GROUND-WATER HYDROLOGY AND QUALITY IN THE VALLEY AND RIDGE AND BLUE RIDGE PHYSIOGRAPHIC PROVINCES OF CLARKE COUNTY, VIRGINIA

by Winfield G. Wright

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CONVERSION FACTORS AND ABBREVIATIONS

The following factors may be used to convert inch-pound units to metric (International System) units.

Multiply inch-pound units	By	To obtain metric unit
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
	Volume	
gallon (gal)	3.785	liter (L)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer [(m^3/s)/km^2]
gallon per minute (gal/min)	0.06308	liter per second (L/s)

Chemical concentration, temperature, and specific conductance are given in metric units. Chemical concentration is expressed in milligrams per liter (mg/L). Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F), and conversely, by using the following equations:

$$°F = (1.8 \times °C) + 32$$
$$°C = (°F - 32) \times 0.5555$$

Specific conductance is expressed in microsiemens per centimeter (µS/cm) at 25 degrees Celsius.

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

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ABSTRACT

In the Valley and Ridge physiographic province in Clarke County, Virginia (valley region), ground water flows through solution-enlarged fractures in carbonate rocks. In the Blue Ridge physiographic province in the county (Blue Ridge region), ground water flows through fractures that are not solution enlarged in igneous and metamorphic rocks. Mixed diffuse-flow and conduit-flow conditions occur in the valley region, but diffuse-flow conditions predominate. Ground water in the carbonate rocks of the valley region flows along solution-enlarged fractures oriented parallel to the axes of the anticlines and synclines, along bedding-plane partings adjacent to and parallel to the bedding of the rocks, and across the bedding of the rocks following cross-strike faults and fractures. Ground water in the Blue Ridge region flows primarily along irregular fracture patterns in the rocks. Steep terrain in the Blue Ridge region facilitates percolation of shallow ground water through the overburden and rapid movement to springs, streams, and the Shenandoah River.

Ground water flows from recharge areas downgradient toward springs, streams, and rivers where it discharges. The direction of flow, however, may change over short distances because flow is controlled by the fractures in the rocks. Dye-tracing studies in the valley region indicated that ground water moved 2 miles from a sinkhole to a spring in about 5 months. Discharges from springs in the valley region are generally much greater than those in the Blue Ridge region because of the well-developed aquifer system of solution-enlarged fractures of the valley region. Hydrographs of discharges from three springs and water levels in one well in Clarke County indicate a net loss of ground water during summer months, because of increased evapotranspiration (ET); reduced ET during the fall months caused increased spring discharges and rising ground-water levels. High-yielding wells are not necessarily located on or near lineaments, possibly because of the highly fractured nature of the rocks in Clarke County.

Analyses of water from wells and springs indicate that ground water in the valley region contains greater concentrations of dissolved constituents, particularly calcium and magnesium, than does ground water in the Blue Ridge region. In the valley region, springs have slightly lower concentrations of dissolved minerals than do water from wells. Hardness concentrations in ground water in the valley region range from 89 to 422 mg/L (milligrams per liter) as calcium carbonate (moderately hard to very hard). Hardness concentrations in the Blue Ridge region range from 4 to 242 mg/L as calcium carbonate (soft to moderately hard).

Ground-water quality throughout much of Clarke County has been affected by human activities. Water from numerous wells throughout the county contained nitrate concentrations greater than the U.S. Environmental Protection Agency maximum contaminant level of 10 mg/L (as nitrogen) for drinking water; concentrations of nitrate greater than 5 mg/L in ground water were scattered throughout the county but are present in a disproportionately larger number of wells in the southwestern part. Water from several wells and springs that contained elevated concentrations of dissolved chloride and dissolved sodium also contained elevated concentrations of dissolved nitrate, thus indicating the possibility of contamination of the ground water by human and(or) animal wastes. Fecal-bacteria contamination was detected in water from about 40 percent of the sites sampled and bacterial contamination was detected in

all four of the springs sampled. Water samples from five springs and one well were analyzed for pesticides; one sample from Morgan Spring, in the valley region, contained diazinon at the detection limit of the laboratory instrument.

INTRODUCTION

Clarke County is located in the Shenandoah Valley and Blue Ridge Mountains of north-central Virginia, middle-Eastern United States (fig. 1). The county, which is now predominantly rural, has the potential for rapid residential and commercial growth because it is located about 50 mi (miles) west of Washington, D.C. The ground-water resources of Clarke County are particularly susceptible to changes resulting from human activities because of the sensitive nature of the **aquifers**[1] consisting of **carbonate rocks** that underlie three-quarters of the county. To minimize the possible consequences of any future changes, the county has established a water-study task force consisting of planners and scientists. This task force directs plans and studies aimed at protecting the ground-water resources of the area. Accomplishments of these efforts include a) an ordinance that limits land use around **sinkholes**, b) septic-system installation guidelines, and c) water-well construction regulations. These efforts are accompanied by a study sponsored by the American Farmland Trust to map the county's land and natural resources using a geographical information system. The U.S. Geological Survey (USGS) is providing information on the hydrology and quality of ground water to assist in land-use and planning decisions made in the county.

Clarke County is predominantly rural and agricultural and covers approximately 174 mi^2 (square miles). Agricultural businesses include apple orchards, cattle and dairy operations, hay and crop farming, and horse breeding. The climate is temperate continental; average annual temperature is 54 °F and annual precipitation is about 40 in/yr (inches per year).

Ground-water-protection and management problems are generally greater in areas that are underlain by carbonate rocks than in areas underlain by most other rock types because of the presence of solution-enlarged sinkholes, conduits, and caves. The generally high **permeability** of these rocks facilitates the infiltration and transport of contaminants from the land surface to the ground-water reservoir. Therefore, there is a need to understand ground-water-flow systems in carbonate rocks as well as in other rock terranes.

To address ground-water protection and management problems and to acquire information for guiding development in Clarke County, Virginia, the U.S. Geological Survey, in cooperation with the Clarke County Water-Study Committee and the Lord Fairfax Planning District Commission, has undertaken a study to describe the ground-water hydrology and quality of the county.

Purpose and Scope

This report provides an assessment of the hydrology and quality of ground water in Clarke County, Virginia. The ground-water-flow systems are described in terms of geologic, hydrologic, and water-quality data; a map of the **water-table** surface is presented; and the effects of natural processes and human activities on ground-water quality in the county are assessed. Hypotheses on the effects of fractures in bedrock on spring locations and well yields are presented by means of diagrams of ground-water-flow systems in the differing rock types. Regional and local characteristics of ground-water flow and springs are described. Interpretations and analyses provided are based on data collected during 1985-88.

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[1]Terms in bold type are defined in the Glossary at the back of the report.

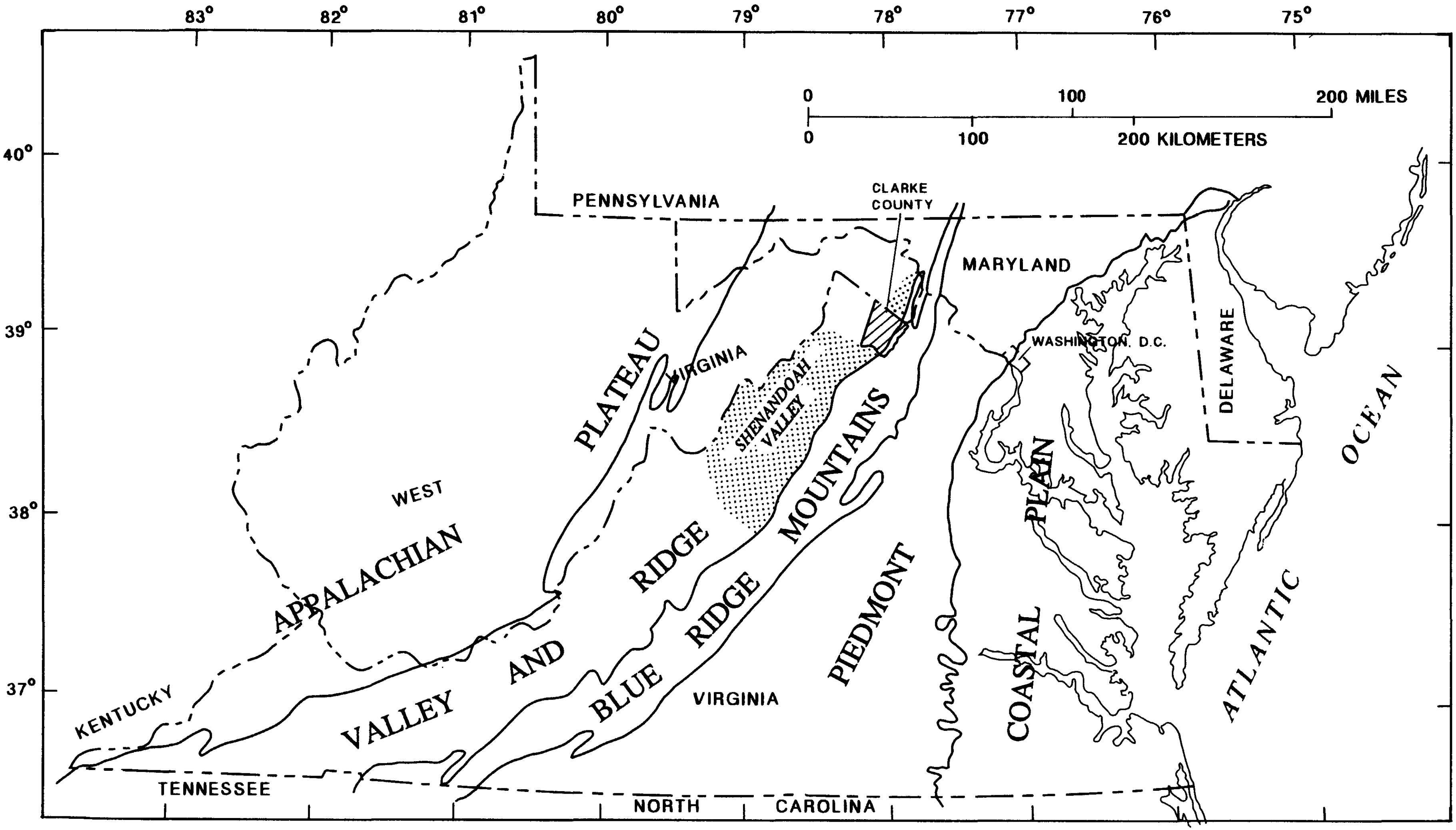


Figure 1.-- Location of Clarke County, Virginia, and physiographic provinces of the Middle-Eastern United States.

Data Sources and Quality Assurance

Existing ground-water data were compiled from previous reports and computerized data bases. Ground-water data were compiled by a computer retrieval of well information collected by the Virginia Water Control Board (VWCB) and stored in the U.S. Environmental Protection Agency (USEPA) STORET data base. Ground-water-quality data were also compiled from the USEPA STORET data base. Data were also compiled from a previous study by Trainer and Watkins (1975).

Additional data were collected for this report. Data from water-level recorders on springs and wells were collected. Geologic information and sinkhole identification were provided by the Virginia Division of Mineral Resources. The Clarke County League of Women Voters helped obtain well-construction records from well drillers in Clarke County. Samples were collected by student interns and analyzed by the Virginia Polytechnic Institute & State University (VPI&SU) Department of Environmental Sciences laboratory. Precipitation data were collected by personnel at the University of Virginia Blandy Experimental Farm and State Arboretum (located in central Clarke County).

In 1986, ground-water-quality samples were collected and analyzed by the USGS to provide a baseline of water-quality data for springs and wells in Clarke County. Eight sites were sampled and samples were analyzed for basic water-quality constituents and pesticides. An additional 31 wells and springs were sampled by the USGS and analyzed for nitrate and fecal-bacteria concentrations. The membrane-filter technique was used to determine the number of colonies per 100 mL (milliliters) of fecal coliform and fecal streptococci.

Ground-water-quality analyses were checked using several different methods. Ground-water-quality analyses from the VWCB were checked by performing ion balances of the major ions from each analysis; analyses in which the difference between cations and anions exceeded 12 percent of the sums of the cations and anions were rejected from the data set. Samples collected and analyzed by the USGS were checked according to the quality-assurance criteria established by Jones, B.E. (1987). Quality assurance for ground-water-quality samples collected by the student interns and analyzed by the VPI&SU laboratory were checked by having the laboratory analyze quality-assurance-standard samples prepared by the USGS laboratory and performing ion balances on the results of field-sample analyses. Analytical results from these standards were within 5 percent of the standard, and ion balances were within 12 percent.

Acknowledgments

Data compilations and interpretations were summations of efforts by groups and individuals within the USGS and outside of the organization. The Clarke County League of Women Voters provided useful well-construction data. Field descriptions and information were provided by student interns Craig Smith and Scott Sandberg, who worked in Clarke County during the summer of 1986 through financial assistance of the Virginia Student Environmental Health Project. Discussions with William K. Jones (Consulting Hydrologist, Charles Town, West Virginia), who performed the dye-tracing study discussed in this report, contributed to the conceptualization of the flow system. Lodging and laboratory facilities were provided by the Blandy Experimental Farm.

GEOLOGIC SETTING

Clarke County is located at the junction of the Valley and Ridge and Blue Ridge physiographic provinces. The Valley and Ridge part of the county includes the Shenandoah River and Opequon Creek drainage basins (fig. 2); these basins drain northward into the Potomac River. The Blue Ridge part of the county consists of the mountainous area east of the Shenandoah River (fig. 2). The crest of the Blue Ridge Mountains forms the eastern border of the county, and Opequon Creek the western border. For the ease of discussion in this report, the parts of the Valley and Ridge and Blue Ridge physiographic provinces in Clarke County are referred to as the "valley region" and the "Blue Ridge region," respectively.

The topography of the valley region differs from that of the Blue Ridge region. Altitudes in the valley range from 650 ft (feet) above sea level along a surface-water divide in the western quarter of the county to about 375 ft above sea level along the Shenandoah River; altitudes exceed 1,900 ft above sea level on the Blue Ridge Mountains. The Shenandoah River approximately follows the contact between the carbonate rocks of the valley region and **igneous** and **metamorphic** rocks of the Blue Ridge region. Rocks in the Blue Ridge region are more resistant to weathering than rocks of the valley region; therefore, the resistant ridges retain their prominent mountainous terrain (Hack, 1965, p. 49).

Overburden

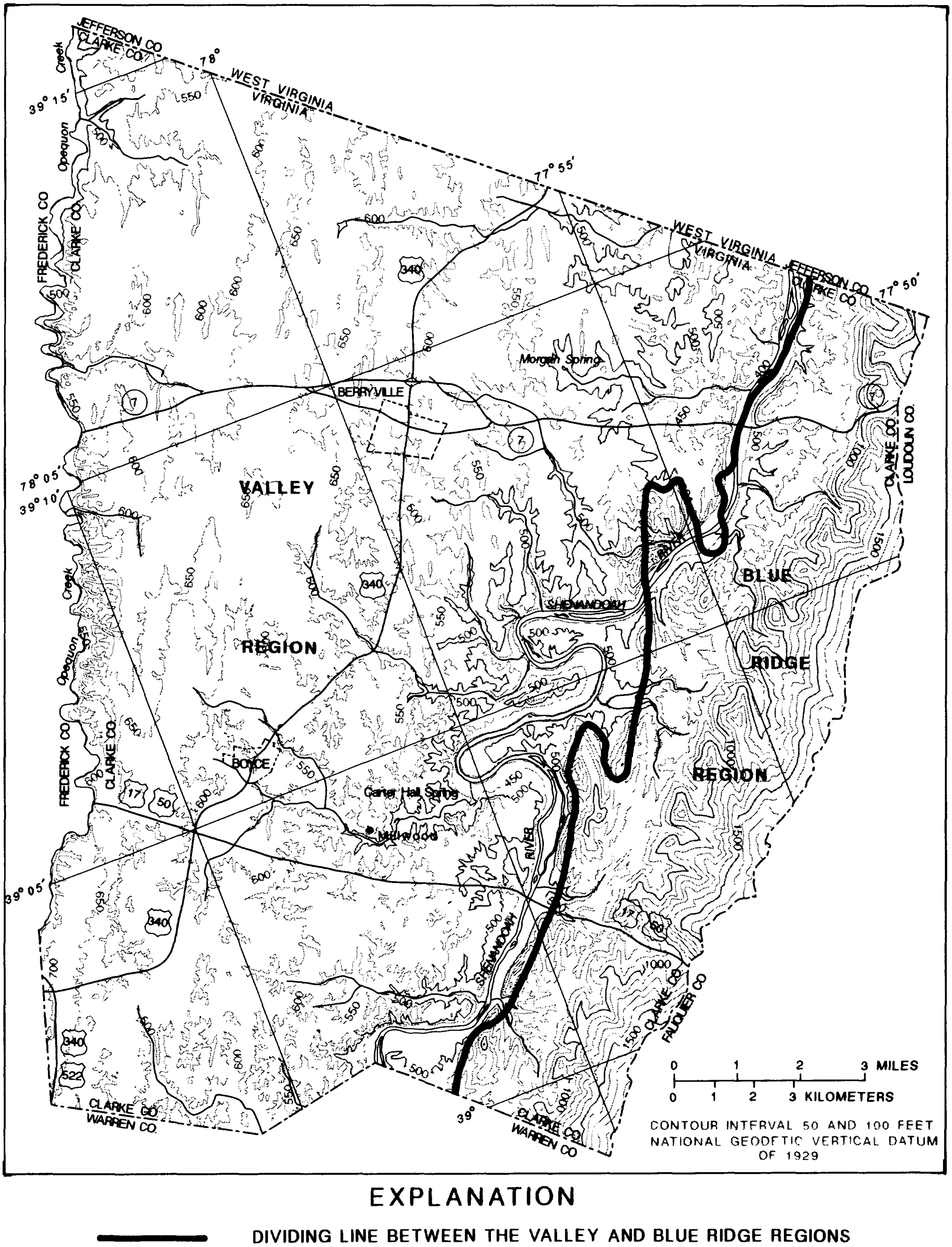
A zone of soil and weathered rock (collectively called **overburden**) overlies the bedrock in Clarke County. Overburden is formed by the chemical and physical weathering of the rocks and also by deposition of alluvium by streams and rivers. Clay, sandy loam, **chert** (flint), and rock fragments are left as weathering products of the rocks (also called **residuum**). Alluvium consists of gravel, sand, silt, and clay.

