EFFECTS OF HIGH-RATE WASTEWATER SPRAY DISPOSAL ON THE WATER-TABLE AQUIFER, HILTON HEAD ISLAND, SOUTH CAROLINA

By Gary K. Speiran

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CONVERSION FACTORS AND ABBREVIATIONS OF UNITS

The following factors may be used to convert the inch-pound units published herein to the International System of units (SI).

Multiply inch-pound units	By	To obtain SI units
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
acre	0.4047	hectare (ha)
mile (mi)	1.609	kilometer (km)
gallon (gal)	3.785	liter (L)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
micromhos per centimeter at 25° Celsius (umhos/cm at 25°C)	1.000	microsiemens per centimeter at 25° Celsius (uS/cm at 25°C)
pound, avoirdupois (lb)	453.6	gram (g)

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ABSTRACT

High-rate spray disposal of wastewater is one of the methods of wastewater disposal used on Hilton Head Island, South Carolina. A study by the U.S. Geological Survey from April 1982 through December 1983 evaluated the effects of high-rate disposal on the water levels and water quality of the water-table aquifer.

Flooding of topographically low areas in the southern part of the site resulted from the application of 10.8 inches of wastewater in 10 days in January 1983. The water table remained more than 2-1/2 feet below land surface in the southern part of the site and more than 5-1/2 feet below land surface at the center of the site when wastewater was applied at rates of up to 5 inches per week in August and December 1983.

A residue of solids remained in the unsaturated zone as a result of wastewater application during the summer of 1983, when rates of evapotranspiration were high. Solids were flushed from the unsaturated zone during periods of lower evapotranspiration, as indicated by specific conductance and concentrations of chloride that were greater in the water-table aquifer than in the wastewater in December 1983. If wastewater application rates are high enough, wastewater will continuously flush most of the solids from the unsaturated zone and a less variable ground-water quality will occur.

Concentrations of ammonia and nitrite plus nitrate in the water-table aquifer were not changed by the application of wastewater. Loading rates to the disposal site were low for ammonia and nitrite plus nitrate as a result of the removal of nutrients by algae in the holding ponds at the wastewater treatment plant.

INTRODUCTION

Barrier islands are located along much of the coast of the Southeastern United States. These islands are separated from the mainland by a network of saltwater wetlands and estuaries that provide the habitat for diverse populations of saltwater plants and animals. Shellfish, which are harvested for recreational and commercial purposes, are among the organisms present. Therefore, these wetlands and estuaries are of considerable ecological and economic importance to the area.

Many of these barrier islands are being developed as resorts. Disposal of wastewater into the estuaries and wetlands is one aspect of development that may have profound effects on the saltwater plants and animals in them.

Land disposal of treated wastewater by spray irrigation is used as an alternative to the discharge of wastewater into the estuaries to minimize the effects of wastewater disposal in the vicinity of Hilton Head Island, South Carolina. Approximately 7 Mgal/d of wastewater are currently produced and 22 Mgal/d will be ultimately produced. Wastewater is sprayed on golf courses and small privately-owned tracts of land and will also be sprayed on yards at private residences, green areas along roads, and other public areas in the future. However, the public service districts responsible for the collection, treatment, and disposal of wastewater cannot control the application of wastewater to all of these areas. Also, capital, land, operational, and maintenance costs are very high for such disposal systems. For these reasons, high-rate application of wastewater to areas used solely for wastewater disposal and to dual-purpose areas used for wastewater disposal and other activities may provide less expensive alternatives for disposal.

The South Carolina DHEC (Department of Health and Environmental Control) has permitted wastewater disposal at spray rates of up to 2 inches per week in coastal areas. However, previous studies in the area have provided a limited evaluation of the capacity of the vegetation, the soil, and the ground-water system to assimilate the wastewater without significant adverse effects on the water levels and water quality. Because of a lack of appropriate data, an evaluation of the capacity of a site located on a barrier island to assimilate the water-quantity and water-quality loadings is of considerable interest.

Major water-quality concerns are those that affect the use of ground water for drinking-water supplies. The primary or health related MCL (maximum contaminate level) for drinking water most likely to be exceeded in the ground water as a result of the application of domestic wastewater is 10 mg/L of nitrate as nitrogen (U.S. Environmental Protection Agency, 1983). THM'S (trihalomethanes), which may be formed by the chlorination of wastewater, are also under consideration for inclusion in the primary standards for drinking water. Secondary or aesthetic MCL's for drinking water likely to be exceeded in the ground water by the application of domestic wastewater are 250 mg/L of chloride and 0.5 mg/L of foaming agents as indicated by MBAS (methyl-blue active substances) (U.S. Environmental Protection Agency, 1981).

PURPOSE AND SCOPE

The purpose of this report is to describe the effects of high-rate (greater than 2 inches per week) application of wastewater on the water levels and water quality of the water-table aquifer at a wastewater disposal site located on a barrier island.

This report presents an evaluation of changes in the water levels and water quality of the water-table aquifer at Hilton Head Island (fig. 1) as a result of the application of treated wastewater. The study period was April 1982 through December 1983. The evaluation was conducted at several application rates. Application of wastewater was limited by the availability of wastewater and the needs for wastewater for irrigating other disposal sites.

DESCRIPTION OF STUDY AREA

Location and Topography

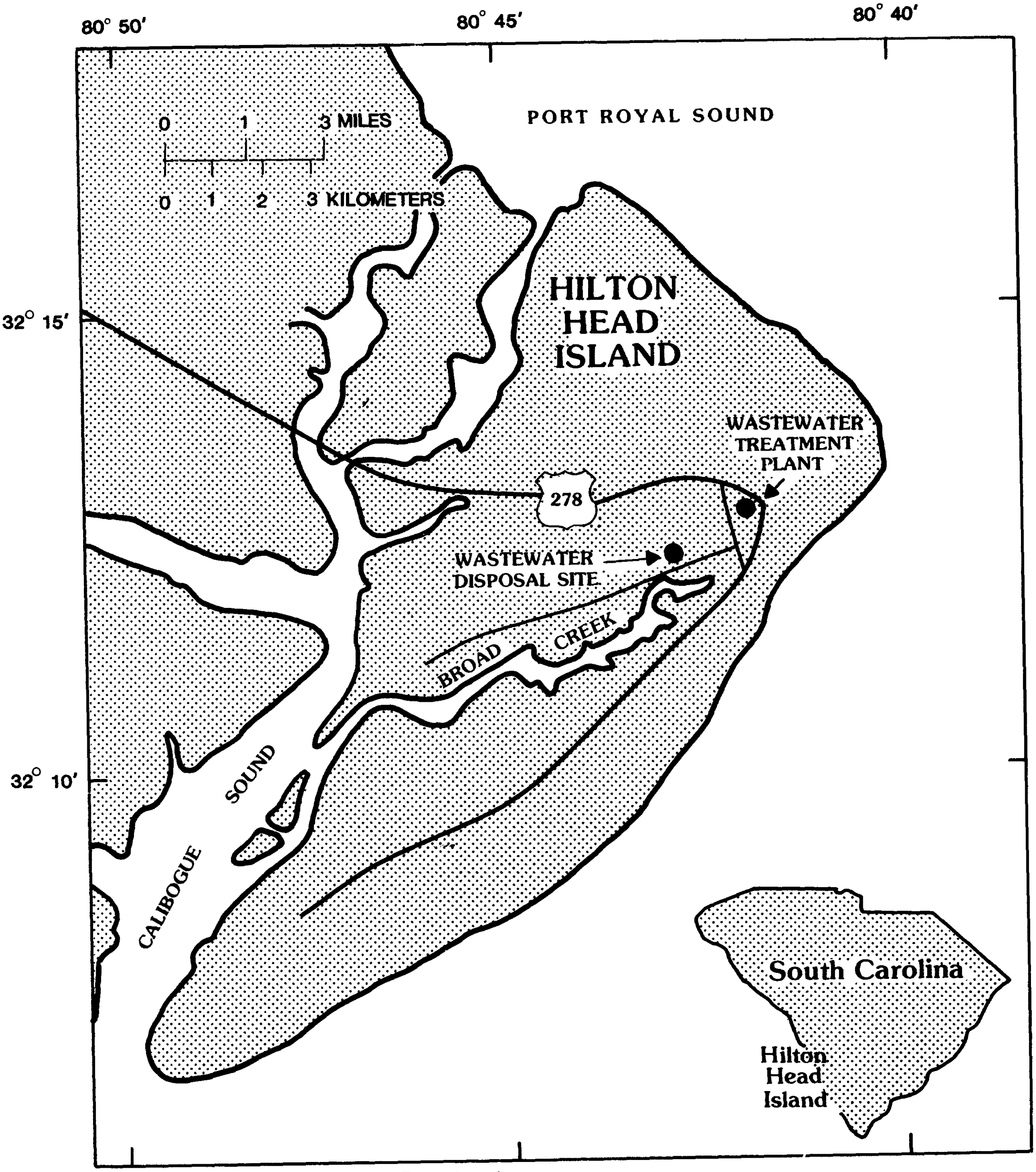
The wastewater disposal site is a 14-acre tract of land about 150 feet north of the saltwater marsh surrounding Broad Creek on Hilton Head Island (fig. 2). It is located in the northeastern corner of the intersection of Marshland Road and Leg-a-Mutton Road. A dirt road runs through the center of the site in a general northwest-southeast direction.

Altitudes range from about 10 to 15 feet above sea level. A topographic high, oriented in an east-west direction, is located in the northern part of the site. The lowest altitudes on the site are along the southern boundary adjacent to Marshland Road and extend approximately 200 feet along the western side of the site and somewhat farther along the eastern side of the site. A 2- to 3-foot high dike borders the site along the eastern, southern, and western boundaries to prevent surface runoff from leaving the site.

Soils

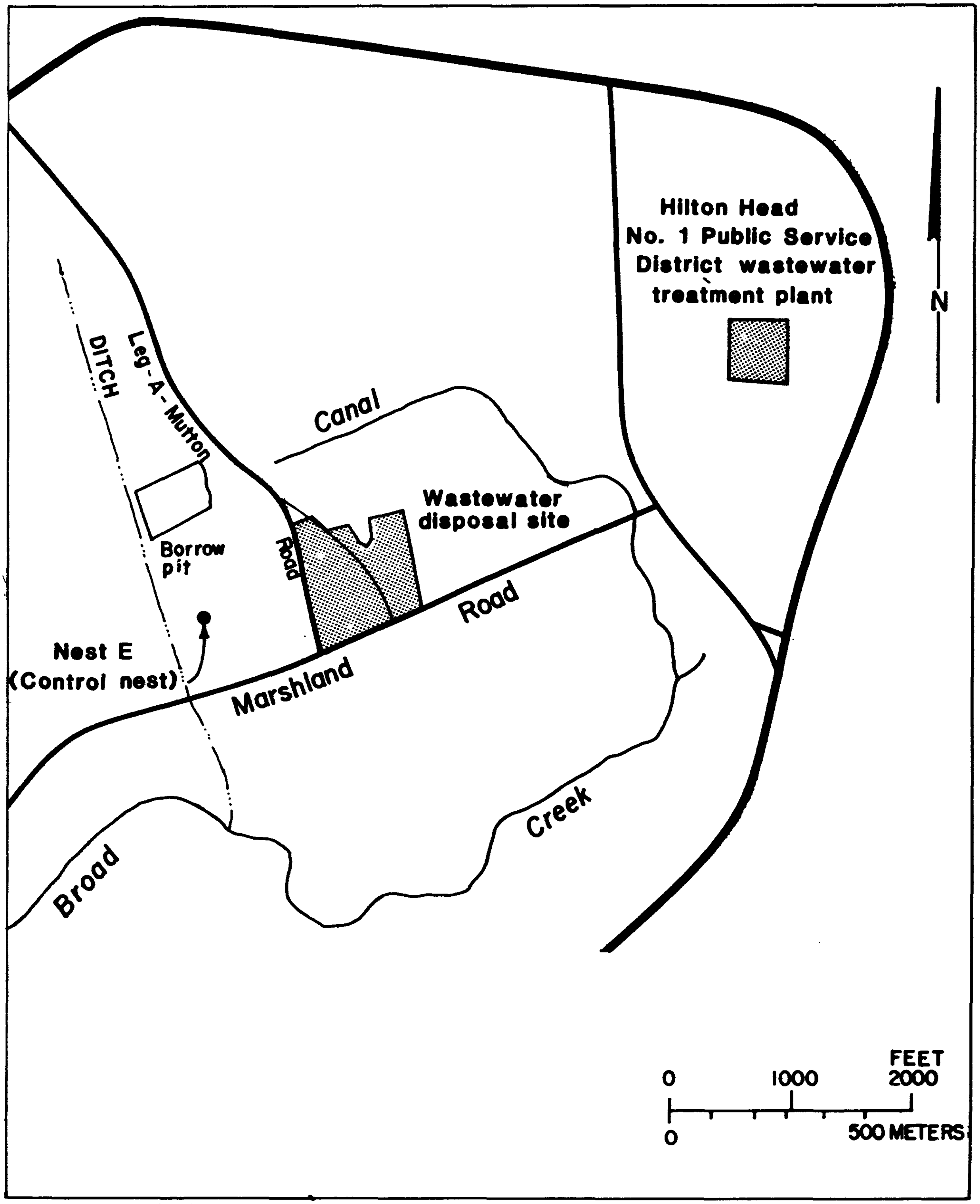
Soils at higher altitudes on the site are generally sandy-beach or barrier-island deposits (Glowacz and others, 1980). The deposits are highly permeable but may be underlain by low-permeability silt and clay. The soils are very-well to moderately-well drained.

