UNITED STATES

DEPARTMENT OF THE INTERIOR

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HYDROLOGY OF THE SAND-AND-GRAVEL AQUIFER IN CENTRAL AND SOUTHERN ESCAMBIA COUNTY, FLORIDA

PRELIMINARY REPORT — NOVEMBER 1973

By

Henry Trapp, Jr.

OPEN-FILE REPORT

FL-74027

PREPARED
IN COOPERATION WITH THE
CITY OF PENSACOLA

Tallahassee, Florida

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ABSTRACT

The sand-and-gravel aquifer is the only fresh-water aquifer in the Pensacola area. Problems related to development of the aquifer include maximum safe yield, local contamination, local salt-water intrusion, corrosiveness of the water, areas of high iron concentration, and increasing nitrate concentration. The city of Pensacola is seeking hydrologic information, including water-quality data, to plan for future expansion of the water-supply system.

This report summarizes the third year's findings of a 6-year study of the sand-and-gravel aquifer. Although the thickness of the aquifer locally exceeds 1,000 feet (300 metres) most of the clean sand layers are no more than 450 feet (140 metres) below land surface. The highest head is at the north edge of the area; the head is drawn down below sea level in areas of heavy pumping. Ground water moves southward from the northern half of the county to be intercepted near Cantonment. Virtually all ground water discharged south of Cantonment derives from local precipitation.

The report contains maps showing concentrations of carbon dioxide, nitrate, and iron in water from the aquifer, potentiometric maps, geo-hydrologic sections, and lithologic and radioactive logs of test holes.

THE PROBLEM

Earlier hydrologic studies show that ample quantities of soft water of low dissolved-solids concentration are obtainable from the sand-and-gravel aquifer in central and southern Escambia County. Some wells drilled for the city of Pensacola have yielded water with unacceptably high amounts of iron and carbon dioxide, and some wells have had disappointingly low yields. The city, therefore, is seeking hydrologic information, including water-quality data, in an effort to avoid well abandonments and to plan for future expansion of the water-supply system.

OBJECTIVES AND APPROACH

This investigation is intended to provide information on the quality and quantity of water available from the sand-and-gravel aquifer, the only fresh-water aquifer in central and southern Escambia County.

The project area extends from the western end of Santa Rosa Island, through Pensacola to State Road 196 (S-196) north of Quintette (fig. 1). During the first year of the project (fiscal year 1971), effort was concentrated in the southern half of the area, generally south of latitude 30°30' N., which approximately coincides with Interstate Highway 10 in southeastern Escambia County. In the second year, data coverage was extended to the northern boundary of the area. When the project was planned, it was intended that the third year be spent in integrating the data on hand, obtaining additional data as needed, and preparing a summary interpretative report. However, before this third year's planned work was done the project was extended another 3 years, providing opportunity to include the construction of an analog or digital model of the aquifer. The third year's goals were changed, as part of the project extension. Instead of integrating the data, a program of drilling deeper (400-ft or 122-m (table 1)) test wells and the planning and preparation of preliminary interpretative material for the model was undertaken. This report contains the results of the third year's test drilling program. It also lists chemical analyses of water samples, and includes interpretative material available at the time.

GENERAL DESCRIPTION OF THE AQUIFER

The sediments making up the sand-and-gravel aquifer are exposed at the surface throughout Escambia County and extend as much as 1,000 feet (300 m) below the surface. A thick clay layer underlies the aquifer in the southern part of the county. The aquifer flow system is bounded by Perdido River and Perdido Bay to the west, Escambia River and Escambia Bay to the east, and Pensacola Bay and the Gulf of Mexico to the south. These bodies of water act as partly penetrating drains.

The aquifer consists primarily of quartz sand, ranging in size from very fine (1/16-1/8 mm) to very coarse (1-2 mm), and commonly with disseminated small quartz pebbles. The sand is locally cemented by iron

Figure 1.--Map showing area of investigation, locations of test holes and wells referred to in text, and locations of cross sections. (Figure is in pocket at end of report.)

Table 1.--Factors for converting English units to International System (SI) units.

minerals into thin layers of hardpan. Layers and lenses of gravel, silt, and clay also occur within the aquifer. Most of these layers and lenses probably extend for only short distances. The variations in porosity and hydraulic conductivity resulting from variations in rock type are important in partly isolating parts of the aquifer from each other and in contributing to variations in hydraulic head with depth.

Most wells and test holes in central and southern Escambia County penetrate less than 300 feet (90 m) of the aquifer, and, consequently, most of the data available apply to this upper section. The upper part of the aquifer generally is noncalcareous and contains few fossils, mostly fresh-appearing woody and carbonized plant remains; in the lower part of the aquifer fossil shells are abundant. Fossiliferous sand locally is near the surface in southwestern Escambia County.

Geohydrologic Sections

Test drilling completed in the past year has generated sufficient data to prepare geohydrologic sections of the sand-and-gravel aquifer. The upper 400 feet (120 m) of the aquifer yields most of water withdrawn and, from examination of the logs of oil tests and other deep bore holes, seems to contain most of the clean, coarser sand. Most of the test holes drilled during the first 2 years of this investigation penetrated only about 200 feet (60 m) or less of the aquifer. To date ten 400-foot (122-m) test holes have been drilled; these are U.S. Geological Survey test holes 12 and 13 (Trapp, 1972, p. A3-A11) and U.S. Geological Survey test holes 25-32 (See Appendix, p. A3-A39.). The locations of the test holes are shown in figure 1, together with lines of section. The geohydrologic sections (figs. 2-6) also include logs of other test holes, wells, and oil tests.

The geohydrologic sections show the intervals of clean sand or gravel, the top of fossiliferous sediment (shell zone) and the top of the Pensacola Clay, which is equivalent to the base of the sand-and-gravel aquifer. The top of the shell zone is a useful reference marker dividing the aquifer into upper and lower zones, and is the only wide-spread marker within the aquifer known to date. The geohydrologic sections show most of the aquifer's clean sand and gravel to be in the upper zone.

For the test holes and wells having gamma-ray logs, the depth intervals of clean sand or gravel were taken as those intervals in which the gamma-ray curve was to the left of the 20 Percent Gamma Reference Line (See section on Radioactivity Logging.). For other wells, clean sand or gravel sections were interpreted from electric logs, where

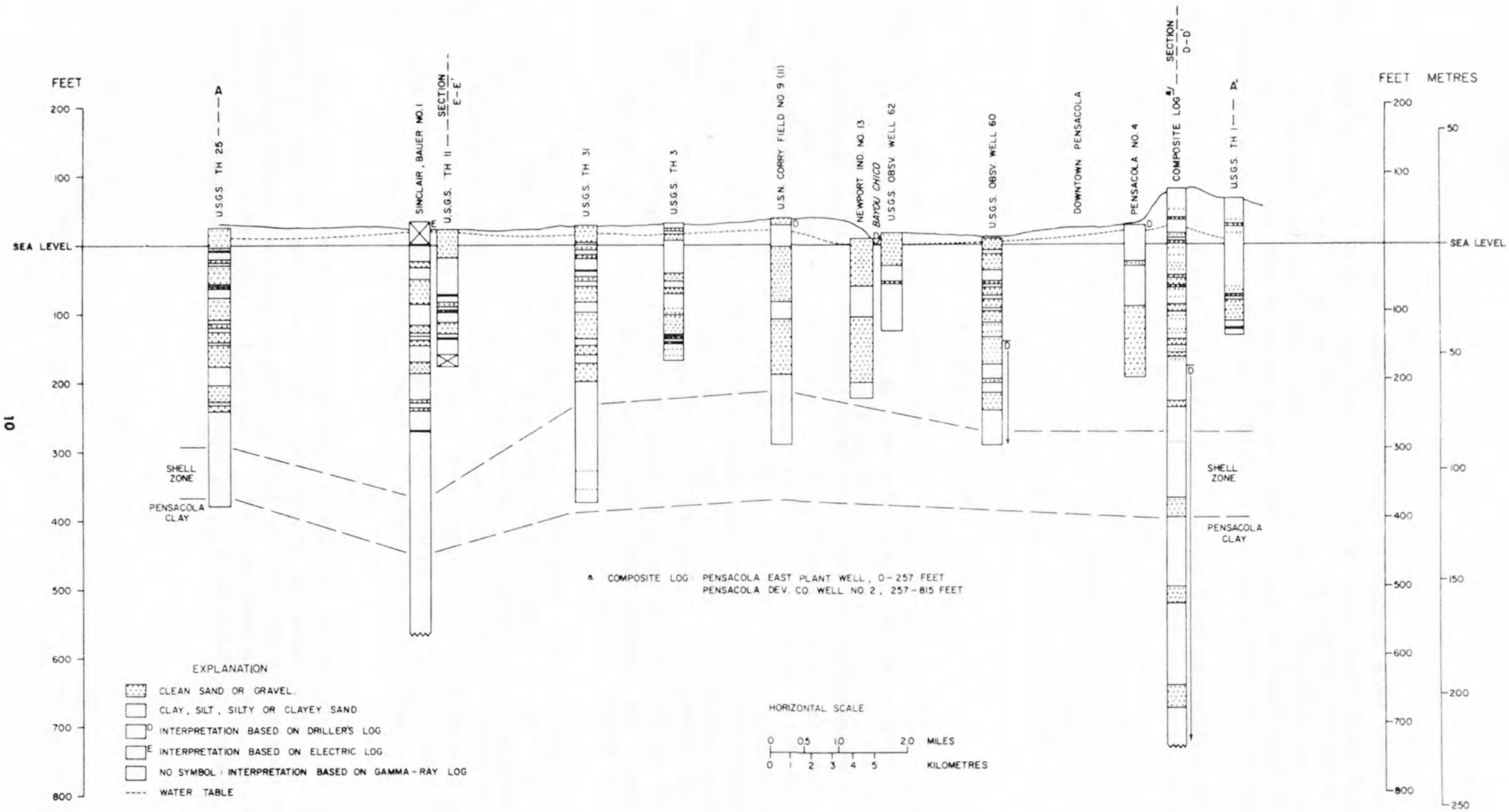

FIGURE 2. GEOHYDROLOGIC SECTION A-A', SOUTHWEST TO NORTHEAST.

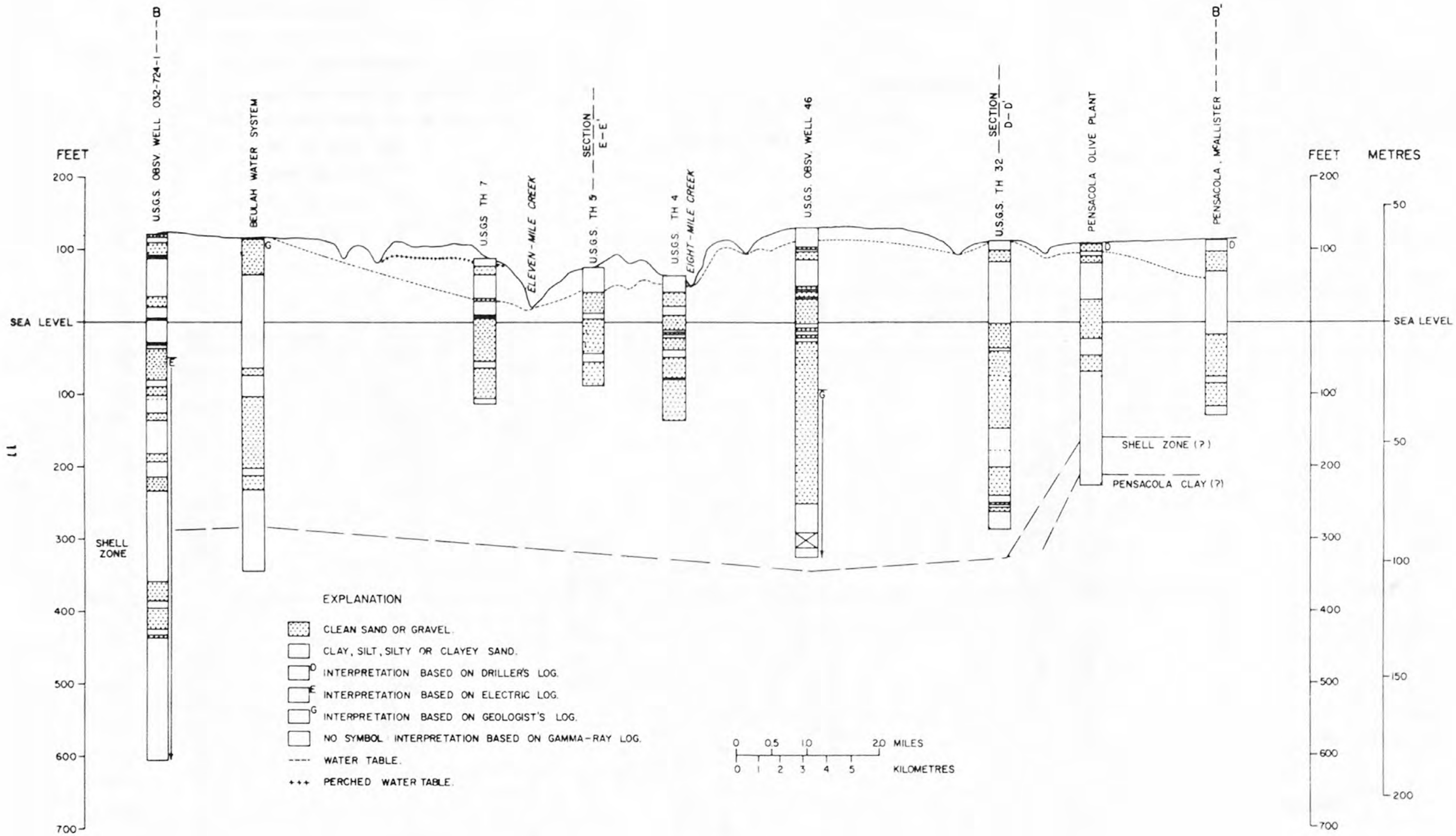

FIGURE 3. GEOHYDROLOGIC SECTION B-B', WEST TO EAST.

