HYDROLOGY OF THE LOW-LEVEL RADIOACTIVE-SOLID-WASTE BURIAL SITE AND VICINITY NEAR BARNWELL, SOUTH CAROLINA

By James M. Cahill

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ABSTRACT

Geologic and hydrologic conditions at a burial site for low-level radioactive waste were studied, and migration of leachates from the buried waste into surrounding unconsolidated sediments were evaluated. The burial site and vicinity are underlain by a sequence of unconsolidated sediments of Late Cretaceous, Tertiary, and Quaternary age. These sediments are deposited over a graben which has been filled with sedimentary rocks of Triassic age.

Hydraulic properties of the sediments beneath the burial site were determined by laboratory and field tests. Laboratory hydraulic conductivity values ranged from about 10^{-7} to 10^{-1} feet per day for the clayey sediments to nearly 22 feet per day for aquifer sands. Field aquifer tests indicate a transmissivity of about 22,000 feet squared per day for Cretaceous sediments and about 6,000 feet squared per day for Tertiary sediments. Aquifer tests indicate heterogeneity in the upper 200 feet of the Tertiary sediments.

Water samples were analyzed from 51 wells, 5 streams, a Carolina bay, and rainfall at the burial site. The total dissolved solids of the ground water ranged from about 7 to 40 milligrams per liter in the upper clayey sediments to about 150 milligrams per liter in the water in the deeper calcareous sediments. The pH of the ground water ranges from 4.8 to 6.5. This slightly acidic water is corrosive to buried metal.

Tritium activity greater than background was detected in sediment cores taken from drill holes adjacent to the burial trenches. High tritium activity occurred at depths above the trench floor. This indicates upward movement of water or vapor to the land surface. Tritium and organic constituents greater than background concentrations were observed in a monitoring well about 10 feet from a trench, indicating lateral migration of radionuclides from the buried waste. Traces of cobalt-60 and tritium greater than background activity were observed in sediment cores collected 5.8 feet beneath the trench floor at one site.

A hydrologic model was used to simulate ground-water flow in the study area. Based on the model results the minimum time of travel for ground water to move from the burial site to the nearest stream, Marys Branch Creek, is about 50 years. Radionuclides will move more slowly than the water, and will diminish in activity, because of dispersion and radioactive decay.

INTRODUCTION

Proper disposal of low-level radioactive wastes resulting from nuclear power, nuclear research, and nuclear medical activities is a high national priority. Because most of the nuclear power generating plants and other nuclear activities are in the eastern section of the country, it is desirable to have satisfactory waste disposal facilities relatively close to the source of production. However, the eastern section of the country is also a region of plentiful precipitation and relatively high recharge rates to ground water. Therefore, safe disposal requires a good understanding of the hydrologic and geologic environment if these wastes are to be stored without harm to the biosphere.

This study of the geohydrology of the burial site for low-level radioactive solid waste near Barnwell, S.C. (fig. 1) was conducted during the period 1975 to 1980 and is one of five commercial burial site studies in the United States. Studies at other burial sites are near West Valley, N.Y.; Maxey Flats, Ky.; Sheffield, Ill.; and Beatty, Nev. These sites are in different geologic and climatic environments. Independent investigations should provide information useful in developing criteria for selection of future burial sites.

Purpose and Scope

The purpose of the study was to determine the geologic and hydrologic conditions near the burial site and to measure migration of leachates from buried waste into the surrounding unconsolidated sediments. The objectives of the study were to: (1) determine the geologic and hydrologic properties of the sediments; (2) define the ground-water system beneath the site and vicinity; (3) determine the extent of radionuclide migration from the buried waste; and (4) predict, using numerical models, the flow paths and time-of-travel of ground water from the burial site to nearest points of surface discharge.

The scope of the study included: (1) drilling wells and collecting sediment cores to determine the lithologic characteristics, thickness, and hydrologic properties of the sediments at and adjacent to the burial site; (2) monitoring streamflow and ground-water levels; and (3) using numerical models to simulate ground-water flow in the vicinity of the burial site.

Acknowledgments

Appreciation is expressed to Mr. Herb Oakley, Regional Vice President of Chem-Nuclear Systems, Inc. at Barnwell, S.C., who provided manpower and

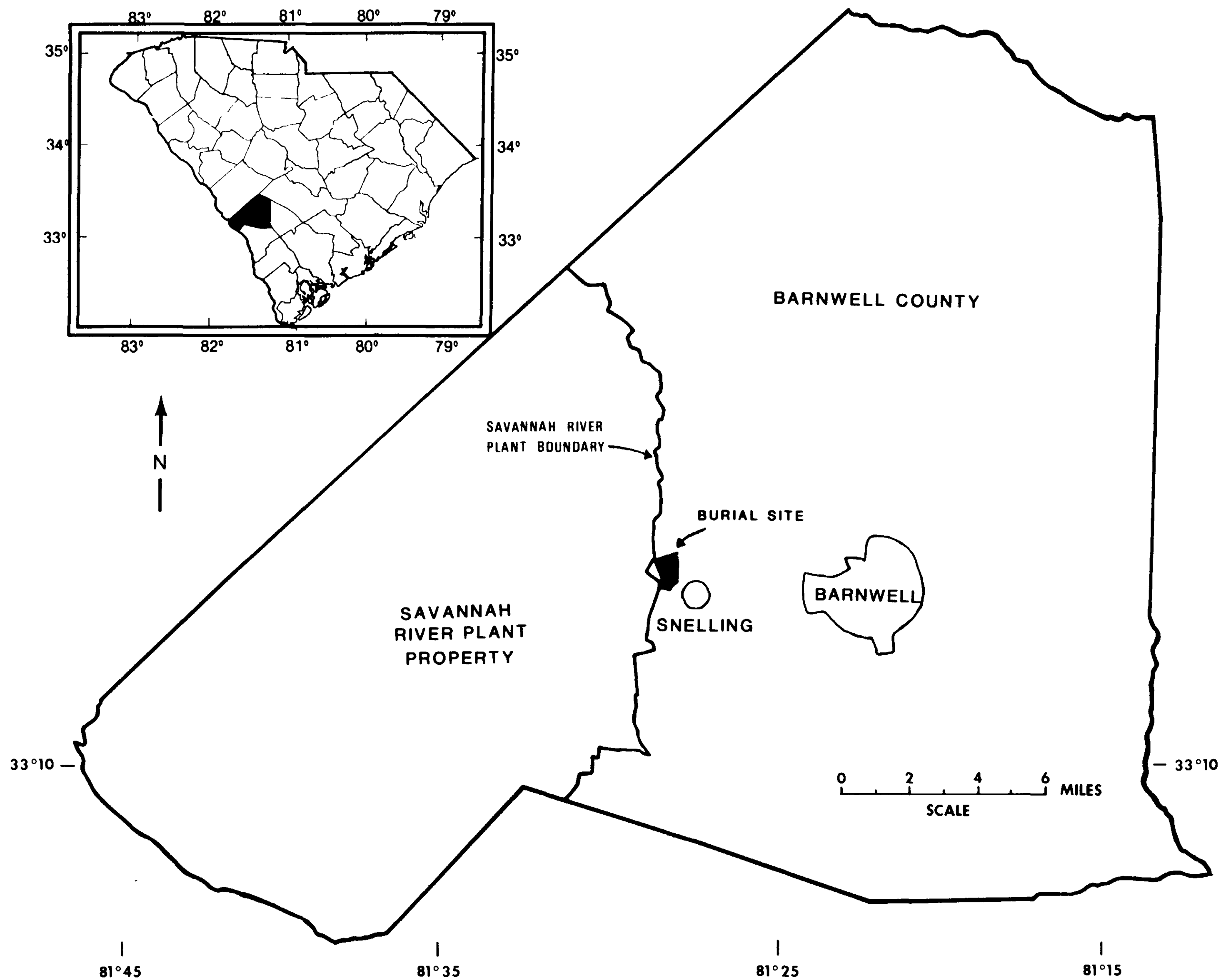


Figure 1.--Location of low-level radioactive-waste burial site near Barnwell, S.C.

cooperative assistance during the study. Mr. H. G. Shealy and staff of the Bureau of Radiological Health, South Carolina Department of Health and Environmental Control provided radiological analyses of water and sediment samples. The South Carolina Geological Survey provided drilling equipment and manpower. Mr. Audry Whitfield of the International Paper Company provided access to company property to collect geologic and hydrologic data in the area. Allied General Nuclear Services provided data on ground water and climate. Local well drillers and residents of the area provided well data and other useful information.

DESCRIPTION OF STUDY AREA

The study area, located in Barnwell County in southwestern South Carolina, comprises an area of about 44 square miles (fig. 2). The low-level radioactive-waste burial site within the study area covers about 0.5 square mile. The burial site is located about 5 miles west of Barnwell, S.C. (fig. 1) near the southeastern edge of the SRP (Savannah River Plant), a U.S. Government nuclear facility.

The study area is located in a sparsely populated area of the state. The area is bounded on the west and northwest by Par Pond, a cooling-water reservoir of SRP, and Lower Three Runs, which is the stream originating below Par Pond Dam. The area is bounded on the east by the Salkehatchie River. The north and south boundaries are latitudes 33°22'30" and 33°10'00", respectively, as shown in figure 2.

Topography of the area is flat to slightly rolling. Altitudes range from about 300 feet above the National Geodetic Vertical Datum of 1929 at the northern end to about 150 feet above NGVD of 1929 at the southern end. The land surface at the burial site is relatively flat with altitudes ranging from about 230 feet to about 260 feet.

Land Use and Vegetation

Predominant land use is timbering and farming. The major cultivated crops are soybeans, corn, wheat, cotton, melons, and pine trees. The pine trees are grown primarily for pulp wood. Noncommercial trees include blackjack oak (*Quercus marilandica*) and turkey oak (*Quercus laevis*). Numerous hydrophytes grow in poorly drained surface depressions and in swampy locations along stream channels.

Climate

The climate of the study area is characterized by warm, humid summers and mild winters. Mean monthly precipitation varied from 5.3 inches in June to 2.18 inches in November during the 22-year period from 1951-73 at the National Weather Service station near Blackville, S.C. (table 1). The Blackville station altitude is about 324 feet above NGVD and located 12 miles northeast of the burial site.

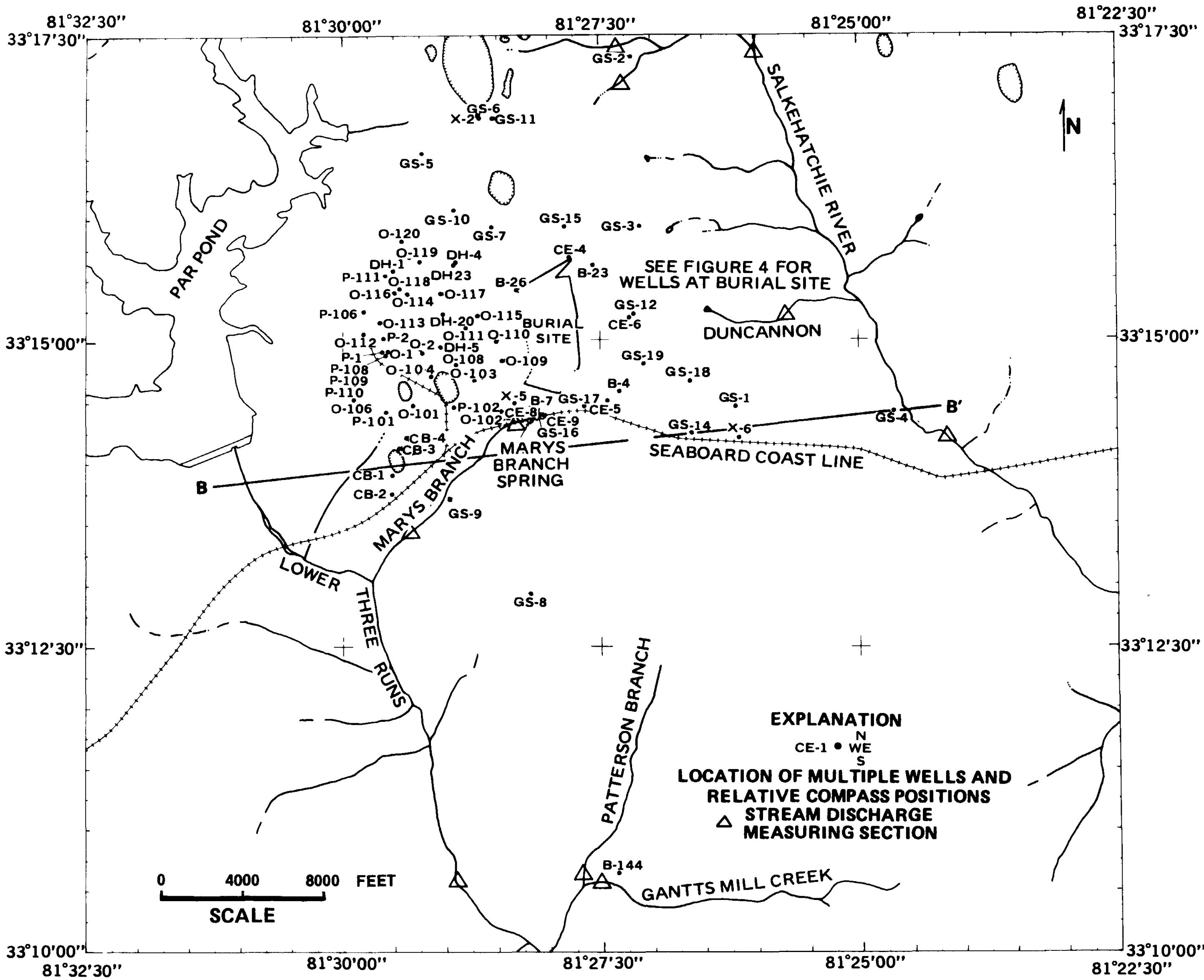


Figure 2.--Locations of wells in study area, Barnwell County, S.C.

Table 1.--Climatological summary showing means and extremes for period 1951-73 at Blackville, S.C. (Data from U.S. National Weather Service)

Latitude N33° 22', Longitude W81° 19', Elevation 324 feet

Month	Temperature (°F)													Precipitation totals (inches)														
	Means			Extremes						Mean number of days										Snow, sleet						Mean number of days		
				High			Low			Max.		Min.																
	Daily maximum	Daily minimum	Monthly	Record	Year	Day	Record	Year	Day	+90°F	-32°F	-32°F	-0°F	Mean	Greatest monthly	Year	Greatest daily	Year	Day	Mean	Maximum monthly	Year	Greatest depth	Year	Day	0.10 or more	0.50 or more	1.00 or more
Jan	57.6	34.3	45.9	79+	59	22	5+	70	10	0	0	15	0	3.91	8.35	64	2.84	64	12	.2	3.0	70	3.0	70	23	7	3	1
Feb	60.2	36.3	48.3	82	62	24	7	73	12	0	0	11	0	4.37	8.33	73	4.00	73	2	1.0	17.0	73	14.0	73	10	8	3	1
Mar	67.1	42.8	55.0	89	63	19	19	60	6	0	0	5	0	4.99	9.50	73	2.44	64	26	.1	1.5	60	--	--	--	8	4	2
Apr	76.5	51.4	64.0	92+	70	29	30+	72	10	1	0	0	0	3.68	12.99	61	4.26	61	1	.0	--	--	--	--	--	6	3	1
May	83.7	59.4	71.5	99	53	27	36	71	4	6	0	0	0	3.93	9.40	70	4.72	70	16	.0	--	--	--	--	--	6	3	1
June	88.4	66.2	77.3	103	52	28	47	72	12	13	0	0	0	5.30	10.60	73	3.87	73	7	.0	--	--	--	--	--	8	4	2
July	90.8	69.3	80.1	105	52	25	54	54	18	21	0	0	0	5.18	9.55	65	4.23	65	29	.0	--	--	--	--	--	8	3	2
Aug	90.2	68.9	79.6	104+	54	6	57+	68	29	19	0	0	0	4.41	9.97	64	4.30	64	29	.0	--	--	--	--	--	7	3	1
Sept	85.8	63.5	74.7	101	57	4	37	67	30	9	0	0	0	3.60	10.75	59	7.53	59	30	.0	--	--	--	--	--	5	2	1
Oct	77.1	52.3	64.7	98	54	7	26	52	30	1	0	1	0	2.52	10.15	59	2.40	59	29	.0	--	--	--	--	--	4	2	1
Nov	68.3	41.8	55.0	91+	61	2	15	70	25	0	0	6	0	2.18	7.00	57	1.91	69	1	.0	--	--	--	--	--	4	1	1
Dec	60.0	36.2	48.1	80+	72	11	4	62	13	0	0	12	0	3.61	8.06	53	3.25	59	18	.0	1.1	58	--	--	--	7	2	1

+Also on earlier dates.

Table 2 shows a comparison of monthly precipitation at the Blackville station and the burial site for the years 1975 to 1978. This table shows that in 1975, Blackville received 4.12 inches more rain than the burial site and that in 1976 the burial site received 3.27 inches more than Blackville. The latest mean annual (1951-80) precipitation reported by the National Weather Service at the Blackville station is 46.62 inches.

Differences in rainfall are probably due to the nature of the storms in the area. Much of the spring and summer precipitation results from locally intense thunderstorms. Very seldom do hurricanes move inland to the burial site. Fall and winter precipitation has a broader coverage, resulting from major weather fronts passing through the area.

Occasionally some snow and sleet occur in the area. Table 1 shows that snowfall amounted to about 17 inches during February 1973. On February 19, 1979, between 3 and 4 inches of wet snow occurred at the burial site causing walls of recently constructed trenches to collapse.

Evaporation is measured daily at the Blackville station in a standard Weather Service-type pan of 4-foot diameter and was measured daily with an identical pan at the burial site for the year 1978. Table 2 shows monthly evaporation at the Blackville station from 1974 to 1978. Evaporation rates were greater at the burial site than at the Blackville station during the summer and fall of 1978.

Site Operation and Waste Burial

The burial site is owned by the State of South Carolina and leased to Chem-Nuclear Systems, Inc. Chem-Nuclear Systems, Inc. was licensed to bury waste at the Barnwell site in May 1971.

Licensing to bury waste at the site is accomplished by the South Carolina Department of Health and Environmental Control, Bureau of Radiological Health. This agency has control over all radiological activities at the site such as waste packaging, trench design, trench construction, radiological monitoring, and perpetual care.

The State conducts an extensive environmental monitoring program in the area. At the time of initial licensing, a fund, controlled by the State, was established for perpetual care. Current contributions to the fund are based on the volume of waste buried at the site.

About 75 percent (by volume) of the radioactive waste buried at the Barnwell site comes from the nuclear power industry. Industrial, research, medical, and academic facilities provide the remaining material. The waste is shipped and buried in containers of various shapes, sizes, and weights. Prior to September 1976, liquid waste was shipped to the burial site to be solidified. Since September 1976, only solid waste has been buried at the site.

Figure 3 depicts the volume of waste buried at the site from January 1975 to December 1979. The increase after 1976 occurred at a time when most of the

Table 2.--Monthly mean soil temperature, total monthly precipitation, and pan evaporation at Blackville, S.C., and at the burial site

Month	Blackville, S.C.															Chem-Nuclear burial site					
	Monthly precipitation (in inches)					Mean monthly soil temperature (degrees Fahrenheit)					Monthly evaporation (inches)					Precipitation (inches)				Evaporation (inches)	
	1974	1975	1976	1977	1978	1974	1975	1976	1977	1978	1974	1975	1976	1977	1978	1975	1976	1977	1978	1977	1978
Jan	3.17	5.13	4.25	3.19	7.36	59.1	53.2	48.2	40.6	43.7	1.80	1.93	2.09	--	--	--	6.04	2.75	9.10	--	4.98
Feb	6.35	5.69	1.60	1.99	1.30	54.4	55.1	56.0	48.5	44.4	2.99	2.13	3.60	3.23	--	7.15	1.18	1.60	.89	--	2.38
Mar	2.83	5.55	3.49	7.42	2.48	59.3	58.2	62.4	60.2	55.0	4.82	4.11	4.11	4.27	3.84	5.60	3.46	7.22	2.61	--	3.46
Apr	3.27	3.67	1.19	.89	4.51	66.3	64.6	69.7	71.1	68.0	7.00	5.17	6.91	6.08	6.74	5.35	1.08	.72	3.87	--	7.90
May	4.38	7.28	5.41	5.68	4.93	75.0	76.7	72.3	77.8	73.3	6.50	5.93	5.77	7.06	6.28	6.65	7.35	3.93	5.79	--	7.14
June	4.03	4.34	11.53	4.64	3.22	78.7	80.6	78.4	82.9	82.4	6.70	6.76	6.24	8.12	7.32	5.69	10.44	2.27	4.40	--	8.50
July	5.90	7.12	1.79	1.79	7.35	80.0	81.3	84.8	87.3	84.9	6.07	6.00	7.16	8.32	7.76	8.46	2.70	.43	4.72	--	8.33
Aug	7.08	5.72	3.02	5.86	3.38	81.8	84.1	83.3	84.2	84.7	5.36	6.70	6.47	6.26	6.23	3.24	2.38	11.20	4.14	--	7.48
Sept	5.58	2.48	5.77	3.66	1.18	79.3	80.1	78.2	81.8	82.2	4.50	4.57	3.81	4.71	5.29	3.03	5.35	3.94	1.28	--	6.87
Oct	.07	1.54	5.24	4.64	0.02	70.0	73.4	66.6	67.7	73.4	4.24	3.57	3.52	3.47	4.71	.64	5.51	4.30	.10	--	5.76
Nov	1.85	1.54	3.64	1.31	1.87	60.9	63.7	54.4	63.4	66.2	2.72	2.41	2.27	3.32	2.95	.95	3.96	1.25	2.41	2.52	3.26
Dec	5.21	4.08	4.19	5.47	2.13	51.1	52.7	47.8	51.4	53.8	1.56	1.96	--	--	2.26	3.26	4.94	3.96	2.47	3.13	2.11
Annual total	49.72	54.14	51.12	46.54	39.73	--	--	--	--	--	54.26	51.24	--	--	--	50.02	54.39	43.57	41.78	--	65.17
Dep. from norm.	3.10	7.52	4.50	-.08	-6.89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

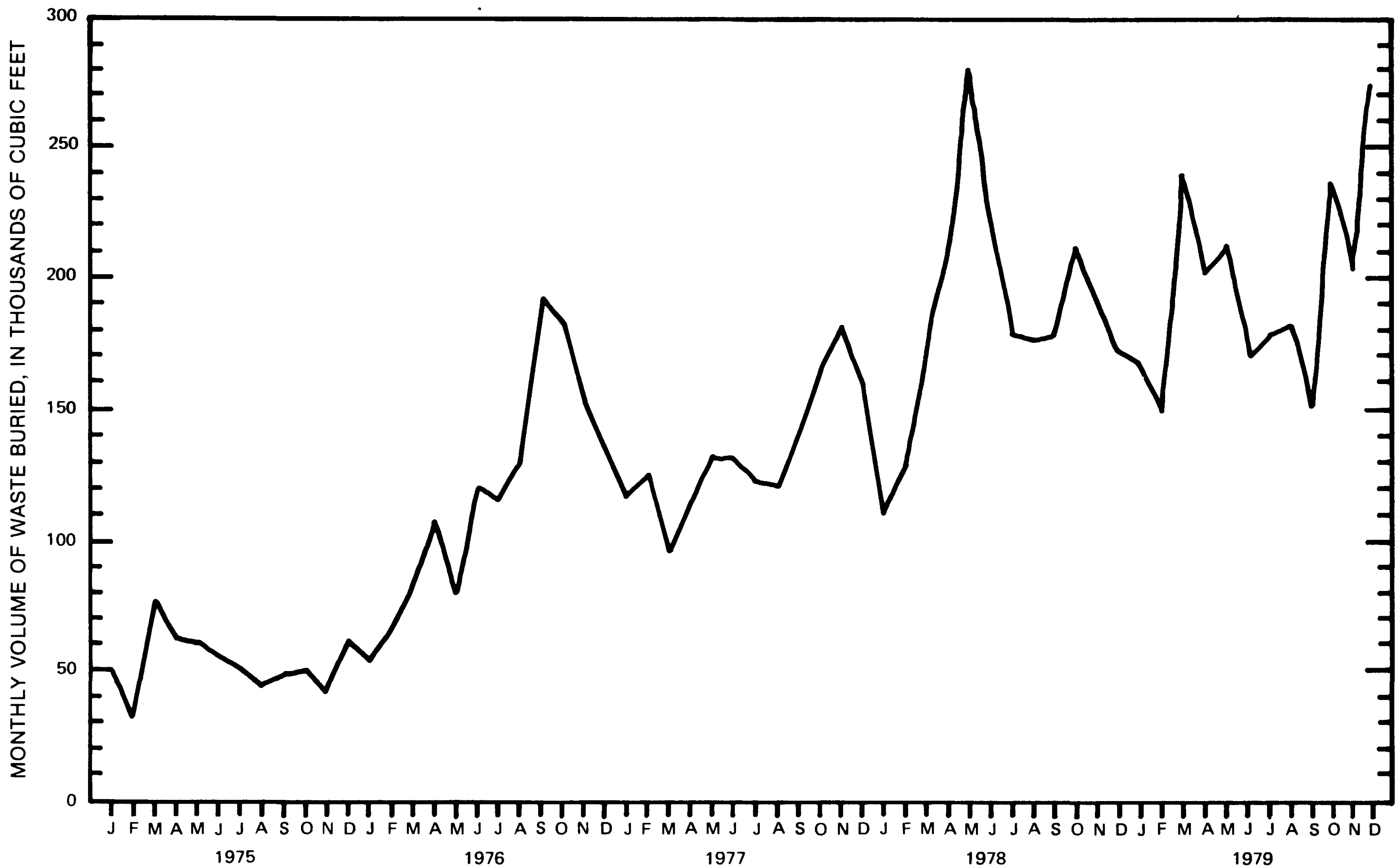


Figure 3.--Monthly volume of solid waste buried at the low-level radioactive-waste burial site near Barnwell, S.C., during 1975-79.

other burial sites in the eastern United States were closed. Prior to November 1979, waste shipments to Barnwell were limited to no more than 2.4 million cubic feet per year. An executive order issued in November 1979 specifies monthly quotas that decrease gradually from 200,000 to 100,000 cubic feet per month by October 1981.

Management with regard to burial of the radioactive waste is primarily one of containment. Wastes are buried in trenches above the water table. Efforts are made to prevent contact of water with the waste material. The trench covers are contoured to facilitate surface drainage, thereby minimizing water percolation through the waste.

Burial trenches are normally 22 feet deep, 50 to 100 feet wide, and 500 to 1,000 feet long. The trench bottom slopes about 0.3 percent from end to end and about 1 percent from side to side. Three-inch diameter pipes are installed vertically at the low side of each trench floor to monitor any water which might enter the trench. Before waste is placed in a trench, about 2 feet of sand is deposited along the bottom to allow water which enters the trench to move towards the drainage system allowing minimal contact between the water and waste.

The first waste was buried in trenches at the south end of the site in May 1971 (figs. 4 and 5). The trenches are numbered in sequence of excavation. Most of the earlier trenches are oriented in a general east-west direction. These trenches are 500 feet or less in length, about 50 feet wide, and spaced about 10 feet apart.

Since 1976, most waste has been buried in longer and wider trenches. These trenches are about 1,000 feet long and about 100 feet wide. These longer trenches are north of the earlier trenches (fig. 4).

Previous Investigations

Cooke (1936) in a reconnaissance report on the geology of the Coastal Plain of South Carolina included information on the general geology and ground-water resources of the area. Cooke (1936) renamed the Middendorf Formation the Tuscaloosa Formation. In recent years the name Middendorf has been used in place of Tuscaloosa in South Carolina. LeGrand (1962) presented a general description on the geology and hydrology of the Atlantic and Gulf Coastal Plains as related to disposal of radioactive wastes. Siple (1967) presented a comprehensive description of the geology and hydrology for the western part of the study area. Law Engineering Testing Company (1970) conducted a preliminary geohydrologic investigation of the upper 100 feet of sediments near the burial site. Allied General Nuclear Services drilled numerous wells to investigate geologic and hydrologic properties at the Barnwell Nuclear Fuel Plant. Siple and Carter (1967) published a brief report on the water resources of Barnwell County. In addition, the U.S. Department of Energy publishes annual geology and hydrology reports pertaining to the nearby Savannah River Plant.

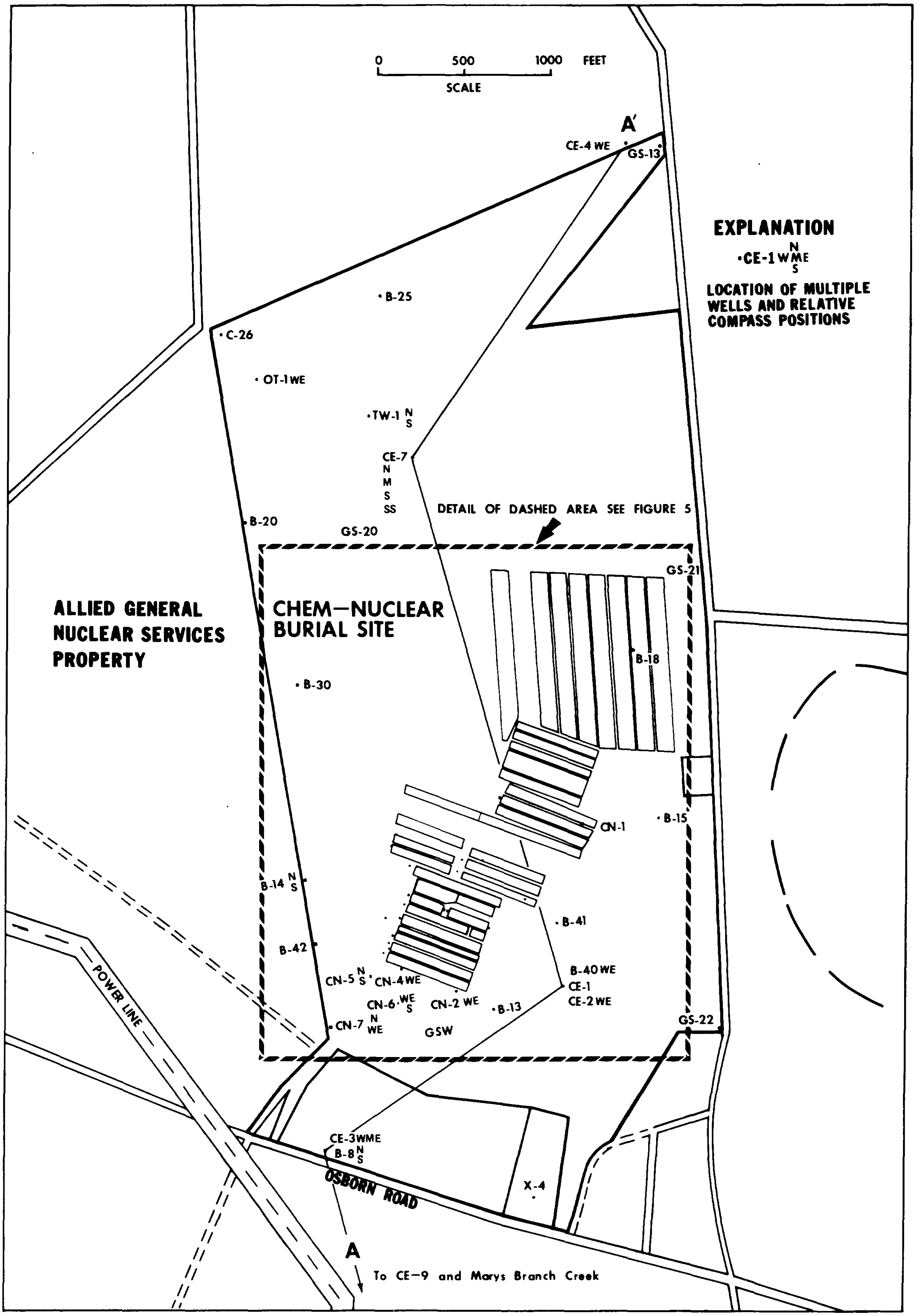


Figure 4.--Location of wells, trenches, and line of section A-A′ at the low-level radioactive-solid-waste burial site near Barnwell, S.C.

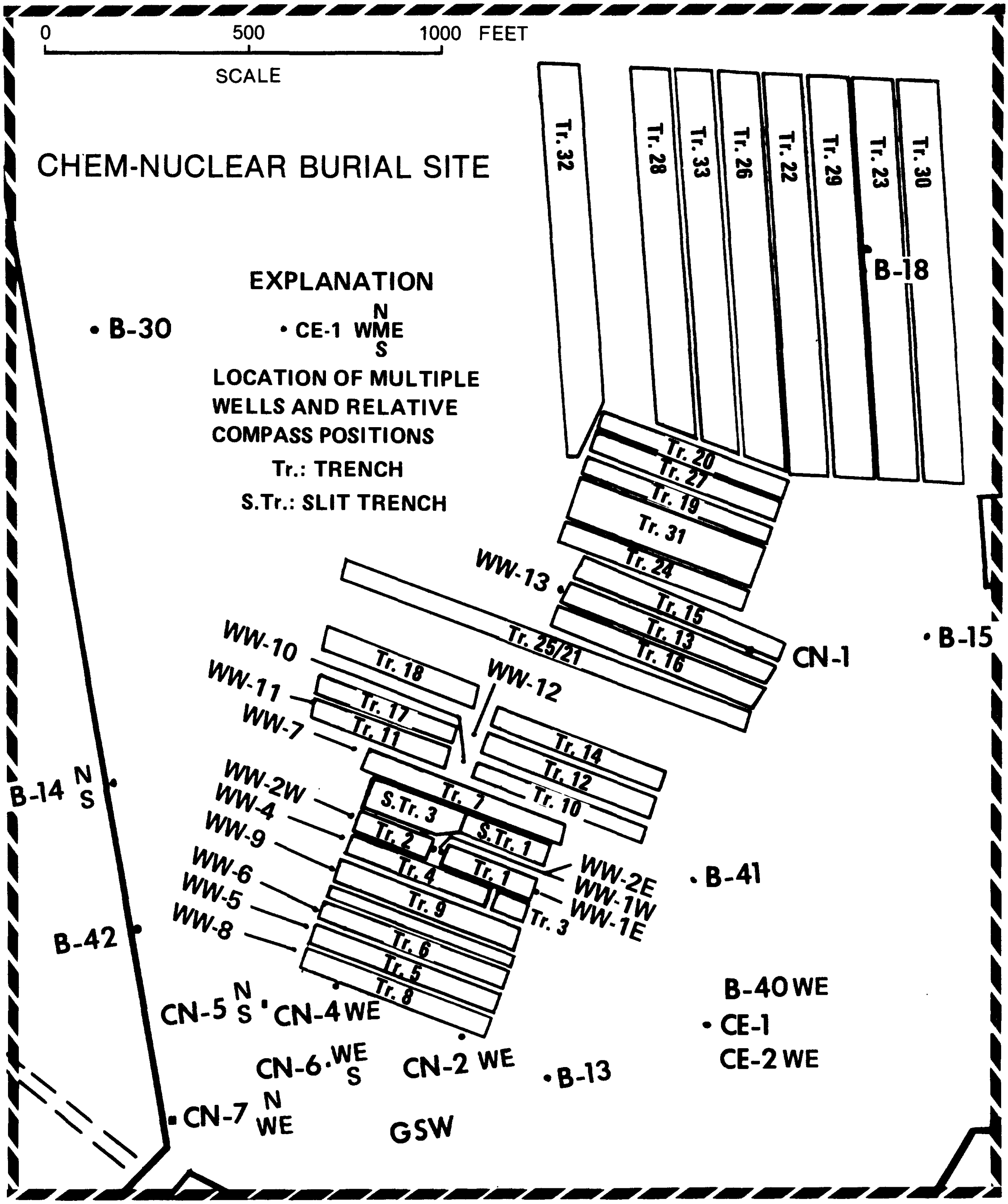


Figure 5.--Location of trenches and wells at the low-level radioactive-solid-waste burial site near Barnwell, S.C.

Well-Numbering System

Well numbers from previous investigations were retained for this study. Generally, wells were designated in consecutive order of drilling with a letter prefix as shown in table 3 and figure 2. Some wells were drilled in clusters. A suffix letter indicates position within a cluster. For example, N indicates the northern well; M, the middle; SS, the southernmost. Wells with the prefix GS were drilled with a 2-inch diameter auger rig to a maximum depth of 65 feet. Well GS-4, for example, was the fourth well drilled with the auger. The prefix CE was used for wells from which sediment cores were taken. Thus, CE-1 was the first well drilled from which sediment cores were obtained.

Wells which were drilled by Law Engineering Testing Company for Chem-Nuclear Services have the prefix B. Wells drilled into the saturated zone at the ends of the trenches prior to 1977 are designated by the prefix WW and by the trench number (well WW-8 was drilled at trench 8). After 1977, clusters of wells were drilled and cored at selected sites near the trenches. These wells are numbered in consecutive order of drilling with the prefix CN followed by a number and its compass heading. Well CN-4W is the western well in the cluster group. Wells which are owned by or drilled for Allied General Nuclear Services are designated by the prefixes P, O, and DH: P indicates that these wells were drilled as piezometer wells, O as observation wells, and DH as drill holes.

The prefix X indicates privately owned wells, and the number indicates the sequence in which they were inventoried. The U.S. Geological Survey collects geohydrologic data from selected wells throughout South Carolina and uses the prefix BW for those wells in Barnwell County. These wells are numbered consecutively in the order in which they were inventoried.

DATA COLLECTION

An extensive test drilling program was undertaken to investigate the hydrologic and physical properties of the sediments in the vicinity of the burial site.

Twenty-eight 1-1/2 to 2-inch diameter wells were augered to depths ranging from 20 to 65 feet to obtain water levels in areas where only minimal data were available. Seven wells were drilled to depths ranging from 310 to 519 feet to obtain geologic and hydrologic information on the deeper sediments. Sixteen 4-inch cased wells were drilled at 7 sites near the burial trenches to depths of less than 80 feet. These wells were used to: (1) determine the thickness of the sediments in which the waste is buried, (2) monitor the water levels and determine direction of water movement in the upper 340 feet of sediments, and (3) determine radionuclide activity in the upper 80 feet of sediments.

An observation-well network was established to obtain continuous water-level measurements in the study area. Water samples were collected from

Table 3.--Description of wells in vicinity of the low-level radioactive-solid-waste burial site near Barnwell, S.C.