Less permeable soils are present in the low areas associated with the Broad Creek flood plain. These soils are marsh and flood-plain deposits (Glowacz and others, 1980) and generally consist of poorly drained clay and silt with a high organic content. Similar silty and organic soils were manually spread over the sandy soils in the open area to the east of the dirt road.



Base from South Carolina Highway Department
Beaufort county highway map 1:126,720

Figure 1.--Location of the wastewater disposal site on Hilton Head Island, South Carolina.



Base from U.S. Department of Agriculture ASCS areal photograph October 1979.

Figure 2.--Location of the wastewater disposal site, major surface-water drainage, and other features

Vegetation

The disposal site has a variety of vegetation with similar types generally located in the same area. The northern half of the site is almost entirely wooded. Very large water oaks are located throughout the north-central part of the site. The southern half of the area with the large water oaks is almost entirely covered with undergrowth less than 1 foot high, but the northern half of this area has little or no undergrowth. To the east and west of the large water oaks are more densely wooded areas covered predominately with smaller water oaks. A small area near the northwest corner of the site is covered with pine trees about 20 feet tall.

The southern half of the site has two major areas of vegetation. East of the dirt road is an open area covered by weeds as high as 6 feet. The types of weeds change seasonally. West of the road are four rows of vegetation that have an east-west orientation. These rows of vegetation alternate between wooded brush that stands between 10 and 15 feet tall and a mixture of grasses and weeds.

Hydrology

Hilton Head Island is a coastal barrier island underlain by about 100 feet of sand and clay. The occurrence of these materials is areally variable as indicated in the drillers' logs of wells BFT-319 (about 1 mile northwest of the spray site) and BFT-313 (about 1/2 mile southeast of the spray site) (table 1). A medium-grain sand is about 25 to 30 feet thick throughout the site, but is about 5 feet thicker at the center of the site than at the southern boundary of the site. The sand extends from near land surface and grades into a plastic clay at a depth of 30 to 35 feet. The sand has a slight organic content. The clay occurs at a similar altitude at other locations on the site. The sand makes up the water-table aquifer, and the clay apparently retards downward movement of water from the aquifer. Clay occurs at a similar altitude in a well at the Hilton Head No. 1 Public Service District wastewater treatment plant (Glowacz and others, 1980). At the treatment plant location the clay was about 5 feet thick. Water levels are generally 4 to 8 feet below land surface where land surface is about 15 feet above sea level and near land surface to 4 feet below land surface where land surface is about 10 feet above sea level.

Deeper sand and clay deposits overlie limestone that begins at a depth of about 100 feet. The upper permeable zone in the limestone is the source of water supplies on Hilton Head Island and is part of the Floridan aquifer system.

The topographic high located in the northern part of the site is a surface-water drainage divide. Surface-water features include a drainage ditch cut 8 to 10 feet into the shallow sand about 1,000 feet west of the site (fig. 2). This ditch passes just west of a borrow pit northwest of the disposal site. The borrow pit is filled with about 10 feet of water. A low swampy area is located east of the ditch and borrow pit and north and east of the site. A canal (fig. 2) has been dug to a depth of about 30 feet to more

Table 1.--Drillers' logs for wells BFT-319 and BFT-313

BFT-319		BFT-313	
Depth (feet)	Description	Depth (feet)	Description
0-45	Sand, streaks of clay	0-19	Sand
45-60	Oyster shell and sand	19-29	Blue mud and marl
60-70	Green clay	29-35	Coarse sand and shell
70-75	Green clay	35-55	Blue mud and shell
75-80	Sandy limestone, hard drilling	55-57	Blue sand and shell
		57-65	Blue marl
80-95	Green clay	65-69	Blue clay
95-150	Limestone	69-83	Blue marl and clay
		83-93	(No description given)
		93-98	Coarse gravel and sand
		98-200	Limestone, white, permeable

effectively drain the swampy area. Water in the canal flows across the northern side of the site from west to east, turns south, and empties into Broad Creek southeast of the site. This canal has probably lowered the level of the water table to the north of the site. Drainage from the southern part of the site empties into Broad Creek and to the adjacent saltwater marsh.

DATA COLLECTION AND ANALYSIS

The data collection network consisted of nests of piezometers and single piezometers. The nests of piezometers were used for monitoring water levels and collecting water-quality samples from selected depths in the water-table aquifer. Each piezometer was constructed with a 1-foot long screen. Nests A, B, and D (fig. 3) were located on the disposal site in a north-south line through the center of the site, approximately parallel to the direction of ground-water flow prior to wastewater application. Nest C was constructed at the eastern side of the site. Nest E was constructed as a control site (fig. 2) about 800 feet west of the spray site. Piezometers located in nests are identified by the nest in which they are located and the depth of the bottom of the piezometer screen, for example, A30.

Two of the piezometers at nests A, B, and E were constructed to a depth of 10 feet. A water-level recorder was installed on one of these piezometers at each nest. The piezometers with water-level recorders are designated A10R, B10R, and E10R. The letter "R" indicates the piezometer had a recorder installed.

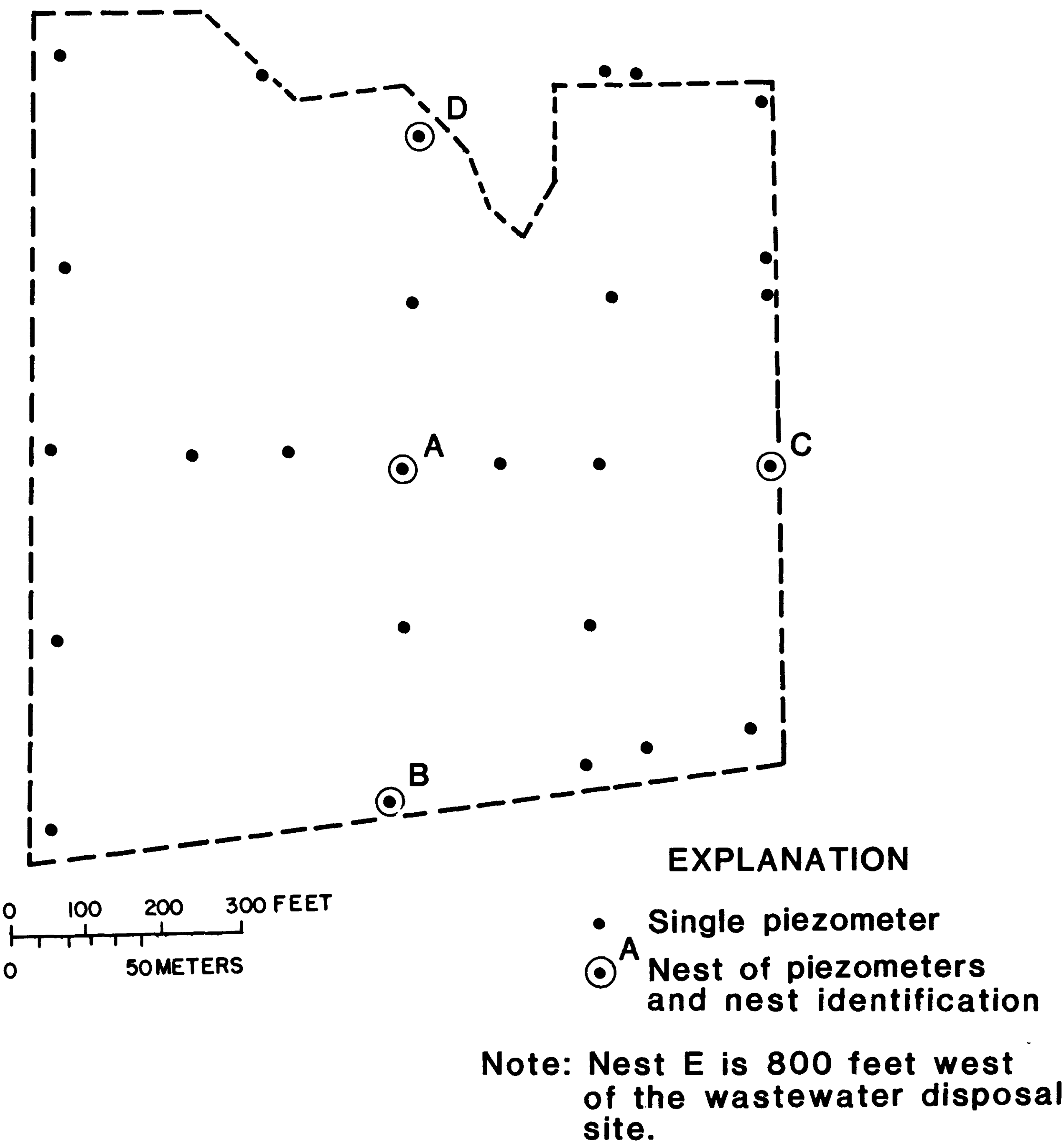


Figure 3.--Location of single piezometers and nests of piezometers at the wastewater disposal site.

The single piezometers were screened in the top of the water-table aquifer and were used for monitoring the water table throughout the site. Each piezometer was constructed with a 1-foot long screen, the top of which was located about 1-1/2 feet below the water table.

Hydrographs, differences in water levels with depth, and maps showing the altitude of the water table were used to evaluate the effects of wastewater application on the flow of ground water. Comparison of the values of various water-quality parameters at selected depths prior to and after periods of wastewater application was used to determine the effects of application on the quality of ground water.

HYDROLOGIC AND WATER-QUALITY CONDITIONS AT THE SITE PRIOR TO APPLICATION OF WASTEWATER

Hydrologic Conditions

Prior to the application of wastewater, the water table at the site had a configuration similar to the topography. A ground-water divide existed through the northern part of the site along an east-west axis (fig. 4). Water levels averaged 8 to 9 feet above sea level. Water levels along the southern boundary of the site were about 2 feet lower than those along the divide. Ground-water flow was to the north and south from the divide.

Water-level changes in piezometer E10R reflect the effects of aquifer properties, recharge by rainfall, discharge by evapotranspiration, and flow through the aquifer to surface-water discharge points (fig. 9). Effects of rainfall and evapotranspiration change seasonally. Water levels declined from October to January, rose and remained high as a result of heavy rainfall and low rates of evapotranspiration from February through April, then generally declined through July as a result of low rainfall and high rates of evapotranspiration. Water levels were variable from August through December because of periodic rainfall and a decline in the rate of evapotranspiration.

