PRELIMINARY HYDROGEOLOGIC STUDY
OF THE AQUIFER STORAGE RECOVERY TESTING SITE,
MYRTLE BEACH, SOUTH CAROLINA

By

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ABSTRACT

The rapid growth and economic development of the Grand Strand area have subjected the Black Creek aquifers to large ground-water withdrawals. Increased water demands have stressed the hydrological system to the point that dewatering of the aquifers probably will occur by the year 1990. One solution to this problem, known as Aquifer Storage Recovery (ASR), is currently being investigated.

The ASR test site is located at the Myrtle Beach Water Treatment Plant, just east of the Atlantic Intracoastal Waterway. Four major sedimentary formations underlie the site and are, in descending order, the shallow deposits and the Peedee, Black Creek, and Middendorf Formations.

Analysis of the hydrologic information indicates that while the Peedee and Black Creek aquifers may be part of a larger system, the Middendorf aquifers are hydraulically independent. Estimates of hydrostatic head differences between the Black Creek and Middendorf aquifers may be as great as 235 feet.

Throughout most of Horry and Georgetown Counties, aquifers of the Black Creek Formation are the principal source of ground water. The water quality may be characterized as a sodium bicarbonate type, that is alkaline, low in iron, and high in chloride, fluoride, and sodium.

Owing to the great depth and salinity of the water, few wells have been drilled into the Middendorf Formation; therefore, detailed hydrogeologic information is sparse.

Feasibility testing of twelve zones for ASR has been recommended: eight zones are in the Black Creek Formation and four in the Middendorf. For this purpose, a test well has been designed.

INTRODUCTION

The Waccamaw Capacity Use Area, which consists of Horry and Georgetown Counties and a portion of Marion County, was established in 1978 to optimize water supply development and protect the ground-water resources of this region. Public water supply currently is obtained almost entirely from aquifers in the Black Creek Formation (Fig. 1).

Water demand increases by a factor of 1.7 during the summer months as a result of the large tourist industry generated by the beaches along the Grand Strand. In the vicinity of Myrtle Beach, the potentiometric surfaces of these aquifers are declining at rates as great as 10 feet per year as a result of the increased pumping that has accompanied continued growth and development. At this rate, the aquifers of the Black Creek Formation will begin to be dewatered by 1990. In addition, ground-water withdrawal in the area has reversed the natural seaward hydraulic gradient, thereby increasing the potential for saltwater intrusion into the aquifers.

A surface-water treatment plant on the Atlantic Intracoastal Waterway (AICW) is currently under construction in Myrtle Beach. At this location, two aquifer storage recovery (ASR) strategies might be feasible. The first strategy would involve injecting surplus treated freshwater from the AICW plant into the Black Creek aquifers during the winter months in order to counter the declining water levels and to reduce the potential for saltwater intrusion. In the second strategy, the surplus freshwater would be stored in the nonpotable aquifers of the Middendorf Formation. In both strategies, the stored water would be recovered in the peak water demand period during the following summer. As part of the initial phase of this ASR project, a test hole is to be drilled through the Black Creek and Middendorf Formations to bedrock in order to obtain core samples, geophysical logs, and other hydrogeologic information.

This report is a site-specific hydrogeologic investigation utilizing available data in the files of the South Carolina Water Resources Commission and other hydrogeologic reports pertaining to the area in the vicinity of the test hole. Geophysical, lithologic, and drillers logs from wells within a 2-mile radius of the test well were examined and used to create hydrogeologic sections of the study area (Fig. 2). A composite hydrogeologic section for the specific test-hole location was drafted.

Pumping test data were analyzed to obtain transmissivity, hydraulic conductivity, storage coefficient and specific-capacity values for the overall formation and for specific units within the formation. Potentiometric levels (water level maps) were calculated and drawn to establish hydrostatic head differences within and between formations. Water quality data for the formation as a whole and specific zones within it were studied to characterize the chemical composition of the formations. Sieve-analysis data were plotted and analyzed to determine physical properties such as effective (D_{90}) and median (D_{50}) diameters, and the uniformity (UC) and sorting (S) coefficients. The values of each of the above parameters were correlated to the test site, using the hydrogeologic sections and correcting for altitude and formation dip. Units within the Black Creek and Middendorf Formations were designated as potential artificial recharge zones, from which special core samples for further testing are to be taken.

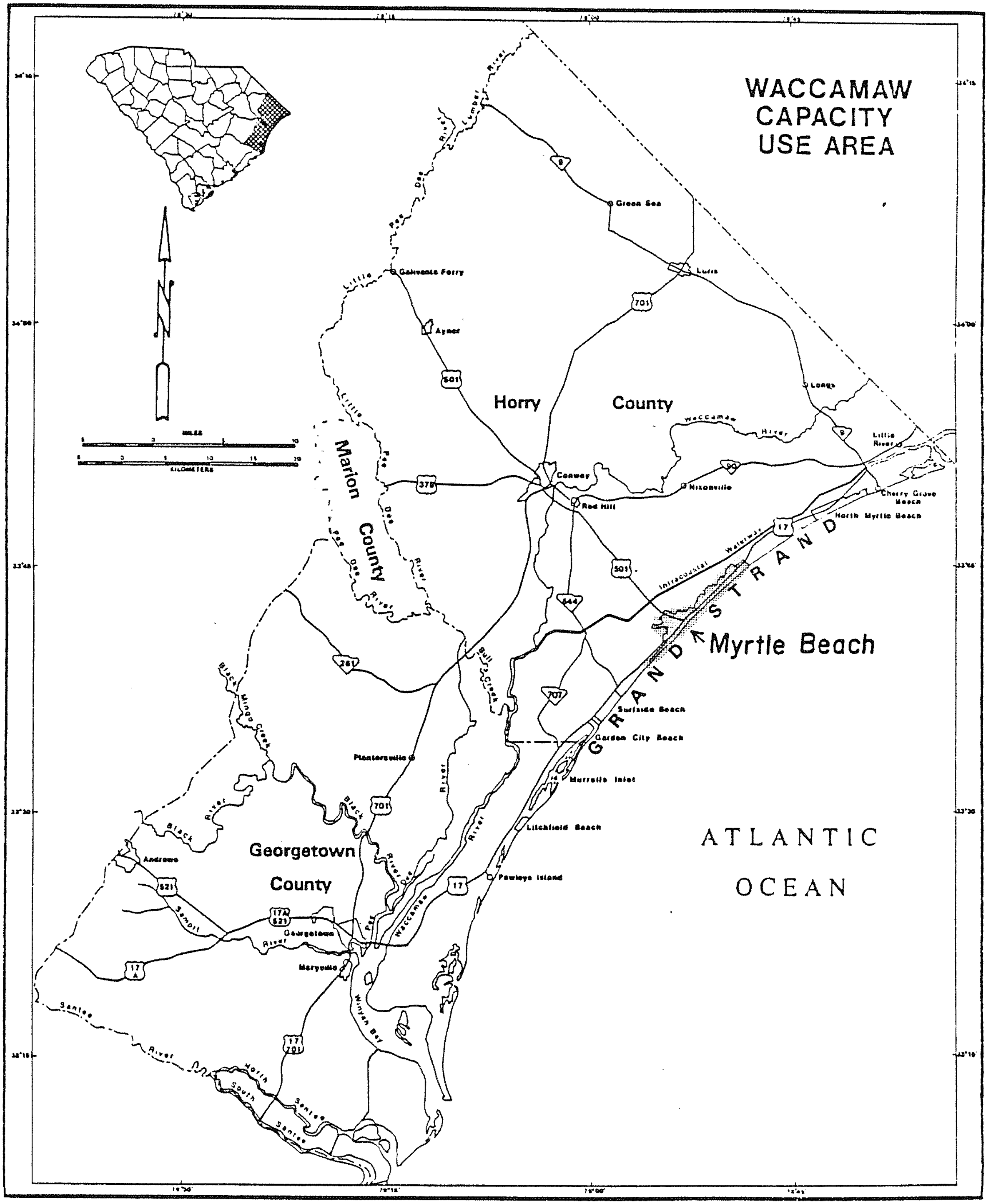
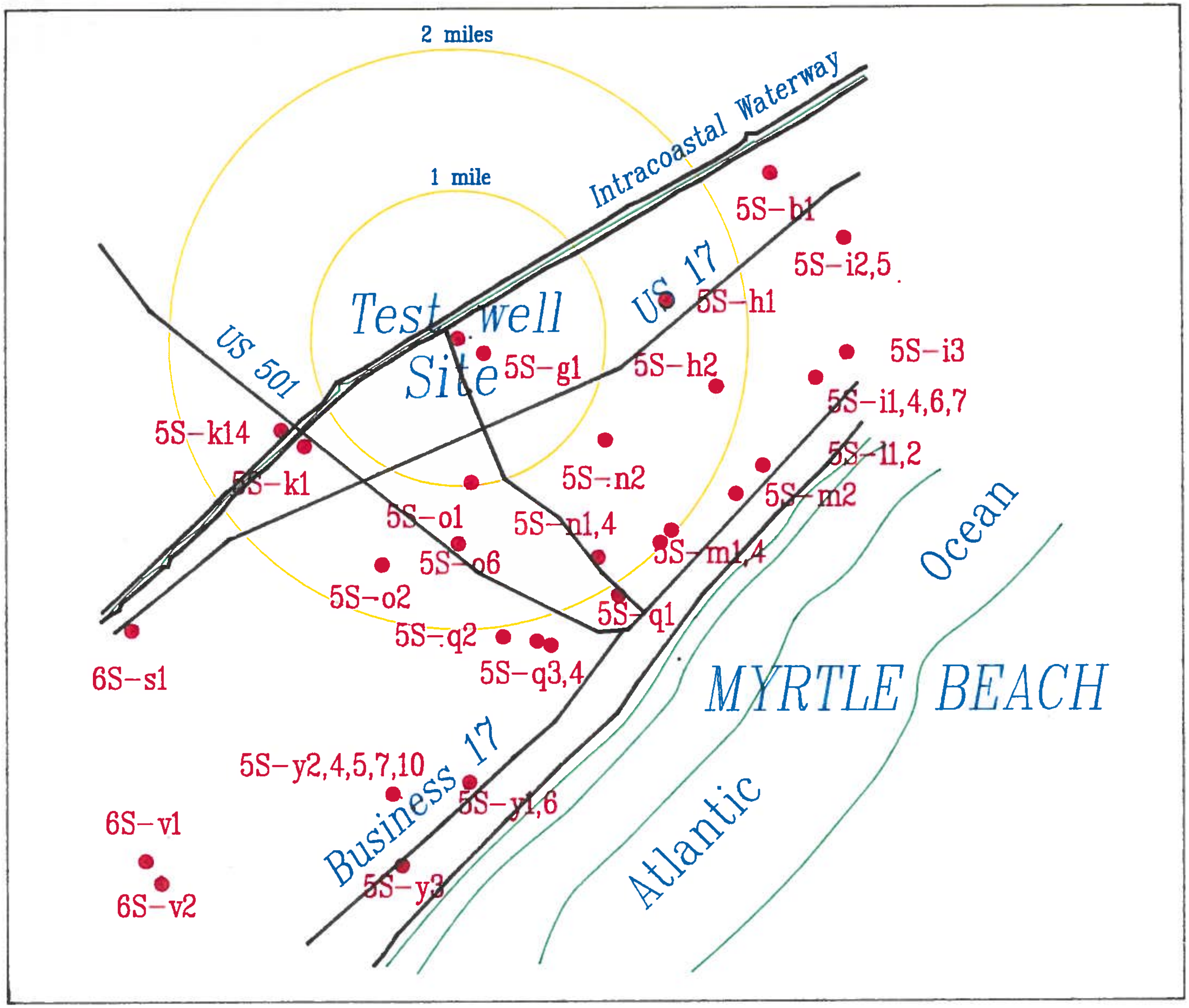


Figure 1. Location of Horry and Georgetown Counties in the Waccamaw Capacity Use Area, South Carolina.



2 miles
1 mile
Intracoastal Waterway
Test well Site
US 501
US 17
Business 17
MYRTLE BEACH
Atlantic
Ocean
5S-b1
5S-i2,5
5S-h1
5S-i3
5S-g1
5S-h2
5S-i1,4,6,7
5S-k14
5S-l1,2
5S-k1
5S-n2
5S-m2
5S-o1
5S-n1,4
5S-m1,4
5S-o6
5S-o2
5S-q1
5S-q2
5S-q3,4
6S-s1
5S-y2,4,5,7,10
5S-y1,6
6S-v1
6S-v2
5S-y3

GEOLOGY

The sediments overlying the crystalline bedrock in the Waccamaw Capacity Use Area have been classified into four principal geologic units. They are the Middendorf, Black Creek and Peedee Formations and shallow deposits. Considerable debate has occurred in recent years over formation boundaries and nomenclature, including the presence or absence of the Cape Fear Formation in this area. For the purpose of this study the units are referred to as described by Zack (1977) and Pelletier (1985), and the formation boundaries approximate aquifer system boundaries.

Crystalline bedrock

The crystalline bedrock is composed of pre-Cretaceous metamorphic and igneous rocks such as schist, gneiss, basalt and granite. Generally, these rocks are very hard and fractured, with much lower permeability than the overlying sedimentary units. The top of the bedrock complex dips to the south-southeast in the Waccamaw area, owing to the Cape Fear Arch, a southeastward plunging basement nose which has its apex just north of the North Carolina-South Carolina line. In Little River, the top of the bedrock lies at approximately -1,300 ft msl (mean sea level) and slopes 550 ft to Georgetown where it lies at -1,850 ft msl (Zack, 1977). The basement structural contours are shown in Figure 3. Only one test well in the Capacity Use Area, located at Brittons Neck (10Q-p2), has penetrated part of the bedrock complex. The low well yields, poor water quality, and excessive drilling depths have discouraged the development of municipal supply wells in this unit.

Middendorf Formation

The Late Cretaceous Middendorf Formation, which unconformably overlies the bedrock, is a result of a deltaic or fluvial depositional environment. It consists of multicolored clay (white, red, yellow, orange, brown, and purple) and white or gray, coarse sand and gravel. The top of the formation lies at approximately -880 ft msl at Little River and -1,080 ft msl at Georgetown and ranges in thickness from 420 to 770 ft, respectively (Fig. 4). The formation dips to the southeast and thickens in the same direction. The Middendorf crops out in the Upper Coastal Plain along the Fall Line throughout the State, where the aquifers of this formation are recharged (Fig. 5). The formation contains salty water in most of the Capacity Use Area, with freshwater possibly occurring only in the extreme western portion of Horry and Georgetown Counties.

Black Creek Formation

The Black Creek Formation, of Late Cretaceous age, overlies the Middendorf Formation. It is composed of dark-gray to light-gray, fine-grained, micaceous, phosphatic and glauconitic sand and clay, considered to be deposited in an estuarine or near-shore marine environment. Thin layers of hard, cemented, calcareous sandstone are numerous throughout this formation, particularly in the upper third. Structural contours of the formation, shown in Figure 6, illustrate a general dip toward the southeast. The formation thickens in the dip direction, but individual bed thickness in this unit may vary

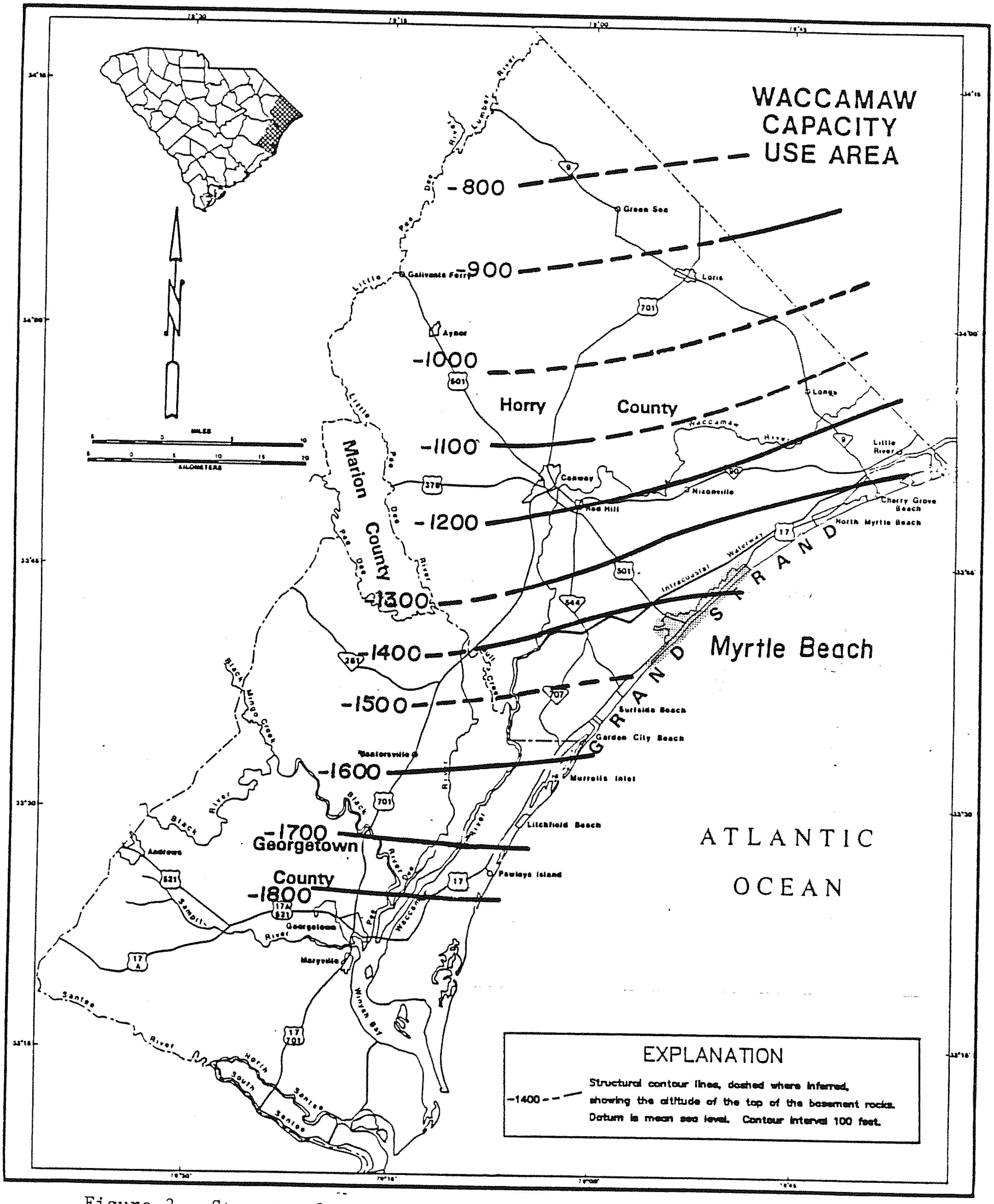


Figure 3. Structural contours on top of basement rocks (after Zack, 1977).

