GEOHYDROLOGY AND THE OCCURRENCE OF VOLATILE ORGANIC COMPOUNDS IN GROUND WATER, CULPEPER BASIN OF PRINCE WILLIAM COUNTY, VIRGINIA

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ABSTRACT

The Culpeper basin of Prince William County comprises an interbedded sequence of sedimentary and basaltic rocks of Late Triassic and Early Jurassic age. This sequence is intersected by diabase intrusives and thermally metamorphosed rocks. The rocks of the Culpeper basin are highly fractured and overlain by a thin cover of overburden. The sedimentary rocks are the most productive aquifers, whereas the igneous and metamorphic rocks generally have poor water-bearing potential.

Ground water in the Culpeper basin generally flows from the uplands (recharge areas) along lineaments (linear-surface expressions of fracture sets) to the lowlands or valleys (discharge areas). The flow system generally is under water-table (unconfined) conditions with the potentiometric surface following the topography. Two cones of depression are present in the Manassas-Manassas Park area in response to pumpage.

Volatile organic compounds have been detected in ground water in 5 areas of the Culpeper basin in the county. Contaminant concentrations and compositions, and possible contaminant migration varies because of rock type, presence of lineaments, and regional flow direction. The dominant volatile organic compounds are tetrachloroethylene (PCE), trichloroethylene (TCE), and 1,1,1-trichloroethane. Concentrations of the volatile organic compounds range from 0.1 to 5,300.0 micrograms per liter. Isolated areas of minor volatile organic contamination also have been identified. Septic systems and domestic and commercial waste-disposal practices may be the means of ground-water contamination in these areas.

INTRODUCTION

Volatile organic compounds have been detected in the ground water in some areas of the Culpeper basin of Prince William County, Virginia. These compounds are suspected carcinogens and are listed as priority pollutants by the U.S. Environmental Protection Agency (Thurman, 1986, p. 229). Prince William County authorities became concerned in 1984 when certain volatile organic compounds were detected in water from a municipal-supply well. Investigations by private consulting firms indicated that ground water in the area surrounding this well also contained volatile organic compounds. Subsequently, the Prince William Health District initiated a ground-water sampling program, which was made available to county residents. Results of this sampling program indicated that ground water in other areas of the Culpeper basin within the county also was contaminated with volatile organic compounds. In response to concerns about the possible effects of the contamination on present and potential future ground-water supply sources, the U.S. Geological Survey, in cooperation with the Prince William Health District, began a comprehensive investigation of the geohydrology and the volatile organic contamination of ground water in the Culpeper basin of the county in February 1987.

Purpose and Scope

This report provides a technical discussion of volatile organic contamination of ground water in the Culpeper basin of Prince William County. The purposes of the report are to (1) identify geologic and hydrologic controls on ground-water movement; (2) document the distribution, composition, and concentration of the various volatile organic compounds; and (3) define areas with ground water contaminated by the volatile organic compounds.

The results of previous studies of the geohydrology and ground-water resources of the Culpeper basin in Prince William County were reviewed. Ground-water samples were analyzed to identify any additional volatile organic contamination. Geologic and hydrologic data were collected, compiled, and entered into a geographic information system (GIS). The GIS was used (1) to store and manage a comprehensive ground-water data base for the Culpeper basin of Prince William County and (2) to spatially manipulate and display various layers of information. Digital data compiled for this study are available from the U.S. Geological Survey for further analysis and future investigations concerning the county's ground-water resources.

Location of Study Area

Prince William County is located in northern Virginia, about 25 miles southwest of Washington, D.C. It is bordered by Loudoun and Fairfax Counties to the north, Stafford County to the south, Fauquier County to the west, and the State of Maryland to the east (fig. 1). The study area covers approximately two-thirds of the county and is part of the Culpeper basin, one of nine sedimentary basins of early Mesozoic age in the Piedmont physiographic province of Virginia (Froelich and Olsen, 1985). The term *Triassic basin* commonly is used locally to describe the section of the Culpeper basin within Prince William County. The city of Manassas (population 24,777), a major industrial and residential center in the county, is located entirely within the Culpeper basin. Kull (1983) estimated that 6.46 Mgal/d (million gallons per day) of ground water are used in Prince William County.

Climate

Climatic data for the study area were obtained from the National Weather Service station 8903 located at Dulles International Airport in Loudoun County. The period of record for the station was 24 years, and the normal values were calculated on the basis of the National Weather Service's current normal time period from 1951 to 1980. The normal annual temperature is 53.8 °F (Fahrenheit); the coldest month is January (31.4 °F) and the warmest is July (75.5 °F). Average precipitation is 40.4 inches per year. Precipitation in an average year would be highest in June, 4.23 in. (inches) and lowest in February, 2.64 in. (National Oceanic and Atmospheric Administration, 1984).

Previous Studies

The first comprehensive investigation of the geology of the early Mesozoic basins in Virginia was conducted by Roberts (1928). Lee (1979) mapped parts of 16 quadrangles at a 1:24,000 scale for the U.S. Geological Survey open-file report on the Triassic and Jurassic geology of the northern part of the Culpeper basin. Lee (1980) also mapped parts of 18 quadrangles at a 1:24,000 scale for the U.S. Geological Survey open-file report on the geology of the southern part of the Culpeper basin.

Cady (1933, 1938) conducted the first comprehensive investigation of the ground-water resources of northern Virginia. Johnston (1960) described ground-water supplies in the shales and sandstones of Fairfax, Loudoun, and Prince William Counties, Virginia. An assessment of the ground-water resources of Prince William County was conducted by Comer (1976) for the Virginia Water Control Board. In 1978, Geraghty and Miller, Incorporated, investigated the availability of ground water for public supply in Prince William County. An additional ground-water supply study was completed in 1982 by Betz-Converse-Murdoch, Incorporated, in which 13 potential well-field sites within the Culpeper basin were selected for potential development. Leavy and others (1983), Posner and Zenone (1983), Leavy (1984), Froelich (1985), Laczniak and Zenone (1985), and Lynch and others (1987) reported on various aspects of the hydrology and geology of the Culpeper basin. Various consulting firms have performed ground-water investigations for private industries located in Prince William County.

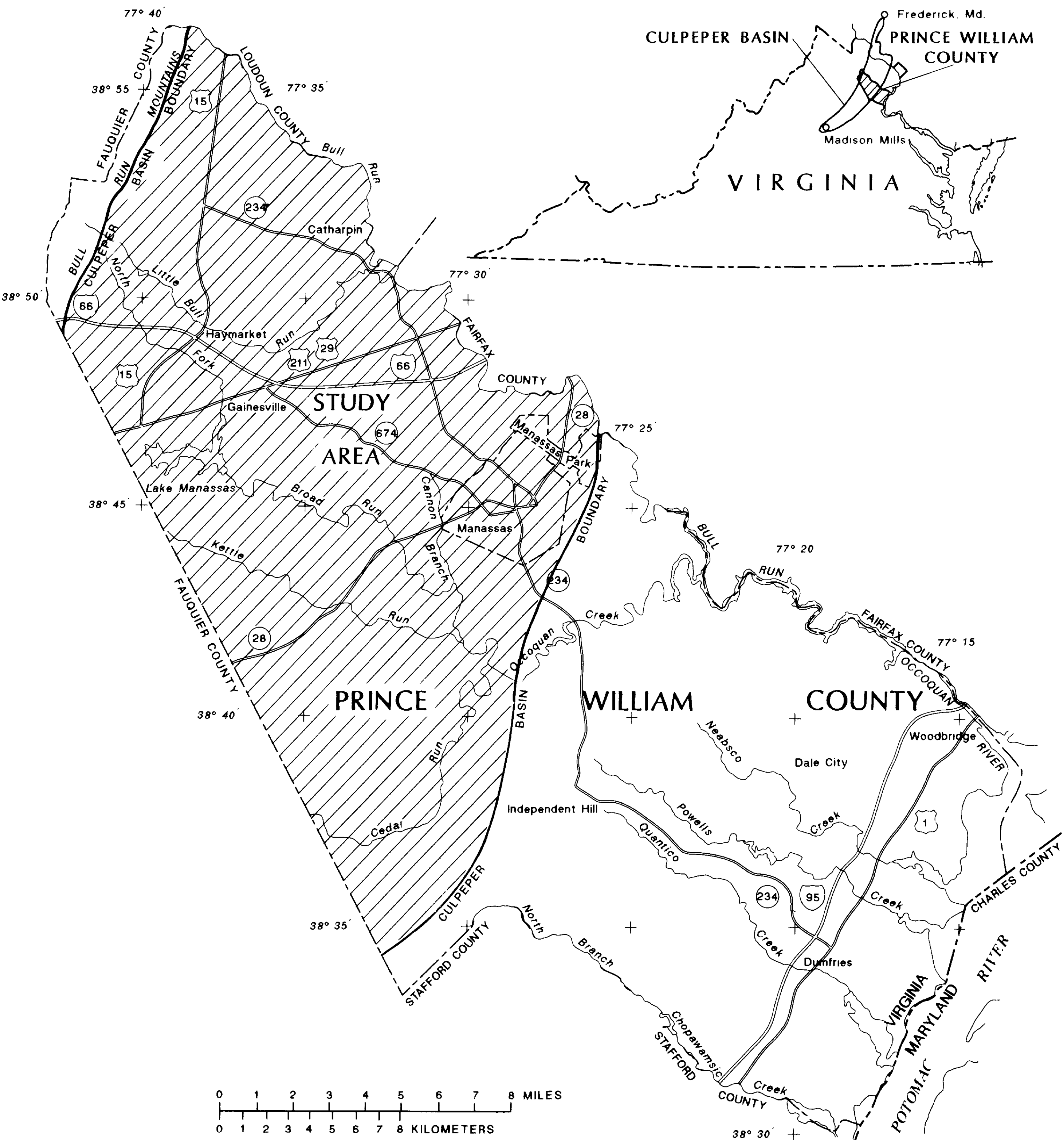

Figure 1.--Location of study area.

Methods

The objectives of this investigation were accomplished by analyzing and synthesizing hydrologic and geologic data available from previous investigations and data collected during this investigation. These data were entered into a GIS which aided in data storage, manipulation of related information, and the generation of graphical output that was used to make analyses and interpretations.

Data Collection

The thickness of overburden, the weathered unconsolidated material that overlies bedrock or solid competent rock, is an important factor in the hydrologic system and the movement of dissolved chemical constituents and compounds in ground water. Overburden thicknesses and depths to bedrock were inventoried from Virginia Water Control Board well-completion reports (GW-2 forms) submitted by local well-drilling firms. Overburden thicknesses at 252 wells were entered into the U.S. Geological Survey's data base and contoured. The contours were consistent with overburden depths from published maps by Lee (1979, 1980), Froelich (1985), and Elder (1986).

Water levels were measured to determine the directions of ground-water flow and possible contaminant migration. Water levels were measured at 97 wells during September 1987 using the following three methods: (1) steel tape, (2) electric tape, and (3) airline. The steel tape method is considered to be the most accurate and accuracy respectively decreases with the two other methods. Airline lengths were provided by the well owners; therefore, these lengths may be approximate, which would affect measurement accuracy. Some of the public-supply wells were equipped with calibrated airlines. Because of the well construction of some public-supply wells, the airline method of water-level measurement was the only measurement method available.

Pumped wells were shut down for 15 to 30 minutes and water-level measurements were made after the water level had reached an approximate static level. However, in the Manassas-Manassas Park area, static levels may have been influenced by nearby pumped wells.

More than 950 water samples were collected for volatile organic analysis by state and local agencies, as well as private consulting firms (table 1). The U.S. Geological Survey collected 19 ground-water samples for

Table 1.–*Number of wells sampled and water samples analyzed for volatile organic compounds by reporting agency in the Culpeper basin of Prince William County*

Number of wells	Number of analyses	Agency
28	28	U.S. Geological Survey
110	206	Prince William Health District
17	212	Prince William County Service Auth.
3	3	Virginia Dept. of Waste Management
97	562	Private consulting firms

volatile organic analysis during August 1987 to verify contaminated areas. Ground-water samples from nine wells were collected by the U.S. Geological Survey during July 1988 to establish background conditions for areas surrounding the proposed water-supply fields. Samples that did not meet accepted quality assurance/quality control guidelines for field and laboratory procedures were deleted from the data base. This investigation used 1,011 analyses collected from 255 wells throughout the Culpeper basin in Prince William

County. Most of these samples were accompanied by approximately 40 to 50 percent duplicates, blanks, rinsate blanks, reagent blanks, matrix spikes, and matrix duplicates. The locations and spatial distribution of volatile organic sampling sites in the Culpeper basin of Prince William County are shown on figure 2.

Geographic Information System

A comprehensive data base, including geologic, hydrologic, and water-quality data, was developed within a GIS. A GIS combines efficient storage, manipulation, and retrieval capabilities of a relational data base with the ability to accurately represent spatially indexed data. It is not limited to a specific source, scale, or projection of data.

A data layer is a set of spatial features which are described by similarly named items or variables. These named items or variables are referred to as attributes of the data layer. Data layers in the GIS data base are classified as direct or derived in this report. Direct data layers include previously published or existing data collected by this investigation. These data were converted to digital format, as necessary. Examples of direct data layers are digital geology and lineaments maps and digitized locations of public-supply wells and hazardous-waste generators. Derived data layers were interpreted from direct or other derived data using the manipulative and graphical capabilities of the geographic information system. An example of a derived data layer is the contour map of thickness of overburden interpreted from overburden measurements, streams, lineaments, soils, and geology. A brief description of each data layer is presented in table 2. For more detailed information, a data dictionary for each layer is given in an Appendix to this report, which includes a description of the attributes, an outline of the structure, and an explanation of the sources of information.

Acknowledgments

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GEOHYDROLOGY

Geology

The Triassic and Jurassic rocks of Prince William County are part of the Culpeper basin (fig. 1), which extends from the Rapidan River near Madison Mills, Virginia, northwestward across the Potomac River and ends just west of Frederick, Maryland (Froelich and Leavy, 1982). The Culpeper basin is part of a series of exposed early Mesozoic sedimentary basins located in eastern North America. The location of the Culpeper basin within the exposed basins of the Newark Supergroup, as well as similar basins buried beneath Coastal Plain deposits or located offshore, is shown on figure 3. The Triassic and Jurassic strata in these basins collectively comprise the Newark Supergroup, which extends from South Carolina to Nova Scotia (Froelich and Olsen, 1985).

Strata in the Prince William County part of the Culpeper basin are collectively referred to as the Culpeper Group (Lee and Froelich, 1989). A.J. Froelich (U.S. Geological Survey, written commun., 1989) states that the

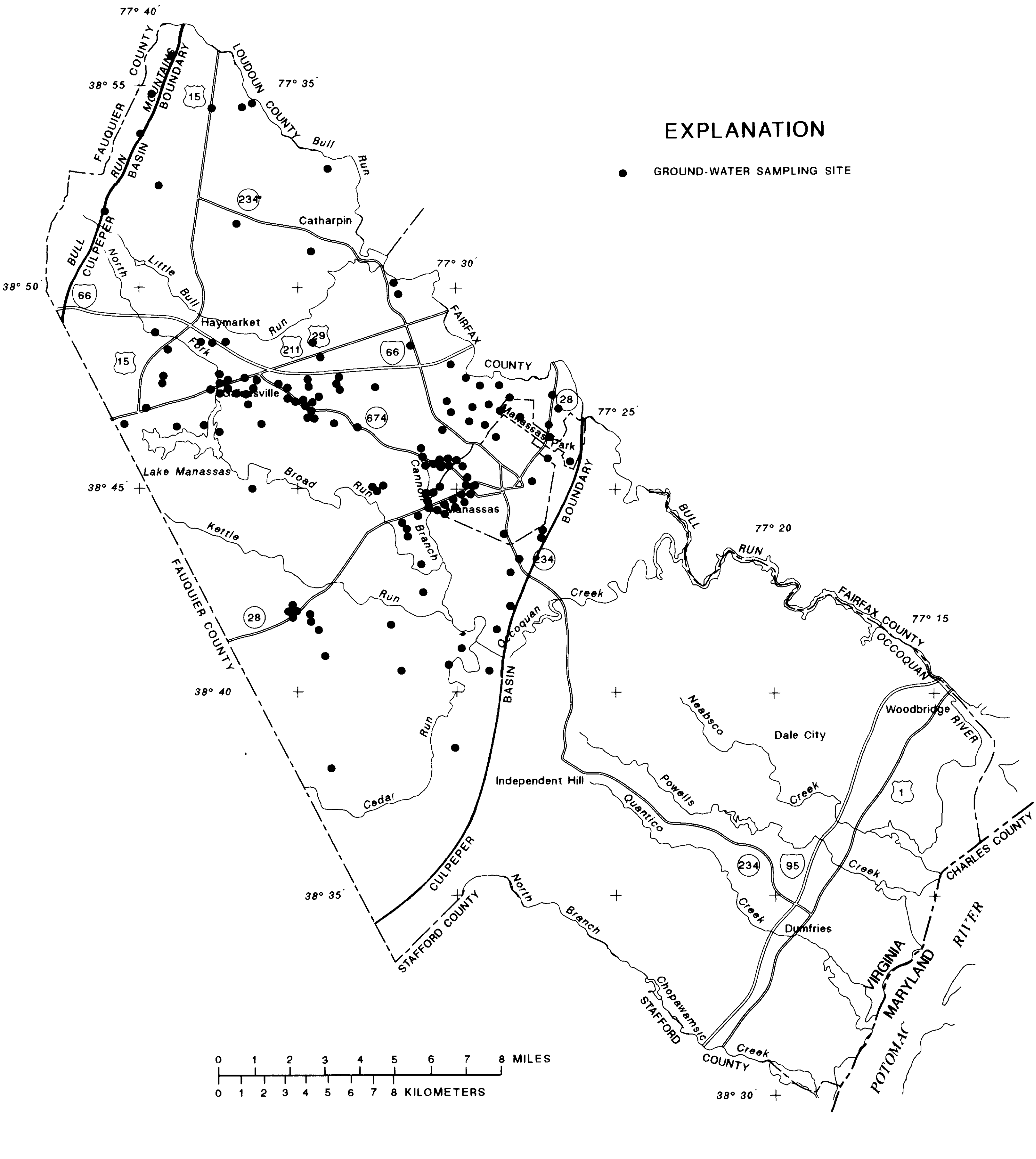


Figure 2.--Location of ground-water sampling sites with samples analyzed for volatile organic compounds.

Table 2.–*Summary of direct and derived data layers used by the geographic information system for the Culpeper basin of Prince William County*

Data layer	Layer type	Coverage type	Source
Bedrock geology	Direct	Polygon	Leavy and others (1983)
Lineaments	Direct	Line	Leavy (1984)
Proposed supply-well fields	Direct	Polygon	Betz-Converse-Murdoch, Inc. (1982)
Hazardous-waste generators	Direct	Point	Virginia Dept. of Health, Toxic Substances List
Public supply-wells	Direct	Point	USGS, SWUDS [1]
Inventoried wells (including volatile organic sampling sites)	Direct	Point	USGS, GWSI [2] Prince William Health Dist. Prince William Co. Serv. Auth. Virginia Dept. of Waste Management Private consulting firms
Hydrography	Direct	Polygon and line	USGS, National Mapping Div. Digital Line Graphs
Roads	Direct	Line	USGS, National Mapping Div. Digital Line Graphs
Pipelines, transmission lines, and miscellaneous transportation	Direct	Line	USGS, National Mapping Div. Digital Line Graphs
Railroads	Direct	Line	USGS, National Mapping Div. Digital Line Graphs
Thickness of overburden	Derived	Polygon and line	USGS, WRD [3]
Potentiometric surface	Derived	Polygon and line	USGS, WRD [4]
Contaminated areas	Derived	Polygon	USGS, WRD [5]

[1] U.S. Geological Survey, State Water Use Data System data base.
[2] U.S. Geological Survey, Ground Water Site Inventory data base.
[3] U.S. Geological Survey interpretive map.--Measurements from drillers' logs were contoured electronically. The contour map was then interpreted and modified using overlays of the overburden point values, streams, lineaments, and geology.
[4] U.S. Geological Survey interpretive map.--Measurements from a synoptic water-level run (September 1987) and digitized stream elevations were contoured electronically. The contour map was then interpreted and modified using overlays of the water-level point values, streams, lineaments, and geology.
[5] U.S. Geological Survey interpretive map.--Areas in which volatile organic compounds were detected in inventoried wells.

lower part of the Culpeper Group, of Late Triassic age, is mainly reddish-brown continental clastic rocks with arkosic sandstone and conglomerate at the base overlain by siltstone and shale. The upper part of the Culpeper Group, of Early Jurassic age, consists of interbedded clastic strata and basalt flows. All of the strata are locally folded and faulted, generally dip (slope inclination) to the west toward a major normal border fault, and are extensively intruded and thermally metamorphosed by Early Jurassic diabase dikes and sheets.

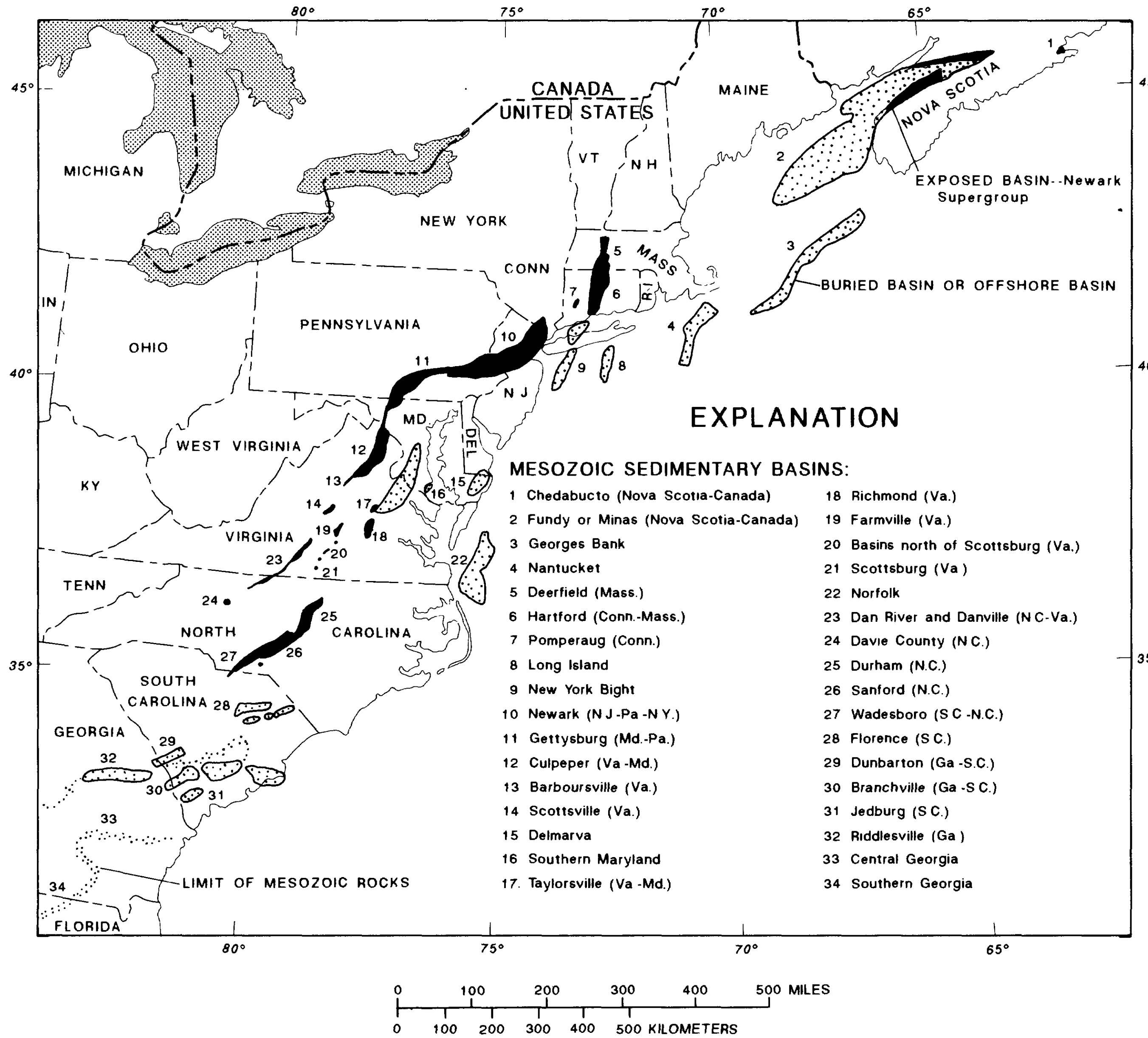


Figure 3.--Location of early Mesozoic sedimentary basins of the eastern United States (modified from Unger, 1988; and Froelich and Olson, 1984).

Formations and Rock Types

The Culpeper basin in Prince William County comprises an interbedded sequence of sedimentary and basaltic rocks of Late Triassic and Early Jurassic age. This sequence is intruded and thermally metamorphosed by Early Jurassic diabase dikes and sheets. Lee (1979) proposed that the Culpeper Group include all of the stratified rocks of Triassic and Jurassic age in the basin. Cady (1933, 1938) and Comer (1976) referred to this group as the Newark Formation and the Newark Group, respectively; terms which have been subsequently abandoned and replaced by Newark Supergroup (Froelich and Olsen, 1984). Pre-Triassic metamorphic and igneous rocks border and underlie the basin but are not discussed in this report. The sedimentary rocks of the Culpeper basin consist of predominantly coarse-grained clastic fluvial and fine-grained lacustrine (lake) deposits of continental origin (Lee, 1979; 1980). Basalts, diabase, and thermally metamorphosed rocks also are present in the basin. Lee (1979, 1980) has mapped unconsolidated upper Tertiary (?) and Quaternary terrace deposits, mountain wash colluvial deposits, and Holocene alluvial deposits overlying the Culpeper Group, the diabase, and the thermally metamorphosed rocks at a scale of 1:24,000. Froelich (1984) mapped the same general units as well as saprolite and lag gravels at a scale of 1:125,000.

The bedrock map of Leavy and others (1983) at a scale of 1:125,000 was used primarily for this investigation (pl. 1). Stratigraphic nomenclature and lithologic descriptions (fig. 4) are primarily from Lee (1979, 1980) with modifications by Lee and Froelich (1989). For the purposes of this report, the igneous (basalt and diabase) and the contact metamorphic (thermally metamorphosed) rocks are discussed separately, because these rocks have geohydrologic characteristics that differ from the enclosing sedimentary rocks. The sedimentary rocks will be discussed in ascending order, basal Triassic strata first. The upper Tertiary (?) and Quaternary deposits will not be described in this report; interested readers should consult Lee (1979, 1980) and Froelich (1984). Descriptions of the rock types in the Culpeper basin are summarized in table 3.

Manassas Sandstone

The Manassas Sandstone is Late Triassic in age and includes the Reston Member at the base. This member intertongues with and is conformably overlain by the Poolesville Member. The Reston Member of the Manassas Sandstone is predominantly a quartz-pebble conglomerate and is only present in the eastern margins of the basin. This unit is represented as the eastern conglomerate on plate 1. The Reston Member is dusky-red to dark-red in color, feldspathic, and contains coarse clasts of mica schist, phyllite, quartzite, vein quartz, and granite. The composite thickness of the Reston Member is about 280 ft. The Poolesville Member is mainly arkosic, crossbedded sandstone cemented by clay, silica, and calcite. Minor amounts of siltstone and shale locally overlie the arkosic sandstone in fining-upward sequences. This unit has a maximum thickness of more than 3,280 ft and comprises the easternmost sandstone on plate 1.

Balls Bluff Siltstone

The Balls Bluff Siltstone conformably overlies the Poolesville Member of the Manassas Sandstone and also is Late Triassic in age. This formation is a dusky-red to dark-grey, feldspathic, calcareous, and ferruginous siltstone. This siltstone is interbedded with layers of sandstone and silty shale throughout the sequence. Lenses of carbonate ooids and aggregates of carbonate concretions also are present. The Balls Bluff Siltstone has a total thickness of 5,545 ft. This formation appears as the siltstone to the east and west of, and within the diabase on plate 1.

Catharpin Creek Formation

The Catharpin Creek Formation is Late Triassic to Early Jurassic in age. This formation is in the western section of the Culpeper basin. The Catharpin Creek Formation contains sandstones, siltstones, and a thick conglomerate at the top. The estimated thickness of this formation is about 1,640 ft. The Goose Creek Member

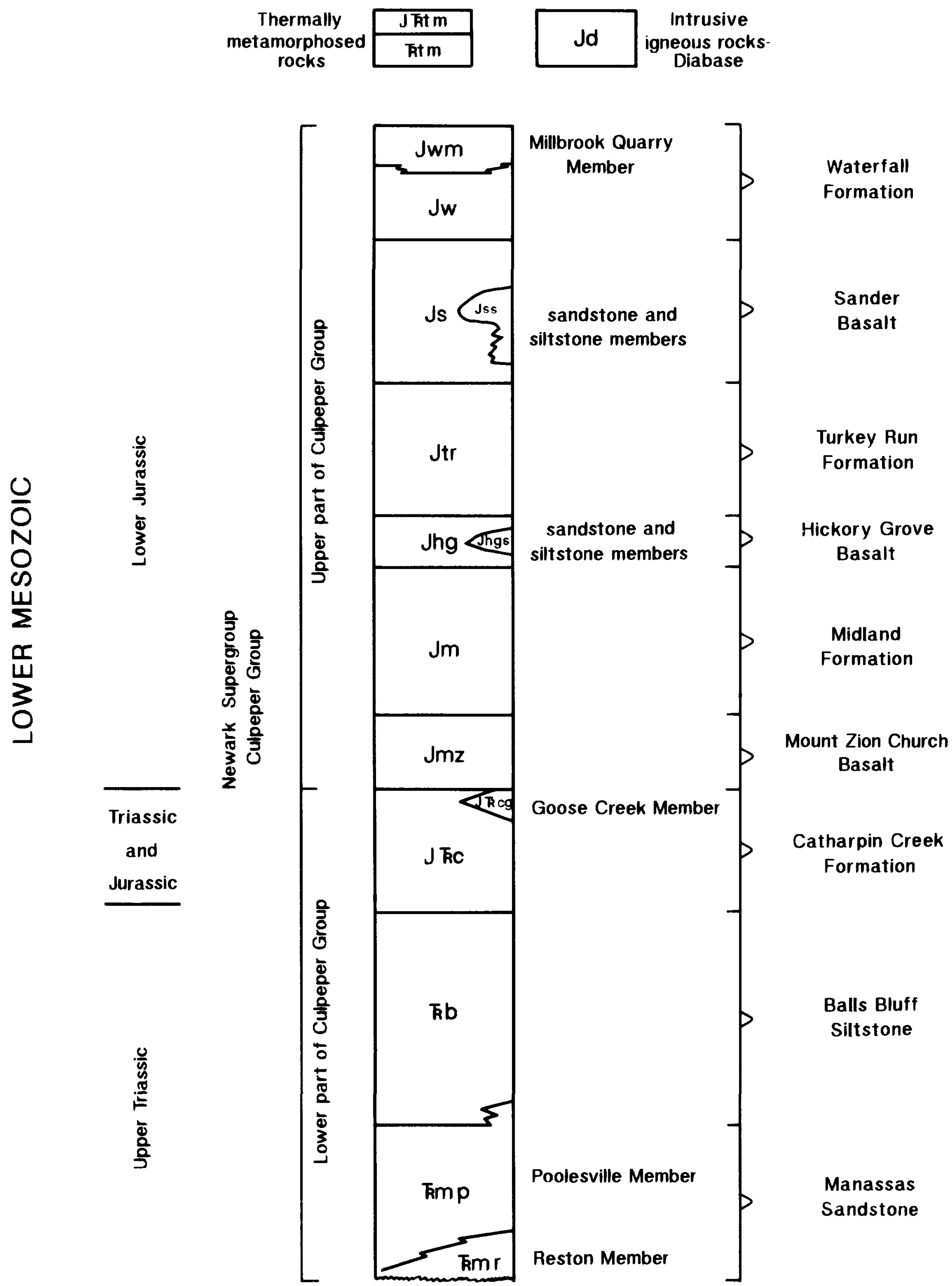


Figure 4.--Stratigraphic relations among the Triassic-Jurassic rocks of the Culpeper Group in Prince William County (modified from Lee, 1979; 1980; and Lee and Froelich, 1989, plate 1).