In Clarke County, overburden thicknesses range from 0 to 80 ft (Edmonds and Steigler, 1982). In the valley region, overburden is thin in the west-central and northwestern parts of the county, which is evident from rock outcrops and greater number of visible sinkholes. Overburden is thick in the central part of the county because of the residuum from the weathered interbeds of **sandstone, siltstone**, and chert (see Bedrock Lithology); this overburden may fill and completely cover many of the sinkholes in this part of the county. Overburden in the Blue Ridge region differs from place to place; however, data are not available to describe the areal distribution of overburden in the Blue Ridge region.

Alluvial gravels have been deposited in a series of terraces along the Shenandoah River in Clarke County. The elevation of the terraces range up to 200 ft above the current river level. The alluvial gravels mainly consist of sandstone and quartzite cobbles and pebbles that originated in the upper Shenandoah Valley (King, 1950). Thicknesses of the terrace deposits range from less than 10 ft to more than 70 ft. Alluvial sand and silt deposits also occur along almost all of the streams in the county; thicknesses of these deposits range from 0 to about 20 ft.

Bedrock Lithology

The bedrock types in the valley region differ from those in the Blue Ridge region. The valley region consists of **sedimentary rocks**. The Blue Ridge region consists of igneous and metamorphic rocks that comprise the relatively steep, mountainous terrain typical of the Appalachian Mountains. Rocks of these regions are subdivided on the basis of the lithology and age of the rocks (fig. 3).



EXPLANATION

DIVIDING LINE BETWEEN THE VALLEY AND BLUE RIDGE REGIONS

Figure 2.--The valley and Blue Ridge regions in Clarke County, Virginia.

The sedimentary rocks of the valley region consist of carbonate rocks including **limestone, dolomite**, and **calcareous shale**; these rocks are interbedded with layers of **argillaceous shale**, sandstone, siltstone, and chert. Cambrian-age rocks in the valley region include, from oldest to youngest, the Tomstown Dolomite (called Shady Dolomite in earlier references), Waynesboro (called Rome in earlier references), Elbrook, and Conococheague Formations. Thickness of these formations ranges from 1,200 to 2,500 ft. Ordovician-age rocks include the Stonehenge Limestone, Rockdale Run Formation, Pinesburg Station Dolomite, Oranda and Edinburg Formations, Lincolnshire Limestone, New Market Limestone, and Martinsburg Formation. Thickness of these formations range from 200 to 800 ft (Edmundson and Nunan, 1973; Rader, 1982; Hubbard, 1990). The Martinsburg Formation can be up to thousands of feet thick in the Martinsburg, West Virginia, area; however, erosion has removed most of this unit in Clarke County and no determination of the thickness is possible (Edmundson and Nunan, 1973, p. 49).

The igneous and metamorphic rocks of the Blue Ridge region include quartzite, **phyllite, slate**, and **basalt**. These Cambrian-age rocks and their approximate thicknesses are, from oldest to youngest: Catoctin Formation--500 ft (although it can be up to thousands of feet thick east of the Blue Ridge); Weverton Formation--200 to 500 ft; Harpers Formation--up to 2,000 ft; and the Antietam Formation--200 to 500 ft (Edmundson and Nunan, 1973).

Structural Geology

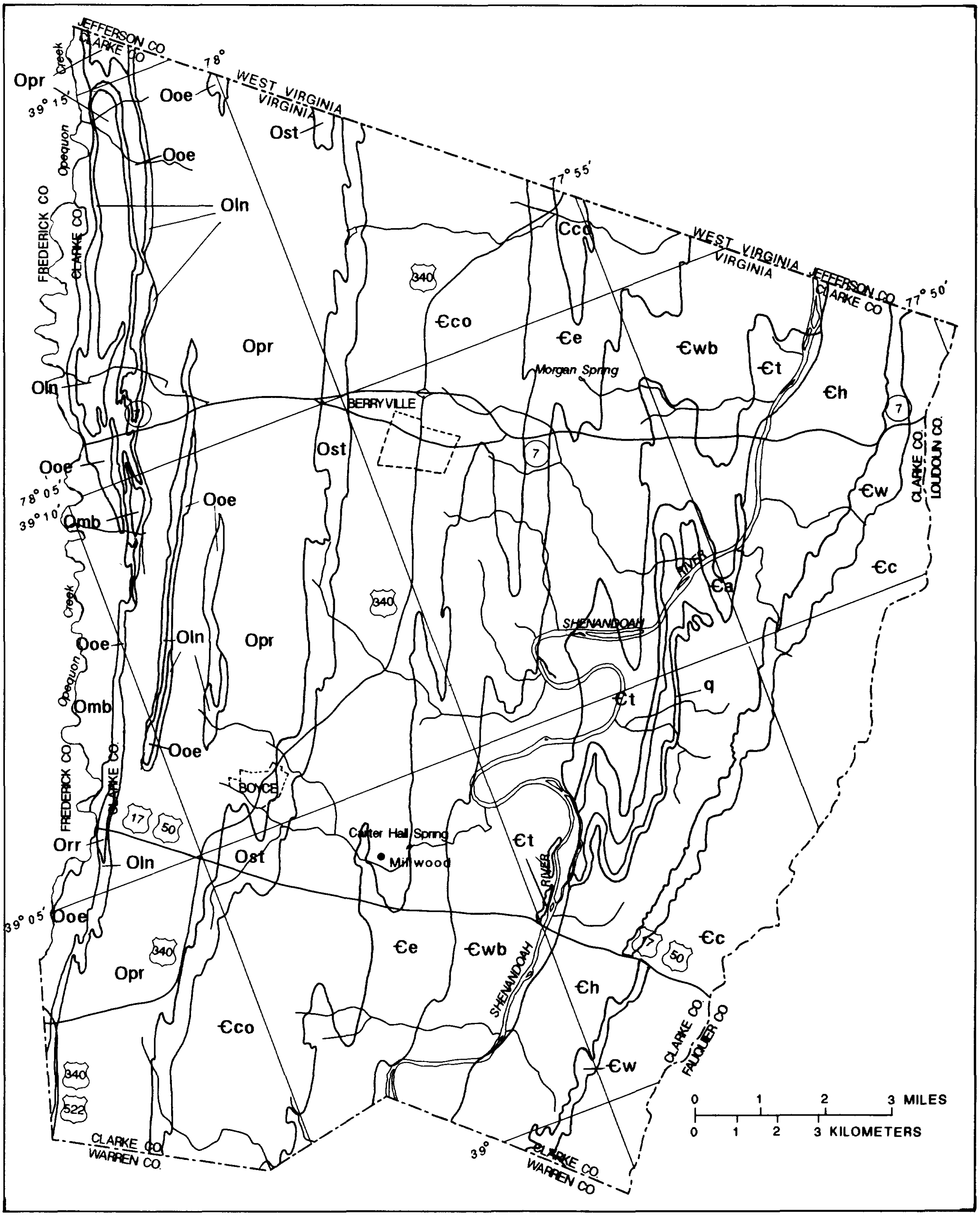
The structure of the rocks in Clarke County was caused by the compressive forces that folded the **strata** into a series of **anticlines** and **synclines** (Epenshade, 1970). The **fold axes** trend about N. 15° to 20° E. and generally plunge (or deepen) at a low angle to the north (fig. 4). Folded strata in the valley and Blue Ridge regions generally **dip** from 10° to 80°; however, some of the beds are vertical, some are flat, and some are overturned. These dips result from the folding and faulting of the strata. The **strike** of the rocks in Clarke County is variable but generally ranges from N. 10° E. to about N. 20° E.

Folds in rocks in Clarke County were caused by the uplift of the Appalachian Mountains and the development of two major structural features. Folds in the valley region were primarily caused by formation of the Massanutten Mountain synclinorium--part of the folding that created Massanutten Mountain (about 20 mi south of Clarke County). Folds in the Blue Ridge region of Clarke County were caused by forces that created the Blue Ridge anticlinorium-- a prominent structure that resulted from the thrusting of older rocks over younger rocks. The anticlinorium extends several hundred miles across southern Pennsylvania, Maryland, and Virginia (Epenshade, 1970, p. 199). Fold axes in Clarke County do not parallel the strike and, as a consequence, the geologic units form a sinuous appearance on the geologic map (fig. 3).

Faults in Clarke County were caused by the compressive stresses resulting from the formation of the Appalachian Mountains. Most of the faults are nearly parallel to the strike of the rocks and trend about N. 15° E. (fig. 4). However, some of the faults are nearly perpendicular to the strike of the strata and trend about N. 75° W. (fig. 4); these are referred to as **cross-strike faults**. The **wind gap** where U.S. highway 50 crosses the Blue Ridge Mountains indicates the location of such a cross-strike fault in the bedrock (fig. 5).

Fractures in Bedrock

Fractures in the bedrock of Clarke County are present as **joints**, faults, and **bedding-plane** separations. Fractures in the rocks create features on land surface if the fractures extend over great distances; these features are referred to as **lineaments**.



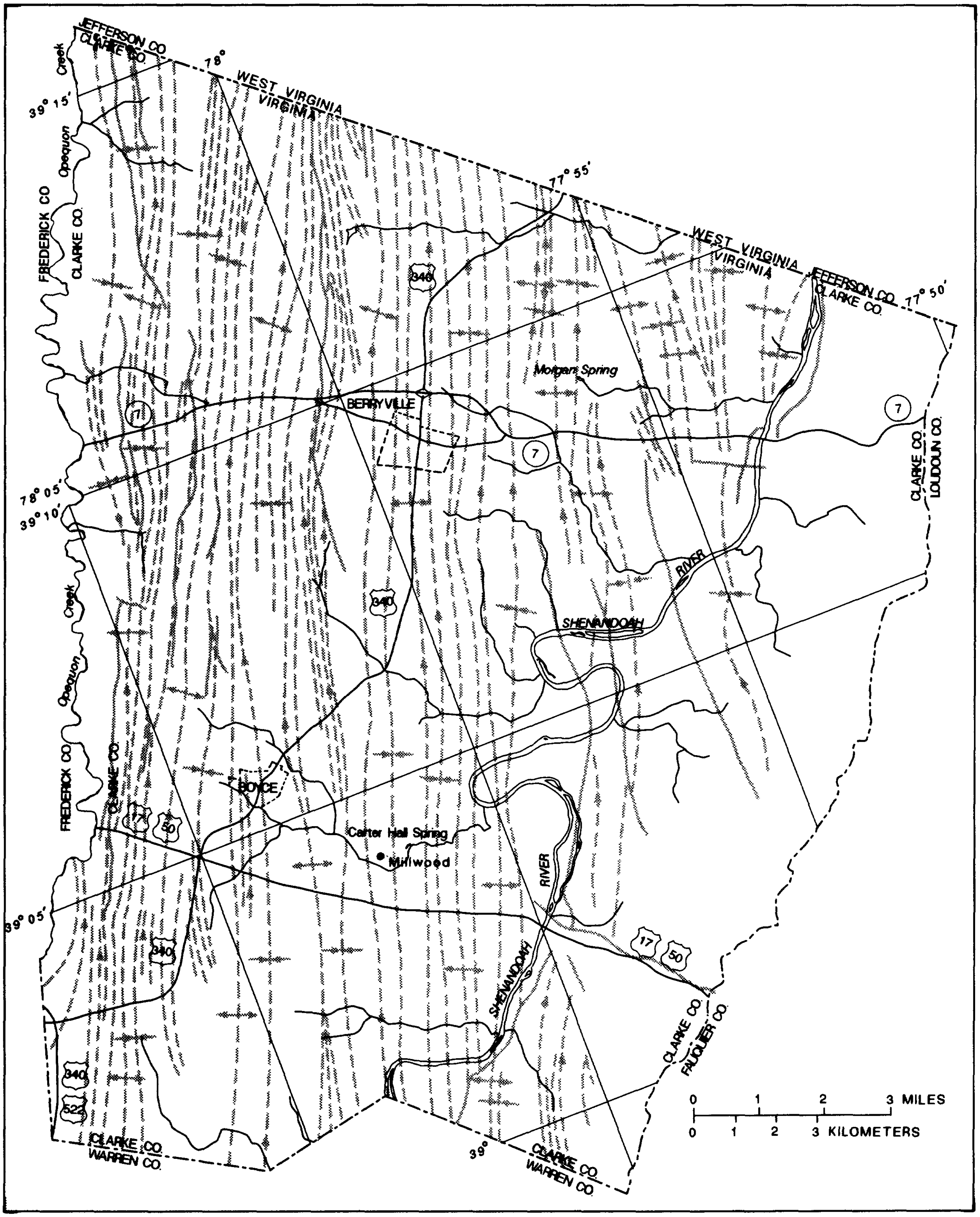
Geology modified from Edmundson and Nunan, 1973, and Gathright and Nystrom, 1974.

Figure 3.--Geologic units, lithologic descriptions, and general range of reported well yields from rocks in Clarke County, Virginia.

EXPLANATION

Geologic period	Geologic unit and map symbol	Lithologic description	Well yields
Ordovician	Martinsburg Formation (Omb)[1]	Bluish-gray to yellow brown, fissile clay shale, and calcareous shale.	Yields range from 5 to 50 gal/min (gallons per minute).
	Oranda and Edinburg (Ooe), Lincolnshire Formation[1] and New Market Limestone (Oln)	Dark-gray, argillaceous limestone with siltstones; dark-gray to black, dense limestone; dark- and bluish-gray limestone.	Yields range from 11 to 50 gal/min; air- and water-filled conduits are common.
	Pinesburg Station Dolomite (Opr) and Rockdale Run Formation (Orr)	Light-gray, fine-grained dolomite; interbedded bluish-gray limestone, and gray limestone; chert deposits; these formations are lateral equivalents.	Yields range from 0 to 200 gal/min; air- and water-filled conduits are common.
	Stonehenge Limestone (Ost)	Laminated, dark-gray limestone.	Yields range from 3 to 40 gal/min.
Cambrian	Conococheague Formation (€co)	Gray to dark-gray limestone with interbeds of light to dark-gray dolomite; friable sandstone layers.	Yields range from 0 to 120 gal/min; mud- and water-filled conduits are common.
	Elbrook Formation (€e)[1]	Limestone and interbeds of dolomite, shale, and siltstone; an occasional bed of sandstone.	Yields range from 2 to 200 gal/min; mud- and water-filled conduits are common.
	Waynesboro Formation (€wb)	Argillaceous limestone and dolomite; variable amounts of purer limestone, siltstone, mudstone, sandstone, and shale.	Yields range from 3 to 100 gal/min; mud-filled conduits are common.
	Tomstown Dolomite (€t)	White to bluish-gray dolomite; bluish-gray limestone with interbeds of sandstone and shale.	Yields range from 2 to 100 gal/min.
	Antietam (€a) and Harpers Formation (€h)	Silica-cemented quartzite; phyllite partings are common, graywacke and quartzite.	Yields range from 0 to 50 gal/min.
	Weverton Formation (€w)[2]	Quartz-pebble conglomerate and orthoquartzite; interbeds of phyllite and ferriginous sandstone.	No available well-yield information; steep outcrops are composed of this unit.
	Catoctin Formation (€c)[1]	Dark-green metabasalt with thin beds of slate.	Yields range from 1 to 100 gal/min.

[1]Unit follows usage of Virginia Division of Mineral Resources
[2]Weverton Formation considered Precambrian age by the U.S. Geological Survey



EXPLANATION

SYNCLINE

ANTICLINE

PLUNGE DIRECTION

FAULT

Geology by Edmundson and Nunan, 1973, and Gathright and Nystrom, 1974.

Figure 4.--Structural geology of Clarke County showing folds and faults.