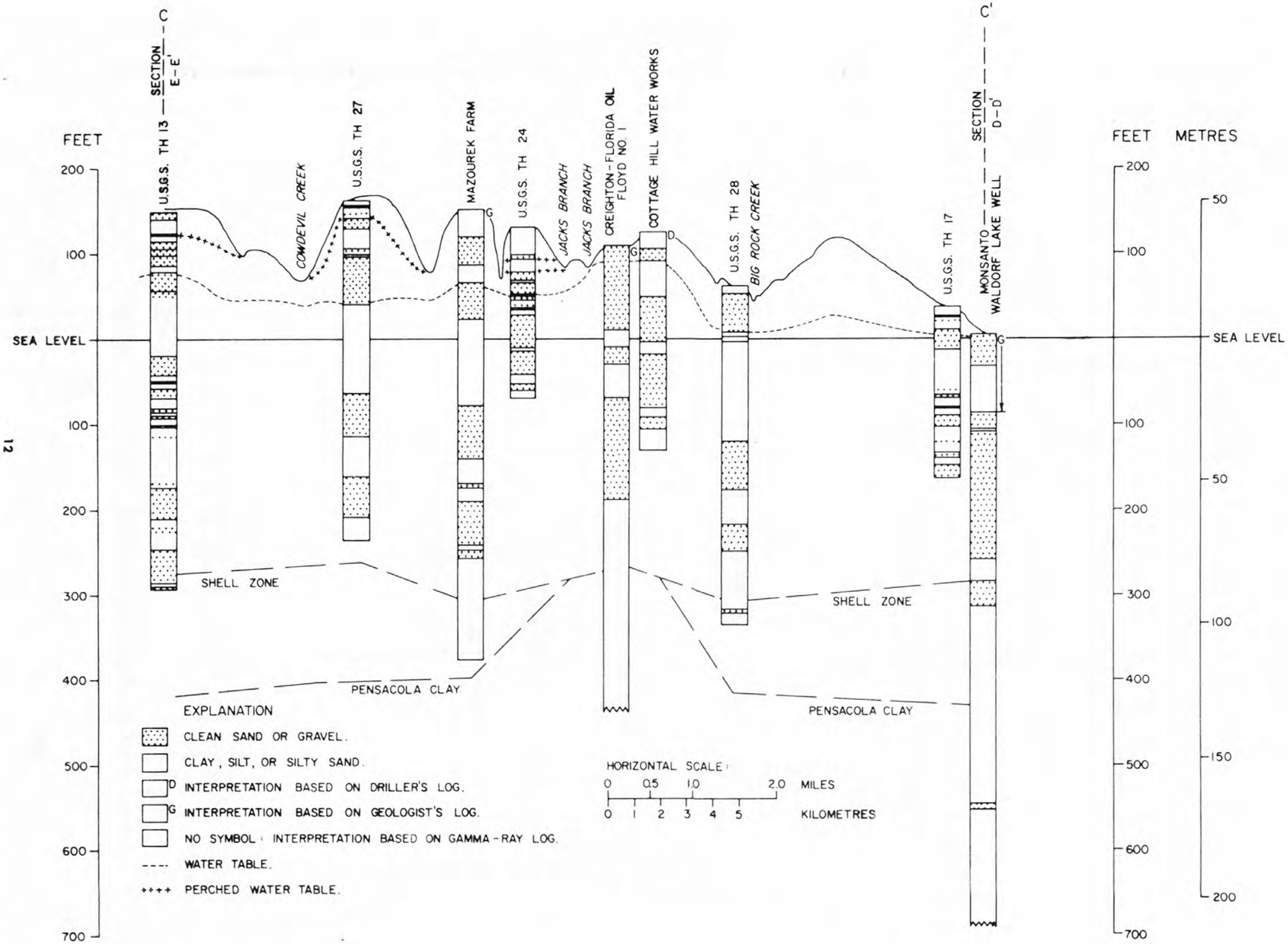

FIGURE 4. GEOHYDROLOGIC SECTION C-C', NORTHWEST TO SOUTHEAST.

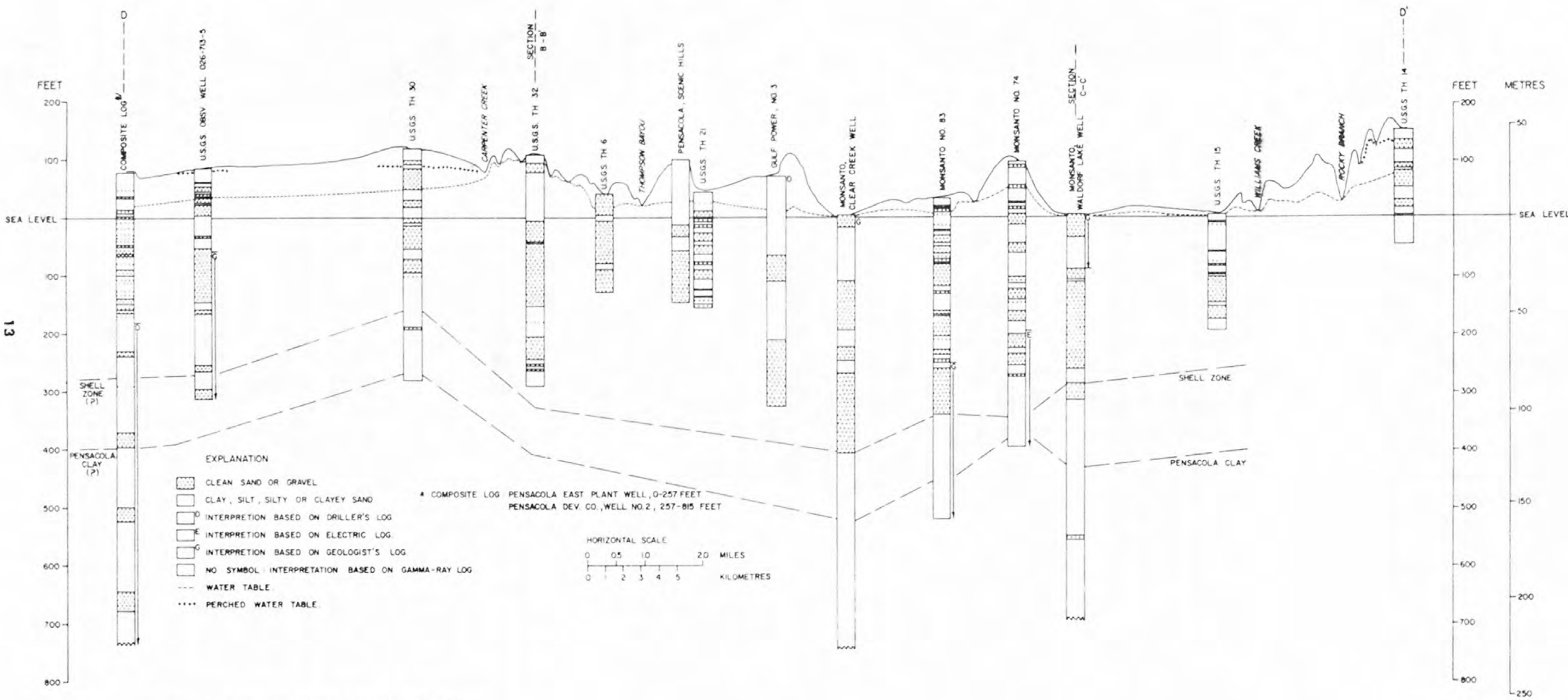

FIGURE 5. GEOHYDROLOGIC SECTION D-D', SOUTH TO NORTH.

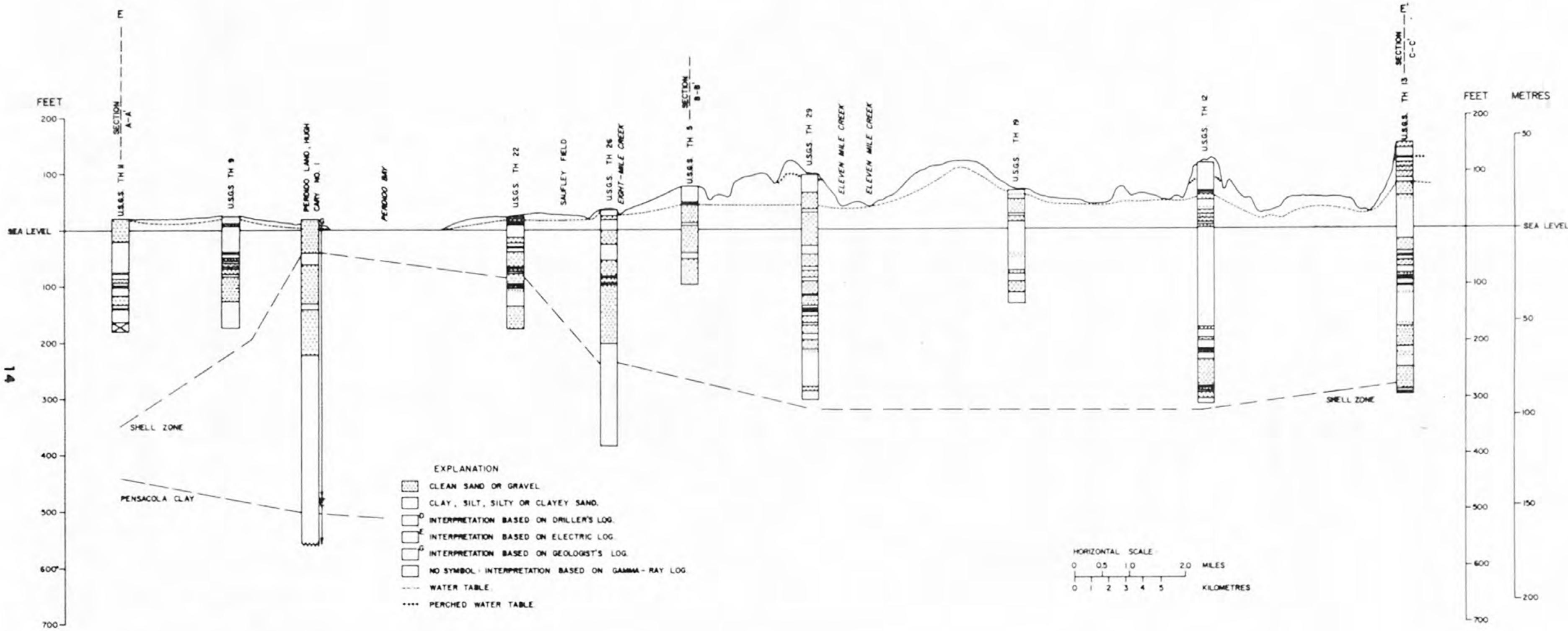

FIGURE 6. GEOHYDROLOGIC SECTION E-E', SOUTH TO NORTH.

available, or from geologist's or driller's logs. The sources of the interpretations are shown on the sections. The intervals between the clean sand or gravel intervals are generally silty or clayey sand and probably act as moderately permeable confining beds.

Correlation of the clean sand or gravel intervals from one well to another is uncertain because of the lateral variability in lithology of the aquifer (Musgrove, Barraclough, and Marsh, 1961, p. 15-16, fig. 5). The top of the shell zone was identified in at least two wells on each geohydrologic section. The Pensacola Clay has been reached by only a few wells in the area, its top has been drawn in where it has been reached and tentatively located below the shell zone where the approximate interval between the Pensacola Clay and the overlying shell zone is known.

Geohydrologic section A-A' (fig. 2) extends northeastward from Test Hole 25 in southwestern Escambia County to just west of Bayou Texar. At the west end of the section, the shell zone was reached at 321 feet (98 m) below land surface in U.S. Geological Survey test hole 25 and the top of the Pensacola Clay was picked from a change in cuttings at 386 feet (118 m). The electric log of the Sinclair, Bauer No. 1 (Florida Bureau of Geology No. W-3364) was used to pick the top of the Pensacola Clay. Near the east end of the section, the Pensacola Clay was picked at 468 feet (143 m) below land surface on the driller's log of the Pensacola Development Co. No. 2. Fossils are not mentioned in the driller's log of this well, and the top of the shell zone was estimated from data obtained from the log of U.S. Geological Survey observation well 60. Along this line of section, the shallowest depth at which the shell zone was found was 260 feet (79 m) below land surface in U.S. Geological Survey test hole 31. Corry Field No. 9 (11) may have encountered it but the driller's log does not mention shells. Almost all of the clean sand and gravel is above the shell zone.

Geohydrologic section B-B' (fig. 3) extends eastward from U.S. Geological Survey observation well 032-724-1 near the junction of U.S. 90 (Mobile Highway) and U.S. 90A (Nine-Mile Road) to the Pensacola McAllister well north of Hagler Field. U.S. Geological Survey observation well 032-724-1 penetrated the top of the shell zone at about 410 feet (125 m) below land surface and probably had not reached the Pensacola Clay at its total depth of 730 feet (223 m). Near the east end of the section, at the Pensacola, Olive Plant well, the driller's log reported shells at 266 feet (81 m) below land surface, the shallowest depth of the shell zone along this section, and the Pensacola Clay was tentatively picked at 319 feet (97 m) below land surface. Thus, the shell zone thins eastward along this section from more than 320 feet (97 m) on the west to 53 feet (16 m) on the east. The electric log of 032-724-1 indicates about 67 net feet (20 m) of clean sand within the shell zone. There was no clean sand in the 53-foot (16- m) thick shell zone near the east end of the section.

Geohydrologic section C-C' (fig. 4) extends southeast from U.S. Geological Survey test hole 13 to Monsanto's deep monitor well at Waldorf Lake, which reached the shell zone at 296 feet (90 m) below land surface, the shallowest depth at which it was reached by any well along this section. The lithologic log of the Creighton-Florida Oil, Floyd No. 1 (Florida Bureau of Geology Well No. W-4597; Marsh, 1966, table 15, p. 116) shows nonfossiliferous sand and gravel directly overlying the Pensacola Clay. This is the only well in the geohydrologic sections in which the shell zone is interpreted as missing.

Geohydrologic section D-D' (fig. 5) extends north-northwest from the Pensacola Development Co. Well No. 2 to U.S. Geological Survey test hole 14 north of Quintette. The top of the Pensacola Clay was tentatively picked on the basis of lithology in the Pensacola Development Co. Well No. 2 and U.S. Geological Survey test hole 30, and more definitely in the Monsanto wells. The shell zone was identified in U.S. Geological Survey observation well 026-713-5, test hole 30, and the Monsanto wells. Along this section, as in figure 2, most of the clean sand and gravel is above the top of the shell zone, which is shallowest at U.S. Geological Survey test hole 30 (280 ft or 85 m below land surface).