Table 3.–*Lithologic summary of rocks of the Culpeper basin in Prince William County*

[Lithologic descriptions modified from Lee (1979, 1980) and Lee and Froelich (1989)]

Lithology	Description	Formation
Quartz-pebble conglomerate	Eastern margin–Dusky-red to dark-red in color. Coarse clasts of mica-schist, quartzite, and vein quartz. Loosely consolidated and grades into a medium- to fine-grained sandstone to the west.	Eastern margin–Reston Member of the Manassas Sandstone
	Western margin–Dusky-yellow to yellow-green in color. Coarse clasts of greenstone, quartzite, limestone, marble, and vein quartz. Firmly cemented by silica and commonly deeply weathered to saprolite.	Western margin–Goose Creek Member of the Catharpin Creek Formation and Millbrook Quarry Member of the Waterfall Formation
Sandstone	East–Dusky-red to very dark-red in color. Very fine- to medium-grained arkosic sandstone. Locally cemented by clay, silica, and calcite.	East–Poolesville Member of the Manassas Sandstone
	West–Dusky-red to dark-red in color. Interlayered with siltstones, minor conglomerate, and shale.	West–Catharpin Creek Formation
Siltstone	East–Dusky-red to dark-gray in color. Arkosic and highly calcareous. Interbedded with sandstones and shale.	East–Balls Bluff Siltstone
	West–Red-brown to gray in color. Arkosic and highly calcareous. Interbedded with gray and black shale and gray to red-brown arkosic sandstone.	West–Catharpin Creek, Midland, Turkey Run, and Waterfall Formations
Diabase	Medium- to medium-dark gray in color. Equigranular; however, can be very coarse-grained. Crystals of augite, pigeonite, labradorite. Granules of magnetite and ilmenite. Pegmatitic and granophyric facies are present.	--
Thermally metamorphosed rocks	Variety of colors are present ranging from gray to olive-black in color. Hornfels are dominant with granulites, marbles, and quartzites also present. Minerals present are hornblende, tourmaline, biotite, cordierite, garnet, andalusite, chlorite, epidote, plagioclase, and quartz.	--
Basalt	Variety of colors are present. Commonly gray, green, or black in color. Locally contains vesicles and is amygdaloidal with calcite and zeolites [1]. Commonly holocrystalline and equigranular. Minerals present labradorite, andesine, augite, and plagioclase.	Mount Zion Church Basalt, Hickory Grove Basalt, and Sander Basalt

[1] From Leavy and others (1983).

is a dusky-yellowish to yellowish-green conglomerate and is present in the central part of the Culpeper basin (pl. 1). This unit is firmly cemented with silica and contains clasts of greenstone, quartzite, limestone, and vein quartz, where fresh; but is deeply weathered to saprolite on upland surfaces. The thickness of this unit has been estimated to be greater than 2,952 ft.

Midland Formation

The Midland Formation is Early Jurassic in age and is composed of clastic sedimentary rocks of fluvial and lacustrine origin. The Midland Formation overlies the Mount Zion Church Basalt and underlies the Hickory

Grove Basalt in the western part of the basin (pl. 1). Sandstone, siltstone, and shale are the dominant rock types of the Midland Formation. The sandstones are dark-red to reddish-brown, micaceous, feldspathic, fine- to medium-grained, and are interbedded with reddish-brown, micaceous siltstone; dark-red to nearly black, calcareous, silty, fossiliferous shale; and argillaceous limestone. Lenses of conglomerate and conglomeratic, coarse-grained, arkosic sandstone also are present. Fossil fish, plant spores, and ostracodes have been identified in strata of the Midland Formation. Total thickness is generally less than 1,000 ft.

Turkey Run Formation

The Turkey Run Formation is Early Jurassic in age and is predominantly composed of a sequence of sandstone, siltstone, and shale. Dark-red to medium-dark-greyish green, micaceous, feldspathic, laminated, very fine- to coarse-grained sandstone, siltstone, and silty shale are characteristic of this sequence. The Turkey Run Formation overlies the Hickory Grove Basalt and underlies the Sander Basalt in the western part of the basin. Minor black, calcareous, fossiliferous laminite also are present. Black phosphatic fish scales have been identified in siltstone and shale beds near the base of the formation in Prince William County. The average thickness of this formation is 1,000 ft.

Waterfall Formation

The Waterfall Formation is Early Jurassic in age and overlies the Sander Basalt in the western margin of the basin. This formation is predominantly composed of interbedded sandstone, siltstone, and conglomerate. Fossiliferous, calcareous shale and black laminite zones are present. The thickness of the Waterfall Formation ranges from 3,773 to 5,638 ft. The Millbrook Quarry Member is the uppermost unit of the Waterfall Formation and contains cobbles of weathered greenstone with minor clasts of quartzite, gneiss, marble, limestone, basalt, and vein quartz. This member is firmly cemented with calcite and silica and is present along the western border fault. Accurate estimates of thickness for the Millbrook Quarry Member are difficult to determine because of the lack of continuous outcrops and bedding features.

Basalts

The basalts, which are extrusive-igneous volcanic rocks, represent three flow series in the western part of the Culpeper basin (Tollo, 1988, p. 105). As previously stated, these basalt flows are interlayered with the sedimentary rocks and are Early Jurassic in age. Three basalt series are present: the Mount Zion Church Basalt, the Hickory Grove Basalt, and the Sander Basalt with thicknesses of 279, 695, and 1,970 ft, respectively. Each of the basalt flow series have lenticular sandstone and siltstone intercalations that may separate individual flows of the series. The thickest and most extensive lenticular sandstone and siltstone intercalations are present in the Sander Basalt, which is evident on plate 1. The basalts commonly are aphanitic, holocrystalline, and equigranular. Minerals present include labradorite, andesine, augite, and plagioclase. Vesicles (cavities formed by the entrapment of gas bubbles during solidification) commonly are present in the upper parts of the basalts. Iron- and copper-sulfide minerals are present within the Sander Basalt and probably are the result of hydrothermal alteration. Well-developed columnar joints are common in the flows.

Diabase

The diabase is an intrusive-igneous rock of Early Jurassic age. The color ranges from a medium- to medium-dark gray. The margins of the diabase are chilled and aphanitic; however, most of the rocks are medium equigranular, but can be very coarse-grained. The diabase consists of an interlocking mosaic of crystals of augite, pigeonite, labradorite, and granules of magnetite and ilmenite. The diabase locally exhibits both pegmatitic and granophyric facies.

Thermally metamorphosed rocks

The thermally metamorphosed rocks are Late Triassic to Early Jurassic in age and are present as contact aureoles surrounding the diabase intrusions (pl. 1). Hornfels, granulites, marble, and quartzites are present, with the hornfels most common. A variety of mineral assemblages are present and proximity to the diabase determines these assemblages. Commonly occurring minerals are hornblende, garnet, tourmaline, biotite, cordierite, andalusite, chlorite, epidote, orthoclase, plagioclase, and quartz. These rocks formed by thermal metamorphism of the country rock proximal to the diabase intrusions.

Structure

A variety of geologic structures are present in the Culpeper basin. The strike (trend) of the rocks ranges from N 15° W to N 45° E (Johnston, 1960, p. 2). These rocks regionally dip to the west and northwest at 0° to 70° angles. Dips are nearly flat and gentle along the eastern margin of the basin, but progressively steepen to the west. The westward steepening of the dip resulted from the downward movement of the basin along the major western border fault during Late Triassic and Early Jurassic time. Lee (1980) believed that the western border fault was more active than the minor eastern faults, which caused the strata to be regionally tilted to the west. The process of subsidence along the major normal fault, which may be listric (Unger, 1988, p. 230), may explain the steeper dips near the western margins of the basin. Lindholm (1977) and Hentz (1981) reported that the steepest dips are concentrated near Thoroughfare Gap. Dips may have been locally disrupted by the intrusion of the diabase sheets (Johnston, 1960. p. 2).

Fractures and lineaments

Fractures are abundant in the Culpeper basin. The term *joints* commonly is used interchangably with fractures in the literature. Joints, however, are defined as partings or cracks in the rock that have no significant displacement. For simplicity, the authors have chosen the term *fracture* to represent any parting in the rock, regardless of displacement. Primary porosity is negligible in the basin strata because of poor sorting and cementation; whereas, secondary porosity in the form of fractures is widespread. Fractures formed as a result of cooling and contraction of igneous rocks and from stresses during tectonic activity (such as subsidence, tilting, uplifting, folding, and especially faulting) and are believed to decrease in size effectiveness and frequency with depth (Laczniak and Zenone, 1985).

Lineaments, which are linear topographic features that may reflect subsurface structures, commonly indicate fracture sets. Faults are a good example of fracture sets that commonly have linear surface expressions. The lineament map from Leavy (1984) was used during this investigation (pl. 2). Leavy (1984) compiled lineament data from various remote-sensing techniques including satellite imagery (Landsat and Seasat) and aerial photography, as well as topographic lineaments, joints, and bedding attitudes. Some of the lineaments are prominent regional features; however, their delineation does not preclude the need for detailed, low altitude, site-specific remote sensing and direct field investigations.

The sedimentary rocks in the study area exhibit two principal sets of fracture orientations, as is evident on plate 2. The first set generally trends parallel to the strike of the bedding, N 15° W to N 45° E, and has steep dips. The second set also dips steeply, but the trend is nearly perpendicular to the strike of the bedding (Johnston, 1960, p. 2). Fracture spacing and bedding-plane partings in the siltstones generally are much closer than in the sandstones and conglomerates (table 4).

Table 4.–*Fracture spacing, bedding forms, and bedding-plane spacings in rocks of the Culpeper basin in Prince William County*

[Modified from Leavy and others (1983, table 1)]

Lithology	Fracture spacing (feet apart)	Bedding form	Bedding-plane spacing (feet apart)	Formation
Quartz-pebble conglomerate	0.3 to 10	Thick-bedded to massive	Greater than 15	Eastern margin–Reston Member of the Manassas Sandstone
				Western margin–Goose Creek Member of the Catharpin Creek Formation and Millbrook Quarry Member of the Waterfall Formation
Sandstone	0.03 to 16	Thin- to thick-bedded	0.03 to greater than 15	East–Poolesville Member of the Manassas Sandstone
				West–Catharpin Creek Formation
Siltstone	0.03 to 0.3	Thin- to medium-bedded	0.03 to 3	East–Balls Bluff Siltstone
				West–Catharpin Creek, Midland, Turkey Run, and Waterfall Formations
Diabase	Variable	Platy to massive	--	--
Thermally metamorphosed rocks	0.03 to 3	Thin- to thick-bedded	--	--
Basalt	0.1 to 0.3	Thin- to thick-flows	3 to greater than 30	Mount Zion Church Basalt, Hickory Grove Basalt, and Sander Basalt

Leavy (1984) stated that the fractures in the igneous rocks have random orientations and curvilinear geometries as a result of cooling processes. He also stated that diabase and basalts, have well-developed columnar joints because of contraction in response to cooling. Fracture spacing within the diabase is highly variable (table 4). Johnston (1960, p. 2) believed that the diabase has two dominant sets of steep-dipping fractures, which trend to the north or to the west.

The thermally metamorphosed rocks have fracture spacings that are similar to those of the parent-sedimentary rocks (table 4); but many of the fractures are healed or filled (A.J. Froelich, U.S. Geological Survey, written commun., 1989). Leavy and others (1983) noted that mineralization of the fractures is common. Watson (1907) and Edmundson (1938) stated that some fractures near the diabase intrusions are filled with barite.

Bedding planes

Bedding planes (planes of deposition) are present in the layered sedimentary rocks of the Culpeper basin. Erosion of the overlying rocks commonly causes a reduction in pressure on these bedding planes forming partings along the layers called stress-relief fractures (Laczniak and Zenone, 1985). The stress-relief fractures tend to decrease with depth. Leavy and others (1983) provided the bedding-plane data presented in this section. The bedding forms and the spacings of bedding planes in the various formations and rock types in the basin are summarized in table 4. Distance from the source of fluvial deposition controlled the overall distribution of rock type, hence the bedding-plane spacings. As the distance from the source increased, velocities, sediment load, and grain size decreased. Conglomerates were deposited nearer the source, sandstones farther, and siltstones and shales farthest. The Balls Bluff Siltstone is thin- to medium-bedded with bedding planes commonly spaced less than 3 ft apart. The sandstones of the Manassas Sandstone and Catharpin Creek Formation commonly are thin- to thick-bedded. These sandstones have a greater spacing between bedding planes than the siltstones, usually 0.03 to 15 ft. The greatest sedimentary bedding-plane spacing is in the massive to thick-bedded conglomerates, where bedding planes commonly are greater than 15 ft. The proximity to the source of detritus (sediments) of the conglomerates and an abrupt change in gradient as the stream entered the basin may explain the massive to thick bedding.

The thermally metamorphosed rocks have remnant bedding from the parent-sedimentary rocks. These metamorphic rocks can be thin- to thick-bedded. Layering, possibly formed in response to exfoliation and sheeting, is present in the diabase, which ranges from platy to massive (A.J. Froelich, U.S. Geological Survey, written commun., 1989)

Faults

Faults are fractures or a zone of fractures where there has been relative displacement of the opposite sides. Faulting in the Culpeper basin is predominately of a normal or gravity type where the hanging wall is downthrown. Fault-plane exposures generally are rare because of intense weathering of the extensively fractured rocks and mantling of alluvial and colluvial deposits. The major faults in the basin are the western border faults with vertical displacement of thousands of feet (Leavy, 1984). Numerous minor faults also are present. The eastern border, generally an erosional unconformity, is commonly cut by high-angle, northeast-striking normal faults with displacements of tens to hundreds of feet (A.J. Froelich, U.S. Geological Survey, written commun., 1989). The downthrown side is to the west and the fault plane dips to the west. In this border-fault zone, high-angle normal and reverse faults are oriented perpendicular to the principal eastern border fault (Leavy, 1984). Numerous minor faults are present within the basin; however, exposures are poor and actual displacements are unknown. Leavy (1984) stated that the slickensides in the fault planes indicate that movement along these minor faults had a horizontal as well as a vertical component of displacement.

Folds

Folds are warps in the layered rocks that formed as a result of deformation of the strata. Most of the strata in the Culpeper basin are homoclinal, tilted or dipping in a westerly direction. Lee (1979) mapped two northeast-trending folds, an anticline and syncline, plunging to the southwest at 6° and 3°, respectively. These folds are located southeast of Nokesville (fig. 5). Dips on the limbs generally range from 3° to 13°. Broad folds or warps related to displacement along the western border fault gently plunge to the west (Lindholm, 1979). The location, axial plane, and plunge directions of these folds is shown on figure 5.

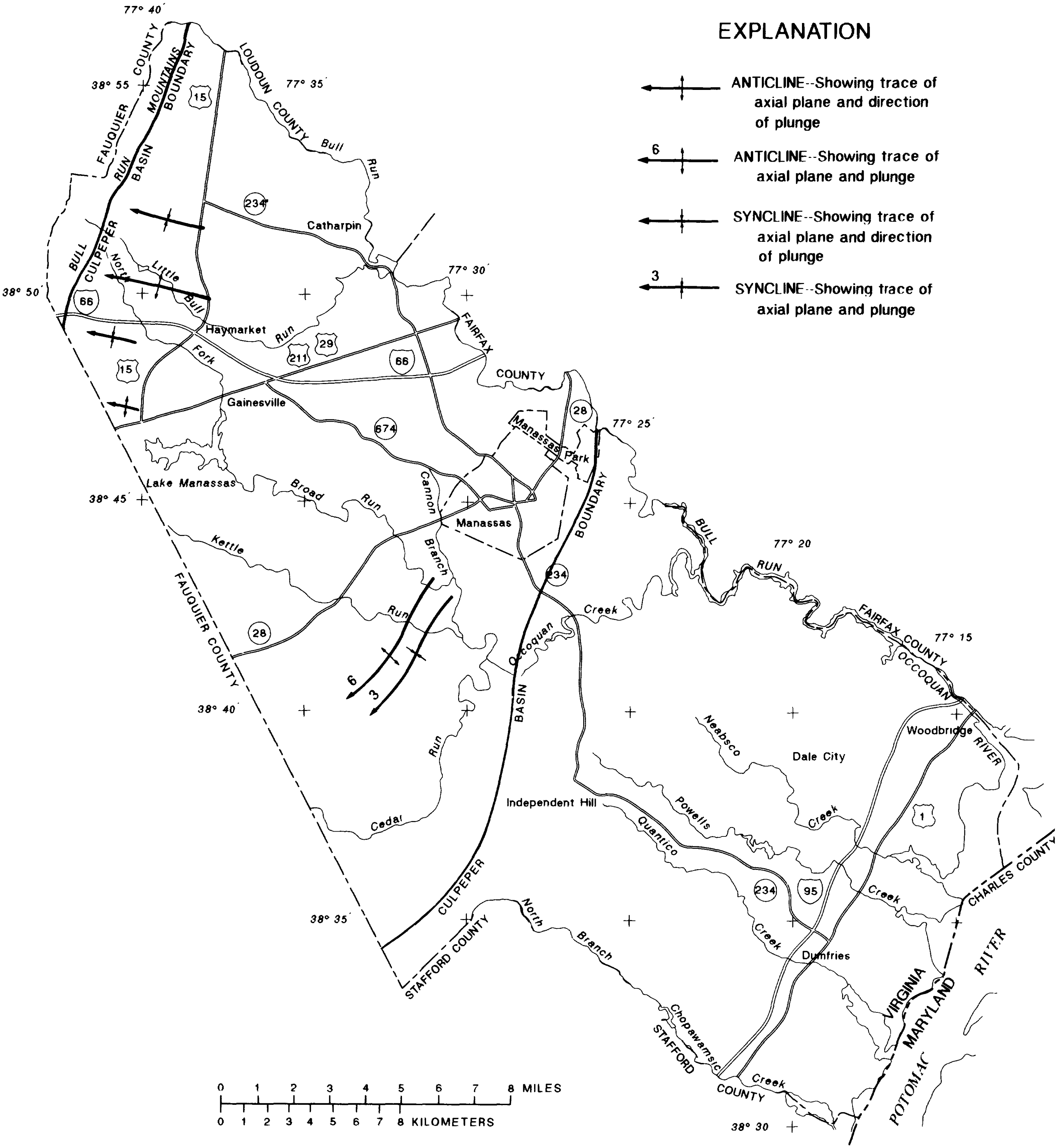


Figure 5.--Location, axial plane, and plunge directions of folds in the Culpeper basin of Prince William County (modified from Leavy and others, 1983).

Dikes, sills, and stocks

Diabase in the Culpeper basin is present in the form of dikes, sills, and stocks (Lee, 1980). Schematic examples of these structures are portrayed on figure 6. The diabase probably intruded into preexisting fractures in the sedimentary and the pre-Triassic crystalline rocks that border and underlie the basin. Leavy (1984) stated that the diabase probably intruded into the local and regional tensional fractures. Dikes, which cut across the sedimentary-bedding planes, followed the near-vertical fractures; whereas sills formed along the bedding planes. Stocks are large, discordant bodies.

A review of the drillers' logs indicated that thin layers of diabase are present at depth within the sandstones and siltstones in the study area. These thin layers of diabase penetrated during drilling probably were sills. Precise prediction of the occurrence of thin diabase bodies in the subsurface is nearly impossible.

Overburden

In this report, overburden is the term applied to unconsolidated material that overlies bedrock (solid competent rock). Thickness of the overburden is an important factor in the hydrologic system and the movement of solutes in ground water. Thin overburden allows easy infiltration and the rapid movement of percolating water along fractures. Overburden consists of soil, weathered bedrock (saprolite), colluvial, terrace or lag gravels, and alluvial deposits. The thickness of overburden map for the Culpeper basin of Prince William County (pl. 3) was generated from (1) drillers' logs, (2) geologic maps by Lee (1979, 1980) and Froelich (1985), and (3) soil maps by Elder (1986). The thickness of overburden averages between 5 and 10 ft over most of the study area. Overburden tends to be thicker along the margins of the basin than along stream valleys towards the center of the basin. The range and average thicknesses of overburden for the various rock types present in the basin are presented in table 5. Average thicknesses of overburden are similar for the various rock types except for the quartz-pebble conglomerates and the diabase, which, locally, are fairly thick.

An area of thick overburden near the western border fault is mapped on plate 3. One of the major components of the overburden in this area is the mountain-wash colluvium. Lee (1979, 1980) stated that the Quaternary mountain-wash colluvial deposits, which mantle the bedrock in this area, range in thickness from 1 to greater than 98 ft. Many drillers' logs from this area indicated the presence of gravels, which are characteristic of the mountain wash that overlies the bedrock. Elder (1986, p. 67) also reported that depths to bedrock in this area can exceed 20 ft.

The two areas of thick overburden near the eastern margin (pl. 3) may be the result of alluvial and colluvial deposits from the uplifted-Piedmont rocks and weathering of the parent-sedimentary rocks, especially the conglomerates. The northern section probably is derived from weathering processes. Froelich (1985) reported that the residuum of weathered bedrock can exceed thicknesses of 23 ft. Areas with overburden thicknesses greater than 23 ft may indicate more intensive weathering facilitated by extensive fracturing (see pl. 2). The southern area probably is derived from weathering and a mantling of colluvial deposits. This area is underlain by the Reston Member of the Manassas Sandstone (see pl. 1). Froelich (1985) stated that this member has residuum ranging from 16 to 100 ft in thickness. Lee (1980) mapped Quaternary mountain-wash colluvial deposits overlying the Reston Member in this area.

Two-isolated thick sections, northeast and southwest of Lake Manassas and northwest of Nokesville are shown on plate 3. A variety of rock types are present in these areas. These two areas are similar because they both contain an abundance of fracture sets (see pl. 2). The abundance of fracture sets probably allowed more intensive weathering of the parent rock, which would facilitate the formation of a thick section of overburden.

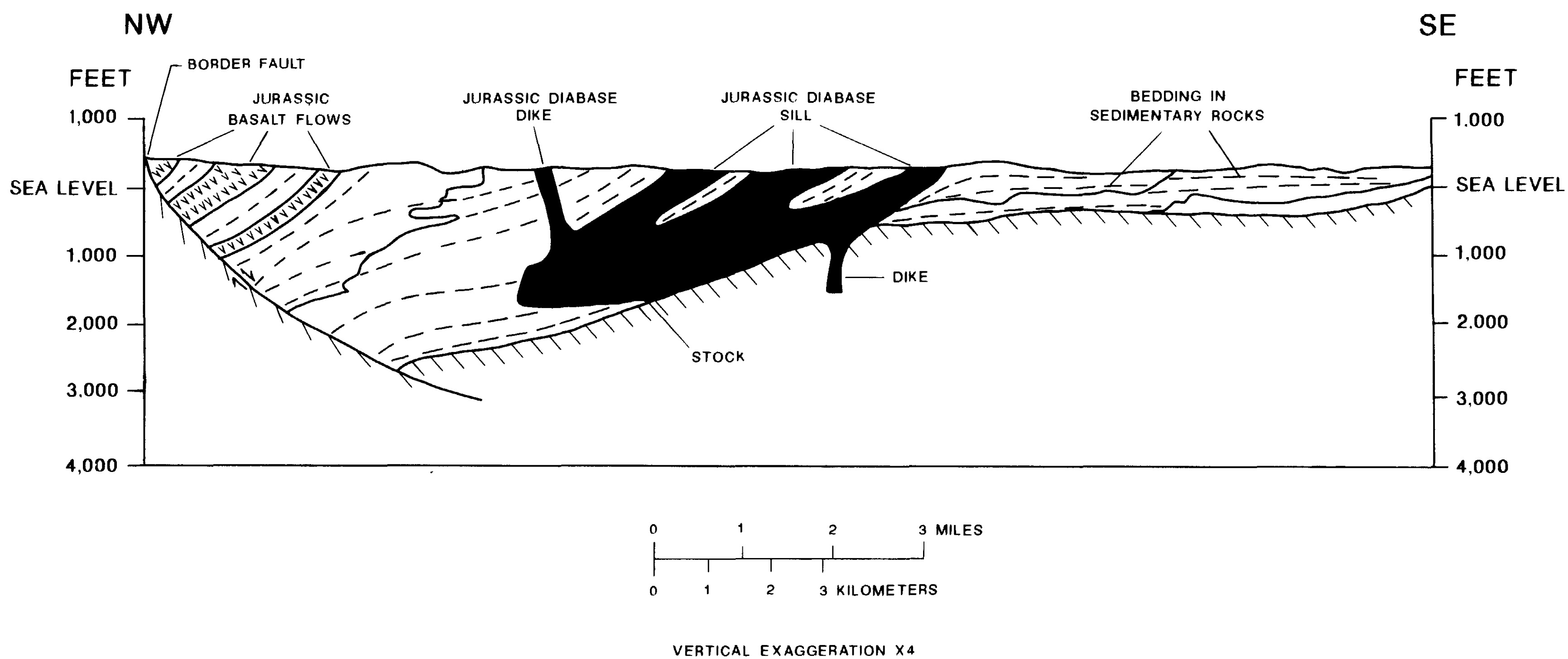


Figure 6.--Generalized geologic section across the Culpeper basin of Prince William County showing dikes, sills, and stocks (modified from Laczniak and Zenone, 1985, fig. 1).

Table 5.–*Range of overburden thickness and averages for the various rock types in the Culpeper basin in Prince William County*

[Modified from Leavy and others (1983, table 1)]

Lithology	Range of thickness (feet)	Average thickness (feet)	Formation
Quartz-pebble conglomerate	0 - 98	49	Eastern margin–Reston Member of the Manassas Sandstone
			Western margin–Goose Creek Member of the Catharpin Creek Formation and Millbrook Quarry Member of the Waterfall Formation
Sandstone	0 - 20	10	East–Poolesville Member of the Manassas Sandstone
			West–Catharpin Creek Formation
Siltstone	0 - 33	10	East–Balls Bluff Siltstone
			West–Catharpin Creek, Midland, Turkey Run, and Waterfall Formations
Diabase	0 - 66[1]	20	--
Thermally metamorphosed rocks	0 - 33	3	--
Basalt	0 - 20	10	Mount Zion Church Basalt, Hickory Grove Basalt, and Sander Basalt

[1] From A.J. Froelich (U.S. Geological Survey, written commun., 1989).

Ground-Water Occurrence and Movement

The various types of rocks in the Culpeper basin of Prince William County have different water-bearing potentials. Fractures associated with lineaments are the major geohydrologic connection within and between the various rock types. Although the flow system is complicated, flow gradients and, consequently, general flow directions are predictable. Ground-water flow also may be controlled by fractures not associated with lineaments. Prediction of ground-water flow along these fractures is difficult. Water quality of the Culpeper basin is highly dependent on the interaction of the various rock types and flow system.

Water-Bearing Potential

The Culpeper basin can be divided into aquifers on the basis of rock type. The degree and nature of the fracturing is related to rock type. Fractures, commonly associated with lineaments, control flow, storage, and availability of ground water in the Culpeper basin. Thus, each rock type has its own water-bearing potential. The water-bearing potential and hydraulic properties for the various rock types in the Culpeper basin of Prince William County are summarized in table 6.

Table 6.–*Water-bearing potential and hydraulic properties for rocks of the Culpeper basin in Prince William County*

[– –, indicates no values have been determined]

Lithology	Water-bearing potential	Hydraulic properties: Transmissivity [1] (feet squared per day)	Specific capacity [2] (gallons per minute per foot)	Storage coefficient [3]	Formation
Siltstone	Very-good to excellent. Closely-spaced fractures and partings with high frequency of intersection. Dissolution of calcite along fractures. Moderately high values of transmissivity. Yields range from 1 to 554 gal/min.	1,000 to 3,600	0.04 to 5.67	0.00002 to 0.002	East–Balls Bluff Siltstone West–Catharpin Creek, Midland, Turkey Run, and Waterfall Formations
Sandstone	Good to very-good. Intersecting open fractures and bedding-plane partings. Moderately high values of transmissivity. Yields range from 1.5 to 735 gal/min.	260 to 3,000	0.06 to 14.70	0.00002 to 0.0002	East–Poolesville Member of the Manassas Sandstone West–Catharpin Creek Formation
Quartz-pebble conglomerate	Moderate. Widely spaced fractures and bedding-plane partings because of thick to massive bedding. Moderate values of transmissivity. Yields range from 3 to 75 gal/min.	1,875 to 2,500	– –	– –	Eastern margin–Reston Member of the Manassas Sandstone Western margin -- Goose Creek Member of the Catharpin Creek Formation and Millbrook Quarry Member of the Waterfall Formation
Basalts	Generally poor. The presence of closely spaced columnar joints and fractures locally may enhance water-bearing potential. Moderately high values of transmissivity.	1,890 to 2,520	– –	– –	Mount Zion Church Basalt, Hickory Grove Basalt, and Sander Basalt
Diabase	Generally poor. Massive to platy, random fracture orientations, and wide spacing between fractures. Low values of transmissivity. Locally may have significant yields. Yields range from 0.75 to 100 gal /min. Dry holes common.	60 to 80	– –	– –	– –
Thermally metamorphosed rocks	Generally poor. Similar to the diabase. Some fractures mineralized. Yields may be affected by parent-sedimentary rocks. Yields range from 3.5 to 60 gal/min. Dry holes common.	60 to 80	– –	– –	– –

[1] Values from Leggette, Brashears, and Graham (1980), Betz-Converse-Murdoch (1982), and Laczniak and Zenone (1985).
[2] Values from Leggette, Brashears, and Graham (1980), and Betz-Converse-Murdoch (1982).
[3] Values from Leggette, Brashears, and Graham (1980), and Betz-Converse-Murdoch (1982).

Siltstones

Siltstones of the Balls Bluff Siltstone, Catharpin Creek, Midland, Turkey Run, and Waterfall Formations have very good to excellent water-bearing potential (Comer, 1976, p. 65). The siltstone aquifer of the Balls Bluff Siltstone is probably the most productive aquifer in the Culpeper basin of Prince William County. Secondary permeability is dominant in the form of open, intersecting fractures and bedding-plane partings. The combination of closely spaced fractures and partings with a high frequency of intersections allows for large amounts of ground-water to be stored and transmitted. Dissolution along these fractures and partings is enhanced by the presence of calcite cement. A thin cover of overburden allows for fairly rapid infiltration and movement along steeply dipping fracture planes.

Well yields are generally highest in the siltstone aquifer of the Balls Bluff Siltstone, ranging from 6 to 554 gal/min (gallons per minute). The siltstone aquifers of the Catharpin Creek, Midland, Turkey Run, and Waterfall Formations commonly yield from 1 to 100 gal/min. These differences in yields probably reflect water-use practices rather than water-bearing potential. Most of the high yields reported from the Balls Bluff Siltstone are from large public-supply wells, which are designed and constructed for high-capacity production. Domestic use dominates in the areas underlain by the siltstone of the other formations.

Betz-Converse-Murdoch (1982, p. 26) determined that yields decrease with depth and concluded that well depths should not exceed 450 to 500 ft. However, most of the high-yielding wells in the Culpeper basin aquifers of Prince William County usually range in depth from 500 to 950 ft. Johnston (1960, p. 4) reported that a 955-foot-deep well at Dulles International Airport yielded 600 gal/min from the siltstone aquifer. Laczniak and Zenone (1985) stated that one of the highest yields reported for the Culpeper basin was 1,000 gal/min from a 1,020-foot-deep well that was finished in siltstone. Cady (1938), Cederstrom (1972), and Comer (1976) support the idea that high yields can be achieved by drilling wells to depths greater than the proposed termination depths.

Declining yields over time have been documented in the Manassas area. This decline in well yields can be attributed to decreasing well efficiency, in response to the influx of silt.

