

HYDROGEOLOGY AND WATER QUALITY OF THE SHALLOW GROUND-WATER SYSTEM IN EASTERN YORK COUNTY, VIRGINIA

By Donna L. Richardson and Allen R. Brockman

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CONVERSION FACTORS, ABBREVIATED WATER-QUALITY UNITS, AND VERTICAL DATUM

<u>Multiply</u>	<u>By</u>	<u>To obtain</u>
<u>Length</u>		
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
<u>Area</u>		
square mile (mi ²)	2.590	square kilometer
<u>Volume</u>		
gallon (gal)	3.785	liter
<u>Flow</u>		
gallon per minute (gal/min)	0.06308	liter per second
gallon per day (gal/d)	0.003785	cubic meter per day

Abbreviated water-quality units: Water-quality units are expressed in this report as milligrams per liter (mg/L). Specific conductance is expressed in microsiemens per centimeter at 25 degrees Celsius ($\mu\text{S}/\text{cm}$).

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 the United States and Canada, formerly called Sea Level Datum of 1929.

HYDROGEOLOGY AND WATER QUALITY OF THE SHALLOW GROUND-WATER SYSTEM IN EASTERN YORK COUNTY, VIRGINIA

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ABSTRACT

This report presents results from a study of the shallow ground-water system in eastern York County in Virginia by the U.S. Geological Survey in cooperation with the York County Department of Environmental Services. The shallow ground-water system consists of approximately the first 200 feet of sediments below land surface and is made up of a layered system of aquifers and confining units. The shallow ground-water system includes the water-table aquifer (Columbia aquifer) and two confined aquifers (Cornwallis Cave and Yorktown-Eastover aquifers). The aquifer generally consists of fine-grained sand and silt with abundant shell material. Ground-water use in the Yorktown-Eastover aquifer primarily is limited to water supply for domestic needs; well yields are low and range from 5 to 9 gallons per minute.

Ground water recharges the shallow system locally through precipitation that infiltrates into the Columbia aquifer and regionally by underflow of ground water into the confined aquifers from upgradient areas. Ground water in the Columbia aquifer flows (1) laterally to local discharge sites in streams, marshes, estuaries, the York River, and the Chesapeake Bay and (2) vertically through the uppermost confining unit to the confined aquifers. Ground water in the confined aquifers also flows laterally and vertically and discharges to the York River and the Chesapeake Bay.

The water quality of the shallow ground-water system in eastern York County reflects the types of sediments in the aquifers and the natural chemical-weathering processes that occur as precipitation enters and flows through the sediments. The ground water is predominantly a calcium bicarbonate type and is characterized by high concentrations of calcium, bicarbonate, and iron. Calcite dissolution of the abundant shell material in the aquifer sediments has produced a median calcium concentration of 80 mg/L (milligrams per liter) in the Columbia aquifer and 78 mg/L in the Yorktown-Eastover aquifer. The dissolution and reduction of ferric iron from the sediment minerals to dissolved ferrous iron has elevated concentrations of iron in the ground water. The median iron concentration is 0.44 mg/L in the Columbia aquifer and 0.39 mg/L in the Yorktown-Eastover aquifer. Although not a risk to human health, high concentrations of calcium and iron are not desirable in a domestic water supply because they can cause mineral deposits on plumbing fixtures and stains on laundry. Water-quality degradation from human-related sources is localized and is not apparent on a regional scale. Chloride concentrations generally are greater in the Yorktown-Eastover aquifer than in the Columbia aquifer. The data analyzed for this study do not indicate saltwater encroachment resulting from pumping; chloride concentrations are similar in pumped and nonpumped areas. Additional monitoring is needed to discern water-quality changes over time.

INTRODUCTION

Rapid population growth in York County, Va., has caused an increase in the demand for freshwater. Most of the county relies on surface-water sources provided by the City of Newport News; however, areas remain in the eastern part of the county where residents depend on individual wells for a domestic

supply. The shallow-aquifer system in the eastern part of York County provides the sole source of fresh ground water, because the deep aquifers in this coastal area contain water with high concentrations of dissolved solids that is considered unsuitable for human consumption (Laczniak and Meng, 1988; Larson, 1981). Increased pumping of water from the shallow aquifers in eastern York County could cause water-level declines and saltwater intrusion. The quality of water in the shallow aquifers could be affected by a variety of human-related sources, including agricultural fertilizers, septic-system effluent, and road salt. In 1989, the U.S. Geological Survey (USGS), in cooperation with the York County Department of Environmental Services, began a study to assess the current quantity and quality of the shallow ground-water resources in the eastern part of York County.

Purpose and Scope

This report describes the hydrogeology and water quality of the shallow ground-water system in the eastern part of York County, Va. The report includes a discussion of (1) the aquifers and confining units, (2) the flow of ground water, and (3) the quality of ground water. The report is an evaluation of the shallow ground-water system and focuses on the first 200 ft of sediments below land surface. Historical water-level and water-quality data were not available for the study area; therefore, a network of observation wells was constructed for the study. Water levels were measured to provide an understanding of the flow of ground water through the multiaquifer system. Water samples were collected and analyzed for major inorganic constituents, nutrients, and metals. The report presents maps that show the regional distribution of chloride and iron concentrations. Summary statistics and graphical summaries of selected chemical constituents provide a general assessment of the ground-water quality.

Description of Study Area

The study area is in the eastern-central part of the Coastal Plain physiographic province of Virginia (fig. 1) and includes the parts of York County east of Yorktown, Va. (fig. 2). The study area is bounded on the north by the York River, on the south by the City of Newport News, and on the east by the Chesapeake Bay and the City of Poquoson. The total land area is approximately 33 mi². The morphology of the area consists of flat-lying terrace deposits that are separated by linear scarps. The major scarp is the Suffolk scarp that is approximately parallel to U.S. Route 17 (fig. 2) and results in a 20 ft change in elevation. Land-surface elevation ranges from approximately 60 ft above sea level in the western part of the study area to sea level along the York River to the north and the Chesapeake Bay to the east.

Previous Investigations

The shallow-aquifer system in the eastern part of York County has not been comprehensively studied prior to this investigation. Reports from previous studies of regional investigations provide information about the ground-water resources of the York County area. Harsh and Laczniak (1990) and Meng and Harsh (1988) examine the hydrogeology of the entire Virginia Coastal Plain physiographic province. Laczniak and Meng (1988) describe the hydrogeology, water quality, and ground-water-flow system of the York-James Peninsula. Ground-water use in the Virginia Coastal Plain is summarized in Kull (1983) and Kull and Laczniak (1987). Additional reports that include information about ground water for the region include those by Larson (1981), Harsh (1980), Virginia Water Control Board (1973), Cederstrom (1945, 1957), and Sanford (1913). Reports that focus on the geology of York County and nearby areas are by Ward (1984), Johnson, Berquist, and Ramsey (1980), Johnson (1969, 1972, 1976), Coch (1971), Bick and Coch (1969), and Roberts (1932).

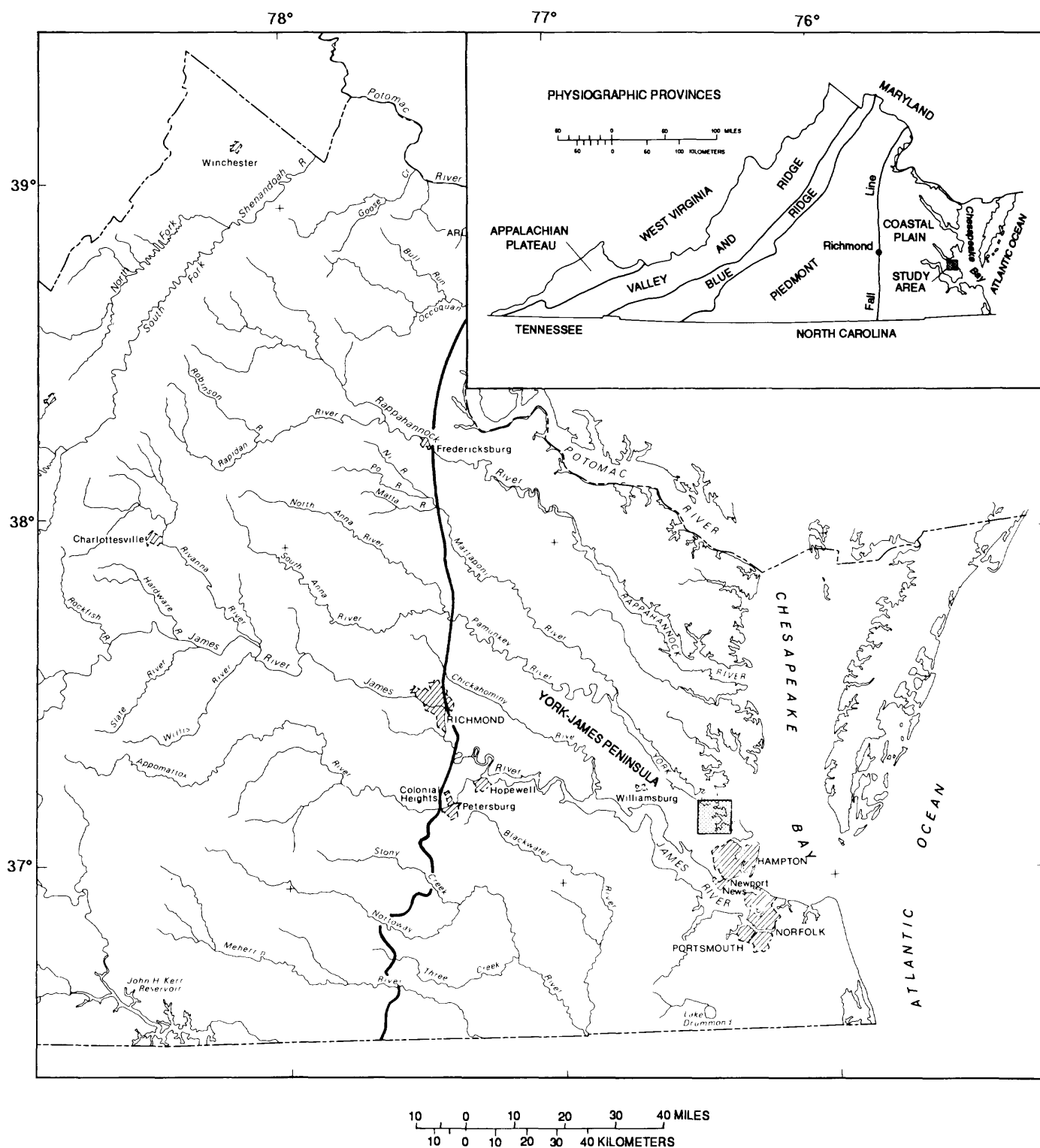
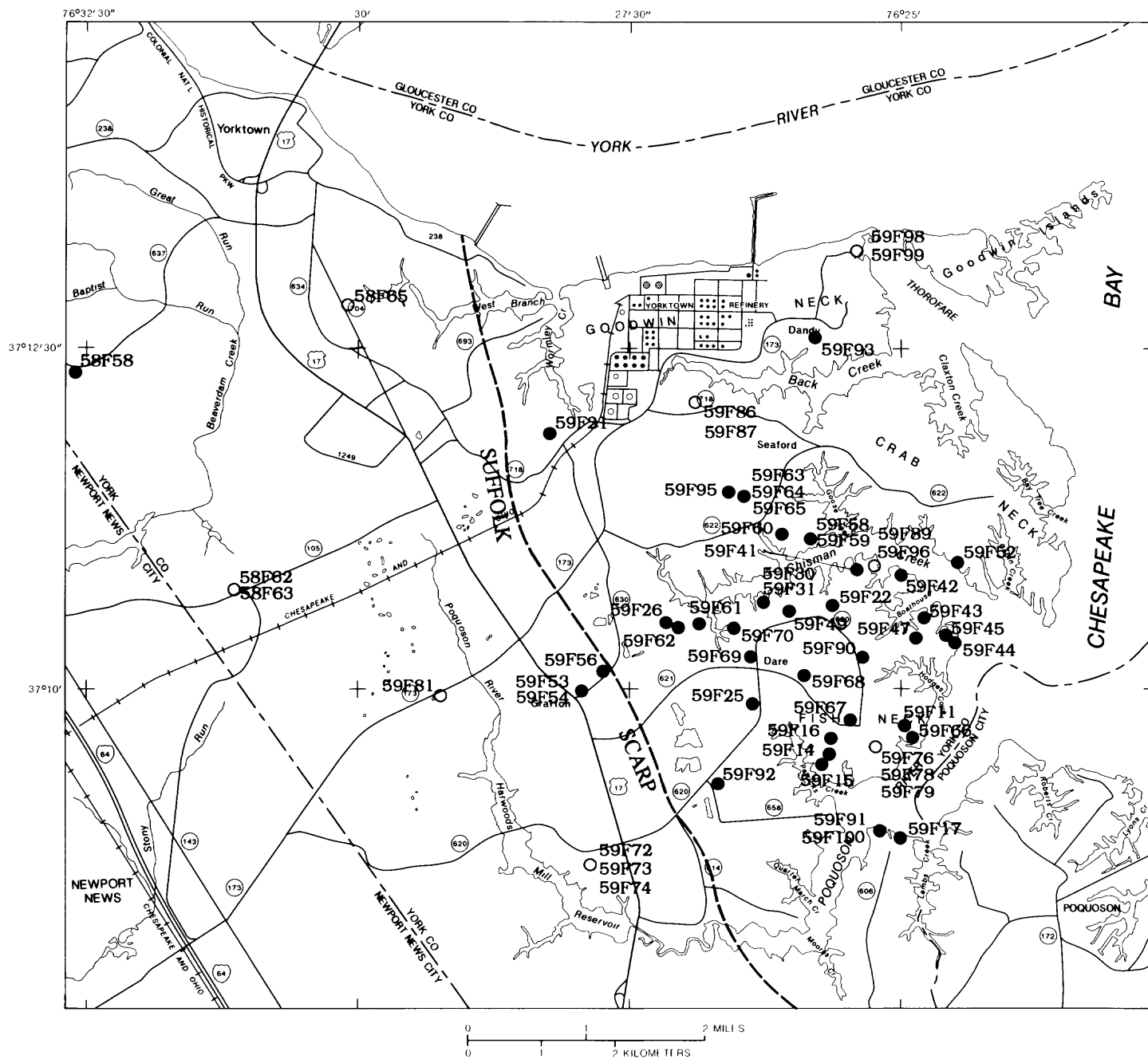


Figure 1.--Location of study area and physiographic regions.



EXPLANATION

- 59F92 WELL AND IDENTIFICATION NUMBER
- 59F81 RESEARCH-WELL AND IDENTIFICATION NUMBER

Figure 2.--Well locations and study area.

Methods of Investigation

Existing hydrogeologic data for the study area were sparse; therefore, most of the data used for this investigation were collected during the study. Eight well clusters were constructed in the eastern part of York County by the Virginia Water Control Board (VWCB) as part of the VWCB's ground-water research-station network. The research-station sites were distributed throughout the eastern part of York County to provide information for the entire study area. A research station typically consists of a cluster of observation wells that are each screened in a different aquifer. Pilot holes drilled to a depth of approximately 200 ft at each of the eight research stations in eastern York County provided formation cuttings, lithologic descriptions, and geophysical logs. This information was used to describe the hydrogeologic framework of aquifers and confining units in the shallow-aquifer system (Brockman, 1992). A total of 16 observation wells were constructed at the research stations. In addition, 15 observation wells were installed in the water-table aquifer by USGS personnel. Water levels at the observation wells were measured throughout the study to provide an understanding of ground-water flow in the shallow-aquifer system. Ground-water quality was investigated by sampling the 31 observation wells and an additional 25 domestic wells. Water-quality samples were collected during 1989-90 by use of standard USGS sampling techniques (Pritt and others, 1990). Field values measured were pH, temperature, specific conductance, and alkalinity. Water samples from observation wells were collected after three well-casing volumes of water had been pumped from the well and field values had stabilized. Water samples from domestic wells were collected from the tap after the water was run for approximately 15 minutes and field values had stabilized. The samples were analyzed by the National Water-Quality Laboratory of the USGS in Arvada, Colo., for major inorganic constituents, nutrients, and metals. All water-quality analyses have an ionic mass-balance error of less than 10 percent.

Acknowledgments

The authors would like to thank Martin Fisher and Connie Bennett of the York County Department of Environmental Services for their cooperation and support. Scott Bruce, John Creason, and Jay Owens of the VWCB provided invaluable assistance throughout the study; much of the data presented are available because of the VWCB drilling operation. Special thanks also are extended to home owners in eastern York County who provided water samples for water-quality analyses.

HYDROGEOLOGY OF THE SHALLOW GROUND-WATER SYSTEM

York County is in the central part of Virginia's Coastal Plain physiographic province and is the northern part of the landmass commonly referred to as the York-James Peninsula. The Coastal Plain consists of layered, mostly unconsolidated, sedimentary deposits that thicken and slope seaward.

The sedimentary deposits form a layered sequence of aquifers and confining units. An aquifer in the Coastal Plain predominantly consists of sand, silt, gravel, and shell material of sufficient saturated thickness and permeability to yield usable quantities of water. A confining unit predominantly is composed of clay and silt of low permeability and is continuous enough to retard the movement of water. Aquifers commonly contain interbedded clay and silt, whereas confining units commonly contain interbedded sand, gravel, and shell material. Aquifers and confining units do not correspond with specific geologic formations; they can include part of a formation, all of a formation, or a combination of all or part of adjacent formations. A complete description of the aquifers and confining units beneath the York-James Peninsula is presented by Lacznia and Meng (1988).

The shallow ground-water system in the eastern part of York County consists of the unconfined Columbia aquifer and two confined aquifers. The Cornwallis Cave aquifer is overlain by the Cornwallis Cave confining unit, and the Yorktown-Eastover aquifer is overlain by the Yorktown confining unit

(fig. 3). The base of the shallow ground-water system is the Eastover-Calvert confining unit, which underlies the Yorktown-Eastover aquifer. Sediments below the Eastover-Calvert confining unit contain water with high concentrations of dissolved solids that is unfit for human consumption (Laczniak and Meng, 1988; Larson, 1981). The following sections briefly describe the aquifers, confining units, and flows in the shallow ground-water system.