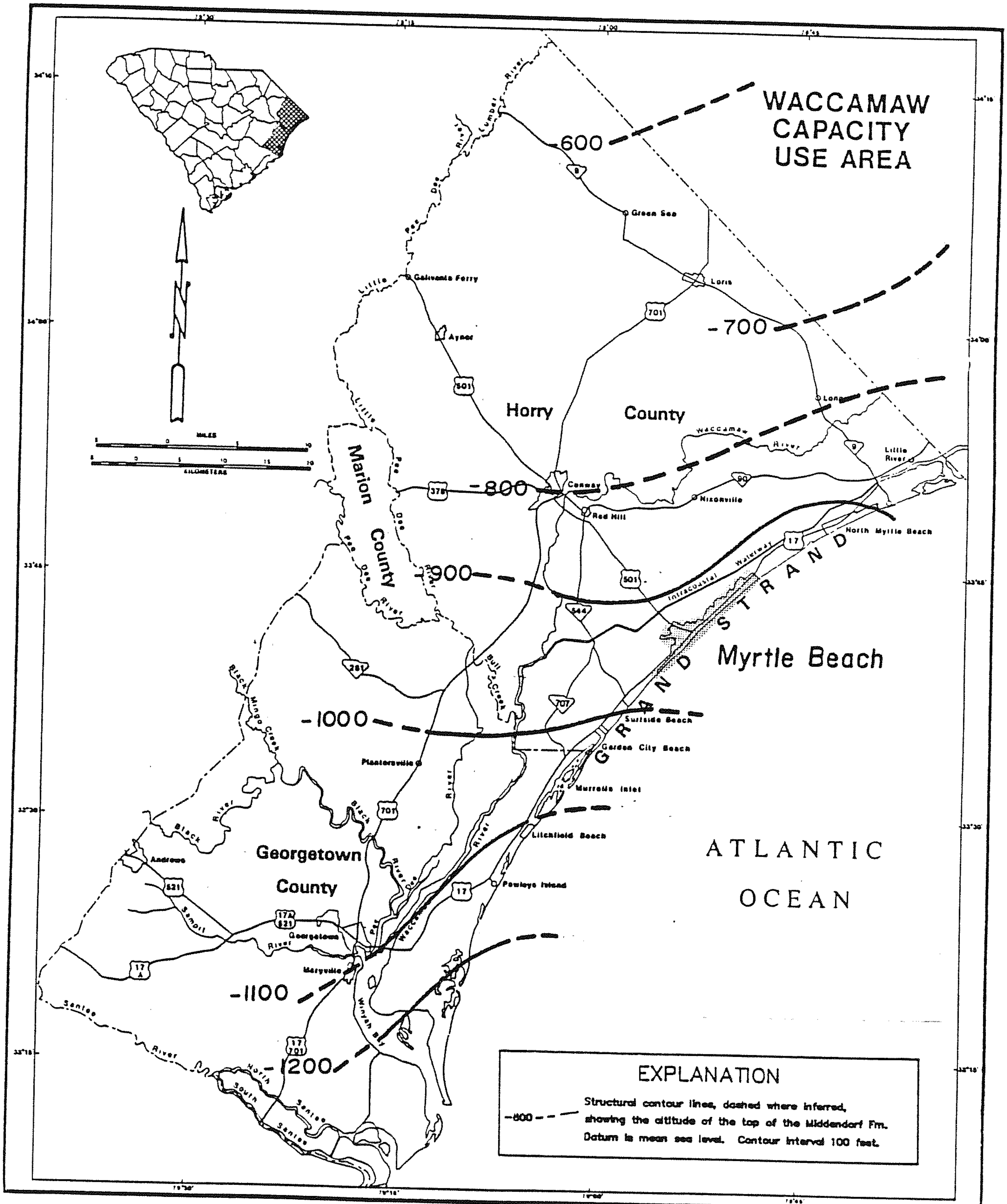


Figure 4. Structural contours on top of the Middendorf Formation (after Zack, 1977).

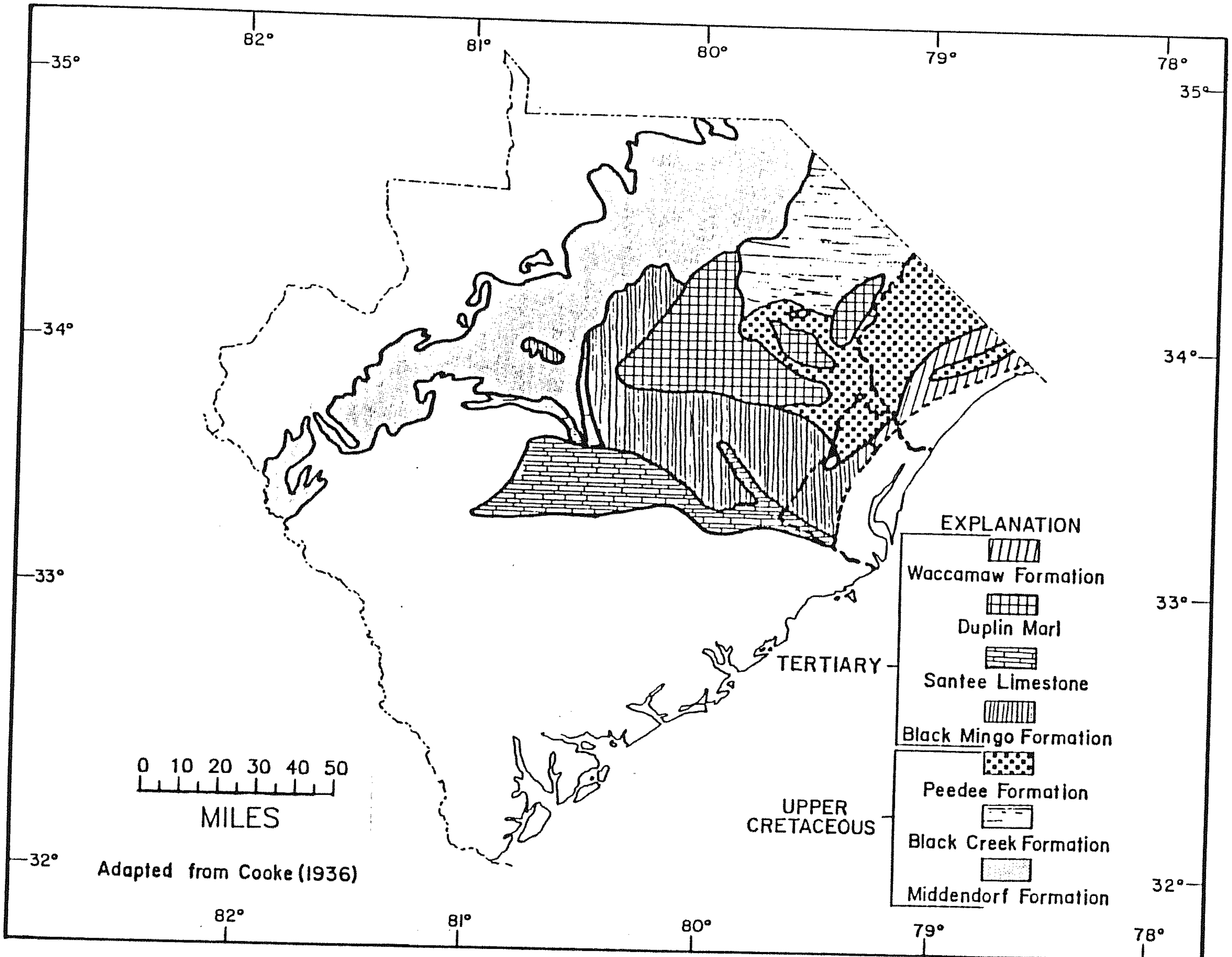


Figure 5. Generalized geologic map of the Coastal Plain showing outcropping Upper Cretaceous and Tertiary sediments that occur in Horry and Georgetown Counties, South Carolina.

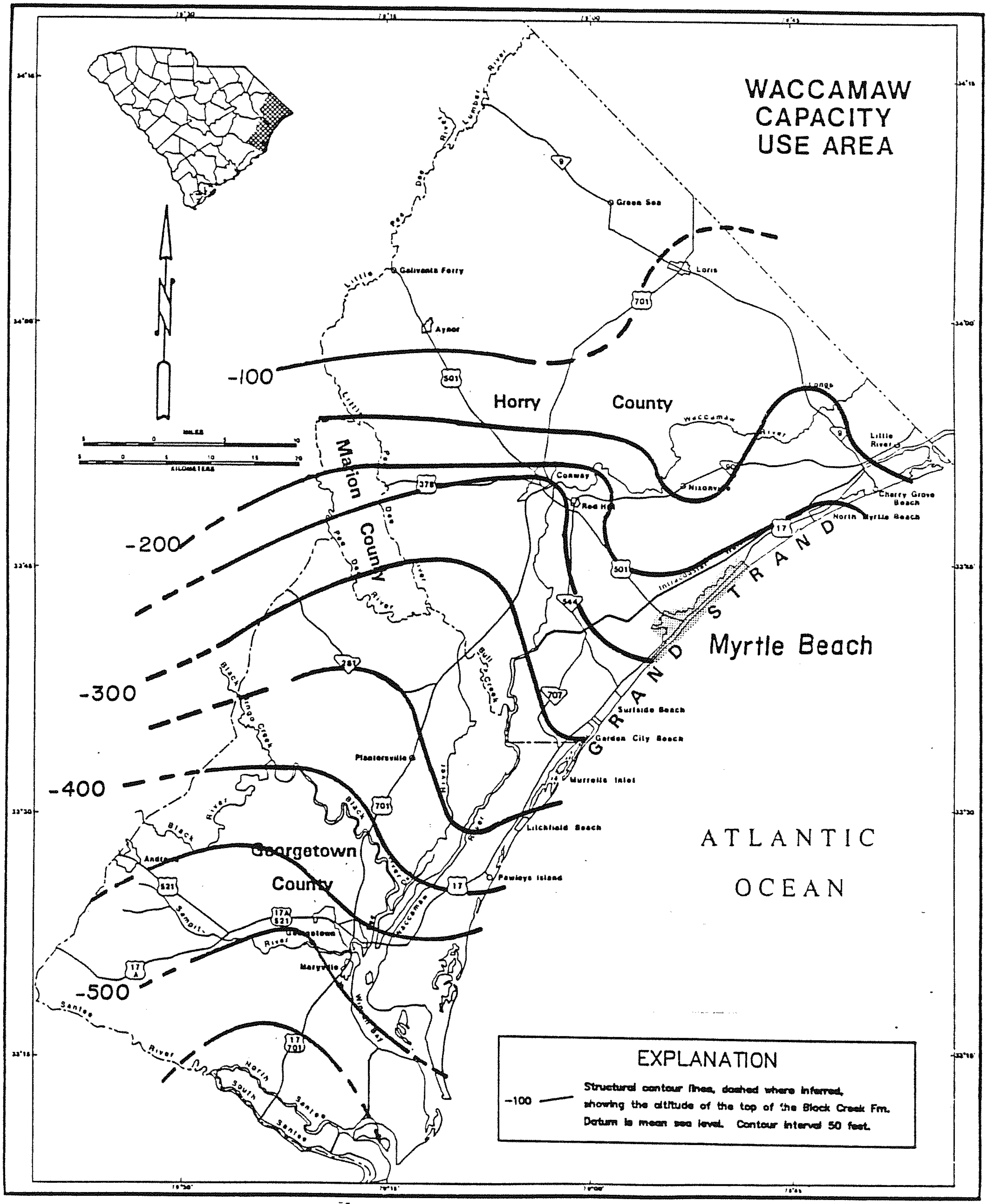


Figure 6. Structural contours on top of the Black Creek Formation (after Pelletier, 1985).

substantially, owing to facies changes. The Black Creek Formation ranges in thickness from 750 ft (-130 and -880 ft msl) at Little River to 620 ft (-460 and -1,080 ft msl) near Georgetown.

Recharge areas for the aquifers of the Black Creek lie within the outcrop area of the Black Creek Formation in the northern portions of the Middle Coastal Plain and northwestern Lower Coastal Plain (Fig. 5). Other recharge areas may be located where potentiometric surface highs exist (Fig. 7), such as the northwestern portion of Horry County and the area near Pawleys Island extending northwestward toward Plantersville in Georgetown County. The recharge may be from the Peedee Formation, as the confining unit between the two aquifer systems is relatively poor. Recharge does not occur at the base of the Black Creek Formation. The tight marine clay between the Middendorf and Black Creek Formations appears to be an effective confining unit. This is evidenced by the differences in water quality, as well as by the large contrast in hydrostatic head. The geophysical and lithologic logs also indicate that the clay unit between the two lowest sand zones in the Black Creek may also be a good confining unit (Plate 1). The majority of public supply wells in the Capacity Use Area are screened in the Black Creek aquifers.

Peedee Formation

The Peedee Formation, the uppermost Cretaceous formation in the Waccamaw Area, consists of thin, interbedded fine-grained sand and clay with intermittent loose shell and coarse sand lenses, which suggests an open-shelf depositional environment. At Little River this formation is 100 ft thick, lying between -30 and -130 msl. It thickens to 270 ft at Georgetown, between -190 and -460 ft msl. The thickness of this formation increases toward the coast. The generalized geologic map of the Coastal Plain (Fig. 5) shows the Peedee Formation cropping out in an area beginning in central Horry and northwestern Georgetown Counties along a line roughly parallel to the present coastline and extending northwestward to the Horry County boundary and westward into central Florence County. A smaller and narrow outcrop area exists just to the east. Both are the primary regions where recharge to this formation occurs.

Shallow Deposits

The shallow deposits are of Tertiary and Quaternary age, consisting of undifferentiated thin beds of fine clayey sand, fine calcareous sand, limestone, and shell. The lower contact of these deposits with the Peedee Formation is located at -30 ft msl at Little River and -190 ft msl at Georgetown. The deposits extend upward to land surface, and thicken and dip gradually toward the coast. Many residences and commercial establishments obtain water from wells in the aquifers in these deposits.

