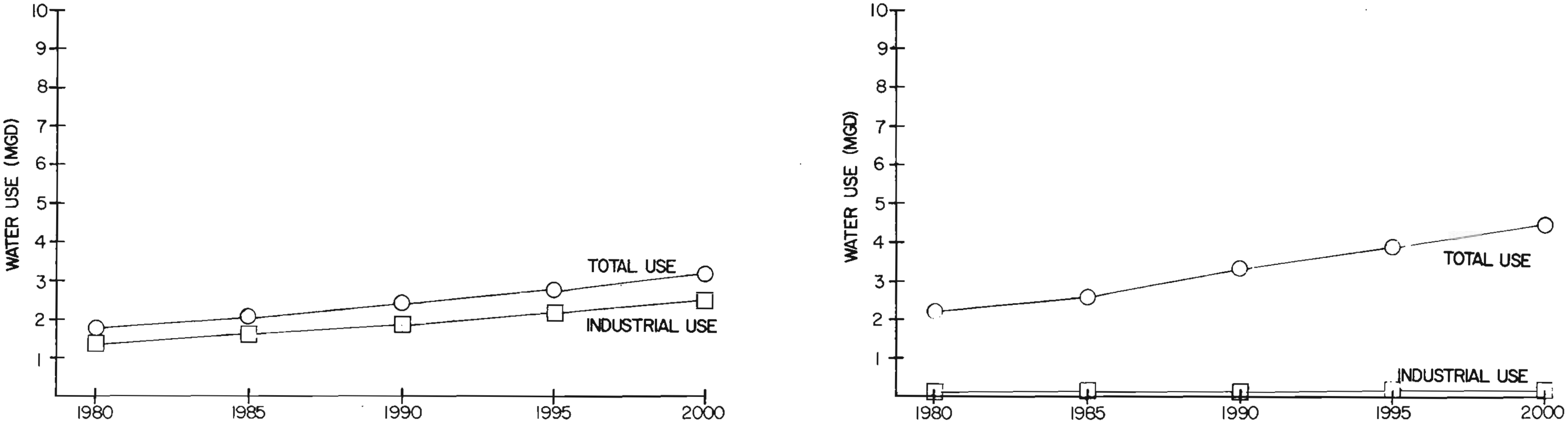
Greenville (Figure 56) withdraws approximately 2.1 mgd of groundwater to supplement water withdrawn from the Tar River. Although groundwater use represents only about 30 percent of Greenville's total water use, groundwater withdrawals have increased by 40 percent since 1970. Farmville (Figure 57) has maintained its withdrawal rate at about 2 mgd, and Dupont (Figure 58) has actually decreased water use approximately 25 percent by recycling water whenever possible. Overall, however, the trends has been towards increased water use over the entire region.

Projected Water Use

Future water use can be approximated from the projected population growth of an area. State population projections were made according to Federal guidelines whereby the State prepared disaggregations at the county level. The county data was then used as the basis for the municipal projections.

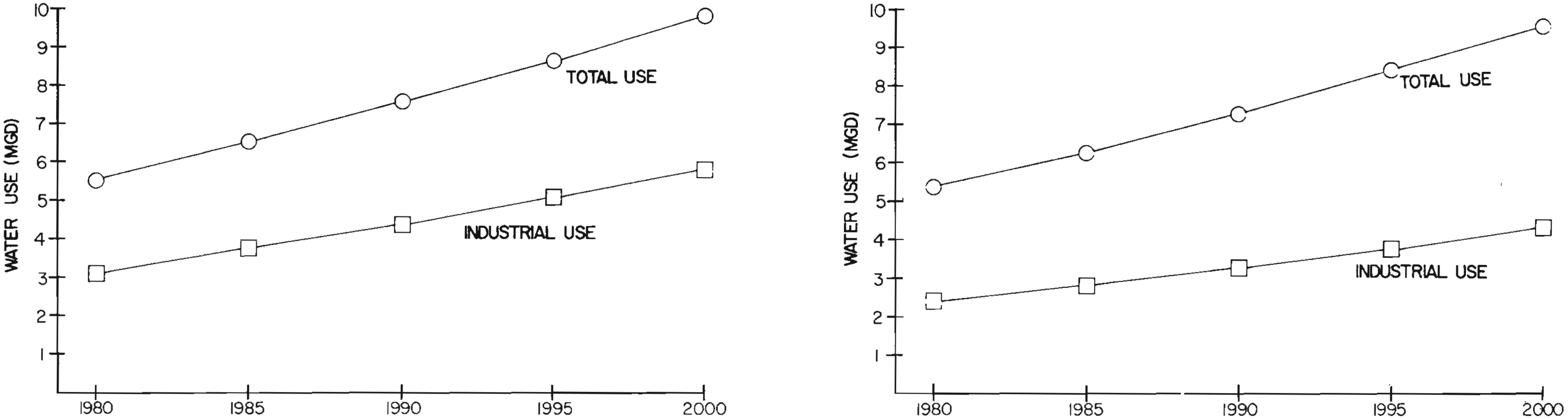
Using the projected populations and per capita water use values, projected water use for nonindustrial purposes was obtained. Industrial water use was projected separately based on OBERS indices of production. The industrial water use was then added to nonindustrial water use to obtain a total water use value.