Aquifers and Confining Units

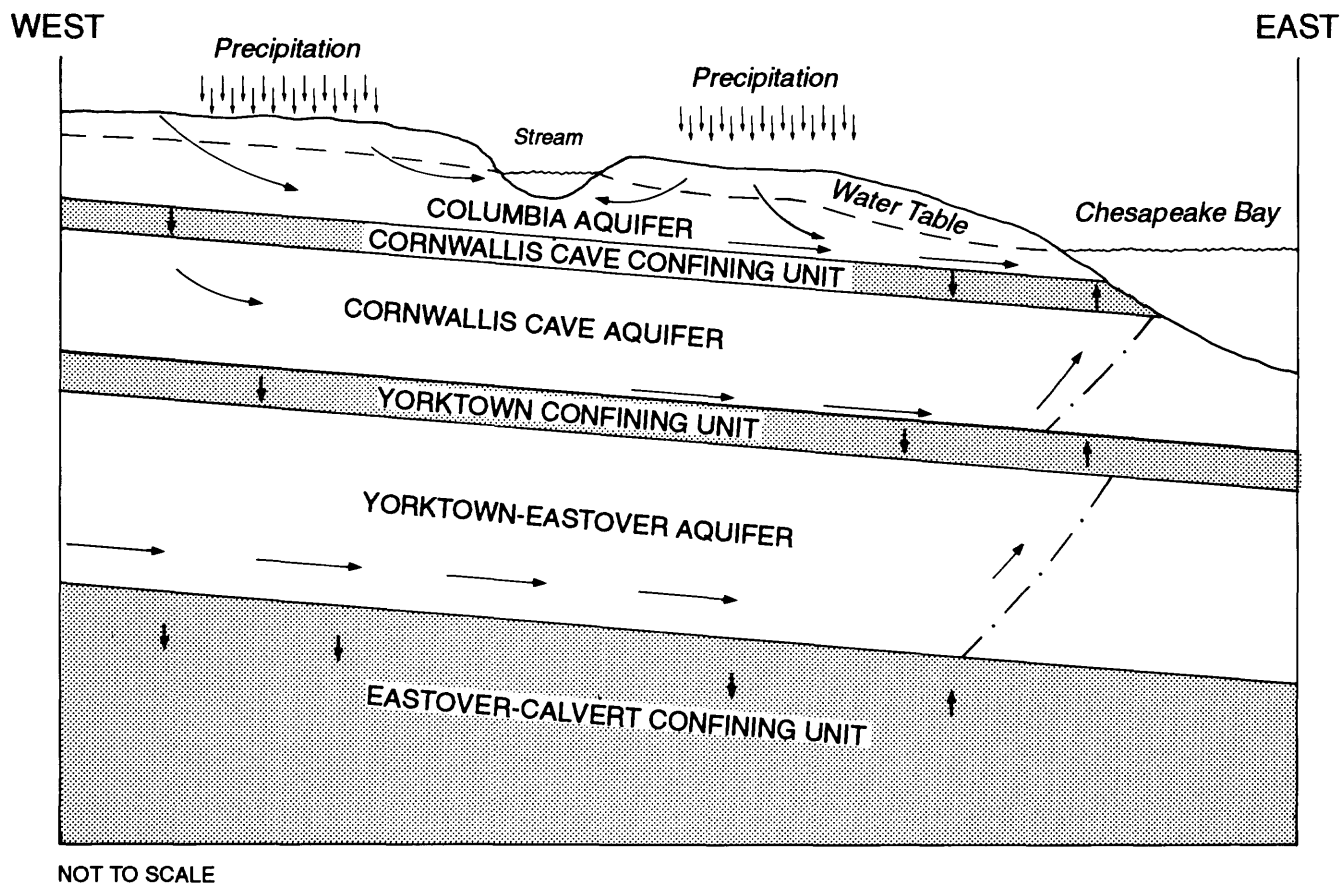
The Columbia aquifer consists of Quaternary and Tertiary sediments (table 1) and is unconfined throughout the study area. The aquifer is composed of yellow to gray sand that has a complex lithology varying from fine to coarse sand, clayey sand, and sandy clay. Mineralogic analyses from the Columbia aquifer indicate that the sediments are primarily quartz with minor amounts of orthoclase and plagioclase, and trace amounts of glauconite, mica, amphibole, galena, dolomite, and other carbonates (Steve Sutley, U.S. Geological Survey, written commun., 1991). The thickness of the Columbia aquifer is highly variable depending on the presence or absence of underlying confining units. Thicknesses generally range from 10 to 30 ft; however, thicknesses greater than 100 ft are present in areas where one or both of the underlying confining units are absent (fig. 4). The Columbia aquifer is a source of recharge to the underlying confined aquifers. Water use is limited to a few rural and domestic users.

The Cornwallis Cave confining unit underlies the Columbia aquifer. The confining unit consists of gray clay or silt with gray sand or shell material of Quaternary and (or) Tertiary age (table 1). The confining unit ranges from 5 to 20 ft in thickness and is continuous throughout most of the study area. The Cornwallis Cave confining unit is missing south of Yorktown and west of the Town of Seaford (fig. 4).

The Cornwallis Cave aquifer underlies the Cornwallis Cave confining unit and includes Tertiary sediments of the Moore House Member of the Yorktown Formation (table 1). This aquifer was identified during the hydrogeologic analysis for this study; the aquifer was not identified in any of the previous regional studies (Meng and Harsh, 1988; Laczniak and Meng, 1988). As a result, the only water-level and water-quality information on the Cornwallis Cave aquifer comes from five observation wells that were constructed for this study. The aquifer is distinctive and mappable in the eastern part of York County and, therefore, was included in this local-scale description of the shallow ground-water system. The aquifer primarily consists of shell material and quartz sand. Solution cavities and karst features are common in the Cornwallis Cave aquifer west of the Town of Grafton. The solution cavities are found in shell accumulations cemented by calcium carbonate and are frequently capped with an iron-oxide ceiling. Mineralogic analyses from the Cornwallis Cave aquifer indicate the sediments are primarily quartz sand with minor amounts of orthoclase, plagioclase, calcite, dolomite, aragonite, and trace amounts of mica, pyrite, and kaolinite (Steve Sutley, U.S. Geological Survey, written commun., 1991). The Cornwallis Cave aquifer is present throughout the study area and generally ranges from 20 to 60 ft in thickness; however, it effectively merges with the Columbia aquifer and (or) the Yorktown-Eastover aquifer where the adjacent confining units are missing (fig. 4). Well records indicate that ground water from this aquifer is not currently being used for any public or domestic supply in this study area.

The Yorktown confining unit underlies the Cornwallis Cave aquifer. The confining unit consists of blue-gray clay, silt, shell, and sand of the Mogarts Beach Member of the Tertiary-age Yorktown Formation (table 1). The thickness of the confining unit generally ranges from 10 to 20 ft, and the confining unit is continuous throughout most of the study area. The Yorktown confining unit is missing in the northeastern part of the study area in the vicinity of the Town of Dandy (fig. 4).

The Yorktown-Eastover aquifer is the lowermost aquifer of the shallow ground-water system. It is composed of fine sand and sandy shell material of the Rushmere and Sunken Meadow Members of the Yorktown Formation and the Cobham Bay Member of the Eastover Formation (table 1). Mineralogic



EXPLANATION

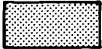
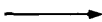

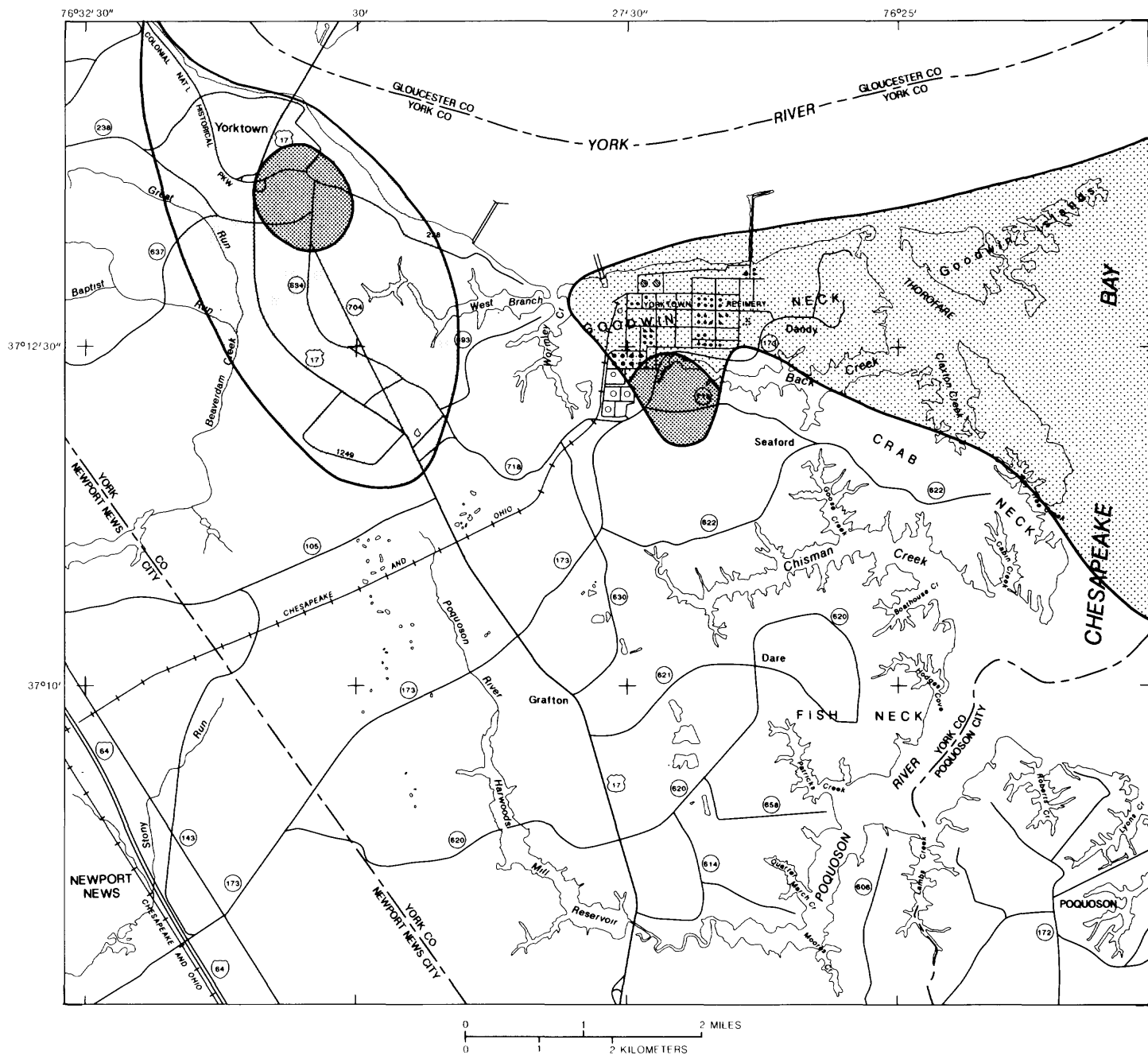
-  CONFINING UNIT
-  MAJOR DIRECTION OF FLOW
-  BOUNDARY BETWEEN FRESHWATER AND SALTWATER

Figure 3.—Schematic of aquifers and confining units in shallow ground-water system.

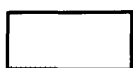
Table 1.--Geologic and hydrogeologic units in the shallow ground-water system

Geologic unit		Hydrogeologic unit
Holocene, Pleistocene, and uppermost Pleistocene formations		Columbia aquifer
Yorktown Formation	Moore House Member	Cornwallis Cave confining unit
	Cornwallis Cave aquifer
	Mogarts Beach Member	Yorktown confining unit
	Yorktown-Eastover aquifer
	Rushmere Member	
	
	Sunken Meadow Member	
Eastover Formation	Cobham Bay Member	Eastover-Calvert confining unit
	
	Claremont Manor Member	
St. Mary's Formation		

Choptank Formation		
-----		Eastover-Calvert confining unit
Calvert Formation		



EXPLANATION



CORNWALLIS CAVE CONFINING UNIT MISSING



CORNWALLIS CAVE AND YORKTOWN CONFINING UNIT MISSING



YORKTOWN CONFINING UNIT MISSING

Figure 4.—Areas of missing confining units.

analyses from the Yorktown-Eastover aquifer indicate the sediments are primarily quartz sand with minor amounts of glauconite, plagioclase, calcite, pyrite, and trace amounts of mica, marcasite, hematite, and galena (Steve Sutley, U.S. Geological Survey, written commun., 1991). Well yields are low and typically range from 5 to 9 gal/min. The Yorktown-Eastover aquifer is continuous throughout the study area except in a small area south of the Town of Yorktown where significant amounts of clay and silt cause the Yorktown-Eastover sediments to act as a confining unit instead of an aquifer. The thickness of the aquifer generally ranges between 40 and 60 ft; however, thicknesses exceed 100 ft in the northeastern part of the study area where one or both of the overlying confining units are absent (fig. 4).

Prior to the development of a public-water system, the Yorktown-Eastover aquifer was the major source of freshwater in the study area. As of 1989, most of the water used is supplied by public surface-water sources provided by the City of Newport News. Several isolated areas, including the entire Fish Neck peninsula, do not yet have access to public water. Water users on the Fish Neck peninsula depend on individual wells in the Yorktown-Eastover aquifer for a freshwater supply. Water use from individual ground-water wells is approximately 60,000 gal/d (Connie Bennett, York County Department of Environmental Services, oral commun., 1991).

The Eastover-Calvert confining unit underlies the Yorktown-Eastover aquifer and marks the base of the shallow ground-water system. The Eastover-Calvert confining unit consists of clay, silt, and fine sand from the Claremont Member of the Eastover Formation and the underlying St. Marys, Choptank, and Calvert Formations (table 1). The confining unit is continuous and extensive; thickness exceeds 200 ft throughout the study area. Aquifers below this confining unit contain water with high concentrations of dissolved constituents that is unsuitable for human consumption (Laczniak and Meng, 1988).

Ground-Water Flow

Local recharge to the shallow ground-water-flow system is by precipitation that falls on the land surface and infiltrates downward through the unsaturated zone into the sediments of the Columbia aquifer. The unconfined Columbia aquifer is highly dissected by shallow streams, rivers, marshes, and inlets; therefore, most of the water in the aquifer travels short flow paths and discharges to these local discharge sites (table 2, fig. 5). For instance, water-level measurements from a well cluster in the Columbia aquifer indicate water discharging into a local stream (fig. 6). Well 59F 63 (fig. 2) is screened in the upper part of the Columbia aquifer (10-15 ft below land surface), and well 59F 64 is screened in the lower part of the Columbia aquifer (40-45 ft below land surface). The higher water level in the deeper well indicates that ground water at this location is flowing vertically in an upward direction to discharge into the local stream.

Some of the water in the Columbia aquifer flows downward through the sediments of the Cornwallis Cave confining unit to recharge the confined Cornwallis Cave aquifer (fig. 3). Ground-water flow is inhibited, but not completely cut off, by the fine-grained sediments of the confining unit. The predominant direction of ground-water flow is laterally through the aquifer and vertically through the confining unit. Because of the local extent of the Cornwallis Cave aquifer and the lack of available hydrogeologic data, details of the effects of the Cornwallis Cave aquifer on the ground-water-flow system are sparse. This aquifer is not used as a water supply in this study area; however, it is of interest because of the abundance of solution cavities in the Cornwallis Cave aquifer west of the Town of Grafton. Water can flow unimpeded along solution cavities, which facilitates the rapid movement of water through the aquifer. Ground-water contamination from surface sources is more of a concern in the solution-cavity areas than it is in the rest of the study area.