Betz-Converse-Murdoch (1982) conducted an aquifer test for well 50T48F located in the siltstone of the Balls Bluff Siltstone (fig. 7). Using drawdown and recovery data combined with the Jacob modification of the Theis nonequilibrium formula, an average transmissivity (measure of the capacity of an aquifer to transmit water) of 2,126 ft^2/d (feet squared per day) was calculated. Leggette, Brashears, and Graham (1980) also conducted an aquifer test for well 51V24H in the siltstone aquifer of the Balls Bluff Siltstone near Chantilly in Fairfax County (fig. 7). Using a modified Theis nonequilibrium formula for leaky aquifer conditions and drawdown data for the pumped and observation wells, transmissivities ranged from 1,672 to 2,985 ft^2/d. Laczniak and Zenone (1985) estimated relative-directional transmissivities between 2,700 to 3,600 ft^2/d for a two-dimensional finite-difference model of the entire Culpeper basin. Transmissivities, determined from aquifer test results and specific-capacity data for wells in Fairfax County, averaged between 1,000 to 2,000 ft^2/d (Zenone and Larson, 1983). The siltstones have excellent water-bearing potential in response to the abundance of open, intersecting fratures, which contributes to the moderately high transmissivities. The studies discussed above indicate that transmissivities are greater along lineaments.

Specific capacity (measure of the capacity of a well to produce water) ranges from 0.04 to 5.67 (gal/min)/ft (gallons per minute per foot of drawdown) for the siltstones. Leggette, Brashears, and Graham (1980, p. 20) conducted a step-drawdown test which showed a decrease in specific capacity with increasing pumping rates. Leggette, Brashears, and Graham stated a decrease in specific capacity is common in rock wells and may relate to yield loss resulting from turbulence caused by increasing entrance velocities at higher pumping rates.

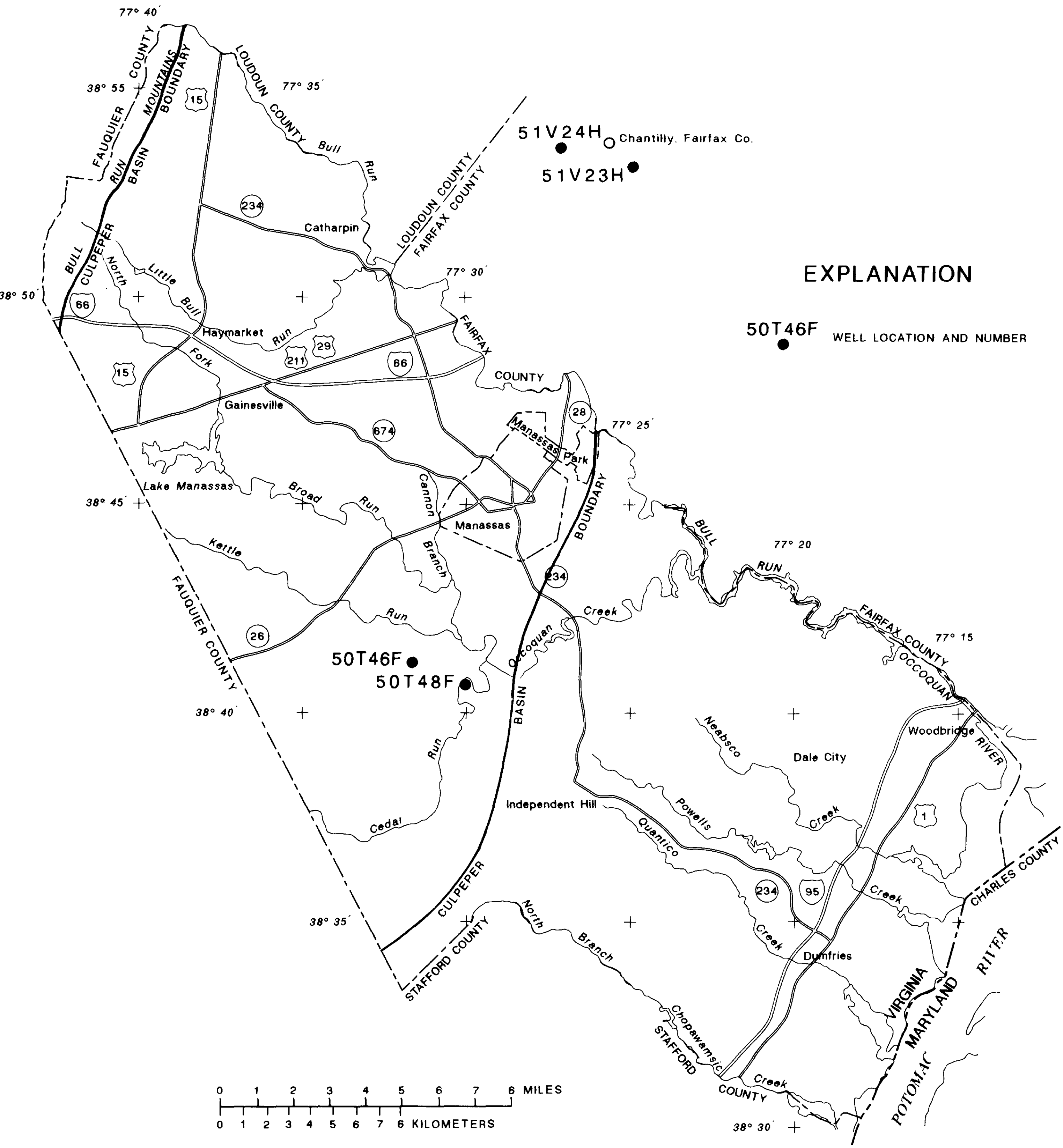


Figure 7.--Location of test wells 50T46F, 50T48F, 51V23H, and 51V24H.

Storage coefficients (measure of the capacity of an aquifer to store water) for the siltstone aquifers have been determined from aquifer tests conducted by Betz-Converse-Murdoch (1982) and Leggette, Brashears, and Graham (1980). These storage coefficients generally range from 0.00002 to 0.002 (dimensionless).

The siltstone aquifers of the Culpeper basin have a high potential for future ground-water use. Betz-Converse-Murdoch (1982, p. 36) selected locations for future supply-well sites in the siltstone of the Balls Bluff Siltstone. A combined estimate of 4.32 Mgal/d was predicted for these sites with an additional 0.86 Mgal/d from a well located in the siltstone aquifer of the Catharpin Creek Formation. Leggette, Brashears, and Graham (1980, p. 43) predicted that a well in Fairfax County could produce 1.0 Mgal/d in the siltstone of the Balls Bluff Siltstone.

Sandstones

Sandstones of the Poolesville Member of the Manassas Sandstone and of the Catharpin Creek Formation have good to very good water-bearing potential (Comer, 1976, p. 65). These sandstones are good aquifers because they have secondary permeability in the form of open, intersecting fractures and bedding-plane partings. Laczniak and Zenone (1985) stated that fractures constitute 5 to 10 percent of the total rock volume; however, weathering and dissolution along these fractures allows for increased storage and the movement of significant amounts of water.

Wells yields in the sandstones of the Manassas Sandstone, ranging from 4 to 735 gal/min, are generally higher than yields in the sandstones of the Catharpin Creek Formation, which range from 1.5 to 175 gal/min. The difference in yields probably reflects water-use practices rather than water-bearing potential.

Betz-Converse-Murdoch (1982, p. 27) determined that yields decrease with depth and concluded that wells in the sandstones should be terminated no deeper than 475 ft. In the sandstones of Fairfax County, Leggette, Brashears, and Graham (1980 p. 43) reached the same conclusions concerning decreasing yields with depth and proposed that wells should be terminated no deeper than 500 ft. However, the high-yielding wells in the Manassas Sandstone usually range in depth between 500 and 1,000 ft. The idea that high yields can be obtained at depths greater than the recommended termination depths for the siltstone aquifers may be true for the sandstone aquifers as well.

Declining yields over time have been documented in the Manassas area. The influx of silt, which decreased well efficiency, is probably the reason for decreasing yields.

Betz-Converse-Murdoch (1982) conducted an aquifer test on test well 50T46F in the sandstone of the Manassas Sandstone (fig. 7). Using the Jacob modification of the Theis nonequilibrium formula, a transmissivity of 2,874 ft^2/d was calculated. This transmissivity is an order of magnitude larger than the transmissivities calculated in well 51V23H for the Manassas Sandstone of Fairfax County near Chantilly (fig. 7), which averaged between 260 and 520 ft^2/d (Leggette, Brashears, and Graham, 1980, p. 10). Laczniak and Zenone (1985) estimated relative-directional transmissivities of 2,250 to 3,000 ft^2/d for their model of the Culpeper basin. Johnston and Larson (1979) used aquifer test results to determine that transmissivities of 500 to 1,000 ft^2/d are probable for the upper 1,000 ft of the sandstone section in Fairfax County. The transmissivity of the sandstones is moderately high, which reflects their very good water-bearing potential. These studies also indicate that transmissivities values are greater along lineaments.

Specific capacity for the sandstones ranges from 0.06 to 14.7 (gal/min)/ft. Leggette, Brashears, and Graham (1980, p. 6) noted that the sandstones are similar to the siltstones in that an increase in pumping rates can decrease the specific capacity of a well.

Storage coefficients of the sandstone aquifers have been determined from aquifer tests conducted by Betz-Converse-Murdoch (1982) and Leggette, Brashears, and Graham (1980). These storage coefficients generally range from 0.00002 to 0.0002.

The sandstone aquifers of the Culpeper basin have a high potential for future ground-water use. Betz-Converse-Murdoch (1982, p. 36) selected locations for future supply-well sites in the sandstone of the Manassas Sandstone. A combined estimate of 1.08 Mgal/d was predicted for these sites. Leggette, Brashears, and Graham (1980, p. 43) predicted that a well in Fairfax County could produce 0.5 Mgal/d from the sandstone of the Poolesville Member of the Manassas Sandstone.

Quartz-pebble conglomerates

Quartz-pebble conglomerates are present in the Reston Member of the Manassas Sandstone, the Goose Creek Member of the Catharpin Creek Formation, and the Millbrook Quarry Member of the Waterall Formation. The quartz-pebble conglomerates have moderate water-bearing potential because of widely spaced fractures and bedding-plane partings associated with their thick to massive bedding. Dissolution of calcite cement can enlarge the fractures and partings present in the Millbrook Quarry Member.

Well data are scarce for the quartz-pebble conglomerate of the Manassas Sandstone. Wells inventoried by the U.S. Geological Survey are finished in the quartz-pebble conglomerates of the Goose Creek Member of the Catharpin Creek Formation and the Millbrook Quarry Member of the Waterfall Formation. Yields generally range from 3 to 75 gal/min and wells depths range from 120 to 830 ft. Values for transmissivity, specific capacity, and storage coefficient have not been determined for the quartz-pebble conglomerate aquifers. Estimated values of relative-directional transmissivities simulated for the conglomerates by Laczniak and Zenone (1985) are the only hydraulic properties available. Laczniak and Zenone (1985) determined that the transmissivities of the quartz-pebble conglomerates range from 1,875 to 2,500 ft^2/d.

The potential of future ground-water use is unknown for the quartz-pebble conglomerates because of the lack of well and aquifer-test data. The possibility of high-yielding wells may be greater near the border faults. Wells that intersect the shear zones associated with the border faults possibly could produce large amounts of water because of significant fracturing, which would increase permeabilities.

Basalts

Significant yields have not been reported from the Mount Zion Church Basalt, the Hickory Grove Basalt, and the Sander Basalt, which are interlayered with the sedimentary rocks in the western part of the basin. However, significant yields may be possible in places where the basalts have closely spaced columnar joints and fractures. The close spacing of these openings indicate favorable conditions for the storage and transmission of significant amounts of water.

One 309-foot-deep well in a basalt aquifer yielded 3 gal/min. Some of the deeper wells in the aquifers of the western part of the basin may have penetrated the basalt flows because of the steep dips that are present in the western margins of the basin. However, drillers' logs from this area tend to be generalized and do not indicate the presence of basalts.

Hydraulic properties have not been determined for the basalts because of the lack of data. Laczniak and Zenone (1985) estimated relative-directional transmissivities that range from 1,890 to 2,520 ft^2/d. Basalts are estimated to have higher transmissivities than those of the diabase and thermally metamorphosed rocks because of the close spacing of the columnar joints.

The basalt aquifers of the Culpeper basin in Prince William County have an unknown potential for future use. The potential is present because of the closely spaced columnar joints or fractures. Further study is needed to define the hydraulic properties of the basalt aquifers and the interlayered sedimentary rocks.

Diabase

Diabase is considered one of the poorest aquifers in the Culpeper basin. Cady (1938, p. 58) and Comer (1976, p. 39) reported that dry wells are common and diabase areas should be avoided if possible. The water-bearing potential of the diabase is poor because of their platy to massive nature, random fracture orientations, and wide spacing between fractures.

Well yields range from 0.75 to 100 gal/min. Yields are commonly low and well depths range from 105 to 590 ft. Cady (1938, p. 58) stated that yields tend to decrease with depth; therefore, if a sufficient amount of water is not encountered in the first 100 ft, the well will probably be a poor producer. Comer (1976, p. 39) recommended that wells in the diabase be terminated at 350 ft. Johnston (1960, p. 2) reported that a 1,000-foot-deep exploratory well was drilled in Herndon, Virginia. The entire well penetrated diabase and had a low yield. Johnston (1960, p. 2) noted that the diabase became softer and coarser with depth, which may have indicated that the well was nearing a lithologic contact.

Values of hydraulic properties of the diabase are sparse. Relative-directional transmissivities, which were estimated for a flow model of the Culpeper basin, range from 60 to 80 ft^2/d (Laczniak and Zenone, 1985). Sufficient data was available for one well to calculate a specific capacity. The yield of this well was 5 gal/min and the specific capacity was 1.25 (gal/min)/ft.

Future use of the diabase aquifer is highly unlikely because of its poor water-bearing potential. However, some areas may produce significant quantities of ground water. The authors have witnessed the drilling of a series of geothermal holes in the diabase just southeast of Gainesville in an area intersected by a lineament determined from Landsat imagery to be perpendicular to the dominant northeasterly lineament trend. These holes were approximately 300 ft deep and yielded approximately 150 gal/min. Domestic, industrial and public-supply wells in this area had previously reported yields from 30 to 100 gal/min. Because of its poor water-bearing potential, the diabase usually restricts movement of ground water. Cross-strike lineaments, however, may provide a pathway or conduit for movement of ground water through the diabase. Extensive geohydrologic study of the diabase and lineaments might provide a clearer understanding of ground-water flow and availability of supply for the future.

Thermally metamorphosed rocks

Thermally metamorphosed rocks tend to be relatively impermeable and, therefore, are poor aquifers. They usually are thick bedded and lack bedding-plane partings that might increase permeability. Watson (1907) and Edmundson (1938) reported that some fractures in these metamorphosed rocks are filled with mineral deposits, which also would reduce permeability. Laczniak and Zenone (1985) stated that the metamorphic rocks are the poorest aquifers in the Culpeper basin, and dry holes are common.

Yields from the thermally metamorphosed siltstones range from 5 to 60 gal/min whereas yields from the metamorphosed sandstones are from 3.5 to 10 gal/min. This difference in yield may reflect bias in the data distribution or could indicate a possible relation between the yield of metamorphic rocks and their parent-sedimentary rocks. Geohydrologic studies in the future may confirm this relation. Well depths range from 100 to 607 ft in the metamorphic rocks.

Hydraulic properties have not been calculated for the thermally metamorphosed rocks of the Culpeper basin. Laczniak and Zenone (1985) provided estimates of relative-directional transmissivities for their flow

model. These transmissivity values of the thermally metamorphic rocks are identical to those of the diabase, ranging from 60 and 80 ft^2/d. Values of specific capacity and storage coefficient have not been calculated because of the sparsity of data.

Future use of the thermally metamorphosed rock aquifers is uncertain because these rocks are adjacent to the diabase but locally may have significant amounts of ground water in the cross-strike lineaments previously mentioned. Further geohydrologic studies of the metamorphic rocks are needed to determine the relation between yield and parent-rock type, and the availability of ground water in the cross-strike lineaments.

Ground-Water Flow System

Concepts and assumptions

Ground-water flow in the Culpeper basin is complicated because of the presence of various rock types with different fracture and bedding-plane characteristics. A conceptualization of the ground-water flow system for the study area is shown on figure 8. In general, ground water flows from the upland recharge areas along fractures commonly associated with lineaments to the lowlands or valleys where ground water discharges to the surface.

The following conditions are assumed for the ground-water flow system of the Culpeper basin in Prince William County: (1) Ground water is unconfined, (2) areal variations in water levels are similar to the topography, (3) gaining streams with water-table altitudes at the streams equal to the elevations of the streams, and (4) flow is controlled by fractures and thus lineaments indicate the principle flow paths. Nutter (1975, p. 11) stated that the stream network in the early Mesozoic strata of Maryland is controlled by lineaments, which also is true in the Culpeper basin of Prince William County. Laczniak and Zenone (1985) believe that the ground-water flow system of the Culpeper basin is actually partially confined and has water-table conditions present in some areas. Because overburden is relatively thin, ground-water storage in the overburden is minimal and the bedrock aquifers are generally not confined. The delineation of gaining and losing reaches of streams, and of partially confined areas was beyond the scope of this investigation.

Water levels in zones penetrated by a well can differ and zones can be confined or unconfined. Therefore, the water levels monitored in such a well reflect the combined influences of the different zones. Analysis of the water-level data indicated that the potentiometric surface generally follows the topography, which is relatively flat across the basin. This relation between topography and water-level altitude is usually indicative of unconfined or water-table conditions.

Directions of flow

The term *potentiometric surface* generally refers to a water-level surface in a single confined aquifer that provides an indication of ground-water flow. However, because of extensive fracturing and interconnection of the various rock types, potentiometric surface in this report is used to describe the water-level surface throughout the ground-water flow system of the Culpeper basin in Prince William County. Variable zones of transmissivity and permeability are dependent on lithology and fracture characteristics. The potentiometric surface is not smooth and continuous everywhere but has isolated-high areas that reflect topographic effects, recharge areas, degree of interconnection of fractures, number and size of ground-water conduits, permeability variations, and the presence of pumped wells. A potentiometric-surface map was drawn from measurements made in 97 wells in September 1987 and from elevations of major streams and tributaries from 7.5-min quadrangles (pl. 4). Water levels during September are generally low; therefore, future users of the potentiometric-surface map need to take this fact into consideration. Maps of the geology, lineaments, topography, streams, and thickness of overburden were used to evaluate the water-level data and construct contours of the potentiometric surface.

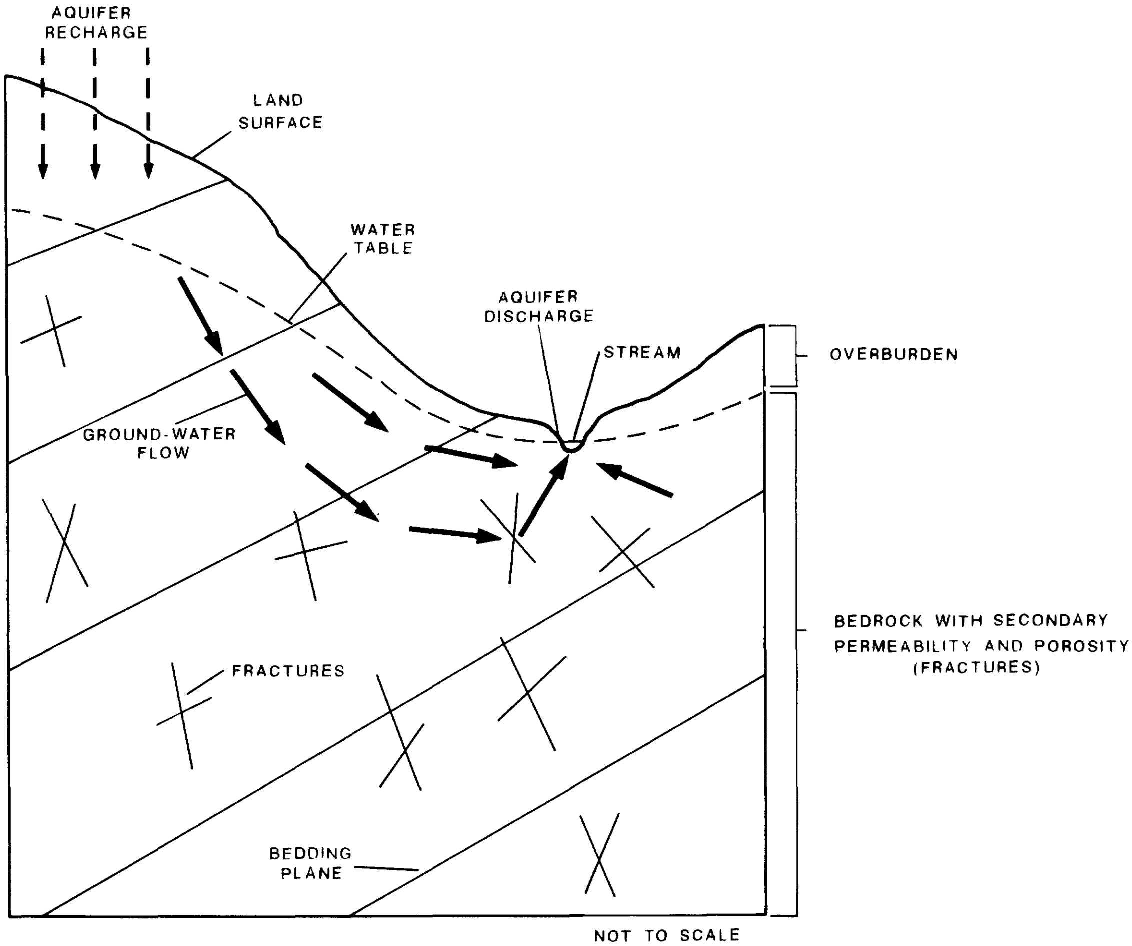


Figure 8.--Schematic diagram showing the conceptualized ground-water flow system in the Culpeper basin of Prince William County (modified from Laczniak and Zenone, 1985, fig. 2).

Flow directions are perpendicular to equipotential lines in ground-water flow systems that are isotropic and homogeneous. The flow system of the Culpeper basin, however, is anisotropic and heterogeneous. In fractured-rock aquifers, such as this one, the fractures act as conduits for ground-water flow. Therefore, gradients are interpreted from the potentiometric surface map; but horizontal flow directions or pathways for ground-water flow are derived from an evaluation of the lineament map.

The potentiometric-surface map is similar to the map of steady-state water levels (under prepumping conditions) computed by the calibrated model of Laczniak and Zenone (1985) (fig. 9); the only significant differences are the cones of depressions in the Manassas-Manassas Park area and the higher water levels and steep gradients present in the western margins of the basin.

The two-dimensional finite-difference model used by Laczniak and Zenone (1985) treated the flow system as confined. However, designation of the flow system as either confined or unconfined may not be important on a basin-wide scale. It is likely that the flow system may be locally confined or unconfined in a given area. Confined aquifers have storage coefficients that range from 0.00005 to 0.005 (Freeze and Cherry, 1979, p. 60). Although, storage coefficients calculated for the Culpeper basin aquifers fall within this range; the combined influence of the confined and unconfined zones may affect the values of storage coefficients.

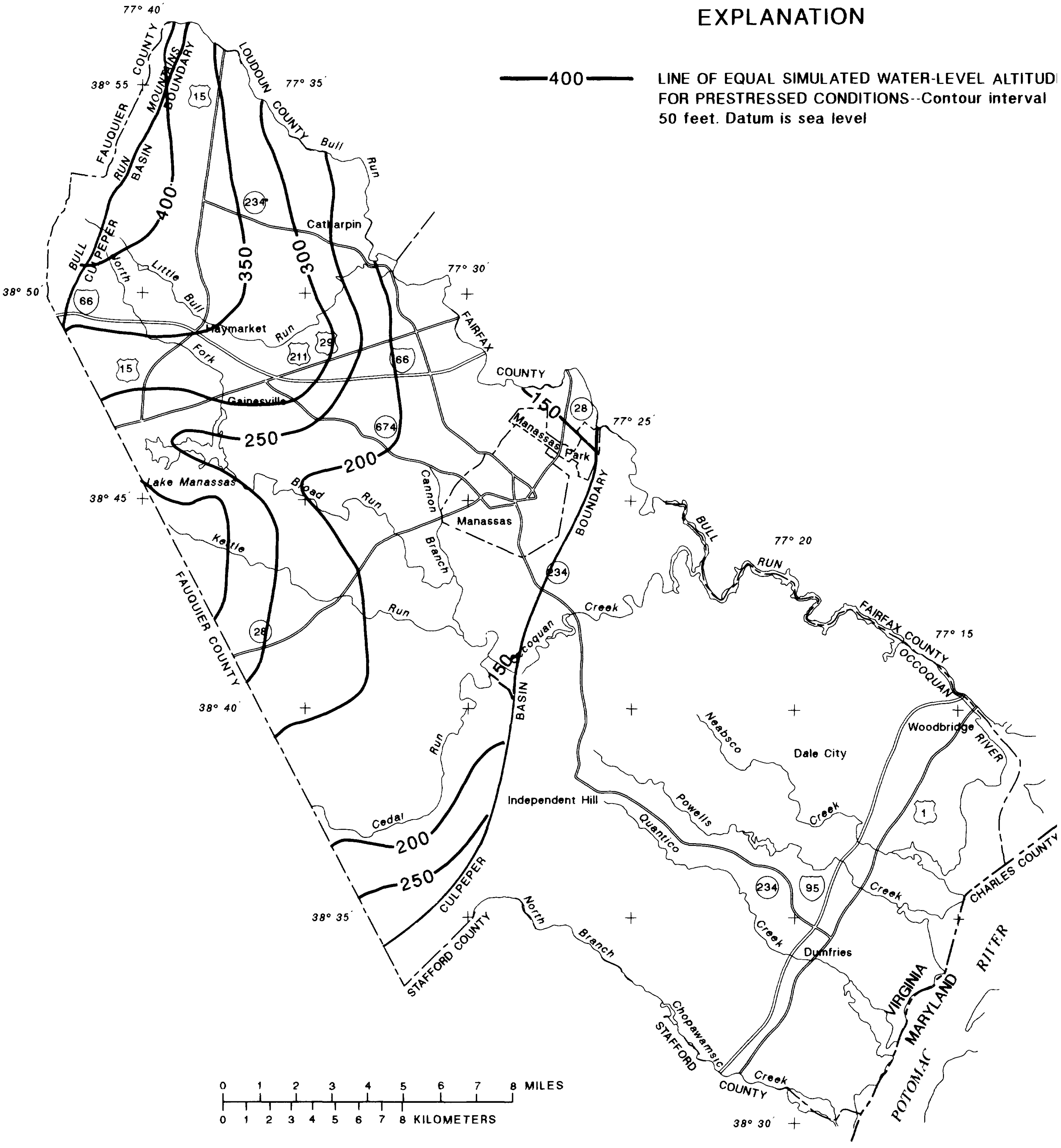


Figure 9.--Simulated steady-state water-level altitudes for prestressed conditions in the Culpeper basin of Prince William County (modified from Laczniak and Zenone, 1985, fig.5).

Precipitation is the dominant means of recharge to aquifers throughout most of the Culpeper basin. Recharge to aquifers occurs by infiltration through the unsaturated zone to the water table of the Culpeper basin except in the vicinity of streams where ground water discharges. Recharge can increase as a result of local geologic or hydrologic conditions. Most of the ground water in the Culpeper basin flows from upland recharge areas along fractures associated with lineaments to the lowland or valley discharge areas. Potentiometric levels are high and flow gradients are steep in the western margin at Bull Run Mountain on plate 4. These steep flow gradients are a reflection of the relief of approximately 500 ft between Bull Run Mountain and the adjacent Culpeper basin. Ground water probably moves along fractures and within the shear zone associated with the western-border fault from the mountain area toward major streams in the basin.

Relief of approximately 50 to 100 ft exists between the Culpeper basin and the Piedmont Uplands to the east. Potentiometric gradients of the eastern margin are not as steep as those of the western margin. The smaller potentiometric gradients of the eastern margin are probably related to the low relief and comparatively high transmissivities of the Manassas Sandstone. The potentiometric surface is relatively flat across most of the rest of the basin. Isolated ground-water highs indicate possible areas of increased local recharge.

Regional ground-water flow in the Culpeper basin of Prince William County is generally towards the east as indicated on plate 4. This poses the same interesting question concerning the diabase and thermally metamorphosed rocks that was previously raised. The water-bearing potentials, hydraulic properties, and effective ground-water recharge rates indicate that these rocks are poor aquifers. Therefore, how does the regional ground-water flow pass through the "ground-water dams" created by the diabase and metamorphic rocks. As stated earlier, the authors believe that the cross-strike lineaments provide the passageway for the regional flow through these rocks. Stream base-flow measurements might be made on streams that follow these lineaments. Flow in the diabase may have a vertical (downward) component, which could explain the low base flows. Base flows could possibly increase to the east in the siltstones and sandstones because of the contribution of ground water from the diabase and thermally metamorphosed rocks. Prediction of contaminant migration could be affected by this anomaly.

Effective recharge

Effective-recharge (ground-water recharge minus evapotranspiration) rates may be estimated by using stream base flows (ground-water discharges to streams) or low flows, assuming that ground-water divides correspond to those of a drainage basin. Previous studies have indicated that effective-recharge rates for sedimentary rocks are higher than those for igneous and metamorphic rocks (table 7). For example, Trainer and Watkins (1975, p. 42) used hydrograph-separation techniques and the 52-percentile discharge on streamflow-duration curves to estimate base flows for small stream basins located in the early Mesozoic basins of Pennsylvania, Maryland, and Virginia. Effective-recharge rates were higher in the basins underlain by siltstones and sandstones, ranging from 3.26 to 7.73 in/yr (inches per year). Basins underlain by diabase had relatively low effective-recharge rates that ranged from 1.76 to 2.44 in/yr.

Laczniak and Zenone (1985) reported similar findings using the 68-percentile discharge on the streamflow-duration curves. Calibrated values for their two-dimensional, finite-difference model indicated that the effective-recharge rates to the quartz-pebble conglomerate, sandstone, and siltstone aquifers were larger than those of the diabase and thermally metamorphosed rocks.

Lynch and others (1987) used frequency-curve analyses to estimate average discharges for 7-day, 2-year and 7-day, 10-year low flows. Base-flow discharges in basins underlain by sedimentary rocks ranged from 0 to 0.03 $(ft^3/s)/mi^2$ (cubic foot per second per square mile), which is equivalent to effective-recharge rates of 0 to 0.40 in/yr. Base-flow discharges in basins underlain by igneous and metamorphic rocks reflect lower effective-recharge rates, 0 to 0.014 in/yr.

Table 7.–*Effective ground-water recharge rates for rocks of the Culpeper basin in Prince William County*

[Recharge rates are in inches per year: – –, indicates no values have been determined]

Lithology	Trainer and Watkins (1975) [1]	Laczniak and Zenone (1985) [2]	Lynch and others (1987) [3]	Formation
Quartz-pebble conglomerate	– –	3.91	0.00 to 0.40	Eastern margin–Reston Member of the Manassas Sandstone; Western margin–Goose Creek Member of the Catharpin Creek Formation and Millbrook Quarry Member of the Waterfall Formation
Sandstone	7.73	4.18	0.00 to 0.40	East–Poolesville Member of the Manassas Sandstone; West–Catharpin Creek Formation
Siltstone	3.26 to 5.97	4.84	0.00 to 0.40	East–Balls Bluff Siltstone; West–Catharpin Creek, Midland, Turkey Run, and Waterfall Formations
Diabase	1.76 to 2.44	0.17	0.000 to 0.014	– –
Thermally metamorphosed rocks	– –	0.17	0.000 to 0.014	– –
Basalt	– –	3.93	0.000 to 0.014	Mount Zion Church Basalt, Hickory Grove Basalt, and Sander Basalt

[1] Estimation of mean-annual stream baseflows from hydrograph separation techniques using the 52-percentile discharge on streamflow-duration curves.
[2] Estimation of mean-annual stream baseflows from hydrograph separation techniques using the 68-percentile discharge on streamflow-duration curves.
[3] Estimation of average discharges for 7-day, 2-year and 7-day, 10-year low flows from frequency-curve analyses.