Projected water use estimates for six selected communities, the seven counties, and the central Coastal Plain region as a whole are shown graphically in Figures 59 through 62. The entire region can expect water use to increase by almost 60 percent during the period 1980 to 2000. On an individual county basis, water use during the same period will increase by 29 percent in Greene County to 67 percent in Pitt County. The six individual communities, however, will show the most dramatic increases in water use, averaging 81 percent growth during the 20-year period. These additional



PROJECTED WATER USE FOR FARMVILLE

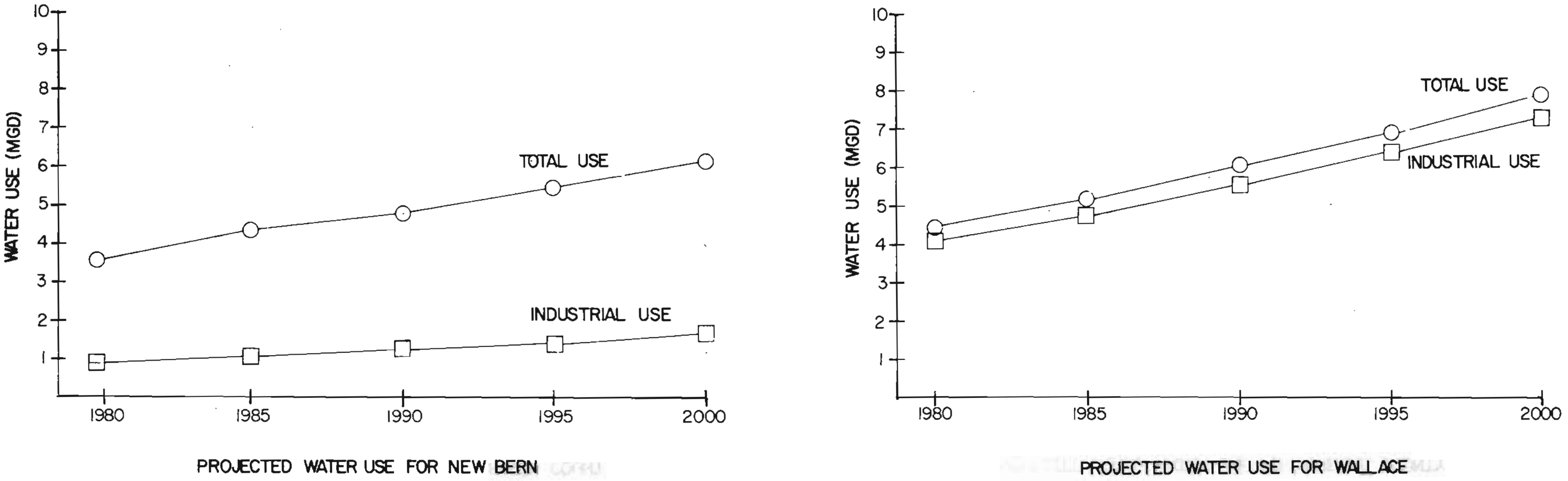
PROJECTED WATER USE FOR JACKSONVILLE



PROJECTED WATER USE FOR GREENVILLE

PROJECTED WATER USE FOR KINSTON

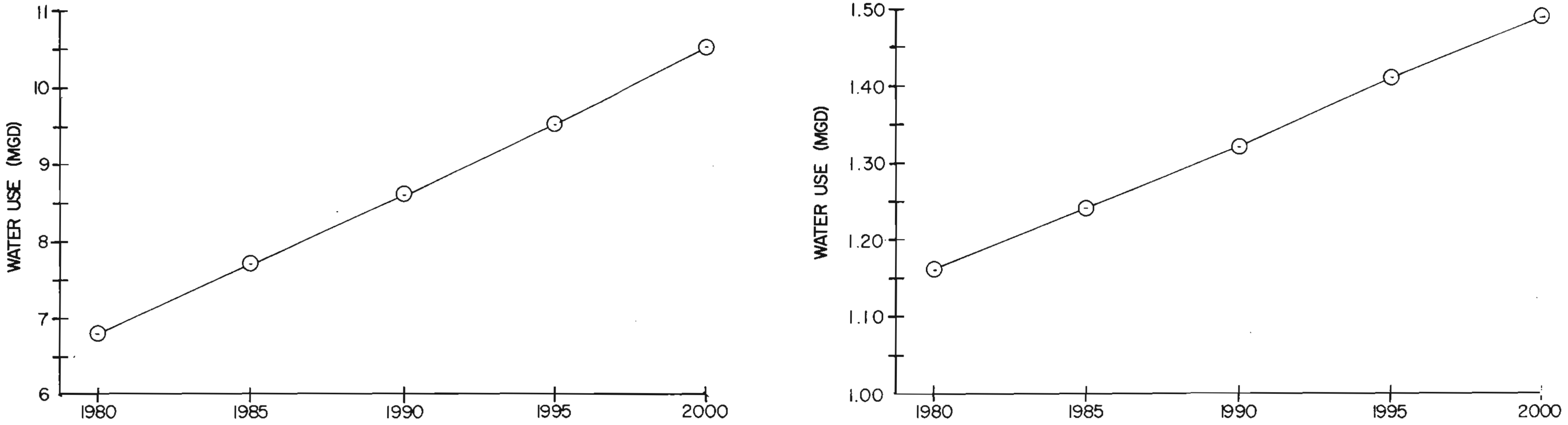
FIGURE 59- PROJECTED WATER USE OF FOUR SELECTED COMMUNITIES



PROJECTED WATER USE FOR NEW BERN

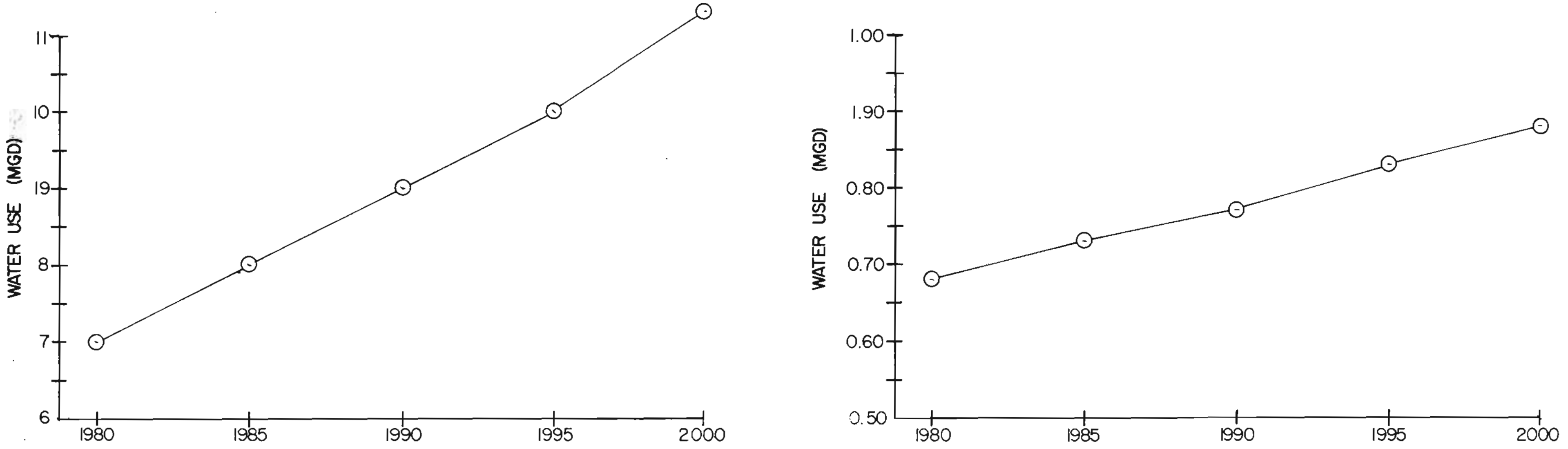
PROJECTED WATER USE FOR WALLACE

FIGURE 60 – PROJECTED WATER USE OF TWO SELECTED COMMUNITIES



PROJECTED TOTAL WATER USE FOR CRAVEN COUNTY

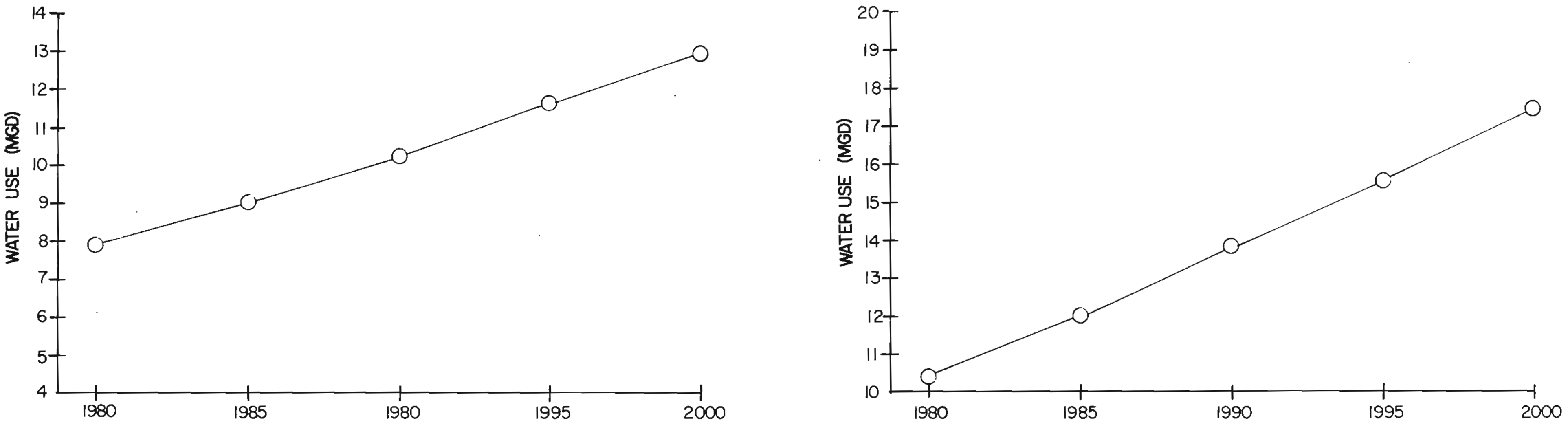
PROJECTED TOTAL WATER USE FOR GREENE COUNTY