Some of the water from the overlying sediments flows downward through the Yorktown confining unit and recharges the Yorktown-Eastover aquifer (fig. 3). The conceptualization of ground-water flow through the Yorktown-Eastover aquifer is based on previous studies that have examined flow on a regional basis (Harsh and Laczniak, 1990; Laczniak and Meng, 1988). Although many domestic wells in

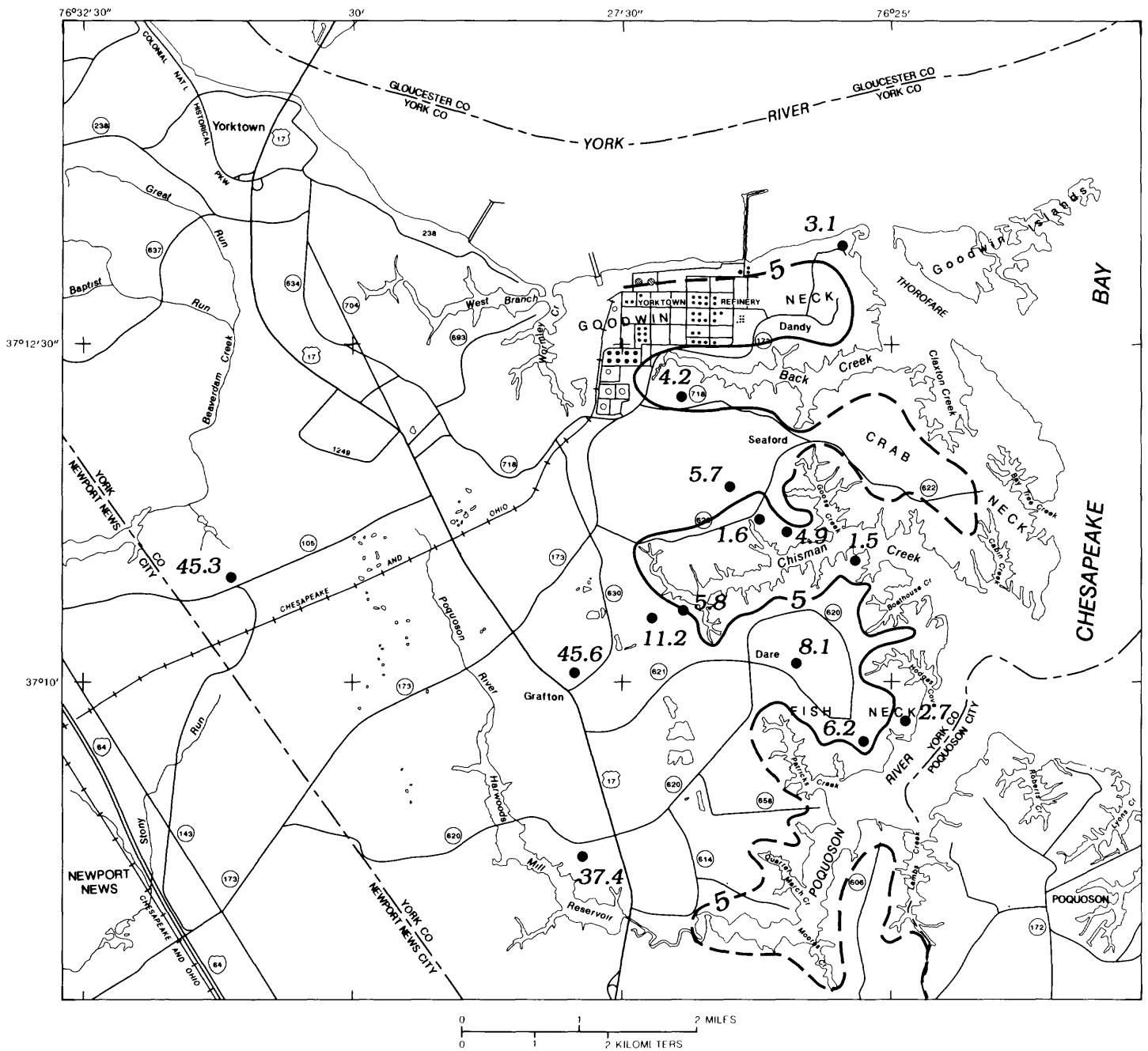
Table 2.--Well construction and water levels on May 5, 1991, for selected observation wells

[Latitude and longitude are reported in degrees, minutes, seconds; ft-bls is feet below land-surface datum; ft-sl is feet above or below sea level datum; YE is Yorktown-Eastover aquifer; CL is Columbia aquifer; USGS is U.S. Geological Survey; and VWCB is Virginia Water Control Board]

USGS well number	VWCB well number	Latitude	Longitude	Altitude	Depth (ft-bls)	Top of screen	Bottom of screen	Water level (ft-sl)	Aquifer
58F 62	SOW 187A	37 10 45	076 31 07	¹ 54.5	140	120	140	44.4	YE
58F 63	SOW 187B	37 10 45	076 31 07	¹ 54.6	28	18	28	45.0	CL
59F 53		37 09 58	076 27 55	55	15	10	15	45.6	CL
59F 59		37 11 06	076 25 51	10	45	40	45	4.9	CL
59F 60		37 11 08	076 26 07	6	15	10	15	1.6	CL
59F 61		37 10 29	076 26 53	12	12	7	12	5.8	CL
59F 62		37 10 29	076 27 09	17	15	10	15	11.2	CL
59F 63		37 11 25	076 26 29	10	15	10	15	5.7	CL
59F 64		37 11 25	076 26 29	10	45	40	45	6.4	CL
59F 66		37 09 39	076 24 53	6	12	9	12	2.7	CL
59F 68		37 10 04	076 25 56	10	9	7	9	8.1	CL
59F 72	SOW 184A	37 08 41	076 27 52	¹ 42.7	131	121	131	33.6	YE
59F 74	SOW 184C	37 08 41	076 27 52	¹ 41.9	20	10	20	37.4	CL
59F 76	SOW 185A	37 09 34	076 25 14	¹ 9.8	120	100	120	-3.6	YE
59F 79	SOW 185D	37 09 34	076 25 14	¹ 9.7	15	5	15	5.9	CL
59F 81	SOW 186A	37 09 58	076 29 15	50.8	132	112	132	31.9	YE
59F 86	SOW 188A	37 12 07	076 26 55	7	99	79	99	4.2	YE
59F 87	SOW 188B	37 12 07	076 26 55	7	30	20	30	4.2	CL
59F 89	SOW 189A	37 10 53	076 25 22	¹ 4.6	97	77	97	-1.3	YE
59F 96	SOW 189B	37 10 53	076 25 22	¹ 4.8	15	5	15	1.5	CL
59F 98	SOW 190A	37 13 13	076 25 25	¹ 3.4	100	80	100	2.0	YE
59F 99	SOW 190B	37 13 13	076 25 25	¹ 3.5	15	5	15	1.6	CL

¹ Surveyed elevation. All other elevations are estimated from 1:24,000 scale topographic maps and are accurate to plus or minus 2.5 feet.

the study area are screened in the Yorktown-Eastover aquifer, the wells were not accessible for water-level measurements because of the type of pump (a vacuum pump) that is used in the wells. The only water-level measurements in the Yorktown-Eastover aquifer that were available for this study were from the VWCB research-station well clusters (table 2, fig. 7-8). Water from the overlying aquifers is the major source of recharge to the Yorktown-Eastover aquifer. An additional source of recharge is regional underflow from upgradient areas west of the study area. Ground-water discharging from the Yorktown-Eastover aquifer follows two major flow paths. Some of the water flows laterally to the north and discharges directly into the deeply incised York River. Some of the water flows laterally to the east where it encounters salty, higher density water and is forced upward through the sediments to discharge in nearshore marshes and beneath the Chesapeake Bay (Laczniak and Meng, 1988; Meng and Harsh, 1988). Hydrographs from research-station well clusters indicate a downward gradient from the Columbia aquifer to the Yorktown-Eastover aquifer throughout much of the year (fig. 8 A,B,C,F,G). The unusual patterns in the water levels in the coastal wells 59F 98 and 59F 99 (fig. 8G) are probably the result of periodic water-level measurements obtained at different points in the tide cycle. The aquifers and



EXPLANATION

- 5 — LINE OF EQUAL WATER LEVEL-- Dashed where approximately located.
In feet above sea level
- 4.2 WELL LOCATION-- Number is water level in feet above sea level

Figure 5.--Water levels on May 5, 1991, at selected observation wells in the Columbia aquifer.

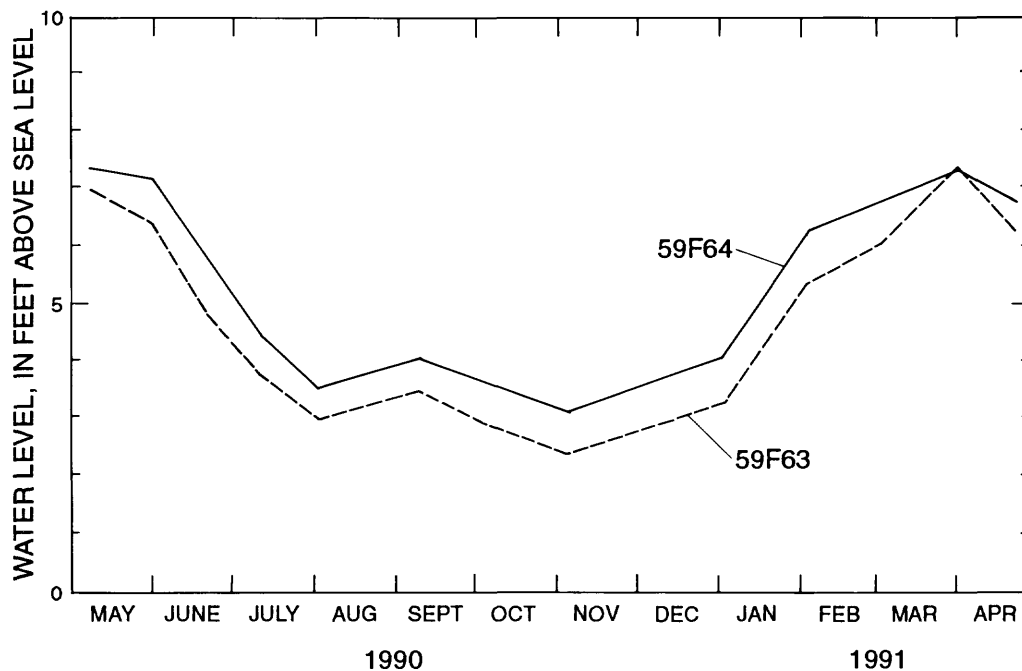
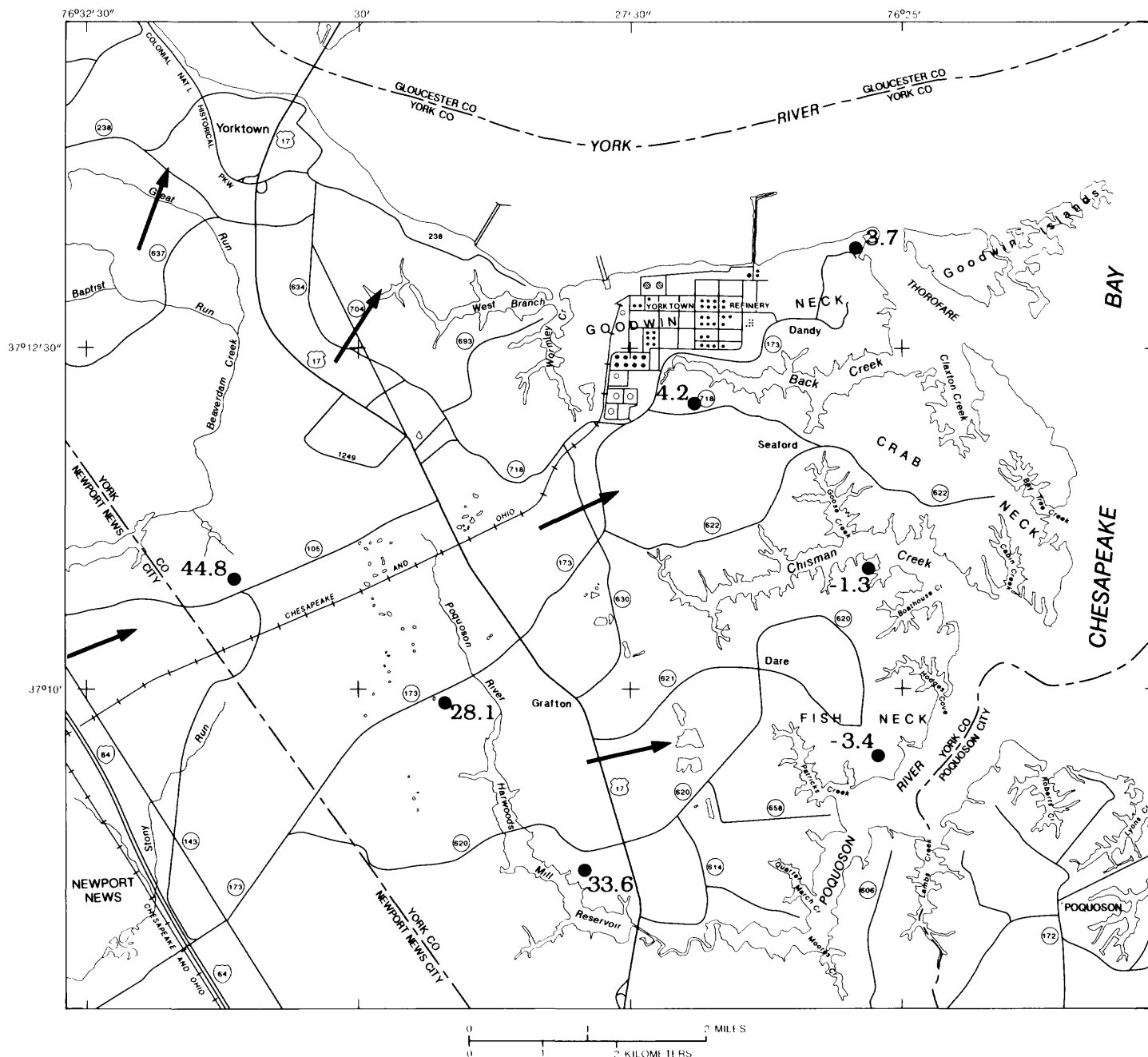


Figure 6.--Water levels in a well cluster in the Columbia aquifer.

confining units are not uniform and continuous throughout the study area (fig. 4). No confining units are between the Columbia and the Yorktown-Eastover aquifers at wells 59F 86 and 59F 87 (fig. 8E). Ground water is able to flow through the sediments more easily at this well cluster than at other well clusters in the study area because of the absence of the confining units.

Ground-water flow in the Fish Neck peninsula area could be affected by water-level declines in the Yorktown-Eastover aquifer (figs. 7, 8B, 8F). The Fish Neck peninsula is the only large area in eastern York County that does not have access to the public supply. The homeowners and small businesses in this area rely on wells screened in the Yorktown-Eastover aquifer to supply their freshwater needs. Water levels in the two wells (59F 76 and 59F 89) screened in the Yorktown-Eastover aquifer on the Fish Neck peninsula are consistently below sea level. Additional water-level measurements are needed to define the extent of the lowered water-levels in the Yorktown-Eastover aquifer.

The extensive Eastover-Calvert confining unit is considered the base of the shallow ground-water-flow system. Significant vertical flow across this confining unit is unlikely because of its thickness; however, small amounts of vertical leakage from underlying aquifers is expected in the eastern part of the study area where upward flow in the regional aquifers discharges to the Chesapeake Bay (Back, 1966; Laczniaik and Meng, 1988).



EXPLANATION

- 44.8 Well location number is water level in feet above or below sea level
- ➔ Conceptualized regional ground-water flow direction

Figure 7.--Water levels on May 5, 1991, at selected observation wells in the Yorktown-Eastover aquifer and conceptualized regional ground-water flow directions.

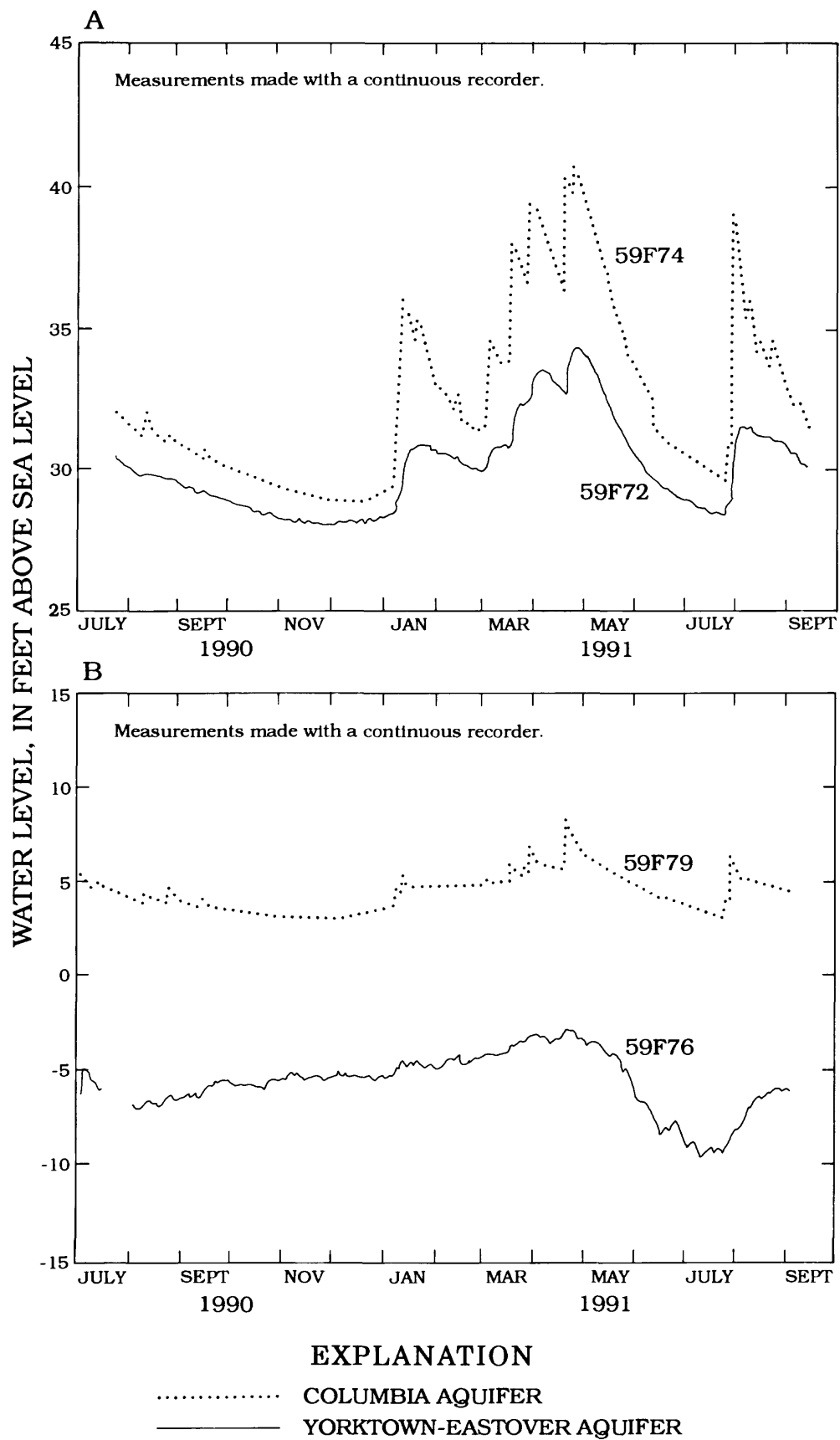


Figure 8.—Water levels in the Columbia and Yorktown-Eastover aquifers at research-station well clusters.