Other studies have estimated the total effective recharge for the entire Culpeper basin. Leggette, Brashears, and Graham (1980, p. 4) used base-flow calculations to estimate an effective recharge of 3.18 in/yr for the entire Culpeper basin of Fairfax County. Laczniak and Zenone (1985) initially assumed an effective-recharge rate of 2.70 in/yr for the entire Culpeper basin from streamflow-duration curves. The overall effective-recharge rate on the basis of their flow simulation was 2.60 in/yr for the entire Culpeper basin.

Ground-water discharge

Natural discharge areas in the Culpeper basin generally are located in the lowlands or valleys. Most of the major streams in the Culpeper basin are discharge areas for the ground-water flow system. The amount of ground-water discharge is directly related to the topography, drainage area, season, lithology, and geologic structures of the area drained. Springs are not abundant in most of the basin because of the relatively flat

topography. Cady (1938, p. 125) reported that perennial springs are abundant in the western margins of the basin because of the greater relief.

Laczniak and Zenone (1985) stated that during stressed conditions, such as droughts, these large streams may reverse from a discharge to a recharge area and contribute significant amounts of water to the ground-water flow system. This reversal is made possible by the extensive fracturing of the sedimentary rocks and relatively thin overburden layer, which is absent in some of the stream beds.

Ground-water also discharges to pumped wells in the Culpeper basin of Prince William County. Two cones of depression caused by pumping have developed in the potentiometric surface in the Manassas-Manassas Park area (pl. 4). Clapp (1911, p. 94) reported that the first public-supply well for this area was drilled in 1905. Numerous supply wells have been drilled since that time and subsequent pumpage has created these cones of depression. The cones of depression expanded outward in all directions as pumping increased. When a recharge area or hydrologic boundary was encountered such as a major stream, the cones ceased to expand in that direction, but continued to expand in other directions until the amount of ground water captured was equal to the amount being pumped. The cones were thus shaped by the drainage patterns which are in turn controlled by major trends in bedding and fracture systems.

Cady (1938, p. 125) stated that water levels in the Manassas-Manassas Park area ranged from 50 to as much as 100 ft below land surface. The cones of depression are not areally extensive relative to their depth because of the relatively low transmissivity of the rocks. Nutter (1975, p. 10) stated that, in fractured-rock flow systems, cones of depressions will be elongated along the direction of the strike of the bedding or along major fracture sets (lineaments). This elongation of the cones of depressions is evident in the Manassas-Manassas Park area.

Water-level fluctuations

Seasonal fluctuations of the potentiometric surface may vary depending on location within the Culpeper basin of Prince William County. The location of wells in the study area that have continual water-level record are shown on figure 10. The U.S. Geological Survey measures water levels in observation wells 49U1 and 49V1, which are located in stream valleys in the western margin of the basin. Seasonal fluctations of the potentiometric surface in the western margin generally range from 4 to 5 ft (fig. 11). Long-term water-level declines are not apparent from the hydrographs; because, pumpage in this area is for domestic use and stress to the system is negligible. Hydrographs for these wells during the 1980-81 drought show that water-level fluctuations are nearly normal for this area and the drought had little effect on the aquifers (fig. 12).

Monitor wells 51U112 and 51U116 (fig. 10) are maintained by the International Business Machine, Incorporated at their facility near Manassas. These monitor wells are located to the southwest of the cones of depression in the Manassas-Manassas Park area. Seasonal fluctuations range from 20 to 30 ft, and are probably in response to pumpage patterns in the Manassas-Manassas Park area as well as to natural hydrologic conditions (fig. 13).

AMBIENT GROUND-WATER QUALITY

Knowledge of the ambient ground-water quality is needed to provide a baseline for evaluating the extent and degree of existing contamination and the effects of development on future trends in water quality. The chemical composition of precipitation and of the overburden and bedrock through which the water moves primarily determines the quality of the ground water. Water-quality data for wells completed in the Culpeper basin of Prince William County are limited. This report presents information collected for a previous Culpeper

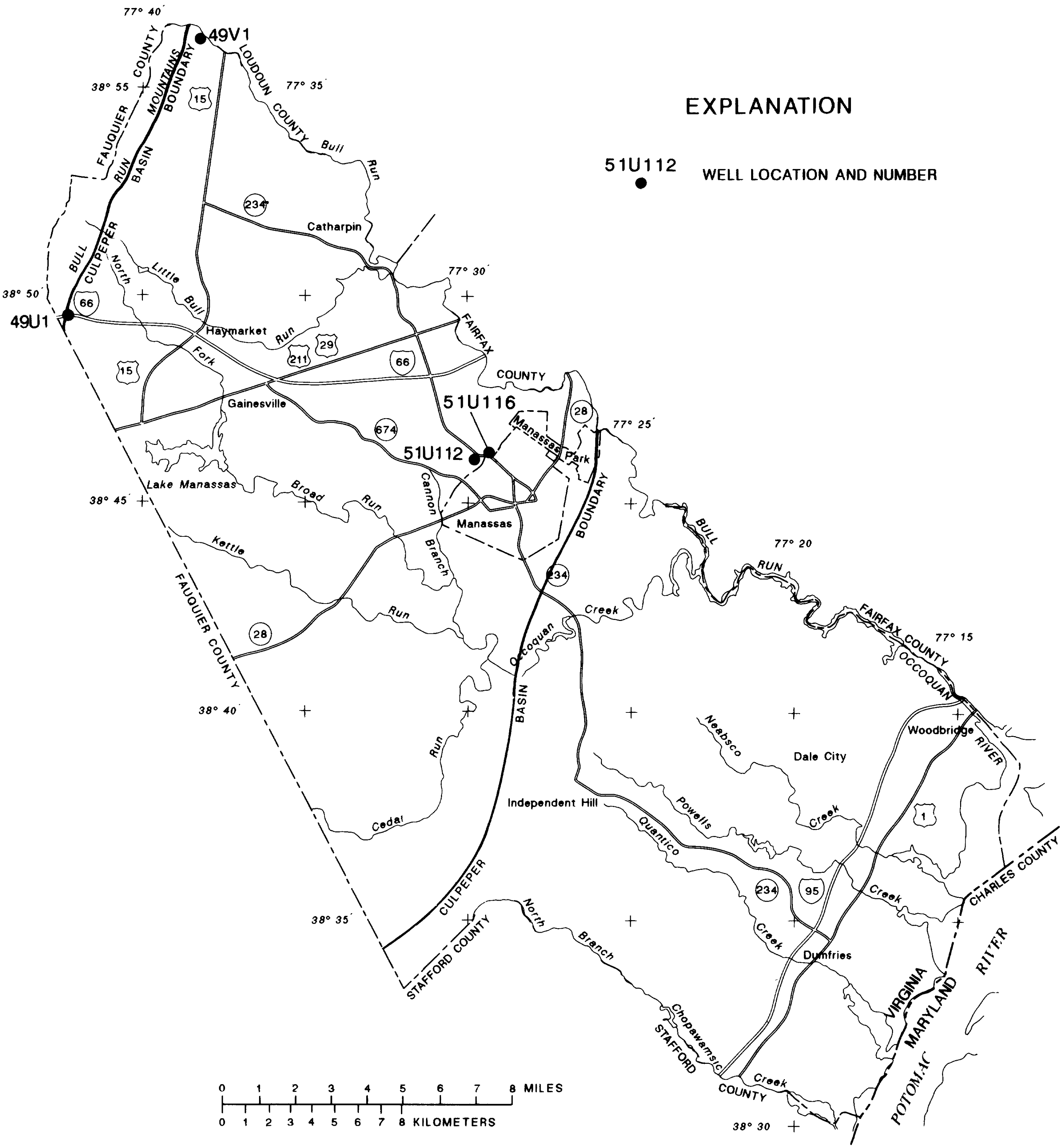


Figure 10.--Location of wells 49U1, 49V1, 51U112, and 51U116 in the Culpeper basin of Prince William County.

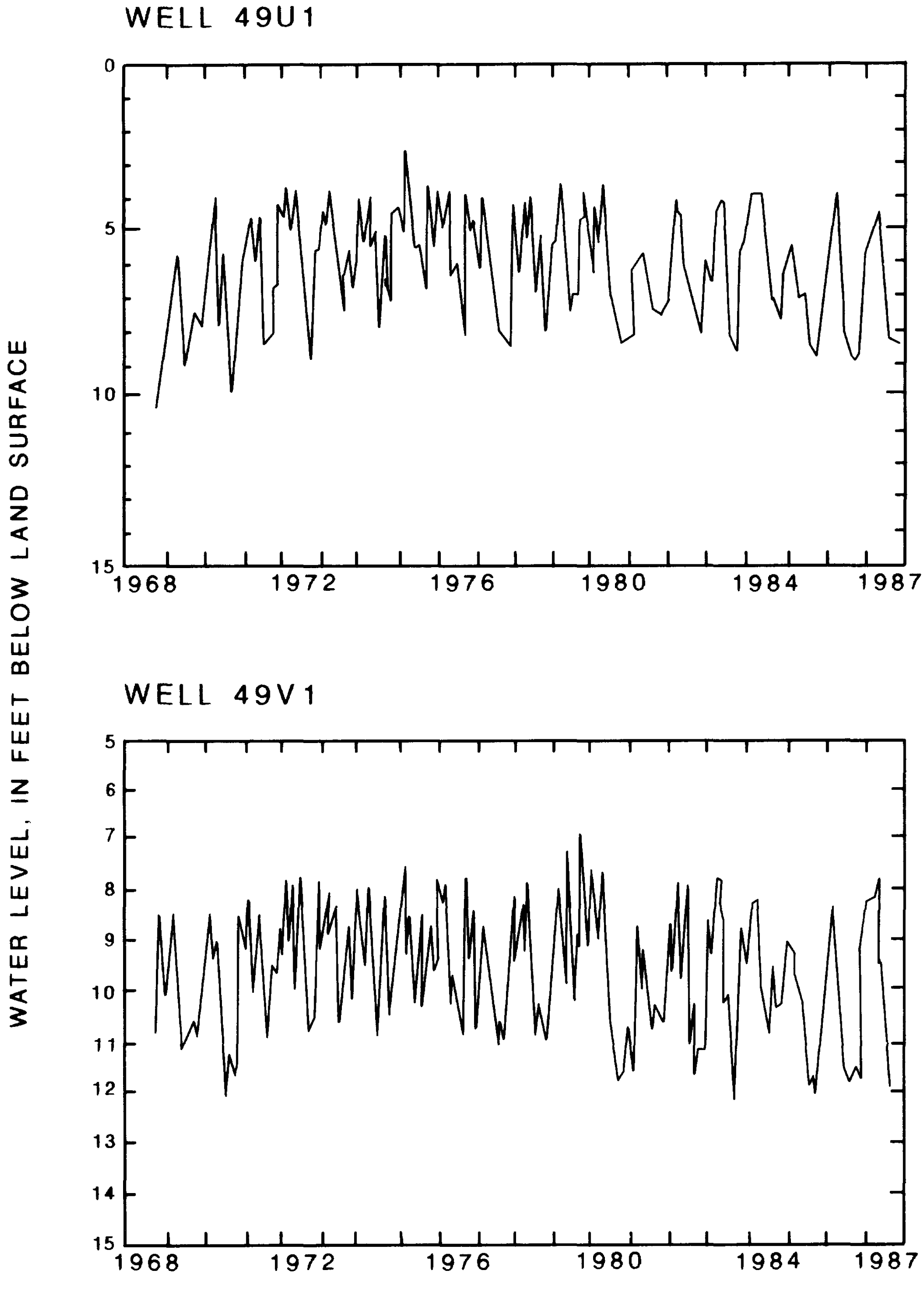


Figure 11.--Hydrographs for observation wells 49U1 and 49V1 from 1968 through 1987.

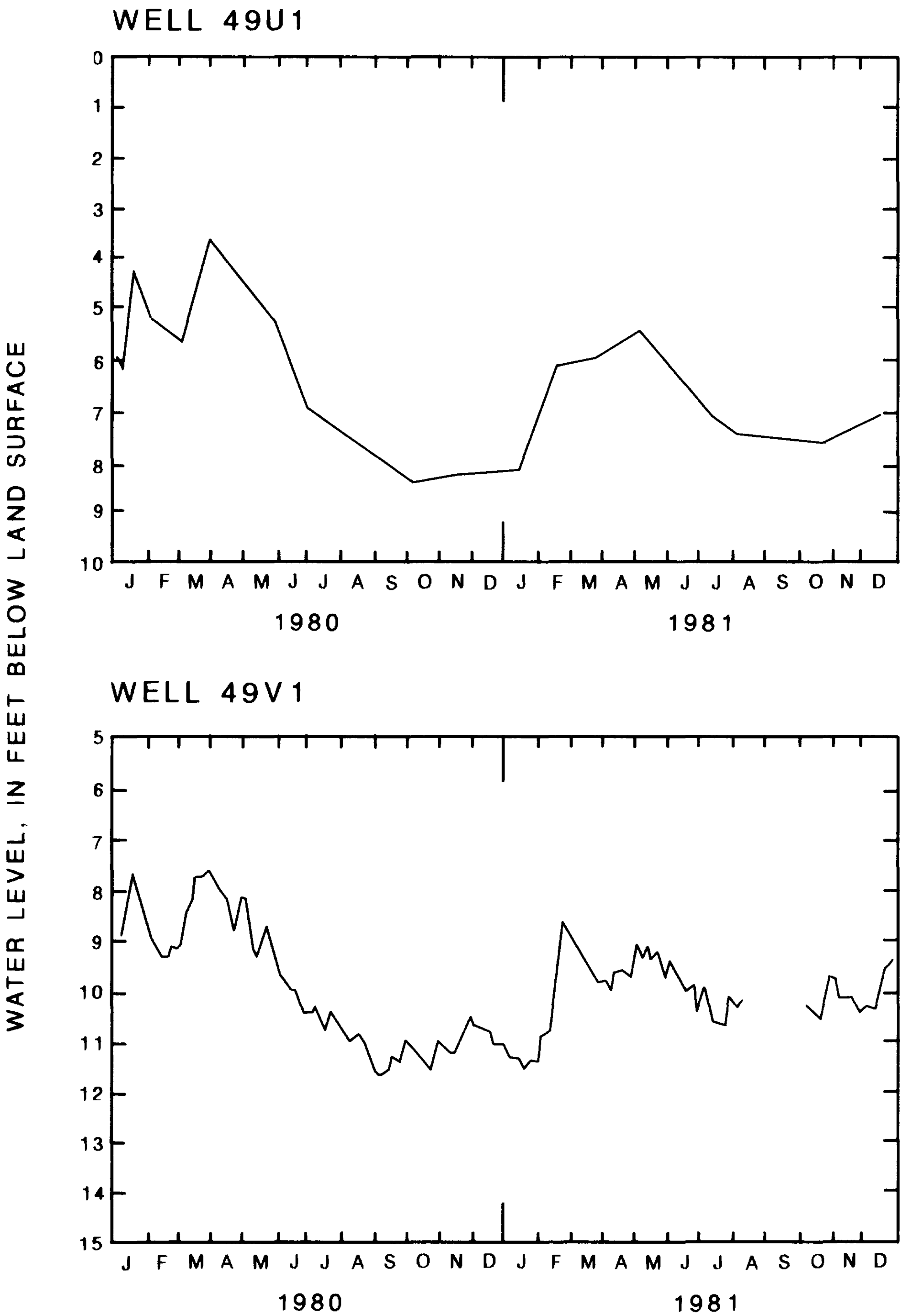


Figure 12.--Hydrographs for observation wells 49U1 and 49V1 from 1980 through 1981 showing the effect of the 1980-81 drought.

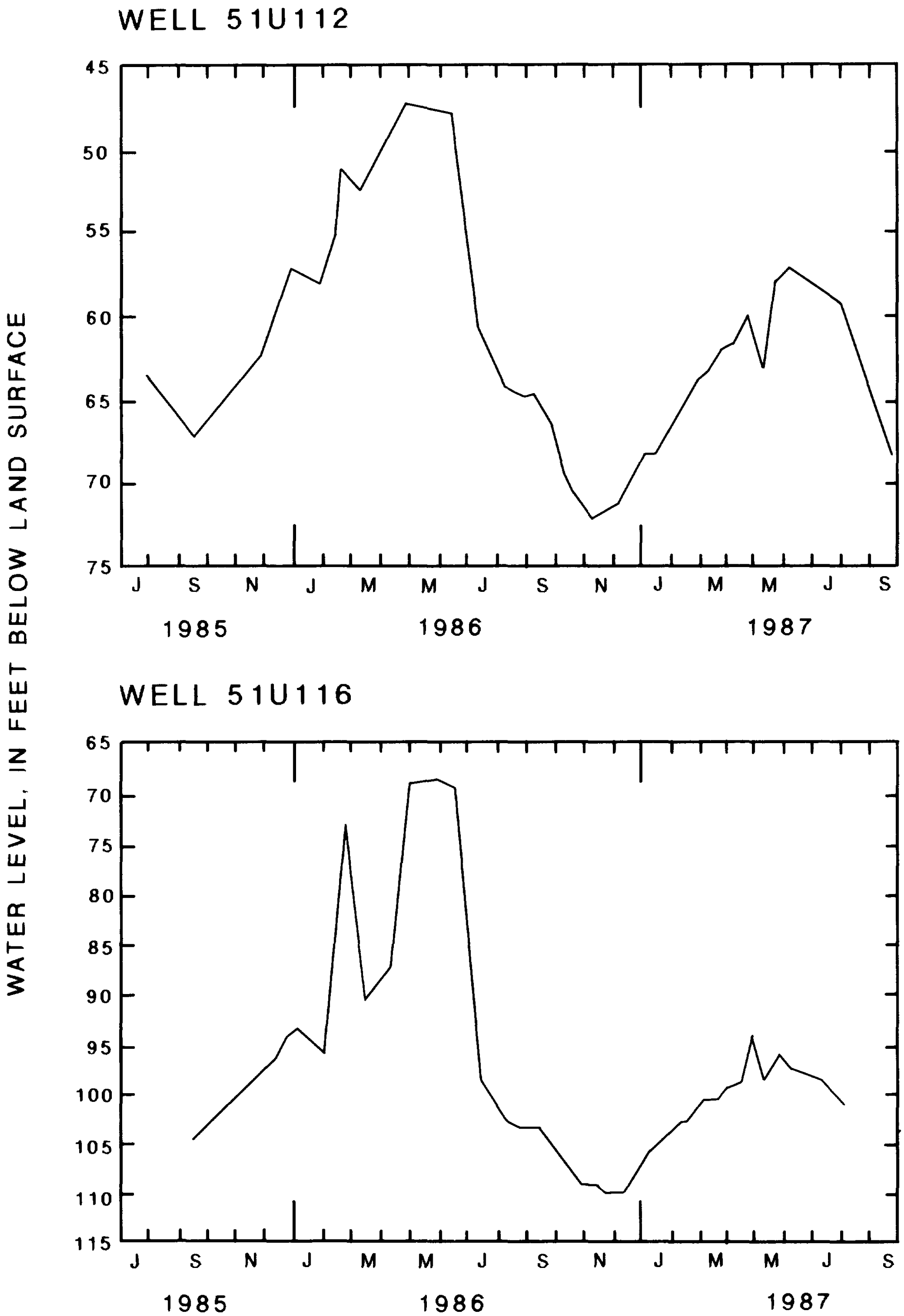


Figure 13.--Hydrographs for monitor wells 51U112 and 51U116 from 1985 through 1987 (Data provided by International Business Machines Corporation).

basin study (Posner and Zenone, 1983) to describe the ambient water quality of the Culpeper basin of Prince William County.

Ground water in the Culpeper basin is predominantly a calcium-magnesium-bicarbonate type (fig. 14). A few areas containing calcium-sulfate type water have been identified.

Concentrations of dissolved solids are a measure of the amount of dissolved mineral matter in water. A high concentration of dissolved minerals is undesirable for many uses and can cause physiological effects as well as corrosion of pipes. Concentrations of dissolved solids greater than 500 mg/L (milligrams per liter) are considered to be high (Posner and Zenone, 1983). The concentration of dissolved solids in the ground water is a concern in the Culpeper basin primarily in areas underlain by the siltstones or sandstones. Water from wells at depths greater than 600 ft in the siltstone commonly show high concentrations of dissolved solids (fig. 15).

Hardness is the result of dissolved divalent cations, primarily calcium and magnesium ions in water, and is expressed as the equivalent concentration of calcium carbonate. Hard water has no known harmful effects on human health; however, it causes the organic molecules in soap to form curds and increases encrustation of pipes, water fixtures, and utensils. The ground water from the Culpeper basin is generally hard with concentrations greater than 120 mg/L as $CaCO_3$ (Hem, 1985, p. 159). High hardness concentrations in water from sedimentary rocks are a result of the dissolution of calcite. Cady (1938, p. 59) reported that the ground water in the diabase also is hard, with concentrations known to be as high as 350 mg/L.

High sulfate concentrations often are associated with high hardness concentrations and high concentrations of dissolved solids. High sulfate concentrations can have a laxative effect on new users and can impart a bitter taste to the water. Gypsum ($CaSO_4 2H_2O$) and pyrite (FeS_2), which are source minerals for sulfate, are present in the siltstones of the Culpeper basin. Highly mineralized water with sulfate also is present near the thermally altered zones that surround the diabase intrusions. Wells at depth can yield water water with elevated sulfate and dissolved solids concentrations because of slow ground-water circulation and long residence times.

Elevated concentrations of other constituents are possibly of local concern, but are not a basin-wide problem. Nitrate, iron, and trace metals are present; however, concentrations rarely exceed the recommended drinking-water standards and criteria established by the U.S. Environmental Protection Agency (1986a, b).

OCCURRENCE AND DISTRIBUTION OF VOLATILE ORGANIC COMPOUNDS

Nature of Volatile Organic Compounds

Volatile organic compounds have a variety of uses in today's society. Volatile organic compounds, such as tetrachloroethylene (PCE), trichloroethylene (TCE), and 1,1,1-trichloroethane (TCA) primarily are used as degreasing solvents. Volatile organic compounds commonly are used in food and drycleaning processes and are found in coatings, dyes, lacquers, paint strippers, gasoline, and aviation fuels. Household-cleaning agents contain a variety of volatile organic compounds. Moore and Ramamoorthy (1984) state that production of these compounds in the United States has increased over the past 20 years.

Volatile organic compounds are composed of aromatic and halogenated aliphatic hydrocarbons. The molecular formulae and maximum contaminant levels of some of the compounds identified in ground water of the Culpeper basin in Prince William County are shown on figure 16. Those volatile organic compounds containing chlorine in their chemical structures are believed to be carcinogenic (Jackson and others, 1985, p. 18). Volatile organic compounds are characterized by high vapor pressures and solubility in water. Chiou (1981) states that volatile organic compounds do not absorb or adsorb to soils because of the presence of highly polar

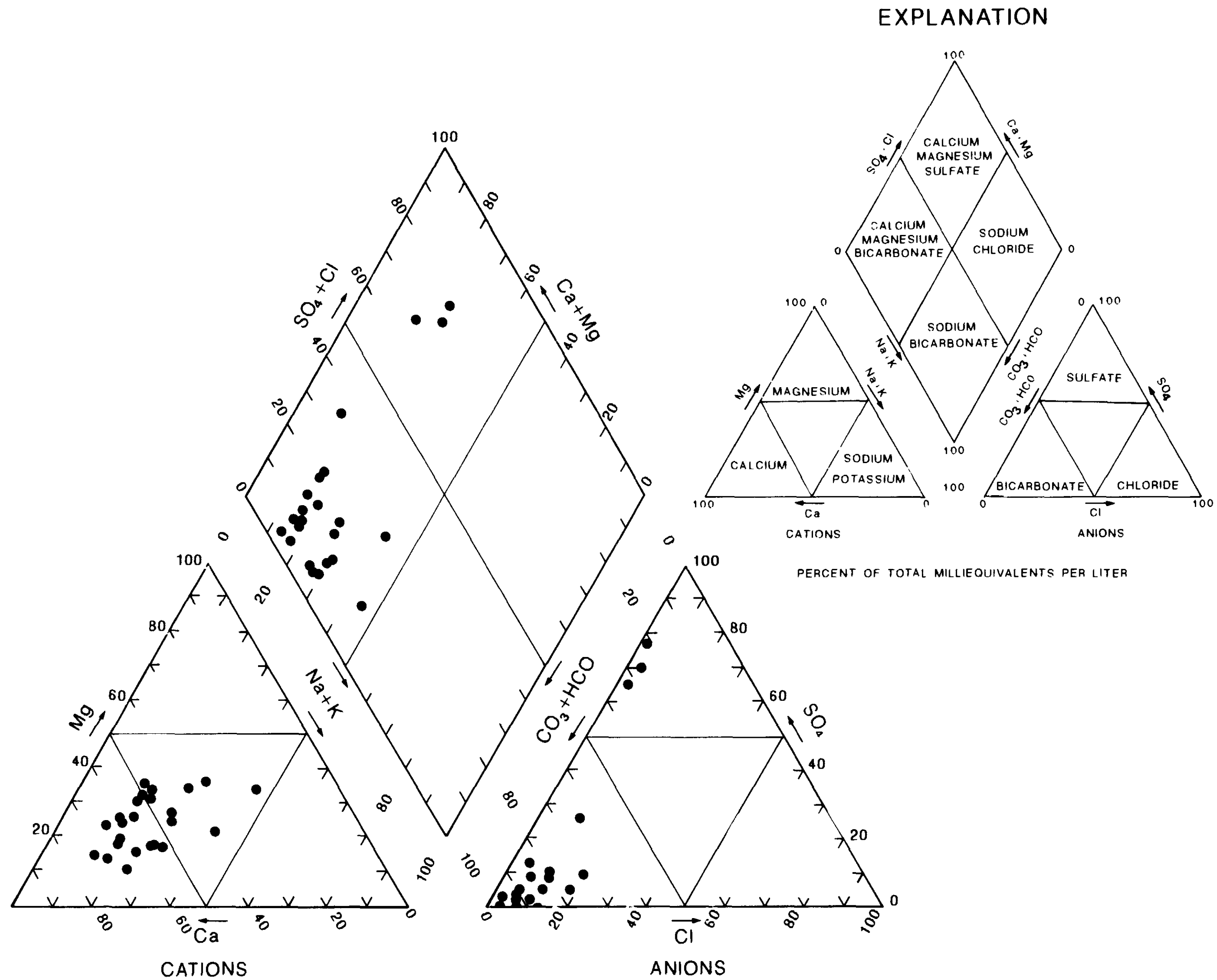


Figure 14.--Ground-water quality in the Culpeper basin of Prince William County.

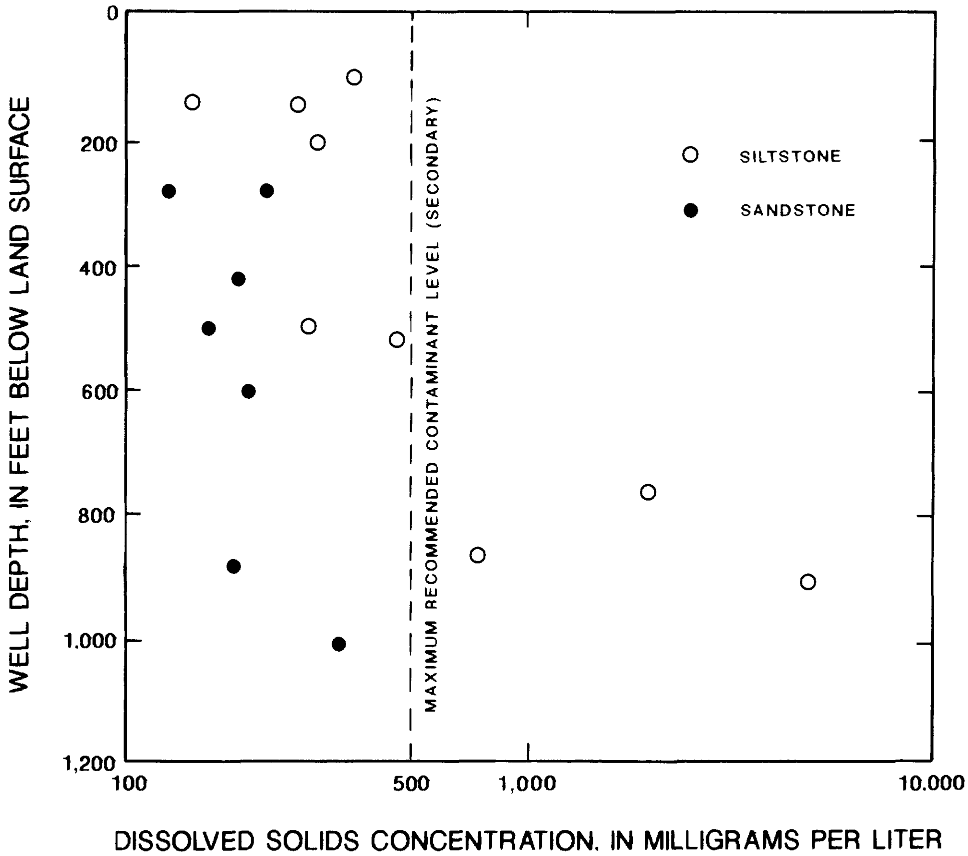


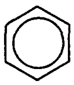
Figure 15.--Relation between well depth and concentrations of dissolved solids in sandstone and siltstone in the Culpeper basin (modified from Powel and Abe, 1985, fig. 18).

polymers of large molar volume in the organic matter of soils. Therefore, volatile organic compounds prefer the absorption of water rather than retention in the soil horizon.

Chemical, biological, and physical processes affect the composition and migration of volatile organic compounds in ground water. Hydrolysis, the chemical reaction of a compound with hydrogen and oxygen in the water molecule, can change the composition of a volatile organic compound. Biodegradation is the metabolic transformation of compounds by microorganisms that are dependent upon ground-water temperature, redox conditions, and nutrient availability (Champ and others, 1979). Dispersion, diffusion, advection, and sorption are physical processes that may alter contaminant concentrations and impede or accelerate contaminant migration (Cherry and others, 1984, p. 55). Anderson (1984, p. 43) states that contaminant migration can be retarded by the diffusion of contaminants from fractures into the rock matrix. However, Anderson also states that dispersion along fractures can accelerate contaminant migration. Migration patterns of these contaminants may be complex because of the susceptibility of volatile organic compounds to these processes.

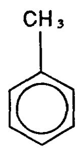
Aromatic Hydrocarbons

Benzene



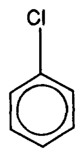
{5}

Toluene (Methylbenzene)



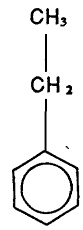
{2,000}

Chlorobenzene



{100}

Ethylbenzene



{700}

Halogenated Hydrocarbons

Methylene Chloride (Dichloromethane)	Chloroform (Trichloromethane)	Carbon tetrachloride (Tetrachloromethane)	Bromoform (Tribromomethane)
CH_2Cl_2	$CHCl_3$	CCl_4	$CHBr_3$
{*}	{*}	{5}	{*}
1,1-dichloroethane	1,2-dichloroethane	1,1-dichloroethylene	Trans-1,2-dichloroethylene
$Cl_2HC\text{-}CH_3$	$ClH_2C\text{-}CH_2Cl$	$Cl_2C{=}CH_2$	$ClHC{=}CHCl$
{*}	{5}	{7}	{100}
1,1,1-trichloroethane	Trichloroethylene (TCE)	1,1,2-trichloroethane	Tetrachloroethylene (PCE)
$H_3C\text{-}CCl_3$	$Cl_2C{=}CHCl$	$Cl_2HC\text{-}CH_2Cl$	$Cl_2C{=}CCl_2$
{200}	{5}	{*}	{5}

1,1,2,2-tetrachloroethane

$Cl_2HC\text{-}CHCl_2$

{*}

EXPLANATION

{5} MAXIMUM CONTAMINANT LEVEL--Concentration in micrograms per liter as established by the U.S. Environmental Protection Agency (1988)

{*} MAXIMUM CONTAMINANT LEVEL HAS NOT BEEN ESTABLISHED

Figure 16.--The molecular formulae and maximun contaminant levels of selected volatile organic compounds (modified from Jackson and others, 1985).

