EFFECTS OF POND IRRIGATION ON THE SHALLOW AQUIFER OF WADMALAW ISLAND, SOUTH CAROLINA

by

Brenda L. Hockensmith

Prepared in cooperation with
Charleston County Council
South Carolina Sea Grant Consortium
Charleston Harbor Project
South Carolina Tomato Association
Leadenwah Preservation Association

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ABSTRACT

A flow model was constructed to simulate the ground-water system on Wadmalaw Island, near Charleston, S.C., in order to assess the potential for well interference and saltwater encroachment as a result of pumping from irrigation ponds.

Hydrologic data were collected from 5 domestic wells, 25 observation wells, and 4 pond staff gages for as much as 21 months. The shallow, unconfined aquifer in the study area is a well-sorted, fine-grained sand. In this aquifer, for the period of record, water levels were lowest during October 1993 and highest during March 1994. Seasonal variations in water level as great as 7 feet have been noted in the aquifer. During irrigation season, pond levels declined only slightly more than the maximum seasonal fluctuation of the water table.

Well interference and saltwater intrusion induced by pond pumping were found to be minimal because of the aquifer's low hydraulic conductivity. Cones of depression centered on irrigation ponds were steep but of small areal extent. Ground-water flow patterns were such that domestic-well contamination from farming practices was minimal.

INTRODUCTION

This study prompted by concern of the residents of Wadmalaw Island about possible adverse effects on the shallow aquifer of increased agricultural irrigation from ponds that are bottomed in the aquifer. Since water for domestic supplies is obtained primarily from wells in the shallow aquifer, concerns focused on the possibility of declines in water levels resulting in saltwater encroachment and a decrease in productivity of domestic wells. Potential degradation of ground-water quality by the introduction of pesticides, used during irrigation, was also a concern. To assess the effects that crop irrigation might have on the shallow water-table aquifer, the South Carolina Department of Natural Resources, Water Resources Division, (formerly the South Carolina Water Resources Commission), with funding from the Charleston County Council, South Carolina Tomato Association, South Carolina Sea Grant Consortium, Charleston Harbor Project, and the Leadenwah Preservation Association, undertook this investigation.

STUDY AREA

Wadmalaw Island is in the lower Coastal Plain of South Carolina, 20 miles southwest of Charleston. The area of this study (Fig. 1) is a 3-square-mile circle near the western end of the island. Leadenwah Creek is on the north and Adams Creek is on the south.

The average temperature is 65° Fahrenheit and average precipitation is 50 inches per year (National Oceanic and Atmospheric Administration, 1992). The topography is dominated by a sand ridge that parallels Leadenwah Drive. Elevations range from 17 ft msl (feet above or below mean sea level) on the sand ridge to less than 5 ft msl near the study-area boundaries.

Agriculture is the principal land use, with residential property located along Leadenwah Creek and near roadways. Figure 2 shows the locations of the agricultural ponds and wells inventoried in the study area.

OBJECTIVES OF THE STUDY

The objectives of this study were to:

1. Determine existing ground-water usage in the study area (source, amount, and type);
2. Determine hydrogeologic properties of the shallow aquifer being utilized;
3. Determine background water quality for the shallow aquifer; and
4. Assess the extent to which crop-irrigation withdrawals affect residential users by
   a. well interference,
   b. saltwater intrusion,
   c. contamination by fertilizers and pesticides.

WELL-NUMBERING SYSTEM

The South Carolina Department of Natural Resources (SCDNR), Water Resources Division, uses a grid system, based on the latitude and longitude coordinates of wells, to assign identification numbers. For this purpose,

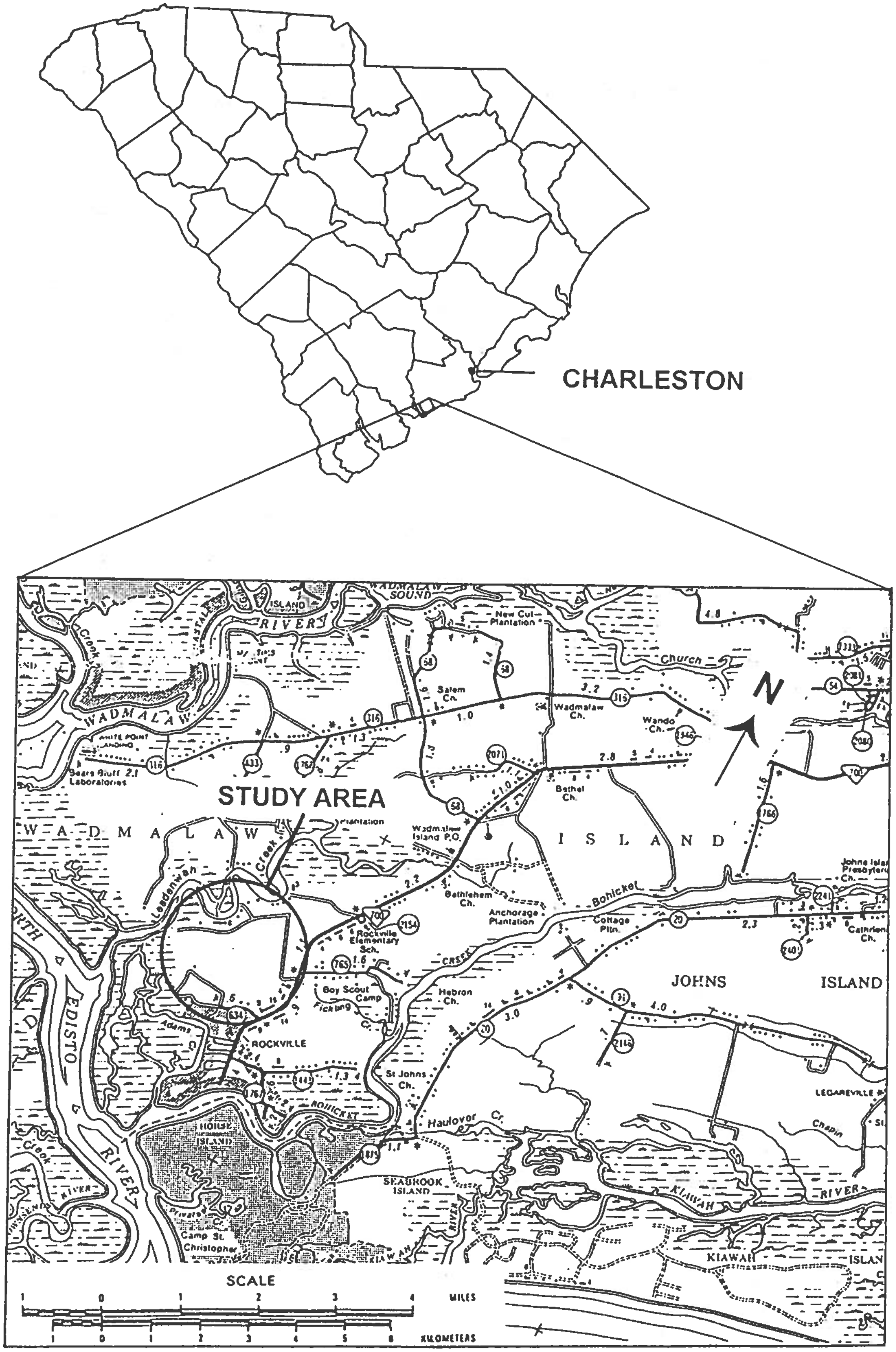


Figure 1. Study area, Wadmalaw Island, Charleston County, S. C.

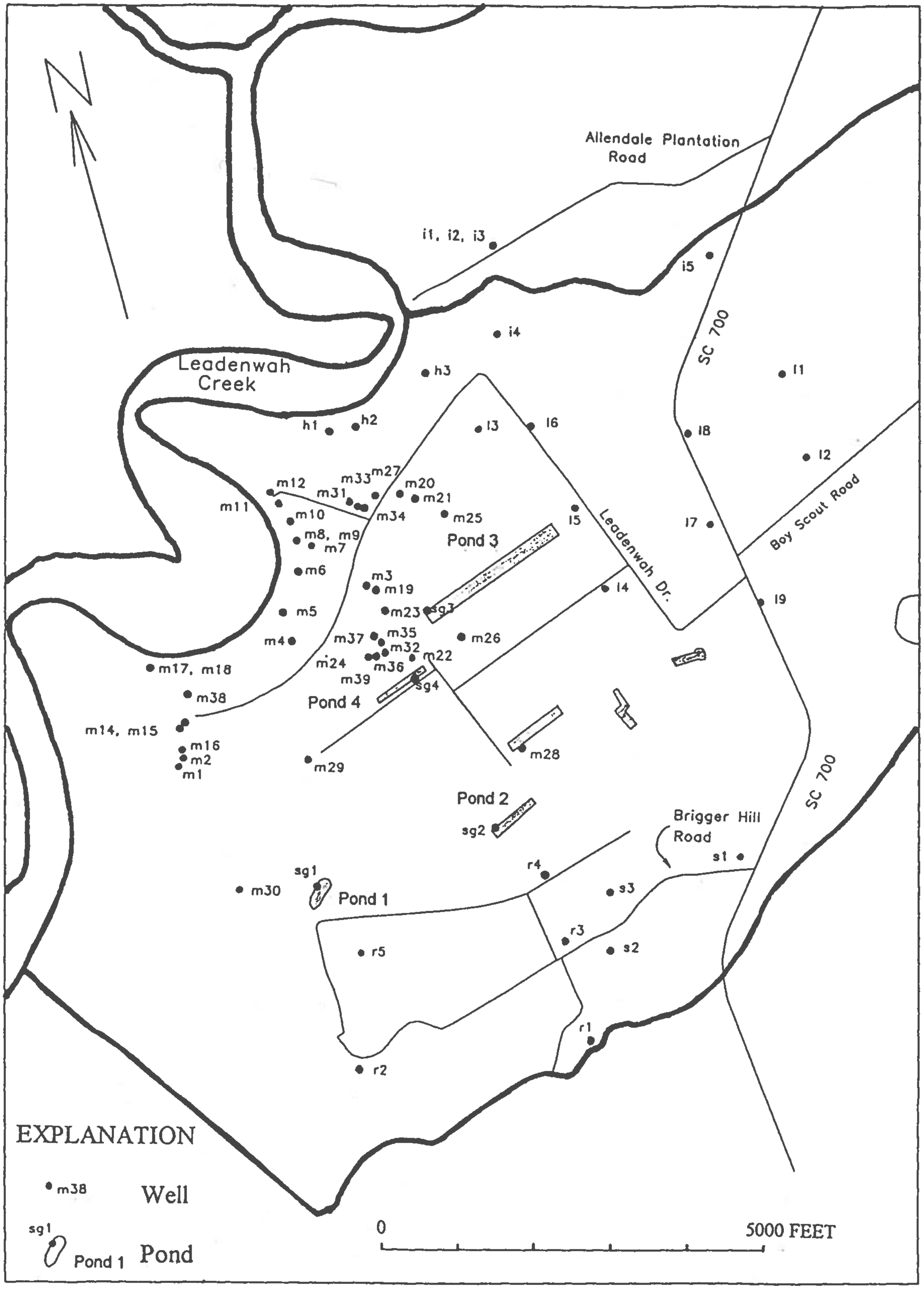


Figure 2. Well locations and major features in the study area.

the State has been divided into major grid blocks, each measuring 5 minutes of latitude by 5 minutes of longitude. These blocks are identified by a number followed by a capital letter and are labeled by number from east to west and by letter from north to south. Each of these major grid blocks has been subdivided into 25 minor blocks, each being a 1-minute square, which have been labeled with lower-case letters from a to y. Within each 1-minute block, the wells are numbered consecutively in the order they were recorded. For example, the well with the number 21FF-m1 was the first well to be located in the 1-minute block "m" of the 5-minute block "21FF". All wells in the study area are in the 21FF 5-minute grid.

ACKNOWLEDGMENTS

Gratitude is extended to the many residents and landowners in the study area for their cooperation and assistance. In particular, thanks are expressed to the following for allowing the installation or use of wells on their property: Thomas Brantley; Indian Mound Trust Corporation; Linda and Bob Kifer; Joe Kelly; William F. Morgan; Bruce Murdy; Edward Poole; James F. Schaffer; John Feraras Seabrook; William Jenkins Seabrook; John M. Settle; Robert Tolbert; R.M. "Sunny" Hanckel, Paul Hanckel, and Rhett Hanckel of Planters Three; and Elizabeth and Charles Wenner.

Thanks are due to Walter J. Sexton of Athena Technologies, Inc., for the use of a vibracore to install many of the wells, and to Mike Waddell of Earth Sciences and Resources Institute for demonstrating its use for installing wells.

The author is indebted to Elizabeth and Charles Wenner for their collection of precipitation data and to Elwood Jones for his assistance in well surveying.

GEOLOGY

Sediments ranging in age from Late Cretaceous to Quaternary underlie the site to a depth of more than 2,600 ft. A generalized description of these stratigraphic units is given in Table 1. The nomenclature for some of these formations has been revised in recent years (Gohn, 1992, and Gohn and Campbell, 1992). The stratigraphic nomenclature of Park (1985) is used locally and has been adopted for this report.

CRETACEOUS DEPOSITS

Overlying the bedrock is the Middendorf Formation of late Cretaceous age. The lower section consists of interbedded red, brown, and yellowish-gray clay, muddy clay and poorly sorted, fine- to coarse-grained feldspathic sand (Cape Fear Formation of Gohn and others, 1977). The upper section contains a fining-upward sequence of feldspathic sand, clayey silt, and sandy clay. The sand is typically mottled red, reddish brown, and grayish green, poorly sorted, and fine to coarse grained. The clay is red, reddish brown, or mottled red and gray-green (Gohn and others, 1977). In the study area, the formation is about 500 ft thick and lies approximately between the depths of -2,200 and -2,680 ft msl.

The Black Creek Formation consists of thick, alternating cycles of fossiliferous silty clay, muddy sand, and clean sand with thinly interbedded sand and clay, and occasional shelly limestone. Gohn and others (1977) described the silty clay and muddy sand as medium gray and gray green in color, calcareous and fossiliferous with some glauconite, phosphate, mica, and pyrite. Black Creek sediments are about 700 ft thick, occurring between -1,500 and -2,200 ft msl at the site.

Above the Black Creek lies the Peedee Formation, which is a thick sequence of olive to medium-gray, calcareous muddy sand and calcareous mud (Gohn and others, 1977). On Wadmalaw Island, it is approximately 500 ft thick and occurs between -1,000 and -1,500 ft msl.

TERTIARY DEPOSITS

The Black Mingo Formation, the oldest Tertiary formation, is about 480 ft thick and located between -520 and -1,000 ft msl in the study area. It is composed of yellow-gray to greenish gray, sandy clay, gray-green silty clay, and muddy sand (Park, 1985).

Overlying the Black Mingo Formation is a creamy-white to gray, fossiliferous limestone known as the Santee Limestone. Two members are recognized within the Santee Limestone, the Moultrie and the Cross. The Moultrie Member, a biosparite and bryozoan hash, is the lower unit. The Cross Member is a brachiopod-bivalve biomicrite. Both are locally rich in phosphate, particularly at the upper contacts (Park, 1985). Beneath the investigation site, the Santee Limestone is nearly 230 ft thick and is present from -300 to -530 ft msl.

The Cooper Formation is a sandy, phosphatic limestone subdivided into three members. The Harleyville Member, the oldest unit, is a clayey, very fine-grained limestone. Overlying the Harleyville Member is a glauconitic, clayey, fine-grained, fossiliferous limestone known as the Parkers Ferry Member. The Ashley Member, the youngest unit, is a phosphatic, muddy, calcareous sand (Ward and others, 1979).

In the study area, the Cooper Formation is about 270 ft thick and lies between the depths of -30 and -300 ft msl. The top of the Cooper Formation forms the base of the shallow aquifer beneath Wadmalaw Island, and the formation acts as a confining unit.

Table 1. Stratigraphic units in the study area (modified from Park, 1985, and McCartan, 1990)

SYSTEM	SERIES	FORMATION	LITHOLOGY
Quaternary	Holocene	Q1	*Q1b:* Pale-orange and blue-gray, clean, fine- to medium-grained quartz sand (beach deposits). *Q1l:* Dark-gray to grayish brown, muddy sand and sandy mud (backbarrier deposits).
	Pleistocene	Q2	*Q2b:* Pale grayish orange, yellowish gray and gray, clean, fine- to medium-grained quartz sand, with some shells (beach deposits). *Q2l:* Dark yellowish orange, grayish orange, and gray, muddy quartz sand with clay, shell, and sand layers (backbarrier deposits). *Q2r:* Gray, gravelly, coarse quartz sand (fluvial deposits).
Tertiary	Oligocene	Cooper	Pale-green, or yellowish to olive-brown, sandy, phosphatic limestone. *Ashley Member:* phosphatic, muddy, calcareous sand. *Parkers Ferry Member:* glauconitic, clayey, fine-grained, abundantly fossiliferous limestone. *Harleyville Member:* phosphatic, calcareous clay to clayey, very fine-grained limestone.
	Eocene	Santee Limestone	Creamy-white to gray, fossiliferous, locally phosphatic limestone. *Cross Member:* Brachiopod-bivalve biomicrite. *Moultrie Member:* Biosparites and bryozoan hash.
	Paleocene	Black Mingo	Fossiliferous, white to pale-gray limestone, green to gray argillaceous sand, carbonate-and silica-cemented sandstone, and dark-gray to black clay.
Cretaceous	Upper Cretaceous	Peedee	Olive to medium gray, fossiliferous, muddy sand and olive to medium gray, silty and sandy calcareous clay.
		Black Creek	Gray to gray-green muddy sand, silty clay, fine-to medium-grained white to gray sand, and shelly limestone with minor amounts of glauconite, phosphate, mica, and pyrite.
		Middendorf	Red, brown, and gray-green, poorly sorted feldspathic sand, and reddish or gray-green clay, silty clay, and clayey silt in lower half. Red, brown, yellow to olive-gray clay and silty clay, and greenish-gray, muddy, locally feldspathic sand in the upper half.
Pre-Cretaceous bedrock		Unnamed	Unknown; possibly diabase, basalt, or quartzitic sandstone.

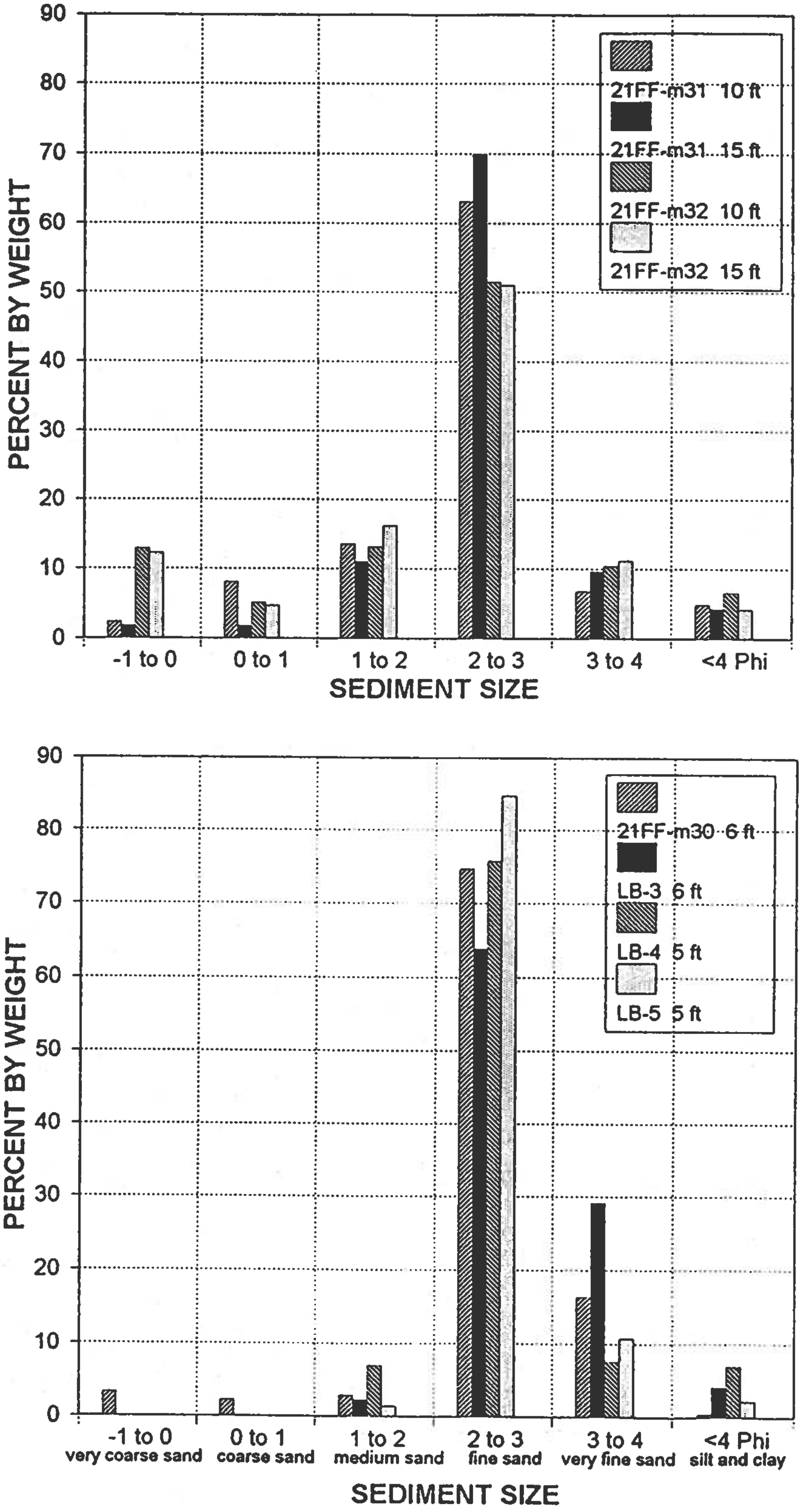


Figure 3. Distribution of sediment size in wells 21FF-m30, 21FF-m31, 21FF-m32 and borings LB-3, LB-4, and LB-5.

SURFICIAL DEPOSITS

The surficial deposits underlying the study area are Quaternary in age. Unit Q2 unconformably overlies the Cooper Formation and consists primarily of shelly, sandy beach deposits. Unit Q2b lithofacies, which are beach and possibly eolian deposits, form the sand ridge paralleling Leadenwah Creek. These sediments consist of fossiliferous, well-sorted, fine-grained sand ranging in color from pale grayish orange or yellowish gray above the water table to gray below the water table (McCartan, 1990). Underlying Unit Q2b are the barrier deposits of Unit Q2l. This unit consists of dark yellowish orange, grayish orange, and gray, muddy, fine-grained quartz sand with clay, shell, and sand layers (McCartan, 1990).

Unit Q1, which overlies Unit Q2, is composed of marine and marginal marine deposits. At the site, it exists in the southwest near Adams Creek and consists of dark gray to grayish brown, muddy sand and sandy mud. These backbarrier facies deposits (Unit Q1l) lie between 6 ft and -33 ft msl.

SITE GEOLOGY

A total of 27 observation wells were installed to a maximum depth of 20 ft. Twenty-five wells were constructed with 2-inch diameter PVC pipe, using Vibracorer methods. Two test holes, drilled to a depth of 50 ft to determine the lithology, were completed at a depth of 20 ft as 4-inch diameter PVC wells, using a hollow-stem auger.

Lithologic logs have been prepared for 21 of these wells (App. A). In all the logs, the uppermost section consists of a yellowish orange, tan or gray, fine-grained sand. Generally, this sand is well sorted, but it contains some clay and shell fragments locally. Thickness of the sand ranges from 14 ft to greater than 20 ft. Where the boreholes penetrated to sufficient depth, the logs indicate that the sand is underlain by dark-gray clay or sandy clay with accessory to abundant shell fragments. These results are consistent with McCartan's (1990) findings of shelly, sandy beach or eolian deposits of Q2b and the backbarrier deposits of Unit Q2l.

Grain-size analysis of several samples collected from auger borings and the observation wells (Fig. 3) showed sizes ranging from -1 phi (2 millimeters) to less than 4.0 phi (0.06 millimeter). Between 50 and 84percent, by weight, fell within the fine sand (2.0 - 3.0 phi) grain size. Most of the samples are well sorted, with 80 percent consisting of very fine to medium sand.

Two geologic sections show the stratigraphy of the surficial units in the study area (Figs. 4, 5, and 6). Section A - A' trends southwest to northeast along the sand ridge. Section B - B' crosses the sand ridge from north to south near the largest irrigation pond. Fine-grained sand (Unit Q2b) extends from 17 ft msl to at least -4 ft msl. Clay and sandy clay (Unit Q2l) underlie the sand to at least -34 ft msl, for a minimum thickness of 30 ft. The shell bed located between -28 and -32 ft msl at 21FF-m31 in Section B - B' is absent at 21FF-m32 in Section A - A'.

A map of the top of the clay is shown in Figure 7. Elevation of the clay ranges from about sea level at well 21FF-r5 to more than 7 ft msl. The elevation of the clay diminishes to the east and west and occurs at -2 ft msl northwest of Pond 3.

HYDROGEOLOGY

CONFINED AQUIFERS

Aquifers of the Santee Limestone and the Black Mingo Formation, located between -300 and -600 ft msl, contain brackish water. At Bears Bluff (22FF-j4), chloride and dissolved-solids concentrations were measured at 658 and 1,996 mg/L (milligrams per liter), respectively. Samples from a well located near Bohicket Creek (20FF-d1) showed chloride increasing, with depth, from 2,400 to 2,700 mg/L.