PROJECTED TOTAL WATER USE FOR DUPLIN COUNTY

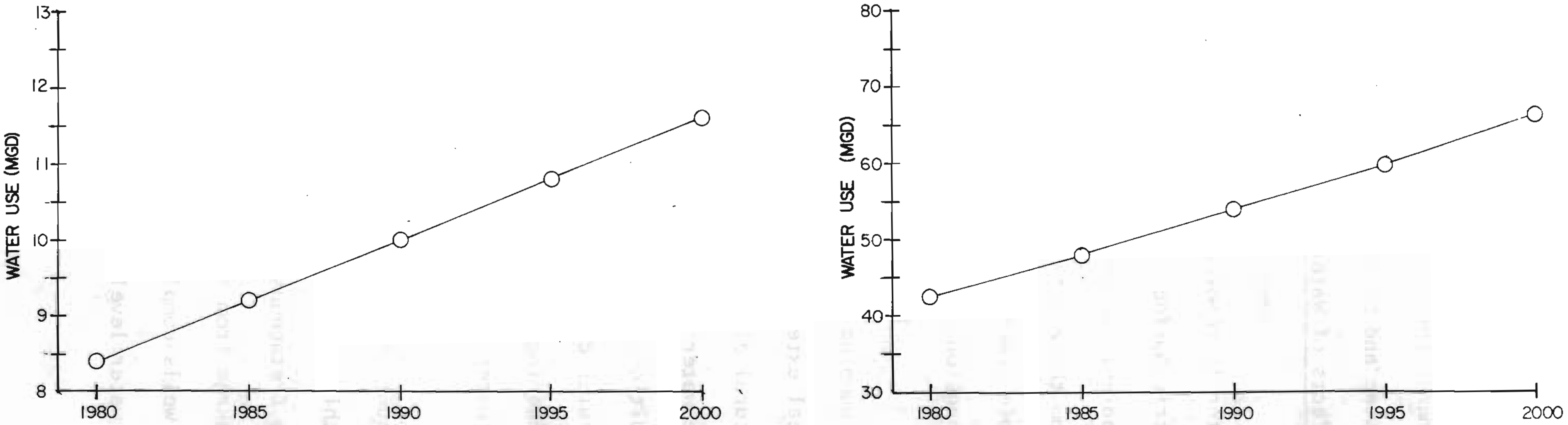
PROJECTED TOTAL WATER USE FOR JONES COUNTY

FIGURE 61 – PROJECTED WATER USE OF FOUR SELECTED COUNTIES



PROJECTED TOTAL WATER USE FOR LENOIR COUNTY

PROJECTED TOTAL WATER USE FOR PITT COUNTY



PROJECTED TOTAL WATER USE FOR ONSLOW COUNTY

PROJECTED TOTAL WATER USE FOR THE SEVEN — COUNTY REGION

FIGURE 62 – PROJECTED WATER USE OF THREE SELECTED COUNTIES AND THE ENTIRE REGION

demands for water in the future will further stress the Cretaceous aquifer system and perpetuate falling water levels.