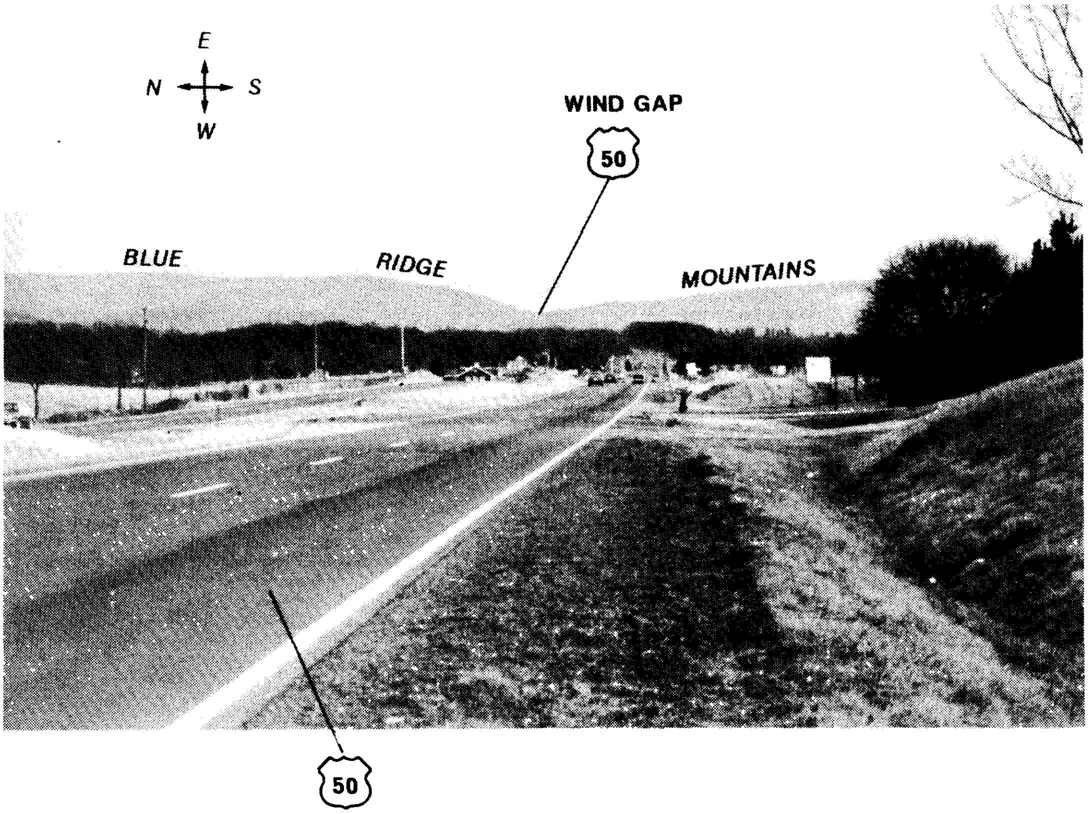


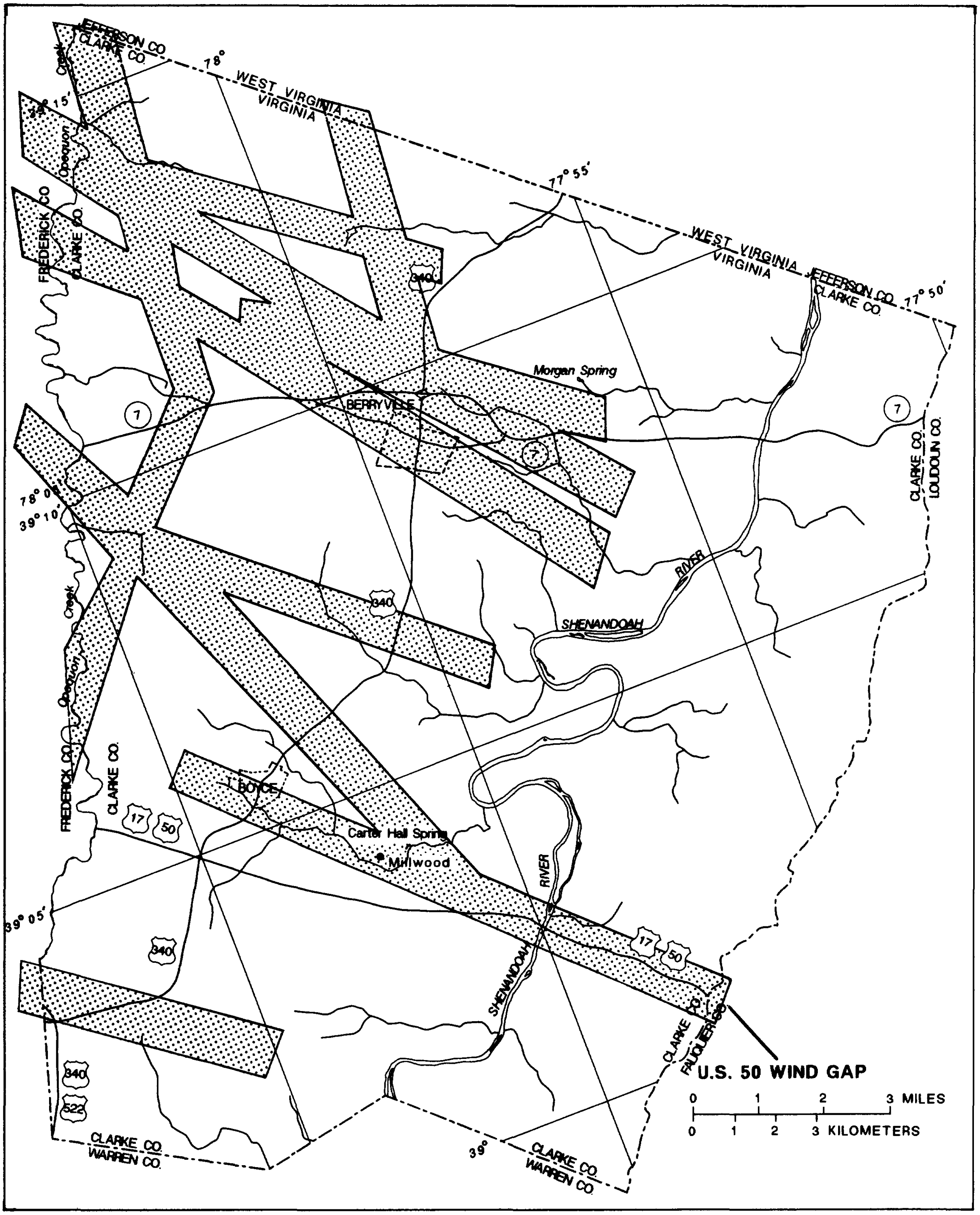
Figure 5.--Wind Gap where U.S. highway 50 crosses the Blue Ridge Mountains, Clarke County, Virginia (view looking east).

Lineaments are indicated by alined valleys, wind and water gaps, upland sags and depressions, soil-tonal features, springs, sinkholes, and caves (Lattman, 1958; Lattman and Parizek, 1964). Lineaments in Clarke County were mapped from aerial photographs and satellite images (Gathright, T.M., II, Virginia Division of Mineral Resources, written commun., 1986) (fig. 6). Lineaments in Clarke County were difficult to define because of the extremely fractured and folded condition of the bedrock; therefore, the lineaments are represented as zones. The wind gap shown in figure 5 coincides with a lineament zone shown in figure 6 that trends northwest-southeast or roughly perpendicular to the strike of the bedrock.

Karst Features

The valley region of Clarke County is underlain by carbonate rocks that have weathered and eroded to form a **karst** terrane. Karst terrane, which has distinctive landforms and drainage systems, forms on rocks that have greater solubility and are more readily dissolved in natural waters than are other rocks (Jennings, 1985, p. 1). Features in Clarke County typical of karst terranes are sinkholes, **sinking streams**, dry stream channels, caves, and springs.

Fractures in the carbonate rocks of Clarke County have been enlarged through the dissolution by ground water. These enlarged fractures provide a more effective underground drainage system. Solution-enlarged fractures open to the land surface are called caves. The



EXPLANATION

LINEAMENT ZONE

Figure 6.--Lineament zones delineated from Landsat imagery. (Gathright, T.M., II, Virginia Division of Mineral Resources, written commun., 1986.)

dynamic enlargement of underground voids by dissolution processes has caused a loss of support for soils and collapse of the land surface to form sinkholes. Locations of sinkholes and caves in Clarke County were mapped by the Virginia Division of Mineral Resources (Hubbard, 1990) (fig. 7).

Pumping and removal of ground water in karst terranes can accelerate the formation of sinkholes. In 1980, land collapsed and sinkholes were formed near the pumping wells that supplied water for the town of Berryville. These sinkholes introduced contaminants into the underground drainage system. Sinkholes also frequently collapse and form in other areas of Clarke County because of natural causes.

In the valley region of Clarke County, development and persistence of large underground conduits, which are subsurface features characteristic of many karst terranes, is hindered by the interbedding of the rocks and the great degree of fracturing of the rocks. Weathering of the interbedded sandstone, siltstone, and chert in the carbonate rocks generates a high-volume residuum which clogs and fills the underground conduits and creates a thick overburden. Sinkholes are less noticeable in Clarke County than in many other karst regions because the sinkholes are overlain by thick overburden--a terrane referred to as **covered karst**.

GROUND-WATER HYDROLOGY

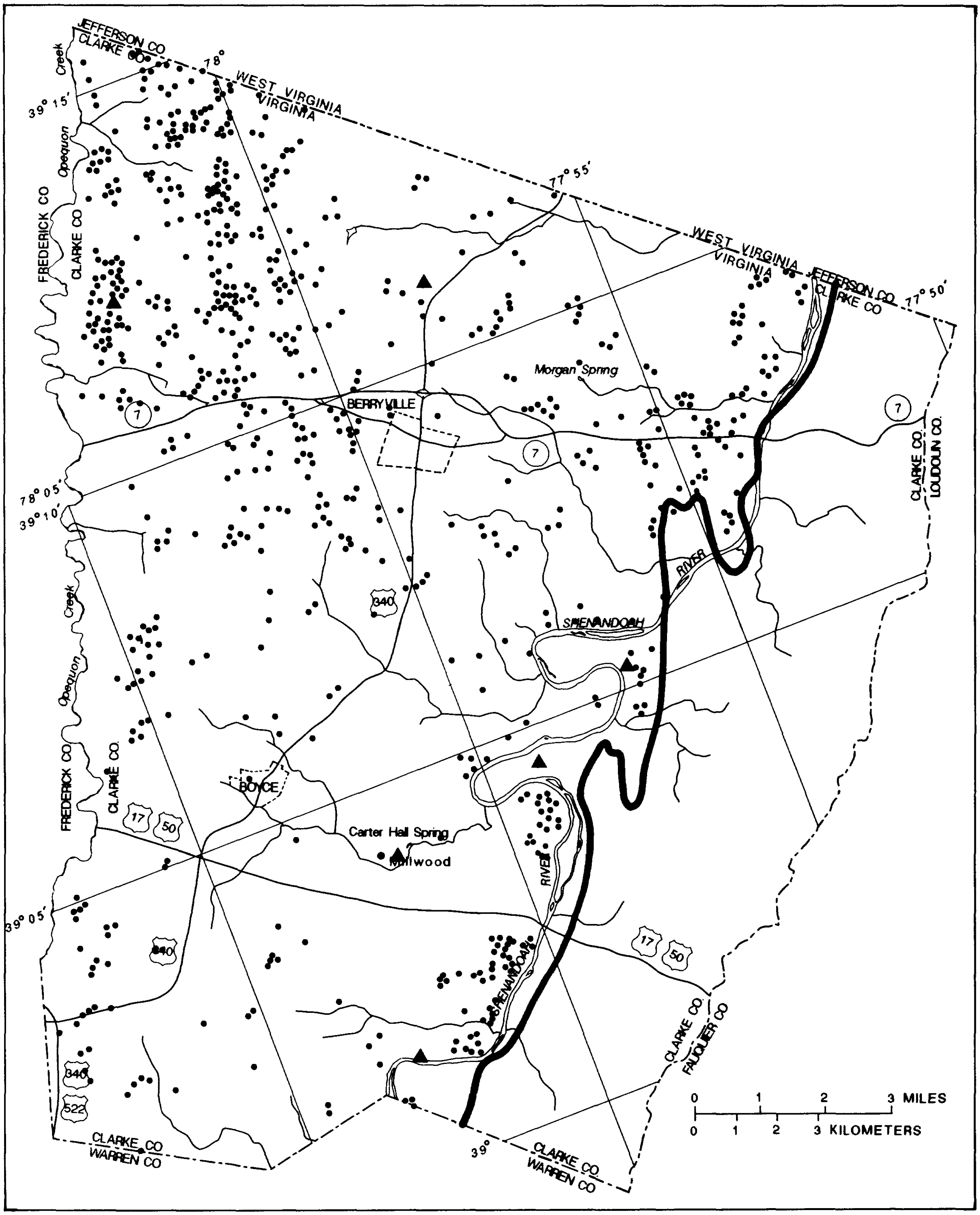
Ground-water flow in the valley and Blue Ridge regions of Clarke County is controlled by fractures, faults, and folds--collectively referred to as **fractured-rock flow**. In the valley region, ground water flows through fractures and bedding planes that have been solution enlarged, whereas in the Blue Ridge region, ground water flows through fractures that have not been solution enlarged. Differences in solution enlargement and in the fracture patterns are reflected in the flow patterns in the two regions.

Ground-Water Flow

Ground-water flow in the valley region is a mixture of **diffuse flow** and **conduit flow**, but diffuse flow is predominant. Ground water flows through solution-enlarged fractures and along solution-enlarged partings in bedding planes of limestones and dolomites. Where a layer of more soluble limestone (for instance, dark-gray or bluish-gray layers) occurs between less soluble interbeds of dolomite, sandstone, siltstone, and(or) chert, ground water flows primarily through conduits dissolved along the limestone interbed. Where solution-enlarged fractures are numerous, many interconnected pathways are created, and ground-water flow is diffuse (White, 1969, 1977; Smith and others, 1976).

Ground-water flow in the valley region is **joint** and **strike controlled** and is chiefly oriented parallel to the axes of the anticlines and synclines and parallel to the strike of the rocks. The resulting directions of ground-water flow are therefore northeast-southwest. Cross-strike faults and fractures provide an avenue for ground-water flow in southeast-northwest directions across the strike of the rocks and orientation of the folds. Some component of ground-water flow also moves in the direction of the plunge of the folds flowing from the surface to deeper points beneath the valley floor in the direction of the plunge. Ground-water flow in the valley region is illustrated in figure 8A.

Ground-water flow in the Blue Ridge region is controlled primarily by irregular fracture patterns in the rocks and by the steep terrain (fig. 8B). Water that has infiltrated the land surface flows as **subsurface-storm flow** through porous overburden to springs and streams



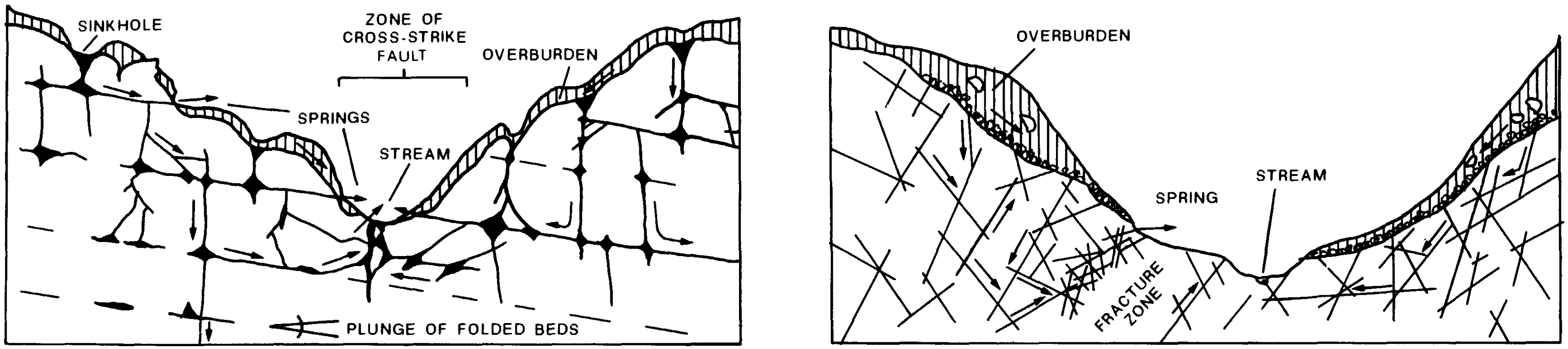
EXPLANATION

DIVIDING LINE BETWEEN THE VALLEY AND BLUE RIDGE REGIONS

• SINKHOLE

▲ CAVE

Figure 7.--Sinkhole distribution and locations of caves in Clarke County, Virginia. (Modified from Hubbard, 1990.)



a) LIMESTONE AND DOLOMITE; VIEW IS PERPENDICULAR TO FOLD AXIS AND ALMOST PERPENDICULAR TO STRIKE

b) METAMORPHIC ROCK

EXPLANATION

GENERALIZED GROUND-WATER FLOW PATH

SOLUTION CHANNELS IN LIMESTONE AND DOLOMITE

FRACTURES IN METAMORPHIC ROCK

Figure 8.--Schematic diagrams of ground-water-flow paths in solution openings and fractures in Clarke County, Virginia.

and to fractures in the rocks. Steep terrain facilitates rapid downgradient ground-water movement to springs, streams, and the Shenandoah River. One deep well on the ridgetop in Clarke County penetrates freshwater about 5,000 ft below land surface (Lovelace, G.W., Federal Emergency Management Agency, written commun., 1986).

Regional ground-water flow in Clarke County can be evaluated with a map of the water table. A water-table map was constructed from water levels measured in wells throughout Clarke County during July and August 1987 and also by using altitudes of springs and streams (fig. 9). The water levels were mapped and lines of equal altitude of the water table were drawn. The water table has highs and lows that generally reflect the topography. In theory, ground water flows down the **hydraulic gradient** perpendicular to water-table contours; however, because of the control exerted by fractures, ground-water flow in Clarke County may not always be perpendicular to the water-table contours. In general, however, ground water flows downgradient from water-level highs in upland areas to lows near springs and streams.

Several features of the water table of Clarke County are evident:

1. A ground-water divide exists along the midwestern part of the valley region. West of the divide, ground water flows to the Opequon Creek, and east of the divide, ground water flows eastward toward the Shenandoah River and its tributaries.

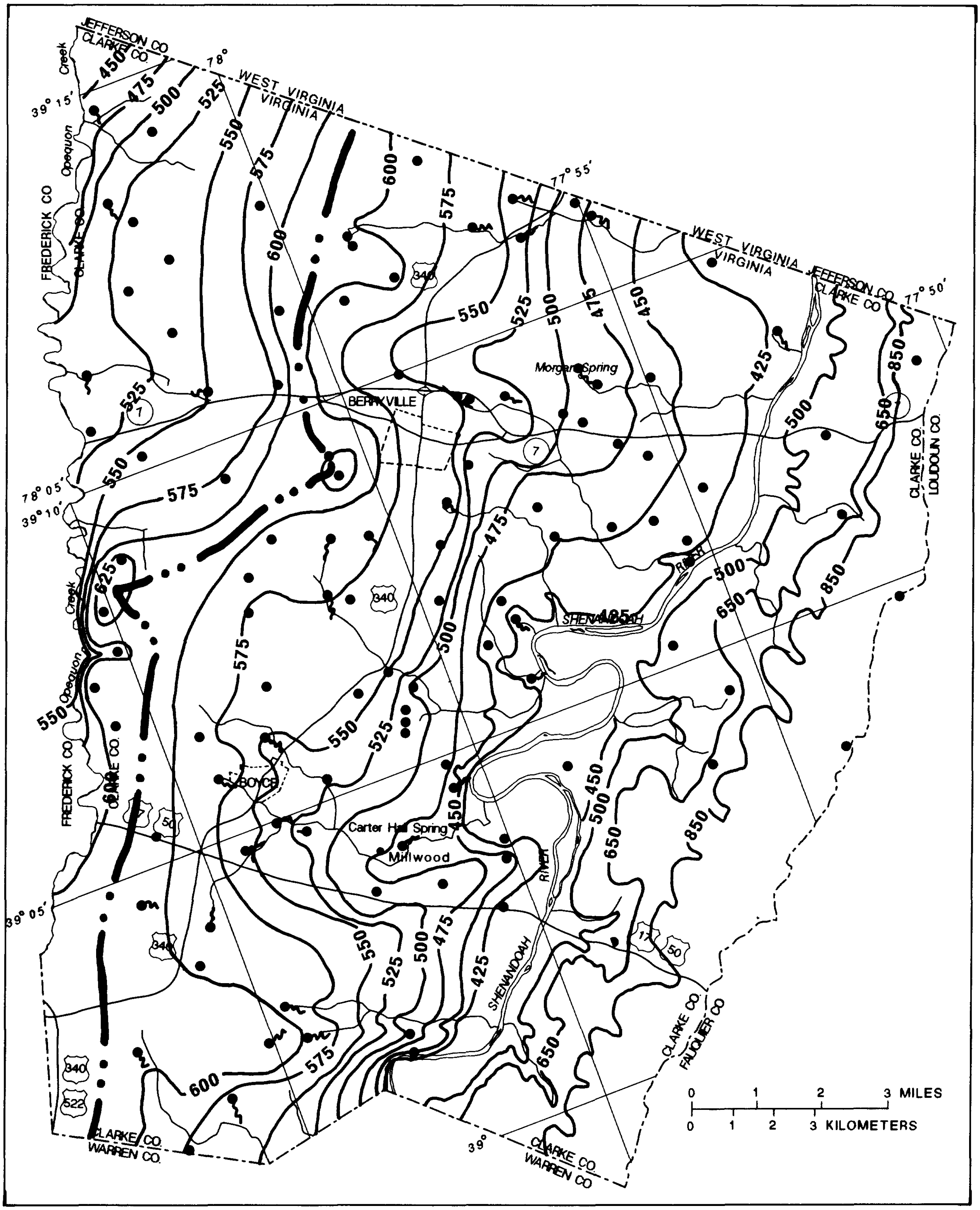
2. In the Blue Ridge region, the highest water-table levels are present at the eastern limit of the county; ground water generally flows westward to the Shenandoah River and its tributaries.

