# HYDROGEOLOGY AND GROUND-WATER QUALITY NEAR A HAZARDOUS-WASTE LANDFILL NEAR PINEWOOD, SOUTH CAROLINA

By Don A. Vroblesky

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# HYDROGEOLOGY AND GROUND-WATER QUALITY NEAR A HAZARDOUS-WASTE LANDFILL NEAR PINEWOOD, SOUTH CAROLINA

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## ABSTRACT

The sediment immediately underlying the disposal area at a hazardous-waste landfill near Pinewood, South Carolina, is composed of fractured opaline claystone. If contaminants were released from the disposal areas into the opaline claystone, they would migrate downward to the Lang Syne water-bearing zone. Dissolved constituents would migrate laterally in the zone until discontinuities in the underlying or overlying confining units allowed discharge downward or upward, depending on head gradients. The direction of transport in the Lang Syne water-bearing zone depends on the area where such hypothetical contamination entered the zone; however, despite short-term variations in transport direction, the contaminants that remain mobile ultimately would migrate toward Lake Marion. The rate of such transport would be slow (less than 2 feet per year) in the Lang Syne water-bearing zone and faster (2-64 feet per year) in the underlying lower Sawdust Landing water-bearing zone.

Dense organic compounds, if released to the claystone, would migrate downward to the Lang Syne water-bearing zone. Transport direction would then be controlled by the slope of the underlying confining unit and probably would be approximately eastward.

Elevated concentrations of iron, sulfate, and manganese are found in a well downgradient from the landfill screened in both the surficial aquifer and the Lang Syne water-bearing zone. The elevated concentrations are caused by rainwater leaching through the stockpiles of excavated opaline-claystone sediments. Cadmium, chromium, and lead also were detected in the ground water downgradient from the landfill, but inconsistencies in the results imply the possibility of analytical error. The leaching of cadmium and chromium from the stainless-steel casing of the well also could be a contributing factor. Elevated concentrations of iron also are found in the Peedee aquifer and are due to natural causes.

The sediments previously described as part of the Black Creek aquifer of the landfill are now known to be from the overlying Peedee Formation and are designated the Peedee aquifer in this report. The Black Creek aquifer, which provides part of the water supply for Sumter, Manning, and Summerton, is deeper at the landfill than previously thought. The Lang Syne-Sawdust Landing aquifer is further divided into the Lang Syne, the upper Sawdust Landing, and the lower Sawdust Landing water-bearing zones, listed in descending order.

# INTRODUCTION

A landfill near Pinewood, S.C., is one of two landfills in the southeastern United States permitted by State and Federal agencies to accept hazardous waste. Since 1977, approximately one billion pounds of ignitable, corrosive, acutely hazardous, reactive, and toxic wastes have been buried at the 279-acre site. Although a considerable amount of hydrogeologic information has been collected in the site boundaries by the site operator, little information is known regarding the relation between the site-specific hydrogeology and the regional hydrogeologic framework. The landfill is located approximately 1,200 ft from Lake Marion; South Carolina's largest reservoir. The potential for contamination of ground water and surface water by possible leakage from the site is an issue of public concern. The regional extent of aquifers, the directions of ground-water flow, and the interaction between ground water and surface water are major factors affecting potential contaminant migration in the vicinity of the landfill. To address the above concern, the U.S. Geological Survey (USGS) in cooperation with the South Carolina Public Service Authority investigated the hydrogeology, streamflow, and sediment quality in the vicinity of the landfill during the period 1987-90.

## Purpose and Scope

The purpose of this report is to describe the hydrogeologic characteristics and the ground-water quality of the area in and surrounding a hazardous-waste landfill near Pinewood, S.C., referred hereafter as the facility. Specific aspects include discussions of the directions and rates of ground-water flow and the probable pathways of contaminant movement in the event of contaminant discharge to the ground water.

The results presented in this report are based, in part, on information collected from five observation-well clusters that were installed within a few miles of the facility as part of this investigation. The information from these wells was used in conjunction with geologic and water-level data from 23 wells screened in the Black Creek aquifer within an approximate 24-mile radius of the facility to define the hydrogeology in the area. Information on the ground-water chemistry was collected during 1988-90 from the observation wells installed during this investigation. Information, collected by the site operator from several wells within the facility, was used in conjunction with data collected during this investigation to determine the hydraulic properties of the aquifers underlying the facility and the directions and rates of regional ground-water flow.

## Previous Investigations

There have been a number of subsurface investigations at the facility. During the period 1972-78, about 20 exploratory borings were made to evaluate the economic potential of the site for extraction of "Fuller's earth", or opaline claystone (Environmental Technology Engineering, Inc., 1988a). Several in-depth investigations at the site have provided hydrogeologic and geologic data needed for design and installation of the landfill. The investigation by Wehran Engineering (1978) included seven deep exploratory borings, the excavation of 32-exploratory test pits, and the installation of several piezometers. Additional borings were made and additional piezometers were installed in later years (Wehran Engineering, 1982; Environmental Technology Engineering, Inc., 1988a; 1989). In addition, hydrogeologic assessments were conducted by Aware Inc. (1985a, 1985b), Waddell (1988), and Gordon and Powell (1989). Site-specific studies are ongoing to further characterize the hydrogeology at the facility.

## Well-Numbering System

Wells drilled by the U.S. Geological Survey as a part of this investigation are identified by informal names designed to allow a group of wells to be readily identified as belonging to the same well cluster. For example, wells Rimini-1A, Rimini-1B, Rimini-1C, Rimini-1D, and Rimini-1E are screened at different depths but located near each other and near the town of Rimini. The number and letter suffix identifies the relative depth of the screen: Rimini-1A is the deepest well, and Rimini-1E is the shallowest well. Additional informal names used to identify drilling sites are the Manchester-1 well site, the Railway-1 well site, the Lake Marion-1 well site, and the Lake Marion-2 well site (plate 1).

In addition to the informal names, wells outside the facility are identified using a county sequential system in which the letter prefix refers to the county and the number refers to the chronological order in which wells were recorded (scheduled) in that county. For example, well SU-302 is the 302d well scheduled in Sumter County. Similarly, the prefix CLA denotes a well in Clarendon County, and the prefix CAL denotes one in Calhoun County.

Observation wells within the facility are identified with the number assigned by the engineering firms that installed the wells. The well-numbering system consists of an alphanumeric identification code followed by a sequential number. The alphanumeric identification code identifies the well by function or by screened horizon. For example, well SL-10 refers to well 10 in the Sawdust Landing water-bearing zone. PSDL and SL are other prefixes assigned to wells in the Sawdust Landing water-bearing zone. Similarly, wells with the prefixes UBC, PBC, LSUBC, and CBC designate wells screened in what was thought to be the Black Creek aquifer. The prefix WT was applied to wells screened in the water-table aquifer, and the prefix OC was applied to wells screened in the opaline-claystone confining unit. Modifications of the aquifer designations have been made as a result of subsequent studies. Thus, the well number does not necessarily indicate the water-bearing zone in which the well is screened.

## Acknowledgments

Special thanks are deserved by the operators of the facility for their cooperative attitude and providing water-level data and access to the facility. The author is especially indebted to Ms. Susan Rogers, of Environmental Technology Engineering, Inc., who provided water-level records for observation wells in the facility.

## DESCRIPTION OF STUDY AREA

The hazardous-waste landfill near Pinewood, S.C. is located approximately 2 miles northeast of the town of Rimini and 5 miles southeast of the town of Pinewood. The area of investigation is in the central part of South Carolina, mostly in Sumter County, also includes parts of Richland, Calhoun, and Clarendon Counties that border the Congaree, Wateree, and Santee Rivers near the facility (fig. 1). The bulk of the data collected during this investigation, however, was collected within a few miles of the facility (area delineated in fig. 1 as the "area of detail map").

The study area is located in the Coastal Plain physiographic province, in which the geology consists of a seaward-thickening wedge of sand, clay, and limestone (Colquhoun and others, 1983). The topography in this upland Coastal Plain area is characterized by gently undulating relief of 25 to 50 ft. The uplands contain low-gradient streams and several Carolina bays, which are shallow oval depressions as large as 2,000 ft across. A steep (10- to 20-percent grade) escarpment 70- to 80-ft high separates the uplands from the Santee River valley in the study area. The study area is underlain by late Cretaceous and younger sediments, which were deposited on a pre-Cretaceous basement of metamorphic and sedimentary rocks.

Several geologic units have been identified in the three-county area surrounding the facility (fig. 2). The deepest sediments investigated are from the Cretaceous Black Creek Group. Overlying the Black Creek Group is the Cretaceous Peedee Formation, formerly mapped within the facility as the Black Creek Formation (Environmental Technology Engineering, Inc., 1988a). Overlying the Peedee Formation are the Paleocene sediments of the Black Mingo Group, which are divided into the Williamsburg Formation and the Rhems Formation. Prowell (1990) showed that the Williamsburg Formation is represented by the Lang Syne Member and the Rhems Formation is represented by the Sawdust Landing Member in the study area. Prior to the biostratigraphic work by Prowell (1990), the Lang Syne Member was thought to be a member of the Rhems Formation (Muthig and Colquhoun, 1988; Colquhoun and others, 1983; Environmental Technology Engineering, Inc., 1988a). The shallowest sediments investigated are the upland fluvial deposits and the Santee alluvium, which are locally confined but function as water-table aquifers in much of the area. Correlation of the formations between the facility and areas approximately 13 miles southeast and approximately 10 miles northeast of the facility (figs. 3 and 4) demonstrates that the geologic units are laterally extensive.

## METHODS OF STUDY

Standard methods were used in this investigation to obtain hydrogeologic information. Specific methods used during observation-well installation and development, determination of aquifer and confining-unit properties and collection of water-level and ground-water-chemistry data are discussed in the following sections.

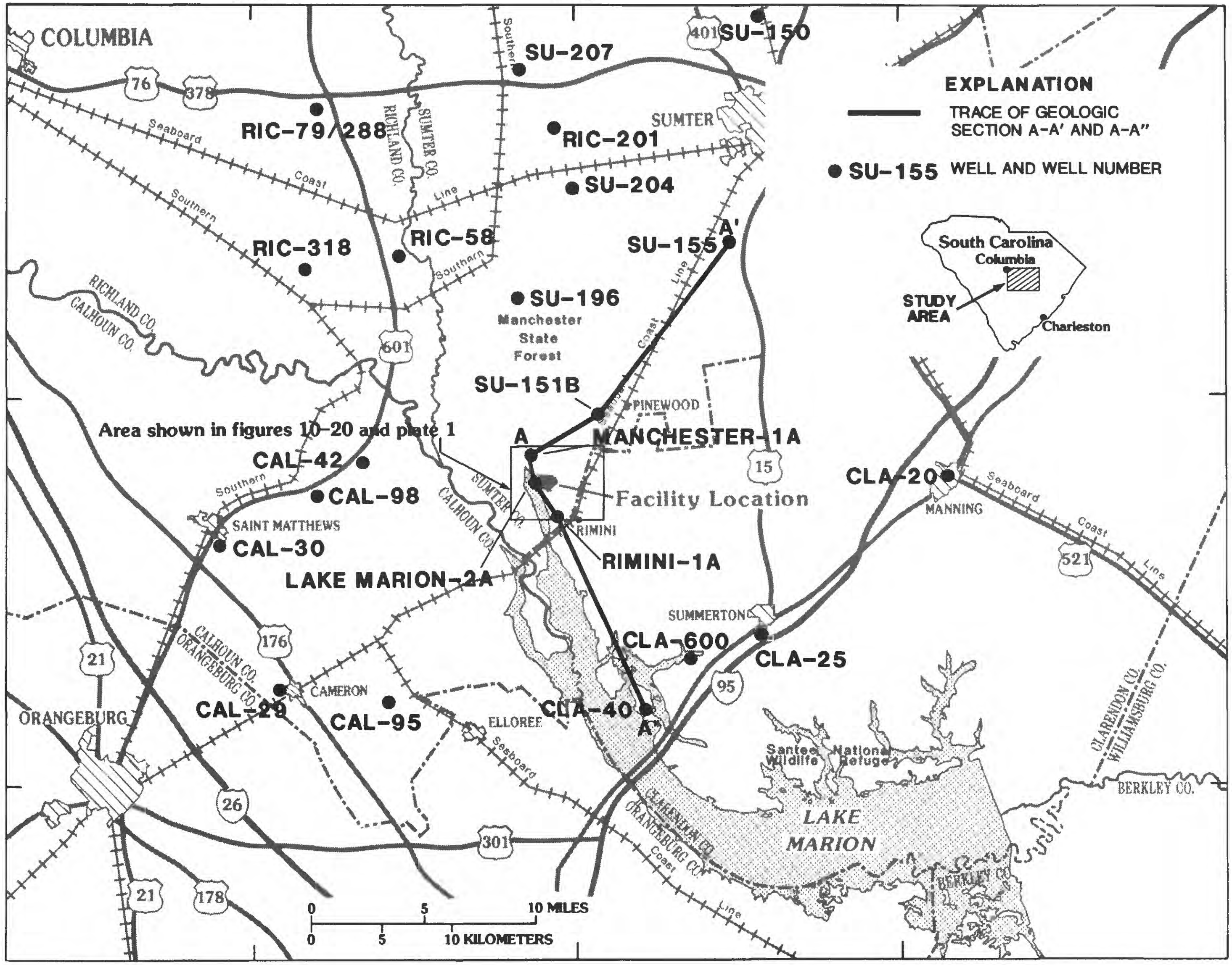


Figure 1.--Study area and location of observation wells and trace of geologic sections A-A' and A-A".

<table>
<tr><th rowspan="2">Geologic Series</th><th colspan="6">Geologic units used in previous investigations</th><th colspan="4">Hydrogeologic units</th></tr>
<tr><th colspan="2">Wehran Engineering (1982)</th><th colspan="2">Environmental Technology Engineering Inc. (1987)</th><th colspan="2">Prowell (1990) and this report</th><th colspan="2">Environmental Technology Engineering Inc. (1987)</th><th colspan="2">This report</th></tr>
<tr><td>Holocene</td><td colspan="2">---</td><td colspan="2">---</td><td colspan="2">Santee alluvium</td><td colspan="2" rowspan="3">Water-table aquifer</td><td colspan="2" rowspan="3">Surficial aquifer</td></tr>
<tr><td>Pleistocene to Pliocene</td><td colspan="2">Quaternary sediment</td><td colspan="2">Plio-Pleistocene sediment</td><td colspan="2">Upland fluvial deposits</td></tr>
<tr><td rowspan="7">Paleocene</td><td rowspan="3">Black Mingo Formation</td><td rowspan="3">Buhrstone unit<br>Red sand unit<br>Opal claystone unit<br>Basal clay unit</td><td rowspan="7">Black Mingo Group</td><td rowspan="3">Lang Syne-Member of the Rhems Formation</td><td rowspan="7">Black Mingo Group</td><td rowspan="3">Lang Syne-Member of the Williamsburg Formation</td></tr>
<tr><td colspan="2">Opaline-claystone unit</td><td colspan="2">Opaline-claystone confining unit</td></tr>
<tr><td colspan="2">Transitional Lang Syne water-bearing unit</td><td rowspan="5">Lang Syne-Sawdust Landing aquifer</td><td>Lang Syne water-bearing zone</td></tr>
<tr><td colspan="2" rowspan="9">Tuscaloosa/ Middendorf Formation</td><td rowspan="4">Sawdust Landing Member of the Rhems Formation</td><td rowspan="4">Sawdust Landing Member of the Rhems Formation</td><td colspan="2">Confining unit</td><td rowspan="3">Upper Sawdust Landing water-bearing zone</td></tr>
<tr><td colspan="2">Secondary Sawdust Landing water-bearing unit</td></tr>
<tr><td colspan="2">Confining unit</td></tr>
<tr><td colspan="2">Primary Sawdust Landing water-bearing unit</td><td>Lower Sawdust Landing water-bearing zone</td></tr>
<tr><td rowspan="6">Upper Cretaceous</td><td colspan="2" rowspan="4">Upper Black Creek Formation</td><td colspan="2" rowspan="4">Peedee Formation (upper part)</td><td colspan="2">Confining unit</td><td colspan="2">Peedee confining unit</td></tr>
<tr><td rowspan="3">Upper Black Creek aquifer</td><td>UBC-A</td><td colspan="2" rowspan="3">Peedee aquifer</td></tr>
<tr><td>Confining unit</td></tr>
<tr><td>UBC-B</td></tr>
<tr><td colspan="2">Lower Black Creek Formation</td><td colspan="2">Peedee Formation (lower part)</td><td colspan="2">Confining unit</td><td colspan="2">Black Creek confining unit</td></tr>
<tr><td colspan="2">Not investigated</td><td colspan="2">Not investigated</td><td colspan="2">Black Creek Group</td><td colspan="2">Not investigated</td><td colspan="2">Black Creek Aquifer</td></tr>
</table>

Figure 2.--The correlation between names of geologic and hydrogeologic names used in previous investigations and names units in this report.

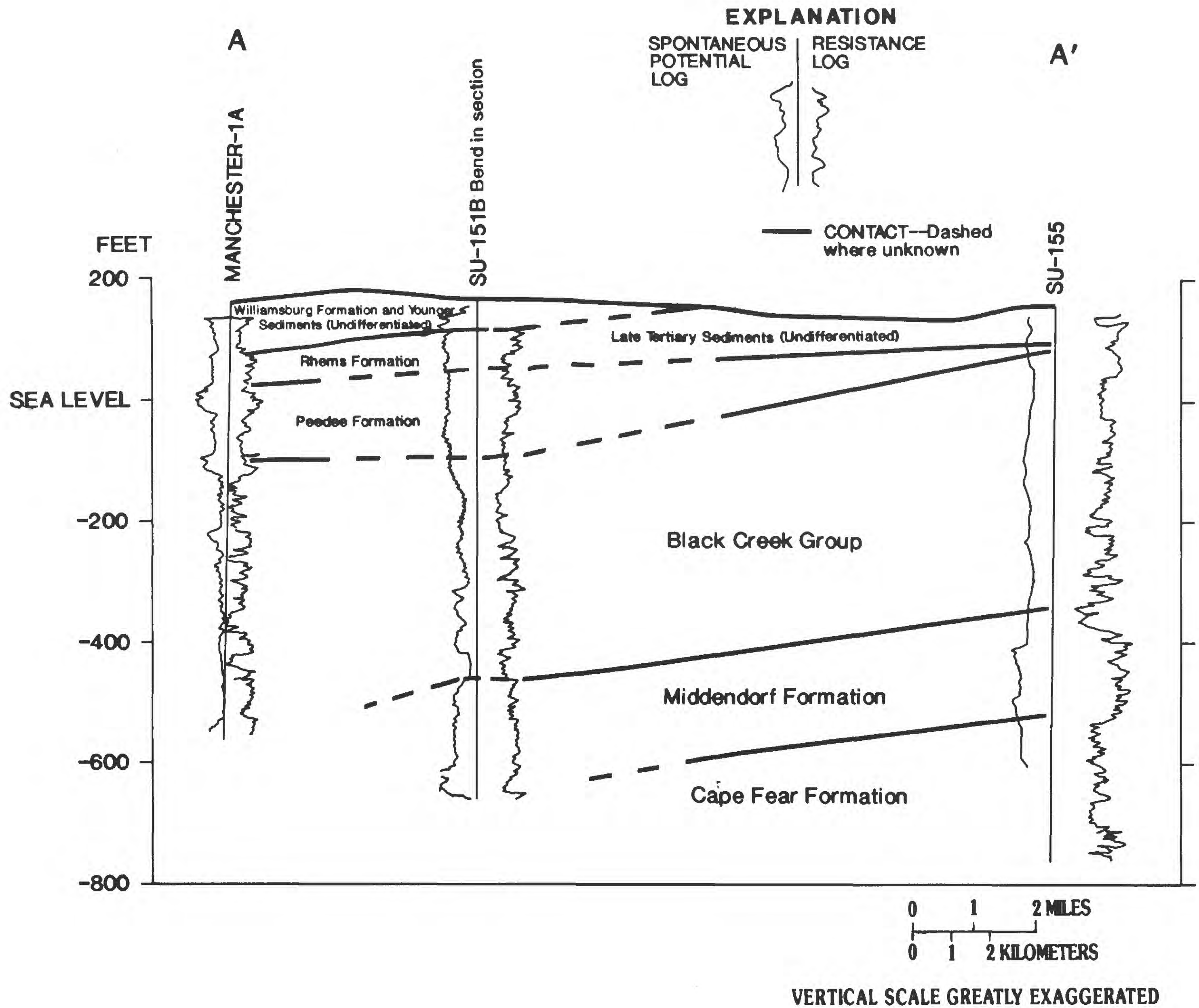


Figure 3.--Geologic section A-A′.

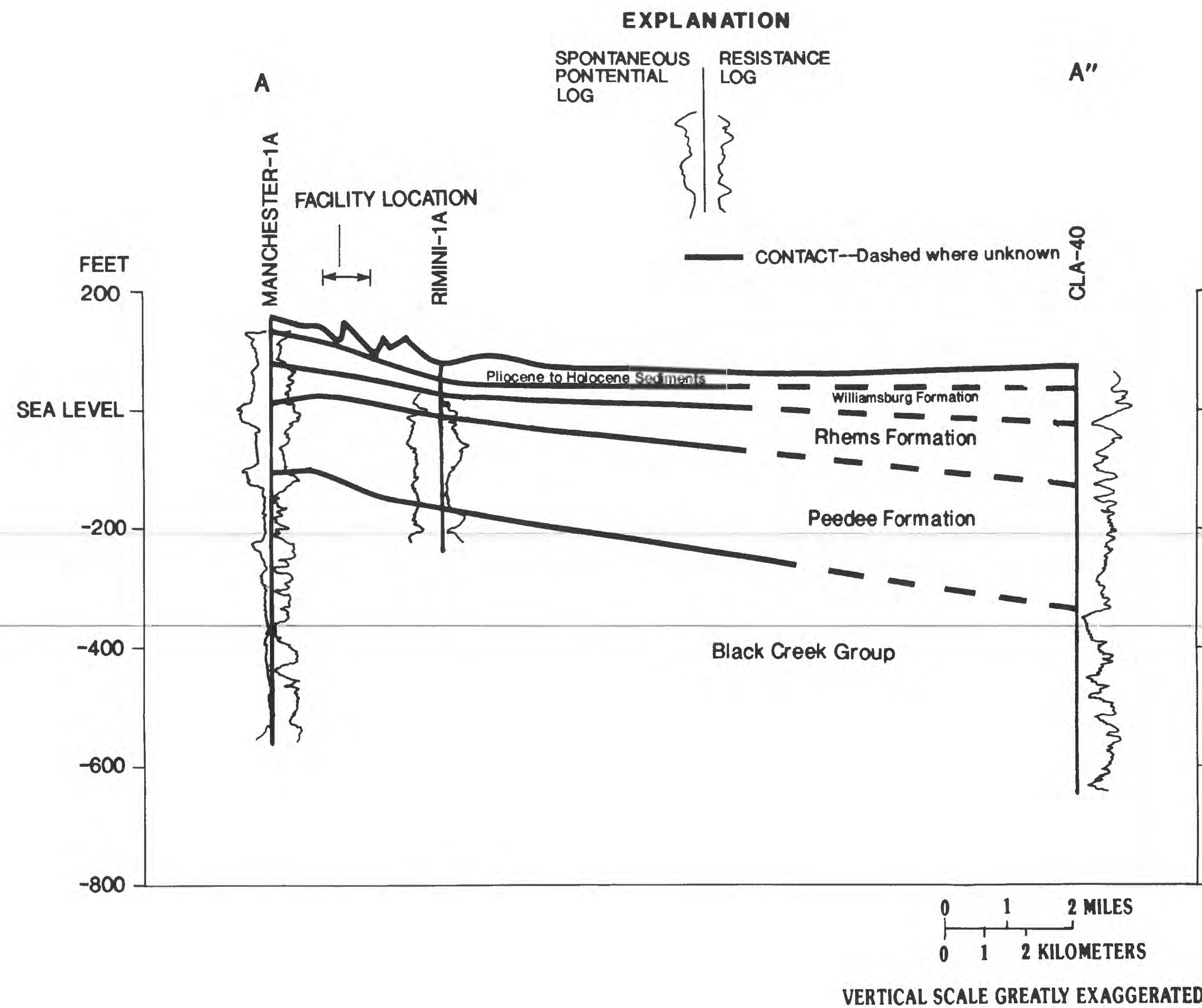


Figure 4.--Geologic section A-A″.

## Observation-Well Installation and Development

Five clusters of observation wells were installed near the facility by the USGS during this investigation. The locations of these well clusters, identified as the Manchester-1 well cluster, the Railway-1 well cluster, the Rimini-1 well cluster, the Lake Marion-1 well cluster, and the Lake Marion-2 well cluster are shown in plate 1. The observation wells were installed by one of two methods, depending on the depth of the well. The shallowest wells, Railway-1D; Rimini-1D and -1F; Lake Marion-1C and -1D; and Manchester-1D, -1E, and -1F, were installed by hollow-stem augering using no drilling mud. The remaining wells were installed with mud-rotary methods using bentonite mud. Core samples were collected during drilling of the deepest well at each site and analyzed in the laboratory for water content, dry density, specific gravity, porosity, and hydraulic conductivity. Geophysical logs were collected in the borehole prior to well installation.

Casings for the wells were constructed of polyvinyl chloride (PVC) or stainless steel, depending on location. Wells in the Lake Marion-1 and -2 well clusters, located between the landfill and the lake, were equipped with steam-cleaned stainless-steel casing. The rest of the wells were constructed of PVC casing.

Once the drilling mud was removed from the borehole, a tremie pipe was used to place fine-grained gravel (effective size of 0.05 in.) around the screen and to a level a few feet above the screen. Granular bentonite was placed above the gravel pack to seal the well screen from overlying units and to keep grout from interfering with the well screen. Bentonite pellets were used in place of granular bentonite in shallow wells. The thickness of the bentonite seal ranged from a few feet to tens of feet, depending on the specific site geology. Portland type-1 cement was used to grout the annular space from the top of the bentonite plug to the surface. The wells were developed by surging water through the well screens. Typical construction of wells installed by the USGS is shown in figure 5. General information regarding construction of each well is given in table 1.

## Determination of Aquifer and Confining-Unit Properties

Hydraulic conductivities of hydrogeologic units were determined by analyzing cored sediment in the laboratory and by conducting aquifer tests in the observation wells. A single-well aquifer pumping test was done in well Rimini-1B, slug tests were done in wells Lake Marion-1C, Lake Marion-2A, Railway-1B, and in a temporary water-table well at the Lake Marion-1 site, and permeameter measurements were made on various cores (R.A Burt, U.S. Geological Survey, written commun, 1986). Single-well pumping tests during a period of steady discharge are inferior to aquifer pumping tests where additional wells, screened in the pumped unit, are used for observation because the hydraulic characteristics of the pumped well can affect the drawdown observed in the well. The aquifer storage coefficient and leakage terms, therefore, cannot be evaluated; however, estimates of the transmissivity and hydraulic conductivity can be obtained. Permeameter tests are laboratory tests made on core samples collected during drilling. The aquifer tests were analyzed by Robert E. Faye (U.S. Geological Survey, written commun., 1991).

NOT TO SCALE

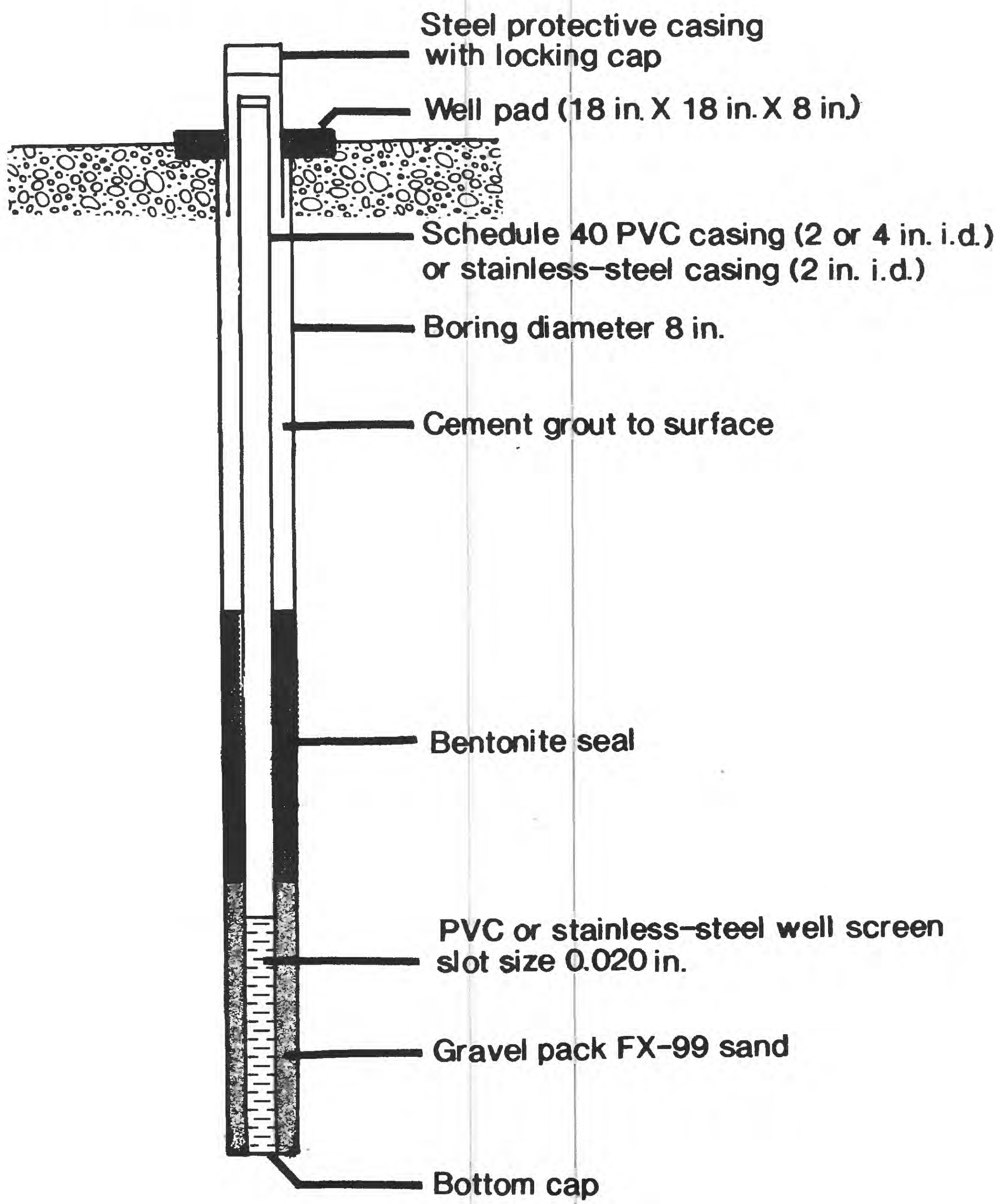


Figure 5.--General construction of wells installed by the U.S. Geological Survey for this investigation.