Water levels in the Floridan aquifer system declined approximately 15 feet between 1880 and 1976 to an altitude of about 2 feet below sea level in the vicinity of the spray site (Hayes, 1979). This was a result of pumping from the aquifer at Hilton Head Island and Savannah, Georgia, and vicinity. Although water levels in the Floridan aquifer system in the vicinity of the site during the study are not known, they have stabilized or continued to decline in the general area since 1976.

Based on water levels in 1976 and the stabilized or continued declining water levels in the area in the Floridan aquifer system, the water table was more than 10 feet higher than water levels in the Floridan aquifer system during the study. However, the gradient was not the same throughout the sediment column, indicating the presence of one or more confining beds between the water table and the Floridan aquifer system. Only a slight vertical gradient in water levels existed within the water-table aquifer at the disposal site prior to application of wastewater (fig. 5). The head difference was generally less than 0.2 foot between the water table and the deepest piezometers at each nest.

If the gradient were uniform between the water table and the Floridan aquifer system, the head difference between piezometers A6 and A30 would have been approximately 2-1/2 feet rather than 0.2 foot. Although the existence of confining layers is indicated by the vertical head difference, the effectiveness of these confining layers and the rate of flow between the water-table aquifer and the Floridan aquifer system cannot be determined with available data.

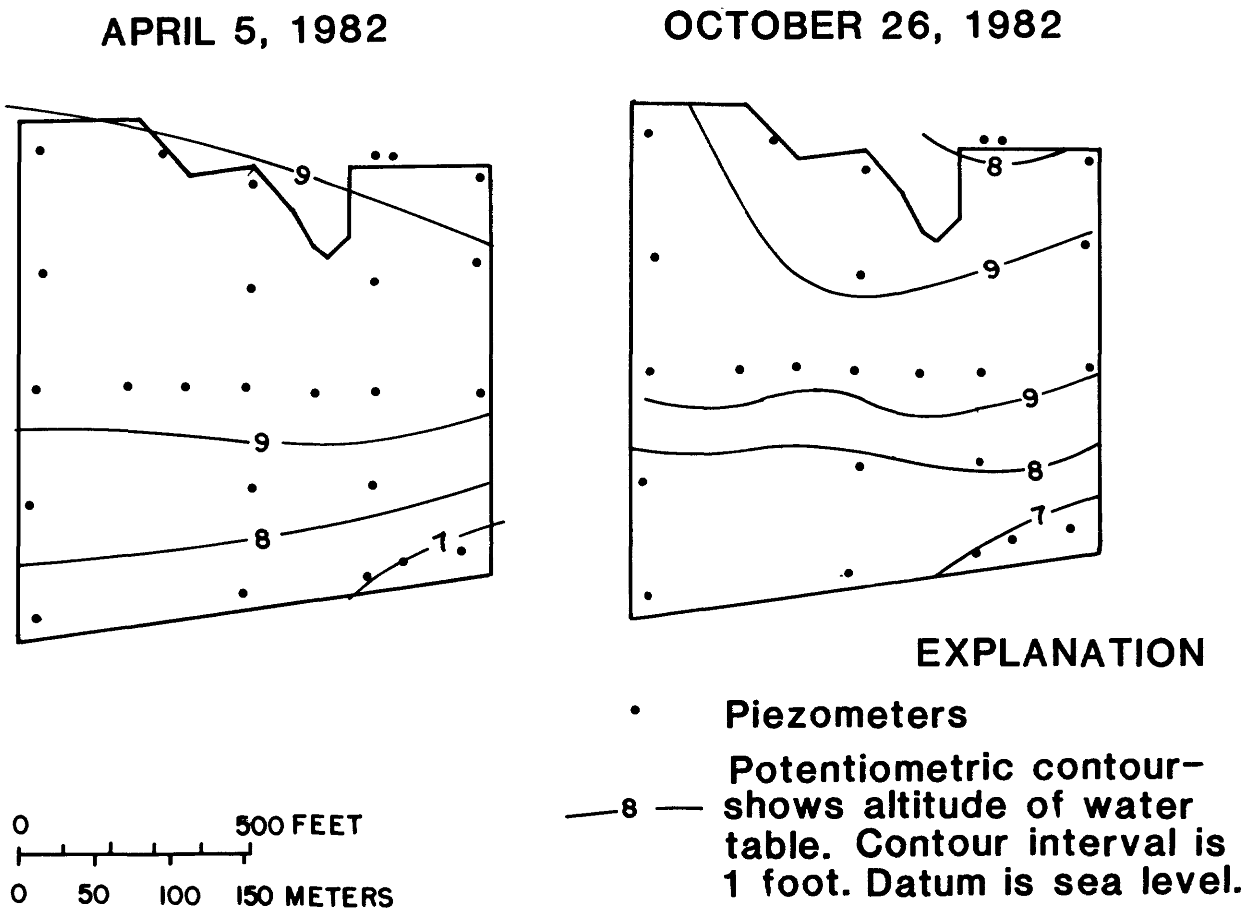


Figure 4.--Altitude of the water table prior to spraying (April 5, 1982, and October 26, 1982) at the wastewater disposal site.

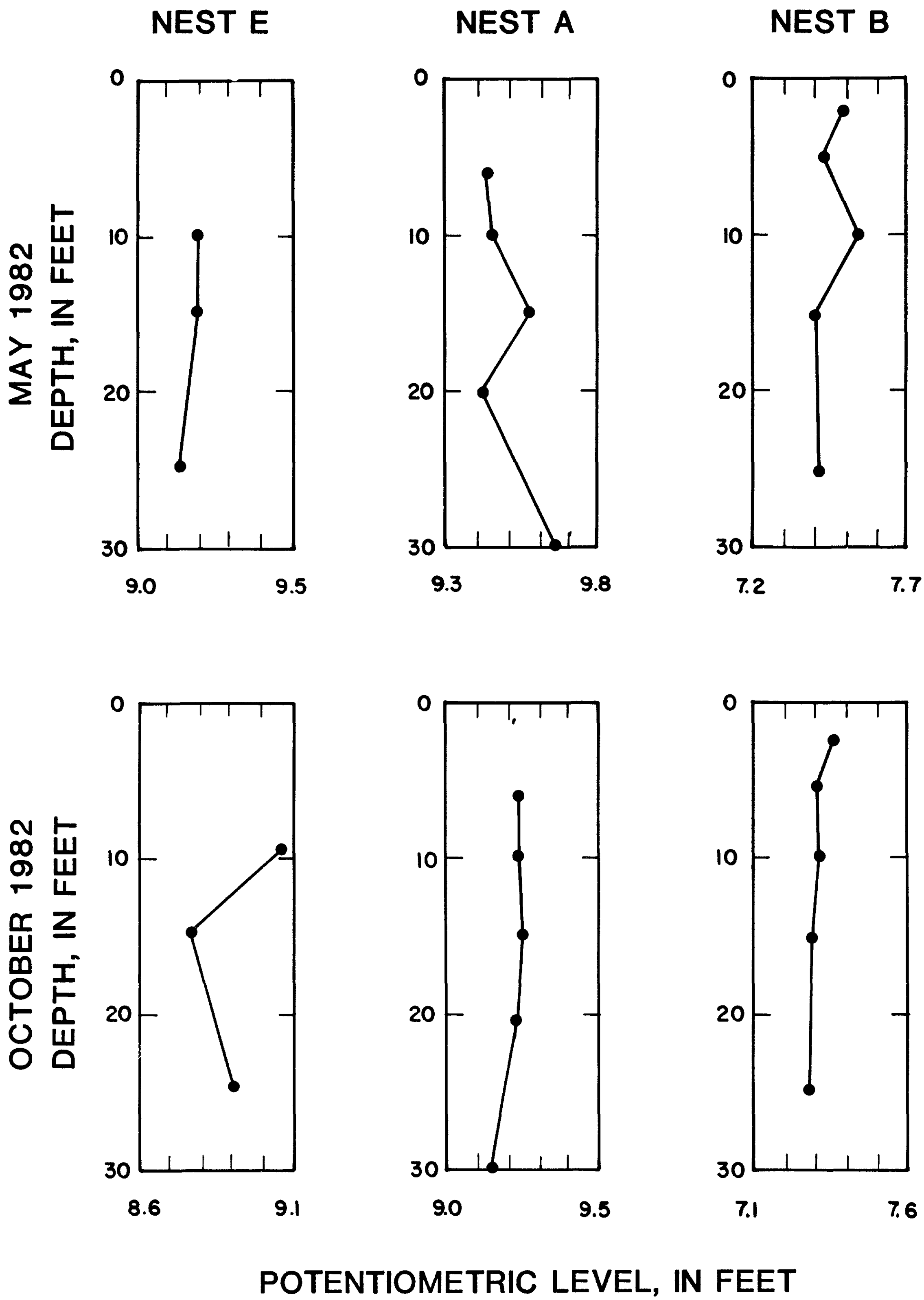


Figure 5.--Potentiometric levels in piezometers at nests E, A, and B prior to wastewater application

Water-Quality Conditions

Water quality varied areally and with depth within the water-table aquifer prior to application of the wastewater. Generally, concentrations of constituents increased with depth and laterally along the ground-water flow paths. Concentrations of water-quality constituents appear to result from dissolution of minerals and decomposition of organic materials in the aquifer. The increase in the concentration of constituents with depth generally occurs because the deeper water has been in contact with aquifer materials longer than the shallower water.

Specific conductance, an indicator of the ionic strength of dissolved constituents, also increased with depth at all nests (fig. 6) except between 6 and 10 feet deep at nest A and between 10 and 15 feet deep at nest D. Concentrations of chloride were less than 25 mg/L in water from all piezometers prior to wastewater application (fig. 6).

The ground water was anaerobic or almost anaerobic in most of the aquifer. Concentrations of dissolved oxygen were generally nondetectable at all nests and all depths. Biochemical uptake of oxygen as a result of the decomposition of organic materials probably caused the ground water to be anaerobic. Because the ground water was anaerobic or almost anaerobic at the top of the water-table aquifer, most of the uptake of dissolved oxygen probably occurred within the unsaturated zone.

A slight hydrogen sulfide odor was observed during drilling and water-quality sample collection. The presence of sulfide also reflected the anaerobic environment.

Concentrations of ammonia were less than 0.05 mg/L as nitrogen at the top of the water-table aquifer and increased with depth at all nests except nest D (fig. 7). The increase in the concentration of ammonia with depth was probably a result of the decomposition of the organic nitrogen in the organic materials in the aquifer. Concentrations of nitrite plus nitrate were nondetectable at all nests prior to the application of wastewater, indicating the lack of nitrification of ammonia within the aquifer because of the anaerobic conditions.

Concentrations of dissolved orthophosphate showed no change with depth at nest D, increases with depth at nests A and E, and an increase followed by a decrease with depth at nest B prior to spraying (fig. 7). The increases probably result from the decomposition of organic materials in the aquifer and subsequent hydrolysis of the resulting polyphosphates. The cause of the decrease with depth is not known.

Concentrations of dissolved organic carbon increased with depth at nests D and E and showed no consistent trend with depth at nests A and B (fig. 7). Concentrations of dissolved organic carbon probably resulted from dissolution of particulate organic carbon within the aquifer.