3. Discharge of ground water to the springs and streams around the Spout Run, Prospect Hill Spring, and Carter Hall Spring area is indicated by a depression in the water table. The depression is alined with and west of the cross-strike fault that has produced the U.S. highway 50 wind gap (figs. 4 and 5).

Recharge and Discharge

Recharge to the ground-water-flow system of the valley and Blue Ridge regions of Clarke County occurs as that part of precipitation that infiltrates into the soil and **percolates** through the overburden into fractures in the bedrock. Where the overburden is thick, it acts as a sponge to store water that slowly recharges the ground-water system. In the valley region, excess precipitation that flows over land surface into sinkholes quickly recharges the ground-water system. Recharge also can occur through irrigation and septic-system drain fields. Water that has recharged the ground-water system flows to springs and streams where it is discharged. Water is also removed from the ground-water system by pumping of wells and through **evapotranspiration** (ET).

Effects of recharge to and discharge from the ground-water system were observed by recording water-level fluctuations in wells and discharge fluctuations in springs. A **hydrograph** from a well at the Scaleby Farm near Boyce in Clarke County shows water levels and precipitation during part of 1987 (fig. 10). Water levels increased as a result of recharge and decreased as a result of discharge. Data are missing for the early part of 1987 and several other time intervals. The first peak on the hydrograph shown in April, when the water level increased about 7 ft, is representative of peaks caused by recharge periods during the early spring months. During the latter part of April and May, the water level receded even though precipitation fell during these months. Lack of response to precipitation is caused by the onset of the growing season and accompanying increased ET, because ET



EXPLANATION

— 500 — WATER-TABLE CONTOUR--Shows altitude of water-table surface. Contour interval 25 feet, except in steep terrain east of the Shenandoah River. Datum is sea level

● WELL IN WHICH MEASUREMENT WAS MADE IN JULY OR AUGUST, 1987

SPRING WHICH REPRESENTS THE POTENTIOMETRIC SURFACE WHEN FLOWING

GROUND-WATER DIVIDE

Figure 9.--Contours of the water-table surface in Clarke County, Virginia, July and August 1987.

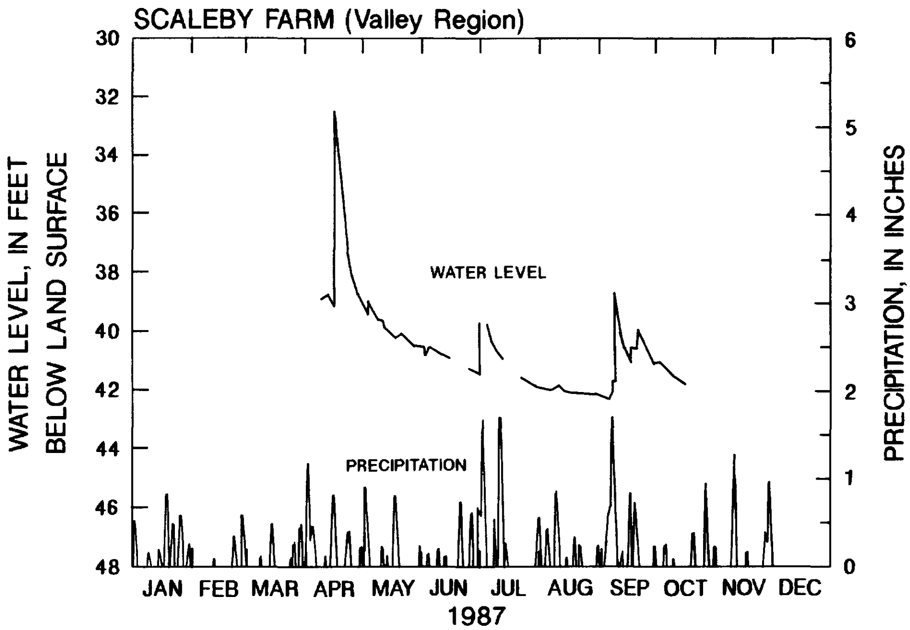


Figure 10.--Hydrograph for a well at Scaleby Farm in Clarke County, Virginia, and precipitation at Blandy Farm, 1987.

intercepts precipitation that would otherwise recharge the ground-water system. Precipitation during June and July caused the water level to rise less than it did during April; the water level continued to recede. In September, precipitation again recharged the ground-water system because ET declines during the fall months.

Springs are natural discharge points for water draining from the ground-water systems and provide much of the baseflow to streams in the area (fig. 11). Many of the springs in the county dry up or cease flowing during the summer. Because of the well-developed aquifer system of solution-enlarged fractures and less-steep terrain of the valley region, discharges from springs in the valley region are greater than discharges from springs in the Blue Ridge region. In the valley region, discharges from Carter Hall Spring range from 2 to 10 ft^3/s (cubic feet per second) [equivalent to 900 to about 4,500 gal/min (gallons per minute)] and discharges from Prospect Hill Spring range from 1 to 3 ft^3/s (450 to 1,400 gal/min). In the Blue Ridge region, discharges from Giuliani Spring range from 0.08 to 2 ft^3/s (36 to 900 gal/min). Appendix A is a tabulation of selected springs in Clarke County.

Hydrographs for three springs (fig. 12) show the effects of recharge to and discharge from the ground-water systems. During the winter and early spring months, the hydrographs show distinct increases in discharge from the springs in response to precipitation. Discharges from the springs decreased or remained steady beginning in late spring and continuing through the summer months because of the onset of ET. Even heavy rains during June and July did not greatly affect discharges from the springs. Discharges from the springs held steady or increased in the fall because of the moderation of ET. Figure 12 presents record for 1987 which was a year of less-than-normal precipitation.

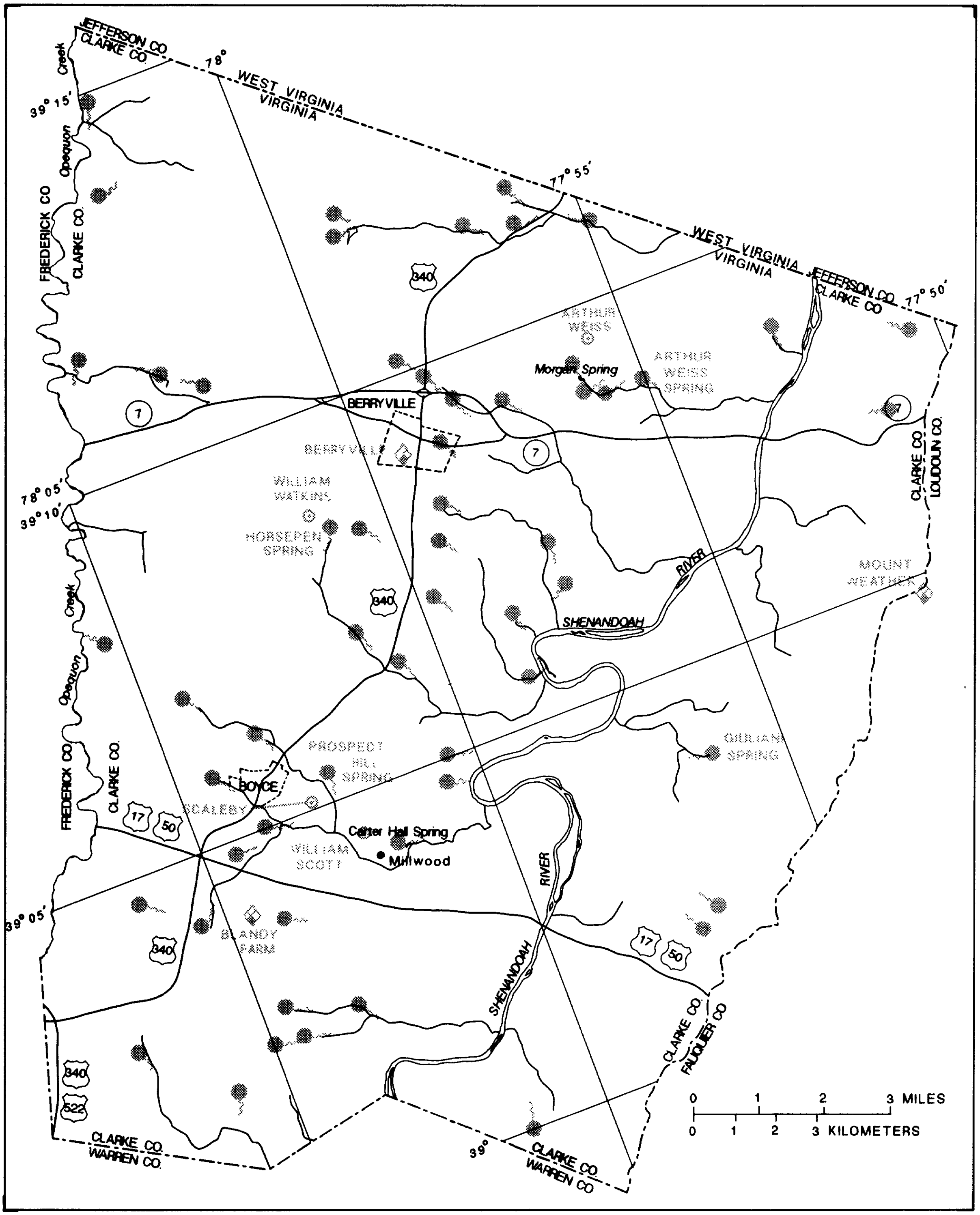
Some generalizations about the springs are indicated by the hydrographs:

1. The maximum discharge from Carter Hall Spring is about three times the minimum discharge; this is characteristic of a diffuse-flow karst aquifer. The discharges also respond sharply to precipitation; this is characteristic of conduit-flow karst aquifers. The Elbrook and Conococheague Formations, through which ground water moves to reach Carter Hall Spring, are probably mixed diffuse-flow and and conduit-flow karst aquifers.

2. The maximum discharge from Horsepen Spring is about 10 times the minimum discharge, and discharge responds quickly to precipitation. The aquifer that feeds Horsepen Spring (the Stonehenge Limestone) is probably a conduit-flow karst aquifer.

3. The maximum discharge from Giuliani Spring is about five times the minimum discharge. The peaks in the hydrograph for this spring are probably caused by the rapid percolation of rainfall through the high-permeability overburden and rapid transmission to the spring.

The recharge area for Carter Hall Spring was estimated using the average discharge for the spring and an estimate of discharge per unit area. From the hydrograph of Carter Hall Spring (fig. 12), the average discharge of the spring is about 4 ft^3/s. Jones and Deike (1981) estimated an average discharge per unit area of about 0.9 $(ft^3/s)/mi^2$ (cubic feet per second per square mile) for a spring in Jefferson County, West Virginia, which is north of Clarke County and has similar hydrogeologic conditions. This recharge estimate also agrees with results obtained by Hobba (1981) for the Jefferson County area. Applying this number, the recharge area to Carter Hall Spring is approximately 4 mi^2. This estimate, however, may not represent an easily definable or discrete area surrounding the spring.



EXPLANATION

HORSEPEN SPRING (spring symbol)	SPRING LOCATION AND NAME
BLANDY FARM (diamond symbol)	PRECIPITATION RECORDING SITE AND NAME
WILLIAM SCOTT (well symbol)	WELL LOCATION AND OWNERS NAME

Figure 11.--Locations of selected wells, springs, and precipitation-recording sites in Clarke County, Virginia.

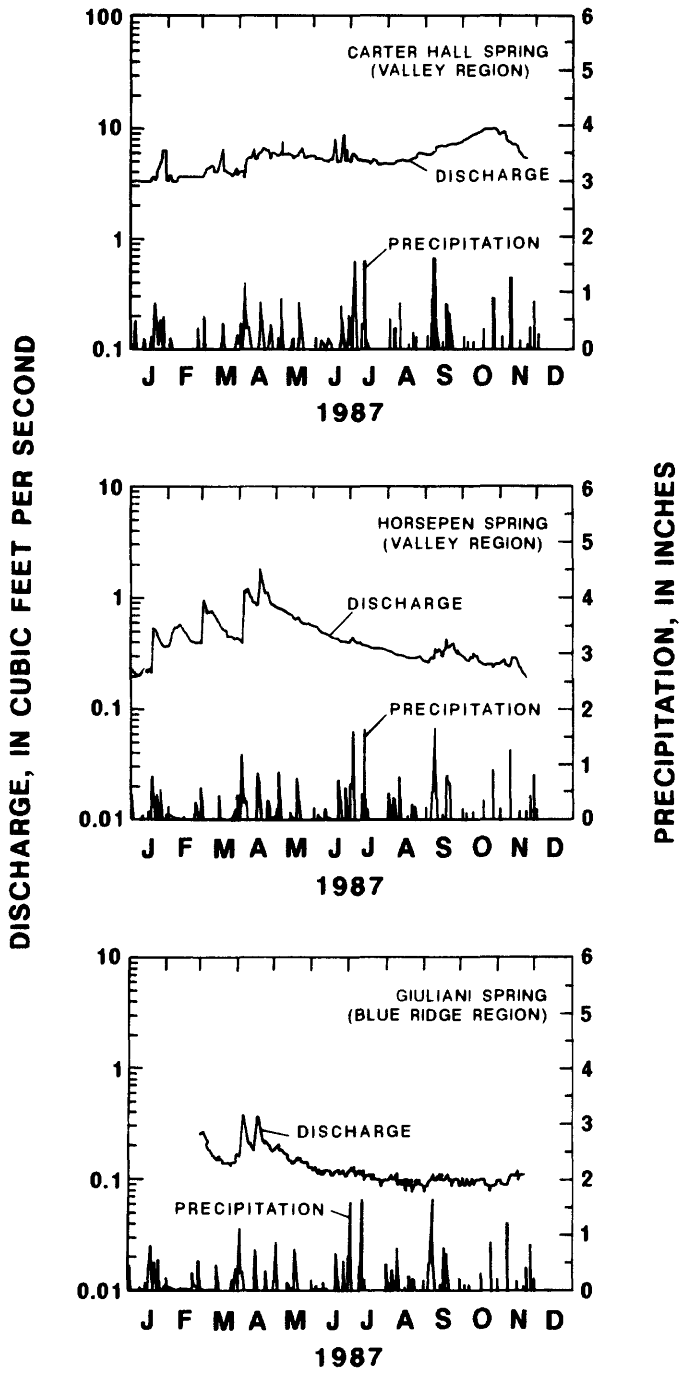


Figure 12.--Discharge hydrographs for three springs in Clarke County, Virginia, and precipitation at Blandy Farm, 1987.

Dye-Tracing Results

Dye-tracing tests were conducted in the Boyce area of Clarke County to help delineate the drainage basin for Prospect Hill Spring (Jones, W.K., 1987). Three dyes were used as tracers--blue dye (optical brightener), green dye (fluorescein sodium), and red dye (Rhodamine WT). Passive dye detectors were placed in Saratoga, Prospect Hill, Carter Hall, and James Springs (fig. 13). Activated charcoal detectors were placed in these springs to adsorb the green and red dyes. Unbleached cotton detectors were also placed in these springs to detect the blue dye. Green and red dyes were extracted from the charcoal detectors and the extraction liquid was qualitatively tested for relative fluorescence in a fluorometer. The qualitative determination of the presence of the optical brightener was tested by holding the cotton detector under a blacklight. Daily water samples were withdrawn from Prospect Hill Spring for quantitative measure of fluorescence and dye recovery at that spring. Dye detectors were changed every 2 weeks for a period of about 6 months.

The dyes were injected into three sinkholes along with 2,000 gallons of water to flush the dye into the ground on July 19, 1986 (fig. 13). The tests were conducted during a dry period when ground-water-flow velocities and dye movement tend to be slower than during other periods. Urine from ducks and cattle masked detection of the blue dye in Saratoga, Carter Hall, and James Springs (Jones, W.K., 1987, p. 20). Blue and green dyes were both detected in water samples from Prospect Hill Spring in early November 1986, and green dye was detected at Saratoga and Carter Hall Springs in the middle of November. The red dye was never detected.