Table 1.--General construction information for wells installed by the U.S. Geological Survey

[S, surficial aquifer; LS, Lang Syne water-bearing zone of the Lang Syne-Sawdust Landing aquifer; USDL, upper Sawdust Landing water-bearing zone of the Lang Syne-Sawdust Landing aquifer; LSDL, lower water-bearing zone of the Lang Syne-Sawdust Landing aquifer; PD, Peedee aquifer; BC, Black Creek aquifer; --, data not available]

| Well number | County well number | Altitude (feet) | Latitude | Longitude | Screen depth (feet) | | Sand/gravel-pack depth (feet) | | Aquifer |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | From | To | From | To | |
| Lake Marion-1A | SU-290 | 84.17 | 33°40'43''N | 08°31'22''W | 122 | 127 | 71 | 142 | PD |
| Lake Marion-1B | SU-291 | -- | 33°40'43''N | 08°03'12''2W | 59.3 | 64.3 | 45 | 64.3 | LSDL |
| Lake Marion-1C | SU-292 | 85.42 | 33°40'43''N | 08°03'12''2W | 20.5 | 25.5 | 20 | 25.5 | LS |
| Lake Marion-1D | SU-293 | 84.80 | 33°40'43''N | 08°03'12''2W | 60.5 | 65.5 | 55 | 65.5 | LSDL |
| Lake Marion-2A | SU-294 | 82.83 | 33°41'30''N | 08°03'13''2W | 50 | 55 | 49 | 59 | LSDL |
| Lake Marion-2B | SU-295 | 82.64 | 33°41'30''N | 08°03'13''2W | 14.5 | 19.5 | 14 | 19.5 | S/LS |
| Manchester-1A | SU-296 | 170.68 | 33°42'38''N | 08°03'15''6W | 285 | 295 | 203 | 725 | BC |
| Manchester-1A | SU-296 | 170.68 | 33°42'38''N | 08°03'15''6W | 395 | 405 | -- | -- | -- |
| Manchester-1A | SU-296 | 170.68 | 33°42'38''N | 08°03'15''6W | 575 | 585 | -- | -- | -- |
| Manchester-1A | SU-296 | 170.68 | 33°42'38''N | 08°03'15''6W | 660 | 680 | -- | -- | -- |
| Manchester-1B | SU-297 | 170.64 | 33°42'38''N | 08°03'15''6W | 159 | 189 | 159 | 189 | PD |
| Manchester-1C | SU-298 | 171.04 | 33°42'38''N | 08°03'15''6W | 119 | 129 | 117 | 129 | LSDL |
| Manchester-1D | SU-299 | 171.19 | 33°42'38''N | 08°03'15''6W | 94 | 104 | 93 | 104 | USDL |
| Manchester-1E | SU-300 | 171.03 | 33°42'38''N | 08°03'15''6W | 72 | 82 | 65 | 82 | LS |
| Manchester-1F | SU-301 | 170.98 | 33°42'38''N | 08°03'15''6W | 25 | 30 | 22 | 30 | S |
| Rimini-1A | SU-302 | 81.90 | 33°40'20''N | 08°03'15''7W | 252 | 262 | 189 | 280 | BC |
| Rimini-1B | SU-303 | 81.86 | 33°40'20''N | 08°03'15''7W | 129 | 139 | 100 | 149 | PD |
| Rimini-1C | SU-304 | 82.30 | 33°40'20''N | 08°03'15''7W | 80 | 90 | 70 | 90 | LSDL |
| Rimini-1D | SU-305 | 82.18 | 33°40'20''N | 08°03'15''7W | 44 | 54 | 34 | 54 | USDL |
| Rimini-1E | SU-306 | 82.43 | 33°40'20''N | 08°03'15''7W | 31 | 37 | 25 | 37 | S |
| Railway-1A | SU-316 | 166.90 | 33°41'29''N | 08°02'93''4W | 190 | 220 | 187 | 220 | PD |
| Railway-1B | SU-317 | 166.91 | 33°41'29''N | 08°02'93''4W | 159 | 161.5 | 159 | 161.5 | LSDL |
| Railway-1C | SU-318 | 166.80 | 33°41'29''N | 08°02'93''4W | 149 | 159 | 146 | 159 | LS |
| Railway-1D | SU-319 | 166.58 | 33°41'29''N | 08°02'93''4W | 20 | 30 | 19 | 30 | S |

## Water-Level Measurements

Water-level measurements were obtained on a monthly basis from all of the observation wells installed during this investigation. The period of record differs among the sites because the wells were installed over a period of about 2 years. The longest period of record is from November 1987 to September 1990 for wells Rimini-1C, -1D, and -1E, and Lake Marion-1A. The shortest period of record is from July 1989 to September 1990 for well Railway-1C. In addition, monthly measurements by Environmental Technology Engineering, Inc. (Susan Rogers, Environmental Technology Engineering, Inc., written commun., 1990) of ground-water levels at selected wells in the facility were incorporated into the data base.

The altitudes of measuring points at all of the wells installed during this investigation were determined by first-order leveling. The altitudes of the selected wells within the facility, which were incorporated into the data base, were remeasured by the USGS using first-order leveling to the same datum as the USGS wells. At observation wells in the facility where the USGS-determined-measuring-point altitude differed slightly from the reported value, the reported water-level altitudes were adjusted to allow more direct comparison to water levels obtained from the USGS wells.

Water-level measurements from the USGS wells were obtained using a weighted steel tape. Flowing artesian wells were measured by attaching a transparent plastic pipe to the top of the well and allowing the water level to rise within the pipe until it stabilized. The water level was then measured using a steel tape along the outside of the transparent pipe.

The potentiometric maps shown in this report were largely constructed from observation-well data in the immediate vicinity of the facility. Data for the Black Creek aquifer, however, were too sparse near the facility to allow adequate analysis of ground-water movement. To determine the direction of ground-water movement in the Black Creek aquifer near the facility, water levels in the aquifer were measured in Sumter, Calhoun, and Clarendon Counties. Wells listed in published documents as being screened in the Black Creek aquifer, but determined during this investigation to actually be screened in the overlying Peedee aquifer or underlying Middendorf aquifer, were not used in this analysis. The two wells used in Calhoun County are irrigation wells that are gravel packed from the screened interval to near land surface; however, geophysical logs of the wells indicate that the formation overlying the Black Creek aquifer are less permeable than the sand in the Black Creek aquifer. Water levels in those wells would be expected to equilibrate to heads in the Black Creek aquifer faster than they are affected by infiltrating water from overlying layers. Thus, water levels in the wells should closely approximate those in the Black Creek aquifer.

## Ground-Water Sample Collection

All observation wells were purged of casing water prior to collecting a water sample for chemical analysis. Generally, two to four well volumes of water were purged from each well, except for wells that were bailed dry after removing less than two well volumes. For pumping, as well as for sampling, the water was removed from the wells by using either an all-Teflon[1] point-source bailer or a helical-rotor submersible pump. Samples for water quality were collected after the water level in the well recovered. In most instances, samples were collected on the same day that the wells were purged, but for wells that recovered slowly, the samples were collected the next day.

Bailers used for ground-water sampling were decontaminated between wells by rinsing three or more times with distilled water. Decontaminating the helical-rotor pump consisted of rinsing the outside of the pump and discharge tubing at least three times with distilled water and pumping approximately 1 liter of distilled water through the system.

Samples were filtered and preserved in the field at the time of collection. Samples for analysis of all inorganic chemical constituents, except sulfide, were filtered through $1.95 \times 10^{-5}$-in. (0.45 micron) membrane filters using a peristaltic pump. Before beginning sample collection at a well, the filter stands and silicon tubing used with the peristaltic pumps were rinsed thoroughly with distilled water and well water. Samples for major cations and metals were preserved with nitric acid. Nutrient samples were preserved with a mixture of mercuric dichloride and sodium chloride and chilled to 4 $^{0}$C (degrees Celsius). Sulfide samples were preserved with zinc acetate. Samples for analyses of anions and laboratory measurement of pH, alkalinity, and specific conductance were chilled to 4 $^{0}$C.

The samples for organic compound and sulfide concentrations were transferred directly from the sampling device into the appropriate bottles to avoid aeration of the samples. Samples for volatile organics were the first samples collected following well recovery. Special care was taken collecting the samples for analyses of volatile organic compounds (VOC) and sulfide to prevent aeration of the sample. For VOC's, two 40-ml vials were filled at each well with a slow, steady stream of water and allowed to overflow several times. When a bailer was used, a bottom-discharge device was attached to obtain a slow stream of water. The glass vials immediately were sealed with Teflon-septa caps and checked for bubbles. If the vials contained bubbles, the vials were emptied and refilled. Samples for analysis of total organic carbon and base-neutral-acid (BNA) organic compounds were collected in amber glass bottles.

All water samples were immediately placed on ice in coolers. At the end of each day or the next day, the samples were packed in the coolers and sent by overnight mail to the U.S. Geological Survey laboratory for analysis.

Dissolved oxygen, temperature, specific conductance, pH, and alkalinity were measured in the field. After well purging, the dissolved-oxygen

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[1]Use of brand, firm, or trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

concentration in water in each well was determined by titration. Temperature, pH, and specific conductance were measured immediately after collection of unfiltered well water in glass beakers.

Water temperature was measured with a mercury-filled glass thermometer marked in increments of 0.1 °C. The pH was read on a digital pH meter equipped with a combination pH electrode and an automatic temperature-compensator probe. The meter was calibrated with pH 4.00 and 7.00 buffers prior to collection of samples. If the pH of the sample was greater than 7.00, the meter was recalibrated with pH 7.00 and 10.00 buffers and the pH was reread on a fresh sample. Specific conductance was measured with a Yellow Springs Instrument[1] model 33 SCT meter.

Alkalinity titrations were done on a 100-ml filtered sample. The sample was stirred slowly, using a battery-powered magnetic stirrer while a Hach[1] Digital Titrator was used to add 0.16 normal sulfuric acid ($H_2SO_4$) solution to the sample until a pH endpoint of 4.5 was reached. Alkalinity was calculated as the endpoint of the cumulative volume of added acid as a function of pH.

The pH meters were calibrated prior to sampling and several times each day during sampling. The conductivity meters were calibrated by the manufacturer, but periodic checks were performed with standards to ensure continued calibration.

For quality control and assurance, split samples were collected on at least 10 percent of the total number of wells sampled. Split samples not showing analytical agreement were reanalyzed when possible.

Analyses of ground-water samples for organic compounds were done for wells Lake Marion-1A, -1C, and -1D and Lake Marion-2A and -2B. The constituents examined and their detection limits are listed in table 2.

## HYDROGEOLOGY

The geologic units are divided into hydrogeologic units (fig. 2) on the basis of lithologic and hydrologic characteristics. The hydrogeologic units investigated in the study area are, from shallowest to deepest, the surficial aquifer, the opaline-claystone confining unit, the Lang Syne-Sawdust Landing aquifer, the Peedee confining unit, the Peedee aquifer, the Black Creek confining unit, and the Black Creek aquifer. The Lang Syne-Sawdust Landing aquifer is further divided into the Lang Syne water-bearing zone, the upper (or secondary) Sawdust Landing water-bearing zone, and the lower (or primary) Sawdust Landing water-bearing zone, again listed from shallowest to deepest. Cross-sectional relations of the hydrogeologic units are shown in figures 6, 7, and 8.

Comparisons of water levels measured in the wells installed during this investigation show a downward hydraulic potential among the aquifers in inland areas and an upward hydraulic potential near Lake Marion (fig. 9). At the farthest inland site, the Railway-1 well site, water levels are highest in the surficial aquifer, approximately 55 ft lower in the Lang

Table 2.--Detection limits of organic compounds analyzed during this study

[μg/L = micrograms per liter]

| Constituent | Detection limit (μg/L) | Constituent | Detection limit (μg/L) |
|---|---|---|---|
| 4-Nitrophenol | 30 | Bis(2-chloroethyoxy) Methane | 5 |
| 4,6-Dinitro-ortho-cresol | 30 | Nitrobenzene | 5 |
| Parachlorometacresol | 30 | Hexachlorobutadiene | 5 |
| Pentachlorophenol | 30 | Hexachlorocyclo-pentadiene | 5 |
| 2,4-Dinitrophenol | 20 | Anthracene | 5 |
| 2,4,6-Trichlorophenol | 20 | 1,-2,-4,Trichlorobenzene | 5 |
| Di-N-Octylphthalate | 10 | Hexachlorobenzene | 5 |
| Benzo(a)pyrene | 10 | Phenol | 5 |
| Indeno | 10 | Cis 1,3-Dichloropropane | 3 |
| Benzoperylene | 10 | Toluene | 3 |
| Benzo B Fluoranthene | 10 | Vinyl chloride | 3 |
| Benzo K Fluoranthene | 10 | 1,2-Di-chloropropane | 3 |
| 1,2,5,6 Dibenzo anthracene | 10 | 1,3-Dichloropropane | 3 |
| 4-Bromophenyl phenyl ether | 5 | Chlorodibromomethane | 3 |
| 4-Chlorophenyl phenyl ether | 5 | Dichlorofluoromethane | 3 |
| Pyrene | 5 | Trichlorofluoromethane | 3 |
| 2,4-Dinitrotoluene | 5 | Methyl bromide | 3 |
| 2,6-Dinitrotoluene | 5 | Methyl chloride | 3 |
| 2,4-Dimethyl phenol | 5 | Methylene chloride | 3 |
| Isophorene | 5 | 2 Chloroethylvinyl ether | 3 |
| N-Butyl Benzyl Phthalate | 5 | 1,1-Dichloroethlyene | 3 |
| Di-N-Butyl Phthalate | 5 | 1,2 Transdichloroethane | 3 |
| 2-Chloronaphthalene | 5 | Trichloroethylene | 3 |
| Acenaphthene | 5 | Tetrachloroethylene | 3 |
| Acenaphthylene | 5 | Bromoform | 3 |
| Phenanthrene | 5 | Carbon tetrachloride | 3 |
| 2,Chlorophenol | 5 | Chloroform | 3 |
| 2-Nitrophenol | 5 | Benzene | 3 |
| Fluorene | 5 | Chlorobenzene | 3 |
| Fluoranthene | 5 | Xylene, total | 3 |
| 1,3-Dichlorobenzene | 3 | DDT | .01 |
| 1,4-Dichlorobenzene | 3 | Dieldrin | .01 |
| Ethyl Benzene | 3 | Endosulfane | .01 |
| Toxaphene | 1 | Endrin | .01 |
| Perthane | .1 | Heptachlor | .01 |
| Chlordane | .1 | Heptachloroxide | .01 |
| PCB | .1 | Lindane | .01 |
| Naphthalene | .1 | Methyoxychlor | .01 |
| Aldrin | .01 | Mirex | .01 |
| DDD | .01 | DDE | .01 |

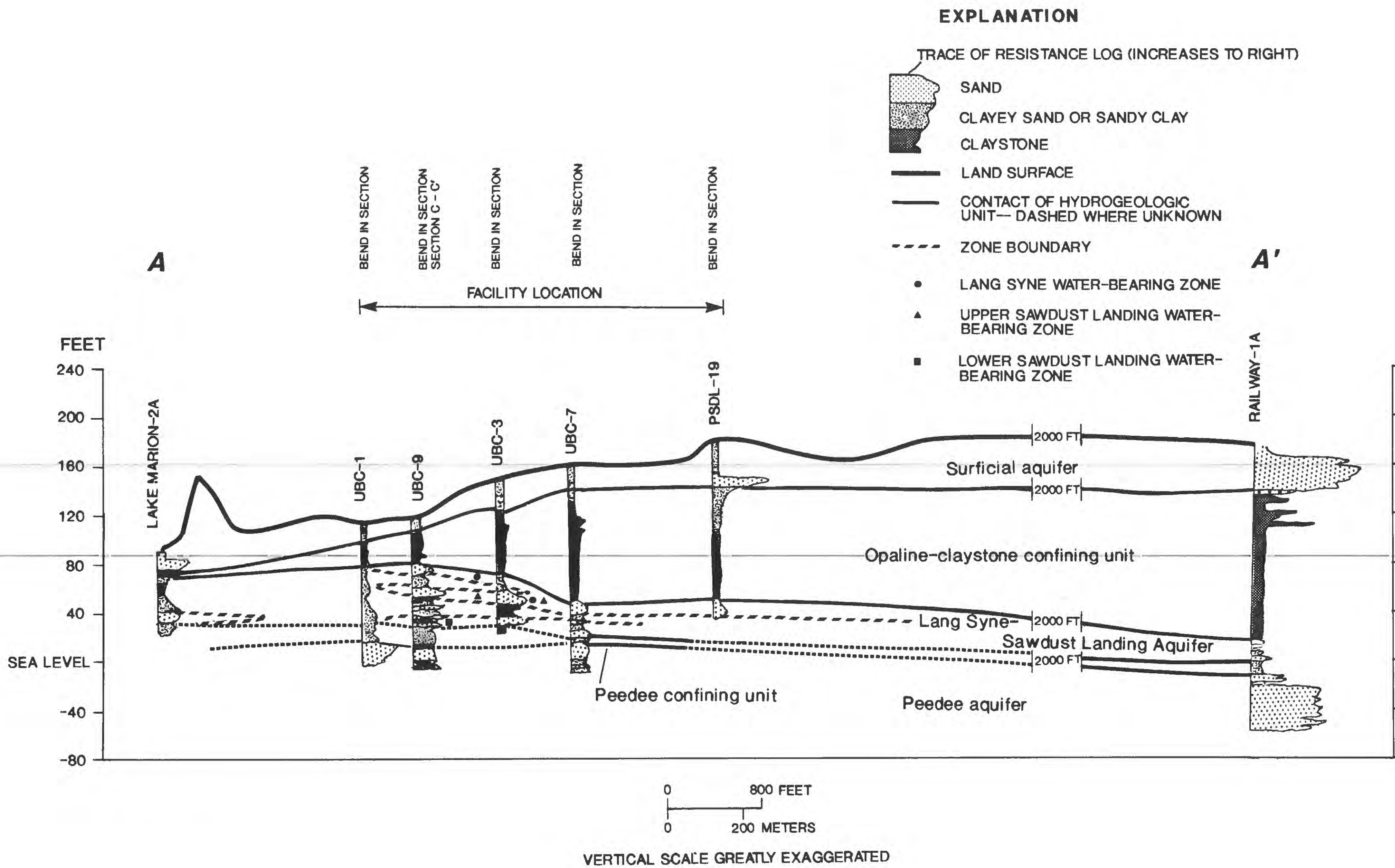


Figure 6.--Hydrogeologic section A-A'.

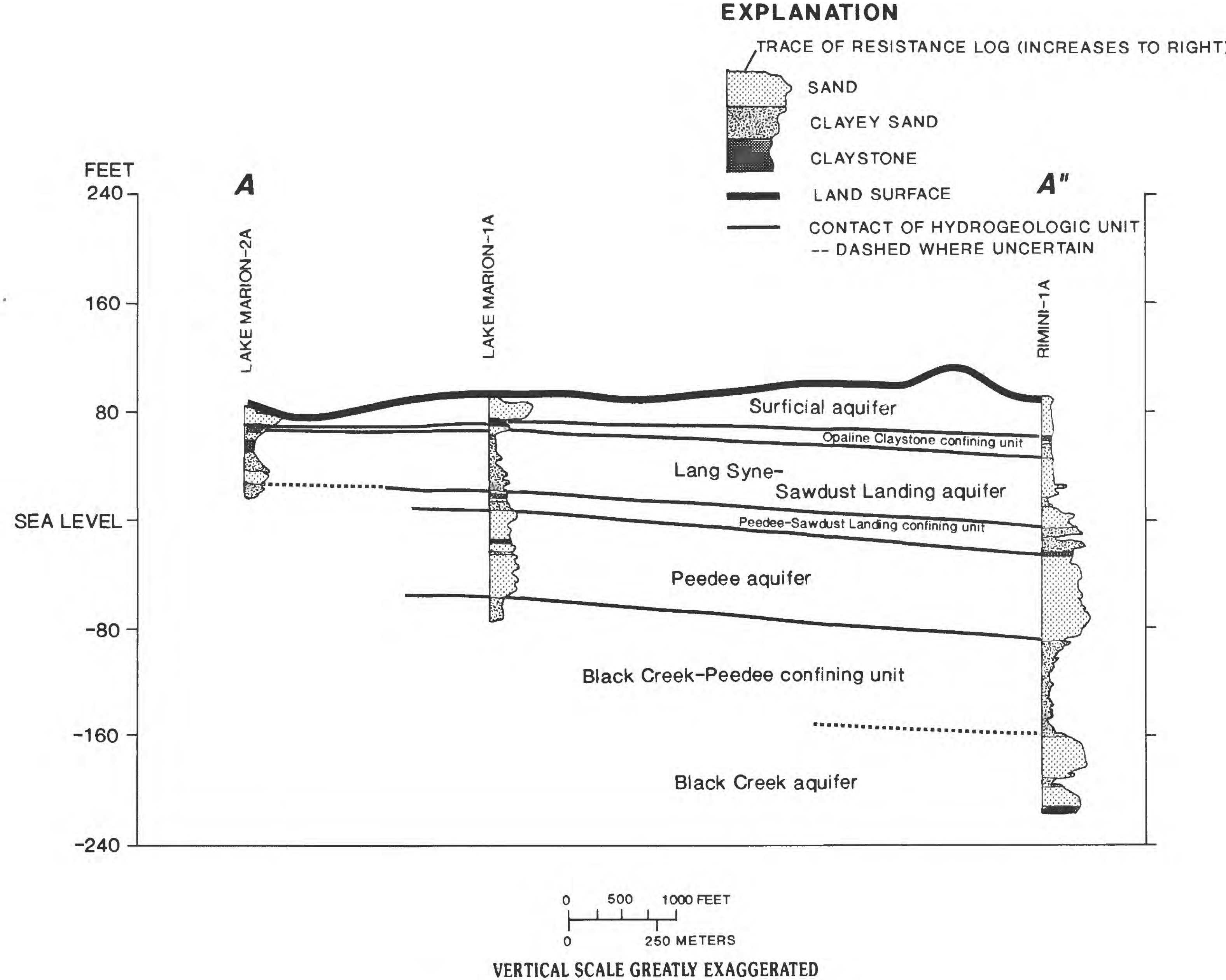


Figure 7.--Hydrogeologic section A-A''.

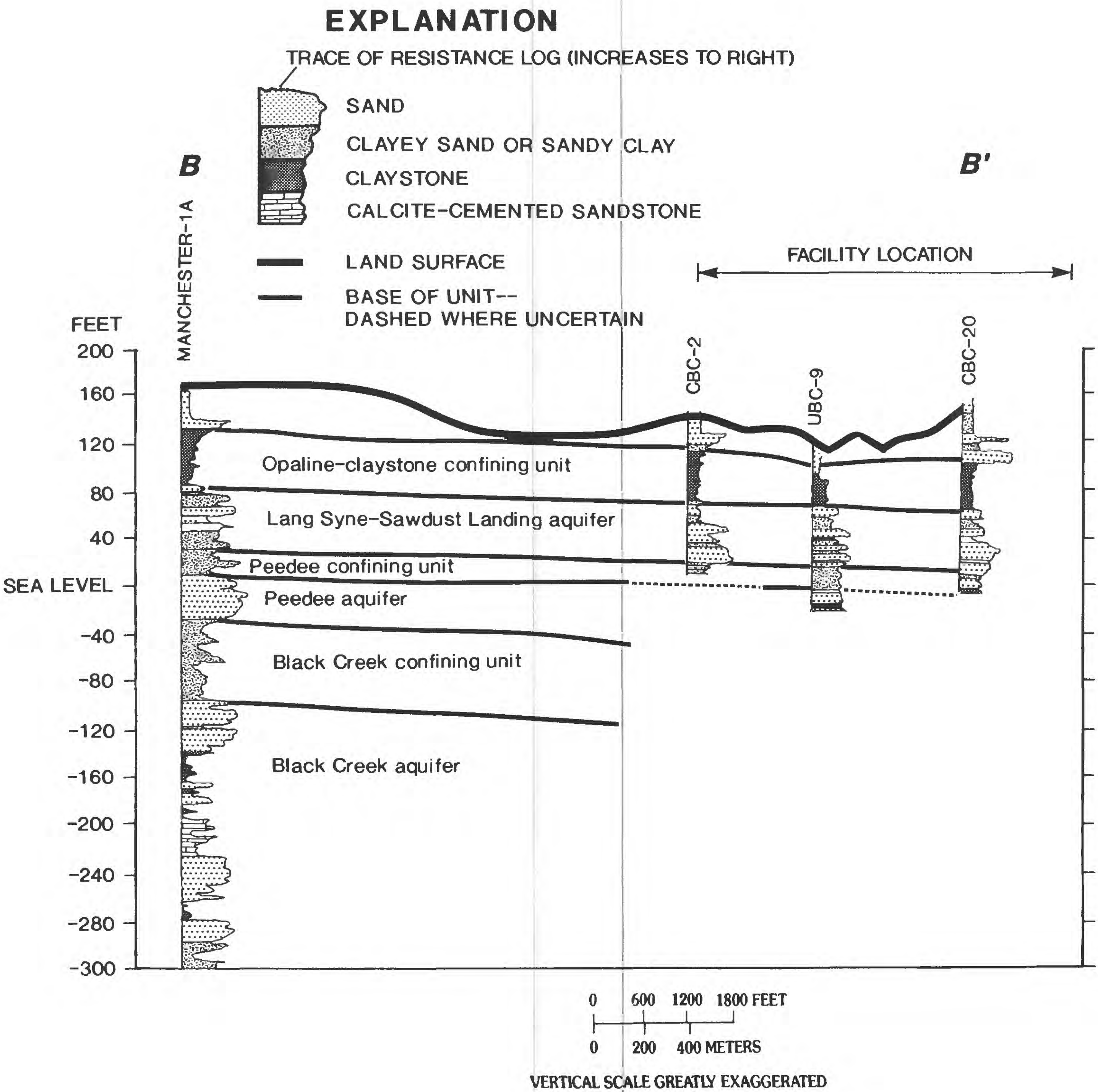


Figure 8.--Hydrogeologic section B-B'.

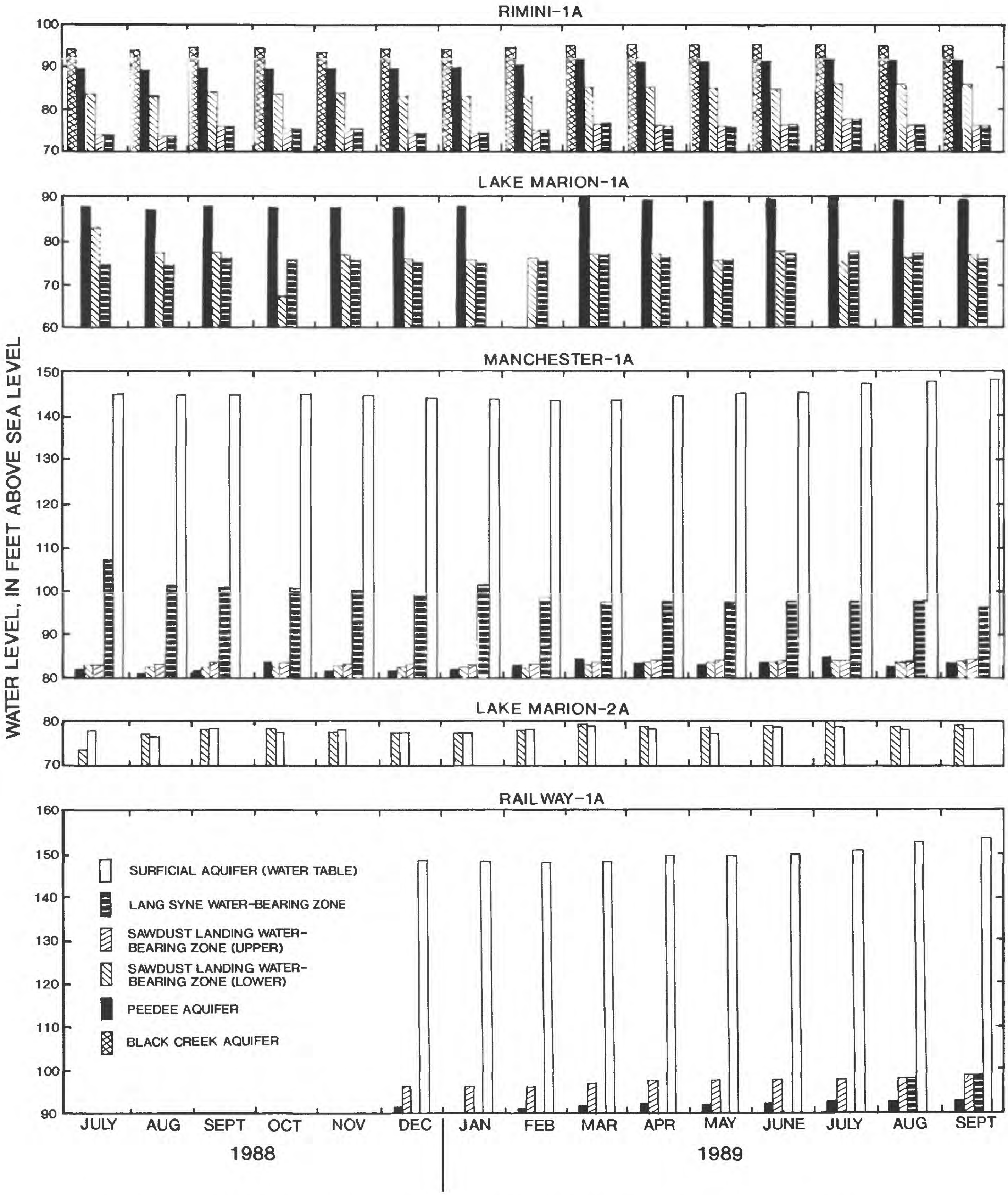


Figure 9.--Histogram plots showing water levels in the various aquifers at observation well clusters, July 1988 to September 1989.