Well	Latitude	Longitude	Depth of well (feet)	Diameter of casing (inches)	Zone of perforation (feet)*	Zone	Water level below land surface (feet)*	Elevation of measuring point (feet)#	Elevation of water surface (feet)#	Date measured	Remarks
GS-1	33°14'27"	81°26'12"	65	2	62.5- 65	1	32.85	237.88	205.03	11/16/79	
GS-2	33°17'19"	81°27'11"	22	2	19.5- 22	1	12.34	236.42	224.08	11/16/79	
GS-3	33°15'56"	81°27'07"	34	2	31.5- 34	1	25.42	248.19	222.77	11/16/79	
GS-4	33°14'25"	81°24'40"	20	2	17.5- 20	1	5.72	177.36	171.64	11/16/79	
GS-5	33°16'32"	81°29'14"	30	2	27.5- 30	1	9.10	244.67	235.57	11/19/79	
GS-6	33°16'51"	81°28'41"	61	2	58.5- 61	1	30.55	287.15	256.60	11/19/79	
GS-7	33°15'56"	81°28'33"	51	2	48.5- 51	1	30.65	271.12	240.47	11/19/79	
GS-8	33°13'00"	81°28'02"	55	2	52.5- 55	1	25.13	220.00	194.87	11/19/79	
GS-9	33°13'53"	81°28'35"	60	2	57.5- 60	1	30.02	205.63	175.61	11/19/79	
GS-10	33°16'04"	81°28'55"	34	2	31.5- 34	1	20.99	257.66	236.67	11/19/79	
GS-11	33°16'50"	81°28'32"	60	2	57.5- 60	1	27.37	283.32	255.95	11/19/79	
GS-12	33°15'13"	81°27'11"	41	2	38.5- 41	1	22.88	238.22	215.34	11/16/79	Destroyed
GS-13	33°15'37"	81°27'47"	32	2	29.5- 32	1	25.60	249.68	224.08	11/16/79	
GS-14	33°14'14"	81°26'38"	44	2	41.5- 44	1	38.83	253.28	214.45	11/19/79	
GS-15	33°15'56"	81°27'50"	61	2	59.5- 62	1	33.09	262.78	229.69	11/16/79	
GS-16	33°14'24"	81°28'06"	35	2	32.5- 35	1	27.80	221.17	193.37	11/16/79	
GS-17	33°14'28"	81°27'39"	39	2	35.5- 38	1	17.61	221.89	204.28	11/16/79	
GS-18	33°14'40"	81°26'38"	42	2	39.5- 42	1	32.34	244.54	212.20	11/19/79	
GS-19	33°14'48"	81°27'05"	49	2	47.5- 50	1	28.40	244.93	216.53	11/16/79	
GS-20	33°15'11"	81°28'07"	45	NA	NA	1	23.70	247.60	223.90	4/15/77	Destroyed
GS-21	33°15'13"	81°27'44"	56	2	Lower 10	1	32.55	252.18	219.63	11/19/79	
GS-22	33°14'46"	81°27'42"	48	2	Lower 10	1	30.70	245.18	214.48	11/19/79	
GS-23	33°14'50"	81°27'52"	18	3	14.0- 18	--	11.51	259.01	247.50	12/21/78	Perched water table
GSW	33°14'48"	81°27'59"	60	2	57.5- 60	1	42.15	258.07	215.92	11/19/79	
B-4E	33°14'35"	81°27'19"	56	1.25	NA	1	24.97	234.86	209.89	11/16/79	
B-4W	33°14'35"	81°27'19"	58	4	NA	1	28.32	237.86	209.54	11/16/79	
B-4S	33°14'35"	81°27'19"	75	1.25	NA	2	26.45	238.16	211.71	11/16/79	
B-7	33°14'26"	81°28'06"	78	4	NA	2	42.83	234.65	191.82	11/16/79	

Table 3.--Description of wells in vicinity of the low-level radioactive-solid-waste burial site near Barnwell, S.C.--Continued

Well	Latitude	Longitude	Depth of well (feet)	Diameter of casing (inches)	Zone of perforation (feet)*	Zone	Water level below land surface (feet)*	Elevation of measuring point (feet)#	Elevation of water surface (feet)#	Date measured	Remarks
B-8N	33°14'39"	81°28'09"	93	1.25	NA	2	51.70	254.88	203.18	2/17/77	Obstructed
B-8S	33°14'39"	81°28'09"	54	1.25	NA	1	49.96	254.74	204.78	11/19/79	
B-13	33°14'47"	81°27'57"	58	1.25	NA	1	37.10	263.04	225.94	7/24/75	Obstructed
B-14N	33°14'55"	81°28'10"	40	1.25	NA	1	27.72	246.82	219.10	11/16/79	
B-14S	33°14'55"	81°28'10"	46	4	NA	1	28.43	247.13	218.70	11/16/79	
B-15	33°14'58"	81°27'47"	50	1.25	NA	1	39.55	260.57	221.02	11/19/79	
B-18	33°15'07"	81°27'48"	81	4	NA	2	45.30	258.28	212.98	11/19/79	
B-20	33°15'15"	81°28'14"	50	4	40- 50	1	34.46	255.14	220.68	11/16/79	4-inch well replaced a 1.25-inch well destroyed in 1978
B-23	33°15'37"	81°27'34"	82	4	NA	2	22.67	243.89	221.22	11/16/79	
B-25	33°15'28"	81°28'05"	44	4	NA	1	38.82	263.58	224.76	11/19/79	
B-26S	33°15'25"	81°29'19"	80	4	NA	2	39.45	264.52	225.07	11/19/79	
B-26N	33°15'25"	81°28'19"	38	1.25	NA	1	38.32	264.88	226.56	11/19/79	
B-30	33°15'06"	81°28'11"	71	1.25	NA	2	24.06	238.79	214.73	7/75	
B-40E	33°14'49"	81°27'53"	80	4	60- 80	2	46.19	258.08	211.89	11/19/79	
B-40W	33°14'49"	81°27'53"	50	4	NA	1	32.82	257.46	224.64	11/19/79	
B-41E	33°14'52"	81°27'53"	55	4	45- 55	1	45.77	259.84	214.07	11/19/79	
B-41W	33°14'52"	81°27'53"	60	4	None	1	41.21	259.88	218.61	5/15/80	
B-42	33°14'51"	81°28'09"	55	4	45- 55	1	35.65	247.40	211.75	11/16/79	
BW-144	33°10'39"	81°27'21"	182	4	open hole	3	NA	NA	NA		Cased to 84'
X-2	33°16'50"	81°28'40"	120	3	NA	2	37.70	286.98	249.28	11/19/79	
X-4	33°14'36"	81°27'55"	86	2	NA	2	54.80	260.10	205.30	11/16/79	
X-5	33°14'29"	81°28'20"	99	4	NA	2	55.66	250.46	194.80	11/16/79	
X-6	33°14'12"	81°26'10"	89	4	NA	2	22.77	226.30	203.53	11/16/79	
C-26	33°15'27"	81°28'16"	50	4	37- 47	1	38.31	263.66	225.35	11/19/79	
CB-1	33°13'54"	81°29'32"	24	3	14- 24	1	9.38	202.13	192.75	11/19/79	
CB-2	33°13'44"	81°29'32"	26	2	16- 26	1	6.80	193.76	186.96	11/19/79	

Table 3.--Description of wells in vicinity of the low-level radioactive-solid-waste burial site near Barnwell, S.C.--Continued

Well	Latitude	Longitude	Depth of well (feet)	Diameter of casing (inches)	Zone of perforation (feet)*	Zone	Water level below land surface (feet)*	Elevation of measuring point (feet)#	Elevation of water surface (feet)#	Date measured	Remarks
CB-3	33°14'07"	81°29'28"	34	3	24- 34	1	10.26	210.13	199.87	11/19/79	
CB-4	33°14'12"	81°29'24"	51	2	41- 51	1	32.28	238.89	206.61	11/19/79	
CE-1	33°14'49"	81°27'53"	519	4	499-519	4	69.63	258.64	189.01	11/19/79	
CE-2E	33°14'49"	81°27'53"	201	4	191-201	3	50.84	259.09	208.25	11/19/79	
CE-2W	33°14'49"	81°27'53"	55	4	45- 55	1	34.98	259.96	224.98	11/19/79	
CE-3M	33°14'39"	81°28'09"	89	4	79- 89	2	46.40	255.14	208.74	11/19/79	
CE-3W	33°14'39"	81°28'09"	58	4	48- 58	1	40.53	254.09	213.56	11/19/79	
CE-3E	33°14'39"	81°28'09"	430	4	420-430	4	NA	NA	NA		Destroyed
CE-4E	33°15'41"	81°27'48"	108	4	98-108	2	25.72	249.59	223.87	11/16/79	
CE-4W	33°15'41"	81°27'48"	233	4	223-233	3	26.06	251.39	225.33	11/16/79	
CE-5	33°14'30"	81°27'26"	210	4	200-210	3	NA	228.85	NA		
CE-6	33°15'11"	81°27'13"	163	4	153-163	2	24.08	238.02	213.94	11/16/79	Destroyed
CE-7S	33°15'19"	81°28'03"	161	4	151-161	3	40.86	257.38	216.52	11/16/79	
CE-7SS	33°15'19"	81°28'03"	50	4	40- 50	1	33.56	259.06	225.50	11/16/79	
CE-7M	33°15'19"	81°28'03"	404	4	394-404	4	70.16	257.94	187.78	11/16/79	
CE-7N	33°15'19"	81°28'03"	74	4	64- 74	2	37.08	258.22	221.14	11/16/79	
CE-8E	33°14'23"	81°28'08"	117	4	107-117	2	30.70	224.43	193.73	11/16/79	
CE-8W	33°14'23"	81°28'08"	182	4	172-182	3	31.01	224.43	193.42	11/16/79	
CE-9	33°14'23"	81°28'03"	404	4	394-404	4	33.82	224.72	190.90	11/16/79	
CN-1W	33°14'58"	81°27'52"	75	3	65- 75	2	43.04	258.14	215.10	11/19/79	
CN-1E	33°14'58"	81°27'52"	50	3	40- 50	1	30.46	257.85	227.39	11/19/79	
CN-2W	33°14'48"	81°28'00"	75	4	65- 75	2	50.46	262.69	212.23	11/19/79	
CN-2E	33°14'48"	81°28'00"	46	4	36- 46	1	51.46	260.68	209.22	11/19/79	
CN-3N	33°14'51"	81°28'05"	48	4	38- 48	1	37.32	249.47	212.15	11/19/79	
CN-3S	33°14'51"	81°28'05"	69	4	59- 69	2	38.38	249.72	211.34	11/19/79	
CN-4E	33°14'50"	81°28'04"	66	4	56- 66	2	40.73	251.79	211.06	11/19/79	
CN-4W	33°14'50"	81°28'04"	42	4	32- 42	1	37.53	251.52	213.99	11/19/79	
CN-5N	33°14'49"	81°28'06"	NA	4	10'	--	40.46	250.60	210.14	11/19/79	

Table 3.--Description of wells in vicinity of the low-level radioactive-solid-waste burial site near Barnwell, S.C.--Continued

Well	Latitude	Longitude	Depth of well (feet)	Diameter of casing (inches)	Zone of perforation (feet)*	Zone	Water level below land surface (feet)*	Elevation of measuring point (feet)#	Elevation of water surface (feet)#	Date measured	Remarks
CN-5S	33°14'49"	81°28'06"	43	4	10'	1	39.95	250.69	210.74	11/19/79	
CN-6S	33°14'48"	81°28'04"	45	4	10'	1	38.43	250.42	211.99	11/19/79	
CN-6E	33°14'48"	81°28'04"	NA	4	10'	--	NA	250.28	NA		Drilling mud left in well
CN-6W	33°14'46"	81°28'04"	75	4	65- 75	2	39.77	250.12	210.35	11/19/79	
CN-7N	33°14'46"	81°28'08"	37	4	NA	1	NA	246.06	NA		Drilling mud left in well
CN-7E	33°14'46"	81°28'08"	45	4	NA	1	NA	247.48	NA	11/19/79	Drilling mud left in well
CN-7W	33°14'46"	81°28'08"	37	4	NA	1	NA	246.86	NA	11/19/79	Drilling mud left in well
OT-1W	33°15'24"	81°28'13"	53	4	43- 53	1	36.59	261.21	224.63	11/16/79	
OT-1E	33°15'24"	81°28'13"	84	4	74- 84	2	36.92	261.16	224.24	11/16/79	
TW-1S	33°15'21"	81°28'06"	170	4	70-170	2	38.08	260.81	222.23	11/19/79	
TW-1N	33°15'21"	81°28'06"	47	4	37- 47	1	36.25	261.80	225.55	11/19/79	
WW-1E	33°14'52"	81°27'58"	57	4	47- 57	1	50.73	263.35	212.62	11/19/79	
WW-1W	33°14'53"	81°28'01"	75	4	65- 75	2	48.44	261.09	212.65	11/19/79	
WW-2E	33°14'53"	81°28'01"	56	4	46- 56	2	47.49	260.75	213.26	11/19/79	
WW-2W	33°14'54"	81°28'03"	64	4	Lower 10'	2	39.62	252.58	212.96	11/19/79	
WW-4	33°14'53"	81°28'03"	62	3	Lower 10'	1	40.17	252.94	212.77	11/19/79	
WW-5	33°14'51"	81°28'05"	58	3	48- 58	1	39.92	251.36	211.44	11/19/79	
WW-6	33°14'52"	81°28'04"	54	3	44- 54	1	39.11	251.09	211.98	11/19/79	
WW-7	33°14'56"	81°28'03"	55	4	45- 55	1	39.80	253.60	213.80	11/19/79	
WW-8	33°14'51"	81°28'05"	55	4	45- 55	1	NA	249.30	NA		Pump installed
WW-9	33°14'53"	81°28'04"	58	4	48- 58	1	38.60	252.44	213.84	11/19/79	
WW-10	33°14'55"	81°28'00"	47	4	37- 47	1	NA	264.04	NA		Observation well
WW-11	33°14'57"	81°28'04"	55	4	45- 55	1	33.18	248.53	215.35	11/19/79	
WW-12	33°14'56"	81°28'00"	53	4	43- 53	1	48.42	254.45	205.63	11/19/79	

Table 3.--Description of wells in vicinity of the low-level radioactive-solid-waste burial site near Barnwell, S.C.--Continued

Well	Latitude	Longitude	Depth of well (feet)	Diameter of casing (inches)	Zone of perforation (feet)*	Zone	Water level below land surface (feet)*	Elevation of measuring point (feet)#	Elevation of water surface (feet)#	Date measured	Remarks
WW-13	33°15'00"	81°27'57"	58	4	48- 58	1	37.45	264.97	227.52	11/19/79	
DH-1	33°15'34"	81°29'30"	92	3	NA	2	33.30	260.94	227.64	11/29/79	
DH-4	33°15'38"	81°28'55"	120	3	NA	2	38.80	270.18	231.38	11/29/79	
DH-5	33°14'57"	81°29'04"	136	3	NA	2	43.25	250.47	207.22	11/29/79	
DH-20	33°15'13"	81°29'03"	41	NA	NA	1	29.70	255.34	225.64	11/29/79	
DH-23	33°15'38"	81°28'55"	52	NA	NA	1	35.50	270.06	234.56	11/29/79	
P-1	33°14'55"	81°29'37"	985	NA	NA	4	NA	NA	NA		
P-2	33°15'01"	81°29'36"	850	NA	NA	4	NA	NA	NA		
P-101	33°14'25"	81°29'35"	27	NA	NA	1	7.70	214.32	206.62	11/29/79	
P-102	33°14'27"	81°28'56"	56	NA	NA	1	29.20	233.60	204.40	11/29/79	
P-106	33°15'14"	81°29'47"	48	NA	NA	1	33.80	258.74	224.94	11/29/79	
P-107	33°14'53"	81°29'35"	53	NA	NA	1	37.00	257.35	220.35	11/29/79	
P-108	33°14'53"	81°29'35"	51	NA	NA	1	36.15	256.72	220.57	11/29/79	
P-109	33°14'53"	81°29'35"	258	NA	NA	3	57.00	258.04	201.04	11/29/79	
P-110	33°14'53"	81°29'35"	258	NA	NA	3	55.20	256.56	201.36	11/29/79	
P-111	33°15'32"	81°29'35"	51	NA	NA	1	28.30	261.75	233.45	11/29/79	
O-1	33°14'55"	81°29'33"	1110	NA	NA	4	NA	NA	NA		
O-2	33°14'54"	81°29'14"	931	6	NA	4	44.33	238.85	194.52	5/15/80	
O-101	33°14'28"	81°29'20"	39	NA	NA	1	22.90	234.92	212.02	11/29/79	
O-102	33°14'25"	81°28'27"	62	3	NA	2	54.90	248.82	193.92	11/29/79	
O-103	33°14'40"	81°28'44"	54	NA	NA	1	38.90	246.87	207.97	11/29/79	
O-104	33°14'43"	81°29'09"	26	NA	NA	1	8.55	224.84	216.29	11/29/79	
O-106	33°14'31"	81°29'53"	33	NA	NA	1	22.70	235.33	212.63	11/29/79	
O-108	33°14'48"	81°28'54"	56	NA	NA	1	39.55	252.25	212.70	11/29/79	
O-109	33°14'50"	81°28'27"	57	NA	NA	1	35.65	249.92	214.27	11/29/79	
O-110	33°14'59"	81°28'30"	49	NA	NA	1	34.15	251.88	217.73	11/29/79	
O-111	33°15'06"	81°28'49"	55	NA	NA	1	37.90	256.94	219.04	11/29/79	
O-112	33°15'03"	81°29'48"	31	NA	NA	1	16.50	250.12	233.62	11/29/79	

Table 3.--Description of wells in vicinity of the low-level radioactive-solid-waste burial site near Barnwell, S.C.--Continued

Well	Latitude	Longitude	Depth of well (feet)	Diameter of casing (inches)	Zone of perfora-tion (feet)*	Zone	Water level below land surface (feet)*	Elevation of measuring point (feet)#	Eleva-tion of water surface (feet)#	Date measured	Remarks
O-113	33°15'09"	81°29'38"	32	NA	NA	1	31.50	254.11	222.61	11/29/79	
O-114	33°15'23"	81°29'23"	31	NA	NA	1	12.85	248.58	235.73	11/29/79	
O-115	33°15'12"	81°28'42"	61	NA	NA	1	33.80	256.78	222.98	11/29/79	
O-116	33°15'23"	81°29'30"	45	NA	NA	1	23.60	250.16	226.56	11/29/79	
O-117	33°15'23"	81°29'04"	47	NA	NA	1	27.00	255.85	228.85	11/29/79	
O-118	33°15'25"	81°29'27"	29	NA	NA	1	26.00	255.46	229.46	11/29/79	
O-119	33°15'39"	81°29'15"	45	NA	NA	1	34.25	270.40	236.15	11/29/79	
O-120	33°15'49"	81°29'26"	57	NA	NA	1	31.40	269.35	237.95	11/29/79	

* Measurement below land surface datum.

Measurement above National Geodetic Vertical Datum (1929).

NA -- Data not available.

selected wells and burial trenches for determination of chemical constituents and radionuclide activity.

Geophysical logs were obtained from wells in the study area to aid in correlating geologic units and in delineating zones of permeable sand units. Detailed lithologic descriptions were made of sediment samples from selected wells.

Eight surface-water partial-record stations were established within the study area. Five of the partial-record stations were measured monthly and three were measured at 3-month intervals. Streamflow measurements were made periodically at streams in the area.

GEOLOGY

The study area is underlain by sediments of the Atlantic Coastal Plain. The sediments, which range in age from Late Cretaceous to Holocene, are relatively unconsolidated and are composed of stratified gravel, sand, silt, clay, and limestone. Thickness of the Coastal Plain sediments ranges from a few feet near the Fall Line to more than 4,000 feet along the Atlantic Coast (Siple, 1967). In the study area, the sediments strike in an average direction of N 60° E and dip southeast about 6 to 20 feet per mile. The unconsolidated sediments rest upon consolidated Triassic rocks (Siple, 1967).

Logs from well 0-1 (fig. 2) which was drilled at the Barnwell Nuclear Fuel Plant, 1-1/2 miles west of the burial site, indicate that the unconsolidated sediments are about 1,050 feet thick in the study area. Figure 6 depicts the electric resistivity, spontaneous or self potential, lithologic, and stratigraphic logs of this well.

Although the unconsolidated sediments are about 1,050 feet thick in the study area, only the upper 500 feet are significant to evaluate the hydrology of the burial site. Deeper deposits are briefly mentioned to familiarize the reader with the sequence of the sedimentary deposits in the area.

Triassic System

The Triassic sedimentary rocks occur in a graben which was formed by normal faults (Siple, 1967). The Triassic rocks are tightly-cemented red claystone, siltstone, fine-grained sandstone, breccia, and fanglomerate. Near the upper surface they have been weathered to less consolidated clay, silt, and sand (Marine, 1979).

Cretaceous System

Cretaceous sediments include the nonmarine Middendorf Formation and the marine Ellenton Formation. The Middendorf consists mainly of fluvial and estuarine deposits of coarse sand and gravel interbedded with diversely colored clay beds or lenses. In the study area it rests upon Triassic rocks and is overlain by sediments of the Ellenton Formation.

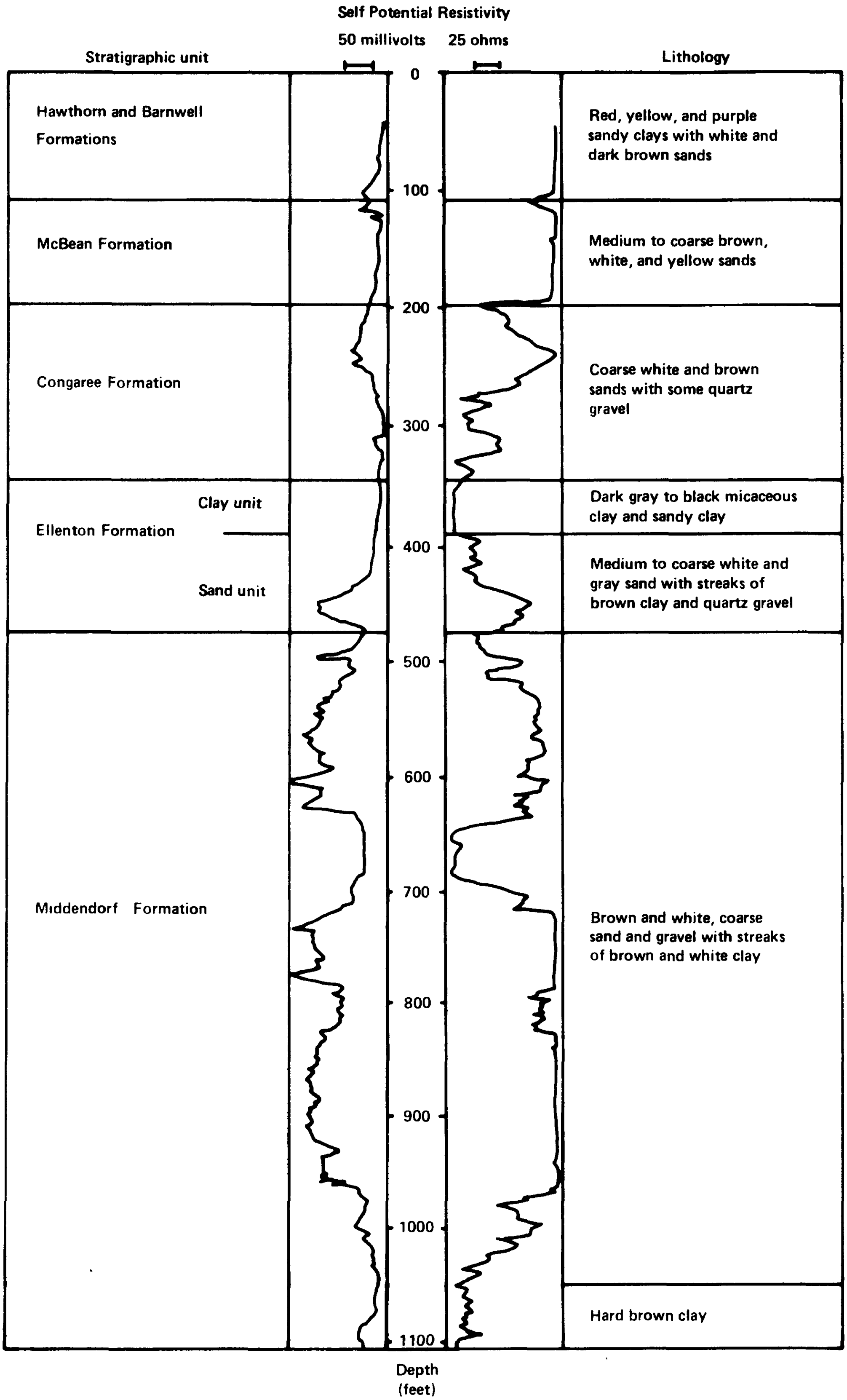


Figure 6.--Stratigraphic interpretation of electric and lithologic logs of well 0-1 at the Allied General Nuclear Services Plant near Barnwell, S.C.

The Middendorf Formation is characterized by highly micaceous and kaolinitic sediments. The predominant Ellenton sands are similar to the Middendorf sands except that they have an abundance of glauconite, lignite, pyrite, and selenite. Formational contact between the Middendorf and Ellenton sands can generally be detected by mineral examination of the sediments. The most characteristic feature of the Ellenton Formation is the dark gray to black lignitic, micaceous silt and clay, 40 to 50 feet thick, in the upper part of the formation. This lithologic unit is detected between 345 to 388 feet by the deflection to the left on the resistivity curve (fig. 6). It hydraulically separates the lower sediments from the Tertiary sediments above.

Figure 7 shows a generalized geologic section (A-A') of the upper 500 feet of sediments in a general north-south direction. The cross section extends from the northeastern corner of the burial site to well CE-9 which is just north of the nearby Marys Branch Spring (figs. 2 and 4). Formational contacts are based on well core samples, electric-resistivity logs, nuclear logs, stratigraphic correlations with nearby wells, and equal thickness data for individual formations (Siple, written commun., 1980).

Tertiary System

The Tertiary System is composed of all the marine sediments above the Ellenton Formation. These sediments consist of the Congaree, McBean, and Barnwell Formations of the Eocene Series and the Hawthorn Formation of the Miocene Series. Most of the permeable zones are sand and occur in the Congaree and McBean Formations. The Barnwell and Hawthorn Formations contain more clays.

The oldest Tertiary deposits in the study area are those of the Congaree Formation which overlie the Ellenton Formation. The formational contact of the Ellenton and Congaree Formation is recognized by the lithologic contrast between the dark clays of the Ellenton and the sandy gravel of the Congaree. This formational contact is also recognizable on electric logs (at 345 feet, fig. 6). The sands of the Congaree are coarser and are a distinct buff in contrast to the orange to yellow McBean sands. This color difference occurs at about the 190-foot depth at the burial site where purple clay lenses are also imbedded within a cemented sand stratum.

The McBean Formation contains white, tan, brown, and yellow clays interbedded with medium to coarse quartz sand. At well CE-4 (fig. 2), carbonate material, typical of the McBean sediments, is present at about 119 to 147 feet. Lenses or beds of silicified limestone occur in this formation east and southeast of the burial site.

The Barnwell Formation consists predominately of brown, maroon, and red clayey sand with a change to yellow sand near its contact with the McBean Formation. The Barnwell sediments generally occur below the water table and contain lenses of sand interbedded with the clays and silts.

The Barnwell and Hawthorn Formations have similar lithologic characteristics. Generally, the color pattern of the Hawthorn is light clayey sand to

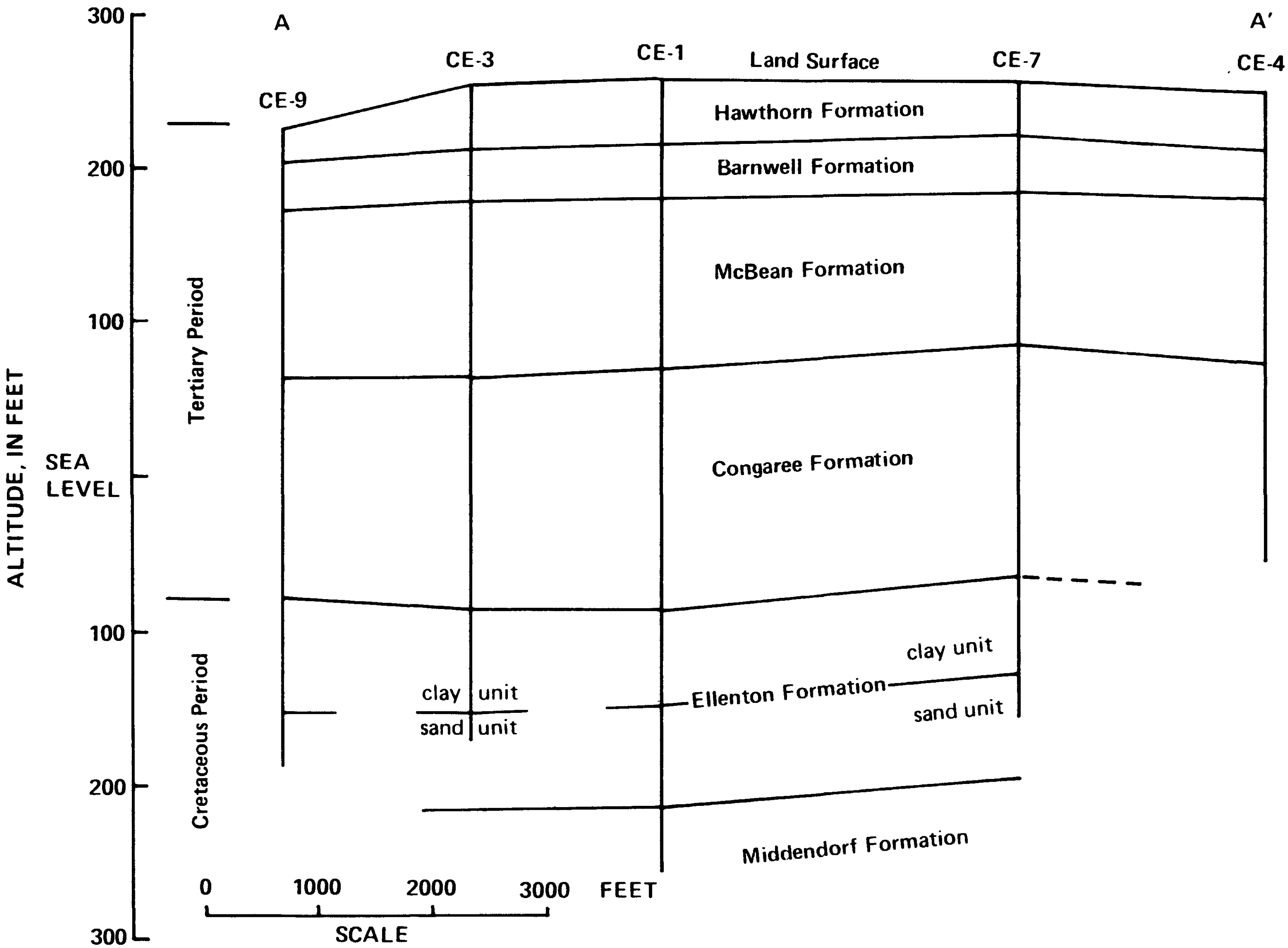


Figure 7.--Stratigraphy along section A-A′ (fig. 4) at the low-level radioactive-solid-waste burial site near Barnwell, S.C. (after Siple 1980).

dark red sandy clay at the base. The upper part of the Hawthorn Formation is generally a tan to reddish color with patches or flecks of kaolinitic material disseminated throughout the formation. The upper part of this formation also contains brown pebbles of ferruginous material. The ferruginous material also is present as thin lateral bands near the surface of the formation.

An unusual feature of the Hawthorn Formation is the numerous clay-filled fissures or clastic dikes that crisscross the clayey sand. The dikes occur in isolated areas between surface depressions, and are particularly conspicuous in exposures in the north-south oriented trenches (fig. 4). The dikes, which may be several inches wide, occur at an altitude of about 235 feet at the burial site. Dikes are not evident in trenches which were excavated at lower altitudes indicating that most of the dikes occur in the upper part of the Hawthorn Formation. Most dikes dip steeply and intersect each other. Evidence of faulting is indicated by offset of some dikes with displacement of a few inches (fig. 8).

The white kaolinitic clays of which the dikes are composed may represent in place modification of the original minerals present. Their source may also have been clayey plastic material that moved up to relieve compressional stress below (Siple, 1967). This is not likely, however, because the deeper sediments are mostly sand, and dikes are found only near the surface. It is more likely that the clays were transported from the land surface and deposited in the fissures. When dry the clays show signs of layering, indicating that filling occurred in phases.

An iron precipitate is found along the contact between the dikes and the surrounding sediments.

Of the several theories on the origin of the fissures, the most likely is that the fissures developed during subsidence of the peculiar topographic depressions known as "Carolina bays." The dikes at the burial site are between two such bays. The Carolina bays will be discussed under the heading of lakes in the study area.

Quaternary System

The Quaternary System in the vicinity of the burial site is represented by beds of wind blown sands which overlie the Hawthorn Formation. The thickness of these beds may range from a few inches to as much as several feet.

HYDROLOGY

Mean annual precipitation (1951-80) is 46.62 inches, about 60 to 70 percent of which is returned to the atmosphere by evapotranspiration. The remaining 30 to 40 percent, or about 14 to 19 inches, percolates through the forest litter and into the porous sands, recharging the aquifer system. Overland flow is rare, occurring only during intense rainfall where forest litter has been removed, as in cultivated fields and along roadways.

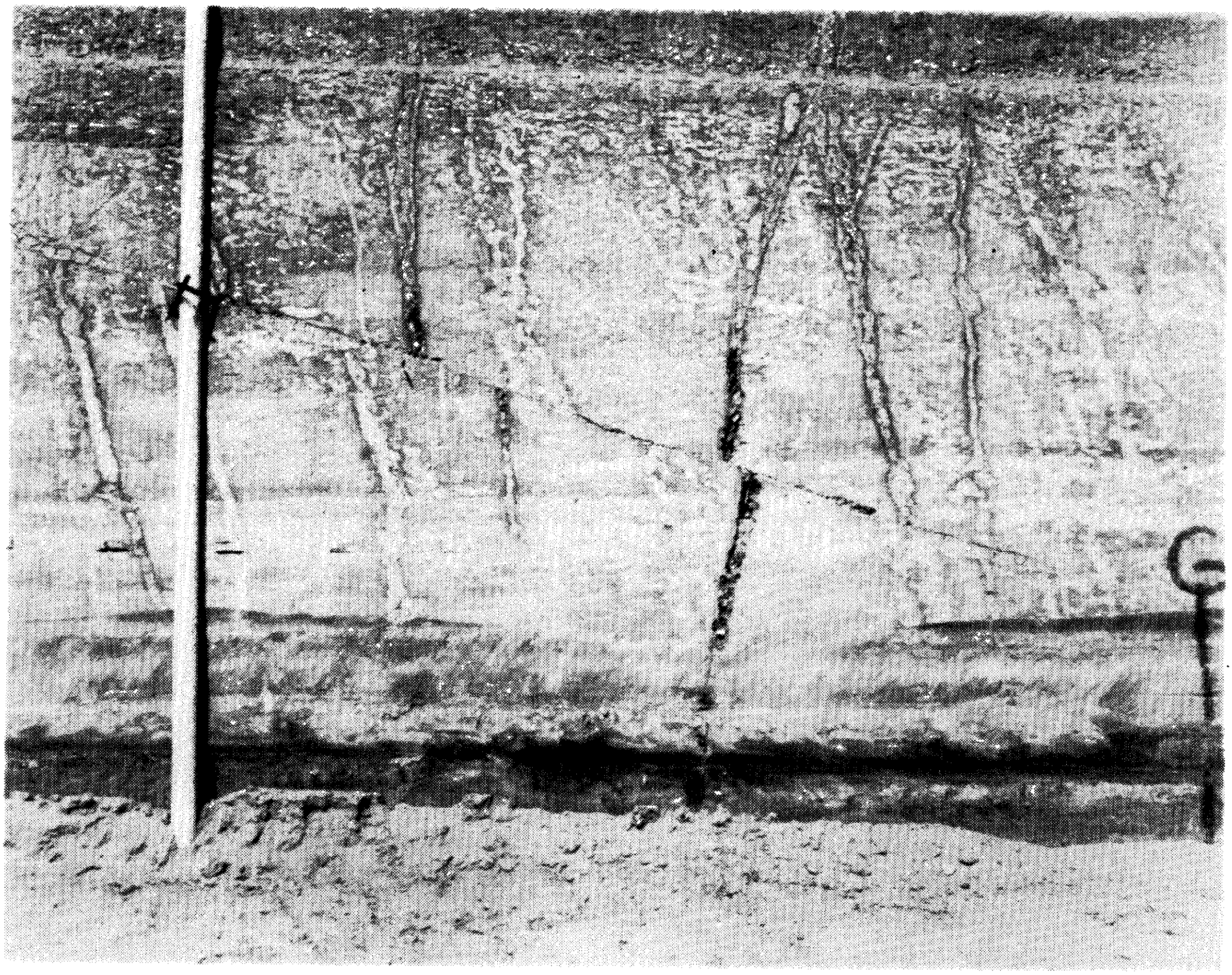


Figure 8.--Offset of "clastic dikes" in west wall of trench 23 at the burial site near Barnwell, S.C. Three-inch-diameter vertical pipe indicates scale.

Streams and Lakes

Streams are fed by ground-water discharge which, on a long-term basis, is equal to recharge of the ground-water system. Many of the creeks originate as springs where confining beds of clayey sand have been eroded. Creeks that flow to the east discharge to the Salkehatchie River, and those that flow to the south or west discharge to Lower Three Runs (fig. 2). The Salkehatchie River flows to the southeast and becomes the Combahee River near the Atlantic Ocean. Lower Three Runs flows to the south and discharges to the Savannah River.

Overland flow and most precipitation that enters the ground-water system at the burial site enters Marys Branch Creek which originates as a spring about 3,000 feet south of the burial site. This creek flows to the southwest and into Lower Three Runs about 2.5 miles downstream. Flow at the spring is about 0.4 ft^3/s and increases 1 mile downstream to about 4.7 ft^3/s.

Comparison of rainfall and streamflow (fig. 9) shows that although the highest rainfall occurs during the summer months, the highest streamflow occurs during the winter months. The discrepancy is due to increased evapotranspiration during the growing season.

Lower Three Runs is controlled by an overflow structure at Par Pond. Par Pond is the largest man-made lake in the area. The water level of this lake is generally kept at an altitude of 200 feet. Most of the runoff from the northwestern section of the study area enters this lake. Figure 10 shows daily rainfall and mean daily discharge for the gaging station near Snelling.

The numerous natural lakes in the area are poorly drained surface depressions known locally as Carolina bays. Some of the Carolina bays are directly connected to the underlying saturated zone. When water levels in the bays are high, the bays recharge the saturated zone and when water levels in the lakes are low, they receive water from the saturated zone. Most of these natural lakes are shallow swamps and marshes. The amount of water lost to evapotranspiration in these swamps and marshes is high.

Figure 11 is an aerial photo of the burial site and vicinity taken during February 1974. Several Carolina bays are outlined with dashed lines. Most of these bays contain water but some are well drained. Some bays seem to be increasing in size, in contrast to most freshwater lakes and ponds which tend to become smaller as a result of sedimentation and encroaching shorelines (Reid and Wood, 1976, p. 47).