Major Areas of Volatile Organic Compounds Contamination

Five major areas of volatile organic contamination have been identified in the Culpeper basin of Prince William County (pl. 5)–

1. Manassas area
2. Gainesville area, site A
3. Gainesville area, site B
4. Broad Run area, site A
5. Broad Run area, site B

Ground water in parts of the areas identified on plate 5 and in figures 17, 18, and 19 is known to be contaminated. Each of these areas is characterized by a distinctive combination of volatile organic compounds. Locations of reference wells used to delineate the major areas of volatile organic contamination are shown on plate 5. Selected analyses of ground-water samples from these reference wells are presented in table 8 (at the end of report). Whenever possible, these data are presented for ground-water samples collected during the duration of this investigation. All available analyses, including the selected analyses, were used to determine the range in concentrations for each volatile organic compound detected in ground water of the five major areas. These ranges are presented in tables 9, 10, 12, 13, and 14.

The following sections discuss each of the five major contaminated areas with respect to location, concentrations and composition of contaminants, and possible contaminant migration. The contaminated areas were delineated by wells in which volatile organic compounds have been detected in the ground water. Accepted quality assurance/quality control guidelines for field procedures established by Pettyjohn and others (1981), Scalf and others (1981), Claassen (1982), and Bradford (1985) were followed. Transport processes, such as diffusion and dispersion, affect contaminant migration, but are not addressed in this report. The actual time that the volatile organic compounds have been in the ground water has been estimated.

Manassas Area

Location

Volatile organic compounds have been detected in 42 wells inventoried in the southwestern part of the city of Manassas. The approximate contaminated area extends south of Lomond Drive to the city of Manassas corporate boundary near Cannon Branch (pl. 5). This area encompasses approximately 2.23 mi^2. Siltstones of the Balls Bluff Siltstone underlie the western section of the area and sandstones of the Poolesville Memeber of the Manassas Sandstone underlie the eastern section. The water-bearing potential of both of these rock types is generally good (Comer, 1976).

Contaminant concentrations and composition

Seventeen volatile organic compounds have been detected in ground water in the Manassas area. The major volatile organic compound detected throughout the area is tetrachloroethylene (PCE) with concentrations that range from 0.1 to 5,300 µg/L (micrograms per liter) (table 9). The maximum contaminant level (5.0 µg/L) established for tetrachloroethylene by the U.S. Environmental Protection Agency (1988) was exceeded in 14 of the 42 contaminated wells. Other volatile organic compounds detected in this area at relatively high concentrations are 1,1,1-trichloroethane, 1,1,2,2-tetrachloroethane, and trichloroethylene (TCE). Trichloroethylene concentrations exceeded the maximum contaminant level of 5.0 µg/L (U.S. Environmental Protection Agency, 1988) in 5 wells. Analyses for volatile organic compounds were provided by the Prince William Health District, Prince William County Service Authority, and private consulting firms.

Possible contaminant migration

Volatile organic compounds have been present in the ground water for 10 to 15 years (Marcus Haynes, Prince William Health District, oral commun., 1987) and apparently are migrating in two directions, to the north-northeast and to the south-southwest (fig. 17). The potentiometric-surface map has shown a ground-water high located on Wellington Road that acts as a ground-water divide (pl. 4). This factor explains the possibility of two directions of contaminant migration. The north-northeast migration has apparently contaminated Prince William County Service Authority well WG-07 (fig. 17). Tetrachloroethylene was first detected in well WG-07 in November 1984 and concentrations have ranged from 124 to 350 µg/L. Two factors control the north-northeast migration, the presence of lineaments and the regional potentiometric gradients (fig. 17). A major lineament identified from Landsat imagery, trending approximately N 17° E, has steep regional potentiometric gradients towards Lomond Drive. These steep regional potentimetric gradients developed in response to pumpage of public-supply wells in the Manassas-Manassas Park area.

Table 9.–*Volatile organic compounds detected in ground water in the Manassas area*

[— —, indicates compound has not been detected below the highest reported concentration; MCL, indicates maximum contaminant level from U.S. Environmental Protection Agency (1988); *, indicates that MCL has not been established for the respective compound. Analytical data provided by the Prince William Health District, Prince William County Service Authority, and private consulting firms]

Compound	Range in concentrations (micrograms per liter)		Number of wells where MCL was exceeded
	Low	High	
Tetrachlororethylene	0.1	5,300	14
1,1,1-trichloroethane	.1	96	0
1,1,2,2-tetrachloroetane	.1	59	*
Trichloroethylene	.3	12	5
1,1-dichloroethylene	.4	13	1
1,1-dichlorethane	.1	4.4	*
1,2-dichloroethane	.1	6.9	1
trans-1,2-dichloroethylene	.3	16	0
Carbon tetrachloride	.2	16	2
1,1,2-trichloroethane	.1	.9	*
Chloroform	.1	68	*
Bromodichloromethane	3.0	13	*
Toluene	1.0	1.4	0
Benzene	1.2	2.9	0
Chlorobenzene	1.0	1.4	*
Dibromochloromethane	— —	.9	*
Trichlorofluoromethane	— —	.2	*

The N 17° E-trending lineament and an additional lineament identified from Landsat imagery, trending approximately N 1° W, have regional potentiometric gradients to the south-southwest (fig. 17). The change in the regional potentiometric gradients along the N 17° E-trending lineament may be attributed to the ground-water divide located on Wellington Road. The regional potentiometric gradients are not as steep in this direction because pumpage is mainly for domestic use and stress to the ground-water flow system is negligible.

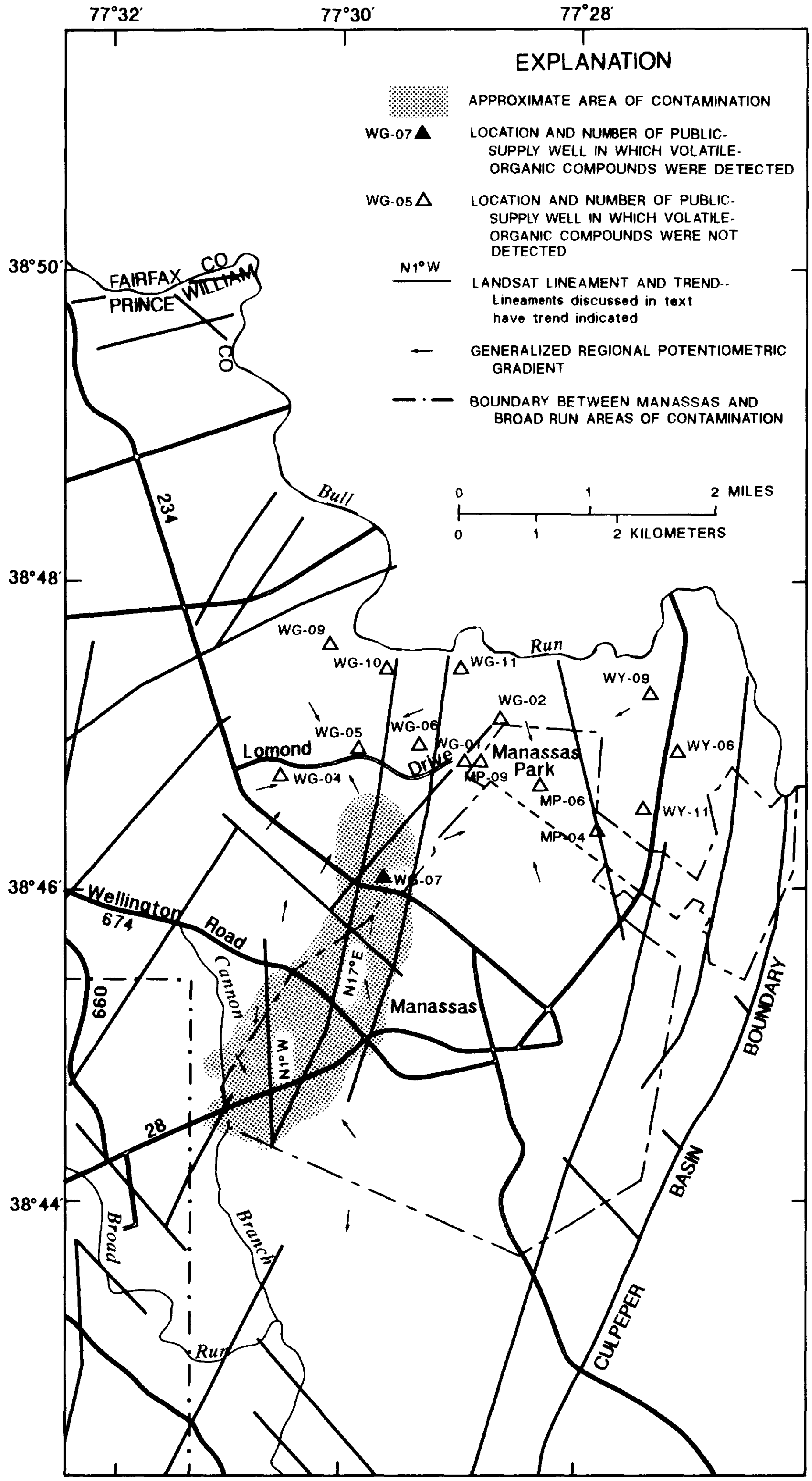


Figure 17.--Generalized regional potentiometric gradients, lineaments, and location of the Prince William County Service Authority well WG-07 and other public-supply wells in the Manassas area (Lineament data from Leavy, 1984).

Gainesville Area, Site A

Location

This site is located north of Wellington Road approximately 1 mile southeast of Gainesville. Volatile organic compounds have been detected in 7 wells inventoried in an area that extends from just south of Interstate 66 to Wellington Road (pl. 5). The approximate contaminated area encompasses about 0.28 mi^2. This site is underlain by diabase, which trends to the northeast.

Contaminant concentrations and composition

Ten volatile organic compounds have been detected in the Gainesville area, site A. The major volatile organic compound detected throughout the site is 1,1,1-trichloroethane with concentrations that range from 5.0 to 630 µg/L (table 10). The maximum contaminant level (200 µg/L) established for 1,1,1-trichloroethane by the U.S. Environmental Protection Agency (1988) was exceeded in 1 well. However, 1,1,1-trichloroethane concentrations that range from 76 to 150 µg/L have been detected in 2 additional wells. Other volatile organic compounds detected in this area at relatively high concentrations that exceed the respective maximum contaminant levels are 1,1-dichloroethylene, tetrachloroethylene, and 1,2-dichloroethane. Analyses for volatile organic compounds were provided by the U.S. Geological Survey, Prince William Health District, and a private consultings firm.

Sampling by the Prince William Health District and a private consulting firm has indicated volatile organic contamination in Piney Branch Creek (pl. 5). Volatile organic compounds, such as 1,1,1-trichloroethane, tetrachloroethylene, trichloroethylene, and 1,1-dichloroethane, have been detected with concentrations that decrease downstream and range from 2.9 to 114 µg/L. The volatile organic compounds evidently are volatizing to the atmosphere and being biodegraded by bacteria present in the surface water. Dilling and others (1975), Jensen and Rosenberg (1975), Helz and Hsu (1978), and Cadena and others (1984) have stressed the importance of solute volatization of volatile organic compounds in surface-water bodies. The evaporation times for 50- and 90-percent removal of various volatile organic compounds are presented in table 11. Turbulence of the surface water as result of varying flow velocities may affect volatization rates. Smith and others (1987, p. 115) stated that biodegradation rates in surface-water bodies are slower relative to the volatization rates.

Possible contaminant migration

Lateral migration of volatile organic compounds has not been significant since their introduction as early as the 1950's (Marcus Haynes, Prince William Health District, oral commun., 1987). This site is underlain by diabase and by 0 to 20 ft of overburden (pl. 3). Marcus Haynes (Prince William Health District, oral commun., 1987) states that dips of the diabase fracture planes have been reported to range from 85° to 90° (vertical). High-capacity pumpage in this area generally is located within the area of contamination. The combination of these factors indicates that contaminant migration may be vertical (downward) rather than lateral.

Contaminants could possibly migrate laterally in two directions. Lineaments on the basis of Landsat imagery, trending N 50° W and N 12° E, are present at this site (fig. 18). Regional potentiometric gradients at this site are towards the east (fig. 18). However, contaminants would tend to migrate to the southeast down gradient along the N 50° W lineament, which intersects the diabase on the east and west. With the regional potentiometric gradients to the east, these cross-strike lineaments may provide a preferred path for this flow gradient. Contamination along the N 12° E lineament is possible; however, the regional potentiometric gradients indicate that ground-water flow is along the N 50° W lineament.

Table 10.–*Volatile organic compounds detected in ground water in the Gainesville area, site A*

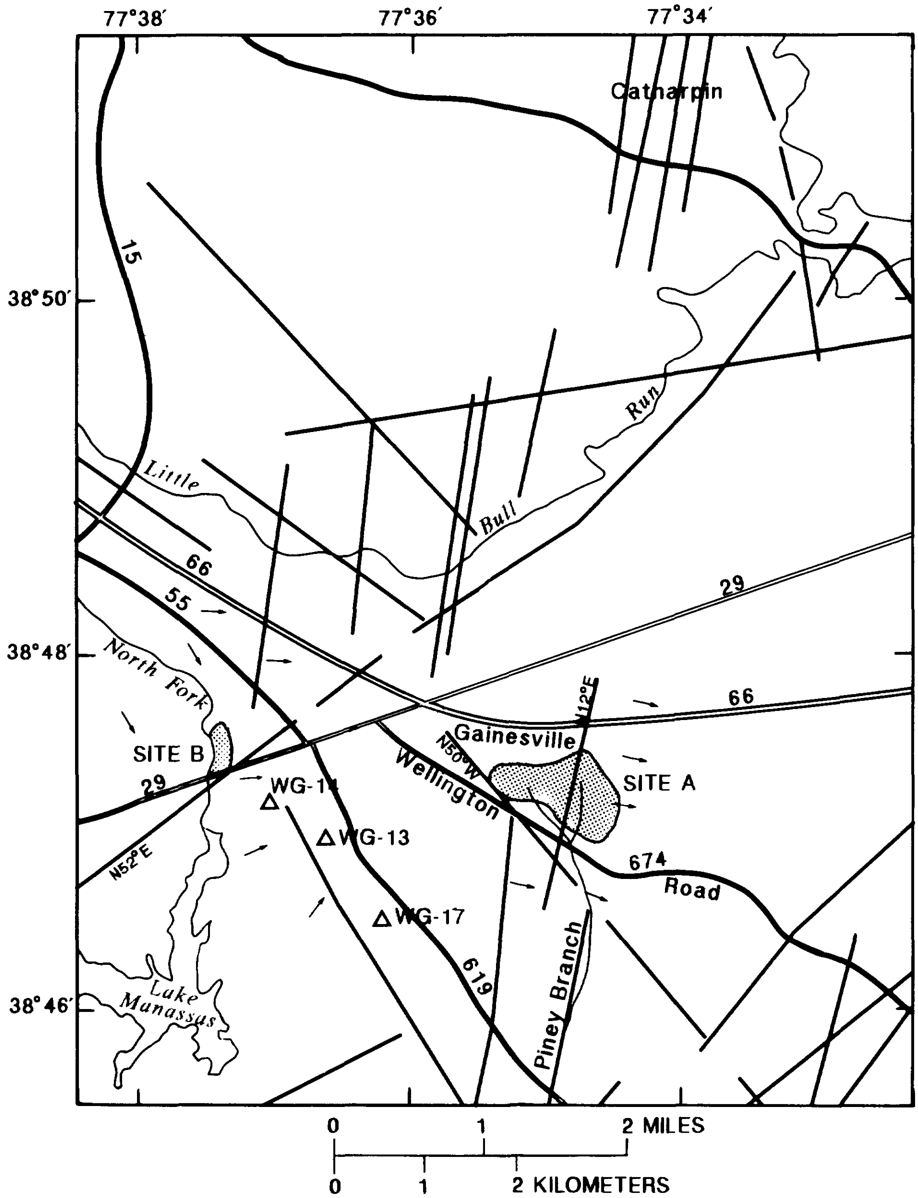
[--, indicates compound has not been detected below the highest reported concentration; MCL, indicates maximum contaminant level from U.S. Environmental Protection Agency (1988); *, indicates that MCL has not been established for the respective compound. Analytical data provided by the U.S. Geological Survey, Prince William Health District, and private consulting firms]

Compound	Range in concentrations (micrograms per liter)		Number of wells where MCL was exceeded
	Low	High	
1,1,1-trichloroethane	5.0	630	1
1,1-dichloroethylene	1.3	168	3
Tetrachlororethylene	2.0	275	2
1,2-dichloroethane	110	143	2
1,1-dichlorethane	2.6	27	*
Benzene	1.5	1.8	0
Trichloroethylene	--	6.7	1
1,1,2-trichloroethane	--	1.7	*
Chlorobenzene	--	1.7	*
1,3-dichlorobenzene	--	12	*

Table 11.–*Evaporation times for 50- and 90-percent removal of chlorinated aliphatic hydrocarbons (1 milligram per liter) at 25 degrees Celsius, 200 revolutions per minute of stirring, and a depth of 6.5 centimeters*

[Modified from Dilling and others (1975)]

Compound	Time (minutes) for evaporation from water	
	50-percent evaporation	90-percent evaporation
1,1,1-trichloroethane	20	65
1,1-dichloroethylene	22	89
Tetrachlororethylene	25	86
1,2-dichloroethane	29	96
1,1-dichlorethane	22	109
1,1,2-trichloroethane	21	102
Trichloroethylene	21	63
Cis-dichloroethylene	18	64
Trans-dichloroethylene	24	83



EXPLANATION

SITE B — APPROXIMATE AREA OF CONTAMINATION AND NAME

WG-14 △ — LOCATION AND NUMBER OF PUBLIC-SUPPLY WELL

N12°E — LANDSAT LINEAMENT AND TREND--Lineaments discussed in text have trend indicated

— GENERALIZED REGIONAL POTENTIOMETRIC GRADIENT

Figure 18.--Generalized regional potentiometric gradients, lineaments and location of public-supply wells in the Gainesville area, sites A and B (Lineament data from Leavy, 1984).

Gainesville Area, Site B

Location

Volatile organic compounds have been detected in 4 wells inventoried approximately 1 mile southwest of Gainesville on U.S. Highway 29. The approximate contaminated area, encompassing about 0.04 mi^2, borders the North Fork to the east and extends approximately 1,500 ft to the north and approximately 900 ft to the south of U.S. Highway 29 (pl. 5). The geology in this area is complex. Sandstones, diabase, and thermally metamorphosed rocks are present. The northern section is underlain by sandstone of the Catharpin Creek Formation whereas the diabase and associated thermally metamorphosed rocks are northeast trending and are present in the southern section of the site.

Contaminant concentrations and composition

Five volatile organic compounds have been detected in ground water in the Gainesville area, site B. The major volatile organic compound detected throughout the site is tetrachloroethylene with concentrations that range from 1.0 to 369 μg/L (table 12). Tetrachloroethylene concentrations exceeded the maximum contaminant level in 3 out of the 4 contaminated wells. Minor concentrations of 1,1-dichloroethylene, 1,1,1-trichloroethane, 1,2-dichloroethane, and trichloroethylene, which are below the respective maximum contaminant levels, have been detected. Analyses for volatile organic compounds were provided by the U.S. Geological Survey and the Prince William Health District.

Possible contaminant migration

Volatile organic compounds may have been introduced into the ground water between 5 to 10 years ago (Marcus Haynes, Prince William Health District, oral commun., 1987). Contaminant migration is probably towards the North Fork, which serves as a discharge area (fig. 18); however, numerous minor surface-water drainage divides are present east of the site, which may coincide with ground-water divides. The regional potentiometric gradients are generally to the east, southeast, and northeast. Ground-water flow along a lineament identified from Landsat imagery, trending N 52° E, would be to the northeast (fig. 18). Prince William County Service Authority wells WG-13 and WG-14 are located within a one-mile radius southeast of the site along a lineament identified from Landsat imagery, trending N 30° W (fig. 18). The presence of the public-supply wells and the N 30° W lineament near this site complicates matters by providing the possibility of the contamination actually being drawn away from the North Fork. Prediction of contaminant migration is complicated further by the presence of Lake Manassas. The effect of Lake Manassas on ground-water levels is uncertain; however, the potentiometric surface flattens in the vicinity of Lake Manassas (pl. 4).

Broad Run Area, Site A

Location

Volatile organic compounds have been detected in 5 wells inventoried 1 mile southwest of the city of Manassas corporate boundary on State Route 28. The approximate contaminated area, encompassing about 0.09 mi^2, extends from State Route 28 to the southern end of Residency Road (pl. 5). This site is underlain by the Balls Bluff Siltstone.

Contaminant concentrations and composition

Eight volatile organic compounds have been detected in ground water in the Broad Run area, site A. The major volatile organic compound detected throughout the site is trichloroethylene with concentrations that range from 2.1 to 3,050 μg/L (table 13). The maximum contaminant level (5.0 μg/L) for trichloroethylene established by the U.S. Environmental Protection Agency (1988) was exceeded in 3 wells. Other volatile organic

Table 12.–*Volatile organic compounds detected in ground water in the Gainesville area, site B*

[--, indicates compound has not been detected below the highest reported concentration; MCL, indicates maximum contaminant level from U.S. Environmental Protection Agency (1988); *, indicates that MCL has not been established for the respective compound. Analytical data provided by the U.S. Geological Survey and the Prince William Health District]

Compound	Range in concentrations (micrograms per liter)		Number of wells where MCL was exceeded
	Low	High	
Tetrachlororethylene	1.0	369	3
1,1-dichloroethylene	1.0	5.7	0
1,1,1-trichloroethane	.9	4.5	0
1,2-dichloroethane	--	1.1	0
Trichloroethylene	--	.3	0

Table 13.–*Volatile organic compounds detected in ground water in the Broad Run area, site A*

[--, indicates compound has not been detected below the highest reported concentration; MCL, indicates maximum contaminant level from U.S. Environmental Protection Agency (1988); *, indicates that MCL has not been established for the respective compound. Analytical data provided by the U.S. Geological Survey, Prince William Health District, Virginia Department of Waste Management, and private consulting firms]

Compound	Range in concentrations (micrograms per liter)		Number of wells where MCL was exceeded
	Low	High	
Trichloroethylene	2.1	3,050	3
1,1-dichloroethylene	.8	225	1
Tetrachlororethylene	.1	9.2	1
Trans-1,2-dichloroethylene	--	20	0
Chloroform	.1	.8	*
1,1,1-trichloroethane	.5	1.0	0
1,1,2,2-tetrachloroethylene	.1	.7	*
Trichlorofluoromethane	--	.4	*

compounds detected at this site in relatively high concentrations are 1,1-dichloroethylene, tetrachloroethylene, and trans-1,2-dichloroethylene. Analyses for volatile organic compounds were provided by the U.S. Geological Survey, Prince William Health District, Virginia Department of Waste Management, and private consulting firms.

The Virginia Department of Waste Management conducted three site investigations in this area in 1986. Significant levels of inorganic and organic compounds were identified in the surficial material (Virginia Department of Waste Management, 1987a). Polychlorinated biphenyls, commonly referred to as PCB's, were detected in the soils, and trichloroethylene and trans-1,2-dichloroethylene were present in the ground water (Virginia Department of Waste Management, 1987b). The Virginia Department of Waste Management (1987c) identified fuel-oil constituents and pesticides in soil samples. A trichloroethylene concentration of 69 µg/L also was detected in an on-site well. Trichloroethylene and other volatile organic compounds currently present in the ground water at this site were not detected in soil samples collected during these investigations.

Possible contaminant migration

Volatile organic compounds have been present in the ground-water for at least 5 to 10 years (Marcus Haynes, Prince William Health District, oral commun., 1987). Contaminants would tend to migrate in one direction. A lineament determined from Landsat imagery, trending N 50° W, has been identified at this site (fig. 19). The regional potentiometric gradients are to the south-southeast. Contaminants would probably migrate downgradient along the lineament to the southeast. Stress from ground-water withdrawals nearby in the Manassas-Manassas Park area apparently has little affect on ground-water levels at this site (pl. 4).

Broad Run Area, Site B

Location

Volatile organic compounds have been detected in 3 wells inventoried approximately 1 mile northwest of the intersection of State Routes 28 and 660. The approximate contaminated area, encompassing about 0.04 mi^2, occupies the western end of Industrial Road (pl. 5). This site is underlain by northeast-trending diabase.

Contaminant concentrations and composition

Four volatile organic compounds have been detected in ground water in the Broad Run area, site B. The major volatile organic compound detected throughout this site is 1,1,1-trichloroethane with concentrations that range from 0.5 to 118 μg/L (table 14). Other volatile organic compounds detected are 1,1-dichloroethylene with minor concentrations of chloroform and tetrachloroethylene. Analyses for volatile organic compounds were provided by the U.S. Geological Survey and Prince William Health District.

Possible contaminant migration

Volatile organic compounds are believed to have been present in the ground water for at least 5 to 10 years (Marcus Haynes, Prince William Health District, oral commun., 1987). This site is underlain by diabase and is unique among the sites evaluated because of the absence of major lineaments. Therefore, like the Gainesville area, site A, contaminant migration may be vertical instead of lateral. Lateral flow is probably to the southwest in the direction of the regional potentiometric gradient (fig. 19). Thus, any lateral migration of the contamination may be to the southwest. Similar to site A of the Broad Run area, the ground-water withdrawals in the Manassas-Manassas Park area have no affect on the ground-water levels at this site (pl. 4).

Minor Areas of Volatile Organic Compounds Contamination

Minor areas of volatile organic contamination have been detected throughout the Culpeper basin of Prince William County. These areas are not areally extensive, and therefore, are not mapped. In most of the areas, only one well has been contaminated. Contaminant composition varies between wells. The volatile organic compounds detected in these wells are in very low concentrations and are below the maximum contaminant levels (U.S. Environmental Protection Agency, 1988). The location of wells sampled are shown on figure 20, and those with minor volatile organic contamination are designated. Various volatile organic compounds occur at random with no apparent pattern. Xylene, chloroform, tetrachloroethylene, 1,1,1-trichloroethane, ethylbenzene and styrene are the most commonly detected volatile organic compounds. The volatile organic compounds that have been detected and the ranges in concentrations are presented in table 15.

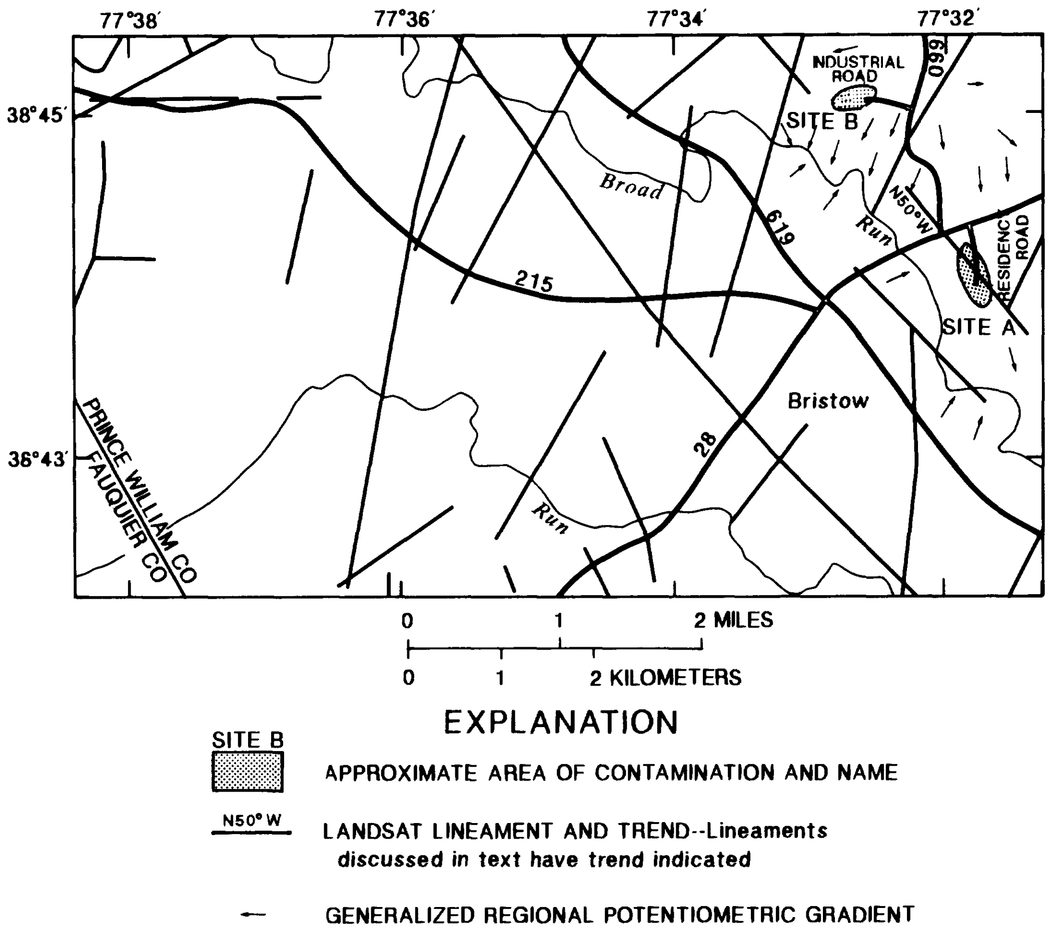


Figure 19.--Generalized regional potentiometric gradients and lineaments in the Broad Run area, sites A and B (Lineament data from Leavy, 1984).

Table 14.–*Volatile organic compounds detected in ground water in the Broad Run area, site B*

[– –, indicates compound has not been detected below the highest reported concentration; MCL, indicates maximum contaminant level from U.S. Environmental Protection Agency (1988); *, indicates that MCL has not been established for the respective compound. Analytical data provided by the U.S. Geological Survey and Prince William Health District]

Compound	Range in concentrations (micrograms per liter)		Number of wells where MCL was exceeded
	Low	High	
1,1,1-trichloroethane	0.5	118	0
1,1-dichloroethylene	– –	37	1
Chloroform	.4	3.0	*
Tetrachlororethylene	– –	.7	0

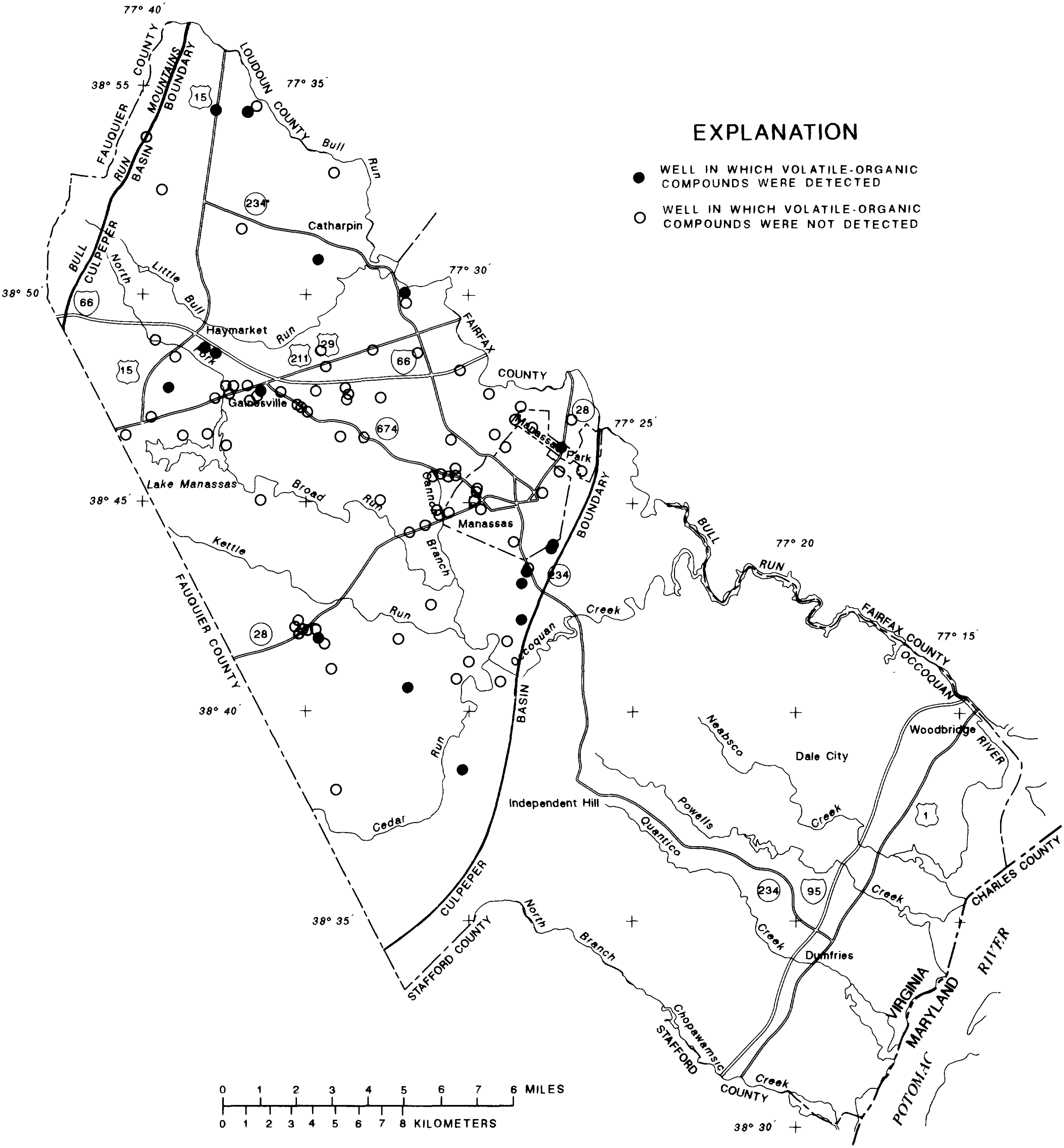


Figure 20.--Location of wells with minor concentrations of volatile organic compounds detected in the Culpeper basin of Prince William County.