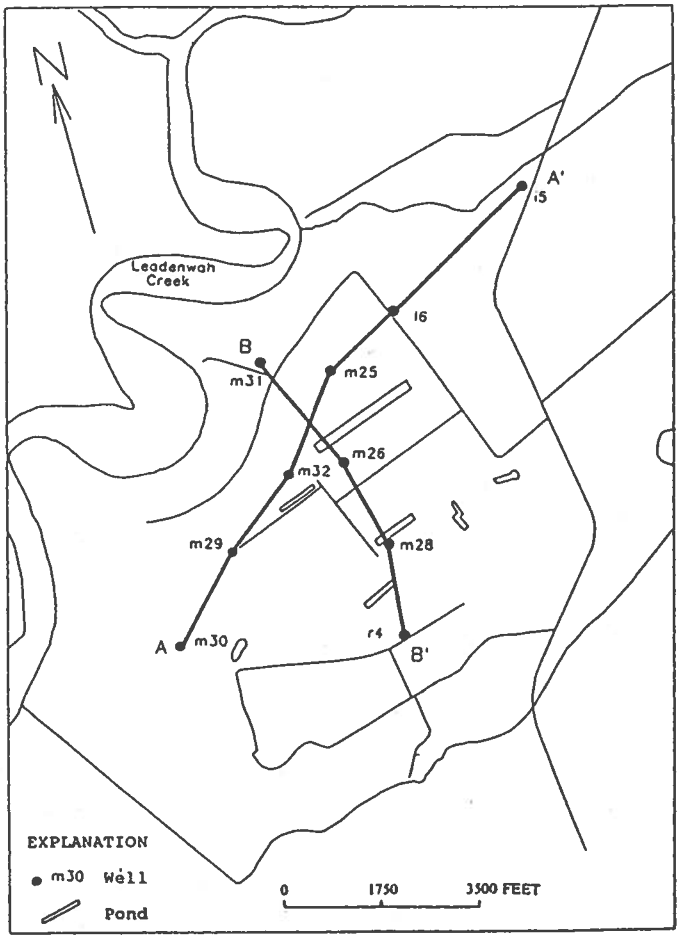


Figure 4. Location of geologic sections.

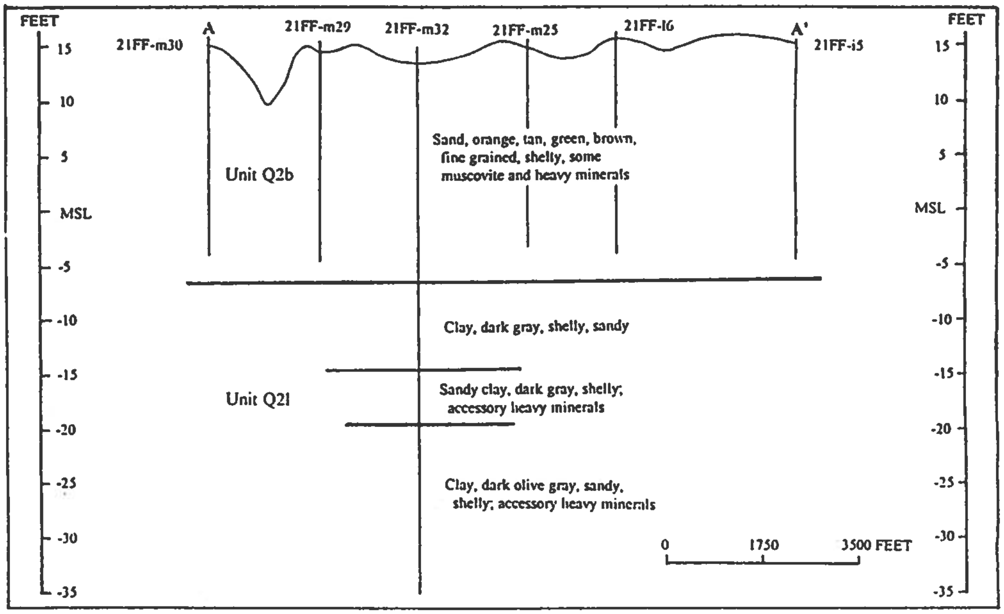


Figure 5. Geologic section A-A', between observation wells 21FF-m30 and 21FF-i5.

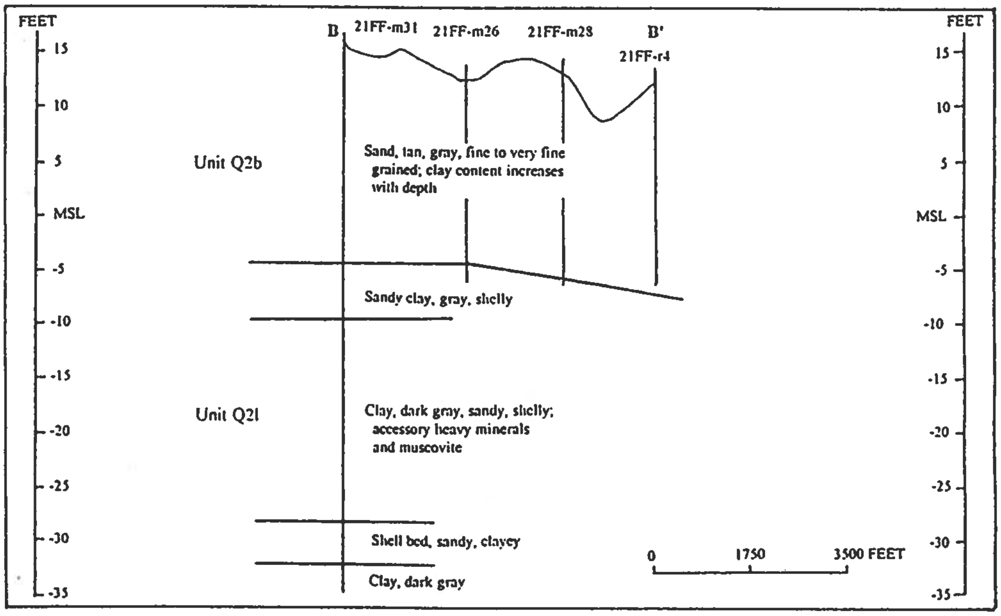


Figure 6. Geologic section B-B', from observation wells 21FF-m31 and 21FF-r4.

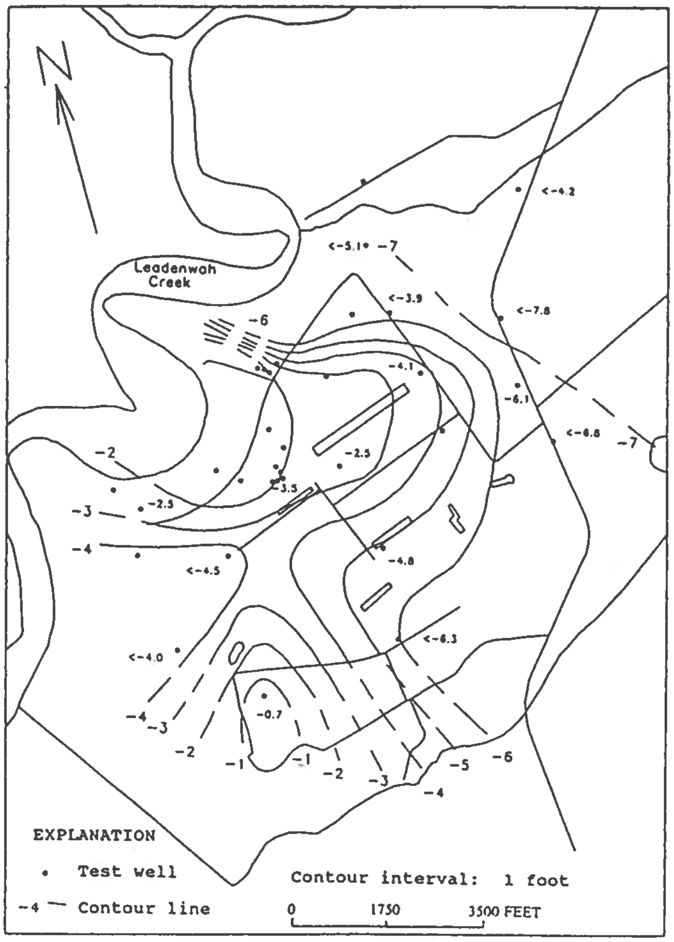


Figure 7. Elevation of the top of the Unit Q2b clay in the study area.

Because the Cooper Formation has low permeability, it acts as a confining layer between the Santee Limestone and the surficial aquifer. The Cooper Formation produces little or no water in most areas. There are, however, locally permeable zones within this formation which may yield water. Park (1985) reported that several driller's logs describe thin, soft, water-bearing limestone beds between the depths of 200 and 250 ft near Edisto Island. In the study area, no wells are known to produce water from this formation.

Aquifers in the Cretaceous formations yield water of varying quality. A water sample from a deep well in the Black Creek Formation on Kiawah Island (20FF-v1) had chloride and dissolved-solids concentrations of 464 and 1,092 mg/L, respectively. Chloride concentrations ranged from 60 to 1,440 mg/L and dissolved solids ranged from 1,200 to 2,830 mg/L for selected depths in the Middendorf Formation at Seabrook Island (20GG-e1) and Kiawah Island (20FF-v1) (Park, 1985). Although water of suitable quality may be available from Cretaceous aquifers, the high cost of drilling discourages its use for domestic supplies.

UNCONFINED AQUIFERS

The water-table aquifer yields relatively good water and provides most of the water supplies in the study area. The water is a hard, calcium bicarbonate type owing to the abundance of shell material in the aquifer matrix. Total dissolved-solids concentrations generally are less than 300 mg/L except near the island margins where the aquifer is hydraulically connected to tidal streams and marshlands. High iron concentrations occur locally.

Aquifer transmissivity and well yields vary greatly, owing to the diversity of depositional environments. J.T. Johnson and Associates, in a 1981 consulting report to the Town of Edisto Beach, reported a transmissivity of 600 ft^2/day (hydraulic conductivity, 13 ft/day) at a well field on Edisto Island. McCready (1991) estimated transmissivities ranging from 350 to 1,800 ft^2/day (hydraulic conductivity, 12 to 60 ft/day) from two tests at the Country Club of Charleston on James Island. Yields as great as 70 gpm (gallons per minute) have been reported from shallow wells in the Mt. Pleasant area (Park, 1985), but yields of 10 to 25 gpm are more typical.

SITE HYDROGEOLOGY

Water-level data for the shallow aquifer were collected at 36 locations. Five domestic wells were measured, and 27 observation wells and four pond staff gages were installed during the study. The five domestic wells provided the longest period of record (Fig. 8). Fourteen observation wells were installed by August 1993 and eight more were in place by January 1994. Four additional wells were located on the perimeter of the study area by May 1994. Hydrographs of the observation wells are presented in Appendix B. A staff gage was set in each of the four irrigation ponds in late March 1993. Measurements were recorded sporadically from October 1992 to May 1993, after which they were taken every two weeks until October 1994. Hydrographs for these wells are similar; water levels were highest in mid-April 1993 and lowest in late October 1993.

The maximum seasonal change recorded in a well was 6.92 ft. This is slightly greater than the maximum fluctuation of 5.65 ft recorded between July 1987 and September 1993 for a shallow well (22GG-x26) located on Edisto Island (Bennett and others, 1994). The hydrograph for this well, shown in Figure 9, is similar to those in the study area during 1993.

The staff-gage hydrographs (Fig. 10) differ from the well hydrographs because of irrigation practices. Ponds 2 and 3 are the principal sources for irrigation water, whereas water from Ponds 1 and 4 is generally used to distribute fertilizers and other chemicals to the crops through the irrigation system. The gages, installed in

March while the fields were being prepared for planting, showed initial water elevations in the ponds that were nearly the same as those in nearby wells (except for SG2, which had no nearby wells).

Water levels in Ponds 1 and 4 declined more than in the other two during the first week of April 1994. By the end of April, most of the fields had been planted. The water elevations remained constant or recovered slightly during late April and early May, then declined through the first week of June. Ponds 1, 2, and 4 recovered somewhat by July, which is consistent with the pattern observed in most observation wells. Water levels in Pond 3 continued to decline through mid-July because irrigation from this pond continued.

The maximum and minimum fluctuations in elevation for the ponds were estimated to be 7.2 ft at Pond 3 and 2.9 ft at Pond 4. The maximum change in water level at Pond 3 was nearly the same as the maximum fluctuation seen in the observation wells for the period of record.

Precipitation data were collected from one station in the study area and three nearby. Daily precipitation data at the site have been recorded by a resident since July 1993 (Fig. 11). The other three stations are permanent recording sites at Charleston International Airport, U. S. Customs House in Charleston, and Edisto Island (Appendix C).

Daily pan evaporation data were obtained from the Charleston Airport weather station (Fig. 12). Evaporation rates are least from October through February.

Precipitation was near normal during February 1993 and substantially above normal during January and March 1993. The recovering water levels reflected the recharge from this rainfall and the low evaporation rates for the period.

Average rainfall during the spring and early summer of 1993 ranged from normal to considerably below normal for most months. Low rainfall combined with the highest evaporation rates of the year contributed to the observed water level declines. Precipitation increased during August 1993 compared to previous months, which accounts for the slight rise in water levels.

Near-normal amounts of rainfall occurred in September and October 1993. Precipitation during this period was less than for the summer months, however, and was reflected by a decline in the water levels for September and October.

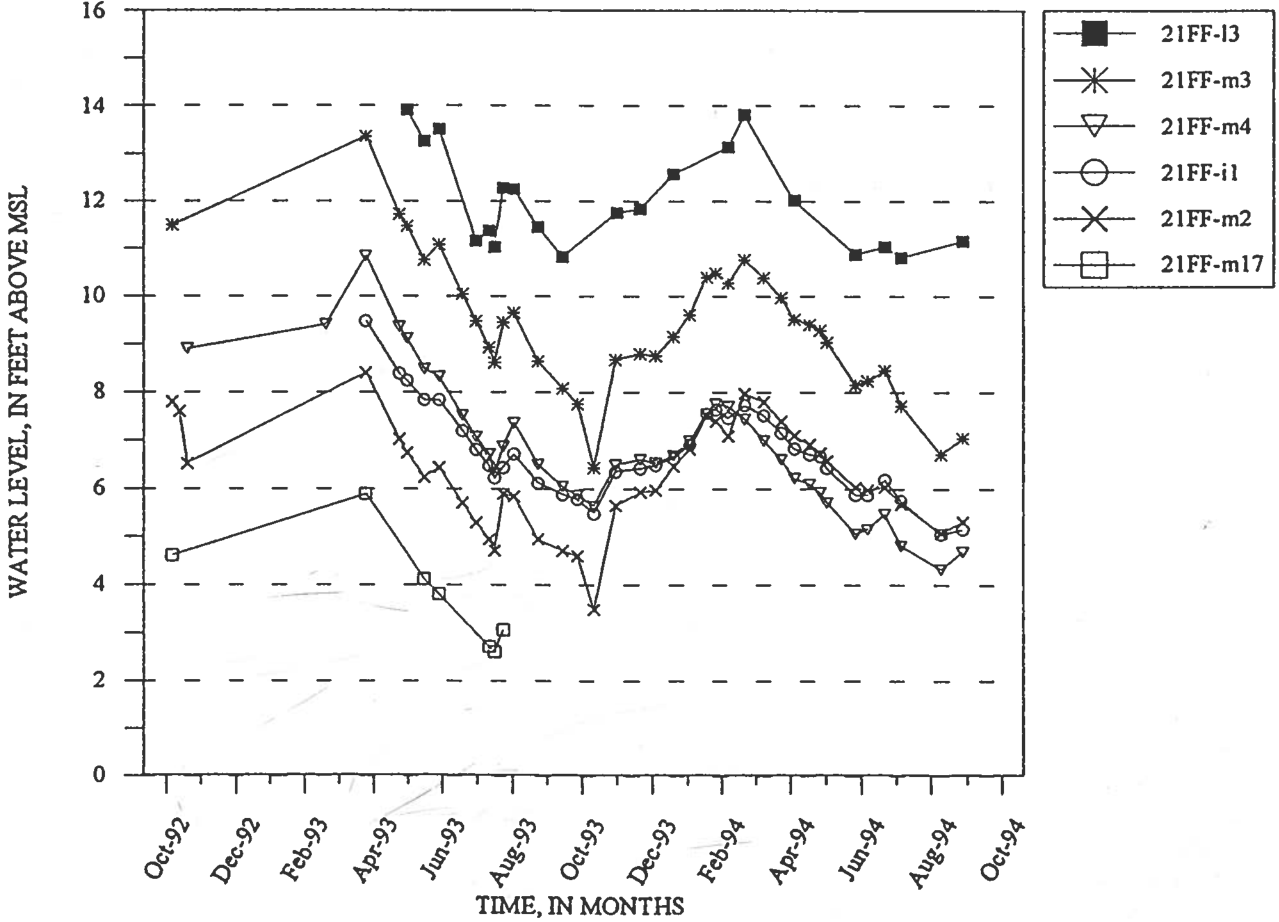


Figure 8. Hydrograph of wells 21FF-13, 21FF-i1, 21FF-m3, 21FF-m2, 21FF-m4, and 21FF-m17.

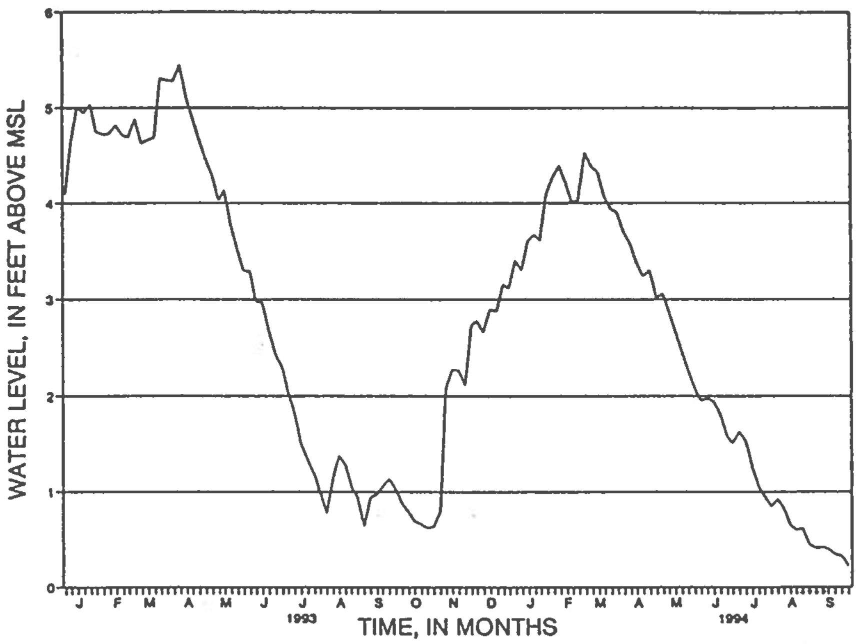


Figure 9. Hydrograph of well 22GG-x26, at Edisto Beach.

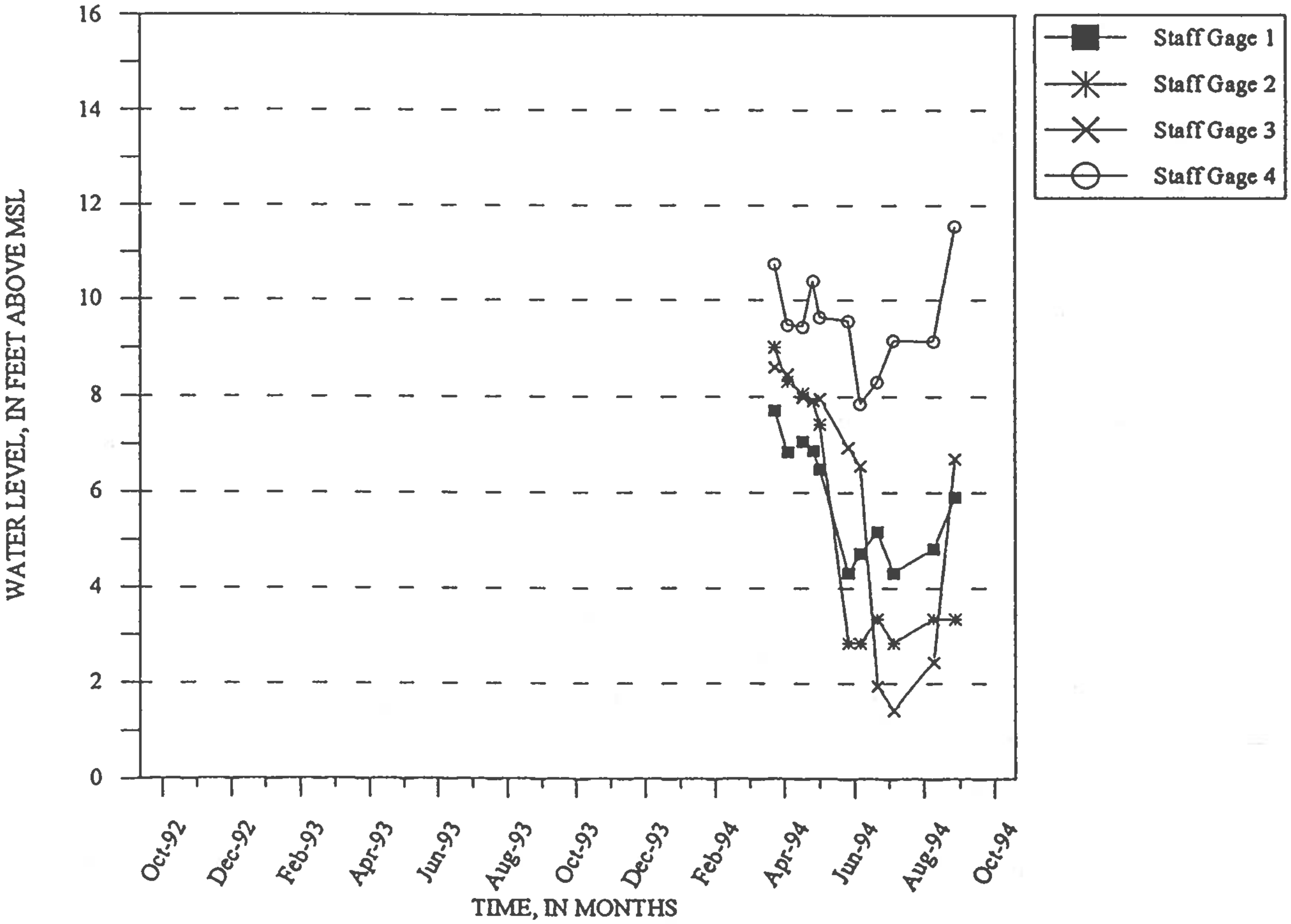


Figure 10. Hydrograph of staff gages 1, 2, 3, and 4.

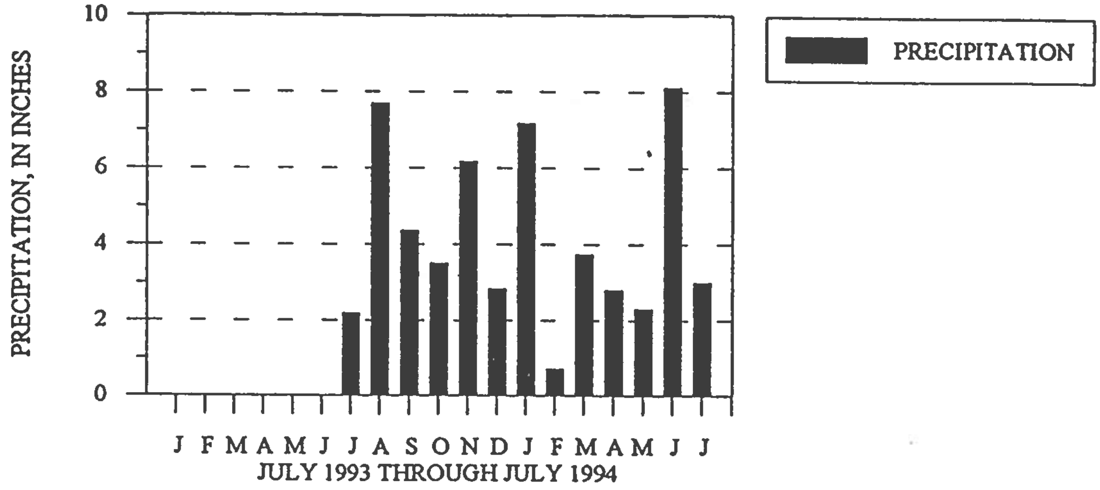


Figure 11. Monthly rainfall in the study area.

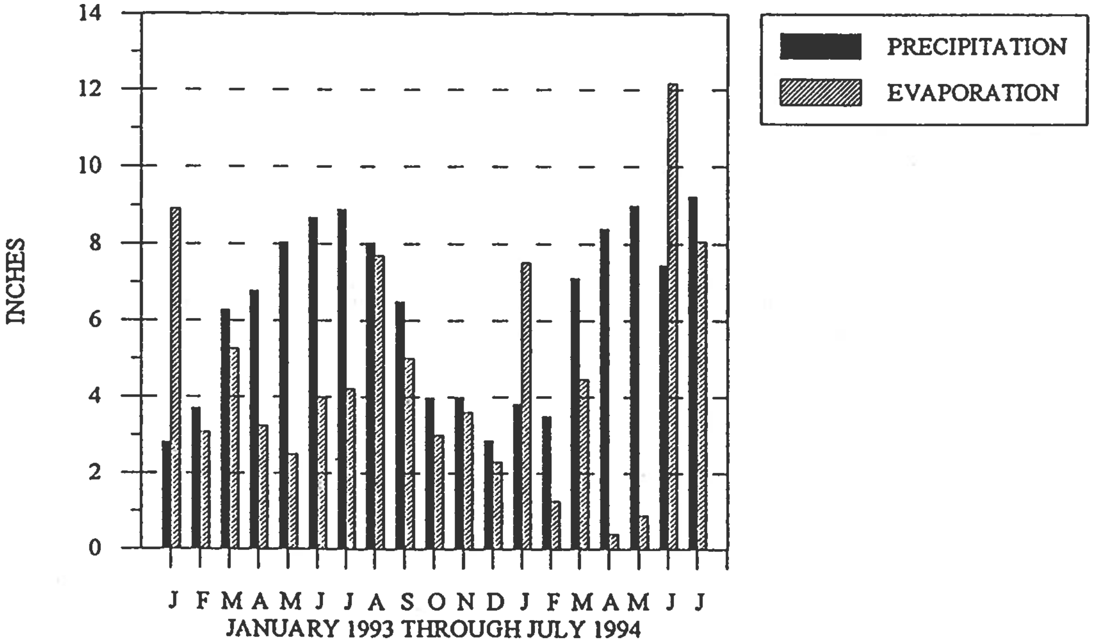


Figure 12. Monthly evaporation rates versus rainfall at the Charleston International Airport.