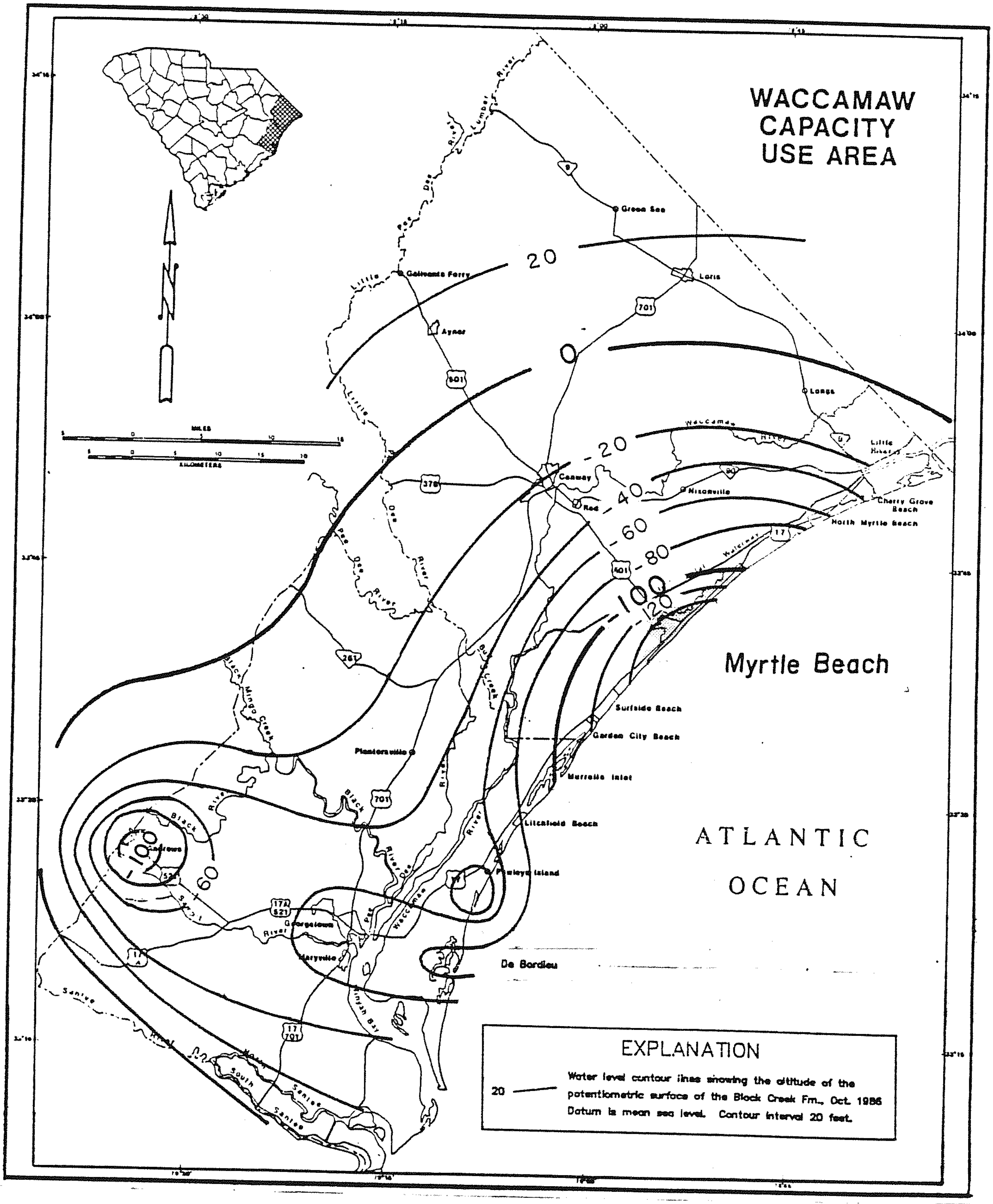


Figure 7. Potentiometric map for the Black Creek aquifers, October 1986.

SITE GEOLOGY

Information on the hydrogeology of the study area was gathered from the Commission files for wells within an approximate 2-mile radius of the test well site and published hydrogeologic reports. The majority of these wells do not penetrate the lower sand units of the Black Creek Formation or the Middendorf Formation. To obtain data for the Middendorf Formation, the research area was expanded outside of Horry County.

The detailed lithology for the test well location (Fig. 2) has been prepared specifically from two nearby wells, 5S-gl and 5S-ol. Well 5S-gl, located at the Myrtle Beach Sewage Treatment Plant and the closest existing well to the test well site, has been drilled to -760 ft msl. This well provides detailed information for the majority of the Black Creek Formation. Well 5S-ol, located 4,600 ft south of 5S-gl, at the Industrial Park, was drilled through the Middendorf Formation and into the bedrock to -1,430 ft msl. Lithologic, drillers, and geophysical logs for each well were used to correlate the units, as shown in Plate 1.

The composite lithologic log for the test well site utilizes data primarily from 5S-gl for the units above -760 msl. Below this depth, information from 5S-ol was used exclusively.

Table 1. Composite lithologic log for wells 5S-gl and 5S-ol

ELEVATION (Feet above (+) or below msl)	DESCRIPTION
+20-60	Sand: quartz, v. fine to coarse, subrounded, olive gray (5 Y 4/1) to yellowish gray (5 Y 7/2), interbedded with silt, clay, and shell (coquina) layers; fossils include pelecypods and gastropods; calcareous.
60-110	Sand: quartz, v. fine to medium, lt. olive gray (5 Y 6/1) with numerous interbedded hard calcareous shell, and soft gray clay layers; minor mica and phosphate.
110-160	Clay: olive gray (5 Y 4/1) with a few streaks of hard, sandy, calcareous shell rock.
160-200	Sand: quartz, v. fine to medium, angular to subangular, lt. olive gray (5 Y 6/1), with interbedded clay layers; moderate mica, minor shell fragments and phosphate; calcareous.
200-220	Clay: gray.
220-245	Sand: quartz, v. fine to medium, subangular to subrounded, olive gray (5 Y 4/1), with interbedded clay and shell layers; moderate mica, minor phosphate; calcareous.
245-280	Clay: interbedded with quartz sand; v. fine to medium, some minor mica, phosphate, glauconite, and shell fragments (including foraminifera and gastropods).
280-310	Sand: quartz, v. fine to coarse, subrounded to subangular, olive gray (5 Y 4/1), interbedded with clay and sandstone layers; moderate shells and shell fragments (including foraminifera), minor mica, phosphate and glauconite; calcareous.
310-360	Clay: gray, interbedded with hard sandstone and sandy clay layers; minor shell fragments, mica, phosphate, and glauconite.
360-430	Sand and sandstone interbedded: v. fine to coarse, olive gray (5 Y 4/1); moderate to minor phosphate, minor shell fragments (including gastropods), mica, and glauconite; calcareous.
430-535	Clay: gray, with some interbedded sand and sandstone layers; minor phosphate, glauconite, shell fragments (including foraminifera), wood, and limonite.

535–570	Sand: v. fine to medium, silty, subangular to subrounded, olive gray (5 Y 4/1); minor shell fragments, mica, phosphate, glauconite, limonite, and wood; some green and gray clay lenses; calcareous.
570–580	Clay: gray.
580–590	Sand: quartz, fine to medium, angular to subangular, olive gray (5 Y 4/1); minor shell fragments, mica, phosphate, glauconite, limonite, with green and gray clay streaks; calcareous.
590–600	Clay: gray and green, sandy.
600–620	Sand: same as 580–590.
620–650	Clay: green and gray, with numerous sand lenses similar to 580–590 in composition.
650–670	Clay.
670–690	Sand: quartz, v. fine to coarse, angular to subangular, olive gray (5 Y 4/1), abundant silt and clay, minor shell fragments, mica, phosphate, glauconite, pyrite, and wood fragments; calcareous.
690–700	Clay: gray.
700–720	Sand: quartz, v. fine to coarse, angular to subangular, olive gray (5 Y 4/1), clayey with clay lenses; minor shell fragments, mica, phosphate, glauconite, pyrite and wood; calcareous.
720–750	Sand: quartz, v. fine to coarse, angular to subangular, olive gray (5 Y 4/1) with interbedded gray clay and sandstone layers; minor shell fragments, mica, phosphate, glauconite, pyrite and wood; calcareous.
750–835	Clay: v. lt. gray (N8).
835–880	Sand: quartz, coarse, angular to subangular, lt. olive gray (5 Y 6/1); abundant abraded shell fragments, interbedded consolidated clay lenses and sandstone; minor mica, limonite, phosphate and glauconite; calcareous.
880–920	Shell hash: lt. olive gray (5 Y 6/1), sandy, coarse, becoming clayey with depth; minor phosphate and pyrite; calcareous.
920–945	Clay.
945–1005	Sand: quartz, medium to coarse, clean, lt. olive gray (5 Y 6/1) to yellowish gray (5 Y 7/2); minor shell fragments, mica, phosphate, glauconite, limonite and pyrite; slightly calcareous; some clay streaks.

1005–1040	Clay: brown and gray; some sand lenses, fine to coarse.
1040–1060	Sand: quartz, fine to coarse, subangular to subrounded, pale yellowish brown (10 YR 6/2) to grayish orange (10 YR 7/4), clayey; minor shell fragments, limonite-stained quartz, mica, phosphate, and glauconite; slightly calcareous.
1060–1080	Clay: with some sand, medium to v. coarse.
1080–1110	Sand: quartz, medium to coarse, subangular to subrounded, yellowish gray (5 Y 7/2); minor mica, phosphate, and limonite-stained quartz; slightly calcareous.
1110–1120	Clay.
1120–1160	Sand: quartz, fine to coarse, angular to subangular, lt. brown (5 YR 5/6), interbedded with some clay lenses; minor, mica, phosphate, glauconite, feldspar, and limonite-stained quartz; slightly calcareous.
1160–1225	Clay: tight.
1225–1270	Sand: quartz, medium to coarse, angular to subangular, clean, yellowish gray (5 Y 7/2); minor phosphate, mica pyrite, glauconite, and feldspar; slightly calcareous.
1270–1280	Clay.
1280–1300	Sand: quartz, same as 1225–1270, but may have some silt or clay.
1300–1350	Sand: medium to coarse, some clay lenses.
1350–1400	Clay: hard, with some sand.
1400–1430	Bedrock.

HYDROGEOLOGY

Shallow Deposits

These deposits consist of thin beds of fine clayey sand, fine calcareous sand, and limestone of Tertiary and Quaternary age and extend to -60 ft msl in the study area. Water-table and artesian conditions occur in these sediments, which are used as a source of water supply in a few places. Generally, however, these aquifers are discontinuous, subject to large water-level fluctuations, and dependent on local rainfall for recharge.

The chemical quality of the water is variable and generally inferior to that of deeper aquifers, especially where there is a free exchange of water between these sediments and surface-water bodies. However, shallow artesian aquifers of the Tertiary formations yield good water. The water is relatively soft; fluoride and chloride occur in very small concentrations; and iron, sulfate, and hydrogen sulfide concentrations are negligible. Data from three shallow wells at the Air Force base, near well 6T-b2, are presented in a Piper diagram (Fig. 8). The figure shows that the predominant cation is sodium, the predominant anion is bicarbonate, and therefore the water is of a sodium bicarbonate type. The ionic concentration has been expressed as percentage in milliequivalents (1 milliequivalent is equal to 1000 times the formula weight divided by the charge.)

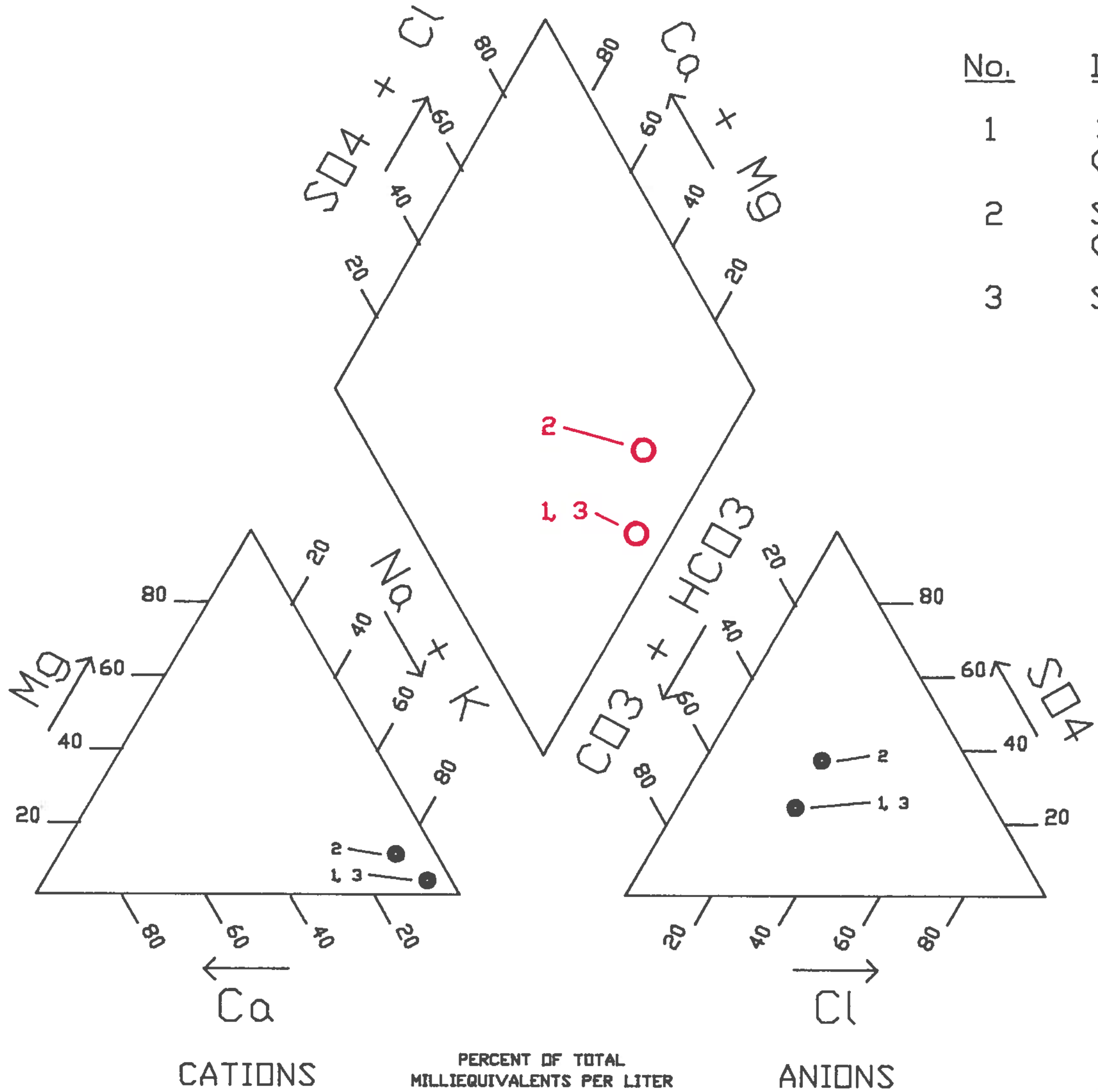
Peedee Formation

The Peedee Formation is the uppermost Cretaceous unit in the State. It was deposited in an open-shelf environment and consists of dark-gray, fine-grained clayey sand with zones of coarse and shelly loose limestone. In the study area this formation is 160 ft thick and lies between -60 and -220 ft msl. In general, the aquifers are under artesian conditions, but they are not used for municipal water supply because of their unsatisfactory water quality and low yield. Reported yields for these aquifers are on the order of 60 to 100 gpm (gallons per minute) (Pelletier, 1985).

Water Quality

Water from the Peedee aquifers is highly variable in quality, ranging from poor to excellent. Throughout most of Horry and Georgetown Counties, these aquifers contain low concentrations of fluoride (< 0.5 mg/L (milligram per liter)) and generally low concentrations of chloride (50 mg/L). Unfortunately, the aquifers contain relatively high concentrations of iron and manganese (> 2 mg/L), calcium (around 100 mg/L), and hydrogen sulfide. High concentrations of chloride have been found along the coastal margin of the area. Many of these water quality problems are localized, with no apparent pattern to their occurrence. In Figure 9, water quality analyses for two wells are presented. The analyses show that the water quality is similar in the wells and that the water is of a calcium bicarbonate type.

AQUIFER STORAGE & RECOVERY



No.	Description
1	Shallow Well 1 (by 6T-b2)
2	Shallow Well 2 (depth = 58 ft.)
3	Shallow Well 3

Figure 8. Water Quality Analysis For Shallow Deposits

AQUIFER STORAGE & RECOVERY

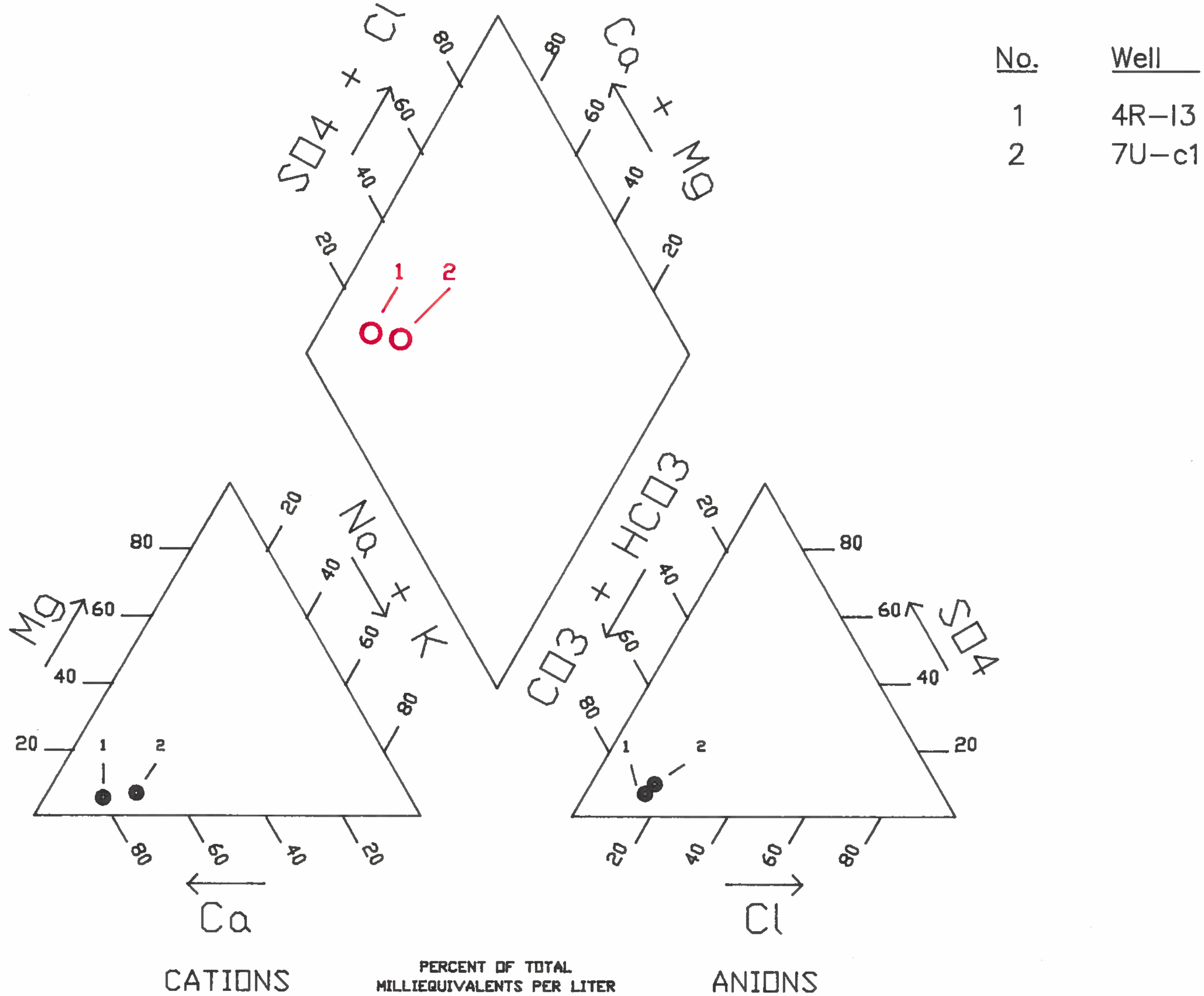


Figure 9. Water Quality Analysis For Peedee Aquifers

Grain-size analysis

The analysis of the unconsolidated sediments of the Peedee Formation indicates a large variation in grain-size distribution and a decrease in the uniformity coefficient (UC) with depth. Available data, representative of the Peedee's upper zone, from -60 to -90 ft msl, are listed in Table 2.