The conclusions that can be drawn from these limited dye-tracing studies in such a complex flow system as the valley region of Clarke County must be interpreted with caution. As stated by Jones, W.K. (1987, p. 20):

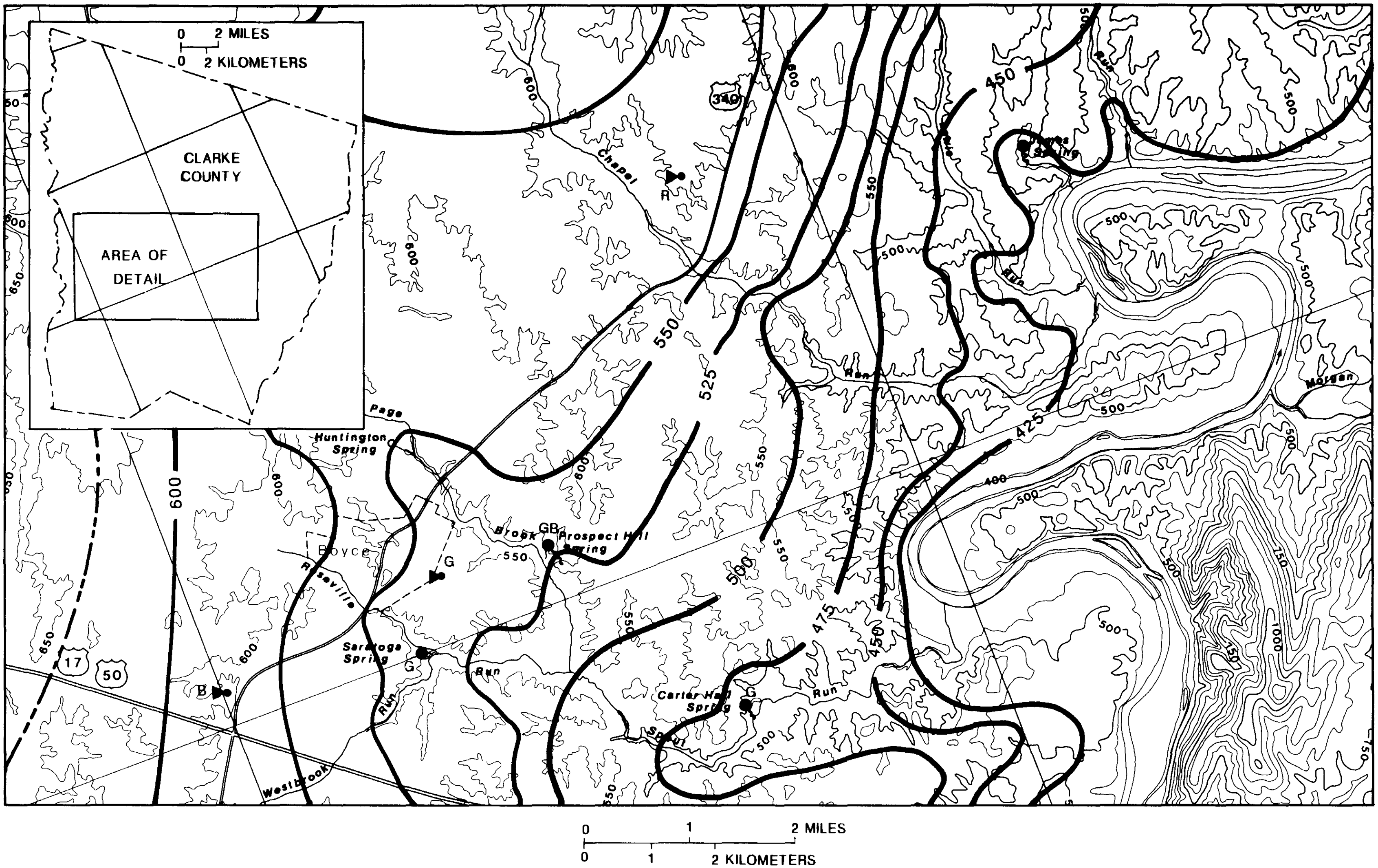
> The loss of the red tracer may indicate that it moved even more slowly than the other dyes, that it went to an unmonitored spring, or that it was diluted below the analytical threshold at the monitored springs. There is not enough data from the two recovered tracers to infer the regional direction or rate of ground-water movement. Sporadic water samples collected from wells near the injection sites did not contain any tracers. The tests demonstrate, however, that a contaminant entering the ground-water system in the immediate vicinity of the tracer-injection sites could be expected to reappear at Prospect Hill Spring (and possibly other springs and streams in the area) within 5 months.

The results of these tests also indicate that ground water, and any possible contaminants, can travel 2 miles or more from recharge points to springs in the Spout Run, Prospect Hill Spring, and Carter Hall Spring area.

Well Yields

The amount of ground water yielded from a well in fractured rock in Clarke County depends on (1) the topographic location, depth, and diameter of the well; (2) the type of rock in which the well is completed; and (3) the number, size, and degree of interconnection of fractures in the rocks. Figure 14 shows a schematic of well construction typical of domestic wells and the types of fractures that provide water to wells in limestone and igneous and metamorphic rocks of Clarke County.

Well yields in Clarke County range from 0 to 460 gal/min (fig. 15). For this report, well yields were evaluated in relation to topographic location, depth, rock type, and nearness to



EXPLANATION

500 WATER-TABLE CONTOUR--Shows altitude of water-table surface. Contour interval is 25 feet. Datum is sea level.

GROUND-WATER DIVIDE

B ▶● LOCATION OF DYE INJECTION AND TYPE OF DYE

G ●~ SPRING WHERE DETECTORS WERE LOCATED AND TYPE OF DYE DETECTED

G GREEN DYE (FLUORESCEIN SODIUM)

B BLUE DYE (OPTICAL BRIGHTENER)

R RED DYE (RHODAMINE WT)

Figure 13.--Results of dye-tracing studies in the vicinity of Prospect Hill Spring, Clarke County, Virginia.

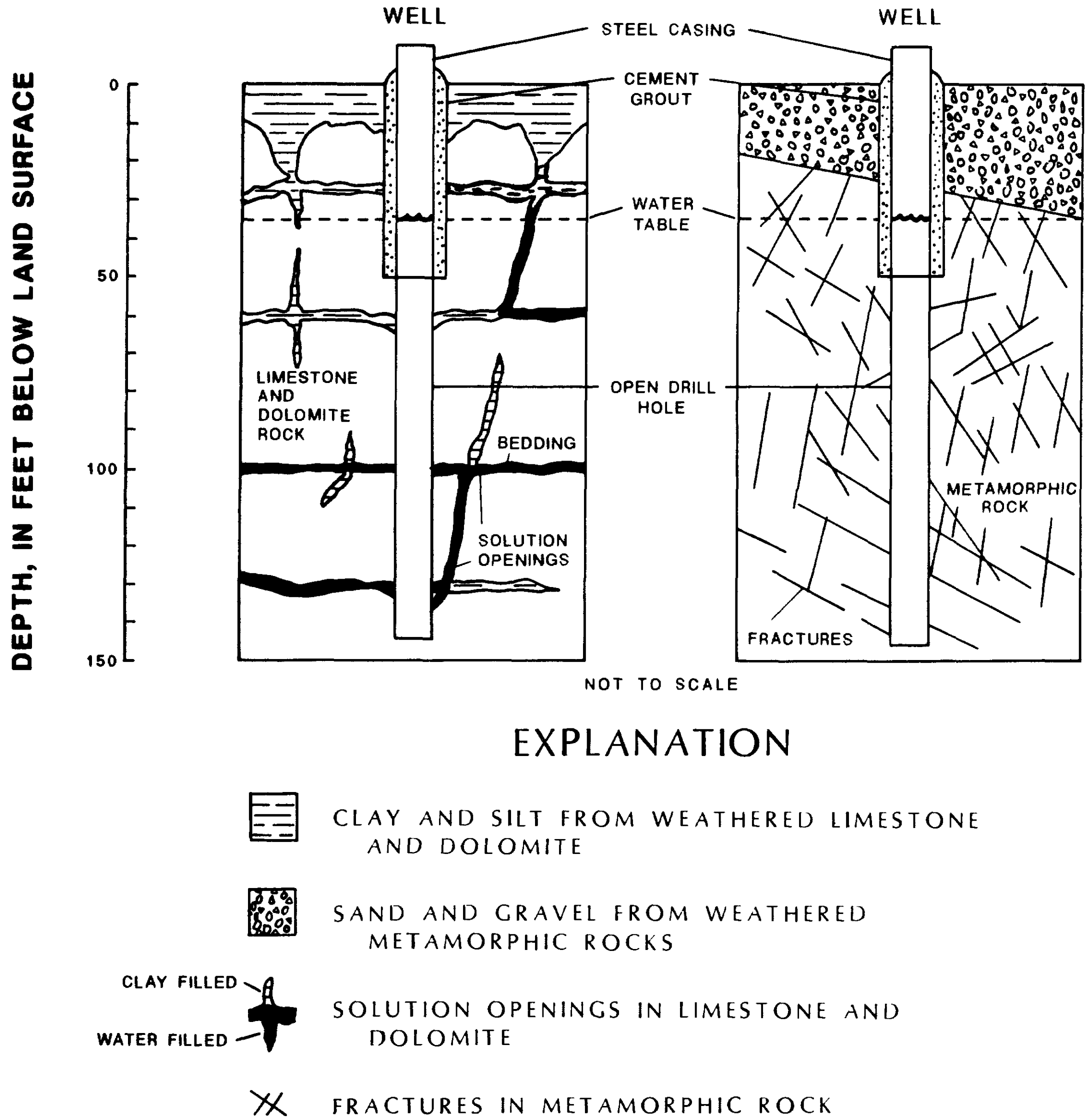
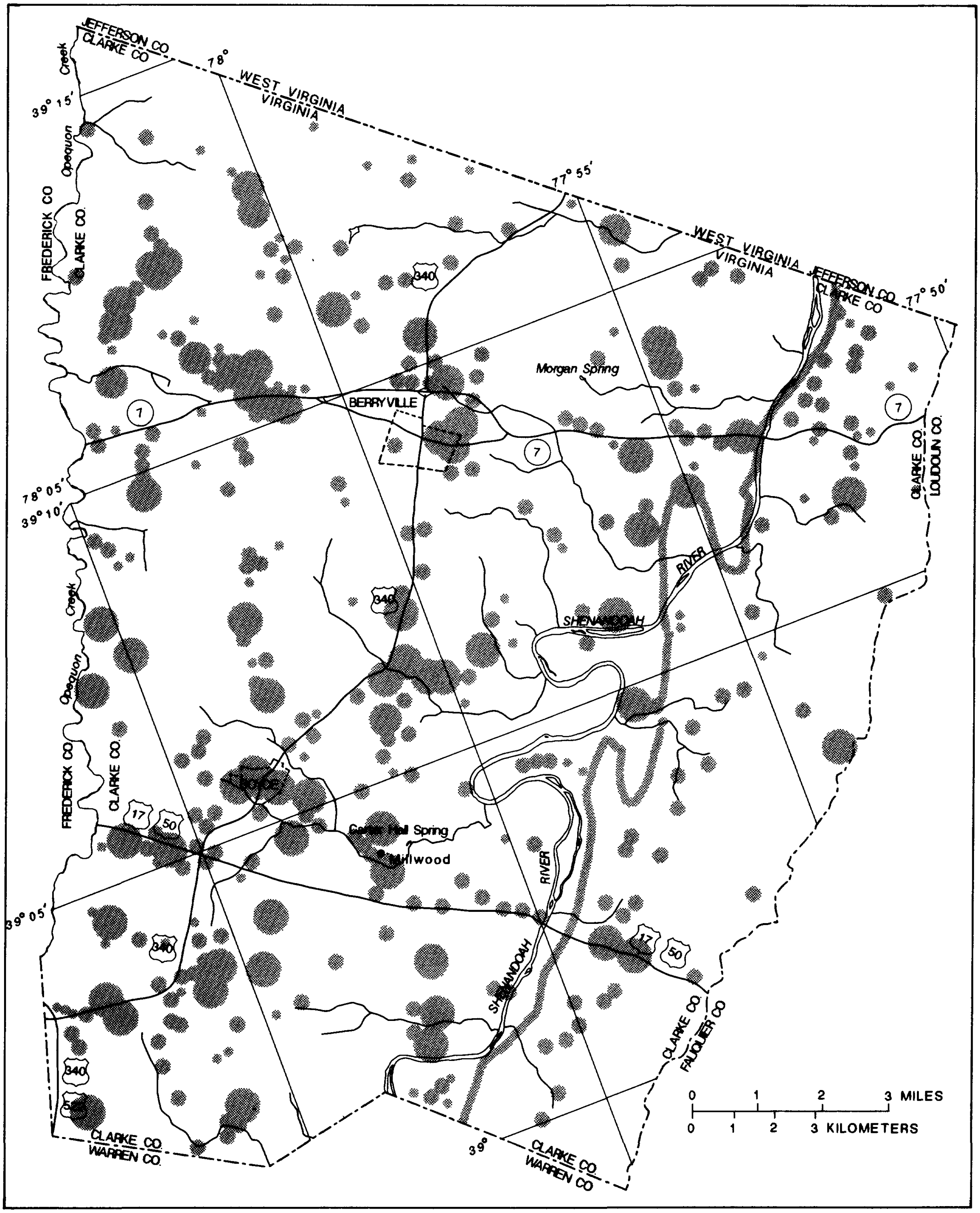


Figure 14.--Schematic diagram of well construction in limestone and dolomite and metamorphic rocks.



EXPLANATION

DIVIDING LINE BETWEEN THE VALLEY AND BLUE RIDGE REGIONS

WELL WITH YIELD GREATER THAN OR EQUAL TO 50 GALLONS PER MINUTE

WELL WITH YIELD OF 5 TO 50 GALLONS PER MINUTE

WELL WITH YIELD LESS THAN OR EQUAL TO 5 GALLONS PER MINUTE

Figure 15.--Location and yield range of selected wells in Clarke County, Virginia.

lineaments; no apparent relation between well yield and any of these factors could be determined. Studies of carbonate aquifers in Pennsylvania (Lattman, 1958; Lattman and Parizek, 1964) indicated a positive correlation between well yield and nearness of the well to lineaments. High yields in Clarke County did not indicate a positive correlation with nearness of the well to lineaments, possibly because of the highly fractured nature of the rocks and the difficulty in identifying lineaments in Clarke County. Differences in well construction and(or) the inexact estimation of well yields provided by well drillers also could contribute to the lack of correlation. Records of selected wells in Clarke County are tabulated in Appendix B at the end of the report.

GROUND-WATER QUALITY

The quality of ground water in Clarke County is affected by natural factors that include the mineral composition of the rocks, chemical quality of recharge water, contact time and contact area between the water and the soil and rock, and the presence of biological organisms that affect water quality (Heath, 1983, p. 64). Factors related to human activities that could affect ground-water quality in Clarke County include leakage from septic systems, application of agricultural fertilizers and pesticides, animal feedlots and barnyard wastes, salt from highway deicing, and infiltration of poor-quality surface water. Table 1 summarizes the source and significance of selected constituents of ground water pertinent to this report. Results of analyses of ground-water samples collected and analyzed by the USGS are shown in table 2.

Natural Factors

Natural ground-water quality in Clarke County chiefly depends on the composition of bedrock. The rocks of the valley region of the county primarily consist of soluble limestone and dolomite interbedded with less readily dissolved rocks. Rocks of the Blue Ridge region primarily contain quartz and feldspar minerals that are less soluble in natural water than are limestone and dolomite; therefore, natural ground water in the valley region contains relatively higher concentrations of dissolved constituents than ground water in the Blue Ridge region.

General characteristics of the natural ground-water quality of Clarke County were described using a water-analysis diagram (fig. 16). This diagram, sometimes referred to as a trilinear diagram or Piper diagram, uses a method initially described by Piper (1944) to indicate the chemical quality of natural water. The water-analysis diagram shows the relations among concentrations of the cations (positively charged ions) and anions (negatively charged ions) in water from wells and springs. The values are expressed as percentages of the total milliequivalents per liter of cations (lower left triangle) or of anions (lower right triangle) and are not expressed as actual concentrations. The central quadrilinear graph shows the combined anionic and cationic chemical quality of the water by a third point, which is at the intersection of the rays projected from the points on the cation and anion graphs.