Syne-Sawdust Landing aquifer, and lowest in the Peedee aquifer. The trend is reversed near the lake at the Rimini-1 and Lake Marion-1 well sites, where the lowest water levels are found in the Lang Syne water-bearing zone, with successively higher water levels in the lower Sawdust Landing water-bearing zone and the Peedee aquifer, respectively. At the Rimini-1 well site, the highest water level occurred in the deepest aquifer investigated, the Black Creek aquifer.

Characteristics of the individual aquifers and confining units are discussed in the following sections. More detailed descriptions of the lithologic logs and well-construction data, the physical properties of core samples, and chemical analyses of ground water are shown in appendixes A, B, and C, respectively. Hydrographs of wells in each of the aquifers are shown in appendix D.

## Surficial Aquifer

The surficial aquifer is the shallowest water-bearing subsurface unit in the study area and includes sediments from the upland fluvial deposits, the Santee alluvium, and, possibly, sandy sequences from the upper part of the Lang Syne Member of the Williamsburg Formation. The upland fluvial deposits are equivalents of the "Plio-Pleistocene sediments" described by Environmental Technology Engineering, Inc. (1988a) in the facility and the Cohaire Formation as mapped by Cooke (1936).

The upland fluvial deposits encountered at the Manchester-1 and Railway-1 well sites are composed of clayey sand that varies in color, clay content, and mineralogy with depth. The sand is fine to very coarse grained, poorly sorted and angular and becomes increasingly clayey with depth. Other minerals include mica, fine-grained opaque minerals, and minor amounts of feldspar. The upper part of the unit contains red and orange oxidation stains. The clay matrix is white at the Manchester-1 well site and brown or tan at the Railway-1 well site. At the base of the unit is a 1- to 2-ft thick bed of very coarse, rounded quartz gravel. The gravel bed overlies an unconformable contact with the Williamsburg Formation (Prowell, 1990). The upland fluvial sediment probably was deposited in a large fluvial system consisting of meandering streams (Prowell, 1990). The Santee alluvium, at the sites investigated, consists of clayey sand containing beds of gravel and less sandy, dense, plastic clay. The base of the unit contains a 1- to 3-ft thick bed of very coarse quartz gravel and cobbles in a matrix of relatively clay-free coarse quartz sand.

The Santee alluvium has received only minimal attention from previous investigators, primarily because it is confined to relatively small areas in the Santee River valley. Prowell (1990) noted, however, that the erosional truncation of the upland fluvial deposits by the Santee River valley, the difference in altitude between the Santee alluvium and the upland fluvial deposits, and the incomplete alteration of carbonaceous matter to lignite in the Santee alluvium implies that the Santee alluvium is substantially younger than the upland fluvial deposits.

Upland fluvial deposits occupy topographically high areas inland from Lake Marion. The base of the upland fluvial deposits is at an altitude of about 145 ft at the Manchester-1 well site and about 135 ft at the Railway-1 well site. The thickness of sand is about 26 ft at the Manchester-1 well site and about 33 ft at the Railway-1 well site.

Environmental Technology Engineering, Inc. (1988a) reported occurrences of upland fluvial sediments in the facility at approximately the same altitude found at the Manchester-1 and Railway-1 well sites. The upland fluvial sediments in the facility attain a maximum thickness of 40 ft in areas where paleochannels incised the underlying clay.

The Santee alluvium was encountered along the edge of the Santee River valley during this investigation in cored holes at the Rimini-1, Lake Marion-1, and Lake Marion-2 well sites. The maximum thickness of Santee alluvium encountered was 18 ft at the Rimini-1 well site.

The surficial aquifer in the facility is absent in areas where the underlying clay crops out and where the sandy material has been excavated and removed during the site operations (Aware, Inc., 1985b; Environmental Technology Engineering, Inc., 1985a). The remaining areas of surficial aquifer within the facility are limited to undeveloped areas in the northern and northeastern parts of the facility, a narrow strip between sections I and II of the facility (fig. 10, plate 1), and the immediate area of the old seepage lagoon along the southwestern side of the facility (Environmental Technology Engineering, Inc., 1988a, 1989).

Sandy sediment has been reported in the uppermost part of the Lang Syne Member of the Williamsburg Formation within the facility (Wehran Engineering, 1978). Where such sediment occurs, it may function as part of the water-table aquifer. Sandy sediment was not found in the uppermost part of the Lang Syne Member outside the facility in the wells drilled during this investigation. Stratigraphic definition of the Lang Syne Member is discussed in the "Opaline-Claystone Confining Unit" section of this report.

The surficial aquifer functions as a water-table aquifer over much of the study area, but it may be confined locally where clay overlies the water-bearing zone, such as in the eastern part of the facility. The source of water in the surficial aquifer is infiltration of rainfall into the soil zone in interstream areas. Heath (1980) estimated that the steady-state infiltration of rainfall into the soil zone in the North Carolina Coastal Plain varies between 5 and 21 inches per year, depending on soil type. Because of similar climate, topography, and soil type in the North Carolina and South Carolina Coastal Plains, those infiltration rates probably are also valid for the South Carolina Coastal Plain.

Of the water that enters the surficial aquifer, most is discharged to streams, evaporated from the soil, or transpired by plants. Kozlowski (1964, p. 140) has estimated that forests in the southern United States lose as much water as 8,000 gallons per acre per day through evapotranspiration. Dennehy and McMahon (1987) determined the evapotranspiration rate in southwestern South Carolina to be 0.03-0.2 in/d during 1983-84. Based on studies in the North Carolina Coastal Plain (Heath, 1980), discharge from the surficial aquifer to the underlying confined aquifers is probably less

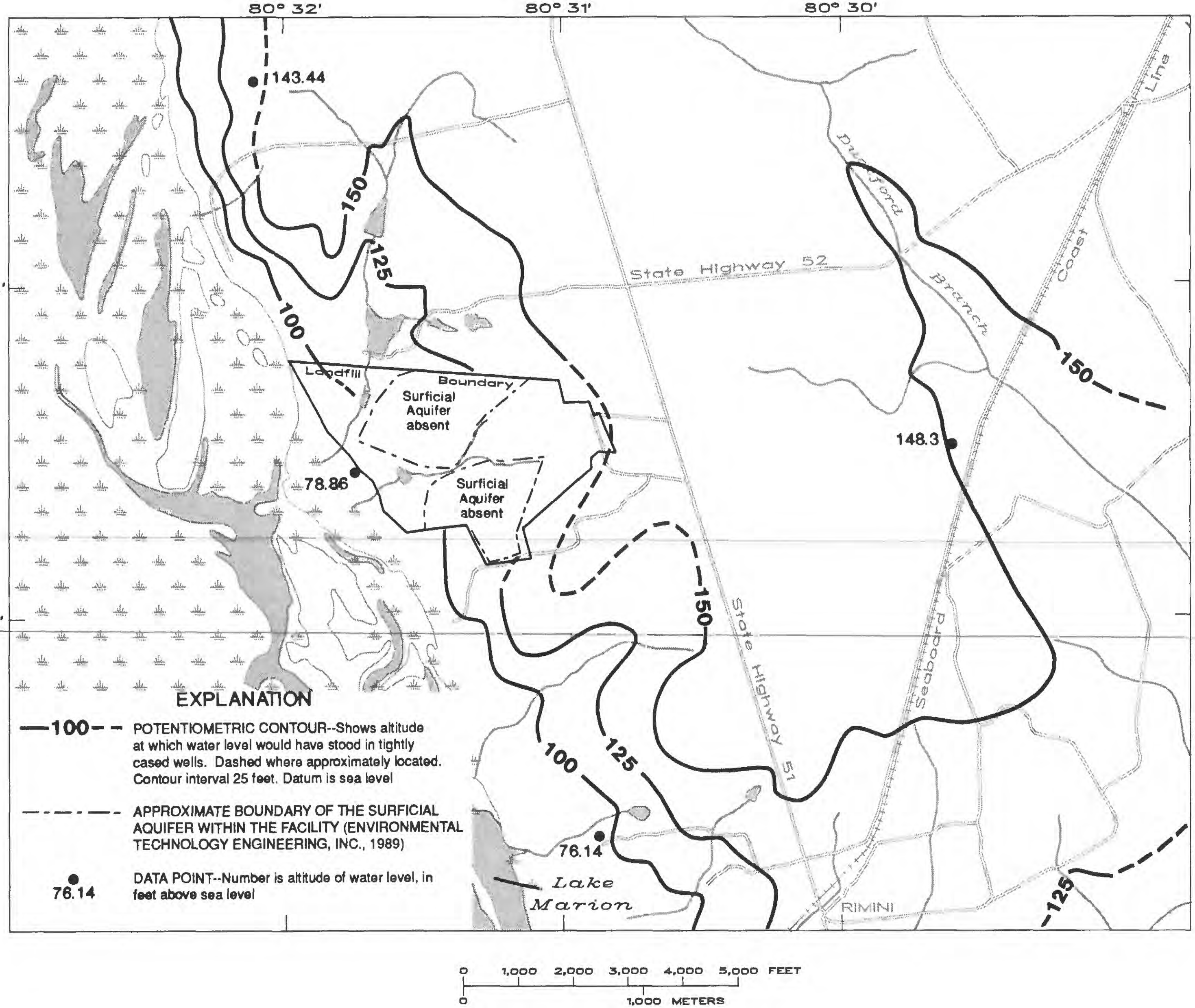


Figure 10.--Potentiometric surface of the surficial aquifer, March 1989.

than 2 in/yr. The remainder of the water in the surficial aquifer discharges to streams or to Lake Marion (fig. 10).

The potential exists for movement of water downward from the surficial aquifer to the underlying confined aquifer through fractures in the confining unit. In the area of surficial-aquifer occurrence within the facility east of the disposal areas, such movement is expected to be minimal because the underlying confining unit is 45- to 90-ft thick. In areas where the confining unit is locally thinner, however, such as along the stream channel between sections I and II of the landfill, the potential for downward leakage through fractures is greater. Such downward movement is examined in more detail later in this report in the discussion of the Lang Syne-Sawdust Landing aquifer.

A slug test at the Lake Marion-1 well site showed the horizontal hydraulic conductivity in the surficial aquifer to be 15 ft/d. Ground-water movement in the surficial aquifer is toward streams and Lake Marion at a rate of about 14 to 23 ft/yr at the Lake Marion-1 well site. This rate was calculated by using a porosity range of 0.3 to 0.5 as typical of sand (Freeze and Cherry, 1979), a hydraulic gradient between the well and the lake of $1.25\times10^{-3}$ ft/ft, and a horizontal hydraulic conductivity of 15 ft/d. Using the same values, except for a hydraulic gradient of $3\times10^{-3}$ ft/ft, ground-water velocity at the Lake Marion-2 well site is 33 to 55 ft/yr.

The surficial aquifer is used for domestic purposes by several residents within a 3-mile radius of the facility. Commonly, the depth of these wells is 25 to 30 ft. Irrigation wells in the area near the facility are screened in deeper aquifers, but they are gravel packed to land surface. Thus, the irrigation wells may derive some water from the surficial aquifer. There are no municipal wells for public supply that receive water from the surficial aquifer near the facility.

## Opaline-claystone Confining Unit

The opaline-claystone confining unit is composed primarily of sediment from the upper Paleocene Lang Syne Member of the Williamsburg Formation but, in this investigation, it is considered to locally include fine-grained material from the overlying upland fluvial deposits. Thus, the unit described in this report is thicker than cited in previous investigations (Environmental Technology Engineering, Inc., 1987, 1988a) where the fine-grained sediment at the base of the upland fluvial deposits was not grouped with the opaline claystone as part of the confining unit. The Lang Syne Member also has been referred to as "opaline claystone" (Wehran Engineering, 1978), or the Tavern Creek bed (Padgett, 1980). In areas where extensively opalized strata crop out, the beds have been termed "buhrstone" (Sloan, 1908; Heron, 1969).

Most of the material composing the opaline-claystone confining unit in the study area is dark green to gray, moderately consolidated, silty clay or claystone to clayey silt or siltstone containing small amounts of fine, rounded, well-sorted quartz sand. Investigations by Prowell (1990) show that the clay is dominantly illite/smectite, with lesser amounts of kaolinite. Other constituents include disseminated carbon, mica, pyrite, granular phosphate, glauconite, secondary opal, and opaque heavy minerals. One-foot-thick beds of silicified bivalve shells and silicified fine- to very coarse-grained sand occur locally at the top of the unit.

The lithology of the Lang Syne Member implies that the sediment was deposited under marine conditions in back-barrier bays and restricted lagoons (Prowell, 1990). The bays and lagoons filled by the sediment of the Lang Syne Member were erosional depressions in the sediment now composing the Sawdust Landing Member of the Rhems Formation.

Secondary opaline silicification has occurred throughout much of the unit (Heron, 1969; Weaver and Wise, 1974). The replacement is particularly extensive near the top of the unit (Sloan, 1908; Heron, 1969), where the opal-rich material exhibits conchoidal fracturing. The opaline concentrations of the unit have been reported to be vertically and horizontally variable, with decreasing opaline content east-southeastward and southwestward across the facility (Waddell, 1988).

With the exception of the degree of opalization, the sediments are lithologically similar at most sites in the facility and in the wells installed during this investigation. However, in well PSDL-17 (plate 1), at the southeastern edge of the facility, a sand lens occurs in about the middle of the opaline claystone confining unit. Interbedded sand also occurs 6.5 miles northwest of the facility at Old Sawdust Pile Landing (fig. 1), where correlative sediment contains 3- to 5-ft thick beds of well-sorted, cross-bedded quartz sand interbedded with in clay similar to that found near the facility.

Wehran Engineering (1978) divided the opaline-claystone unit in the facility into four lithofacies: the buhrstone unit, the red sand unit, the opal-claystone unit, and the basal clay unit, listed in descending order. The buhrstone unit is typically a silicified fossiliferous limestone with abundant cavities formed by dissolution of shell material (Environmental Technology Engineering, Inc, 1988a). The red sand unit has been described as an orange to rust-brown discontinuous unit consisting of cross-bedded, medium-grained sand to laminated silt and clays (Wehran Engineering 1978). It occurs mainly in the northeastern half of the facility, reaching a maximum thickness of about 45 ft northeast of section I (Ebasco Services, Inc., 1986, p. 112). The opaline claystone is medium- to dark-gray clay in unweathered samples and light gray or white in outcrop. The basal clay is a discontinuous, black, hard, semiconsolidated to consolidated clay with seams of fine sand and silt and traces of fine gravel at the base.

Steeply inclined planar joints and (or) fractures are found throughout the consolidated areas of the unit. Indication that displacement has occurred along the joints and (or) fractures includes bedding offsets apparent on exposed surfaces with in the facility. Additional evidence for displacement is that some steeply inclined fractures found in cores from wells drilled during this investigation contained slickensided surfaces near the base of the unit. The distance between adjacent joints or fractures ranges from a few inches to several feet. Wehran Engineering (1978) noted that the joint apertures typically are a fraction of an inch in width.

The opaline-claystone confining unit is continuous at most areas within the facility (Environmental Technology Engineering, Inc., 1986), but it thins and is locally absent west and southwest of the facility (figs. 5, 6, and 9). For example, the opaline-claystone confining unit is about 14 ft thick at well Rimini-1A but is absent 38 ft away at well Rimini-1E and is only about 2 ft thick at the Lake Marion 2 well site (fig. 11). The unit is locally absent west of landfill section II at well PSDL-4 (fig. 9). Wehran Engineering, Inc. (1978) and Waddell (1988) reported the unit to be locally absent southwest of the disposal areas. The unit thickens northeastward (Environmental Technology Engineering, Inc., 1986) and eastward across the facility, and is 124 ft thick at the Railway-1 well site (fig. 9).

Laboratory permeability tests done on a core of opaline claystone from the Manchester-1 well site showed the vertical hydraulic conductivity of the material to be $4.3\times10^{-5}$ ft/d; however, fluid movement within the opaline claystone is controlled by secondary porosity within joints and fractures. Evidence for such control is shown by slug tests in the claystone conducted by Aware, Inc. (1985b) showing a hydraulic conductivity of about $3 \times 10^{-3}$ ft/d. Moreover, an investigation by Environmental Technology Engineering, Inc. (1988a) showed a downward hydraulic potential in the two wells open to the claystone and showed that one well in the claystone is probably hydraulically connected to the underlying Lang Syne water-bearing unit by fracture porosity.

The low hydraulic conductivity ($3.1\times10^{-3}$ to $4.3\times10^{-5}$ ft/d) of the opaline-claystone confining unit and the presence of fracture zones connected to the underlying water-bearing unit imply that the dominant direction of fluid movement in the claystone is vertical. Thus, contaminants entering the claystone would be expected to migrate downward to underlying, more permeable units, rather than to extensively migrate laterally within the fracture system of the claystone.

## Lang Syne-Sawdust Landing Aquifer

The basal sand in the Lang Syne Member of the Williamsburg Formation and water-bearing zones in the underlying Sawdust Landing Member of the Rhems Formation are considered in this report to compose the Lang Syne-Sawdust Landing aquifer. The individual water-bearing zones of the aquifer have been cited in previous investigations of the facility as the transitional Lang Syne, the secondary Sawdust Landing, and the primary Sawdust Landing aquifers (listed from shallowest to deepest) (Environmental Technology Engineering, Inc., 1988a) (fig. 2). The water-bearing units are combined as a single aquifer in this investigation because they are hydraulically connected in the eastern part and east of the facility.

As will be shown later in this section, the hydrology of the site indicates that if contaminants were to leak from the disposal areas to the opaline claystone, they probably would migrate downward to the Lang Syne water-bearing zone. Once in the water-bearing zone, transport would be lateral in a direction depending on the point of entrance into the zone. Regardless of the initial transport direction, the ultimate movement of such dissolved contaminants would be toward Lake Marion.

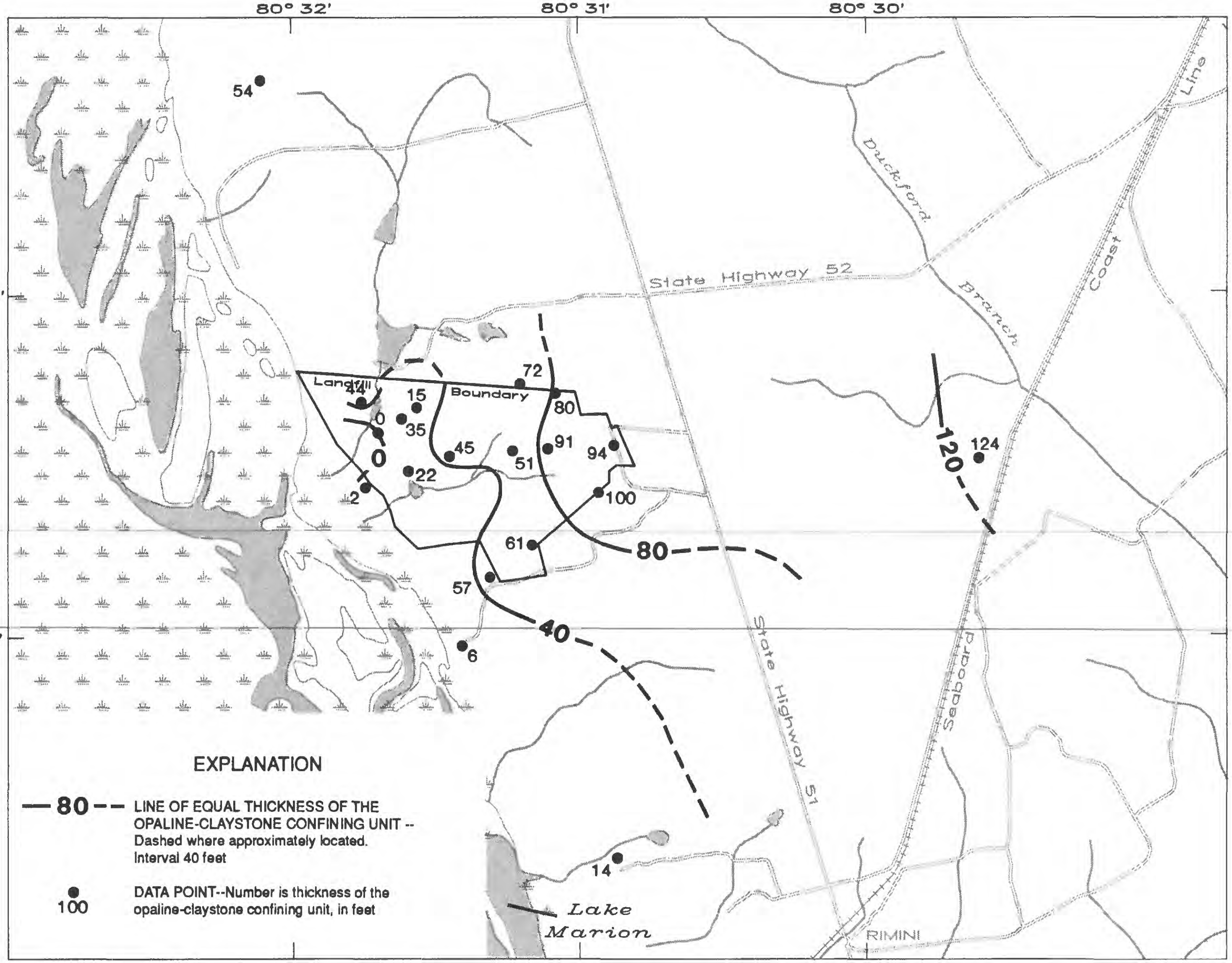


Figure 11.--Thickness of the opaline-claystone confining unit.

Specific characteristics of individual water-bearing zones differ from site to site. The Lang Syne water-bearing zone is a thin (2 to 6 ft) sandy facies encountered at the base of the opaline claystone in all of the wells that were installed during this investigation and in most of the wells drilled within the facility (Environmental Technology Engineering, Inc. 1988a). At most locations, the Lang Syne water-bearing zone consists of fine- to medium- or coarse-grained quartz and potassium feldspar sand and gravel in a green clayey matrix. The zone at the Lake Marion-2 well site, however, consists of a thin (2 in.) bed of white sand, and the combined sequences of opaline-claystone confining unit and the uppermost sand in the Lang Syne-Sawdust Landing aquifer and are only about 2.5 ft thick. At the Railway-1 well site, the Lang Syne water-bearing zone consists of two beds of poorly sorted clayey sand about 1 ft thick each, separated by about 3 ft of black clay. The sand layers contain mica, shell fragments, and shark teeth. The zone at the Lake Marion-1 well site is silicified.

The underlying upper (or secondary) Sawdust Landing water-bearing zone is composed of discontinuous sand or sandy clay lenses. At the Rimini-1 well site, the zone is composed of 29 ft of well-sorted sand in a clay matrix; at the Lake Marion-1 well site, however, the material is dominantly silty clay. At the Lake Marion-2 and Manchester-1 well sites, the material is dominantly clayey sand or sandy clay. Similar lithologic variability is reported for the upper Sawdust Landing water-bearing zone within the facility (Environmental Technology Engineering, Inc., 1988a). At the Railway-1 well site and in the eastern part of the facility, the upper Sawdust Landing water-bearing zone is absent due to Paleocene erosion.

The material composing the lower (or primary) Sawdust Landing water-bearing zone is coarser grained and more continuous than the sand bodies in the upper Sawdust Landing water-bearing zone. The lower Sawdust Landing water-bearing zone is typically composed of sand or gravel in the wells drilled for this investigation. Similar lithology and continuity has been reported for the lower Sawdust Landing water-bearing zone at most well sites within the facility; however, the zone is locally dominated by silty clay (such as at well UBC-1) (Environmental Technology Engineering, Inc., 1987; 1988a). The thickness of the lower Sawdust Landing water-bearing zone at the wells drilled during this investigation ranged from about 6 in. at the Lake Marion-1 well site to about 15 ft at the Rimini-1 well site. Thicknesses of this water-bearing zone at the remaining well sites were 9 ft, 4 ft, and 1.5 ft at well sites Manchester-1, Lake Marion-2, and Railway-1, respectively.

The top of the Lang Syne-Sawdust Landing aquifer generally dips to the east and southeast (fig. 12). The aquifer thins eastward from about 47-ft thick at well UBC-9, near the disposal areas, to about 14-ft thick at the Railway-1 well site (fig. 6). The area of maximum potential recharge in the Lang Syne-Sawdust Landing aquifer is north and northeast of the facility between the Manchester-1 well site and Sumter, where sandy parts of the aquifer crop out or subcrop beneath surficial sands. In that area, recharge to the aquifer occurs in interstream regions and discharge occurs as baseflow to streams. Part of the water recharging the aquifer moves downdip to confined parts of the aquifer. Potential for additional recharge is greatest where the overlying confining unit is thin and fractured.

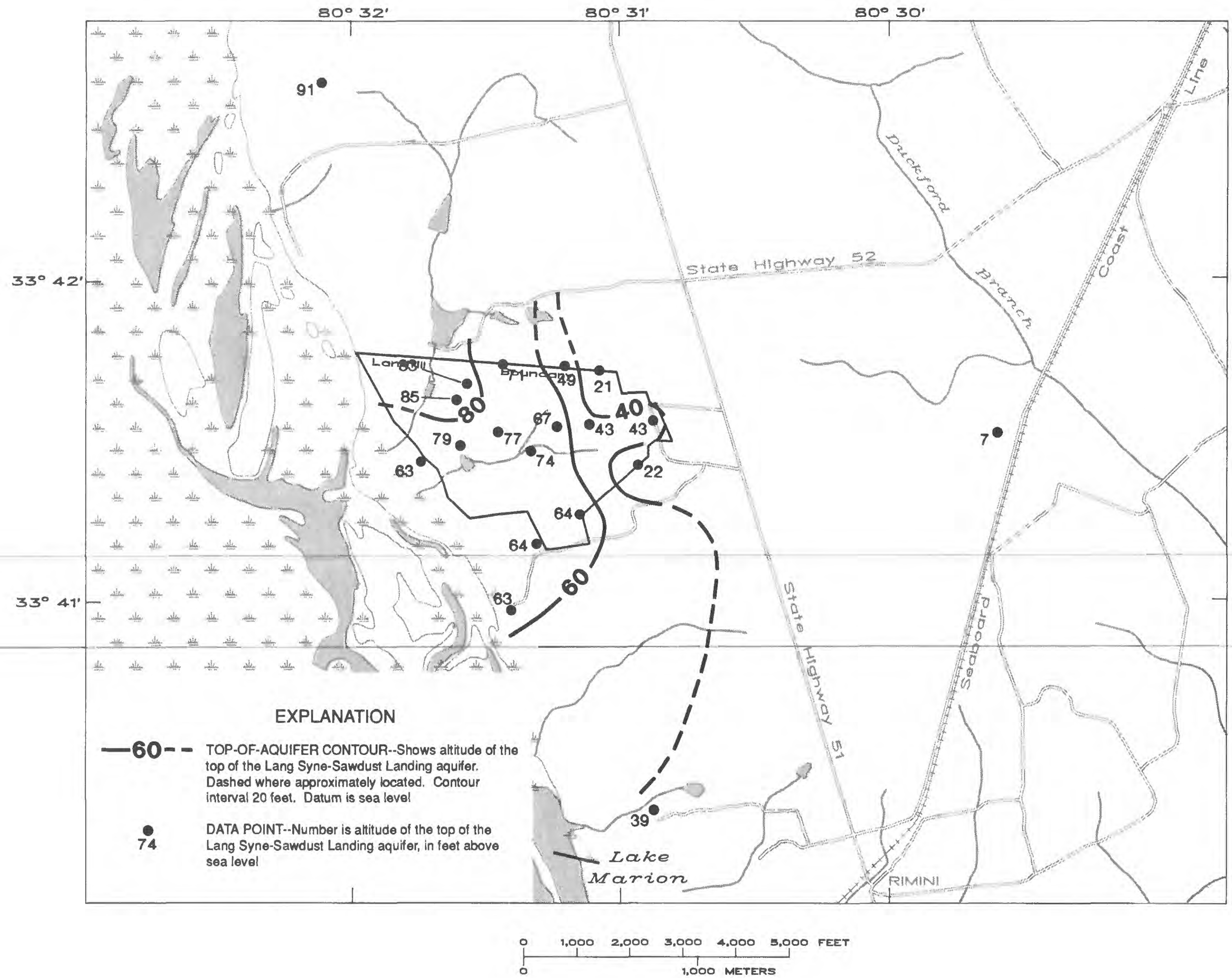


Figure 12.--Altitude of the top of the Lang Syne-Sawdust Landing aquifer.

The hydrology of the Lang Syne-Sawdust Landing aquifer is complex, and, despite the large number of observation wells installed at or within the facility, specific flow paths are not clearly defined. The complexity is due to Paleocene erosion of the Rhems Formation and subsequent deposition of the Williamsburg Formation on the eroded surface. The Lang Syne water-bearing zone is, therefore, hydraulically isolated from the upper and lower Sawdust Landing water-bearing zones in some areas and hydraulically connected to them in other areas.

Vertical hydraulic isolation or poor vertical hydraulic connection between the aquifer sands occurs in the central and western parts of the facility where continuous clay, silt, and silty clay layers of various thickness (2 to 10 ft) separate the sands (Environmental Technology Engineering, Inc., 1988a). For example, the water level in the Lang Syne water-bearing zone near the center of the facility at well SL-6, was 16.7 ft higher than the water level in the next underlying water-bearing zone in nearby well SL-7 in September 1989.

Vertical hydraulic connection between the sands occurs in the eastern part of the facility and east of the facility. The Lang Syne water-bearing zone truncates the upper Sawdust Landing water-bearing zone in the eastern part of the facility near well UBC-7 (fig. 6). At the Railway-1 well site east of the facility, where the upper Sawdust Landing water-bearing zone has been removed by erosion, the Lang Syne water-bearing zone is hydraulically connected to the lower Sawdust Landing water-bearing zone. Evidence for such hydraulic connection at the Railway-1 well site was observed during a pumping test of the well screened in the Lang Syne water-bearing zone when water-level response was noted in the adjacent well screened in the lower Sawdust Landing water-bearing zone.