Effects of Water Withdrawals

When a well, completed in the Cretaceous aquifer system, is pumped, water is removed from storage from the surrounding aquifer and the potentiometric surface is lowered creating a cone of depression with a hydraulic gradient towards the well. Under confined conditions, the water removed from the aquifer causes a drop in artesian head, but does not normally cause dewatering. Instead, the water is released from storage due to the expansion of the water and compression of the aquifer.

The amount the water level is lowered is a function of the rate of pumping, the transmissivity and storage coefficient of the aquifer, the areal extent of the aquifer, and the location and quantity of recharge and natural discharge. As pumping continues and the cone of depression expands, the water level in the well continues to decline in order to provide the additional head necessary to remove water from storage at increasingly greater distances. The rates of expansion of the cone of depression and the deepening of the water level decrease with time as increasingly larger volumes of water are removed from storage with continued horizontal expansion.

A cone of depression continues to deepen and expand until the amount of water being withdrawn is balanced by an equal amount of recharge within the radius of influence. Equilibrium of a cone of depression within the Cretaceous aquifer system occurs when the cone intercepts sufficient leakage from the overlying source beds to equal pumpage. The hydrographs of wells completed in the system (Figures 38 to 47) show continued deepening of water levels within the cones of depression, indicating that equilibrium has not yet been reached.

The high degree of confinement and the low storage coefficient of the Cretaceous aquifer system result in a cone of depression which deepens rapidly and is areally extensive. These characteristics of the aquifer system often result in interference, whereby cones of depression of pumping wells are superimposed upon each other and water-level elevations within the cones are lower than those elevations which would have resulted had not interference occurred.

The extent and magnitude of changes in the groundwater regime of the study area caused by the withdrawal of water from the Cretaceous aquifer system can be appreciated by reviewing earlier groundwater reports. Brown (1959, p.57) in his Greenville area report referred to flowing wells along Contentnea Creek, especially near Lindell and northeast of Hookerton. Furthermore, he reported that artesian pressures are generally within a few feet of land surface throughout the area. LeGrand (1960, p.50) also reported on water levels in his Wilmington area report. Referring to the groundwater resources of Lenior County he wrote that "the artesian head in the Black Creek and Peedee formations is above land surface in much of the county and in those areas flowing wells can be developed. Most of the flows come from the Black Creek formation, but in the valleys east and south of Kisnton the Peedee is the source of flows from relatively shallow depths. Owing to the small amount of artesian water used, there has been no regional lowering of head in the county." He added that, "local cones of depression exist around the city wells at Kinston and around the Dupont Plant near Grifton. The extent of pumpage is great enough to cause some of the previous flowing wells to stop flowing within a radius of a few miles from the centers of both cones."

Inspection of the map illustrating the potentiometric surface of the Cretaceous Lower Sand Unit in 1979 (Figure 37) shows that water levels in those areas referred to by Brown have declined between 50 and 80 feet since his report was released. Similarly, water levels in Lenoir County have declined between 10 and 80 feet since LeGrand published his observations. In effect, the cones of depression around the numerous pumping centers have deepened and expanded to the extent that the entire Cretaceous aquifer system underlying the study area is now stressed by heavy pumping.

Correlation of Water Levels and Withdrawal Rates

Visual inspection of the hydrographs of monitor wells (Figures 38 to 47) indicate that changes in water levels in the Cretaceous aquifer system generally reflect changes in the pumping rates of water systems in the study area. Carrying this observation a step further, the mean pumping rates of selected water systems were plotted against the mean annual water-level elevations of nearby monitor wells. Lines of best fit were drawn through the points, and correlation coefficients were calculated. In the four cases analyzed, the correlation coefficients ranged from -0.92 to -0.97. These values show a high degree of correlation between the data sets, which indicates that the increasing rates of withdrawal have a causal effect on declining water levels in the study area.

Sufficient historical data was available to project water-level elevations at Cove City and Kinston. Utilizing the water-use projections and the equations derived from the linear regression analyses, future water-level elevations at the two pumping centers were estimated. Such estimates can be useful in preventing pumping water levels from eventually being drawn down below the top of the aquifer unit. The initial consequence of deeper pumping water levels is higher pumping costs; however, the eventual outcome may be dewatering of the confined unit and the coincident problems of decreased aquifer efficiency, lower well yields, lesser water quality, and land subsidence.