Ground water in the carbonate rocks of the valley region is predominantly a calcium magnesium bicarbonate type of water (see insert in fig. 16 for explanation of water types). Water from wells has a high percentage of calcium (50 to 95 percent), a low percentage of magnesium (5 to 45 percent), and low percentages of sodium and potassium (0 to 20 percent) among all the cations. Combined carbonate (CO_3) and bicarbonate (HCO_3) species dominate the anions ranging from 80 to almost 100 percent of the total anions. Compared to water from wells, water from some of the springs in carbonate rocks of the valley

Table 1.--Source and significance of selected constituents of ground water in Clarke County, Virginia

[Maximum contaminant levels and secondary maximum contaminant levels are for public drinking-water supplies and are from U.S. Environmental Protection Agency (1986); mg/L = milligrams per liter]

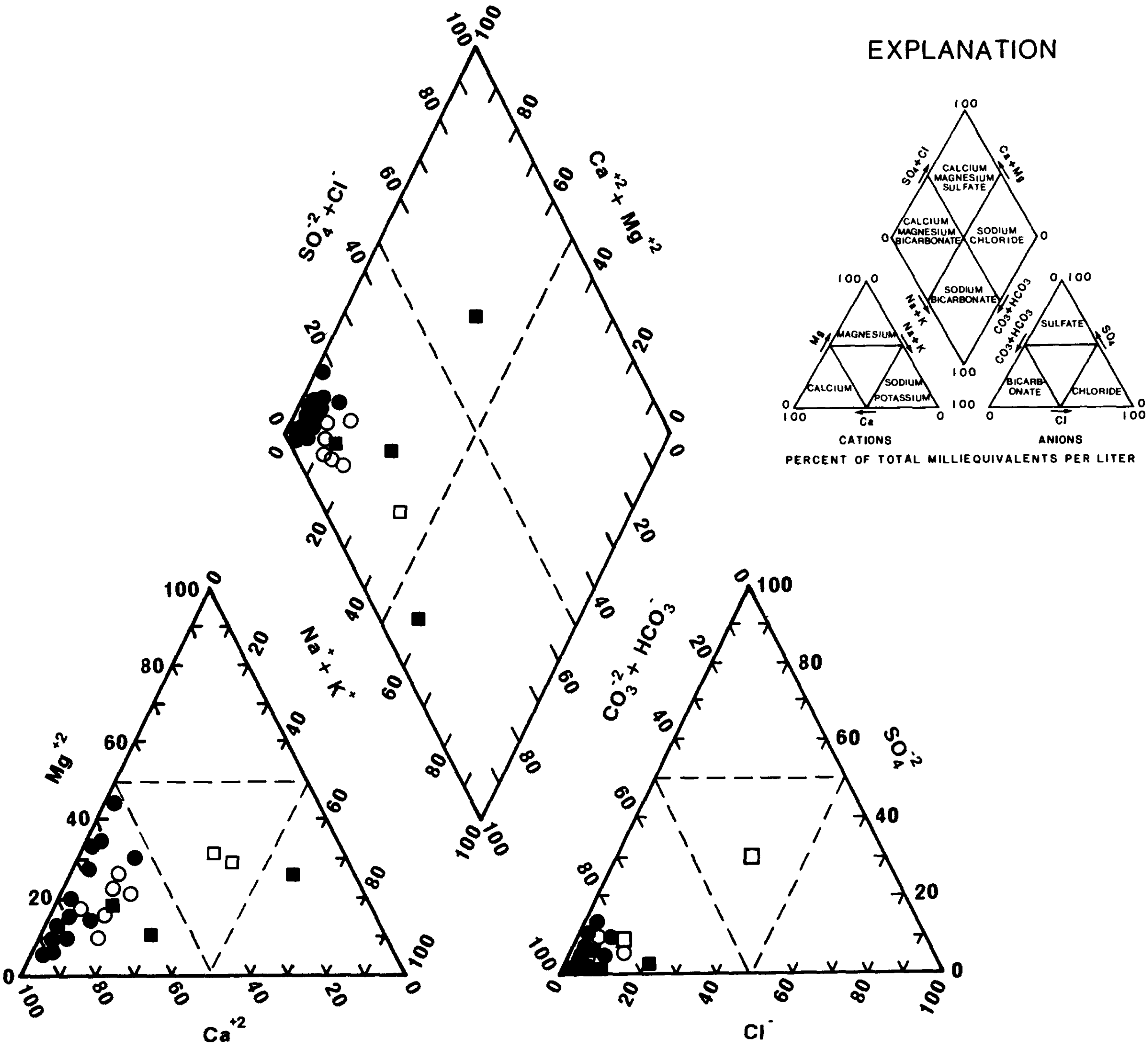
Constituent	Source	Significance
Calcium (Ca) Magnesium (Mg)	Dissolved from practically all rocks and soils, but especially from limestone, dolomite, and gypsum.	Causes most of the hardness and scale-forming properties of water; detergent-consuming (see hardness).
Sodium (Na)	Dissolved from practically all rocks and soils; may be derived from highway salts, sewage, and industrial wastes.	More than 50 mg/L sodium and potassium in the presence of suspended matter causes foam in boilers which accerlates scale formation and corrosion. High sodium consumption has been associated with heart disease.
Chloride (Cl)	Dissolved from rocks and soils; present in sea water, deep ground water, sewage, industrial wastes, highway salts, and fertilizers.	May impart salty taste above 250 mg/L and increase corrosiveness of water; secondary maximum contaminant level is 250 mg/L.
Nitrate (NO_3)	Fertilizers, decaying organic matter, sewage, and animal waste.	Nitrate encourages growth of algae and other organisms which produce undesirable taste and odors; concentrations in excess of the suggested limit are suspected as a cause of methemoglobinemia (blue baby syndrome) in infants; maximum contaminant level is 10 mg/L as nitrogen.
Hardness as calcium carbonate (as $CaCO_3$)	Divalent cations, primarily calcium and magnesium in most water.	Consumes soap and synthetic detergents; produces scales in hot water heaters, pipes, and boilers.
Fecal coliform Fecal streptococci	Wastes from human and animal intestines.	Indicates contamination from human and(or) animal waste; maximum contaminant level are four colonies per 100 milliliters in more than one sample when less than 20 are examined per month.

Table 2.--Water-quality data for selected springs and wells in Clarke County, Virginia

[Values are in milligrams per liter (mg/L) as the constituent unless otherwise indicated; "--" indicates no determination was made for that constituent for the stated sample-collection date; BRL indicates that concentrations were below the reporting limit of the laboratory; "field" headings are measurements performed immediately after collection; < indicates less than indicated value; temperature is in degrees Celcius (°C); µS/cm indicates microsiemens per centimeter at 25 °C]

Site name	Site identifier	Sample date	Field water temperature (°C)	Field specific conductance (µS/cm)	Field dissolved oxygen concen-tration	Field pH (units)	Alkalinity as calcium carbonate	Nitrite plus nitrate as nitrogen
Giuliani Spring	01636320	09-05-1986	14.2	45	6.2	8.2	10	0.1
Horsepen Spring	01636330	05-16-1986	12.5	615	8.3	6.9	300	3.5
Morgan Spring	01636340	05-15-1986	12.5	535	8.3	7.0	240	6.0
Prospect Hill Spring	01636310	05-16-1986	12.0	595	8.5	6.8	280	3.1
		09-04-1986	12.4	480	7.9	7.8	256	3.1
		12-11-1986	11.5	555	--	7.1	--	3.2
Carter Hall Spring	01636315	05-15-1986	13.0	530	7.6	7.1	270	3.2
Arthur Weiss well	390931077553301	05-15-1986	14.5	797	7.1	7.0	364	6.6
Arthur Weiss spring	390834077550201	09-04-1986	16.2	479	4.4	8.3	246	4.5
William Scott well	390436078021201	05-15-1986	15.0	673	8.7	6.8	321	4.7
William B. Watkins well	390814078011501	05-16-1986	15.0	575	8.3	7.0	290	1.9

Site name	Phosphorus, total as phosphorus	Phosphorus, dissolved as phosphorus	Calcium	Magnesium	Sodium	Potassium	Chloride	Sulfate	Hardness as calcium carbonate	Fecal coliform (colonies per 100 milliliters)	Fecal streptococci (colonies per 100 milliliters)
Giuliani Spring	BRL	0.021	1.3	0.8	1.5	0.9	1.0	1.0	7	--	--
Horsepen Spring	BRL	BRL	120	5.3	5.3	2.4	13.0	15	321	40	140
Morgan Spring	.01	BRL	82	17	2.9	3.1	8.9	15	275	--	--
Prospect Hill Spring	BRL	.01	110	8.9	2.7	1.8	7.3	15	311	--	--
	BRL	BRL	110	9.3	2.7	1.8	6.0	15	313	--	--
	--	--	--	--	--	--	--	--	--	<1	29
Carter Hall Spring	.01	.01	86	14	3.3	2.0	8.3	12	272	--	--
Arthur Weiss well	.01	.01	110	35	8.3	3.7	13.0	25	418	--	--
Arthur Weiss spring	.02	.02	71	28	6.1	3.1	15.0	28	290	--	--
William Scott well	.041	.041	95	23	2.9	14.0	4.0	26	332	--	--
William B. Watkins well	.01	.01	100	8.4	2.7	1.6	6.4	16	284	--	--



EXPLANATION

■ WELL IN METAMORPHIC ROCK OF THE BLUE RIDGE REGION

● WELL IN CARBONATE ROCK OF THE VALLEY REGION

□ SPRING IN METAMORPHIC ROCK OF THE BLUE RIDGE REGION

○ SPRING IN CARBONATE ROCK OF THE VALLEY REGION

Figure 16.--Diagram showing percentages of major ions in water from selected springs and wells in Clarke County, Virginia.

region has slightly lower percentages of calcium and greater percentages of sodium and potassium. The high concentrations of calcium and bicarbonate in ground water in the valley region partly explains the presence of travertine (massive concretions of calcium carbonate) and marl (calcium-rich clay) deposits in the sediments at several springs in Clarke County (Hubbard, 1985).

Ground-water types throughout the Blue Ridge region range from calcium magnesium bicarbonate to calcium magnesium sulfate and sodium bicarbonate types. Water from springs and wells has variable percentages of calcium (about 15 to 60 percent of total cations), low percentages of magnesium (about 10 to 30 percent of total cations), and variable percentages of sodium and potassium (about 10 to 60 percent of total cations) among all the cations. The large percentages of sodium and potassium relative to total cations may have resulted from weathering of feldspar minerals in rocks of the Blue Ridge region. The percentages of each anion among all anions in water from the Blue Ridge region differ little from those in water in the valley region.

Hardness, which is primarily attributable to the presence of calcium and magnesium ions, is one of the natural properties of interest to ground-water users in Clarke County, because three-quarters of the county is underlain by limestone and dolomite, which contribute to hardness in water. Encrustation of hot-water tanks and water pipes increases as hardness increases. Hardness ranged from 89 to 422 mg/L as $CaCO_3$ (calcium carbonate) in the valley region and from 4 to 242 mg/L as $CaCO_3$ in the Blue Ridge region (fig. 17). According to the hardness classification of Hem (1985), ground water throughout most of the valley region of Clarke County is very hard (table 3). In the Blue Ridge region, hardness of the ground water ranged from soft to very hard, but is generally soft to moderately hard. Thus, hardness in ground water is generally much greater in the valley region than in the Blue Ridge region.

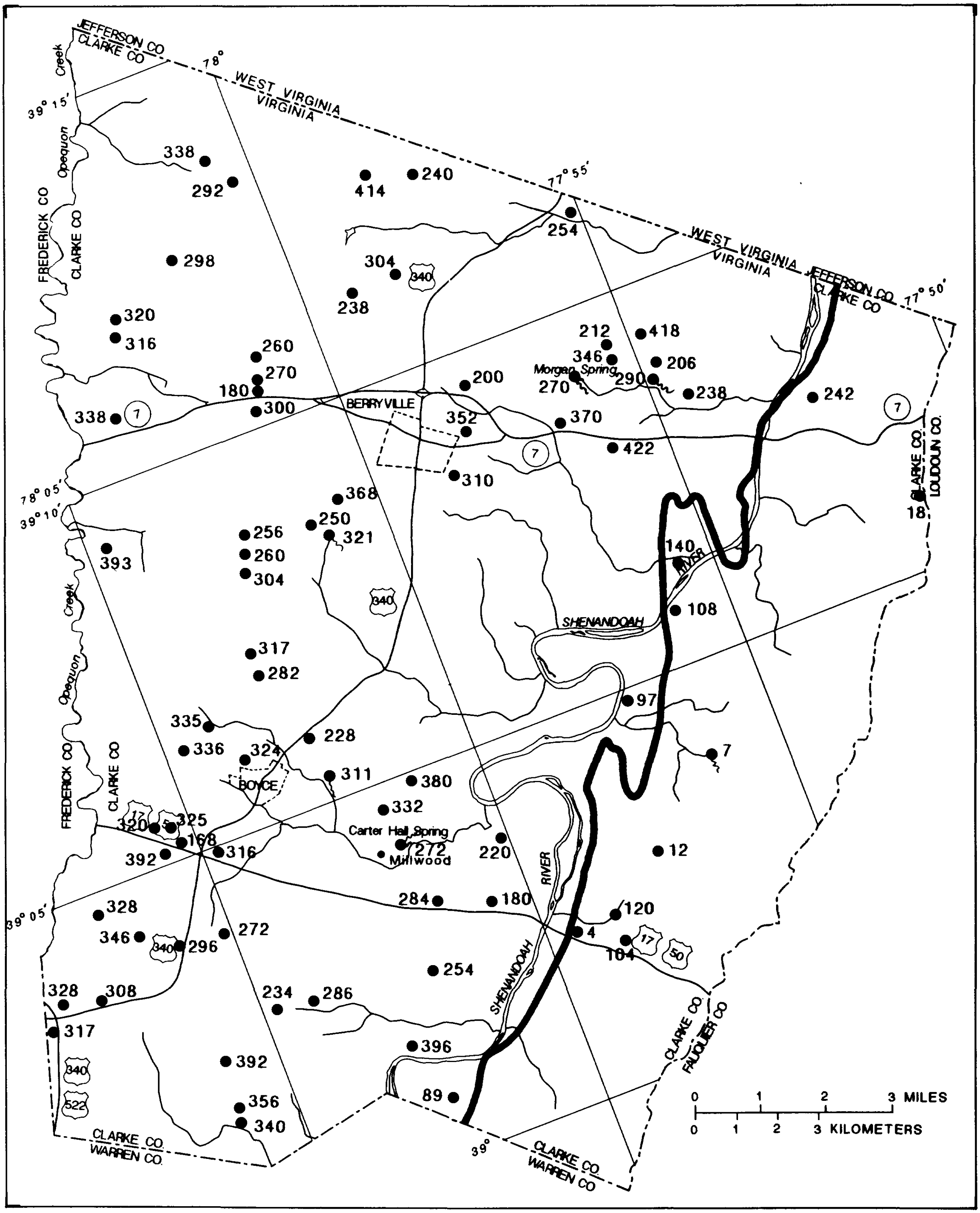
Table 3.--Classification of hardness for different ranges in concentration

[Hardness ranges are in milligrams per liter as calcium carbonate (Hem, 1985, p. 159)]

Classification	Hardness
Soft	0 - 60
Moderately hard	61 - 120
Hard	121 - 180
Very hard	Greater than 180

Effects of Human Activities

Data indicate that ground-water quality in Clarke County has been affected by human activities. Because of the types of contaminants identified, ground-water contamination is probably associated with **nonpoint sources**. Table 4 lists possible **point** and nonpoint sources of ground-water contamination and the pathways for contamination into the subsurface in the valley region and the Blue Ridge region. The table also indicates that human activities can combine with hydrologic factors to adversely affect the quality of ground water.



EXPLANATION

DIVIDING LINE BETWEEN THE VALLEY AND BLUE RIDGE REGIONS

● 272 WELL LOCATION AND HARDNESS CONCENTRATION, IN MILLIGRAMS PER LITER AS CALCIUM CARBONATE

● 272 SPRING LOCATION AND HARDNESS CONCENTRATION, IN MILLIGRAMS PER LITER AS CALCIUM CARBONATE

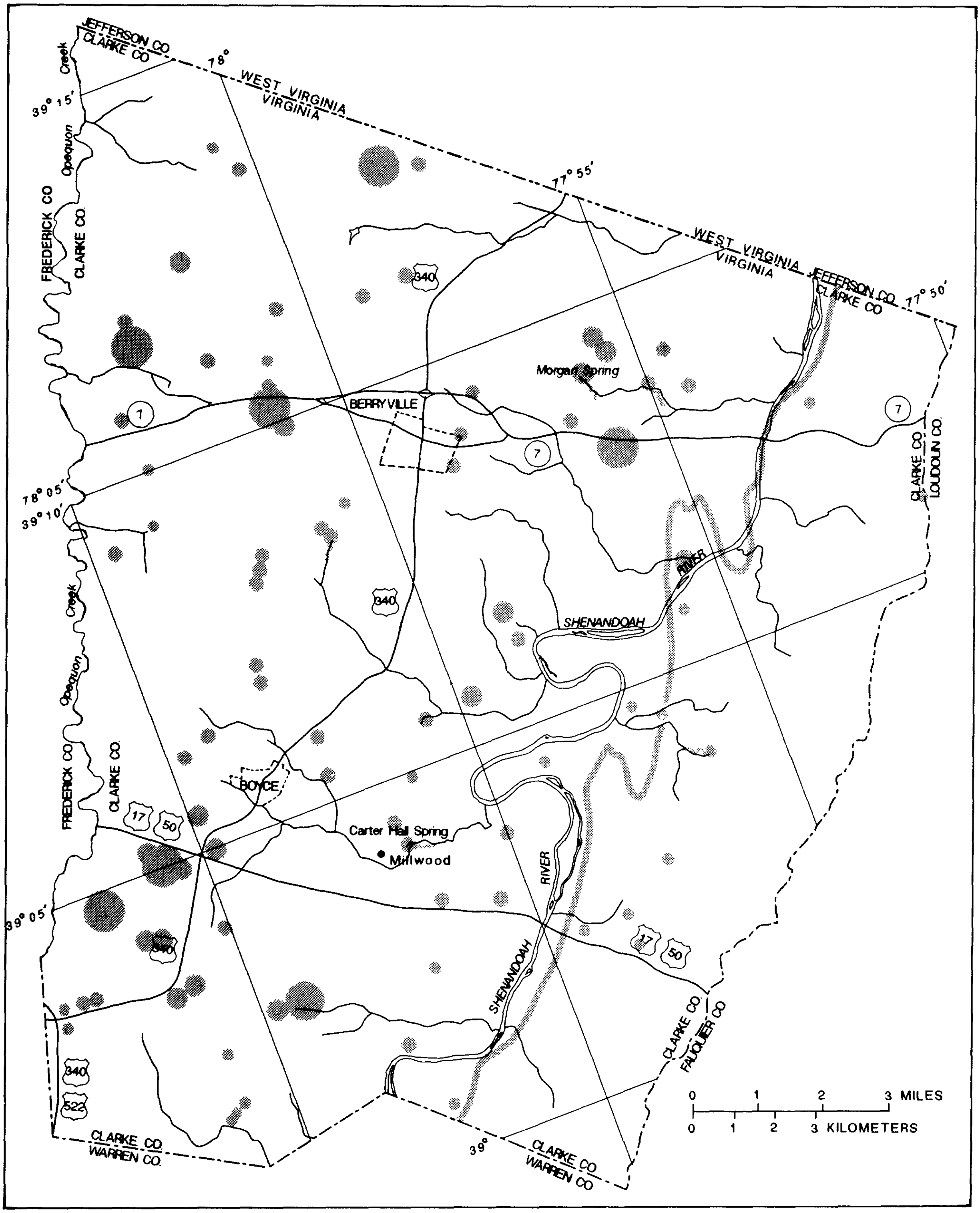
Figure 17--Hardness concentrations in water from wells and springs in Clarke County, Virginia.