The distribution of water levels in the Lang Syne water-bearing zone within the facility is a function of several factors. Relatively high water levels were found along the northern and southeastern boundaries of the facility at wells PSDL-1 and PSDL-17, respectively, indicating the probable movement of ground water into water-bearing sand beneath the facility from offsite areas toward the north and southeast (figs. 13 and 14). Water levels measured in the Lang Syne water-bearing zone, however, are higher in the central part of the facility at well SL-6 than in nearby wells. Moreover, the water level at well SL-6 was 16.7 ft higher than in the next underlying water-bearing zone in the Sawdust Landing Member in September 1989. The relatively high water levels in the central part of the facility imply a local source of recharge to the Lang Syne water-bearing zone.

To test the potential for downward movement of water to the Lang Syne water-bearing zone through the overlying confining unit, Environmental Technology Engineering, Inc. (1987, p. 73) sampled wells SL-8 and SL-9 in the Lang Syne and upper Sawdust Landing water-bearing zones, respectively, and found detectable tritium in both wells. The presence of tritium implies that the water was in contact with the atmosphere after 1953 (Drever, 1982). Calculated ground-water velocities for the Lang Syne water-bearing zone (0.04-1.6 ft/yr) indicate that this water is too young to have been

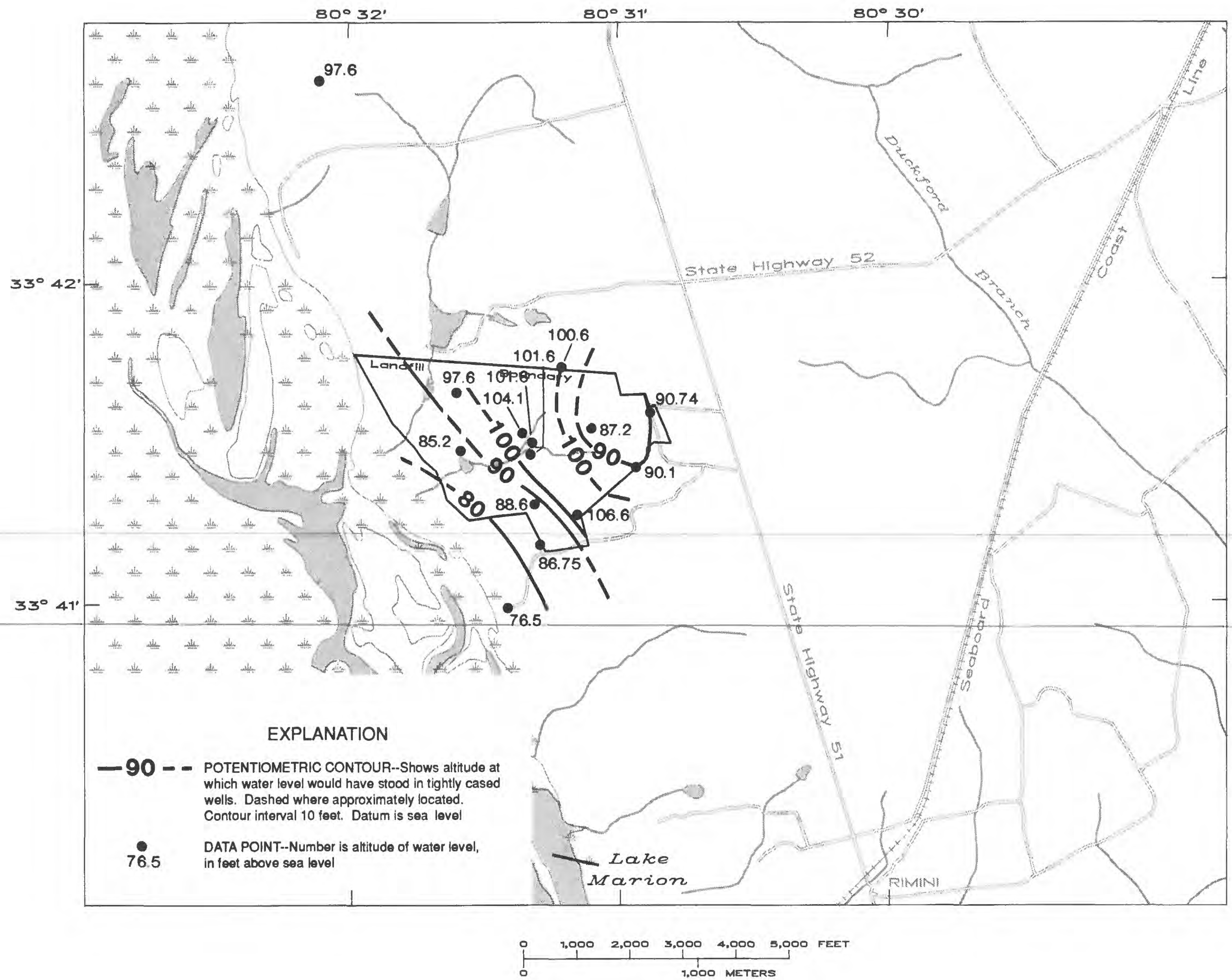


Figure 13.--Potentiometric surface of the Lang Syne water-bearing zone of the Lang Syne-Sawdust Landing aquifer, March 1989.

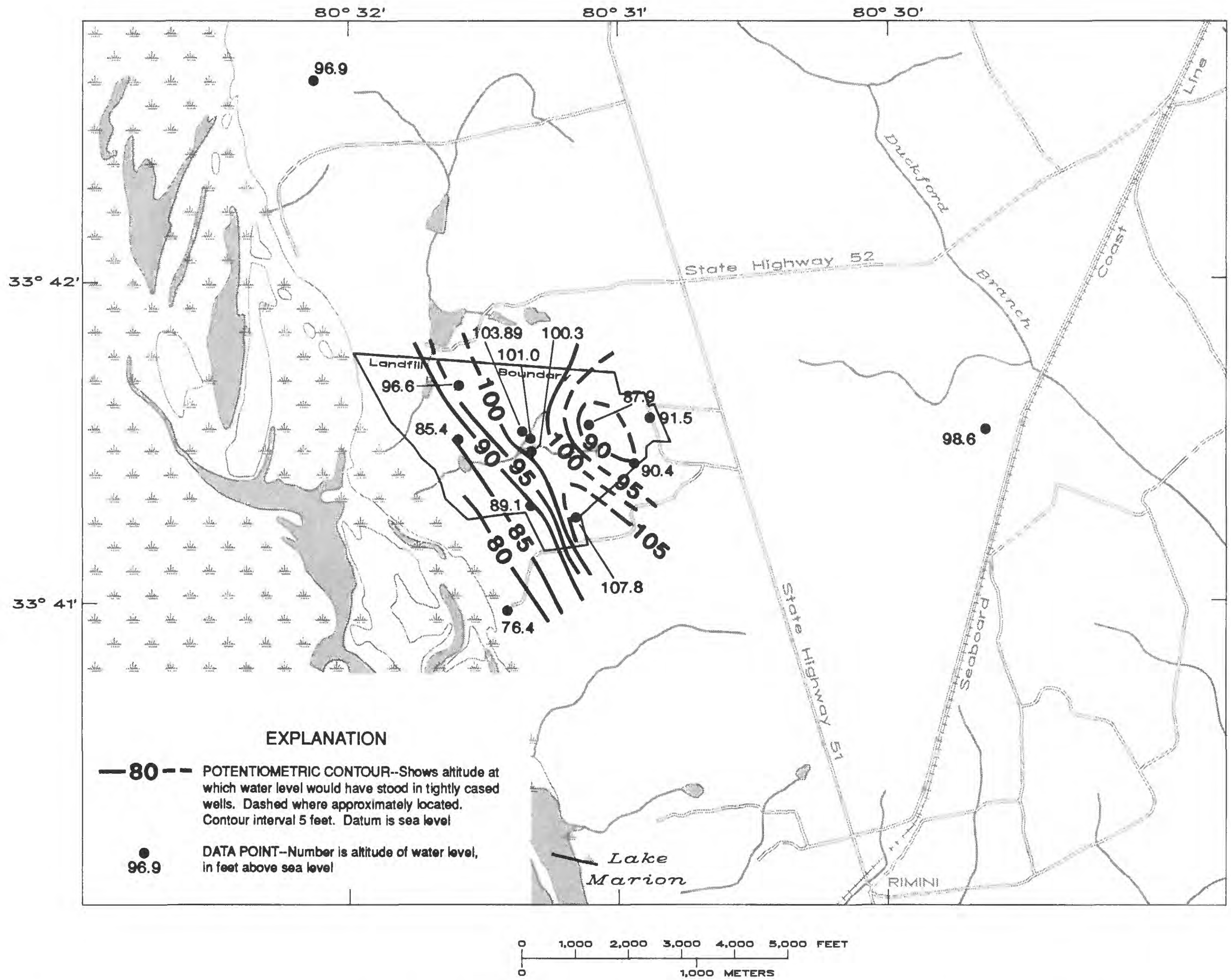


Figure 14.--Potentiometric surface of the Lang Syne water-bearing zone of the Lang Syne-Sawdust Landing aquifer, September, 1989.

transported from offsite recharge areas; therefore, it represents water that has migrated vertically downward through the opaline-claystone confining unit.

The overlying confining unit in the central part of the facility at well SL-6 is fractured (Environmental Technology Engineering, Inc., 1987) and is in an area where erosion has thinned the confining unit to about 35 ft. The thinned area is in a topographic trough oriented southwest-northeast between section I and section II areas of the facility (fig. 11 and plate 1) and contains a stream.

The ground-water mounding at well SL-6 is probably due in part to increased recharge in the area and may be partly related to excavation of overburden material during construction of the disposal pits. Excavation of the pits resulted in a decrease in overburden pressure with a corresponding decrease in hydrostatic pressure in the underlying water-bearing zone. Immediately following excavation, therefore, the water levels in the water-bearing zone beneath the excavated areas would be lower than water levels in the unexcavated areas, such as the area near well SL-6.

An example of this effect can be seen at well PSDL-11 on the eastern side of section II of the landfill (pl. 1). The well is screened in a fine-grained part of the Lang Syne water-bearing zone. The water level in this well was approximately 2 ft higher than that in well SL-6 farther south (and farther from the excavation) during the early part of 1988. As excavation of section II continued through 1988 and 1989, however, water levels in well PSDL-11 sharply declined, and by September 1989, the water level at well PSDL-11 was approximately 6.4 ft lower than the water level at well SL-6 (Susan Rogers, Environmental Technology Engineering, Inc., written commun., 1990).

The pressure changes and resultant water movement due to excavation of overburden material may partly explain why water levels are higher near well SL-6 than farther north in the facility but cannot account for why they are higher near well SL-6 than in the eastern part of the facility where excavation has been limited. The dominant factors controlling the water levels in the Lang Syne water-bearing zone in the eastern part of the facility appear to be the limited potential for downward leakage of recharge water through the overlying confining unit and increased vertical hydraulic connection between the Lang Syne water-bearing zone and underlying sands. Unlike the area of locally high water levels at well SL-6, where the overlying confining unit is 36 ft thick and fractured, the Lang Syne water-bearing zone at well B-52A (eastern part of the facility) is overlain by approximately 90 ft of confining material (fig. 11) having no prominent fractures except for in the bottom 15 ft. Thus, the potential for downward movement of water through the overlying confining unit near well B-52A is relatively small.

The relatively low water levels on the eastern side of the facility also may reflect the degree of vertical hydraulic connection between water-bearing zones in the aquifer. It is in that area that the Lang Syne water-bearing zone is hydraulically connected to underlying water-bearing zones in the Sawdust Landing Member. Although September 1989 water levels in the Lang Syne water-bearing zone were 16.7 ft higher than in the next underlying sand at wells SL-6 and SL-7 where the zones are not hydraulically connected, they were only about 1-ft higher at wells B-52A and SL-17 in the area of interconnection. Water in the Lang Syne water-bearing zone may be discharging downward to water-bearing zones in the Sawdust Landing Member near well B-52A resulting in lower water levels in the water-bearing zone. The water-bearing sand beds in the upper part of the Sawdust Landing Member are too discontinuous to reliably determine if a corresponding ground-water mound occurs in the upper Sawdust Landing water-bearing zones.

Water levels in Lang Syne water-bearing zone allow two interpretations of the direction of ground-water movement, depending on the as yet unknown degree of hydraulic continuity of the zone. If the Lang Syne water-bearing zone is more or less hydraulically continuous across the facility, then the water levels at well SL-6 represent a ground-water mound. West of the mound, ground-water movement is westward, toward Lake Marion, but east of the mound, ground-water movement is eastward toward the area of relatively low-water levels on the eastern side of the facility near well B-52A where downward leakage of the water to lower water-bearing sands probably occurs.

Alternatively, if the Lang Syne water-bearing zone in the eastern part of the facility is not continuous with the zone in the central and western parts of the facility, then ground-water movement is in a westerly direction from the Railway well cluster toward the facility, where it probably discharges downward into lower sands in the Lang Syne-Sawdust Landing aquifer in the vicinity of well B-52A. Once in the lower sands, ground-water movement is westward, toward Lake Marion. Under this alternative hypothesis, ground water probably enters the Lang Syne water-bearing zone in the central and western parts of the facility by recharge through fractures in the overlying opaline claystone and moves westward toward Lake Marion. Although considerations of the environment of deposition imply that Lang Syne water-bearing zone is more or less continuous in the area of investigation, additional hydrogeologic data are needed for final resolution of the issue.

There is also a potential for exchange of water between the Lang Syne water-bearing zone and streams or the surficial aquifer where erosion has thinned or removed the intervening opaline-claystone confining unit west of the disposal areas. The sparse data on water levels in the Lang Syne water-bearing zone in the western part of the facility near the southernmost stream imply that if such an exchange is occurring within the facility it is likely to be downward from the stream or water-table aquifer to the Lang Syne water-bearing zone. More information regarding stream/aquifer water-level relations near the stream in the northwestern part of the facility is required to accurately assess the exchange of water in that area. The data are also too sparse to determine the potential for the exchange of water between streams, the surficial aquifer, and the Lang Syne water-bearing zone in the area between the facility and Lake Marion.

The horizontal hydraulic conductivity of the Lang Syne water-bearing zone at well Lake Marion-1C was determined by the slug-test method to be 0.008 ft/d. Environmental Technology Engineering, Inc. (1988a) reported similar results (geometric mean of 0.0037 ft/d) from slug tests in the Lang Syne water-bearing zone within the facility. Environmental Techology Engineering, Inc. (1988a) constructed a ground-water-flow model of the facility and determined that horizontal hydraulic conductivity values of 0.0037 to 0.1 ft/d produced acceptable agreement between measured and simulated water levels. The hydraulic gradient toward the lake determined in this investigation is 0.007 to 0.013 ft/ft. The average rate of ground-water movement in the Lang Syne water-bearing zone is, therefore, 0.04 to 1.6 ft/yr, using a range of porosity of 0.3 to 0.5 and a range of horizontal hydraulic conductivity of 0.1 to 0.008 ft/d.

The varying degrees of hydraulic connection between the Lang Syne water-bearing zone and overlying sources of water indicate that in areas where the opaline claystone is thin and fractured, contaminants that might leak from the landfill to the claystone would probably migrate downward to the Lang Syne water-bearing zone. Such areas are found between and probably beneath landfill sections I and II. Dissolved contaminants reaching the Lang Syne water-bearing zone would then be transported laterally until discontinuities in the underlying or overlying confining unit allowed them to be discharged downward or upward, depending on the head gradient.

The low horizontal hydraulic conductivity indicates that transport of non-reactive contaminants would be slow (0.04-1.6 ft/yr). Movement of contaminants that react with the aquifer matrix would be even slower. If the contaminants were in the form of free product denser than water, such as a concentrated pulse of chlorinated organic solvent, the transport direction would then depend on the slope of the confining unit beneath the water-bearing zone, and probably would be approximately eastward.

The horizontal hydraulic conductivity from aquifer tests at sites within the facility ranged from 0.05 to 1.00 ft/d for the upper Sawdust Landing water-bearing zone (Environmental Technology Engineering, Inc., 1988a). The distribution of water levels in the upper Sawdust Landing water-bearing zone is not discussed in this report because of the probable lack of hydraulic continuity among the sand lenses composing the zone.

Water levels in the lower Sawdust Landing water-bearing zone show ground-water movement to be west-southwesterly, toward Lake Marion, across the entire facility (fig. 15). Despite the approximate 1- to 2-ft difference in water levels in March and September 1989, the flow directions did not change substantially (figs. 15 and 16). The direction of flow indicates that if dissolved contaminants were to enter the water-bearing sand of the Lang Syne-Sawdust Landing aquifer and remain mobile, they ultimately would be transported toward Lake Marion, despite potential temporary movement in the opposite direction in the upper parts of the aquifer.

Slug tests in the lower Sawdust Landing water-bearing zone were conducted in wells Lake Marion-2A and Railway-1B. Transmissivity values were 0.02 $ft^2/d$ at well Lake Marion-2A and 0.05 $ft^2/d$ at well Railway-1B. Environmental Technology Engineering, Inc. (1988a) reported the range of horizontal hydraulic conductivity measurements derived from aquifer tests in the lower Sawdust Landing water-bearing zone within the facility to be 1 to

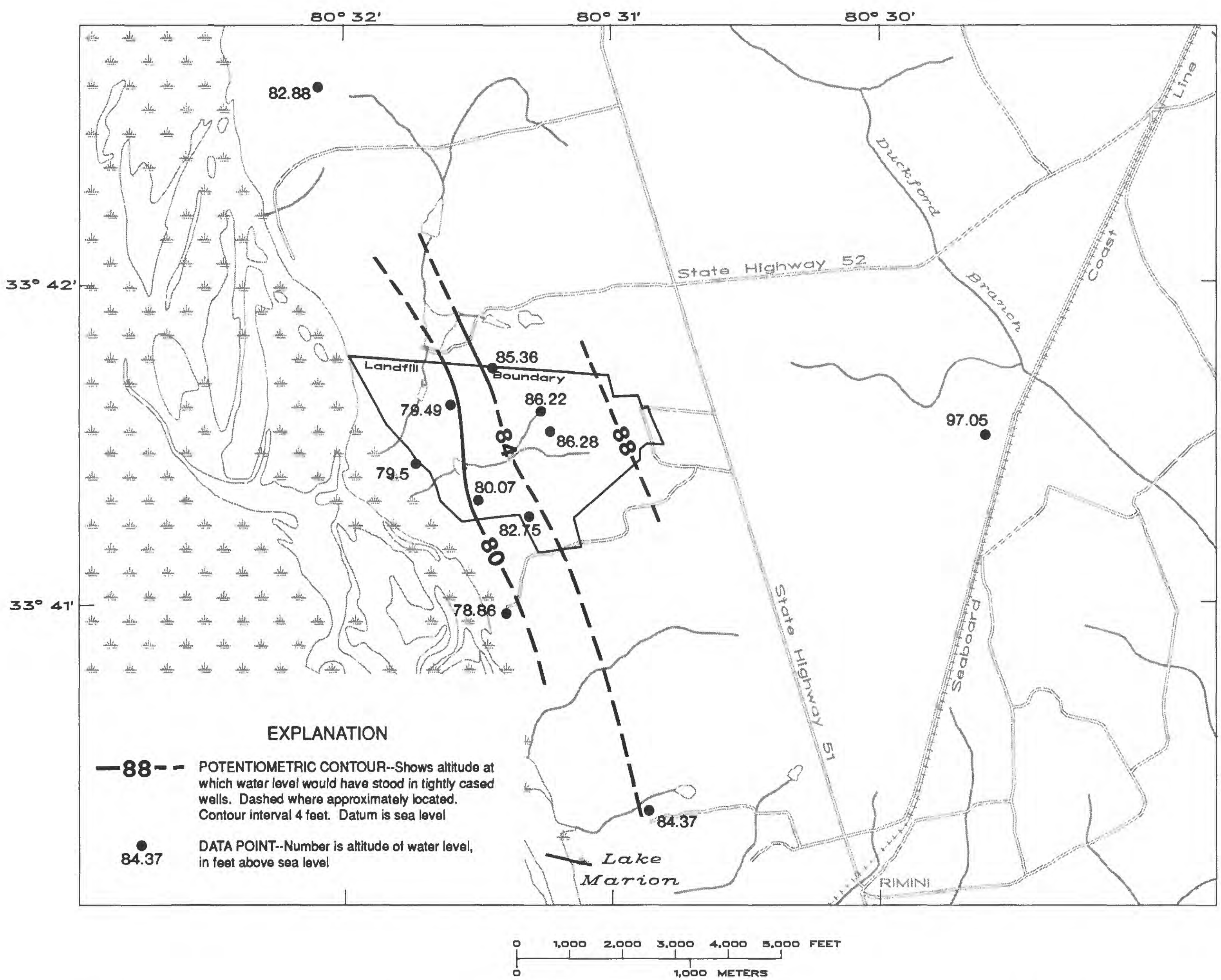


Figure 15.--Potentiometric surface of the lower Sawdust Landing water-bearing zone of the Lang Syne-Sawdust Landing aquifer, March 1989.

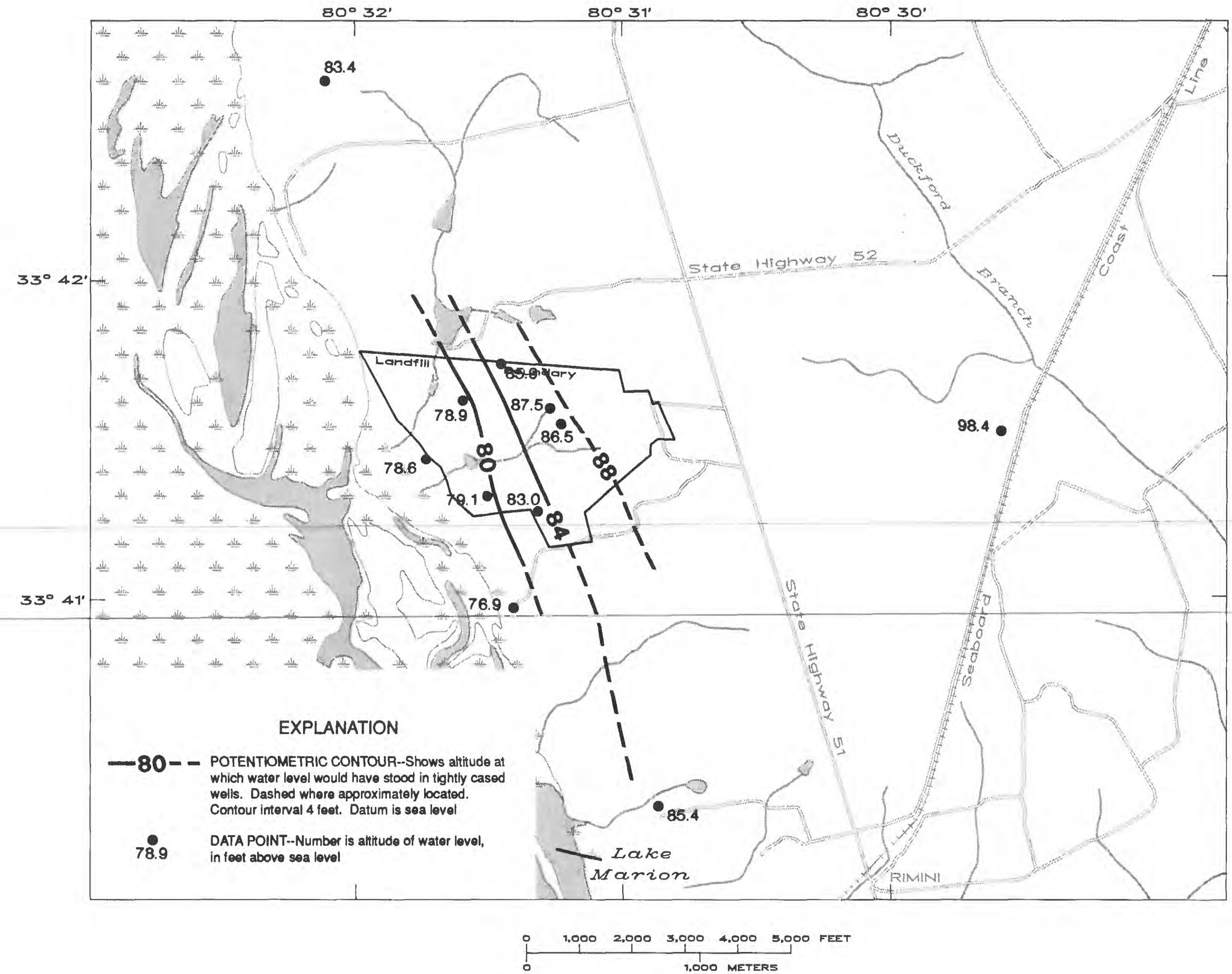


Figure 16.--Potentiometric surface of the lower Sawdust Landing water-bearing zone of the Lang Syne-Sawdust Landing aquifer, September 1989.

10 ft/d. The ground-water velocity in the zone in the interval between wells CBC-11 and Lake Marion-2A is about 2 to 64 ft/yr, using a range of horizontal hydraulic conductivity from 1 to 10 ft/d, a hydraulic gradient of 0.0033 ft/ft, and a range of porosities from 0.3 to 0.5.

Vertical hydraulic conductivities of cored samples from confining units in the Lang Syne-Sawdust Landing aquifer were determined by laboratory analysis (appendix B). The vertical hydraulic conductivity of the sandy clay between the Lang Syne and upper Sawdust Landing water-bearing zone ranged from $1.2 \times 10^{-4}$ ft/d to $2.6 \times 10^{-1}$ ft/d at the wells installed during this investigation and averaged $2.8 \times 10^{-3}$ ft/d at coreholes within the facility (Aware, Inc., 1985b). The vertical hydraulic conductivity of the clay and sandy clay between the upper and lower Sawdust Landing water-bearing zones ranged from $8.2 \times 10^{-6}$ ft/d to $5.4 \times 10^{-5}$ ft/d at wells installed during this investigation and from $1.55 \times 10^{-3}$ ft/d to $1.68 \times 10^{-3}$ ft/d at coreholes within the facility (Environmental Technology Engineering, Inc., 1988a).

Although most of the domestic wells within about 3 miles of the facility are open to the surficial aquifer, at least one domestic well south of the facility near Rimini is screened in the Lang Syne-Sawdust Landing aquifer. Irrigation wells in the area are screened in deeper aquifers but are gravel packed to the surface. Thus, water from the Lang Syne-Sawdust Landing aquifer probably contributes to the water pumped from the irrigation wells. The town of Manning obtains most of its water from deeper aquifers, but some wells also are screened partly in sediments that may be equivalent to the Lang Syne-Sawdust Landing aquifer. Municipal water supplies from other areas near the facility obtain their water from deeper aquifers.

## Peedee Confining Unit

The Peedee confining unit is composed dominantly of sediment from the upper part of the Cretaceous Peedee Formation. The material is a sandy clay containing fine- to coarse-grained quartz sand with mica, feldspar, garnet, monazite, and dark heavy minerals. The matrix typically is light-gray kaolinite, although pale grayish-green to dark-gray clay is present at the Railway-1 well site. X-ray analysis indicated that illite/smectite clay is also present (Prowell, 1990). At the Manchester-1 well site, the unit contains red stains in the upper 10 ft and moderate amounts of lignite, carbonaceous clay, and pyritized wood near the base. The Peedee-Sawdust Landing confining unit within the facility consists of blue-green to gray silty clay to clay (Aware Inc., 1985b) and massive, gray to purple or maroon clay beds with localized mottled yellowing (Environmental Technology Engineering, Inc., 1988a).

The Peedee confining unit is present at all of the USGS well sites and was reported by Environmental Technology Engineering, Inc. (1988a) to be continuous within the facility. The thickness of the confining unit outside the facility ranges from 16 ft at the Railway-1 well site to 25 ft at the Manchester-1 and Rimini-1 well sites (fig. 17). Clay thickness within the facility is reported to range from 2 to 11 ft, becoming thinner toward the east (Environmental Technology Engineering, Inc., 1988a).

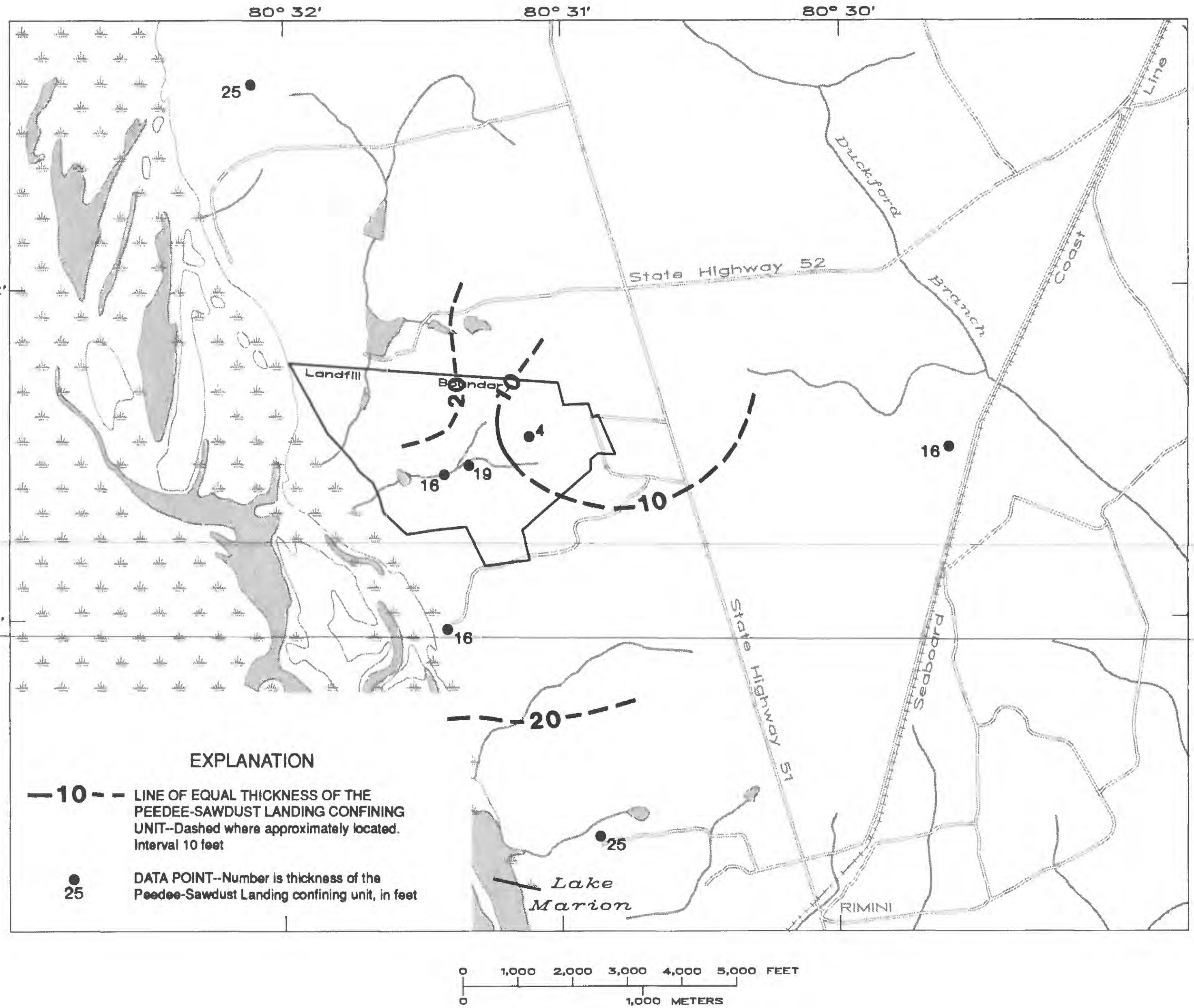


Figure 17.--Thickness of the Peedee confining unit.