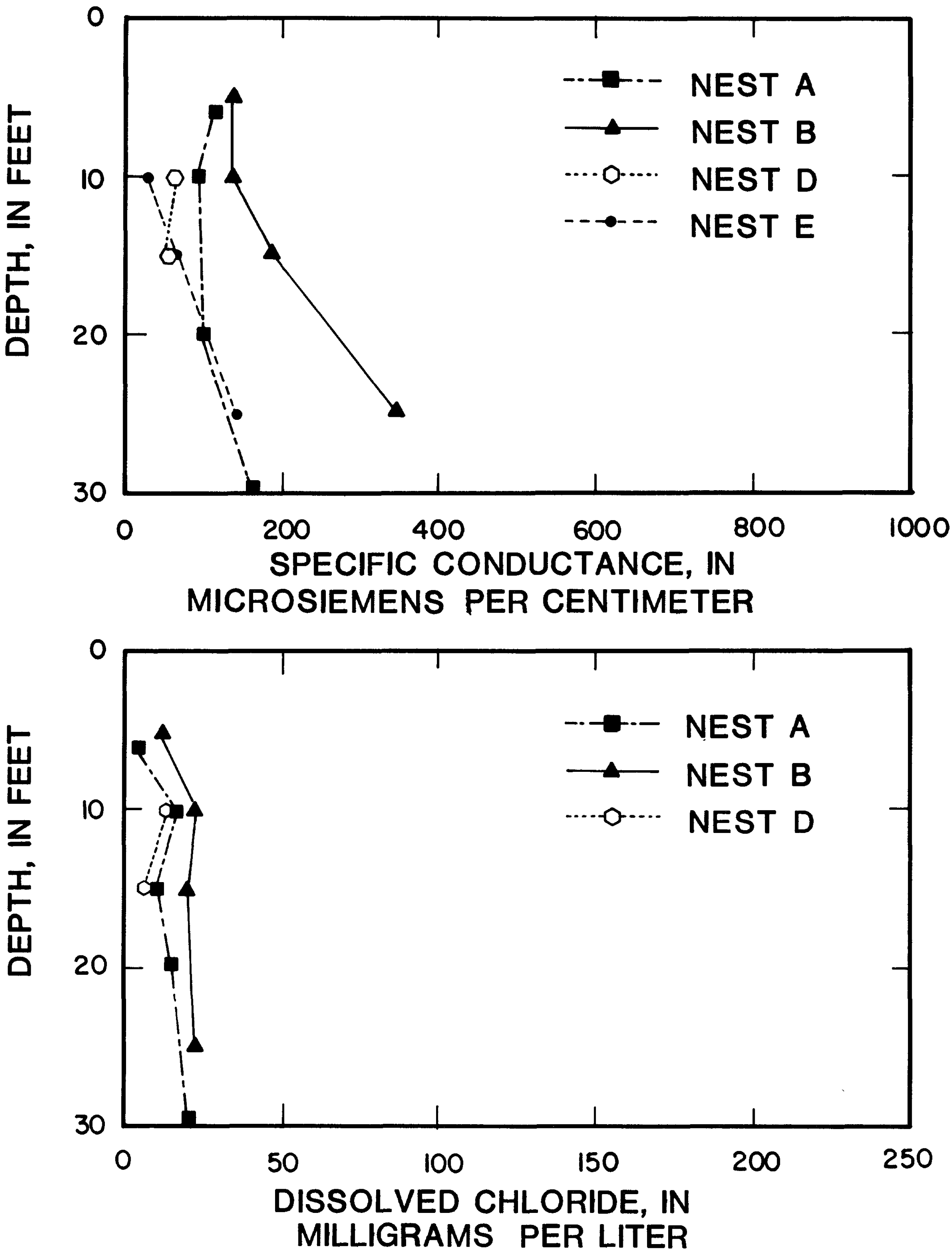


Figure 6.--Specific conductance and concentrations of dissolved chloride in ground-water samples collected from selected depths at nests A, B, D, and E prior to wastewater application

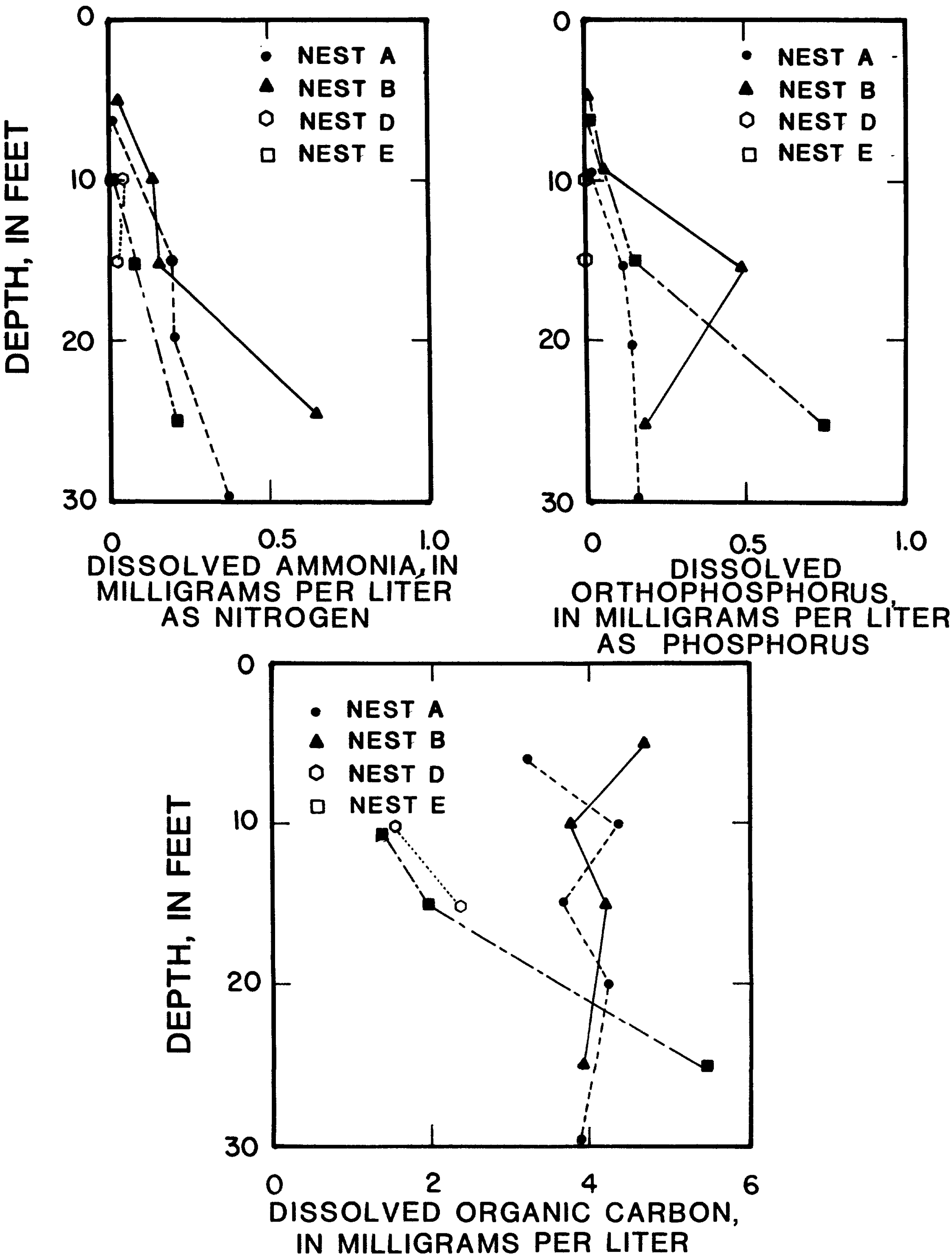


Figure 7.--Concentrations of dissolved ammonia, dissolved orthophosphorus, and dissolved organic carbon in ground-water samples collected from selected depths at nests A, B, D, and E prior to wastewater application

Concentrations of dissolved organic carbon did not increase with depth at all nests because concentrations resulted from both intermediate products and end products of the decomposition of organic carbon. The carbon end products of the decomposition of organic carbon in an anaerobic environment are carbon dioxide and methane. Carbon dioxide is an inorganic form of carbon that is a part of other reactions. Methane, which is a gas consisting of organic carbon, will not remain in solution and cannot be detected quantitatively with the sampling and preservation techniques used for samples of dissolved organic carbon.

WASTEWATER TREATMENT AND WASTEWATER APPLICATION FACILITIES AND PROCEDURES

The wastewater treatment plant consists of the treatment system and holding ponds. Wastewater treatment consists of primary treatment, secondary activated sludge treatment with a several-hour hydraulic retention time, final settling, and chlorination. The wastewater is primarily from domestic sources. After treatment, the wastewater is stored in holding ponds that have a 21-day hydraulic retention time. The treatment plant is located approximately 1 mile from the disposal site (fig. 2). Wastewater from the holding ponds is disposed of by spraying on two golf courses and at the disposal site.

The wastewater application system at the site includes a high-pressure system and a low-pressure system (fig. 8). The high-pressure system applies wastewater through pulsating-type spray heads having a spray radius of approximately 120 feet. The high-pressure system is surrounded by a 100-foot wide buffer zone on all sides to reduce movement of wastewater aerosols from the site. The low-pressure system consists of a network of PVC (polyvinylchloride) pipes 2 and 3 inches in diameter lying on the surface of the ground within the buffer zone along the northern, western, and southern boundaries of the site. Small streams of wastewater discharge about 2 feet out of 1/8 inch holes spaced 8 feet apart. The low-pressure system did not appear to apply wastewater evenly throughout the area.

The dates of application, total gallons, and inches of wastewater applied to the site are given in table 2. Inches of wastewater are based on the area to which wastewater was applied on that date. In January the entire spray application system was used. From April 1 through July 15 the low-pressure system along the southern boundary of the site and spray heads numbered 2, 3, 5, 6, 8, 9, and 10 (fig. 8) were shut off to avoid flooding in low areas. From July 16 through December, the low-pressure system along the southern boundary of the site and spray heads numbered 8, 9, and 10 remained off.

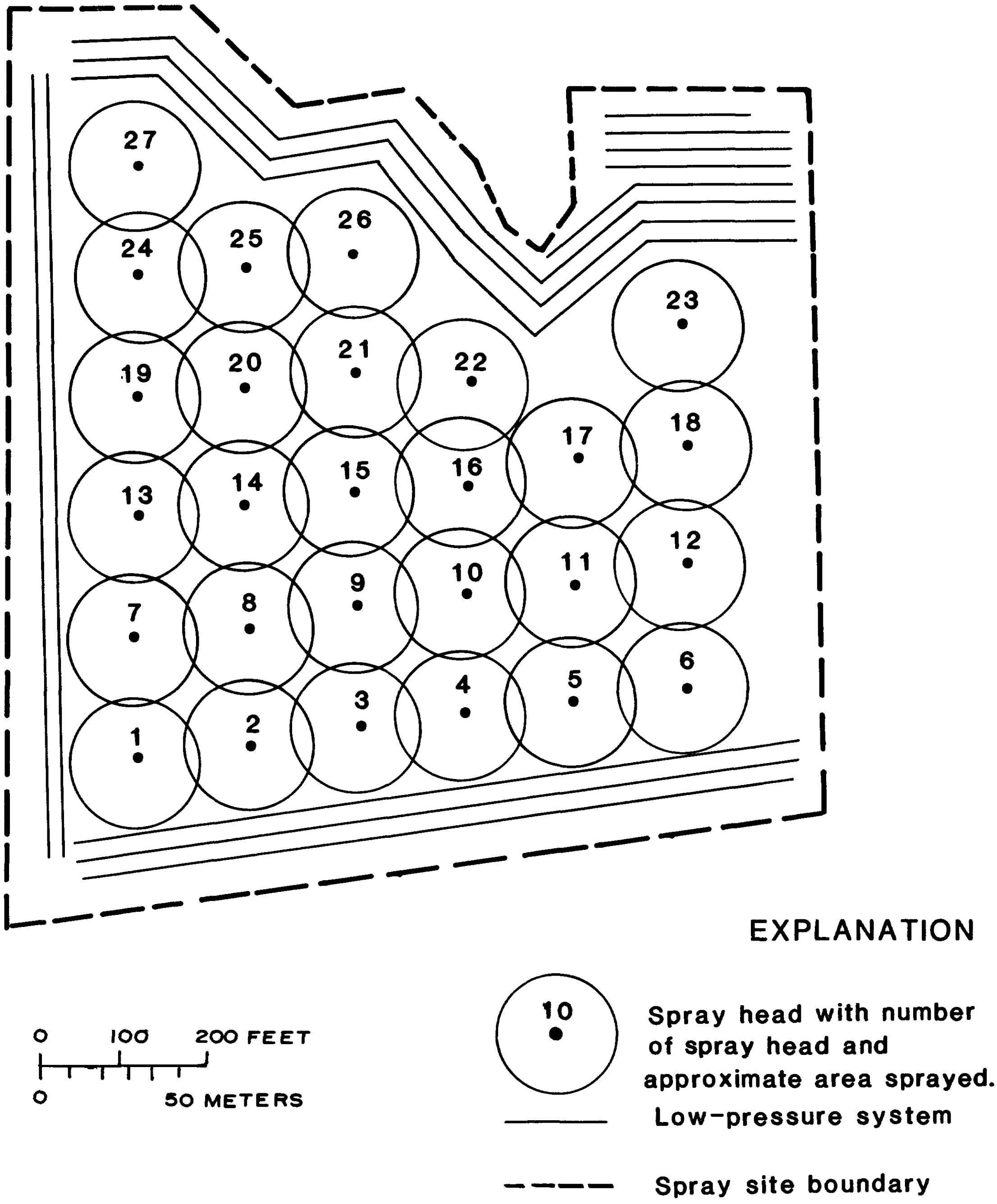


Figure 8.--Configuration of the high-pressure system of spray heads and low-pressure system for wastewater application on the wastewater disposal site