Table 4.--Possible sources of ground-water contamination and pathways for contaminants to the ground-water system in Clarke County, Virginia

Source of contamination	Pathway to ground-water system: Carbonate rocks (valley region)	Pathway to ground-water system: Igneous and metamorphic rocks (Blue Ridge region)
• Septic tanks and drain fields • Agricultural fertilizers • Livestock waste and feedlot runoff • Agricultural pesticides • Public and private sanitary landfills • Underground storage tanks • Highway deicing salt • Municipal and industrial waste-disposal lagoons • Urban and construction runoff	• Well can provide an avenue for movement of shallow, contaminated ground water unless the well has been properly cased and grouted.	• Well can provide an avenue for movement of shallow, contaminated ground water unless the well has been properly cased and grouted.
	• Surface runoff can enter the ground through the annular space between the drill hole and casing unless this space is properly grouted.	• Surface runoff can enter the ground through the annular space between the drill hole and casing unless this space is properly grouted.
	• Infiltration can move through the overburden to solution channels, wells, and springs.	• Infiltration can move through the permeable overburden to fractures, wells, and springs.
	• Part or all of a stream can sink into solution channels (referred to as a sinking stream).	
	• Surface runoff may flow into sinkholes, which are a direct pathway to subsurface solution channels.	

Concentrations of dissolved nitrate differ areally throughout Clarke County (fig. 18). Concentrations of nitrate in water from wells and springs ranged from less than 1 to 75 mg/L as nitrogen (N). Concentrations of nitrate were greater than 5 mg/L as N in a disproportionately large number of wells in the southwestern part of the county; concentrations of dissolved nitrate were greater than the USEPA maximum contaminant level of 10 mg/L as N (U.S. Environmental Protection Agency, 1986) in water from wells throughout the county. Concentrations of nitrate greater than 10 mg/L as N in drinking water can cause methemoglobinemia (blue-baby syndrome) in young infants (Clark and others, 1977). Elevated concentrations of nitrate in ground water in Clarke County can be derived from over-application of fertilizers on agricultural land and from human and(or) animal wastes.

Water from wells and springs throughout the county has been contaminated by fecal bacteria, which generally are indicative of contamination by human and(or) animal wastes. Concentrations of fecal coliform ranged from less than 1 to 210 colonies per 100 mL. Concentrations of fecal streptococci ranged from less than 1 to 910 colonies per 100 mL (fig. 19). The USEPA has established a limit of 4 colonies per 100 mL for fecal coliform in community and noncommunity water systems (U.S. Environmental Protection Agency, 1986); about 40 percent of the sites sampled in Clarke County exceeded the USEPA limit. In general, however, bacteria concentrations greater than 1 colony per 100 mL in ground water of Clarke County is indicative of greater-than-natural concentrations resulting from human and(or) animal waste.



EXPLANATION

DIVIDING LINE BETWEEN THE VALLEY AND BLUE RIDGE REGIONS

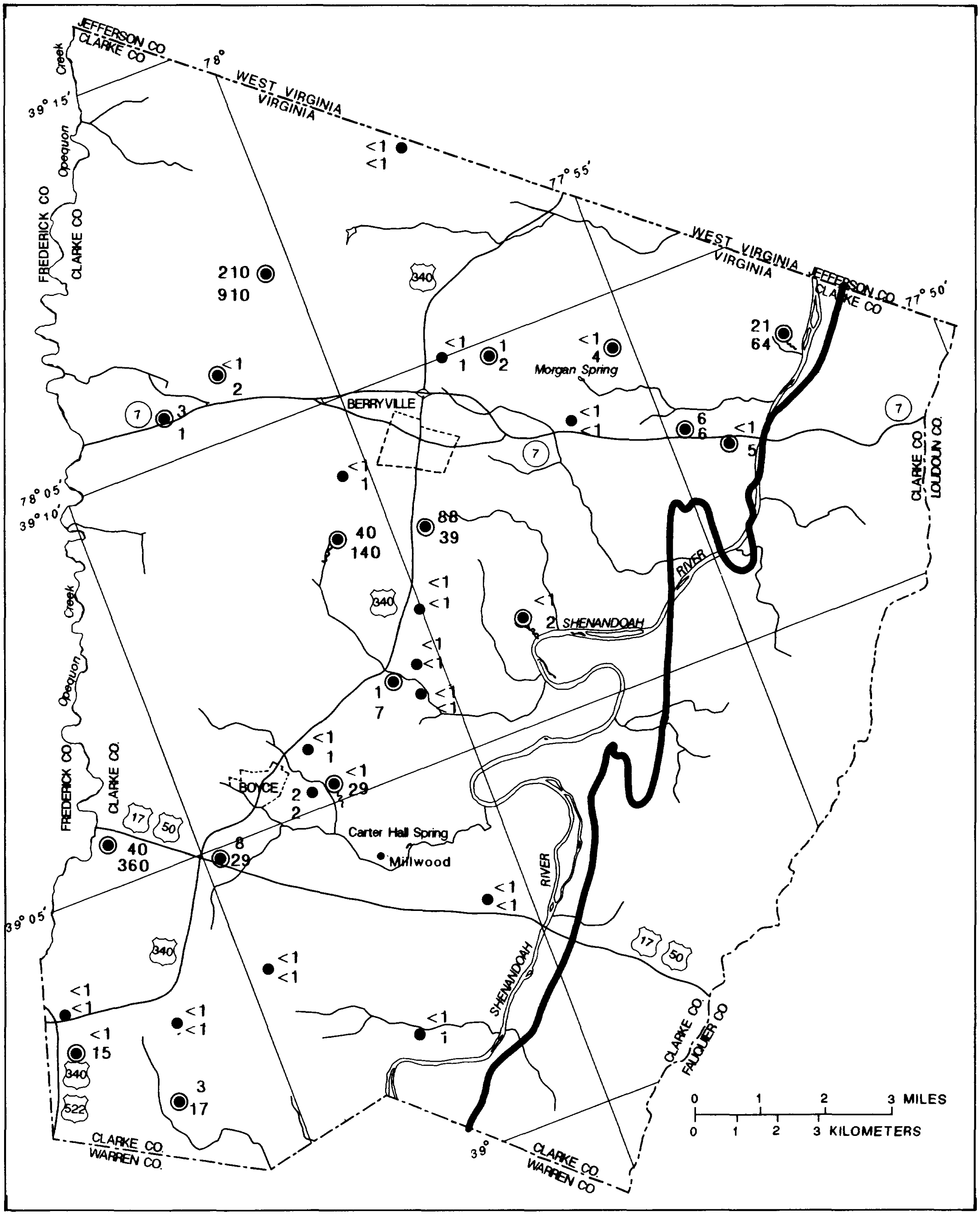
WELLS--Size of symbol indicates concentration of dissolved nitrate

- LESS THAN 1mg/L AS N (MILLIGRAMS PER LITER AS NITROGEN)
- EQUAL TO OR GREATER THAN 1 AND LESS THAN 5 mg/L AS N
- EQUAL TO OR GREATER THAN 5 AND LESS THAN 10 mg/L AS N
- EQUAL TO OR GREATER THAN 10 mg/L AS N

SPRING--Size of symbol indicates concentration of dissolved nitrate

- LESS THAN 1 mg/LAS N
- EQUAL TO OR GREATER THAN 1 AND LESS THAN 5 mg/L AS N
- EQUAL TO OR GREATER THAN 5 AND LESS THAN 10 mg/L AS N

Figure 18.--Dissolved nitrate concentrations in water from wells and springs in Clarke County, Virginia.



EXPLANATION

DIVIDING LINE BETWEEN THE VALLEY AND BLUE RIDGE REGIONS

WELL ● 8 COLONIES OF FECAL COLIFORM PER 100 mL (PER 100 MILLILITERS OF WATER)

29 COLONIES OF FECAL STREPTOCOCCI PER 100 mL

SPRING 71 COLONIES OF FECAL COLIFORM PER 100 mL

64 COLONIES OF FECAL STREPTOCOCCI PER 100 mL

<1 LESS THAN ONE COLONY OF FECAL BACTERIA PER 100 mL

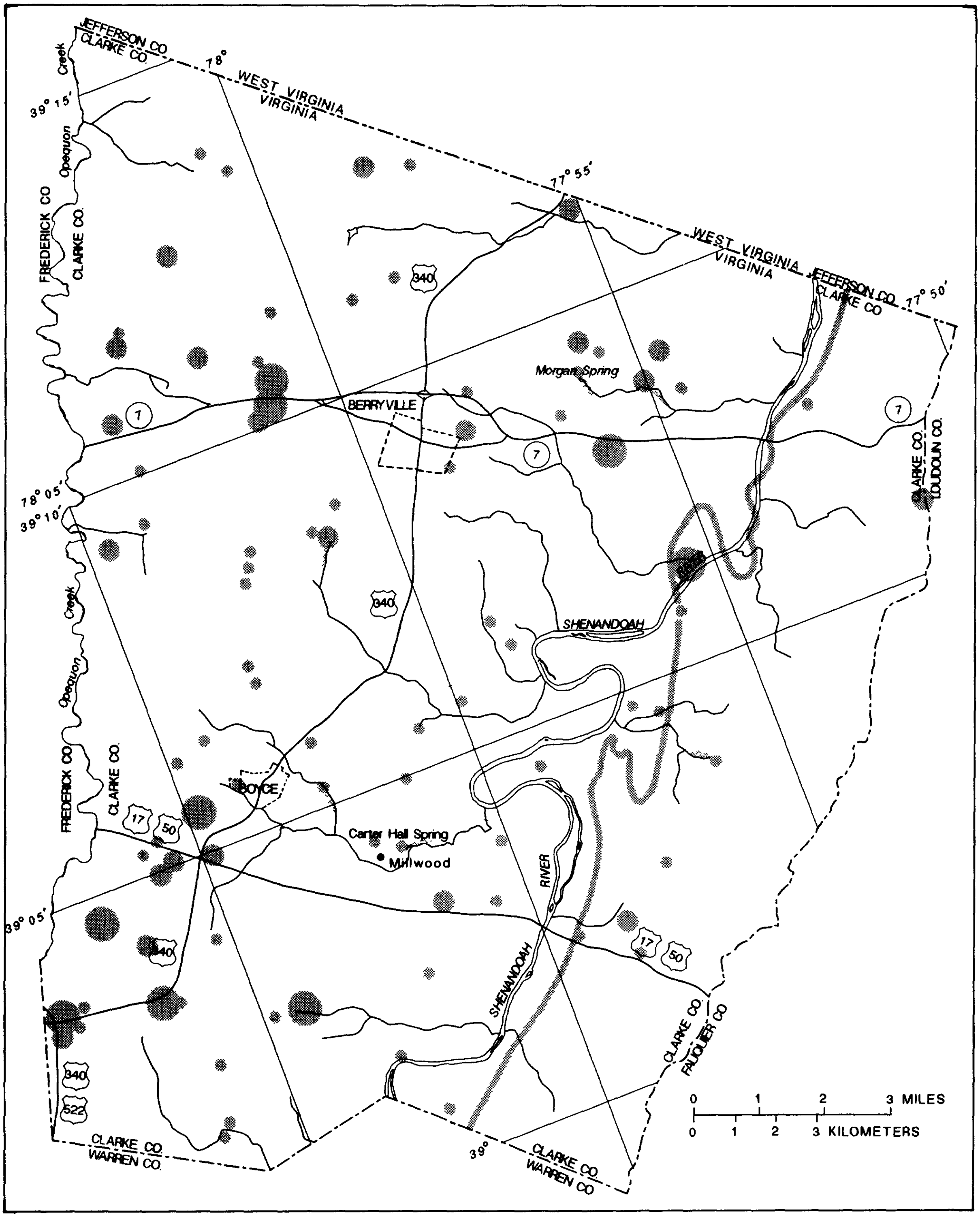
◉ BACTERIA CONCENTRATIONS SUSPECTED TO BE GREATER THAN NATURAL

Figure 19.--Fecal-bacteria concentrations in water from wells and springs in Clarke County, Virginia, December 1986.

Elevated concentrations of dissolved chloride in water from wells and springs in Clarke County indicate possible effects of human activities. Effects of human activities are indicated because many of the sites where water contained elevated chloride concentrations correspond to sites (for instance, in the southwestern part of the county) where water contained elevated nitrate concentrations. Although the data cannot be used to readily determine chloride concentrations caused by natural factors, concentrations greater than 10 mg/L probably result from the effects of human activities. Concentrations of dissolved chloride in water from wells and springs ranged from 1 to 70 mg/L (fig. 20); chloride concentrations were greater than or equal to 10 mg/L at 31 percent of the sites. No concentrations exceeded the USEPA limit of 250 mg/L for drinking water (U.S. Environmental Protection Agency, 1986). Elevated concentrations of chloride in the county's ground water could be caused by a number of possible sources related to human activities--septic drain fields, agricultural feedlots and barnyards, highway deicing salt, and fertilizers.

Some of the sites where concentrations of sodium in ground water were elevated correspond to sites where concentrations of nitrate and chloride were elevated. For the purposes of this report, elevated concentrations of dissolved sodium are those greater than or equal to 10 mg/L. Concentrations of dissolved sodium in water from wells and springs in Clarke County ranged from 1 to 110 mg/L (fig. 21); at 41 percent of the sites, concentrations exceeded 10 mg/L. The sources of elevated concentrations of dissolved sodium in ground water are similar to those of chloride--septic drain fields, agricultural feedlots and barnyards, and highway deicing salt.

Pesticides used in Clarke County include insecticides and fungicides used in orchard operations, herbicides used in farming, and insecticides used on the Blue Ridge Mountains to control the gypsy moth. Six locations in Clarke County--five springs and one well--were sampled and analyzed for pesticides. The springs sampled were Carter Hall, Prospect Hill, Morgan, Arthur Weiss, and Horsepen Springs; the well sampled for pesticides was Arthur Weiss' well. These samples were intentionally collected in late spring following weekly and biweekly applications of pesticides to orchards during the early growing season (L. Kauf, Clarke County Extension Agency, oral commun., 1986). The compounds that were analyzed and their detection limits are listed in table 5, and the sampling dates are shown in table 2. No pesticides were detected in water from five of six sites. Diazinon, used as an insecticide, was reported in water from Morgan Spring at the 0.01-microgram-per-liter detection limit of the laboratory instrument. Because of the limited areal distribution of sampling points and limited period of sampling, the results may not represent the spatial and temporal distribution of pesticides in ground water in Clarke County.



EXPLANATION

DIVIDING LINE BETWEEN THE VALLEY AND BLUE RIDGE REGIONS

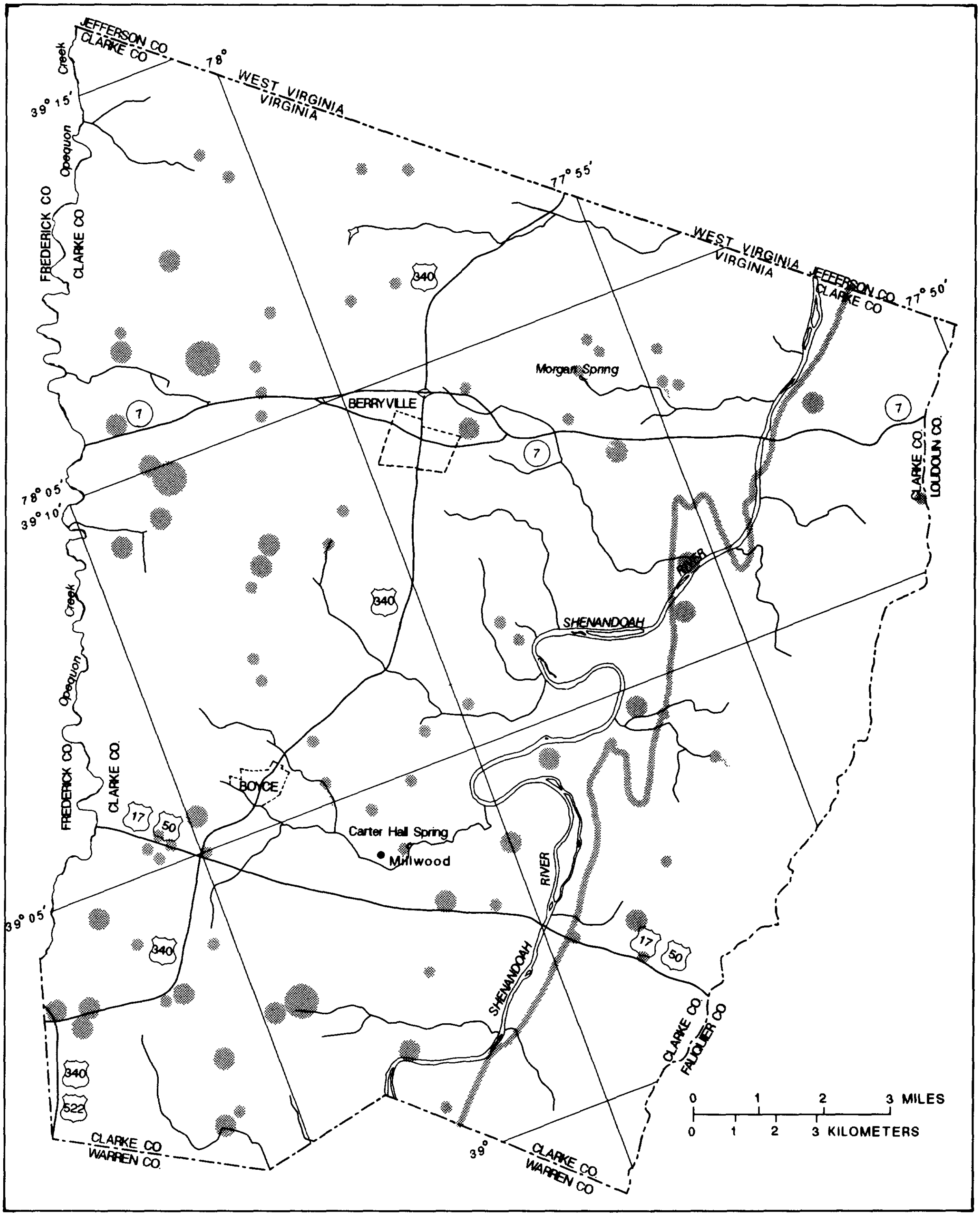
WELLS--Size of symbol indicates concentration of dissolved chloride

- LESS THAN 10 mg/L (MILLIGRAMS PER LITER)
- EQUAL TO OR GREATER THAN 10 AND LESS THAN 25 mg/L
- EQUAL TO OR GREATER THAN 25 mg/L

SPRINGS--Size of symbol indicates concentration of dissolved chloride

- LESS THAN 10 mg/L
- EQUAL TO OR GREATER THAN 10 AND LESS THAN 25 mg/L

Figure 20.--Concentrations of dissolved chloride in water from wells and springs in Clarke County, Virginia.