Laboratory analyses of cored samples from the Peedee confining unit indicated vertical hydraulic conductivities of $1.0 \times 10^{-5}$ ft/d at the Rimini-1 well site and $1.3 \times 10^{-5}$ ft/d at the Manchester-1, Railway-1, and Lake Marion-1 well sites (appendix B). Environmental Technology Engineering (1988a) reported values of vertical hydraulic conductivity ranging from $2.3 \times 10^{-4}$ ft/d to $3.3 \times 10^{-4}$ ft/d within the facility. A 31-hour aquifer test in the Peedee aquifer by Environmental Technology Engineering, Inc. (1988a) at well UBC-4 in the facility showed no evidence of hydraulic interconnection across the confining unit.

## Peedee Aquifer

The Peedee aquifer (fig. 18) is composed of sediment from the upper part of the Upper Cretaceous Peedee Formation. It was encountered in four of the five cored holes installed during this investigation. The remaining cored hole, at the Lake Marion-2 well site, was too shallow to intercept the aquifer.

Stratigraphic correlation of the sediment composing the Peedee aquifer has been attempted by several investigators. Wehran Engineering, Inc. (1982) in early work at the site, tentatively assigned the material to the Tuscaloosa/Middendorf Formation. Later investigations by Environmental Technology Engineering, Inc. (1987) showed the sediment to be substantially younger, and, because the material was lithologically similar to material from the Black Creek Group, it was named the Black Creek aquifer. Recent biostratigraphic work by Prowell (1990) showed that the material within the facility is equivalent to the Peedee Formation described by Stephenson (1923), Sohl and Christopher (1983), and Sohl and Owens (1989). Sediment from the Black Creek Group at the facility is, therefore, deeper than previously thought.

Previous studies (Environmental Technology Engineering, Inc., 1987; 1988a) divided the upper part of the Peedee aquifer into two aquifers separated by a 2- to 13-ft thick confining unit. The upper aquifer was designated UBC-A and the lower aquifer, UBC-B. The thickness of UBC-A was reported to range from 5 to 16 ft; the thickness of UBC-B was not determined because of the small number of wells penetrating the unit (Environmental Technology Engineering, Inc., 1988a). The confining unit separating UBC-A and UBC-B was absent, however, at the Rimini-1 and Manchester-1 well sites installed outside the facility during this investigation; therefore, the Peedee aquifer is considered to be a single hydrologic unit in this report.

The Peedee aquifer is composed of channel sands from a restricted-marine lower-delta-plain depositional environment (Prowell, 1990). The sand is quartzose and is fine to very coarse grained, moderately sorted, and subangular. Minor amounts of kaolinite are present between grains. Accessory minerals include mica crystals, pyrite, rutilated quartz, garnet monazite, feldspar, pyritized wood, and fine-grained, dark, heavy minerals. Cross-bedding is evident at the Railway-1 well site. Carbonaceous clay layers, 1- to 2-feet thick, are present at approximately 10-ft intervals at the Railway-1 and Lake Marion-1 well sites. The sand becomes better sorted, finer grained, and less consolidated with depth at the Rimini-1 well site. Environmental Technology Engineering, Inc. (1988a) reported that within the facility the aquifer is composed of light-gray, well-sorted, micaceous quartz sand with lignite and a zone of gray clay.

The Peedee aquifer dips toward the southeast (fig. 18) and is thickest west and south of the facility (66-ft thick at the Lake Marion-1 well site and 64-ft thick at the Rimini-1 well site). It thins to 30 ft north of the facility at the Manchester-1 well site. The aquifer is at least 36 ft thick at the Railway-1 well site east of the facility, but the boring may not have penetrated the full thickness of the aquifer. Observation wells in the facility typically do not penetrate the full thickness of the Peedee aquifer.

The outcrop of the Peedee aquifer, where most of the recharge occurs, was reported by previous studies to be west of Sumter and Clarendon Counties (Park, 1980; Colquhoun and others, 1983); however, recent biostratigraphic work by Prowell (1990) has shown that the Peedee Formation extends farther north than previously thought. Exposures of the upper part of the Peedee Formation occur along the Congaree River between Devils Elbow and Bates Mill Creek (D.C. Prowell, U.S. Geological Survey, oral commun., 1990) (fig. 1), and the strike of the formation in the subsurface is approximately northeastward. Therefore, recharge to the Peedee aquifer probably occurs between Pinewood and Sumter where the aquifer is near land surface (20-60 ft deep). The northern part of this section is shown in figure 3.

Water levels measured in the Peedee aquifer within the facility were from wells in the UBC-B zone of the aquifer (as defined by Environmental Technology Engineering, Inc. (1988a)); the zone considered to be most representative of the hydrogeologic zone in which the USGS wells are screened. The data indicate that ground water moves generally northwestward beneath the facility. Variations in water levels from March to September 1989 were less than 1 ft and had no measurable effect on flow direction (figs. 19 and 20). The altitude of water levels measured in the aquifer ranged from about 75 to 95 ft above sea level within and near the facility during 1989. The altitude of the water level in the Peedee aquifer on the opposite (western) side of Lake Marion at well CAL-29 in Cameron (fig. 1) was substantially higher (130 ft above sea level) than water levels in the Peedee aquifer near the facility.

An aquifer test of the Peedee aquifer, in which well Rimini-1B was pumped at 31 gallons per minute, yielded a transmissivity of approximately 4,400 $ft^2/d$. Therefore, ground-water movement between wells Railway-1A and Manchester-1B is approximately 65 to 105 ft/yr, using a range of porosity between 0.3 and 0.5, a hydraulic gradient of 0.0006, a transmissivity of 4,400 $ft^2/d$, and an aquifer thickness of 30 ft. The Peedee aquifer does not appear to be hydraulically connected to the Lang Syne-Sawdust Landing aquifer in the facility (Aware, Inc., 1985b).

Although most domestic supply wells within about 3 miles of the facility obtain water from shallower aquifers, some domestic wells near Packs Landing (fig. 1) obtain ground water from the Peedee aquifer. The towns of Manning and Summerton (fig. 1) may obtain part of their water for

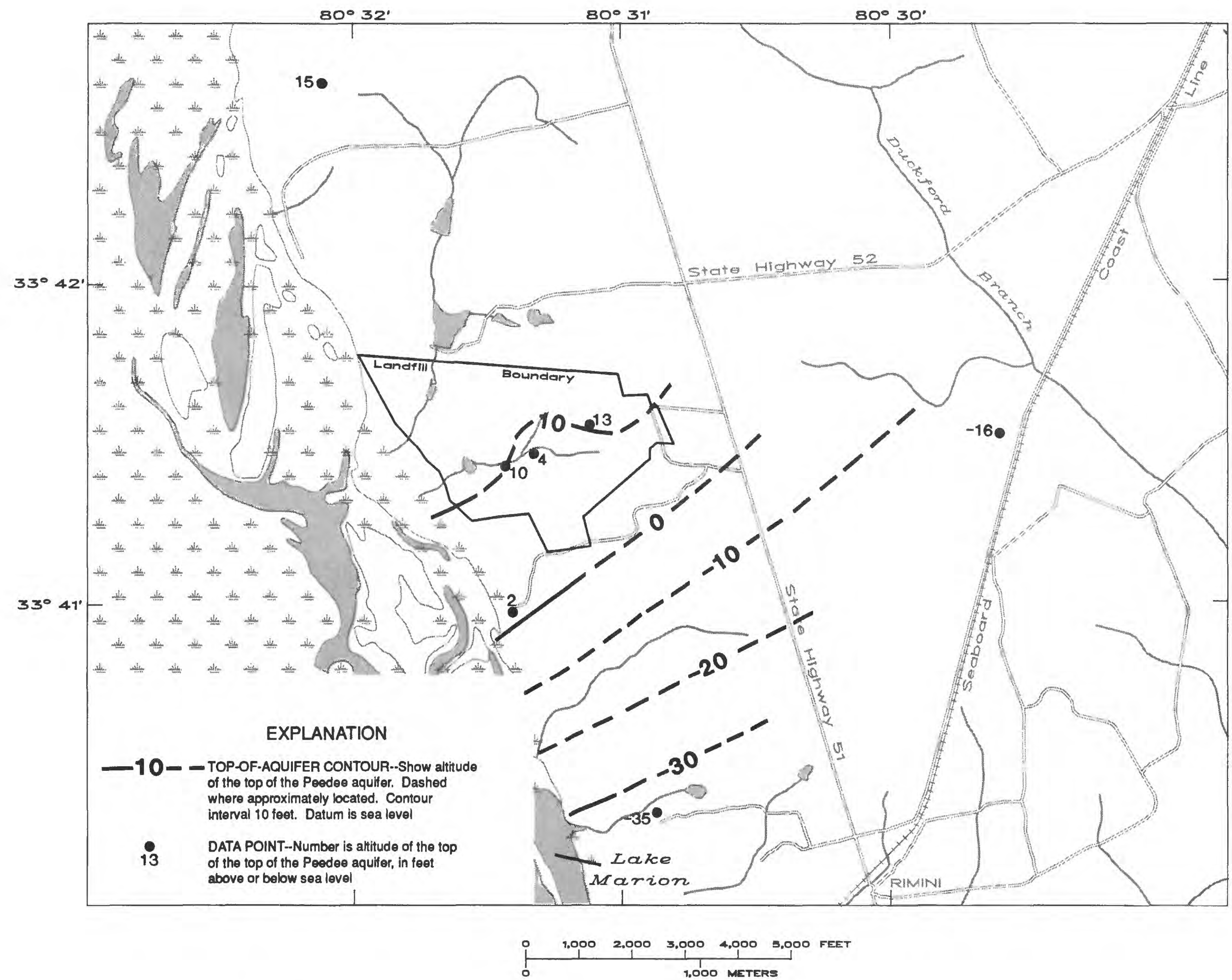


Figure 18.--Altitude of the top of the Peedee aquifer.

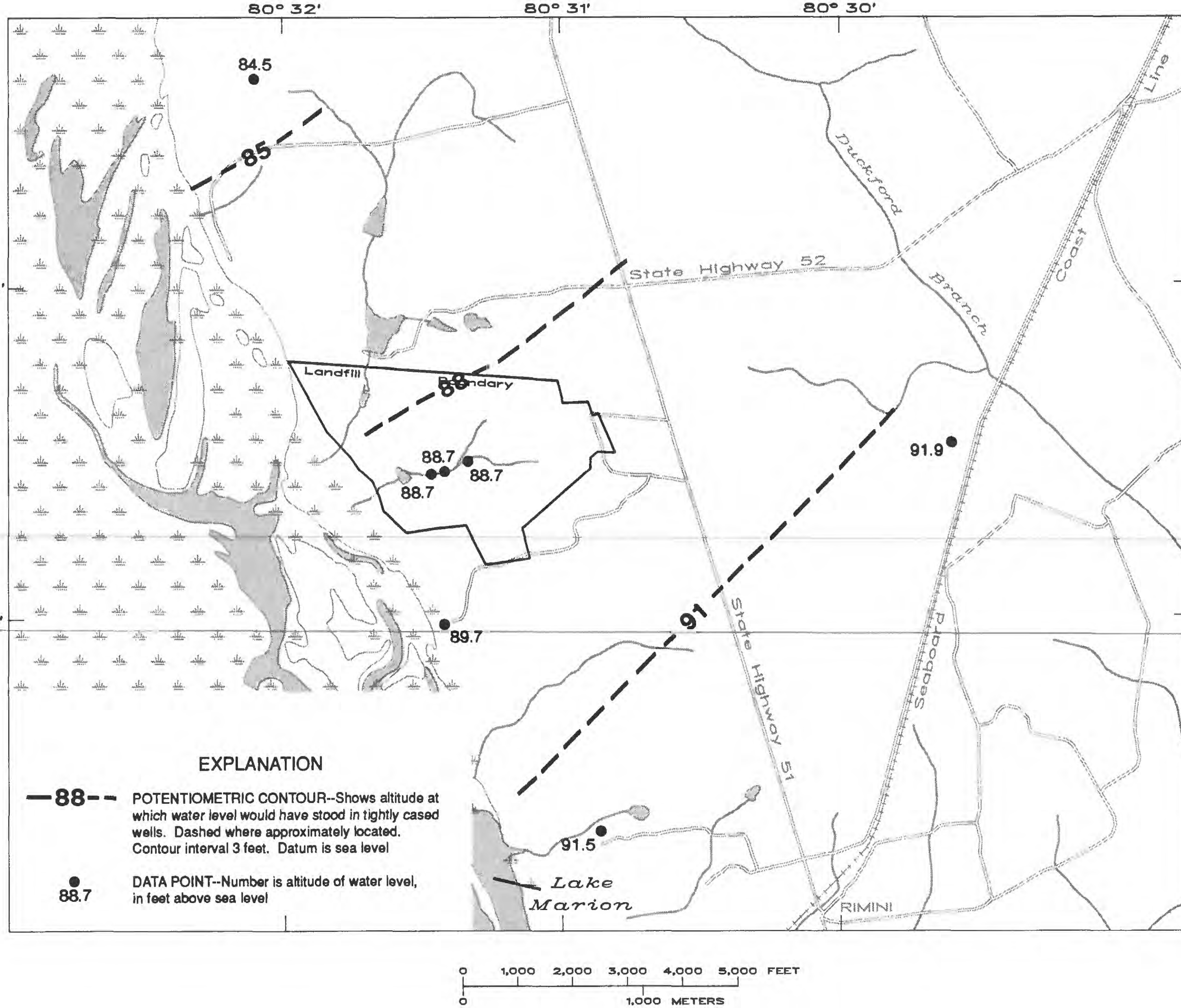


Figure 19.--Potentiometric surface of the Peedee aquifer, March 1989.

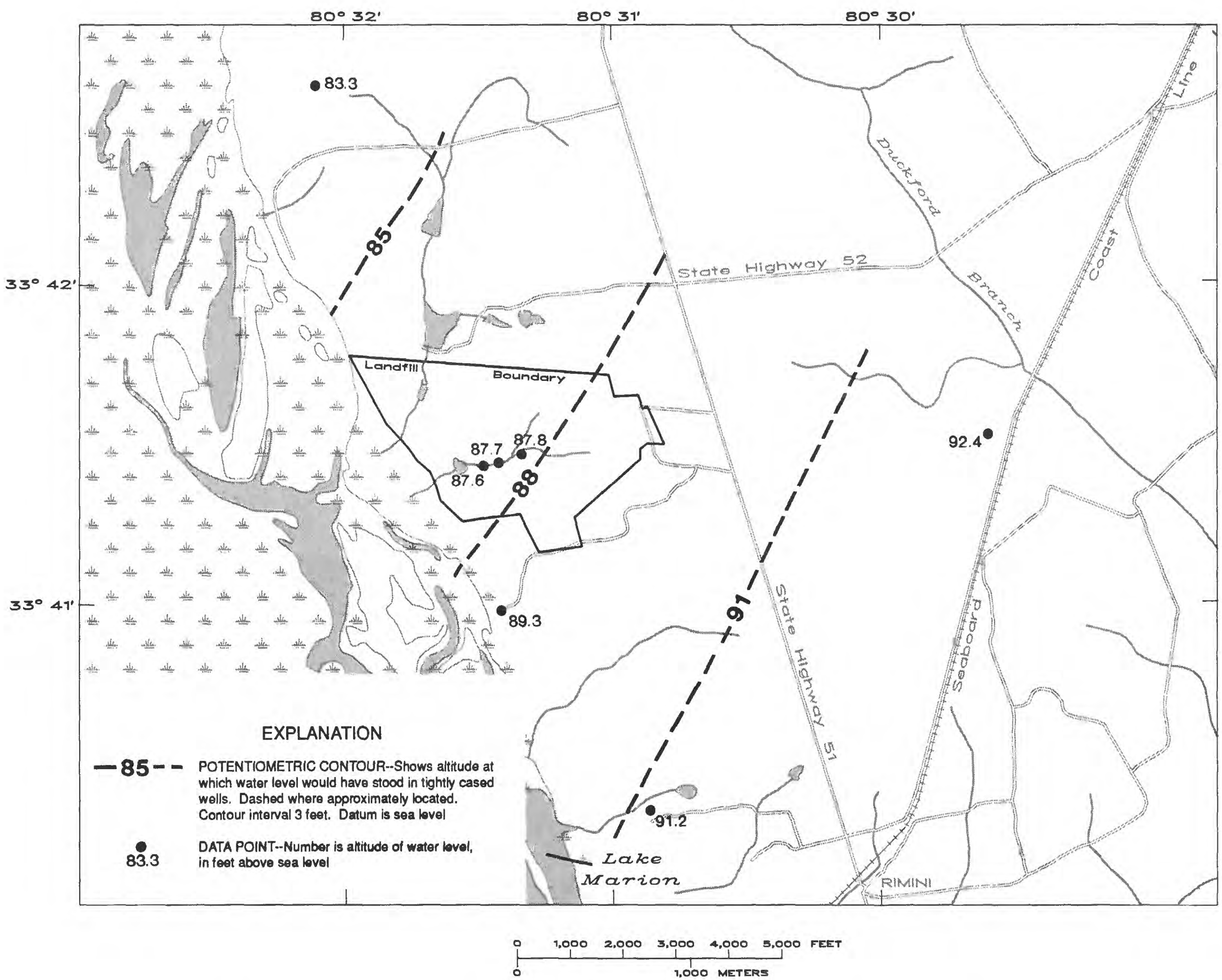


Figure 20.--Potentiometric surface of the Peedee aquifer, September 1989.

public supply from the Peedee aquifer. Several former production wells were screened in the aquifer within the facility (Peckman, 1986, p. 28).

## Black Creek Confining Unit

The Black Creek confining unit is composed of sediment from the lower part of the Peedee Formation. The sediment was mapped as the lower Black Creek Formation in earlier studies of the facility (Environmental Technology Engineering, Inc., 1988a). Despite the lithologic similarity of the sediment in this unit to Black Creek Group sediment, Prowell (1990) demonstrated that the beds in the study area are equivalent to the Peedee Formation as described by Stephenson (1923), Sohl and Christopher (1983), and Sohl and Owens (1989).

The sediment of the Black Creek confining unit is characteristic of deposition in open-marine conditions near a source of sediment supply (Prowell, 1990). Typically it is dark-green to gray carbonaceous clay to clayey sand laminated with fine, sub-angular, well-sorted quartz sand and silt. Associated minerals include muscovite, biotite, garnet, feldspar, glauconite, lignite, and granular phosphate. Bivalve and gastropod molds also are present. Calcium-carbonate cement was present through a 10-ft section of the core at the Rimini-1 well site.

A map is not shown for the thickness of the Black Creek confining unit because only two wells near the facility, Manchester-1 and Rimini-1, penetrated the entire thickness. The unit was 72 ft thick at both well sites.

Laboratory analysis of cored samples from the Black Creek confining unit showed similar values of vertical hydraulic conductivity at the Rimini-1 and Lake Marion-1 well sites. The values were $1.2 \times 10^{-4}$ ft/d and $1.7 \times 10^{-5}$ ft/d at the Rimini-1 well site and $3.6 \times 10^{-4}$ ft/d at the Lake Marion-1 well site.

Analysis of cored samples from the Manchester-1 well site showed the vertical hydraulic conductivity of the Black Creek confining unit to be substantially greater ($2.8 \times 10^{-1}$ ft/d) than the vertical hydraulic conductivity measured in the Black Creek confining unit at the other sites. Electric logs indicate that the zone from which the sample was collected (221 ft below land surface) may be sandier than the rest of the confining unit, and, therefore not representative of the unit as a whole (fig. 8).

## Black Creek Aquifer

The Black Creek aquifer is the deepest hydrogeologic unit investigated during this study. The sediment composing the Black Creek aquifer is correlative with the strata formerly called the Black Creek Formation (Stephenson, 1912; 1923), but later termed the Black Creek Group (Owens, 1988). Biostratigraphic work by D.C. Prowell (U.S. Geological Survey, written commun., 1989) indicates that the upper part of the Black Creek aquifer is equivalent to the Donoho Creek Formation (Black Creek

Group) described by Sohl and Owens (1989). Prowell also found that the middle and lower geologic units of the aquifer are equivalent in age to the Bladen and Tar Heel Formations (Black Creek Group), respectively, described by Sohl and Owens (1989).

Designation of the top of the Black Creek aquifer has differed among authors. Aucott and others (1987) locally included sediment from the overlying formations, such as the Peedee Formation or Tertiary-age water-bearing sediment in the Black Creek aquifer. Alternatively, Colquhoun and others (1983) separated the Peedee aquifer system from the Black Creek aquifer system in the same general area between Manning and Sumter. Park (1980) mapped the Black Creek and Peedee aquifers east of Sumter County and included sediment from the upper part of the Black Creek Group in the Peedee aquifer. The approach used in this investigation is to assign sandy sediment from the Peedee Formation to the Peedee aquifer and sandy sediment from the Black Creek Group to the Black Creek aquifer in the immediate vicinity of the facility. The separation is based on biostratigraphic control and on the presence of a confining unit between the two aquifers in the wells installed during this investigation. The top of the Black Creek Group dips toward the south or southeast in the vicinity of the facility (fig. 21).

The lithology of the Black Creek aquifer at the Manchester-1 well site can be divided into three depositional sequences. Work by Prowell (1990) shows that the sequences are deltaic and represent a transition from lower delta plain to prodelta and shallow delta-front conditions.

The deepest sequence encountered at the Manchester-1 well site was in the interval 542 to 725 ft below land surface (371 to 554 ft below sea level). The sediment represents deposition on a lower delta plain and is characterized by thick (30 to 80 ft) beds of loose sand separated by thinner (10 to 20 ft) beds of carbonaceous clay. The 80-ft thick bed of sand contains thin (1 to 2 ft) layers of carbonaceous clays spaced at about 5- to 10-ft intervals. The sand is fine to very coarse grained, poorly sorted, and contains gravel and pyritized lignite. The clay in the lower sequence ranges from light-tan and gray colored to dark brown and brown-gray. Pale-green clay also was encountered. The clay is highly fractured.

The middle zone, encountered at a depth of 389 to 541 ft below land surface (271 to 370 ft below sea level), is a delta-front deposit, consisting of sand and laminated carbonaceous clay. Most of the sand is in a 35-ft thick sequence at the top of the middle zone. It is very fine- to fine-grained quartz sand with mica, glauconite, granular phosphate, and lignite. Thin (1 ft) beds of carbonaceous clay occur within the sand zone. The lower 80 percent, approximately, of the middle zone is dominated by gray to black carbonaceous clay laminated with fine- to very fine-grained quartz sand. The clay becomes sandier near the base, where cross-bedding is evident. Associated minerals include glauconite, mica, granular phosphate, and lignite.

The uppermost sequence, penetrated at a depth of 258 to 388 ft below land surface (87 to 218 ft below sea level) represents a deltaic system prograding from prodelta to shallow delta front. The lower 31 ft contains

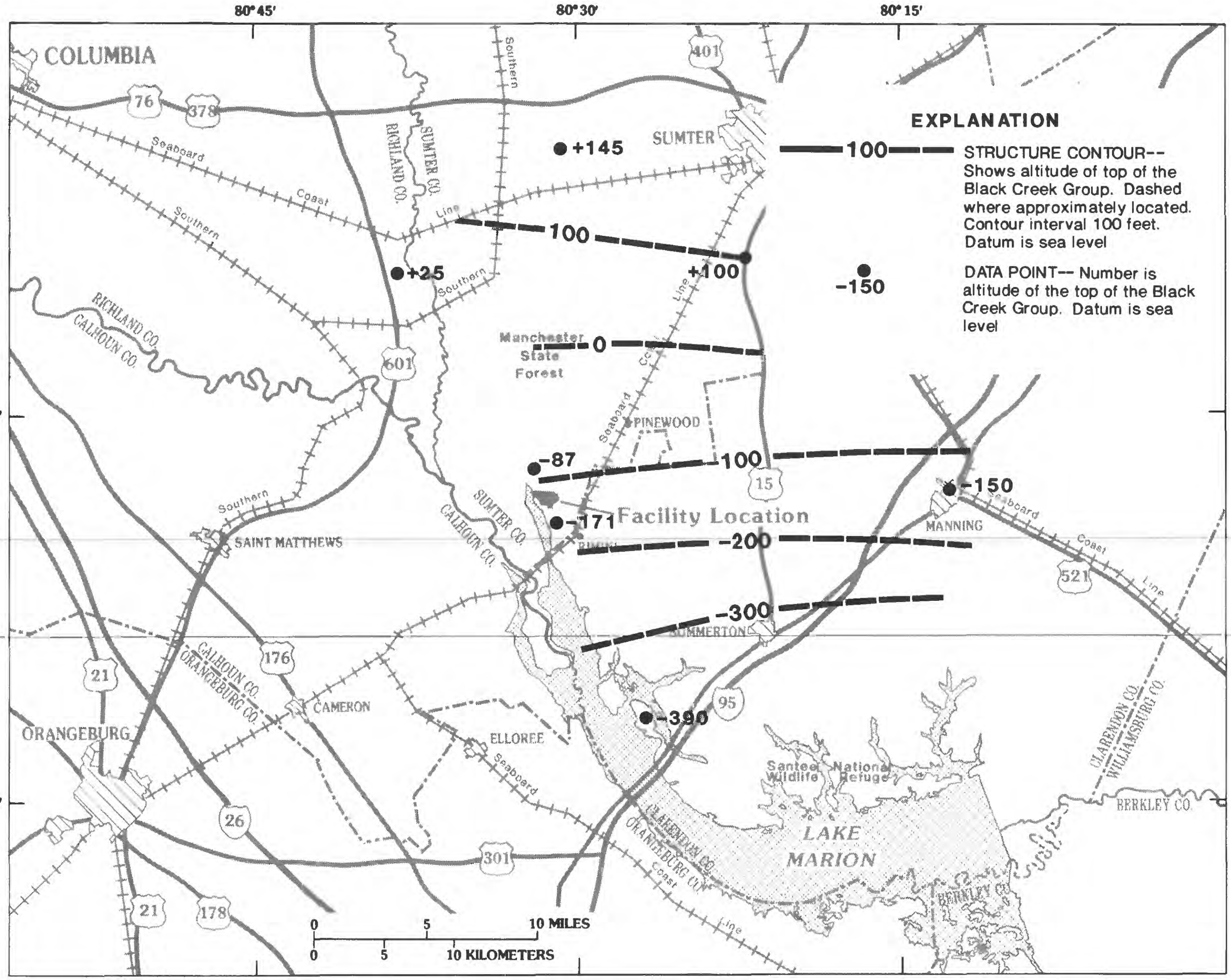


Figure 21.--Altitude of the top of the Black Creek Group.

dark-green silty to sandy clay with thin (less than 1 ft) beds of limestone and marl. The sediment grades upward into beds of fine-grained, cross-bedded quartz sand (3 to 11 ft thick) and thin (2 to 6 in.) beds of carbonaceous clay containing shell molds. Associated minerals include mica, glauconite, phosphatic grains, and heavy minerals. X-ray analysis of the clay shows that it is dominantly illite/smectite with lesser amounts of kaolinite (Prowell, 1990).

The upper 56 ft of the aquifer is dominantly fine- to very fine-grained, well-sorted quartz sand. Carbonaceous clays are present as laminae near the base, and light-gray to green clay is present as matrix in the upper half. Associated minerals include mica, glauconite, small phosphatic grains, garnet, monazite, feldspar, and heavy minerals. Shark teeth are present near the base, and pyritized lignite is present in the upper half of the section.

The Black Creek aquifer is a multiaquifer system. Several discrete sand horizons were penetrated in a 367-ft section of the aquifer at the Manchester-1 well site. Individual sand bodies range in thickness from 79 ft to less than 10 ft. Although no wells installed during this investigation penetrate the entire Black Creek aquifer, the thickness of the aquifer in the study area can be derived from regional studies, which show the thickness to be about 370 ft near Manning (Colquhoun and others, 1983) and about 440 ft thick at well SU-155 (fig. 3) near Sumter (D.C. Prowell, U.S. Geological Survey, written commun., 1989). Near Pinewood at well SU-151B, the sediment comprising the Black Creek Group is about 375-ft thick, with the lower 40 ft being dominantly clay (fig. 3). Thus, the thickness of the Black Creek aquifer beneath the facility probably ranges from 360 to 440 ft.

Recharge to the Black Creek aquifer occurs in the interstream areas in the Black Creek Group outcrop, and discharge occurs as baseflow to streams. Sediment from the Black Creek Group is exposed along the Congaree River north and northeast of Big Beaver Creek (D.C. Prowell, U.S. Geological Survey, oral commun., 1990) (fig. 1). The outcrop area extends northeastward, generally toward Sumter. The boundaries of the outcrop and subcrop area of the Black Creek Group are not shown on a map in this report because they have not been mapped in sufficient detail; however, the approximate location is apparent in figure 22 as recharge and discharge areas north and northeast of the junction of the Congaree and Wateree Rivers.

The distribution of hydraulic head in the Black Creek aquifer indicates that ground-water movement is dominantly toward discharge areas in the the valleys of the Congaree, Wateree, and Santee Rivers. Part of the water recharging the aquifer moves downdip to confined portions of the aquifer.