Table 15.–*Volatile organic compounds detected in ground water in the minor areas of contamination in the Culpeper basin of Prince William County*

[--, indicates compound has not been detected below the highest reported concentration; MCL, indicates maximum contaminant level from U.S. Environmental Protection Agency (1988); *, indicates that MCL has not been established for the respective compound. Analytical data provided by the U.S. Geological Survey and Prince William Health District]

Compound	Range in concentrations (micrograms per liter)		Number of wells where MCL was exceeded
	Low	High	
Xylene	0.5	13	0
Chloroform	1.0	6.0	*
Tetrachlororethylene	1.0	3.0	0
Styrene	.2	2.8	0
1,1,1-trichloroethane	1.6	4.5	0
Ethylbenzene	.6	.9	0
1,1-dichloroethylene	--	5.7	0
1,2-dichloroethane	--	2.7	0
Toluene	--	1.4	0
Bromodichloromethane	--	1.0	*

Explanation of the volatile organic contamination for each of these wells is beyond the scope of this investigation; however, some generalizations are possible. In the western section of the study area, the use of septic tanks is the dominant means of sewage disposal. Sponenberg and others (1985) state that chemical additives that accelerate the decomposition in septic tanks can introduce volatile organic compounds into the ground water. Except for the borders of the Culpeper basin of Prince William County, the average overburden thickness of 5 to 10 ft allows for fairly rapid infiltration to the rock aquifer. Different soil and rock types with varying thicknesses of overburden can either impede or enhance infiltration. Septic drainfields are located in the more permeable soil types.

Another source of volatile organic contamination may be household and commercial products that are deposited into the septic tanks or directly on the land surface. Solvents, which are used to clean grease-laden mechanical parts, often are poured out on the surface. These solvents eventually may reach the aquifer. Spills and leaking underground storage tanks (commercial and residential) can introduce benzenes, xylenes, and other petroleum-related compounds to the ground-water flow system.

SUMMARY AND CONCLUSIONS

Volatile organic compounds have been detected in the ground water of some areas of the Culpeper basin of Prince William County, Virginia. Contamination of a public-supply well has caused the county to be concerned about the present water-resources and the possible effects that present-day contamination may have in the future. The U.S. Geological Survey, in cooperation with the Prince William Health District, conducted a comprehensive geohydrologic investigation to evaluate the extent of ground-water contamination within the Culpeper basin of the county.

The Culpeper basin of Prince William County comprises an interbedded sequence of sedimentary and volcanic rocks, which range in age from Late Triassic to Early Jurassic. This sequence is intersected by diabase intrusives and thermally metamorphosed rocks. The basin formed between upthrown blocks along normal faults at the basin borders. The rocks dip to the west and strike to the northeast. Dips are gentle in the eastern

margins of the basin and steepen in the western margins. The rocks of the Culpeper basin are highly fractured and are generally overlain by a thin cover of overburden. Overburden thickness averages from 5 to 10 ft; however, the overburden is much thicker near the basin margins.

The sedimentary rocks are the most productive aquifers, whereas the igneous and metamorphic rocks generally have poor water-bearing potential. The siltstones and sandstones are the most productive aquifers in the Culpeper basin of Prince William County. Compared to the igneous and metamorphic rocks, and the conglomerates, fracture spacing in the siltstones and sandstones tends to be closer and fractures have a larger number of intersections. The high productivity of the siltstone and sandstone aquifers is related to the close fracture spacing and presence of numerous fracture intersections. The diabase and metamorphic rocks appear to be productive in areas intersected by east-west trending lineaments (linear-surface expressions of fracture sets).

Recharge to aquifers of the Culpeper basin occurs by infiltration of precipitation through the unsaturated zone to the water table. Most ground water in the Culpeper basin flows from upland recharge areas along lineaments to the lowland or valley discharge areas. Most of the flow system is generally under water-table conditions and the configuration of potentiometric surface reflects the topography. Two cones of depression in the potentiometric surface have formed in the Manassas-Manassas Park area in response to pumpage. Seasonal fluctuations in water levels are exaggerated in the areas surrounding the cones of depression. Effective ground-water recharge is related to rock type. Ambient ground-water quality is predominantly a calcium-magnesium-bicarbonate type.

Five independent areas of major volatile organic contamination have been identified in the Culpeper basin. These areas are (1) Manassas area; (2) Gainesville area, site A; (3) Gainesville area, site B; (4) Broad Run area, site A; and (5) Broad Run area, site B. Each area has different contaminant concentrations, compositions, and possible contaminant migration because of the rock type, lineaments, and regional potentiometric gradients present. The dominant volatile organic compounds present are tetrachloroethylene (PCE), trichloroethylene (TCE), and 1,1,1-trichloroethane. Concentrations of the volatile organic compounds range from 0.1 to 5,300 µg/L. Isolated areas of minor volatile organic contamination also were identified. These areas have very low concentrations of volatile organic compounds and may be derived from septic systems, leaking underground storage tanks, or the disposal of domestic and commercial wastes.

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Table 8.–*Selected water-quality analyses from reference wells used to delineate major areas of volatile organic contamination in the Culpeper basin of Prince William County*

[Values, in micrograms per liter; nd, indicates that compound was not detected; –, indicates no analysis for that particular compound; <, indicates less than value shown; VOC, volatile organic compounds; USGS, U.S. Geological Survey; PWHD, Prince William Health District; IBM, International Business Machine, Inc.; Well number and location shown on plate 5]

Well number	Other identifier	Area of VOC contamination	Latitude	Longitude	Date sampled	Agency	Bromo-dichloro-methane	Carbon tetra-chloride	1,2-dichloro-ethane	Bromo-form	Dibromo-chloro-methane	Chloroform	Toluene	Benzene	Chloro-benzene
1		Gainesville B	384738	0773724	07-01-1987	PWHD	nd	nd	**1.1**	nd	nd	nd	nd	nd	nd
2		Gainesville B	384750	0773726	03-25-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
3		Gainesville B	384746	0773721	03-25-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
4		Gainesville B	384747	0773711	03-25-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
5		Gainesville B	384740	0773717	03-25-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
6		Gainesville B	384728	0773742	03-05-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
7		Gainesville B	384736	0773715	03-05-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
8	50U110	Gainesville B	384735	0773728	08-26-1987	USGS	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
9		Broad Run B	384505	0773626	04-15-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
10		Gainesville B	384841	0773808	04-08-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
11		Gainesville B	384837	0773804	04-08-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
12		Manassas	384403	0772724	04-27-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
13		Manassas	384359	0772725	04-22-1987	PWHD	nd	nd	nd	nd	nd	**1.0**	nd	nd	nd
14	50U116	Broad Run B	384511	0773222	08-27-1987	USGS	<.2	<.2	<.2	<.2	<.2	**.4**	<.2	<.2	<.2
15		Broad Run B	384505	0773238	04-08-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
16		Broad Run B	384508	0773239	04-13-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
17		Broad Run B	384506	0773244	04-13-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
18		Broad Run B	384505	0773237	04-13-1987	PWHD	nd	nd	nd	nd	nd	**3.0**	nd	nd	nd
19		Manassas	384812	0773015	04-23-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
20		Broad Run A	384417	0773145	03-03-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
21	50U117	Gainesville A	384718	0773512	08-26-1987	USGS	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
22	50U118	Gainesville A	384712	0773503	08-26-1987	USGS	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23		Gainesville B	384747	0773645	05-12-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
24		Gainesville A	384638	0773357	04-08-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
25		Manassas	384441	0773008	07-21-1987	IBM	–	<1.0	–	–	–	<1.0	<1.0	<1.0	<1.0
26		Gainesville A	384635	0773310	05-19-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
27		Manassas	384215	0772822	05-19-1987	PWHD	nd	nd	nd	nd	nd	**3.0**	nd	nd	nd
28		Broad Run A	384233	0773109	05-26-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
29		Broad Run A	384317	0773111	05-26-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
30		Gainesville A	384732	0773242	05-27-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd

Table 8.–*Selected water-quality analyses from reference wells used to delineate major areas of volatile organic contamination in the Culpeper basin of Prince William County*–Continued

[Values, in micrograms per liter; nd, indicates that compound was not detected; –, indicates no analysis for that particular compound; <, indicates less than value shown; Well number and location shown on plate 5]

Well number	Chloro-ethane	Ethyl-benzene	Bromo-methane	Chloro-methane	Methylene chloride	Tetra-chloro-ethylene	Trichloro-fluoro-methane	1,1-dichloro-ethane	1,1-dichloro-ethylene	1,1,1-trichloro-ethane	1,1,2-trichloro-ethane	1,1,2,2-tetrachloro-ethane	1,2-dichloro-benzene	1,2-dichloro-propane	Trans-1,2 dichloro-ethylene
1	nd	nd	nd	nd	nd	**5.7**	nd	nd	nd	nd	nd	nd	nd	nd	nd
2	nd	nd	nd	nd	nd	**19.6**	nd	nd	**1.0**	**0.9**	nd	nd	nd	nd	nd
3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
6	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
7	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
8	<0.2	<0.2	<0.2	<0.2	<0.2	**2.2**	<0.2	<0.2	<0.2	<.2	<0.2	<0.2	<0.2	<0.2	<0.2
9	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
10	nd	nd	nd	nd	nd	nd	nd	nd	nd	**1.6**	nd	nd	nd	nd	nd
11	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
12	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
13	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
14	<.2	<.2	<.2	<.2	<.2	<0.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
15	nd	nd	nd	nd	nd	**.7**	nd	nd	**37.0**	**118.1**	nd	nd	nd	nd	nd
16	nd	nd	nd	nd	nd	nd	nd	nd	nd	**.5**	nd	nd	nd	nd	nd
17	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
18	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
19	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
20	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
21	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
22	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
24	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
25	–	–	–	<1.0	<5.0	**45.0**	–	<1.0	<1.0	<1.0	<1.0	<1.0	–	–	<1.0
26	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
27	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
28	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
29	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
30	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

Table 8.–*Selected water-quality analyses from reference wells used to delineate major areas of volatile organic contamination in the Culpeper basin of Prince William County*–Continued

[Values, in micrograms per liter; nd, indicates that compound was not detected; –, indicates no analysis for that particular compound; <, indicates less than value shown; Well number and location shown on plate 5]

Well number	Trichloro-benzenes	1,3-dichloro-propene	1,3-dichloro-benzene	1,4-dichloro-benzene	Chloroethyl-vinyl ether	Dichloro-fluoro-methane	Trans-1,3-dichloro-propene	Cis-1,3-dichloro-propene	Ethylene dibromide	Vinyl chloride	Trichloro-ethylene	Styrene	Dibromo-methane	Xylene
1	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
2	nd	–	nd	nd	nd	nd	–	–	nd	nd	**0.3**	nd	nd	nd
3	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
4	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
5	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
6	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
7	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
8	–	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<.2	<0.2	–	<0.2
9	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
10	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
11	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
12	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	**0.5**	nd	**0.5**
13	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
14	–	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	–	<.2
15	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
16	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
17	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
18	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
19	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
20	nd	–	nd	nd	nd	nd	–	–	nd	nd	**84.5**	nd	nd	nd
21	–	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	–	<.2
22	–	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	–	<.2
23	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
24	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
25	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
26	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
27	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
28	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
29	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
30	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd

Table 8.–*Selected water-quality analyses from reference wells used to delineate major areas of volatile organic contamination in the Culpeper basin of Prince William County*–Continued

[Values, in micrograms per liter; nd, indicates that compound was not detected; –, indicates no analysis for that particular compound; Well number and location shown on plate 5]

Well number	Cis-1,2-dichloro-ethylene	Methyl ethyl ketone	Trans & cis 1,3-dichloro-propane	Trihalo-methanes	Dibromo-chloro-propane	Remarks
1	nd	–	nd	nd	nd	
2	nd	–	nd	nd	nd	
3	nd	–	nd	nd	nd	
4	nd	–	nd	nd	nd	
5	nd	–	nd	nd	nd	
6	nd	–	nd	nd	nd	
7	nd	–	nd	nd	nd	
8	–	–	–	–	–	
9	nd	–	nd	nd	nd	
10	nd	–	nd	nd	nd	
11	nd	–	nd	nd	nd	
12	nd	–	nd	nd	nd	
13	nd	–	nd	**1.0**	nd	
14	–	–	–	–	–	
15	nd	–	nd	nd	nd	
16	nd	–	nd	nd	nd	
17	nd	–	nd	nd	nd	
18	nd	–	nd	**3.0**	nd	
19	nd	–	nd	nd	nd	
20	nd	–	nd	nd	nd	
21	–	–	–	–	–	
22	–	–	–	–	–	
23	nd	–	nd	nd	nd	
24	nd	–	nd	nd	nd	
25	–	–	–	–	–	
26	nd	–	nd	nd	nd	
27	nd	–	nd	**3.0**	nd	
28	nd	–	nd	nd	nd	
29	nd	–	nd	nd	nd	
30	nd	–	nd	nd	nd	

Table 8.–*Selected water-quality analyses from reference wells used to delineate major areas of volatile organic contamination in the Culpeper basin of Prince William County*–Continued

[Values, in micrograms per liter; nd, indicates that compound was not detected; –, indicates no analysis for that particular compound; <, indicates less than value shown; VOC, volatile organic compounds; USGS, U.S. Geological Survey; PWHD, Prince William Health District; IBM, International Business Machine, Inc.; Well number and location shown plate 5]

Well number	Other identifier	Area of VOC contamination	Latitude	Longitude	Date sampled	Agency	Bromo-dichloro-methane	Carbon tetra-chloride	1,2-dichloro-ethane	Bromo-form	Dibromo-chloro-methane	Chloroform	Toluene	Benzene	Chloro-benzene
31		Gainesville A	385055	0773441	05-18-1987	PWHD	nd	nd	nd	nd	nd	**2.0**	nd	nd	nd
32		Gainesville A	385136	0773701	06-03-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
33		Manassas	385010	0773205	06-29-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
34		Gainesville A	384717	0773428	07-29-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	**1.5**	nd
35		Gainesville A	384736	0773445	07-29-1987	PWHD	nd	nd	**143.1**	nd	nd	nd	nd	nd	nd
36		Gainesville A	384732	0773524	07-29-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
37	50U 48D	Gainesville B	384733	0773625	07-29-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
38	50U 47D	Gainesville A	384744	0773622	07-27-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
39		Manassas	384838	0773134	08-11-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
40		Manassas	384953	0773158	08-11-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
41		Gainesville A	384840	0773259	08-11-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
42		Manassas	384625	0772710	08-12-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
43		Manassas	384330	0772808	08-13-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
44		Manassas	384521	0772743	08-24-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
45		Gainesville B	384640	0773802	08-25-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
46	49U 59	Gainesville B	384636	0773849	08-28-1987	USGS	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
47	51U111	Manassas	384554	0772915	08-28-1987	USGS	<.2	<.2	<.2	<.2	<.2	**5.1**	<.2	<.2	<.2
48		Gainesville B	384731	0773726	10-05-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
49		Broad Run A	384212	0773510	10-05-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
50		Manassas	384307	0772822	10-06-1987	PWHD	nd	nd	nd	nd	nd	nd	**1.4**	nd	nd
51		Manassas	384500	0773050	01-25-1988	IBM	–	<1.0	–	–	–	<1.0	<1.0	**1.1**	<1.0
52		Manassas	384541	0773026	12-02-1987	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
53		Manassas	384645	0772941	07-23-1987	IBM	–	<1.0	–	–	–	<1.0	<1.0	<1.0	**1.0**
54		Manassas	384444	0773053	07-23-1987	IBM	–	<1.0	–	–	–	<1.0	<1.0	<1.0	<1.0
55		Manassas	384500	0773104	02-25-1986	IBM	<1.0	<1.0	**3.1**	<20.0	<1.0	<1.0	<1.0	<1.0	<1.0
56		Manassas	384446	0773056	07-23-1987	IBM	–	<1.0	–	–	–	<1.0	<1.0	<1.0	<1.0
57		Manassas	384620	0772946	07-23-1987	IBM	–	<1.0	–	–	–	<1.0	<1.0	<1.0	**1.4**
58		Manassas	384516	0772932	01-26-1988	IBM	–	<1.0	–	–	–	<1.0	<1.0	<1.0	<1.0
59		Broad Run A	384407	0773136	01-05-1988	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd
60		Gainesville B	384836	0773744	03-09-1988	PWHD	nd	nd	nd	nd	nd	nd	nd	nd	nd

Table 8.–*Selected water-quality analyses from reference wells used to delineate major areas of volatile organic contamination in the Culpeper basin of Prince William County*–Continued

[Values, in micrograms per liter; nd, indicates that compound was not detected; –, indicates no analysis for that particular compound; <, indicates less than value shown; Well number and location shown on plate 5]

Well number	Chloro-ethane	Ethyl-benzene	Bromo-methane	Chloro-methane	Methylene chloride	Tetra-chloro-ethylene	Trichloro-fluoro-methane	1,1-dichloro-ethane	1,1-dichloro-ethylene	1,1,1-trichloro-ethane	1,1,2-trichloro-ethane	1,1,2,2-tetrachloro-ethane	1,2-dichloro-benzene	1,2-dichloro-propane	Trans-1,2 dichloro-ethylene
31	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
32	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
33	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
34	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
35	nd	nd	nd	nd	nd	**275.4**	nd	**16.8**	**168.0**	**306.4**	nd	nd	nd	nd	nd
36	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	**1.7**	nd	nd	nd	nd
37	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
38	nd	nd	nd	nd	nd	**1.6**	nd	nd	nd	nd	nd	nd	nd	nd	nd
39	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
40	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
41	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
42	nd	nd	nd	nd	nd	**1.0**	nd	nd	nd	nd	nd	nd	nd	nd	nd
43	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
44	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
45	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
46	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
47	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
48	nd	nd	nd	nd	nd	**368.5**	nd	nd	nd	nd	nd	nd	nd	nd	nd
49	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
50	nd	**.9**	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
51	–	–	–	<1.0	<5.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<1.0	–	–	<1.0
52	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
53	–	–	–	<1.0	<5.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<1.0	–	–	<1.0
54	–	–	–	<1.0	<5.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<1.0	–	–	<1.0
55	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	–	<1.0	<1.0
56	–	–	–	<1.0	<5.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<1.0	–	–	<1.0
57	–	–	–	<1.0	<5.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<1.0	–	–	<1.0
58	–	–	–	<1.0	<5.0	<1.0	–	<1.0	<1.0	**1.0**	<1.0	<1.0	–	–	<1.0
59	nd	nd	nd	nd	nd	**1.9**	nd	nd	nd	nd	nd	nd	nd	nd	nd
60	nd	nd	nd	nd	nd	nd	nd	nd	nd	**1.6**	nd	nd	nd	nd	nd

Table 8.–*Selected water-quality analyses from reference wells used to delineate major areas of volatile organic contamination in the Culpeper basin of Prince William County*–Continued

[Values, in micrograms per liter; nd, indicates that compound was not detected; –, indicates no analysis for that particular compound; <, indicates less than value shown; Well number and location shown on plate 5]

Well number	Trichloro-benzenes	1,3-dichloro-propene	1,3-dichloro-benzene	1,4-dichloro-benzene	Chloroethyl-vinyl ether	Dichloro-fluoro-methane	Trans-1,3-dichloro-propene	Cis-1,3-dichloro-propene	Ethylene dibromide	Vinyl chloride	Trichloro-ethylene	Styrene	Dibromo-methane	Xylene
31	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
32	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
33	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	**8.5**
34	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
35	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
36	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
37	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
38	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
39	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
40	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
41	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
42	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
43	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
44	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
45	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
46	–	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	–	<0.2
47	–	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	–	<.2
48	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
49	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
50	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	**12.7**
51	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
52	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd
53	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
54	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
55	–	–	–	–	<1.0	<1.0	–	<1.0	–	<20.0	<1.0	–	–	–
56	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
57	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
58	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
59	nd	–	nd	nd	nd	nd	–	–	nd	nd	**15.7**	nd	nd	nd
60	nd	–	nd	nd	nd	nd	–	–	nd	nd	nd	nd	nd	nd

Table 8.–*Selected water-quality analyses from reference wells used to delineate major areas of volatile organic contamination in the Culpeper basin of Prince William County*–Continued

[Values, in micrograms per liter; nd, indicates that compound was not detected; –, indicates no analysis for that particular compound; Well number and location shown on plate 5]

Well number	Cis-1,2-dichloro-ethylene	Methyl ethyl ketone	Trans & cis 1,3-dichloro-propane	Trihalo-methanes	Dibromo-chloro-propane	Remarks
31	nd	–	nd	2.0	nd	
32	nd	–	nd	nd	nd	
33	nd	–	nd	nd	nd	
34	nd	–	nd	nd	nd	
35	nd	–	nd	nd	nd	
36	nd	–	nd	nd	nd	
37	nd	–	nd	nd	nd	
38	nd	–	nd	nd	nd	
39	nd	–	nd	nd	nd	
40	nd	–	nd	nd	nd	
41	nd	–	nd	nd	nd	
42	nd	–	nd	nd	nd	
43	nd	–	nd	nd	nd	
44	nd	–	nd	nd	nd	
45	nd	–	nd	nd	nd	
46	–	–	–	–	–	
47	–	–	–	–	–	
48	nd	–	nd	nd	nd	
49	nd	–	nd	nd	nd	
50	nd	–	nd	nd	nd	
51	–	–	–	–	–	
52	nd	–	nd	nd	nd	
53	–	–	–	–	–	
54	–	–	–	–	–	
55	–	–	–	–	–	
56	–	–	–	–	–	
57	–	–	–	–	–	
58	–	–	–	–	–	
59	nd	–	nd	nd	nd	
60	nd	–	nd	nd	nd	

Table 8.–*Selected water-quality analyses from reference wells used to delineate major areas of volatile organic contamination in the Culpeper basin of Prince William County*–Continued

[Values, in micrograms per liter; nd, indicates that compound was not detected; –, indicates no analysis for that particular compound; <, indicates less than value shown; VOC, volatile organic compounds; USGS, U.S. Geological Survey; PWHD, Prince William Health District; IBM, International Business Machine, Inc.; DUNN, Dunn Geoscience Corp.; Well and location shown on plate 5]

Well number	Other identifier	Area of VOC contamination	Latitude	Longitude	Date sampled	Agency	Bromo-dichloro-methane	Carbon tetra-chloride	1,2-dichloro-ethane	Bromo-form	Dibromo-chloro-methane	Chloroform	Toluene	Benzene	Chloro-benzene
61	50U 76E	Gainesville A	384842	0773432	08-26-1987	USGS	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
62	50U 70G	Gainesville B	384725	0773640	08-26-1987	USGS	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
63	49U 60	Gainesville B	384844	0773825	08-26-1987	USGS	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
64	50T 52	Broad Run A	384352	0773138	08-26-1987	USGS	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
65	50T 51	Broad Run A	384401	0773139	08-27-1987	USGS	<.2	<.2	<.2	<.2	<.2	**.5**	<.2	<.2	<.2
66	51T105	Manassas	384326	0772810	08-27-1987	USGS	<.2	<.2	<.2	<.2	<.2	**.5**	<.2	<.2	<.2
67	WELL #4	Manassas	384633	0772733	08-28-1987	USGS	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
68	WELL #6	Manassas	384702	0772833	08-28-1987	USGS	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
69	WELL #9	Manassas	384652	0772802	08-28-1987	USGS	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
70	51U 4H	Manassas	384551	0772631	08-28-1987	USGS	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
71	51T 1A	Manassas	384402	0772836	08-28-1987	USGS	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
72	50U127	Gainesville A	384819	0773424	07-19-1988	USGS	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
73	50U128	Gainesville B	384627	0773730	07-19-1988	USGS	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
74	51U144	Manassas	384553	0772716	07-21-1988	USGS	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
75		Manassas	384441	0773014	06-17-1986	IBM	<1.0	<1.0	<1.0	<20.0	<1.0	<1.0	<1.0	<1.0	<1.0
76		Manassas	384440	0773013	07-30-1987	IBM	–	<1.0	–	–	–	<1.0	<1.0	<1.0	<1.0
77		Manassas	384440	0773037	06-17-1986	IBM	<1.0	**15.0**	<1.0	<20.0	<1.0	<1.0	<1.0	<1.0	<1.0
78		Manassas	384451	0773003	06-17-1986	IBM	<1.0	<1.0	<1.0	<20.0	<1.0	<1.0	<1.0	<1.0	<1.0
79		Manassas	384439	0773042	10-08-1985	IBM	<1.0	**1.1**	<1.0	<20.0	<1.0	<1.0	<1.0	<1.0	<1.0
80		Manassas	384453	0772957	06-11-1985	PWHD	–	nd	nd	–	–	–	nd	nd	nd
81		Manassas	384503	0772931	07-24-1987	IBM	–	<1.0	–	–	–	<1.0	<1.0	<1.0	<1.0
82		Broad Run A	384417	0773147	07-01-1985	PWHD	–	nd	nd	–	–	–	nd	nd	nd
83		Broad Run A	384413	0773143	06-03-1986	PWHD	–	nd	nd	–	–	–	nd	nd	nd
84	MW-01	Manassas	384607	0772950	04-14-1987	DUNN	<1.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0	<1.0	<1.0
					04-14-1987	DUNN	<1.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0	<1.0	<1.0
					04-14-1987	DUNN	<1.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0	<1.0	<1.0
85	MW-02	Manassas	384609	0772941	04-15-1987	DUNN	<1.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0	<1.0	<1.0
					04-15-1987	DUNN	<1.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0	<1.0	<1.0
					04-15-1987	DUNN	<1.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0	<1.0	<1.0

Table 8.–*Selected water-quality analyses from reference wells used to delineate major areas of volatile organic contamination in the Culpeper basin of Prince William County*–Continued

[Values, in micrograms per liter; nd, indicates that compound was not detected; –, indicates no analysis for that particular compound; <, indicates less than value shown; Well number and location shown on plate 5]

Well number	Chloro-ethane	Ethyl-benzene	Bromo-methane	Chloro-methane	Methylene chloride	Tetra-chloro-ethylene	Trichloro-fluoro-methane	1,1-dichloro-ethane	1,1-dichloro-ethylene	1,1,1-trichloro-ethane	1,1,2-trichloro-ethane	1,1,2,2-tetrachloro-ethane	1,2-dichloro-benzene	1,2-dichloro-propane	Trans-1,2 dichloro-ethylene
61	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
62	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
63	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
64	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
65	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
66	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
67	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
68	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
69	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
70	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
71	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
72	<.2	<.2	<.2	<.2	<9.8	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
73	<.2	<.2	<.2	<.2	<10.0	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
74	<.2	<.2	<.2	<.2	<7.6	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
75	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	**41.0**	<1.0	<1.0	–	<1.0	<1.0
76	–	–	–	<1.0	<5.0	**68.0**	–	<1.0	<1.0	<1.0	<1.0	<1.0	–	–	<1.0
77	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	–	<1.0	<1.0
78	<1.0	<1.0	<1.0	<1.0	<1.0	**3.8**	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	–	<1.0	<1.0
79	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	–	<1.0	<1.0
80	nd	nd	nd	–	nd	nd	nd	–	nd	nd	–	–	–	nd	nd
81	–	–	–	<1.0	<5.0	<1.0	–	<1.0	**1.6**	**3.7**	<1.0	<1.0	–	–	<1.0
82	nd	nd	nd	–	nd	nd	nd	–	nd	nd	–	–	–	nd	nd
83	nd	nd	nd	–	nd	**9.2**	nd	–	**225.0**	nd	–	–	–	nd	nd
84	<1.0	<1.0	<5.0	<5.0	<1.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<2.0	–	<1.0	<1.0
	<1.0	<1.0	<5.0	<5.0	<1.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<2.0	–	<1.0	<1.0
	<1.0	<1.0	<5.0	<5.0	<1.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<2.0	–	<1.0	<1.0
85	<1.0	<1.0	<5.0	<5.0	<1.0	**33.0**	–	<1.0	<1.0	<1.0	<1.0	<2.0	–	<1.0	<1.0
	<1.0	<1.0	<5.0	<5.0	<1.0	**73.0**	–	<1.0	<1.0	<1.0	<1.0	<2.0	–	<1.0	<1.0
	<1.0	<1.0	<5.0	<5.0	<1.0	**94.0**	–	<1.0	<1.0	<1.0	<1.0	<2.0	–	<1.0	<1.0

Table 8.–*Selected water-quality analyses from reference wells used to delineate major areas of volatile organic contamination in the Culpeper basin of Prince William County*–Continued

[Values, in micrograms per liter; nd, indicates that compound was not detected; –, indicates no analysis for that particular compound; <, indicates less than value shown; Well number and location shown on plate 5]

Well number	Trichloro-benzenes	1,3-dichloro-propene	1,3-dichloro-benzene	1,4-dichloro-benzene	Chloroethyl-vinyl ether	Dichloro-fluoro-methane	Trans-1,3-dichloro-propene	Cis-1,3-dichloro-propene	Ethylene dibromide	Vinyl chloride	Trichloro-ethylene	Styrene	Dibromo-methane	Xylene
61	–	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	–	<0.2
62	–	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	–	<.2
63	–	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	–	<.2
64	–	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	**3.9**	<.2	–	<.2
65	–	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	–	<.2
66	–	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	–	<.2
67	–	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	–	<.2
68	–	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	–	<.2
69	–	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	–	<.2
70	–	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	–	<.2
71	–	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	–	<.2
72	–	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	–	<.2
73	–	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	–	<.2
74	–	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	–	<.2
75	–	–	–	–	<1.0	<1.0	–	<1.0	–	<20.0	<1.0	–	–	–
76	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
77	–	–	–	–	<1.0	<1.0	–	<1.0	–	<20.0	<1.0	–	–	–
78	–	–	–	–	<1.0	<1.0	–	<1.0	–	<20.0	<1.0	–	–	–
79	–	–	–	–	<1.0	<1.0	–	<1.0	–	<20.0	<1.0	–	–	–
80	–	nd	–	nd	–	nd	–	–	nd	nd	**1.9**	nd	nd	nd
81	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
82	–	nd	–	nd	–	nd	–	–	nd	nd	nd	nd	nd	nd
83	–	nd	–	nd	–	nd	–	–	nd	nd	**554.0**	nd	nd	nd
84	–	–	–	–	<10.0	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
	–	–	–	–	<10.0	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
	–	–	–	–	<10.0	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
85	–	–	–	–	<10.0	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
	–	–	–	–	<10.0	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
	–	–	–	–	<10.0	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–