Departures from normal differed at the stations. At the Customs House, precipitation was near normal for most months, but February and March were substantially below normal. The Charleston Airport station recorded normal rainfall for most months, but above-average rainfall for January and below-average for February. Precipitation in the study area was most similar to that recorded for the Edisto station. In this case, precipitation was much above average until February, which had 1.3 inches. Water levels rose and then leveled off during February, and then rose slightly to the recorded high in March.

In March and April 1994, rainfall was below normal at the three stations, averaging less than 2 inches for the period. Rainfall on Wadmalaw Island was closer to normal, with at least 2 inches occurring each month. Evaporation at the Airport station during March and April was the highest since July 1993. The high evaporation rate and the low recharge from rainfall caused water levels to decline. Precipitation greatly increased during June 1994 and is reflected by a slight rise in water levels in most wells.

Maps showing the surface of the water table for selected dates are shown in Figures 13 through 16. Figure 13 shows the water surface on October 28, 1993, when it was at its lowest elevation. The water surface mimics the topography, with the highest water levels along the sand ridge trending southwest-northeast. Two distinct high points on the ridge are centered on wells 21FF-i5 and 21FF-m29. On the north flank of the sand ridge, water flows toward Leadenwah Creek. East of Pond 3, water levels decline toward the southeast and water flows toward well 21FF-l4. On the southeast flank of the ridge near well 21FF-m29, water flows predominantly southward.

The potentiometric map of March 24, 1994 (Fig. 14), for the seasonal high water levels is similar to that of October 1993. In this case, the highest water levels are on the ridge near well 21FF-l5. There is no isolated potentiometric high at well 21FF-m29, as there was in the October 1993 map. Flow directions are primarily the same as during October 1993.

The potentiometric surface was nearly the same on April 19, 1994 (Fig. 15), as on March 24, 1994. Most water levels declined 1 ft or less during this period. The addition of staff gages provided better definition of the contour lines in the vicinity of the ponds. By July 5, 1994, a cone of depression had formed around Pond 3 (Fig. 16). The depression is more than 6 ft deep but does not greatly influence the four nearest wells, located 400 to 900 ft from the pond. Smaller, shallower cones occurred around ponds 1 and 2.

AQUIFER HYDRAULICS

General Definitions

The hydraulic properties of an aquifer must be understood to predict the effects of local discharge or recharge on the ground-water flow. The three primary parameters are hydraulic gradient, transmissivity (T), and storage coefficient (S) or, in the case of an unconfined aquifer, specific yield.

Hydraulic gradient is the change in the total head with distance in a given direction (Fetter, 1980). Ground-water flow is from areas of higher head to areas of lower head. Transmissivity (T) is the rate at which ground water will pass through a unit width of aquifer under a unit hydraulic gradient.

Specific yield is a measure of an unconfined aquifer's ability to release water from or take water into storage. For a unit volume of aquifer, the specific yield is the volume of water an aquifer releases from storage under gravity drainage. The normal range for specific yield is 0.01 to 0.3.

Another useful term is hydraulic conductivity (K). Hydraulic conductivity is defined as the unit volume of water that passes through a cross-sectional unit area, under a unit change in head for a unit length of time. It is equal to the aquifer transmissivity divided by the aquifer thickness. An aquifer with a hydraulic conductivity of 1 ft/day will transmit 1 ft^3 of water a day through a 1-ft^2 area under a gradient of 1-ft head decrease per 1 ft of flow length.

The hydraulic properties of a well in a given aquifer greatly influence its production. These are screened (or intake) interval, well efficiency, and available drawdown. A measure of the productivity of a well is the specific capacity. It is the rate of discharge divided by the drawdown after a given time has elapsed, usually 24 hours.

Aquifer Tests

Slug tests were made at 18 observation wells to determine hydraulic conductivity (K) of the shallow aquifer. A slug test, or bailer test, involves the addition or removal of a known volume from a well and measuring the water level as it declines or recovers. The slug tests were made and analyzed according to the method of Bouwer and Rice (1976) and Bouwer (1989). At least two tests were done at each well.

Hydraulic conductivity ranged from 3 to 22 ft/day (Table 2), with an average of 9 ft/day. Fetter (1980) cites K values between 0.28 and 28 ft/day for silty or fine sand and 28 and 2,830 ft/day for well-sorted sand. Morris and Johnson (1967) cited representative K values of 8.2 and 39 ft/day for fine and medium sand, respectively.

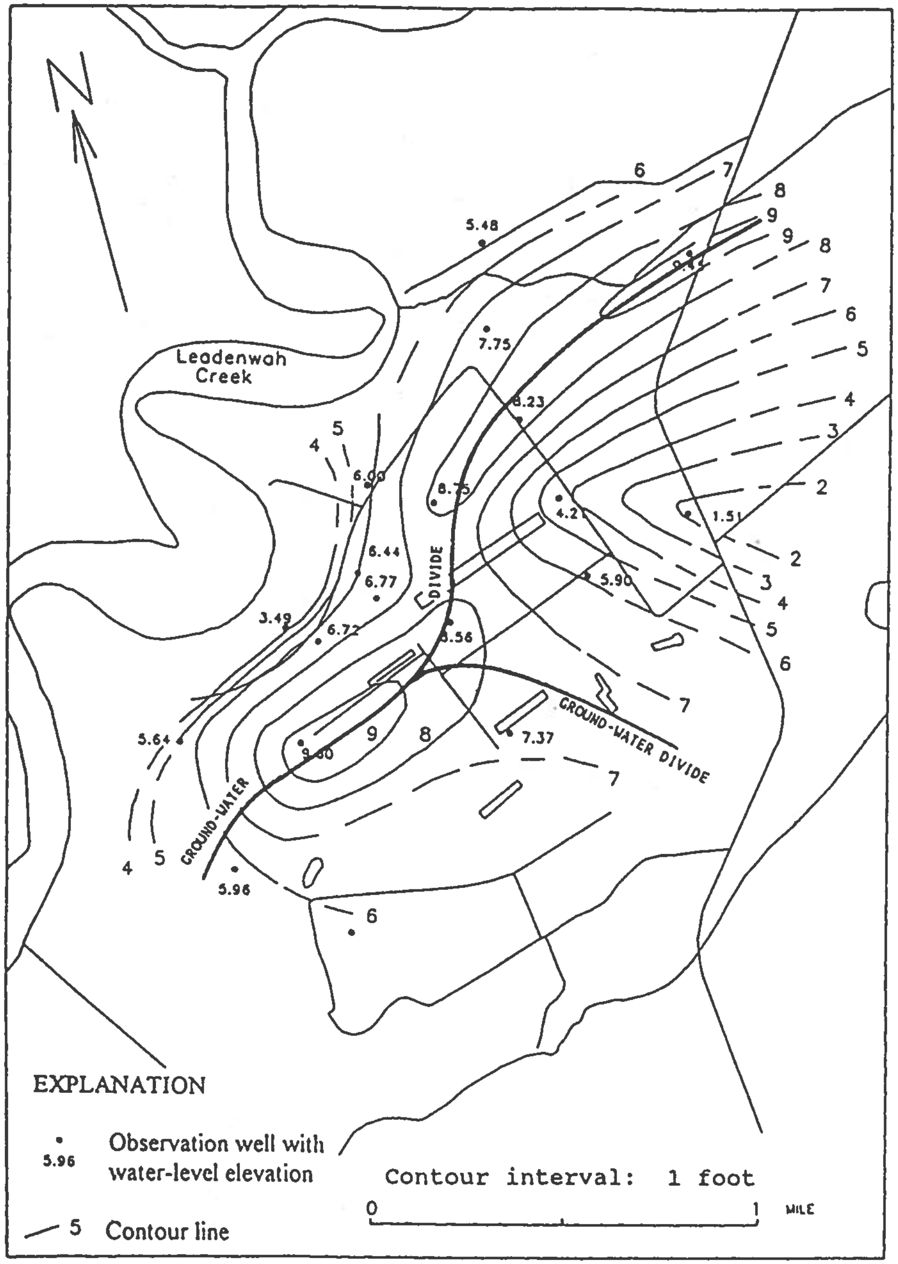


Figure 13. Water table map of the study area for October 28, 1993.

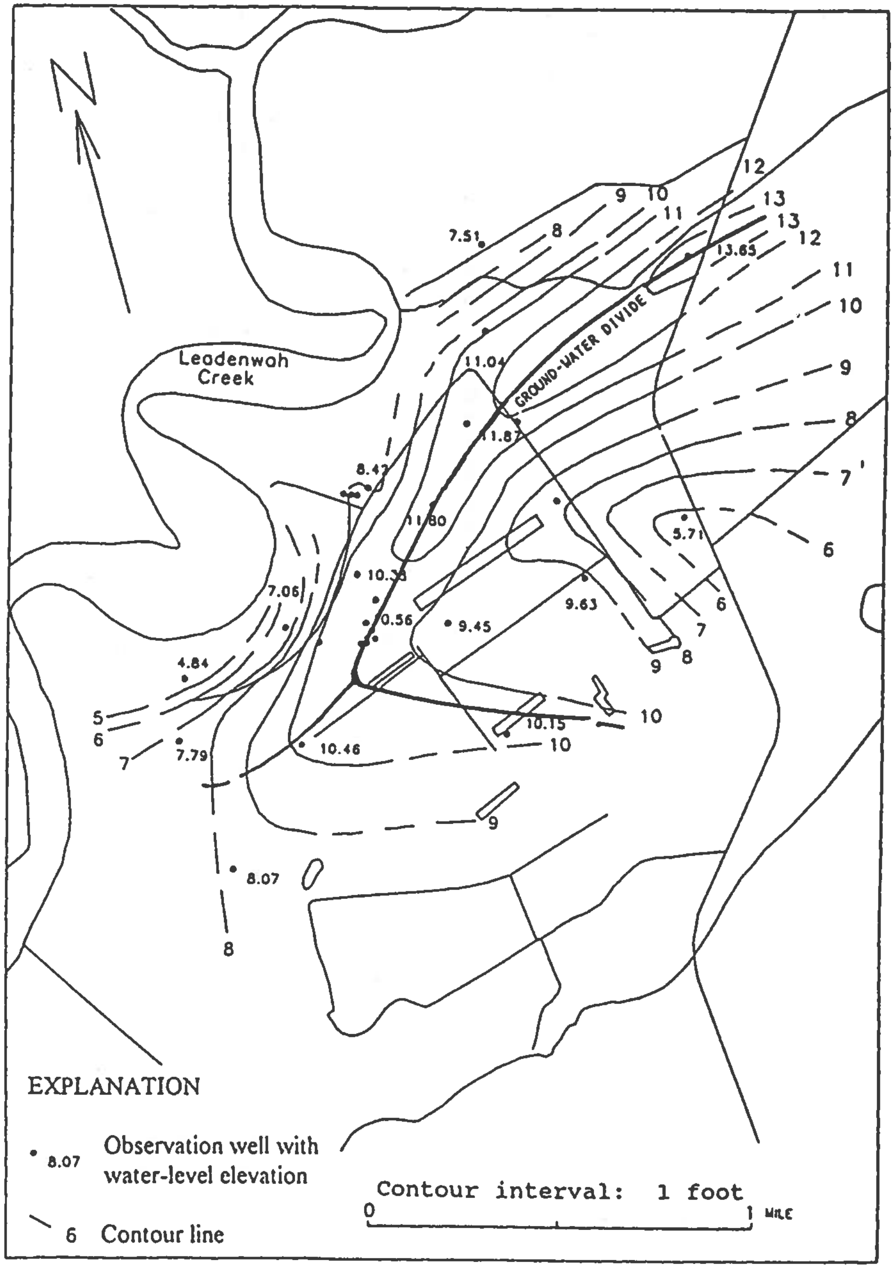


Figure 14. Water table map of the study area for March 24, 1994.

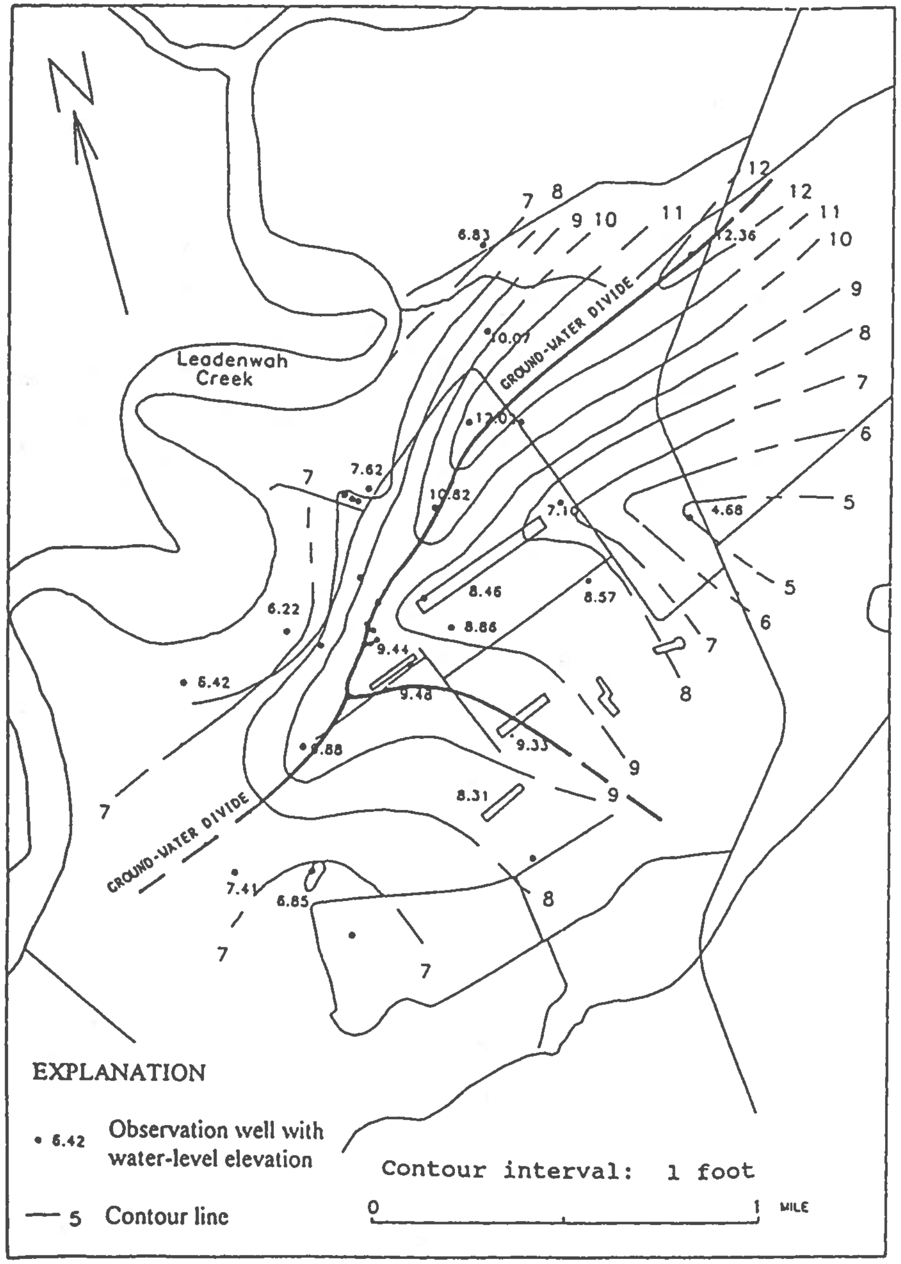


Figure 15. Water table map of the study area for April 19, 1994.

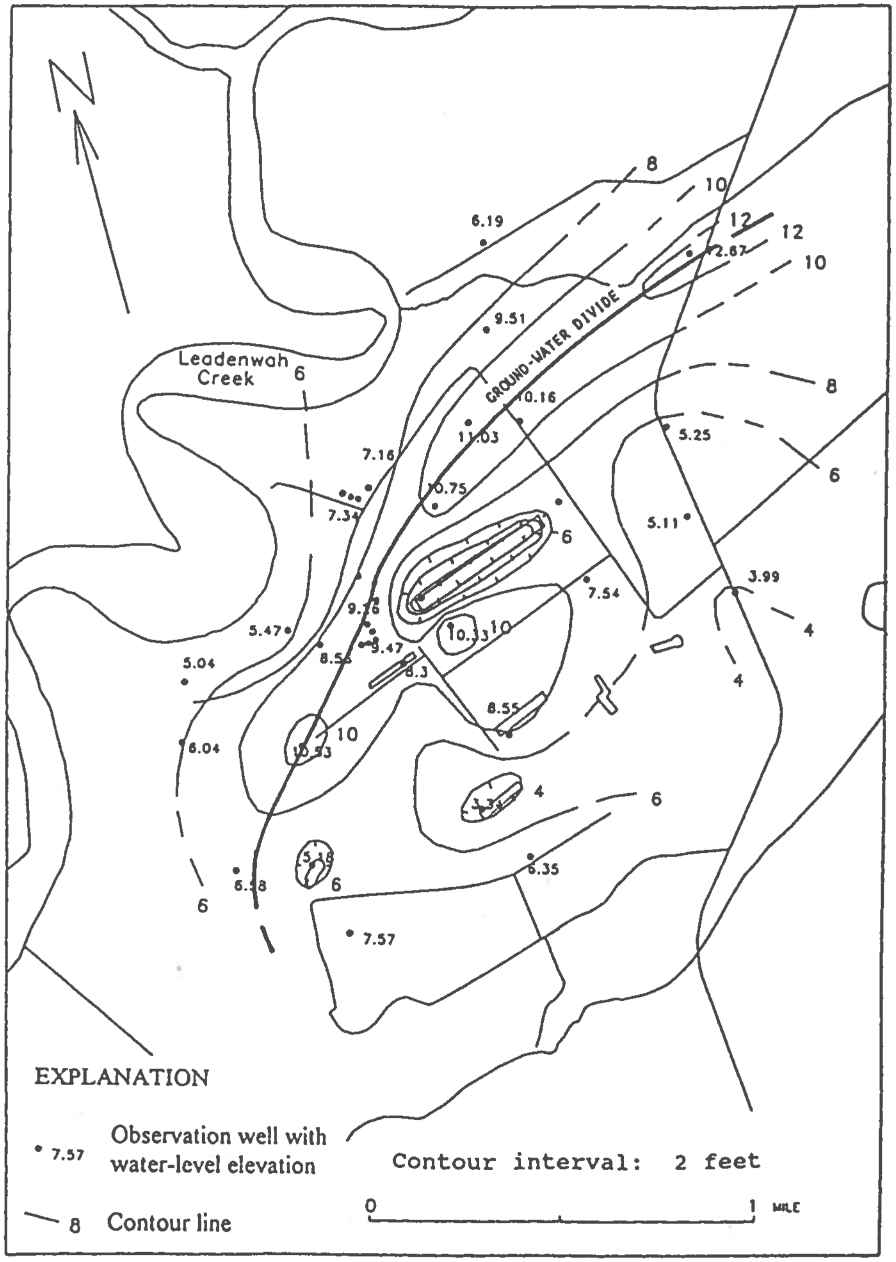


Figure 16. Water table map of the study area for July 5, 1994.

Table 2. Hydraulic-conductivity values from slug tests of selected observation wells

Well	Hydraulic conductivity (ft/day)
21FF-i4	4
-i5	5
-l6	8
-l4	5
-l5	9
-l7	12
-m23	13
-m25	6
-m26	6
-m27	7
-m28	3
-m29	9
-m30	17
-m33	8
-m34	5
-m35	22
-m36	18
-m38	10
Average	9

Inasmuch as the aquifer consists of clean, fine-grained sand, the estimates of K obtained from slug tests are reasonable on the basis of the above ranges of K values.

Two pumping tests were made to obtain additional information. A pumping test involves pumping a well at a constant rate while measuring the water level in the pumped and/or observation wells.

The first test was at well 21FF-m32, which was pumped at a constant rate of 5 gpm for 100 hours. Water levels in the pumping well and observation well 21FF-m35 were recorded by means of a pressure transducer and a digital data logger. Water-level measurements were made with an electric tape in wells 21FF-m32, -m35,-m36, -m37, and -m39.

The data were analyzed according to Neuman's (1975) delayed-yield method. Transmissivity (T) was about 270 ft^2/day. Hydraulic conductivity, based on 13.5 ft of aquifer thickness, was 20 ft/day, which was within the range of values estimated from slug tests. Calculated vertical hydraulic conductivity (Kv) was 0.5 ft/day, or about 0.025 times the horizontal hydraulic conductivity. Specific capacity was 1.0 gpm/ft.

A second aquifer test was made at well 21FF-m31, near the intersection of Leadenwah Drive and Landing Road. The well was pumped at 1.9 gpm for 100 hours. Water levels in the pumped well and observation wells 21FF-m33 and -m27 were recorded on data loggers. Measurements by electric tape were recorded for these three wells and for 21FF-m34. Analysis of these data indicated that the aquifer transmissivity was about 190 ft^2/day. The aquifer was 9.5 ft thick at the start of the test, and the estimated K was 20 ft/day. Kv values ranged from 1.47 to 2.7 ft/day. Specific yield was estimated at 0.01 to 0.03. Specific capacity was 0.5 gpm/ft.

WATER QUALITY

Background water quality of the shallow aquifer was determined by sampling 13 domestic-supply wells and observation wells in the study area. A total of 25 water samples were collected, with 10 samples taken in November 1993, 11 samples in March 1994, and 4 in June 1994. Analyses were done by the SCDNR Laboratory. Anion data were unavailable for the March and June sampling runs. Duplicate samples were sent to Davis and Floyd Laboratories in June 1994. The results of these analyses are in Table 3.

Calcium bicarbonate type water was most commonly obtained from sampled wells. Calcium was the dominant cation for most samples, ranging in concentration from 0.9 to 65 mg/L. In two wells, 21FF-i4 and -m4, where anion data were available, the dominant anion was sulfate.

In a few wells, 21FF-l6, -m27, -m31, and -m38, sodium was the dominant cation. Sodium concentration ranged from 3.7 to 37 mg/L. Where sodium was the dominant cation and anion data were available, the water type was sodium chloride. Three of the four wells with dominant sodium cation are located nearer to saltwater bodies than other sampled wells.

A sample from well 21FF-m27, taken in November, showed calcium and sodium percentages nearly equal. In March, however, the sodium percentage was much greater than the calcium. This suggests that the chemical composition of the aquifer might vary seasonally, particularly near saltwater bodies.

Water in the shallow aquifer of the study area was generally low in chloride, sodium, fluoride, and total dissolved solids. Iron ranged from 0.17 to 5.9 mg/L, often exceeding the recommended limit of 0.3 mg/L.

Water samples from selected wells near agricultural land were collected to screen for pesticides. Because permission was not granted to sample wells located on farmland, the two nearest wells, 21FF-m23 and -m25, were selected. Wells 21FF-l7 and -m38, located in discharge areas on opposite sides of the ground-water divide, were also sampled.