Geohydrologic section E-E' (fig. 6) extends north from U.S. Geological Survey test hole 11 in southwest part of Escambia County to U.S. Geological Survey test hole 13 in the northwest corner of the project area. U.S. Geological Survey test hole 11 did not reach the shell zone or Pensacola Clay, but their approximate depths were inferred using the log of nearby Sinclair, Bauer No. 1 (fig. 2). The shell zone was encountered at 60 feet (16 m) below land surface in the Perdido Land, Hugh Cary No. 1 (Florida Bureau of Geology Well No. W-4091; Marsh, 1966, table 15, p. 113) and at 107 feet (33 m) below land surface in U.S. Geological Survey test hole 22 (Trapp, 1973, p. A37-A38). Farther north, in U.S. Geological Survey test holes 26 and 13, the shell zone is encountered at greater depths, and the 430-foot (131-m) U.S. Geological Survey test hole 12 and 400-foot (122-m) U.S. Geological Survey test hole 29 did not reach it. Relatively clean sand and gravel were found within the shell zone in the Perdido Land, Hugh Cary No. 1 and U.S. Geological Survey test holes 22 and 13. However, in U.S. Geological Survey test hole 13, cuttings indicated that the sand in the shell zone was finer and less clean than the sand immediately above.

Wells off the lines of geohydrologic section that reportedly encountered the top of the shell zone at shallow depths include the following, with the depths given: U.S. Geological Survey test hole 23, near the west gate of the Naval Air Station, 118 feet or 36 metres (Trapp, 1973, p. A40); Vichy Springs well at Warrington, 6 feet (2 m) (Florida Bureau of Geology W-223 as logged by Charles W. Hendry, Jr.); U.S. Navy Yard well at the site of the present Naval Air Station, surface to 26 feet (8 m) (Florida Bureau of Geology W-222½ as logged by Applin); and the Layne Central test well on Santa Rosa Island, 25 feet or 8 metres (Marsh, 1966, table 15, p. 111).

The geohydrologic sections show that the shell zone of the sand-and-gravel aquifer ranges between 200 feet (60 m) and 450 feet (140 m) below land surface within the area of this investigation, except in parts of southwestern Escambia County and Santa Rosa Island, where it is shallower. Most of the clean sand and gravel in the aquifer is above the shell zone. The sand layers in the shell zone are generally isolated from the overlying "main" part of the aquifer by confining beds.

Clay Seams

Clay seams within the sand-and-gravel aquifer are generally no more than 2 or 3 feet (0.6 to 0.9 m) thick. Thicker beds which the drillers describe as "clay" or "marl" are generally clayey or silty sand. If a well is screened opposite a clay seam, clay may flow into the well, causing the discharged water to be turbid or milky. Clay suspended in water from U.S. Geological Survey test hole 25 (Appendix, p. A2-A5) was identified as being mostly kaolinite.

If a thin clay seam causes the water from a well with a short screen to be turbid, relocating the screen a few feet may solve the problem. Large-capacity wells (arbitrarily defined, for this study, as wells capable of yielding 1,000 gallons per minute or 63 l/s or more) require a screen length on the order of 100 feet (30 m) in the sand-and-gravel aquifer. It may be best to drill a preliminary test hole and run an electric or gamma-ray survey before designing the casing and screen for such a well. Clay seams would be delineated by the logs, and could be blanked off.

WATER LEVELS

Water Table, Head and Potentiometric Surface

The rock (including unconsolidated sediments) forming the upper part of the earth's crust contains numerous small pores. In clay or silt these pores are abundant but extremely small. Sand and gravel have fewer but larger openings. The many pores in the rock serve as the storage space for water and also the paths by which it moves. That part of the upper earth's crust in which pores are filled with water is known as the zone of saturation. If an uncased hole is excavated into permeable material below the top of the zone of saturation, water will flow freely into it. The level at which water stands in the hole represents the water table at this point. It is free to rise and fall with changes in the amount of water entering and leaving the saturated zone (recharge and discharge). The water table is not a flat surface but generally reflects, in a subdued way, the irregularities of topography. It intersects the land surface at springs, streams, and lakes.

The level at which water stands in a well cased substantially below the water table is generally not identical to the water table. This is because the water in the ground is usually in motion, moving from points of higher head (potential energy level) to lower head. If there is a downward component to the ground-water movement, the head must be lower at depth than just below the water table. If beds of low permeability intervene, such as clay or silt, the difference in head can be substantial.

The water levels, or heads, in wells constructed in the same water-bearing zone establish a "potentiometric surface." This would be the water table in wells screened at the water table. Other potentiometric surfaces would be defined by levels in wells screened at various horizons below the water table. In flowing wells, the potentiometric surface is above ground.

Potentiometric Maps

Preparation of the water table map in the 1972 interim report (Trapp, 1973, p. 11, fig. 2) was complicated by the problem of distinguishing perched water tables from the regional water table. Data from the latest test drilling indicate that parts of the surface then mapped as the water table actually were local perched water tables.

The potentiometric surface maps prepared for this report used data from wells that are screened from 100 to 300 feet (30 to 90 m) below land surface, which is the depth range where virtually all the large-capacity wells in central and southern Escambia County are screened.

Figure 7 shows the approximate altitude of water levels in sand-and-gravel aquifer wells 100 to 300 feet (30 to 90 m) deep during the spring-summer, 1973. The control used for this map was, in order of decreasing reliability: (1) water levels in observation wells and other wells 100 to 300 feet (30 to 90 m) deep measured in June 1973, (2) water levels in wells in the same depth range, measured or reported at some

Figure 7.--Map showing the approximate altitude of water levels in sand-and-gravel aquifer wells 100-300 feet (30-90 m) in depth, spring-summer, 1973. (Figure is in pocket at end of report.)

time other than June 1973, (3) water levels in other wells, and (4) topography. Pumping and static levels were used as control for the cones of depression caused by pumping, but an accurate or detailed depiction of the cones of depression was not possible at the map scale used. The actual pumping levels at wells were generally not shown. Well losses account for part of the drawdowns and the deepest parts of the cones have such small radii that they cannot be shown on the map.

The highest measured point on the potentiometric surface was 82 feet (25 m) above mean sea level at the north end of the study area near the junction of S-196 and S-95A. This height is based on an old reported measurement, but its approximate accuracy is confirmed by a measurement of 77 feet (24 m) above mean sea level in U.S. Geological Survey test hole 14, about 0.5 mile (0.8 km) to the northeast. Water levels are also high near Ensley (near the center of the map) and near Hagler Field.

Areas of high-water levels are topographically high and not excessively affected by pumping. Pumping levels in large-capacity wells generally are below sea level. Where several heavily pumped wells are close together, the cones of depression coalesce so that the drawdown caused by each pumping well affects the water level in all the other surrounding wells. This may lower the water level to below sea level over a substantial area. Areas in which this has occurred include the area from the Naval Air Station to downtown Pensacola (this might also be interpreted as several separate areas of depressed head), and the areas around the Gulf Power Crist Steam Plant, the Monsanto plant, and the St. Regis plant.

The horizontal component of ground-water flow is from high to low points on the potentiometric surface. The natural direction of movement in most of the area is away from the topographic highs and eventually into a river or bay. There must be southward movement of ground water from the area of high-water levels at the north edge of figure 7, but probably none of this water moves south of Cantonment.

Musgrove, Barraclough, and Grantham (1965, p. 38) noted that the runoff in Jacks Branch (a tributary of the Perdido River northwest of Cantonment) was the lowest of any stream gaged in the Perdido River basin because of an "unusually low base flow or seepage to the stream." Only 30 percent of the total runoff was base flow, as compared to 55 to 75 percent of the total runoff in other streams in the area. Direct runoff per unit surface area is about the same as in the other streams. Apparently low base flow in Jacks Branch is the result of the interception of natural discharge by the northern well field of the St. Regis plant. The valley of Jacks Branch is a trough on the potentiometric surface. Ground water moving from the north end of the project cannot cross the reversal of gradient represented by the combination of Jacks Fork trough, the large compound cone of depression at Cantonment, and the trough associated with the valley of Big Rock Creek, a tributary of the Escambia River. Therefore, practically all the ground water pumped from wells in the area of Escambia County south of Cantonment comes from local recharge--that is, rainfall on the area.

Figure 8 shows the approximate altitude of the average potentiometric surface for the interval of the sand-and-gravel aquifer 100 to 300 feet (30 to 90 m) below land surface before development. The principal control points for this map are from old reports of water levels at city wells and observation wells before heavy pumping began nearby and observation wells at sites 2 miles (3 km) or more from large-capacity wells. The potentiometric surface was assumed to be at mean sea level along the coast except where flowing wells were reported, where it was assumed to be about 10 feet (3 m) above sea level. The general configuration of the contours was otherwise drawn to follow the spring-summer, 1973, map. Jacob and Cooper (1940, p. 44-45) reported that in 1886, water levels in wells at the Pensacola water works were 4 to 6 feet (1 to 2 m) below land surface. This was the year when the pumping station (located on the site of the present city plant) was put in operation. They also reported that in 1940 the static level was about 13 feet (4 m) below land surface in Pensacola Well No. 5 at the water works. In June 1973, the static water level in Pensacola Well No. 6 at the water works was measured at 28.5 feet (8.7 m) below land surface. Although the relative elevations of the first well in 1886, No. 5, and No. 6 are not known, the land surface is fairly flat at the water works, and so the measuring points are approximately at equal elevations. If the reported initial water level at the water works was correct, the level had declined 7 to 9 feet (2 to 3 m) by 1940, and about 22 to 25 feet (7 to 8 m) by 1973. Some of the difference could be attributable to differences in rainfall before the measurement, but most of the difference between 1886 and 1973 was probably caused by pumping, particularly at Pensacola Well No. 8, the East Plant, and Pensacola Well No. 9, all of which are within 1 mile (1.6 km) of the water works.

On March 18, 1940, the water level in U.S. Geological Survey observation well 46 at Ensley was 59.7 feet (18.2 m) above mean sea level. On June 11, 1973, the level was 52.3 feet (15.9 m). In 1940, there were no large-capacity wells within 7 miles (11 km) of U.S. Geological observation well 46. In 1973, the water level in U.S. Geological Survey observation well 46 was affected by two public-supply wells (Pensacola Broad and Ensley wells) within a radius of 1 mile (1.6 km) and about 30 other large-capacity wells within 7 miles (11 km).

Figure 8.--Map showing the approximate altitude of the average potentiometric surface in the interval 100 to 300 feet (30 to 90 m) below land surface in the sand-and-gravel aquifer before development. (Figure is in pocket at end of report.)

The earliest recorded water-level measurement at U.S. Geological Survey observation well 45, at the St. Regis plant at Cantonment, was about 62 feet (19 m) above mean sea level on March 18, 1940. At that time, the paper mill was not yet in operation and no large-capacity wells were closer than Pensacola, about 13 miles (21 km) away. In June 1973, the water level averaged about 33 feet (10 m) above mean sea level in U.S. Geological Survey observation well 45. The decline has been caused by heavy industrial pumping within a short distance of the well.

QUALITY OF WATER

General

Natural water contains dissolved gases and dissolved and suspended mineral matter. Water in contact with soils or rocks will dissolve some mineral matter. The quantity of dissolved mineral matter in water depends primarily on the length of time and type of rocks or soil with which the water has been in contact. Ground water commonly is more mineralized than surface water becuase it remains in contact with rocks and soil for much longer periods.

As ground water percolates through the upper part of the sand-and-gravel aquifer, it encounters little soluble material and remains soft and relatively unmineralized. The aquifer is composed largely of quartz sand (silica), which is not very soluble. The abundant precipitation in the Pensacola area and the high permeability of the aquifer are factors tending to keep the ground water moving and from remaining in contact with soluble materials.

However, water in the upper sand-and-gravel aquifer contains dissolved carbon dioxide. Some of this gas may come from the atmosphere and be carried by rain into the aquifer, but most of it originates in the decay of vegetation in the soil. Carbon dioxide, when dissolved in water, forms carbonic acid. This is a weak acid, but its presence can make the water corrosive to metals. When carbonate or bicarbonate ions are present in a solution with carbon dioxide and carbonic acid, they tend to buffer the solution or reduce the acid effect by raising the pH (Hem, 1970, p. 92-93). In water from the sand-and-gravel aquifer, which is low in dissolved mineral matter, including bicarbonate and carbonate, buffering is minimized, and corrosive effects are strong. Corrosion is further enhanced by the generally low iron content of the water.

Hydrogen sulfide locally is present in trace amounts in water from the sand-and-gravel aquifer. The probable source of the gas is the decomposition of organic material buried in the aquifer. In this investigation, hydrogen sulfide has not been determined in chemical analyses, but its presence can be detected by its characteristic "rotten eggs" odor. Concentrations of a few hundredths of a milligram per litre of water would produce a noticeable odor; but only faint odors have been noted in this investigation. In the concentrations encountered, the only probable adverse effect would be the odor associated with the water. In higher concentrations it would have a corrosive effect.

Hydrogen-ion concentration is expressed in terms of pH units. The pH affects the corrosive powers of water and partly determine the proper treatment that may be necessary in water-treatment plants. A pH of 7.0 indicates the the water is neither acid nor alkaline. Readings progressively lower than 7.0 denote increasing acid characteristics and those progressively higher than 7.0 denote increasing alkaline characteristics. The pH of most ground water in the United States ranges from 6.0 to 8.5. The pH of water from the upper part of the sand-and-gravel aquifer is at the lower end of this range or, commonly, even lower (more acid).

The U.S. Public Health Service (1962) established standards for drinking water furnished by interstate carriers. The standards are generally used to evaluate the suitability of public-water supplies in the United States (Hem, 1970, p. 321-322). Concentrations of dissolved mineral constituents in water from the sand-and-gravel aquifer generally fall well below the limits recommended by the Public Health Service except for iron, arsenic, and fluoride, which locally exceed the recommended limit. Nitrate is an indication of possible pollution by sewage or animal wastes, and excessive concentrations are hazardous to the health of both man and animals. The U.S. Public Health Service recommended (1962, p. 7-8, 47-51) 45 mg/l (milligrams per litre) as the upper limit for drinking water. No samples analyzed in the course of this investigation exceeded that limit, but concentrations approaching it were detected.