At Cove City, it was assumed that the top of the Cretaceous Lower Sand Unit occurs at 400 feet below sea level, and the pumping water level is 90 feet below sea level. Therefore, the pumping water level could be drawn down an additional 310 feet before it reaches the top of the unit. Assuming that proper well spacing in the future will mitigate the effects of further interference, at the projected rate of water use, the unit could provide water until the middle of the next century before dewatering would begin. As a wise management practice, however, dewatering is a condition that must be avoided. Therefore, pumping rates should be held constant or even reduced long before pumping water levels approach the top of the unit. The estimate may also be optimistic as the possiblity of introducing saline water into the pumping wells was not considered in the calculations. Therefore, as water levels are drawn down, the possibility of such an occurrence should be evaluated and the estimates modified, if necessary.

At Kinston, the top of the Cretaceous Lower Sand Unit is between 130 and 180 feet below sea level and the pumping water levels are between 62 and 142 feet below sea level. The amount of avilable drawdown at these wells ranges from 38 to 94 feet. Applying the situation at Kinston to the same analysis as was employed in the Cove City example, indicates that pumping water levels in a majority of the wells will be approaching the top of the aquifer unit by the year 2000. In two wells, however, the water levels may be near the top of the aquifer units by as early as 1990. As in Cove City, the declining water levels must be anticipated and pumping rates adjusted accordingly. In fact, serious efforts towards stabilizing water levels in the Kinston area should be initiated immediately, as groundwater "mining" may be occurring at this time. Since, the Cretaceous Lower Sand Unit underlying Kinston does not contain saline water, the contamination of water supplies by excessive concentrations of chloride is not a problem.

WATER MANAGEMENT

Need for Management

Until recently, it was thought that groundwater supplies in the Coastal Plain of North Carolina were virtually limitless. Because it was generally accepted that there were adequate amounts of groundwater to meet any need, little water management was practiced. It is now apparent from the record of progressively declining water levels that the total quantity of water that can be withdrawn from the Cretaceous aquifer system is limited.

As was discussed in an earlier section, the Cretaceous aquifer system is currently the primary source of water for most of the central Coastal Plain, and will continue to be an important water source in the future. Since projections show that water use will increase with continued industrial and urban growth in the area, measures to insure the availability of adequate quantities of quality water are advisable.

Safe Yield

Water system managers often express a desire for an upper estimate of the amount of water that may be withdrawn from an aquifer unit. The concept of safe yield was introducted by O. E. Meinzer to estimate the maximum supply of water that can be pumped perennially from an aquifer without causing a decrease in overall water quantity or quality. Walton (1970, p.608) used the term, "practical sustained yield" to describe essentially the same concept. It was accepted that safe yield was limited by the long-term mean annual recharge of the groundwater reservoir. It was also recognized that safe yield could be further reduced by the transmissive properties of the aquifer unit. Under the assumptions of this concept, storage depletion or groundwater "mining" occurred when withdrawals continually exceeded the mean annual recharge.

Because an estimate of safe yield also depended upon, among other things, an unchanging balance between pumping, recharge, and natural discharge, changes in any of these factors would cause changes in the estimate of safe yield. The inability to control or predict changes in the many variables was a major deficiency of the concept. As a result, safe yield was a subject of controvery regarding its psuedohydrologic character (Kazmann, 1965, p.161), and has now fallen into disuse. Therefore, no safe yield values were estimated for communities in the study area.

Recommendations

Management efforts should be directed at two major areas: existing well systems and future well systems. Existing systems should be monitored regularly in order that water-use and water-level data are well documented. Each production well should be equipped with a metering device for recording the amount of water withdrawn. Also, the pumping water level of each well should be measured monthly. Utilizing the data, optimum pumping rates and pumping water levels should be established. Maintaining optimum pumping rates and water levels will limit the total yield of a water system, but will also limit pumping costs, and prevent dewatering of the confined unit and its coincident problems.

In the case of future well systems, existing hydrogeologic data should be evaluated and the proposed system planned accordingly. Production wells should be designed and constructed in a manner that insures maximum efficiency to reduce drawdowns to the extent possible. Also, permanent pumps should be matched to the tested capacities of the wells. Complete well design and construction information should be made available to the water system manager by the project engineer or drilling contractor. During the test drilling and well construction, pertinent hydrogeologic data should be collected and also filed with the water system manager. The data should include, but not be limited to, the driller's log, formation samples, geophysical logs, water quality analyses, record of static water level, and pumping test results. The hydrogeologic data, well design information, and well maintenance records should be retained by the water system manager for future reference. This information can aid in solving any well problems which may develop in the future, and in planning additions to the well field.