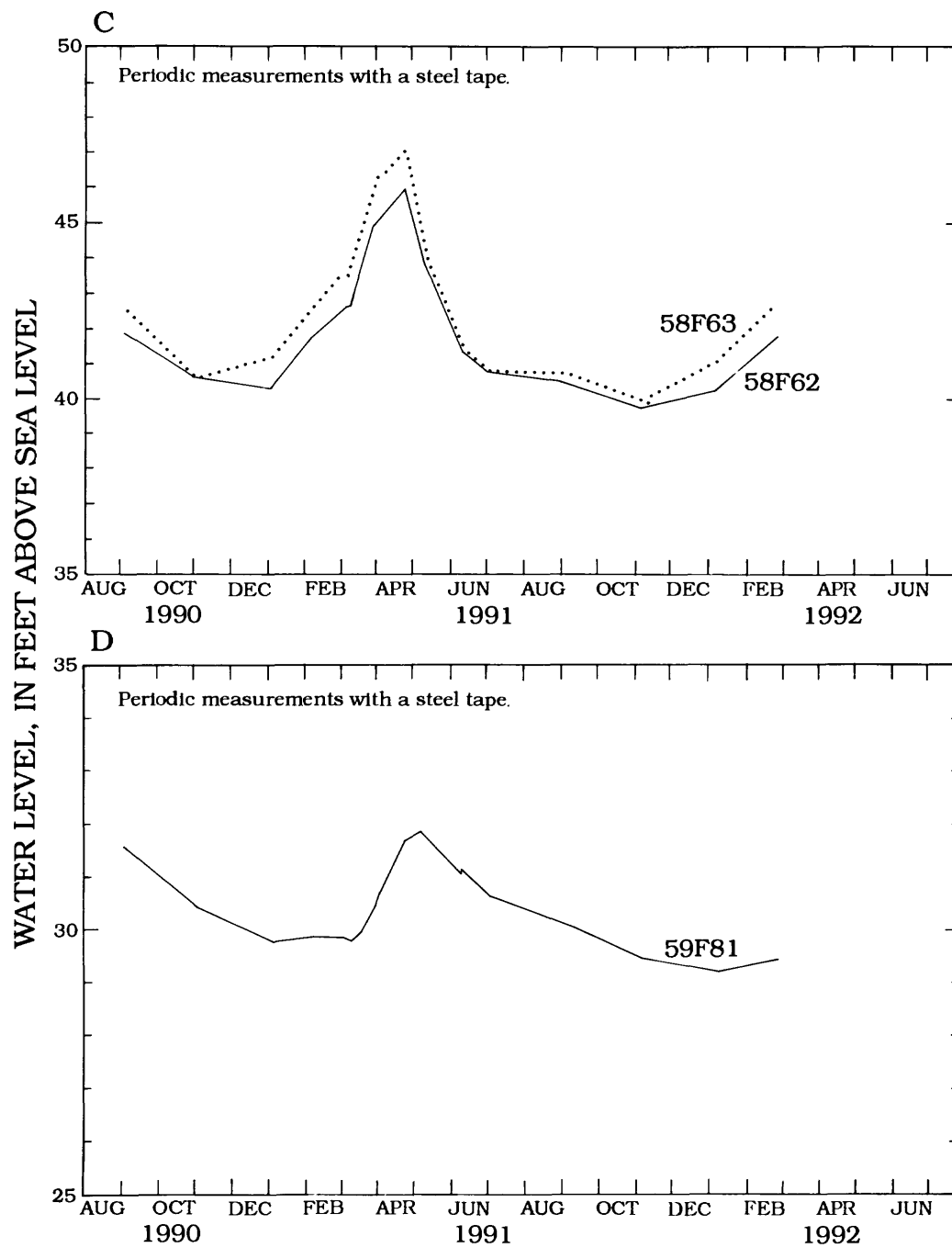


Figure 8.--Continued

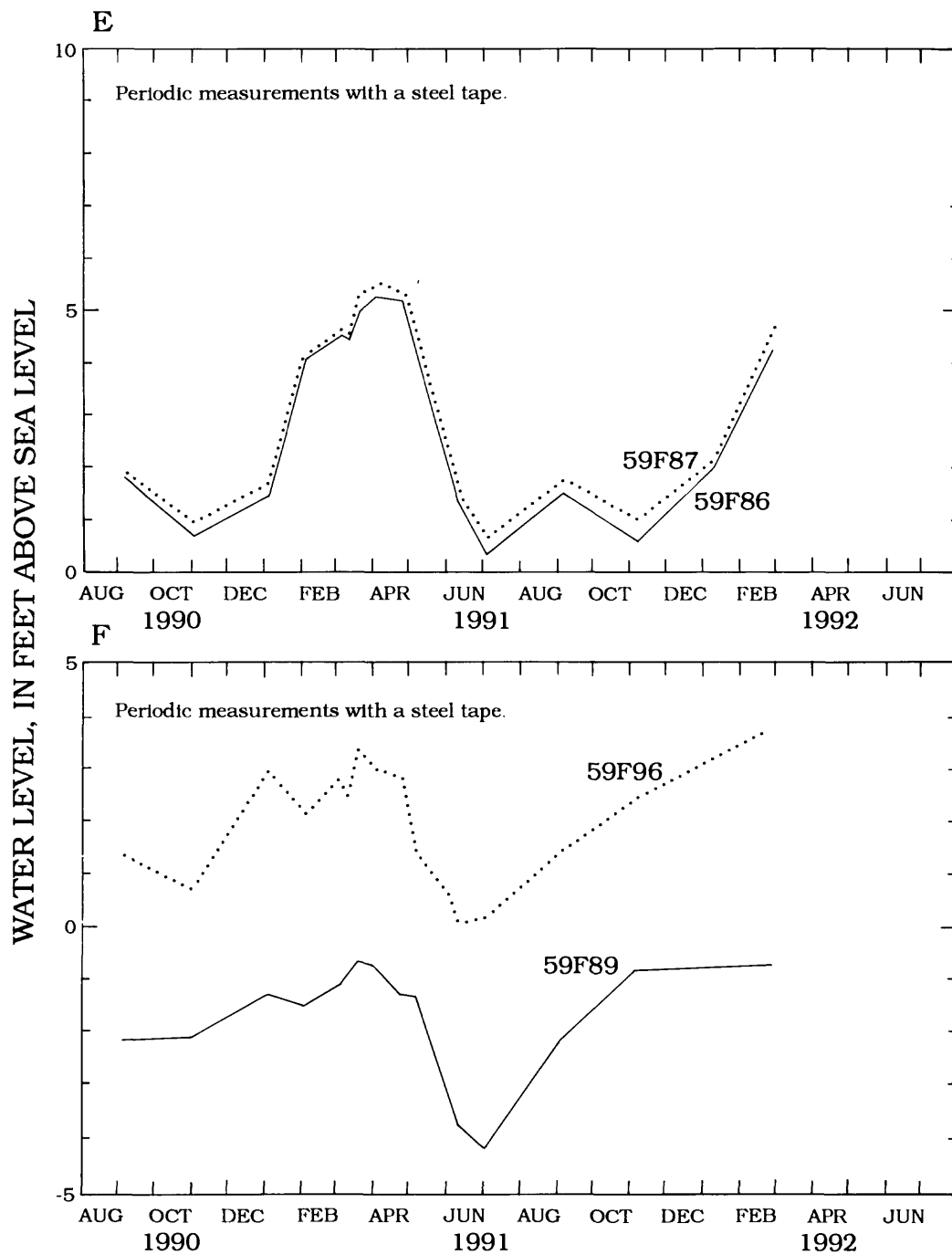


Figure 8.--Continued

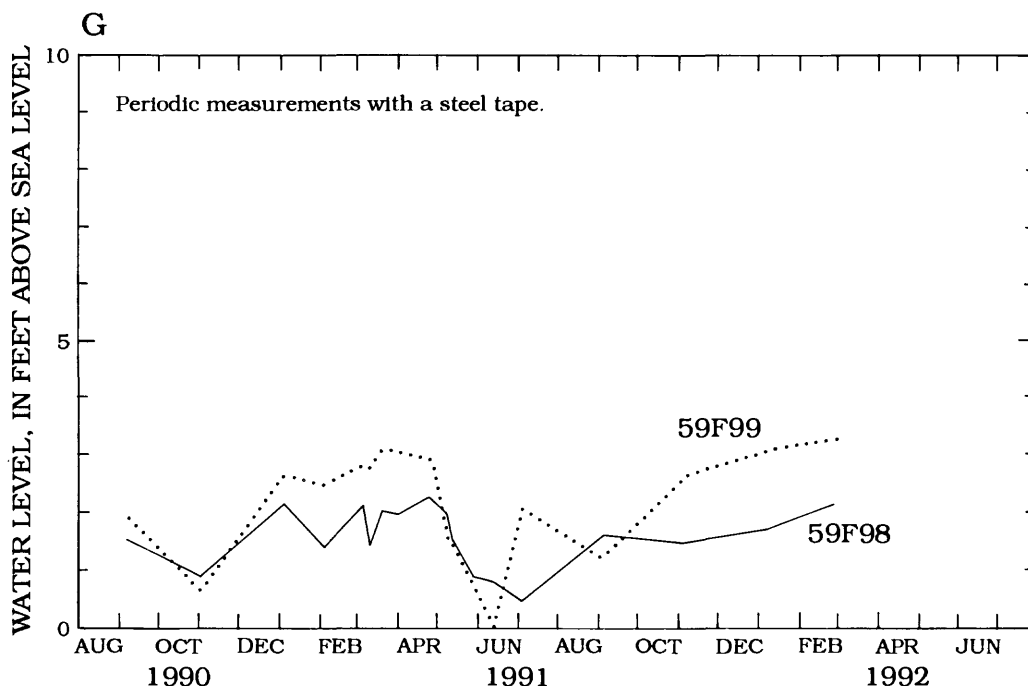


Figure 8.--Continued

WATER QUALITY

The quality of ground water is affected by the (1) chemical characteristics of precipitation, (2) natural processes that take place as water travels through the sediments beneath the ground, and (3) results of human interactions with the ground-water system. Water-quality samples were collected at 16 VWCB research-station wells, 15 USGS water-table wells, and 25 domestic wells to characterize the general water quality of the shallow aquifers in eastern York County. Water-quality analyses in the shallow aquifers (table 3, at end of report) indicate a chemical composition that is predominantly consistent with a composition controlled by natural processes. Water samples from only a few of the wells sampled for the study reflect potential effects from human-related activities. All water-quality analyses presented in this report are for the dissolved form (0.45-mm (micrometer) filtered sample) of the constituent unless otherwise indicated. The water-quality discussions are limited to the Columbia and Yorktown-Eastover aquifers, because of the lack of water-quality data for the Cornwallis Cave aquifer.

General Ground-Water Quality

The chemical composition of natural water in the study area is the result of the types of sediments in the aquifers and the natural chemical-weathering processes that occur as water enters and flows through

the sediments. Precipitation that recharges the shallow ground-water system typically contains high concentrations of oxygen from the atmosphere but otherwise low concentrations of dissolved constituents. Table 4 presents some of the major chemical constituents in precipitation collected approximately 20 mi north of the study area. Precipitation infiltrates into and through the soil zone, which contains abundant organic matter. Organic matter is oxidized, and the oxygen in the water is depleted. Carbon dioxide (CO₂) in gaseous form, generated by the decay of organic matter and root respiration, reacts with the water (H₂O) to produce carbonic acid (H₂CO₃), which increases the rate of dissolution of the minerals in the sediments, as follows:



Concentrations of dissolved constituents in ground water continue to increase as the water flows downward into the saturated Columbia aquifer (the unconfined aquifer) and then into the Cornwallis Cave and Yorktown-Eastover aquifers (the confined aquifers). Stiff diagrams of water-quality analyses from water in representative wells in the Columbia and Yorktown-Eastover aquifers indicate generally smaller concentrations of dissolved constituents in the Columbia aquifer (fig. 9) than in the Yorktown-Eastover aquifer (fig. 10). Another important natural process that affects the chemical composition of the ground water in the study area is carbonate dissolution. Calcite dissolves rapidly from the abundant shell material in the marine sediments in a reaction in which the concentrations of calcium and magnesium cations and bicarbonate anions in the ground water are increased. Silicate minerals also dissolve to produce sodium, potassium, calcium, bicarbonate, silicic acid, and other ions (Hem, 1985). The oxidation of pyrite in the sediments is a source of iron and sulfate ions in the ground water. The weathering of glauconite in the sediments is a source of potassium and iron ions. The depletion of oxygen that results from various weathering reactions produces anaerobic water. The reduction of iron from the minerals in the sediments is a process that takes place in anaerobic ground water. Ferric iron in the minerals becomes reduced and dissolved as ferrous iron in a chemical reaction that produces bicarbonate and increases the alkalinity of the ground water, as follows:

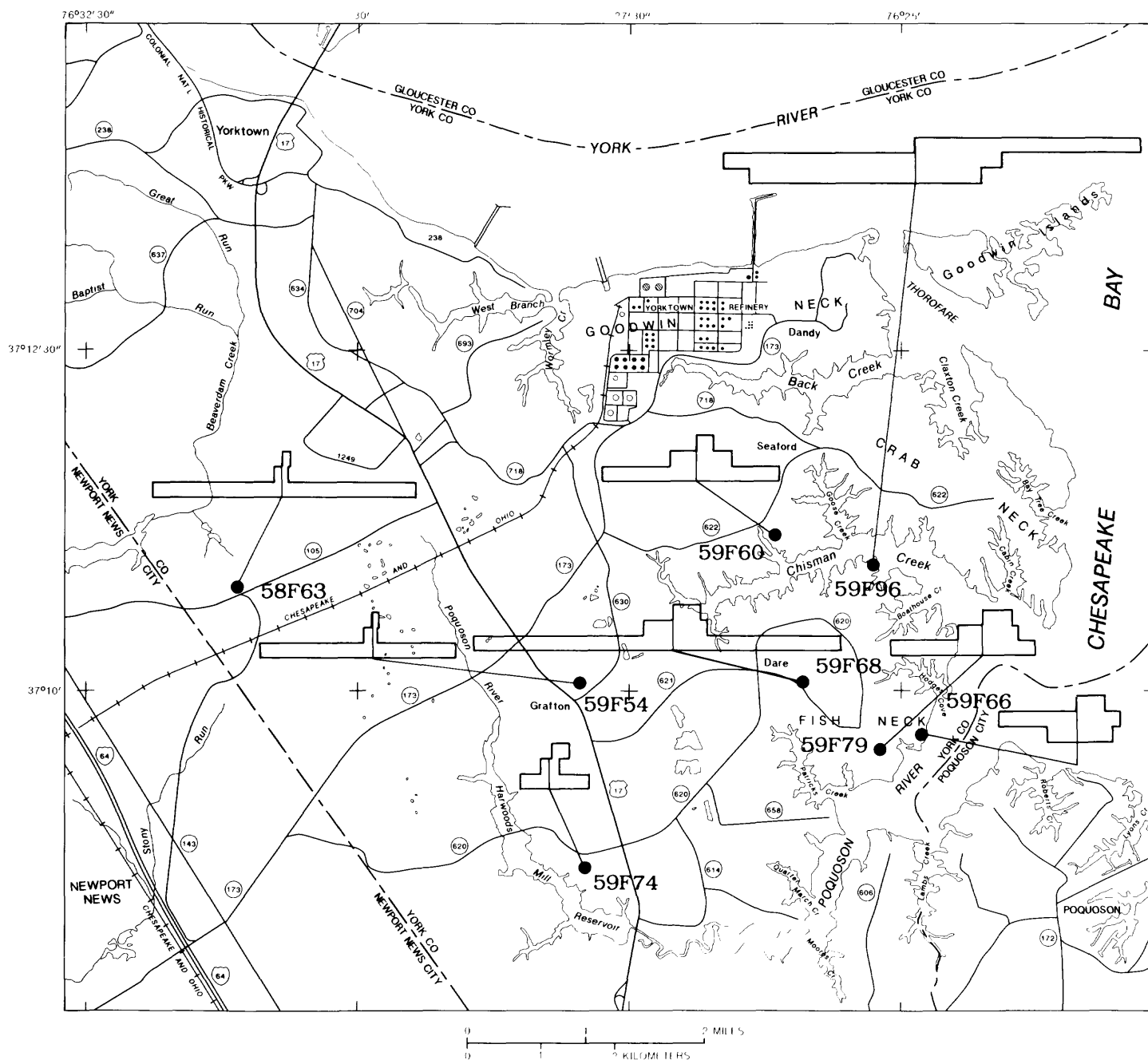


As a result of carbonate dissolution, organic-matter oxidation, pyrite and glauconite weathering, and iron reduction, the ground water in the shallow aquifers of eastern York County has low concentrations of dissolved oxygen and high concentrations of calcium, bicarbonate, and iron.

Table 4.--Average composition of precipitation from a station located at Haven Beach, Mathews County, Virginia, November 1990 through March 1991

[source: written commun., D.J. Burdige, Old Dominion University, 1991;
mg/L is milligrams per liter]

Constituent	Concentration (mg/L)
Calcium	0.09
Magnesium	.14
Sodium	1.13
Potassium	.07
Sulfate	2.70
Chloride	2.18
Nitrate	1.87



EXPLANATION

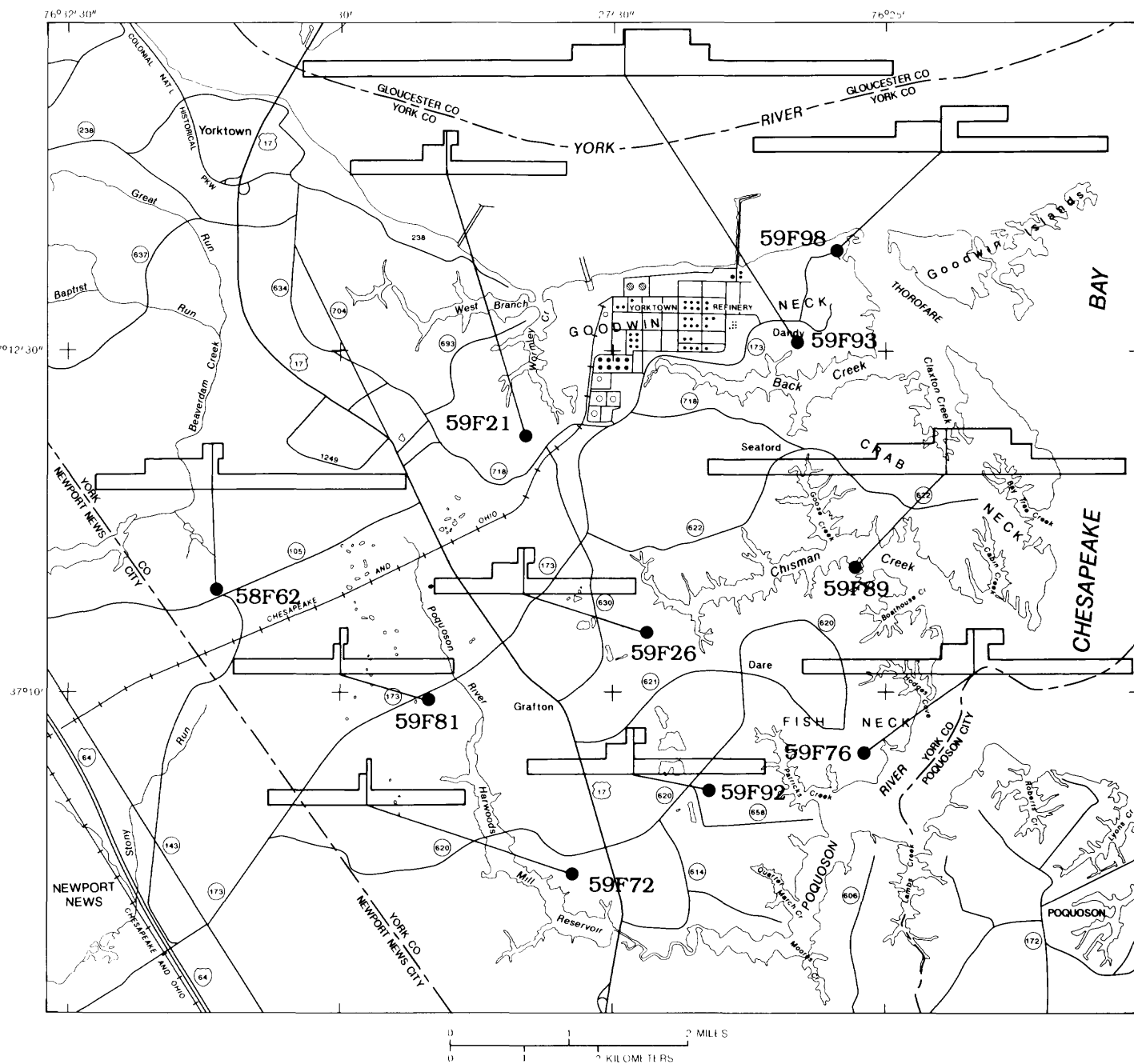
● 59F60
WELL AND IDENTIFICATION
NUMBER

K — Na — SO₄ — Cl
Ca+Mg — HCO₃

5 0 5

CONCENTRATION, IN MILLIEQUIVALENTS PER LITER

Figure 9.--Diagrams illustrating water quality in the Columbia aquifer.