The set of samples has been divided for the purpose of this analysis into two classes.

Lower class (-72 to -91 ft msl):

- has the coarsest particles, with an effective diameter (D_{90}) ranging from 0.0018 to 0.035 inch; average is 0.026 inch, corresponding to coarse sand.

- uniformity coefficient (UC) is 2 to 4, representative of a well-sorted sample.

Upper class (-60 to -71 ft msl):

- samples show a much smaller effective diameter (D_{90}), ranging from 0.003 to 0.009 inch; average is 0.005 inch, corresponding to fine sand.

- UC varies from 1.8 to 9.8, indicating a poorly sorted sample. The upper class samples have a grain-size distribution four times larger than those of the lower class.

This analysis indicates that the D_{90} is greater and the UC smaller in samples of the lower interval; hence, it could be expected that the porosity, and therefore the hydraulic conductivity, increases with depth in the -60 to -90 ft msl zone.

Black Creek Formation

This Late Cretaceous formation consists of dark-gray clay interbedded with gray or white, fine to very-fine, glauconitic, phosphatic, and micaceous quartz sand. Thin but continuous layers of hard, impervious calcareous sandstone are abundant in sand beds of the upper third of the formation. These layers of hard, cemented calcareous sandstone may have as little as 2 percent porosity and make water well drilling very difficult (Zack, 1977). The aquifers in this formation are the principal source of water for wells in the Waccamaw Area.

Hydraulic Conductivity

The supply for most large-capacity wells is a water-bearing zone called the "principal sand aquifer" (Spigner and others, 1977). This zone, in the study area, is located between -360 and -430 ft msl and is 70 ft thick. Data from aquifer tests indicate that the average hydraulic conductivity of the principal water-bearing sand is 220 gpd/ft^2 (gallons per day per square foot) (Zack, 1977).

TABLE 2. Grain-size analysis of Peedee Formation

DEPTH* (feet)	D_{90} (inch)	D_{75} (inch)	D_{50} (inch)	D_{40} (inch)	D_{25} (inch)	S	LOG S	UC
62-64	0.003	0.005	0.014	0.024	0.076	15.2	1.18	8
64-65	.005	.005	.016	.0295	.08	16	1.2	9.8
65-67	.0098	.0118	.0196	.018	.022	1.86	.27	1.8
67-72	.0032	.0035	.0126	.02	.039	7.8	.89	6.25
72-75	.03	.043	.059	.063	.087	2.01	.30	2.1
75-77	.035	.046	.06	.07	.090	1.97	.29	2
77-81	.0196	.046	.063	.079	.09	1.94	.29	4.03
81-91	.018	.035	.059	.067	.08	2.46	.39	3.7

D_{90} = 90 percent retained size
S = sorting coefficient
UC = uniformity coefficient
LOG S = $\log_{10}$ of S

* Depth in feet below mean sea level
Data obtained from well 5S-y12 (see Appendix B).

In the study area, approximate values of hydraulic conductivity by zones are as follows:

Table 3. Black Creek hydraulic conductivity values

SCREEN ELEVATION [feet]	AQUIFER THICKNESS [feet]	TRANSMISSIVITY [gpd/ft]	HYDRAULIC CONDUCTIVITY [gpd/ft²]
-224 to -234	24	26	2.6
-377 to -387	86	4,400	63
-668 to -678	14	370	26
-338 to -606	180	*16,000	* 83
-526 to -606	94	10,000	110

*Theoretical value calculated from composite sample.

The hydraulic conductivities shown in Table 3 are less than half those reported by Zack (1977). Nevertheless, wells in the vicinity of the study area tapping the same units and with even smaller hydraulic conductivities yield 400 to 500 gpm (Table 4). It is reasonable, therefore, to expect yields of 500 gpm or greater at the test site.

Table 4. Well inventory of pumping tests for Black Creek wells

SCWRC NO.	SCREENED INTERVAL	T [gpd/ft]	K [gpd/ft²]	THICKNESS [ft]	SPECIFIC CAPACITY
3R-b2	308–700	21,700	820	250	9.7
3R-b2	308–412	11,670	104	111	4.8
3R-f2	326–622	7,480	50	150	3.8
3R-o7	290–658	18,700	97	192	5.4
4R-s1	340–624	9,720	67	140	3.7
4R-x2	346–602	11,000	73	150	5.4
5S-g1	366–634	15,000	82	184	5.7
5S-g1	252–262	26	1.5	23	.03
5S-g1	405–415	4,400	63	70	1.4
5S-g1	554–640	1,630*	19	86	
5S-g1	696–706	367	22	17	.3
5S-i8	370–660	15,000	97	154	5.8
5S-y10	369–635	14,000	82	165	8.0
6T-b4	395–597	8,830	104	84	3.2
6T-h1	334–680	23,200	180	129	5.9
6T-i1	314–746	23,200	71	200	6.3

Screened interval is in feet below land surface. Entire interval is not screened in every well.
Specific capacity is in gallons per minute per foot of drawdown.

* Theoretical value: Calculated from the composite pumping test.

Water Levels

Water levels in Horry and Georgetown Counties have been measured on a semi-annual basis in a number of wells since 1975. Potentiometric maps of the area (Pelletier, 1985) show two cones of depression, the largest at Myrtle Beach and the other at Georgetown. The rate of decline of the hydrostatic head was estimated by Pelletier to be about 10 feet per year at Myrtle Beach. The cone of depression at Georgetown has stopped expanding since the city started using alternately ground-water and surface-water sources to supply its water system.

Presently, the water level contour map shows three major discharge areas (Fig. 7):

LOCATION	POTENTIOMETRIC SURFACE [feet msl]
Myrtle Beach	- 140
Andrews	- 100
De Bordieu	- 80

The potentiometric levels in the vicinity of Pawleys Island suggest that recharge may be occurring as a result of an increase in the hydraulic conductivity between the Black Creek and the Peedee or that the confining unit between the two formations may be discontinuous. Presently an attempt is being made to locate additional wells to verify this data.

Near the study area, historical data indicate that some Black Creek wells flowed at the surface as recently as the late 1950's. Records for well 5S-b1, located 2.5 miles northeast of the test site, show a potentiometric high of -37 ft msl in February 1975, the earliest recorded date, and a low value of -125 ft msl in October 1986, which is a decline of 88 feet in 11 years. If the potentiometric surface was once above ground at this site, then the total hydrostatic head decline may be in excess of 145 feet.

The potentiometric surface in the study area is at -110 ft msl. This has created a considerable hydraulic gradient across the Black Creek's geological boundaries with neighboring aquifers.

The Peedee and Black Creek Formations appear to be hydraulically connected (Zack, 1977) where confining clay beds cause only short-term hydraulic independence in parts of these aquifers. Pelletier noted that although water levels in the Peedee are dropping at a slower rate than in the Black Creek, these two aquifers may be part of a larger system.

The Black Creek and Middendorf aquifers appear to be hydraulically independent. According to Zack, there is little, if any, leakage between these aquifers, despite the large observed hydrostatic head difference. Recent data from wells at Calabash, just across the North Carolina line, suggest that:

- The hydrostatic head difference between the Middendorf (screen interval -992 to -1,002 ft msl) and the bottom aquifer of the Black Creek (screen interval -760 to -770 ft msl) is about 55 ft.

- The "principal sands" have the least hydrostatic head of all aquifers in the the Black Creek Formation in the study area. This is the result of the heavy pumping from this unit along the Grand Strand.

The hydrostatic head difference between the Black Creek and Middendorf could be anywhere from 195 to 235 ft (see Middendorf water level section).

Specific Capacity

Reported specific capacities of wells screened in the Black Creek aquifers range from 1.1 to 11 gpm/ft of drawdown (Aucott and Newcome, 1986); average is 4.8 gpm/ft. In the vicinity of the study area the specific capacity is about 7 gpm/ft (Table 4).

Storage Coefficient

Values for storage coefficient reported by Zack (1977) for the Black Creek Formation in this area range between 0.00017 and 0.00041, with an average being 0.00025. Storage coefficient is defined as the volume of water which an aquifer releases or takes into storage per unit surface area per unit change in potentiometric head. The units are: volume/(area x length), therefore it is dimensionless.

Water Quality

The water in the Black Creek aquifers is of a sodium bicarbonate type, the sodium (NA^{+}) being the major cation and the bicarbonate (HCO_3^{-}) the most important anion (Fig. 10). The water is generally soft, alkaline, and low in iron, but it has objectionable concentrations of chloride, fluoride, sodium, and total dissolved solids.

Discrete water samples from well 6T-b2 at the Myrtle Beach Air Force Base indicate that (Figs. 11 and 12):

- Total dissolved solids (TDS) is above drinking-water standards (500 mg/L) and increases with depth; the most predominant ions are HCO_3^{-}, Na^{+}, and Cl^{-}, in order of magnitude;

- Sodium (Na^{+}) concentration increases with depth. The sodium-rich clays (deposited in a marine environment) exchange sodium for calcium ions as follows:

$$CaCO_3 + H_2CO_3 = 2HCO_3^{-} + Ca^{++}$$
$$Ca^{++} + 2Na\text{-}(Clay) = 2Na^{+} + Ca\text{-}(Clay)$$

  Once calcite has reached equilibrium, the concentration of Ca^{++} is maintained low, whereas the concentration of the HCO_3^{-} is maintained high for values of pH normally encountered in ground water (Freeze and Cherry, 1979).

AQUIFER STORAGE & RECOVERY

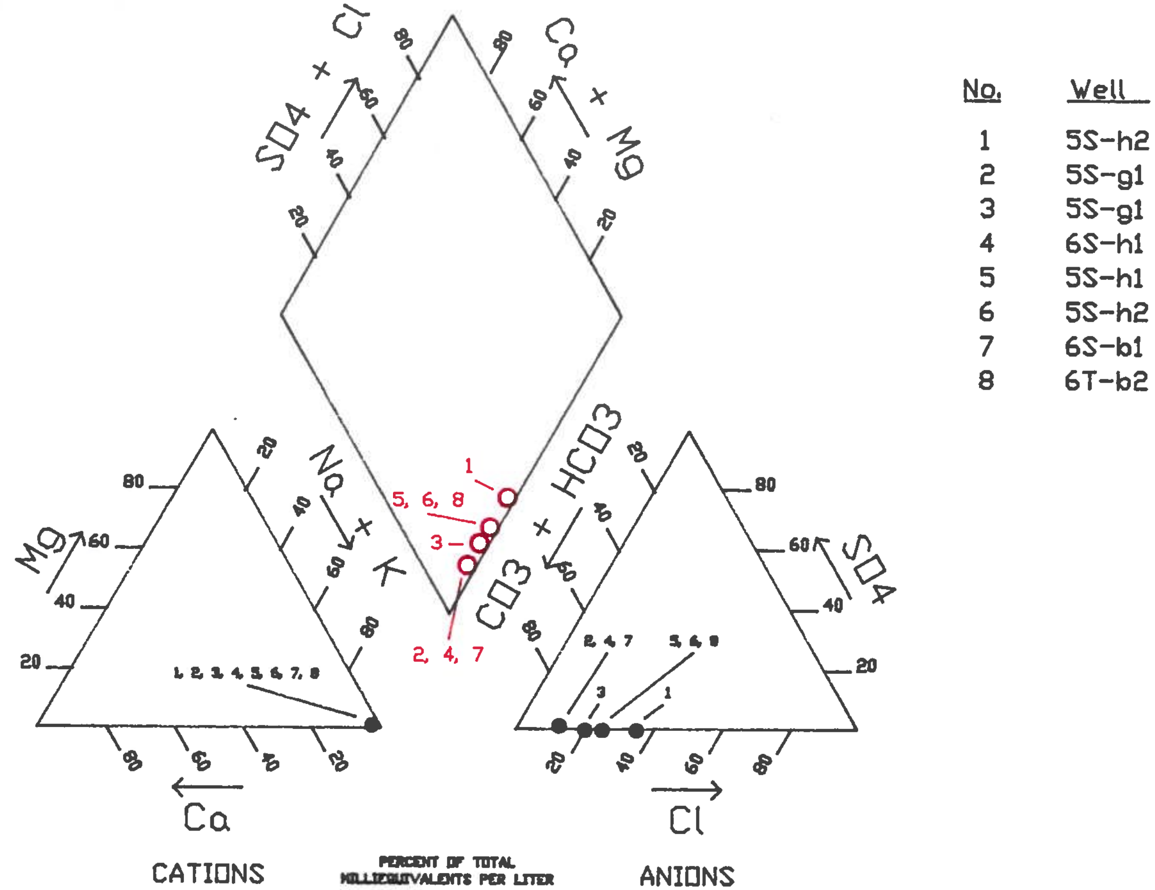
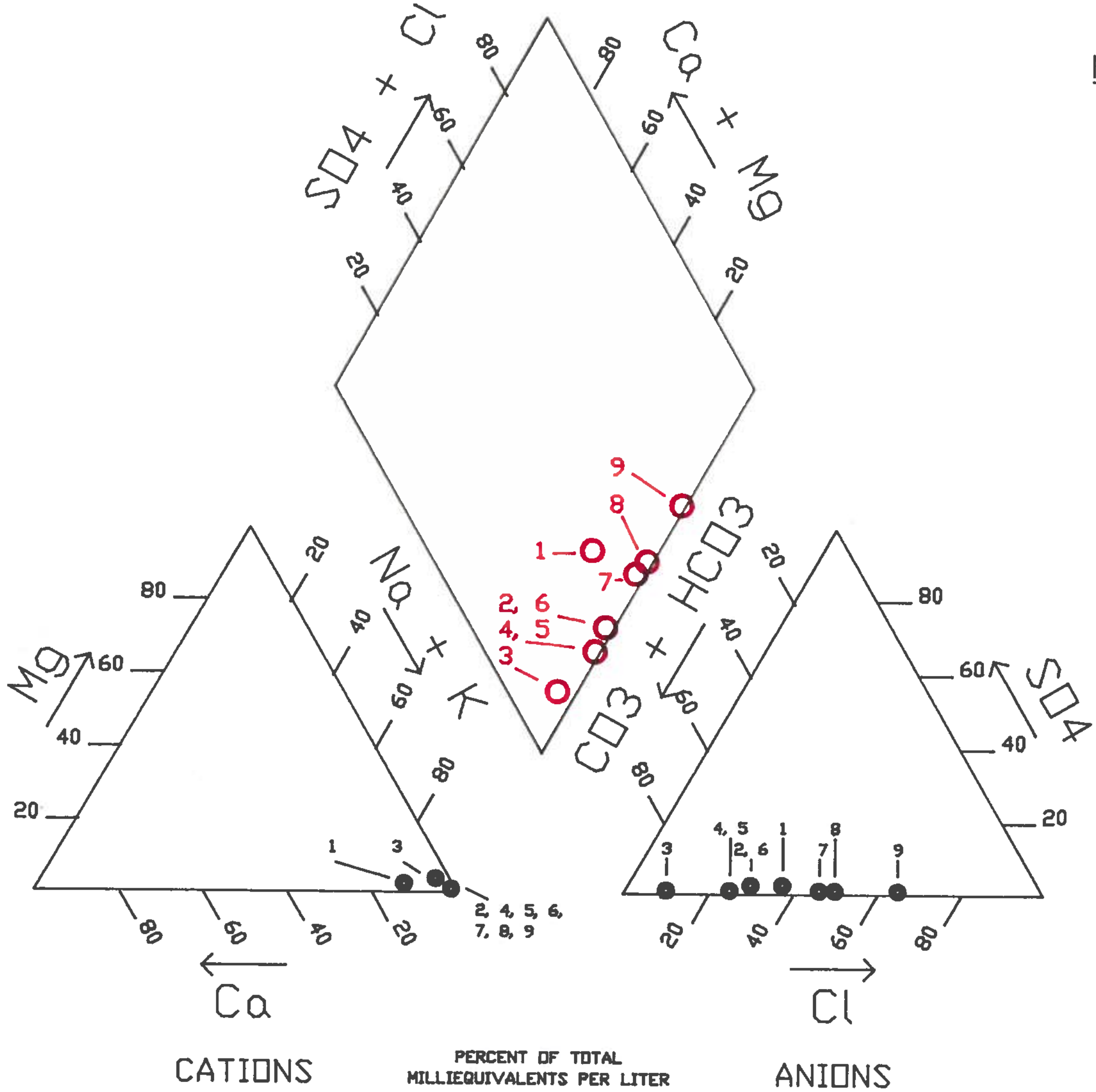