Two pesticides, methyl bromide and paraquat, were selected for analysis. Methyl bromide is a fumigant used

Table 3. Analyses of background water quality for selected domestic and observation wells

Well number	Analysis	Temperature (Celsius)	Alkalinity pH 4.5 (mg/L)	Conductivity (umho/cm)	pH Field/Lab (SU)	Acidity (mg/L)	Bromide (ug/L)	Chloride (mg/L)	Fluoride (mg/L)	Nitrate/nitrite (mg/L)	Ortho-phosphate (mg/L)	Specific conductance (umho/cm)	Sulfate (mg/L)	Dissolved solids (mg/L)	Aluminum dissolved (ug/L)
11/93															
21FF-i4	SCWRC	20.0	6	175	6.2/7.3	5.8	1,700	11	0	0	0	145	38	119	20
21FF-i5	SCWRC	20.6	39	162	6.0/7.5	3.5	0	14	0	0	0	128	0	85	30
21FF-l3	SCWRC	20.1	77	234	8.0/8.0	3.0	0	14	0	0	0	188	1.9	147	40
21FF-l6	SCWRC	20.4	5	171	5.9/7.0	7.8	0	17	0	0	0	142	1.4	106	40
21FF-l7	SCWRC	20.1	182	658	7.7/8.3	3.0	320	55	0.6	0	0	528	7.5	403	30
21FF-m4	SCWRC	20.5	92	624	8.1/8.1	1.8	0	43	0.8	0	0	514	130	414	30
21FF-m23	SCWRC	22.5	94	395	7.4/8.1	4.8	250	27	0.5	0	0	308	25	230	20
21FF-m24	SCWRC	21.5	91	334	7.4/7.9	4.8	-	-	-	-	-	-	-	-	2900
21FF-m25	SCWRC	20.5	23	200	5.6/7.5	5.5	0	14	0	1.6/0	0	160	12	101	20
21FF-m27	SCWRC	20.7	32	197	6.7/7.1	21	0	16	0	0	0	170	6.6	121	30
3/94															
21FF-i4	SCWRC	16.8	7	168	6.0/5.7	9.5						119		122	10
21FF-i5	SCWRC	18.2	34	148	6.1/6.1	6.5						105		118	20
21FF-l3	SCWRC	19.6	49	232	8.3/7.7	4.0						163		153	0
21FF-l6	SCWRC	18.1	1	179	5.4/5.1	26						126		111	120
21FF-l7	SCWRC	17.2	21	730	7.6/7.4	12						521		465	0
21FF-m23	SCWRC	19.1	96	351	7.6/7.6	7.5						218		241	20
21FF-m25	SCWRC	17.8	34	205	6.2/6.4	17						145		138	10
21FF-m27	SCWRC	19.0	21	169	5.9/5.8	14						120		114	10
21FF-m31	SCWRC	17.8	3	66	5.6/5.1	15						46		97	30
21FF-m32	SCWRC	18.5	73	410	7.5/7.5	6.5						260		310	20
21FF-m38	SCWRC	18.3	15	135	6.1/5.9	15						101		99	10
6/94															
21FF-l7	SCWRC	17.8	187	615	7.6/	4.5						540		355	0
	DF				/7.6		<2000	77	0.2	<0.05	0.16	584	<3.0	367	
21FF-m23	SCWRC	20.3	90	368	7.5/	5.5						313		213	30
	DF				/7.2		<2000	43	<0.1	<0.05	0.31	340	8	203	
21FF-m25	SCWRC	18.7	27	200	6.3/	7.0						183		106	20
	DF				/6.4		<2000	22	<0.1	1.6	0.11	194	10		
21FF-m38	SCWRC	18.8	11	138	6.2/	7.0						128		84	30
	DF				/6.0		<2000	28	<0.1	<0.05	<0.03	139	3	103	

Table 3. Analyses of background water quality for selected domestic and observation wells (continued)

Well number	Analysis	Boron dissolved (ug/L)	Calcium dissolved (ug/L)	Chromium dissolved (ug/L)	Copper dissolved (ug/L)	Iron dissolved (ug/L)	Lead dissolved (ug/L)	Lithium dissolved (ug/L)	Magnesium dissolved (mg/L)	Manganese dissolved (ug/L)	Potassium dissolved (mg/L)	Silicon dissolved (mg/L)	Sodium dissolved (mg/L)	Strontium dissolved (ug/L)	Vanadium dissolved (ug/L)	Zinc dissolved (ug/L)
11/93																
21FF-i4	SCWRC	0	9.9	60	11	630	74	0	1.4	20	2.7	2.4	4.9	140	8	11
21FF-i5	SCWRC	0	11	69	11	690	<50	0	0.9	10	0.4	3.4	7.9	150	0	8
21FF-l3	SCWRC	0	26	62	9	2500	<50	0	0.9	40	0.4	4.2	9.1	150	3	13
21FF-l6	SCWRC	0	2.2	63	1	1000	72	0	2.2	10	0.5	2.5	16	100	4	11
21FF-l7	SCWRC	90	47	52	12	180	62	10	9.2	70	8.9	2.1	37	160	4	7
21FF-m4	SCWRC	0	65	87	9	300	<50	10	3.6	40	0.9	5.6	16	390	6	9
21FF-m23	SCWRC	20	42	110	11	4800	<50	10	2.7	90	1.7	2.3	9.2	300	9	10
21FF-m24	SCWRC	70	36	93	8	5900	<50	10	3.7	80	7.9	8.3	3.7	240	16	19
21FF-m25	SCWRC	70	11	110	15	2100	<50	0	3.3	20	6.8	3.2	6.3	110	14	13
21FF-m27	SCWRC	0	11	82	16	530	<50	0	1.6	20	1.2	3.4	12	180	0	12
3/94																
21FF-i4	SCWRC	0	16	8	6	1200	<50	0	2.4	20	1.8	2.9	5.9	80	1	0
21FF-i5	SCWRC	0	13	7	4	840	<50	0	1.3	10	0.2	4.3	11	80	1	5
21FF-l3	SCWRC	0	33	7	5	820	<50	0	1.1	30	0.2	5.9	8.6	160	1	1
21FF-l6	SCWRC	0	0.9	6	5	560	<50	0	4.5	0	0.2	3.3	23	30	1	1
21FF-l7	SCWRC	0	63	20	3	280	<50	10	13	90	6	21	56	500	1	0
21FF-m23	SCWRC	0	43	6	4	750	<50	0	2.1	30	0.6	6.4	19	230	2	0
21FF-m25	SCWRC	0	16	8	4	2500	<50	0	5.7	20	5.3	3.2	5.8	70	12	1
21FF-m27	SCWRC	0	9.5	10	6	120	<50	0	2.9	10	0.5	3.7	16	70	2	2
21FF-m31	SCWRC	0	2.1	6	5	680	<50	0	1.2	10	0.2	2.8	8.7	30	2	2
21FF-m32	SCWRC	0	59	10	7	1000	<50	0	6.2	60	4	6.2	5.6	310	2	0
21FF-m38	SCWRC	0	5.9	6	1	2900	<50	0	2.2	20	0.2	3.5	12	60	2	2
6/94																
21FF-l7	SCWRC	50	53	78	11	170	<50	10	11	80	8	21	37	520	12	9
	DF		58			170	<5		13	90	8		43			
21FF-m23	SCWRC	0	41	62	26	2300	<50	10	2	50	0.9	7.5	14	300	3	6
	DF		48			2600	<5		2.6	60	<2.0		17			
21FF-m25	SCWRC	20	15	77	17	3000	<50	0	4.1	30	5.6	3.5	4	160	14	8
	DF		18			3400	<5		5.6	30	5.8		5			
21FF-m38	SCWRC	0	8.4	110	31	4400	<50	0	1.6	20	0.4	3.1	9.7	170	6	7
	DF		8.3			4400	<5		2.4	10	<2.0		12			

to control most annual and perennial weeds, soil fungi, and nematodes for tomato crops. Paraquat is used as an herbicide to kill green foliage (W.P. Cook, Ted Whitwell, 1994; and U.S. Environmental Protection Agency, 1988).

Samples examined for pesticides were collected in June 1994. In all samples pesticides were below detection limits. Methyl bromide was less than 0.010 mg/L. Paraquat and paraquat dichloride were below detection limits of 0.004 and 0.0072 mg/L, respectively (North Coast Laboratories, 1994).

WATER USE

Users of shallow ground water in the study area include permanent and seasonal residents, livestock, and agriculture. Land use distribution is shown in Figure 17. The actual water use in the study area is not known; however, estimates have been made on the basis of population. Water use for livestock was considered negligible when compared to that for other uses.

Water use by inhabitants was estimated by multiplying the number of houses, the average number of residents per household, and per capita use. One hundred thirty-nine houses were inventoried within the study area boundaries. Most are concentrated along roads or waterways as shown on Figure 18. The estimated population of 430 persons was based on an average of 3.1 persons per household (South Carolina State Development Board, 1990). Total water use was calculated to be 21,500 to 38,700 gpd (gallons per day), assuming that each person uses between 50 and 90 gpd.

Agricultural water use was estimated to be greater than any other use. According to Dr. Wilton Cook (1994, oral communication), irrigation applied through drip systems for tomato crops is 0.15 to 0.25 inch per day. This translates to 4,000 to 6,800 gpd per acre. These estimates correspond to the water use figures of 4,000 to 5,000 gpd per acre reported by Mr. Jimmy Schaffer (oral communication, 1993).

Because water use estimates vary with the volume of water applied to the irrigated acreage, water use was calculated by evaluating the potential pumpage volume. At each irrigation pond, the pumps are fitted with 4-inch diameter discharge pipes. The maximum rate that water can be pumped practically through a 4-inch pipe is 200 gpm. If the pumps run 24 hours per day, then each pond can theoretically yield 288,000 gpd. Both the Planters Three and Schaffer farms have two ponds (Planters Three uses ponds 1 and 2, whereas the Schaffer farm uses ponds 3 and 4). Each farm can pump a maximum of 576,000 gpd. It is more likely that the ponds are pumped at 12-hour intervals or less; therefore, maximum pumpage volumes might be about 288,000 gpd per farm.

Agricultural irrigation is likely to be applied at a rate of 2,000 to 4,000 gpd per actual planted acre for each farm, based on the practical pump volumes and maximum acreage.

GROUND-WATER FLOW MODEL

MODEL CONSTRUCTION

A model was constructed to simulate the ground-water flow conditions of the study area. This model uses the U.S. Geological Survey three-dimensional, finite-difference ground-water flow model entitled MODFLOW (McDonald and Harbaugh, 1988). The study area was discretized as one layer composed of 25 rows and 30 columns. Cells are 400 ft per side and represent a total area of 160,000 ft2. The y-axis is oriented north 20 degrees west. A reference point in the model is a vertical benchmark at the Little Rock Baptist Church. Complete model specifications are listed in Appendix D.

The bottom of the water-table aquifer is defined by the elevation of the clay layer (Fig. 7). Where data are absent, the elevation of the clay layer is interpolated from existing data. Land-surface elevation is used as the top of the aquifer.

Aquifer-head boundary conditions are as follows. Cells bordering Leadenwah, Adams, and Fickling Creeks and the adjacent marsh are designated as constant-head cells. Water levels in these cells do not change during model runs. The lowest constant-head value is 3.2 ft msl and is based on the mean tide level 3 miles upstream of the entrance to Leadenwah Creek (National Oceanic and Atmospheric Administration, 1993). Other constant-head values are based on conservative estimates of stream gradients along the creeks and marshes. The northeast model boundary has no-flow cells and represents a ground-water divide. All cells within the above boundaries are active, whereas cells outside these boundaries are no-flow cells.

Additional input for the model includes hydraulic conductivity and specific yield. The hydraulic conductivity and specific yield derived from pumping tests and slug tests are the basis for assigning cell parameters.

CALIBRATION

Model calibration involves the adjustment of selected variables so that model estimates of aquifer water levels closely resemble historical data. Eight water-level data sets from October 1993 through July 1994 were used to calibrate the model. Table 4 lists the starting-head dates, the simulated-head dates, and a calibration number used for reference. The model calibration runs were set up to simulate aquifer heads at roughly 1-month intervals. For

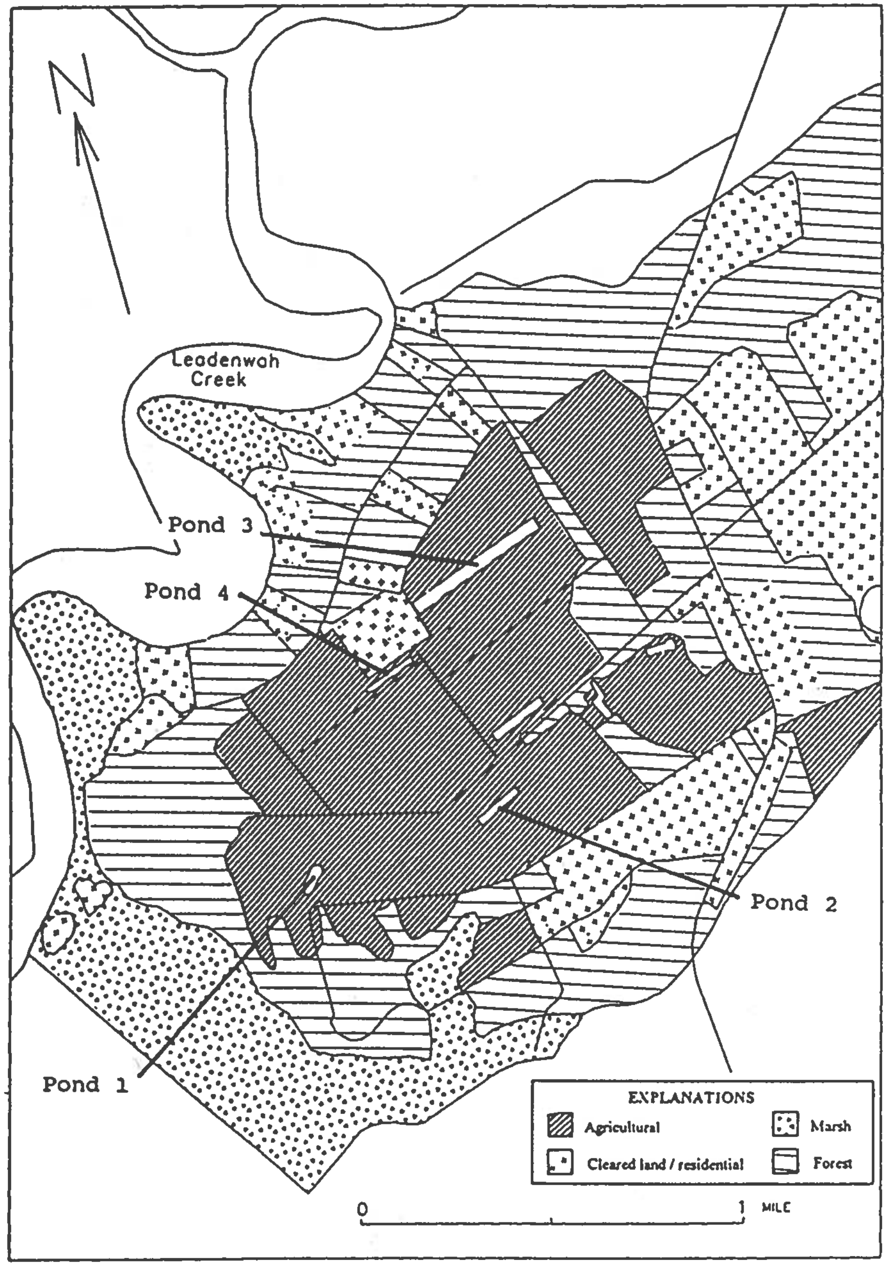


Figure 17. Land use in the study area.

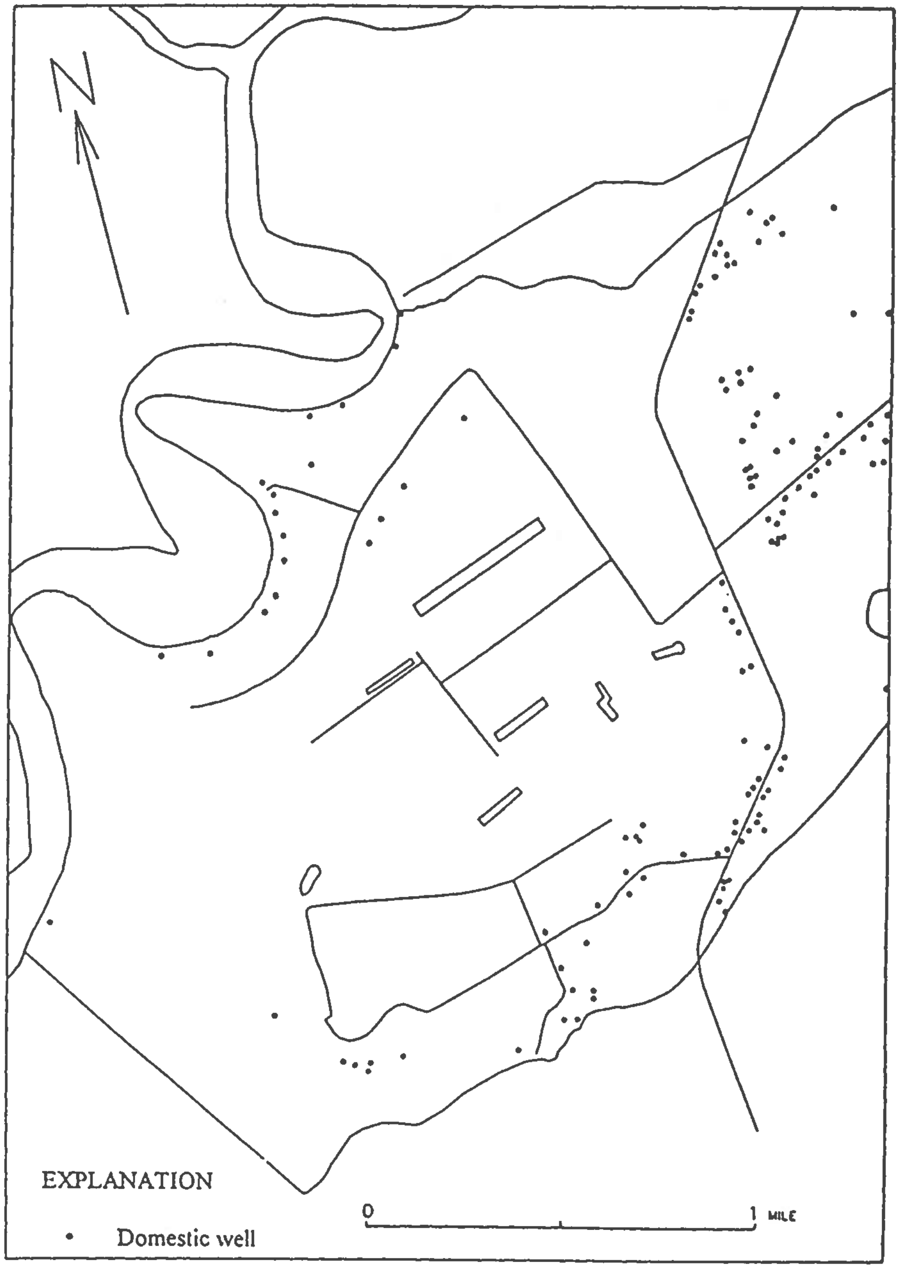


Figure 18. Location of domestic wells in the study area.

example, in calibration 1, October 28, 1993, water-level elevations were used as the starting heads to simulate December 7, 1993, aquifer heads. Data utilized for the calibrations included the recorded potentiometric lows and highs for the aquifer.

Table 4. Model starting-head and simulated-head dates

CALIBRATION NUMBER	STARTING-HEAD DATE	SIMULATED-HEAD DATE
1	10/28/93	12/07/93
2	12/07/93	01/04/94
3	01/04/94	02/21/94
4	02/21/94	03/24/94
5	03/24/94	04/19/94
6	04/19/94	05/17/94
7	05/17/94	07/05/94

Mass balance calculations to simulate actual aquifer water levels must account for any recharge and discharge that may occur during the period of simulation. In the study area, the water table aquifer is recharged by precipitation. Discharge occurs as base flow to streams, evapotranspiration, and pumpage from wells and ponds.

Recharge input is derived from precipitation data collected at the study area. An average precipitation rate for each simulation period was calculated by dividing the total amount of rainfall by the number of days in that period. These values are listed in Table 5.

Only a portion of the total precipitation becomes recharge to the aquifer. One factor that influences this is the soil infiltration capacity, which is the maximum rate at which water may enter a soil under a given set of conditions. The quality of water entering the soil, soil type, soil surface conditions (for example, mulch or vegetation covered or compacted), and water content of the soil all affect the infiltration capacity. If precipitation exceeds the soil infiltration capacity, water pools at the soil surface and becomes runoff. In addition, rainfall is not likely to have occurred uniformly throughout the study area. The precipitation intensity and quantity probably varied from one location to the next during each rainfall event. All of these factors contribute to the uncertainty in the percentage of precipitation becoming recharge to the aquifer. It has been suggested by Hewlett (1982) that in temperate climates approximately 75 percent of all precipitation becomes soil water, in the form of soil moisture or ground water. In light of this discussion, recharge was limited to a maximum of 75 percent of precipitation for the model calibration.

Evapotranspiration input is based on pan evaporation data from Charleston International Airport. However, the conditions under which these data are collected do not exactly match open-water or land evaporation conditions. Estimates of natural evaporation obtained by multiplying pan evaporation by 1.0 to 0.5 are commonly used but are considered unreliable (Hewlett, 1982).

Pan evaporation also does not consider transpiration which is the return of water that has been circulated through plant structures to the atmosphere. Transpiration is dependent on the type of vegetation and plant stage of growth, as well as atmospheric conditions, and is difficult to ascertain. For cypress and loblolly pine forests with shallow water tables in the Coastal Plain of South Carolina, it has been experimentally determined that evapotranspiration is about 70 percent of pan evaporation (Tom Williams, Hobcaw Barony Research Facility, telephone conversation, July 1995). It is likely that a similar relationship between evapotranspiration and pan evaporation exists in the study area. For the purpose of model calibration, evapotranspiration values ranged from 60 to 80 percent of pan evaporation.

The model was most sensitive to recharge and evapotranspiration. These variables were changed until the model results most closely resembled the measured heads,

Table 5. Precipitation and evapotranspiration used for model calibration

Calibration number	Days	Precipitation		Evapotranspiration	
		Total (in)	Average rate (ft/day)	Total (in)	Average rate (ft/day)
1	40	6.69	0.014	5.24	0.011
2	28	4.50	.013	2.21	.007
3	48	6.03	.010	4.14	.007
4	31	3.38	.009	6.24	.017
5	26	.71	.002	6.78	.022
6	28	4.46	.013	7.29	.022
7	49	10.70	.018	12.19	.021

then some adjustments to the hydraulic conductivity and specific yield were made.

Once the background model was completed, irrigation from ponds was simulated. Domestic water use was not sufficiently large to be included in the calibration. Irrigation from ponds was entered for the last four calibration periods. Pumpage from the ponds was simulated as a well or series of wells in the cells nearest the pond location. The cells corresponding to the ponds are listed in Appendix D. Since the amount of water used for irrigation is not well known (see WATER USE), the pumpage was determined by trial and error until the simulated water level nearly matched that of the pond water level elevation. Simulating the irrigation pumpage in this manner is not ideal, because the pond is a flat surface of equal elevation, whereas a pumping well will resemble a cone with the water level elevation increasing with distance from the well. In addition, the volume of the pond is entirely water, whereas any simulation by a well must account for water displacement within the aquifer matrix. Pumpage estimates used by the model, therefore, are likely to be low.

RESULTS

During the process of model calibration, a good fit between the measured and simulated water tables was achieved when the recharge was set at 50 percent of average precipitation and the evapotranspiration was set at 65 percent of average pan evaporation, except at pond cells where evapotranspiration was set at 100 percent. Minor adjustments were made to the hydraulic conductivity and specific yield, particularly when these parameters were not well known, to facilitate a better fit. Maps of model-derived aquifer heads are included in Appendix E.

Error Analysis

Water-level data from wells were compared to model-generated water levels for cells nearest the wells for each of the simulation dates. The results are shown in Table 6. Positive errors indicate that the model undersimulates the water level at that point, whereas negative errors indicate an oversimulation of water levels. A frequency distribution curve for the total model error is shown in Figure 19. In this figure, the frequency recorded is the number of errors falling within the 0.5 interval equal to or less than the error value. There are 32 errors whose values are greater than -1 and are less than or equal to -0.5.

The error curve shows that there is a bimodal distribution in the errors about -1 and 1. Examination of the frequency distribution curves for each of the simulation dates reveals the reason for this (Fig. 20).

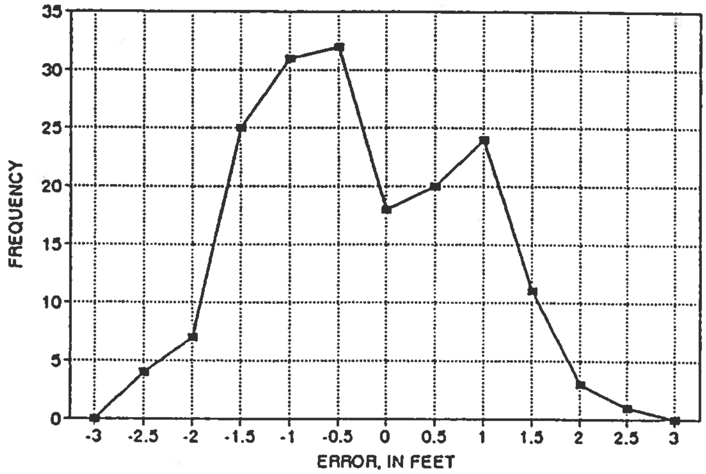


Figure 19. Frequency distribution curve for total model error.

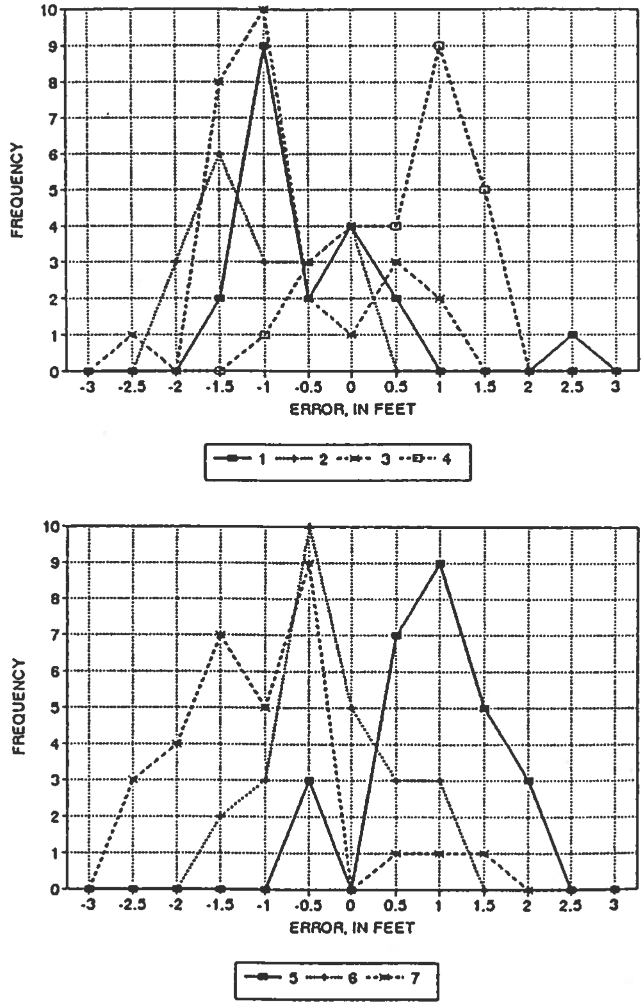


Figure 20. Frequency distribution curve for model error for calibrations 1 through 7.