The common feature of the bays is that they are elliptical basins with the long axis oriented roughly northwest-southeast. The orientation of the major and minor axes has been proposed by Kaczorowski (1977) as being caused by wind activity and wave action. Other theories that explain the origin of these bays are: meteor impact (Melton and Schriever, 1933), meteoric shock waves (Prouty, 1952), ocean currents (Cooke, 1954), and solution of the underlying surface by water (LeGrand, 1953; Siple, 1967).

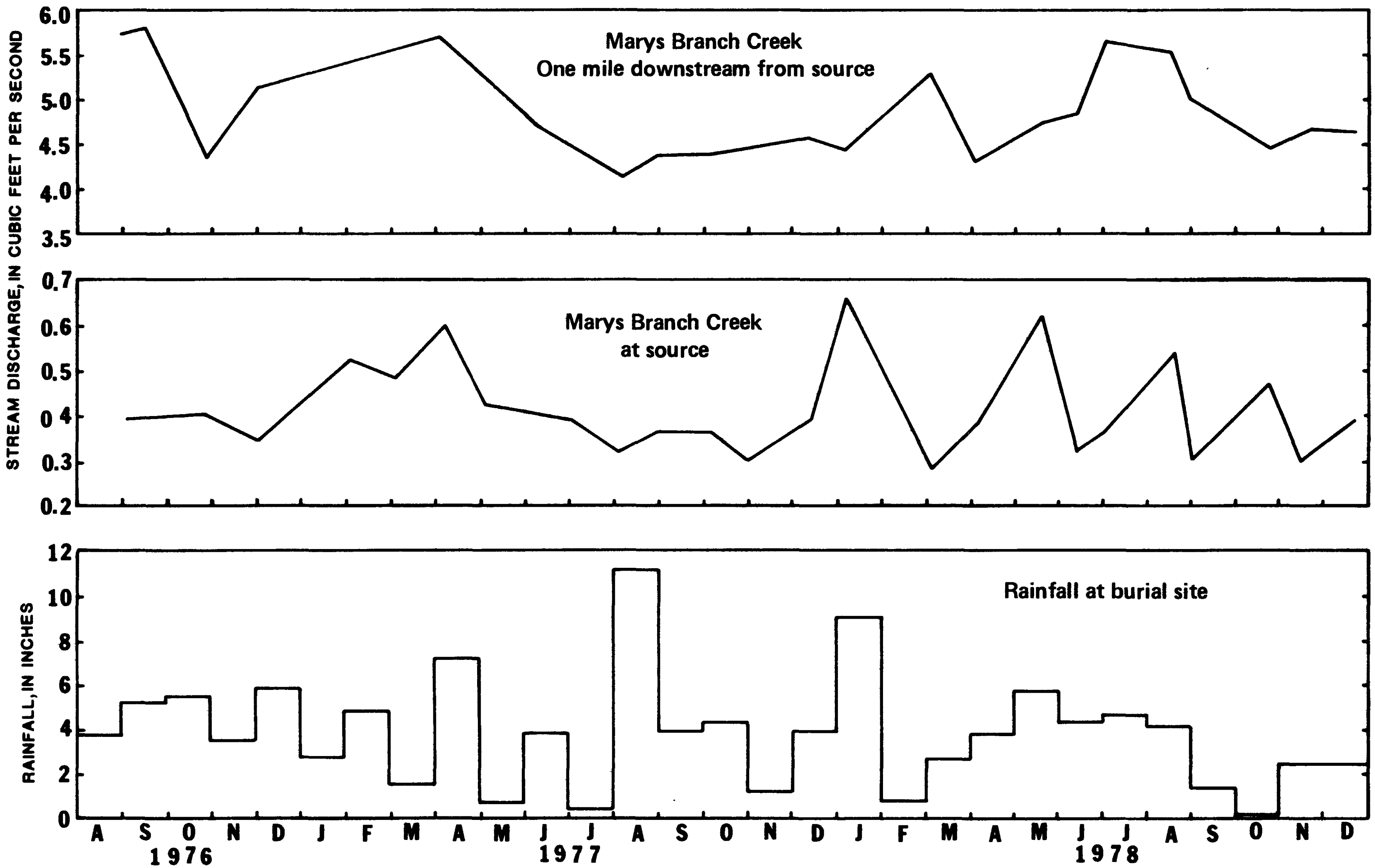


Figure 9.--Monthly rainfall in the vicinity of the low-level radioactive-waste burial site and stream discharge of Marys Branch Creek at its source and 1 mile downstream, from August 1976 to December 1978.

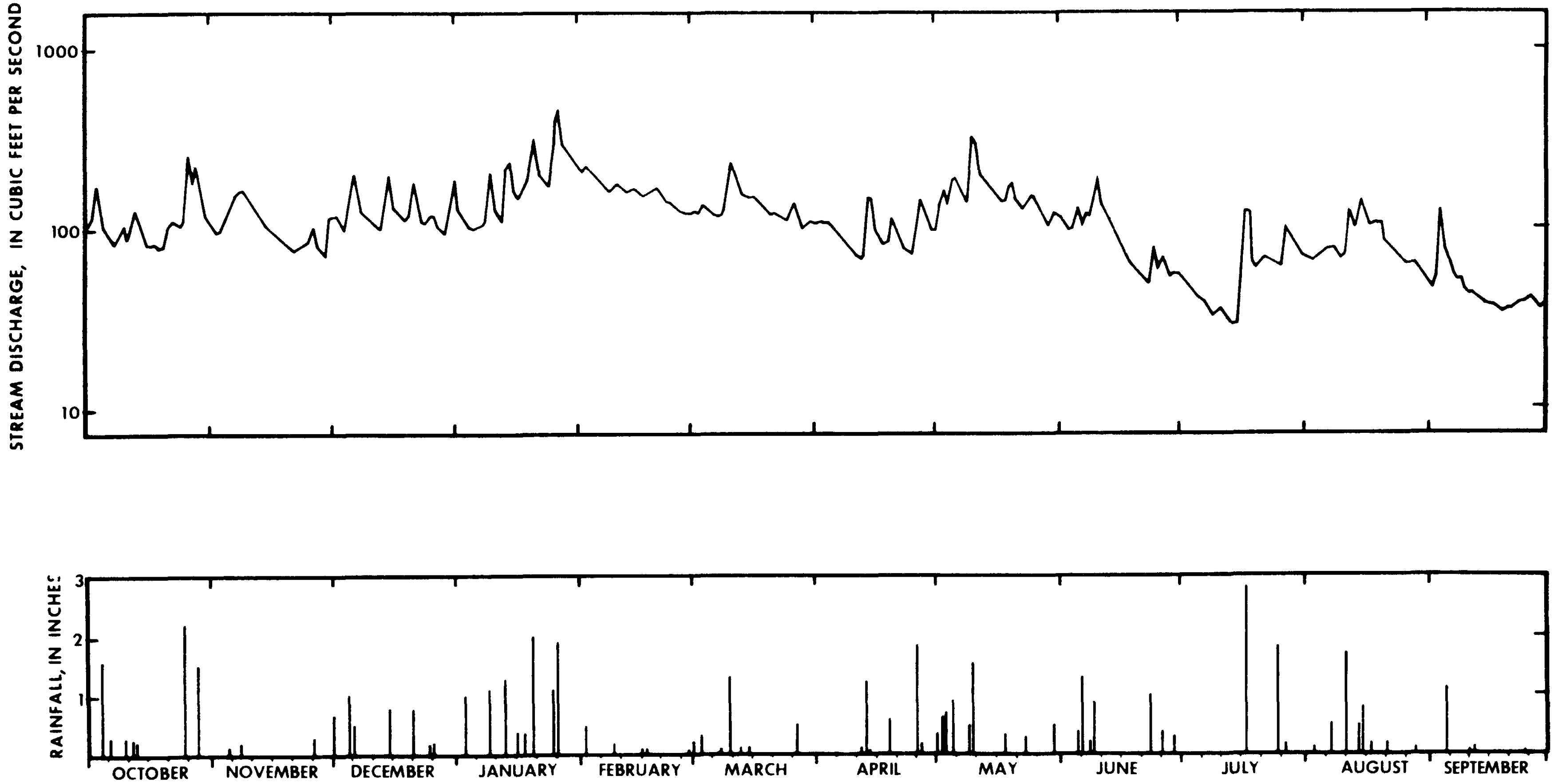


Figure 10.--Stream discharge of Lower Three Runs near Snelling, S.C., for water year 1978.

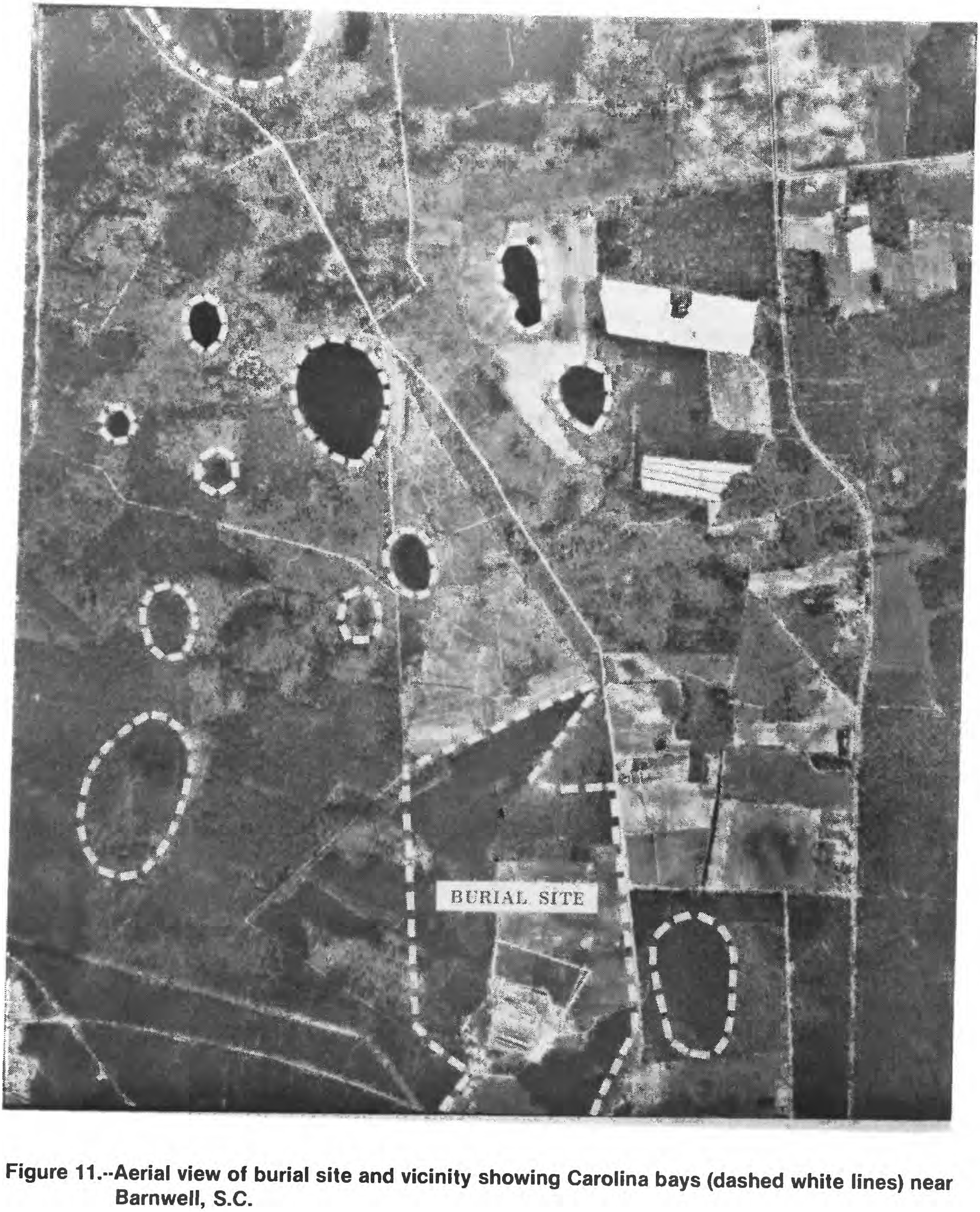


Figure 11.--Aerial view of burial site and vicinity showing Carolina bays (dashed white lines) near Barnwell, S.C.

Because Carolina bays are numerous in the South Carolina Coastal Plain, their origin could have some significance in future burial site selection. If solution of underlying calcareous sediments is responsible for the origin of the bays, they may serve as avenues for downward movement of water. Siple (1967), in discussing test borings drilled along the major and minor axes of a Carolina bay at the Savannah River Plant, mentions a collapsed structure in the center of the bay which could have been caused by solution of calcareous material. The calcareous zone beneath the rim of the bay was more cavernous than at the center. However, a test well drilled to a depth of 75 feet in the center of a bay at the western edge of the burial site showed no calcareous material. The material was typical of clayey sediments of the Hawthorn or upper Barnwell Formations.

Sediments adjacent to a Carolina bay in the study area were investigated by drilling wells in a line extending north and in a line extending south of the bay. Well CB-3 was drilled about 50 feet from the northern shoreline, and well CB-4 was drilled about 1,000 feet farther north (fig. 2). Yellow fine to coarse sand was present in well CB-3 at 30 feet and in CB-4 at 50 feet. Sediments above the sand bed were unsaturated clayey material.

Wells CB-1 and CB-2 were drilled at the southern end of the bay. Well CB-1 was drilled about 50 feet from the southern shoreline and well CB-2 about 1,000 feet farther south. These wells are located down gradient from the bay. Sand was predominant from the surface down in both of these wells. The sharp interface between sand and clay at the bay gives strong evidence of settling. Formation of the basin, therefore, was probably caused by solution of the underlying sediments and subsequent settling, which in turn caused the fissures in the area. The prevailing wind direction is from the southwest and is perpendicular to the long axis of the bay, indicating, therefore, that wind action is probably not responsible for elongation.

Unsaturated Zone

The unsaturated zone is that part of the sediment column in which the void spaces between sediment particles are not completely occupied by water. This zone extends from land surface to just above the water table where most of the capillary fringe is saturated. The unsaturated zone is comprised of the eolian sands and part of the Hawthorn Formation.

Thickness of the unsaturated zone varies from about 45 feet near the southern end to about 28 feet at the eastern and western edges of the burial site. In the vicinity of the trenches, thickness of the unsaturated zone varies from 33 feet at trench 11 to about 45 feet at trench 2. Buried wastes are 8 to 26 feet above the water table.

Precipitation that is not lost to evapotranspiration or overland runoff percolates downward through the unsaturated zone at a rate that is controlled primarily by the hydraulic conductivity and percent saturation of the unsaturated sediments.

The sediments in the unsaturated zone are generally fine-grained sands mixed with minor amounts of clay and silt. Excavation of trenches has exposed isolated patches of coarse sand that seldom exceed 600 square feet in area.

Porosity is relatively high, 30 to 40 percent for the Hawthorn and upper sediments of the Barnwell. Hydraulic conductivity in the unsaturated zone, however, is generally low, because the silts and clays fill the voids within the fine-grained sands. Figure 12 shows the particle size distribution of a sample of the upper clayey sands. The unsaturated hydraulic conductivity increases with increasing percent saturation. For example, the saturated hydraulic conductivity of a sediment core from the bottom of trench 23, measured in the laboratory, was $5x10^{-3}$ ft/d at 100 percent saturation, but was computed to be $2.7x10^{-6}$ ft/d at 75 percent saturation using the technique described by Brooks and Corey (1964) (fig. 13). This sediment core is a typical example of the clayey sand at the burial site.

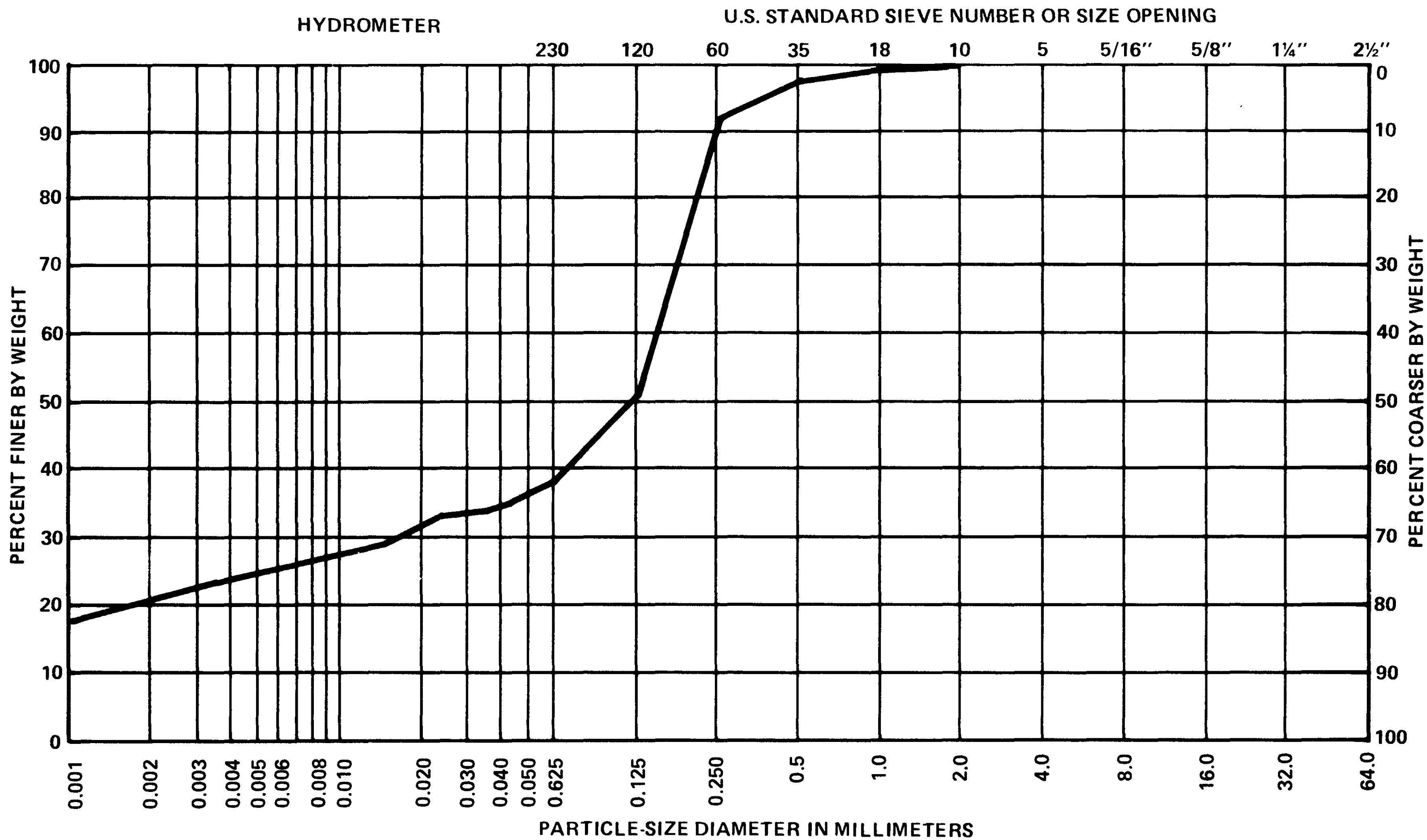
Laboratory measurements on sediment cores indicate that after drainage by gravity, the sediments remain about 50 percent saturated. This level of saturation corresponds to a hydraulic conductivity of less than 10^{-7} ft/d (fig. 13). Therefore, virtually all of the movement of water through the unsaturated zone occurs when the sediments are nearly saturated.

Another factor affecting downward movement of water through the unsaturated zone is the clastic dikes mentioned previously. Precipitation of iron along contacts of the dikes indicates that the contacts were at one time avenues of water movement. Because the iron precipitate has filled the pores at the contacts of the dikes and the sediment walls, and the clays have low hydraulic conductivity, it is likely that these dikes now impede the vertical movement of water.

Shallow depressions, such as Carolina bays, occur in the discontinuous clayey Hawthorn sediments at the burial site. Water is ponded in these depressions after rains to form surface-water bodies. At some locations the depressions are covered with surface sands and percolated water collects in the depressions to form perched water bodies. Figure 14 shows contours of the contact between the aeolian sands and the clayey sediments at the top of the Hawthorn and depicts two depressions in a small area at the southeast part of the burial site. The pond at the lower right (fig. 14) is a depression where the clayey sediments are exposed and water is ponded after rain falls in the area. The other depression is centered around the 244-foot contour and is covered by about 14 feet of surface sand.

A perennial perched water body occurs in the depression around the 244-foot contour (fig. 14). The saturated thickness of this perched water body is generally about 9 feet at a water-level altitude of about 252 feet. Water moving from the perched water body through the unsaturated zone provides a continuous source of recharge to the saturated zone.

The water table of the perched water body depends on the amount and frequency of rain in the area and surface soil moisture requirements. Figure 15 compares the perched water-table fluctuations with rainfall. The water level



	CLAY SIZES	SILT SIZES	SAND SIZES					GRAVEL SIZES				
	< 0.004 mm	0.004 - 0.0625 mm	V. fine .0625-.125	Fine .125-.25	Medium .25-.5	Coarse .5-1	V. coarse 1-2	V. fine 2-4	Fine 4-8	Medium 8-16	Coarse 16-32	V. coarse 32-64
PERCENT OF SIZE	23.6	14.0	13.0	41.5	5.9	1.7	0.3	0	0	0	0	0

Figure 12.--Particle-size distribution of well borings obtained at a depth of 47 feet in well CE-1 near Barnwell, S.C.

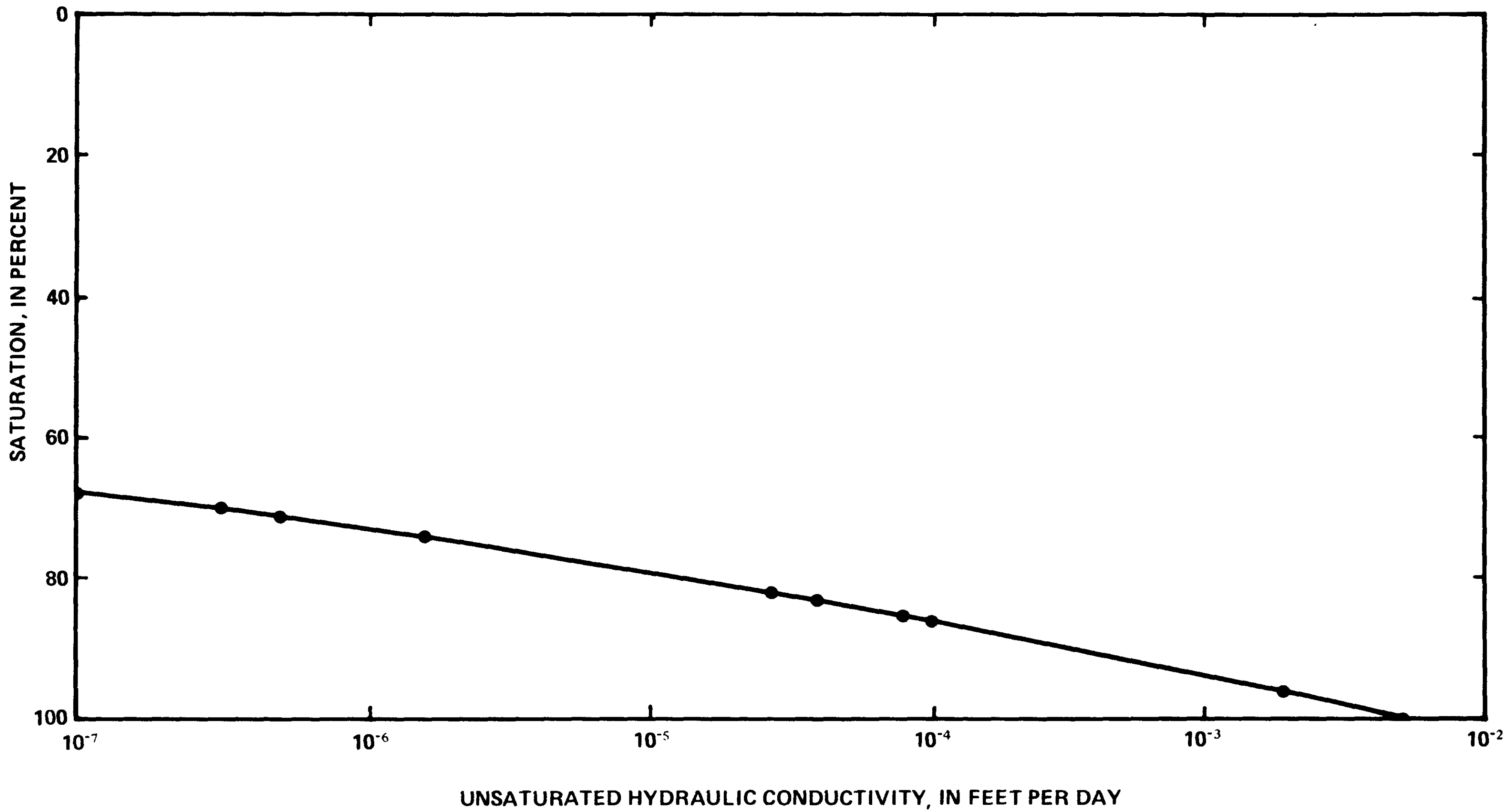


Figure 13.--Computed unsaturated hydraulic conductivity versus percent saturation of a sediment core obtained from the floor of trench 23 at the low-level radioactive-solid-waste burial site near Barnwell, S.C.

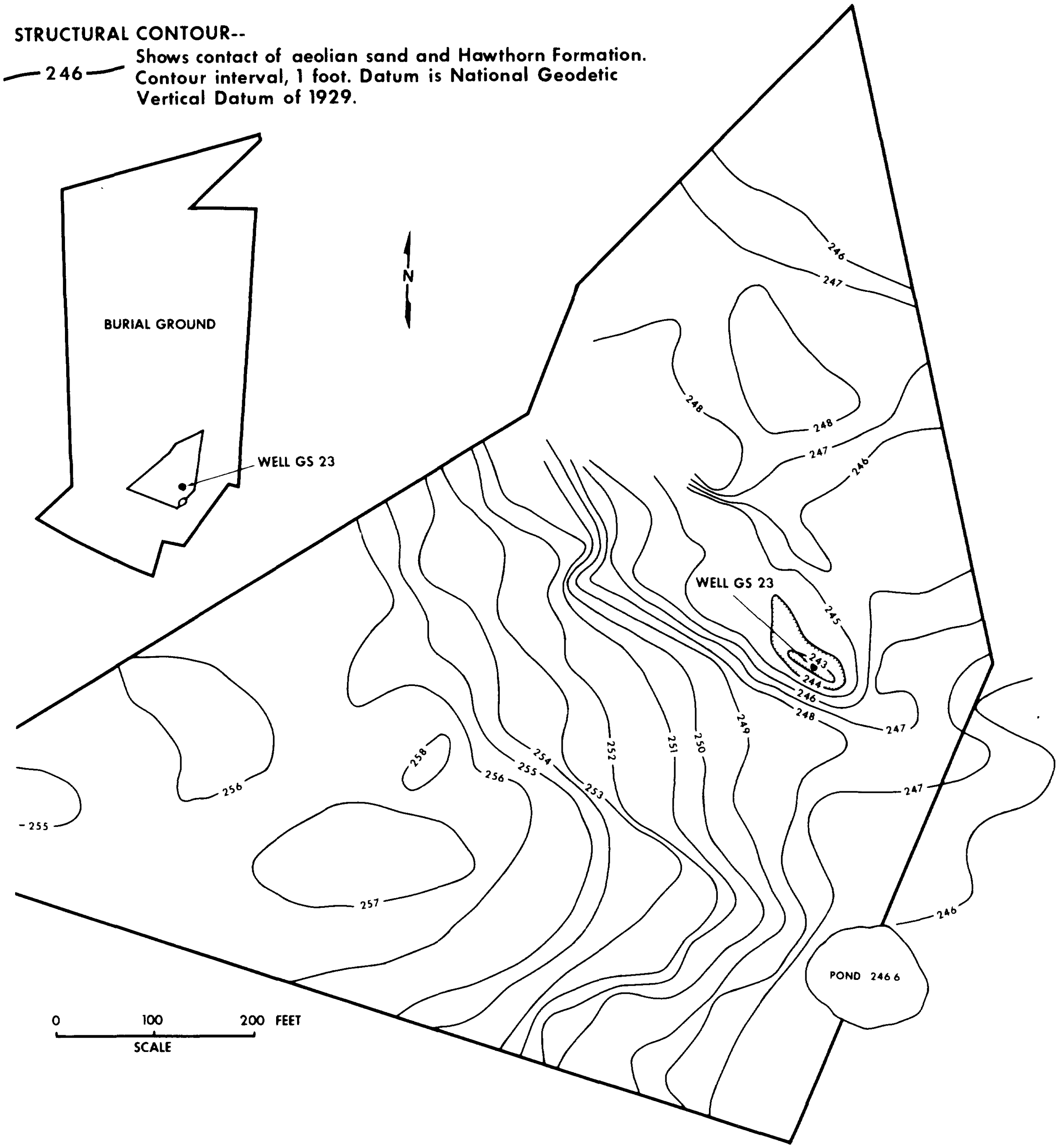


Figure 14.--Top of the Hawthorn Formation at the southern area of the burial site near Barnwell, S.C.

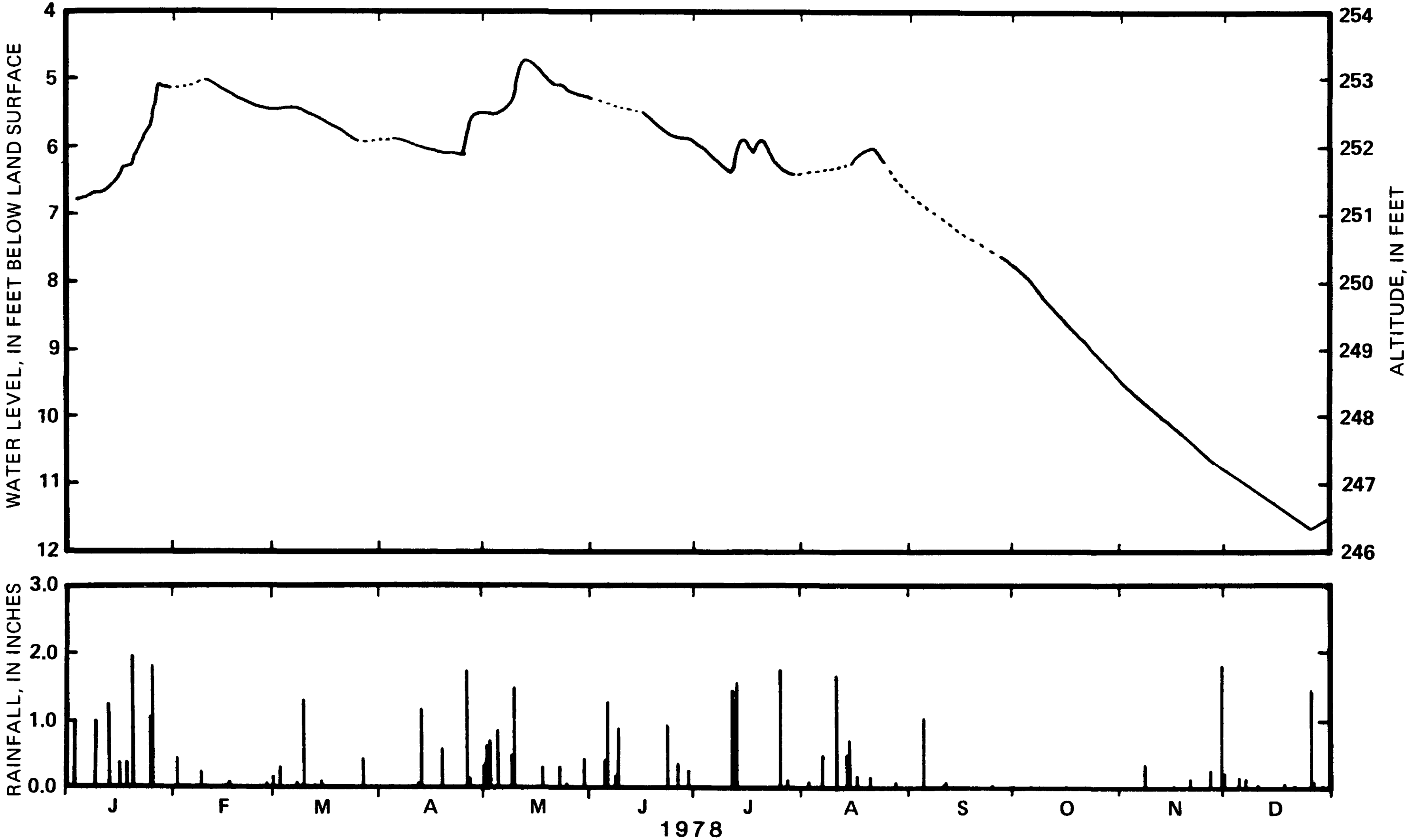


Figure 15.--Comparison of rainfall to water level in well GS-23 at the perched water body in the southeastern area of the low-level radioactive-waste burial site near Barnwell, S.C.

continued to decline after a 2-inch rain in November following a relatively dry September through early November as the rain was utilized to satisfy the deficiency in soil moisture. In the last week of December, a 1.4-inch rain caused water levels to rise 0.3 foot in the perched water table.

Moisture deficiency in the unsaturated sediments influences the amount of recharge to the saturated zone. On September 5, 1979, during hurricane David, about 5 inches of rain fell in the study area with little overland runoff occurring. Hurricane David followed a period of little rainfall and a 3-week period of warm temperatures and strong winds. Water levels in the regional saturated zone did not rise more than 0.2 foot after this storm, indicating that sediments in the unsaturated zone intercepted most of the water that was not lost to evapotranspiration.

Aquifers

An aquifer is a formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs (Lohman and others, 1972, p. 2).

The direction of water movement in the saturated zone is from points of recharge toward points of discharge. The quantity and rate of water movement through the sediment is dependent on the transmissivity.

Transmissivity of the aquifer is defined as the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient (change in head per unit of distance in a given direction). Transmissivity is expressed in feet squared per day in this report. The transmissivity is equal to the hydraulic conductivity of the aquifer material times the saturated thickness of the aquifer.

Estimates of transmissivity of the water-bearing sediments are based on aquifer tests and on laboratory determinations of hydraulic conductivity of sediment cores.

Hydraulic conductivities of cores taken at different depths and locations in the vicinity of the burial site are shown in table 4. Horizontal hydraulic conductivities range from 10^{-7} to 10^{-1} ft/d for confining or semi-confining beds to nearly 22 ft/d for sands. The vertical hydraulic conductivity in the upper 150 feet of sediments averages about 0.003 ft/d for the semi-confining beds and about 3 ft/d for the sands.

The ability of an aquifer to function as a reservoir is expressed as its storage coefficient. The storage coefficient is the volume of water an aquifer releases or takes into storage per unit surface area of the aquifer, per unit change in head (Lohman and others, 1972). The storage coefficient is dimensionless.

Four major water-bearing zones were delineated based on water level and hydraulic characteristics of the sediments (figs. 16 and 17). Figure 16 shows the potentiometric surfaces of the four zones on a cross section from the

Table 4.--Laboratory hydraulic and lithologic determinations from undisturbed sediment cores at the radioactive-waste burial site near Barnwell, S.C.

Well no.	Aquifer zone	Sample depth (feet)	Horizontal hydraulic conductivity (feet/day)	Vertical hydraulic conductivity (feet/day)	Porosity (percent)	Lithologic description
CE-1	1	47	3.3×10^{-3}	2.1×10^{-3}	--	Purple clay, coarse grain sand with bedded white and red-brown zones.
	1	47.5	3.1×10^{-3}	6.6×10^{-4}	39-43	Purple sandy clay.
	1	51	6.9×10^{-3}	4.9×10^{-5}	44-45	Brown sand, grayish red silty sandy with iron stain and aquiswirls throughout and large, subrounded quartz crystals.
	1	56.5	5.6×10^{-5}	5.6×10^{-5}	42-43	Very coarse (pebbly) quartz crystals within interbed white and brown sand and purple clay.
	1	57	5.6×10^{-4}	--	--	Cleaner, gray-white sand with some coarse grains, but not as pebbly.
	1	61	3.6×10^{-3}	--	--	Gray clay with some medium coarse grain quartz crystals uniform, medium grain, 2 73 3.9×10^{-1} 2.3×10^{-4} 36 unconsolidated brown-yellow, sand, slightly lighter and coarser grain sand.
	2	92	1.2×10^{1}	--	40	Medium grain, loose, subrounded, pink sandy, very wet.
	2	136	5.6×10^{0}	--	20	Little darker, more consolidated, less wet, clayey sand.
	2	139.5	3.2×10^{-2}	--		Fine grain, brown clayey sand with brown clay globs and 2" of sandstone.
	2	141		2.8×10^{-7}	--	Brown clay.
	2	152	5.2×10^{-1}	1.9×10^{-1}	--	Uniform, medium grain, subrounded, wet, brown-yellow sand.
	2	172.5	5.9×10^{-4}	7.9×10^{-6}	44	Dark sandy clay with bleached aquiswirls.
	3	175.5	3.9×10^{-1}	--	--	Medium grain subrounded, tan sand, fine grain, wet, tan sand.
	3	184.5	2.5×10^{0}	5.9×10^{0}	--	Fine-medium grain, subangular-subrounded, wet, loose, tan sand 183' purple clay within same.

Table 4.--Laboratory hydraulic and lithologic determinations from undisturbed sediment cores at the radioactive-waste burial site near Barnwell, S.C.--Continued

Well no.	Aquifer zone	Sample depth (feet)	Horizontal hydraulic conductivity (feet/day)	Vertical hydraulic conductivity (feet/day)	Porosity (percent)	Lithologic description
CE-1 cont.	3	199	--	2.6×10^{-4}	--	Very wet fine-medium grain tan sand with zones of brown and purple clay (2-3") and 3 213 8.9×10^{-1} -- 20 clayey sand (3-4"); also containing black organic matter (lignite).
	3	229	--	2.3×10^{0}	41	(Tan) sand with black organics, brown clayey sand.
	3	295	5.9×10^{-1}	1.3×10^{0}	38-42	Fine-medium grain, subrounded, green-tan sand, little coarser and greener as go down.
	3	298.5	--	2.2×10^{1}	41	
	3	312.5	2.6×10^{-2}	--	--	Brown-yellow coarse sand interbedded with brown clay.
	3	336	--	5.2×10^{-3}	--	Medium grain, wet, loose, subround, brown-yellow sand; with clear crystals.
	3	339.5	8.2×10^{-1}	--	41	
	3	340	1.9×10^{-1}	--	37	Dark brown clayey sand (343'), dark green compact clay; lighter (gray-green) as go down, waxy and very hard.
	3	344	--	2.5×10^{-5}	--	
	4	433	--	6.2×10^{0}	--	Pebbly dark green-black clay interbed with fine-medium grain light gray, clayey sand (N7.5) with some pebbles, sand zones becoming lighter as go down, wet and micaceous.
	4	437.5	--	7.2×10^{-1}	34	
	4	443	2.0×10^{-3}	2.3×10^{-3}	--	
	4	471	--	5.9×10^{-1}	34	Fine-medium grain, subround, very wet, white sand darker and coarser as go down.
	4	490.5	--	5.2×10^{-1}	--	Fine-medium grain, wet, micaceous light gray sand, medium grain same.
	4	500	--	7.9×10^{-2}	--	
	4	517.5	1.8×10^{-1}	--	--	Fine-medium light gray mica clayey sand.
CE-3	1	47.5	2.5×10^{-3}	--	--	Interbedded purple and sandy clay with aquiswirls containing white clay and iron stain.
	1	48	1.9×10^{0}	--	40	
	1	69	3.3×10^{-1}	--	--	Brown clayey sand interbedded with purple clay.