EXPLANATION

● 59F21
WELL AND IDENTIFICATION
NUMBER

K Na SO₄ Cl
Ca+Mg HCO₃

5 0 5

CONCENTRATION, IN MILLIEQUIVALENTS PER LITER

Figure 10.--Diagrams illustrating water quality in the Yorktown-Eastover aquifer.

Spatial Distribution and Statistical Summaries of pH and Selected Constituents

A summary and discussion of the major chemical constituents in the ground water of eastern York County are presented in this section. Boxplots and statistical comparisons of the data are used to characterize and compare the chemistry of the water in the Columbia and Yorktown-Eastover aquifers. Nonparametric statistics are used in this report, because they are considered to be robust techniques that are not hindered by the assumption of a normal distribution of data. The Mann-Whitney hypothesis test is used to examine the data for the two major aquifers and ascertain whether apparent differences in the data are actual or are because of chance variability. The Mann-Whitney test is a nonparametric t-test procedure involving rank-transformed data (Iman and Conover, 1983). The null hypothesis for the Mann-Whitney test states that no real differences exist between the data in the Columbia and Yorktown-Eastover aquifers. The level of significance (alpha value) for the test is 0.05, which represents the maximum probability of rejecting the null hypothesis when it is true. If the probability (p-value) for the attained significance level is smaller than the level of significance (alpha value), the null hypothesis is rejected.

U.S. Environmental Protection Agency (USEPA) drinking-water regulations are presented to provide a means of comparing the ground-water quality in eastern York County with recognized standards for drinking water. Two sets of regulations were established under the Safe Drinking Water Act of 1986. The Maximum Contaminant Level (MCL) is an enforceable standard established for constituents that can cause adverse human-health effects. The Secondary Maximum Contaminant Level (SMCL) is a nonenforceable standard established for constituents that can adversely affect the odor, appearance, taste, or usability of the drinking water (U.S. Environmental Protection Agency, 1989). The Virginia Water Control Board has set ground-water standards for selected constituents (Southeastern Virginia Planning District Commission, 1990); therefore, the Virginia standards are also presented.

pH and Major Inorganic Constituents

A summary of pH and the major inorganic constituents provides information about the chemical composition of the ground water in the eastern part of York County. Boxplots and statistical comparisons of data from the Columbia and Yorktown-Eastover aquifers illustrate the differences in ground water from the unconfined aquifer and ground water from the confined aquifer system.

pH

The hydrogen-ion activity of water is expressed as pH, the negative base-10 log of the hydrogen-ion activity in the solution in moles per liter. The pH in the Columbia aquifer ranges from 4.4 to 7.5 with a median value of 6.7 (table 5). The pH in the Yorktown-Eastover aquifer ranges from 6.8 to 7.9 with a median value of 7.2 (table 6). The pH of 37 percent of water samples from wells in the Columbia aquifer was less than 6.5, which is the lower limit of the USEPA SMCL for pH. The Virginia Water Control Board ground-water standard for pH ranges from 6.5 to 8.5 for the Coastal Plain physiographic province (Southeast Virginia Planning District Commission, 1990). Data on pH (and other selected constituents) in water from the Columbia and Yorktown-Eastover aquifers are summarized graphically in the boxplots in figure 11. The analysis of boxplots and Mann-Whitney hypothesis test indicates a significant difference (p-value < 0.001) in pH between the two aquifers. The pH of precipitation that recharges the Columbia aquifer generally ranges from 3.7 to 5.0 (D.J. Burdige, Old Dominion University, written commun., 1991). As the ground water flows through the sediments, chemical reactions consume hydrogen ions (see discussion at beginning of water-quality section), and the pH of the ground water increases.

Dissolved oxygen

The dissolved oxygen concentration was measured in several of the wells that were sampled to confirm the hypothesis that reducing conditions prevail in ground water in eastern York County.

Table 5.--Summary statistics for water-quality analyses from the Columbia aquifer

[all analyses are for the dissolved constituent unless otherwise noted; $\mu\text{S}/\text{cm}$ is microsiemens per centimeter at 25 degrees Celsius; mg/L is milligrams per liter; < is less than; CaCO_3 is calcium carbonate; N is nitrogen]

Water-quality constituent	Number of samples	Maximum concentration	Minimum concentration	Median concentration
Specific conductance, $\mu\text{S}/\text{cm}$	22	6,820	100	478
pH, standard units	22	7.5	4.4	6.7
Dissolved Oxygen, mg/L	9	6.8	1.4	2.9
Hardness, mg/L as CaCO_3	21	960	16	210
Calcium, mg/L	21	230	3.9	80
Magnesium, mg/L	21	94	1.4	4.5
Sodium, mg/L	21	910	2.9	19
Potassium, mg/L	21	11	<.10	.9
Alkalinity, mg/L as CaCO_3	20	271	9	131
Sulfate, mg/L	21	220	5.8	49
Chloride, mg/L	22	2,500	4.9	29
Fluoride, mg/L	21	.60	<.10	.20
Dissolved solids, residue at 180°C, mg/L	20	4,670	62.0	268
Nitrite + Nitrate, Mg/L as N	21	16.0	<.100	<.100
Ammonium, mg/L as N	21	.750	<.010	.030
Phosphorus, total, mg/L	21	.070	<.010	<.010
Iron, mg/L	21	140	.009	.44
Manganese, mg/L	21	.72	.002	.13

Table 6.--Summary statistics for water-quality analyses from the Yorktown-Eastover aquifer

[all analyses are for the dissolved constituent unless otherwise noted; $\mu\text{S}/\text{cm}$ is microsiemens per centimeter at 25 degrees Celsius; mg/L is milligrams per liter; < is less than; CaCO_3 is Calcium Carbonate; N is Nitrogen]

Water-quality constituent	Number of samples	Maximum concentration	Minimum concentration	Median concentration
Specific conductance, $\mu\text{S}/\text{cm}$	28	1,850	322	935
pH, standard units	27	7.9	6.8	7.2
Dissolved Oxygen, mg/L	3	0.4	0.5	0.4
Hardness, mg/L as CaCO_3	22	630	130	260
Calcium, mg/L	22	220	29	78
Magnesium, mg/L	22	35	1.1	14
Sodium, mg/L	22	140	4.9	6
Potassium, mg/L	22	17	.20	8.8
Alkalinity, mg/L as CaCO_3	20	421	131	261
Sulfate, mg/L	22	310	<1.0	14
Chloride, mg/L	29	170	3.0	74
Fluoride, mg/L	22	.50	<.10	.20
Dissolved solids, residue at 180°C, mg/L	22	956	193	394
Nitrite + Nitrate, mg/L as N	22	<.100	<.100	<.100
Ammonium, mg/L as N	22	.450	.030	.255
Phosphorus, total, mg/L	22	.120	<.010	<.010
Iron, mg/L	22	5.5	.007	.39

Concentrations of dissolved oxygen in water samples from the nine wells measured in the Columbia aquifer ranged from a minimum of 1.4 mg/L to a maximum of 6.8 mg/L with a median concentration of 2.9 mg/L (table 3, at end of report and table 5). The low concentrations of dissolved oxygen in the water-table aquifer indicate that oxygen is rapidly depleted from the water as it travels through the organic-rich

soil zone and through the Columbia aquifer. The dissolved-oxygen concentration in the water decreases as it flows downward through the aquifer sediments. The dissolved-oxygen concentrations measured in the Yorktown-Eastover aquifer were 0.4, 0.4, and 0.5 mg/L in wells 59F 76, 59F 98, and 59F 86, respectively (table 3, at end of report and table 6).

Hardness

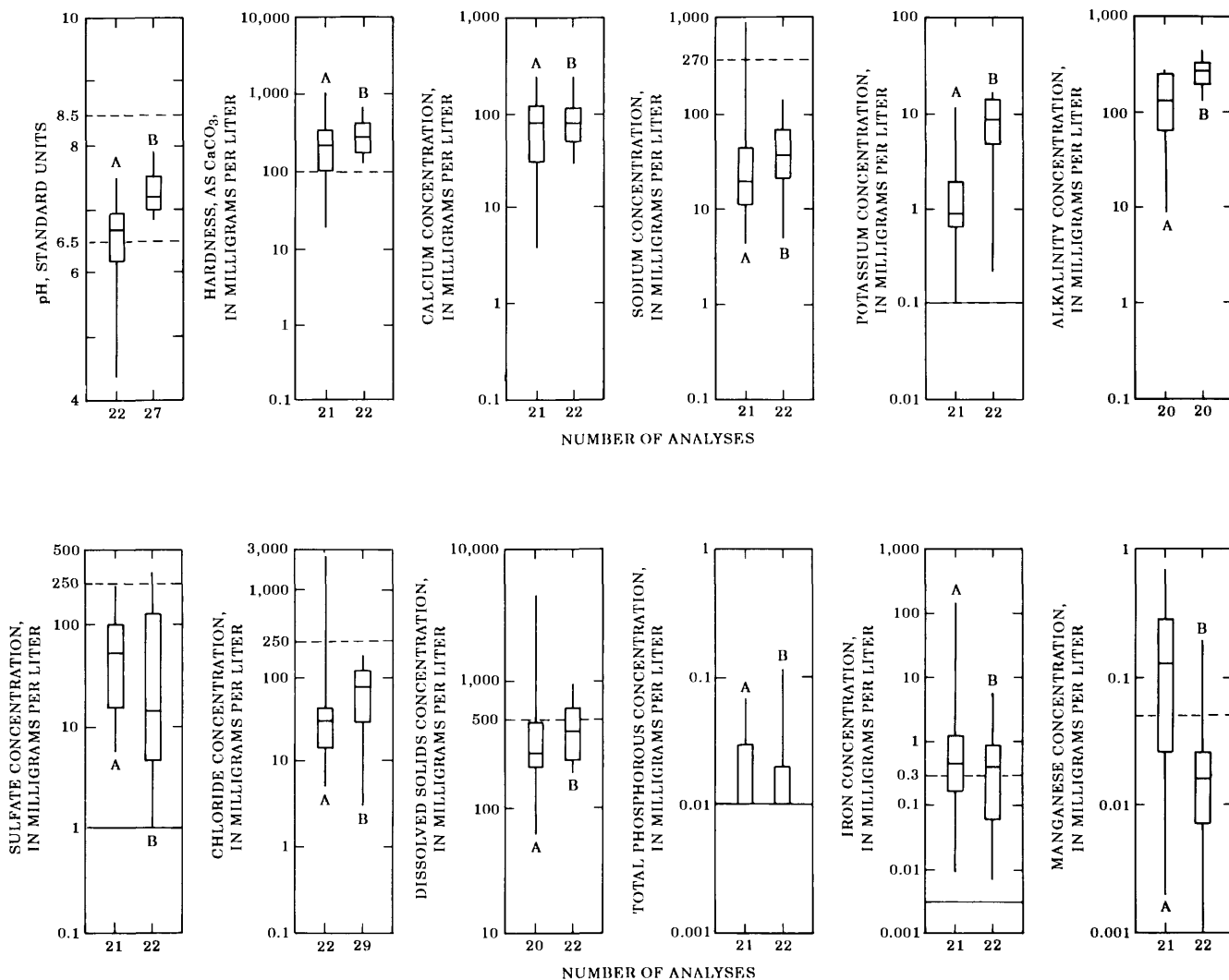
Excessive hardness is a common problem with the ground water in the study area. Hardness is calculated as the sum of the concentrations of calcium and magnesium ions and is expressed in this report in terms of an equivalent concentration of calcium carbonate (in mg/L as CaCO_3). Dufor and Becker (1964) developed a classification scheme that defines relative hardness in ranges of (1) 0 to 60 mg/L, defined as "soft," (2) 61 to 120 mg/L, defined as "moderately hard," (3) 121-180 mg/L, defined as "hard," and (4) more than 180 mg/L, defined as "very hard." Hardness in the Columbia aquifer ranges from a minimum of 16 mg/L to a maximum of 960 mg/L with a median concentration of 210 mg/L (table 5). Hardness in the Yorktown-Eastover aquifer ranges from a minimum of 130 mg/L to a maximum of 630 mg/L with a median concentration of 260 mg/L (table 6). A hardness of more than 100 mg/L is considered objectionable for ordinary domestic use, because the calcium and magnesium in the water form insoluble compounds with soap that decrease the effectiveness of soap as a cleanser. In addition, the elevated concentrations of calcium can precipitate to form encrustations in pumps, pipes, and plumbing fixtures. Hard water is a nuisance; however, it is not associated with any negative health effects (U.S. Environmental Protection Agency, 1989). Relatively inexpensive water-softening devices are commercially available for treating hard water. Hardness concentrations in water samples from 76 percent of the wells sampled from the Columbia aquifer exceed 100 mg/L. Hardness concentrations in 100 percent of the wells sampled from the Yorktown-Eastover aquifer exceed 100 mg/L. Analysis of the boxplots (fig. 11) and the Mann-Whitney hypothesis test indicates no significant difference (p-value of 0.155) in hardness concentrations between the two aquifers. Hardness concentrations in the study area reflect the elevated calcium concentrations that result from the abundant shell material in the aquifer sediments.

Calcium

Calcium is the predominant cation in the shallow ground water of eastern York County. The concentration of calcium in the Columbia aquifer ranges from 3.9 to 230 mg/L with a median concentration of 80 mg/L (table 5). The concentration in the Yorktown-Eastover aquifer ranges from 29 to 220 mg/L with a median concentration of 78 mg/L (table 6). There are no harmful health effects associated with elevated concentrations of calcium in ground water (U.S. Environmental Protection Agency, 1989). The Mann-Whitney hypothesis test indicates no significant difference (p-value of 0.585) in calcium concentrations between the two aquifers. The major source of calcium in the ground water is the dissolution of calcite in shell material which is abundant in both the Columbia aquifer and the Yorktown-Eastover aquifer.

Sodium

Sodium is another major cation present in ground water. The concentration of sodium in the Columbia aquifer ranges from 2.9 to 910 mg/L with a median concentration of 19 mg/L (table 5). The concentration in the Yorktown-Eastover aquifer ranges from 4.9 to 140 mg/L with a median concentration of 36 mg/L (table 6). Elevated sodium concentrations can cause health problems for people on sodium-restricted diets. The State of Virginia currently has adopted a 270 mg/L ground-water standard for sodium in drinking water (Southeastern Virginia Planning District Commission, 1990). The boxplots (fig. 11) indicate generally lower sodium concentrations in the Columbia aquifer than in the Yorktown-Eastover aquifer; however, the Mann-Whitney hypothesis test indicates that the difference is not significant (p-value of 0.061). Sources of sodium in ground water include mineral dissolution, cation exchange, and sea water.



EXPLANATION

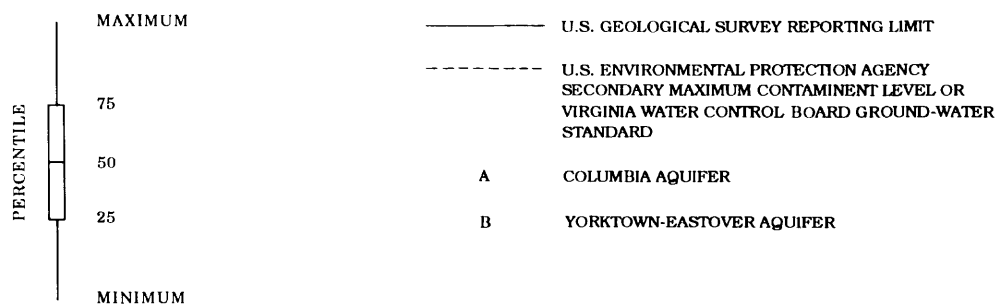


Figure 11.--Summaries of water-quality analyses for selected constituents.

Potassium

Potassium is generally not found in high concentrations in ground water. Potassium is relatively abundant in soils; however, it does not readily stay in a dissolved state (Hem, 1985). Potassium concentrations in the Columbia aquifer range from less than the detection limit of 0.10 to 11 mg/L with a median concentration of 0.9 mg/L (table 5). Potassium concentrations in the Yorktown-Eastover aquifer range from 0.20 to 17 mg/L with a median concentration of 8.8 mg/L (table 6). The boxplots (fig. 11) and Mann-Whitney hypothesis test indicate a significant difference (p -value < 0.001) in the concentrations of potassium between the two aquifers. Sources of potassium include the dissolution of orthoclase feldspar and the weathering of glauconite in the sediments. The concentrations of potassium are expected to be elevated in the confined Yorktown-Eastover aquifer with respect to the overlying Columbia aquifer, because the water in the Yorktown-Eastover aquifer has been in contact with the minerals in the sediments for a longer period of time than has the water in the Columbia aquifer.