Ground water in the Black Creek aquifer in the vicinity of the facility is moving toward Lake Marion. Ground-water levels on the opposite (southwestern) side of Lake Marion are 10 to 20 ft higher than water levels near the facility at the Rimini-well cluster, indicating that ground water

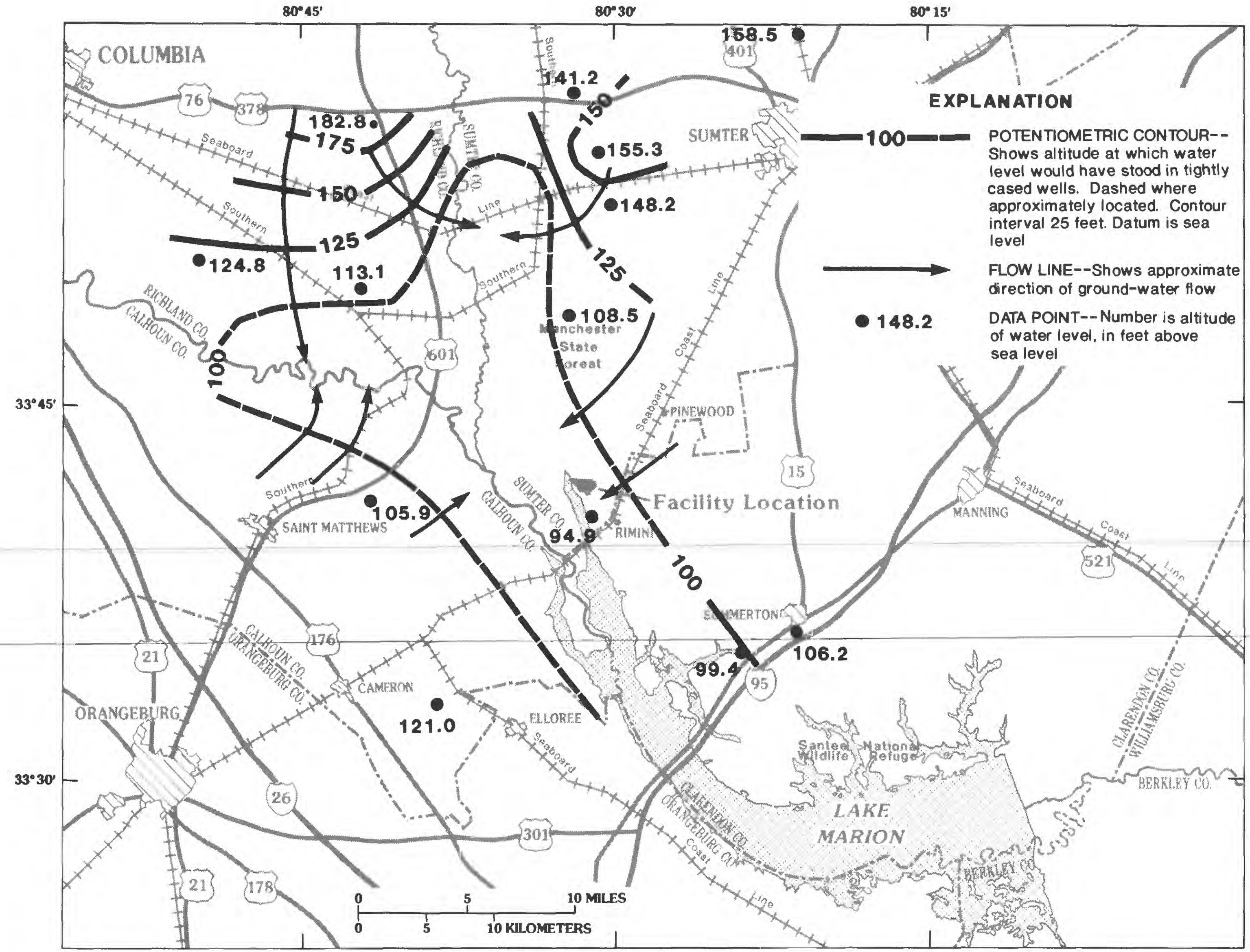


Figure 22.--Potentiometric surface of the Black Creek aquifer, 1989.

in the Black Creek aquifer probably does not flow westward under the lake from the facility. There is uncertainty associated with this conclusion, however, because in a regional examination of a multiaquifer system, such as the Black Creek aquifer, it is often not clear whether the measured water levels represent the same water-bearing zones. It is unlikely that substantial discharge occurs to the lake near the facility because the aquifer is deep (approximately 150 ft below the lake) at that site. Ground-water movement in the Black Creek aquifer beneath the lake may be northwestward toward the regional discharge areas in the Wateree and Congaree River valleys as described by Aucott and others (1987) or southeastward toward the deeper flow system.

No aquifer tests were done in the Black Creek aquifer during this investigation; however, transmissivity values for the Black Creek aquifer near the study area have been reported (Aucott and Newcome, 1986). A transmissivity of 7,000 $ft^2/d$ was reported for the combined Middendorf-Black Creek aquifers in Sumter; 4,200 $ft^2/d$ for the Black Creek aquifer at Shaw Air Force Base, and 1,900 $ft^2/d$ for the Black Creek aquifer at Eastover (well RIC-52).

The Black Creek aquifer provides part of the ground water used for public supply in Sumter, Manning, and Summerton (fig. 1). At least one irrigation well, located between Pinewood and Sumter, is screened in the Black Creek aquifer.

## GROUND-WATER QUALITY

During this investigation, water samples from the surficial aquifer were collected for chemical analysis from wells Manchester-1F, Railway-1D, Rimini-1E, and from the combined surficial aquifer and Lang Syne water-bearing zone at well Lake Marion-2B (appendix C). Concentrations of cadmium exceeding the U.S. Environmental Protection Agency (USEPA) (1987) Maximum Contaminant Level (MCL) of 10 µg/L were detected in water from well Lake Marion-2B on two out of a total of four sampling dates. On one out of a total of four sampling dates, water from the well contained chromium at a concentration exceeding the USEPA MCL of 50 µg/L (Feb. 1990); however, there is uncertainty associated with the analysis because laboratory results from analyses of three split samples collected from well Lake Marion-2B during the February 1990 sampling showed a range of chromium concentrations from 16 to 90 µg/L. Water from wells Lake Marion-2A and Lake Marion-2B contained lead concentrations exceeding the USEPA MCL of 50 µg/L during the January 1990 sampling but not on other sampling dates (appendix C).

The pH of water in all of the wells in the surficial aquifer was at or below the secondary maximum contaminant level (SMCL) lower limit of 6.5 to 8.5 for drinking water established by the USEPA (1987). Field-measured pH values of water in the background wells in the surficial aquifer were 4.8 in well Manchester-1F (north of facility), 5.3 in well Railway-1D (east of the facility) and 6.5 in well Rimini-1E (south of the facility). The pH of water in the combined surficial aquifer and Lang Syne water-bearing zone downgradient from the landfill at well Lake Marion-2B was 4.1 to 4.3.

Concentrations of iron (395 mg/L, in February 1990) sulfate (380 to 1,465 mg/L), and manganese (4,700 to 14,100 µg/L) in water from well Lake Marion-2B exceeded the USEPA SMCLS (0.3 mg/L, 250 mg/L, and 50 µg/L, respectively).

The low pH values in water from background wells in the surficial aquifer are largely the result of infiltration of rainwater. Measurements by the USGS of pH in rainfall during 1989 typically ranged between 4.1 and 5.5 at the Santee National Wildlife Refuge, approximately 20 miles southwest of the facility (National Atmospheric Deposition Program, 1988).

The probable source for the excessive concentrations of iron and sulfate in water from well Lake Marion-2B is dissolution of pyrite in the opaline claystone that has been excavated from sites in the facility and stored near the well. When exposed to oxygen, pyrite can be oxidized to ferrous iron and sulfuric acid, which can contribute to the low pH values found in well Lake Marion-2B. Additional evidence of the presence of leachable sulfate in the sediment is the reported precipitation of gypsum (calcium sulfate) on the claystone as it dries out (Environmental Technology Engineering, Inc., 1988a).

Excessive concentrations of iron and manganese occur in the surficial aquifer at the Rimini-1 well cluster where the ground water contains no dissolved oxygen and reactions are methanogenic (Chapelle and Lovely, 1990). Iron concentrations as high as 16.9 mg/L and manganese concentrations as high as 660 µg/L in water from well Rimini-1D, are probably due to the leaching of iron and manganese from grain coatings in the aquifer matrix under low-Eh conditions.

The analytical inconsistencies imply that the cadmium, chromium, and lead results may have been affected by sample contamination or analytical error; however, alternate hypotheses for sources of cadmium and chromium are discussed below. Contribution by the well-casing material is a possibility because both cadmium and chromium have been shown to leach from stainless steel in low-pH environments (Parker and others, 1990). Some uncertainty in the analytical data from the wells within the facility also should be noted because those wells are constructed of stainless steel (Environmental Technology Engineering, Inc., 1987). Continued monitoring using a pvc-cased well or wells, could help to evaluate the influence of casing material. Another possibility is that the constituents are present in the ground water. Cadmium and chromium were not detected in nearby surficial-aquifer well WT-11 within the facility when the well was sampled and analyzed by Environmental Technology Engineering, Inc. in November 1989. Cadmium and chromium occasionally have been detected, however, in water from wells completed in the Lang Syne-Sawdust Landing aquifer within the facility upgradient from well Lake Marion-2B (Environmental Technology Engineering, Inc., 1988a, 1989; GSX Services of South Carolina, 1990). Although well Lake Marion-2B obtains most of its water from the surficial aquifer, the screened interval is also open to the Lang Syne water-bearing zone.

Ground-water contamination by volatile organic compounds has been reported in the surficial aquifer within the facility north of section I and east of section II (Environmental Technology Engineering, Inc, 1988b).

The contaminants include chlorinated ethanes and ethylenes, as well as toluene and ethyl benzene. Average concentrations of selected volatile organic compounds during 1988 were 40,800 µg/L of tetrachloroethylene, 1,580 µg/L of 1,1,1-trichloroethane, 1,530 µg/L of trans 1,2-dichloroethylene, and 495 µg/L of trichloroethylene. Detailed water-table maps of the contaminated area constructed by Environmental Technology Engineering, Inc. (1989) show that most of the shallow ground water in the contaminated area discharges to streams within the facility that drain to Lake Marion.

Ground-water in all three of the water-bearing zones of the Lang Syne-Sawdust Landing aquifer contained iron and manganese concentrations exceeding USEPA SMCL's (0.3 mg/L and 50 µg/L, respectively). In the wells installed during this investigation, the concentrations of iron ranged from 0.02 to 0.34 mg/L in the Lang Syne water-bearing zone. Higher concentrations of iron (74 to 395 mg/L) were obtained in water from well Lake Marion-2B. Iron concentrations ranged from 0.01 to 3.9 mg/L in the lower Sawdust Landing water-bearing zone and 1.0 to 16.9 mg/L in the upper Sawdust Landing water-bearing zone (wells Manchester-1D and Rimini-1D). The concentration of manganese ranged from 30 to 360 µg/L in the Lang Syne water-bearing zone. Manganese concentrations ranged from less than 10 to 90 µg/L in the lower Sawdust Landing water-bearing zone and from 160 to 660 µg/L in the upper Sawdust Landing water-bearing zone.

The range of pH in water from wells in the Lang Syne-Sawdust Landing aquifer (5.6 to 11.1) includes values outside of the USEPA SMCL range of 6.5 to 8.5 for drinking water. The excessively high values (9.1 and 11.1) may be due to problems encountered during well installation resulting in partial grouting of the well screens.

Ground water from several wells screened in the Lang Syne-Sawdust Landing aquifer within the facility have been reported to contain halogenated organic compounds. Water from well PSDL-21 screened in the Lang Syne water-bearing zone within the facility contained 480 to 500 µg/L total halogenated organic compounds (GSX Services of South Carolina, 1990). Water from well SL-13, adjacent to well PSDL-21 but screened in a deeper sand, contained 56 µg/L chromium, which is greater than the MCL of 50 µg/L, and 31 µg/L of total halogenated organic compounds. Well SL-1, screened in the Lang Syne water-bearing zone at the northwestern corner of section I contained 14 µg/l of total halogenated organic compounds (GSX Services of South Carolina, 1990). Halogenated organic compounds were not detected in water from wells completed in the Lang Syne-Sawdust Landing aquifer downgradient from the landfill during this investigation.

Ground water in wells screened in the Peedee aquifer in the study area contained iron in concentrations ranging from 0.63 to 1.8 mg/L exceeding the USEPA SMCL of 0.3 mg/L for drinking water. However, locally high concentrations of iron occur naturally in the Cretaceous-age aquifers in South Carolina.

No observation wells installed during previous investigations of the facility extended to the Black Creek aquifer, and of the wells drilled during this investigation, only well Rimini-1A extended to the Black Creek aquifer. No constituents were found in water from this well at concentrations greater than USEPA MCLs or SMCL's for drinking water.

## SUMMARY

Hydrogeologic units and ground-water quality in the vicinity of a hazardous-waste landfill near Pinewood, South Carolina were investigated during 1987-90. Upland fluvial deposits and the Santee alluvium compose a surficial, water-table aquifer over much of the area, but are locally confined where clay overlies the water-bearing zone. The aquifer in the vicinity of the landfill facility is absent in areas where the underlying clay crops out and where the sandy material has been excavated and removed during site operations. Ground water in the surficial aquifer is moving toward streams and Lake Marion at a rate of about 14 to 55 ft/yr.

The opaline-claystone confining unit underlies the surficial aquifer. The confining unit is continuous in most of the facility, but it thins and is locally absent west and southwest of the facility. The unit thickens northeastward and eastward across the facility, and is 124 ft thick at the Railway-1 well site.

The basal sand in the Lang Syne Member of the Williamsburg Formation and water-bearing zones in the underlying Sawdust Landing Member of the Rhems Formation are considered in this report to compose the Lang Syne-Sawdust Landing aquifer. The Lang Syne-Sawdust Landing aquifer is divided into the Lang Syne, the upper (or secondary) Sawdust Landing, and the lower (or primary) Sawdust Landing water-bearing zones, listed from shallowest to deepest. The water-bearing zones of the aquifer are hydraulically connected in the eastern part of the facility and east of the facility.

The Lang Syne water-bearing zone is a sand facies (typically 2-6 ft thick) at the base of the opaline claystone. The upper Sawdust Landing water-bearing zone is composed of discontinuous sand or sandy clay lenses. The lower Sawdust Landing water-bearing zone within the facility is coarser grained and more continuous than the sand bodies in the upper Sawdust Landing water-bearing zones. Limited vertical hydraulic interconnection exists among individual water-bearing zones of the Lang Syne-Sawdust Landing aquifer near the center of the facility.

Ground-water movement in the Lang Syne water-bearing zone in the central and western parts of the facility and east of the facility is southwestward, toward Lake Marion. If occurrences of the zone in the eastern part of the facility are hydraulically continuous with occurrences of the zone in the central and western parts of the facility, then there is a localized component of ground-water movement from eastward from the central part of the facility toward the potentiometric low in the eastern part of the facility. The average rate of ground-water movement in the Lang Syne water-bearing zone is probably less than 2 ft/yr. The average ground-water velocity in the lower Sawdust Landing water-bearing zone in the interval between wells CBC-11 and Lake Marion-2A is 2 to 64 ft/yr.

In areas where the opaline claystone is thin and fractured, contaminants leaking from the landfill into the claystone would probably migrate downward to the Lang Syne water-bearing zone. Such areas occur between, and probably beneath, sections 1 and II of the landfill. Once in the Lang Syne water-bearing zone, contaminants could be expected to migrate

laterally until discontinuities in one of the bounding confining units allowed discharge of water out of the zone. Such contamination ultimately would be transported toward Lake Marion, despite potential temporary movement in the opposite direction in parts of the Lang-Syne water-bearing zone. If the contaminants were in the form of free product denser than water, such as a concentrated pulse of chlorinated organic solvent, the transport direction would depend on the slope of the confining unit beneath the water-bearing zone and would probably be eastward.

The Peedee confining unit is composed of light-gray, sandy clay from the upper part of the Cretaceous Peedee Formation. It is present in all wells drilled for this investigation and ranges in thickness from 2 to 25 ft. The vertical hydraulic conductivity of this unit ranges from $1.0 \times 10^{-5}$ to $3.3 \times 10^{-4}$ ft/day.

The Peedee aquifer is composed of sediment formerly considered to be part of the Black Creek Formation but now known to be from the upper part of the Upper Cretaceous Peedee Formation. Ground water in the aquifer moves generally northwestward beneath the facility. The Peedee aquifer does not appear to be hydraulically connected to the overlying Lang Syne-Sawdust Landing aquifer in the facility.

The Black Creek confining unit is composed of clay to clayey sand from the lower part of the Peedee Formation. The thickness of the unit is about 72 ft at the two wells penetrating it. The vertical hydraulic conductivity of this unit is $1.7 \times 10^{-5}$ to $3.6 \times 10^{-4}$ ft/day.

The Black Creek aquifer is a multiaquifer system and is the deepest hydrogeologic unit investigated during this study. Ground-water movement in upgradient areas is dominantly toward discharge areas in the valleys of the Congaree, Wateree, and Santee Rivers.

Several water-quality characteristics in water from some wells in the surficial aquifer that were sampled during this investigation did not comply with drinking water standards. The pH values for water from the surficial aquifer commonly are less than the recommended range (6.5 to 8.5) for use as drinking water. The low pH values are caused partly by infiltration of low-pH rainwater into the aquifer.

The probable source for the excessive concentrations of iron and sulfate in well Lake Marion-2B, which receives water from both the surficial aquifer and the Lang Syne water-bearing zone, is dissolution of pyrite present in the opaline claystone that has been excavated from sites in the facility and stored near the well. This also contributes to the low pH of water in well Lake Marion-2B.

Ground water in several wells completed in the Lang Syne-Sawdust Landing aquifer during this investigation contained water with iron concentrations exceeding the USEPA SMCL of 0.3 mg/L. Cadmium, chromium, and lead were detected in well Lake Marion-2B, and lead was detected in well

Lake Marion-2A; however, analytical inconsistencies imply the possibility of sample contamination or laboratory error.

Ground water in wells completed in the Peedee aquifer in the study area contained iron concentrations ranging from 0.63 to 1.8 mg/L, which exceeded the USEPA SMCL of 0.3 mg/L for drinking water. Ground water in the one well in the Black Creek aquifer that was sampled, Rimini-1A, contained no constituents in concentrations that exceeded USEPA MCL's or SMCL's for drinking water.

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## APPENDIXES

A. Descriptive Logs of Cores from U.S. Geological Survey Wells Installed During This Investigation.

B. Physical Properties of Core Samples.

C. Chemical Analyses of Ground Water, October 1988 through February 1990.

## APPENDIX A

Descriptive logs of cores from U.S. Geological Survey wells installed during this investigation.

Site: Lake Marion-1
Altitude of land surface: 86 ft.

| | Depth (feet) | Thickness (feet) |
|---|---|---|
| Sandy Clay: fine-medium, poorly sorted, angular quartz sand in brown/light, gray kaolin matrix, massive to poorly bedded; accessory minerals include mica and dark heavy minerals; unit is sandier with depth and has a thin (12 in.) gravel bed at the base. | 15 | 15 |
| Clayey Sand: fine, well-sorted quartz sand and silt in a matrix of dark-green/gray clay; massive to poorly bedded; accessory minerals include fine mica and glauconite; bryzoans at 19 ft; silicified bed of coarse sand and lignite at 24 ft. | 24 | 9 |
| Sandy Clay: massive light-green clay with minor amounts of angular to rounded quartz sand, fine mica, garnet, pyrite, and dark heavy minerals; green clay changes to darker yellow/green with exposure to air. | 42 | 18 |
| Sandy Clay: dense light-green clay containing moderate amounts of fine - very coarse quartz sand, feldspar, and mica with small amounts of rounded smokey quartz gravel; reddish stains in core at 55 ft and 60 to 65 ft suggest iron oxide minerals; pale-green clay changing to darker yellow/green suggests illite/smectite composition; thin layer of fine gravel (6-12 in.) is present at base of unit (66 ft). | 66 | 24 |
| Clay to Sandy Clay: pale-gray plastic kaolinitic clay containing small amounts of fine quartz sand and silt; thin, clayey sand beds are present at 69 and 75 ft and are composed of poorly sorted, fine-very coarse, angular quartz sand in a kaolin matrix; accessory minerals include garnet, monazite, and dark, heavy minerals. | 82 | 16 |
| Sand: fine-coarse, subangular quartz in a carbonaceous clay matrix; accessory minerals include abundant large mica, minor amounts of feldspar, garnet, and dark, heavy minerals; thin (1-2 ft) carbonaceous silty, clay beds are present about every 10 ft. | 148 | 66 |
| Silty Clay: dark-green/gray carbonaceous clay containing fine quartz sand and silt; accessory minerals include mica and dark, heavy minerals with some feldspar and garnet. | 170 | 22 |

Descriptive logs of cores from U.S. Geological Survey wells installed during this investigation.

Site: Lake Marion-1
Altitude of land surface: 86 ft.

| | Screen depths (feet) | Altitude of measuring point (feet) |
|---|---|---|
| Lake Marion 1A (SU-290) | 122 to 127 | 89.41 |
| Lake Marion 1B (SU 291) | 59.3 to 64.3 | --- |
| Lake Marion 1C (SU-292) | 20.5 to 25.5 | 87.63 |
| Lake Marion 1D (SU-293) | 60 to 65 | 87.38 |

APPENDIX A--Continued

Descriptive logs of cores from U.S. Geological Survey wells installed during this investigation.

| | Depth (feet) | Thickness (feet) |
|---|---|---|
| Site: Lake Marion-2<br>Altitude of land surface: 82 ft | | |
| No recovery | 2 | 2 |
| Clayey Sand: fine to very coarse, angular to subangular poorly sorted quartz, in brown to pale-gray clay matrix; accessory minerals include mica, feldspar, monazite, garnet and dark heavy minerals; generally clayey at top and sandier towards base; a 2-ft thick bed of very coarse quartz gravels and cobbles marks base of unit. | 17 | 15 |
| Claystone: well-laminated carbonaceous clay and very fine white quartz sand and silt; accessory minerals include abundant mica, pyrite, garnet, and fine dark heavy minerals; slickensides on fracture at 18 ft; 2 in. of white sand at the base of the unit. | 19 | 2 |
| Sandy Clay: fine to very coarse, angular quartz sand in dense pale-green clay matrix; accessory minerals include large white feldspars, mica, garnet, rutilated quartz, and dark heavy minerals; small gravels at 26 ft and very clayey from 26 to 32 ft; unit gets sandier with depth; loose sand from 50 to 54 ft; some zones stained red/purple. Coarse quartz/garnet/feldspar layer marks base of unit. | 54 | 35 |
| Sandy Clay: fine to coarse angular quartz sand in white to light-gray kaolin matrix; accessory minerals include minor feldspar, mica, garnet, pyritized wood, smokey quartz, monazite, rutilated quartz, and dark heavies; abundant lignite. | 66 | 12 |

| | Screen depths (feet) | Altitude of measuring point (feet) |
|---|---|---|
| Lake Marion - 2A (SU-294) | 50 to 55 | 84.58 |
| Lake Marion - 2B (SU-295) | 14.5 to 19.5 | 84.68 |

APPENDIX A--Continued

Descriptive logs of cores from U.S. Geological Survey wells installed during this investigation.

| | Depth (feet) | Thickness (feet) |
|---|---|---|
| Site: Manchester-1<br>Altitude of land surface: 171 ft | | |
| Clayey Sand: fine to coarse, poorly sorted, angular sand in red/orange clay matrix; no mica or feldspar. | 19 | 19 |
| Clayey Sand: fine to coarse, poorly sorted, sub-angular to angular quartz sand in white clay matrix; accessory minerals include mica, feldspar, and fine-grained dark opaques; evidence of crossbedding; one-foot thick layer of large quartz gravel (2 in.) at base. | 26 | 7 |
| Silty Clay: fine sand and silt, well-sorted, quartz in a dark gray-green clay matrix; well - laminated even beds about 0.25 to 1.0 in. thick; one-foot thick beds of silicified bivalve shells and silicified fine to very coarse sand at top of unit; accessory minerals in bulk of unit are mica, pyrite, glauconite, fine-grained opaques and carbon fragments; also noted in this unit are shell mold fine burrows (at 62-66 ft), steeply inclined fractures (some with slickenslides (72-76 ft)), and conchoidal fracturing. | 80 | 54 |
| Lag Bed, Sand: fine to medium sub-rounded quartz in dark-green clay matrix; some coarse grains and well-rounded quartz gravel; accessory minerals include mica, glauconite, garnet, and a few fossil fragments. | 83 | 3 |
| Lag Bed, Sandy Clay: fine to coarse, poorly-sorted quartz sand in light-green clay matrix; accessory minerals include large micas, feldspars, and opaque heavy minerals. | 86 | 3 |
| Clayey Sand: fine to very coarse, poorly sorted, angular quartz sand in pale-green/gray clay matrix; accessory minerals include large feldspars, large mica, rutilated quartz, garnet, pyrite, and opaque heavy minerals; some small beds of quartz grit and beds of smoky quartz and feldspar gravel are present; small-scale crossbedding and minor amounts of lignite and pyritized wood are also present; unit is very sandy from 100 to 109 ft and 129 to 131 ft and very clayey from 82.5 to 86 ft and 109 to 116 ft. | 131 | 45 |

APPENDIX A--Continued

Descriptive logs of cores from U.S. Geological Survey wells installed during this investigation.

Site: Manchester
Altitude of land surface: 171 ft

| | Depth (feet) | Thickness (feet) |
|---|---|---|
| Sandy To Silty Clay: fine, sub-rounded, well-sorted quartz sand and silt in light gray kaolin; accessory minerals include mica, rutilated quartz, garnet, monazite, pyrite, and fine-grained dark heavy minerals; generally stained with red oxidation in upper 10 ft; lower zones contain moderate amounts of lignite, carbonaceous clays, and pyritized wood. | 156 | 25 |
| Sand: fine to very coarse, moderately sorted, sub-angular quartz sand in a slight kaolin matrix; accessory minerals include medium to large mica flakes, pyrite, rutilated quartz, garnet monazite, pyritized wood, and fine-grained dark heavy minerals. | 186 | 30 |
| Clay and Fine Sand: carbonaceous clay laminated with fine, sub-angular, well-sorted quartz sand and silt; accessory minerals include abundant white mica, garnet, minor feldspar glauconite, biotite, and granular phosphate; lignite fragments are abundant; and brown chert fragments were found at 193 ft, and bivalve and gastropod molds at about 206 to 215 ft; a thin bed of phosphatic material is present at the base of the unit at 258 ft. | 258 | 72 |
| Sand: very fine to fine, sub-angular to sub-rounded, well-sorted quartz sand; accessory minerals include abundant mica and glauconite, small phosphatic grains, garnet, monazite feldspar, and fine-grained dark heavy minerals; large lignitic fragments are common and many show signs of pyritization; a light-gray/green clay matrix binds the sand grains and is most prominent in the middle of the unit. | 295 | 37 |
| Fine Sand and Clay: sub-angular, well-sorted quartz sand laminated with carbonaceous clays; accessory minerals include glauconite, fine-grained dark heavy minerals, mica, and granular phosphate; cross-beds, shell molds, and shark teeth are also present; phosphate-pebble bed is present at base of unit. | 314 | 19 |

APPENDIX A--Continued

Descriptive logs of cores from U.S. Geological Survey wells installed during this investigation.

| | Depth (feet) | Thickness (feet) |
|---|---|---|
| Site: Manchester-1<br>Altitude of land surface: 171 ft | | |
| Clay and Fine Sand: beds of carbonaceous clay (2 to 6 in. thick) containing thin quartz sand laminae interbedded with thick (3 to 5 ft) beds of sub-angular, well-sorted, very fine to fine quartz sand; accessory minerals include fine to coarse mica abundant glauconite, fine-grained phosphatic grains, fine-grained dark heavy minerals; shell molds are present in clay layers and cross-bedding and bioturbation is present in sandy layers. | 358 | 44 |
| Sandy Clay and Limestone: dark-green silty to sandy clay containing sub-angular, well-sorted quartz sand; thin (6 to 12 in.) beds of limestone and marl are present throughout the unit; granular phosphate and mica are also present; aragontic bivalve and gastropod shells are common. | 389 | 31 |
| Sand: very fine to fine, sub-rounded, well-sorted quartz sand; accessory minerals include mica, glauconite and granular phosphate; cross-bedding is present in thin layers and very lignitic, thin sand beds are common; a thin bed of phosphate pebbles marks the base of the unit; thin (12 in.) carbonaceous clay beds at depths of 406 ft, 411 ft, and 414 ft. | 415 | 26 |
| Sand: very fine to fine, sub-rounded, well-sorted quartz sand with lignitic fragments, abundant mica, and minor amounts of glauconite and granular phosphate. | 424 | 9 |
| Clay and Fine Sand: very carbonaceous sandy clay laminated with very fine to fine, sub-rounded quartz sand; accessory minerals include abundant glauconite, mica, granular phosphate, and fragments of lignite; shell molds are common above 445 ft and small crossbeds are present below 445 ft; pyritized lignite and leaf fragments are present in the lower 10 ft of the unit. | 542 | 118 |
| Clay: slightly silty, micaceous, light tan/gray to pale-green clay; evidence of extreme fracturing and leached organic matter. | 561 | 19 |

Descriptive logs of cores from U.S. Geological Survey wells installed during this investigation.

| | Depth (feet) | Thickness (feet) |
|---|---|---|
| Site: Manchester-1<br>Altitude of land surface: 171 ft | | |
| Sand: very fine to fine, sub-angular to sub-rounded well-sorted quartz; accessory minerals include abundant mica, some glauconite, rutilated quartz, pyrite, and fine-grained dark heavy minerals; beds of lignitic fragments and thin beds of very carbonaceous clay are also present; crossbedding and small-scale slump faults (1 in.) are also present. | 593 | 32 |
| Clay: Dark-brown to brown-gray plastic and sticky, no sand or silt, minor mica, highly fractured. | 611 | 18 |
| Sand: fine to very course, subangular, poorly sorted quartz; accessory minserals include mica, feldspar, and fine, dark heavy minerals; some sand layers are rich in lignite, much of which is pyritized; carbonaceous clays occur in thin (1 to 2 ft) beds spaced every 5 to 10 ft; cross-bedding is evident in sands in upper unit. | 665 | 54 |
| Sand: fine to very coarse, subangular poorly sorted, quartz; accessory minerals include mica, feldspar, rutilated quartz, monzite, and dark, heavy minerals; abundant pyrite and large lignite fragments also present; unit also contains small, rounded, smoky quartz gravel; thin carbonaceous clay bed at about 675 ft. | 690 | 25 |
| Clay: carbonaceous clay laminated with very fine to fine quartz sand; abundant mica and lignitic material. | 699 | 9 |
| Sand: fine to very coarse, angular, poorly sorted quartz; accessory minerals include mica, garnet, monazite, and dark, heavy minerals; loose nature suggests almost no clay matrix. (Poor recovery) | 725 | 26 |

APPENDIX A--Continued

Descriptive logs of cores from U.S. Geological Survey wells installed during this investigation.