Table 2.--Wastewater application rates, January through December 1983

Date	Thousands of gallons applied	Inches applied	Date	Thousands of gallons applied	Inches applied
January 11	1,431	3.7	July 20-		
13	944	2.4	31	85	.26
18	906	2.3			
20	939	2.4	August 2	232	.71
			3	232	.71
April 1	202	0.71	4	232	.71
4	143	.50	5	232	.71
5	174	.62	6	232	.71
6	154	.54	7	232	.71
8	242	.86	8	232	.71
11	100	.35	9	232	.71
12	100	.35	10	232	.71
13	100	.35	11	232	.71
15	150	.42	12	232	.71
16	50	.18	13	232	.71
18	115	.41	14	232	.71
21	100	.35	15	232	.71
22	100	.35			
25	131	.46	September 15-		
29	177	.62	October 25	3,923	12
April 30-			October 26	234	.72
May 8	624	2.02	27	234	.72
			28	232	.71
May 9	158	.56			
11	136	.48	November 2	199	.61
25	98	.35	28	155	.48
27	103	.36	29	224	.68
			30	8	.02
June 2	101	.36			
3	100	.35	December 1	232	.71
7	110	.39	2	185	.57
8	100	.35	3	239	.73
9	103	.36	4	239	.73
10	133	.47	5	239	.73
13	102	.36	6	239	.73
14	106	.38	7	235	.72
15	90	.32	14	212	.65
			15	237	.72
June 16-			16	238	.73
July 19	141	.49	17	238	.73
			18	238	.73

Application of wastewater began January 10, 1983. A total of 10.8 inches of wastewater was applied in 10 days in January. This application rate resulted in flooding of the southern part of the site, and spraying was discontinued until the ponding of water had dissipated in early April.

Application rates varied during the April through July period but were about 2 inches per week during periods when spraying was conducted regularly. Application rates were about 5 inches per week from August 2 through August 15 and December 1 through December 18. Little wastewater was applied between August 15 and December 1.

The concentrations of various water-quality constituents in the wastewater generally were low. Specific conductance ranged from 660 to 820 umhos/cm in the wastewater. Concentrations of chloride in the wastewater ranged from 110 to 130 mg/L. Concentrations of nitrite plus nitrate nitrogen were nondetectable in the wastewater during the summer and were only 4.0 mg/L as nitrogen in December 1983. Concentrations of dissolved ammonia were less than 1 mg/L as nitrogen throughout the period. Concentrations of dissolved orthophosphorus ranged from 0.46 mg/L during August to 4.0 mg/L during December.

Concentrations of nitrite plus nitrate, ammonia, and dissolved orthophosphorus are probably low because of algal uptake in the holding ponds. This is indicated by the high pH and high concentrations of dissolved oxygen in the wastewater. The greatest effects were noted on August 10, 1983, when the pH of the wastewater was 10.4 units and the concentration of dissolved oxygen was greater than 20 mg/L in the holding pond.

Concentrations of MBAS in the wastewater ranged from 0.12 to 0.21 mg/L during the study. The magnitude of all water-quality constituents measured in the wastewater remained less than the maximum MCL's for drinking water.

EFFECTS OF APPLICATION OF WASTEWATER ON WATER LEVELS AND WATER QUALITY OF THE SITE

Water Levels

The hydrographs for piezometers A10R, B10R, and E10R show responses of the water table to aquifer characteristics, discharge from the aquifer to the surface water, wastewater application, evapotranspiration, and rainfall. The water levels in these piezometers, inches of wastewater applied, and inches of rainfall are shown in figure 9.

Water levels in E10R, where the unsaturated zone was 5 to 8 feet thick, changed less in response to rainfall than water levels in A10R where the unsaturated zone was 2 to 5 feet thick. Similarly, water levels in A10R changed less in response to rainfall than water levels in B10R, where the

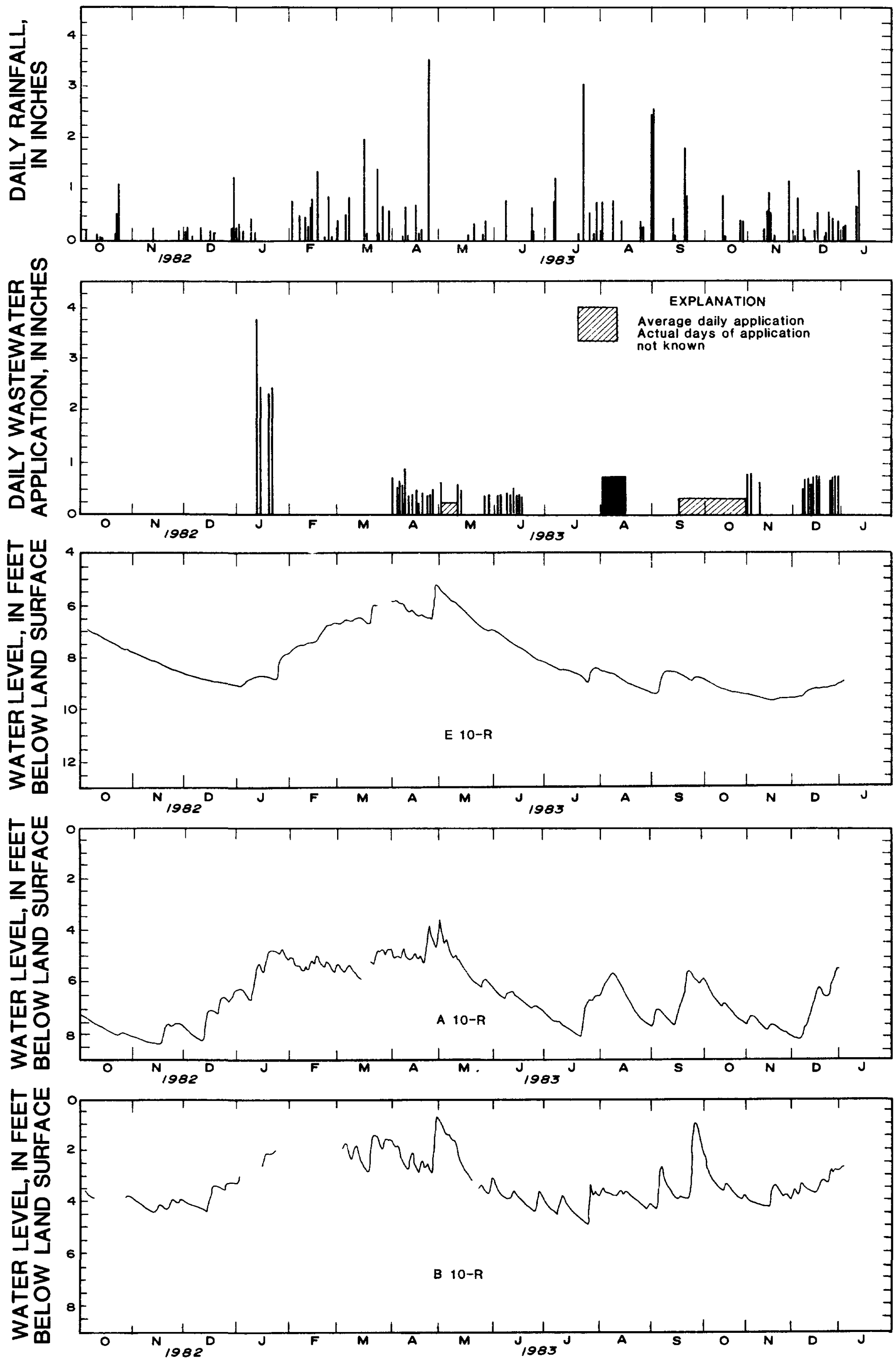


Figure 9.–Water levels in piezometers A10R, B10R, and E10R; inches of wastewater inches of wastewater applied; and inches of rainfall at the wastewater disposal site, October 1982 through December 1983

unsaturated zone was generally 1 to 3 feet thick. Because the unsaturated sediments consisted of similar grain-size sand at all nests, differences in responses of water levels to rainfall probably resulted from the different thicknesses of the unsaturated zone at each nest. Water in the unsaturated zone is retained as a film around individual grains of material and in the smaller interstices between grains. As a result the retention capacity is greater in a thick unsaturated zone than in a thin unsaturated zone consisting of physically similar materials.

Application of wastewater in January 1983 resulted in flooding of the site along the southern boundary and in other low areas. Potentiometric levels in the water-table aquifer increased at all nests (fig. 9), and a mound was created at the center of the spray site (fig. 10). The level of the ponded water reflected the water table as indicated by a comparison of water levels in piezometers at nest B with the level of the ponded water surrounding these piezometers. The low areas remained flooded through the end of March, partly as a result of the heavy rainfall during February and March.

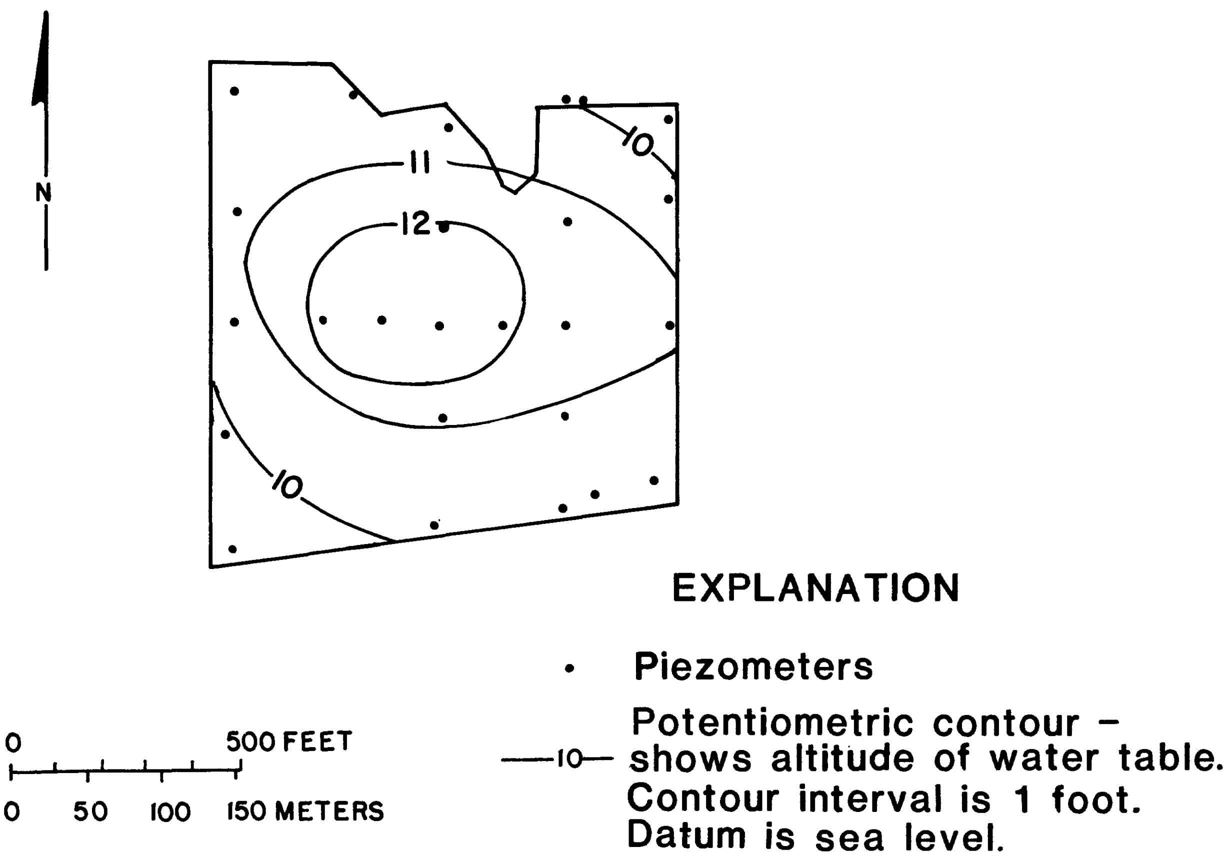


Figure 10.--Altitude of the water table at the wastewater disposal site, January 26, 1983

The extended period of ponding may also have resulted from controls on flow of water through the aquifer. Flow through the aquifer from the center of the site was restricted by the reduction in thickness of the aquifer at the southern boundary of the site. The permeability of the water-table aquifer south of the site in the vicinity of Broad Creek also may have reduced flow through the aquifer. Although data are not available on the characteristics of the aquifer, the aquifer may consist of finer grain-size and less permeable sediments to the south than at the site.