Table 4.--Laboratory hydraulic and lithologic determinations from undisturbed sediment cores at the radioactive-waste burial site near Barnwell, S.C.--Continued

Well no.	Aquifer zone	Sample depth (feet)	Horizontal hydraulic conductivity (feet/day)	Vertical hydraulic conductivity (feet/day)	Porosity (percent)	Lithologic description
CE-3	2	79	$2.2x10^0$	$2.5x10^0$	--	Very wet fine-medium brown-yellow sand.
cont.	2	93	--	$1.2x10^0$	--	Dark pink, wet fine-medium sand.
	2	101	--	$3.3x10^{-3}$	--	4-5" reddish clay, pink tan wet sand.
	2	102	$3.6x10^0$	--	41	
	2	139	$5.6x10^{-1}$	--	35	Brown-yellow fine-medium sand with white streaks and clayey layers.
	2	149	$8.2x10^{-1}$	$1.5x10^0$	43	
	3	172	$2.0x10^{-1}$	$8.9x10^{-2}$	42-43	Yellow-green clayey sand, dark green sandy clay.
	3	178	$1.6x10^0$	$2.5x10^0$	36-39	Fine-medium wet brown sand.
	3	183	$1.7x10^0$	$1.8x10^0$	43	Tan sand interbedded with clayey sand.
	3	189	$3.6x10^0$	$2.6x10^0$	43-44	Light brown sand with lignite.
	3	281	$1.2x10^1$	$1.6x10^0$	41-44	Tan sand.
	3	338	$1.5x10^{-3}$	$7.9x10^{-3}$	42-43	Gray clay with pebbles and brown sandy clay zones.
	4	420	--	$2.9x10^0$	--	Gark clay and clayey sand, slightly pebbly.
	4	423	$9.5x10^0$	$7.9x10^0$	43-45	--
CE-4	1	28	$1.7x10^{-1}$	$2.7x10^{-1}$	--	Fine-medium grain tan-red sand.
	1	38	$7.9x10^0$	$3.9x10^0$	--	
	1	48	$1.5x10^{-1}$	--	--	
	1	68	$3.9x10^0$	$4.6x10^0$	--	Fine-medium yellow sand.
	2	98	$1.4x10^{-1}$	$2.0x10^{-2}$	--	Light brown sandy clay in brown clay with lignite.
	2	109	--	$3.6x10^{-1}$	--	
	2	118	$7.2x10^{-2}$	$2.0x10^{-1}$	--	White sandy clay with brown sandy clay lenses.
CE-5	1	21	$1.8x10^{-4}$	$2.9x10^{-4}$	--	Light gray solid clay.
	1	50	$1.8x10^0$	$1.3x10^0$	44	Wet tan fine-medium sand.
	2	88	$1.5x10^{-1}$	$5.9x10^{-1}$	36	Fine-medium yellow sand with thin brown clayey sand.
	3	183	$4.6x10^{-1}$	$6.2x10^{-2}$	--	Layered white and brown fine sand with limestone clumps.
	3	192	$2.8x10^0$	$2.6x10^0$	43	Layered fine sand, white-brown-yellow.
CE-6	1	32	$3.3x10^0$	$3.3x10^0$	42	White fine sand some clay; cross bedding.
	1	57	$2.0x10^0$	$2.2x10^0$	42-43	Fine-medium tan sand.
	1	61	--	$2.6x10^{-1}$	--	

Table 4.--Laboratory hydraulic and lithologic determinations from undisturbed sediment cores at the radioactive-waste burial site near Barnwell, S.C.--Continued

Well no.	Aquifer zone	Sample depth (feet)	Horizontal hydraulic conductivity (feet/day)	Vertical hydraulic conductivity (feet/day)	Porosity (percent)	Lithologic description
CE-6	1	71	1.1×10^{0}	2.1×10^{0}	44	Fine-medium tan and yellow sand.
cont.	2	97	6.2×10^{0}	1.4×10^{1}	43	Fine-medium yellow sand.
	2	117	3.0×10^{0}	3.2×10^{0}	--	Fine-medium brown sand and white and brown clayey sand interbedded with white clay, some lignite.
	2	122	3.0×10^{-1}	1.6×10^{-2}	--	Fine sand yellow interbedded with tan clay and lignite.
	2	152	3.0×10^{0}	3.2×10^{0}	--	Fine red sand interbedded with pink and green sand and lignite, and pink and red clay.
CE-7	1	53	1.6×10^{-4}	5.6×10^{-5}	34	Purple and white clay with red fine sand.
	2	97	3.3×10^{0}	1.5×10^{1}	--	Fine yellow sand.
	2	117	9.5×10^{0}	7.5×10^{0}	42-45	
	2	132	1.7×10^{0}	8.5×10^{0}	40	
CE-8	1	34	2.0×10^{0}	1.6×10^{0}	40	Coarse sand in brown and white clayey sand and white clay matrix.
	1	48	2.6×10^{-1}	2.5×10^{-1}	43	Fine-medium brown-yellow sand interbedded with fine white clayey sand with lignite.
	1	51	3.9×10^{-1}	6.2×10^{-2}	--	Compact fine brown-yellow sand, clayey sand lenses.
	2	91	1.0×10^{0}	1.7×10^{0}	42-43	Medium tan and yellow sand.
	2	115	5.2×10^{-1}	1.2×10^{-1}	--	Fine yellow-clayey sand, brown sandy clay and clay.
	2	117	7.2×10^{-1}	8.9×10^{-1}	--	Layered fine yellow and brown sand with white and brown sandy clay, clay and lignite.
	2	136	8.5×10^{-1}	4.6x10-1	--	Fine brown sand interbedded with brown-white sandy clay (marbled).

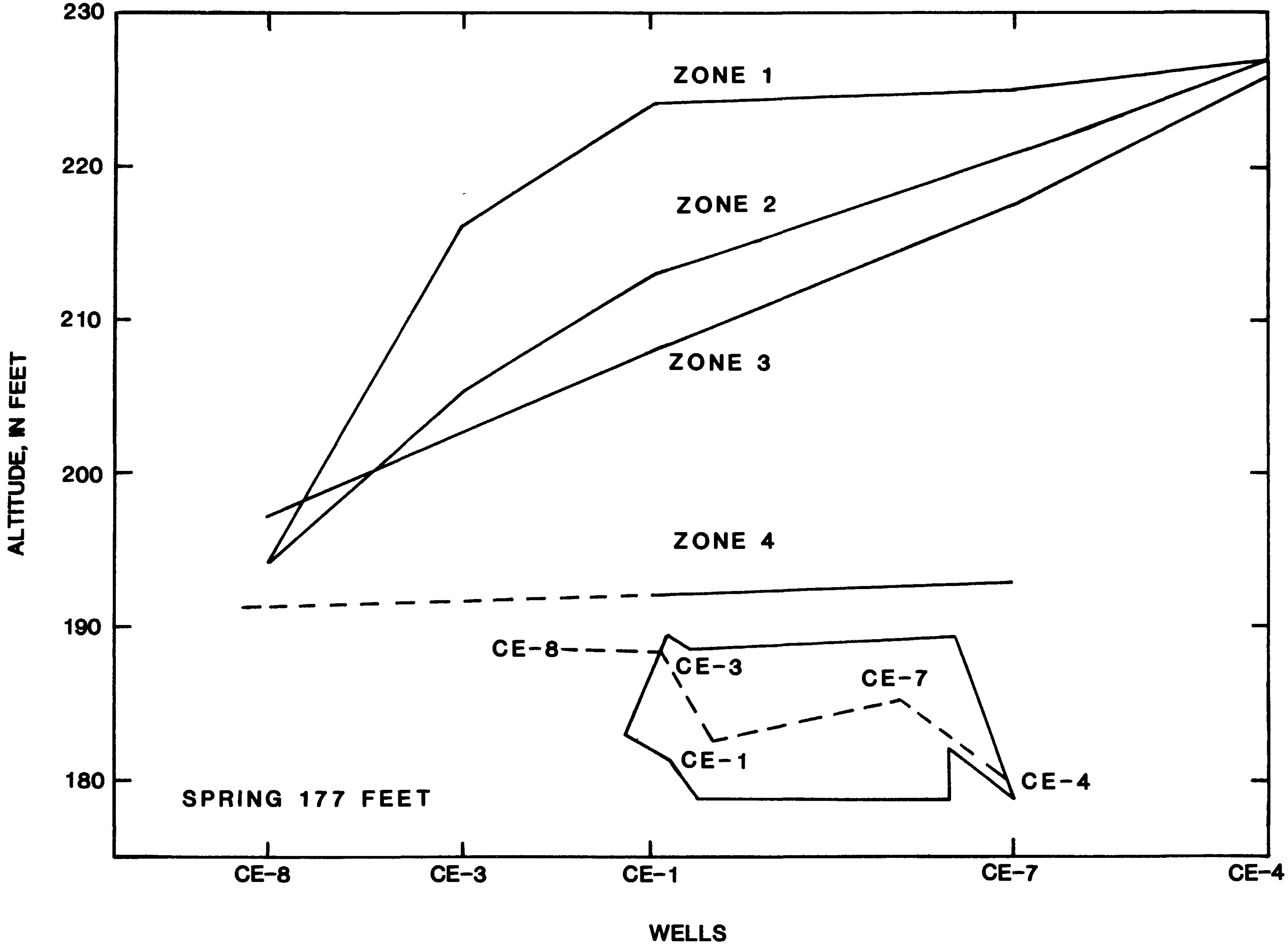


Figure 16.-Potentiometric surface of four water-bearing zones during August 1977 at the low-level radioactive-solid-waste burial site near Barnwell, S.C.

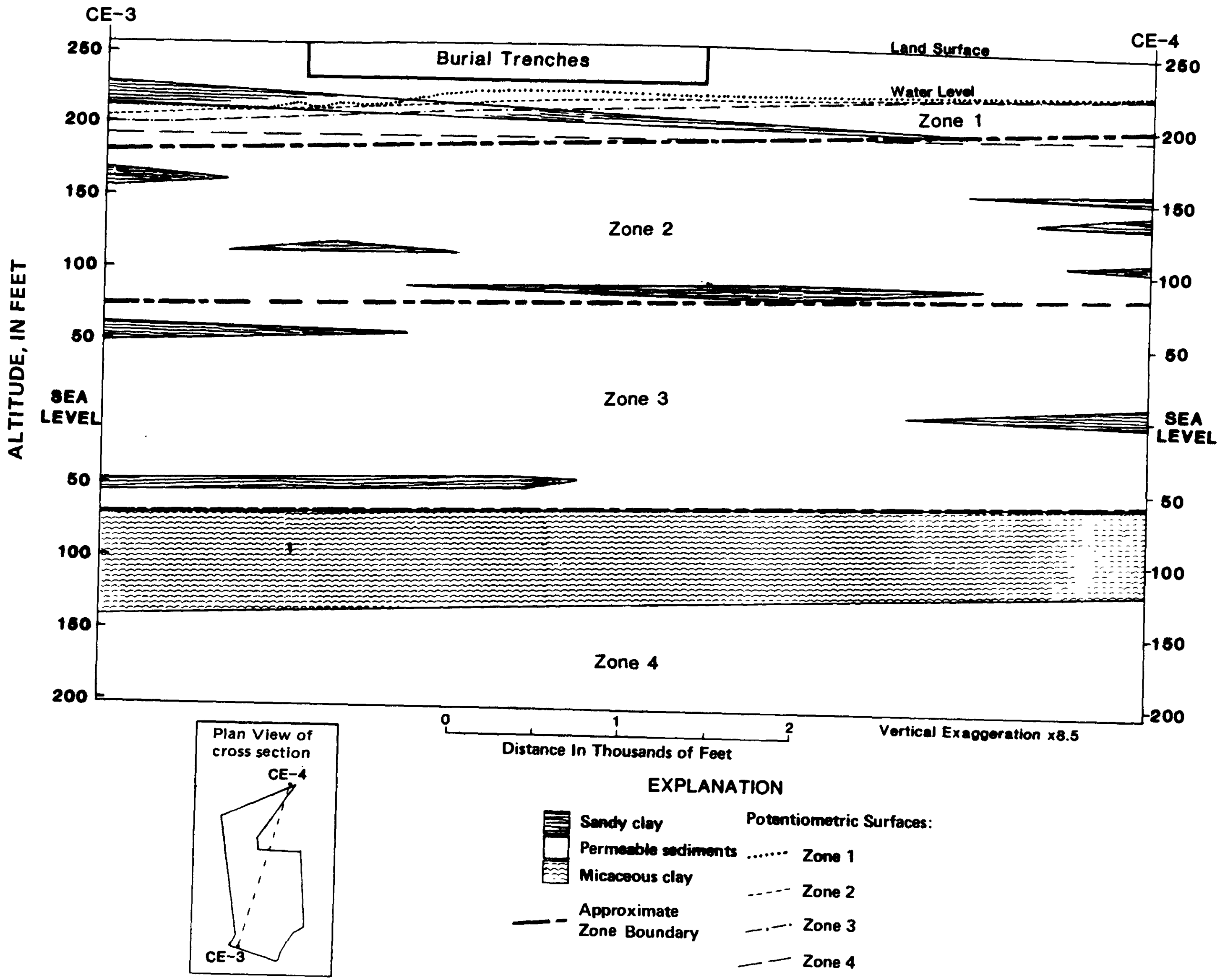


Figure 17.--Cross section through the burial site showing the thickness of the four ground-water bearing zones and potentiometric surfaces during November 1979.

northeast edge of the burial site to the spring located about 3,000 feet south of the site. The potentiometric surfaces indicate that the upper three zones discharge to the spring and that the lower zone does not. Figure 17 is a cross section from well CE-4 southwest to well CE-3 showing the thickness of the four zones and the potentiometric surfaces during November 1979. The upper zone (zone 1) is in the clayey sands of the Hawthorn and Barnwell Formations, zone 2 is in the sands of the lower part of the Barnwell and upper part of the McBean Formations, zone 3 is in the lower part of the McBean and Congaree Formations, and zone 4 is in the sands of the Ellenton Formation and the upper part of the Middendorf Formation. Zones 2 and 3 are separated by discontinuous silt and clay beds. Zone 4 is separated from the upper zones by the Ellenton silty clay bed which has a low hydraulic conductivity. The vertical hydraulic conductivity of the Ellenton silty clay bed was determined by laboratory tests to be about $3x10^{-7}$ ft/d.

Ground water in the study area occurs under water table, semiconfined, and artesian conditions. The upper 340 feet of saturated sediments in the vicinity of the burial site generally exhibit water table or semiconfined conditions; below 400 feet, conditions are artesian. Under water-table conditions the water surface is free to rise and fall. Under artesian conditions the aquifer is overlain by a less permeable layer that acts as a confining bed. When an artesian aquifer is penetrated by a well, hydrostatic pressure causes the water level in the well to rise above the base of the confining bed.

Zone 1

The sediments of zone 1 which are in the lower part of the Hawthorn and upper part of the Barnwell Formations are composed mostly of sand intermixed with silt and clay and form a predominately water-table aquifer. This zone extends from the water table down to about 70 feet beneath the land surface. The saturated part of zone 1 varies seasonally and averages about 22 feet thick at the northern boundary of the burial site and about 32 feet thick at the southern boundary.

Water-level altitude in this zone ranges from about 170 feet above NGVD south of the burial site to about 240 feet above NGVD north of the burial site (fig. 18).

Recharge to zone 1 is not uniform over the area. The potentiometric surface (fig. 18) shows three distinct water-table mounds in the vicinity of the trenches during November 1979. The largest is southeast of the trenches where the water level is about 224 feet above NGVD. This mound receives continuous recharge from the overlying perched water table.

Other mounds occur in the vicinity of trenches 13 and 8 where the water levels are about 226 and 214 feet above NGVD, respectively. These water-table mounds indicate that water is seeping into the nearby burial trenches and short-circuiting the unsaturated flow regime. The mound in the vicinity of

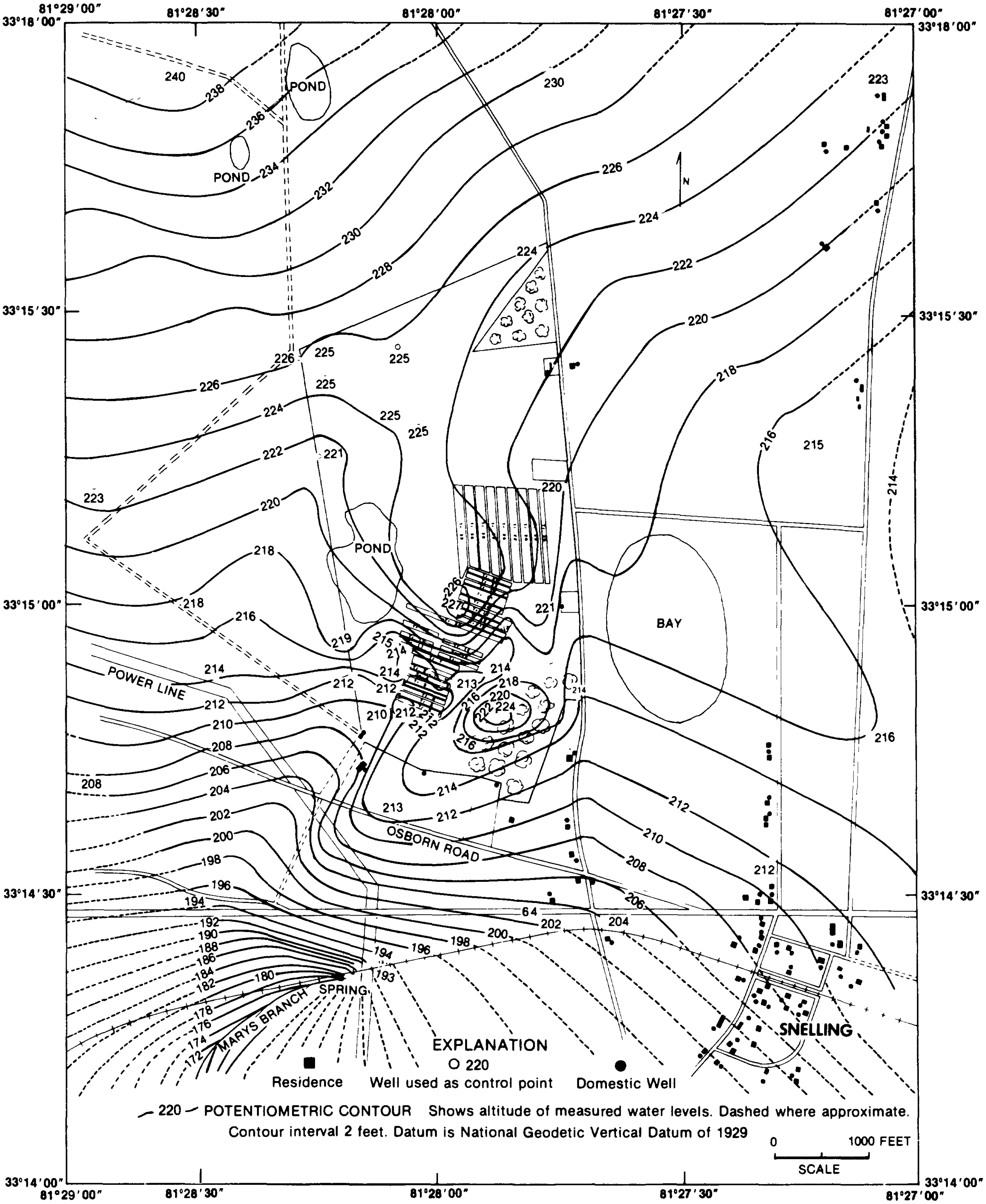


Figure 18.--Potentiometric surface of zone 1 (clayey sediments) during November 1979 at the low-level radioactive-solid-waste burial site and vicinity near Barnwell, S.C.

trench 13 is caused by a topographic low which accumulates water that subsequently percolates downward along the edges of the nearby trenches. Radionuclides have not been detected in monitoring wells near trench 13, which indicates that contaminates at this site have not percolated to the saturated zone. However, tritium and leachates have been detected in monitoring well CN-4 near trench 8, indicating that water is percolating downward through the waste in that trench.

The direction of water flow can be inferred from water-level contour maps. Flow is perpendicular to the equipotential lines. Most of the ground water in zone 1 from the burial site flows southerly and discharges into Marys Branch Creek about 1,000 feet downstream from the spring (fig. 18). Analysis of the water-level contour map indicates that nearly all precipitation at the burial site will either flow downward or move horizontally to the creek. This becomes evident when streamlines are extended perpendicular to the equipotential contours from the northern part of the burial site, at locations where the water-level altitudes are 225 feet, to the creek. Water in zone 1 generally moves in the same direction as water on the land surface. The average gradient of ground water in zone 1 ranges from about 0.25 to 1 foot per 100 feet.

Regional water levels have fluctuated about 3 to 5 feet during 1976 to 1979 from a 5-year average (fig. 19). Generally, the water levels rise during the winter months and decline during the summer months.

Hydraulic conductivities of zone 1 were determined from slug test data using techniques developed by Bouwer and Rice (1976) and Cooper and others (1967). The former method yields hydraulic conductivities ranging from 0.008 to 36 ft/d and the latter method, from 0.006 to 22 ft/d. These test results indicate little difference in the two methods. Although the storage coefficient can be determined by the Cooper method, it was not always suitable for all wells because water levels in some wells reached equilibrium less than 3 minutes after the slug was injected. Table 5 shows the hydraulic conductivity at different locations based on these tests.

The transmissivity of zone 1 was estimated by multiplying the hydraulic conductivity by the saturated thickness. Estimates of transmissivity ranged from 0.25 to 400 ft^2/d.

Storage coefficients, based on techniques by Cooper and others (1967) and Papadopulos and others (1973), ranged from 0.0001 to 0.1. Lower storage values generally occurred in sandy clay sediments and the larger values in sandy sediments.

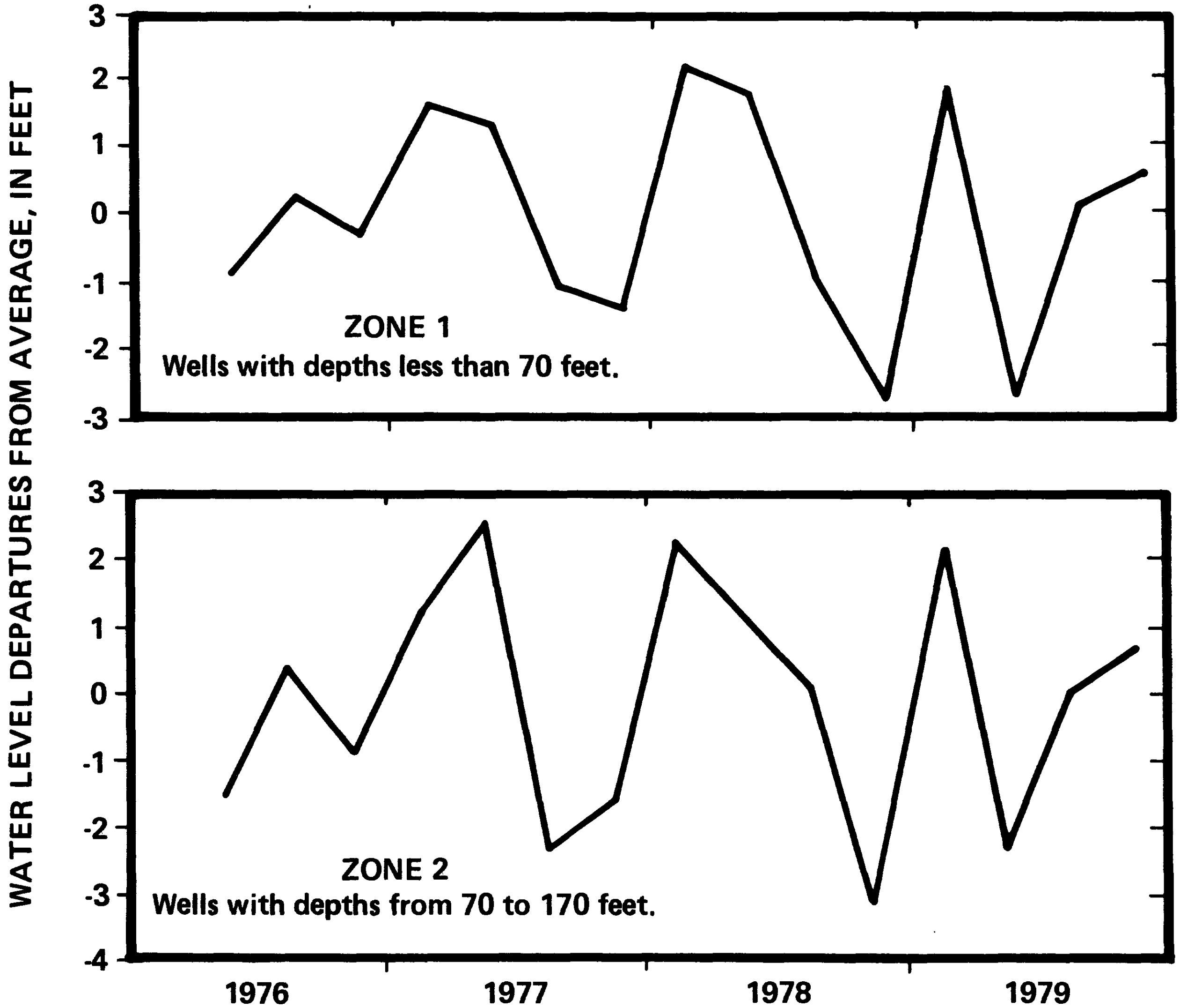


Figure 19.--Regional water-level departures from 5-year average of wells in zones 1 and 2 in the study area, Barnwell County, S.C.

Table 5.--Computed hydraulic conductivity in zone 1 using slug test methods described by Bouwer and Rice (1976) and graphical method by Cooper and others (1967)

Well no.	Date	Well depth (feet)	Elevation[1] of measuring point (feet)	Water level below land surface (feet)	Hydraulic conductivity methods (feet per day)		Approximate saturate thickness (feet)	Storage coefficients
					Bouwers & Rice	Cooper & others		
GS-1	3/8/77	65	237	30.09	0.89	0.40	40	10^{-3}
GS-3	3/16/77	34	248	21.45	0.14	0.13	40	--
GS-4	3/8/77	20	177	5.06	36.0	--	20	--
GS-5	3/15/77	30	244	7.83	0.42	0.40	35	--
GS-6	3/11/77	61	287	29.06	0.18	0.30	40	--
GS-7	3/15/77	51	271	26.64	2.92	1.24	50	--
GS-8	3/17/77	55	220	18.33	7.29	6.90	45	10^{-4}
GS-9	3/17/77	60	205	27.20	1.87	2.53	40	10^{-3}
GS-10	3/15/77	34	257	17.97	0.49	0.69	30	--
GS-11	3/16/77	60	283	22.91	6.23	1.98	40	10^{-2}
GS-12	3/2/77	41	238	21.97	0.55	0.13	40	10^{-2}
GS-13	3/11/77	32	247	20.98	8.89	3.97	40	10^{-2}
GS-14	3/14/77	44	258	36.38	18.1	22.10	25	--
GS-16	3/7/77	35	220	26.55	2.92	2.07	30	10^{-3}
GS-17	3/9/77	39	221	16.21	21.5	--	25	--
GS-18	3/14/77	42	242	30.18	0.02	0.007	30	10^{-1}
GS-19	3/3/77	50	245	27.27	2.23	3.60	30	--
GS-20	3/16/77	45	246	26.01	2.12	1.36	30	--
GS-W	4/21/77	70	258	40.50	0.008	0.006	30	--

[1]Above National Geodetic Vertical Datum of 1929.

Zone 2

Zone 2 is composed predominantly of very fine to medium Eocene sands in the lower part of the Barnwell and the upper part of the McBean Formations. Most of the sands have a yellow color caused by silt and clay particles that have been tinted by iron leached from above. The sand grains are subrounded and composed of quartz. Discontinuous clay lenses in zone 2 range from a few inches to a few feet thick. The top of zone 2 is about 70 feet below land surface and the base is identified by silt and clay bedding. The thickness of this zone is about 100 feet.

Zone 2 is the main source of domestic water in the vicinity of the burial site. Yields are ample for domestic use, and wells penetrating the complete thickness produce over 200 gal/min.

In November 1979, water levels ranged from about 170 feet above NGVD south of the burial site to 230 feet above NGVD north of the burial site (fig. 20). The water levels in zone 2 ranged from a few tenths to about 10 feet lower than water levels in zone 1. Figure 20 indicates that a ground-water mound occurs near trench 8. The occurrence of mounds in zones 1 and 2 in the vicinity of trench 8 indicates that water percolates locally from zone 1 to zone 2.

In some locations the water levels in zone 2 change suddenly due to barometric pressures indicating that the aquifer is locally confined. Figure 21 shows daily water-level fluctuations from January 29 to March 1, 1976 for a well penetrating this zone. The abrupt changes in water levels are probably due to barometric changes during storms that moved through the area.

The horizontal direction of water movement in zone 2 is similar to that of zone 1. Analysis of the water level contours in zone 2 indicates that most of the recharge entering this zone at the burial site will discharge into Marys Branch Creek downstream from the spring (fig. 20). Most of the ground water contribution to Marys Branch Creek is derived from zone 2.

Vertical hydraulic conductivities of zone 2, determined by laboratory tests, ranged from about 2.8×10^{-7} ft/d at a depth of 141 ft in well CE-1 to 15 ft/d at a depth of 97 ft in well CE-7. Horizontally hydraulic conductivities ranged from 5.9×10^{-4} ft/d at a depth of 172.5 ft in well CE-1 to 12 ft/d at a depth of 92 ft in well CE-1 (table 4).

Zone 3

Zone 3 consists mostly of fine to medium sand in the lower part of the McBean and the upper part of the Congaree Formations. The sand is generally subrounded quartz and appears to be beach sand. Lenses of interbedded clay are present and limestone and consolidated calcareous material also occurs within this zone in the eastern and southern part of the study area.

Zone 3 occurs between the depths of about 170 and 350 feet. The top of zone 3 is below the silt and clay beds that separate this zone from zone 2, and the bottom is the thick silty clay bed of the Ellenton Formation (fig. 7). Wells penetrating zone 3 have yields ranging from 200 to 650 gal/min.

Wells tapping zone 3 east of the burial site near the Salkehatchie River and in the southern part of the study area flow. Most of these flowing wells are in limestone or consolidated calcareous material. Small diameter wells have been allowed to flow freely for many years.

Water levels of wells penetrating zone 3 indicate that ground water flows toward the east in the northern section of the study area and south toward Lower Three Runs in the southern part of the area.

Water for the city of Barnwell is obtained from zone 3. Yields of city wells range from 250 to 650 gal/min. Drawdowns range from 24 to 96 feet. The nonpumping water levels in most of these wells are near the land surface.

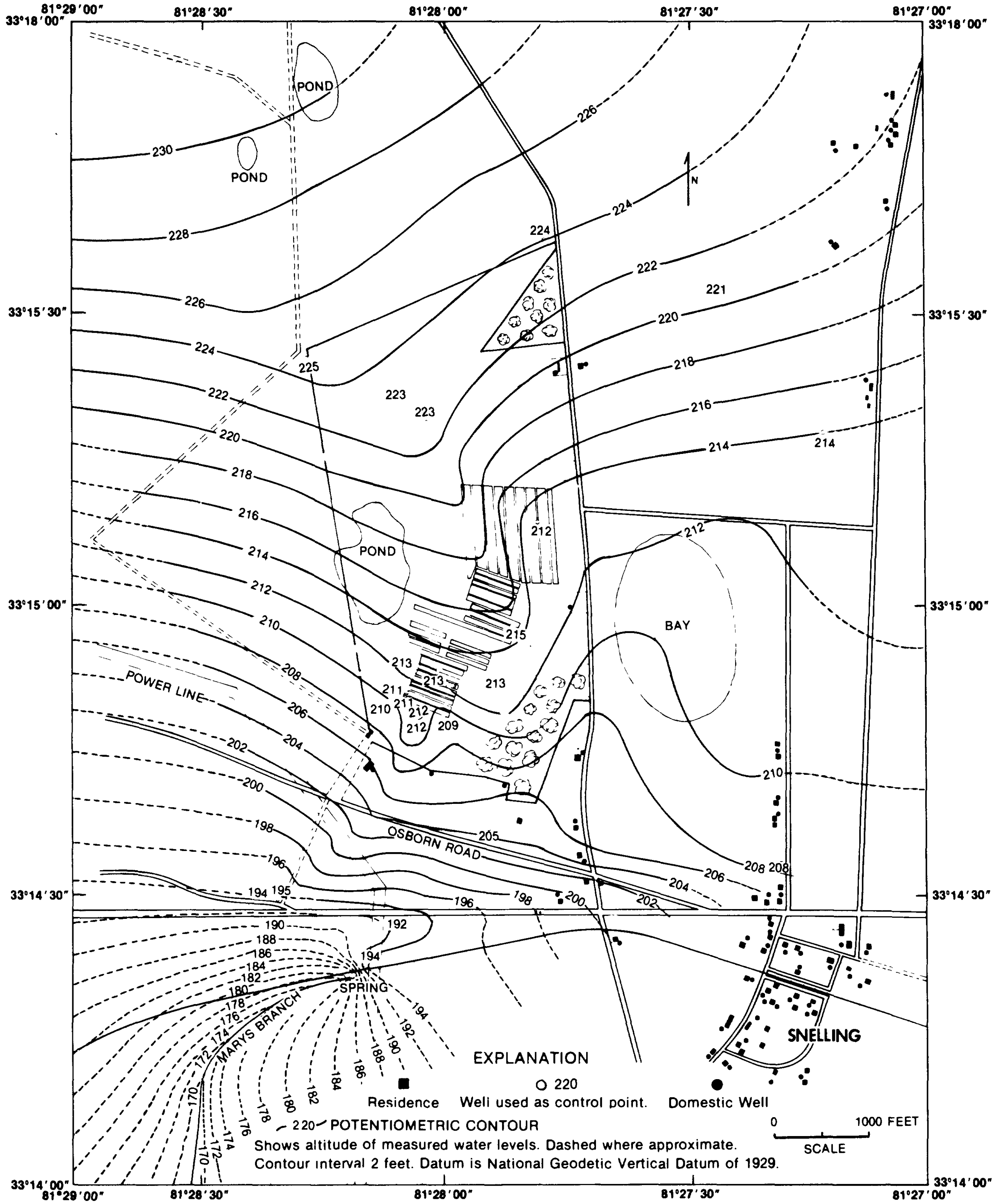


Figure 20.--Potentiometric surface of zone 2 during November 1979 at the low-level radioactive-solid-waste burial site and vicinity near Barnwell, S.C.

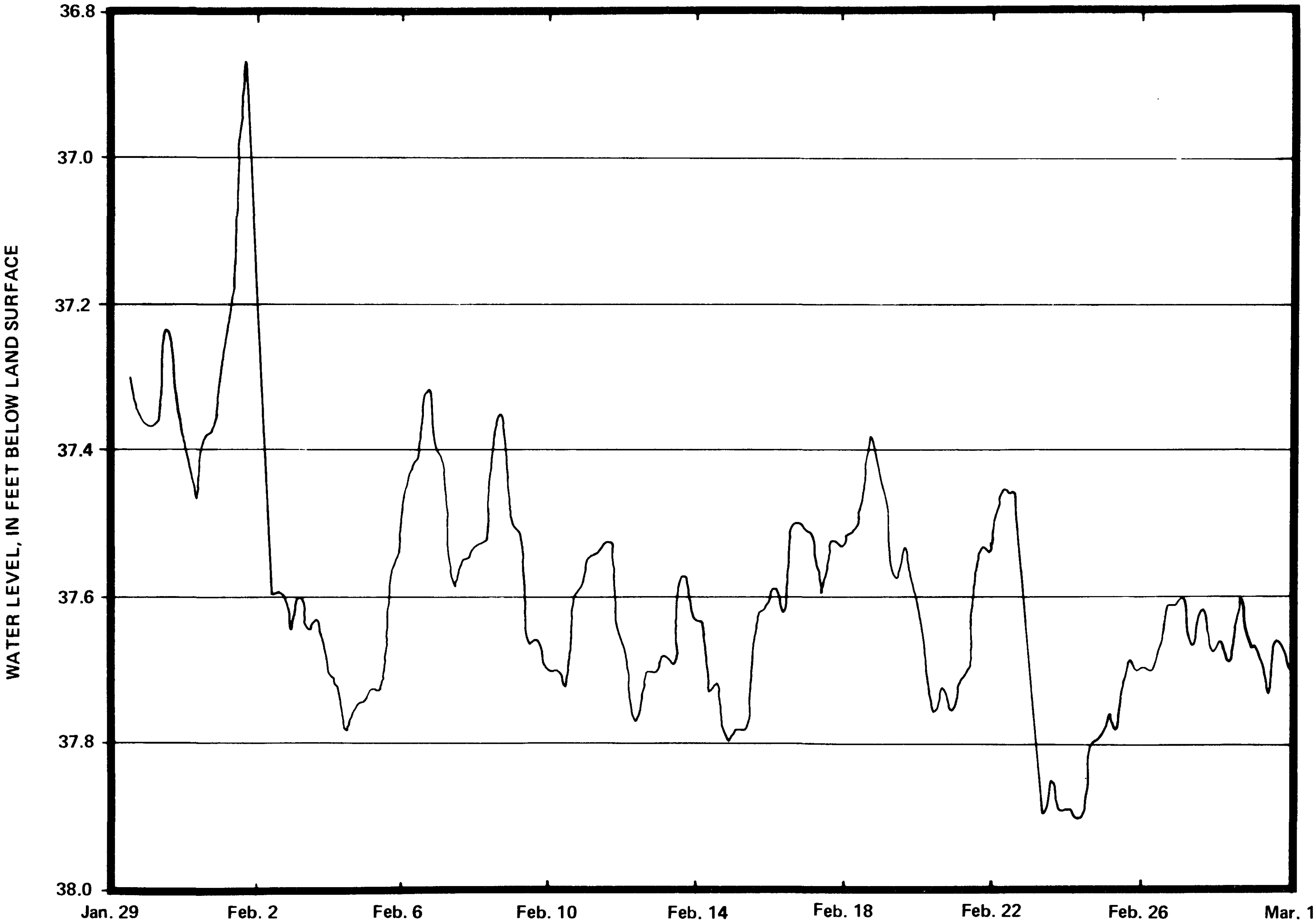


Figure 21.--Daily water-level fluctuations of well B-26 (zone 2) during 1976.