Site: Manchester-1
Altitude of land surface: 171 ft

| | Screen depths (feet) | Altitude of measuring point (feet above sea level) |
|---|---|---|
| Manchester-1A (SU-296) | 285 to 295 | 174.06 |
| Manchester-1A (SU-296) | 395 to 405 | --- |
| Manchester-1B (SU-297) | 159 to 189 | 173.42 |
| Manchester-1C (SU-298) | 119 to 129 | 173.21 |
| Manchester-1D (SU-299) | 94 to 104 | 173.69 |
| Manchester-1E (SU-300) | 72 to 82 | 173.43 |
| Manchester-1F (SU-301) | 25 to 30 | 173.48 |

Descriptive logs of cores from U.S. Geological Survey wells installed during this investigation.

| | Depth (feet) | Thickness (feet) |
|---|---|---|
| Site: Rimini-1<br>Altitude of land surface: 90 ft. | | |
| <u>Sand</u>: fine to very coarse, angular, poorly sorted in matrix of pale to gray sticky clay; several very coarse gravel layers and one bed of dark-gray clay mark base of unit. | 28 | 28 |
| <u>Siltstone</u>: well-sorted silt, clay, and fine sand, in pale yellow-green clay matrix; low density of samples suggests low clay percentage in matrix; samples are highly fractured (conchoidal) partial silification in matrix. | 42 | 14 |
| <u>Sand</u>: fine to medium, well-sorted quartz, sub-angular grains, in pale-green clay matrix; Accessory minerals include mica, feldspar, and unidentified dark heavy minerals. | 71 | 29 |
| <u>Sandy Clay</u>: probably kaolin with minor amounts of fine to very coarse quartz sand, tan to off-white color. | 76 | 5 |
| <u>Sand</u>: fine to very coarse, sub-angular, moderate to poorly sorted quartz; accessory minerals include mica, feldspar, garnet, monazite and dark heavy minerals; samples have pale-gray overall color due to smokey quartz sand grains and carbon disseminated in kaolin matrix. | 91 | 15 |
| <u>Sandy Clay</u>: soft kaolin containing fine to coarse quartz sand; accesories include mica, large feldspars, garnet, monazite, and rutilated quartz; samples are high in carbon lignite. | 116 | 25 |
| <u>Sand</u>: fine to very coarse, poorly sorted, sub-angular quartz in matrix of soft kaolin with abundant carbon; accessory minerals include large mica flakes, garnet and dark heavy minerals. Thin (1 to 2 ft) carbonaceous clay layers are present approximately every 10 ft. Sand becomes better sorted and finer grained below 150 ft and is extremely loose. | 180 | 64 |

APPENDIX A--Continued

Descriptive logs of cores from U.S. Geological Survey wells installed during this investigation.

| | Depth (feet) | Thickness (feet) |
|---|---|---|
| Site: Rimini-1<br>Altitude of land surface: 90 ft | | |
| Sandy to Silty Clay: dark-gray to green massive to well-bedded clay containing fine quartz sand and silt, and abundant mica; some beds contain abundant fine carbon, and ammonites are dispersed throughout the strata with concentrations in a few thin beds (e.g., 207 ft); calcium carbonate cement is present from 220 to 230 ft; pyrite and/or animal borrows noted from below 240 ft. | 252 | 72 |
| Sand: fine-medium quartz with well-rounded grains of coarse quartz and phosphatic pebbles; the matrix is dark gray-green clay containing mica. | 253 | 1 |
| Sand: medium to coarse, well-rounded moderately sorted quartz with significant amounts of glauconite and mica; accessory minerals include dark heavy minerals and lignite fragments; a pale gray-green clay forms a weak matrix around the sand and recovery is poor. | 286 | 33 |
| Clayey Silt to Silty Clay: thin (0.25 in.) beds of alternating silt sand and clay, dark-gray to green; mica, fine-grained dark heavy minerals and fine-grained glauconite are also present. | 292 | 6 |
| Clayey Silt to Sand: massive bedding mostly quartz and fine glauconite in a clayey, carbonate-rich matrix; a thin bed of shells and phosphate pebbles marks the basal contact. | 296 | 4 |
| Laminated Clay: dark-gray to black, with a 2 ft thick bed of medium clayey sand from 299 to 301 ft; the sand bed is mostly quartz with glauconite, mica, lignite, and dark heavy minerals; it also contains whole bivalve shells and a slight carbonate cement in the matrix clay. | 300 | 10 |

Descriptive logs of cores from U.S. Geological Survey wells installed during this investigation.

Site: Rimini-1
Altitude of land surface: 90 ft

| | Screen depths (feet) | Altitude of measuring point (feet above sea level) |
|---|---|---|
| Rimini-1A (SU-302) | 252 to 262 | 84.22 |
| Rimini-1B (SU-303) | 129 to 139 | 85.04 |
| Rimini-1C (SU-304) | 80 to 90 | 84.66 |
| Rimini-1D (SU-305) | 44 to 54 | 84.67 |
| Rimini-1E (SU-306) | 31 to 37 | 84.64 |

APPENDIX A--Continued

Descriptive logs of cores from U.S. Geological Survey wells installed during this investigation.

| | Depth (feet) | Thickness (feet) |
|---|---|---|
| Site: Railway-1<br>Altitude of land surface: 163 ft | | |
| Clayey Sand: fine to very coarse, poorly-sorted, angular quartz sand in brown to tan clay matrix; accessory minerals include mica, fine-grained dark heavies, and minor feldspar; upper one-half of unit contains red/orange oxidation stains; bed of coarse quartz gravel (12-in. thick) marks the base of unit. | 33 | 33 |
| UNCOMFORMITY | 152 | -- |
| Silty Clay to Claystone: fine to medium, sub-rounded, well-sorted quartz sand and silty in a dark-green clay matrix; well-laminated beds about 0.1 to 1.0 in. thick; beds from 42 to 52 ft contain shells (abundant at 42 to 44 ft) as does indurated sand bed at 58 to 60 ft; minerals include mica (muscovite and biotite), pryite, fine dark heavies, phosphate and carbon fragments; below 62 ft this formation is a very low density siltstone; upper 5 ft is orange due to oxidation (weathering); basal part of formation consists of two 12 in. beds of coarse clayey sand and fine-grained gravel separated by several feet of black clay; sand layers are poorly-sorted, and contain mica, shell fragments, and shark teeth. | 152 | 119 |
| Lag Bed: sand | 157 | 5 |
| UNCONFORMITY | 164 | -- |
| Sandy Clay: fine to very coarse, poorly-sorted, angular quartz sand in dense pale-green clay matrix; accessory minerals include abundant pyrite, mica, garnets, and dark heavy minerals; unit is fairly uniform with the exception of a 6-in. thick sand bed at 160 ft; top of unit is marked by pyrite-filled fractures; coarse 18 in. sand and gravel bed base. | 164 | 7 |

Descriptive logs of cores from U.S. Geological Survey wells installed during this investigation.

| | Depth (feet) | Thickness (feet) |
|---|---|---|
| Site: Railway-1<br>Altitude of land surface: 163 ft | | |
| UNCONFORMITY | 192 | -- |
| Sandy Clay: fine to medium, moderately-sorted, sub-angular quartz sand in white kaolin matrix; accessory minerals include abundant pyrite, lignite, pyritized lignite, mica, and dark heavy minerals; some clay layers are pale-gray/green to dark gray (generally below 179 ft); carbonaceous clays are well-laminated. | 192 | 28 |
| Sand: fine to very coarse, poorly-sorted, angular quartz sand in a kaolin matrix; accessory minerals include large mica, garnets, feldspar, monazite, pyrite, dark heavies, and abundant lignite (large gragment at 196 ft); matrix is high in dispersed carbon and sand is very loose below 196 ft; evidence of crossbedding in cores. | 216 | 24 |
| Clayey Sand: fine to coarse, moderately sorted, sub-angular quartz in med. gray kaolin matrix; accessory minerals include large micas, garnet, monazite, lignite, and fine dark heavies. Thin bedding, no evidence of crossbeds. | 231 | 15 |

| | Screen depths (feet) | Altitude of measuring point (feet above sea level) |
|---|---|---|
| Railway-1A (SU 316) | 190 to 220 | 166.90 |
| Railway-1B (SU 317) | 159 to 161.5 | 166.61 |
| Railway-1C (SU 318) | 149 to 159 | 166.80 |
| Railway-1D (SU 319) | 20 to 30 | 166.58 |

APPENDIX B

Physical properties of core samples

[--, indicates data not available; OC, indicates opaline claystone confining unit; SDL, indicates confining zone in the Lang Syne-Sawdust Landing aquifer; PD, Peedee confining unit ; BC, Black Creek confining unit]

| Well number | Sample depth (feet below land surface) | Water content (percent) | Dry density (pounds per cubic (feet) | Specific gravity | Porosity (percent) | Hydraulic conductivity (feet per day) | Hydrologic unit |
|---|---|---|---|---|---|---|---|
| Rimini-1A | 72 | 15.6 | 113.5 | 2.56 | 29.0 | $8.2 \times 10^{-6}$ | SDL |
| Rimini-1A | 98 | 18 | 107.2 | 2.63 | 34.7 | $1 \times 10^{-5}$ | PD |
| Rimini-1A | 214 | 29.6 | 93.2 | 2.56 | 39.7 | $1.2 \times 10^{-4}$ | BC |
| Rimini-1A | 248 | 30.1 | 90.9 | 2.54 | 42.7 | $1.7 \times 10^{-5}$ | BC |
| Lake Marion-1A | 41 | 18.2 | 108.5 | 2.6 | 33.1 | $8.1 \times 10^{-5}$ | SDL |
| Lake Marion-1A | 64 | 19.5 | 103.7 | 2.58 | 35.6 | $8.4 \times 10^{-4}$ | SDL |
| Lake Marion-1A | 78 | 16.4 | 114.9 | 2.59 | 28.9 | $1.3 \times 10^{-5}$ | PD |
| Lake Marion-1A | 68 | 31.2 | 91.8 | 2.6 | 43.7 | $3.6 \times 10^{-4}$ | BC |
| Manchester-1A | 48 | 62.2 | 60 | -- | -- | $4.3 \times 10^{-5}$ | OC |
| Manchester-1A | 112 | 15.3 | 118.7 | -- | -- | $5.4 \times 10^{-5}$ | SDL |
| Manchester-1A | 139 | 23.8 | 101.6 | -- | -- | $1.3 \times 10^{-5}$ | PD |
| Manchester-1A | 221 | 28 | 101 | -- | -- | $2.8 \times 10^{-1}$ | BC |
| Lake Marion-2A | 20 | 23.5 | 96 | -- | -- | $2.6 \times 10^{-1}$ | SDL |
| Lake Marion-2A | 25 | 20.8 | 107.7 | -- | -- | $6.2 \times 10^{-4}$ | SDL |
| Railway-1A | 158 | 17.8 | 106.1 | -- | -- | $1.2 \times 10^{-4}$ | SDL |
| Railway-1A | 164 | 18.2 | 109.8 | -- | -- | $3.1 \times 10^{-3}$ | PD |
| Railway-1A | 177 | 27.9 | 96.4 | -- | -- | $1.3 \times 10^{-5}$ | PD |

APPENDIX C

Table C-1.--Major constituents and properties of ground-water samples, October 1988 through February 1990

[All concentrations are for dissolved species and reported in milligrams per liter (mg/L) unless noted otherwise; µS/cm, microsiemens per centimeter; <, less than; ---, data not available]

| Constituent or property | Concentrations in water for indicated wells and sampling date | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Lake Marion 1A | Lake Marion 1C | Lake Marion 1D | Lake Marion 2A | | | Lake Marion 2B | | | |
| | 10/20/88 | 07/19/89 | 07/19/89 | 10/20/88 | 01/30/90 | 03/14/91 | 10/20/88 | 01/30/90 | 02/28/90 | 03/14/91 |
| pH, in units | 7.3 | 7.1 | 8.7 | 7.1 | 6.3 | 7 | 4.3 | 4.1 | 4.1 | 4.2 |
| Specific conductance, lab, in µS/cm | 116 | 214 | 221 | 240 | 148 | 147 | 740 | 1,790 | 1,150 | 1,130 |
| Total alkalinity, as $CaCO_3$ | 45 | 85 | 32 | 76 | --- | --- | <1 | --- | --- | --- |
| Total hardness, as $CaCO_3$ | 37 | 64 | 61 | 26 | --- | --- | 190 | --- | --- | --- |
| Calcium | 11 | 22 | 22 | 7.7 | --- | --- | 51 | --- | 124.45 | --- |
| Magnesium | 2.3 | 2.2 | 1.4 | 1.5 | --- | --- | 16 | --- | 90.25 | --- |
| Sodium | 6.2 | 20 | 10 | 38 | --- | --- | 3.5 | --- | 13.8 | --- |
| Potassium | 5 | 4.3 | 8.8 | 3.5 | --- | --- | 1.8 | --- | .72 | --- |
| Iron | 1.5 | .19 | .02 | .47 | --- | --- | 74 | --- | 395 | --- |
| Bicarbonate | 51 | 103.2 | 38 | .02 | --- | --- | --- | --- | --- | --- |
| Sulfate | 9.7 | 16 | 59 | 33 | --- | --- | 380 | --- | 1,465 | --- |
| Chloride | 1.6 | 2.3 | 1.9 | 3.5 | --- | --- | 8.9 | --- | 11.86 | --- |
| Silica, as $SiO_2$ | 13 | 20 | 6.5 | 14 | --- | --- | 17 | --- | --- | --- |
| Ammonia nitrogen | .06 | .06 | .08 | .09 | --- | --- | .46 | --- | --- | --- |
| Nitrate plus nitrite nitrogen | <.1 | .04 | .02 | <.1 | --- | --- | <.1 | --- | --- | --- |
| Nitrate nitrogen | <.02 | <.04 | <.02 | <.02 | --- | --- | <.02 | --- | .37 | --- |
| Nitrite nitrogen | <.01 | <.01 | .01 | <.01 | --- | --- | <.01 | --- | --- | --- |
| Organic plus ammonia nitrogen | <.2 | .39 | .22 | --- | --- | --- | --- | --- | --- | --- |
| Total phosphorus | .09 | .07 | .05 | .11 | --- | --- | .1 | --- | --- | --- |
| Orthophosphate phosphorus | .02 | .05 | .04 | .09 | --- | --- | --- | --- | --- | --- |
| Hydrolyzable plus orthophosphate phosphorus | .02 | .05 | .04 | .1 | --- | --- | .01 | --- | --- | --- |
| Total organic carbon | .2 | 3.7 | 1.4 | 1.1 | --- | --- | 3.7 | --- | --- | --- |

Table C-1.--Major constituents and properties of ground-water samples, October 1988 through February 1990--Continued

[All concentrations are for dissolved species and reported in milligrams per liter (mg/L) unless noted otherwise; µS/cm, microsiemens per centimeter; <, less than; ---, data not available]

| | Concentrations in water for indicated wells and sampling date | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Manchester 1B 12/15/88 | Manchester 1C 09/08/89 | Manchester 1D 09/08/89 | Manchester 1E 09/08/89 | Manchester 1F 12/15/88 | Rimini 1A 05/12/88 | Rimini 1B 05/12/88 | Rimini 1C 05/12/88 | Rimini 1D 05/12/88 | Rimini 1E 05/12/88 |
| pH, in units | 6.7 | 11.1 | 6.4 | 5.6 | 4.8 | 8.1 | 7.3 | 7.3 | 7.4 | 6.5 |
| Specific conductance, lab, in µS/cm | 140 | 936 | 179 | 273 | 103 | 191 | 93 | 103 | 180 | 147 |
| Total alkalinity, as $CaCO_3$ | 62 | 207 | 64 | 4.3 | <.1 | 86 | 32 | 38 | 85 | 64 |
| Total hardness, as $CaCO_3$ | 56 | 200 | 57 | 47 | 28 | 42 | 27 | 32 | 63 | 48 |
| Calcium | 19 | 79 | 18 | 25 | 5.8 | 13 | 8.4 | 9.7 | 19 | 14 |
| Magnesium | 2.1 | .1 | 3 | 5.9 | 3.2 | 2.2 | 1.5 | 1.8 | 3.7 | 3.2 |
| Sodium | 3.5 | 16 | 4 | 8 | 4 | 19 | 2.7 | 4.2 | 11 | 8.2 |
| Potassium | 3.3 | 3.9 | 3.6 | 3.8 | 1.1 | 7.3 | 6.4 | 5.6 | 4.2 | 3 |
| Iron | 1.2 | .01 | 1 | .03 | .03 | .03 | 1.8 | 3.9 | 16.9 | 15 |
| Bicarbonate | 76 | --- | --- | --- | 1.22 | 100 | 38.4 | 47 | 100 | 78 |
| Sulfate | 1.5 | 13 | 14 | 90 | 25 | 6.8 | 10 | 8.9 | 1.2 | <.1 |
| Chloride | 2.6 | 3 | 4.7 | 3.4 | 9.2 | 1.8 | 1.2 | 1.2 | 4 | 4.5 |
| Silica, as $SiO_2$ | 22 | 14 | 27 | 34 | 9.6 | 21 | 14 | 14 | 32 | 4 |
| Ammonia nitrogen | --- | 1.2 | .09 | .14 | <.01 | .05 | .04 | .03 | .07 | .1 |
| Nitrate plus nitrite nitrogen | 1.1 | .05 | .05 | .08 | 7.4 | <.02 | <.02 | <.02 | <.02 | <.02 |
| Nitrate nitrogen | 1.1 | .03 | .02 | .07 | 7.4 | <.02 | <.02 | <.02 | <.02 | <.01 |
| Nitrite nitrogen | <.01 | .02 | .03 | .01 | <.01 | <.01 | <.01 | <.01 | <.01 | .01 |
| Organic plus ammonia nitrogen | <.2 | 2 | .3 | 1.6 | <.2 | .2 | <.2 | <.2 | .2 | <.2 |
| Total phosphorus | .5 | .03 | .21 | .08 | .02 | .39 | .35 | .42 | .24 | .9 |
| Orthophosphate phosphorus | .3 | <.02 | .12 | .01 | <.01 | .37 | .29 | .05 | .01 | .08 |
| Hydrolyzable plus orthophosphate phosphorus | .4 | <.02 | .14 | .08 | .02 | --- | --- | --- | --- | --- |
| Total organic carbon | 1.6 | 4.1 | 4.4 | 2.5 | <.2 | .9 | .2 | .9 | --- | .5 |

Table C-1.--Major constituents and properties of ground-water samples, October 1988 through February 1990--Continued

[All concentrations are for dissolved species and reported in milligrams per liter (mg/L) unless noted otherwise; µS/cm, microsiemens per centimeter; <, less than; ---, data not available]

| Constituent or property | Railway 1A 02/01/89 | Railway 1B 05/19/89 | Railway 1B 09/27/89 | Railway 1C 05/19/89 | Railway 1C 09/27/89 | Railway 1D 12/14/88 |
|---|---|---|---|---|---|---|
| pH, in units | 6.7 | 9.1 | 9.1 | 7.1 | 7.5 | 5.3 |
| Specific conductance, lab, in µS/cm | 149 | 88 | 164 | 205 | 276 | 31 |
| Total alkalinity, as $CaCO_3$ | 59 | 35 | 62 | 98 | 129.1 | 2.9 |
| Total hardness, as $CaCO_3$ | 51 | 38 | 36.05 | 140 | 112.54 | 4 |
| Calcium | 17 | 14 | 13 | 45 | 38 | 1.2 |
| Magnesium | 2 | .8 | .8 | 5.8 | 4.9 | .20 |
| Sodium | 7.6 | 18 | 15 | 7.70 | 10 | 2.9 |
| Potassium | 3.5 | 6.2 | 5.7 | 3.8 | 4.7 | 1.2 |
| Iron | .63 | .04 | .04 | .34 | .02 | <.01 |
| Bicarbonate | 72 | 43.2 | 75 | 182.9 | 157.4 | 8 |
| Sulfate | 7.5 | 14 | 9.6 | 6.4 | 9.4 | 1.4 |
| Chloride | 2.5 | 2.1 | 2.1 | 2.1 | 2.6 | 3.5 |
| Silica, as $SiO_2$ | 19 | 28 | 38 | 27 | 30 | 8.1 |
| Ammonia nitrogen | .07 | --- | .02 | --- | <.07 | .01 |
| Nitrate plus nitrite nitrogen | <.02 | --- | .11 | --- | .03 | .85 |
| Nitrate nitrogen | <.02 | <.02 | .09 | <.02 | .02 | .85 |
| Nitrite nitrogen | <.01 | --- | .03 | --- | .01 | <.01 |
| Organic plus ammonia nitrogen | .21 | --- | .52 | --- | .24 | <.2 |
| Total phosphorus | .35 | --- | .03 | --- | <.02 | .02 |
| Orthophosphate phosphorus | .21 | --- | .02 | --- | <.01 | <.01 |
| Hydrolyzable plus orthophosphate phosphorus | --- | --- | .04 | --- | <.02 | .02 |
| Total organic carbon | .5 | --- | 5.1 | --- | .8 | .3 |

Table C-2.--Trace elements concentrations in ground water, October 1988 through February 1990

[All concentrations reported in micrograms per liter (µg/L); <, less than; ---, data not available]

| Constituent or property | Lake Marion 1A 10/20/88 | Lake Marion 1C 07/19/89 | Lake Marion 1D 07/19/89 | Lake Marion 2A 10/20/88 | Lake Marion 2A 01/30/90 | Lake Marion 2A 03/14/91 | Lake Marion 2B 10/20/88 | Lake Marion 2B 01/30/90 | Lake Marion 2B 02/28/90 | Lake Marion 2B 03/14/91 |
|---|---|---|---|---|---|---|---|---|---|---|
| Aluminum | <10 | 400 | 60 | <10 | --- | --- | 9,900 | --- | --- | --- |
| Antimony | --- | --- | --- | --- | 460 | --- | --- | 360 | <400 | --- |
| Arsenic | < 1 | <1 | 1 | 1 | 2 | --- | <1 | <2 | --- | --- |
| Barium | 68 | <100 | <100 | 27 | --- | --- | 40 | --- | 270 | --- |
| Boron | 50 | 20 | <20 | 20 | --- | --- | 20 | --- | --- | --- |
| Bromide | 26 | <10 | <10 | 39 | --- | --- | 1,100 | --- | --- | --- |
| Cadmium | <1 | <1 | <1 | <1 | <5 | <10 | 9 | 29 | 18 | <10 |
| Chromium | <1 | <1 | <1 | 1 | <20 | <30 | 2 | <20 | 70* | <30 |
| Copper | 1 | 2 | <1 | 5 | <20 | --- | 52 | <20 | --- | --- |
| Lead | <5 | 3 | <1 | <5 | 70 | <5 | <5 | 275 | <50 | 10 |
| Lithium | 6 | 30 | 20 | 4 | --- | --- | 5 | --- | --- | --- |
| Manganese | 56 | 70 | 10 | 89 | --- | --- | 4,700 | --- | 14,100 | --- |
| Mercury | .6 | <.1 | <.1 | <.1 | --- | --- | <.1 | <.2 | --- | --- |
| Molybdenum | <1 | 6 | 5 | 3 | --- | --- | <1 | --- | --- | --- |
| Nickel | --- | --- | --- | --- | <40 | --- | --- | 210 | 225 | --- |
| Selenium | <1 | <1 | <1 | <1 | <2 | --- | <1 | <2 | <2 | --- |
| Silver | --- | --- | --- | --- | <10 | --- | --- | 32 | 20 | --- |
| Strontium | 130 | 180 | 180 | 83 | --- | --- | 170 | --- | --- | --- |
| Vanadium | 2 | <1 | 10 | 2 | --- | --- | 50 | --- | --- | --- |
| Zinc | 9 | --- | --- | 27 | 64 | --- | 92 | 250 | 282 | --- |

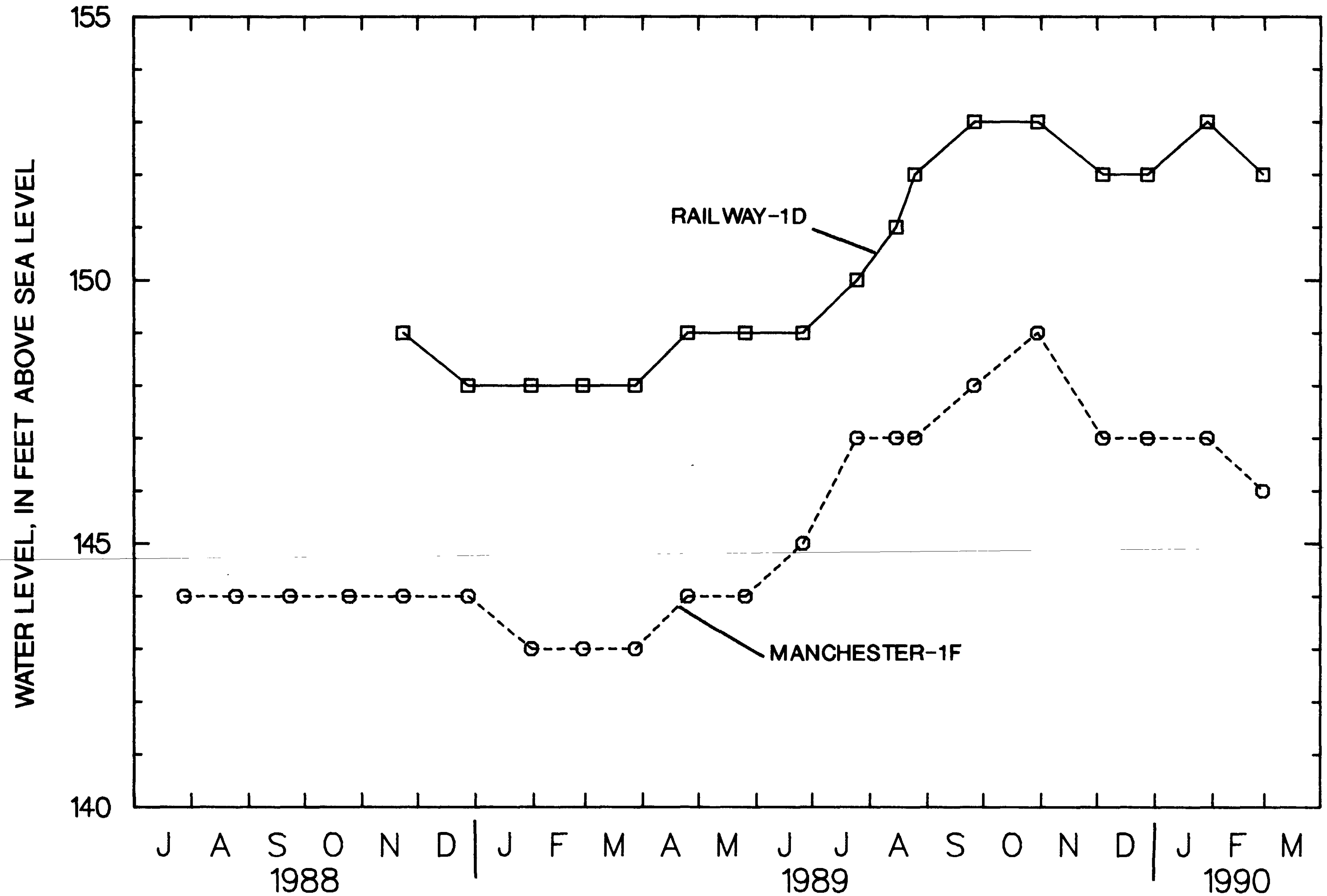
| Constituent or property | Manchester 1B 12/15/88 | Manchester 1C 09/08/89 | Manchester 1D 09/08/89 | Manchester 1E 09/08/89 | Manchester 1F 12/15/88 | Rimini 1A 05/12/88 | Rimini 1B 05/12/88 | Rimini 1C 05/12/88 | Rimini 1D 05/12/88 | Rimini 1E 05/12/88 |
|---|---|---|---|---|---|---|---|---|---|---|
| Aluminum | 20 | 400 | <10 | 100 | 80 | 10 | <10 | <10 | 10 | <10 |
| Arsenic | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Barium | <100 | <100 | <100 | <100 | <100 | <100 | <100 | <100 | <100 | 100 |
| Boron | <20 | 30 | 20 | 40 | <20 | 70 | <20 | <20 | <20 | <20 |
| Bromide | <10 | 20 | 120 | 20 | 90 | <10 | <10 | <10 | 20 | 30 |
| Cadmium | 1 | <1 | <1 | <1 | 2 | <1 | <1 | <1 | <1 | <1 |
| Chromium | 1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Copper | <1 | 3 | 4 | 3 | 200 | <1 | 1 | 2 | 2 | 1 |
| Lead | <5 | 2 | <1 | 2 | 5 | <5 | <5 | <5 | <5 | <5 |
| Lithium | <10 | 10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| Manganese | 80 | 10 | 160 | 360 | 10 | 20 | 50 | 90 | 660 | 489 |
| Mercury | <.1 | <.1 | <.1 | <.1 | 1.4 | .6 | .1 | .3 | .3 | <.1 |
| Molybdenum | <1 | 5 | 1 | <1 | <1 | 2 | <1 | <1 | 2 | <1 |
| Selenium | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Strontium | 180 | 350 | 100 | 70 | 60 | 219 | 120 | 100 | 170 | 130 |
| Vanadium | <1 | 4 | <1 | 7 | <1 | <1 | <1 | 2 | <1 | <1 |

Table C-2.--Trace elements concentrations in ground water, October 1988 through February 1990--Continued