Sampling Methods

The test wells drilled during fiscal year 1973 were developed with compressed air. Those with water levels within vacuum-lift range (less than about 24 ft, or 7 m) were sampled with a centrifugal pump. The others were sampled by bailing, and in each case at least twice the original volume of water in the casing was bailed before the sample was collected. Standard "complete" chemical analyses (determination of major dissolved ion species and of some physical properties) were run on the samples, also determinations of nutrients, total organic carbon, and trace metals. Bailing was unsatisfactory for sampling trace metals. Trace-metal (including iron) concentrations were much higher in samples that had been bailed as compared to the concentrations in samples from pumped wells. The relatively high concentrations of iron, maganese, zinc, and lead in the bailed samples probably represent products of the corrosion of the casing and screen, incompletely removed by bailing. Samples from pumped wells were collected after removing a larger volume of water at a higher discharge rate, so that corrosion products were much more dilute and the samples more nearly approached the composition of the natural ground water. All bailed samples were more or less turbid, and the high trace-metal content may have been associated with the turbidity. Concentrations of other constituents in the bailed samples may also have been affected by the sampling method, but probably to a lesser degree. The trace-metal (including iron) concentrations of bailed samples are not given in this report.

Carbon Dioxide

Figure 9 shows the distribution of dissolved carbon dioxide in water from the sand-and-gravel aquifer in central and southern Escambia County, as determined from water samples taken during the current investigation. The most striking feature of the map is the generally high concentration of carbon dioxide in the southwestern part of the area--especially south and west from the junction of Lillian Highway (S-298) and Fairfield Drive (S-289A) and extending southeast to the U.S. Naval Air Station. Concentrations were as high as 131 mg/l.

Smaller areas of generally high carbon dioxide concentration are along Bayou Chico north of Warrington, between S-292 and U.S. 29 at the northwest edge of Pensacola, at the junction of Pine Forest Road (S-297) and I-10, around the junction of Beulah Road and U.S. 90 (northeast corner of Sec.17, T.1 S., R.31 W.), along the Perdido River (at the U.S. 90 crossing and at Muscogee), at Cantonment, and at the Monsanto plant. Elsewhere in the area, carbon dioxide concentrations are generally less than 30 mg/l.

Nitrate

Nitrate has been found in samples of water from the sand-and-gravel aquifer as far back as 1924. It probably originated from pollution of the ground water by human, animal, and industrial wastes.

Figure 10 shows nitrate concentration in water samples collected 1970-72 from shallow and deep wells in the sand-and-gravel aquifer. The concentrations may change with depth, but data are insufficient to determine whether this is so. Nitrate was generally absent in water from rural areas. Exceptions may be explained by contamination from septic tanks and livestock operations.

Nitrate concentrations in ground water generally exceed 5 mg/l within Pensacola itself and in the adjoining urban areas from Bayou Chico northeast to the junction of I-110 and Brent Lane (S-296), and

Figure 9.--Map showing dissolved carbon dioxide in water from wells in the sand-and-gravel aquifer. (Figure is in pocket at end of report.)

Figure 10.--Map showing nitrate in water from wells in the sand-and-gravel aquifer. (Figure is in pocket at end of report.)

along Mobile Highway (U.S. 90) northeast of Saufley Field, around the junction of Pine Forest Road (S-297) and I-10, and in the vicinity of Gonzalez and Cantonment. Other, less well defined areas of nitrate in excess of 5 mg/l are indicated by analyses from one or two wells each.

Iron

Concentrations of dissolved iron in water from the sand-and-gravel aquifer in the Pensacola area locally exceed the limit of 300 μg/l (micrograms per litre) recommended by the U.S. Public Health Service (1962, p. 7-8, 42-43) for drinking water.

Figure 11 shows, by means of symbols, the occurrence of various concentrations of iron in the sand-and-gravel aquifer. Although some of the iron occurs naturally in the ground water, much iron in water originates in the corrosion of the casing and other metallic well parts. Differences in iron concentrations in water samples may be caused by differences in well construction, age of the well, corrosiveness of the water, and length of pumping before sampling, as well as by differences in the natural iron concentration in the ground water.

Whatever the origin of iron in water, the concentrations can vary substantially in water from wells within a short distance of each other, or from different depths at the same location. Therefore, it was not considered practical to show the iron values on figure 11 by means of lines of equal concentration. Instead, symbols were superimposed over each well symbol, showing the approximate concentration. The symbols representing the two lowest concentration ranges indicate water meeting the U.S. Public Health Service's drinking water standards.

Although the iron concentration in a sample from an isolated well may not be representative of the iron concentration in the ground water of the surrounding area, samples from several wells in the same area, all yielding water low in iron, are a good indication that the iron concentration in the ground water is low in that vicinity. High iron concentrations in water from recently drilled wells or from wells with plastic casing indicate reliably that the ground water contains a large amount of iron. In figure 11, areas have been outlined in which all the wells sampled yielded water containing 300 μg/l or less of iron. These areas include a north-trending strip beginning in downtown Pensacola and extending northwest along Mobile Highway (U.S. 90) and north along U.S. 29 to Cantonment. A branch extends east to the Escambia River north of U.S. 90A, and another extends southwest from Gonzalez to the junction of U.S. 90 and U.S. 90A.

Figure 11.--Map showing dissolved iron in water from wells in the sand-and-gravel aquifer. (Figure is in pocket at end of report.)

TEST DRILLING PROGRAM

From December 1972 through April 1973, a contractor drilled eight 400-foot test holes. No cores were taken. The holes were cased for use as observation wells with 2-inch (5 cm) galvanized-iron pipe and with 3 to 6 feet (1 to 2 m) of stainless steel well screen. Electric and caliper surveys were run in U.S. Geological Survey test hole 32 before casing was installed. After the casing was set, radioactivity surveys were run. Only radioactivity logs were obtained on the other wells.

The wells were developed by backwashing with the mud pump on the drill rig, then pumped by air lift.

Records and logs of the test holes are given in the Appendix.

Radioactivity Logging

Gamma-ray and neutron logs were run on all the 400-foot (122 m) wells. The gamma-ray log shows the natural gamma radiation of the material penetrated and is plotted on a scale with radioactivity increasing to the right. In general, clay and shale are more radioactive than clean sand and gravel; and so the log can be used to interpret the types and thicknesses of material penetrated (Schlumberger Ltd., 1969, p. 53-55).

The neutron log provides a measure of the hydrogen content of the formation. Hydrogen content is a function of the amount of water present in water-saturated material, and this, in turn, depends on the porosity of the material and the amount of water absorbed or bound up chemically in it. The neutron probe utilizes a radioactive source and a detector. The source bombards the formation opposite the device with neutrons. When the hydrogen concentration of the material surrounding the neutron source is large, most of the neutrons are slowed down or captured within a short distance of the source. The neutron count at the detector increases for decreased hydrogen concentration (therefore, decreased water) and decreases as the hydrogen concentration increases.

Increased water content is shown by deflection to the left on the neutron log. Clay beds have a high water content and, therefore, are represented by deflections to the extreme left on the neutron logs. Dense materials with very low porosity are depicted by deflections to the right. In the sand-and-gravel aquifer, these dense materials might be hardpan layers. Sand falls between these extremes. Sand with either a high effective porosity or high clay content causes deflections to the left on the log. Thus, the neutron log must be interpreted in conjunction with a gamma-ray log showing the degree of "cleanness" of sand beds (Schlumberger Ltd., 1969, p. 47-51).

A qualitative interpretation method, adapted from one developed by the Lane-Wells Company (McGaha, Mellies, and Terry, no date) for oil-bearing limestone, has been applied to the project's gamma-ray and neutron logs. A vertical line is drawn on the gamma-ray log 20 percent of the distance between the minimum and maximum radioactivities recorded on the log (Appendix, Test Hole 25). This is labeled "20 Percent Gamma Reference Line," and the parts of the curve to the left of the line represent the cleanest sand zones. Similarly, a line is drawn on the neutron log half way between the maximum and minimum values below the sharp deflection to the right at the top of the water-saturated zone (approximately the water table). This is the "50 Percent Neutron Reference Line." The parts of the neutron curve representing the highest water saturation are left of this line. These parts of the curve represent clay, clayey silt, and clayey sand as well as sand with high effective porosity. However, those zones that are represented both on the gamma-ray log by deflections to the left of the 20 Percent Gamma Reference Line and on the neutron log to the left of the 50 Percent Neutron Reference Line are potentially the most productive sand zones in the well. In the descriptions of the logged wells in the Appendix, the location and net thickness of the potentially most productive sand are cited for each where possible. Quantitative values of porosity cannot be assigned to these zones from the logs, but when core analysis data are available, quantitative estimates can be made by comparing curve deflections to measured porosities.

If the maximum and minimum values on the gamma-ray and neutron logs are assumed to represent the same values of natural radioactivity and hydrogen concentration from hole to hole, the thickness of the potentially most productive sand in each hole would have approximately the same relationship to the specific capacity of a hypothetical well at each site, screened at each potentially most productive sand zone, and 100 percent efficient. The distribution of potentially most productive sand penetrated at each test hole is discussed in the Appendix.

Electric Logging

An electric survey, consisting of a spontaneous-potential (SP) and a single-point resistance log was run on Test Hole 32 (Appendix, p. A25-A27). Only a brief mention of electric-log qualitative interpretation can be made here. In general, the spontaneous-potential (left) curve is convex outward (to the left) opposite permeable zones, and approaches a vertical line close to the center through impermeable material. The resistance increases (curve moves outward) opposite sands and sandstones and decreases (curves move inward) opposite clays and shales. In general, the SP curve parallels the gamma-ray curve. In a sand-clay sequence, the resistance curve (right) may roughly parallel the neutron curve.

SUMMARY AND CONCLUSIONS

1. Evidence available to date indicates that the top of the fossiliferous part (the shell zone) of the sand-and-gravel aquifer ranges between 200 and 450 feet (60 and 140 m) below land surface everywhere within the area of investigation except in parts of southwestern Escambia County and Santa Rosa Island, where it is shallower.

2. The part of the sand-and-gravel aquifer above the shell zone contains much more clean sand or gravel than does the shell zone, except in parts of southwestern Escambia County and Santa Rosa Island where the top of the shell zone is substantially shallower than 200 feet (60 m) below land surface.

3. The clean sand layers in the shell zone are generally isolated from the overlying "main" part of the aquifer by confining beds.

4. Thin clay seams opposite the screened section of a well may cause the water discharged by the well to be turbid or milky. Their existence can be determined by means of an electric or gamma-ray survey of a well or test hole.

5. The average potentiometric surface for that part of the sand-and-gravel aquifer 100 to 300 feet (30 to 90 m) below land surface was highest--82 feet (25 m) or more above mean sea level--at the north edge of the area of investigation as of spring-summer, 1973. High water levels were also found near Ensley, near the center of the mapped area, and around Hagler Field.

6. The average potentiometric surface for that part of the sand-and-gravel aquifer 100 to 300 feet (30 to 90 m) below land surface was drawn down below mean sea level in spring-summer, 1973, in areas of heavy pumping, such as between the Naval Air Station and downtown Pensacola, and the areas around the Gulf Power Crist Steam Plant, the Monsanto plant, and the St. Regis plant.

7. Although ground water moves southward from the highest part of the potentiometric surface at the northern edge of the mapped area, virtually none of this reaches the southern half of the area. A reversal in gradient represented by the combination of the large compound cone of depression at Cantonment and the Jacks Branch and Big Rock Creek valley troughs in the potentiometric surface forms a barrier to further movement to the south. Virtually all the ground water pumped from wells south of the reversal in gradient comes from local recharge--that is, rainfall on the same area.

8. Water levels declined 7 to 9 feet (2 to 3 m) between 1886 and 1940 and 22 to 25 feet (7 to 8 m) between 1886 and 1973 at the site of the Pensacola Water Works. In 1973, the level at the water works was affected by the pumping of three large-capacity wells within 1 mile (1.6 km).

9. The water level in U.S. Geological Survey observation well 46 at Ensley declined about 7.4 feet (2.3 m) between 1940, when there were no large-capacity wells in operation within 7 miles (11 km) and 1973, when two public-supply wells were in operation within a radius of about a mile (1.6 km), and about 30 large wells within 7 miles (11 km).

10. The water level in U.S. Geological Survey observation well 45, at the St. Regis plant at Cantonment, declined about 29 feet (9 m) between 1940, when there were no large-capacity wells in operation within 13 miles (21 km), and 1973 when there was heavy industrial pumping within a short distance of the well.

11. The 400-ft (122-m) deep test holes penetrated saturated material that was predominately sand and gravel with varying amounts of clay. In general, more than 50 percent of the sand-and-gravel sections could be considered water bearing; but as determined by radioactivity logs, the aggregate thickness of high permeable, most productive zones in each well ranged from a minimum of 5 feet to a maximum of 138 feet (2 to 42 m). U.S. Geological Survey test holes 26, 29, and 32 in the central part of the study area showed the greatest thickness of potentially most productive sand; U.S. Geological Survey test holes 27 and 28, to the north, a moderate thickness of potentially most productive sand; and U.S. Geological Survey test holes 25, 30, and 31, to the south, the least thickness of potentially most productive sand.

12. Water samples from U.S. Geological Survey test holes 30 and 31 were typical of sand-and-gravel aquifer water: low in dissolved solids, hardness, and pH, and containing dissolved carbon dioxide. Samples from U.S. Geological Survey test holes 25, 26, 27, and 32 had higher dissolved solids and hardness than typical sand-and-gravel aquifer water; water from test hole 28 had above-average hardness, and the pH of water from test holes 26, 27, 29, and 32 was higher than that of typical water. Reported chemical constituents were within the limits recommended by the U.S. Public Health Service (1962, p. 7-8, 42-43) for drinking water except for iron and manganese in test hole 25. Dissolved solids, hardness, and pH tend to be higher in deeper zones in the aquifer.

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Table 1.--Factors for converting English units to International System (SI) units.

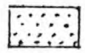
The following factors may be used to convert the English units published herein to the International System of Units (SI):

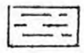
Multiply English units	By	To obtain SI units
inches (in.)	25.4	millimetres (mm)
feet (ft)	.3048	metres (m)
miles (mi)	1.609	kilometres (km)
gallons per minute (gal/min)	.06309	litres per second (l/s)

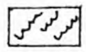
APPENDIX

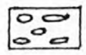
Records and Logs of U.S. Geological Survey Test Holes

The accompanying logs are graphic representations of the materials and conditions encountered in drilling, sampling, and geophysical testing of the test holes discussed. The following symbols are used throughout this Appendix.