Some wells flow during periods of high rainfall and when pumpage is at a minimum.

Distance between the Barnwell City wells and waste burial site is 6 or more miles. These wells are not located in the flow path of ground water from the burial site.

Vertical hydraulic conductivities, determined in the laboratory from sediment cores, ranged from about 2.5×10^{-5} ft/d at a depth of 344 ft in well CE-1 to 22 ft/d at a depth of 298.5 ft in well CE-1. Horizontal hydraulic conductivities ranged from 1.5×10^{-3} ft/d at a depth of 338 ft in well CE-3 to 19 ft/d at a depth of 340 ft in well CE-1 (table 4).

A transmissivity of 1,020 ft^2/d was computed for zone 3 using an average horizontal conductivity of 6 ft/d and an average thickness of 170 feet. Values of transmissivity for zone 3 were also estimated from the specific capacity of wells in the city of Barnwell. The specific capacity can be used to estimate the transmissivity of an aquifer when screen loss is negligible and the drawdown is constant with time. These conditions were met in this case. Transmissivities computed using the specific capacity ranged from about 2,300 to 4,000 ft^2/d. These values were obtained by applying the technique described by Brown (1963, p. 336-338) and using a storage coefficient of 0.0002 from Siple (1967, p. 52).

Aquifer Tests of Tertiary Sediments

The transmissivity of the Tertiary sediments was determined also by aquifer performance tests conducted north of the burial trenches. The pumping well penetrated the complete thickness of zone 2. Water levels were observed in nearby wells that penetrated zones 1, 2, and 3. Figure 22 is a sketch of the pumping well and zones of perforation of the observation wells used in the aquifer test analysis.

The pumped well was drilled to a depth of 170 feet where a clay lens was encountered. The upper 70 feet of the well were cased with 12-inch diameter PVC (polyvinyl chloride) pipe. A cement grout was emplaced between the well casing and well bore. After the cement grout had set for 72 hours, the drilling was continued to a depth of 170 feet with a diameter slightly less than 12 inches. The well was finished with 8-inch diameter PVC casing that was screened from 70 to 170 feet. Gravel was then introduced between the well bore and the well casing.

An electric submersible pump, set at 150 feet, was used to pump the well. The discharge was regulated with a gate valve that was installed in the discharge pipe. The water was discharged in a field about 1,700 feet northeast from the pumping and observation wells. The discharged water was allowed to spread over the land surface, and because of the sandy terrain the water flowed only a short distance before it percolated downward.

The aquifer tests were conducted in two stages. In stage one the well was pumped at 150 gal/min for about 6 days after which the water levels in the

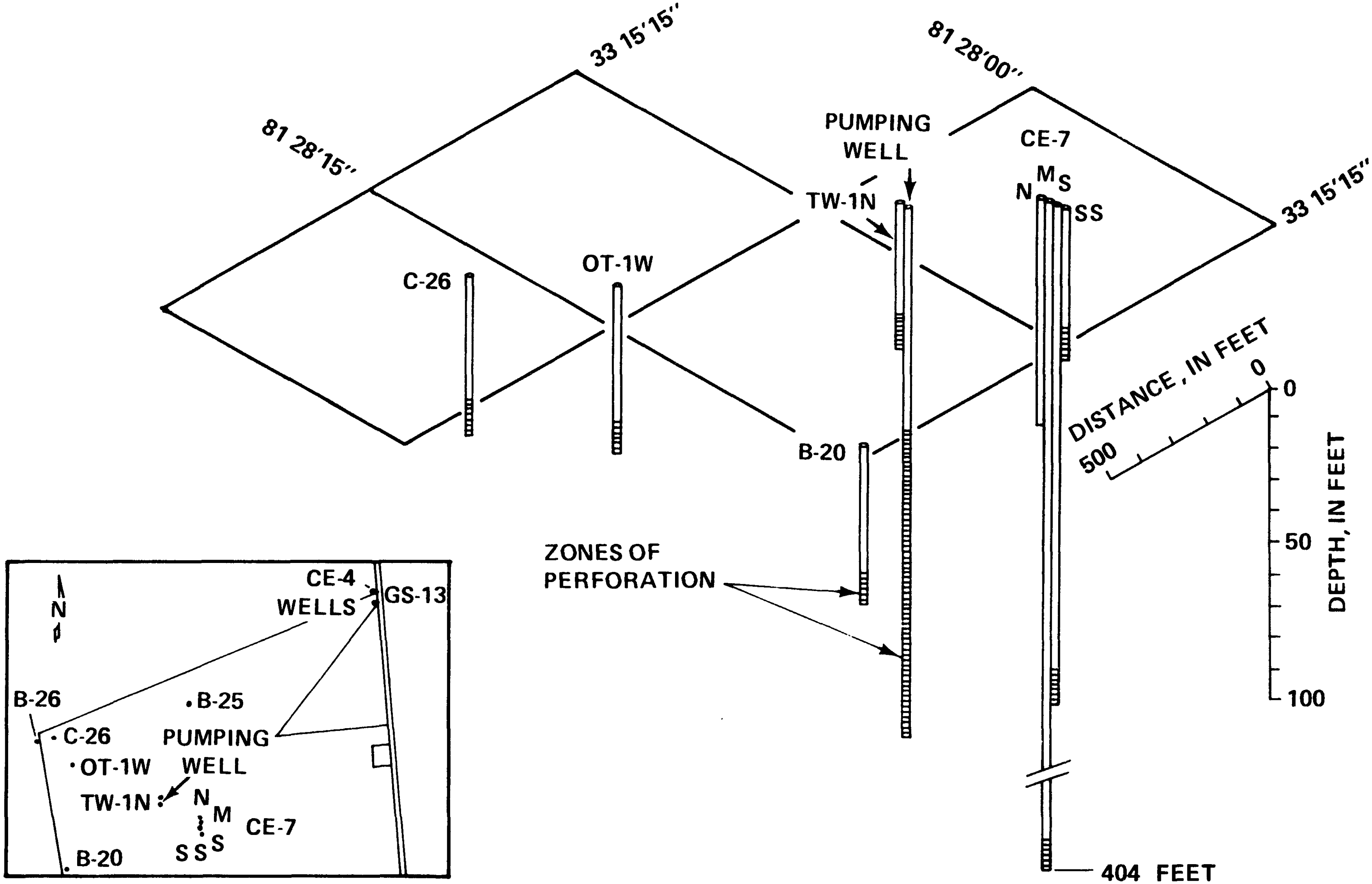


Figure 22.--Location and zone of perforation of pumping well and observation wells at the low-level radioactive-waste burial site near Barnwell, S.C.

observation wells were allowed to recover. In stage two the pumping rate was 225 gal/min for 3 days after which water levels were allowed to recover. The water levels in all nearby wells were monitored during the pumping and recovery periods.

Aquifer test data were analyzed using the methods presented by Lohman (1972). Transmissivities of the Tertiary sediments were analyzed using those curves for unconfined aquifers with vertical movement because those curves best suited the observed aquifer conditions. Table 6 lists the description of wells used for observation during the aquifer test.

Table 6.--Description of wells used for observation during the aquifer test near Barnwell, S.C.

Well	Well depth (feet)	Radial distance (feet)	Perforation zone (feet)	Potentio-metric surface at beginning of test (feet)	Aquifer zone	Perforation in geologic formation
B-20	50	860	39-48	223.9	1	Barnwell
B-25	44	530	40-44	226.9	1	Barnwell
B-26	80	970	80-90	227.1	2	McBean
C-26	47	900	40-50	227.4	1	Barnwell
OT-1W	53	640	45-53	226.4	1	Barnwell
OT-1E	84	640	74-84	226.3	2	McBean
CE-7SS	50	400	40-50	228.9	1	Barnwell
CE-7N	74	400	64-74	228.3	2	McBean
CE-7S	161	400	151-161	224.3	2	McBean
CE-7M	404	400	394-404	193.0	4	Ellenton
GS-13	32	1,170	27-32	227.8	1	Hawthorn
CE-4E	108	1,180	98-108	228.0	2	McBean
CE-4W	233	1,180	223-233	227.9	3	Congaree
TW-1N	47	20	45-55	226.4	1	Barnwell
Test well	170	0	70-168	224.6	2	McBean

Mass plots of the data obtained from the observation wells are shown in figures 23 and 24. Figure 23 depicts the drawdown data when pumpage was 150 gal/min and figure 24 depicts the drawdown when pumpage was 225 gal/min. These data are logarithmic plots of changes in water levels in observation wells (s) versus time in days, divided by the squared radial distance from the pumped well to the observation well (t/r^2).

The mass plot curves in figures 23 and 24 are not parallel in the beginning of the pumping period but tend to converge at a later time, thus indicating that the aquifer is vertically anisotropic. Figure 25 shows the

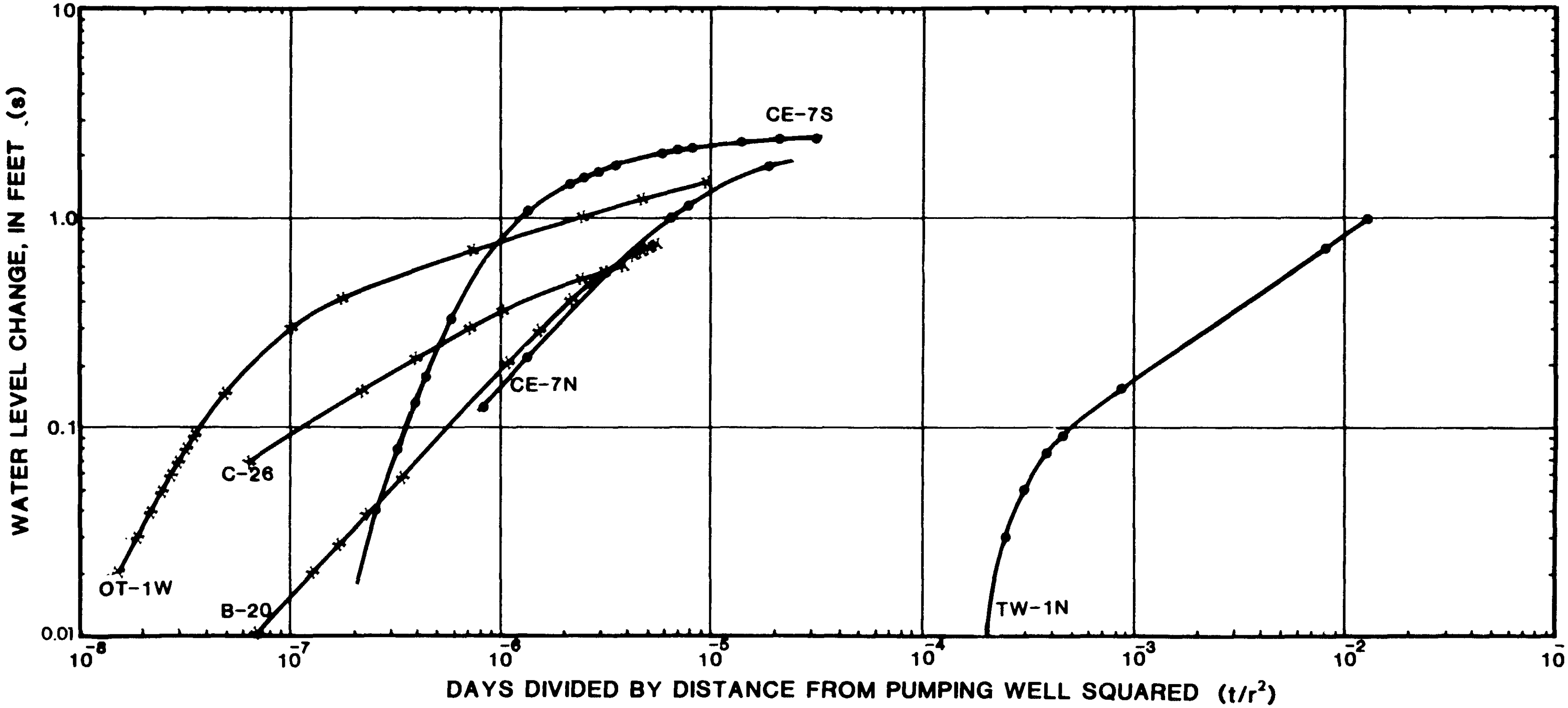


Figure 23.--Logarithmic mass plots of drawdown data from observation wells when pumpage was 150 gallons per minute.

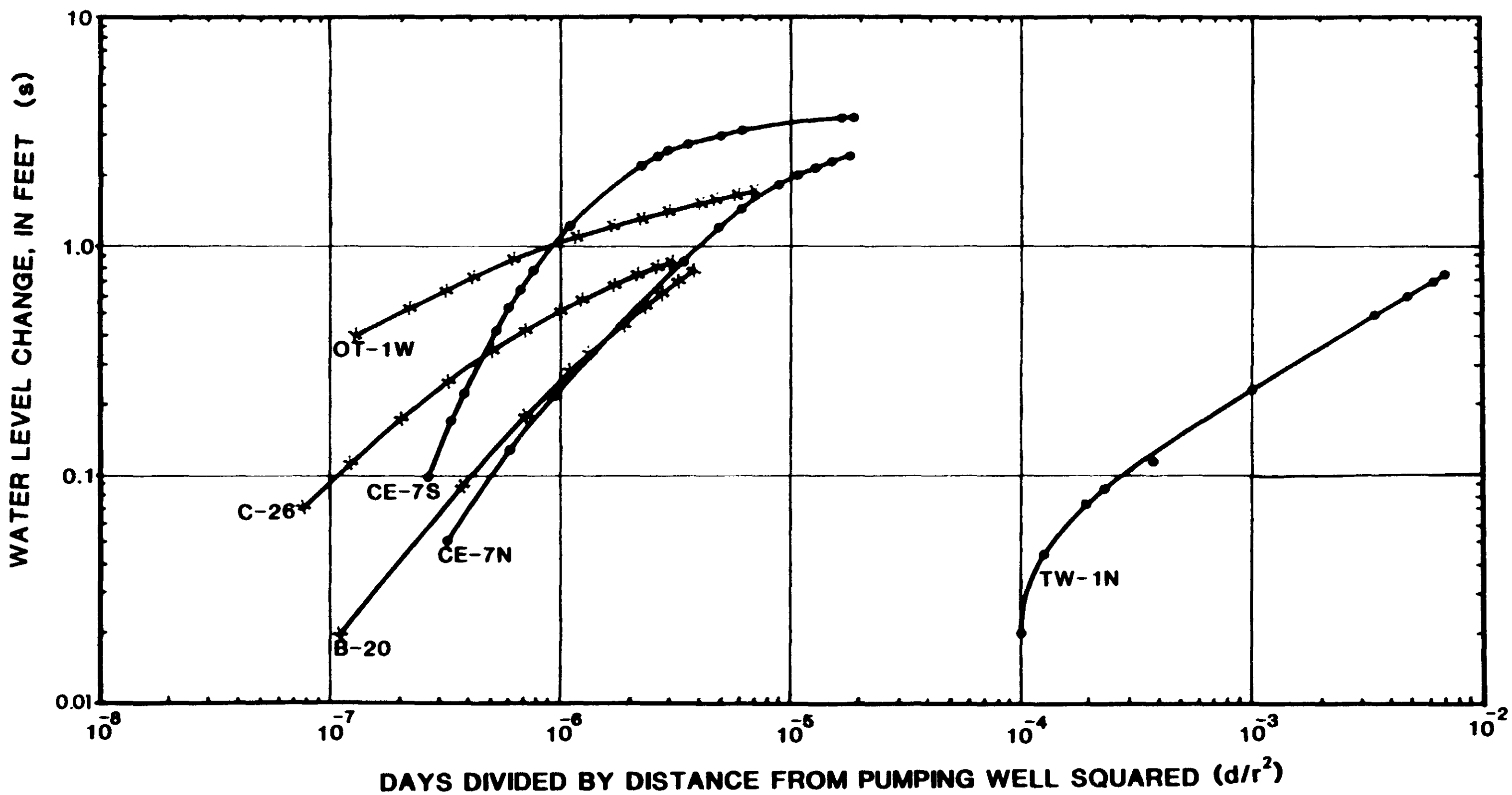


Figure 24.--Logarithmic mass plots of drawdown data from observation wells when pumpage was 225 gallons per minute.

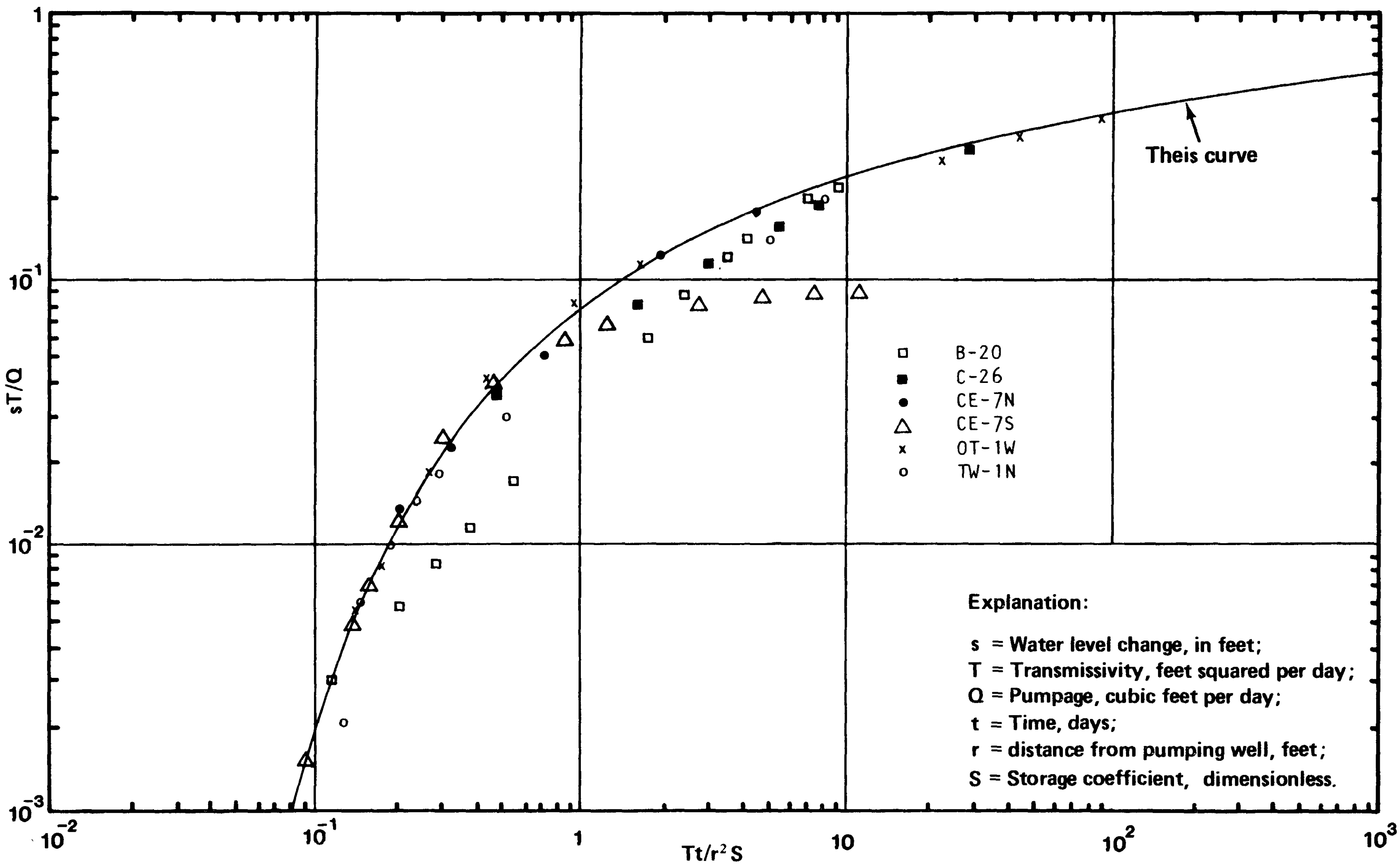


Figure 25.--Arrangement of mass plot data to match Theis curve to demonstrate the effects of anisotrophy when pumpage is 150 gallons per minute.

arrangement when well data for a pumping rate of 150 gal/min were shifted vertically and horizontally. With the exception of data plots from well CE-7S, the curves converge. Well CE-7S is screened from 151 to 161 feet. The decrease in the rate of water level decline in this well may be due to downward leakage around the well casing.

Water-level data from the observation wells fit best the Theis curve which applies to theoretical confined aquifers even though unconfined aquifer conditions exist at the test site. This indicates that zone 2 was not pumped sufficiently in quantity and duration to establish leakage through the less permeable material that separates the water-transmitting zones. A plot of the water-level data indicates that transmissivity of the upper 200 feet of saturated sediments ranges between 3,000 to 6,000 ft^2/d.

Data obtained from the two pumping periods at the test site indicate that the saturated sediments are heterogeneous and anisotropic. Observation wells within the pumped zone, the same distance from the pumped well, but screened at different depths, showed water level responses which indicate heterogeneity and hydraulic interconnection of the upper three zones.

Zone 4

Zone 4 consists of about 650 feet of sediments (Middendorf Formation) between the base of the silty clay bed of the Ellenton Formation, which occurs at a depth of about 400 feet (fig. 17) and the top of the Triassic sedimentary rocks at a depth of about 1,050 feet (fig. 6). Zone 4 consists of medium to coarse sands and gravel beds intermixed with clay deposits of various colors and is the most productive aquifer in the area. The sands and gravels are mostly quartzitic, and the clays are mostly kaolin.

Most water in zone 4 discharges into the Savannah River. Siple (1960) presented a potentiometric surface for water in these sediments and indicated that some of the small streams within the Savannah River Plant area receive water from this zone.

Siple (1967) described aquifer performance tests that were conducted in this zone at the Savannah River Plant. The tests were conducted at sites about 12 and 17 miles northeast of the study area. At the 12-mile site the transmissivity ranged from 14,000 to 53,500 ft^2/d, and the storage coefficient ranged from 0.0002 to 0.0008. At the 17-mile site the computed transmissivity ranged from 4,500 to 20,000 ft^2/d, and the storage coefficient was 0.0003.

In 1971, an aquifer test was conducted by Allied General Nuclear Services at their plant on a well penetrating most of zone 4 (Allied General Nuclear Services written commun., 1976). This test was made to determine if there was direct connection between zone 4 and the aquifers above.

The test site was located about 1-1/2 miles west of the waste burial trenches. Well P-1 (fig. 26) was pumped at 2,000 gal/min for 1,075 hours, and water levels in most wells on the plant property were measured.

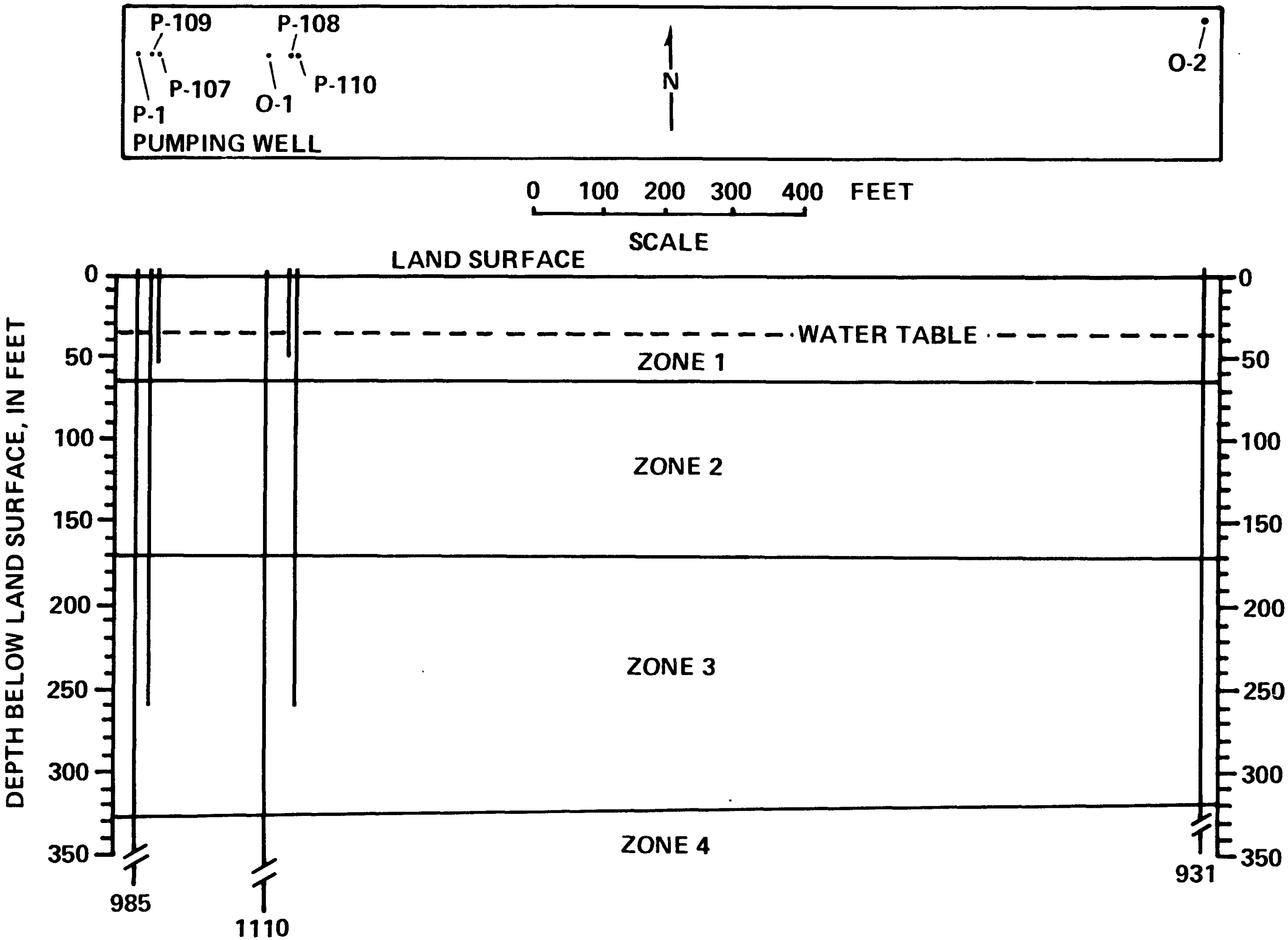


Figure 26.--Location and depths of wells used in aquifer performance test of zone 4 at the Barnwell Nuclear Fuel Plant near Barnwell, S.C. (data from Allied General Nuclear Services).

The pumped well was 985 feet deep and was screened in zone 4. Two observation wells were also drilled into this formation to monitor the water levels. Well 0-1, 200 feet east of the pumped well, was drilled to 1,110 feet. Well 0-2, 1,500 feet east of the pumped well, was drilled to about 1,000 feet. Four shallower wells were also drilled within 300 feet of the pumped well. Wells P-107 and P-108 were drilled to depths of about 50 feet to monitor water levels in zone 1. The pre-pumpage water-level altitude in these wells was about 215 feet above NGVD. Wells P-109 and P-110 were drilled to depths of about 260 feet to monitor water levels in zone 3. The water-level altitude in these wells was about 199 feet above NGVD.

The observed water-level measurements are listed in table 7. Water levels in the shallower observation wells in zones 1 and 3 showed no response due to pumpage, indicating poor hydraulic connection between the Cretaceous and the Tertiary sediments.

Table 7.--Water levels below top of casing in wells near the pumped well during the performance test at the Barnwell Nuclear Fuel Plant near Barnwell, S.C. Test began on November 11, 1971 [Data from Allied General Nuclear Services.]

Date	Wells			
	P-107	P-108	P-109	P-110
Nov. 17, 1971	43.75	42.60	60.35	58.65
Nov. 23, 1971	43.85	43.00	60.38	58.77
Nov. 26, 1971	42.10	41.84	59.30	57.41
Nov. 27, 1971	42.58	41.52	60.02	57.58
Nov. 28, 1971	42.42	41.26	60.00	57.52
Nov. 29, 1971	42.58	41.67	59.67	57.75
Nov. 30, 1971	42.37	41.68	59.07	57.15
Dec. 1, 1971	43.08	42.10	59.25	57.54
Dec. 2, 1971	43.33	42.15	59.22	57.42
Dec. 6, 1971	42.60	41.67	59.07	57.52
Dec. 8, 1971	42.55	41.63	59.05	57.45
Dec. 14, 1971	42.65	41.57	59.17	57.43
Dec. 21, 1971	42.31	41.30	59.00	57.34
Dec. 28, 1971	42.72	41.72	58.93	57.60
Jan. 11, 1972	42.08	41.17	58.95	57.32
Elevation of Measuring Point above NGVD	257.37	256.74	258.04	256.56

Influence of pumpage was observed only in zone 4. The water level declined about 18 feet in well 0-1 and declined about 13 feet in well 0-2. The effect of pumpage was not observed in a well penetrating the same water-bearing zone about 11 miles north of the pumped well.

Although well P-1 was pumped for about 45 days, only the data for the first 6 days were used in the test analysis because of power and pump failure.

The Theis nonequilibrium equation (Theis, 1935) was used to analyze the test data using water-level measurements from wells 0-1 and 0-2. The observation well data plots superposed on the Theis curve are shown in figure 27. Computations of transmissivity and storage are also shown on the graphs.

The data obtained from the observation wells indicated values of 22,000 ft^2/d for transmissivity and 0.00001 for storage coefficient. This transmissivity value is well within the range Siple (1967, p. 32) reported for this aquifer at the Savannah River Plant, but the storage coefficient was less than that reported by Siple.

Interrelation Between Streams and Water-Bearing Zones

The upper aquifers and streams in the area are interrelated. Water enters the area as rainfall and moves from the surface of the ground through the water-bearing zones to streams. Figure 28 shows a generalized hydrologic section from just west of Par Pond Dam to just east of the Salkehatchie River (fig. 2). This figure indicates that the stream beds fully penetrate zone 1 and part of zone 2. Flow lines indicate that water discharge to the streams is derived from zones 1 and 2.

Aquifer performance tests indicate that zones 1, 2, and 3 are interconnected even though there are differences in water levels with depth. The aquifer tests indicate that an insignificant amount of water moves between zones 3 and 4.

Water-level contours of the potentiometric surfaces of zones 1 and 2 at the burial site (figs. 18 and 20) indicate local recharge and discharge into Marys Branch Creek. Zone 3 does not receive significant recharge from the upper zones in the vicinity of the burial site and discharges into Lower Three Runs with little contribution to Marys Branch Creek.

Figure 29 shows water-level fluctuations for the four zones at the burial site. This figure shows that the upper three zones fluctuate nearly simultaneously but with different magnitudes. The water levels in the three zones show a continuous rise from January 1978 until the spring or summer months. In January 1978 about 9 inches of rain fell in the area (table 2) which caused water levels to rise in the upper three zones. During February, 1 inch of rain fell, and the water level in zone 2 remained relatively constant. When 5.8 inches of rain fell in May, the water levels began to rise in the three upper zones with zones 2 and 3 showing the greatest response. During the period June through October the water levels in zones 2 and 3 declined because of lack of rainfall. The water level in zone 1 (CE-2W) showed the least fluctuation. This well is located southeast of the trenches and is adjacent to the perched water body (fig. 14). The greatest fluctuation was in well B-26S (zone 2) which is located at the northwest corner of the burial site (fig. 4).

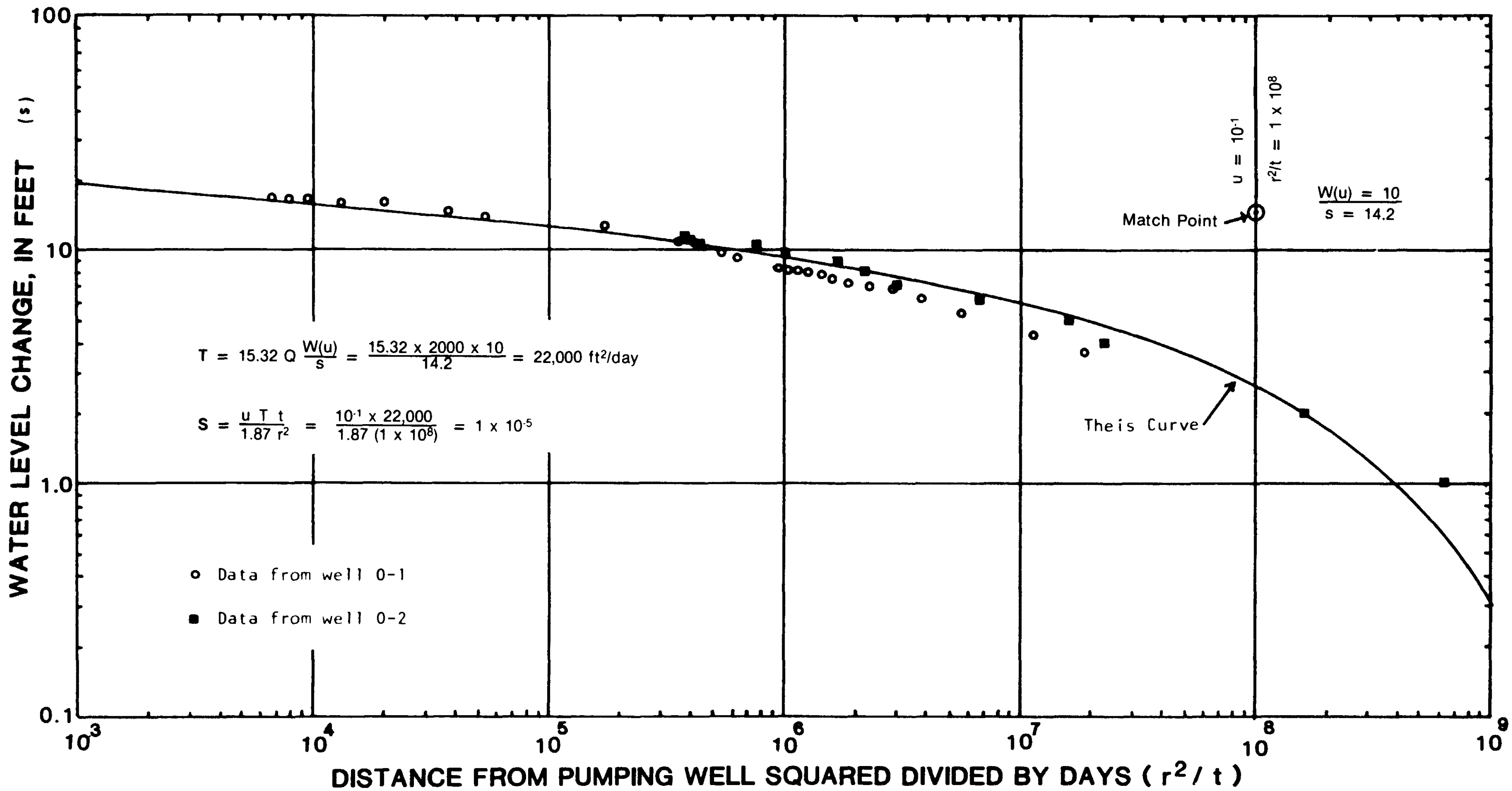


Figure 27.--Logarithmic drawdown data plots of well 0-1 and 0-2 while pumping well P-1 2,000 gallons per minute at Allied General Nuclear Services near Barnwell, S.C.

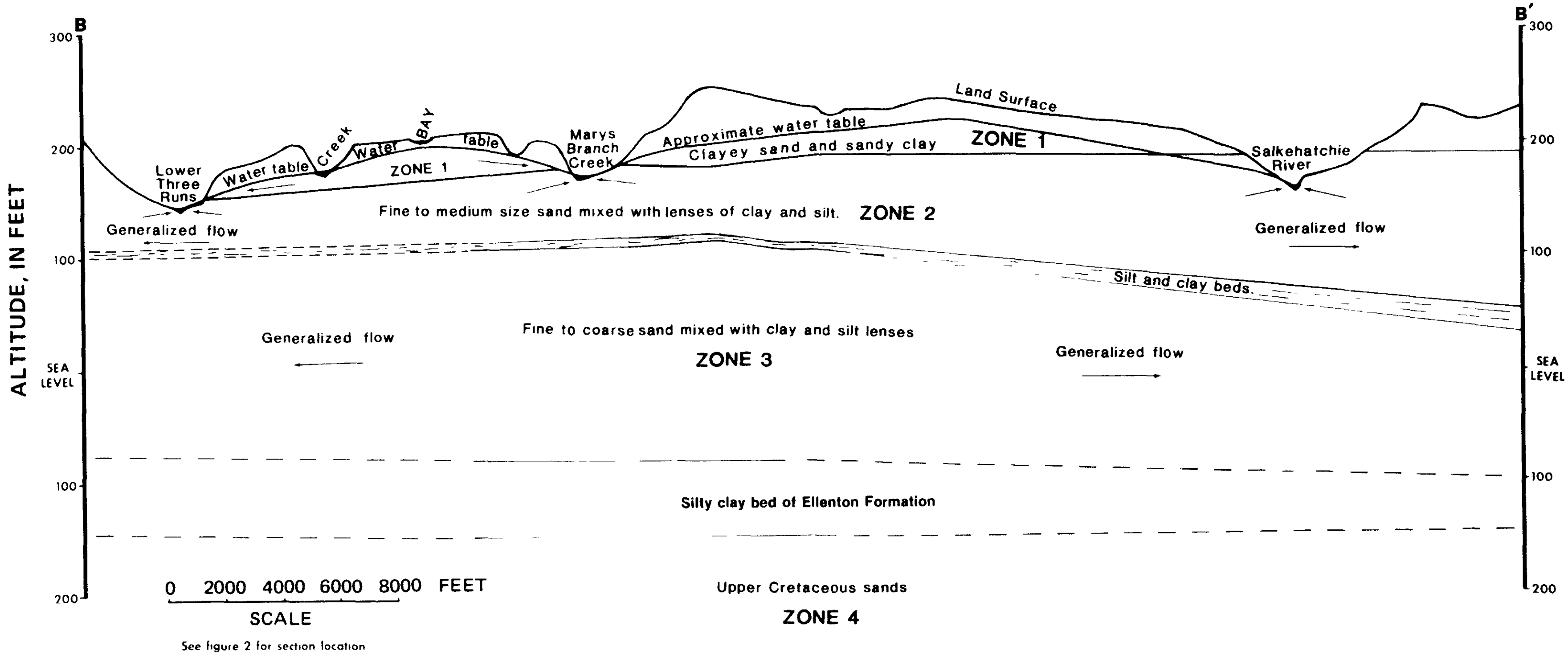


Figure 28.--Hydrologic section along B-B′ near the low-level radioactive-solid-waste burial site near Barnwell, S.C.