Well fields should be located, to the extent practical, in areas where pumping will have minimal effects on regional interference. Similarly, wells within the fields should be properly spaced in relation to each other to mitigate the effects of localized interference.

When planning future well systems, the feasibility of withdrawing water from units overlying the Cretaceous Lower Sand Unit should be investigated. The Castle Hayne and Yorktown hydrogeologic units underlying many areas in the eastern part of the central Coastal Plain are capable of supplying moderate to large quantities of water. These units are underutilized due to the fact that the water they yield usually requires more treatment than water withdrawn from the Lower Cretaceous Sand Unit. In the future, however, the Castle Hayne and Yorktown Units may be the only economical alternatives to the Cretaceous aquifer system. While relatively little water is pumped from the Cretaceous Upper Sand Unit, additional withdrawals from the unit would be self-defeating, as pumping water from the Cretaceous Upper Sand would decrease recharge to the Cretaceous Lower Sand.

There are several other measures which also deserve consideration and could be implemented if conditions warrant. Public water systems could strive to conserve water by encouraging their customers to limit water use to actual needs. Simple conservation practices result in more efficient use of water and eliminate waste. Industries could also contribute to water conservation by reducing their water requirements and by recycling process water where practical and economical. In addition, certain industries could investigate the possibility of using water of the lowest quality feasible for the intended use.

Two final alternatives offered for future consideration are collector wells and the conjunctive use of groundwater and surface water. Application of these alternatives, however, is limited to those areas in proximity to streams or rivers. For maximum advantage, collector wells are located adjacent to surface recharge sources. Utilizing horizontal screens arranged towards the surface water source in a semi-radial fashion, the collector well induces infiltration of water into the aquifer from the stream or river. The major disadvantage to this method of water recovery is the fact that water induced from a stream or river will require more treatment than that water withdrawn from the Cretaceous Lower Sand Unit.

Conjunctive use of groundwater and surface waters, as currently practiced in Greenville, is a viable alternative to municipalities located in proximity to major streams or rivers. While surface water use requires treatment beyond the budgets of small communities, larger municipalities, whose rates of growth and development demand increasingly greater amounts of water, could finance the necessary treatment facilities. For instance, conjunctive use would be the most practical alternative for a municipal system in an area where pumping water levels are approaching the top of the confined unit. Because treatment plant design and construction requires a considerable amount of time, adoption of conjunctive use practices must be anticipated, and construction begun in time to meet projected water demands.

SUMMARY

Groundwater is the principal source of water for most municipal, industrial, and domestic water systems in the central Coastal Plain of North Carolina. Since the late 1960's the potentiometric surface of the principal hydrogeologic unit has declined significantly in response to increasing pumping rates.

Sediments underlying the study area consist of gravel, sand, silt, clay, limestone, and combinations of these lithologies. They are formed into layers or lenses varying in lithology, thickness, and texture. The sediments are divided into stratigraphic units on the basis of superposition and range in age from Lower Cretaceous to Recent.

The sediments are also subdivided into hydrogeologic units on the basis of hydraulic conductivity and other hydrologic characteristics.

The Water Table Unit is continuous over the entire area. Groundwater within the unit is unconfined. Recharge occurs on the interfluves and averages 9.5 inches annually, or about 18 percent of total annual precipitation. The Water Table Unit is not an important source of water to wells, but does serve as a groundwater reservoir supplying baseflow to streams and recharge to the lower units.

The Yorktown Unit occurs as a confining bed in the western part of the study area. Towards the east, the unit grades from clay and silt to sand and shells forming a confined aquifer.

The Castle Hayne Unit is a confined aquifer system present in the eastern half of the study area. The limestone and sand unit is characterized by relatively high transmissivities and is capable of sustaining well yields up to 1000 gpm in the study area. Recharge to the Castle Hayne is due primarily to leakage through the overlying confining bed and averages 240,000 gal/da/mi^2.

The Cretaceous Upper Sand Unit consists of interbedded sand and clay layers and occurs in the eastern three-fourths of the study area. The unit, which attains a maximum thickness of 100 feet, contains groundwater under confined conditions. Groundwater flow patterns within the unit have been modified by leakage to the Lower Unit as a result of heavy withdrawals. Water level records for much of the unit show a trend of declining water levels also due to leakage. Recharge to the unit is through the overlying confining bedsand averages 56,000 gal/da/mi^2. The limited thickness of the unit is reflected by relatively low transmissivity values. As a result, well yields are typically between 20 and 100 gpm.