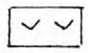
Sand: 

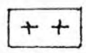
Clay or Shale: 

Silt: 

Gravel or scattered pebbles: 

Iron cementation or staining: 

Mica grains (usually muscovite): 

Carbonaceous material: 

The locations of all test holes are shown in figure 1. See table 1 for factors to convert English units to the International System (SI) units.

Test Hole 25 (302052N0872341.1)

Test Hole 25 was drilled north of State Road 292A (S-292A), about 1.7 miles (2.7 km) northeast of Perdido Bay Country Club and 0.9 mile (1.4 km) northeast of the junction of S-293. Although the well penetrated about 170 feet (52 m) of water-saturated sand and gravel with an apparently low clay content, the combination of gamma-ray and neutron logs indicates only about 12 feet (4 m) of potentially most productive sand.

A condensed interpretative lithologic log follows, based on the examination of cuttings samples and radioactivity logs:

	Thickness (feet)	Depth (feet)
Sand, medium-grained, subround. Interval includes 5 feet of potentially most productive sand.	30	30
Sand, silt to medium-grained, clayey. Interval includes 1 foot of potentially most productive sand.	10	40
Clay, silty and sandy, with layers of fine subangular quartz gravel and coarse sand	17	57
Sand, medium-grained to coarse, subround, with a trace of gravel	16	73
Gravel, fine, subangular to round, mostly quartz, sandy; interbedded with sandy clay in lower 10 feet.	17	90
Sand, clayey, with some gravel.	15	105
Sand, very coarse, well sorted, subangular, interbedded with fine, subangular quartz gravel; clayey in lower 7 feet.	32	137
Clay.	3	140
Sand, very coarse, well sorted, with some gravel. Interval includes 2 feet of potentially most productive sand	8	148
Sand, fine, clayey, plastic	5	153
Sand, very fine to very coarse, mostly fine, with a trace of gravel. Trace of muscovite flakes in lower part.	14	167
Clay, white	2	169
Sand, medium-grained to very coarse, mostly coarse, subangular to subround, clean	11	180
Sand, very fine to very coarse, poorly sorted but predominantly medium-grained, clayey in lower 5 feet. Interval includes 3 feet of potentially most productive sand.	29	209

	Thickness (feet)	Depth (feet)
Sand, very fine, clayey, interbedded with sandy clay.	41	250
Sand, very fine to coarse, predominantly fine, subangular, slightly clayey. Interval includes 1 foot of potentially most productive sand.	20	270
Clay, very fine sandy, with thin layers of fine, somewhat clayey gravel.	51	321
Sand, very fine to very coarse grading to fine gravel, clayey, with a trace of pelecypod shell fragments	9	330
Clay, sandy, with fragments and small whole shells of pelecypods, interbedded with gravel composed largely of pelecypod and gastropod fragments and whole shells and a few quartz and chert pebbles	56	386
Pensacola (?) Clay:		
Shale, dark, slightly indurated, plus clay as above .	14	400

The screen was originally set from 170 to 173 feet (52 to 53 m). The water from this zone was milky in appearance, and remained so even though pumped for about 24 hours with an air compressor. According to R. C. Dickson, recently retired manager of the Warrington office of People's Water Company (oral commun., 1973), the water appeared similar to that causing the abandonment of some of the wells in this area. In his experience, wells yielding this kind of water never clear up.

The gamma-ray log shows a deflection to the right from 167 to 169.5 feet (50.9 to 51.7 m), indicating a thin clay seam. B. J. Anderson of the U.S. Geological Survey (written commun., Aug. 28, 1973) found that a sample of suspended solids filtered from water pumped from the well consisted of 73 percent kaolinite, 15 percent illite, 1 percent montmorillonite (clay minerals), 1 percent mixed layer clay minerals, and 10 percent quartz. Thus, the material causing the water's milkiness was mostly clay, the probable source being the thin clay seam indicated by the gamma-ray log.

The water sample taken May 31, 1973, with the screen between 170 and 173 feet (52 to 53 m), had a pH of 5.3 and a carbon dioxide concentration of 75 mg/l. The dissolved iron concentration was 9,700 µg/l, total manganese was 160 µg/l, and there was no nitrate. Dissolved solids (residue) were 136 mg/l, hardness was 28 mg/l, and sulfate was 44 mg/l, higher than in typical sand-and-gravel aquifer waters. Iron and manganese exceeded the limits of 300 µg/l and 50 µg/l recommended by the U.S. Public Health Service (1962, p. 7-8; 42-43) for drinking water.

Following the first water sampling, the well casing was raised to relocate the screen between 142 and 145 feet (43 and 44 m). Water pumped from the well after the screen was relocated was turbid, but light tan in color rather than milky as before. The gamma-ray log shows a deflection to the right from 137.5 to 139.5 feet (41.9 to 42.5 m) indicating another clay seam that may be the source of the turbidity after relocation of the screen. A water sample collected July 11, 1973, had a dissolved solids concentration of 57 mg/1, hardness of 12 mg/1, and sulfate of 0.8 mg/1, closer to typical sand-and-gravel aquifer water than in the first sample. During sampling, the pump was laboring, raising the temperature of the water to 36.7°C, as compared to 24.3°C in the first sample. The concentrations of some of the constituents must have been affected, particularly dissolved carbon dioxide. The reported values for carbon dioxide and pH are not considered valid for the water at aquifer temperature.

Only manganese, at 70 µg/1, exceeded U.S. Public Health Service (1962, p. 7-8, 42-43) recommended limits for drinking water.

Well Name: U.S.G.S. TH 25

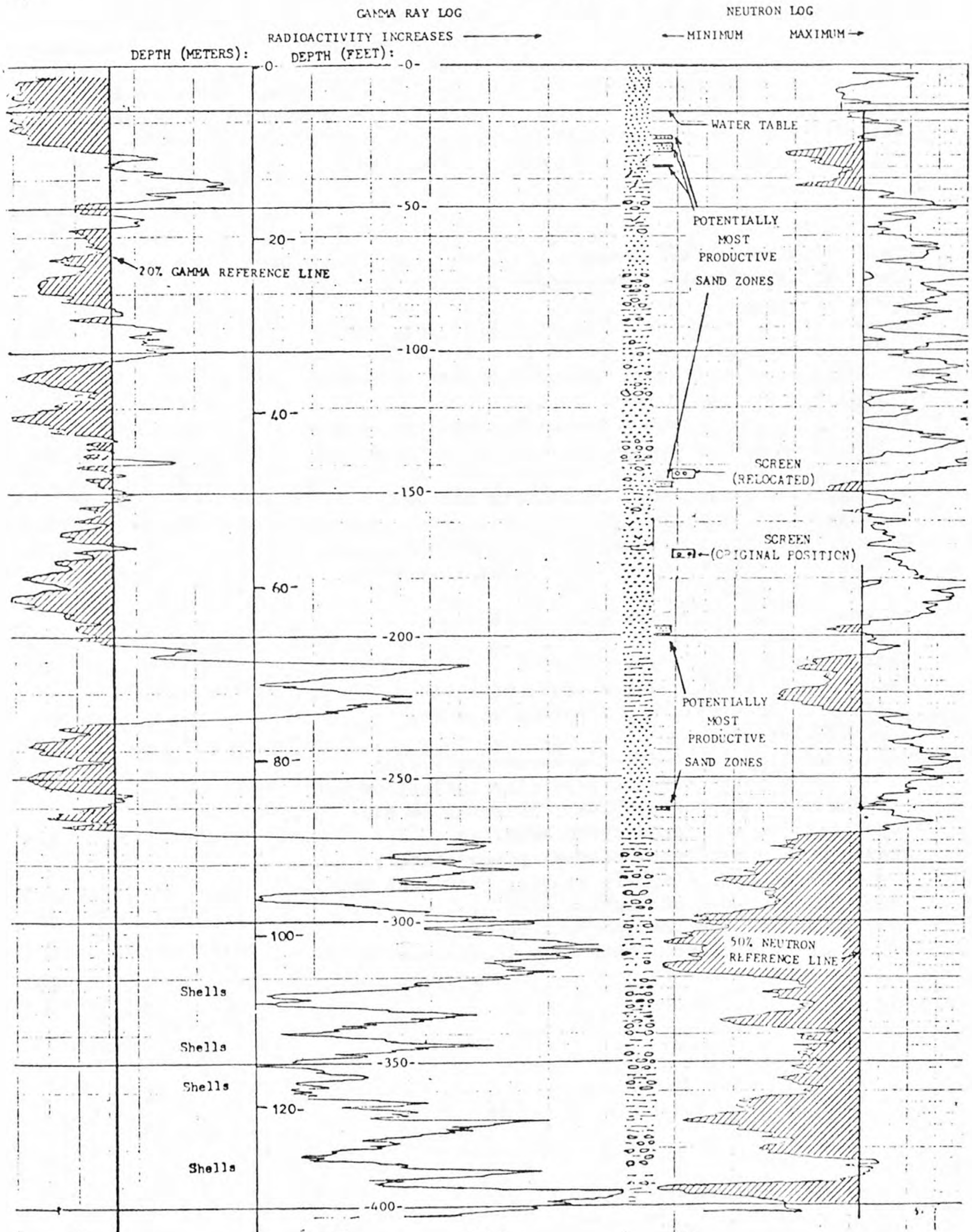
Location Number: 302052N0872341.1

Location Description: In borrow pit area N of S292A, 0.92 mi. E of jnctn S293.

Alt. LSD: 26 feet Diam.: 2 inches

Depth: 404 feet Depth to top of screen: 142 feet (present) 170 feet (original)

Water level: 16.6 feet below LSD Date meas.: 4/14 1973



Test Hole 26 (302908N0871946.1)

Test Hole 26 was drilled 0.45 mile (0.72 km) northeast of Saufley Field, at the end of Pawnee Drive. A massive section of sand and gravel was penetrated between 34 and 240 feet (10 to 73 m) of which 49 feet (15 m) were potentially most productive sand.

A condensed interpretative lithologic log follows, based on the examination of cuttings samples, the driller's comments, and radioactivity logs:

	Thickness (feet)	Depth (feet)
Sand, fine to coarse, loose	4	4
Clay, silty, organic, interbedded with fine, clayey sand.	30	34
Gravel, fine, composed of quartz, ironstone, and chert, somewhat clayey, with layers of fine clayey sand. Interval includes 5 feet of potentially most productive sand	14	48
Sand, fine, angular to subangular, somewhat clayey with some gravel and thin layers of varicolored clay.	19	67
Gravel, very fine, interbedded with coarse clayey sand and sandy clay.	55	122
Gravel, very fine, and medium-grained sand. Interval includes 5 feet of potentially most productive sand	9	131
Gravel, very fine, interbedded with sand and sandy clay.	25	156
Sand, very fine to very coarse.	18	174
Sand, poorly sorted, interbedded with fine gravel. Interval is all potentially most productive sand	16	190
Sand, very fine to coarse, predominantly fine. The lower part contains gray clay inclusions and a few white quartz pebbles. Interval is all potentially most productive sand.	16	206
Sand, very fine to very coarse, predominantly medium-grained, slightly clayey. Interval is all potentially most productive sand.	7	213
Sand as above, but less porous, becoming increasingly clayey (with clay inclusions) in lower 20 feet	47	260

	Thickness (feet)	Depth (feet)
Sand, very fine to very coarse, predominantly fine and medium-grained, subround to sub angular. Contains clay inclusions and specks of organic material	14	274
Clay, very fine sandy, with pelecypod shell fragments and small high-spired gastropods, interbedded with very fine clayey sand containing shells.	62	336
Gravel, fine, subangular to angular, composed of chert and quartz pebbles and shell fragments, clayey, grading to coarse sand in lower part, interbedded with very fine sandy clay	53	389
Clay, very fine, sandy.	7	396
Gravel as above, interbedded with clay.	16	412

The well was screened from 398 to 404 feet (121 to 123 m) in order to obtain a water sample from the lower, fossiliferous part of the sand-and-gravel aquifer. A sample collected June 28, 1973, had a pH of 8.9, no carbon dioxide, dissolved solids (residue) of 61 mg/l, and hardness of 30 mg/l. The high pH and hardness are not typical of the sand-and-gravel aquifer. The analyzed constituents were within the limits recommended by the U.S. Public Health Service (1962, p. 7-8, 42-43).

Well Name: U.S.G.S. TH 26

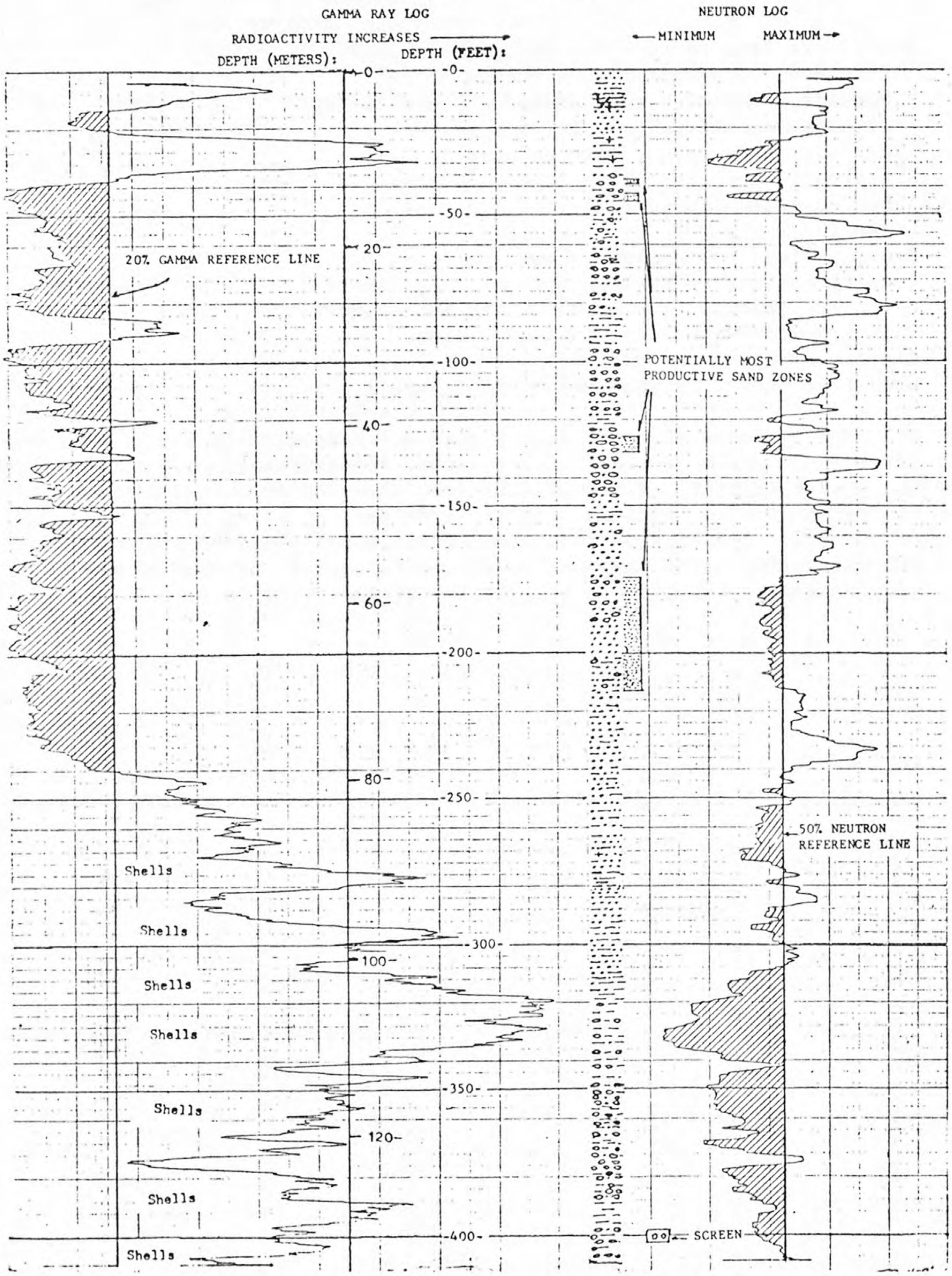
Location Number: 302908N0871946.1

Location Description: 0.45 mi. NE of Saufley Field. 390' N of ℄ Huntsville Ave.; 22' W of ℄ Pawnee Dr.