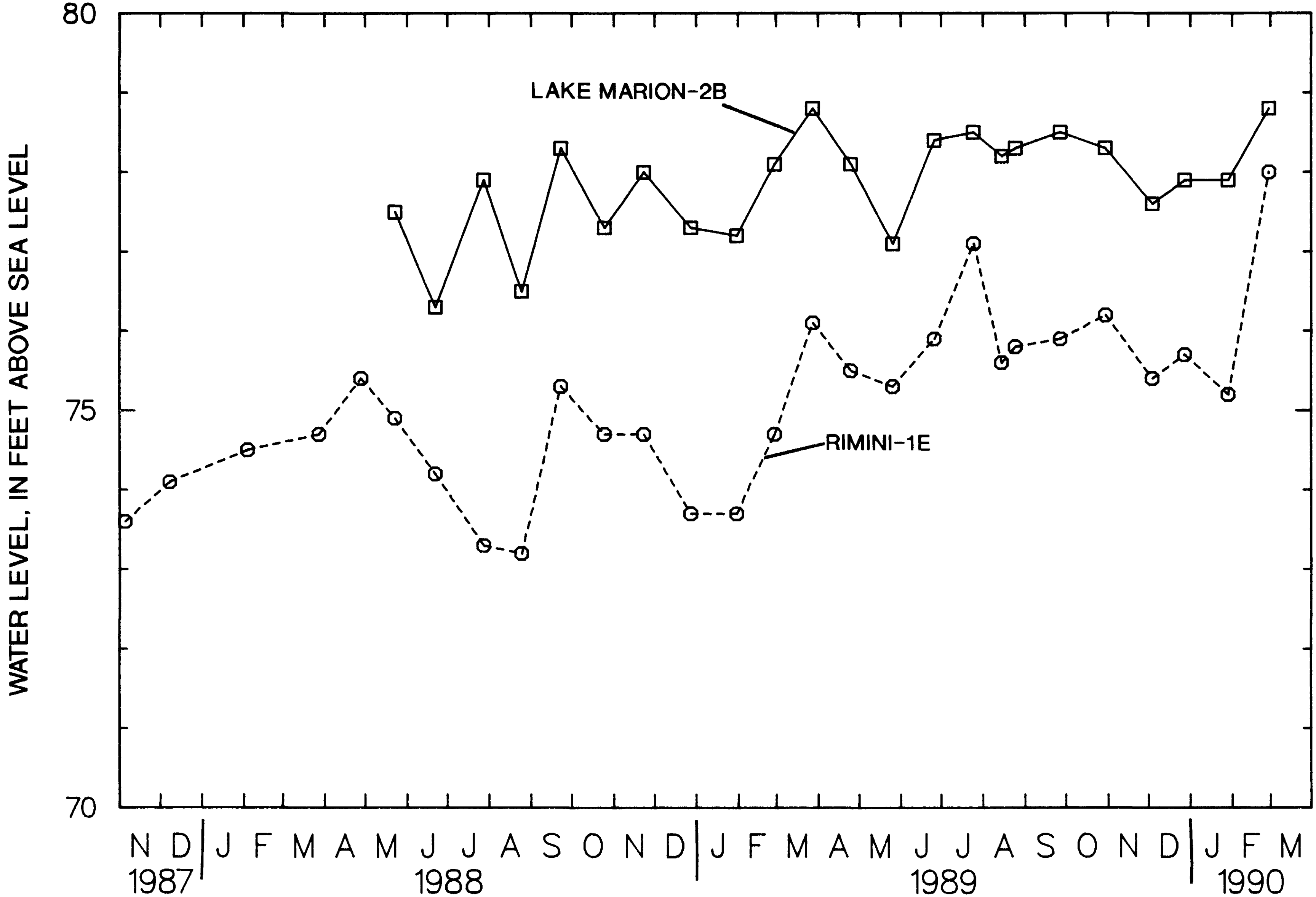
[All concentrations reported in micrograms per liter (µg/L); <, less than; ---, data not available]

| Constituent or property | Railway 1A | Railway 1B | | Railway 1C | | Railway 1D |
|---|---|---|---|---|---|---|
| | 02/01/89 | 05/19/89 | 09/27/89 | 05/19/89 | 09/27/89 | 12/14/88 |
| Aluminum | 10 | 20 | 30 | <10 | <10 | 10 |
| Arsenic | <1 | <1 | <1 | <1 | <1 | <1 |
| Barium | <100 | <100 | <100 | 300 | 200 | <100 |
| Boron | <20 | <20 | <20 | <20 | <20 | <20 |
| Bromide | --- | 30 | 30 | 10 | 50 | 20 |
| Cadmium | <1 | <1 | <1 | 1 | <1 | 4 |
| Chromium | <1 | <1 | <1 | <1 | <1 | 1 |
| Copper | <1 | 1 | 8 | <1 | 2 | 5 |
| Lead | <5 | <5 | <1 | <5 | <1 | <5 |
| Lithium | <10 | 20 | 20 | <10 | <10 | <10 |
| Manganese | 36 | <10 | <10 | 30 | 40 | <10 |
| Mercury | <.1 | --- | .3 | 1.4 | <.1 | .2 |
| Molybdenum | 1 | 5 | 2 | <1 | 1 | <1 |
| Selenium | <1 | <1 | <1 | <1 | <1 | <1 |
| Strontium | 170 | 210 | 250 | 400 | 320 | 40 |
| Vanadium | 3 | <1 | <1 | <1 | <1 | <1 |

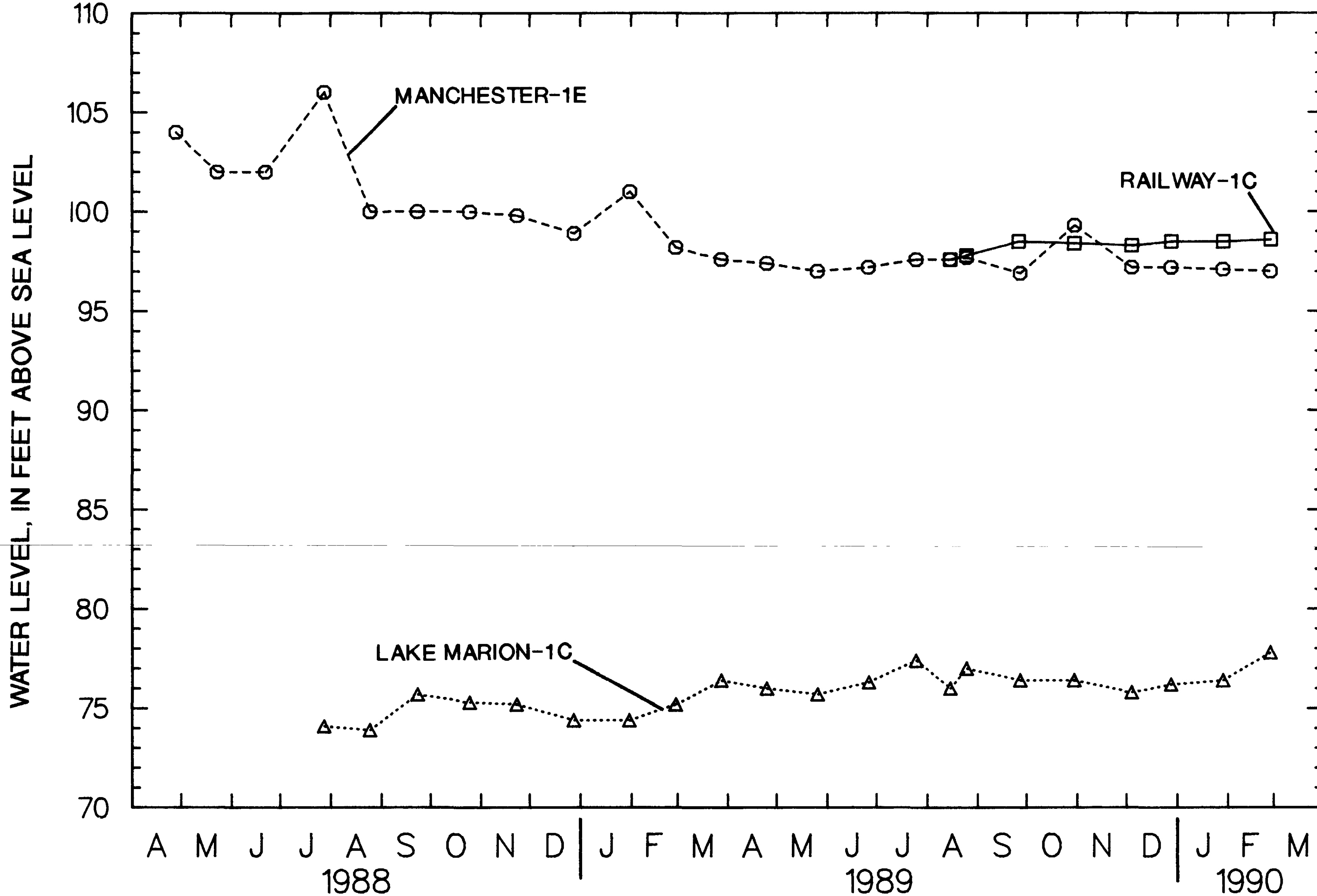
*Uncertainty is associated with this analysis because three split samples showed differing concentrations rangings from 16 to 90 µg/L.



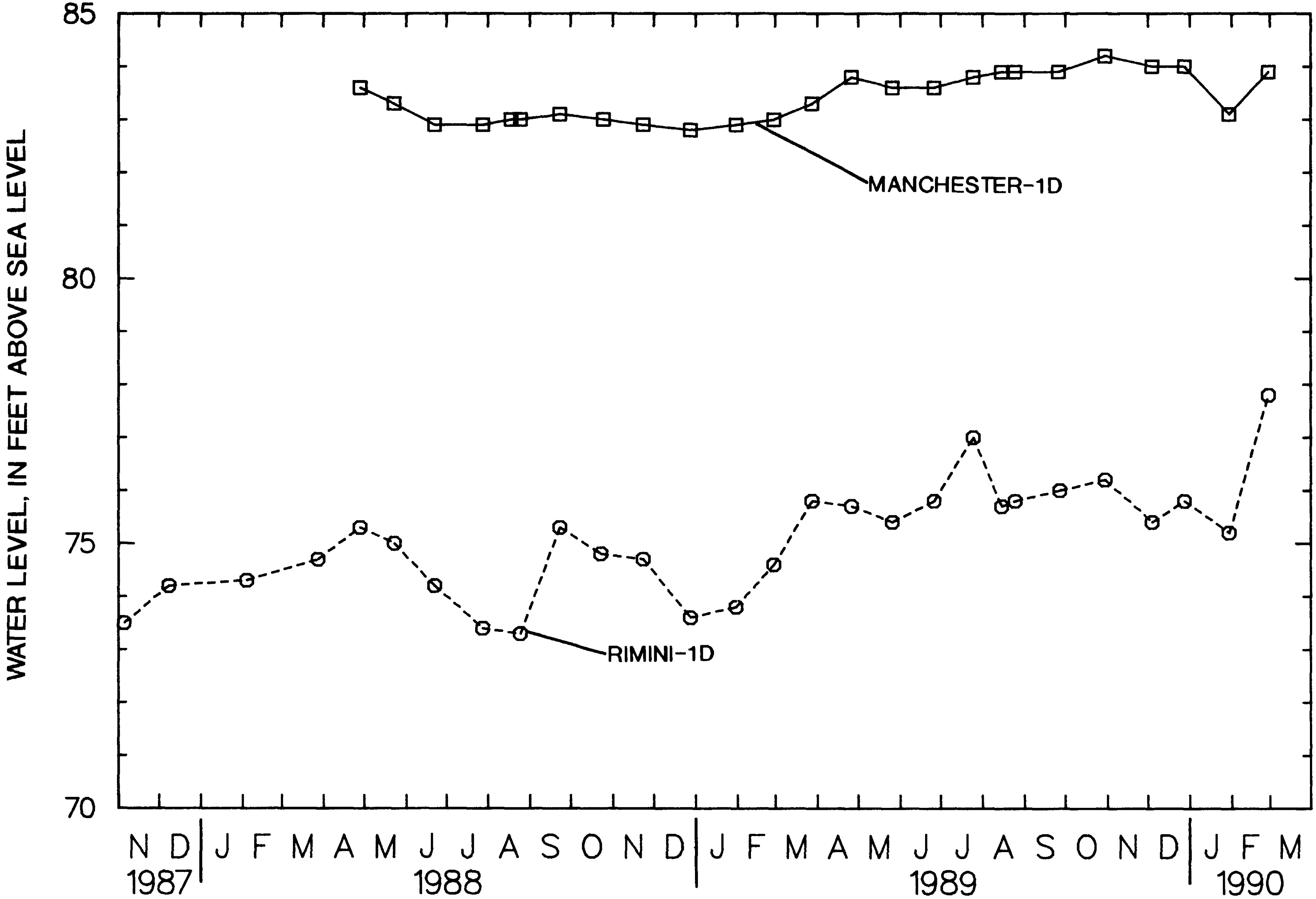

D-1.--Wells in the surficial aquifer.



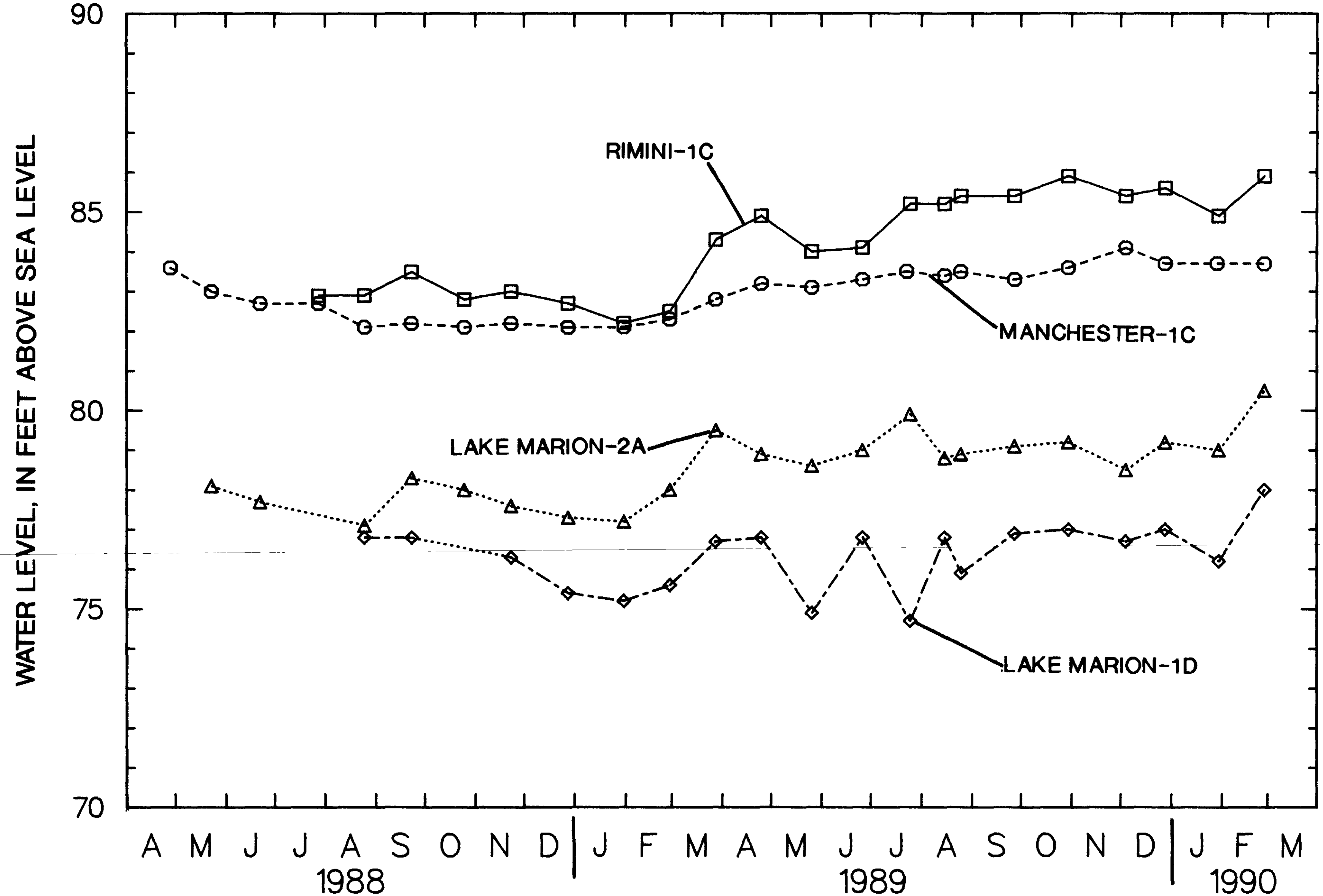

D-1.--Wells in the surficial aquifer--Continued.



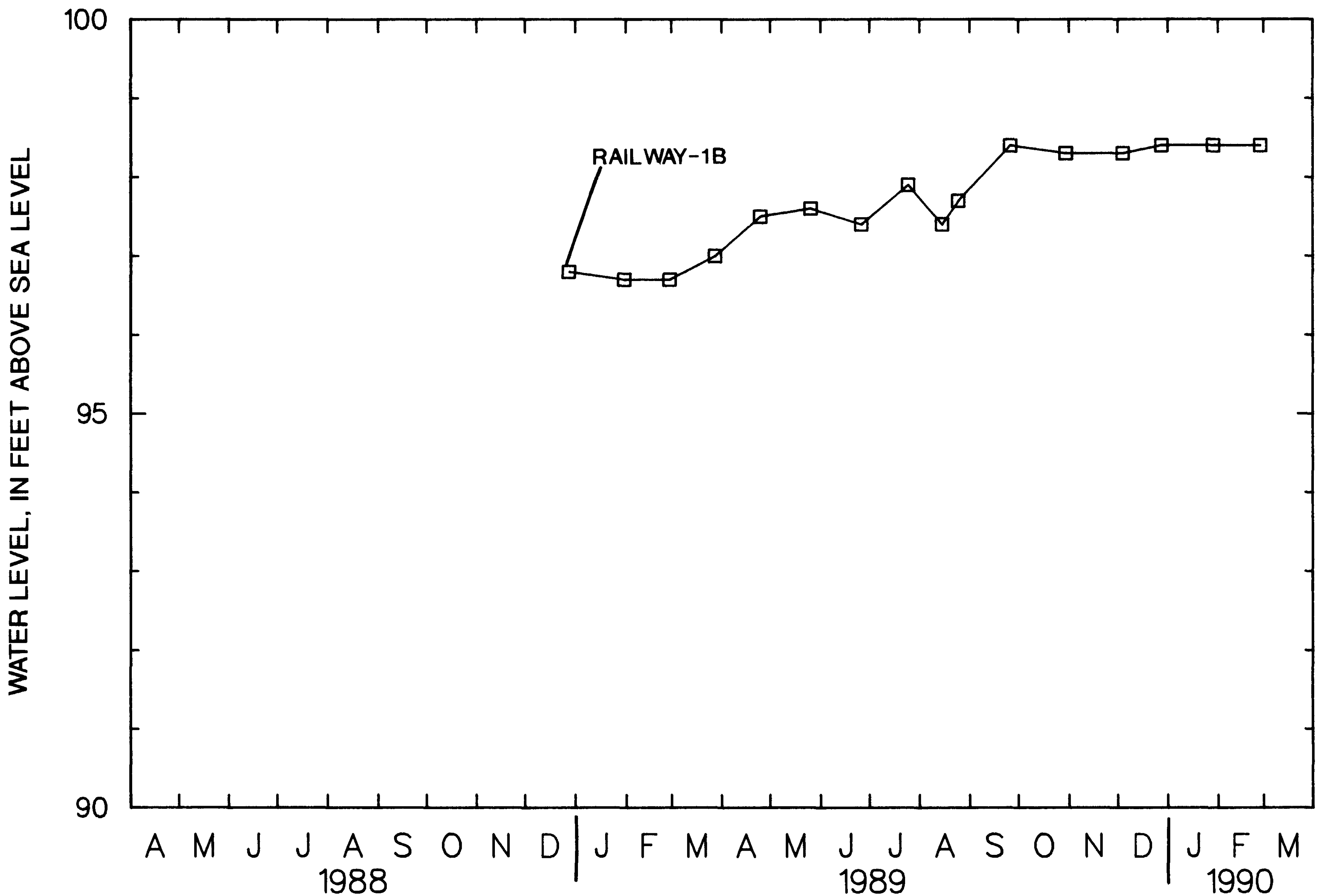

D-2.--Wells in Lang Syne water-bearing zone of the Lang Syne-Sawdust Landing aquifer.



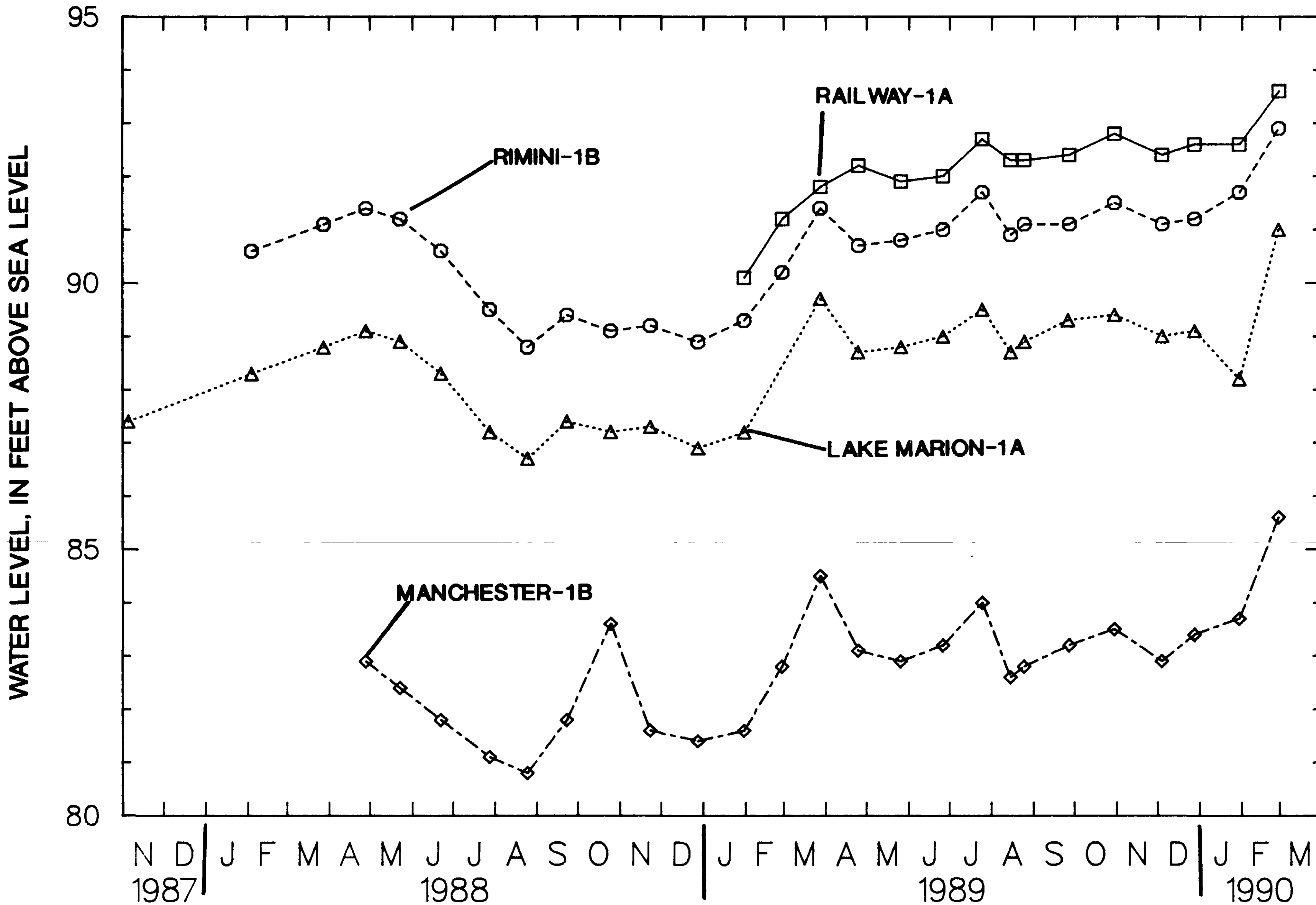

D-3. Wells in the upper Sawdust Landing water-bearing zone of the Lang Syne-Sawdust Landing aquifer.



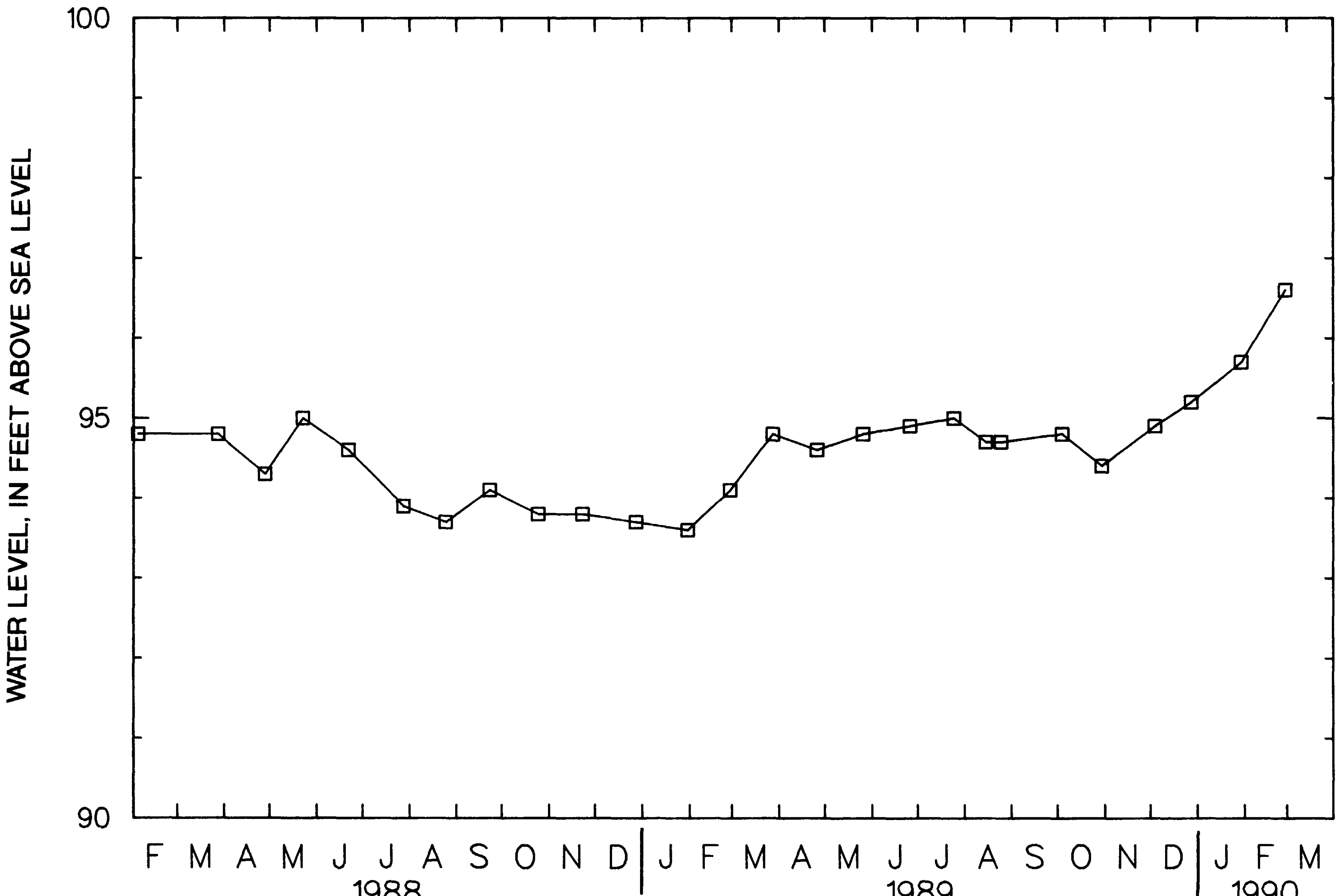

D-4.--Wells in the lower Sawdust Landing water-bearing zone of the Lang Syne-Sawdust Landing aquifer.




D-4.--Wells in the lower Sawdust Landing water-bearing zone of the Lang Syne-Sawdust Landing aquifer--Continued.




D-5.--Wells in the Peedee aquifer.




D-6.--Well Rimini-1A in the Black Creek aquifer.

## CONVERSION FACTORS AND VERTICAL DATUM

| Multiply | By | To obtain |
|---|---|---|
| inch (in.) | 25.4 | millimeter |
| inch (in.) | 25,400 | micrometer |
| inch per day (in/d) | 25.4 | millimeter per day |
| inch per year (in/yr) | 25.4 | millimeter per year |
| foot (ft) | 0.3048 | meter |
| foot per day (ft/d) | 0.3048 | meter per day |
| foot per foot (ft/ft) | 1 | meter per meter |
| foot per year (ft/yr) | 0.3048 | meter per year |
| cubic foot per day per square foot times foot of aquifer thickness ($[(ft^3/d)/ft^2]ft$) | 0.0929 | cubic meter per day per square meter times meter of aquifer thickness |
| cubic foot per day ($ft^3/d$) | 0.0283 | cubic meter per day |
| mile (mi) | 1.609 | kilometer |
| gallon (gal) | 3.785 | liter |
| acre | 4,047 | square meter |
| gallon (gal) | 0.0038 | cubic meter |
| gallon (gal) | 0.0038 | millilter |
| gallon per day (gal/d) | 0.0038 | cubic meter per day |
| gallon per acre per day | 0.0002 | gallons per square meter per day |
| pound per square inch ($lb/in^2$) | 6.895 | kilopascal |

Water temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by using the following equation:

$$°F = 1.8\ (°C) + 32$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Specific electrical conductance of water is expressed in microsiemens per centimeter at 25 °C (µS/cm). This unit is identical to micromhos per centimeter at 25 °C, formerly used by the U.S. Geological Survey.

Chemical concentration in water is expressed in milligrams per liter (mg/L) and micrograms per liter (µg/L).

Transmissivity is in units of cubic feet per day per square feet times feet of aquifer thickness ($[(ft^3/d)/ft^2]ft$), abbreviated in this report to square feet per day ($ft^2/d$).