Table 6. Model calibration error analysis

	MEASURED WATER LEVEL							MODEL-PREDICTED WATER LEVELS							CALCULATED ERROR						
WELL NO.	12/07	01/04	02/21	03/2	04/19	05/17	07/05	12/07	01/04	02/21	03/24	04/19	05/17	07/05	12/07	01/04	02/21	03/2	04/19	05/17	07/05
21FF-m23	9.06	10.31	10.51	10.37	9.1	8.93	9.26	10.6	11.8	12	10	8.5	9.8	10.5	-1.5	-1.5	-1.5	0.4	0.6	-0.9	-1.2
21FF-m24	8.89	10.21	10.41	10.22	8.89	8.44	8.56	10.1	11.2	11.4	9.5	8.1	9.2	10.1	-1.2	-1.0	-1.0	0.7	0.8	-0.8	-1.5
21FF-m25	10.37	10.91	11.7	11.8	10.82	10.6	10.75	11.6	12.5	12.8	11.8	10.5	11.6	12.5	-1.2	-1.6	-1.1	0.0	0.3	-1.0	-1.8
21FF-l4	7.66	8.27	9.57	9.63	8.57	8.09	7.54	7.9	9.1	9.5	8.5	7.5	8.1	8.6	-0.2	-0.8	0.1	1.1	1.1	-0.0	-1.1
21FF-l5	6.77	8.45	8.41	8.21	7.1	6.64	7.07	7.2	8.7	10	7.6	6.3	7	7	-0.4	-0.3	-1.6	0.6	0.8	-0.4	0.1
21FF-m28	9.18	9.8	10.36	10.15	9.33	9.02	8.55	10.3	11.5	11.5	9.6	8.1	9.4	10.2	-1.1	-1.7	-1.1	0.6	1.2	-0.4	-1.6
21FF-i4	9.34	9.87	10.83	11.04	10.07	9.47	9.57	11	12	12.1	11.6	10.7	11.4	12	-1.7	-2.1	-1.3	-0.6	-0.6	-1.9	-2.4
21FF-l6	10.5	11.64	11.9	11.87	10.54	10	10.16	10.9	12.1	13	11.4	10.1	10.9	11.9	-0.4	-0.5	-1.1	0.5	0.4	-0.9	-1.7
21FF-m29	10.75	11.53	10.73	10.46	9.88	10.02	10.53	11.9	13.1	12.6	11	9.5	10.9	12.1	-1.2	-1.6	-1.9	-0.5	0.4	-0.9	-1.6
21FF-m26	9.69	10.4	9.64	9.45	8.86	9.18	10.33	10.7	11.9	12.2	9.1	7.9	8.8	9.2	-1.0	-1.5	-2.6	0.3	1.0	0.4	1.1
21FF-m27	7.51	7.89	8.39	8.42	7.62	7.25	7.16	8.9	10	10.3	9.5	8.4	9	9.9	-1.4	-2.1	-1.9	-1.1	-0.8	-1.8	-2.7
21FF-i5	11.84	13.38	13.8	13.65	12.36	11.98	12.67	12.6	13.6	14.6	12.9	11.8	12.8	13.5	-0.8	-0.2	-0.8	0.8	0.6	-0.8	-0.8
21FF-l7	5.57	nm	6.01	5.71	4.68	4.33	5.11	3.4	6.6	7.7	6.4	5.4	5.2	5.8	2.2		-1.7	-0.7	-0.7	-0.9	-0.7
21F-m30	7.19	7.21	8.07	8.07	7.41	7.1	6.58	7	7.5	7.2	7	6.5	7.1	7.5	0.2	-0.3	0.9	1.1	0.9	0.0	-0.9
21FF-m33			8.99	9.16	8.43	7.97	7.15			8.7	7.7	6.6	7.3	7.8			0.3	1.5	1.8	0.7	-0.6
21FF-m34			9.14	9.21	7.58	8.13	7.34			10.3	8.6	7.2	8.1	8.4			-1.2	0.6	0.4	0.0	-1.1
21FF-m35			10.86	10.56	9.44	9.02	9.31			12.7	10	8.5	9.7	10.1			-1.8	0.6	0.9	-0.7	-0.8
21FF-m36			10.88	10.52	9.47	9.1	9.44			12.6	10	8.4	9.6	10.2			-1.7	0.5	1.1	-0.5	-0.8
21FF-m37			10.82	10.55	9.44	9.01	9.14			12	10	8.5	9.8	10.5			-1.2	0.6	0.9	-0.8	-1.4
21FF-38			6.97	7.13	6.42	5.91	5.04			6.3	6	4.6	5.9	6.3			0.7	1.1	1.8	0.0	-1.3
21FF-m39			10.83	10.49	9.47	9.12	9.47			12.6	10	8.4	9.6	10.2			-1.8	0.5	1.1	-0.5	-0.7
21FF-r4							6.35							8.4							-2.1
21FF-r5							7.57							6.8							0.8
21FF-l9							3.99							5.7							-1.7
21FF-l8							5.25							7.3							-2.1
21FF-31	7.33	7.56	8.83	9.01	8.32	7.87	7.06	7.1	8.8	8.7	7.7	6.6	7.3	7.8	0.2	-1.2	0.1	1.3	1.7	0.6	-0.7
21FF-m32	10.57	10.9	10.93	10.67	9.42	9.02	9.32	11.3	12.8	12.7	10	8.5	9.7	10.1	-0.7	-1.9	-1.8	0.7	0.9	-0.7	-0.8
21FF-i1	6.42	6.64	7.46	7.51	6.83	6.43	6.19														
21FF-m3	8.79	9.15	10.28	10.38	9.52	9.04	8.45	9.8	10.9	11.4	10.4	9.4	10.2	11.1	-1.0	-1.8	-1.1	-0.0	0.1	-1.2	-2.7
21FF-l3	11.83	12.57	13.14	17.81	12.02		11.03	12	13.3	13.3	12.4	10.7	11.9	12.7	-0.2	-0.7	-0.2		1.3		-1.7
21FF-m2	6.61	6.69	7.7	7.79	7.1	6.58	6.04	8	9	8.8	8.1	6.9	7.9	8.8	-1.4	-2.3	-1.1	-0.3	0.2	-1.3	-2.8
21FF-m4	5.93	6.46	7.09	7	6.22	5.72	5.47	7.1	7.6	8.1	7.4	6.2	7	7.5	-1.2	-1.1	-1.0	-0.4	0.0	-1.3	-2.0

Errors for calibrations 4 and 5 tend to be positive. Water levels are greatest during this period and the positive errors reveal that the model tends to underestimate the water table during these times. Conversely, errors for the other calibrations tend to be negative. There appears to be a trend toward greater negative errors as the water levels decline in a season. This is an indication that the percentages used for recharge and evapotranspiration probably change seasonally and that the model results are best under average aquifer conditions.

The total number of data points for all calibrations is 176. Errors range from -2.8 to 2.2 and the average error is -0.5. There are 10 errors less than or equal to 2.0 and one error greater than 2.0. Of these, six negative errors occur for the calibration period ending in July. Wells 21FF-m27, 21FF-i4, and 21FF-m4 are located in cells adjacent to constant-head cells, and the errors noted for these cells are probably a result of boundary effects. 21FF-m2 is also likely to have boundary effects resulting from its location near the western edge of the study area, within two cells of a boundary to the west and south. Since well 21FF-r4 is located on a cell face, the error represents the greater of the two possible errors, the other being -1.2 which is acceptable. 21FF-l8 is located near the eastern study area boundary. The error seen in this well might be attributed to the poor hydraulic information obtained from this particular well. In the case of wells 21FF-m3 and 21FF-m26, the reason for the magnitude of the error is not known. The magnitude of error for the other calibration periods ranges from 0 to 1.8 and from 0.3 to 1.5, respectively, for these wells.

Pumpage Simulations

Pond irrigation discharges from the calibration periods are listed in Table 7. The pumping rates are based on continuous pumping for the entire calibration period. Rates range from 0 to 25,750 ft3/day (0 to 134 gpm). The maximum pumping rate is comparable to the maximum capacity of 200 gpm per pond discussed in an earlier section.

Table 7. Model-derived irrigation pond pumpage

Calibration number	Pond pumpage rate (ft^3/day)			
	Pond 1	Pond 2	Pond 3	Pond 4
4	2,700	0	4,550	0
5	2,000	0	0	0
6	4,300	250	7,250	2,100
7	5,850	6,700	25,750	6,820

According to these results, the greatest amount of water is pumped from Pond 3. This is reasonable, as it has the largest storage capacity of any of the ponds. These results also indicate that the least amount of water is available from Pond 2 under the calibration conditions. A greater volume than that derived from the model is expected from this pond. The discrepancy between actual and calibration pumpage for Pond 2 probably is a result of the sparseness of data south of the pond. Further data collection would be required to more closely calibrate the model in this area.

Examination of the pumpage results by calibration period indicate that the greatest amount of pumpage occurs during calibration number 7. Pumpage indicated for period 5 is low as a result of the model undersimulating water levels when the aquifer water levels are high.

Water Budget Analysis

Model output for each calibration includes a water budget analysis. The results are listed in Table 8. The top portion of Table 8 lists the cumulative volumes, in cubic feet, that enter or exit the aquifer. Since the length of time is different for each calibration period, these volumes cannot be directly compared between the calibration periods. Instead, it is more helpful to compare the rates of change in cubic feet per day. These are listed in the bottom portion of Table 8.

The water budget provides an independent check of the overall acceptability of the numerical solution of the model. If the percent discrepancy between the outflow and inflow of the model is small, then the solution should be acceptable. In all instances, this value is essentially zero for each of the calibration runs.

A closer look at the water budget reveals how the aquifer is responding to the fluxes in the model. For the calibration period ending in December, the net rate of change in storage is roughly 273,000 ft^3/day (out:storage - in:storage). The storage term indicates whether water is being removed from storage and thus released into the flow regime (in:storage) or is taken into storage and thereby removed from the flow regime (out:storage). Water calculated as being removed from the flow regime and becoming a net increase in storage is reflected in a net increase in the calculated model head values.

The largest rate of change in storage occurs for calibration period 5. Starting heads were at the maximum recorded for that period; therefore, the lower simulated heads required that water be released from storage at a much greater rate than other periods. Conversely, during calibration period 1, starting heads were at a recorded low when the aquifer was most receptive to taking water into storage. This is noted by the large rate at which water is removed from the flow regime (out: storage).

Table 8. Water budget for model calibrations

	CALIBRATION PERIODS						
	1	2	3	4	5	6	7
CUMULATIVE VOLUMES (FT^3)	10/28 - 12/07/93	12/07/93 - 01/04/94	01/04 - 02/21 94	02/21- 03/24/94	03/24 - 04/19/94	04/19 - 05/17/94	05/19 - 07/05/94
IN:							
STORAGE	73260	267930	379500	4674400	8018800	2173100	1190500
CONSTANT HEAD	79472	0	0	0	0	0	0
WELLS	0	0	0	0	0	0	0
RECHARGE	22036000	14817000	19861000	11136000	2342700	14684000	35244000
EVAPOTRANSPIRATION	0	0	0	0	0	0	0
TOTAL IN	22189000	15085000	20241000	15811000	10362000	16857000	36434000
OUT:							
STORAGE	10985000	6895000	5952000	467310	58301	2120600	5661600
CONSTANT HEAD	1993600	2255000	2997100	2064500	1089200	1626000	3326100
WELLS	0	0	0	224750	52000	389200	2210900
RECHARGE	0	0	0	0	0	0	0
EVAPOTRANSPIRATION	9210200	5934700	11292000	13054000	9162100	12721000	25236000
TOTAL OUT	22189000	15085000	20241000	15811000	10362000	16857000	36434000
IN-OUT	-104	-55	-84	-37	-14	-60	-12
PERCENT DISCREPANCY	0	0	0	0	0	0	0
RATES (FT^3/DAY)							
IN:							
STORAGE	1831.5	9568.8	7906.3	150790	308420	77610	24296
CONSTANT HEAD	1986.8	0	0	0	0	0	0
WELLS	0	0	0	0	0	0	0
RECHARGE	550910	529170	413770	359240	90105	524430	719260
EVAPOTRANSPIRATION	0	0	0	0	0	0	0
TOTAL IN	554720	538740	421680	510020	398520	602040	743560
OUT:							
STORAGE	274630	246250	124000	15074	2242.3	75735	115540
CONSTANT HEAD	49840	80536	62440	66597	41893	58071	67879
WELLS	0	0	0	7250	2000	13900	45120
RECHARGE	0	0	0	0	0	0	0
EVAPOTRANSPIRATION	230250	211950	235240	421100	352390	454330	515020
TOTAL OUT	554730	538740	421680	510030	398520	602040	743560
IN-OUT	-2.625	-2	-1.75	-1.1563	-0.5	-2.125	-0.1875
PERCENT DISCREPANCY	0	0	0	0	0	0	0

SIMULATIONS

Model simulations were conducted to estimate how the aquifer will react under selected conditions. In the first case, the potentiometric map of the lowest recorded water levels for the study (October 28, 1993) was used as starting heads. In this simulation, there is no recharge and the evapotranspiration rate is 0.024 ft/day or 65 percent of the daily pan evaporation rate calculated from the maximum monthly pan evaporation recorded at Charleston Airport from January 1993 through June 1994. After 30 days under these conditions, water levels declined more than 1.5 ft near 21FF-m29 and about 1 ft at 21FF-l6 (Fig. 21). Water levels continued to decline between 30 and 60 days (Fig. 22), and by 90 days several cells have gone dry.

Two simulations were run to determine the maximum pumpage possible for 30 and 60 days under these conditions. The simulated potentiometric heads after 30 days are illustrated in Figure 23. In this case, ponds 1 through 4 may be pumped at a maximum constant rate of 3,400, 8,000, 13,600, and 4,800 ft^3/day (17, 41, 70, and 25 gpm), respectively, without dry cells occurring. Maximum pumpage rates decrease by 33 to 46 percent to 2,200, 4,400, 7,400 and 3,200 ft^3/day (11, 23, 39, and 17 gpm) for ponds 1 through 4, respectively, if sustained for 60 days (Fig. 24).

In the second case, optimum conditions were assumed. Conditions included starting heads set between 0.5 and 1 ft below land surface and the average precipitation and pan evaporation for the months of March and April. Average precipitation and pan evaporation were 0.011 and 0.013 ft^3/day, respectively.

The first simulation assumes these conditions for 30 days. The second simulation assumes these conditions for 60 days, which, comparing to actual springtime conditions, would translate into an average March and a wet April. In the third simulation, the maximum pumpage is predicted for the same conditions for 30 days without forming dry cells. At 30 days, water levels have declined a maximum of about 1 ft (Fig. 25). Between 30 and 60 days, water levels decline another half foot or less (Fig. 26).

When maximum pumpage is simulated under these conditions for 30 days, water levels are shown to decline 3 to more than 7 ft in the ponds (Fig. 27). In this case, ponds 1 through 4 may be pumped at a maximum constant rate of 9,400, 11,500, 29,600, and 11,000 ft3/day (49, 59, 153, and 57 gpm), respectively without dry cells occurring. However, the cones of depression created by the pumpage are steep and do not extend more than a few hundred feet beyond the pond edges. This is an indication that the ponds probably would be pumped dry before causing well interference.

CONCLUSIONS

Interference effects on domestic wells from pond irrigation are expected to be minimal, even though the aquifer has a low hydraulic conductivity. Values from slug tests averaged 9 ft/day and from aquifer tests 20 ft/day. Inasmuch as the hydraulic conductivity is low, the cones of depression formed about the irrigation ponds are steep sided but small in areal extent. Evidence for this is the July 1994 potentiometric map, which shows a cone of depression more than 6 ft deep formed about Pond 3. At the same time, water levels were not greatly influenced in the nearest wells located 400 to 900 ft from the pond.

Saltwater intrusion is unlikely to occur as a result of pumping from the irrigation ponds for the same reasons that well-interference effects are minimal. Declines in ground-water levels resulting from pond pumpage occur at distances too small to induce saltwater intrusion.

Irrigation is limited by the low hydraulic conductivity of the aquifer, which restricts replenishment of the ponds when pumping occurs; therefore, large storage volumes are required for extensive irrigation. In the event pond levels are low following the spring and early summer irrigation period, a second or late summer season of irrigation may not be feasible.

Contamination of domestic wells from agricultural practices is likely to be minimal. Ground-water flow patterns isolate much of the agricultural land from Leadenwah Creek and domestic wells north of Leadenwah Drive. Ground water is expected to be recirculated on agricultural lands, owing to cones of depression and to drip irrigation practices during the irrigation season. The potential for contaminant migration, if present, is least during this period. Samples from four wells were found to have levels below detection limits for the two chemicals chosen to be screened for pesticides.

Adverse effects of irrigation are most likely to occur near the irrigated field located north of the ground-water divide where flow is toward Leadenwah Creek. Pollution effects may be likely but well interference is not likely under present conditions in this area.

Model simulations indicate that under extreme drought conditions, pumping from ponds would be limited to a maximum sustained rate of 70 gpm in Pond 3 for a period of 30 days. If drought conditions were to persist for 60 days, pumping rates would have to decrease by 33 to 46 percent in order to prevent ponds going dry. At optimum conditions, predicted pumpage could be sustained at about 150 gpm in Pond 3 for 30 days.

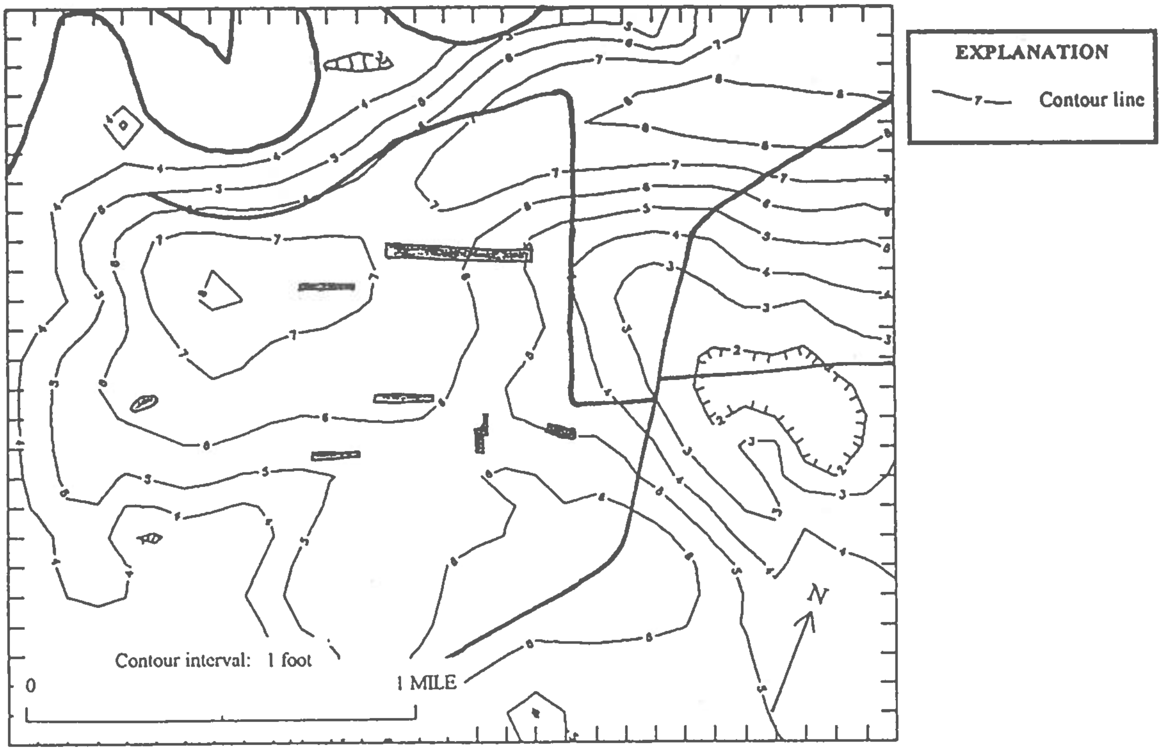


Figure 21. Model-estimated aquifer heads for case 1 after 30 days.

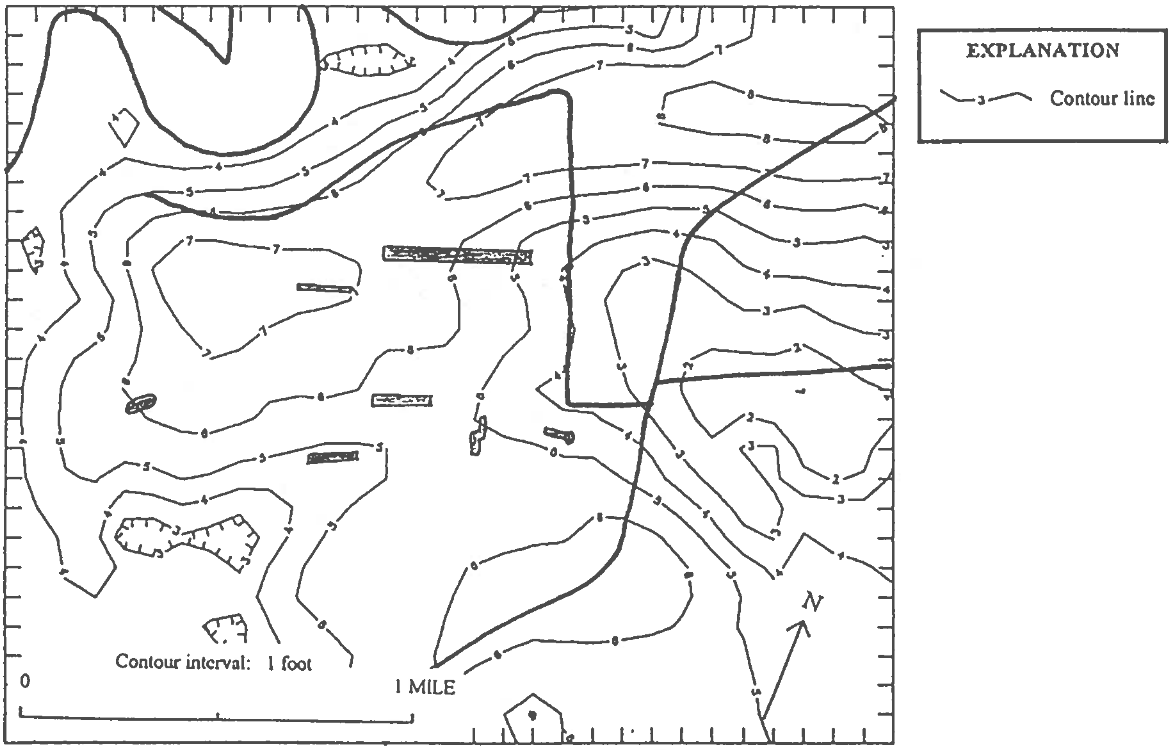


Figure 22. Model-estimated aquifer heads for case 1 after 60 days.

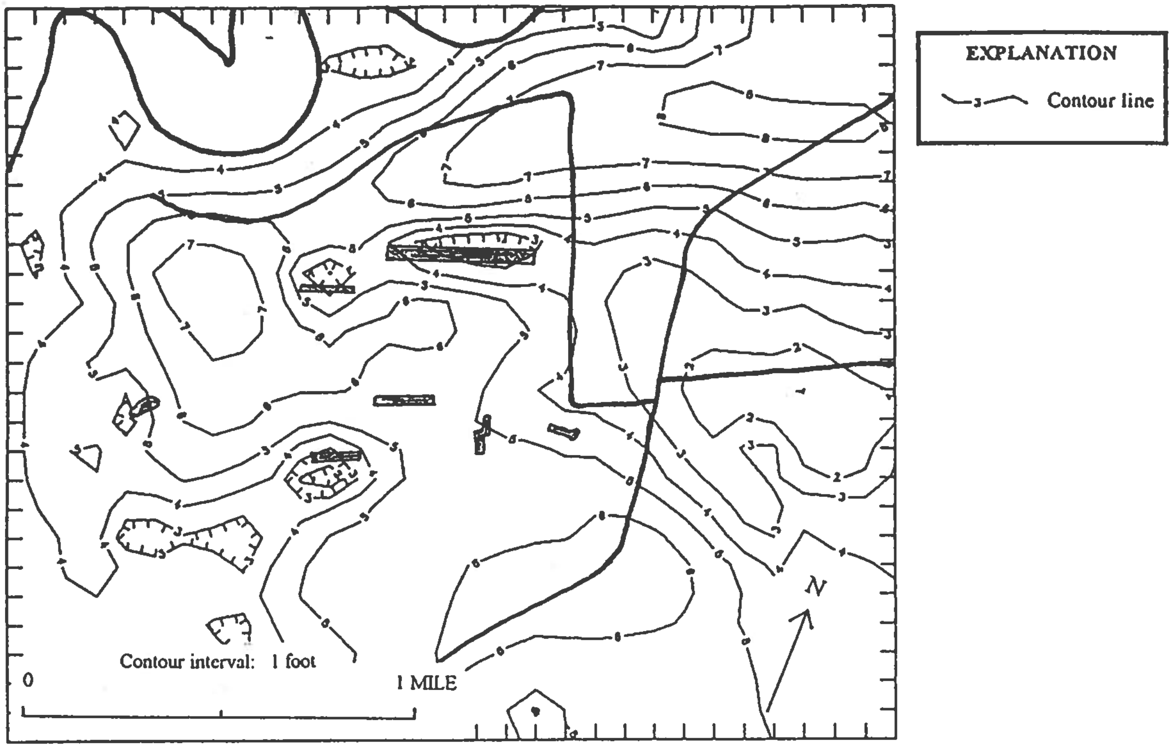


Figure 23. Model-estimated aquifer heads for case 1 after 30 days of maximum pond pumping.