Alt. LSD: 35 feet Diam.: 2 inches

Depth: 409 feet Depth to top of screen: 398 feet

Water level: 0.87 feet ~~below~~ above LSD Date meas.: 4/13 1973



Test Hole 27 (304008N0872116.1)

Test Hole 27 was drilled 0.2 mile (0.3 km) west of U.S. 29, 4 miles (6.4 km) north of Cantonment. Two layers of relatively clean sand and gravel were penetrated below the water table: from 228 to 280 feet, (69 to 85 m) with 25 feet (8 m) of potentially most productive sand; and from 325 to 274 feet (99 to 114 m) with 17 feet (5 m) of potentially most productive sand.

A condensed interpretative lithologic log follows, based on the examination of cuttings samples, the driller's comments, and radioactivity logs:

	Thickness (feet)	Depth (feet)
Sand, medium-grained to very coarse, predominantly coarse above becoming predominantly medium-grained below, subangular to subround, contains a few small quartz pebbles in upper part, slightly clayey in lower part	34	34
Clay, fine, sandy; interbedded with clayey sand in lower part.	24	58
Sand, fine, interbedded with varicolored sandy clay .	15	73
Sand, fine to very coarse, subangular, and fine angular gravel.	27	100
Sand, very fine to very coarse, subangular, with fine gravel, the gravel increasing downward	22	122
Sand and gravel as above, but clayey, interbedded with silty to sandy clay.	106	228
Sand, very fine to very coarse, poorly sorted, subangular, with a trace of fine subangular gravel composed of white quartz and black chert. Interval includes 19 feet of potentially most productive sand	42	270
Gravel, fine subangular. Interval includes 6 feet of potentially most productive sand.	10	280
Sand, fine to medium-grained, subangular, clayey, interbedded with very fine to fine gravel and silty to sandy clay	45	325
Sand, very fine to very coarse, mostly medium-grained to coarse, subangular to subround, becoming coarser downward	25	350
Gravel, very fine to fine, angular to subangular, mostly black chert, with some white quartz. Interval includes 3 feet of potentially most productive sand	10	360

	Thickness (feet)	Depth (feet)
Sand, very fine to very coarse, mostly medium-grained and coarse, with some gravel as above. Interval is all potentially most productive sand.	14	374
Sand as above but clayey, interbedded with clay.	26	400

The well was screened from 262 to 266 feet (80 to 81 m). A water sample taken June 6, 1973, had a pH of 6.1, a dissolved carbon dioxide concentration of 31 mg/l, 32 mg/l bicarbonate, 56 mg/l (sum) of dissolved solids, and a hardness of 15 mg/l. Hardness, dissolved solids, bicarbonate and pH were higher than in typical sand-and-gravel aquifer water. The reported concentrations of constituents are within the limits recommended for drinking water by the U.S. Public Health Service (1962, p. 7-8, 42-43).

Well Name: U.S.G.S. TH 27

Location Number: 304008N0872116.1

Location Description: 4 mi. N of Cantonment, 0.2 mi. W of U.S. 29 NWSESW Sec.21, T. 2 N., R. 31 W.

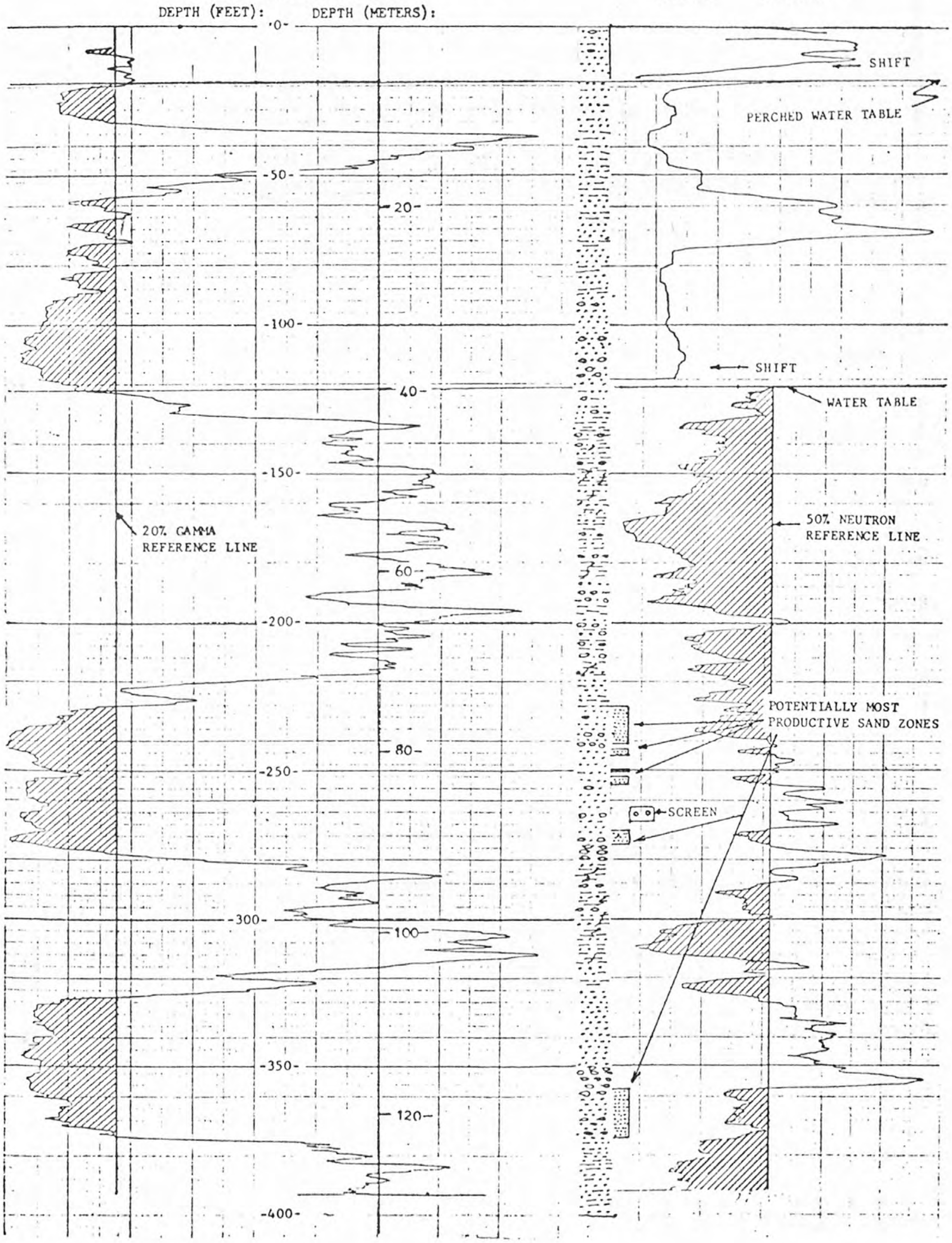
Alt. LSD: 165 feet Diam.: 2 inches

Depth: 393 feet Depth to top of screen: 262 feet

Water level: 122.1 feet below LSD Date meas.: 4/2 1973

GAMMA RAY LOG NEUTRON LOG

RADIOACTIVITY INCREASES ⟶ ⟵ MINIMUM MAXIMUM ⟶



Test Hole 28 (303723N0871826.1)

Test Hole 28 was drilled at the deadend of Eden Road in the Cottage Hill area, 0.9 mile (1.4 km) east of Old Palafox Road (S-95A). Two sections of predominantly clean sand and gravel were penetrated below the water table: from 170 to 242 feet (52 to 74 m) with 19 feet (6 m) of potentially most productive sand; and from 291 to 342 feet (89 to 104 m) with 1 foot (0.3 m) of potentially most productive sand.

A condensed interpretative lithologic log follows, based on the examination of cuttings samples, the driller's comments, and radio-activity logs.

	Thickness (feet)	Depth (feet)
Sand, very fine to medium-grained, mostly fine, subangular, clayey, plastic, with a thin concretionary layer	10	10
Sand, fine, well sorted, subangular to subround, with small flakes of muscovite	8	18
Sand, fine to coarse, mostly medium-grained	12	30
Sand, very fine to very coarse, poorly sorted, with fine subangular white chert and quartz gravel. Slightly clayey in lower part	10	40
Gravel, fine, subangular, composed of white chert and quartz.	15	55
Sand, poorly sorted, ranging from very clayey to clean but mostly clayey, interbedded with plastic clay and gravel as above.	115	170
Sand, very fine to very coarse, mostly medium-grained, subangular to subround, with white and dark chert gravel. Trace of carbonized wood. Interval includes 19 feet of poten tially most productive sand	72	242
Clay, sandy	11	253
Sand, very fine to very coarse, mostly coarse, subangular, slightly clayey	27	280
Clay, sandy, with thin layers of clayey sand and gravel.	11	291
Sand and fine gravel, fairly clean with 1 foot of potentially most productive sand	23	314
Sand and fine gravel, fairly clean.	20	334
Clay, sandy	5	339
Gravel, fine, somewhat clayey	3	342

	Thickness (feet)	Depth (feet)
Clay, varicolored, sandy, with thin layers of clayey sand and gravel. Trace of shells--may be contamination.	39	381
Gravel, fine, becoming clayey downward.	10	391
Clay, varicolored, sandy.	9	400

The well was screened from 227 to 231 feet (69 to 70 m). A water sample taken June 6 had a pH of 5.2, a dissolved carbon dioxide concentration of 34 mg/l, and a dissolved solids (residue) of 21 mg/l. The hardness was 12 mg/l, above average for the sand-and-gravel aquifer. The other reported constituents were in the normal range, and did not exceed U.S. Public Health Service (1962, p. 7-8, 42-43) recommended limits for drinking water.

Well Name: U.S.G.S. TH 28

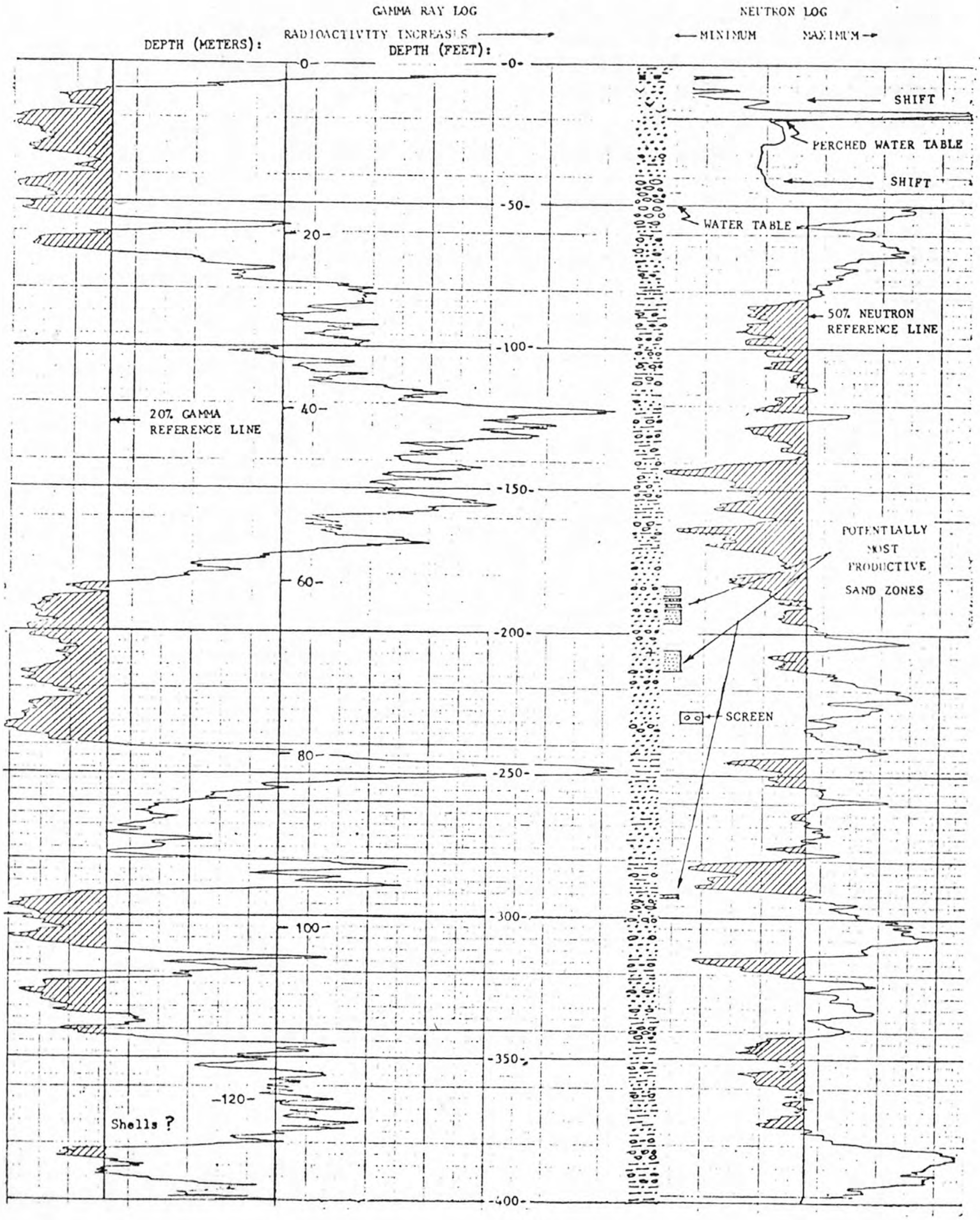
Location Number: 303723N0871826.1

Location Description: At dead-end Eden Road. NESWSW Sec.1, T. 1 N., R. 31 W.