The Cretaceous Lower Sand Unit consists of interbedded sand and clay and occurs throughout the entire study area. The unit, which attains a maximum thickness of 700 feet, contains groundwater under confined conditions. The unit has a mean transmissivity of 3,750 ft^2/da and a storage coefficient of 2.3×10^{-4}. Recharge, which averages 55,000 gal/da/mi^2, is the result of leakage from the overlying source beds.

Since the late 1960's, water levels in the Cretaceous aquifer system have declined significantly due to large-scale municipal and industrial withdrawals. These withdrawals have caused regional depression of the potentiometric surface, with water levels near major pumping centers declining 80 feet in 15 years.

Water quality in the study area varies between the hydrogeologic units. Water quality in the Cretaceous Lower Sand is generally excellent except in those areas where residual sea water remains within the sediments. Water in the overlying units is of lesser quality, frequently requiring some degree of treatment.

Withdrawal rates have increased signigicantly during the last 20 years. Water-use projections indicate the trend will continue. Comparison of past pumping reates with declining water levels shows a high degree of correlation. Realization that groundwater supplies are limited suggests that water management is advisable.

ACKNOWLEDGEMENTS

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APPENDIX 1 - LOG OF TEST WELL 027j5 AT MAURY, NORTH CAROLINA

Depth (Feet)	Thickness (feet)	Description of Sample
		Quaternary - surficial sands
0-14	14	Sand, grey, fine to medium, with clay
14-17	3	Clay, grey, with fine to medium sand
17-25	8	Clay, grey,with silt and mica
25-40	15	Clay, grey, with fine sand and shell fragments
		Upper Cretaceous - Peedee formation
40-55	15	Sand, grey, fine to medium, with clay, marcasite, and lignitized plant fragments
55-65	10	Clay, grey, with fine sand and lignitized plant fragments
65-70	5	Clay, dark grey, with silt and mica
70-80	10	Clay, dark grey, with silt and mica
		Upper Cretaceous - Black Creek formation
80-90	10	Clay, dark grey, with silt, fine sand, and mica
90-100	10	Clay, dark grey, with silt, sand, mica, and shell fragments
100-110	10	Sand, grey, with silt and lignitized plant fragments
110-120	10	Sand, grey, with silt and marcasite
120-130	10	Silt, dark grey, with clay, mica, and marcasite
130-140	10	Clay, dark grey, with silt, mica, and marcasite
140-150	10	Clay, dark grey, with silt and mica
150-160	10	Clay, grey, with fine sand, mica, and shell fragments
160-170	10	Sand, grey, fine to medium, with clay
170-180	10	Sand, grey, fine to medium, with clay
180-190	10	Clay, dark grey, with fine sand and mica

Depth (feet)	Thickness (feet)	Description of Sample
		Upper Cretaceous - Tuscaloosa formation
190-200	10	Sand, grey, fine to medium, with clay
200-210	10	Clay, grey, with fine sand and mica
210-220	10	Clay, grey, with fine to medium sand
220-230	10	Clay, grey, with fine sand and mica
230-240	10	Clay, grey, with fine to medium sand and mica
240-250	10	Clay, grey, with silt, mica, and fine sand
250-260	10	Clay, grey, with silt and mica
260-270	10	Clay, grey, with silt and mica
270-280	10	Clay, grey, with silt, sand, and lignitized plant fragments
280-290	10	Clay, grey, with silt, mica,and fine sand
290-300	10	Sand, grey, fine to medium, with silt and mica
300-320	20	Sand, grey, fine to medium, with silt and mica
320-330	10	Sand, grey, medium
330-340	10	Sand, grey, fine to medium, with some silt and clay
340-350	10	Sand, grey, fine, with silt, clay, and mica
350-360	10	Sand, grey, medium, with silt
360-370	10	Silt, grey, with fine sand and clay
370-380	10	Sand, red, medium,with silt
380-390	10	Sand, brown, medium
390-400	10	Clay, brown, with fine to medium sand
400-410	10	Sand, brown, medium, with some clay
410-420	10	Sand, brown, fine to medium

Depth (feet)	Thickness (feet)	Description of Sample
420-427	7	Sand, brown, fine to medium, with silt
427-440	13	Clay, brown, with silt and fine sand
440-450	10	Clay, brown, with silt, mica, and fine sand
450-460	10	Clay, brown, with silt and mica
460-470	10	Clay, brown, with fine to medium sand
470-500	30	Sand, brown, fine to medium, with clay
500-510	10	Clay, brown, with silt and mica
510-520	10	Sand, brown, fine to medium, with silt
520-540	20	Sand, brown, fine to medium, with clay
540-565	25	Sand, brown, fine to medium

TOTAL DEPTH 565 FEET

Description by Robert Glaser