Figure 10. Water quality diagram for Black Creek aquifers

AQUIFER STORAGE & RECOVERY



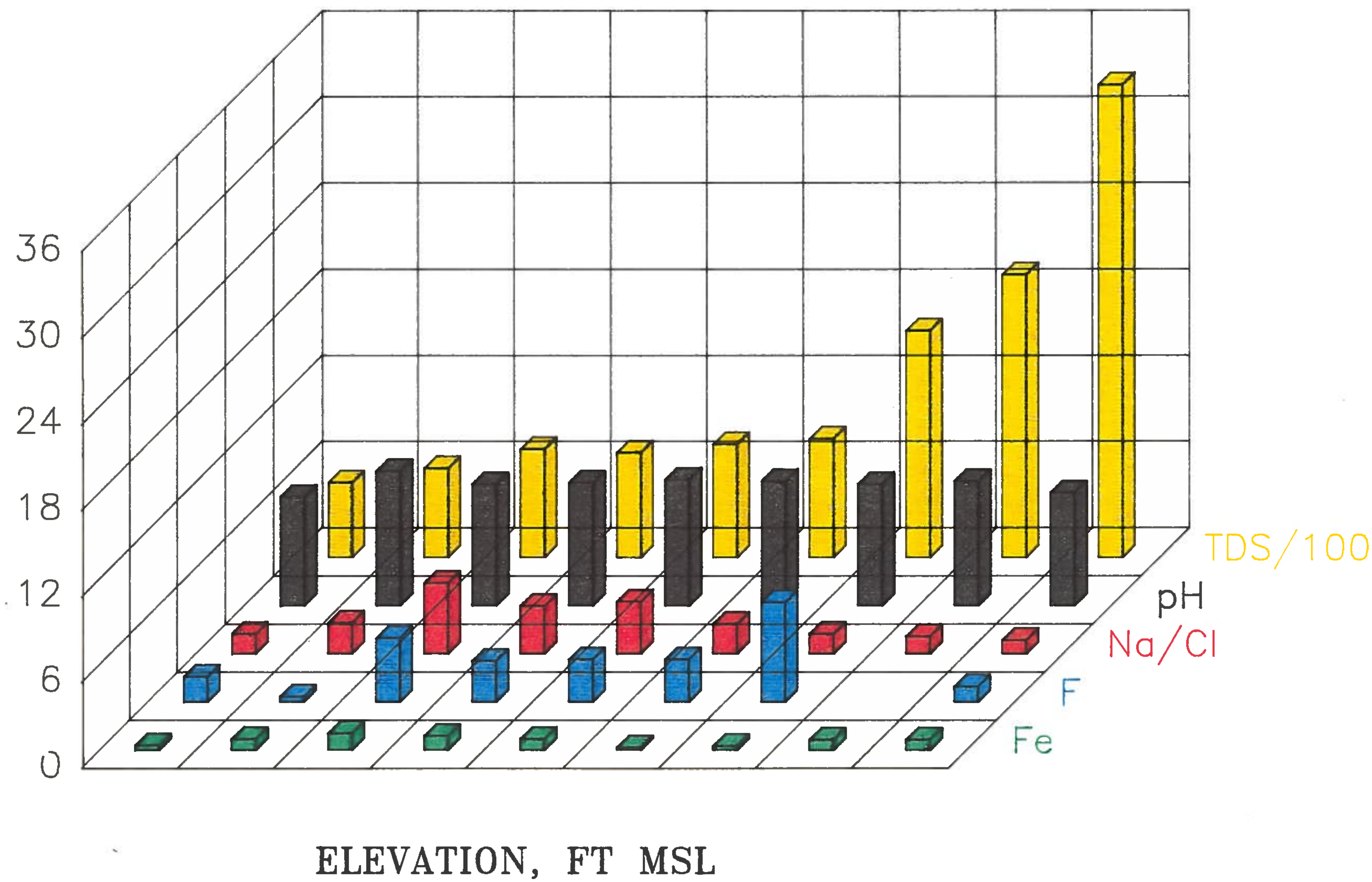
No.	Depth (ft.)
1	321 - 340
2	376 - 407
3	450 - 463
4	540 - 560
5	695 - 700
6	770 - 790
7	840 - 860
8	890 - 910
9	1045 - 1054

Figure 11. Water Quality Analysis For Well 6T-b2

AQUIFER STORAGE & RECOVERY

WATER QUALITY DIAGRAM

WELL 6T-b2



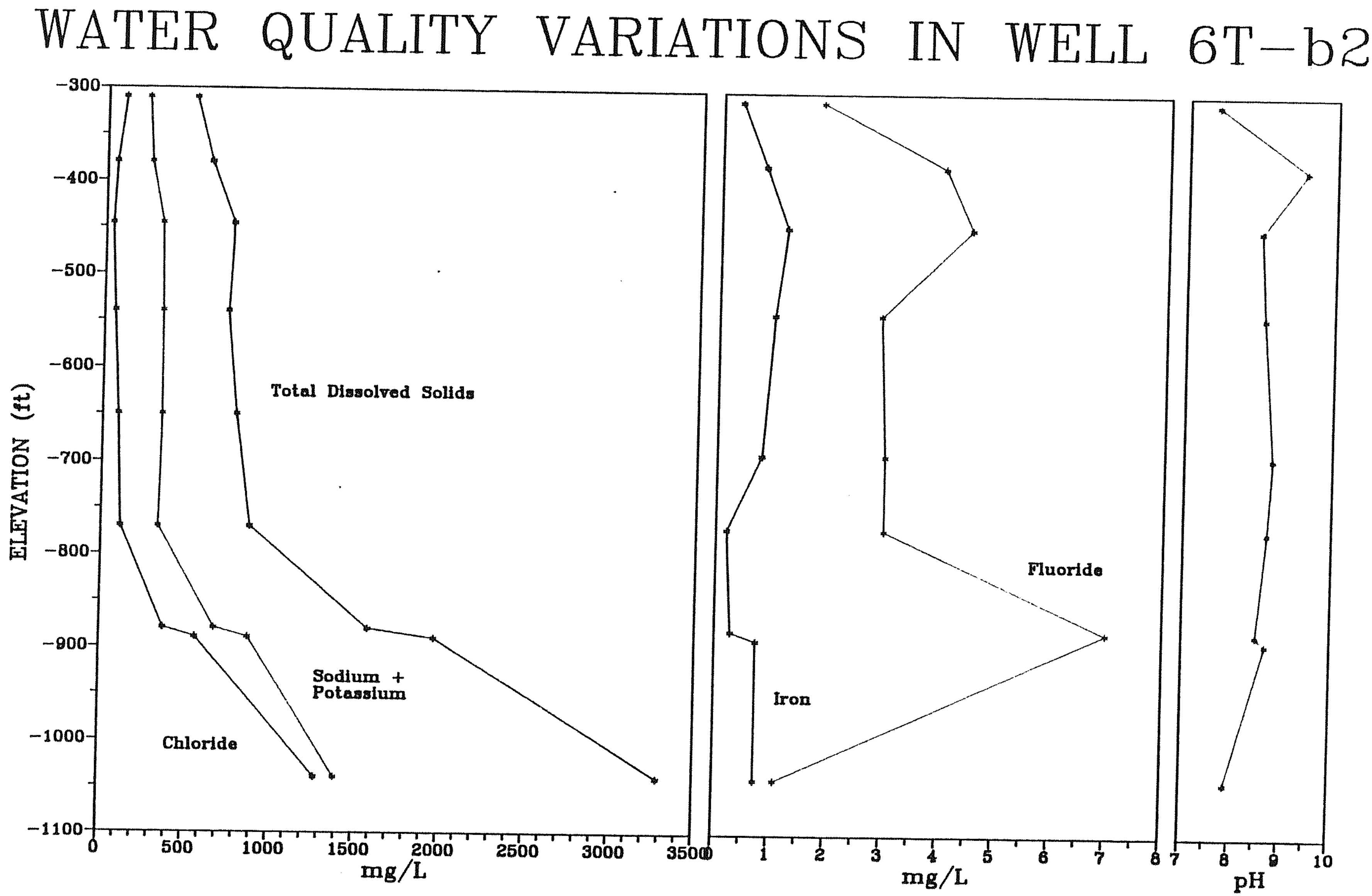


Figure 12. Water quality variations with depth in well 6T-b2.

- Chloride (Cl^-) concentration decreases with depth to -446 ft msl, below which it increases. Chloride becomes the dominant anion and water shifts toward a sodium chloride type with increasing depth (Fig. 12). These high chloride concentrations, according to Zack, are due to "incompletely flushed saltwater" trapped during deposition.

- The pH decreases little with depth, and it is often close to 8. The maximum value is 9.4 at -390 ft msl. High values of pH at this depth may be explained by the dissociation of calcium carbonate (found in the hard, cemented, calcareous sandstones) into bicarbonate:

$$CaCO_3 + HOH = HCO_3^- + OH^- + Ca^{++}$$

  The hydroxyl ions produced during this hydrolysis reaction could cause the pH to reach values as high as 10 (Garrels and Christ, 1965). However, as water percolates downdip the bicarbonate is produced by the carbon dioxide (CO_2):

$$CO_2 + HOH = H_2CO_3$$
$$H_2CO_3 = H^+ + HCO_3^-$$

  and the pH drops back to approximately 8 (Zack, 1980).

- Fluoride (F^-) ranges from 1.8 to 7 mg/L. The source of fluoride is the mineral fluorapatite (contained in fossil shark teeth). The dissolution of calcite exposes fossil shark teeth which releases fluoride ions to the ground water in exchange for hydroxyl ions, according to Zack (1980).

- Iron (Fe^{++}) concentration range from 0.2 to 1.2 mg/L, and shows no trend in its variation. Most wells in the study area have multiple screens and obtain a mixed water with concentrations of iron below the drinking-water standards; thus iron, although present in objectionable concentrations in some zones of the Black Creek, is not a problem in the study area.

- Calcium (Ca^{++}) concentration normally is low, just a few tens of milligrams per liter. In the upper zones of the Black Creek the calcium to sodium ratio is high; however, it declines with depth. The amount of calcium in solution decreases as it is replaced by sodium on the clays, and thus the calcium to sodium ratio approaches that encountered in ancient seawater.

Grain-Size Analysis

The grain-size distribution analysis shows a wide variation of the effective diameter (D_{90}) and a more conservative distribution of the uniformity coefficient (UC) with depth (Table 5); data for this analysis were obtained from 6S-b1, 5S-o1, 5S-o2, and 5S-h2. Data have been corrected for dip and elevation. The results of the analysis can be summarized as follows:

TABLE 5. Black Creek sieve analyses

DEPTH*	Q_{90}	Q_{50}	S	UC	SAND V. FINE	SAND FINE	SAND MEDIUM	SAND COARSE	SAND V. COARSE	PEBBLES V.FINE
355-365	0.007	0.013	1.336	2.14	7.0	30.0	37.0	14.0	6.0	6.0
385-430	.023	.030	1.142	1.43	.5	.5	5.0	71.0	21.0	2.0
430-450	.008	.019	1.541	3.0						
450-470	.005	.024	2.191	8.4						
470-500	.005	.025	2.236	8.0						
500-510	.008	.018	1.461	2.56	3.0	13.0	39.0	23.0	11.0	11.0
510-520	.007	.015	1.464	2.32						
550-575	.010	.015	1.225	1.64	2.0	10.0	64.0	9.0	6.0	9.0
630-640	.009	.015	1.291	1.78	2.0	10.0	64.0	9.0	6.0	9.0
720-747	.006	.016	1.633	3.00	4.0	27.0	38.0	31.0		
750-765	.007	.012	1.282	1.86	4.0	36.0	49.0	11.0		
840-862	.014	.030	1.464	2.36	2.0	17.0	56.0	25.0		
862-885	.008	.018	1.500	2.50	3.0	54.0	32.0	11.0		

Q_{90} = 90 percent-retained size
S = sorting coefficient
UC = uniformity coefficient

* depth in feet below mean sea level.
Units are in inches.

- the largest D_{90} is 0.023 inch between -385 and -430 ft msl; while the smallest is 0.005 inch at -450 to -500 ft msl (Fig. 13);

- very fine (VF) pebbles are present only above -650 ft msl, with the largest percentage (12) between -450 and -500 ft msl;

- the percentage of coarse and very coarse sand decreases with depth. At the -385 to -430 ft msl interval there is 71 percent of coarse sand and 21 percent of very coarse sand; whereas between -862 and -885 ft msl there is only 11 percent of coarse sand and none of the very coarse sand;

- medium sand is present in all the samples and varies from 30 to 50 percent except at the -385 to -430 ft msl interval where it is only 5 percent;

- the very fine particles (very fine sand, silt and clay) represent in general, 4 percent of the samples except between -430 and -500 ft msl where they are as much as 29 percent;

- most of the samples are well sorted, except for those in the -450 to -500 ft msl interval, which are normally sorted;

- the smallest value of the sorting coefficient is 1.43 at the -385 to -430 ft msl interval, and the largest is 2.8 at the -450 to -500 ft msl interval.

On the basis of this grain-size distribution analysis, the -385 to -430 ft msl interval has the best physical properties of all the samples:

- smallest UC;
- largest D_{90}; D_{90} = coarse sand;
- D_{50} = very coarse sand;
- largest percentage of coarse sand;
- smallest percentage of fine particles.

This zone corresponds to what others have identified as the "principal sand aquifer"; for example, Pelletier (1985) estimated the depth to the principal sand in the study area to be between -380 and -420 ft msl.

Grain-size distribution curves are included in Appendix A.

Middendorf Formation

The Middendorf Formation, of Late Cretaceous age, contains medium to coarse, white or gray sand and thin layers of multicolored silty clay. In the study area, the Middendorf has been identified, by Zack (1977), between -940 and -1,420 ft msl.

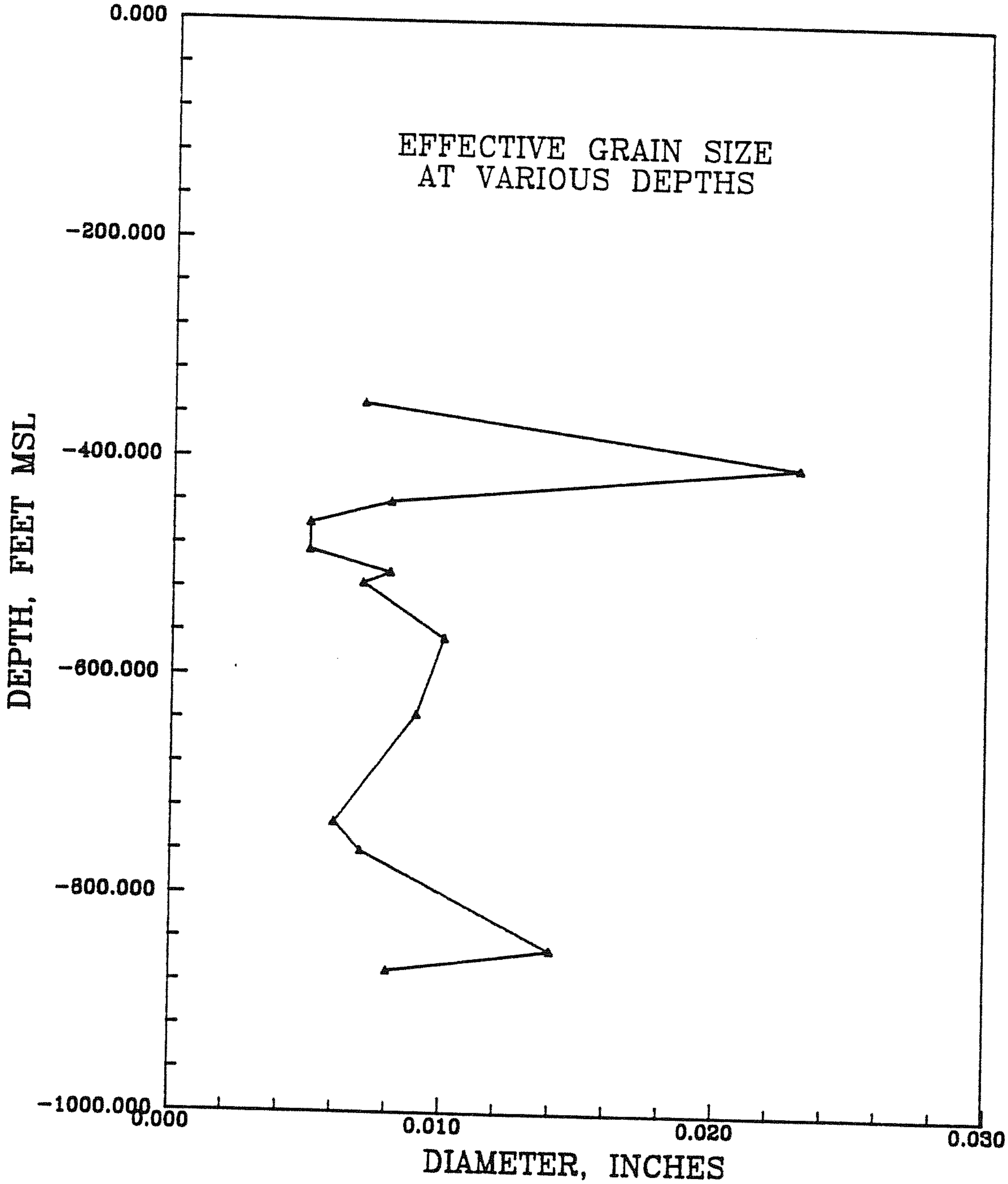


Figure 13. Effective grain size at various depths.