Alkalinity

Alkalinity is defined as the capacity of a solution to neutralize acid. In natural waters, alkalinity is produced primarily by the presence of dissolved bicarbonate and carbonate (Hem, 1985). Because several solute species (in addition to carbonate and bicarbonate) can contribute to the alkalinity of water, alkalinity is commonly reported in an equivalent amount of calcium carbonate (mg/L as CaCO_3). Bicarbonate is the predominant anion in the shallow ground-water system in eastern York County. The alkalinity of the Columbia aquifer ranges from 9 to 271 mg/L with a median concentration of 131 mg/L (table 5). The alkalinity of the Yorktown-Eastover aquifer ranges from 131 to 421 mg/L with a median concentration of 261 mg/L (table 6). The boxplots (fig. 11) and Mann-Whitney hypothesis test indicate a significant difference (p -value of 0.001) in alkalinity concentrations between the two aquifers. The principal source of bicarbonate in the shallow aquifers of eastern York County is the dissolution of carbonate minerals. The reduction of iron also is a source of bicarbonate that increases the alkalinity of the ground water in the study area.

Sulfate

Dissolved sulfur in ground water primarily is in the oxidized form of the sulfate ion. The concentration of sulfate in the Columbia aquifer ranges from 5.8 to 220 mg/L with a median concentration of 49 mg/L (table 5). The concentration of sulfate in the Yorktown-Eastover aquifer ranges from the detection limit of 1.0 mg/L to a maximum of 310 mg/L with a median concentration of 14 mg/L (table 6). The concentration of sulfate exceeds the USEPA SMCL of 250 mg/L in only one well sampled for this study. Elevated levels of sulfate can give ground water an objectionable taste and can produce a laxative effect on humans (Hem, 1985). An apparent difference in sulfate concentrations between the Columbia aquifer and the Yorktown-Eastover aquifer can be seen in the boxplots (fig. 11); however, the Mann-Whitney hypothesis test does not indicate that the difference is significant (p -value of 0.166). Sulfate concentrations generally are higher in the Columbia aquifer than in the Yorktown-Eastover aquifer. Sources of sulfate include precipitation and the oxidation of pyrite in the aquifer sediments. Sulfate concentrations could be lower in the Columbia aquifer than in the Yorktown-Eastover aquifer, because sulfate is being reduced to sulfide as it moves through the anaerobic water.

Chloride

Chloride concentrations in the shallow aquifers in eastern York County are a water-quality concern. Chloride is considered a conservative ion, because it does not significantly react with other ions or adsorb to mineral surfaces. Chloride is moved by advective dispersive transport and will follow ground-water-flow paths. Precipitation naturally has low (0-10 mg/L) chloride concentrations (table 4), and chloride rarely is found in minerals in aquifer sediments in the eastern United States; therefore, the source of chloride in ground water usually is related to human activity and (or) interactions with sea water. Chloride concentrations in the Columbia aquifer range from a minimum of 4.9 mg/L to a

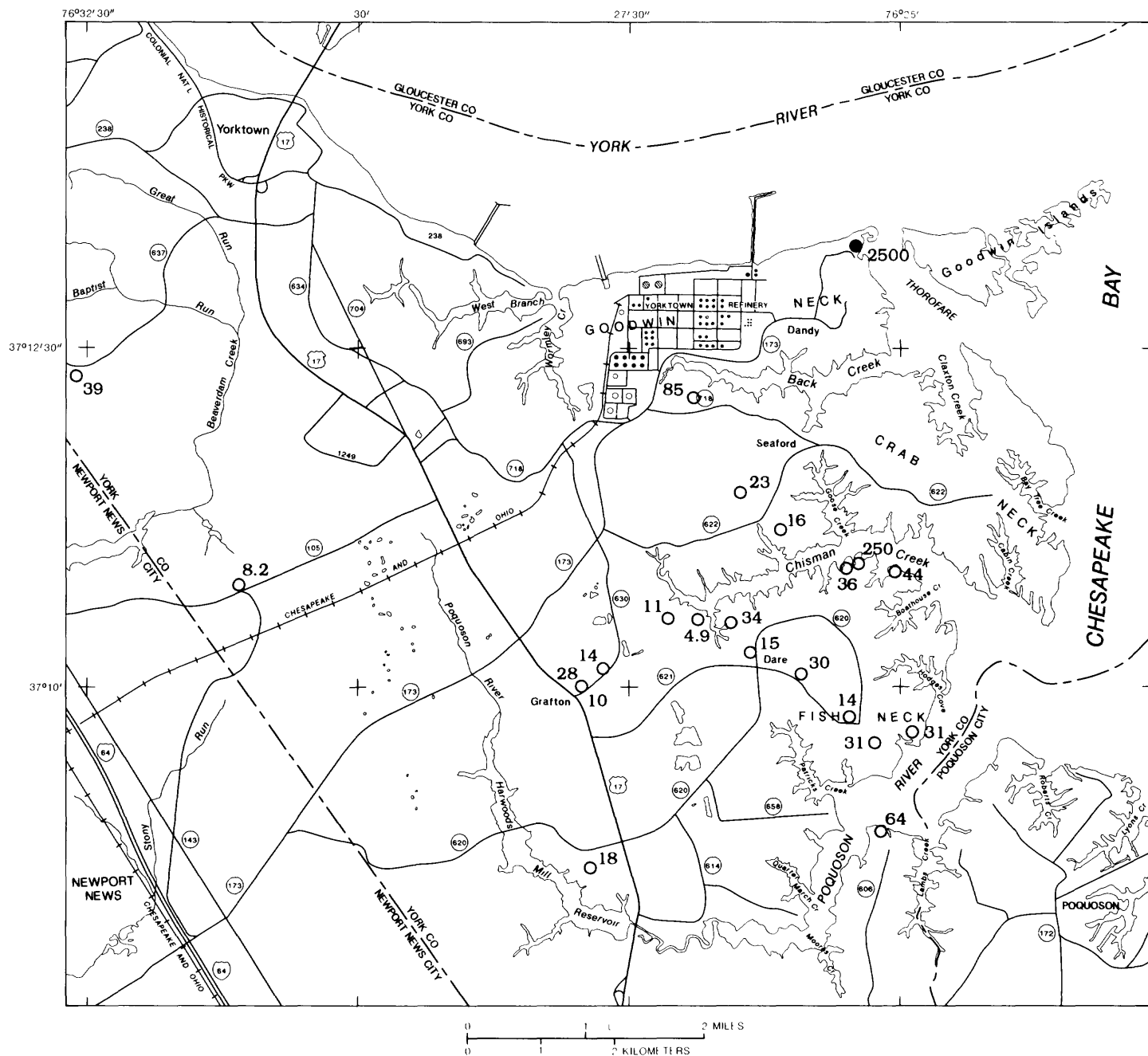
maximum of 2,500 mg/L with a median concentration of 29 mg/L (table 5). Chloride concentrations in the Yorktown-Eastover aquifer range from a minimum of 3.0 mg/L to a maximum of 170 mg/L with a median concentration of 74 mg/L (table 6). Chloride concentrations in water for only one well sampled during this study exceeded the USEPA SMCL of 250 mg/L. Water containing more than 250 mg/L can have an objectionable taste. Water in the Yorktown-Eastover aquifer generally has greater chloride concentrations than water in the Columbia aquifer (fig. 11). The Mann-Whitney hypothesis test indicates a significant difference between the two aquifers with a p-value of 0.028.

Analysis of the areal distribution of chlorides in the Columbia aquifer (fig. 12) and stiff diagrams (fig. 9) indicates local incidences of elevated chloride concentrations (greater than 50 mg/L). The elevated chloride concentrations in the Columbia aquifer could come from a variety of sources. Human-related sources of chloride are domestic effluents, road salting, and agricultural and domestic fertilizers. The usual natural source of chloride is sea water. Elevated chloride concentrations in ground water sampled for this study are generally found in wells located along the coast. In coastal areas, salt spray, tidal fluctuations, and periodic flooding of lowlands could cause elevated chloride concentrations in the Columbia aquifer. The data indicate that the source of elevated chloride concentrations is not related to human activity.

The areal distribution of chlorides in the Yorktown-Eastover aquifer (fig. 13) and stiff diagrams (fig. 10) confirm the data summarized by the boxplots (fig. 11) and indicate chloride concentrations generally are higher in the Yorktown-Eastover aquifer than they are in the Columbia aquifer. Chloride concentrations are also higher in the eastern part of the study area near the coast than they are in the central and western part of the study area. The source of the higher chlorides in the Yorktown-Eastover aquifer in the eastern part of the study area could result from small amounts of vertical leakage through the Eastover-Calvert confining unit from underlying aquifers, where upward flow from regional aquifers containing high concentrations of dissolved solids is discharging to the Chesapeake Bay (Back, 1966; Laczniaak and Meng, 1988; and Harsh and Laczniaak, 1990).

Where chloride data are available at the same location for both aquifers, chloride concentrations in the Yorktown-Eastover aquifer exceed chloride concentrations in the Columbia aquifer with three exceptions: Chloride concentrations in water in wells 59F 99 (2,500 mg/L) and 59F 96 (250 mg/L), screened in the Columbia aquifer, exceed chloride concentrations in water in wells 59F 98 (74 mg/L) and 59F 89 (72 mg/L), screened in the Yorktown-Eastover aquifer. These well clusters are located within 20 ft of the coast. Because the Columbia aquifer is unconfined, there is a direct hydraulic connection between the Columbia aquifer and the adjacent saltwater body. The extremely high chloride concentration in well 59F 99 is a result of periodic flooding from the adjacent saltwater body. Flow between the Columbia aquifer and the Yorktown-Eastover aquifer is inhibited by at least one confining unit at each location; therefore, the chloride concentrations in the Yorktown-Eastover aquifer do not directly reflect the interaction between the unconfined aquifer and the surface-water sources. Chloride concentrations in water in one inland well cluster are larger in the Columbia aquifer than in the Yorktown-Eastover aquifer. The chloride concentration is 18 mg/L in water in well 59F 74, screened in the Columbia aquifer. The chloride concentration is 3.0 mg/L in water in well 59F 72, screened in the Yorktown-Eastover aquifer. This anomalously low chloride concentration in the Yorktown-Eastover aquifer could be a result of recharge from regional flow from the Yorktown-Eastover aquifer west of the study area.

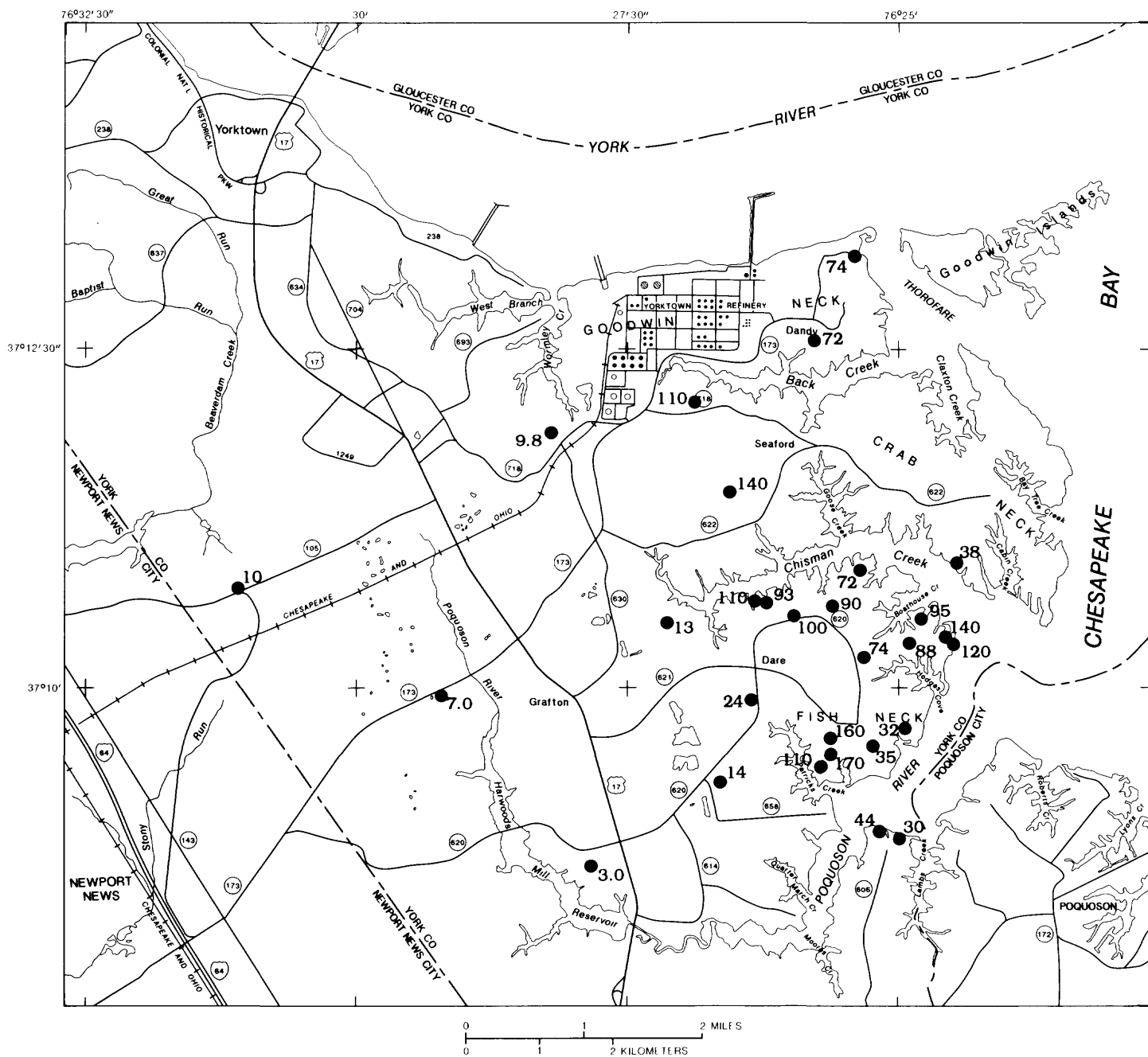
A major concern for the water quality in the confined Yorktown-Eastover aquifer in eastern York County is saltwater encroachment from decreased water levels induced by pumping. If pumpage stress causes water levels to decline in the freshwater part of a coastal aquifer, saltwater from adjacent sediments can be induced into the aquifer that previously contained freshwater. Although chloride concentrations are elevated in several areas that could be influenced by water-level declines (see ground-water flow section), it is not possible to conclude from the available data that saltwater encroachment is occurring as a result of pumping. Chloride concentrations are equally high in several areas that are not currently influenced by pumping (fig. 13). The location of the offshore boundary between the freshwater in the aquifers and the adjacent sea water is unknown and depends on freshwater heads, saltwater heads,



EXPLANATION

- 2500 WELL WHERE GROUND-WATER CONTAINS CONCENTRATIONS GREATER THAN THE U.S. ENVIRONMENTAL PROTECTION AGENCY SECONDARY MAXIMUM CONTAMINANT LEVEL--Number is chloride concentration in milligrams per liter
- 15 WELL WHERE GROUND-WATER CONTAINS CONCENTRATIONS LESS THAN OR EQUAL TO THE U.S. ENVIRONMENTAL PROTECTION AGENCY SECONDARY MAXIMUM CONTAMINANT LEVEL--Number is chloride concentration in milligrams per liter

Figure 12.--Distribution of chloride concentration in the Columbia aquifer.



EXPLANATION

- 30 WELL LOCATION-- Number is chloride concentration in milligrams per liter

Figure 13.--Distribution of chloride concentration in the Yorktown-Eastover aquifer.

and the dispersive properties of the aquifer sediments. Water with elevated chloride concentrations in wells in the eastern part of the study area could be in the natural transition zone between freshwater and saltwater, where upward flow from the deeper aquifers is discharging to the Chesapeake Bay. Simulations of saltwater-interface movement in Yorktown-Eastover aquifer with large hypothetical water-level declines on the Eastern Shore of Virginia indicate that the interface moves slowly and over long periods of time (Richardson, 1991). Water-quality samples collected at regular intervals for a period of time at observation wells in those areas that are a concern for potential saltwater encroachment can assist in discerning water-quality changes over time. Chloride concentrations at all wells sampled in the Yorktown-Eastover aquifer were below the USEPA SMCL for chloride (250 mg/L).

Dissolved solids

The dissolved-solids concentration is a measure of the amount of dissolved mineral matter in water. The dissolved-solids concentrations can be measured directly or calculated as the sum of the concentrations of the various dissolved constituents. The values presented in this report are measured from the residue remaining after evaporation of part of the sample. The dissolved-solids concentration in the Columbia aquifer ranges from 62 to 4,670 mg/L with a median concentration of 268 mg/L (table 5). The dissolved-solids concentration in the Yorktown-Eastover aquifer ranges from 193 to 956 mg/L with a median concentration of 394 mg/L (table 6). The USEPA SMCL of 500 mg/L is exceeded in water in 4 of 20 wells (20 percent) sampled in the Columbia aquifer and in water in 10 of 22 wells sampled (45 percent) in the Yorktown-Eastover aquifer. No negative health effects are associated with elevated concentrations of dissolved solids; however, water with concentrations greater than 500 mg/L can have an unpleasant taste and can result in the formation of mineral deposits in pipes and plumbing fixtures. The boxplots and Mann-Whitney hypothesis test indicate no significant difference (p-value of 0.148) in dissolved-solids concentrations between the two aquifers. The dissolution of minerals from the sediments and the presence of saline water in coastal areas typically are the major sources of dissolved solids in ground water.

Major Nutrients

Nutrients are elements that are essential for plant and animal growth. The amount of dissolved nutrients in natural ground water is relatively small; however, the water quality of the ground water in many areas of the United States has been degraded by an increase in nutrients as a result of human-related activities.

Nitrate

Nitrate is a stable anion under oxidizing conditions and is readily transported in ground water. Organic nitrogen is converted by soil bacteria into nitrate through the process of nitrification. The process of nitrification requires a source of dissolved oxygen; therefore, nitrogen either remains in the organic form or is converted to ammonium in anaerobic waters (Robertson, 1979). Nitrate concentrations in this report are presented as nitrite plus nitrate concentration in terms of equivalent elemental nitrogen (concentration of $\text{NO}_2 + \text{NO}_3$, in mg/L, as N). This analysis is essentially a measure of the nitrate concentration, because nitrite concentrations in ground water are minimal.