Hydrographs for A10R and B10R are similar for the period from April through the end of July. Wastewater application rates averaged about 2 inches per week during this period. Response of ground-water levels to wastewater applications appeared to be small and were generally masked by the periodic rainfall. On April 23, low areas of the site were flooded as a result of 3.5 inches of rainfall.

The water level in A10R rose from July 22 through August 9 in response to rainfall and wastewater application, then fell even though wastewater application continued until August 15. The water table remained more than 5-1/2 feet below land surface at nest A and 3-1/2 feet below land surface at nest B during this time.

The mound in the water table also occurred at the center of the spray site during the 2-inch per week application of wastewater in April and the 5-inch per week applications of wastewater in August and December (fig. 11). Water levels at the south side of the site in the vicinity of nest B were about 1 foot higher in December than in August as a result of a lower rate of evapotranspiration in December than in August.

Vertical gradients in water levels during the period of wastewater application appear to be affected by a combination of rainfall, wastewater application, and evapotranspiration (fig. 12). Vertical head differences were generally less than 0.1 foot between the shallowest and deepest piezometers at nests A, B, and E. There appeared to be a slight downward gradient off-site at nest E during most of the period (fig. 12).

At nest A a slight downward gradient between a depth of 15 to 20 feet and a depth of 30 feet may reflect recharge from rainfall and wastewater application. At depths shallower than 15 feet the gradient appears to be upward. The upward gradient probably results from the loss of water by evapotranspiration from the unsaturated zone and the upward movement of water from the water table through the unsaturated zone by capillary action to replace water lost by evapotranspiration. At nest B it appears that a slight upward gradient also exists at times.

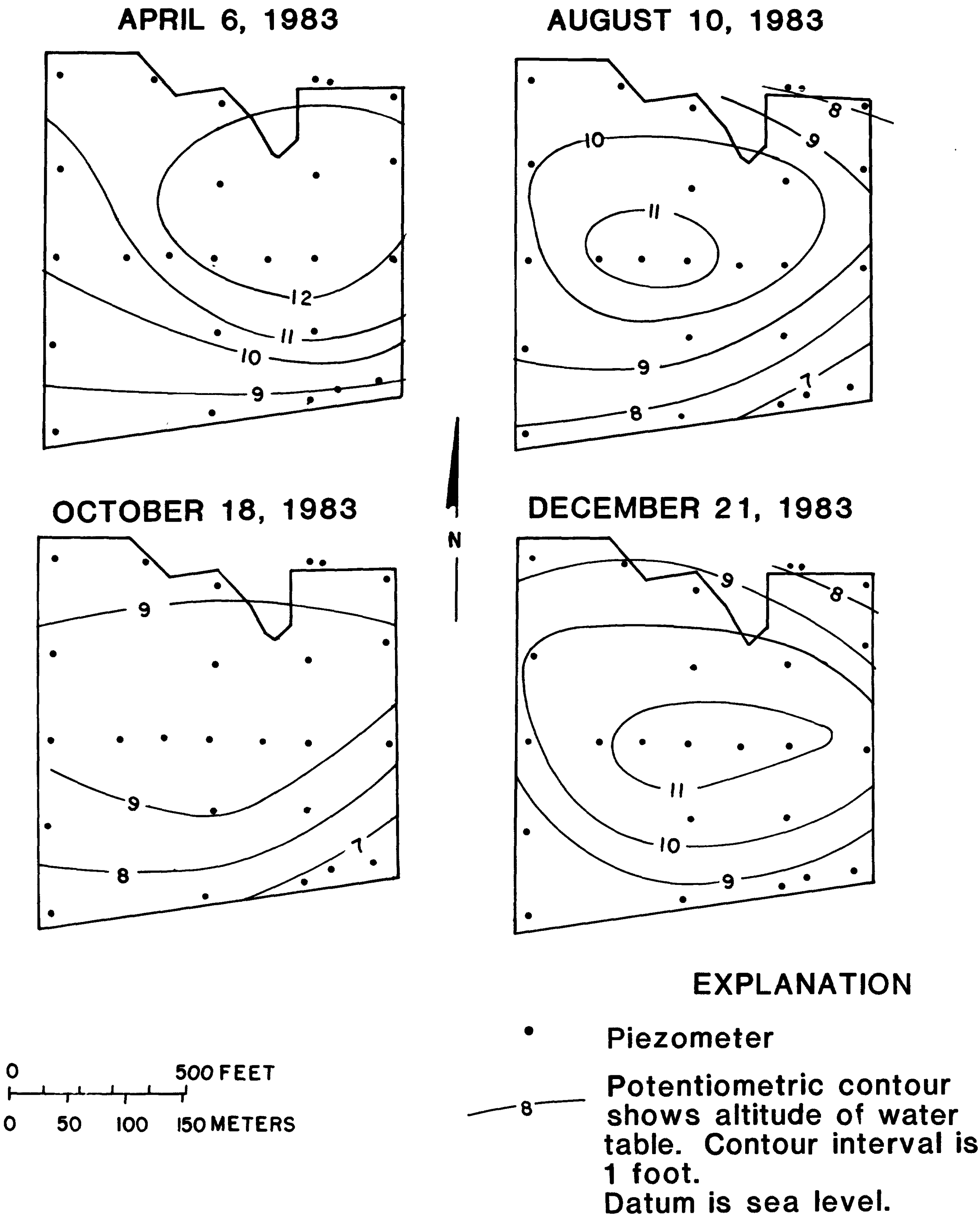


Figure 11.--Altitude of the water table at the wastewater disposal site, April, August, October, and December 1983

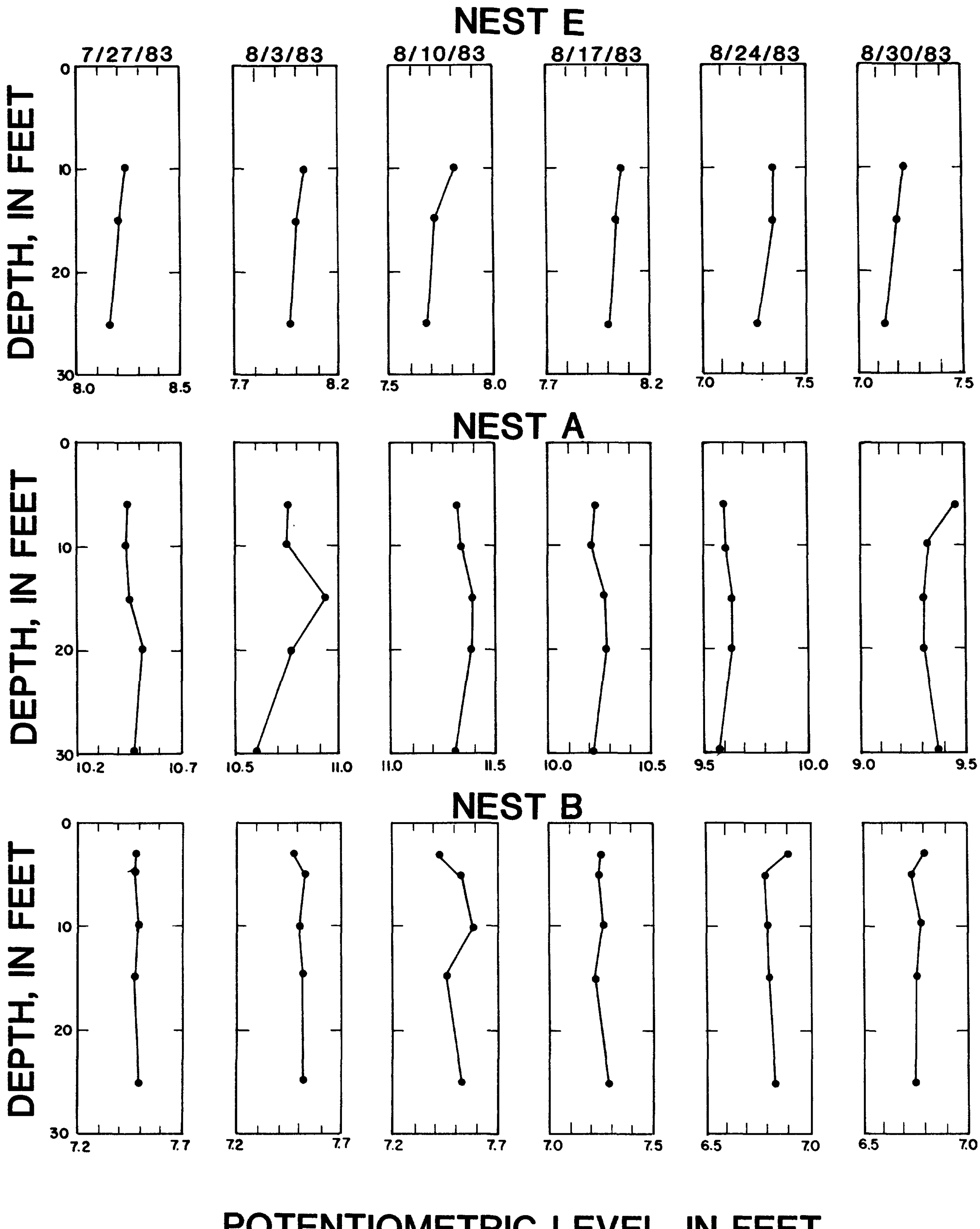


Figure 12.--Potentiometric levels in piezometers at nests E, A, and B at the wastewater disposal site, July 27 through August 31, 1983

The higher potentiometric level in B10 than in other piezometers at nest B on August 10, 1983, coincides with a peak in the hydrograph for B10R. On all other dates for which vertical profiles are shown at nest B, water levels in B10R were declining. The more extreme vertical gradient at nest A on August 3, 1983, coincides with a rise in water levels in A10R.

Water Quality

The ground-water quality at nest E changed little throughout the study (figs. 13 and 14). Thus, changes in water quality at other nests probably resulted from the application of wastewater. The greatest changes in ground-water quality occurred in the shallowest piezometers at nest A (figs. 15, 16, and 17) and to a depth of 15 feet.

Specific conductance and concentrations of chloride initially increased as a result of wastewater application (figs. 15 and 16). However, specific conductance and concentrations of chloride in A6 decreased between April and August. Specific conductance increased slightly during August, but remained well below that observed in April, although wastewater was applied at higher rates in August than in April. In December, both specific conductance and the concentration of chloride increased in A6 to levels greater than in the wastewater.