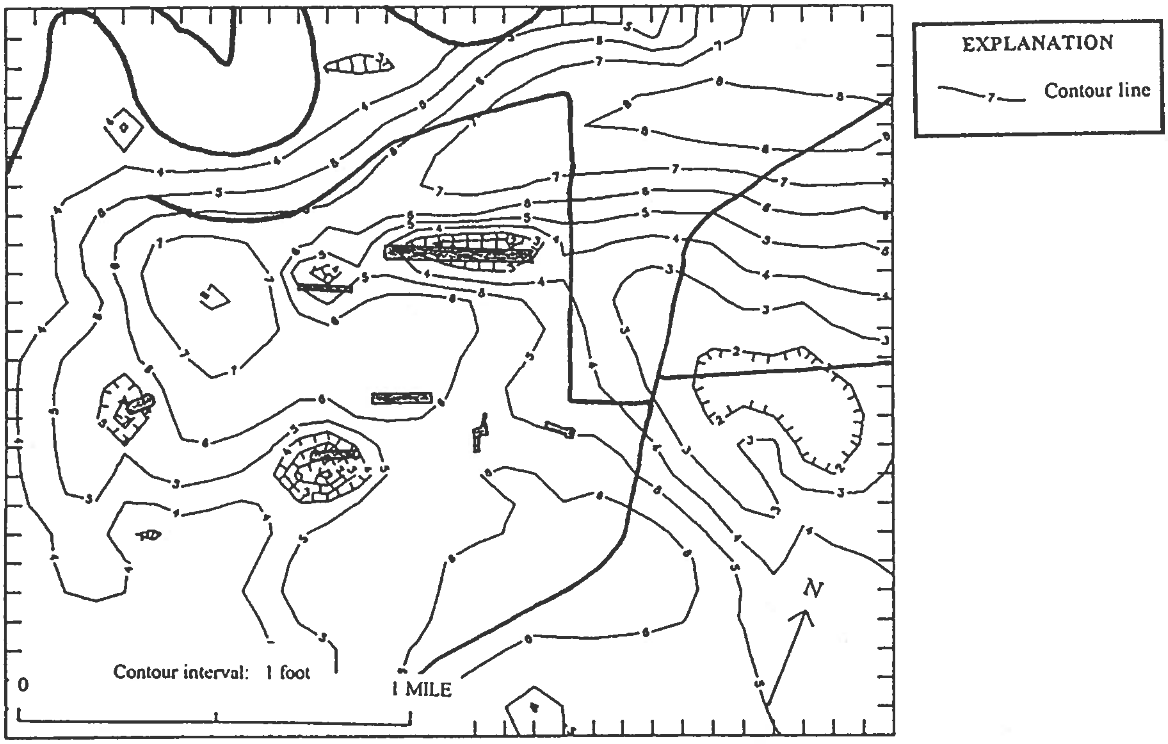


Figure 24. Model-estimated aquifer heads for case 1 after 60 days of maximum pond pumping.

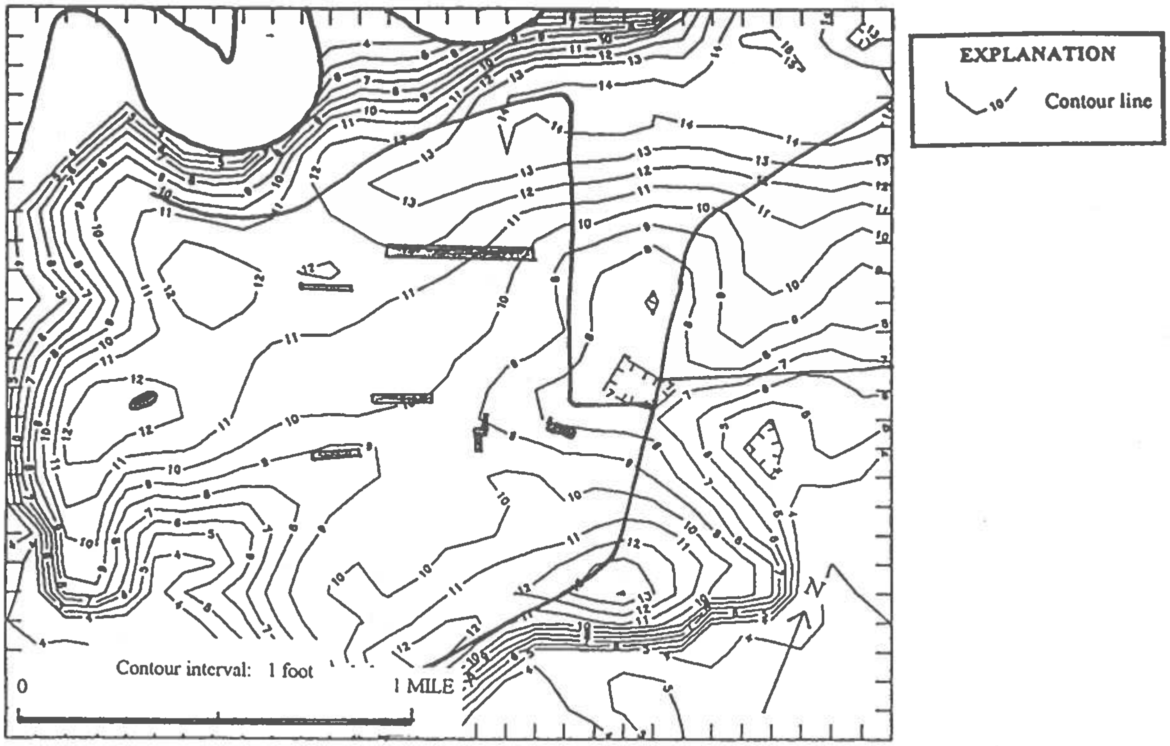


Figure 25. Model-estimated aquifer heads for case 2 after 30 days.

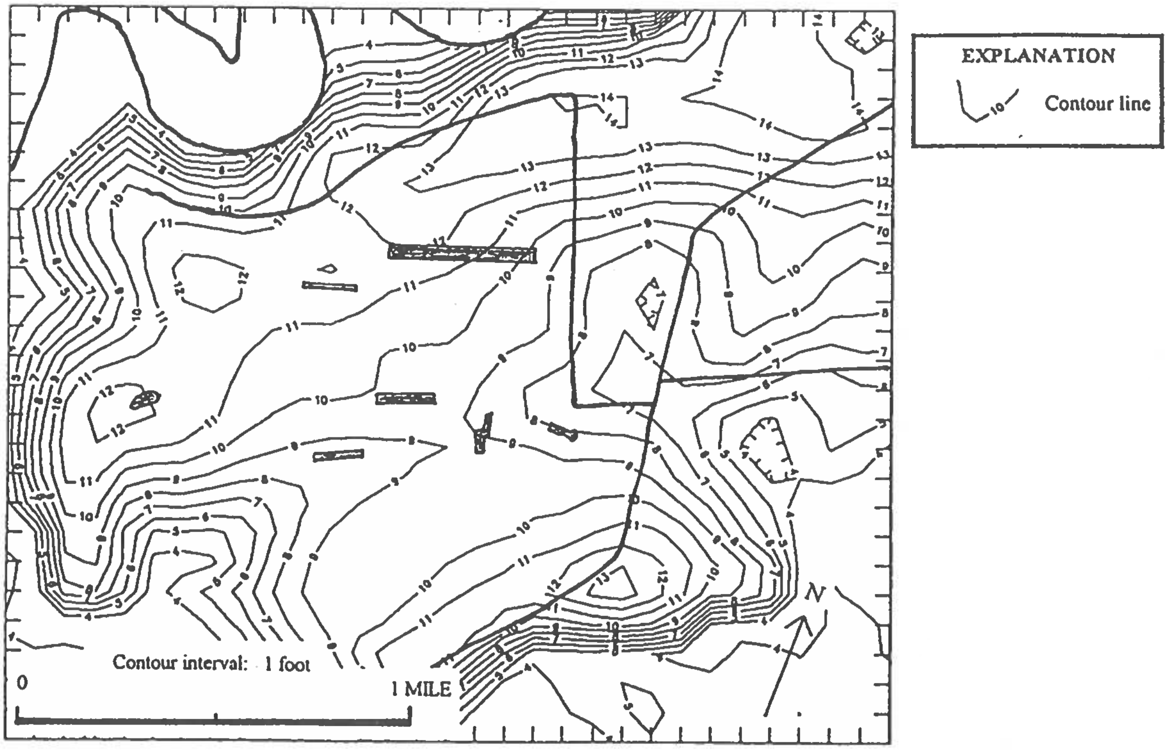


Figure 26. Model-estimated aquifer heads for case 2 after 60 days.

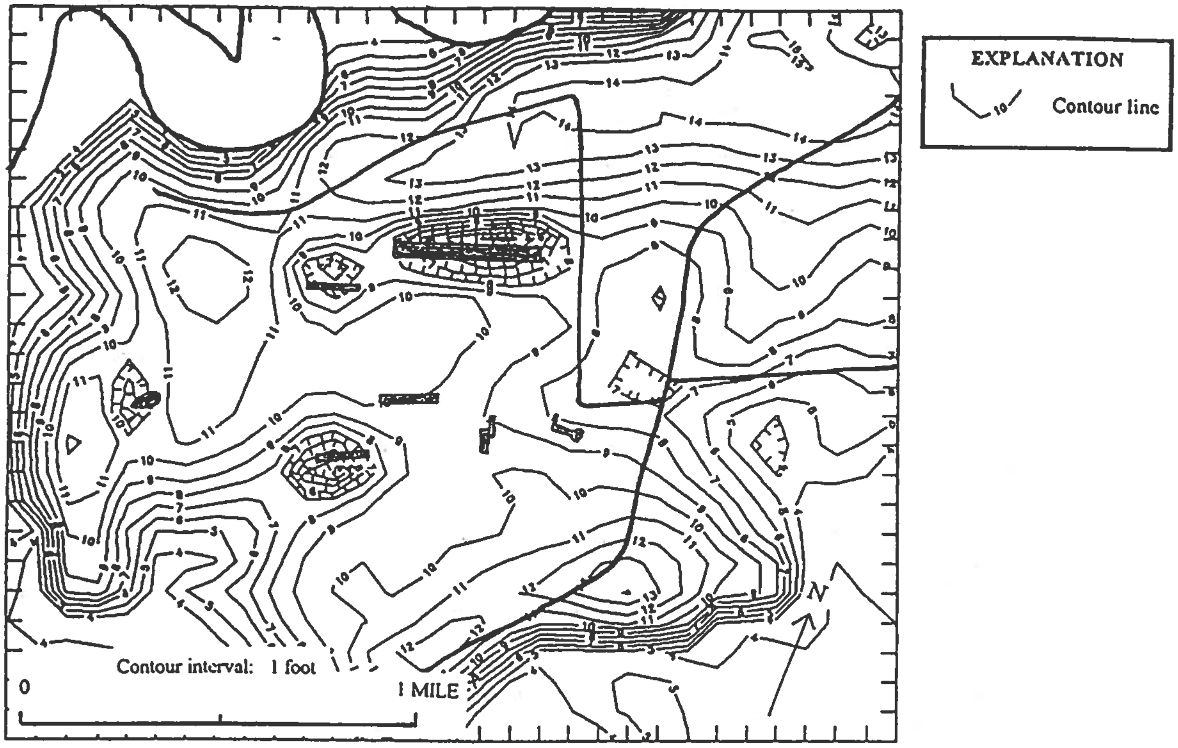


Figure 27. Model-estimated aquifer heads for case 2 after 30 days of maximum pond pumping.

REFERENCES CITED

Bathke, G. R., and others, 1992, Managing pesticides for crop productivity and water quality protection; database supplement to Agricultural Chemicals Handbook: Clemson University Cooperative Extension Service Publication EC 670.

Bennett, C.S., Cooney, T.W., Jones, K.H., and Drewes, P.A., 1994, Water resources data South Carolina-water-year 1993: U.S. Geological Survey Water-Data Report SC-93-1, p. 480.

Bouwer, Herman, 1989, The Bouwer and Rice slug test - an update: Groundwater, v. 27, no. 3, p. 304-309.

Bouwer, Herman, and Rice, R.C., 1976, A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells: Water Resources Research, v. 12, no. 3, p. 423-428.

Cook, W.P., and Whitwell, Ted, 1994, Tomato Weed Control: in Agricultural Chemicals Handbook, Clemson University Cooperative Extension Service Publication EC 670, p. 277-278.

Driscoll, Fletcher G., 1986, Groundwater and wells, 2nd ed.: Johnson Filtration Systems, Inc., St. Paul, Minn., p. 414-417.

Fetter, C.W., Jr., 1980, Applied hydrogeology: Charles E. Merrill, Columbus, Ohio, p. 75.

Freeze, R.A, and Cherry, J.A., 1979, Groundwater: Prentice-Hall, Englewood Cliffs, N.J., p. 29.

Gohn, G. S., 1992, Revised nomenclature, definitions, and correlations for the Cretaceous formations in USGS-Clubhouse Crossroads #1, Dorchester County, South Carolina: U.S. Geological Survey Professional Paper 1518, 39 p.

Gohn, G.S., and Campbell, B.G., 1992, Recent revisions to the stratigraphy of subsurface Cretaceous sediments in the Charleston, South Carolina, area: South Carolina Geology, v. 34, nos. 1 & 2, p. 25-38.

Gohn, G.S., Higgins, B.R., Smith, C.C., and Owens, J.P., 1977, Lithostratigraphy of the deep corehole (Clubhouse Crossroads Corehole 1) near Charleston, South Carolina: in Rankin, D.W., editor, Studies related to the Charleston, South Carolina, earthquake of 1886 - a preliminary report: U.S. Geological Survey Professional Paper 1028, p. 91-114.

Hewlett, J. D., 1982, Principles of forest hydrology: University of Georgia Press, Athens, Ga., 183 p.

McCartan, Lucy, Weems, R.E., and Lemon, E.M., Jr., 1990, Quaternary stratigraphy in the vicinity of Charleston, South Carolina, and its relationship to local seismicity and regional tectonism: U.S. Geological Survey Professional Paper 1367-A, 39 p.

McDonald, M. G., and Harbaugh, A. W., 1988, A modular three-dimensional finite-difference ground-water flow model, U.S. Geological Survey Technical Water-Resources Investigation, Bk. 6., Chap. A1, 548 p.

Morris, D.A., and Johnson, A.I., 1967, Summary of hydrologic and physical properties of rock and soil materials, as analyzed by the hydrologic laboratory of the U.S. Geological Survey 1948-60: U.S. Geological Survey Water-Supply Paper 1839-D, 42 p.

National Oceanic and Atmospheric Administration, 1993, Tide tables 1994, high and low predictions, East Coast of North and South America: U.S. Department of Commerce.

National Oceanic and Atmospheric Administration, Climatography No. 81, South Carolina.

Neuman, S.P., 1975, Analysis of pumping test data from anisotropic unconfined aquifers considering delayed gravity response: Water Resources Research, v. 11, p. 329-342.

Park, A.D., 1985, The ground-water resources of Charleston,Berkeley, and Dorchester Counties, South Carolina: South Carolina Water Resources Commission Report No. 139, 145 p.

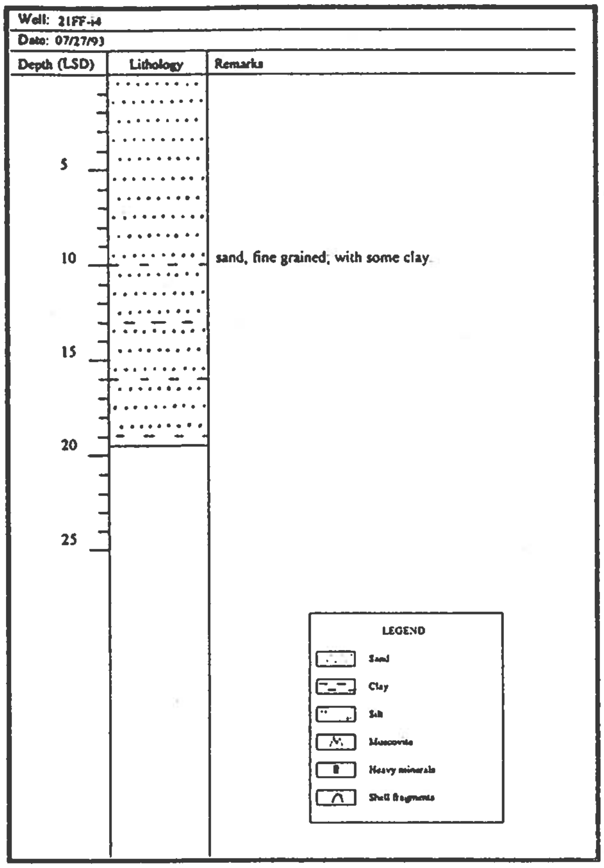
South Carolina State Development Board, Office of Research and Statistical Services, 1990, U.S. census data PNULL19.

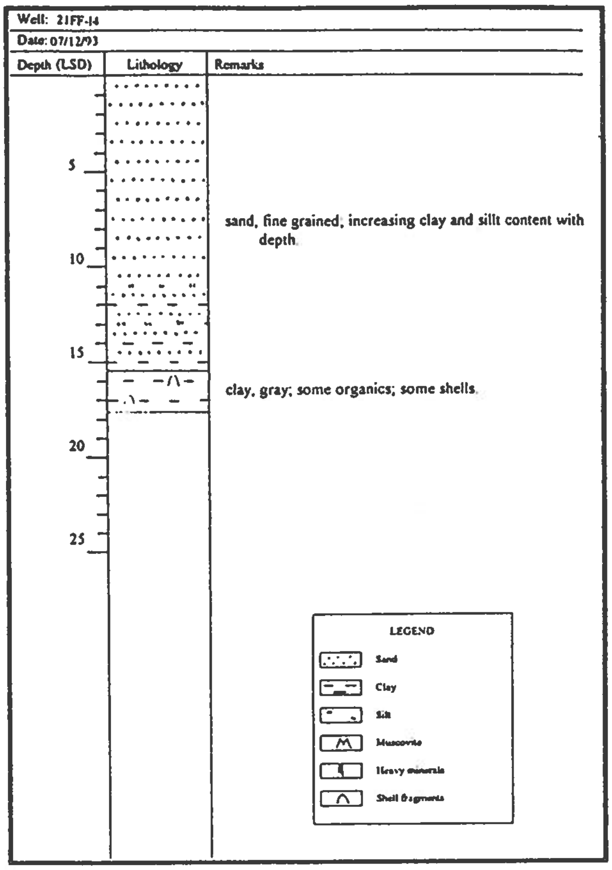
U.S. Environmental Protection Agency, 1988, Pesticide fact handbook: Noyes Data Corp, Park Ridge, N. J., v.1, p. 506-512, 596-605.

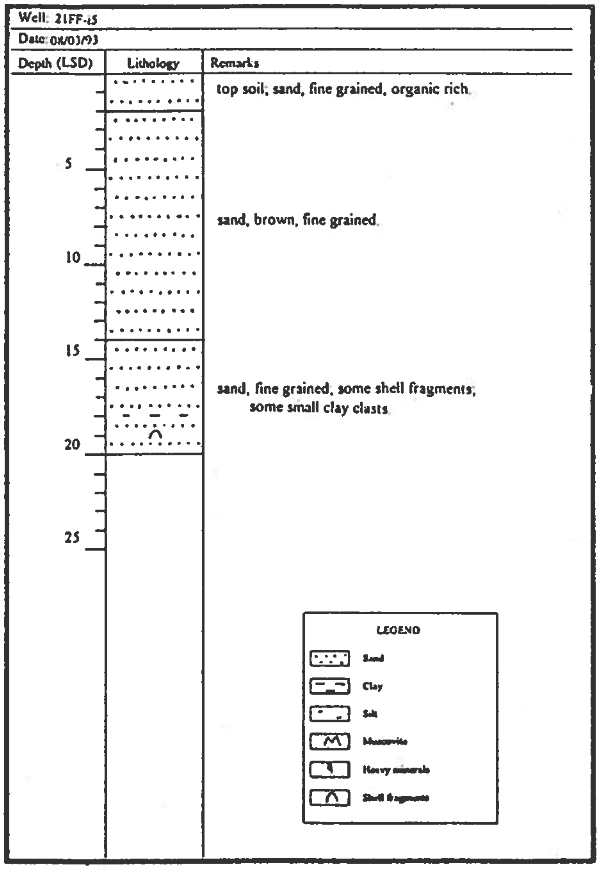
Ward, L.W., Blackwelder, B.W., Gohn, G.S., and Poore, R.Z., 1979, Stratigraphic revision of Eocene, Oligocene, and Lower Miocene formations of South Carolina: South Carolina Geological Survey, Geologic Notes, v. 23, no. 1, p. 2-32.

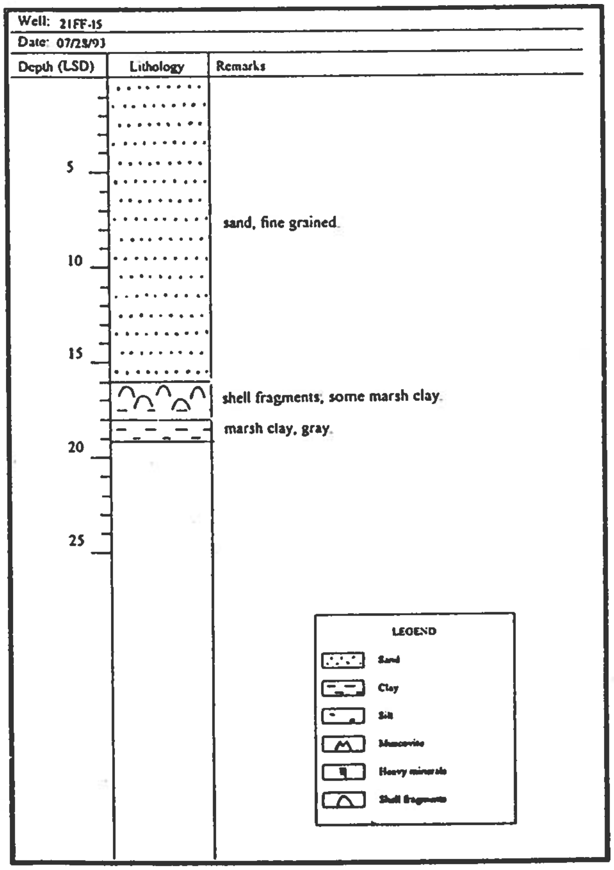
Walton, W. C., 1987, Groundwater pumping tests: Lewis Publishers, Chelsea, Mich., 201 p.

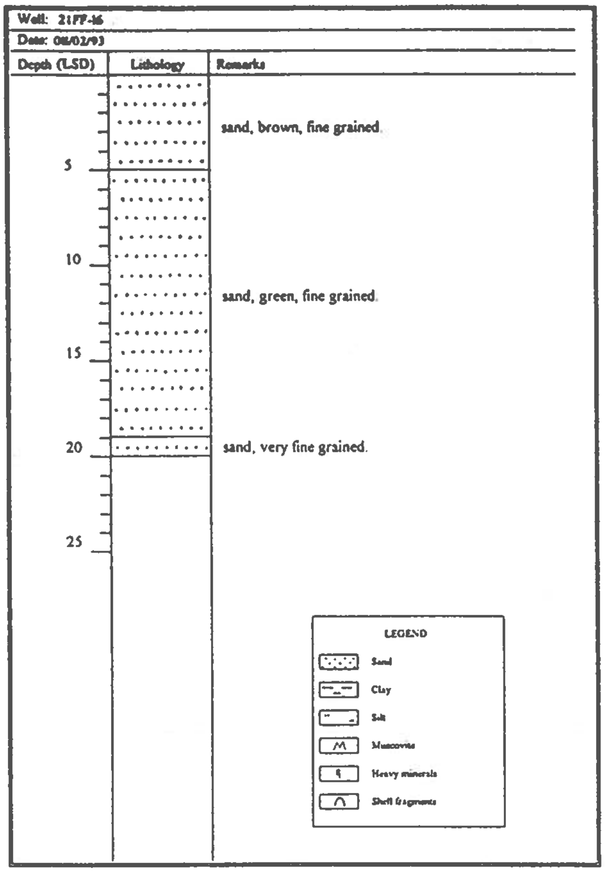
APPENDIX A. LITHOLOGIC LOGS









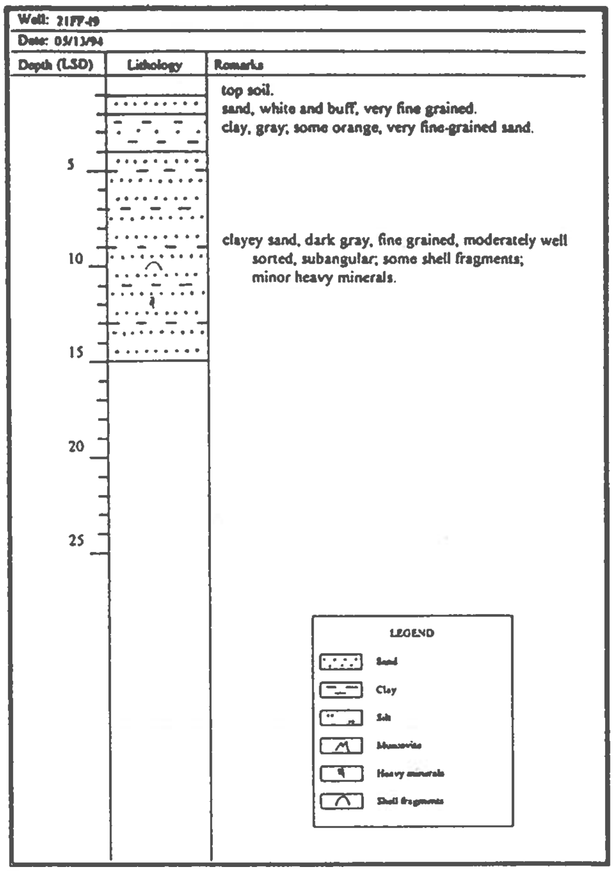

Well: 21FF-16

Date: 08/02/93

sand, brown, fine grained.

sand, green, fine grained.

sand, very fine grained.