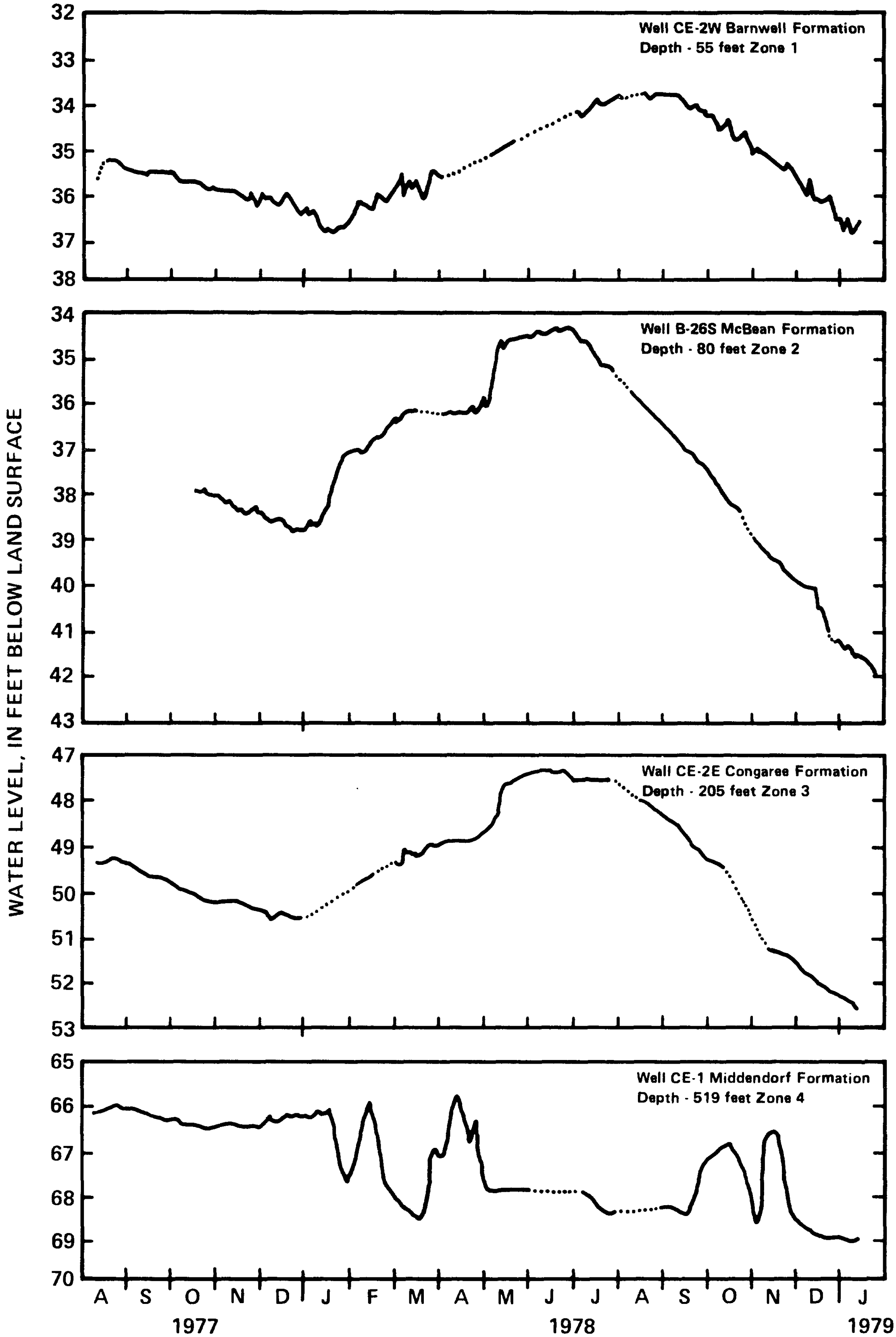


Figure 29.--Water-level fluctuations in the four water-bearing zones at the radioactive-waste burial site near Barnwell, S.C.

Figure 29 shows that well CE-1 in zone 4 does not reflect water-level fluctuations of the upper zones but responds to pumping from zone 4 and long-term seasonal fluctuations. The short-term water fluctuations are probably caused by pumpage from this zone at the Barnwell Nuclear Fuel plant about 1-1/2 miles west of well CE-1. The Savannah River Plant, almost 6 miles west, also pumps water from zone 4.

The thickness of the clayey sand in zone 1 influences vertical water movement and therefore partially controls the water levels in zones 1 and 2. Where the clayey sand beds are thin, the water levels in zones 1 and 2 are less than 1 foot apart. The fence diagram in figure 30 shows where the clayey sand bed is thin at well CN-3. At this location the water level in zone 1 is about 1 foot higher than that in zone 2. About 500 feet southeastward at well GS-W, the clayey sand bed is thicker and the water level in zone 1 is about 7 feet higher than that in zone 2. The sand layer at GS-W is at least 70 feet below land surface and the overlying sediments are mostly clayey sand and sandy clay.

Recharge to the water-bearing zones, on the average, is equal to discharge from the water-bearing zones. The amount of ground-water recharge can be estimated by measuring the discharge (streamflow). During October and early November 1978, about one-tenth inch of rain fell in the area. During this period, evapotranspiration losses were low, and freezing was not a factor in reducing streamflow. Recharge to the upper three water-bearing zones was computed using streamflow measurements obtained in mid-November.

The streamflow was about 4.7 ft^3/s about 1 mile downstream from the spring at Marys Branch Creek. The surface drainage area and ground-water basin at this site are about 4.4 and 4.6 square miles, respectively. Discharge per unit area is about 1.07 ft^3/s per square mile, which is equivalent to 33,743,520 cubic feet per year over an area of 27,878,400 square feet and is equal to a 1.21-foot water column. Therefore, annual discharge from the aquifer would be about 1.21 feet or 14.5 inches. Because Marys Branch Creek only intercepts zone 1 and the top of zone 2, some underflow may not be accounted for.

Lower Three Runs intersects zones 1 and 2 and some of zone 3 in the southern part of the study area. Based on a discharge measurement made November 16, 1978 of 77 ft^3/s for a surface drainage area of 59.3 square miles the amount of discharge is computed as 1.47 feet or 17.6 inches. The 17.6-inch estimate may not accurately reflect recharge due to the effect of leakage from Par Pond.

Duncannon is a small creek that flows east to the Salkehatchie River. This stream intercepts zone 1 and the upper part of zone 2. The surface drainage area is about 1.32 square miles and streamflow was about 1.3 ft^3/s or about 14 inches of discharge. Therefore the estimated recharge to the water-bearing zones appears to range from about 14 to 17 inches or about 40 percent of the precipitation in the area.

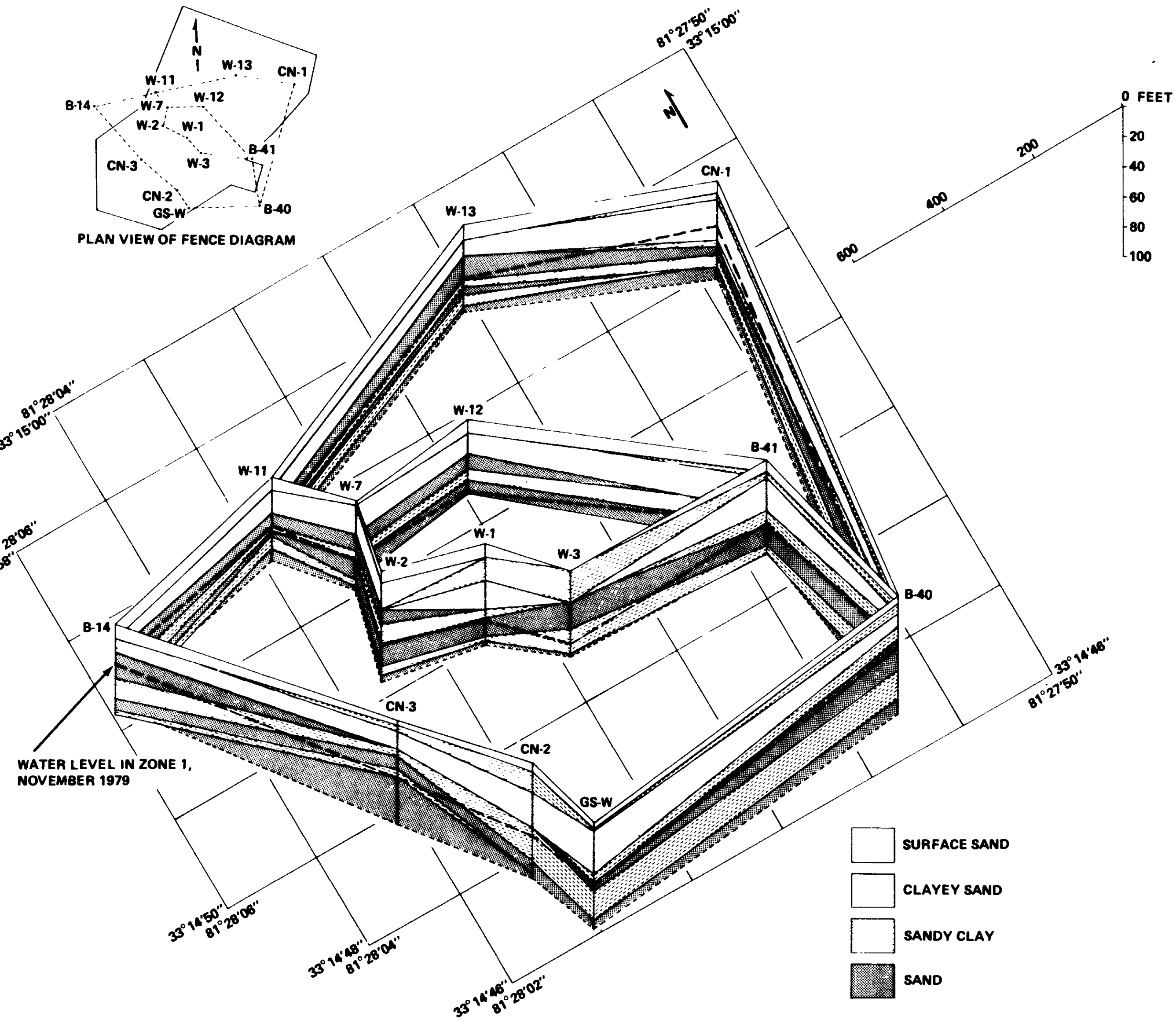


Figure 30.--Fence diagram showing the upper 80 feet of sediments at the waste burial site near Barnwell, S.C.

Chemical and Physical Characteristics of Water and Sediments

Quality of Ground Water and Surface Water

Water and sediment samples were collected and analyzed to obtain information on regional water quality and movement of leachates from the burial site. The information includes water chemistry, tritium activity, gamma emitting radionuclides, clay mineral determinations, and geophysical logs.

Table 8 is a tabulation of the chemical analyses of water from 51 wells, 5 streams, 1 Carolina bay, and of rainfall at the burial site. All water has low constituent concentrations with rainwater lowest. The data show that precipitation undergoes little chemical alteration as it passes through the ground-water system and into streams. Total dissolved solids in the ground water ranged from about 7 to 40 mg/L (milligrams per liter) for the clayey sediments in zone 1 to about 150 mg/L in water in the calcareous sediments of zone 3. Most variations in constituent concentrations are due to local changes in sediment mineralogy and are not necessarily related to depth. Specific conductance ranged from about 11 to 250 micromhos.

Variations in concentrations of iron, aluminum, and manganese do not indicate a relation to well depth or sediment types.

The dissolved solids concentrations of water in streams was less than 30 mg/L. The concentration of chlorides in the stream water ranged from about 1.8 to 3.3 mg/L. Fluoride concentrations in all samples were less than 0.5 mg/L.

Temperature of ground water ranged from about 16 to 24° C. Ground-water temperatures correlated to ambient temperature rather than to well depth. Stream temperatures closely equalled the ambient temperature.

Radioactivity of Water from Trench and Nearby Monitoring Wells

Water samples were collected from the drains in trenches 5, 6, 7, 8, 13, and 22 and were analyzed for radiological, organic, and biological concentrations in February and March 1978. In addition, water samples were collected from nearby wells: WW-5, WW-6, WW-7, CN-1E, CN-3N, and CN-4W. The samples were analyzed by Brookhaven National Laboratory (BNL). The results from these analyses were published in Progress Report No. 8 (Colombo and others, 1978, p. 39-42) and are summarized in table 9.

Water from monitoring wells WW-5, CN-1E, CN-3N, and CN-4W (fig. 4) had relatively high pH (8.4 to 11.4) and specific conductance (23 to 1,600) (table 9). These high values are attributed to the dissolution of the cement grout used in the wells. Water from other nongrouted wells drilled to the same depth have a pH less than 7. Ground water at the burial site is acidic with pH ranging from 4.8 to 6.5. Metal well casings have been corroded due to the acidity of the water.

Water from trench 7 had tritium activity of $6.4X10^8$ pCi/L (picocuries per liter of water). Water from trenches 5 and 8 (fig. 5) had detectable amounts of cesium-137 and cobalt.

The amount of dissolved organic carbon in the ground water above background level in zone 1 can be used as an indicator that leachates have entered the saturated zone. The background level of dissolved organic carbon in the ground water at the burial site is about 5 mg/L. Water from monitoring well CN-4W contained a dissolved organic concentration of 11 mg/L at a depth of 32 to 42 feet.

Water from monitoring well CN-1E, open from 40 to 50 feet below ground surface in zone 1, and located between trenches 13 and 15, had 15 mg/L of dissolved organic carbon. This well did not show evidence of tritium above background levels which, in the study area, is between 1,000 to 3,000 pCi/L.

The only well from which water samples show evidence of lateral tritium migration below the water table is CN-4W which is 42 feet deep, open from 32 to 42 feet (zone 1), and is 10 feet south of trench 8. Water samples from this well combined alpha and beta emitters, evidence of buried waste contamination. Water from this well is sampled periodically and the tritium activity has ranged from 100,000 to 200,000 pCi/L. The tritium activity of a water sample collected on March 21, 1980, was 128,000 pCi/L. Tritium has not migrated downward into the more permeable sand of zone 2 as indicated from analysis of water from well CN-4E (66 feet deep and open from 56 to 66 feet in zone 2) which is also located 10 feet south of trench 8.

Tritium was the most abundant radioisotope in the trench and well waters, which is not particularly surprising because it is a very mobile radionuclide.

In the spring of 1979, personnel from the BNL collected water from trenches 3, 5, 6, 8 and 25/21 (fig. 5). The trench water was analyzed for inorganic, organic, and radioisotope constituents. The analytical procedure and results of the analysis are presented by Weiss and Colombo (1980).

Table 10 shows the chemical analysis of the trench water as determined by the BNL personnel. This tabulation shows that constituent concentrations are greatest in trench 8.

Total carbon analysis of the trench water was used as an indicator of leachates moving from the buried waste. The carbon constituent ranged from about 13 to 300 mg/L. Water from trench 8 showed a concentration of 130 mg/L of inorganic carbon, and 170 mg/L of organic carbon. The water from trench 6, which is located about 70 feet north of trench 8, showed the least amount of carbon. Water from trench 6 had 11 mg/L of inorganic and 2 mg/L of organic carbon.

Table 8.--Chemical analyses of ground and surface water in the vicinity of the low-level radioactive-solid-waste burial site near Barnwell, S.C. (analysis in mg/L unless otherwise indicated)

Site no.	Well depth (ft)	Date of sample collection	Alkalinity (as $CaCO_3$)[(a)]	Aluminum (Al) (μg/L)	Bicarb (HCO_3)	Calcium (Ca)	Chloride (Cl)	Fluoride (F)	Hardness (total) (b)	Iron (Fe) (μg/L)
GS- 1	65	2/14/77	12	10	15	2.2	3.2	0.0	7	10
GS- 2	22	5/26/77	13	30	16	3.8	1.4	0	12	20
GS- 3	34	2/10/77	10	30	12	2.8	3.6	0.1	9	20
GS- 4	20	2/24/77	11	60	14	1.8	2.0	0	5	530
GS- 5	30	2/16/77	14	10	17	2.0	0.5	0	5	0
GS- 6	61	2/16/77	28	120	34	12	2.4	0.3	30	10
GS- 7	51	2/23/77	8	10	10	0.6	2.0	0	2	20
GS- 8	55	2/24/77	16	10	20	1.0	7.8	0	4	10
GS- 9	60	2/24/77	10	10	12	1.0	1.5	0	3	20
GS-10	34	2/23/77	11	10	14	3.0	0	0	10	40
GS-11	60	3/1/77	8	0	10	0.8	2.1	0	2	30
GS-12	41	2/11/77	8	30	10	0.9	3.2	0.1	3	10
GS-13	32	2/10/77	20	30	20	3.2	3.5	0.2	9	20
GS-14	44	2/14/77	25	0	30	1.2	5.0	0	3	20
GS-15	61	2/10/77	14	40	17	1.1	3.4	0.1	5	10
GS-16	35	2/28/77	16	20	20	1.1	2.8	0	3	10
GS-17	38	4/21/77	8	30	10	2.0	5.7	0	12	230
GS-18	42	2/10/77	25	30	31	1.9	6.4	0.1	12	20
GS-19	49	2/14/77	25	10	30	1.5	7.6	0.1	4	10
GS-20	45	2/14/77	2	10	3	1.5	1.5	0	4	10
GS-W	70	2/16/77	12	10	15	5.2	6.7	0.2	13	20
B-7	78	6/29/76	2	--	2	2.2	1.5	0	6	30
B-8S	54	3/30/77	29	50	35	10	2.4	0	33	0
B-40W	50	2/3/77	14	60	23	2.6	2.4	0.1	8	820
B-40E	80	7/1/78	4	40	--	0.5	2.2	0	2	10
CB-1	24	6/2/77	8	140	10	2.0	0.5	0	7	50
CB-2	26	6/3/77	8	30	10	3.5	3.6	0	12	90
CB-3	34	6/3/77	8	60	10	1.1	1.3	0	4	140
CB-4	51	6/3/77	7	80	8	2.9	2.8	0	9	60
T.B.*	--	6/3/77	9	100	11	1.0	3.2	0	4	450
X-2	120	2/16/77	35	10	43	1.8	2.7	0	5	1600
DH-4	120	2/10/78	11	--	13	5.5	2.0	0.4	17	50
DH-5	136	2/8/78	0	70	0	19	4.8	0.4	51	680
DH-23	52	2/10/78	19	60	23	1.6	1.3	0.1	6	30
0-108	56	2/8/78	0	320	0	0.8	5.2	0.1	10	30
O-111	55	2/8/78	2	90	2	0.8	1.9	0.1	3	50
O-115	61	2/8/78	1	120	1	0.5	1.6	0	4	30
CE-1	519	4/7/77	22	50	27	4.9	2.8	0.1	13	20
CE-2E	201	8/9/79	13	130[(a)]	--	5.1	2.3	0	14	190(a)
CE-2W	55	11/9/77	7	60	8	0.6	1.5	0.2	2	20
CE-7S	161	8/17/78	40	700	28	17	2.5	0.1	43	10

Magnesium (Mg)	Manganese (Mn) (µg/L)	NO_2 + NO_3 (as N)	Orthophosphate as P	Phosphate (PO_4) (ortho)	Potassium (K) (mg/L)	Silica (SiO_2) (mg/L)	Sodium (Na) (mg/L)	Sulfate (SO_4) (mg/L)	Spec. cond. (micromhos 25°C)	pH	Water temp. (°C)
0.3	30	0.19	0	0	0.6	2.1	1.7	0.6	32	--	20
0.7	50	0.99	0	0	0.9	2.5	0.8	5.5	60	--	--
0.4	10	0.02	0	0	0.7	0.7	2.9	0.2	25	--	16.5
0.1	20	0.42	0	0	0.4	5.3	1.7	1.2	25	--	18
0.1	0	0	0	0	0.4	0.4	2.9	0.8	19	--	17
0.1	10	0.82	0	0	2.5	0.4	2.7	3.2	68	--	18
0.1	20	0.01	0	0	0.6	4	2.1	0.5	13	--	20
0.3	10	2.2	0	0	0.6	5.8	8.3	0.1	67	--	19
0.1	40	0.89	0	0	0.1	3.8	1.9	0.2	23	--	18
0.7	150	0.99	0	0	0.5	3.0	2.4	2.6	29	--	20
0.1	10	0.08	0	0	0.2	4.4	1.8	0.2	19	--	19
0.1	20	0.04	0	0	0.7	0.5	3.2	0.4	22	--	19.5
0.2	90	--	--	--	0.7	2.9	2.6	3.7	58	6.5	16.5
0.1	20	0.35	0	0	1.8	12	3.5	1.5	65	--	19
0.6	40	0.03	0	0	0.8	1.1	4.9	1.6	34	--	17
0.1	20	0.56	0	0	1.7	8.0	4.3	0.7	38	--	18
1.8	50	3.4	0	0	1.6	6.3	3.6	0.1	82	--	22
1.7	60	0.11	0	0	2.1	5.1	3.4	1.6	55	--	17
0.1	80	0.29	0	0	0.8	3.8	5.3	8.4	85	--	18
0.1	20	0.67	0	0	0.4	5.1	1.0	0.5	11	--	18.5
0.1	10	0.21	0	0	2.2	0.2	5.2	3.0	14	--	16
0.1	10	0.54	0	0	0.7	7.9	1.5	0.6	18	--	24
1.9	50	0.76	0	0	0.2	5.5	1.8	0.4	--	--	--
0.3	320	4.6	0.01	0.03	1.3	4.0	2.0	3.6	42	--	--
0.3	20	0.20	--	--	0.9	8.6	1.2	0.8	15	5.3	19.5
0.5	150	0.06	0	0	0.5	2.9	2.7	3.2	--	--	--
0.7	80	0.01	0	0	0.07	6.0	2.7	1.4	--	--	--
0.2	60	0.39	0	0	0.9	0.7	5.2	3.6	--	--	--
0.4	40	0.73	0	0	0.7	5.8	2.2	3.1	--	--	--
0.3	780	0.06	0.04	0.12	0.7	0.5	.9	2.2	20	--	--
0 1	70	0	0	0	0.9	6.4	2.2	0.4	17	--	18
0.8	50	0.33	0	0	1.5	9.6	1.8	9.8	53	--	16
0.9	100	--	--	--	1.4	12	17	11	180	--	16
0.5	20	0.49	0	0	0.3	4.3	1.2	1.1	49	--	16
1.9	10	2.3	0	0	1.5	4.4	1.2	0.5	45	--	17
0.2	10	0.26	0	0	0.5	11	1.3	1.2	19	--	16
0.6	0	0.86	0	0	0.1	4.5	1.0	0.3	19	--	17
0.3	40	0.01	0	0	7.6	0.3	12	20	120	--	19
0.3	20(a)	0	--	--	0.7	10	1.7	0.6	52	5.8	20.4
0.1	0	0.55	0	0	0.9	6.5	2.8	0.7	--	--	--
0.1	0	0	--	--	2.3	7.3	4.5	5.4	130	--	21

Table 8.--Chemical analyses of ground and surface water in the vicinity of the low-level radioactive-solid-waste burial site near Barnwell, S.C. (analysis in mg/L unless otherwise indicated)--Continued

Site no.	Well depth (ft)	Date of sample collection	Alkalinity (as $CaCO_3$)[a]	Aluminum (Al) (µg/L)	Bicarb (HCO_3)	Calcium (Ca)	Chloride (Cl)	Fluoride (F)	Hardness (total) (b)	Iron (Fe) (µg/L)
CE-8W	182	12/14/76	16	50	20	3.9	2.4	0.2	11	10
CN-1E	50	2/11/77	8	--	10	3.4	3.9	0.1	9	30
CN-1W	75	2/11/77	46	--	56	8.2	16	0.2	23	10
CN-3S	69	4/28/77	11	160	13	3.6	1.6	0	10	20
TW-1S	170	8/17/78	10	90(a)	--	2.4	1.4	0	8	40(a)
OT-1W	53	8/16/78	1	180(a)	--	1.1	2.4	0	4	10(a)
OT-1E	84	8/10/76	2	330(a)	--	1.0	1.9	0	4	10(a)
BW-144	182	9/8/78	100	20	--	39	2.3	0	100	10
P-2*	850	12/17/79	19	--	--	3.5	2.5	0.2	11	30
M.S.*	--	12/27/79	2	--	--	0.5	1.8	0	2	20
M.S.G.*	--	12/27/79	2	--	--	1.9	2.3	0	7	50
B.I.W.*	340	12/17/79	0	--	--	2.2	1.5	0.1	7	830
C.W.#7*	--	12/17/79	31	--	--	13	2.4	0.2	34	110
Dun.*	--	2/2/77	6	70	7	1.6	2.7	0.1	5	50
Pat.*	--	9/8/78	2	70	--	0.7	2.9	0	3	60
Har.*	--	9/8/78	22	60	--	8.3	3.3	0	23	90
Prec.*	--	8/17/78	4	--	--	0.6	0.6	0.1	2	20

(a) -- Total

(b) -- as $CaCo_3$

* T.B. -- Thunder Bay
Dun. -- Duncannon Creek
Pat. -- Patterson Branch
Har. -- Harley Branch
Prec. -- Rainfall

Magnesium (Mg)	Manganese (Mn) (μg/L)	NO_2 + NO_3 (as N)	Orthophosphate as P	Phosphate (PO_4) (ortho)	Potassium (K) (mg/L)	Silica (SiO_2) (mg/L)	Sodium (Na) (mg/L)	Sulfate (SO_4) (mg/L)	Spec. cond. (micromhos 25°C)	pH	Water temp. (°C)
0.2	10	0.29	0.23	0.71	0.3	9.2	8.7	8.1	--	--	--
0.2	10	0.26	0	0	0.7	5.3	3.0	2.9	27	--	19.0
0.5	10	0.16	0	0	23	11	16	13	180	--	19.5
0.3	40	0.75	0	0	0.2	6.2	1.5	0.4	--	--	--
0.4	10(a)	0.5	--	--	0.4	6.3	1.4	0.3	24	5.6	19.5
0.3	0	1.4	--	--	0.3	4.8	3.0	0.5	26	5.2	22
0.4	60	0.62	--	--	0.2	5.1	1.5	0.3	17	4.8	19.5
1.1	10	0.08	0	0	0.7	12.	1.5	1.4	250	7.3	19.0
0.5	3	0.06	0.71	2.2	1.1	18	1.7	0.4	41	5.3	21.0
0.3	7	0.62	0.03	0.09	0.6	8.0	1.5	0.1	18	--	17.0
0.5	7	0.43	0.05	0.15	0.4	7.1	1.8	0.1	31	--	--
0.4	30	0.06	0.01	0.03	1.4	13	1.4	9.8	37	4.5	18.0
0.4	0	0.07	0.53	1.6	0.6	15	1.6	0.6	78	6.8	19.0
0.3	10	0.6	0.01	0.03	0.4	5.6	1.8	1.3	--	--	--
0.4	140	0.3	0	0	0.9	4.8	1.6	1.5	15	6.8	--
0.5	20	0.29	0.06	0.18	0.7	10	2.0	1.2	66	6.0	--
0.1	30	0.53	--	--	1.1	0.3	1.2	2.1	21	5.3	--

M.S. -- Marys Branch Creek at source
M.S.G. -- Marys Branch Creek 1 mile downstream from source
B.I.W. -- Barnwell industrial well
C.W.#7 -- Barnwell City Well No. 7
P-2 -- Allied General Nuclear Services production well

Table 9.--Field measurements, radionuclides,[a] and dissolved organic carbon[a] of trench and well water (zone 1) from the low-level radioactive-solid-waste burial site near Barnwell, S.C. [number in ( ) = 2σ% counting uncertainty]

Sample location	Date sampled	pH	Temperature ° C	Specific cond. (μmho/cm at 25°C)	Gross alpha (pCi/L)	Gross beta (pCi/L)	Tritium (pCi/L)	Radionuclide concentration (pCi/L) Cesium-137	Radionuclide concentration (pCi/L) Cobalt-60	Dissolved organic carbon (mg/L)
Trench 5D1	2/22/78	5.9	14	580	$<6x10^1$	$1.4x10^3(21)$	$1.3x10^7(<1)$	$1.8x10^2(13)$	$2.8x10^2(12)$	130
Trench 6D1	2/22/78	5.9	13	360	$<6x10^1$	$<3x10^2$	$1.0x10^6(<1)$	$<1.8x10^1$	$<1.8x10^1$	6.1
Trench 7D1	2/23/78	6.5	17	1370	$1.0x10^3(21)$	$3.6x10^3(10)$	$6.4x10^8(<1)$	$3.6x10^1(28)$	$<1.8x10^1$	3.0
Trench 8D1	2/22/78	6.3	15	750	$<6x10^1$	$8x10^2(32)$	$3.5x10^7(<1)$	$<1.8x10^1$	$7\ x10^1(24)$	180
Trench 13 D3	2/23/78	6.3	17	380	$<6x10^1$	$<3x10^2$	$1.7x10^6(<1)$	$1.1x10^2(18)$	$<1.8x10^1$	280
Trench 22 D8	2/23/78	6.7	14	45	$<6x10^1$	$<3x10^2$	$1.2x10^6(<1)$	$8\ x10^1(24)$	$<1.8x10^1$	1
Well WW 5	3/1/78	8.4	18	23	$<6x10^0$	$<2x10^1$	$9.7x10^2(28)$	$<1.8x10^1$	$<1.8x10^1$	2-3.7
Well WW 6	3/1/78	6.8	18	35	$<6x10^0$	$<2x10^1$	$1.4x10^3(21)$	$<1.8x10^1$	$<1.8x10^1$	1
Well WW 7	2/23/78	5.9	--	30	$<6x10^0$	$<2x10^1$	$1.1x10^3(24)$	$<1.8x10^1$	$<1.8x10^1$	2-3.9
Well CN-1E	3/1/78	9.6	18	164	$<6x10^0$	$<2x10^1$	$1.5x10^3(20)$	$<1.8x10^1$	$<1.8x10^1$	15
Well CN-3N	3/1/78	11.4	18	1600	$<6x10^0$	$<2x10^1$	$9.7x10^2(28)$	$<1.8x10^1$	$<1.8x10^1$	4.5
Well CN-4W	3/1/78	10.4	18	205	$3x10^1(33)$	$1.2x10^2(15)$	$1.9x10^5(<1)$	$<1.8x10^1$	$<1.8x10^1$	11

[a]Analyses made by Brookhaven National Laboratory, Upton, N.Y.

Table 10.--Concentration of dissolved nonmetals and metals in trench water samples taken at the low-level radioactive-waste burial site near Barnwell, S.C. (from Weiss and Colombo, 1980)

Dissolved component (mg/L)	Trenches 8	6	25/21	3	5
Total Alkalinity (as $CaCO_3$)	600	40	80	100	200
Inorganic Carbon	130	11	38	24	--
DOC	170	2	12	7	--
Hardness (Ca+Mg) (as $CaCO_3$)	160	44	66	20	81
Residue (180°C)	650	330	185	80	385[a]
Chloride	85	90	42	7	10
Nitrogen (N) (ammonia)	59	1.4	25	0.3	--[b]
Nitrogen (N) (NO_2^- + NO_3^-)	8.0	23	15	<0.04	<0.1
Phosphate	<0.5	<0.5	<0.5	<0.5	<0.5
Silica	6.0	5.8	5.0	4.3	7.6
Sulfate	34	18	56	<5	7
Sulfide	<1	<1	<1	<1	<1
Total Anions (meq/L)	16	4	5.7	2.3	4.4
Barium	<1	<1	<1	<1	<1
Calcium	34	16	21	4.0	3.2
Cesium	<0.1	<0.1	<0.1	<0.1	<0.1
Iron	1.2	0.4	0.2	0.15	1.5
Lithium	<0.1	<0.1	<0.1	<0.1	<0.1
Magnesium	18	1.0	3.3	2.5	3.3
Manganese	0.72	0.45	0.32	0.24	0.34
Potassium	12	1.4	3.5	1.0	4.6
Sodium	87	29	37	2.3	20
Strontium	<0.1	<0.1	<0.1	<0.1	<0.1
Total Cations[c] (meq/L)	12	2.3	4.8	0.55	2.9

[a]Filtered acidified sample.

[b]Insufficient sample for analysis.

[c]Includes nitrogen as NH_4^+.

Radioactivity of Sediment Cores

Wells were drilled near some of the older trenches to depths of 75 feet to determine the extent of radionuclide migration from the trenches. Sediment cores were obtained at 2 to 5 foot intervals and were examined for gamma-emitting radionuclides and tritium as HTO. The cores showed no indications of man-made gamma emitters. Analyses of moisture in all cores indicated the greatest tritium activity near the land surface adjacent to the burial trenches (fig. 31). The greatest tritium activity, about 1,800,000 pCi/L, was detected in moisture in sediment cores from well CN-4 (fig. 4) at about 10 feet below land surface. A high activity of tritium was detected in well CN-2 at a depth of 15 feet. Well CN-2 is located about 10 feet south from the east end of trench 8 (fig. 5). A tritium activity of about 18,000 pCi/L was detected in a core from well CN-3 at a depth of about 5 feet. Well CN-3 is located about 15 feet northwest of trench 8. Tritium activity of about 70,000 pCi/L was detected in soil moisture at 5 feet at well CN-1. Tritium activity near background level was detected in soil moisture in cores from wells CN-5, CN-6, and CN-7. These wells are located about 200 feet southwest from the burial trenches.

The occurrence of high tritium activity in the unsaturated zones near the land surface indicates that tritium migrates upward either as vapor or as soil moisture. The high activity near the land surface may be due to a combined effect of rainfall and soil moisture evaporation. Soil moisture evaporation would tend to move the tritium upward by capillarity, and rainfall would tend to move it downward.

Table 11 shows the clay mineral determinations including cation exchange capacity, moisture content, and percent of sands and clays from cores obtained at well CN-4. X-ray analyses of the clays indicate that the sediments consist mostly of quartz and kaolinite. There is little mixed-layered clay minerals which would retard radionuclide migration. The cation exchange capacity of the sediments is less than 3.1 milliequivalents per 100 grams of sediment. The greatest soil moisture content is below 20 feet or about the same depth as the floor of trench 8.

Radioactivity of Sediments Beneath Trench Floors

Cores were collected from within 4-inch diameter steel pipes that were driven through the buried waste past the floor of trenches 2, 5, 7, and 8 using a method described by Prudic (1979). Sediment cores were obtained continuously from beneath the waste to a depth of 10 feet above the water table.

Figure 32 shows graphically the change in tritium activity in the sediments with depth. One billion pCi/L of tritium was detected in cores obtained at the west end of trench 7. Cores from trench 8, near well CN-4 (fig. 5), showed a relatively high tritium activity which decreased with depth. The tritium activity in the moisture from cores beneath trench 5 was greater than one million pCi/L. Less than one million pCi/L of tritium was detected in cores from beneath the west end of trench 2.

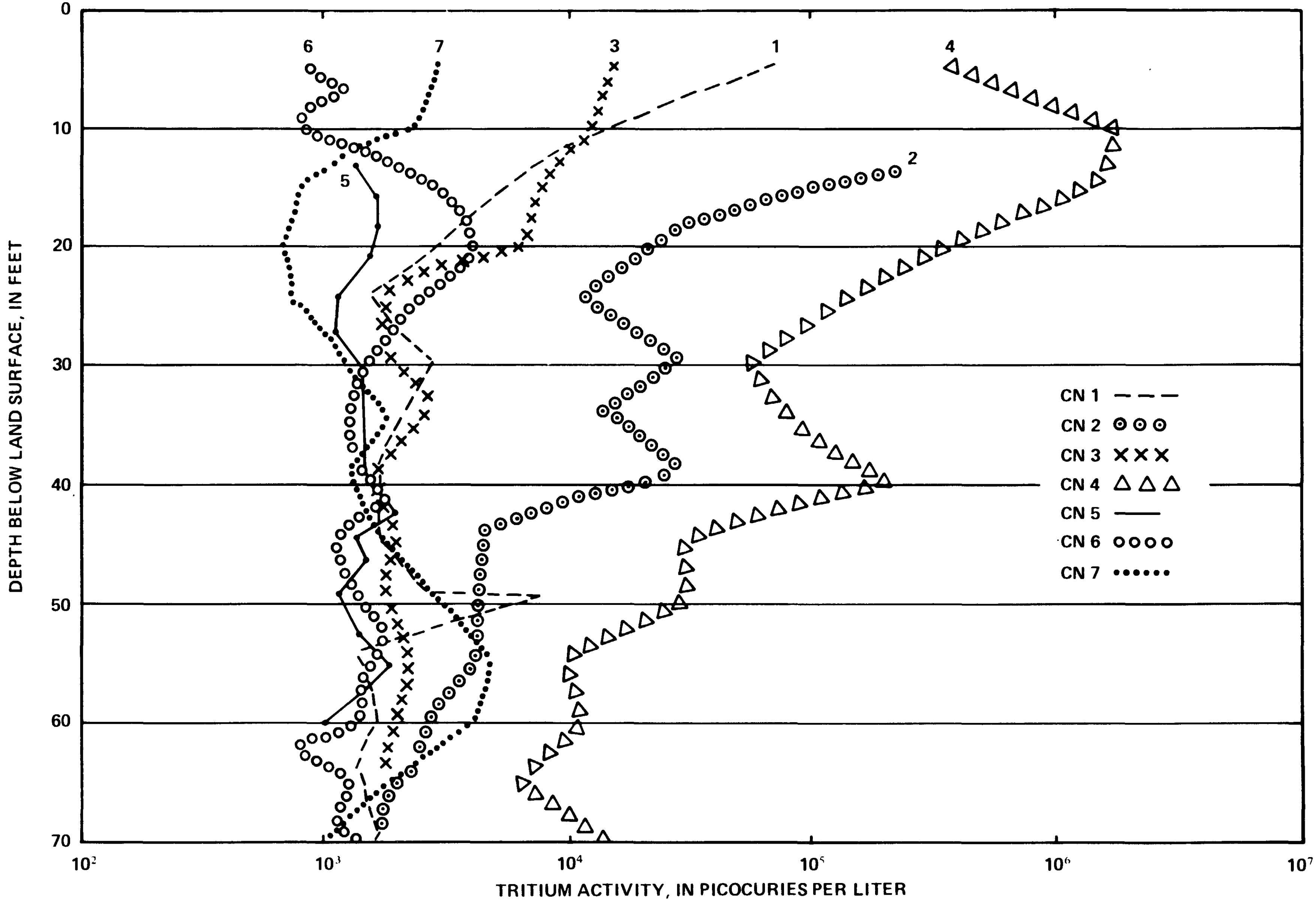


Figure 31.--Tritium activity in water extracted from core samples taken at the low-level radioactive-solid-waste burial site near Barnwell, S.C.

Table 11.--Clay-fraction determinations, cation-exchange capacity, moisture content, tritium content, and percentage of sand and clays in borings obtained from well CN-4 at the low-level radioactive-solid-waste burial site near Barnwell, S.C.