Table 8.–*Selected water-quality analyses from reference wells used to delineate major areas of volatile organic contamination in the Culpeper basin of Prince William County*–Continued

[nd, indicates that compound was not detected; –, indicates no analysis for that particular compound; Well number and location shown on plate 5]

Well number	Cis-1,2-dichloro-ethylene	Methyl ethyl ketone	Trans & cis 1,3-dichloro-propane	Trihalo-methanes	Dibromo-chloro-propane	Remarks
61	–	–	–	–	–	
62	–	–	–	–	–	
63	–	–	–	–	–	
64	–	–	–	–	–	
65	–	–	–	–	–	
66	–	–	–	–	–	
67	–	–	–	–	–	
68	–	–	–	–	–	
69	–	–	–	–	–	
70	–	–	–	–	–	
71	–	–	–	–	–	
72	–	–	–	–	–	
73	–	–	–	–	–	
74	–	–	–	–	–	
75	–	–	–	–	–	
76	–	–	–	–	–	
77	–	–	–	–	–	
78	–	–	–	–	–	
79	–	–	–	–	–	
80	nd	–	–	–	nd	
81	–	–	–	–	–	
82	nd	–	–	–	nd	
83	nd	–	–	–	nd	
84	–	–	–	–	–	Sample depth 75 ft
	–	–	–	–	–	Sample depth 145 ft
	–	–	–	–	–	Sample depth 185-190 ft
85	–	–	–	–	–	Sample depth 125 ft
	–	–	–	–	–	Sample depth 150 ft
	–	–	–	–	–	Sample depth 185-190 ft

Table 8.–*Selected water-quality analyses from reference wells used to delineate major areas of volatile organic contamination in the Culpeper basin of Prince William County*–Continued

[Values, in micrograms per liter; –, indicates no analysis for that particular compound; <, indicates less than value shown; VOC, volatile organic compounds; DUNN, Dunn Geoscience Corp.; IBM, International Business Machine, Inc.; Well number and location shown on plate 5]

Well number	Other identifier	Area of VOC contamination	Latitude	Longitude	Date sampled	Agency	Bromo-dichloro-methane	Carbon tetra-chloride	1,2-dichloro-ethane	Bromo-form	Dibromo-chloro-methane	Chloroform	Toluene	Benzene	Chloro-benzene
86	MW-03	Manassas	384605	0772932	04-14-1987	DUNN	<1.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0	<1.0	<1.0
					04-15-1987	DUNN	<1.0	<1.0	<1.0	<2.0	<1.0	**1.0**	<1.0	<1.0	<1.0
					04-15-1987	DUNN	<1.0	<1.0	<1.0	<2.0	<1.0	**4.0**	<1.0	<1.0	<1.0
87	MW-04	Manassas	384620	0772934	04-16-1987	DUNN	<1.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0	<1.0	<1.0
					04-16-1987	DUNN	<1.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0	<1.0	<1.0
					04-16-1987	DUNN	<1.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0	<1.0	<1.0
88	MW-05	Manassas	384618	0772921	04-15-1987	DUNN	<1.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0	<1.0	<1.0
					04-15-1987	DUNN	<1.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0	<1.0	<1.0
					04-15-1987	DUNN	<1.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0	<1.0	<1.0
89	MW-06	Manassas	384609	0772917	04-17-1987	DUNN	<1.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0	<1.0	<1.0
					04-17-1987	DUNN	<1.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0	<1.0	<1.0
					04-17-1987	DUNN	<1.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0	<1.0	<1.0
					04-17-1987	DUNN	<1.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0	<1.0	<1.0
90	MW-08	Manassas	384537	0772950	04-17-1987	DUNN	<1.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0	<1.0	<1.0
					04-17-1987	DUNN	<1.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0	<1.0	<1.0
					04-17-1987	DUNN	<1.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0	<1.0	<1.0
91	MW-09	Manassas	384602	0772945	04-22-1987	DUNN	<1.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0	<1.0	<1.0
					04-22-1987	DUNN	<1.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0	<1.0	<1.0
					04-22-1987	DUNN	<1.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0	<1.0	<1.0
92	OF-08	Manassas	384548	0772958	01-20-1988	IBM	–	<10.0	–	–	–	<10.0	<10.0	<10.0	<10.0
93	OF-15	Manassas	384443	0773019	01-20-1988	IBM	–	<1.0	–	–	–	<1.0	<1.0	<1.0	<1.0
94	OF-17	Manassas	384427	0773117	01-28-1988	IBM	–	<1.0	–	–	–	<1.0	<1.0	<1.0	<1.0
95	OF-43	Manassas	384518	0772940	02-01-1988	IBM	–	<1.0	–	–	–	<1.0	<1.0	<1.0	<1.0
96	HO-02	Manassas	384504	0772932	07-24-1987	IBM	–	<1.0	–	–	–	<1.0	<1.0	<1.0	<1.0
97	HO-03	Manassas	384513	0772943	02-18-1986	IBM	<1.0	<1.0	<1.0	<20.0	<1.0	<1.0	<1.0	<1.0	<1.0
98	HO-04	Manassas	384541	0773029	02-01-1988	IBM	–	<1.0	–	–	–	<1.0	<1.0	<1.0	<1.0
99	HO-05	Manassas	384541	0773030	01-29-1988	IBM	–	<1.0	–	–	–	<1.0	<1.0	<1.0	<1.0
100	HO-06	Manassas	384541	0773032	01-29-1988	IBM	–	<1.0	–	–	–	<1.0	<1.0	<1.0	<1.0
101	HO-12	Manassas	384543	0773037	10-15-1985	IBM	<1.0	<1.0	<1.0	<20.0	<1.0	<1.0	<1.0	<1.0	<1.0
102	HO-15	Manassas	384542	0773041	10-15-1985	IBM	<1.0	<1.0	<1.0	<20.0	<1.0	<1.0	<1.0	<1.0	<1.0

Table 8.–*Selected water-quality analyses from reference wells used to delineate major areas of volatile organic contamination in the Culpeper basin of Prince William County*–Continued

[Values, in micrograms per liter; –, indicates no analysis for that particular compound; <, indicates less than value shown; Well number and location shown on plate 5]

Well number	Chloro-ethane	Ethyl-benzene	Bromo-methane	Chloro-methane	Methylene chloride	Tetra-chloro-ethylene	Trichloro-fluoro-methane	1,1-dichloro-ethane	1,1-dichloro-ethylene	1,1,1-trichloro-ethane	1,1,2-trichloro-ethane	1,1,2,2-tetrachloro-ethane	1,2-dichloro-benzene	1,2-dichloro-propane	Trans-1,2 dichloro-ethylene
86	<1.0	<1.0	<5.0	<5.0	<1.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<2.0	–	<1.0	<1.0
	<1.0	<1.0	<5.0	<5.0	<1.0	**36.0**	–	<1.0	<1.0	<1.0	<1.0	<2.0	–	<1.0	<1.0
	<1.0	<1.0	<5.0	<5.0	<1.0	**32.0**	–	<1.0	<1.0	<1.0	<1.0	<2.0	–	<1.0	<1.0
87	<1.0	<1.0	<5.0	<5.0	<1.0	**31.0**	–	<1.0	<1.0	<1.0	<1.0	<2.0	–	<1.0	<1.0
	<1.0	<1.0	<5.0	<5.0	<1.0	**27.0**	–	<1.0	<1.0	<1.0	<1.0	<2.0	–	<1.0	<1.0
	<1.0	<1.0	<5.0	<5.0	<1.0	**11.0**	–	<1.0	<1.0	<1.0	<1.0	<2.0	–	<1.0	<1.0
88	<1.0	<1.0	<5.0	<5.0	<1.0	**44.0**	–	<1.0	<1.0	<1.0	<1.0	<2.0	–	<1.0	<1.0
	<1.0	<1.0	<5.0	<5.0	<1.0	**73.0**	–	<1.0	<1.0	<1.0	<1.0	<2.0	–	<1.0	<1.0
	<1.0	<1.0	<5.0	<5.0	<1.0	**86.0**	–	<1.0	<1.0	<1.0	<1.0	<2.0	–	<1.0	<1.0
89	<1.0	<1.0	<5.0	<5.0	<1.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<2.0	–	<1.0	<1.0
	<1.0	<1.0	<5.0	<5.0	<1.0	**30.0**	–	<1.0	<1.0	<1.0	<1.0	<2.0	–	<1.0	<1.0
	<1.0	<1.0	<5.0	<5.0	<1.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<2.0	–	<1.0	<1.0
	<1.0	<1.0	<5.0	<5.0	<1.0	**29.0**	–	<1.0	<1.0	<1.0	<1.0	<2.0	–	<1.0	<1.0
90	<1.0	<1.0	<5.0	<5.0	<1.0	**9.0**	–	<1.0	<1.0	<1.0	<1.0	<2.0	–	<1.0	<1.0
	<1.0	<1.0	<5.0	<5.0	<1.0	**150.0**	–	<1.0	<1.0	<1.0	<1.0	<2.0	–	<1.0	**5.0**
	<1.0	<1.0	<5.0	<5.0	<1.0	**160.0**	–	<1.0	<1.0	<1.0	<1.0	<2.0	–	<1.0	**4.0**
91	<1.0	<1.0	<5.0	<5.0	<1.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<2.0	–	<1.0	<1.0
	<1.0	<1.0	<5.0	<5.0	<1.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<2.0	–	<1.0	<1.0
	<1.0	<1.0	<5.0	<5.0	<1.0	**1.0**	–	<1.0	<1.0	<1.0	<1.0	<2.0	–	<1.0	<1.0
92	–	–	–	<10.0	<10.0	**5,320.0**	–	<10.0	<10.0	<10.0	<10.0	<10.0	–	–	**16.0**
93	–	–	–	<1.0	<5.0	**11.4**	–	<1.0	<1.0	<1.0	<1.0	<1.0	–	–	<1.0
94	–	–	–	<1.0	<5.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<1.0	–	–	<1.0
95	–	–	–	<1.0	<5.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<1.0	–	–	<1.0
96	–	–	–	<1.0	<5.0	<1.0	–	**1.0**	**1.5**	**3.6**	<1.0	<1.0	–	–	<1.0
97	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	**1.5**	<1.0	<1.0	–	<1.0	<1.0
98	–	–	–	<1.0	<5.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<1.0	–	–	<1.0
99	–	–	–	<1.0	<5.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<1.0	–	–	<1.0
100	–	–	–	<1.0	<5.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<1.0	–	–	<1.0
101	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	–	<1.0	<1.0
102	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	–	<1.0	<1.0

Table 8.–*Selected water-quality analyses from reference wells used to delineate major areas of volatile organic contamination in the Culpeper basin of Prince William County*–Continued

[Values, in micrograms per liter; –, indicates no analysis for that particular compound; <, indicates less than value shown; Well number and location shown on plate 5]

Well number	Trichloro-benzenes	1,3-dichloro-propene	1,3-dichloro-benzene	1,4-dichloro-benzene	Chloroethyl-vinyl ether	Dichloro-fluoro-methane	Trans-1,3-dichloro-propene	Cis-1,3-dichloro-propene	Ethylene dibromide	Vinyl chloride	Trichloro-ethylene	Styrene	Dibromo-methane	Xylene
86	–	–	–	–	<10.0	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
	–	–	–	–	<10.0	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
	–	–	–	–	<10.0	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
87	–	–	–	–	<10.0	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
	–	–	–	–	<10.0	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
	–	–	–	–	<10.0	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
88	–	–	–	–	<10.0	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
	–	–	–	–	<10.0	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
	–	–	–	–	<10.0	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
89	–	–	–	–	<10.0	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
	–	–	–	–	<10.0	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
	–	–	–	–	<10.0	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
	–	–	–	–	<10.0	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
90	–	–	–	–	<10.0	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
	–	–	–	–	<10.0	–	<1.0	<1.0	–	<1.0	**6.0**	–	–	–
	–	–	–	–	<10.0	–	<1.0	<1.0	–	<1.0	**2.0**	–	–	–
91	–	–	–	–	<10.0	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
	–	–	–	–	<10.0	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
	–	–	–	–	<10.0	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
92	–	–	–	–	–	–	<10.0	<10.0	-	<10.0	**11.0**	–	–	<10.0
93	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
94	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
95	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
96	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
97	–	–	–	–	<1.0	<1.0	–	<1.0	–	<20.0	<1.0	–	–	–
98	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
99	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
100	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
101	–	–	–	–	<1.0	<1.0	–	<1.0	–	<20.0	<1.0	–	–	–
102	–	–	–	–	<1.0	<1.0	–	<1.0	–	<20.0	<1.0	–	–	–

Table 8.–*Selected water-quality analyses from reference wells used to delineate major areas of volatile organic contamination in the Culpeper basin of Prince William County*–Continued

[–, indicates no analysis for that particular compound; Well number and location shown on plate 5]

Well number	Cis-1,2-dichloro-ethylene	Methyl ethyl ketone	Trans & cis 1,3-dichloro-propane	Trihalo-methanes	Dibromo-chloro-propane	Remarks
86	–	–	–	–	–	Sample depth 80 ft
	–	–	–	–	–	Sample depth 130 ft
	–	–	–	–	–	Sample depth 180-190 ft
87	–	–	–	–	–	Sample depth 120-125 ft
	–	–	–	–	–	Sample depth 165 ft
	–	–	–	–	–	Sample depth 190 ft
88	–	–	–	–	–	Sample depth 125 ft
	–	–	–	–	–	Sample depth 175 ft
	–	–	–	–	–	Sample depth 190 ft
89	–	–	–	–	–	Sample depth 100 ft
	–	–	–	–	–	Sample depth 135-140 ft
	–	–	–	–	–	Sample depth 170-175 ft
	–	–	–	–	–	Sample depth 190 ft
90	–	–	–	–	–	Sample depth 110-120 ft
	–	–	–	–	–	Sample depth 145-150 ft
	–	–	–	–	–	Sample depth 175-190 ft
91	–	–	–	–	–	Sample depth 75 ft
	–	–	–	–	–	Sample depth 125 ft
	–	–	–	–	–	Sample depth 185-190 ft
92	–	–	–	–	–	
93	–	–	–	–	–	
94	–	–	–	–	–	
95	–	–	–	–	–	
96	–	–	–	–	–	
97	–	–	–	–	–	
98	–	–	–	–	–	
99	–	–	–	–	–	
100	–	–	–	–	–	
101	–	–	–	–	–	
102	–	–	–	–	–	

Table 8.–*Selected water-quality analyses from reference wells used to delineate major areas of volatile organic contamination in the Culpeper basin of Prince William County*–Continued

[Values, in micrograms per liter; –, indicates no analysis for that particular compound; <, indicates less than value shown; VOC, volatile organic compounds; IBM, International Business Machine, Inc.; PWHD, Prince William Health District; Well number and location shown on plate 5]

Well number	Other identifier	Area of VOC contamination	Latitude	Longitude	Date sampled	Agency	Bromo-dichloro-methane	Carbon tetra-chloride	1,2-dichloro-ethane	Bromo-form	Dibromo-chloro-methane	Chloroform	Toluene	Benzene	Chloro-benzene
103	HO-16	Manassas	384538	0773043	06-25-1985	IBM	<1.0	<1.0	<1.0	<20.0	<1.0	<1.0	<1.0	<1.0	<1.0
104	HO-17	Manassas	384543	0773049	10-22-1985	IBM	<1.0	<1.0	<1.0	<20.0	<1.0	<1.0	<1.0	<1.0	<1.0
105	HO-18	Manassas	384543	0773044	10-22-1985	IBM	<1.0	<1.0	<1.0	<20.0	<1.0	<1.0	<1.0	<1.0	<1.0
106	HO-19	Manassas	384541	0773044	10-22-1985	IBM	<1.0	<1.0	<1.0	<20.0	<1.0	<1.0	<1.0	<1.0	<1.0
107	HO-22	Manassas	384545	0773023	01-26-1988	IBM	–	<1.0	–	–	–	<1.0	<1.0	<1.0	<1.0
108	HO-23	Manassas	384546	0773023	02-01-1988	IBM	–	<1.0	–	–	–	<1.0	<1.0	<1.0	<1.0
109	HO-24	Manassas	384547	0773023	01-29-1988	IBM	–	<1.0	–	–	–	<1.0	<1.0	<1.0	<1.0
110	HO-25	Manassas	384549	0773024	01-29-1988	IBM	–	<1.0	–	–	–	<1.0	<1.0	<1.0	<1.0
111	HO-26	Manassas	384515	0772935	06-05-1985	PWHD	<0.4	<0.6	**0.1**	<0.9	<0.6	**0.2**	<1.2	<0.9	<1.2
112	HO-28	Manassas	384440	0773103	10-08-1985	IBM	<1.0	**1.1**	<1.0	<20.0	<1.0	<1.0	<1.0	<1.0	<1.0
113	HO-30	Manassas	384435	0773052	06-05-1985	PWHD	<.4	<.6	<.6	<.9	<.6	**.3**	<1.2	<.9	<1.2
114	HO-31	Manassas	384438	0773043	06-05-1985	PWHD	<.4	<.6	<.6	<.9	<.6	<.3	<1.2	<.9	<1.2
115	HO-34	Manassas	384441	0773034	07-21-1987	IBM	–	<1.0	–	–	–	<1.0	<1.0	<1.0	<1.0
116	HO-35	Manassas	384447	0773017	06-05-1985	PWHD	<.4	<.6	<.6	<.9	<.6	**.3**	<1.2	<.9	<1.2
117	HO-40	Manassas	384509	0773036	01-25-1988	IBM	–	<1.0	–	–	–	<1.0	**1.1**	<1.0	<1.0
118	HO-41	Manassas	384433	0773041	06-05-1985	PWHD	<.4	<.6	<.6	<.9	<.6	**.1**	<1.2	<.9	<1.2
119	HO-42	Manassas	384427	0773035	06-05-1985	PWHD	<.4	<.6	<.6	<.9	<.6	**.1**	<1.2	<.9	<1.2
120	HO-43	Manassas	384427	0773027	06-05-1985	PWHD	<.4	<.6	<.6	<.9	<.6	<.3	<1.2	<.9	<1.2
121	HO-44	Manassas	384506	0772935	07-24-1987	IBM	–	<1.0	–	–	–	<1.0	<1.0	<1.0	<1.0
122	HO-45	Manassas	384549	0773106	06-05-1985	PWHD	<.4	<.6	<.6	<.9	<.6	**.3**	<1.2	<.9	<1.2
123	HO-46	Manassas	384552	0773109	06-05-1985	PWHD	<.4	<.6	<.6	<.9	<.6	<.3	<1.2	<.9	<1.2
124	HO-49	Manassas	384447	0773001	07-21-1987	IBM	–	<1.0	–	–	–	<1.0	<1.0	<1.0	<1.0
125	HO-53	Manassas	384447	0772953	10-01-1985	IBM	<1.0	**11.0**	<1.0	<20.0	<1.0	**50.0**	<1.0	<1.0	<1.0
126	HO-54	Manassas	384443	0772953	06-05-1985	PWHD	<.4	<.6	<.6	<.9	<.6	<.3	<1.2	<.9	<1.2
127	HO-55	Manassas	384444	0772956	10-01-1985	IBM	<1.0	<1.0	<1.0	<20.0	<1.0	<1.0	<1.0	**1.6**	<1.0
128	HO-56	Manassas	384440	0773007	06-05-1985	PWHD	<.4	<.6	<.6	<.9	<.6	<.3	<1.2	<.9	<1.2
129	HO-61	Manassas	384604	0773114	06-05-1985	PWHD	<.4	<.6	<.6	<.9	<.6	<.3	<1.2	<.9	<1.2
130	HO-64	Manassas	384444	0773030	07-24-1987	IBM	–	<1.0	–	–	–	<1.0	<1.0	<1.0	<1.0
131	HO-65	Manassas	384633	0773032	07-22-1987	IBM	–	<1.0	–	–	–	<1.0	<1.0	<1.0	<1.0
132	HO-68	Manassas	384459	0772946	07-21-1987	IBM	–	<1.0	–	–	–	<1.0	<1.0	<1.0	<1.0

Table 8.–*Selected water-quality analyses from reference wells used to delineate major areas of volatile organic contamination in the Culpeper basin of Prince William County*–Continued

[Values, in micrograms per liter; nd, indicates that compound was not detected; –, indicates no analysis for that particular compound; <, indicates less than value shown; Well number and location shown on plate 5]

Well number	Chloro-ethane	Ethyl-benzene	Bromo-methane	Chloro-methane	Methylene chloride	Tetra-chloro-ethylene	Trichloro-fluoro-methane	1,1-dichloro-ethane	1,1-dichloro-ethylene	1,1,1-trichloro-ethane	1,1,2-trichloro-ethane	1,1,2,2-tetrachloro-ethane	1,2-dichloro-benzene	1,2-dichloro-propane	Trans-1,2 dichloro-ethylene
103	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	–	<1.0	<1.0
104	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	–	<1.0	<1.0
105	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	–	<1.0	<1.0
106	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	–	<1.0	<1.0
107	–	–	–	<1.0	<5.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<1.0	–	–	<1.0
108	–	–	–	<1.0	<5.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<1.0	–	–	<1.0
109	–	–	–	<1.0	<5.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<1.0	–	–	<1.0
110	–	–	–	<1.0	<5.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<1.0	–	–	<1.0
111	nd	<1.4	nd	nd	**0.3**	**0.1**	nd	**1.0**	**0.9**	**34.8**	**0.1**	**1.0**	nd	<1.2	<0.3
112	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	–	<1.0	<1.0
113	nd	<1.4	nd	nd	**1.1**	<.8	nd	<0.9	<.6	**0.1**	<1.0	<3.4	nd	<1.2	<.3
114	nd	<1.4	nd	nd	**.9**	<.8	nd	<.9	<.6	<.8	<1.0	<3.4	nd	<1.2	<.3
115	–	–	–	<1.0	<5.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<1.0	–	–	<1.0
116	nd	<1.4	nd	nd	**1.0**	**.3**	nd	<.9	<.6	**.1**	<1.0	**0.3**	nd	<1.2	<.3
117	–	–	–	<1.0	<5.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<1.0	–	–	<1.0
118	nd	<1.4	nd	nd	**.3**	<.8	nd	<.9	<.6	**.1**	<1.0	<3.4	nd	<1.2	<.3
119	nd	<1.4	nd	nd	<.6	**.1**	nd	**.3**	**.4**	**.8**	<1.0	**.1**	nd	<1.2	<.3
120	nd	<1.4	nd	nd	<.6	**.1**	nd	<.9	<.6	**.1**	<1.0	**.2**	nd	<1.2	<.3
121	–	–	–	<1.0	<5.0	<1.0	–	<1.0	**1.5**	**3.3**	<1.0	<1.0	–	–	<1.0
122	nd	<1.4	nd	nd	<.6	**.1**	nd	<.9	<.6	**.1**	<1.0	**.1**	nd	<1.2	<.3
123	nd	<1.4	nd	nd	<.6	**.1**	nd	<.9	<.6	**.1**	<1.0	**.1**	nd	<1.2	<.3
124	–	–	–	<1.0	<5.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<1.0	–	–	<1.0
125	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	–	<1.0	<1.0
126	nd	<1.4	nd	nd	<.6	<.8	nd	<.9	<.6	**.1**	<1.0	<3.4	nd	<1.2	<.3
127	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	–	<1.0	<1.0
128	nd	<1.4	nd	nd	<.6	<.8	nd	<.9	<.6	**.1**	<1.0	**.1**	nd	<1.2	<.3
129	nd	<1.4	nd	nd	**1.0**	<.8	nd	<.9	<.6	**.2**	<1.0	<3.4	nd	<1.2	<.3
130	–	–	–	<1.0	<5.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<1.0	–	–	<1.0
131	–	–	–	<1.0	<5.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<1.0	–	–	<1.0
132	–	–	–	<1.0	<5.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<1.0	–	–	<1.0

Table 8.–*Selected water-quality analyses from reference wells used to delineate major areas of volatile organic contamination in the Culpeper basin of Prince William County*–Continued

[Values, in micrograms per liter; nd, indicates that compound was not detected; –, indicates no analysis for that particular compound; <, indicates less than value shown; Well number and location shown on plate 5]

Well number	Trichloro-benzenes	1,3-dichloro-propene	1,3-dichloro-benzene	1,4-dichloro-benzene	Chloroethyl-vinyl ether	Dichloro-fluoro-methane	Trans-1,3-dichloro-propene	Cis-1,3-dichloro-propene	Ethylene dibromide	Vinyl chloride	Trichloro-ethylene	Styrene	Dibromo-methane	Xylene
103	–	–	–	–	<1.0	<1.0	–	<1.0	–	<20.0	<1.0	–	–	–
104	–	–	–	–	<1.0	<1.0	–	<1.0	–	<20.0	<1.0	–	–	–
105	–	–	–	–	<1.0	<1.0	–	<1.0	–	<20.0	<1.0	–	–	–
106	–	–	–	–	<1.0	<1.0	–	<1.0	–	<20.0	<1.0	–	–	–
107	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
108	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
109	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
110	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
111	–	–	nd	nd	nd	–	nd	<0.1	–	nd	<0.4	–	–	–
112	–	–	–	–	<1.0	<1.0	–	<1.0	–	<20.0	<1.0	–	–	–
113	–	–	nd	nd	nd	–	nd	<.1	–	nd	<.4	–	–	–
114	–	–	nd	nd	nd	–	nd	<.1	–	nd	<.4	–	–	–
115	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
116	–	–	nd	nd	nd	–	nd	<.1	–	nd	<.4	–	–	–
117	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
118	–	–	nd	nd	nd	–	nd	<.1	–	nd	<.4	–	–	–
119	–	–	nd	nd	nd	–	nd	<.1	–	nd	<.4	–	–	–
120	–	–	nd	nd	nd	–	nd	<.1	–	nd	<.4	–	–	–
121	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
122	–	–	nd	nd	nd	–	nd	<.1	–	nd	<.4	–	–	–
123	–	–	nd	nd	nd	–	nd	<.1	–	nd	<.4	–	–	–
124	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
125	–	–	–	–	<1.0	<1.0	–	<1.0	–	<20.0	<1.0	–	–	–
126	–	–	nd	nd	nd	–	nd	<.1	–	nd	<.4	–	–	–
127	–	–	–	–	<1.0	<1.0	–	<1.0	–	<20.0	<1.0	–	–	–
128	–	–	nd	nd	nd	–	nd	<.1	–	nd	<.4	–	–	–
129	–	–	nd	nd	nd	–	nd	<.1	–	nd	<.4	–	–	–
130	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
131	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
132	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0

Table 8.–*Selected water-quality analyses from reference wells used to delineate major areas of volatile organic contamination in the Culpeper basin of Prince William County*–Continued

[–, indicates no analysis for that particular compound; Well number and location shown on plate 5]

Well number	Cis-1,2-dichloro-ethylene	Methyl ethyl ketone	Trans & cis 1,3-dichloro-propane	Trihalo-methanes	Dibromo-chloro-propane	Remarks
103	–	–	–	–	–	
104	–	–	–	–	–	
105	–	–	–	–	–	
106	–	–	–	–	–	
107	–	–	–	–	–	
108	–	–	–	–	–	
109	–	–	–	–	–	
110	–	–	–	–	–	
111	–	–	–	–	–	
112	–	–	–	–	–	
113	–	–	–	–	–	
114	–	–	–	–	–	
115	–	–	–	–	–	
116	–	–	–	–	–	
117	–	–	–	–	–	
118	–	–	–	–	–	
119	–	–	–	–	–	
120	–	–	–	–	–	
121	–	–	–	–	–	
122	–	–	–	–	–	
123	–	–	–	–	–	
124	–	–	–	–	–	
125	–	–	–	–	–	
126	–	–	–	–	–	
127	–	–	–	–	–	
128	–	–	–	–	–	
129	–	–	–	–	–	
130	–	–	–	–	–	
131	–	–	–	–	–	
132	–	–	–	–	–	

Table 8.–*Selected water-quality analyses from reference wells used to delineate major areas of volatile organic contamination in the Culpeper basin of Prince William County*–Continued

[Values, in micrograms per liter; –, indicates no analysis for that particular compound; <, indicates less than value shown; VOC, volatile organic compounds; PWCSA, Prince William County Service Authority; GTI, Groundwater Technology, Inc.; IBM, International Business Machine, Inc.; Well number and location shown on plate 5]

Well number	Other identifier	Area of VOC contamination	Latitude	Longitude	Date sampled	Agency	Bromo-dichloro-methane	Carbon tetra-chloride	1,2-dichloro-ethane	Bromo-form	Dibromo-chloro-methane	Chloroform	Toluene	Benzene	Chloro-benzene
133	HO-69	Manassas	384623	0772851	11-04-1987	IBM	–	<1.0	–	–	–	<1.0	<1.0	<1.0	<1.0
134	WG-01	Manassas	384702	0772842	07-09-1987	PWCSA	<0.4	<0.6	<0.6	<0.9	<0.6	<0.3	<1.2	<0.9	<1.2
135	WG-02	Manassas	384721	0772824	07-09-1987	PWCSA	<.4	<.6	<.6	<.9	<.6	<.3	<1.2	<.9	<1.2
136	WG-04	Manassas	384657	0773019	07-09-1987	PWCSA	<.4	<.6	<.6	<.9	<.6	<.3	<1.2	<.9	<1.2
137	WG-05	Manassas	384707	0772937	11-18-1987	IBM	–	<1.0	–	–	–	<1.0	<1.0	<1.0	<1.0
138	WG-06	Manassas	384710	0772907	07-09-1987	PWCSA	<.4	<.6	<.6	<.9	<.6	<.3	<1.2	<.9	<1.2
139	WG-07	Manassas	384615	0772928	07-09-1987	PWCSA	<.4	<.6	<.6	<.9	<.6	<.3	<1.2	<.9	<1.2
140	WG-08	Manassas	384715	0773026	07-09-1987	PWCSA	<.4	<.6	<.6	<.9	<.6	<.3	<1.2	<.9	<1.2
141	WG-09	Manassas	384751	0772952	07-09-1987	PWCSA	<.4	<.6	<.6	<.9	<.6	<.3	<1.2	<.9	<1.2
142	WG-10	Manassas	384740	0772923	07-09-1987	PWCSA	<.4	<.6	<.6	<.9	<.6	<.3	<1.2	<.9	
143	WG-11	Manassas	384741	0772844	07-09-1987	PWCSA	<.4	<.6	<.6	<.9	<.6	<.3	<1.2	<.9	
144	WG-13	Gainesville B	384710	0773637	07-09-1987	PWCSA	<.4	<.6	<.6	<.9	<.6	<.3	<1.2	<.9	[illegible]
145	WG-14	Gainesville B	384724	0773703	07-09-1987	PWCSA	<.4	<.6	<.6	<.9	<.6	<.3	<1.2	<.9	<1.2
146	WG-17	Gainesville B	384640	0773611	07-09-1987	PWCSA	<.4	<.6	<.6	<.9	<.6	<.3	<1.2	<.9	<1.2
147	WY-06	Manassas	384705	0772654	07-09-1987	PWCSA	<.4	<.6	<.6	<.9	<.6	<.3	<1.2	<.9	<1.2
148	WY-09	Manassas	384728	0772706	08-13-1987	PWCSA	<.4	<.6	<.6	<.9	<.6	<.3	<1.2	<.9	<1.2
149	WY-11	Manassas	384644	0772711	07-09-1987	PWCSA	<.4	<.6	<.6	<.9	<.6	<.3	<1.2	<.9	<1.2
150		Gainesville A	384717	0773509	03-27-1987	GTI	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
151		Gainesville A	384712	0773502	03-27-1987	GTI	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
152		Gainesville A	384710	0773457	03-27-1987	GTI	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
153		Gainesville A	384728	0773343	03-27-1987	GTI	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
154		Gainesville A	384734	0773346	02-11-1987	GTI	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
155		Gainesville A	384740	0773544	03-27-1987	GTI	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
156		Gainesville A	384650	0773441	03-27-1987	GTI	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
157		Gainesville A	384716	0773522	01-28-1987	GTI	–	–	<1.0	–	–	<1.0	–	–	<1.0
158	ARC 02	Gainesville A	384706	0773435	03-24-1987	GTI	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
159	ARC 05	Gainesville A	384741	0773443	03-26-1987	GTI	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
160	ARC 06	Gainesville A	384741	0773440	03-26-1987	GTI	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.8	<1.0
161	ARC 07	Gainesville A	384739	0773447	03-24-1987	GTI	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
162	ARC 09	Gainesville A	384730	0773524	03-25-1987	GTI	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.7