Well: 21FF-19

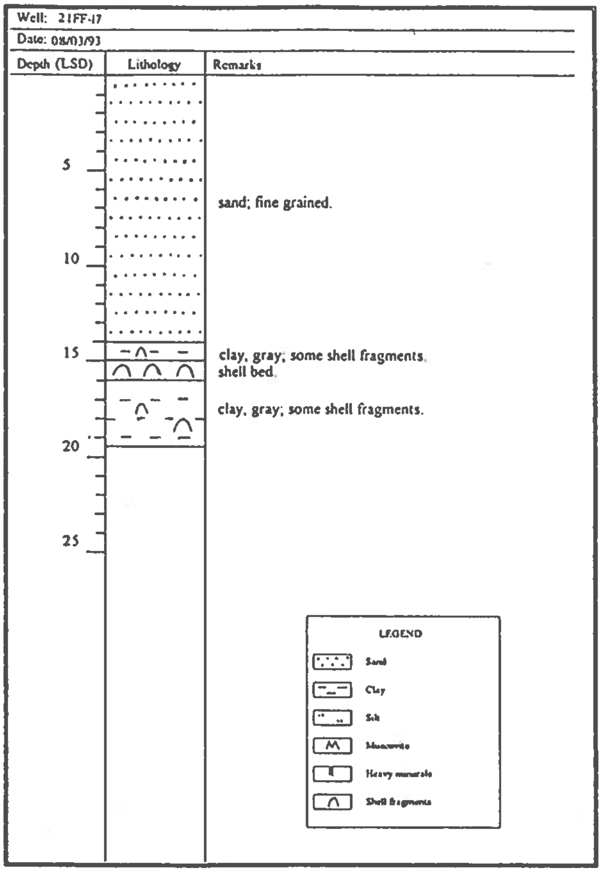
Date: 05/13/94

top soil.

sand, white and buff, very fine grained.

clay, gray; some orange, very fine-grained sand.

clayey sand, dark gray, fine grained, moderately well sorted, subangular; some shell fragments; minor heavy minerals.


Well: 21FF-17

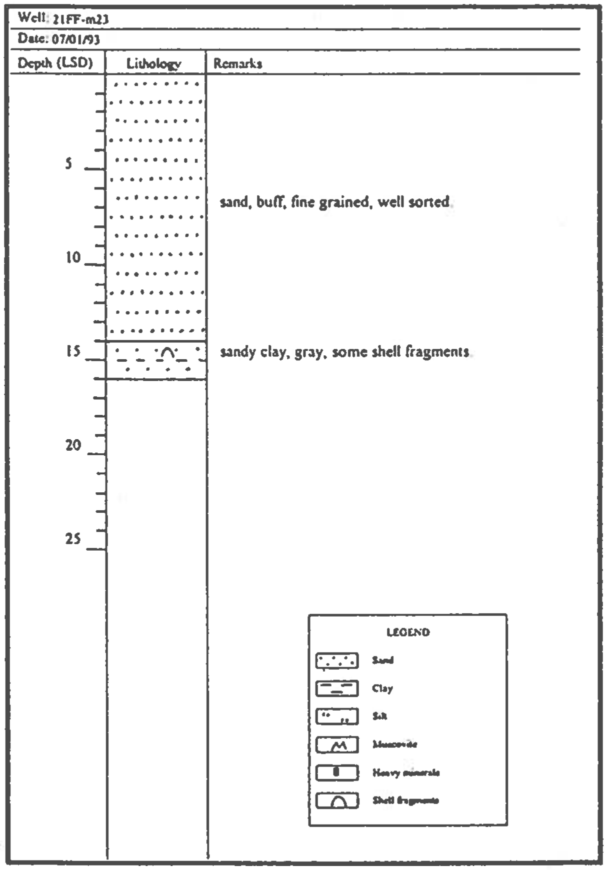
Date: 08/03/93

sand; fine grained.

clay, gray; some shell fragments.

shell bed.

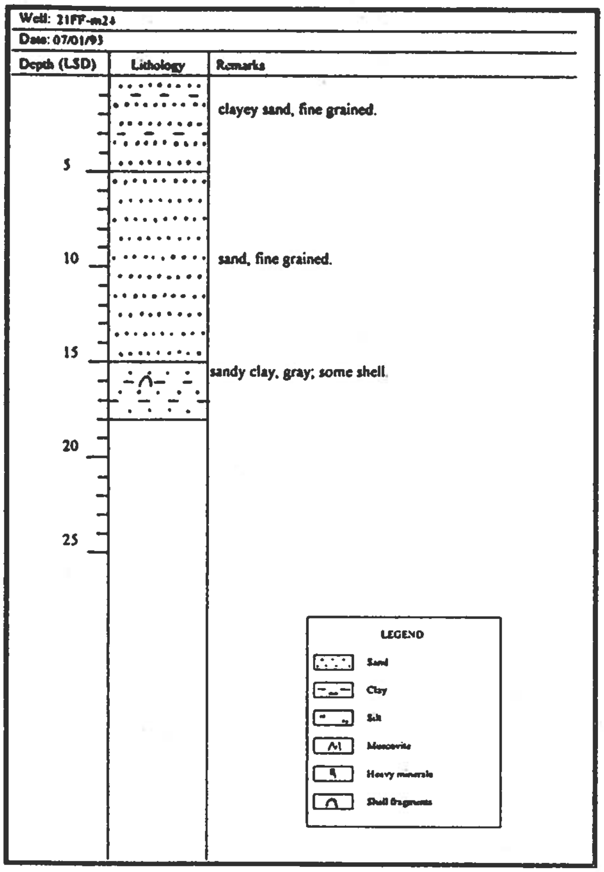
clay, gray; some shell fragments.

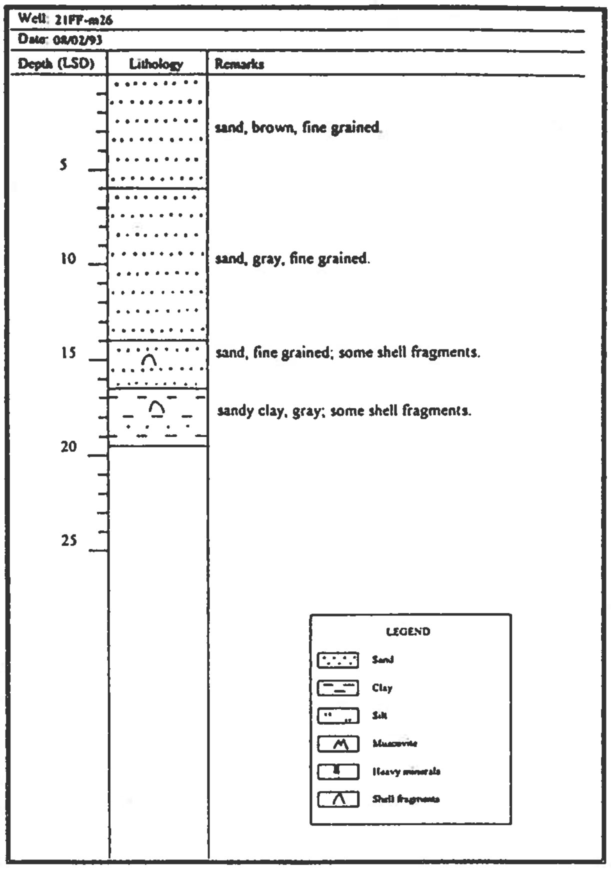

Well: 21FF-m23

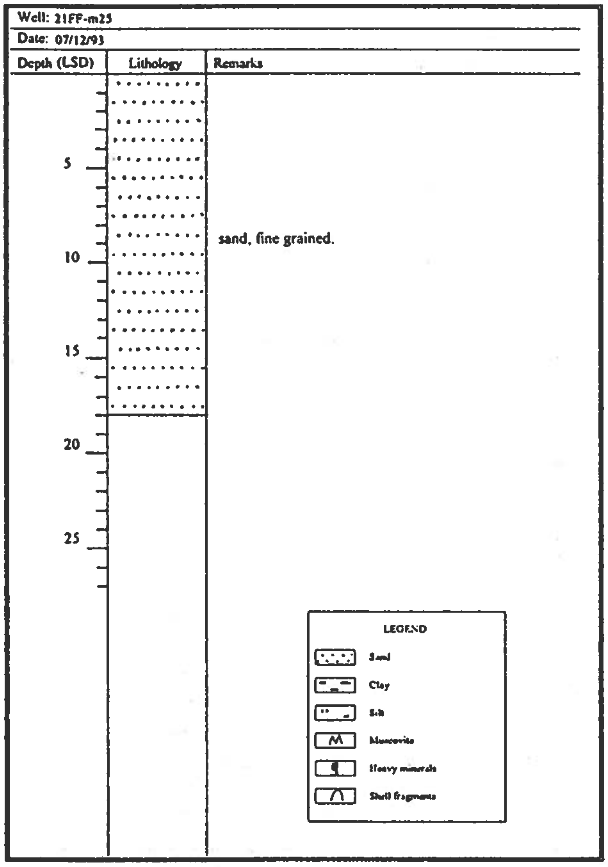
Date: 07/01/93

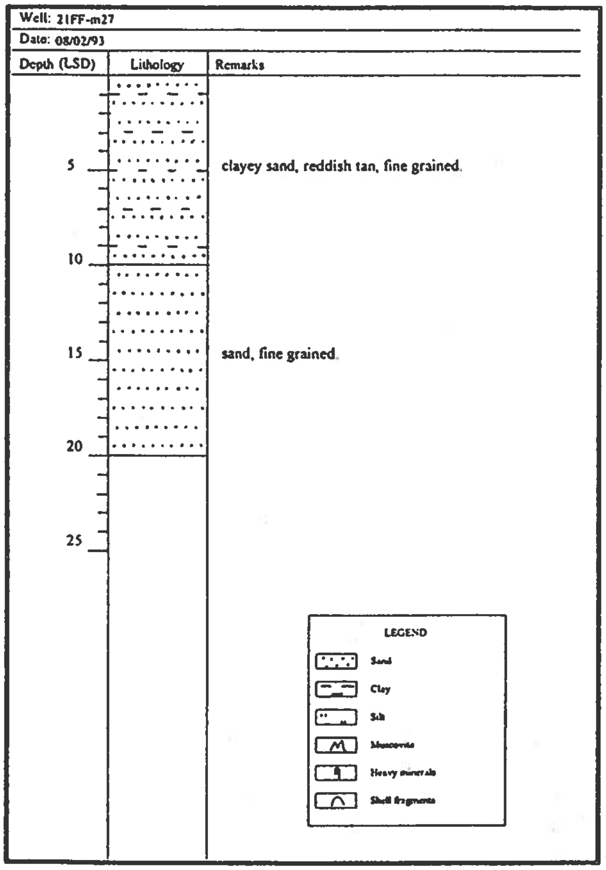
sand, buff, fine grained, well sorted.

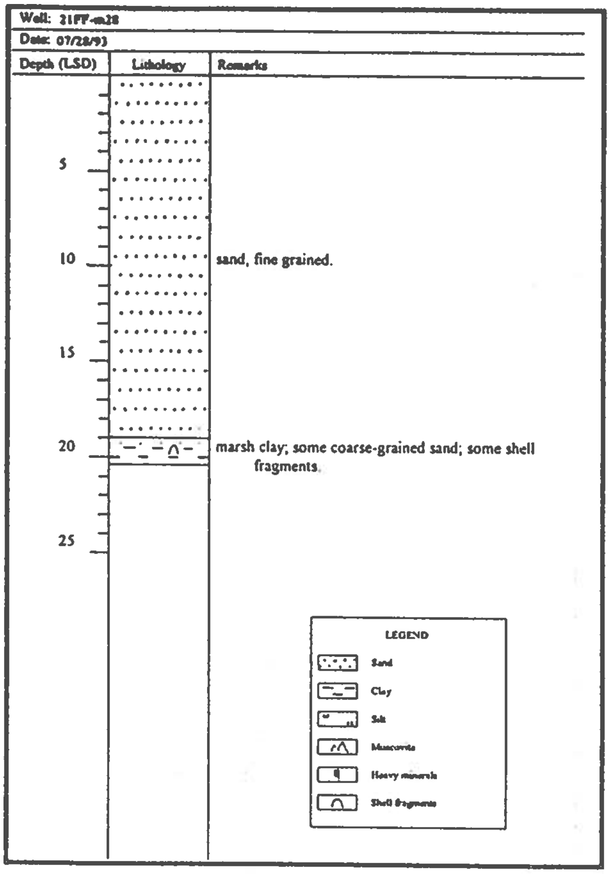
sandy clay, gray, some shell fragments.

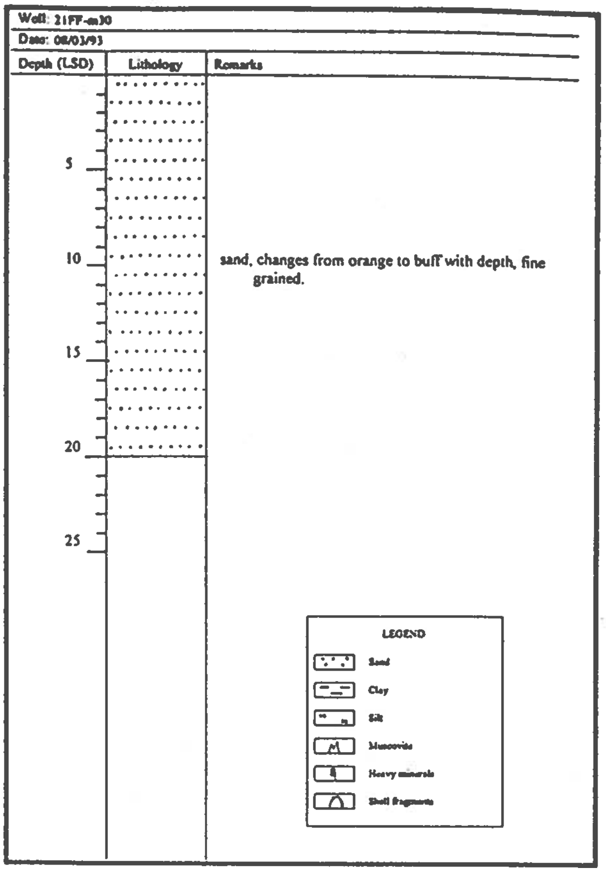

Well: 21FF-m24
Date: 07/01/93
Depth (LSD)
Lithology
Remarks
5
10
15
20
25
clayey sand, fine grained.
sand, fine grained.
sandy clay, gray; some shell.
LEGEND
Sand
Clay
Silt
Muscovite
Heavy minerals
Shell fragments

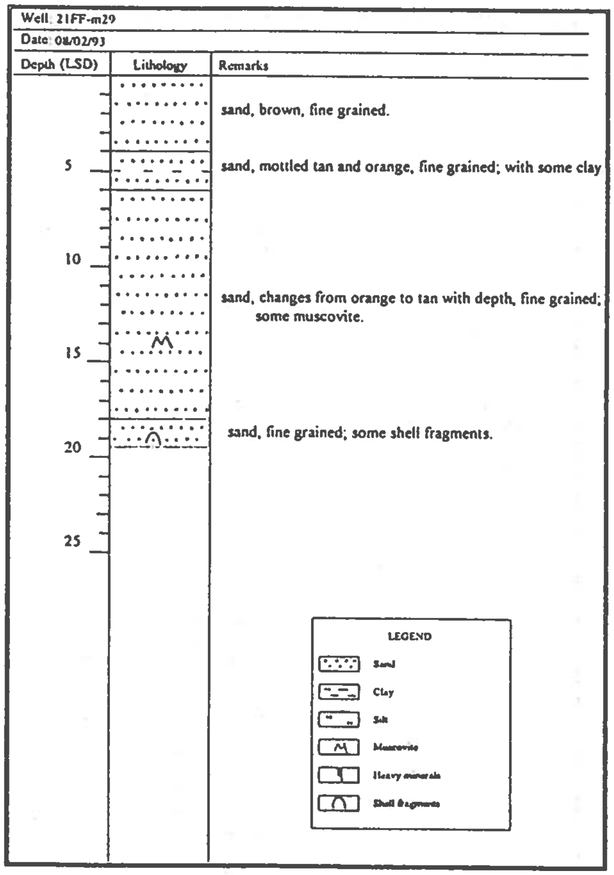

Well: 21FF-m26
Date: 08/02/93
Depth (LSD)
Lithology
Remarks
5
10
15
20
25
sand, brown, fine grained.
sand, gray, fine grained.
sand, fine grained; some shell fragments.
sandy clay, gray; some shell fragments.
LEGEND
Sand
Clay
Silt
Muscovite
Heavy minerals
Shell fragments

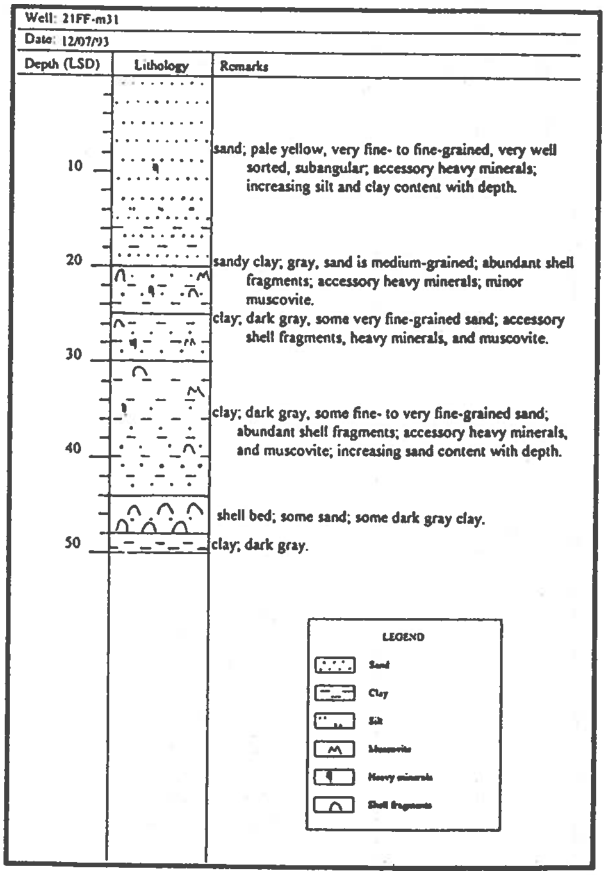

Well: 21FF-m25
Date: 07/12/93
Depth (LSD)
Lithology
Remarks
5
10
15
20
25
sand, fine grained.
LEGEND
Sand
Clay
Silt
Muscovite
Heavy minerals
Shell fragments

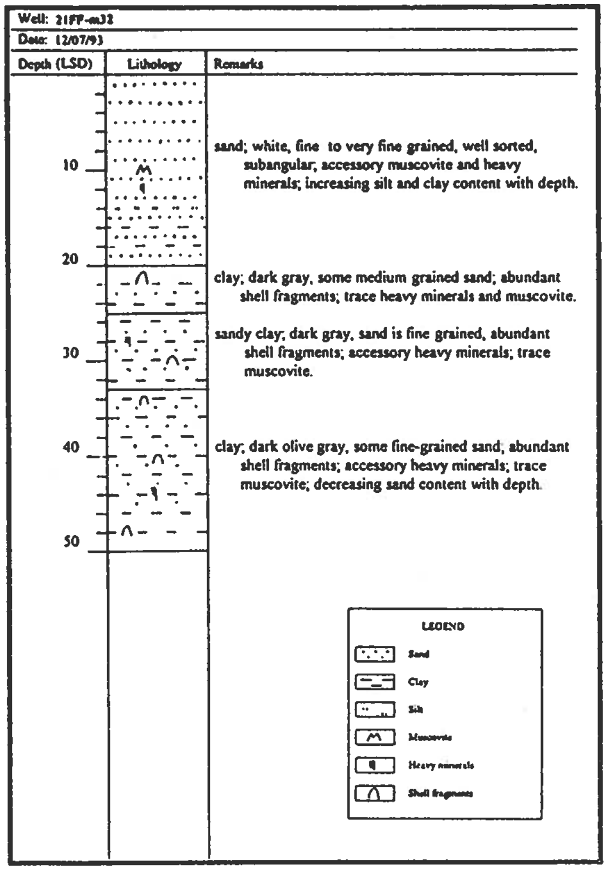

Well: 21FF-m27
Date: 08/02/93
Depth (LSD)
Lithology
Remarks
5
10
15
20
25
clayey sand, reddish tan, fine grained.
sand, fine grained.
LEGEND
Sand
Clay
Silt
Muscovite
Heavy minerals
Shell fragments


Well: 21FF-m28
Date: 07/28/93
Depth (LSD)
Lithology
Remarks
5
10
15
20
25
sand, fine grained.
marsh clay; some coarse-grained sand; some shell fragments.
LEGEND
Sand
Clay
Silt
Muscovite
Heavy minerals
Shell fragments


Well: 21FF-m30
Date: 08/03/93
Depth (LSD)
Lithology
Remarks
5
10
15
20
25
sand, changes from orange to buff with depth, fine grained.
LEGEND
Sand
Clay
Silt
Muscovite
Heavy minerals
Shell fragments


Well: 21FF-m29
Date: 08/02/93
Depth (LSD)
Lithology
Remarks
5
10
15
20
25
sand, brown, fine grained.
sand, mottled tan and orange, fine grained; with some clay
sand, changes from orange to tan with depth, fine grained; some muscovite.
sand, fine grained; some shell fragments.
LEGEND
Sand
Clay
Silt
Muscovite
Heavy minerals
Shell fragments


Well: 21FF-m31
Date: 12/07/93
Depth (LSD)
Lithology
Remarks
10
20
30
40
50
sand; pale yellow, very fine- to fine-grained, very well sorted, subangular; accessory heavy minerals; increasing silt and clay content with depth.
sandy clay; gray, sand is medium-grained; abundant shell fragments; accessory heavy minerals; minor muscovite.
clay; dark gray, some very fine-grained sand; accessory shell fragments, heavy minerals, and muscovite.
clay; dark gray, some fine- to very fine-grained sand; abundant shell fragments; accessory heavy minerals, and muscovite; increasing sand content with depth.
shell bed; some sand; some dark gray clay.
clay; dark gray.
LEGEND
Sand
Clay
Silt
Muscovite
Heavy minerals
Shell fragments



Well: 21FF-m32

Date: 12/07/93

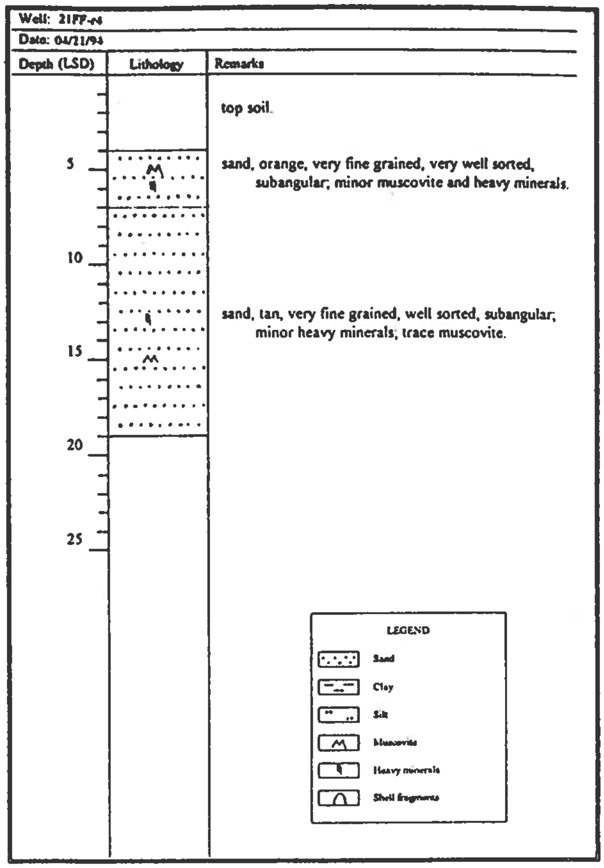
Depth (LSD) | Lithology | Remarks

sand; white, fine to very fine grained, well sorted, subangular; accessory muscovite and heavy minerals; increasing silt and clay content with depth.

clay; dark gray, some medium grained sand; abundant shell fragments; trace heavy minerals and muscovite.

sandy clay; dark gray, sand is fine grained, abundant shell fragments; accessory heavy minerals; trace muscovite.

clay; dark olive gray, some fine-grained sand; abundant shell fragments; accessory heavy minerals; trace muscovite; decreasing sand content with depth.