Depth (feet below land surface)	Clay-fraction determination by X-ray diffraction (weight percent) (1)									(1)	(2)	(2)	(2)	
	Quartz	Potassium feldspar	Plagioclase feldspar	Chlorite	Kaolinite	Illite	Montmorillonite	Mixed-layered clay minerals	Total	Cation exchange (milliequivalents per 100 grams of soil)	Percent moisture (grams per gram)	Tritium (picocuries per liter of water)	Sand (percent)	Silt and clay (percent)
5	72	0	0	0	33	0	0	0	105	1.7	10.8	$3.5x10^5$	75	25
10	48	0	0	0	36	0	0	1	85	2.8	16.3	$1.8x10^6$	51	49
15	60	0	0	0	30	0	0	0	90	2.6	14.8	$1.4x10^6$	66	34
20	58	0	0	0	33	0	0	0	91	3.1	15.4	$3.7x10^5$	56	44
25	50	0	0	0	40	0	0	0	90	2.1	20.0	$1.3x10^5$	61	39
30	58	0	0	0	30	0	0	0	88	1.5	17.0	$5.5x10^4$	63	37
35	69	0	0	0	30	0	0	0	99	1.3	21.3	$8.1x10^4$	73	27
40	61	0	0	0	33	0	0	0	94	1.9	20.6	$2.0x10^5$	69	31
45	69	0	0	0	26	0	0	1	96	2.7	18.9	$2.9x10^4$	71	29
50	73	0	0	0	27	0	0	0	100	2.3	23.7	$3.0x10^4$	72	28
55	73	0	0	0	26	1	0	1	99	2.7	23.3	$1.0x10^4$	76	24
60	80	2	0	0	16	1	0	1	99	2.3	24.1	$1.2x10^4$	83	17
65	85	0	0	1	2	1	0	4	92	2.6	23.4	$6.5x10^3$	85	15
70	76	0	3	0	7	2	0	1	89	2.1	29.9	$1.5x10^4$	84	16

(1) Analysis made by U.S. Geological Survey, Lakewood, Colo.

(2) Analysis made by South Carolina Bureau of Radiological Health.

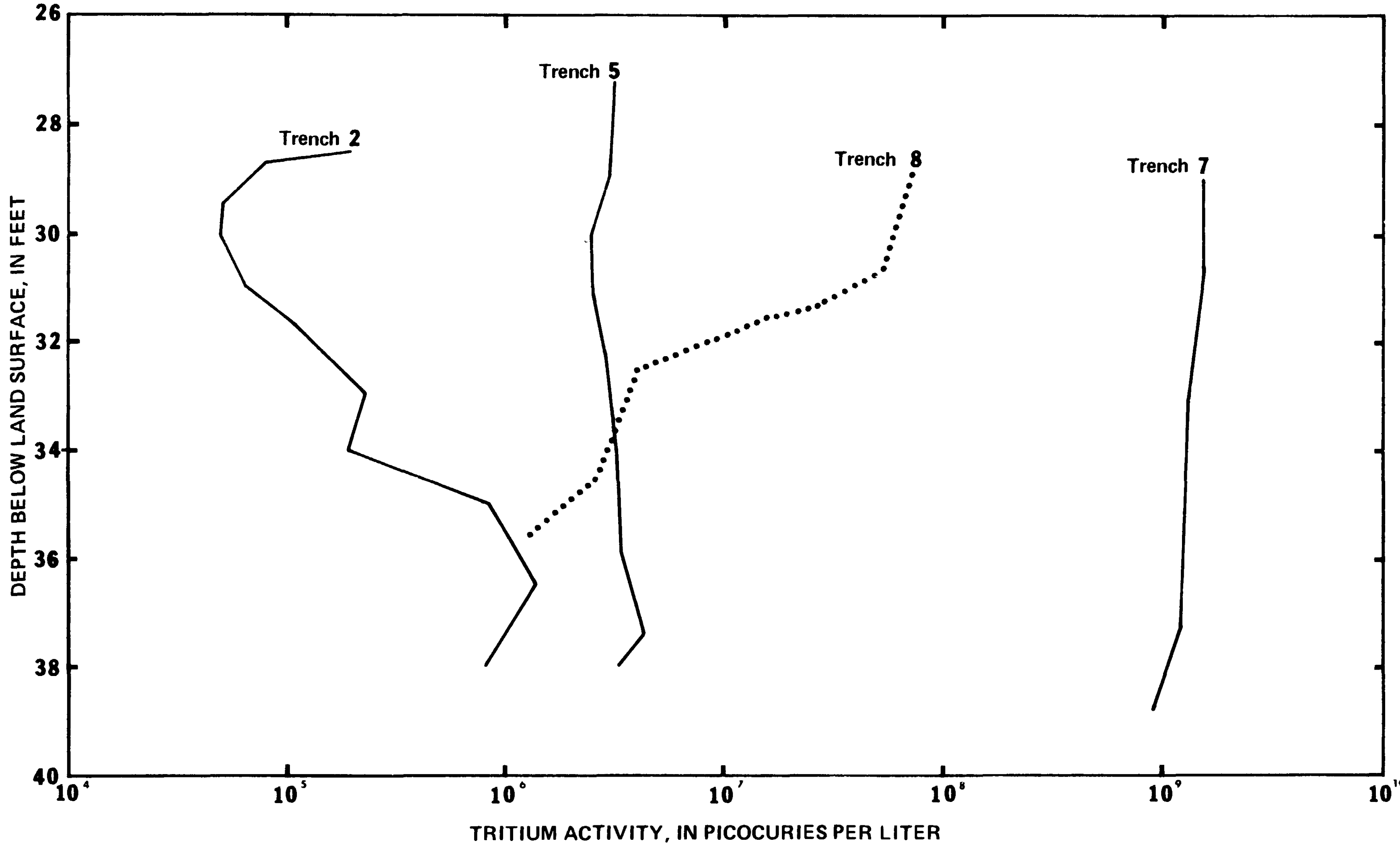


Figure 32.--Tritium activity in water extracted from core samples taken from beneath buried waste trenches at the low-level radioactive-solid-waste burial site near Barnwell, S.C.

Table 12 shows the laboratory analysis of tritium (HTO) activity, soil moisture content, and cobalt-60 activity of the sediment cores from trench 2. Analyses of the sediment cores showed the presence of cobalt-60 beneath the floor of trench 2. The highest activity of cobalt, 690 pCi/g (picocurie per gram of sediment), was detected in a zone 0.5 to 0.8 foot beneath the trench floor. A cobalt activity of 2.4 pCi/g was detected in the zone 5.7 to 6.0 feet beneath the trench floor. Cobalt was not present below 6.0 feet of the trench floor.

Table 12.--Tritium, cobalt-60, and moisture content in sediments beneath waste at trench 2 (analysis by South Carolina Bureau of Radiological Health)

Depth below land surface (feet)	Tritium (pCi/L)	Moisture content (g/g)	Cobalt-60 (pCi/g)
28.2 - 28.5	190,300 ± 436	5.3	20.8 ± 3.1
28.5 - 28.8	78,800 ± 281	13.7	690 ± 51
29.2 - 29.5	49,800 ± 223	16.0	609 ± 47
30.0 - 30.2	48,700 ± 221	20.5	22.9 ± 4.3
30.7 - 31.0	65,600 ± 256	12.7	3.2 ± 1.5
31.5 - 31.8	87,100 ± 295	14.6	4.8 ± 2.0
32.9 - 33.2	228,600 ± 478	12.8	8.2 ± 2.8
33.7 - 34.0	189,300 ± 435	14.2	2.4 ± 1.6
34.7 - 35.0	851,500 ± 923	16.5	0
35.5 - 35.8	1,081,000 ± 1,040	16.5	0
36.3 - 36.5	1,383,000 ± 1,126	19.9	0
37.4 - 38.0	824,800 ± 908	25.0	0
38.9 - 39.2	77,200 ± 278	25.5	0

Geophysical Logs of Trench Waste and Sediments

Geophysical logs were made of the inplace buried waste and sediments in trenches 5, 7, and 8. Approximate depths of the trench floors below land surface are 25, 26, and 25 feet respectively. The geophysical logs included: (1) a caliper log to give an indication of diameter of the cored hole and to verify the depth of the steel pipe beneath the trench floor, (2) a neutron log to detect the moisture content of the sediments, (3) a gamma-ray log to detect any gamma emitting isotopes, and (4) a gamma spectral analysis of the gamma emitting isotopes.

The logs for the borehole through trench 5 are shown in figure 33. The caliper log indicates that the bottom of the steel pipe is 26 feet and 1.6 feet below the trench floor. The hole extends to a depth of 34.6 feet and is about 3 inches in diameter below the pipe and is reduced to 2 inches below 30.6 feet. The neutron log indicates that the material in the trench is dry to a depth of 16 feet. Some relatively wet zones occur at depths of 16 to

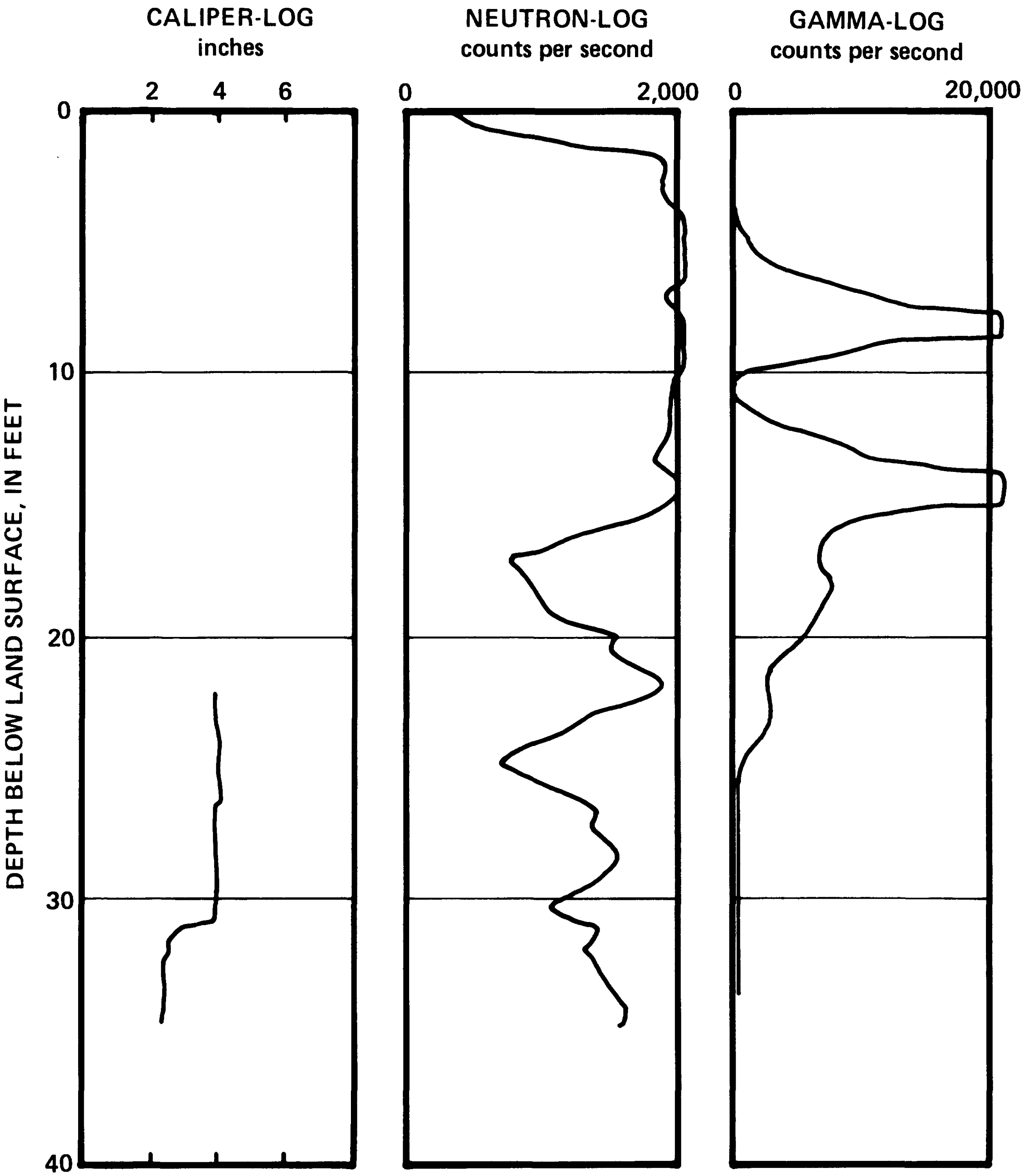


Figure 33.--Geophysical borehole logs of trench fill and sediments underlying trench 5, at the low-level radioactive-solid-waste burial site near Barnwell, S.C.

19.5 feet, 23 to 26 feet, and at 30 feet. The gamma logs show major peaks at about 8 and 14.5 feet where the maxima are off-scale or greater than 25,000 cps (counts per second). The radioisotope cesium-137 was identified at a depth of 6 feet. However, gamma spectra and laboratory radiochemical analysis did not indicate the occurrence of man-made isotopes beneath the trench floor (Scott Keys, 1979, written commun.).

The geophysical logs from the borehole beneath trench 7 (fig. 34) show that the base of the steel-driven pipe was about 27.6 feet below land surface and 1.6 feet below the bottom of the trench. The neutron log indicates that the material filling the trench was dry to a depth of about 17 feet. The gamma ray log indicated that the base of the waste was about 26 feet and that radioactivity greater than 10,000 cps occurred at a depth of about 17 to 26 feet or at about the same depth where the highest moisture content occurred. The gamma spectrum analysis indicated relatively high activity of cesium-137 with some cobalt-60 at a depth of 17 feet. The gamma spectra did not indicate the presence of artificial radioisotopes in the sediments beneath the trench floor.

The caliper log obtained at trench 8 (fig. 35) shows that the base of the steel pipe was driven to a depth of about 29 feet. The gamma log indicated that the base of the waste was at about 25 feet. The neutron log indicates that the waste has a relatively uniform moisture content except for a wetter zone between 12 to 17 feet. The neutron log also indicates the highest moisture content at a depth of about 34 to 37.6 feet.

The gamma log indicates high gamma activity, 27,000 cps, between 8 and 24 feet where the gamma spectra indicated presence of cobalt-60 and cesium-137 in the buried waste at about 8 feet. However, the spectra did not indicate presence of gamma emitting artificial isotopes in the sediments beneath the trench floor.

Hydrologic Modeling

A digital finite-difference model of 3-dimensional ground-water flow (Trescott, 1975) was used to simulate steady-state hydrologic conditions of the water-bearing zones and streams in the area. The model provided insight on the movement of water through the water-bearing zones to the streams. Although the model was not verified by pumpage or other stresses on the aquifer system, it did aid in the interpretation of water-level altitudes in the zones where little or no data were available. It also provided information on the quantity of water each zone contributed to the streams. Water movement and flow to the streams from zones having different water-level altitudes is necessary to establish a reliable network of monitoring wells to observe radionuclide migration.

The model is designed to solve the basic finite-difference equation in three dimensions expressed as (Trescott, 1975):

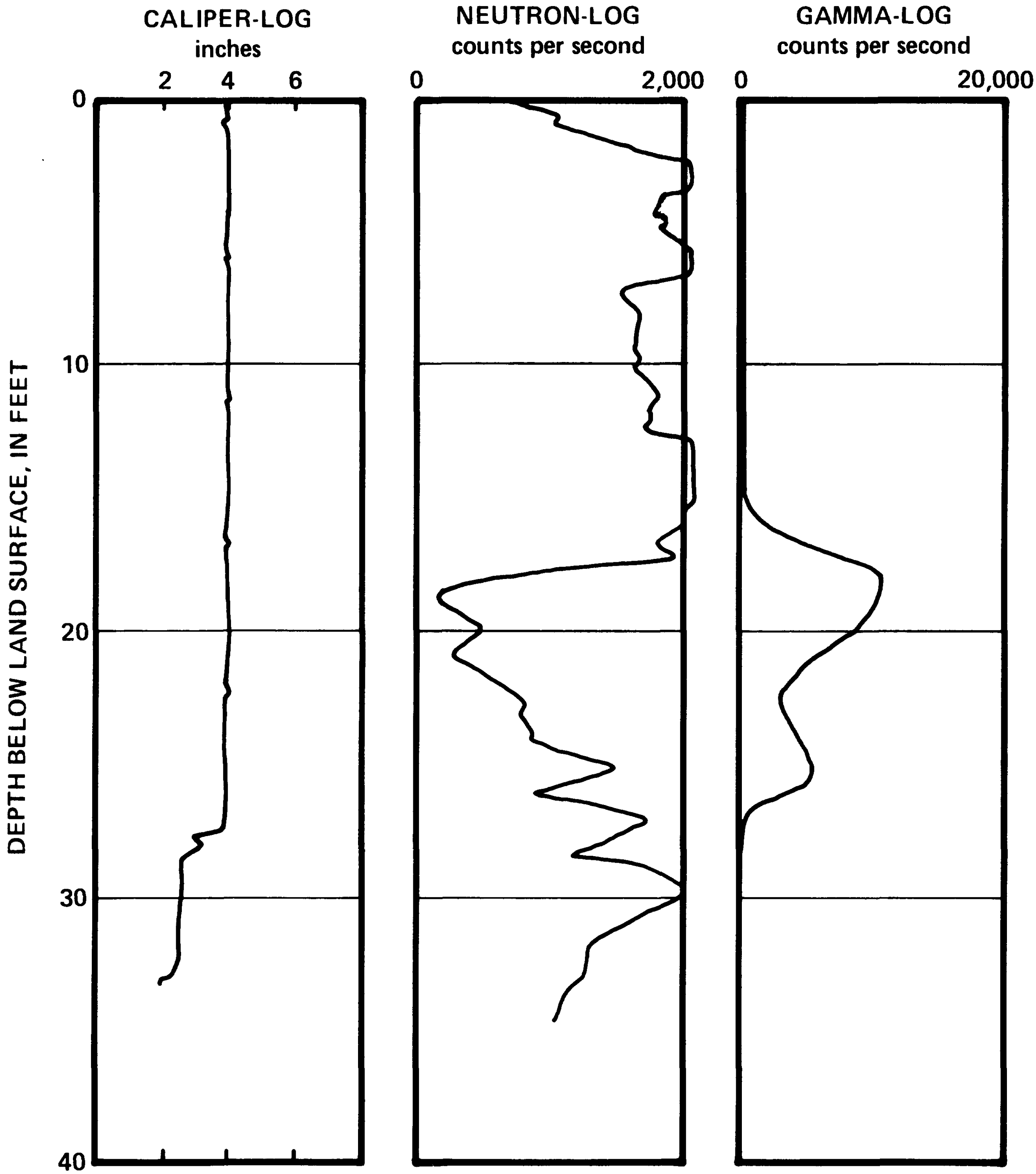


Figure 34.--Geophysical borehole logs of trench fill and sediments underlying trench 7, at the low-level radioactive-solid-waste burial site near Barnwell, S.C.

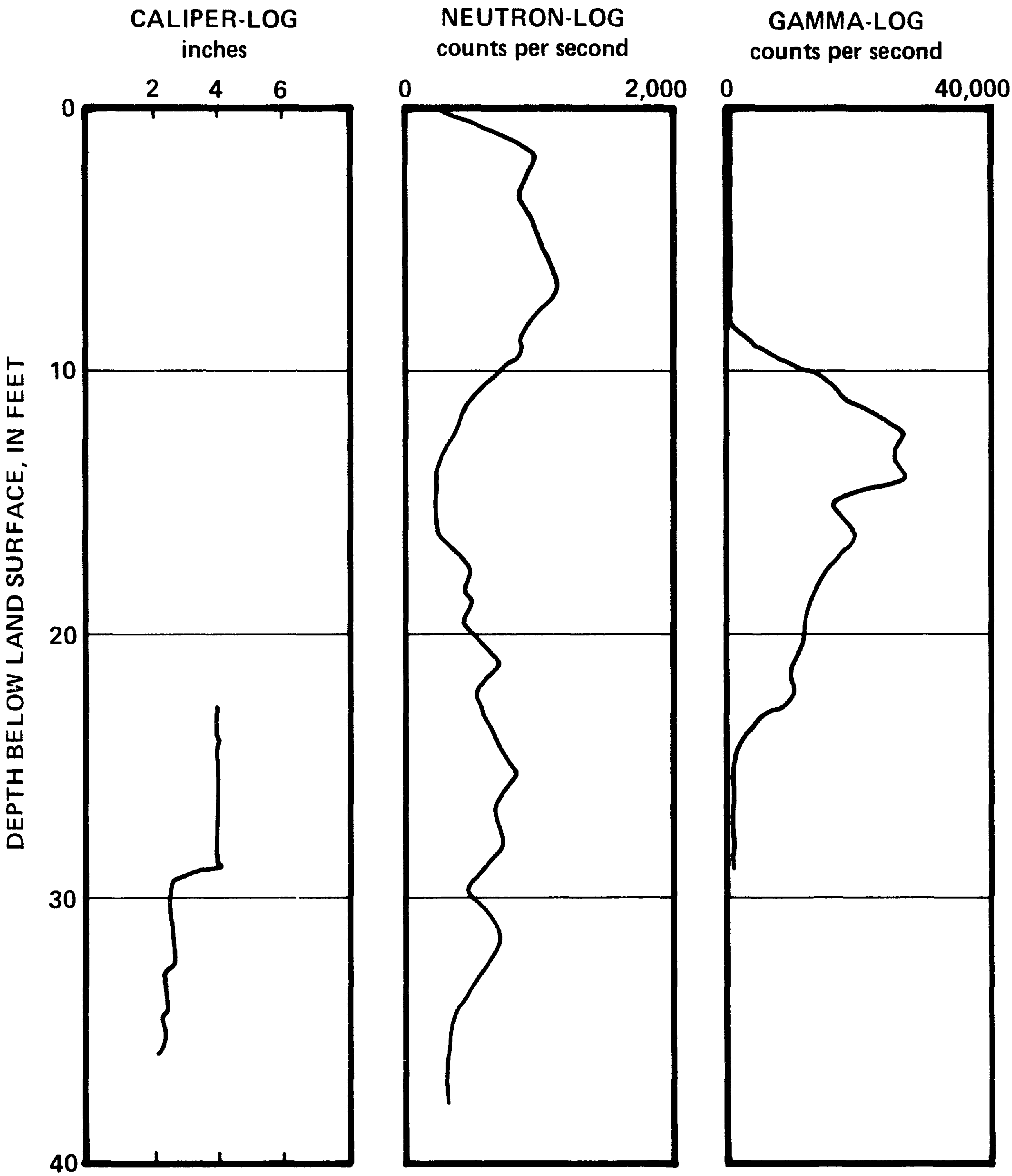


Figure 35.--Geophysical borehole logs of trench fill and sediments underlying trench 8, at the low-level radioactive-solid-waste burial site near Barnwell, S.C.

$$\partial/\partial x\ (T_{xx}\ \partial h/\partial x) + \partial/\partial_y\ (T_{yy}\ \partial h/\partial y) + b\ \partial/\partial z\ (K_{zz}\ \partial h/\partial z)$$

$$= S\ \partial h/\partial t + bW(x,y,z,t) \qquad (1)$$

where: T_{xx} = principal component of the transmissivity tensor in the x direction, in feet squared per day;
h = hydraulic head, in feet;
T_{yy} = principal component of the transmissivity tensor in the y direction, in feet squared per day;
b = thickness of the hydrogeologic unit, in feet;
K_{zz} = principal component of hydraulic conductivity in the z direction, in feet per day;
S = storage coefficient, dimensionless;
t = time, in days; and
W(x,y,z,t) = volumetric flux per unit volume, per day.

The model area was increased about 27 square miles more than the 44 square mile study area to minimize ponding effect at the streams. Expansion was about 10,700 feet north, 9,000 feet south, 3,000 feet west of Lower Three Runs, and 2,000 to 4,000 feet east of the Salkehatchie River.

Hydrologic assumptions in the model are that the water-bearing zones receive vertical recharge, the sediments are isotropic within a model unit, all units are saturated, and steady-state conditions prevail. Recharge to the system is by infiltration from precipitation, and discharge is mostly to streams within the area. The amount of water pumped from the water-bearing zones is insignificant compared to recharge by precipitation and discharge to streams. Leakage from zone 1 to zones 2 and 3 (see figs. 17 and 28 for zone delineation) appears to be relatively steady as indicated by similar water-level fluctuations. Leakage from zone 3 to zone 4 is assumed to be negligible. Hence, the confining bed between zones 3 and 4 is considered to be the base of the model. Flow between the confining layers is assumed to be only vertical and flow within the aquifers (zones) horizontal. The procedure in modeling the hydrologic system has been described by Bredehoeft and Pinder (1970).

The model simulates three layers (zones) and uses a block-centered grid system (fig. 36). The grid defines 27 rows of blocks aligned north and south and 31 columns of blocks aligned east and west. Block size varies as shown in figure 36, ranging from 1,000 feet by 1,000 feet to 6,000 feet by 5,000 feet. Stream channels penetrate zones 1 and 2, and most of the blocks are placed so that a stream channel could be located near the center of the blocks. The stream beds and stream-water surfaces are considered to have the same altitude so that leakage is to the streams.

The vertical hydraulic conductivity of sediments between zone 1 and zone 2 is not uniform throughout the study area. The water levels of zone 1 are about 1/2 to 10 feet greater than zone 2. The water-level gradient of zone 2 is less than the water-level gradient in zone 1. More water moves laterally to streams from zone 2 than zone 1 because of the higher transmissivity.

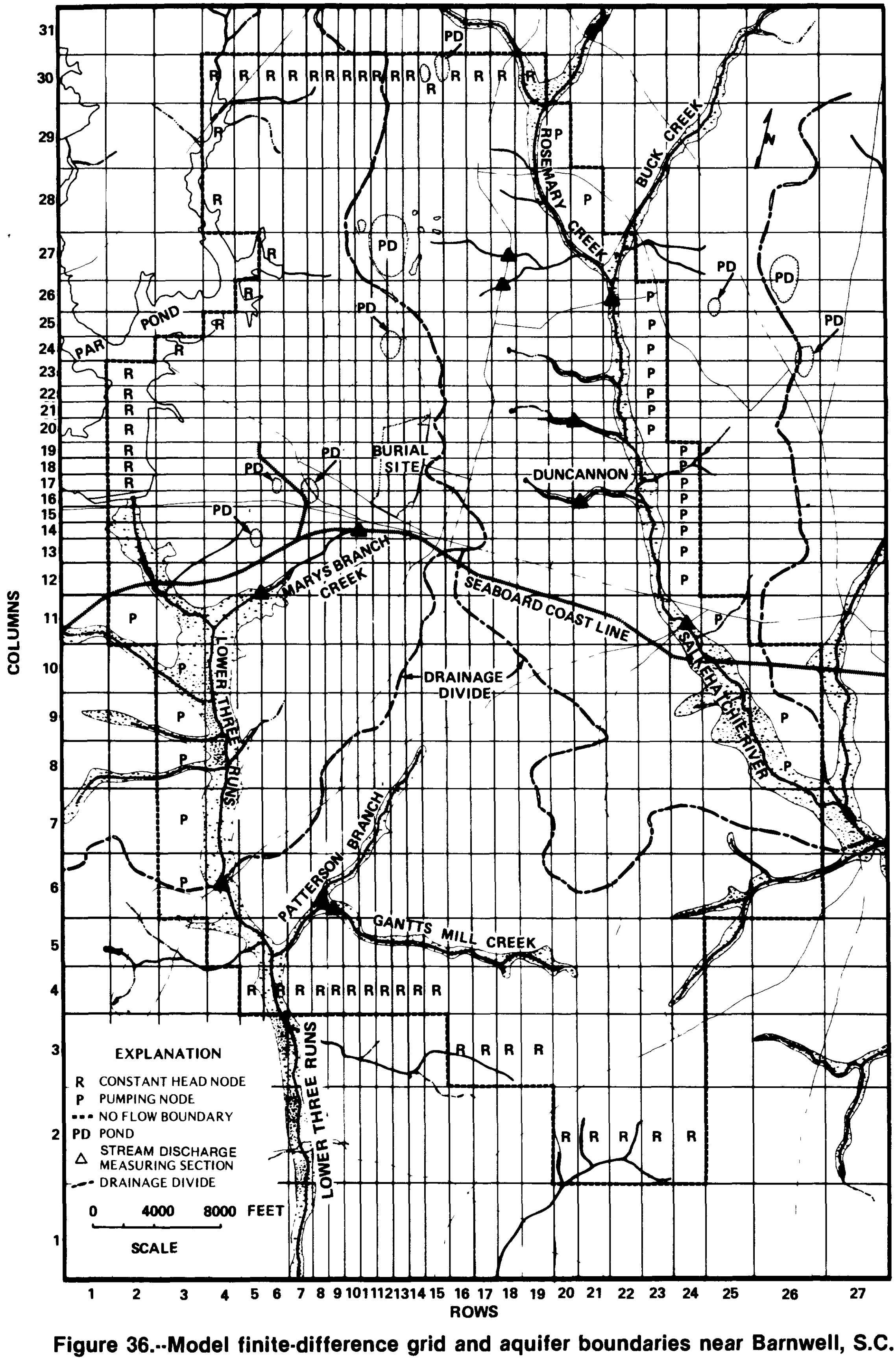


Figure 36.--Model finite-difference grid and aquifer boundaries near Barnwell, S.C.

The initial water levels at blocks other than constant-head were assigned an altitude of 250 feet above NGVD in the upper two zones and 200 feet above NGVD in zone 3. The water levels at the northern boundary constant-head nodes ranged from 270 to 230 feet above NGVD. The water levels at the southern boundary constant-head nodes were 160 feet above NGVD. The water level of Par Pond was maintained at 200 feet.

Constant-head blocks define the northern boundary and the southern boundary for all zones. The eastern boundary of zone 3 was simulated as constant flux out of the modeled area by a line of pumping wells. The western boundary was simulated with a constant-head at Par Pond and a line of constant pumping wells (constant flux boundary) in zone 3 west of Lower Three Runs (fig. 36) to simulate lateral outflow from the study area in the unconfined sediments.

Ground-water discharge in the model consisted of streamflow to the Salkehatchie and Lower Three Runs streams, and pumpage from zone 3 along the east and west boundaries.

Leakage to streams was determined by the equation:

$$Q = (K'/b')(A_s/A_b)(H_s - H_a) \qquad (2)$$

where: Q = leakage to the streams;
K' = hydraulic conductivity of the confining stream bed, in feet per day;
b' = thickness of the confining stream bed, in feet;
A_s = areas of the stream in square feet;
A_b = area of model block, in square feet;
H_s = water-level altitude in streams, in feet; and
H_a = water-level altitude in aquifer, in feet.

Equation 2 is the input to the model to solve the leakage equation (TK) based on the difference in water-level altitudes between the aquifer and surface stream. The leakage value is multiplied by the area of the model block to yield units of volume divided by time.

The altitude of the water surface in the stream is about the same as the topographic altitude. Pumpage from zone 3 simulates the constant flux boundary and is adjusted to regulate the stream leakage in the model by reducing the water-level altitude in the model near the streams.

A recharge rate of 15 inches per year was used for most of the area (see section on Interrelation Between Streams and Water-Bearing Zones). A recharge rate of 30 inches was used near ponds and in the vicinity of perched water tables where recharge to the ground-water system is continuous. The model was not sensitive to recharge differences of 1 or 2 inches.

The model was calibrated by comparing computed water levels with observed water levels in the three zones. Calibration also included comparing the computed seepage to streams with observed stream discharges. The comparisons were for field measurements obtained during November 15-17, 1978, when evapotranspiration and rainfall were minimal.

Initial transmissivities were determined from slug test data in zone 1 and from laboratory hydraulic conductivity values multiplied by the thicknesses of zones 2 and 3. Transmissivities obtained from laboratory hydraulic conductivities were about 380 ft^2/d and about 620 ft^2/d for zones 2 and 3, respectively. These values are considerably lower than those transmissivity values used in the model. Transmissivities from the slug test data and aquifer performance test closely matched the values used in the model.

Model transmissivities were adjusted as necessary during calibration to minimize the differences between computed heads and observed heads and stream discharges. Trial and error was used to adjust the transmissivities and interlayer leakance (TK values) in the model to match the observed water levels and streamflow. The final transmissivity values used in the model are referred to as "adjusted" transmissivities.

The adjusted transmissivities in zone 1 (table 13) ranged from about 6 to 600 ft^2/d. The lowest transmissivities occurred near Par Pond and the highest occurred southeast of the burial site. The transmissivity in the trench area ranged from about 30 to 180 ft^2/d.

Adjusted transmissivity values for zone 2 are shown in table 14. These transmissivity values ranged from about 120 to 4,500 ft^2/d. Higher transmissivities occurred near the streams. Transmissivities in the vicinity of the burial site ranged from about 300 to 4,500 ft^2/d.

Adjusted transmissivities for zone 3 ranged from about 600 ft^2/d just east of the burial site to about 6,000 ft^2/d near the Salkehatchie River (table 15). Transmissivities ranged from about 1,200 to 4,800 ft^2/d in the vicinity of the burial site.

The model transmissivities of the upper three zones at the burial site ranged from about 1,500 to 9,500 ft^2/d as compared to the estimated 3,000 to 6,000 ft^2/d determined from the aquifer tests in zones 1, 2, and upper part of 3 at the northern section of the site. Large changes in transmissivities (50 percent) resulted in only small changes in the computed water levels.

The initial TK values, K'/b' (hydraulic conductivity of the confining bed divided by its thickness), used in the model between the water-bearing zones were determined from laboratory hydraulic conductivities which were divided by an estimated thickness of 10 ft for the semi-confining layers. The adjusted TK values between zones 1 and 2 are shown in table 16 and the TK values between zones 2 and 3 in table 17. TK values (1/d) that controlled vertical leakage between zones 1 and 2 ranged from about 0.002 near the burial site to 0.02 near Par Pond. TK values between zones 2 and 3 ranged from about 0.0002 to 0.03 with an average of about 0.0004 at the burial site. Changes in TK values between zones 1 and 2 had little effect on the computed water levels. However, a small change in the TK values between zones 2 and 3 had significant effect on computed water levels in all zones.

A comparison of observed point water levels and contours of computed water levels for zone 1 are shown in figure 37. The difference in computed and observed water levels averaged less than 2 feet.

Table 13.--Transmissivity values, in feet squared per day, used in upper model layer (zone 1)

Col-	Rows																									
umns	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	9	9	9	9	6	12	27	9	9	9	9	9	9	9	15	15	0	0	0	0	0	0	0	0
29	0	0	0	9	9	9	9	6	12	27	9	9	9	9	9	9	9	15	15	0	0	0	0	0	0	0	0
28	0	0	0	9	9	9	9	6	12	27	9	9	9	9	9	9	9	15	15	30	0	0	0	0	0	0	0
27	0	0	0	0	9	36	24	36	12	27	9	9	9	15	9	9	9	15	15	18	18	0	0	0	0	0	0
26	0	0	0	0	9	60	36	60	24	60	36	9	24	15	18	9	9	15	15	18	15	90	0	0	0	0	0
25	0	0	0	30	30	60	36	60	60	60	60	24	45	24	27	9	24	15	15	18	18	90	0	0	0	0	0
24	0	0	30	30	30	15	15	60	30	60	60	45	60	45	30	36	48	30	30	36	54	90	0	0	0	0	0
23	0	6	30	30	24	15	24	45	30	60	60	60	60	60	360	450	72	36	108	108	96	180	0	0	0	0	0
22	0	6	30	30	24	24	24	45	30	75	60	60	90	90	540	450	72	60	54	144	144	180	0	0	0	0	0
21	0	6	30	15	24	24	45	45	30	75	60	120	180	180	540	600	108	120	270	144	144	180	0	0	0	0	0
20	0	6	30	15	24	36	45	15	24	45	30	60	90	180	360	600	360	180	270	300	216	270	0	0	0	0	0
19	0	6	30	15	24	24	30	15	18	30	30	60	90	180	360	450	300	180	270	300	360	270	90	0	0	0	0
18	0	6	30	15	24	24	24	24	18	24	30	30	90	90	450	450	300	180	270	300	360	300	450	0	0	0	0
17	0	6	30	15	24	18	18	24	12	24	30	30	90	90	450	450	300	90	270	300	360	300	450	0	0	0	0
16	0	6	30	15	24	15	12	15	6	15	30	30	90	90	450	450	150	90	270	300	360	300	450	0	0	0	0
15	0	6	15	15	24	9	6	15	6	15	30	30	90	90	300	450	90	90	270	300	360	300	450	0	0	0	0
14	0	6	15	9	12	9	6	9	15	24	45	30	90	90	150	210	90	90	270	300	360	300	450	0	0	0	0
13	0	6	15	9	9	9	6	6	9	9	15	30	48	30	30	60	30	54	180	300	360	300	450	0	0	0	0
12	0	6	15	9	9	9	6	6	9	9	15	30	30	30	60	30	60	24	60	180	240	300	450	0	0	0	0
11	0	0	30	30	9	9	6	6	6	6	15	24	30	30	45	45	24	24	24	180	240	300	180	180	0	0	0
10	0	0	0	30	6	9	6	9	9	9	45	24	30	30	45	45	24	24	24	60	60	180	180	180	180	0	0
9	0	0	0	30	9	9	9	12	9	12	45	45	36	45	36	45	45	27	27	60	45	90	180	180	180	0	0
8	0	0	0	30	18	18	18	18	18	18	45	45	36	36	27	27	27	18	24	45	30	90	90	180	180	0	0
7	0	0	0	30	18	18	18	18	27	27	45	45	36	36	27	27	27	15	15	30	30	60	60	90	90	45	0
6	0	0	0	30	27	27	27	27	60	27	45	45	36	36	27	27	27	9	9	30	30	24	24	24	90	45	0
5	0	0	0	30	15	15	15	15	30	27	36	36	27	27	27	27	27	9	9	24	30	24	24	24	0	0	0
4	0	0	0	0	9	9	9	9	9	27	36	27	27	27	15	18	18	9	9	18	24	24	24	24	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	9	9	9	12	18	24	24	24	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	12	24	24	24	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

NOTE: 0 values indicate no-flow boundaries.