Hydraulic Conductivity

Available data suggest that the hydraulic conductivity of the Middendorf in South Carolina decreases toward the coast. Table 6 lists data from Aiken County, located on the west-central boundary of South Carolina and Georgia, to Florence Counties, which is located west of Horry County. This trend has been reported by Aucott and others (1987), who explained that the small increase in saturated thickness (the aquifer thickens toward the coast) is offset by the increase of clayey material, causing a decrease in the hydraulic conductivity. Aucott also noted that despite the decrease in the hydraulic conductivity near the coast, the Middendorf aquifer has transmissivity values equal to or greater than those of the surrounding aquifers. Unfortunately, the hydraulic properties of this aquifer are not well known in the study area.

Table 6. Hydraulic conductivities for the Middendorf Formation

COUNTY	RANGE	MEAN	MEDIAN
Aiken	850 - 2500	1500	1100
Richland	250 - 590	380	300
Florence	78 - 550	290	250

Hydraulic conductivity is expressed as gpd/ft^2

Water Levels

An estimate of the average potentiometric head for the Middendorf aquifers, in the study area, has been based on the information on three wells in the area. These wells are screened in different zones of the Middendorf and are located in Horry, Georgetown, and Marion Counties. Table 7 shows the location and the water level of these wells:

Table 7. Middendorf hydrostatic heads

WELL	LOCATION	DEPTH (feet)	WATER LEVEL (feet msl)	MEAS. POINT ELEVATION (feet msl)	WATER ELEVATION (feet msl)
10Q-p2	Brittons Neck	1,010-1,030	+ 54.6	+30	+ 84.6
2Q-j2	Calabash	1,042-1,052	+ 55.6	+50	+105.6
10W-m4	Georgetown	1,344-?	+113.2	+10	+123.2

Assuming these data to be accurate, the potentiometric level for the Middendorf in the study area could be presumed to be higher than +85 ft msl and lower than +123 ft msl and most likely about +110 ft msl. Therefore, the difference in hydrostatic head between the Black Creek and Middendorf in the study area is calculated to be not greater than 233 ft and not less than 195 ft, and most likely about 220 ft. The potentiometric level of the Black Creek in the study area is -110 ft msl (Fig. 7).

Water Quality

Most of the wells tapping the Middendorf aquifers have been reported to yield saline water in Horry and Georgetown Counties. Zack (1977) suggested that the saline water is diluted connate water, and it probably is present throughout most of Horry and Georgetown Counties.

POTENTIAL ZONES FOR TESTING

The information collected and presented in previous sections has been used to select eight zones in the Black Creek and four zones in the Middendorf as potential units for testing the feasibility of the Aquifer Storage Recovery Project in the study area. The selection of the Black Creek zones are based on results obtained from the study of hydraulic conductivity, water levels, lithologic and geophysical logs, water quality data, and grain-size distribution analyses. The Middendorf zones, because of the scarcity of data, have been selected entirely on the basis of lithologic and geophysical log studies.

Table 8 lists the different zones in the Black Creek and Middendorf and shows the hydrogeologic and geochemical properties that are available.

TABLE 8. Quantitative description of zones in the Black Creek and Middendorf Formations

Zone	Aquifer	Material	D_{90}	CU	B	K	T	Alkalinity	HCO_3^-	Fe^{++}	Ca^{++}	F	Na^+	Cl^-	pH	TDS
220- 245	BC	S			24	2.6	62									
280- 310	BC	S					240		288	0.33	18.4	1.80	247	108	7.6	525
400- 430	BC	S/ST	0.023	1.43	96	63	4,400	540	511	1.20	4.8	4.5	340	42	8.5	758
535- 570	BC	S	.010	1.64				460	441	1.0	2.0	2.9	350	67	8.6	734
600- 620	BC	S	.009	1.78	100	112	10,600									
670- 690	BC	S			14	26	370	500	480	.8	2.0	3.0	354	96	8.8	792
720- 750	BC	S/C	.006	3.00				508	460	.2	2.4	3.0	336	118	8.7	880
780- 835	CU	C														
840- 855	BC	ST/S	.014	2.36				780	806	.3	6.4	7.0	625	380	8.5	1,582
920- 945	CU	C														
950-1000	MD	S						830	933	.75	8.0		879	570	8.7	1,972
1010-1030	CU	C														
1080-1155	MD	S/C														
1160-1220	CU	C														
1230-1265	MD	S														
1300-1350	MD	S														
1360-1400	CU	C														

Zone is given in feet below mean sea level.
BC, MD, and CU represent Black Creek and Middendorf Formations, and confining units, respectively.
D_{90} is 90-percent-retained size in inches.
UC is uniformity coefficient.
B is thickness of aquifer in feet.
H is hydraulic conductivity in gallons per day per square foot.
T is transmissivity in gallons per day per foot.
Concentration is expressed in milligrams per liter.

HYPOTHETICAL WELL DESIGN

The information presented in previous sections will be used to design a hypothetical well to tap the upper aquifers of the Middendorf Formation. This well should be used only as reference for the construction and final design of the test well. Data used here have been inferred from neighboring wells, and it may not be accurate.

Analyses of geophysical and lithological logs suggest that screens be placed between -945 and -1,150 ft msl. In selecting these zones the intention has been to learn about the potential aquifers and their confining beds with regard to the feasibility of ASR.

The depths and brief descriptions of these zones are presented in the following table. For a complete description, refer to the lithologic logs in the Site Geology section.

Table 9. Aquifers and confining beds for the upper Middendorf Formation

ELEVATION	DESCRIPTION
-945 to -1,005	Sand; quartz, medium to coarse, clean
-1,005 to -1,040	Clay
-1,040 to -1,060	Sand; quartz, fine to coarse, clayey
-1,060 to -1,080	Clay
-1,080 to -1,110	Sand; quartz, medium to coarse
-1,110 to -1,120	Clay
-1,120 to -1,150	Sand; quartz, fine to coarse

The study of this log and logs for the principal sands in the Black Creek (-360 to -430 ft msl) suggests that hydrologic conditions in the Middendorf aquifers may be better than or equal to the principal sands. Considering this premise true, the following values that have been assumed for the principal sands will be used in this design:

- discharge 500 gpm;
- effective diameter (D_{90}) 0.023 inch;
- uniformity coefficient 1.2;
- 70-percent retained size 0.027 inch.

Casing Diameter

The criteria used in selecting the casing diameters have been the pump diameter and the uphole velocity (< 5 ft/sec). Driscoll (1986) recommended a 14-inch OD casing for expected yields between 500 and 1,000 gpm. The casing extends from land surface to a depth of -75 ft msl. It will be cemented in place with a 3-inch minimum annular space grouting. The second and third casings have a 8- and 6-inch nominal diameter and must meet or exceed the following specifications:

Table 10. Casing specifications

NOMINAL SIZE (inches)	O.D. (inches)	WALL THICKNESS (inches)	WEIGHT (pounds/ foot)	CLASS	SCHEDULE (psi)	GRADE A (psi)
6	6.625	.28	18.97	STD	40	1,520
8	8.625	.322	28.55	STD	40	1,340
14	14.0	.375	54.57	STD	30	960

Casing Material

Water quality analyses for the Middendorf show high concentrations of sodium, chloride, and total dissolved solids. The conductivity, thus, is expected to be great enough to encourage electrolytic corrosion. The electrolytic corrosion would probably be intensified because of the presence of the chloride, which is a corrosive agent in itself. It is important, therefore, to select a corrosion-resistant material. Under these circumstances, a stainless-steel Type 304 casing would be most recommended. Otherwise, a steel casing with appropriate epoxy type coating that is resistant to corrosion is desirable.

Well Depth

The total depth of the drilled hole is expected to be 1,420 ft. The well should be completed to an elevation of -1,160 ft msl.

Screens

In designing the screens, two alternatives are presented:

- naturally developed well;
- filter pack.

Naturally developed.—Slot size is equal to 50-percent-retained size. Slot size is 0.032 inch (Appendix A).

Filter pack.—The particle size of the filter pack is obtained by multiplying D_{70} by a factor between 4 and 10 (Driscoll, 1986). For the present situation a factor of 5 has been used because the formation is uniform. Filter-pack particle size is 5 x 0.026 or 0.135 inch (Fig. 14). The characteristics of the filter pack should be:

- clean;
- well rounded;
- 90- to 95-percent quartz grains;
- UC 2.5 or less.
- thickness of at least 3 inches and no more than 8 inches.

AQUIFER STORAGE RECOVERY

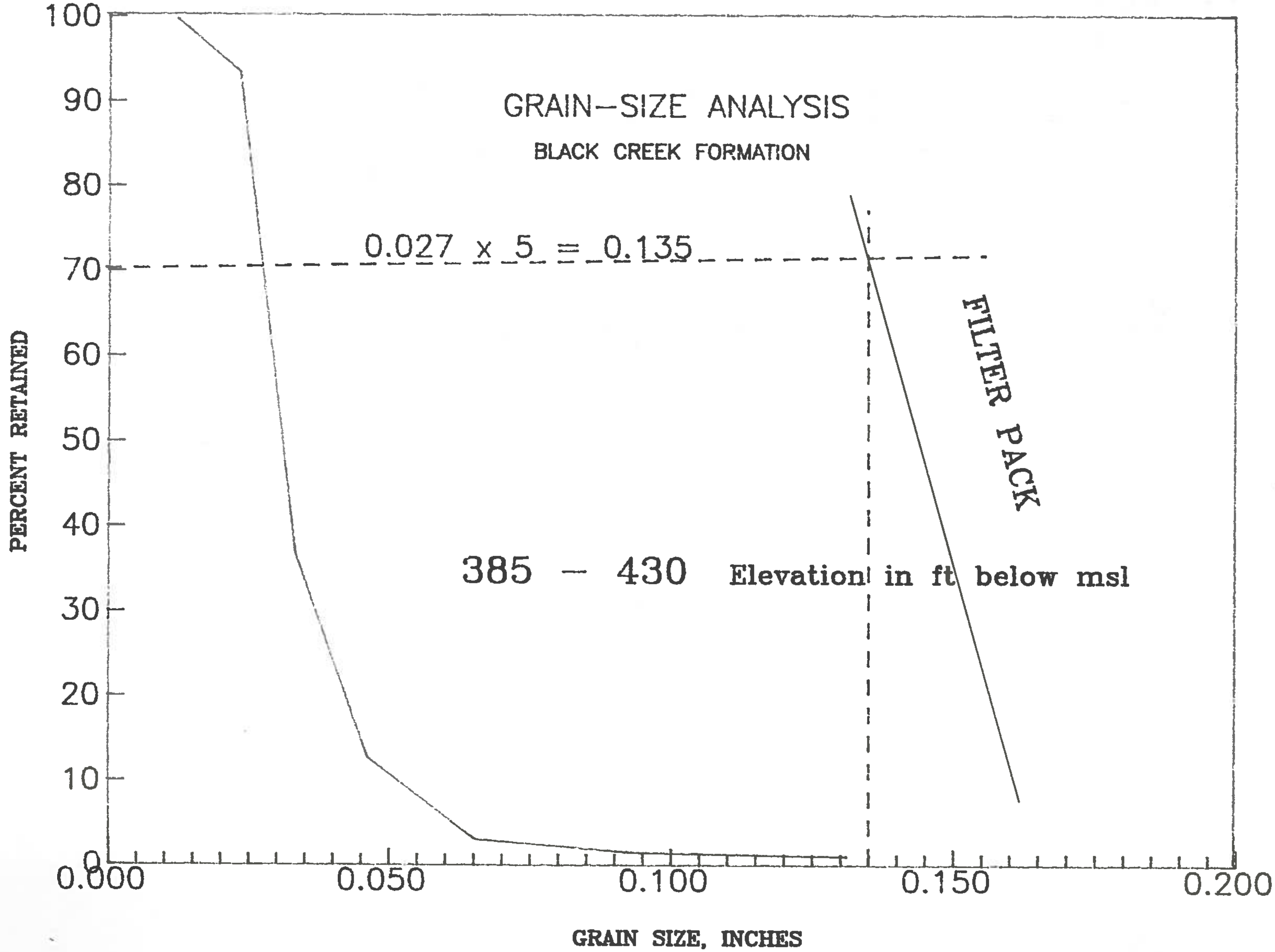


Figure 14. Filter Pack Design

Screen Slots for the Case of a Filter Pack

The design of the screen slots has been such as to maintain entry velocities less than 0.1 ft/sec. The following table summarizes the performance of 6- and 4-inch screens.

Table 11. Screen parameters

ELEVATION* (feet msl)	LENGTH (feet)	DISCHARGE (gpm)	OPEN AREA (sq. ft)		VELOCITY (ft/sec)	
			4-inch	6-inch	4-inch	6-inch
945-1,005	60	192	17.5	48	0.02	0.01
1,040-1,060	20	77	7	21	.02	.01
1,080-1,110	30	115	10.5	24	.02	.01
1,120-1,150	30	115	10.5	24	.02	.01

* Elevation is in feet below msl.

Calculations for Table 11 consider that the 6-inch screen has a slot size equal to 0.123 inch, and the 4-inch screen equal to 0.03 inch. Both diameters satisfy the velocity criterion; however, the larger screen diameter is selected because the well may be used as an ASR prototype.

Screen length.--Best results are obtained when confined aquifers are screened in 80 to 90 percent of the thickness of the water-bearing sediments. In the present situation, however, the whole thickness of the individual aquifer is screened in consideration of the uncertainty of the data.

Volume of filter pack

The following table gives the approximate volume of filter-pack material for 4- and 6-inch screens:

Table 12. Filter-pack volume

BOREHOLE DIAMETER (inches)	SCREEN DIAMETER (inches)	VOLUME (cu ft)	THICKNESS (inches)
10	4	103	3
10	6	80	2

Based on a length of 220 feet of filter pack.

Well-Design Summary

The following summarizes the specifications of the test well and is illustrated in Figure 15.

Discharge: 500 GPM
Total depth: 1,180 FT
Casing:

DEPTH* (feet)	DIAMETER (inches)	LENGTH (feet)
0 - 75	14 OD.	75
0 - 920	8	920
1,025 - 1,060	6	35
1,080 - 1,100	6	20
1,130 - 1,140	6	10
1,170 - 1,180	6	10

* Depth below land surface.

Material: corrosion-resistant steel, (ASTM - 409)

Screen: slot size 0.123 inch

DEPTH* (feet)	DIAMETER (inches)	LENGTH (feet)
970 - 1,025	6	55
1,060 - 1,080	6	20
1,100 - 1,130	6	30
1,140 - 1,170	6	30

* Depth below land surface.

Material: stainless steel.