The low concentrations of all nitrogen species in the ground water in eastern York County reflect the ambient ground-water quality and indicate the absence of regional contamination from human-related sources. The nitrite plus nitrate concentration in the Columbia aquifer ranges from less than the detection limit of 0.100 to 16.0 mg/L with the median concentration also less than the detection limit (tables 3, 5). None of the samples from the Yorktown-Eastover aquifer exceeded the detection limit. The boxplots are not presented for nitrate, because of the lack of variability in the analyses. The Mann-Whitney hypothesis test indicates no significant difference (p-value of 0.070) between the nitrite plus nitrate concentrations in the Columbia aquifer and those in the Yorktown-Eastover aquifer. The Maximum Contaminant Level for

nitrate concentration is 10 mg/L, and the VWCB has established a 5-mg/L standard for ground water in Virginia (Southeastern Virginia Planning District Commission, 1990). Elevated nitrate concentrations are a health risk to humans, because they can cause methemoglobinemia (blue-baby syndrome) in small children (Hem, 1985). The most common sources of elevated nitrate concentrations in ground water are animal wastes, septic effluents, and agricultural fertilizers. Well 59F 100 was the only well sampled during the study that yielded water that exceeded the water-quality standards with a nitrite plus nitrate concentration of 16 mg/L; the well is located adjacent to a house that is sewerred by a septic system and downgradient from agricultural fields. Water-quality analyses from the shallow aquifers in eastern York County do not indicate nitrate contamination for the entire region; however, localized water-quality degradation can occur at individual wells that are affected by human-related activities.

Phosphorus

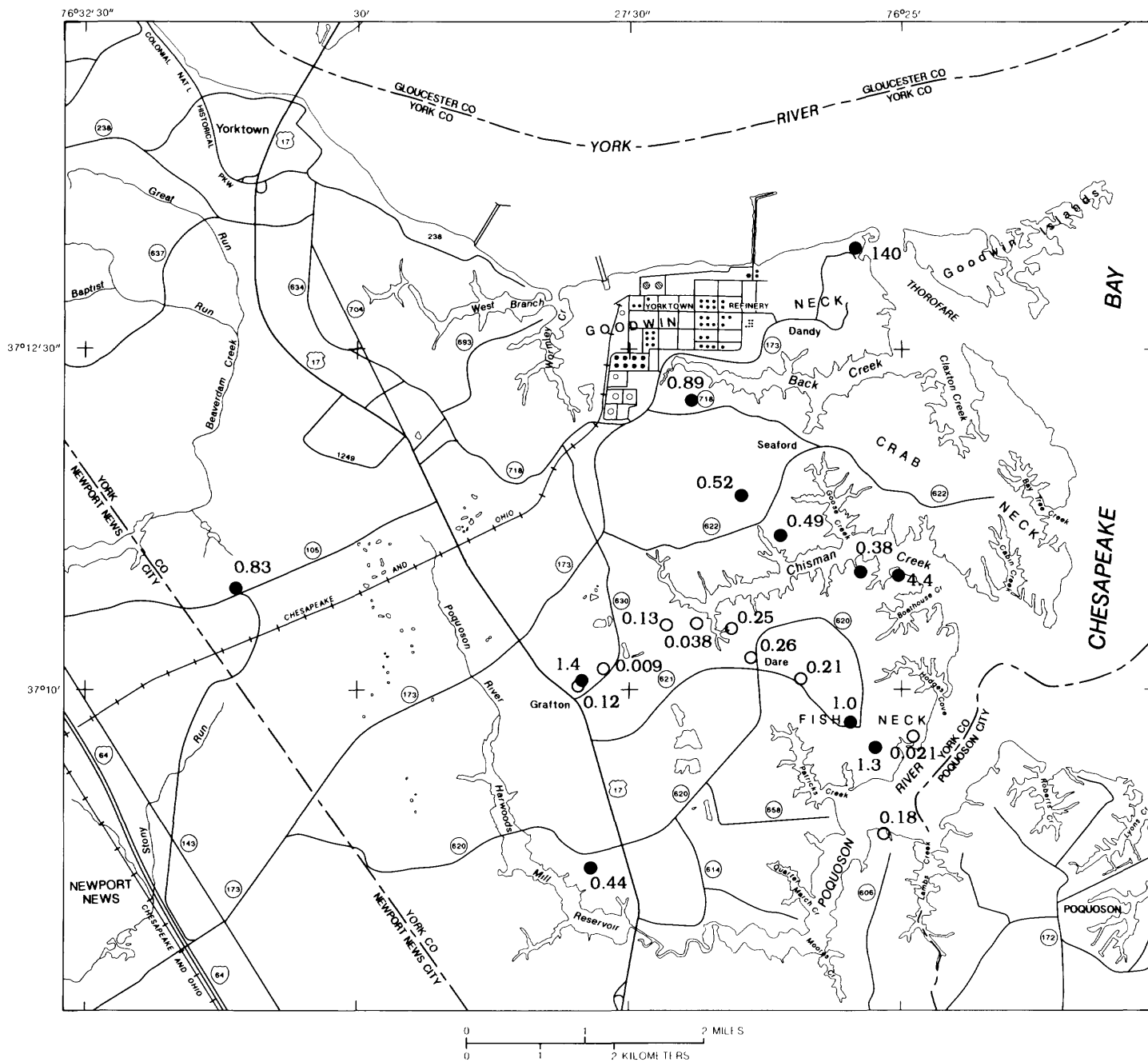
Phosphorus availability in water bodies often is the limiting factor that controls growth of aquatic plants. Where excess phosphorus in ground water discharges into surface-water bodies, nutrient loads and eutrophication rates increase. Total phosphorus concentrations in the Columbia aquifer range from less than the detection limit of 0.010 to 0.070 mg/L with a median concentration less than the detection limit (table 5). Total phosphorus concentrations in the Yorktown-Eastover aquifer range from less than the detection limit of 0.010 to 0.120 mg/L with a median concentration less than the detection limit (table 6). The boxplots (fig. 11) and Mann-Whitney hypothesis test indicate no significant difference (p-value of 0.424) in total phosphorus concentrations between the two shallow aquifers. The total phosphorus concentrations in eastern York County are indicative of the ambient ground-water quality and do not reflect contamination from human-related activities, such as animal wastes, septic effluents, and agricultural fertilizers.

Major Metals

Iron and manganese are commonly found in ground water. A statistical summary and description of these two chemical constituents are presented in this section for the Columbia and Yorktown-Eastover aquifers.

Iron

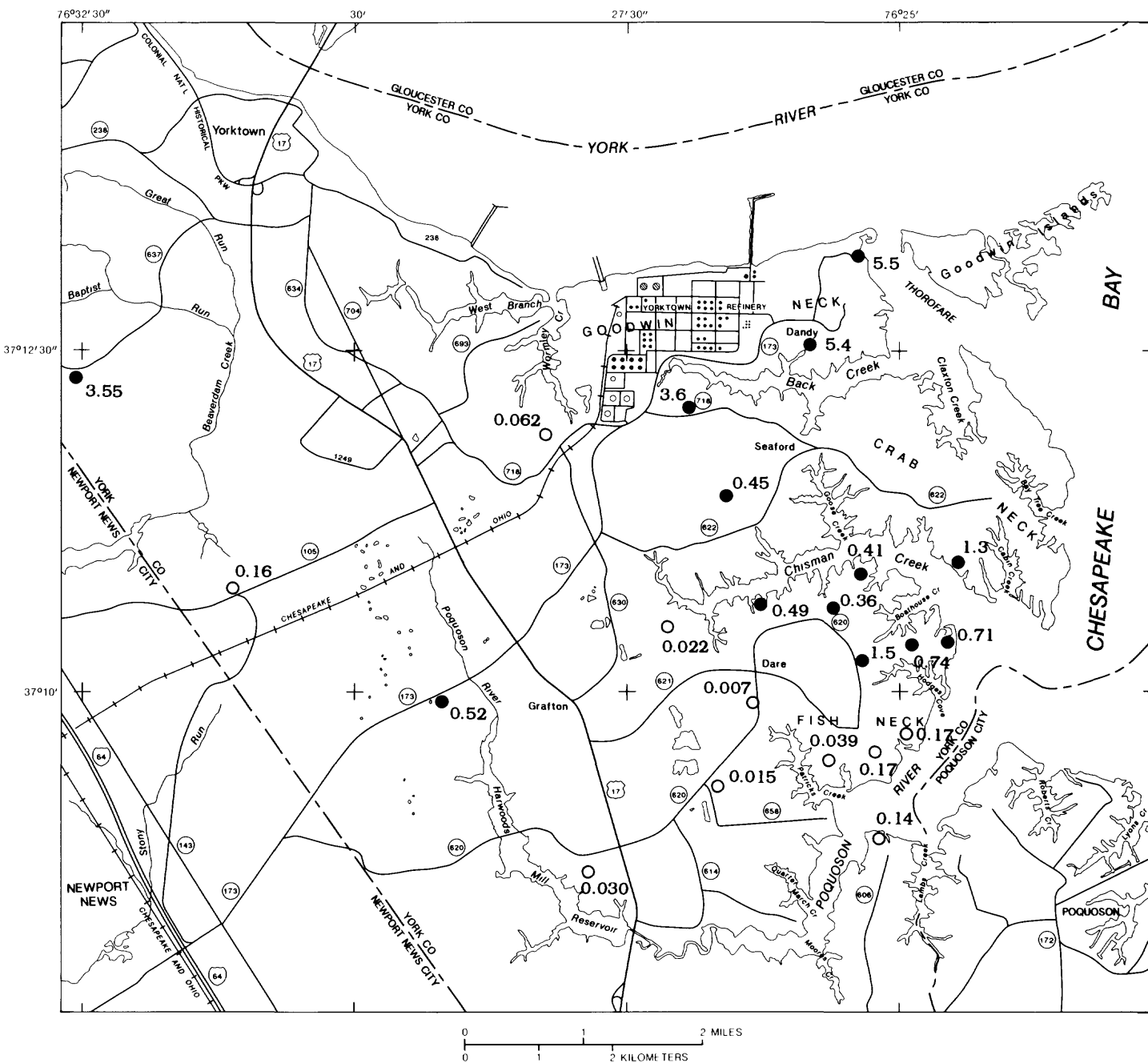
The ground water in the shallow aquifer system of eastern York County is characterized by high concentrations of iron. Iron concentrations in water from wells in the Columbia aquifer range from 0.009 to 140 mg/L with a median concentration of 0.44 mg/L (table 5). Iron concentrations in the Yorktown-Eastover aquifer range from 0.007 to 5.5 mg/L with a median concentration of 0.39 mg/L (table 6). The median iron concentration in both shallow aquifers exceeds the USEPA SMCL of 0.30 mg/L for iron. Elevated concentrations of iron are not a health concern for humans. However, iron concentrations in excess of 0.3 mg/L can cause rust-colored staining of plumbing fixtures and laundered goods, and elevated iron concentrations can give drinking water an objectionable taste. The boxplots (fig. 11) and the Mann-Whitney hypothesis test indicate no significant difference (p-value of 0.520) in iron concentrations between the two shallow aquifers. The major source for the iron in the ground water is the dissolution of minerals in the sediments. The reduction of ferric iron to dissolved ferrous iron occurs readily in the anoxic ground water of the shallow aquifers in eastern York County. The areal distributions of iron concentrations in the Columbia and Yorktown-Eastover aquifers, respectively, are shown in figures 14 and 15. Elevated iron concentrations are scattered throughout the study area; however, ground-water samples from wells in the northeastern part of the study area contain several anomalously elevated iron concentrations. The source of the elevated iron concentrations is uncertain. Mineralogic analyses of sediments throughout the study area indicate no significant difference between the aquifer sediments in the northeastern part of the study area and the aquifer sediments in areas with lower iron concentrations.



EXPLANATION

- 0.83 WELL WHERE GROUND-WATER CONTAINS CONCENTRATIONS GREATER THAN THE U.S. ENVIRONMENTAL PROTECTION AGENCY SECONDARY MAXIMUM CONTAMINANT LEVEL--Number is iron concentration in milligrams per liter
- 0.13 WELL WHERE GROUND-WATER CONTAINS CONCENTRATIONS LESS THAN OR EQUAL TO THE U.S. ENVIRONMENTAL PROTECTION AGENCY SECONDARY MAXIMUM CONTAMINANT LEVEL--Number is iron concentration in milligrams per liter

Figure 14.--Distribution of iron concentration in the Columbia aquifer.



EXPLANATION

- 0.74 WELL WHERE GROUND-WATER CONTAINS CONCENTRATIONS GREATER THAN THE U.S. ENVIRONMENTAL PROTECTION AGENCY SECONDARY MAXIMUM CONTAMINANT LEVEL--Number is iron concentration in milligrams per liter
- 0.14 WELL WHERE GROUND-WATER CONTAINS CONCENTRATIONS LESS THAN OR EQUAL TO THE U.S. ENVIRONMENTAL PROTECTION AGENCY SECONDARY MAXIMUM CONTAMINANT LEVEL--Number is iron concentration in milligrams per liter

Figure 15.--Distribution of iron concentration in the Yorktown-Eastover aquifer.

Manganese

High concentrations of manganese are commonly associated with high concentrations of iron. Manganese is not an essential constituent of the common minerals found in Coastal Plain sediments; however, it can substitute for iron, magnesium, or calcium in silicate structures (Hem, 1985). Manganese concentrations in the Columbia aquifer range from 0.002 to 0.72 mg/L with a median concentration of 0.13 (table 5). Manganese concentrations in the Yorktown-Eastover aquifer range from less than the detection limit of 0.001 to 0.20 mg/L with a median concentration of 0.016 mg/L (table 6). The median manganese concentration for the Columbia aquifer exceeds the USEPA SMCL of 0.05 mg/L. There are no known negative health effects associated with elevated concentrations of manganese. Manganese in water supplies can oxidize to form black stains on plumbing fixtures. The boxplots (fig. 11) and Mann-Whitney hypothesis test indicate manganese concentrations are significantly higher (p-value < 0.001) in the Columbia aquifer than in the Yorktown-Eastover aquifer.

Discussion of Analyses of Water Quality

An assessment of the current (1989) quality of ground water in the shallow ground-water-flow system in eastern York County was conducted using data describing the chemical composition of the ground water from 56 wells. The data were analyzed by use of graphical and statistical techniques, and the data were compared to drinking-water regulations developed by the USEPA and the VWC. Potential sources for individual constituents were examined based on the ground-water-flow system, expected natural processes, and human-related activities.

Analyses of water from the shallow aquifers indicate a chemical composition that is consistent with the expected ambient ground-water quality. Dissolution of calcite in the abundant shell material in the shallow aquifers produces water that is very hard and contains a high concentration of calcium and bicarbonate. Water flows slowly through the fine-grained sediments of the shallow aquifers, and dissolved oxygen in the water is rapidly depleted. Reduction of ferric iron in the aquifer sediments to dissolved ferrous iron takes place readily in anaerobic water; therefore, the ground water contains high concentrations of dissolved iron. The weathering of pyrite and glauconite in the sediments also releases iron. Iron concentrations in water from 45 percent of the wells sampled exceeded the USEPA SMCL for iron. Although high concentrations of hardness, calcium, bicarbonate, and iron do not pose a human-health risk, the levels found in much of the eastern part of York County are undesirable for drinking water. Natural sources of chlorides and the conceptualization of the ground-water-flow system can explain the distribution of chlorides in the shallow aquifers. The chloride concentration in the ground water exceeded the SMCL (250 mg/L) in only one well sampled during this study. The nearness of salty surface-water sources could cause the high chloride concentrations along the coast in the Columbia aquifer. Chloride concentrations could be higher in the Yorktown-Eastover aquifer than they are in the Columbia aquifer because of upward leakage from regionally discharging deep aquifers.

Human-related activities also are a potential source for certain chemical constituents in ground water. Septic-system effluent, agricultural and domestic fertilizers, and road salting can cause elevated concentrations of nitrogen, phosphorous, and chloride. Nitrogen and phosphorous levels are near or below detection limits throughout the shallow aquifer system of eastern York County. Although elevated concentrations of these constituents were observed in a few wells, the predominant background levels indicate that there is no widespread contamination from human-related activities. Water-level declines from pumping can cause saltwater intrusion in coastal areas. Available data are insufficient to conclude that saltwater intrusion is occurring in eastern York County. Water-quality samples collected at regular intervals in areas of potential concern can assist in discerning water-quality changes over time.

SUMMARY

Public-water supplies are available for most of York County; however, many residents in the eastern part of the county still depend on individual wells in the shallow ground-water system for a freshwater supply. This report is an assessment of the current (1989) condition of the shallow ground-water resources in the eastern part of York County.

The shallow ground-water system consists of approximately the first 200 ft of sediments below land surface and is a layered sequence of three aquifers separated by two intervening confining units. The Columbia aquifer is the unconfined aquifer and generally ranges from 10 to 30 ft in thickness. The Columbia aquifer primarily is composed of fine to coarse grained sand with some shell material and is rarely used for a domestic supply. The Cornwallis Cave aquifer is confined by the Cornwallis Cave confining unit and generally ranges from 20 to 60 ft in thickness. The Cornwallis Cave aquifer is primarily composed of calcite shell material and quartz sand and is not used as a water supply. The Yorktown-Eastover aquifer generally ranges from 40 to 60 ft in thickness. The Yorktown-Eastover aquifer primarily is composed of fine sands with abundant shell material and is the sole freshwater supply for some domestic users. Well yields are small and range from 5 to 9 gal/min. The base of the shallow ground-water system is the Eastover-Calvert confining unit, which underlies the Yorktown-Eastover aquifer. Sediments below the Eastover-Calvert confining unit (approximately 200 ft below land surface) contain ground water with high concentrations of dissolved constituents that is unfit for human consumption.

The shallow system is recharged locally by precipitation that infiltrates into the Columbia aquifer and regionally by underflow from the confined aquifers in upgradient areas. Water in the Columbia aquifer flows (1) laterally to local discharge sites in streams, marshes, estuaries, the York River, and the Chesapeake Bay and (2) vertically through the uppermost confining unit to the confined aquifers. Water in the confined aquifers also flows laterally and vertically along regional flow paths and discharges to the York River and the Chesapeake Bay.