Well: 21FF-r4

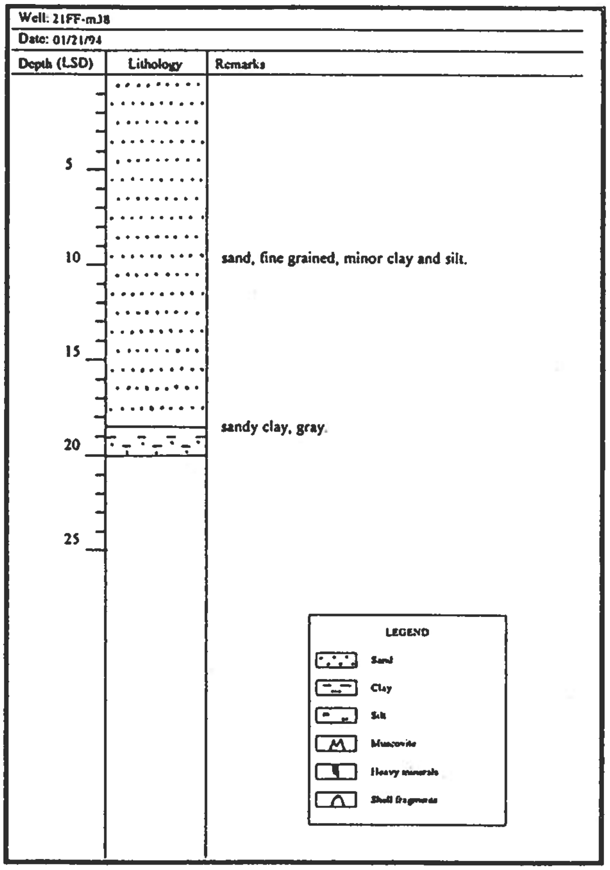
Date: 04/21/94

Depth (LSD) | Lithology | Remarks

top soil.

sand, orange, very fine grained, very well sorted, subangular; minor muscovite and heavy minerals.

sand, tan, very fine grained, well sorted, subangular; minor heavy minerals; trace muscovite.



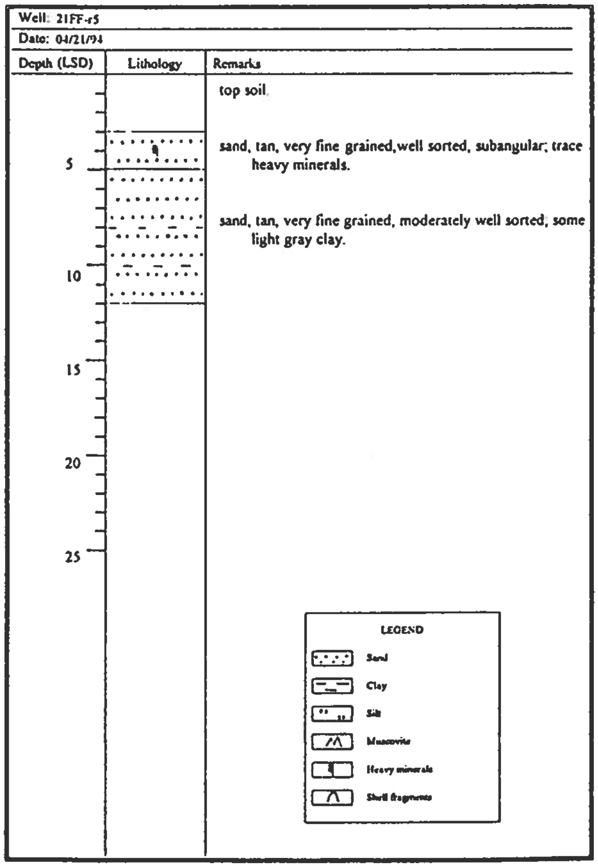
Well: 21FF-m38

Date: 01/21/94

Depth (LSD) | Lithology | Remarks

sand, fine grained, minor clay and silt.

sandy clay, gray.



Well: 21FF-r5

Date: 04/21/94

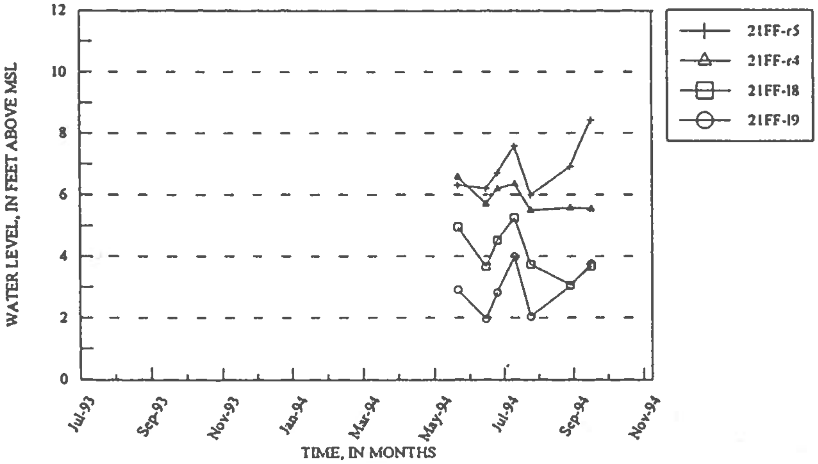
Depth (LSD) | Lithology | Remarks

top soil.

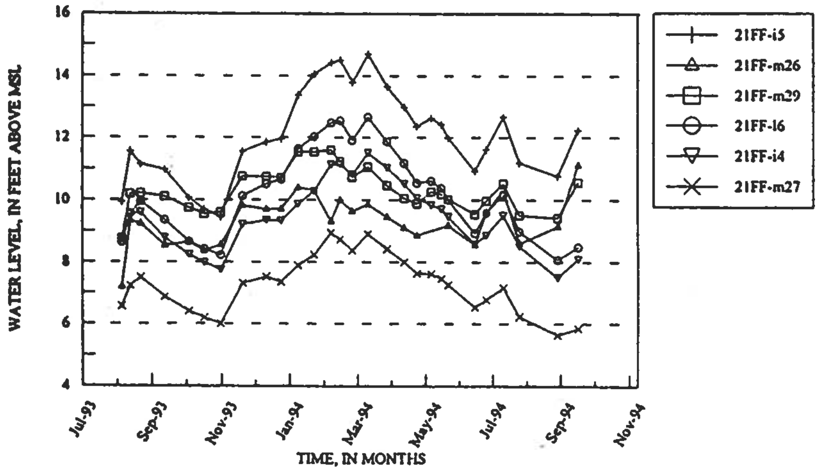
sand, tan, very fine grained, well sorted, subangular; trace heavy minerals.

sand, tan, very fine grained, moderately well sorted, some light gray clay.

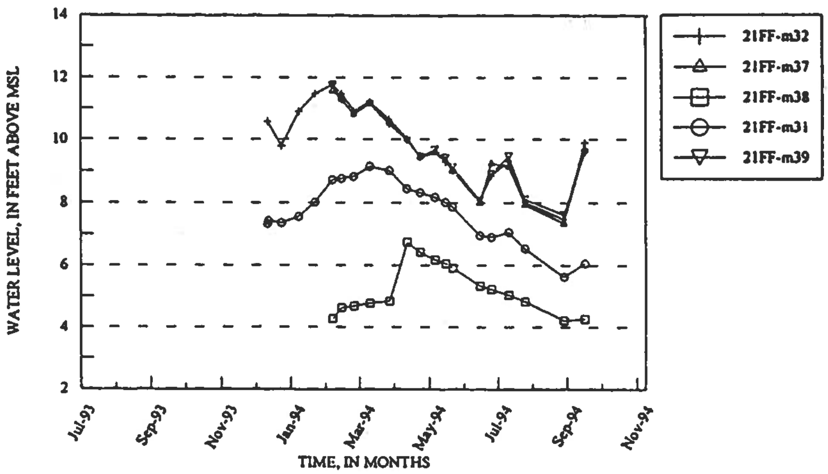
APPENDIX B. HYDROGRAPHS OF OBSERVATION WELLS



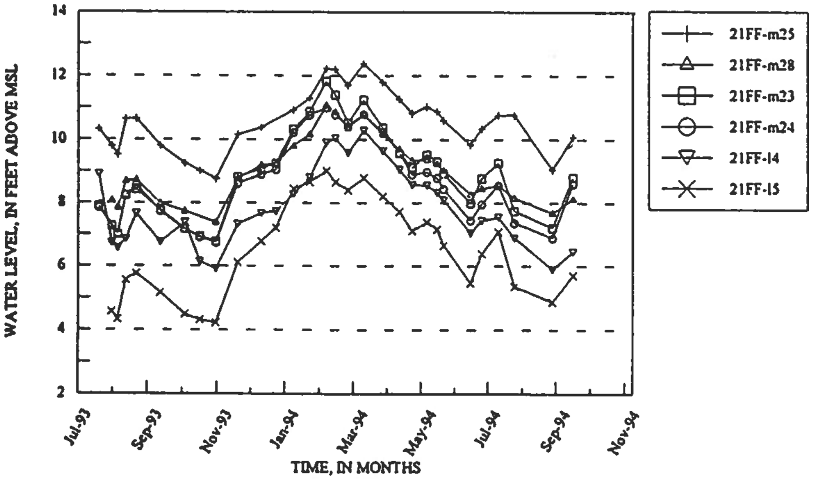
Hydrographs of wells 21FF-r5, 21FF-r4, 21FF-18, and 21FF-19.



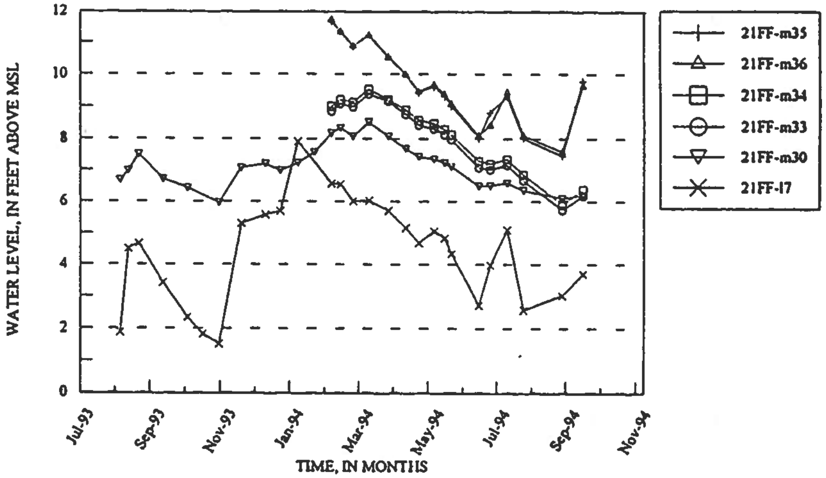
Hydrographs of wells 21FF-i5, 21FF-m26, 21FF-m29, 21FF-I6, 21FF-i4, and 21FF-m27.



Hydrographs of wells 21FF-m32, 21FF-m37, 21FF-m38, 21FF-m31, and 21FF-m39.

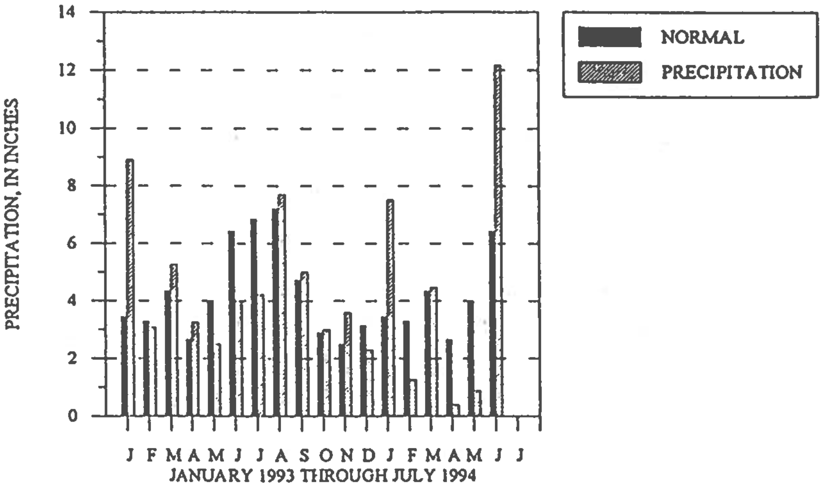


Hydrographs of wells 21FF-m25, 21FF-m28, 21FF-m23, 21FF-m24, 21FF-I4, and 21FF-I5.

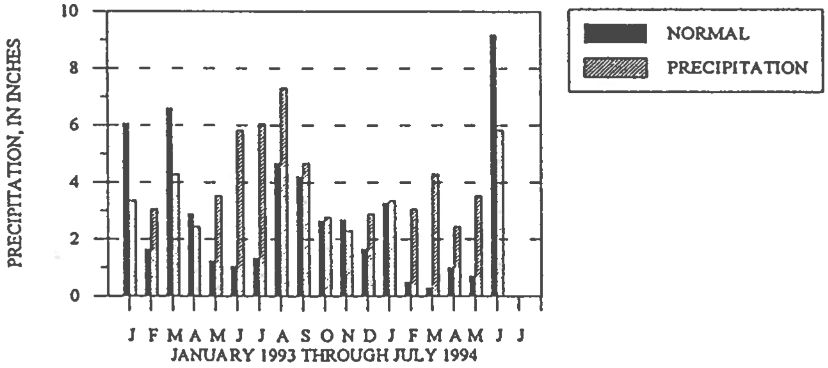


Hydrographs of wells 21FF-m35, 21FF-m36, 21FF-m34, 21FF-m33, 21FF-m30, and 21FF-I7.

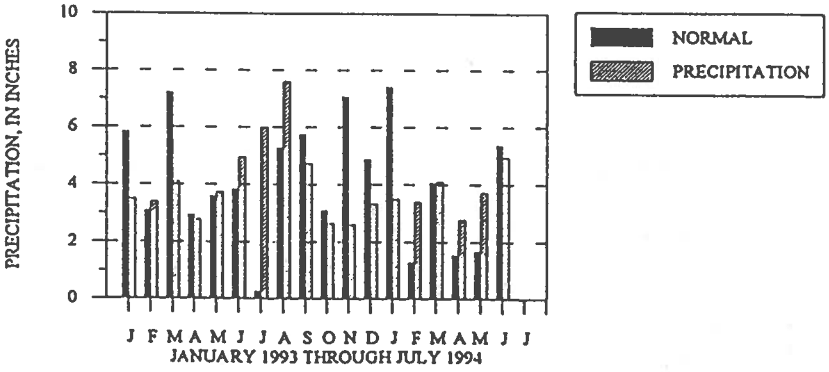
APPENDIX C. PRECIPITATION DATA



Precipitation at the Charleston International Airport.



Precipitation at the U.S. Customs House.



Precipitation at Edisto Beach, S.C.

APPENDIX D. MODEL SPECIFICATIONS

- Model grid is composed of 30 columns and 25 rows. Cells size are square with 400 feet per side and total area of 160,000 square feet.

- The Y-axis of the grid is oriented North 20 degrees West.

- The coordinates of the model grid are as follows:
  Northwest corner (near 0, 0): 32°37'47"N, 80°13'23"W
  Northeast corner (near 30, 0): 32°38'29"N, 80°11'12"W
  Southwest corner (near 25, 0): 32°36'12"N, 80°12'41"W
  Southeast corner (near 30, 25): 32°36'56"N, 80°10'30"W

- Little Rock Baptist Church Benchmark:
  Station: 10 138 PID: CK2602
  Latitude/Longitude: 32°37'30"N/80°11'23"W
  Benchmark Elevation: 1.685 meters (5.53 feet)

  This model reference point is located at the center of the cell face adjoining cells 25, 16 and 26, 16 (column, row).

- Model boundaries are as follows:
  - Leadenwah creek and adjacent marsh are constant head (-1);
  - Edges of marshes adjacent to Adams Creek and Fickling Creek are constant head (-1);
  - Beyond these boundaries are no flow cells (0);
  - All others within study area are active (1).

- Water level constraints:
  - Mean Tide Level on Leadenwah Creek (3 mi. from entrance) is 3.24 ft above msl.
  - Other tidal points Bohicket Creek at Rockville and the North Edisto River at Point of Pines, where mean tide levels are 3.09 and 3.07 ft, respectively.

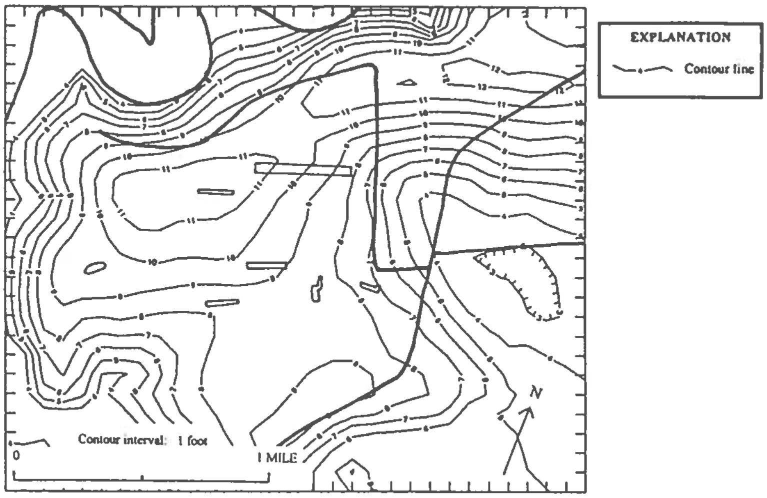
- Pond cell locations
  The model cells cooresponding to the ponds are as follows:

Pond	Model Cell (row,column)
Pond 1	14,5
Pond 2	16,11; 16,12
Pond 3	9,14; 9,15; 9,16; 9,17; 9,18
Pond 4	10,11; 10,12

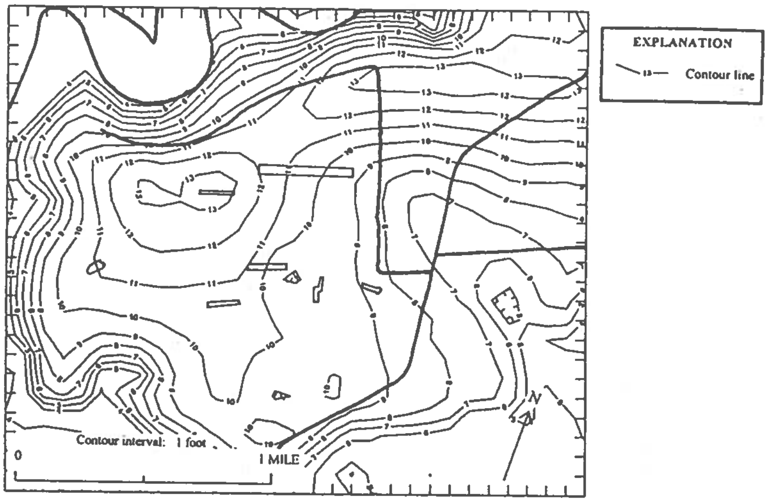
- The model is set up to utilize the following MODFLOW packages:

PACKAGE	ABBREVIATION
Basic	BAS
Block-centered flow	BCF
Recharge	RCH
Well	WEL
Evapotranspiration	ET
Strongly Implicit Procedure	SIP

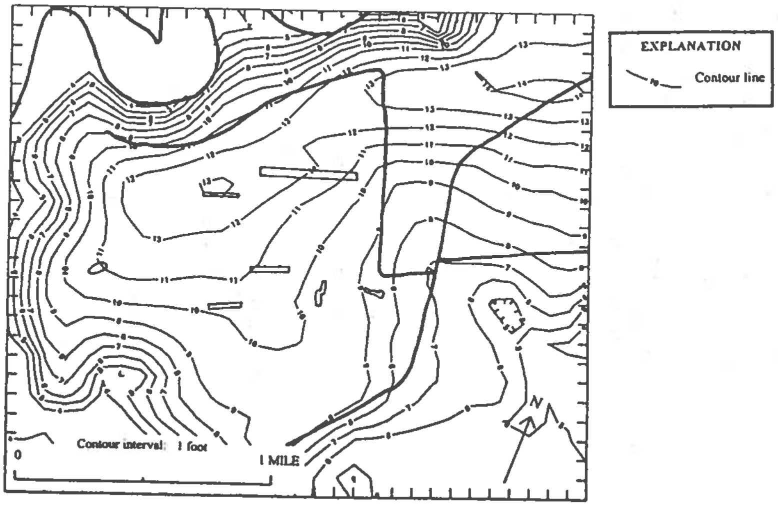
APPENDIX E. MODEL-DERIVED AQUIFER HEADS FOR CALIBRATIONS



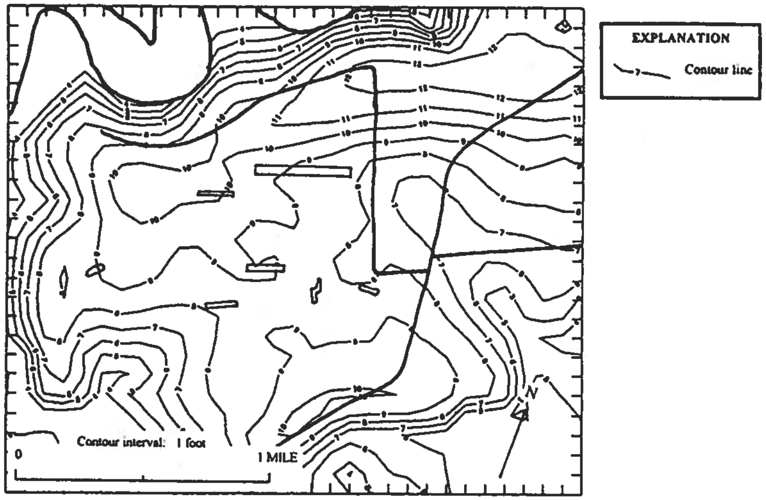
Aquifer heads after calibration period 1



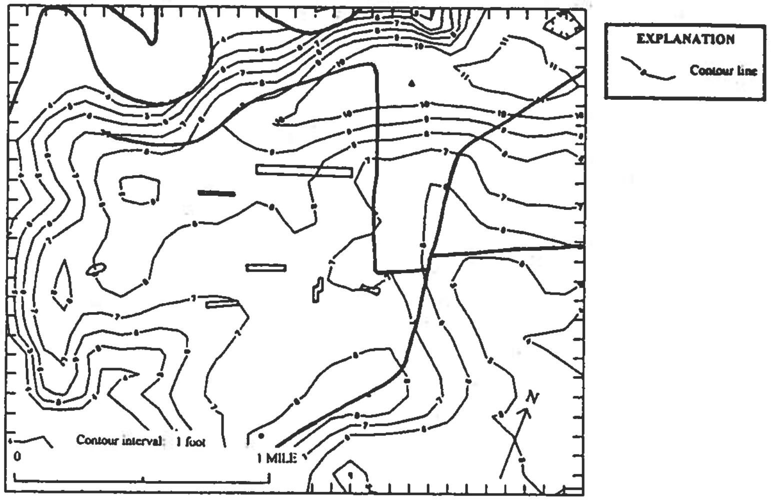
Aquifer heads after calibration period 2



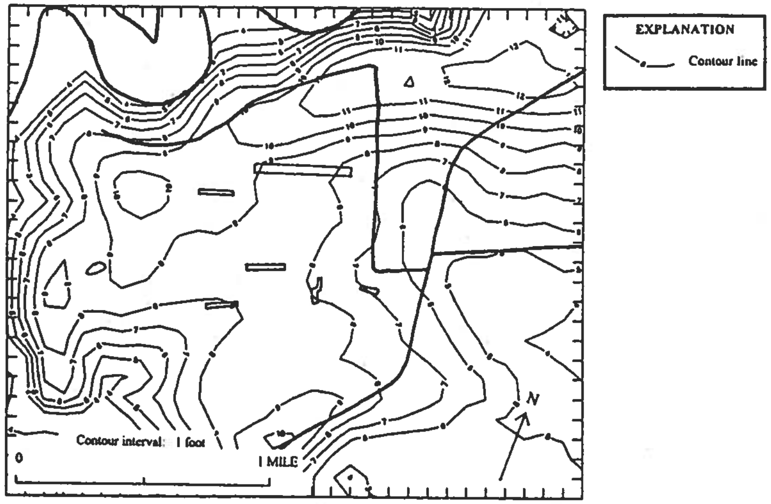
Aquifer heads after calibration period 3



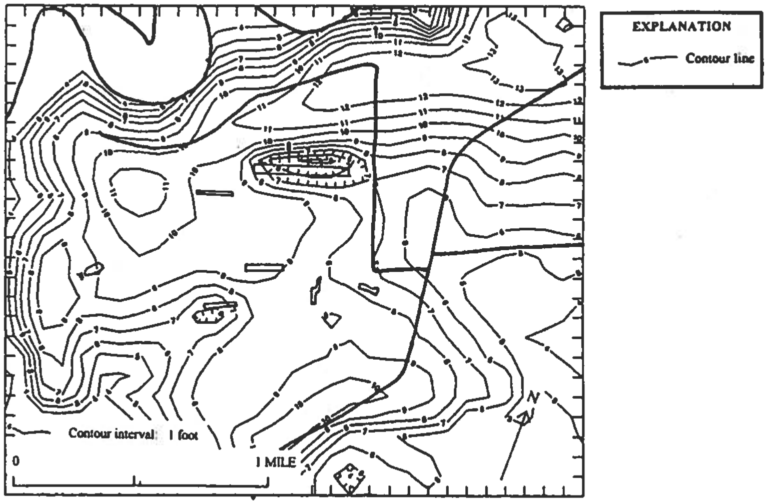
Aquifer heads after calibration period 4



Aquifer heads after calibration period 5



Aquifer heads after calibration period 6



Aquifer heads after calibration period 7