The trends in specific conductance and concentrations of chloride probably resulted from seasonal changes in the rates of evapotranspiration. In the winter, rates of evapotranspiration were low. Rates of evapotranspiration increased in the spring and summer, then decreased in the fall and winter. During periods of low rates of evapotranspiration, most of the wastewater probably reached the water table. Uptake of much of the wastewater by evapotranspiration probably occurred before the wastewater reached the water table during periods of high rates of evapotranspiration. Evapotranspiration of wastewater from the unsaturated zone left a residue of dissolved solids that remained in the unsaturated zone during the period. Water moving through the unsaturated zone to the water table would have washed some of the residue from the unsaturated zone to the water table, but the amount appears to be small. After evapotranspiration decreased in the fall, rainfall and wastewater probably washed the residue of solids from the unsaturated sediments. This conclusion is supported by the increase in the specific conductance and the concentration of chloride in the samples from A6 in December. The wash of the residue of solids from the unsaturated zone caused the specific conductance and concentration of chloride to increase to levels greater than those in the wastewater.

The amount of solids residue in the unsaturated zone is probably affected by the rate of wastewater application. At very low application rates, little residue is left because of the low loading of dissolved solids. However, at intermediate rates, the buildup of solids is probably the greatest. When a large residue is washed from the unsaturated zone, concentrations of chloride in the ground water will be high. Such concentrations will likely occur in pulses that will subsequently disperse as the pulse moves through the aquifer. If wastewater application rates are high enough, wastewater will continuously flush most of the solids from the unsaturated zone. Thus, high-rate wastewater application may maintain a less variable water quality in the water-table aquifer than low-rate wastewater application.

Although wastewater application increased specific conductance and concentrations of chloride in the water-table aquifer, it did not increase the concentration of nitrite plus nitrate or ammonia, even when wastewater was applied at 5 inches per week. Throughout the period of wastewater application, concentrations of nitrite plus nitrate were nondetectable in all piezometers at nest A. Concentrations of ammonia in piezometer A6 ranged from nondetectable to no greater than 0.02 mg/L. There was little or no change in concentrations of ammonia in all piezometers at nest A throughout the study (fig. 17).

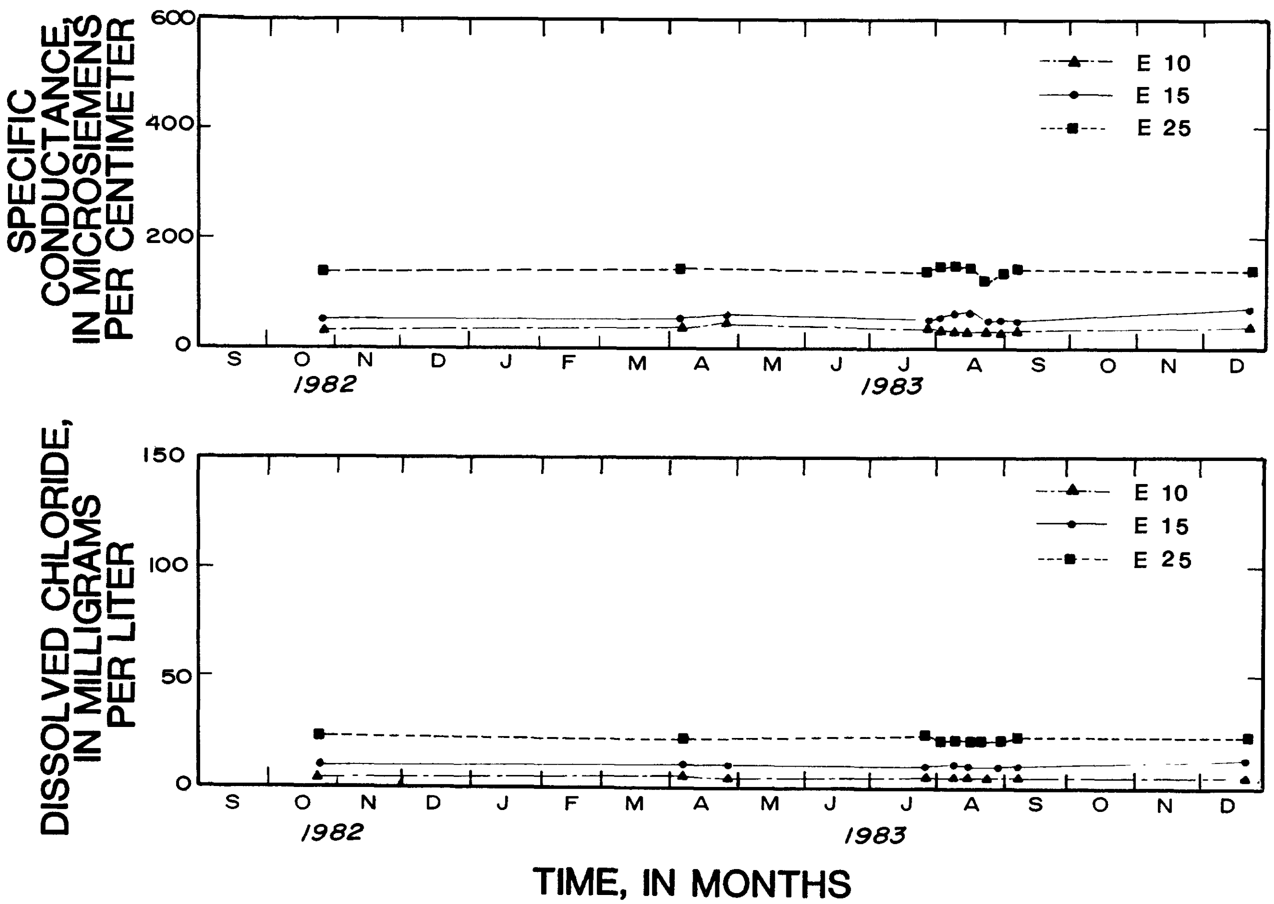


Figure 13.--Specific conductance and concentrations of dissolved chloride in ground-water samples collected from selected depths at nest E, October 1982 through December 1983

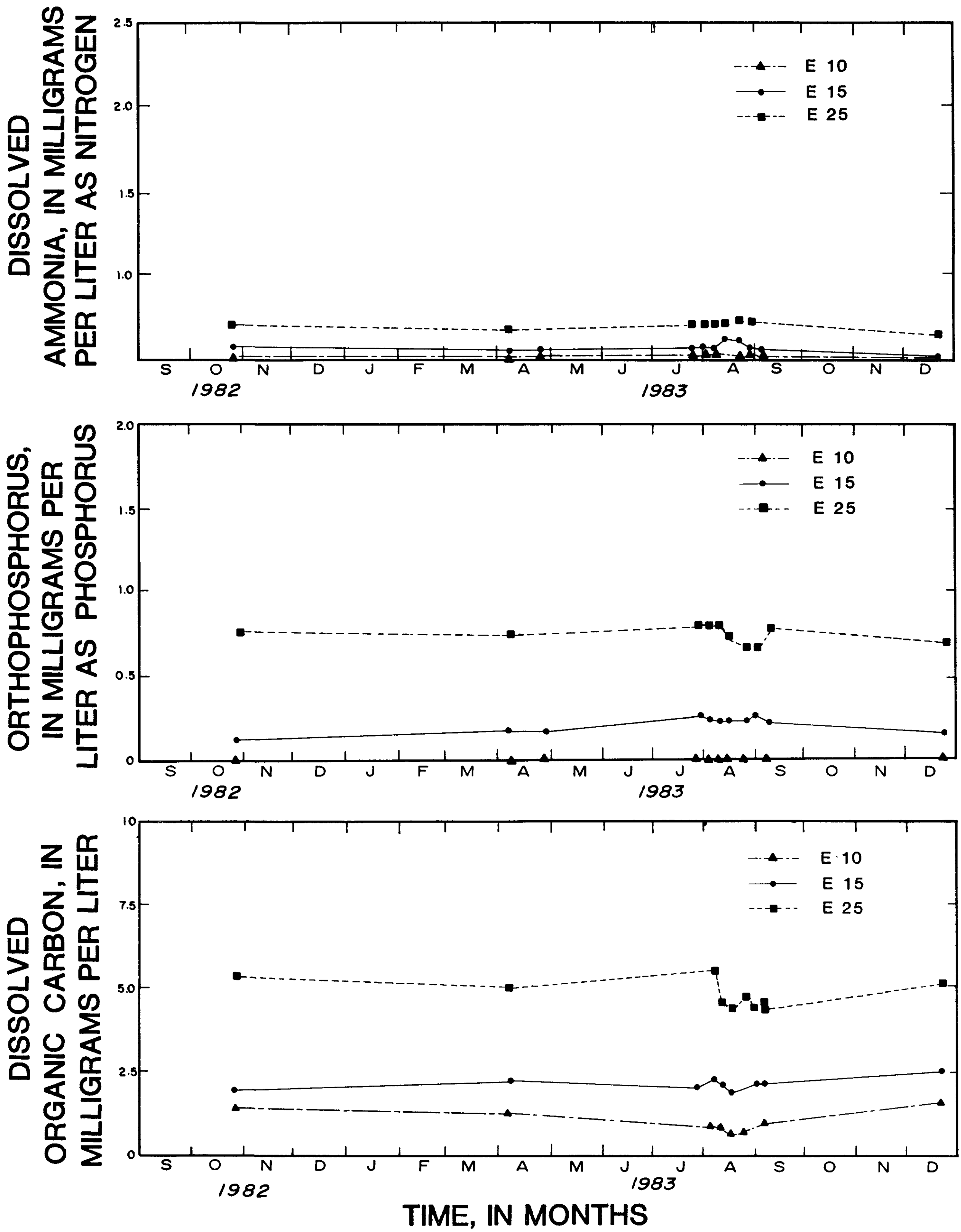


Figure 14.– Concentrations of dissolved ammonia, dissolved orthophosphorus, and dissolved organic carbon in ground-water samples collected from selected depths at nest E, October 1982 through December 1983