The ground water in eastern York County is predominantly a calcium bicarbonate type and is characterized by high concentrations of calcium, bicarbonate, and iron. Dissolution of calcite in the abundant shell material in the aquifer sediments has produced a median calcium concentration of 80 mg/L in the Columbia aquifer and 78 mg/L in the Yorktown-Eastover aquifer. The dissolution and reduction of ferric iron from the minerals in the sediments to dissolved ferrous iron has produced high concentrations of dissolved iron in the ground water. The median iron concentration is 0.44 mg/L in the Columbia aquifer and 0.39 mg/L in the Yorktown-Eastover aquifer. Water-quality degradation from human-related sources is localized. Chloride concentrations generally are greater in the Yorktown-Eastover aquifer than in the Columbia aquifer. Elevated chloride concentrations along the coast in the Yorktown-Eastover aquifer could reflect the upward leakage from deep regional aquifers discharging to the Chesapeake Bay. Saltwater encroachment caused by water-level declines as a result of withdrawals from the Yorktown-Eastover aquifer in the Fish Neck peninsula area is another possible explanation of elevated chloride concentrations; however, chloride concentrations are no greater on the Fish Neck peninsula than in other coastal areas. The Fish Neck peninsula relies entirely on domestic wells screened in the Yorktown-Eastover aquifer for a freshwater supply. Water-levels are consistently below sea level at two locations on the Fish Neck peninsula. Additional water-level data are needed to determine the extent of the water-level decline. Monitoring of chlorides in coastal areas can determine if the water chemistry is changing over time. Chloride concentrations did not exceed the U.S. Environmental Protection Agency's Secondary Maximum Contaminant Level of 250 mg/L chloride in water from any of the wells in the Yorktown-Eastover aquifer that were sampled for this study.

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Table 3.--Selected constituents from water-quality analyses of observation wells

[ft-BLS is feet below land surface, all analyses are for the dissolved constituent unless otherwise noted, $\mu\text{S}/\text{cm}$ is microsiemens per centimeter, mg/L is milligrams per liter, < is less than, -- indicates analysis is not available, CL is Columbia aquifer, CC is Cornwallis Cave aquifer, YE is Yorktown-Eastover aquifer, USGS is U.S. Geological Survey, and VWCB is Virginia Water Control Board]

USGS well number	VWCB well number	Screened interval (ft-BLS)	Aquifer	Date	Specific conductance ($\mu\text{S}/\text{cm}$)	pH (stand-ard units)	Dissolved Oxygen (mg/L)	Hard-ness (mg/L as CaCO_3)	Cal-cium (mg/L as Ca)	Magne-sium (mg/L as Mg)	So-dium (mg/L as Na)	Potas-sium (mg/L as K)	Alka-linity (mg/L as CaCO_3)
58F 58		25- 30	CL	06-20-90	580	6.6	--	240	88	6.0	24	1.3	209
58F 62	SOW 187A	120-140	YE	09-05-90	595	7.4	--	190	50	15	48	10	303
58F 63	SOW 187B	18- 28	CL	09-05-90	402	7.3	--	210	80	1.4	5.4	.90	208
58F 65	SOW 191A	90-110	CC	11-29-90	384	7.4	--	200	75	2.3	8.3	1.4	196
59F 11		80-115	YE	08-30-89	790	7.2	--	260	94	6.9	28	8.3	260
59F 14		80-120	YE	07-17-90	950	7.9	--	160	34	18	140	13	252
59F 15		80-120	YE	08-31-89	1,200	7.1	--	--	--	--	--	--	--
59F 16		80-120	YE	08-31-89	1,550	7.2	--	--	--	--	--	--	--
59F 17		80-120	YE	08-31-89	640	--	--	--	--	--	--	--	--
59F 21		80-130	YE	07-17-90	365	7.7	--	160	49	8.1	17	6.2	187
59F 22		80-120	YE	07-18-90	920	7.4	--	340	79	35	66	17	316
59F 25		95-115	YE	08-30-89	485	7.3	--	130	29	13	31	9.3	185
59F 26		95-115	YE	07-18-90	352	7.9	--	140	44	6.9	21	5.1	177
59F 30		65-110	YE	08-29-89	1,100	7.0	--	180	39	19	91	13	257
59F 31		90-110	YE	08-30-89	1,300	6.9	--	--	--	--	--	--	--
59F 41		^a 12	CL	08-31-89	920	6.9	--	--	--	--	--	--	--
59F 42		^a 22	CL	08-29-89	1,100	7.1	--	310	110	8.5	39	4.7	265
59F 43		^a 90	YE	08-30-89	1,750	6.9	--	--	--	--	--	--	--
59F 44		^a 130	YE	08-30-89	1,750	6.9	--	--	--	--	--	--	--
59F 45		^a 110	YE	08-29-89	1,850	7.0	--	420	120	29	89	15	314
59F 47		90-130	YE	08-29-89	1,550	6.8	--	390	110	27	76	15	291
59F 49		90-110	YE	08-30-89	1,450	7.1	--	--	--	--	--	--	--
59F 52		65- 95	YE	08-08-90	387	7.5	--	150	58	1.5	12	1.5	131
59F 53		10- 15	CL	06-19-90	100	5.1	--	16	3.9	1.5	15	.80	9
		10- 15	CL	03-17-92	--	--	2.2	--	--	--	--	--	--
59F 54		40- 45	CL	06-26-90	323	7.5	--	180	67	2.4	4.0	.70	133
		40- 45	CL	03-17-92	--	--	1.4	--	--	--	--	--	--
59F 56		8- 13	CL	06-26-90	450	7.1	--	210	80	2.8	9.1	1.2	186
59F 58		10- 15	CL	03-17-92	--	--	3.9	--	--	--	--	--	--
59F 59		40- 45	CC	06-26-90	238	7.5	--	100	37	2.2	7.9	.80	72
		40- 45	CL	03-17-92	--	--	1.9	--	--	--	--	--	--
59F 60		10- 15	CL	06-26-90	400	6.4	--	150	55	3.7	21	.50	128
59F 61		7- 12	CL	06-26-90	140	6.2	--	37	12	1.6	2.9	.90	20
		7- 12	CL	03-17-92	--	--	1.6	--	--	--	--	--	--
59F 62		10- 15	CL	06-19-90	200	6.4	--	78	27	2.6	13	.70	121
		10- 15	CL	03-17-92	--	--	4.6	--	--	--	--	--	--

Table 3.--Selected constituents from water-quality analyses of observation wells--Continued

Sulfate (mg/L as SO ₄)	Chloride (mg/L as Cl)	Fluoride (mg/L as F)	Dissolved solids, residue at 180°C	Nitrogen, nitrite residue (mg/L)	Nitrogen, NO ₂ +NO ₃ (mg/L as N)	Nitrogen, ammonia (mg/L as N)	Nitrogen ammonia+ organic (mg/L)	Phosphorus (mg/L as P)	Iron (mg/L as Fe)	Manganese (mg/L as Mn)	USGS well number
60	39	0.10	—	0.010	<.100	0.020	—	0.030	3.5	0.18	58F 58
9.3	10	<.10	302	<.010	<.100	.400	.80	<.010	.16	.027	58F 62
8.4	8.2	<.10	238	<.010	<.100	.040	.20	<.010	.83	.024	58F 63
14	8.3	.30	235	<.010	<.100	.140	.20	.060	.97	.062	58F 65
17	32	.20	252	—	<.100	.160	—	.020	.17	.016	59F 11
11	170	.30	538	<.010	<.100	.240	.50	.020	.039	.003	59F 14
—	110	—	—	—	—	—	—	—	—	—	59F 15
—	160	—	—	—	—	—	—	—	—	—	59F 16
—	30	—	—	—	—	—	—	—	—	—	59F 17
1.8	9.8	.20	203	<.010	<.100	.150	<.20	<.010	.062	.006	59F 21
94	90	.30	573	<.010	<.100	.400	.40	.030	.36	.007	59F 22
6.0	24	.40	231	—	<.100	.300	—	<.010	.007	<.001	59F 25
7.3	13	.20	207	<.010	<.100	.180	<.20	<.010	.022	<.001	59F 26
10	93	.40	504	—	<.100	.450	—	.030	.49	.007	59F 30
—	110	—	—	—	—	—	—	—	—	—	59F 31
—	36	—	—	—	—	—	—	—	—	—	59F 41
38	44	.20	355	—	<.100	.250	—	<.010	4.4	.035	59F 42
—	95	—	—	—	—	—	—	—	—	—	59F 43
—	120	—	—	—	—	—	—	—	—	—	59F 44
130	140	.10	669	—	<.100	.340	—	.010	.71	.015	59F 45
120	88	.20	592	—	<.100	.380	—	<.010	.74	.016	59F 47
—	100	—	—	—	—	—	—	—	—	—	59F 49
<1.0	38	.30	237	<.010	<.100	.100	<.20	.120	1.3	.063	59F 52
6.0	28	<.10	68	<.010	<.100	.030	—	<.010	1.4	.022	59F 53
—	—	—	—	—	—	—	—	—	—	—	—
11	10	.20	200	<.010	<.100	<.010	<.20	.010	.12	.046	59F 54
—	—	—	—	—	—	—	—	—	—	—	—
13	14	.20	259	<.0102	.50	<.010	<.20	.030	.009	.002	59F 56
—	—	—	—	—	—	—	—	—	—	—	59F 58
18	10	.40	152	<.010	<.100	.040	.60	.130	.015	.012	59F 59
—	—	—	—	—	—	—	—	—	—	—	—
49	16	.30	235	<.010	<.100	.030	.50	.060	.49	.26	59F 60
19	4.9	.20	62	<.010	<.100	<.010	<.20	.030	.038	.009	59F 61
—	—	—	—	—	—	—	—	—	—	—	—
17	11	.30	135	<.010	<.100	.010	—	.050	.13	.14	59F 62
—	—	—	—	—	—	—	—	—	—	—	—

Table 3.--Selected constituents from water-quality analyses of observation wells--Continued

[ft-BLS is feet below land surface, all analyses are for the dissolved constituent unless otherwise noted, $\mu\text{S}/\text{cm}$ is microsiemens per centimeter, mg/L is milligrams per liter, < is less than, -- indicates analysis is not available, CL is Columbia aquifer, CC is Cornwallis Cave aquifer, YE is Yorktown-Eastover aquifer, USGS is U.S. Geological Survey, and VWCB is Virginia Water Control Board]

USGS well number	VWCB well number	Screened interval (ft-BLS)	Aquifer	Date	Specific conductance ($\mu\text{S}/\text{cm}$)	pH (stand-ard units)	Dis-solved Oxygen (mg/L)	Hard-ness (mg/L as CaCO_3)	Cal-cium (mg/L as Ca)	Magne-sium (mg/L as Mg)	So-dium (mg/L as Na)	Potas-sium (mg/L as K)	Alka-linity (mg/L as CaCO_3)
59F 63		10- 15	CL	06-20-90	690	6.8	—	380	140	6.8	19	1.3	254
		—	—	03-17-92	—	—	5.4	—	—	—	—	—	—
59F 64		40- 45	CC	06-26-90	600	7.3	—	280	100	8.5	17	5.1	277
		—	—	03-17-92	—	—	0.5	—	—	—	—	—	—
59F 66		9- 12	CL	06-19-90	390	6.2	—	50	17	1.9	58	0.60	56
59F 67		6- 9	CL	06-22-90	250	6.8	—	130	47	4.2	15	<.10	114
59F 68		7- 9	CL	06-22-90	670	7.0	—	320	120	4.5	22	.50	265
59F 69		7- 9	CL	06-22-90	475	6.9	—	270	100	4.6	14	.10	261
59F 70		7- 9	CL	06-22-90	930	6.7	—	450	160	12	31	1.4	253
59F 72	SOW 184A	121-131	YE	07-05-90	322	7.0	—	160	60	1.9	6.7	.20	—
59F 73	SOW 184B	50- 60	CC	07-10-90	463	7.3	—	200	77	1.7	26.	.60	244
59F 74	SOW 184C	10- 20	CL	07-10-90	165	5.9	—	54	19	1.5	9.0	2.5	52
59F 76	SOW 185A	100-120	YE	07-03-90	625	7.7	—	270	93	9.0	23	7.1	253
		—	—	03-17-92	—	—	.4	—	—	—	—	—	—
59F 78	SOW 185C	40- 50	CC	09-04-90	397	7.6	—	170	61	3.2	12	1.3	185
		—	—	03-17-92	—	—	.4	—	—	—	—	—	—
59F 79	SOW 185D	5- 15	CL	07-03-90	480	6.6	—	150	51	5.5	18	1.2	82
		—	—	03-17-92	—	—	6.8	—	—	—	—	—	—
59F 81	SOW 186A	112-132	YE	09-04-90	348	7.4	—	170	66	1.1	4.9	.80	178
59F 86	SOW 188A	79- 99	YE	09-05-90	1,480	6.9	—	630	220	19	64	8.3	379
		—	—	03-17-92	—	—	.5	—	—	—	—	—	—
59F 87	SOW 188B	20- 30	CL	09-05-90	980	7.0	—	350	130	7.2	58	8.8	271
		—	—	03-17-92	—	—	2.9	—	—	—	—	—	—
59F 89	SOW 189A	77- 97	YE	09-06-90	990	7.3	—	370	99	31	51	15	283
59F 90		^a 110	YE	07-18-90	1,000	7.3	—	440	140	22	49	12	362
59F 91		^a 110	YE	07-27-90	579	7.6	—	260	77	17	18	9.9	262
59F 92		^a 126	YE	07-27-90	403	7.8	—	170	54	7.7	21	6.0	207
59F 93		^a 97	YE	07-27-90	1,100	7.0	—	510	190	7.6	39	2.9	421
59F 95		^a 90	YE	07-27-90	—	—	—	340	92	26	90	15	—
59F 96	SOW 189B	5- 15	CL	09-06-90	1,280	6.4	—	260	86	12	140	.90	101
59F 98	SOW 190A	80-100	YE	09-06-90	775	7.1	—	300	110	6.1	33	2.6	262
		—	—	03-17-92	—	—	.4	—	—	—	—	—	—
59F 99	SOW 190B	5- 15	CL	09-06-90	6,820	4.4	—	960	230	94	910	11	—
		—	—	03-17-92	—	—	1.4	—	—	—	—	—	—
59F 100		^a 25	CL	07-27-90	483	5.8	—	110	34	7.3	47	2.4	34

^a Depth of well; information on screen interval not available

Table 3.--Selected constituents from water-quality analyses of observation wells--Continued

Sulfate (mg/L as SO ₄)	Chloride (mg/L as Cl)	Fluoride (mg/L as F)	Dissolved solids, residue at 180°C	Nitrogen, nitrite residue (mg/L)	Nitrogen, NO ₂ +NO ₃ (mg/L as N)	Nitrogen, ammonia (mg/L as N)	Nitrogen ammonia+ organic (mg/L)	Phosphorus (mg/L as P)	Iron (mg/L as Fe)	Manganese (mg/L as Mn)	USGS well number
170	23	0.20	471	<0.010	<0.100	0.100	—	0.070	0.52	0.28	59F 63
—	—	—	—	—	—	—	—	—	—	—	—
21	25	.20	366	<0.010	<1.00	.160	.50	.040	.22	.045	59F 64
—	—	—	—	—	—	—	—	—	—	—	—
66	31	<.10	215	<0.010	.900	.020	—	.070	.021	.028	59F 66
26	14	.50	206	<0.010	<1.00	.110	.80	.030	1.0	.13	59F 67
49	30	.30	413	<0.010	<1.00	.020	.20	<.010	.21	.097	59F 68
—	—	—	—	—	—	—	—	—	—	—	—
20	15	.60	342	<0.010	<1.00	.150	.50	.010	.26	.14	59F 69
220	34	.40	660	<0.010	<1.00	.020	.30	<.010	.25	.63	59F 70
4.5	3.0	<.10	193	—	<1.00	.030	—	.020	.030	.010	59F 72
3.4	18	<.10	271	—	<1.00	.060	—	<.010	.28	.094	59F 73
5.8	18	.20	91	—	<1.00	<.010	—	<.010	.44	.10	59F 74
—	—	—	—	—	—	—	—	—	—	—	—
21	35	<.10	361	—	<1.00	.140	—	.010	.17	.020	59F 76
—	—	—	—	—	—	—	—	—	—	—	—
6.1	11	<.10	209	<0.010	<1.00	.050	.20	.050	.24	.065	59F 78
—	—	—	—	—	—	—	—	—	—	—	—
52	31	.20	277	—	.100	.020	—	<.010	1.3	.18	59F 79
—	—	—	—	—	—	—	—	—	—	—	—
3.3	7.0	<.10	194	<0.010	<1.00	.070	.40	.010	.52	.023	59F 81
310	110	<.10	956	<0.010	<1.00	.310	.70	<.010	3.6	.13	59F 86
—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—
120	85	<.10	567	<0.010	<1.00	.150	.60	<.010	.89	.30	59F 87
—	—	—	—	—	—	—	—	—	—	—	—
130	72	<.10	601	<0.010	<1.00	.310	.40	<.010	.41	.022	59F 89
130	74	.20	650	<0.010	<1.00	.270	.20	.040	1.5	.024	59F 90
4.5	44	.50	350	<0.010	<1.00	.120	.30	.020	.14	.010	59F 91
<1.0	14	.40	238	<0.010	<1.00	.150	<.20	.010	.015	.003	59F 92
—	—	—	—	—	—	—	—	—	—	—	—
130	72	.20	726	<0.010	<1.00	.150	<.20	.010	5.4	.071	59F 93
79	140	.20	640	<0.010	<1.00	.300	.50	.010	.45	.025	59F 95
130	250	<.10	718	<0.010	<1.00	.030	.40	<.010	.38	.68	59F 96
21	74	<.10	426	<0.010	<1.00	.430	.50	<.010	5.5	.20	59F 98
—	—	—	—	—	—	—	—	—	—	—	—
140	2,500	<.10	4,670	<0.010	<1.00	.7501	.0	<.010	140	.72	59F 99
—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—
56	64	<.10	332	.070	16.0	.030	1.0	.020	.18	.026	59F 100