Table 8.–*Selected water-quality analyses from reference wells used to delineate major areas of volatile organic contamination in the Culpeper basin of Prince William County*–Continued

[Values, in micrograms per liter; nd, indicates that compound was not detected; –, indicates no analysis for that particular compound; <, indicates less than value shown; Well number and location shown on plate 5]

Well number	Chloro-ethane	Ethyl-benzene	Bromo-methane	Chloro-methane	Methylene chloride	Tetra-chloro-ethylene	Trichloro-fluoro-methane	1,1-dichloro-ethane	1,1-dichloro-ethylene	1,1,1-trichloro-ethane	1,1,2-trichloro-ethane	1,1,2,2-tetrachloro-ethane	1,2-dichloro-benzene	1,2-dichloro-propane	Trans-1,2 dichloro-ethylene
133	–	–	–	<1.0	<5.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<1.0	–	–	<1.0
134	nd	<1.4	nd	nd	<0.6	<0.8	nd	<0.9	<0.6	<0.8	<1.0	<3.4	nd	<1.2	<0.3
135	nd	<1.4	nd	nd	<.6	<.8	nd	<.9	<.6	<.8	<1.0	<3.4	nd	<1.2	<.3
136	nd	<1.4	nd	nd	<.6	**.4**	nd	<.9	<.6	<.8	<1.0	<3.4	nd	<1.2	**.6**
137	–	–	–	<1.0	<5.0	<1.0	–	<1.0	<1.0	<1.0	<1.0	<1.0	–	–	<1.0
138	nd	<1.4	nd	nd	<.6	<.8	nd	<.9	**.6**	<.8	<1.0	<3.4	nd	<1.2	<.3
139	nd	<1.4	nd	nd	<.6	**275.0**	nd	<.9	<.6	<.8	<1.0	<3.4	nd	<1.2	<.3
140	nd	<1.4	nd	nd	<.6	<.8	nd	<.9	<.6	<.8	<1.0	<3.4	nd	<1.2	<.3
141	nd	<1.4	nd	nd	<.6	<.8	nd	<.9	<.6	<.8	<1.0	<3.4	nd	<1.2	<.3
142	nd	<1.4	nd	nd	<.6	<.8	nd	<.9	<.6	<.8	<1.0	<3.4	nd	<1.2	<.3
143	nd	<1.4	nd	nd	<.6	<.8	nd	<.9	<.6	<.8	<1.0	<3.4	nd	<1.2	<.3
144	nd	<1.4	nd	nd	<.6	<.8	nd	<.9	<.6	<.8	<1.0	<3.4	nd	<1.2	<.3
145	nd	<1.4	nd	nd	<.6	<.8	nd	<.9	<.6	<.8	<1.0	<3.4	nd	<1.2	<.3
146	nd	<1.4	nd	nd	<.6	<.8	nd	<.9	<.6	<.8	<1.0	<3.4	nd	<1.2	<.3
147	nd	<1.4	nd	nd	<.6	<.8	nd	<.9	<.6	<.8	<1.0	<3.4	nd	<1.2	<.3
148	nd	<1.4	nd	nd	<.6	<.8	nd	<.9	<.6	<.8	<1.0	<3.4	nd	<1.2	<.3
149	nd	<1.4	nd	nd	<.6	<.8	nd	<.9	<.6	<.8	<1.0	<3.4	nd	<1.2	<.3
150	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
151	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
152	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
153	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
154	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
155	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
156	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
157	<1.0	–	–	<1.0	<1.0	**3.0**	–	<1.0	<1.0	<1.0	–	–	–	–	<1.0
158	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	**6.6**	**16.0**	**150.0**	<1.0	<1.0	<1.0	<1.0	<1.0
159	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
160	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
161	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	**2.6**	**26.0**	**76.0**	<1.0	<1.0	<1.0	<1.0	<1.0
162	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0

Table 8.–*Selected water-quality analyses from reference wells used to delineate major areas of volatile organic contamination in the Culpeper basin of Prince William County*–Continued

[Values, in micrograms per liter; nd, indicates that compound was not detected; –, indicates no analysis for that particular compound; <, indicates less than value shown; Well number and location shown on plate 5]

Well number	Trichloro-benzenes	1,3-dichloro-propene	1,3-dichloro-benzene	1,4-dichloro-benzene	Chloroethyl-vinyl ether	Dichloro-fluoro-methane	Trans-1,3-dichloro-propene	Cis-1,3-dichloro-propene	Ethylene dibromide	Vinyl chloride	Trichloro-ethylene	Styrene	Dibromo-methane	Xylene
133	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
134	–	–	nd	nd	nd	–	nd	<0.1	–	nd	<0.4	–	–	–
135	–	–	nd	nd	nd	–	nd	<.1	–	nd	<.4	–	–	–
136	–	–	nd	nd	nd	–	nd	<.1	–	nd	**.3**	–	–	–
137	–	–	–	–	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	<1.0
138	–	–	nd	nd	nd	–	nd	<.1	–	nd	<.4	–	–	–
139	–	–	nd	nd	nd	–	nd	<.1	–	nd	**7.0**	–	–	–
140	–	–	nd	nd	nd	–	nd	<.1	–	nd	<.4	–	–	–
141	–	–	nd	nd	nd	–	nd	<.1	–	nd	<.4	–	–	–
142	–	–	nd	nd	nd	–	nd	<.1	–	nd	<.4	–	–	–
143	–	–	nd	nd	nd	–	nd	<.1	–	nd	<.4	–	–	–
144	–	–	nd	nd	nd	–	nd	<.1	–	nd	<.4	–	–	–
145	–	–	nd	nd	nd	–	nd	<.1	–	nd	<.4	–	–	–
146	–	–	nd	nd	nd	–	nd	<.1	–	nd	<.4	–	–	–
147	–	–	nd	nd	nd	–	nd	<.1	–	nd	<.4	–	–	–
148	–	–	nd	nd	nd	–	nd	<.1	–	nd	**.9**	–	–	–
149	–	–	nd	nd	nd	–	nd	<.1	–	nd	<.4	–	–	–
150	–	–	<1.0	<1.0	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
151	–	–	<1.0	<1.0	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
152	–	–	<1.0	<1.0	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
153	–	–	<1.0	<1.0	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
154	–	–	<1.0	<1.0	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
155	–	–	<1.0	<1.0	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
156	–	–	<1.0	**1.8**	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
157	–	–	–	–	–	–	–	–	–	<1.0	<1.0	–	–	–
158	–	–	<1.0	<1.0	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
159	–	–	<1.0	<1.0	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
160	–	–	<1.0	<1.0	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
161	–	–	<1.0	<1.0	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–
162	–	–	**12.0**	<1.0	–	–	<1.0	<1.0	–	<1.0	<1.0	–	–	–

Table 8.–*Selected water-quality analyses from reference wells used to delineate major areas of volatile organic contamination in the Culpeper basin of Prince William County*–Continued

[Values, in micrograms per liter; –, indicates no analysis for that particular compound; <, indicates less than value shown; Well number and location shown on plate 5]

Well number	Cis-1,2-dichloro-ethylene	Methyl ethyl ketone	Trans & cis 1,3-dichloro-propane	Trihalo-methanes	Dibromo-chloro-propane	Remarks
133	–	–	–	–	–	
134	–	–	–	–	–	
135	–	–	–	–	–	
136	–	–	–	–	–	
137	–	–	–	–	–	
138	–	–	–	–	–	
139	–	–	–	–	–	Pre-filtration raw water
140	–	–	–	–	–	
141	–	–	–	–	–	
142	–	–	–	–	–	
143	–	–	–	–	–	
144	–	–	–	–	–	
145	–	–	–	–	–	
146	–	–	–	–	–	
147	–	–	–	–	–	
148	–	–	–	–	–	
149	–	–	–	–	–	
150	–	<5.0	–	–	–	
151	–	<5.0	–	–	–	
152	–	<5.0	–	–	–	
153	–	<5.0	–	–	–	
154	–	<5.0	–	–	–	
155	–	<5.0	–	–	–	
156	–	<5.0	–	–	–	
157	–	–	–	–	–	
158	–	<5.0	–	–	–	
159	–	<5.0	–	–	–	
160	–	<5.0	–	–	–	
161	–	<5.0	–	–	–	
162	–	<5.0	–	–	–	

APPENDIX

APPENDIX: Geographic-information-system data dictionary

DATA LAYER: Bedrock geology of the Culpeper basin in Prince William County, Virginia

COVERAGE NAME: PWGEO.UTM

COVERAGE TYPE: Polygon

SOURCE: U.S. Geological Survey, Geologic Division

Leavy, B.D., Froelich, A.J., and Abram, E.C., 1983, Bedrock map and geotechnical properties of rocks of the Culpeper basin and vicinity, Virginia and Maryland: U.S. Geological Survey Miscellaneous Investigations Series Map I-1313-C, 1 sheet, scale 1:125,000.

CONTACT: U.S. Geological Survey
Branch of Distribution
1200 South Eads Street
Arlington, Virginia 22202

SCALE: 1:125,000

ACCURACY: National Map Accuracy Standards, not more than 10 percent of points tested shall be in error by more than approximately 422.4 ft.

PROJECTION INFORMATION: Standard Universal Transverse Mercator projection
Universal Transverse Mercator Zone 18

MAP UNITS: Meters

PROCESSING: Digitized from the mylar stable-base map by the Water Resources Division state office in Richmond, Virginia.

INFO ATTRIBUTE FILE: PWGEO.UTM.PAT

INFO ITEM DEFINITIONS:
AREA,4,12,F,3
PERIMETER,4,12,F,3
PWGEO#,4,5,B
PWGEO.UTM-ID,4,5,B
TYPE,5,5,C

INFO USER-DEFINED ITEM DESCRIPTIONS:

1) TYPE - type of lithology
   - B - Basalt
   - J - Diabase
   - T - Thermally metamorphosed rocks
   - S1 - Siltstone
   - S2 - Sandstone
   - S3 - Quartz conglomerate
   - S4 - Limestone conglomerate

DATA LAYER: Lineaments of the Culpeper basin in Prince William County, Virginia

COVERAGE NAME: LIN

COVERAGE TYPE: Line

SOURCE: U.S. Geological Survey, Geologic Division

Leavy, B.D., 1984, Map showing planar and linear features in the Culpeper basin and vicinity, Virginia and Maryland: U.S. Geological Survey Miscellaneous Investigations Series Map I-1313-G, 1 sheet, scale 1:125,000.

CONTACT: U.S. Geological Survey
Branch of Distribution
1200 South Eads Street
Arlington, Virginia 22202

SCALE: 1:125,000

ACCURACY: National Map Accuracy Standards, not more than 10 percent of points tested shall be in error by more than approximately 422.4 ft.

PROJECTION INFORMATION: Standard Universal Transverse Mercator projection
Universal Transverse Mercator Zone 18

MAP UNITS: Meters

PROCESSING: Digitized from the mylar stable-base map by the Water Resources Division state office in Richmond, Virginia.

INFO ATTRIBUTE FILE: LIN.AAT

INFO ITEM DEFINITIONS:
FNODE#,4,5,B
TNODE#,4,5,B
LPOLY#,4,5,B
RPOLY#,4,5,B
LENGTH,4,12,F,3
LIN#,4,5,B
LIN-ID,4,5,B
TYPE,10,10,C
BUFF,5,5,N,1

INFO USER-DEFINED ITEM DESCRIPTIONS:
1) TYPE
AIR - defined by aerial photography
AIRSAT - defined by both aerial photography and satellite imagery
LANDSAT - defined by Landsat satellite imagery
DIABASE - diabase and basalt lineaments

2) BUFF
This item can be used to set variable buffer distances for the different types of lineaments.

APPENDIX: Geographic-information-system data dictionary–Continued

DATA LAYER: Prince William County proposed supply-well fields

COVERAGE NAME: SUPPLY

COVERAGE TYPE: Polygon

SOURCE: Betz-Converse-Murdoch, Inc., 1982, Groundwater supply study for Prince William County, Virginia: 65 p.

CONTACT: Prince William Health District
9301 Lee Avenue
Manassas, Virginia 22110
703-335-6343

SCALE: 1:24,000

ACCURACY: National Map Accuracy Standards, not more than 10 percent of points tested shall be in error by more than approximately 40 ft.

PROJECTION INFORMATION: Standard Universal Transverse Mercator projection
Universal Transverse Mercator Zone 18

MAP UNITS: Meters

PROCESSING:

Sites for proposed supply-well fields in Prince William County were located in a ground-water development investigation by Betz-Converse-Murdoch. The well fields were delineated on U.S. Geological Survey 7.5-min quadrangle maps. The well-field sites were digitized by the Water Resources Division state office in Richmond, Virginia.

INFO ATTRIBUTE FILE: SUPPLY.PAT

INFO ITEM DEFINITIONS:

AREA,4,12,F,3
PERIMETER,4,12,F,3
PWALL#,4,5,B
PWALL-ID,4,5,B
SITE,2,2,C
SELECT,1,1,C

INFO USER-DEFINED ITEM DESCRIPTIONS:

1) SITE - site identification number

2) SELECT - indicates selection status of site
Y - site recommended for development
N - site not recommended for development

DATA LAYER: Hazardous-waste generators

COVERAGE NAME: SRC.ALL

COVERAGE TYPE: Polygon

SOURCES: Virgina Department of Health, Toxic Substances List
U.S. Geological Survey 7.5-min quadrangle maps

CONTACT: Virginia Department of Health
Bureau of Toxic Substances
109 Governor Street
Madison Building 918A
Richmond, Virginia 23219
804-786-1763

SCALE: 1:24,000

ACCURACY: National Map Accuracy Standards, not more than 10 percent of points tested shall be in error by more than approximately 40 ft.

PROJECTION INFORMATION: Standard Universal Transverse Mercator projection
Universal Transverse Mercator Zone 18

MAP UNITS: Meters

PROCESSING:

Point locations from the Virginia Department of Health's Toxic Substance List were field located on U.S. Geological Survey 7.5-min quadrangle maps. The geographic coordinates were converted to Universal Tranverse Mercator coordinates using the ARC/INFO [1] project command. The building outlines or industrial complex boundaries were then digitized to create polygons representing potential source areas. Not all sites present in the Toxic Substances List are included.

INFO ATTRIBUTE FILE: SRC.ALL

INFO ITEM DEFINITIONS:

AREA,4,12,F,3
PERIMETER,4,12,F,3
SRC#,4,5,B
SRC.ALL-ID,4,5,B
NAME,35,35,C
NUM,5,5,C

INFO USER-DEFINED ITEM DESCRIPTIONS:

1) NAME - name of company

2) NUM - The unique identification number given by the Health Department to each user or generator on the Toxic Substances List. Additional sources that are not included on the Virginia Department of Health's Toxic Substances List are given three digit numbers prefixed by 'GS'.

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

DATA LAYER: Prince William County public-supply wells

COVERAGE NAME: PWUSE

COVERAGE TYPE: Point

SOURCE: U.S. Geological Survey, Water Resources Division, State Water-Use Data System (SWUDS)

CONTACT: U.S. Geological Survey
3600 West Broad Street, Room 606
Richmond, Virginia 23230
804-771-2427

SCALE: 1:24,000

ACCURACY: National Map Accuracy Standards, not more than 10 percent of points tested shall be in error by more than approximately 40 ft.

PROJECTION INFORMATION: Standard Universal Transverse Mercator projection
Universal Transverse Mercator Zone 18

MAP UNITS: Meters

PROCESSING:

Ground-water users were retrieved from SWUDS by county FIPS code. Only those users who withdraw greater than 10,000 gallons per day are entered into SWUDS. The locations of the water users were taken directly from SWUDS and were field located. The geographic coordinates were converted to Universal Transverse Mercator coordinates using the ARC/INFO project command.

INFO ATTRIBUTE FILE: PWUSE.PAT

INFO ITEM DEFINITIONS:

AREA,4,12,F,3
PERIMETER,4,12,F,3
PWUSE#,4,5,B
PWUSE-ID,4,5,B

DATA LAYER: Inventoried wells

COVERAGE NAME: PWALL

COVERAGE TYPE: Point

SOURCES: U.S. Geological Survey, Water Resources Division, Ground Water Site Inventory (GWSI)
Prince William Health District
Prince William County Service Authority
Virginia Department of Waste Management
Private consulting firms

CONTACTS: U.S. Geological Survey
3600 West Broad Street, Room 606
Richmond, Virginia 23230
804-771-2427

Prince William Health District
9301 Lee Avenue
Manassas, Virginia 22110
703-335-6343

SCALE: 1:24,000

ACCURACY: National Map Accuracy Standards, not more than 10 percent of points tested shall be in error by more than approximately 40 ft.

PROJECTION INFORMATION: Standard Universal Transverse Mercator projection
Universal Transverse Mercator Zone 18

MAP UNITS: Meters

PROCESSING:

Well sites were field located on U.S. Geological Survey 7.5-min quadrangle maps. Latitudes and longitudes of point locations were digitized from the 7.5-min quadrangle maps using a 3-point orientation. The geographic coordinates were converted to Universal Transverse Mercator coordinates using the ARC/INFO project command.

INFO ATTRIBUTE FILE: PWALL.PAT

INFO ITEM DEFINITIONS:

AREA,4,12,F,3
PERIMETER,4,12,F,3
PWALL#,4,5,B
PWALL-ID,4,5,B
TYPE,10,10,C
ID,11,12,C
MARK,2,3,I

INFO USER-DEFINED ITEM DESCRIPTIONS:

1) TYPE - type of site.
GWSI - well in U.S. Geological Survey Ground-Water Site Inventory data base.
USGSVOC - well sampled by the U.S. Geological Survey for volatile organic compounds.
WCHECK - well sampled in Prince William Health District's water-quality sampling program.
VOC - well sampled by Prince William Health District, Prince William County Service Authority, Virginia Department of Waste Management, and private consulting firms specifically for volatile organic compounds.

2) ID - unique ID number for each well.

3) MARK - number of the marker symbol used for plotting.

APPENDIX: Geographic-information-system data dictionary–Continued

DATA LAYER: Prince William County hydrography

COVERAGE NAME: PWST

COVERAGE TYPE: Polygon and line

SOURCE: U.S. Geological Survey, National Mapping Division
U.S. GeoData Digital Line Graph data

CONTACT: U.S. Geological Survey
National Cartographic Information Center
507 National Center
Reston, Virginia 22092
703-860-6045

SCALE: 1:100,000

ACCURACY: National Map Accuracy Standards, not more than 10 percent of points tested shall be in error by more than approximately 158 ft.

PROJECTION INFORMATION: Standard Universal Transverse Mercator projection
Universal Transverse Mercator Zone 18

MAP UNITS: Meters

PROCESSING:

Digital Line Graph (DLG) data are available in half 1:100,000 scale map sheets. These map sheets contain sixteen individual 7.5-min quadrangle maps that are not edgematched. Edgematching is the process of connecting the lines on the boundaries of the individual maps. A magnetic tape of the DLG data was purchaced from National Mapping Division. The DLG files were converted to ARC/INFO coverages and edgematched. The edgematched coverage was clipped to the county boundary and the polygon attributes were checked using the 7.5-min quadrangle maps.

INFO ATTRIBUTE FILES: PWST.PAT (polygon)
PWST.AAT (line)

INFO ITEM DEFINITIONS:

PWST.PAT - AREA,4,12,F,3
PERIMETER,4,12,F,3
PWST#,4,5,B
PWST-ID,4,5,B
MAJOR1,6,7,I
MINOR1,6,7,I
MAJOR2,6,7,I
MINOR2,6,7,I

PWST.AAT - FNODE#,4,5,B
TNODE#,4,5,B
LPOLY#,4,5,B
RPOLY#,4,5,B
LENGTH,4,12,F,3
PWST#,4,5,B
PWST-ID,4,5,B
MAJOR1,6,7,I
MINOR1,6,7,I
MAJOR2,6,7,I
MINOR2,6,7,I
MAJOR3,6,7,I
MINOR3,6,7,I

INFO USER-DEFINED ITEM DESCRIPTIONS:

The following is a list of the DLG major and minor attributes found in the hydrography data for Prince William County. National Mapping Division provides a complete list of all possible DLG attributes in the Digital Line Graph Data Users Guide.

Major Codes:
50 - Hydrography
59 - Coincident feature

Minor Codes:
101 - Reservoir
111 - Marsh, wetland, swamp, bog
200 - Shoreline
202 - Closure line, (water-water)
204 - Apparent limit
412 - Stream
413 - Braided stream
421 - Lake or pond
605 - Right bank
606 - Left bank

APPENDIX: Geographic-information-system data dictionary–Continued

DATA LAYER: Prince William County roads

COVERAGE NAME: PWRD

COVERAGE TYPE: Line

SOURCE: U.S. Geological Survey, National Mapping Division
U.S. GeoData Digital Line Graph data

CONTACT: U.S. Geological Survey
National Cartographic Information Center
507 National Center
Reston, Virginia 22092
703-860-6045

SCALE: 1:100,000

ACCURACY: National Map Accuracy Standards, not more than 10 percent of points tested shall be in error by more than approximately 158 ft.

PROJECTION INFORMATION: Standard Universal Tranverse Mercator projection
Universal Tranverse Mercator Zone 18

MAP UNITS: Meters

PROCESSING:

Digital Line Graph (DLG) data are available in half 1:100,000 scale map sheets. These map sheets contain sixteen individual 7.5-min quadrangle maps that are not edgematched. Edgematching is the process of connecting the lines on the boundaries of the individual maps. A magnetic tape of the DLG data was purchaced from National Mapping Division. The DLG files were converted to ARC/INFO coverages and edgematched. The edgematched coverage was clipped to the county boundary to produce the final road network.

INFO ATTRIBUTE FILE: PWRD.AAT

INFO ITEM DEFINITIONS:

FNODE#,4,5,B
TNODE#,4,5,B
LPOLY#,4,5,B
RPOLY#,4,5,B
LENGTH,4,12,F,3
PWRD#,4,5,B
PWRD-ID,4,5,B

APPENDIX: Geographic-information-system data dictionary–Continued

DATA LAYER: Prince William County pipelines, transmission lines, and miscellaneous transportation

COVERAGE NAME: PWTR

COVERAGE TYPE: Line

SOURCE: U.S. Geological Survey, National Mapping Division
U.S. GeoData Digital Line Graph data

CONTACT: U.S. Geological Survey
National Cartographic Information Center
507 National Center
Reston, Virginia 22092
703-860-6045

SCALE: 1:100,000

ACCURACY: National Map Accuracy Standards, not more than 10 percent of points tested shall be in error by more than approximately 158 ft.

PROJECTION INFORMATION: Standard Universal Transverse Mercator projection
Universal Tranverse Mercator Zone 18

MAP UNITS: Meters

PROCESSING:

Digital Line Graph (DLG) data are available in half 1:100,000 scale map sheets. These map sheets contain sixteen individual 7.5-min quadrangle maps that are not edgematched. Edgematching is the process of connecting the lines on the boundaries of the individual maps. A magnetic tape of the DLG data was purchaced from National Mapping Division. The DLG files were converted to ARC/INFO coverages and edgematched. The edgematched coverage was clipped to the county boundary to produce the final coverage.

INFO ATTRIBUTE FILE: PWTR.AAT

INFO ITEM DEFINITIONS:

FNODE#,4,5,B
TNODE#,4,5,B
LPOLY#,4,5,B
RPOLY#,4,5,B
LENGTH,4,12,F,3
PWRR#,4,5,B
PWRR-ID,4,5,B
MAJOR1,6,7,I
MINOR1,6,7,I

INFO USER-DEFINED ITEM DESCRIPTIONS:

The following is a list of the DLG major and minor attributes found in the data for Prince William County. National Mapping Division provides a complete list of all possible DLG attributes in the Digital Line Graph Data User's Guide.

Major Codes:
190 - Pipelines, transmission lines, miscellaneous transportation

Minor Codes:
201 - Pipeline
202 - Power transmission line
203 - Telephone or telegraph line
403 - Landing strip, airport, perimeter of airport

APPENDIX: Geographic-information-system data dictionary–Continued

DATA LAYER: Prince William County railroads

COVERAGE NAME: PWRR

COVERAGE TYPE: Line

SOURCE: U.S. Geological Survey, National Mapping Division
U.S. GeoData Digital Line Graph data

CONTACT: U.S. Geological Survey
National Cartographic Information Center
507 National Center
Reston, Virginia 22092
703-860-6045

SCALE: 1:100,000

ACCURACY: National Map Accuracy Standards, not more than 10 percent of points tested shall be in error by more than approximately 158 ft.

PROJECTION INFORMATION: Standard Universal Transverse Mercator projection
Universal Transverse Mercator Zone 18

MAP UNITS: Meters

PROCESSING:

Digital Line Graph (DLG) data are available in half 1:100,000 scale map sheets. These map sheets contain sixteen individual 7.5-min quadrangle maps that are not edgematched. Edgematching is the process of connecting the lines on the boundaries of the individual maps. A magnetic tape of the DLG data was purchaced from National Mapping Division. The DLG files were converted to ARC/INFO coverages and edgematched. The edgematched coverage was clipped to the county boundary to produce the final railroad network.

INFO ATTRIBUTE FILE: PWRR.AAT

INFO ITEM DEFINITIONS:

FNODE#,4,5,B
TNODE#,4,5,B
LPOLY#,4,5,B
RPOLY#,4,5,B
LENGTH,4,12,F,3
PWRR#,4,5,B
PWRR-ID,4,5,B
MAJOR1,6,7,I
MINOR1,6,7,I
MAJOR2,6,7,I
MINOR2,6,7,I
MAJOR3,6,7,I
MINOR3,6,7,I
MAJOR4,6,7,I
MINOR4,6,7,I

INFO USER-DEFINED ITEM DESCRIPTIONS:

The following is a list of the DLG major and minor attributes found in the railroad data for Prince William County. National Mapping Division provides a complete list of all possible DLG attributes in the Digital Line Graph Data User's Guide.

Major Codes:
180 - Railroad
181 - Multiple element

Minor Codes:
2 - Tunnel portal
201 - Railroad
208 - Railroad siding
210 - Arbitrary line extension (join, closure)
602 - Overpassing, on bridge
605 - Underpassing

DATA LAYER: Thickness of overburden of the Culpeper basin in Prince William County, Virginia

COVERAGE NAME: OB

COVERAGE TYPE: Polygon and line

SOURCES: Driller's logs and other digital data layers (geology, lineaments, stream network)

CONTACT: U.S. Geological Survey
3600 West Broad Street, Room 606
Richmond, Virginia 23230
804-771-2427

SCALE: 1:100,000

ACCURACY: This map represents interpreted data; therefore, no quantitative value of accuracy can be expressed.

PROJECTION INFORMATION: Standard Universal Transverse Mercator projection
Universal Transverse Mercator Zone 18

MAP UNITS: Meters

PROCESSING:

Driller's logs were used to create a point coverage of overburden thicknesses throughout the study area. TIN, ARC/INFO's surface-modeling package, was used to contour the points. The original TIN contour map was interpreted and modified using overlays of the point locations, streams, lineaments, and geology. The geologic maps of Lee (1979, 1980), a map of the geotechnical properties of surface materials in the Culpeper basin (Froelich, 1985), and a soil map of Prince William County (Elder, 1986) were used to confirm the modified contour map of thickness of overburden. Arc and polygon labels were added to produce the final polygon and line coverages.

INFO ATTRIBUTE FILES: OB.PAT (polygon)
OB.AAT (line)

INFO ITEM DEFINITIONS:

OB.PAT - AREA,4,12,F,3
PERIMETER,4,12,F,3
OB#,4,5,B
OB-ID,4,5,B
CNT,4,4,I

OB.AAT - FNODE#,4,5,B
TNODE#,4,5,B
LPOLY#,4,5,B
RPOLY#,4,5,B
LENGTH,4,12,F,3
OB#,4,5,B
OB-ID,4,5,B
CNT,4,4,I

INFO USER-DEFINED ITEM DESCRIPTIONS:

1) CNT - Overburden thickness contour values

DATA LAYER: Potentiometric surface of the Culpeper basin of Prince William County, Virginia

COVERAGE NAME: POTSFC

COVERAGE TYPE: Polygon and line

SOURCES: U.S. Geological Survey synoptic water-level survey (September 1987)
Other digital data layers (geology, lineaments, stream network)

CONTACT: U.S. Geological Survey
3600 West Broad Street
Richmond, Virginia 23230
804-771-2427

SCALE: 1:100,000

ACCURACY: This map represents interpreted data; therefore, no quantitative value of accuracy can be expressed.

PROJECTION INFORMATION: Standard Universal Transverse Mercator projection
Universal Transverse Mercator Zone 18

MAP UNITS: Meters

PROCESSING:

A synoptic water-level survey was conducted by the U.S. Geological Survey for the Culpeper basin of Prince William County in September 1987. The water levels were used along with digitized altitudes along major stream channels to create a point coverage of the potentiometric surface throughout the study area. TIN, ARC/INFO's surface modeling package, was used to contour the points. The original TIN contour map was interpreted and modified using overlays of the water-level point values, stream altitudes, stream network, lineaments, and geology. Arc and polygon labels were added to produce the final potentiometric surface polygon and line coverages.

INFO ATTRIBUTE FILES: POTSFC.PAT (polygon)
POTSFC.AAT (line)

INFO ITEM DEFINITIONS:

POTSFC.PAT - AREA,4,12,F,3
PERIMETER,4,12,F,3
POTSFC#,4,5,B
POTSFC-ID,4,5,B
WL,4,4,I

POTSFC.AAT - FNODE#,4,5,B
TNODE#,4,5,B
LPOLY#,4,5,B
RPOLY#,4,5,B
LENGTH,4,12,F,3
POTSFC#,4,5,B
POTSFC-ID,4,5,B
WL,4,4,I

INFO USER-DEFINED ITEM DESCRIPTIONS:

1) WL - Potentiometric surface contour values

APPENDIX: Geographic-information-system data dictionary–Continued

DATA LAYER: Major areas of volatile organic contamination in the Culpeper basin of Prince William County, Virginia

COVERAGE NAME: CONAREAS

COVERAGE TYPE: Polygon

SOURCES: Wells sampled by U.S. Geological Survey, Prince William Health District, Prince William County Service Authority, Virginia Department of Waste Management, and private consulting firms.

CONTACT: U.S. Geological Survey
3600 West Broad Street, Room 606
Richmond, Virginia 23230
804-771-2427

SCALE: 1:100,000

ACCURACY: This map represents interpreted data; therefore, no quantitative value of accuracy can be expressed.

PROJECTION INFORMATION: Standard Universal Transverse Mercator projection
Universal Transverse Mercator Zone 18

MAP UNITS: Meters

PROCESSING:

Areas in which volatile organic compounds were detected in any concentration were delineated on U.S. Geological Survey 7.5-min quadrangle maps. The areas were digitized by the Water Resources Division state office in Richmond, Virginia.

INFO ATTRIBUTE FILES: CONAREAS.PAT (polygon)

INFO ITEM DEFINITIONS:

CONAREAS.PAT - AREA,4,12,F,3
PERIMETER,4,12,F,3
CONAREAS#,4,5,B
CONAREAS-ID,4,5,B
SITE,15,15,C

INFO USER-DEFINED ITEM DESCRIPTIONS:

1) SITE - Site names used to differentiate between areas of related contamination:
Manassas
Gainesville A
Gainesville B
Broad Run A
Broad Run B