Table 14.--Transmissivity values, in feet squared per day, used in middle model layer (zone 2)

Col-	Rows																									
umns	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	90	1200	1200	1200	1200	1200	3000	0	0	0	0	0	0	0
29	0	0	0	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	90	1200	1200	1200	1200	1200	3000	0	0	0	0	0	0	0
28	0	0	0	1200	1200	1200	1200	1200	1200	1200	600	600	600	90	1200	1200	1200	1200	1200	3000	1500	0	0	0	0	0	0
27	0	0	0	0	2400	2400	900	1200	600	1200	600	600	300	150	300	300	1200	3000	1800	3000	3000	3000	0	0	0	0	0
26	0	0	0	0	4500	2400	1800	1800	1500	1200	600	600	150	150	300	300	1200	3000	1800	3000	3000	3000	1500	0	0	0	0
25	0	0	0	4500	4500	1500	900	750	1500	900	600	900	300	240	900	1800	2400	2400	4500	3000	3000	3000	1500	0	0	0	0
24	0	0	4500	4500	1200	900	900	750	900	600	600	600	600	450	900	1350	2400	3000	4500	4500	4500	3000	1500	0	0	0	0
23	0	3600	2400	2400	300	300	900	300	300	300	300	300	300	600	600	1350	2400	3000	3000	4500	4500	4500	1500	0	0	0	0
22	0	3600	2400	4500	600	600	300	300	300	300	300	300	300	900	1200	1350	2400	3000	3750	4500	4500	4500	1500	0	0	0	0
21	0	3600	3600	3600	600	600	300	300	300	300	300	300	300	900	1200	2700	4500	4500	3750	4500	4500	4500	1500	0	0	0	0
20	0	3600	4500	4500	1200	1800	300	300	900	900	300	300	300	450	1800	2700	4500	4500	4500	4500	4500	4500	1500	0	0	0	0
19	0	3600	4500	4500	2400	2400	600	1200	2400	1800	900	1200	450	450	2400	2700	4500	4500	4500	4500	4500	4500	3000	1500	0	0	0
18	0	3600	4500	1650	1200	1200	900	1500	1950	1950	1950	750	450	450	900	1800	2700	4500	3750	4500	4500	4500	4500	1500	0	0	0
17	0	3000	4500	1650	1200	1200	1950	3600	3600	4500	3600	750	450	450	900	1800	2700	2400	3000	4500	4500	4500	4500	1500	0	0	0
16	0	3000	600	600	600	750	1950	3600	4500	4500	4500	750	450	450	450	900	900	1200	2400	4500	4500	4500	4500	1500	0	0	0
15	0	3000	600	360	600	750	3000	3600	4500	3600	4500	750	600	600	600	900	900	1200	1200	4500	4500	4500	4500	1500	0	0	0
14	0	3000	300	150	390	750	3000	3600	4500	3600	3600	600	600	600	450	600	600	1950	4500	4500	4500	4500	4500	1500	0	0	0
13	0	3000	150	150	390	750	1950	1200	1500	1950	3300	1650	1800	1650	600	1800	3000	3000	3000	4500	4500	4500	4500	1500	0	0	0
12	0	3000	150	150	390	240	450	450	900	900	1800	1650	1500	1650	600	1800	3000	3000	1950	4500	4500	4500	4500	3000	0	0	0
11	0	3000	450	120	120	450	450	450	450	450	900	1200	1200	900	600	600	600	1800	1800	4500	4500	4500	4500	3600	2400	0	0
10	0	0	300	150	450	450	450	450	450	450	450	600	600	240	240	240	240	750	750	2700	4500	4500	4500	3600	2400	3000	0
9	0	0	300	150	150	600	600	450	450	600	450	600	240	240	240	240	240	240	240	1200	600	4500	4500	3600	2400	3000	0
8	0	0	300	150	150	150	150	150	150	300	150	600	150	300	300	300	300	300	300	600	600	3600	4500	1800	600	3000	0
7	0	0	300	150	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	600	600	600	1800	600	600	3000	0
6	0	0	300	150	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	600	600	600	600	600	600	3000	0
5	0	0	0	300	300	300	300	300	300	300	300	600	300	300	300	300	300	300	300	600	600	600	600	600	0	0	0
4	0	0	0	0	300	300	300	300	300	300	300	600	300	300	300	300	300	300	300	600	600	600	600	600	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	300	300	300	300	600	600	600	600	600	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	600	600	600	600	600	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

NOTE: 0 values indicate no-flow boundaries.

Table 15.--Transmissivity values, in feet squared per day, used in bottom model layer (zone 3)

Col-	Rows																									
umns	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	4800	4800	4800	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	4500	0	0	0	0	0	0	0
29	0	0	0	6000	4800	4800	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	4500	0	0	0	0	0	0	0
28	0	0	0	6000	6000	6000	3000	3000	2400	2400	3000	3000	3000	2400	2400	2400	2400	2400	1800	4500	4500	0	0	0	0	0	0
27	0	0	0	0	1800	1800	900	900	900	900	900	900	900	2400	2400	2400	2400	1800	1800	4500	4500	4500	0	0	0	0	0
26	0	0	0	0	4800	3600	1800	1200	600	600	600	600	600	1200	2400	2400	1800	1800	1800	4500	4500	4500	4500	0	0	0	0
25	0	0	0	4800	4800	3600	1800	1800	1200	1200	1200	600	600	600	2400	1800	1800	1800	1800	4500	4500	4500	4500	0	0	0	0
24	0	0	4800	4800	4800	4800	2400	2400	1800	1800	1800	2400	2400	2400	1800	1800	1800	1800	1800	4500	4500	4500	4500	0	0	0	0
23	0	6000	4800	6000	6000	6000	3000	3000	2400	2400	2400	2400	2400	2400	2220	1800	1800	1800	1800	4500	4500	4500	4500	0	0	0	0
22	0	6000	4800	6000	6000	6000	3000	3000	2400	2400	2400	2400	2400	2400	1800	1800	1800	1800	1800	4500	4500	4500	4500	0	0	0	0
21	0	6000	6000	6000	6000	6000	3000	3000	2400	2400	2400	2400	2400	2400	1800	1800	1800	1800	1800	4500	4500	4500	4500	0	0	0	0
20	0	6000	4800	4800	6000	6000	3000	3000	3000	3000	3000	1200	1200	1200	900	900	900	1800	1800	6000	6000	6000	4500	0	0	0	0
19	0	6000	4800	4800	6000	6000	3000	3000	3000	3000	3000	1200	1200	1200	900	900	900	1800	1800	6000	6000	6000	4500	4500	0	0	0
18	0	6000	4800	4800	6000	6000	3000	3000	3000	3000	3000	1200	1200	1200	600	900	900	1800	1800	6000	6000	6000	4500	4500	0	0	0
17	0	6000	4800	4800	4800	4800	3000	3000	3000	3000	3000	1200	1200	1200	600	900	900	1200	1200	6000	6000	6000	4500	4500	0	0	0
16	0	4800	4800	4800	6000	6000	4800	4800	4800	4800	4800	1200	1200	2400	600	600	600	1200	1200	6000	6000	6000	4500	4500	0	0	0
15	0	4800	4800	4800	4800	4800	4800	4800	4800	4800	4800	1200	1200	2400	600	600	600	1200	1200	6000	6000	6000	4500	4500	0	0	0
14	0	4800	4800	4800	4800	4800	4800	4800	4800	4800	4800	1200	3000	2400	2400	900	1200	3000	3000	6000	6000	6000	4500	4500	0	0	0
13	0	4800	4800	4800	4800	6000	4800	4800	4800	4800	4800	3600	3600	2400	2400	1800	1200	3000	3000	6000	6000	6000	4500	4500	0	0	0
12	0	6000	6000	4800	4800	6000	4800	4800	4800	4800	4800	3600	4800	4800	4800	3600	2400	3000	3000	6000	6000	6000	4500	4500	0	0	0
11	0	4800	6000	2400	4800	6000	3600	4800	4800	4800	4800	4800	4800	6000	6000	6000	4200	4200	4200	6000	6000	6000	4500	6000	6000	0	0
10	0	0	4800	4800	3600	3600	3600	4800	4800	4800	4800	4800	4800	6000	6000	6000	6000	4800	4800	6000	6000	6000	6000	6000	6000	6000	0
9	0	0	4800	2400	3600	3600	3600	4800	4800	4800	4800	4800	4800	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	0
8	0	0	2400	2400	3600	3600	4800	4800	4800	4800	4800	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	0
7	0	0	2400	2400	3600	3600	3600	4800	6000	6000	6000	6000	6000	4800	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	0
6	0	0	2400	2400	4800	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	0
5	0	0	0	2400	4800	4800	4800	4800	4800	4800	4800	4800	4800	4800	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	0	0	0
4	0	0	0	0	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6000	6000	6000	6000	6000	6000	6000	6000	6000	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6000	6000	6000	6000	6000	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

NOTE: 0 values indicate no-flow boundaries.

Table 16.--TK values in 1/d (hydraulic conductivity of confining bed divided by its thickness) of middle layer aquifer (zone 2) used as a confining bed between zones 1 and 2 (multiply numbers in table by 10^{-3} to obtain values used in model)

Col-	Rows																										
umns	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	5	2	5	5	10	20	10	10	10	10	10	10	5	5	5	10	0	0	0	0	0	0	0	0
29	0	0	0	20	2	5	5	10	20	10	10	10	20	10	10	5	5	5	10	0	0	0	0	0	0	0	0
28	0	0	0	20	2	5	5	10	20	10	10	10	20	20	20	10	10	5	10	10	0	0	0	0	0	0	0
27	0	0	0	0	2	5	3	30	30	10	10	10	8	10	20	10	10	10	20	20	10	0	0	0	0	0	0
26	0	0	0	0	2	8	6	10	30	10	10	10	8	20	20	10	10	10	20	20	20	4	0	0	0	0	0
25	0	0	0	14	2	8	6	15	30	10	10	10	8	20	20	10	10	10	20	20	20	4	0	0	0	0	0
24	0	0	4	4	4	5	5	10	20	10	15	15	12	20	20	10	10	6	20	20	20	4	0	0	0	0	0
23	0	100	4	4	4	5	3	6	20	10	15	15	12	20	20	10	10	6	20	20	20	2	0	0	0	0	0
22	0	100	4	4	2	4	5	6	20	10	15	15	12	20	40	10	10	6	20	20	20	4	0	0	0	0	0
21	0	100	4	4	2	3	5	10	20	10	4	4	6	20	40	10	10	6	20	20	20	4	0	0	0	0	0
20	0	200	4	2	2	2	2	4	10	4	2	2	3	6	20	10	20	4	20	20	20	4	0	0	0	0	0
19	0	200	4	2	2	2	2	4	4	4	2	2	3	6	20	5	20	4	20	20	20	20	20	0	0	0	0
18	0	200	8	3	3	3	3	4	4	4	4	6	15	9	30	15	4	4	10	20	20	60	20	0	0	0	0
17	0	200	8	3	3	3	2	4	4	4	4	8	30	6	15	15	4	4	10	20	20	60	20	0	0	0	0
16	0	200	10	2	2	2	3	5	4	4	4	8	30	9	15	8	4	4	10	10	20	60	20	0	0	0	0
15	0	200	20	3	2	2	3	6	4	4	4	6	6	15	15	4	4	8	10	10	10	30	10	0	0	0	0
14	0	200	200	4	3	2	10	10	4	4	6	6	6	60	15	4	4	4	10	10	10	30	10	0	0	0	0
13	0	200	200	4	3	2	10	15	2	6	6	6	6	20	15	9	3	3	10	4	4	10	10	0	0	0	0
12	0	200	40	4	4	4	10	20	4	6	6	6	6	20	10	9	3	2	7	4	4	20	50	0	0	0	0
11	0	0	200	200	4	10	10	10	5	6	6	6	6	20	10	6	4	4	15	10	20	50	50	20	0	0	0
10	0	0	0	200	10	10	10	6	5	6	6	6	6	20	10	6	3	4	10	20	20	40	60	20	50	0	0
9	0	0	0	200	10	10	10	6	5	6	6	6	10	20	10	6	3	4	10	20	20	40	60	50	50	0	0
8	0	0	0	200	10	10	10	10	5	6	6	6	20	20	10	6	6	8	10	20	20	40	60	50	50	0	0
7	0	0	0	200	10	10	10	10	10	20	20	20	20	10	20	10	10	10	10	20	20	40	60	50	50	50	0
6	0	0	0	200	20	20	20	20	20	30	20	20	20	20	20	20	10	10	10	30	20	40	50	50	50	50	0
5	0	0	0	20	20	20	20	20	20	30	20	20	20	20	20	20	10	10	10	30	20	40	40	50	0	0	0
4	0	0	0	0	20	10	20	10	10	10	10	10	10	10	10	10	10	10	10	15	15	20	15	50	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	10	10	10	15	15	20	15	50	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	15	20	15	50	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

NOTE: 0 values indicate no-flow boundaries.

Table 17.--TK values in 1/d (hydraulic conductivity of confining bed divided by its thickness) of lower layer aquifer (zone 3) used as a confining bed between zones 2 and 3 (multiply numbers in table by 10^{-4} to obtain values used in model)

Col-	Rows																										
umns	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	5	5	1	5	5	5	1	5	1	1	1	1	1	1	1	1	20	0	0	0	0	0	0	0
29	0	0	0	5	5	1	5	1	3	1	5	1	1	1	1	1	1	1	1	20	0	0	0	0	0	0	0
28	0	0	0	5	5	1	1	1	1	1	5	1	2	2	2	2	2	1	1	20	1	0	0	0	0	0	0
27	0	0	0	0	8	2	2	2	2	2	3	2	4	4	4	4	4	4	4	40	1	3	0	0	0	0	0
26	0	0	0	0	8	4	4	4	4	2	3	2	4	4	4	4	4	4	4	40	20	6	1	0	0	0	0
25	0	0	0	8	8	4	4	4	4	2	2	2	4	4	4	4	4	4	4	40	20	6	2	0	0	0	0
24	0	0	5	8	5	2	2	4	4	4	4	4	6	4	4	4	4	4	4	40	40	4	2	0	0	0	0
23	0	100	5	8	5	2	2	4	4	4	4	4	6	4	12	12	12	12	6	40	40	2	2	0	0	0	0
22	0	100	14	8	5	2	2	4	4	4	4	4	6	4	12	12	12	12	6	40	80	2	2	0	0	0	0
21	0	100	14	8	5	2	2	2	2	2	2	2	2	4	16	16	16	12	6	40	80	2	2	0	0	0	0
20	0	200	28	24	15	15	9	2	2	2	2	2	2	2	5	8	8	6	6	40	80	2	2	0	0	0	0
19	0	200	28	24	15	45	24	2	2	2	2	4	4	2	3	3	6	6	6	40	80	10	2	40	0	0	0
18	0	200	28	24	15	45	30	2	2	15	20	8	4	4	3	4	2	6	3	40	80	20	20	40	0	0	0
17	0	200	28	24	15	45	80	4	4	80	50	10	4	4	3	3	1	4	2	40	80	40	40	80	0	0	0
16	0	200	40	24	24	60	100	4	4	90	60	8	2	2	2	2	1	4	2	20	80	40	40	80	0	0	0
15	0	200	40	30	30	60	100	30	6	90	100	4	4	4	2	2	1	4	2	20	40	20	40	40	0	0	0
14	0	200	200	30	10	60	100	30	6	90	120	4	8	10	2	2	2	2	2	20	40	20	40	40	0	0	0
13	0	200	200	30	10	80	300	15	3	90	30	15	2	2	2	2	2	2	2	20	40	20	40	40	0	0	0
12	0	200	40	30	10	100	90	15	3	30	15	15	2	2	2	2	2	2	2	20	40	20	20	40	0	0	0
11	0	40	200	60	20	15	30	15	3	30	15	15	8	15	2	2	15	2	2	20	40	20	40	90	90	0	0
10	0	0	200	300	9	15	30	15	3	30	15	15	8	15	3	2	15	2	2	20	40	20	40	90	90	90	0
9	0	0	40	300	15	15	15	15	3	15	15	15	8	15	3	8	15	15	15	20	40	20	40	90	90	90	0
8	0	0	40	300	15	15	15	15	9	15	15	15	8	15	8	8	15	15	15	20	40	20	40	90	90	90	0
7	0	0	40	200	10	10	10	10	6	10	40	20	5	10	5	10	10	10	10	20	40	20	40	90	90	90	0
6	0	0	40	200	40	40	40	20	40	40	40	20	20	20	10	10	10	10	10	20	40	20	40	90	90	90	0
5	0	0	0	40	40	40	40	20	40	40	40	20	20	20	10	10	10	10	10	20	40	20	40	90	0	0	0
4	0	0	0	0	20	20	20	20	20	20	20	20	20	20	10	10	10	10	10	20	40	20	40	90	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	10	10	10	20	40	20	40	90	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	40	20	40	90	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

NOTE: 0 values indicate no-flow boundaries.

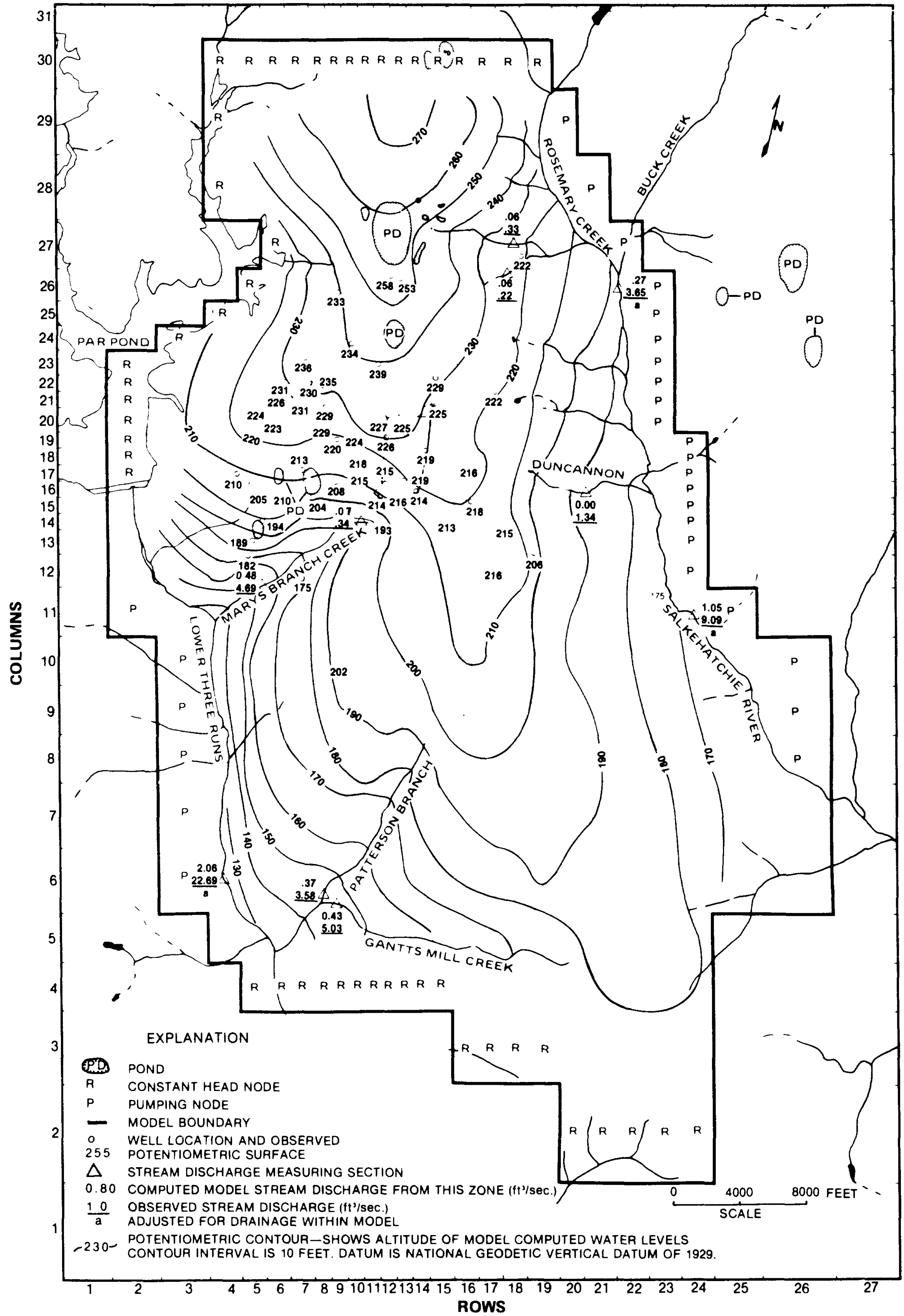


Figure 37.--Computed potentiometric contours of zone 1, observed water-level altitudes, and computed stream discharges from this zone at selected sites near Barnwell, S.C.

The computed discharge from zone 1 to streams is compared with observed discharge (fig. 37). The computed discharge from zone 1 was about 10 percent of the streamflow.

Figure 38 shows a comparison of the observed point water levels and contours of computed water levels for zone 2. The maximum difference between the computed and the observed water level at any one point was less than 3 feet. Figure 38 also shows the observed and computed discharge from zone 2 to the streams. The comparison indicates that about 90 percent of the streamflow was from zone 2.

Figure 39 shows the observed point water levels and contours of computed water levels for zone 3. The total computed model stream discharge to observed field stream discharge is also shown.

The computed discharge to the streams from zones 1 and 2 is within 22 percent of observed streamflow. The greatest difference in computed and observed streamflow occurs where streamflow is less than 0.25 ft^3/s. The difference is less than 15 percent where streamflow is greater than about 1 ft^3/s. Model results indicate that about 93 percent of the total surface discharge from the study area was streamflow contributed from zones 1 and 2 and about 7 percent from zone 3.

Figure 40 shows graphically the differences in the computed and the observed water levels for each zone which gives an indication of the success of model calibration. The larger differences between the computed and observed water levels occurred at distances away from the burial site.

The model was not verified because data sets other than those used in calibration were not available.

The Effect of Hydrology on Movement of Buried Waste

The effect of ground-water movement on the mobility of leachates from the burial site cannot be completely evaluated with the information available. However, maximum rate of movement of radionuclides can be estimated based on the rate and direction of water movement through the saturated zone to points of discharge into nearby streams. Some radionuclides, such as tritium, migrate with water and others can be adsorbed by the sediments. Indications are that tritium can also migrate as a vapor through the unsaturated zone to the land surface and into the atmosphere.

The potentiometric contours in the near vicinity of the burial site indicate that rainfall recharges zones 1 and 2 locally. Ground-water movement is to Marys Branch Creek. Thus, rainfall at the burial site either returns to the atmosphere as evapotranspiration or reaches the water table and discharges to Marys Branch Creek through zones 1 and 2.

The average horizontal velocity of water moving through the saturated zone is estimated from the relation:

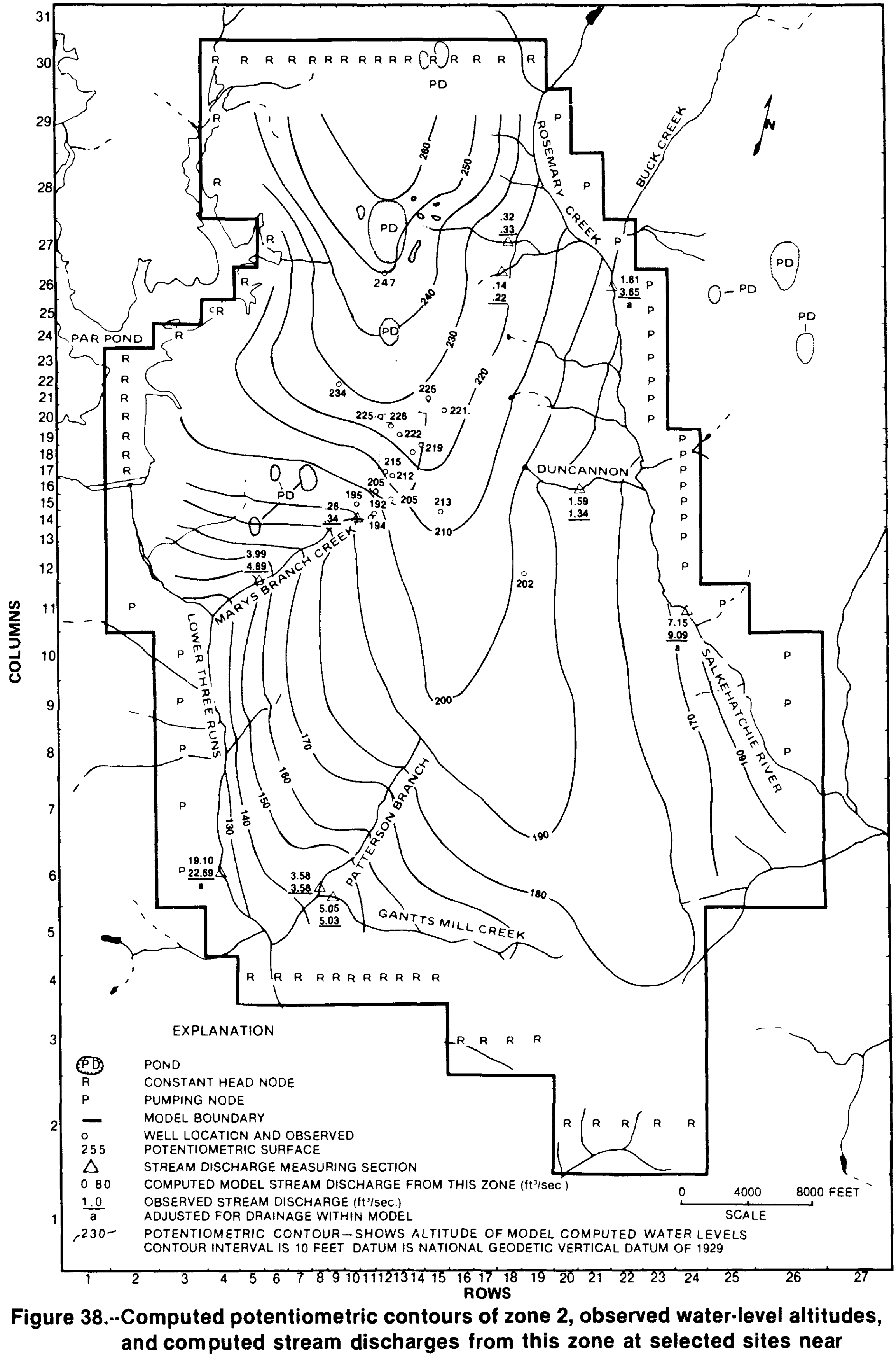


Figure 38.--Computed potentiometric contours of zone 2, observed water-level altitudes, and computed stream discharges from this zone at selected sites near Barnwell, S.C.

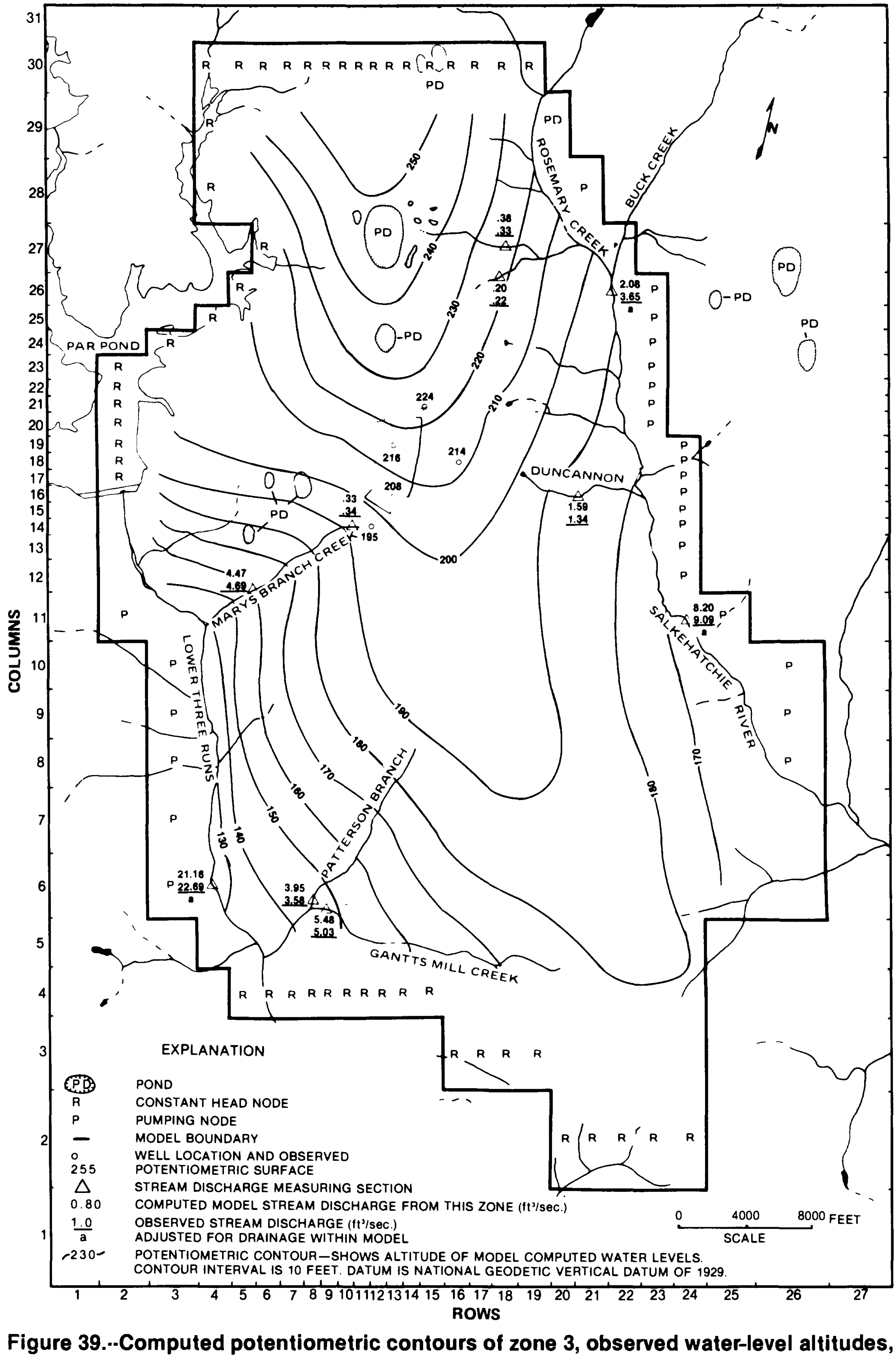


Figure 39.--Computed potentiometric contours of zone 3, observed water-level altitudes, and computed total stream discharges at selected sites near Barnwell, S.C.

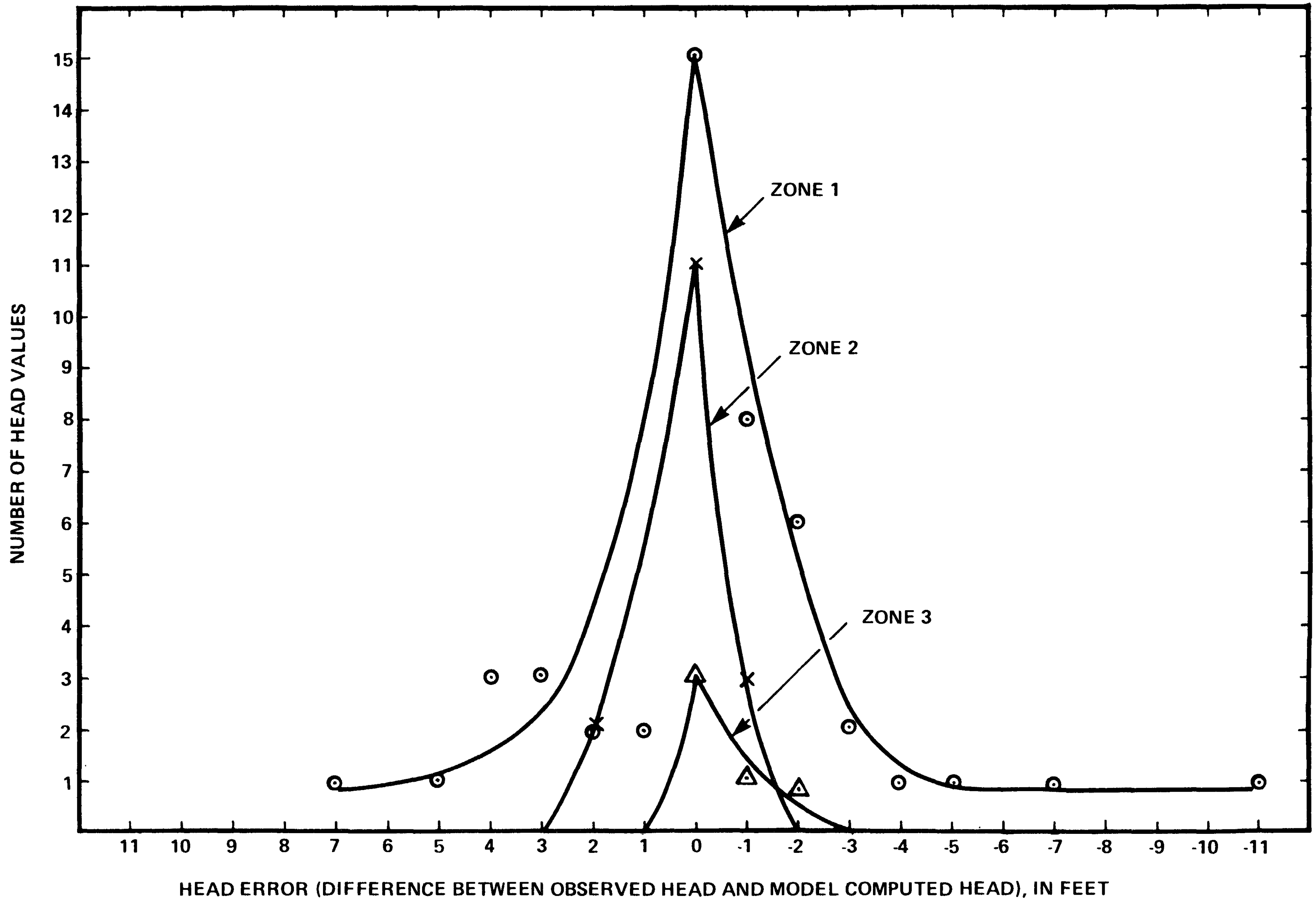


Figure 40.--Distribution of head error for each zone in model.

$$\bar{v} = Ki/n \quad , \qquad (3)$$

where: $\bar{v}$ = average ground-water velocity, in feet per day;
K = hydraulic conductivity, in feet per day;
i = hydraulic gradient, in feet per foot; and
n = effective porosity, as a dimensionless ratio of volume of interconnected voids to the total volume.

The effective porosity is assumed to equal the average total porosity of about 40 percent (table 4).

The average horizontal hydraulic conductivity in the vicinity of the burial site in zone 1 is about 1.5 ft/d, and the average hydraulic gradient is about 1.1 feet per 100 feet. The computed average horizontal velocity, based on these values, is about 0.04 ft/d. From the potentiometric contours (fig. 37), it can be inferred that the shortest distance that water will travel from the southern trenches to a point of discharge at Marys Branch Creek is 3,235 feet. With an average water velocity of 0.04 ft/d it will take a minimum of about 220 years for water in zone 1 to move horizontally from the trench area to the stream.

Water in zone 1 will move downward into zone 2. The average velocity that water will move downward is estimated as 0.007 ft/d based on the assumptions that zone 1 is 25 feet thick, has an average vertical hydraulic conductivity of 0.02 ft/d, and an average water level of 3.5 feet above zone 2.

The average horizontal hydraulic conductivity of zone 2 is about 10.5 ft/d, and the average hydraulic gradient is about 0.97 foot per 100 feet (fig. 38). Therefore, the computed average horizontal water velocity is about 0.25 ft/d. From the potentiometric contours (fig. 38) the shortest distance that water will travel from the trench area to the discharge point at Marys Branch Creek is about 3,600 feet. Thus, it will take a minimum of about 40 years for water in zone 2 to reach this stream.

Water from beneath the burial site will also move into zone 3 and to a discharge point. The average hydraulic conductivity of zone 3 is about 17 ft/d. The average hydraulic gradient of this zone is about 0.1 foot per 100 feet towards the discharge point at Lower Three Runs (fig. 39). Based on these values the average horizontal ground-water velocity is about 0.043 ft/d. It will take about 1,030 years for water to travel about 16,000 feet from the burial trenches to where water in zone 3 might discharge into Lower Three Runs.

The time required for radionuclides to travel from the burial site to the nearest stream, Marys Branch Creek, is difficult to estimate. Some radionuclides, such as tritium, migrate as rapidly as water, while others are slowed down by attraction to sediment particles. Furthermore, the rate of water movement through the unsaturated zone is highly variable depending on degree of saturation. The following example represents the most rapid migration that can be expected.

The sediments near trench 8 appear to be nearly saturated with water. Tritium from the trench is migrating through these sediments to the saturated zone, as evidenced by tritium activity as great as 200,000 pCi/L in water samples from a well 10 feet south of the trench. Water moves slowly in zone 1, but it tends to move from zone 1 to zone 2 because zone 2 has a lower water level. At an average downward velocity of 0.007 ft/d, water will take about 10 years to descend 25 feet through zone 1 and into zone 2. Horizontal water velocity in zone 2 exceeds that in zone 1. The water will take about 40 years at the minimum, to move the 3,600 feet through zone 2 to Marys Branch Creek, for a total of about 50 years of travel.

During this time the radioactivity of the tritiated water will be reduced from 200,000 pCi/L to 12,500 pCi/L by 4 half-lives of radioactive decay. The activity will be further reduced by dispersion and dilution, so that the activity of the eventual discharge to Marys Branch Creek may approach background levels (between 1,000 to 3,000 pCi/L). For comparison, the U.S. Nuclear Regulatory Commission's maximum permissible concentration for tritium in unrestricted areas is 3 million pCi/L.

SUMMARY

The Barnwell low-level radioactive-waste burial site is underlain by a sequence of unconsolidated upper Cretaceous, Tertiary, and Quaternary sediments deposited on a downfaulted Triassic basin of indefinite extent. The Tertiary and younger sediments are separated hydraulically from the upper Cretaceous sediments by a silty clay bed about 60 to 70 feet thick at a depth of about 340 feet (fig. 6).

The waste is buried in Miocene sediments consisting of sandy clay, clayey sand, and fine to medium sand. These sediments are underlain by Eocene sands which supply most of the domestic water in the area.

Recharge in the area is derived from rainfall that averages about 47 inches a year. About 30 to 40 percent of the rainfall recharges the ground-water system. Discharge from the area occurs as evapotranspiration and streamflow.

Ground water moves through the sands which are interbedded with lenses of clay and clayey sand. The transmissivity of the sediments generally increases with depth. The lower zones are recharged by leakage from above. Four water-bearing zones were identified in the area. Only in the upper three zones is water free to move from one zone to the other.

Ground water in the area is low in dissolved solids and slightly acidic. The low pH makes the water corrosive.

One radionuclide, tritium, was detected at greater than background activity in the saturated zone. The tritium was detected in a shallow well about 10 feet south of the trenches. Inorganic and organic constituents also have been detected in this well indicating the movement of leachates from the trenches.

Sediment samples were obtained from beneath the trench floor at four trenches. The only gamma-emitting radioisotope detected beneath the trench floor that does not occur under natural conditions was cobalt-60. This isotope was detected in the unsaturated zone to a depth of 5.8 feet beneath waste that has been covered since 1972. Tritium activity greater than background was detected in nearly all of the sediment cores from beneath the trenches. Tritium appears to migrate upward as well as downward from the buried waste, and may enter the atmosphere by evaporation.

Radionuclide activity greater than background has not been detected in water from zone 2.

Data obtained from a hydrologic digital model of the study area were used to calculate discharges to streams from various zones and the average water velocity in the saturated zones. The average horizontal water velocity in the upper saturated clayey sediments (zone 1) is about 0.04 ft/d. The average horizontal water velocity in the underlying sandy sediments (zone 2) is about 0.25 ft/d. Water in zone 3 has an average horizontal velocity of about 0.043 ft/d and discharges into Lower Three Runs. The minimum travel time for water to move from the burial site to the closest stream, Marys Branch Creek, is about 50 years, based on vertical movement through zone 1 and horizontal flow through zone 2 to the nearby creek.

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