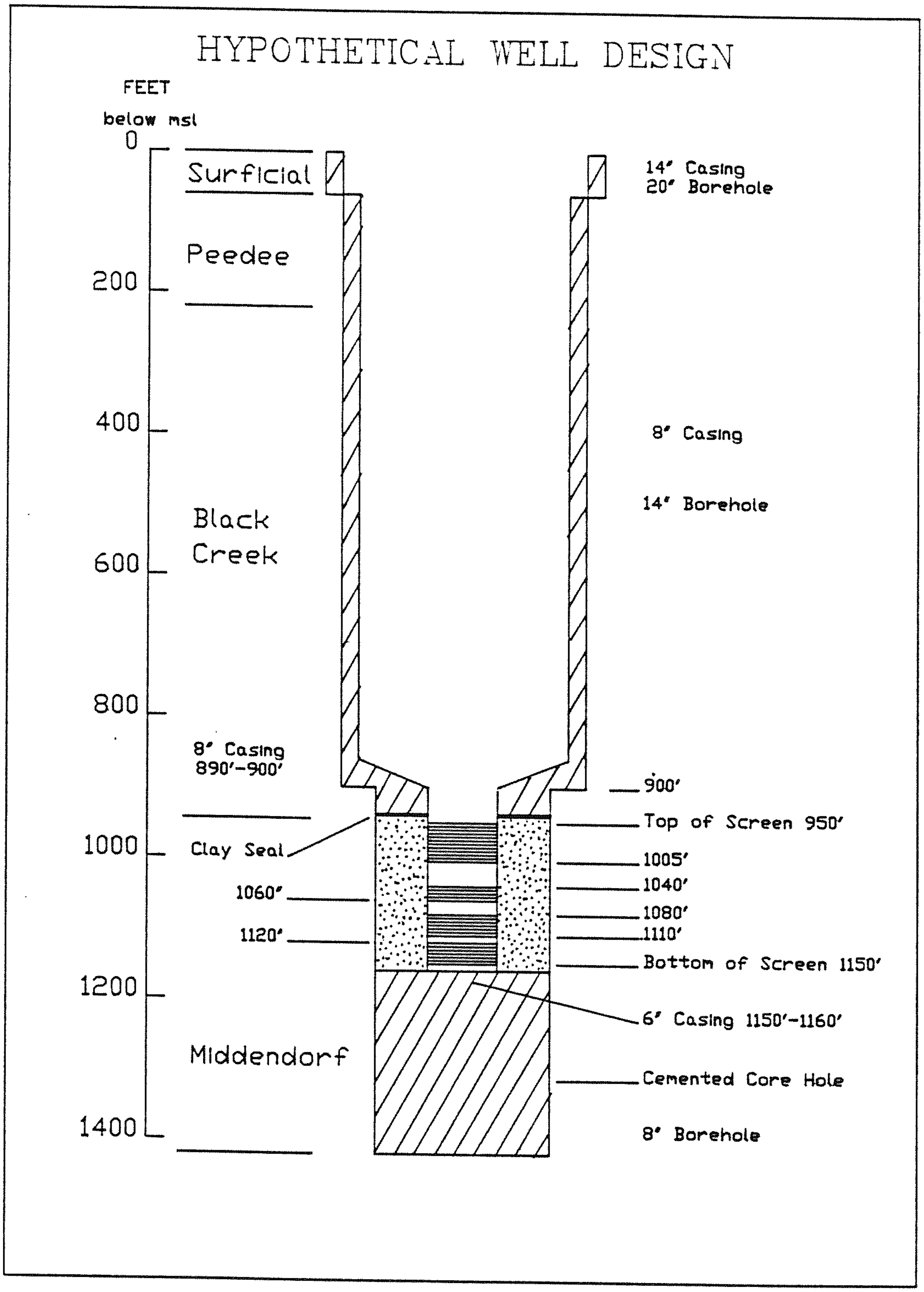


Figure 15. Hypothetical design of monitor well.

SUMMARY

The geologic data collected from wells in the ASR study area showed good lithologic correlation. This information was used to synthesize a lithologic log for the ASR site.

The sediments underlying the project area are divided into the following units:

Formation	Elevation (ft below msl)
Shallow deposits	0 - 60
Peedee Formation	60 - 220
Black Creek Formation	220 - 940
Middendorf Formation	940 - 1,400

There is an ongoing dispute with regard to the above formation boundary locations. For the purpose of this study, the units are referred to as described by Zack (1977) and Pelletier (1985).

Sufficient hydrogeologic data exist for the Black Creek aquifers near the ASR test well site, whereas very little information is available for the Middendorf Formation throughout Horry and Georgetown Counties. At the conclusion of this phase of the project, the test hole will be converted into an observation well for the Middendorf Formation.

The Black Creek and Peedee Formations appear to be hydraulically connected where the confining clay beds cause only short-term hydraulic independence. The Black Creek and Middendorf Formations, because of the large hydrostatic head difference, seem to be hydraulically independent.

It has been estimated in this report that the hydrostatic head difference between the Black Creek and the Middendorf at this site may range from 195 to 235 ft.

The hydrostatic heads for the different aquifers in the Black Creek decrease as these units get closer to the "principal sand aquifer". This unit is located in the upper third of the formation and supplies most of the ground water used in the region. Overdevelopment of this aquifer has resulted in a hydrostatic head decline of more than 130 feet at the test site, assuming wells once flowed.

The chemical quality of water from the shallow unconfined deposits is variable and generally inferior to that of deeper aquifers; however, some shallow artesian sand aquifers yield good water.

Water quality in the Peedee aquifers ranges from poor to excellent. The water contains low concentrations of fluoride and chloride and high concentrations of iron, manganese, and hydrogen sulfide. Many of these water quality problems are localized, with no apparent patterns to their occurrence.

Water from the Black Creek aquifers is of a sodium bicarbonate type. The water is generally soft, low in iron, and alkaline, but it has objectionable concentrations of chloride, fluoride, sodium, and total dissolved solids.

Throughout most of Horry and Georgetown Counties, the Middendorf aquifers yield saline water. Zack (1977) suggests that the saline water is dilute connate water.

Eight zones in the Black Creek Formation and four zones in the Middendorf have been selected as potential units for aquifer storage-recovery feasibility testing.

The information contained in this report was used to design a hypothetical well to tap the upper aquifers of the Middendorf Formation. These specifications should be used only as a guide for the drilling and construction of the test well.

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APPENDICES

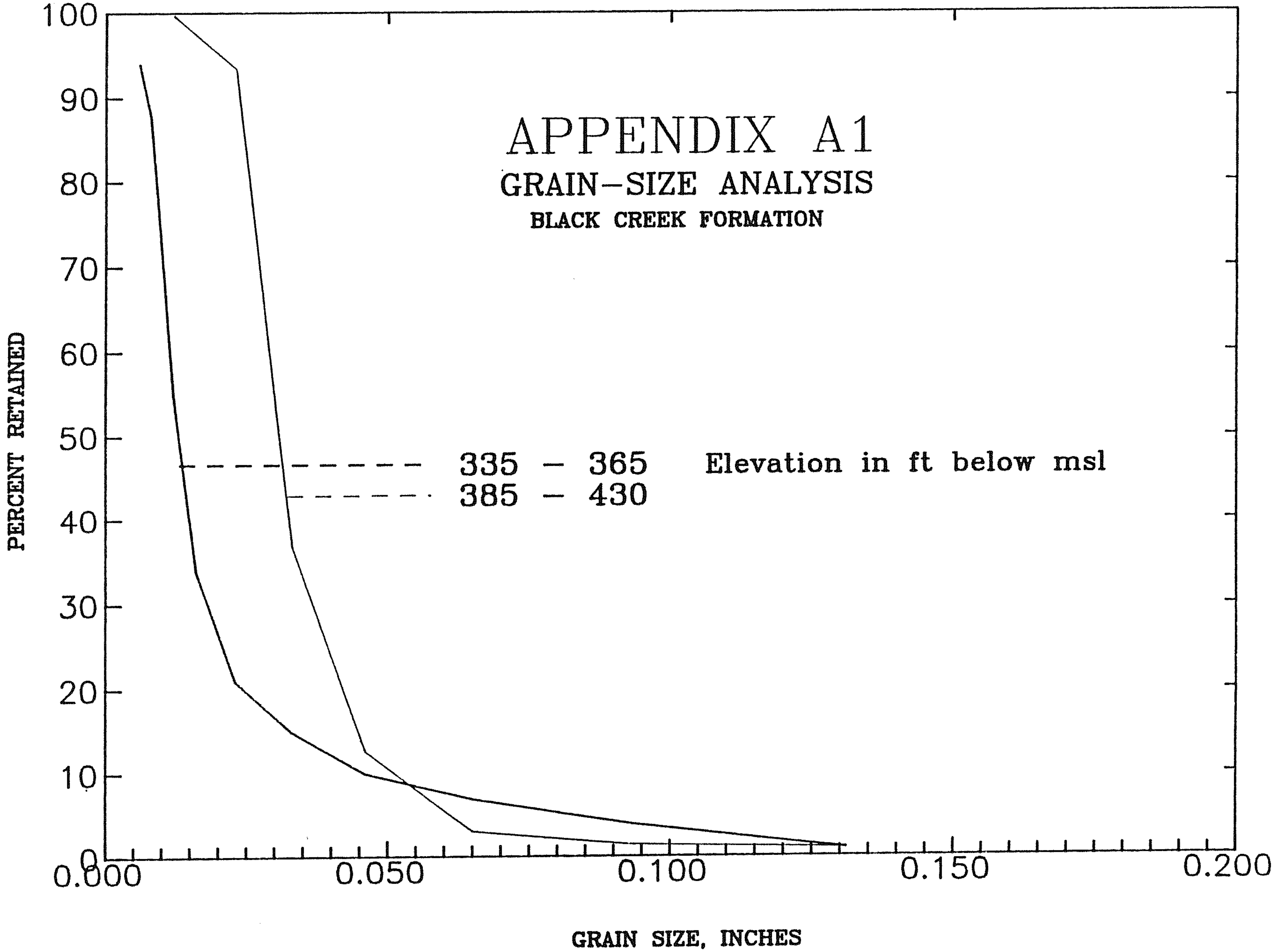
APPENDIX A

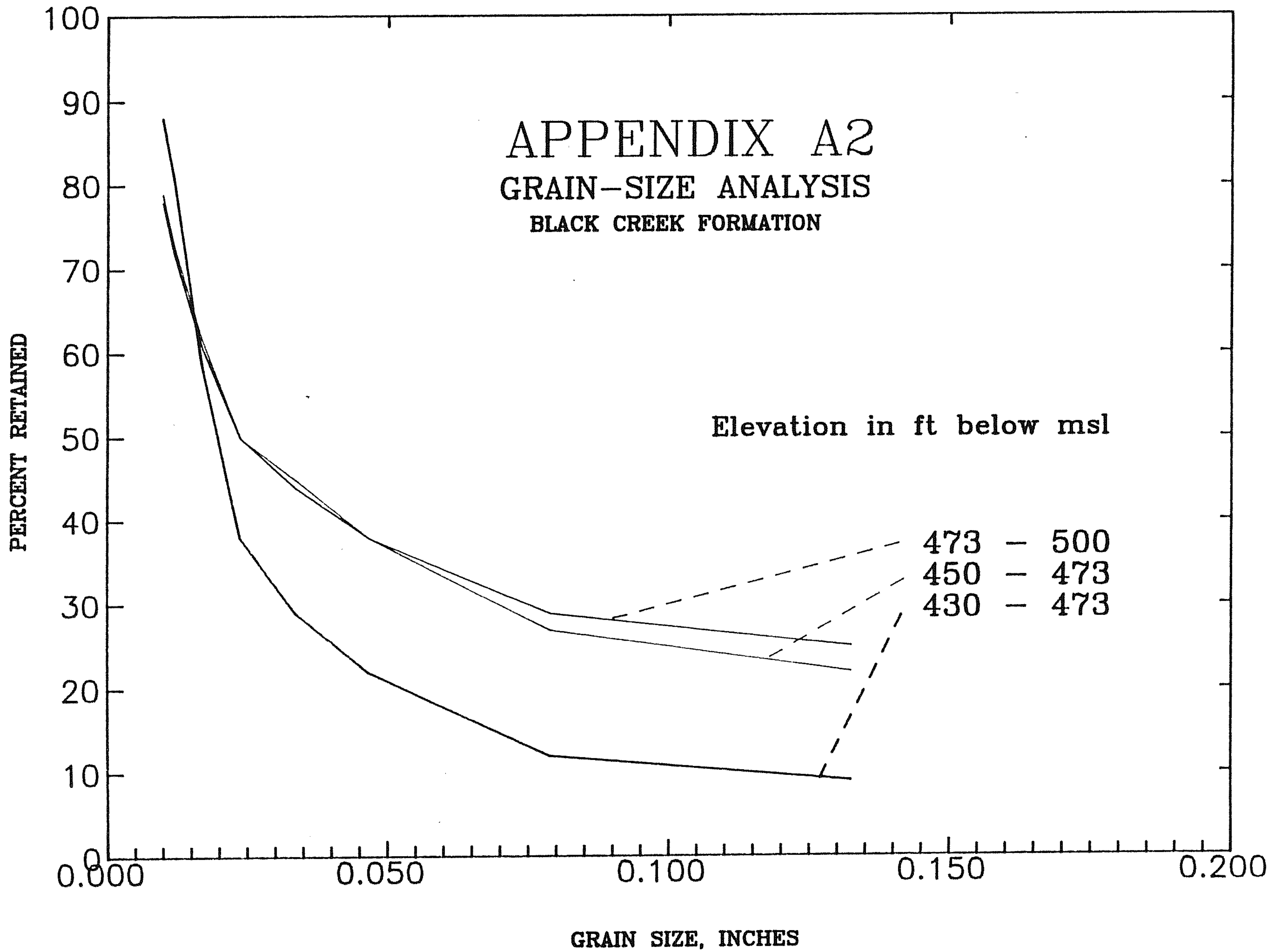
A1. Black Creek Formation grain-size analyses from -355 to -430 ft msl.

A2. Black Creek Formation grain-size analyses from -430 to -500 ft msl.

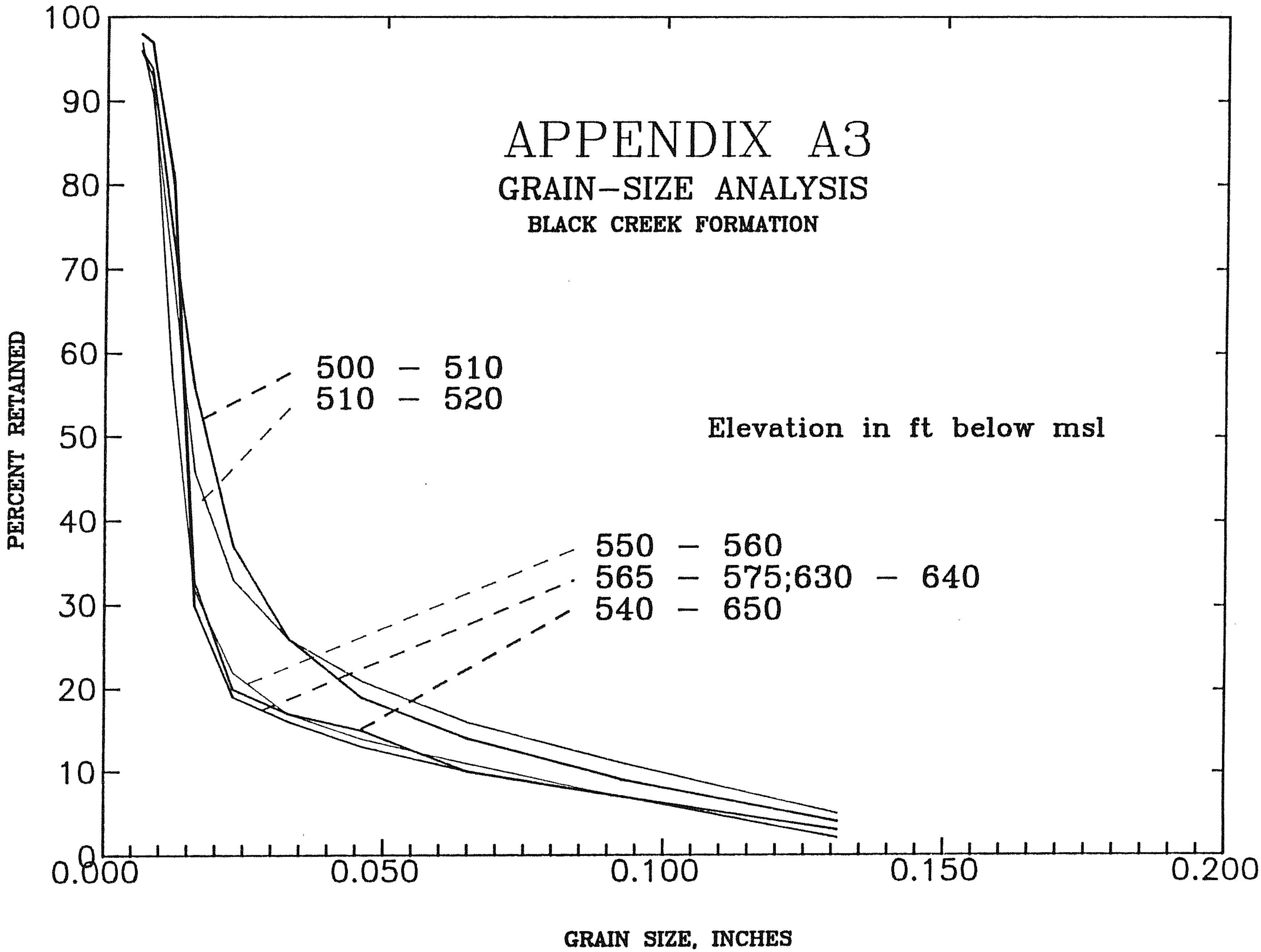
A3. Black Creek Formation grain-size analyses from -500 to -650 ft msl.