Alt. LSD: 65 feet Diam.: 2 inches

Depth: 399 feet Depth to top of screen: 227 feet

Water level: 50.1 feet below LSD Date meas.: 4/14 1973



Test Hole 29 (303216N0871941.1)

Test Hole 29 was drilled in Pine Forest Estates at a right-angle bend in Calico Drive, 0.25 mile (0.4 km) north of Nine-Mile Road (U.S. 90A) and 0.8 mile (1.3 km) west of Pine Forest Road (S-297). A predominantly clean sand and gravel section was penetrated from the water table at 55 feet to 311 feet (17 to 95 m) with 131 feet (40 m) of potentially most productive sand.

A condensed interpretative lithologic log follows, based on the examination of cuttings samples, the driller's log, and radioactivity logs:

	Thickness (feet)	Depth (feet)
Clay, silty, plastic.	10	10
Sand, medium-grained, subangular, iron stained, clayey, with layers of clay as above.	22	32
Sand, very fine to coarse, becoming coarser downward, iron stained, fairly clean, with thin ironstone concretionary layer, with very fine to fine white chert gravel.	13	45
Gravel, very fine to fine, mostly fine, angular and subangular, composed of white chert and frosted quartz, slightly clayey in part, with thin layers of sandy clay	23	68
Sand, fine to coarse, mostly medium-grained, with gravel as above. Interval includes 2 feet of potentially most productive sand.	10	78
Gravel, very fine to fine, mostly fine, angular and subangular, with very fine to very coarse poorly sorted sand. Interval includes 8 feet of potentially most productive sand	12	90
Sand, very fine to very coarse, predominantly coarse above, becoming medium-grained and slightly clayey downward. Interval includes 21 feet of potentially most productive sand.	30	120
Sand, fine to very coarse, mostly medium-grained and coarse, subangular, clean. Interval is all potentially most productive sand.	7	127
Clay, with very fine to fine angular disseminated sand and thin beds of clayey medium-grained sand and fine gravel	15	142

	Thickness (feet)	Depth (feet)
Sand, very fine to very coarse, partly iron cemented in upper part with thin streaks of gray clay and some gravel. Interval includes 16 feet of potentially most productive sand	23	165
Clay and mostly clayey sand. Interval includes 2 feet of potentially most productive sand.	7	172
Sand, very fine to very coarse, predominantly medium-grained, subangular above, fine and clayey below. Interval includes 8 feet of potentially most productive sand.	18	190
Sand, very fine to very coarse, predominantly fine, subangular, clean. Interval includes 9 feet of potentially most productive sand	10	200
Sand, mostly medium-grained, subangular and subround, with some very fine subangular gravel in the upper part and small clay balls in the lower part. Interval includes 14 feet of potentially most productive sand.	25	225
Sand, mostly medium-grained, partly iron cemented. Interval includes 4 feet of potentially most productive sand	5	230
Sand, very fine to medium-grained, subangular to subround, clayey in upper part, partly iron cemented below, with thin sandy clay layers and a trace of gravel. Interval includes 13 feet of potentially most productive sand.	37	267
Sand, very fine to very coarse, mostly medium-grained above, becoming fine below, subangular to subround, slightly clayey. Interval is all potentially most productive sand.	18	285
Clay, sandy, with thin layers of clayey sand.	9	294
Sand, mostly medium-grained subround quartz, with some iron staining. Clay inclusions in upper part, thin clay layers toward base of interval. Interval includes 9 feet of potentially most productive sand	29	323
Clay, silty to sandy, with layers of clayey sand and fine gravel	48	371
Sand, very fine to very coarse, mostly fine, subround to subangular somewhat clayey, with traces of gravel and fine muscovite flakes.	15	386
Clay, sandy	8	394
Sand, very fine to very coarse, mostly fine, subround to subangular, slightly clayey. Traces of gravel and fine muscovite flakes.	6	400

The screen was set from 164 to 168 feet (50 to 51 m). A water sample taken June 7, 1973, had a pH of 6.0, a dissolved carbon dioxide concentration of 19 mg/l, 25 mg/l dissolved solids (residue), and 2 mg/l hardness. The pH was above average for water from the sand-and-gravel aquifer. The other reported constituents were in the normal range, and did not exceed U.S. Public Health Service (1962, p. 7-8, 42-43) recommended limits for drinking water.

Well Name: U.S.G.S. TH 29

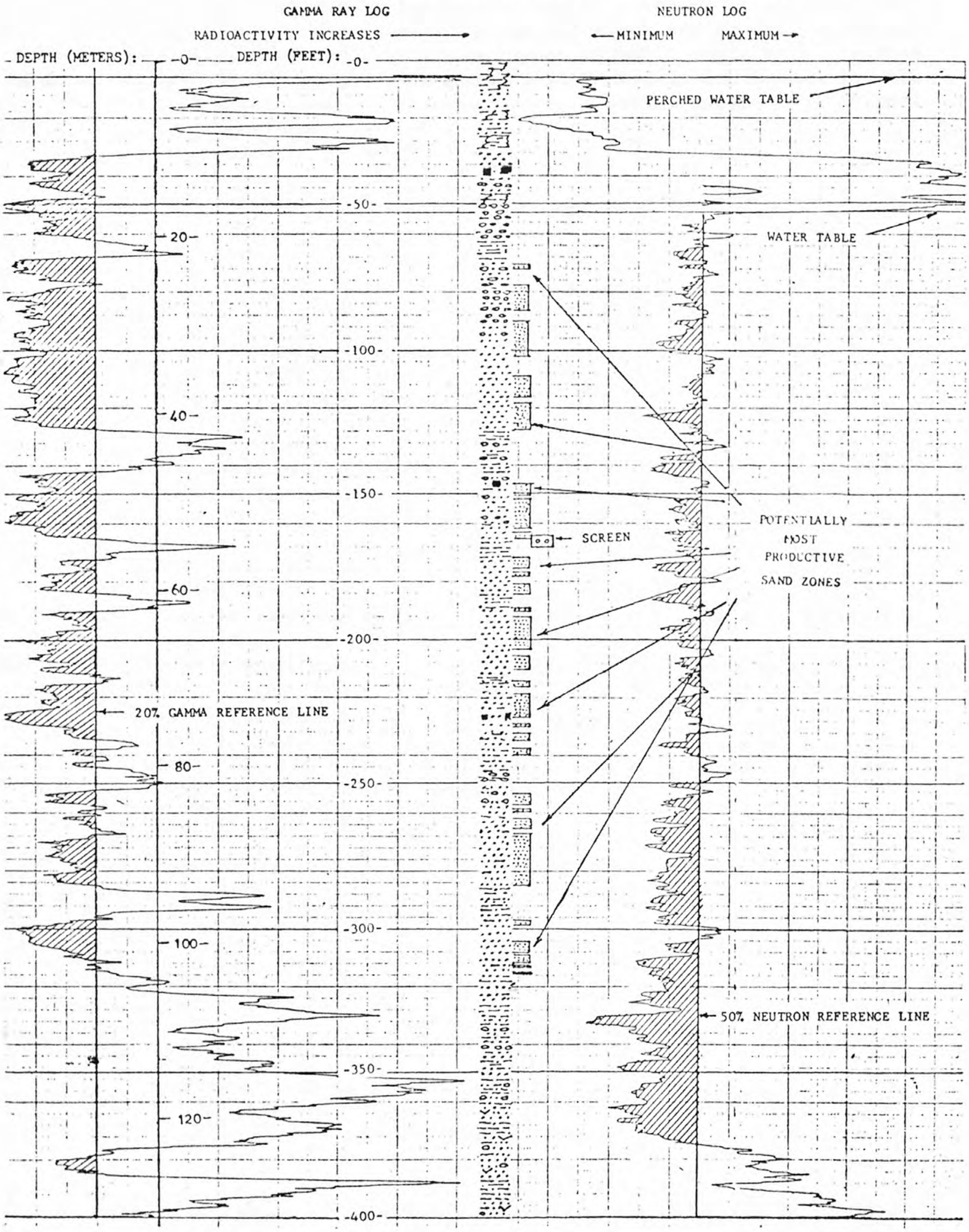
Location Number: 303216N0871941.1

Location Description: .25 mi. N of Ninemile Road, .8 mi. W of Pine Forest Road.

Alt. LSD: 96 feet Diam.: 2 inches

Depth: 400 feet Depth to top of screen: 164 feet

Water level: 54.9 feet below LSD Date meas.: 4/18 1973



Test Hole 30 (302937N0871501.1)

Test Hole 30 was drilled in the Oakfield area, on the west side of Lucy Street, 252 feet (77 m) south of Pinestead Street. Beds of relatively clean sand and gravel were penetrated below the water table from 90 to 100 feet (27 to 30 m), from 111 to 174 feet (34 to 53 m), from 190 to 214 feet (58 to 65 m), and from 307 to 312 feet (94 to 95 m). The lowermost interval comprised 5 feet (2 m) of potentially most productive sand.

A condensed interpretative lithologic log follows, based on the examination of cuttings samples, the driller's log, and radioactivity logs:

	Thickness (feet)	Depth (feet)
Sand, very fine to very coarse, mostly medium-grained, subround to subangular	1	1
Sand, black above to dark yellowish brown below, very fine to very coarse, mostly fine, clayey with abundant organic material	8	9
Clay, sandy	9	18
Sand, very fine to very coarse, mostly medium-grained, angular to subangular, some clayey inclusions.	12	30
Clay, sandy	5	35
Sand, very fine to very coarse, mostly coarse, grading to very fine gravel. Trace of iron-cemented sandstone.	15	50
Sand, very fine to very coarse, predominantly medium-grained, clayey in part.	14	64
Sand, very fine to very coarse, predominantly medium-grained to coarse and clean at top, becoming fine to medium-grained, clayey, in lower part.	26	90
Sand, fine to coarse, mostly medium-grained subangular, clean, with a trace of gravel	10	100
Sand, very fine to fine, subangular, very clayey, plastic, grading to sandy clay.	11	111
Sand, very fine to medium-grained, mostly fine, subangular to subround, clean	9	120
Sand, fine to very coarse, predominantly coarse, subangular, clean, with very fine to fine angular frosted quartz gravel and a layer of fine very clayey sand from 127 to 132 feet	20	140

	Thickness (feet)	Depth (feet)
Sand, very fine to very coarse, mostly fine and medium-grained, clean, with a trace of fine gravel.	34	174
Sand, medium-grained, subangular, very clayey, plastic, grading to sandy clay.	16	190
Sand, very fine to very coarse, mostly coarse and medium-grained, becoming clayey in lower part, with thin beds of clayey sand	55	245
Sand, very fine to very coarse, poorly sorted above, mostly fine below, clayey, with black organic inclusions.	11	256
Clay, sandy, interbedded with fine clayey sand. . . .	24	280
Sand, very fine to very coarse, poorly sorted, clayey, with abundant shell fragments, becoming less clayey, less fossiliferous below	20	300
Sand, very fine to very coarse, poorly sorted, slightly clayey to clean, with some shell fragments. Interval includes 5 feet of potentially most productive sand	22	322
Clay, sandy, interbedded with very fine to very coarse subangular clayey sand and clayey shell gravel. The sand is mostly fine. Black organic material and shells extend throughout	65	387
Pensacola (?) Clay:		
Clay, not sandy	13	400

The well was screened from 170 to 174 feet (52 to 53 m). A water sample taken June 13, 1973, had a pH of 5.8, a dissolved carbon dioxide concentration of 17 mg/l, 42 mg/l dissolved solids and 6 mg/l hardness. The reported constituents were in the normal range for the sand-and-gravel aquifer and did not exceed U.S. Public Health Service (1962, p. 7-8, 42-32) recommended limits for drinking water.