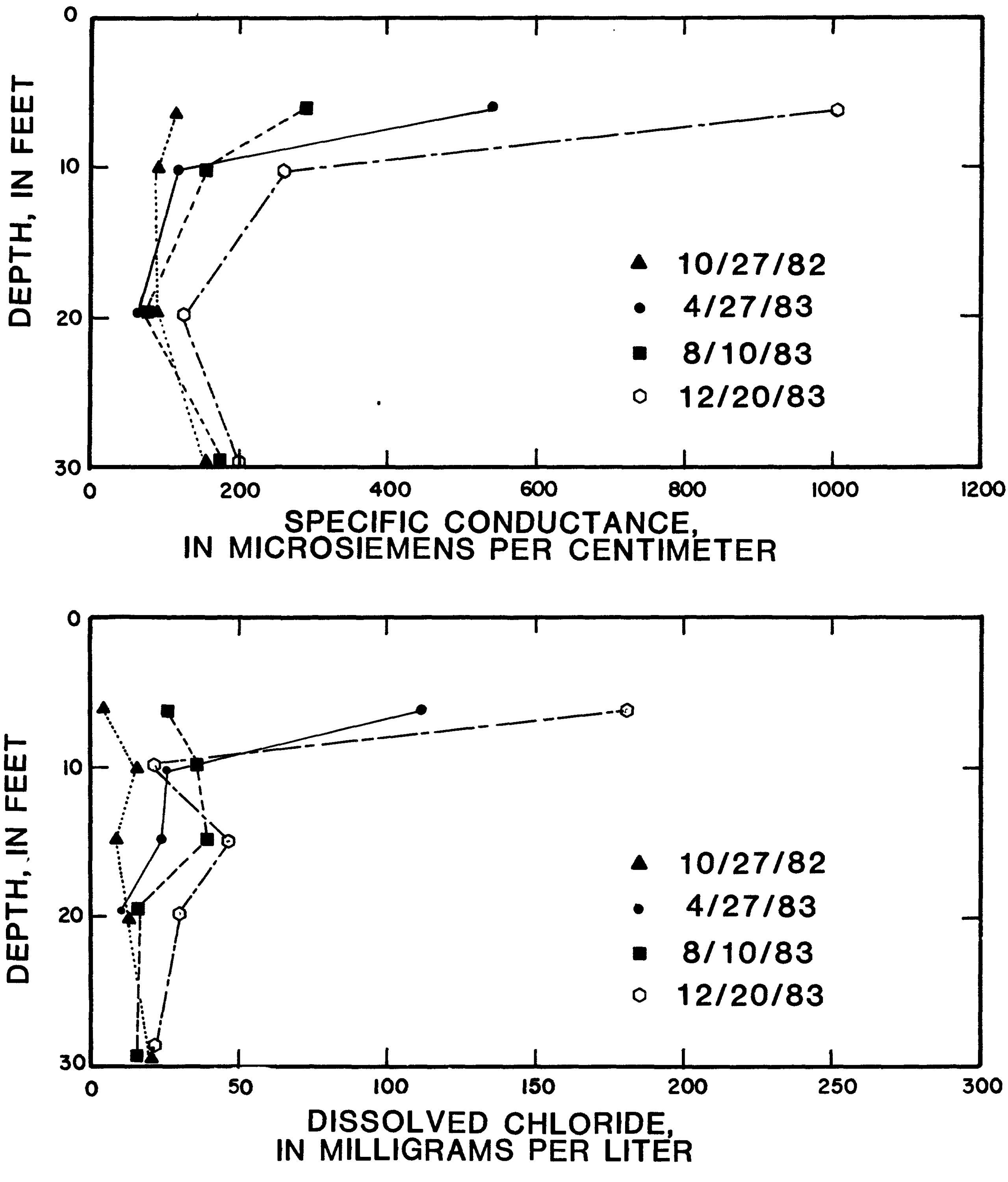


Figure 15. --Specific conductance and concentrations of dissolved chloride in ground-water samples collected from selected depths at nest A, October 27, 1982; April 27, 1983; August 10, 1983; and December 20, 1983

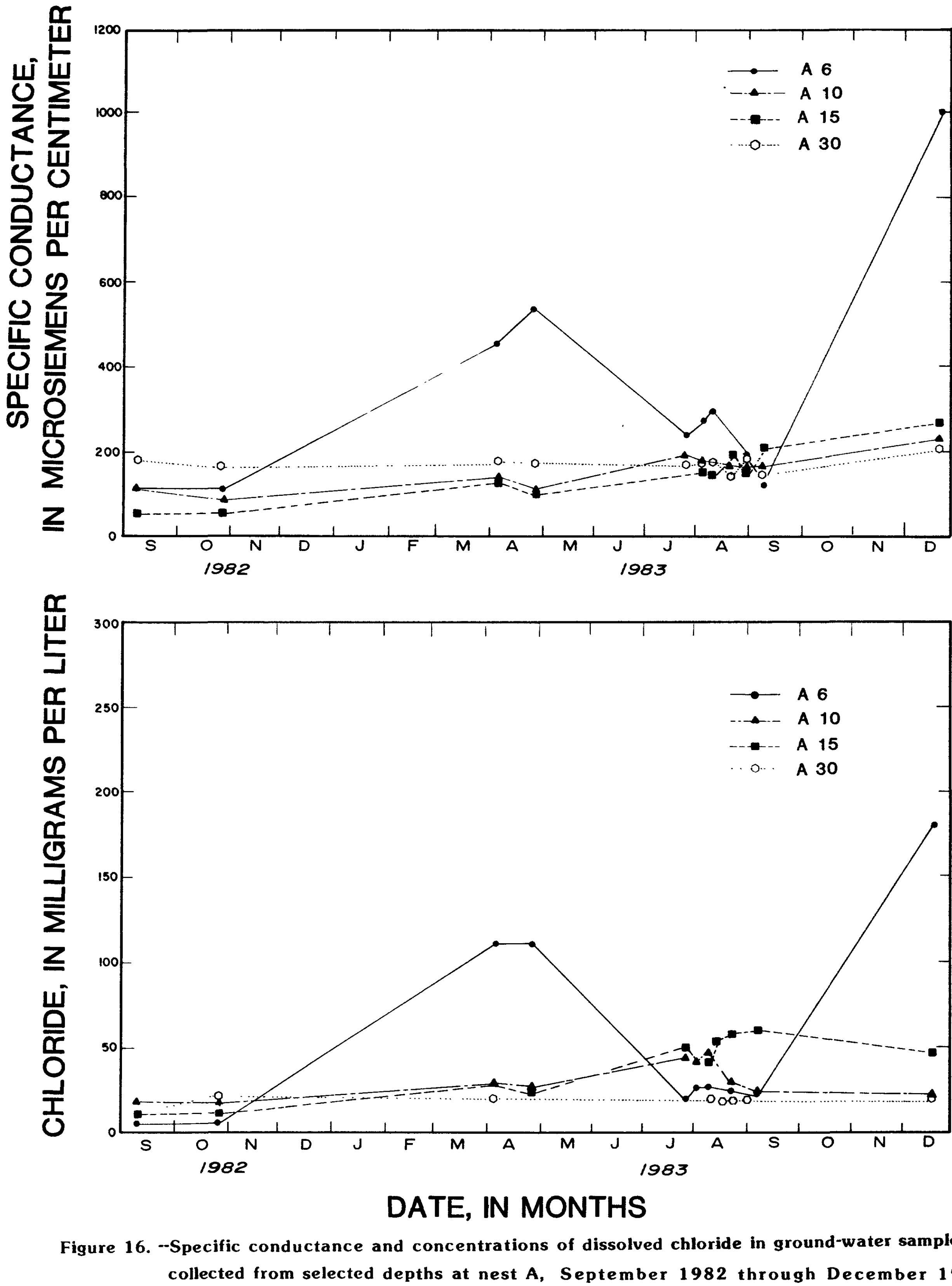


Figure 16. --Specific conductance and concentrations of dissolved chloride in ground-water samples collected from selected depths at nest A, September 1982 through December 1983

The increase in concentrations of ammonia with depth in the aquifer is a result of the decomposition of organics within the aquifer as noted for the period prior to wastewater application. Concentrations of ammonia in the ground water would have been greater at the top of the aquifer than deeper in the aquifer, if concentrations had increased as a result of wastewater application. Thus, the soils and vegetation at the disposal site apparently assimilated the low nitrogen loading to the site.

The ground water generally remained anaerobic or almost anaerobic at nests A, B, D, and E throughout the study. The anaerobic ground water may be one of the most significant aspects of the natural water quality affecting the changes in ground-water quality resulting from wastewater application. If loadings of ammonia and nitrite plus nitrate are high, the anaerobic environment will inhibit the nitrification of ammonia and promote the denitrification of nitrate to nitrogen gas. Because of this, it is unlikely that the MCL of 10 mg/L of nitrate as nitrogen will be exceeded by high nitrogen loadings.

Although organic carbon is present in the formation and in the wastewater, there may not be enough organic carbon for the denitrification of heavy loads of nitrate. If this occurs, supplemental additions of organic carbon could aid complete denitrification. The potential for nitrogen uptake by the vegetation and soils and for denitrification within the aquifer could not be fully evaluated because of the low rates of nitrogen loading to the site.

MBAS remained at background levels in the ground water at all nests throughout the study. THM's were nondetectable in all samples of ground water analyzed for these constituents.

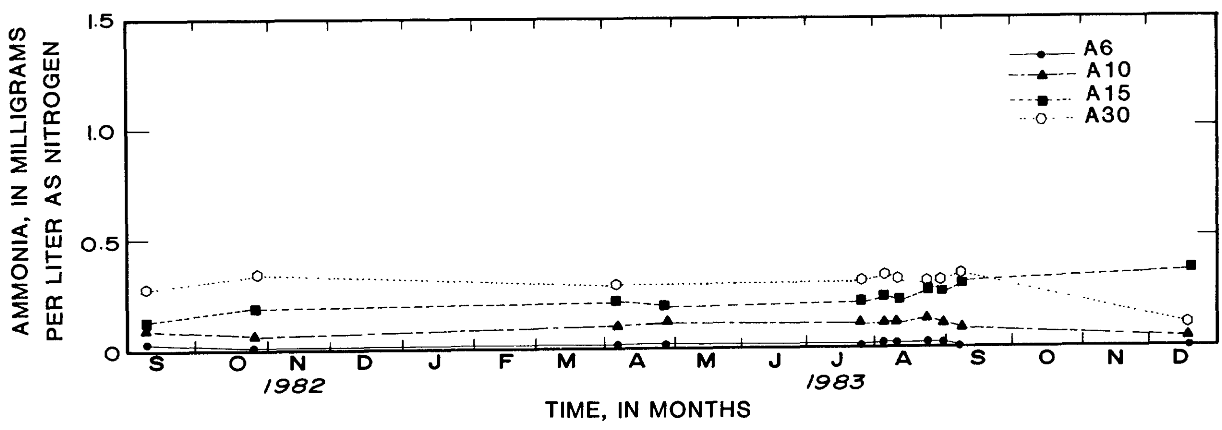


Figure 17.--Concentrations of dissolved ammonia in ground-water samples collected from selected depths at nest A, September 1982 through December 1983

SUMMARY AND CONCLUSIONS

Wastewater was applied at rates of up to 5 inches per week in August and December 1983. The water table remained more than 5-1/2 feet below land surface at nest A and more than 2-1/2 feet below land surface at nest B during both periods of wastewater application. However, ponding occurred in topographically low areas in the southern part of the site when 10.8 inches of wastewater was applied in 10 days in January 1983. This ponding reflected the level of the water table. Disposal sites with low topographic areas and a shallow water table may require close monitoring to operate the sites at high disposal rates.

The major effects of wastewater application on ground-water quality were increases in specific conductance and concentrations of chloride to a depth of 15 feet (the upper 10 feet of the water-table aquifer). An apparent residue of solids in the unsaturated zone occurred during the summer when the rate of evapotranspiration was high. Flushing of the residue of solids caused an increase in specific conductance and the concentration of chloride in the ground water in December 1983 to levels greater than those in the wastewater. If wastewater application rates are high enough, wastewater will continuously flush most of the solids from the unsaturated zone and a less variable ground-water quality will occur.

Concentrations of ammonia and nitrite plus nitrate in the ground water were not affected by wastewater application at rates up to 5 inches per week. Uptake by algae in holding ponds at the wastewater treatment plant greatly reduced the concentration of ammonia and nitrite plus nitrate in the wastewater, resulting in low loadings to the site.

The conclusion of this study is that high-rate application of wastewater (up to 5 inches per week) can be used at selected locations on Hilton Head Island without significant changes in the ground-water levels and water quality during times of the year that evapotranspiration is high or low if the water table is low. However, proper site selection and design are extremely important in developing and operating an optimum high-rate wastewater disposal site.

Factors to consider for proper site selection are sites with (1) high permeability soils throughout the area that wastewater is applied, (2) few or no low areas in or near the area that wastewater is applied, (3) a water table several feet below land surface, (4) a limited amount of dense vegetation that would inhibit even application of wastewater, and (5) a natural ground-water quality that would improve the quality of the wastewater. Factors to consider for proper design are a distribution system that (1) applies wastewater evenly throughout the area, (2) has a minimum of interference from vegetation in the even application of wastewater, and (3) does not apply wastewater in or near low areas.

Additional studies would be required to determine the application rates, including rates greater than 5 inches per week, that can be assimilated without adverse effects on the environment of specific sites at various times of the year. Such studies should include application of wastewater having loadings of ammonia and nitrate greater than previously studied. Because Hilton Head Island is primarily a summer resort, the greatest amount of wastewater will be produced in the summer when wastewater can be applied at the highest rates because the water table is low and evapotranspiration is high. The rates of wastewater application needed to continuously flush solids from the unsaturated zone to the water table should also be evaluated as a part of such studies.

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