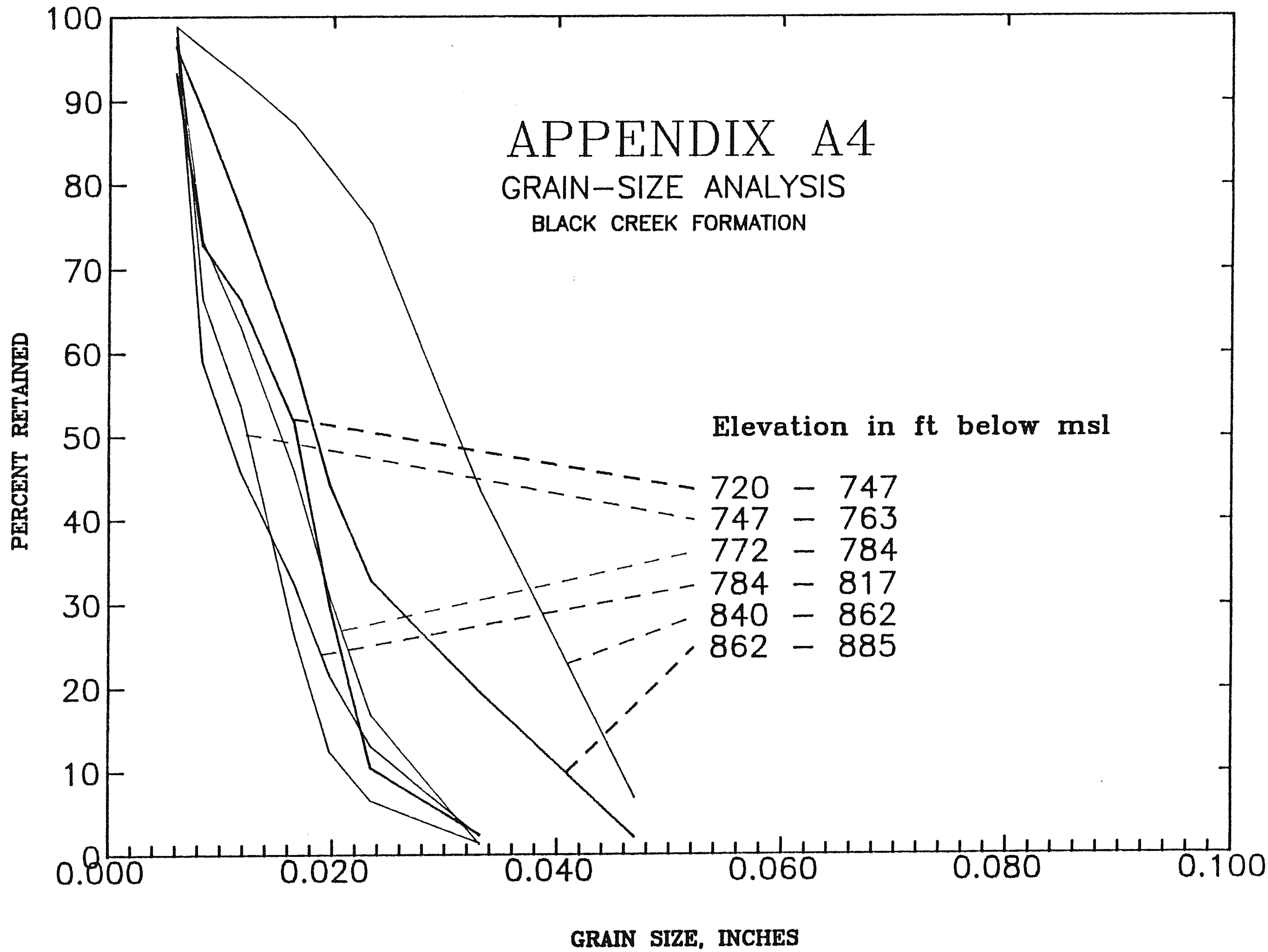
A4. Black Creek Formation grain-size analyses from -720 to -880 ft msl.


APPENDIX A1
GRAIN–SIZE ANALYSIS
BLACK CREEK FORMATION
335 – 365 Elevation in ft below msl
385 – 430
PERCENT RETAINED
100
90
80
70
60
50
40
30
20
10
0
0.000
0.050
0.100
0.150
0.200
GRAIN SIZE, INCHES



APPENDIX A2
GRAIN-SIZE ANALYSIS
BLACK CREEK FORMATION
Elevation in ft below msl
473 - 500
450 - 473
430 - 473
PERCENT RETAINED
GRAIN SIZE, INCHES
100
90
80
70
60
50
40
30
20
10
0
0.000
0.050
0.100
0.150
0.200

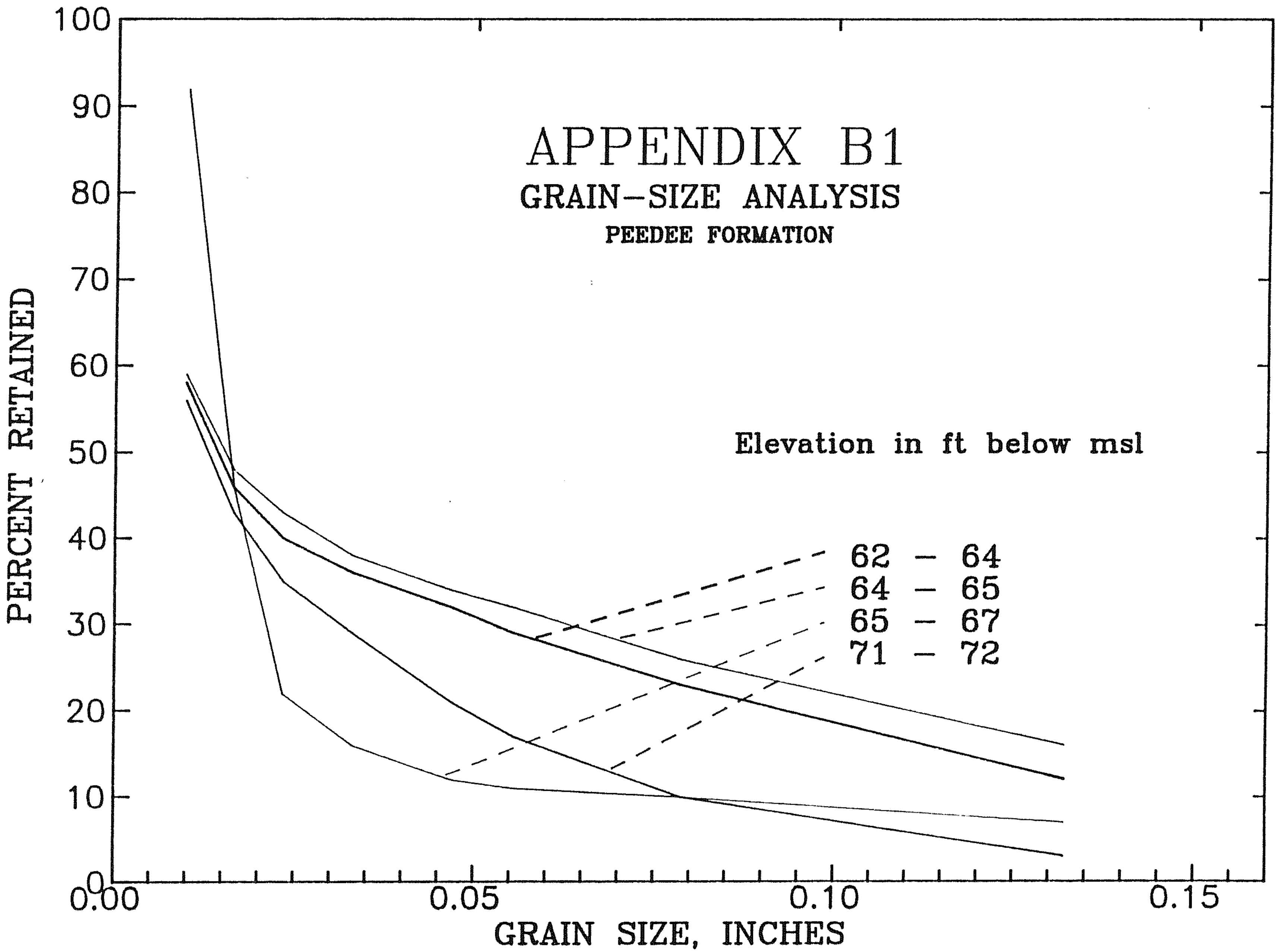

APPENDIX A3
GRAIN-SIZE ANALYSIS
BLACK CREEK FORMATION
PERCENT RETAINED
100
90
80
70
60
50
40
30
20
10
0
500 - 510
510 - 520
Elevation in ft below msl
550 - 560
565 - 575;630 - 640
540 - 650
0.000
0.050
0.100
0.150
0.200
GRAIN SIZE, INCHES


APPENDIX A4
GRAIN-SIZE ANALYSIS
BLACK CREEK FORMATION
Elevation in ft below msl
720 – 747
747 – 763
772 – 784
784 – 817
840 – 862
862 – 885
PERCENT RETAINED
0
10
20
30
40
50
60
70
80
90
100
0.000
0.020
0.040
0.060
0.080
0.100
GRAIN SIZE, INCHES

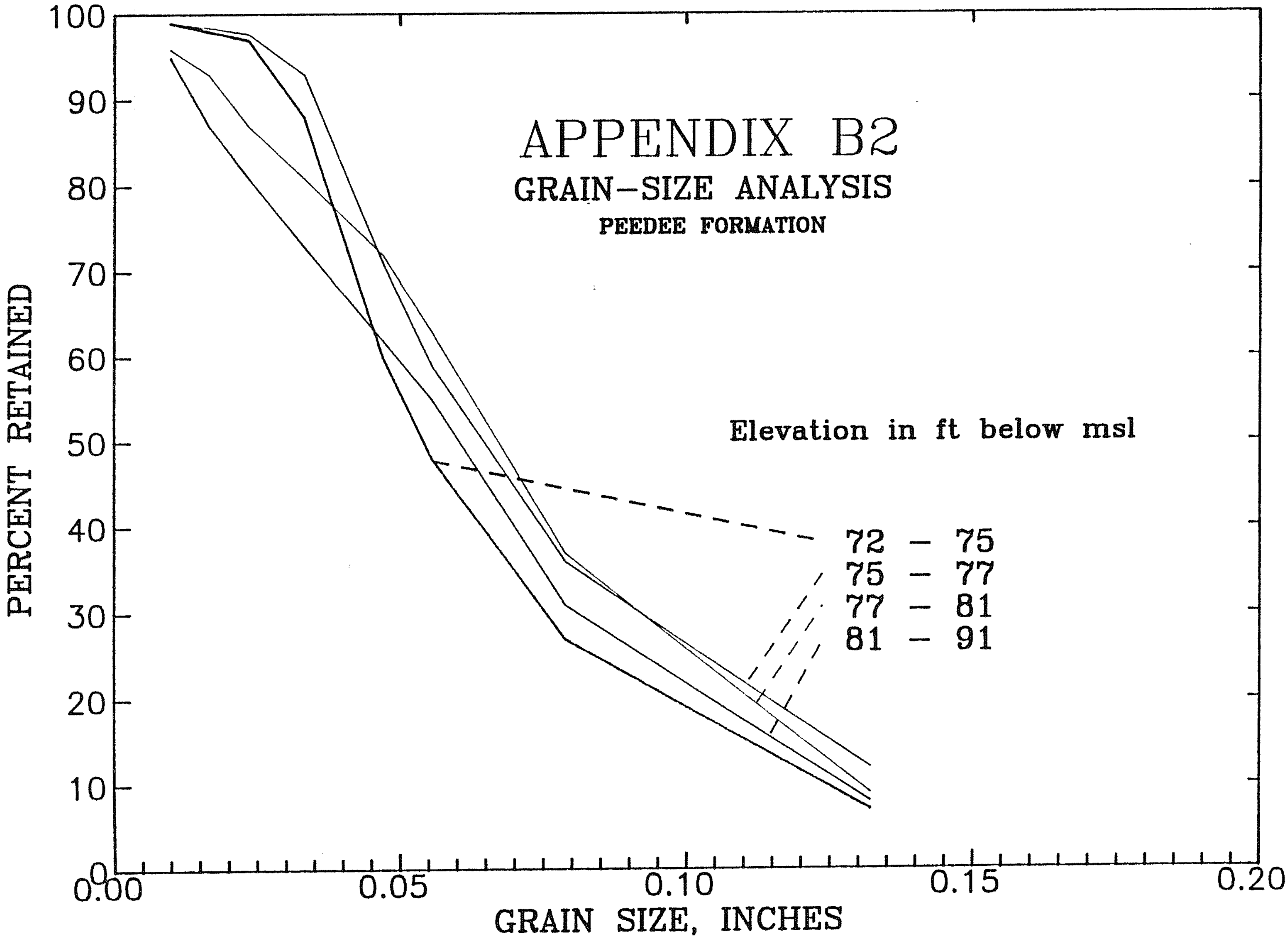
APPENDIX B

B1. Shallow deposits grain-size analyses from 62 to 72 feet.

B2. Shallow deposits grain-size analyses from 77 to 91 feet.



APPENDIX B1
GRAIN-SIZE ANALYSIS
PEEDEE FORMATION
Elevation in ft below msl
62 - 64
64 - 65
65 - 67
71 - 72
PERCENT RETAINED
GRAIN SIZE, INCHES
100
90
80
70
60
50
40
30
20
10
0
0.00
0.05
0.10
0.15


APPENDIX B2
GRAIN-SIZE ANALYSIS
PEEDEE FORMATION
Elevation in ft below msl
72 - 75
75 - 77
77 - 81
81 - 91
PERCENT RETAINED
100
90
80
70
60
50
40
30
20
10
0
0.00
0.05
0.10
0.15
0.20
GRAIN SIZE, INCHES

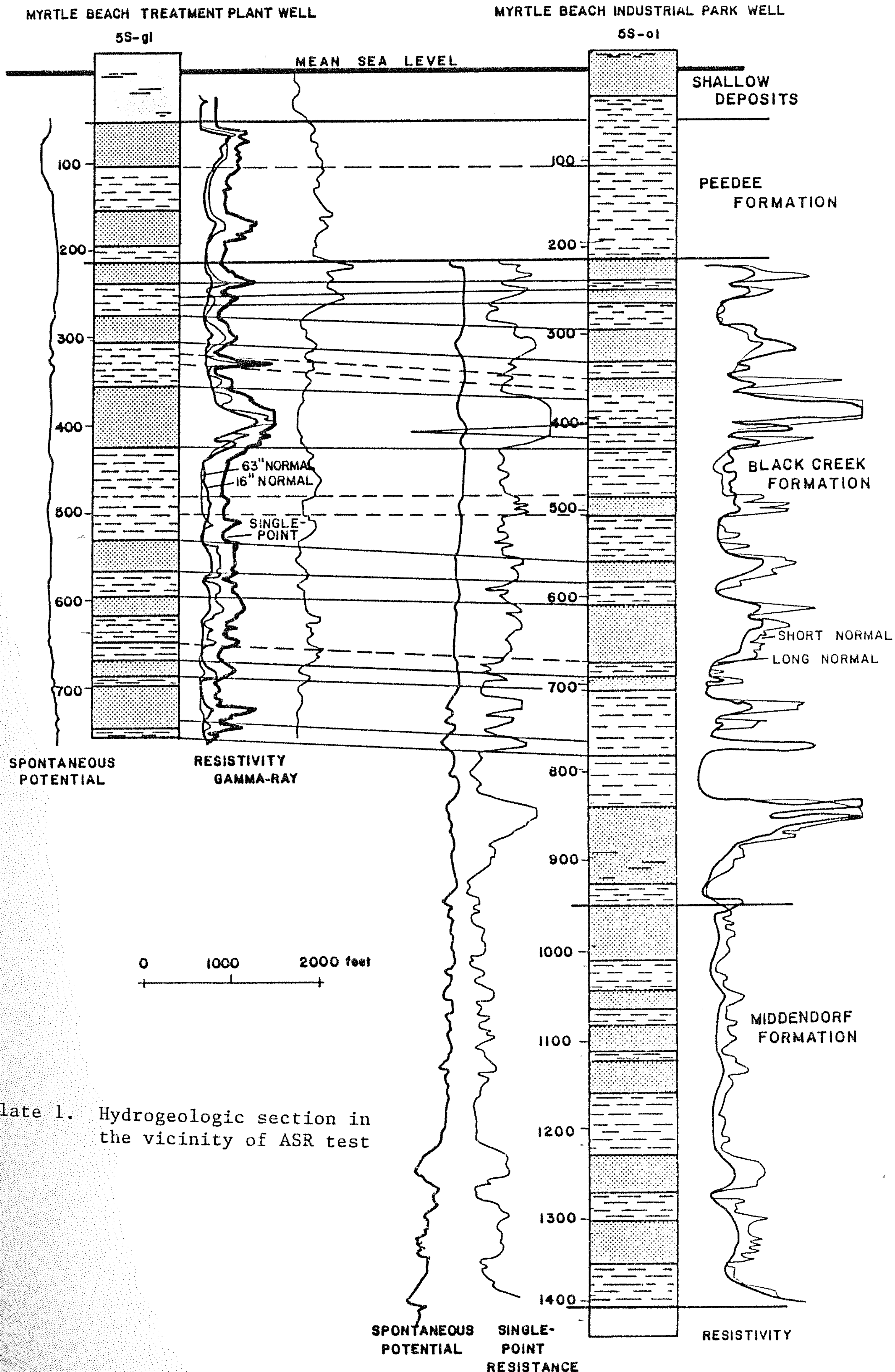


Plate 1. Hydrogeologic section in the vicinity of ASR test