Well Name: U.S.G.S. TH 30

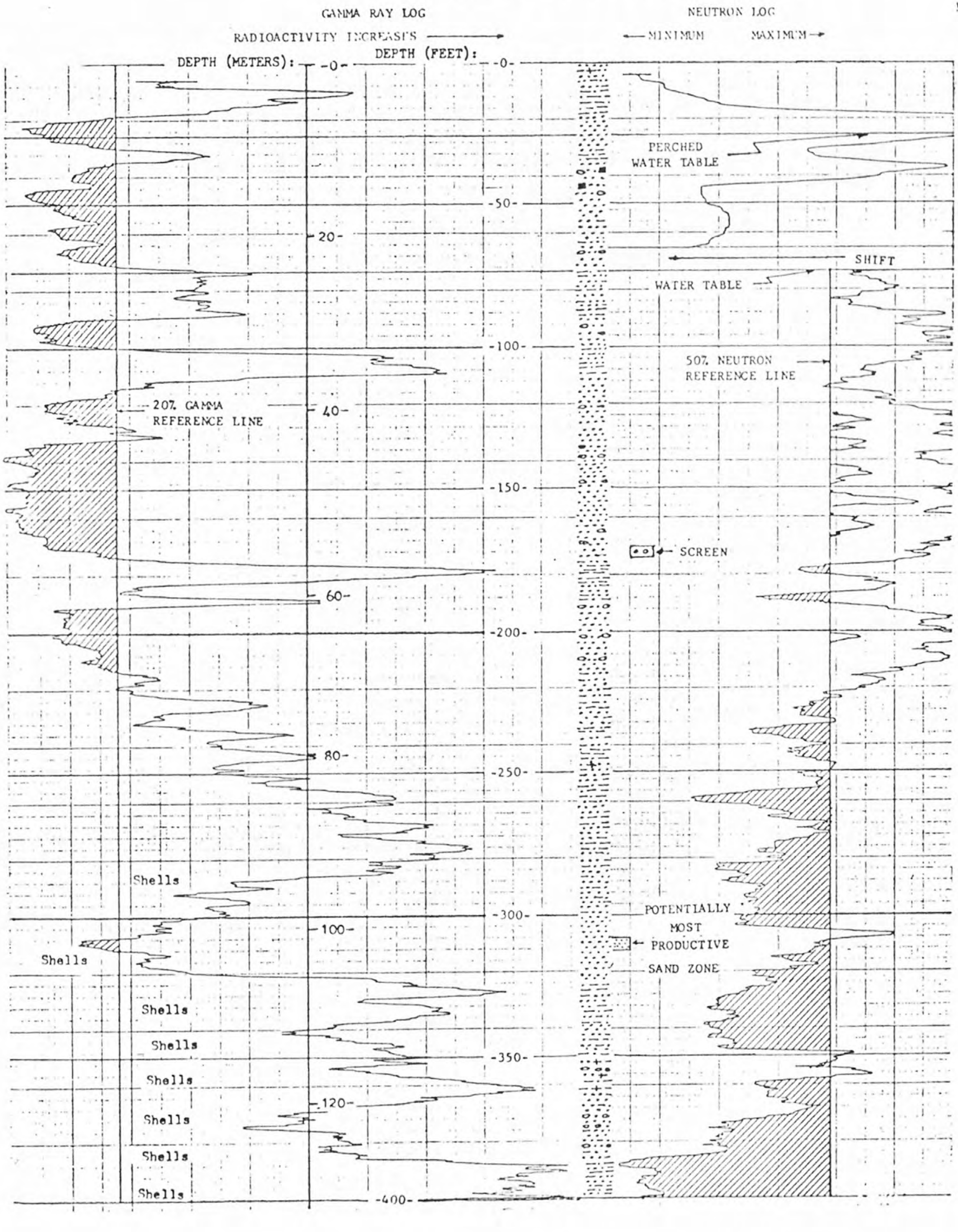
Location Number: 302937N0871501.1

Location Description: In Oakfield area. 26' W of ℄ Lucy St., 252' S of ℄ Pinestead St.

Alt. LSD: 121 feet Diam.: 2 inches

Depth: 390 feet Depth to top of screen: 170 feet

Water level: 72.2 feet below LSD Date meas.: 4/14 1973



Test Hole 31 (302355N0872003.1)

Test Hole 31 was drilled 1 mile (1.6 km) west of the junction of U.S. 98 and Fairfield Drive (S-289A), and 0.33 mile (0.53 km) south of U.S. 98. Although the well penetrated about 140 feet (43 m) of water-saturated sand and gravel with an apparently low clay content, the combination of gamma-ray and neutron logs indicate about 25 feet (8 m) of potentially most productive sand, of which 21 (6 m) feet are within 50 feet (15 m) of land surface, where it would not be practical to place a screen in a large-capacity well because of exposure during drawdown.

A condensed interpretative lithologic log follows, based on the examination of cuttings samples, the driller's log, and radioactivity logs:

	Thickness (feet)	Depth (feet)
Sand, very fine to coarse, mostly medium-grained above, coarse below, subround to subangular, becoming clayey below, dark organic staining. Interval includes 10 feet of potentially most productive sand	24	24
Sand, very fine to very coarse, mostly medium-grained to coarse, subangular to subround, clean, interbedded with fine subangular quartz gravel and poorly sorted clayey sand. Upper part of interval includes 12 feet of potentially most productive sand	66	90
Sand, very fine to very coarse, predominantly coarse in upper part, fine below, clean, grading to fine angular quartz gravel	22	112
Clay, silty, plastic.	14	126
Sand, very fine to very coarse, poorly sorted, subangular, with very fine gravel in upper part, clayey in lower part.	10	136
Gravel, very fine, quartz, with poorly sorted sand. .	21	157
Sand, very fine to very coarse, poorly sorted, becoming increasingly clayey downward	14	171
Clay, sandy	4	175
Sand as above and fine gravel	14	189
Sand, fine, clayey, interbedded with coarser clean sand with trace of gravel. Interval includes 1 foot of potentially most productive sand.	9	198

	Thickness (feet)	Depth (feet)
Sand, very fine to very coarse, predominantly medium-grained, clean, above; becoming more poorly sorted, slightly clayey below, subround and subangular, with very fine gravel	30	228
Sand, very fine to fine, subangular, increasingly clayey downward, with clay in ball-like inclusions.	11	239
Clay, silty	9	248
Sand, very fine to very coarse, poorly sorted, somewhat clayey, grading to very fine subangular quartz gravel	12	260
Sand as above, but less clayey, and with a few shell fragments	11	271
Sand, very fine to very coarse, poorly sorted, very clayey, with shell fragments	11	282
Gravel, composed partly of shell fragments, slightly clayey, with some clayey sand as above.	16	298
Sand, very fine to very coarse, mostly very fine and fine, subangular, somewhat clayey, plus very fine gravel containing shell fragments.	20	318
Interbedded sand, gravel, and shells as above, increasingly clayey downward.	24	342
Clay, sandy	6	348
Sand, very fine to coarse, mostly fine, subangular, slightly clayey, with shell gravel as above. Interval includes 2 feet of potentially most productive sand	18	366
Sand as above, but generally more clayey. Shells include whole small pelecypods. Interval includes 1 foot of potentially most productive sand.	27	393
Clay, sandy, less fossiliferous than above.	7	400

The well was screened from 209 to 213 feet (64 to 64 m). A water sample taken April 17, 1973, had a pH of 5.2, a dissolved carbon dioxide concentration of 24 mg/l, 35 mg/l dissolved solids (residue), 7 mg/l hardness, and a dissolved iron concentration of 40 μg/l. The reported constituents were within limits recommended by the U.S. Public Health Service (1962, p. 7-8, 42-43).

Well Name: U.S.G.S. TH 31

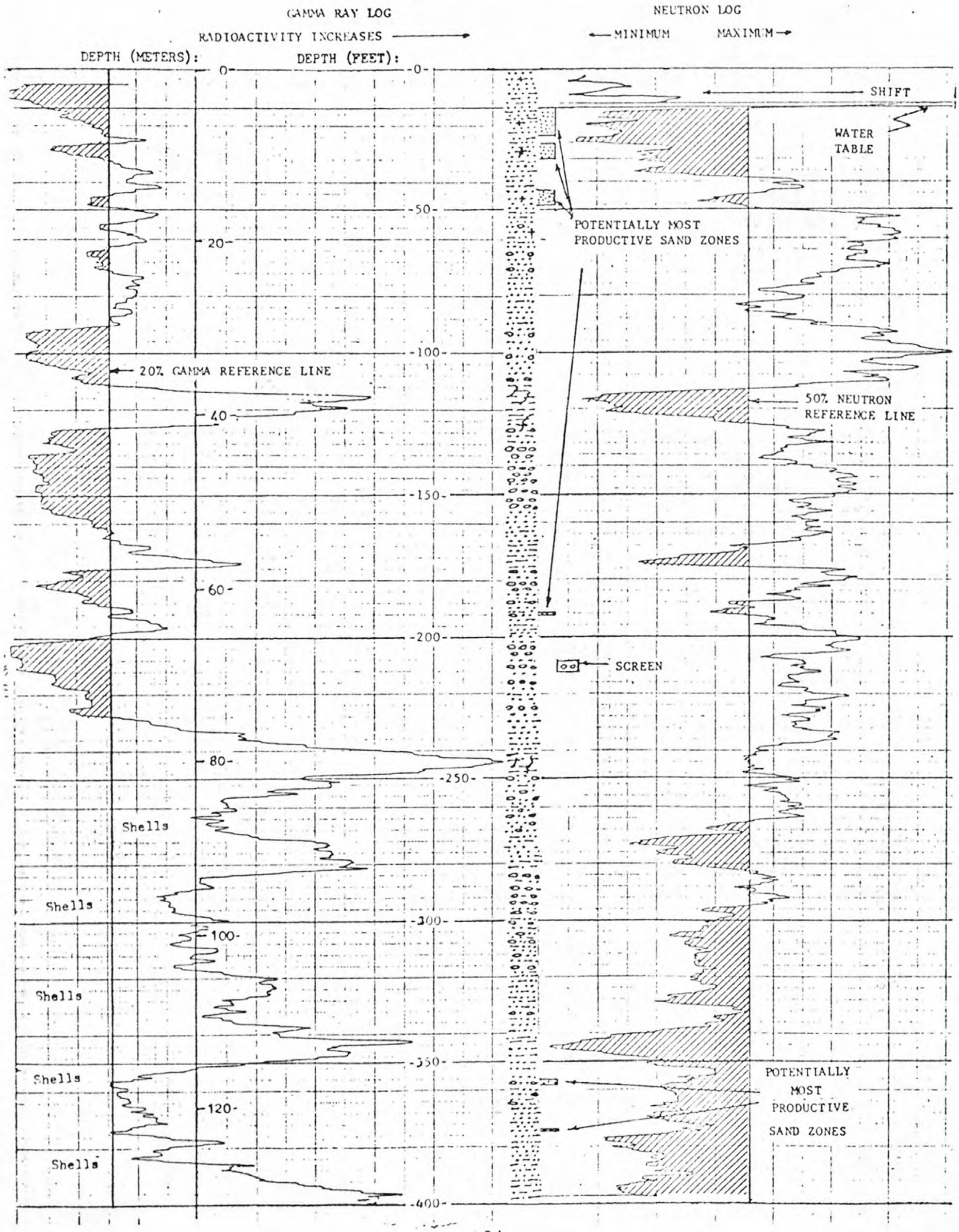
Location Number: 302355N0872003.1

Location Description: 1 mi. W of jnctn U.S. 98 and Fairfield Dr., .33 mi. S of U.S. 98

Alt. LSD: 28 feet Diam.: 2 inches

Depth: 400 feet Depth to top of screen: 209 feet

Water level: 16 feet below LSD Date meas.: 4/12 19 73



Test Hole 32 (303106N0871348.1)

Test Hole 32 was drilled on the south side of Johnson Avenue, about 0.25 mile (0.4 km) northwest of Whitmire Cemetery. Predominantly clean sand and gravel sections were penetrated from 117 feet and 260 feet (36 to 79 m), with 92 feet (28 m), of potentially most productive sand, and from 315 to 377 feet (96 to 115 m), with 46 feet (14 m) of potentially most productive sand.

A condensed interpretative lithologic log follows, based on the examination of cuttings samples, the driller's log, and caliper, electric and radioactivity logs:

	Thickness (feet)	Depth (feet)
Sand, fine to medium-grained, subangular, slightly clayey.	4	4
Sand, very fine to very coarse, poorly sorted, subangular, clean above, becoming clayey downward.	11	15
Gravel, very fine to fine, subangular, quartz, interbedded with sand as above. Interval includes 3 feet of potentially most productive sand.	15	30
Sand, poorly sorted, with inclusions of medium-grained, subangular, very clayey, plastic sand. . .	13	43
Sand, very fine to fine, very clayey, interbedded with sandy clay	38	81
Sand, very fine to very coarse, predominantly fine, slightly clayey, interbedded with sandy clay in lower part.	36	117
Sand, very fine to very coarse, predominantly fine to medium-grained, subangular to subrounded, clean, interbedded with very fine to fine quartz gravel, slightly clayey in lower part. Interval includes 1 foot of potentially most productive sand.	13	130
Sand, very fine to very coarse, predominantly fine, with some gravel. Interval includes 15 feet of potentially most productive sand.	20	150
Sand, very fine to very coarse, predominantly medium-grained and coarse, subangular to subround. Upper part is clayey; lower 11 feet includes interbedded fine gravel and is all potentially most productive sand.	35	185

	Thickness (feet)	Depth (feet)
Sand, very fine to very coarse, poorly sorted, subangular, clean, interbedded with clayey sand and clean gravel. Interval includes 19 feet of potentially most productive sand.	21	206
Sand, very fine to very coarse, predominantly medium-grained, slightly clayey in lower part. Interval includes 27 feet of potentially most productive sand	34	240
Sand, very fine to very coarse, poorly sorted, clean at top, predominantly medium-grained, slightly clayey below. Interval includes 19 feet of potentially most productive sand.	21	261
Sand, very fine to very coarse, mostly fine, mostly clayey. Interval includes 2 feet of potentially most productive sand.	37	298
Clay, silty, with a few thin streaks of clayey sand .	17	315
Sand, very fine to very coarse, mostly fine and medium-grained, subangular, clean. Interval includes 29 feet of potentially most productive sand.	34	349
Gravel, dark, very fine to fine, subangular, mostly dark smoky quartz with trace of ironstone. Interval is all potentially most productive sand. .	8	357
Sand, poorly sorted, clayey	6	363
Gravel, as from 349 to 357 feet but with thin streaks of clayey sand. Interval includes 9 feet of potentially most productive sand.	14	377
Sand, poorly sorted, clayey, with thin layers of gravel as above	15	392
Clay, silty, plastic.	8	400

The well was screened from 374 to 378 feet (114 to 115 m). A water sample taken June 14, 1973, had a pH of 6.71, dissolved solids (residue) concentration of 51 mg/l, sulfate concentration of 9.2 mg/l, bicarbonate concentration of 38 mg/l, and total hardness of 14 mg/l; all of which are above average for water from the sand-and-gravel aquifer. A possible explanation for the atypical water is that the sampling depth was greater than the depth range from which most of the aquifer's water samples have been taken. Dissolved carbon dioxide was 16 mg/l. Except for trace metals (including iron), the values for which are questionable because of the sampling method, the constituents were within the limits recommended by the U.S. Public Health Service (1962, p. 7-8, 42-43) for drinking water.

Well Name: U.S.G.S. TH 32

Location Number: 303106N0871348.1

Location Description: 20' SW of ℄ Johnson Ave., .25 mi. NW of Whitmire Cemetery.

Alt. LSD: 112 feet Diam.: 2 inches

Depth: 400 feet Depth to top of screen: 374 feet

Water level: 82.1 feet below LSD Date meas.: 4/20 1973