EXPLANATION

DIVIDING LINE BETWEEN THE VALLEY AND BLUE RIDGE REGIONS

WELLS--Size of symbol indicates concentration of dissolved sodium

- LESS THAN 10 mg/L (MILLIGRAMS PER LITER)
- EQUAL TO OR GREATER THAN 10 AND LESS THAN 50 mg/L
- EQUAL TO OR GREATER THAN 50 mg/L

SPRINGS--Size of symbol indicates concentration of dissolved sodium

- LESS THAN 10 mg/L

Figure 21.--Concentrations of dissolved sodium in water from wells and springs in Clarke County, Virginia.

Table 5.--Detection limits for pesticide compounds for which waters from springs and wells in Clarke County, Virginia, were analyzed

Pesticide compound	Detection limit of laboratory instrument, in micrograms per liter
Ethylan	0.10
PCN	.10
Aldrin	.002
Lindane	.002
Chlordane	.10
DDD	.002
DDE	.002
DDT	.002
Dieldrin	.002
Endosulfan	.002
Endrin	.002
Ethion	.01
Toxaphene	1.0
Heptachlor	.002
Heptachlor epoxide	.002
Methoxychlor	.01
PCB	.10
Malathion	.01
Parathion	.01
Diazinon	.01
Methyl parathion	.01
Picloram	.01
2,4-D	.01
2,4,5-T	.01
Mirex	.01
Silvex	.01
Ethyl trithion	.01
Dicamba	.01
2,4-DP	.01

SUMMARY AND CONCLUSIONS

Ground water in the valley region of Clarke County flows through solution-enlarged fractures in carbonate rocks (karst aquifers), whereas ground water in the Blue Ridge region flows through fractures that are not solution enlarged in igneous and metamorphic rocks. In the valley region, the ground-water-flow system is a mixture of diffuse-flow and conduit-flow conditions, with diffuse-flow conditions predominant. Ground water in the carbonate rocks of the valley region flows along solution-enlarged fractures oriented parallel to the axes of the anticlines and synclines, along bedding-plane partings adjacent to and parallel to the bedding of the rocks, and across the bedding of the rocks following cross-strike faults and fractures. In the Blue Ridge region, the ground-water-flow system is primarily controlled by irregular fracture patterns in the igneous and metamorphic rocks, and by the steep terrain. Steep terrain facilitates percolation of shallow ground water through the overburden and rapid movement to springs, streams, and the Shenandoah River.

Regional ground-water flow--indicated by a map of the water table--is generally toward springs, streams, the Shenandoah River, and the Opequon Creek. The directions of ground-water flow at specific locations in the county may change over short distances because flow is primarily controlled by fractures in the rocks. A depression in the water table around Spout Run, Prospect Hill Spring, and Carter Hall Spring indicates discharge of ground water to this area; this depression is alined with and west of the cross-strike fault that has produced the U.S. highway 50 wind gap.

Hydrographs of three springs and a well in Clarke County show the effects of recharge, discharge, and evapotranspiration (ET). Recharge to the ground-water system is indicated by peaks on the hydrographs during the winter and early spring months when ET is low. Ground-water discharge to springs and streams is indicated by the receding water levels of a well hydrograph. Recharge to the ground-water system is lower during the summer compared to winter because ET intercepts infiltration that would normally percolate to the water table. During autumn months, the hydrographs indicate that precipitation more effectively recharges the ground-water system because of decreasing ET in the fall. The characteristics of the hydrographs also indicate the karst aquifers of the valley region are probably a combination of diffuse-flow and conduit-flow conditions, particularly in the interbedded limestone and dolomite of the Elbrook and Conococheague Formations where Carter Hall and Prospect Hill Springs are located. Predominantly conduit-flow conditions prevail in the Stonehenge Limestone where Horsepen Spring is located.

Qualitative dye-tracing studies in the vicinity of Spout Run, Prospect Hill Spring, and Carter Hall Spring indicated that dye injected into the ground-water system through sinkholes moved 2 mi in 5 months. The dye-tracing tests also indicated that sinkholes are a direct link between land surface and the ground-water systems in the valley region of the county.

Yields of wells range from 0 to 460 gal/min in Clarke County. High-yielding wells are not necessarily located on or near lineaments, possibly because of the highly fractured nature of the rocks in Clarke County.

Natural ground-water quality of Clarke County depends on the type of rocks through which the water flows. Because ground water in the valley region flows mainly through fractures in soluble limestone and dolomite, it contains greater concentrations of dissolved calcium and magnesium than does ground water in the Blue Ridge region. Water from springs in the valley region has slightly lower percentages of dissolved calcium and magnesium compared to water from wells. The concentrations of sodium and potassium are greater percentagewise in ground water in the Blue Ridge region than in the valley region, indicating the dissolution of feldspar minerals partly comprising the igneous and metamorphic rocks.

Ground water is mostly very hard in the valley region and soft to very hard in the Blue Ridge region. Concentrations of hardness in ground water, which is primarily caused by dissolved calcium and magnesium, ranged from 89 to 422 mg/L as $CaCO_3$ in the valley region. Concentrations of hardness in ground water ranged from 4 to 242 mg/L as $CaCO_3$ in the Blue Ridge region.

Ground-water quality throughout much of Clarke County has been affected by human activities; the sources of the contaminants are probably nonpoint. Concentrations of dissolved nitrate greater than the USEPA maximum contaminant level of 10 mg/L as N were reported in water from wells throughout the county; concentrations greater than 5 mg/L as N were present in a disproportionately large number of wells in the southwestern part of the county. Well water that contained elevated concentrations of chloride and sodium commonly contained elevated concentrations of nitrate, indicating contamination of the ground water by human and(or) animal wastes. Fecal-bacteria contamination was detected in water from about 40 percent of the sites sampled throughout the county and in all four of the springs sampled. Water samples from five springs and one well were analyzed for pesticides; no pesticides were detected in water from five of six sites. Diazinon was reported in water from Morgan Spring at the 0.01-microgram-per-liter detection limit of the laboratory instrument.

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GLOSSARY

[Unless otherwise noted, definitions were obtained from Bates and Jackson, 1980]

Anticline.-- A fold that is generally convex upward.

Aquifer.-- A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs (Lohman, 1972, p. 2).

Argillaceous.-- Pertaining to, largely composed of, or containing clay-sized particles or clay minerals.

Basalt.-- A general term for dark-colored, iron-rich igneous rock.

Bedding plane.-- A planar or nearly planar bedding surface that visibly separates successive layers of stratified rock.

Calcareous shale.-- A shale containing calcium carbonate in the form of finely precipitated materials.

Carbonate rock.-- A rock consisting chiefly of carbonate minerals such as limestone or dolomite.

Chert.-- A hard, extremely dense or compact sedimentary rock, consisting mainly of interlocking crystals of quartz; occurs principally as nodular segregations (chert nodules) in limestones and dolomites; the term flint is essentially synonymous.

Conduit flow.-- Condition in carbonate aquifer where ground-water flow paths have been localized by solutional modification into well-integrated systems of conduits (White, 1969, p. 3).

Covered karst.-- Karst that forms below a soil cover that subdues its topographic features.

Cross-strike fault.-- A fault whose strike crosses at a high angle the strike of the constituent strata or the general trend of the regional structure.

Diffuse flow.-- Condition in carbonate aquifer where ground-water flow moves through interconnected, small solution cavities; solution cavities limited in size and number, often being mainly solutionally-widened joints or bedding planes (White, 1969, p. 1); circulation of ground water in karst aquifers under conditions in which all, or almost all, openings in the karstified rock intercommunicate and are full of water in the zone of saturation (Monroe, 1970, p. 7).

Dip.-- The angle that a bedding plane makes with the horizontal, measured perpendicular to the strike of the structure.

Dolomite.-- A carbonate sedimentary rock of which more than 50 percent of the rock by weight or areal percentage consists of the mineral calcium-magnesium carbonate.

Evapotranspiration.-- Loss of water from a land area through transpiration of plants and evaporation from the soil.

Fault.-- A fracture or zone of fractures along which there has been displacement of the sides relative to one another and parallel to the fracture.

Feldspar.-- A group of abundant rock-forming minerals of general formula $MAl(Al,Si)_3O_8$, where M = K, Na, Ca, Ba, Rb, Sr, and Fe; they occur as components of all kinds of rocks (crystalline schists, migmatitites, gneisses, granites, and most magmatic rocks).

Formation.-- A body of rock strata that is unified with respect to adjacent strata by consisting of a certain rock type or combination of types.

Fold.-- A curve or bend of a planar structure such as rock strata.

Fold axis.-- The line which, moved parallel to itself, generates the form of a fold.

Fractured-rock flow.-- Ground-water flow through water-bearing openings in bedrock consisting of fractures along which the rocks have been broken by tectonic forces. These openings are referred to as secondary openings, in contrast to primary openings which were formed at the same time as the rock (Heath, 1988, p. 15).

Hydraulic gradient.-- In an aquifer, the rate of change of total head per unit distance of ground-water flow at a given point and in a given direction.

Hydrograph.-- A graph showing stage, flow, velocity, or other characteristics of water with respect to time.

Igneous rock.-- A rock or mineral that solidified from molten or partly molten material.

Joint.-- A surface of fracture or parting in a rock without displacement.

Joint-controlled flow.-- Ground-water flow that follows closely spaced joints, typically in angular patterns (Deike, 1969).

Karst.- A type of topography that is formed on limestone, gypsum, and other rocks by dissolution, and that is characterized by sinkholes, caves, and underground drainage.

Limestone.-- A sedimentary rock consisting chiefly (more than 50 percent by weight or areal percentage) of calcium carbonate, primarily in the form of the mineral calcite.

Lineament.-- A linear topographic feature of regional extent that is believed to represent a zone of fractures.

Metamorphic rock.-- Any rock derived from preexisting rocks by mineralogical, chemical, and(or) structural changes in response to changes in temperature, pressure, shearing stress, and chemical environment.

Nonpoint source.-- Pollution from sources that cannot be defined as discrete points, such as areas of crop production, timber, surface mining, disposal of refuse, and construction.

Overburden.-- The loose soil, silt, sand, gravel, or other unconsolidated material overlying bedrock, either transported or formed in place; formed in place is called *residuum*.

Percolation.-- According to Heath (1983, p. 4), recharge of the saturated zone occurs by *percolation* of water from the land surface through the unsaturated zone.

Permeability.-- Technically referred to as hydraulic conductivity, the capacity of a rock to transmit water (Heath, 1983, p. 12).

Point source.-- Pollution resulting from any confined, discrete source, such as a pipe, ditch, tunnel, well, container, or concentrated animal-feeding operation.

Phyllite.-- A metamorphosed rock, intermediate between slate and mica schist.

Quartzite.-- A metamorphic rock consisting mainly of quartz and formed by recrystallization of sandstone; quartz grains that have been so completely and solidly cemented with secondary silica that the rock breaks across or through the grains rather than around them.

Recharge.-- The process or amounts involved in the absorption and addition of water to the zone of saturation.

Residuum.-- An accumulation of rock debris formed by weathering and remaining essentially in place after all but the least soluble constituents have been removed.

Sandstone.-- A medium-grained clastic sedimentary rock composed of rounded or angular fragments of sand (usually quartz sand) cemented in a fine-grained matrix (commonly silica, iron oxide, or calcium carbonate).

Sedimentary rock.-- A rock resulting from consolidation of loose sediment that has accumulated in layers.

Shale.-- A fine-grained detrital sedimentary rock, formed by the consolidation of clay, silt, or mud.

Siltstone.-- An indurated silt having the texture and composition of shale; mudstone in which silt predominates over clay.

Sinkhole.-- A circular or closed depression; they may be basin, funnel, or cylindrical in shape; a distinction may be made between those formed mainly by direct solution of the limestone surface (solution sinkhole), and those formed by collapse over a cave (collapse sinkhole); closed depressions receiving a stream are known as swallow holes or stream sinks (Monroe, 1970, p. 16); referred to as a doline by Europeans.

Sinking stream.-- A surface stream that disappears underground in a karst region.

Slate.-- A compact, fine-grained metamorphic rock that was formed from shale and can be broken into slabs and thin plates.

Strata.-- A layer of sedimentary rock.

Strike.-- The direction or trend taken by a structural surface, such as a bedding plane, as it intersects the horizontal.

Strike-controlled flow.-- Ground-water flow oriented parallel to the strike of the rocks; typically strike-oriented solution cavities in carbonate rocks (Deike, 1969).

Subsurface-storm flow.-- The runoff water infiltrating the subsurface soil and moving toward streams as ephemeral shallow perched ground water above the main ground-water level; synonymous with storm seepage, throughflow, ground-water runoff.

Syncline.-- A fold which is generally concave upward.

Water table.-- That surface in a ground-water body at which the water pressure is atmospheric; defined by the levels at which water stands in wells that penetrate the ground-water body (Lohman, 1972, p. 14).

Wind gap.-- A shallow notch in the crest of upper part of a mountain ridge; possibly a former water gap, now abandoned by the stream that formed it.

APPENDIXES

Appendix A.-- Records of selected springs in Clarke County, Virginia

[Approximate discharges are in gallons per minute (gal/min); altitudes are in feet above sea level; dash indicates no data; source is USEPA STORET data base]

Explanation of symbols:

Omb - Martinsburg Formation
Ooe - Oranda and Edinburg Formations
Opr - Pinesburg Station Dolomite
Orr - Rockdale Run Formation
Ost - Stonehenge Limestone
Cco - Conococheague Formation
Ce - Elbrook Formation
Cwb - Waynesboro Formation
Ct - Tomstown Dolomite
Ca - Antietam Formation
Ch - Harpers Formation

Local identifier explanation:

Prefix	Quadrangle name
46XS	Stephenson
47XS	Berryville
48XS	Round Hill
45WS	Stephens City
46WS	Boyce
47WS	Ashby Gap
48WS	Bluemont
46VS	Linden

Local identifier		Latitude degrees minutes seconds	Longitude degrees minutes seconds	Approximate discharge, gal/min	Altitude, feet	Name or owner	Formation
47XS	4	39 09 47	77 58 39	120	575	LEE SPRING	Cco
47XS	5	39 09 23	77 58 10	40	545	GEORGE WASHINGTON SPRING	Cco
47XS	3	39 08 42	77 52 42	50	420	HOLY CROSS ABBEY-COOL SPRING	Ct
46WS	3	39 05 19	78 02 37	700	510	PROSPECT HILL SPRING	Cco
48WS	1	39 07 10	77 51 19	10	880	HORSESHOE CURVE REST-SPRING	Ch
46XS	6	39 13 28	78 02 38	-	540	LOUISE EDENS-SPRING	Ooe
46XS	1	39 14 43	78 02 19	400	460	WADESVILLE SPRING	Ooe
46XS	7	39 11 25	78 04 02	1,500	505	AFFLICK SPRING	Opr
46WS	1	39 04 08	78 01 38	2,000	460	CARTER HALL SPRING	Cco
46WS	23	39 04 57	78 03 37	350	540	SARATOGA FARM SPRING	Ost
47WS	2	39 06 18	77 58 32	500	430	PRICE/JAMES SPRING	Ce
47XS	14	39 11 33	77 56 08	10	525	MCLEAN SPRING	Cco
47XS	16	39 10 58	77 55 00	-	-	C.P.WOLFE	Cco
47XS	17	39 09 13	77 57 27	5	560	AUDLEY FARMS SPRING	Cco
47XS	18	39 08 51	77 55 55	5	475	W.B.CLAGETT	Ce
47WS	12	39 06 35	77 57 35	-	-	R.G.BUCKLEY	Cwb
46XS	8	39 07 33	78 01 30	5	-	W.B.WATKINS	Ost
46WS	21	39 04 44	78 04 19	-	555	E.B.STROSNIDER	Ost
47XS	15	39 07 39	77 59 23	-	560	-	Cco
47XS	19	39 11 52	77 58 59	-	620	-	Ost
47XS	20	39 11 25	77 56 57	-	575	-	Cco
46WS	2	39 06 53	78 04 14	80	608	PAGEBROOK SPRING	Orr
46WS	4	39 05 48	78 04 16	-	580	BUTLER SPRING	Orr
46WS	5	39 06 03	78 03 14	75	600	HUNTINGDON SPRING	Orr
46WS	6	39 02 49	78 07 11	-	610	GREENWAY COURT SPRING	Orr
47XS	6	39 11 36	77 56 07	-	520	CLIFTON FARM SPRING	Cco
46WS	7	39 01 47	78 05 54	100	580	FEDERAL HILL SPRING	Cco
46WS	8	39 03 46	78 04 00	50	580	BLANDY FARM/RATTLESNAKE SPRING	Cco
46WS	9	39 02 18	78 05 01	-	625	WOLFE MARSH SPRING	Cco
46WS	10	39 02 11	78 04 25	-	585	MONTANA HALL SPRING	Cco
46WS	11	39 02 40	78 04 35	-	580	BENNETT SPRING	Cco
46WS	12	39 02 26	78 03 20	-	560	LONG BRANCH SPRING	Cco
46WS	13	39 04 36	78 06 15	30	615	WESTBROOK SPRING	Orr
46WS	14	39 04 01	78 05 19	-	590	FRITTS SPRING	Ost
46WS	15	39 04 10	78 01 32	-	475	GLEN OWEN SPRING	Ce
46WS	16	39 04 56	78 00 33	-	490	CLAY HILL SPRING	Ce
46WS	17	39 04 44	78 00 24	300	435	SHAN HILL SPRING	Ce
46WS	18	39 04 36	78 00 38	-	470	SIPE SPRING	Ce

Appendix A.-- Records of selected springs in Clarke County, Virginia--Continued

46WS 19	39 06 24	78 00 51	-	490	OLD CHAPEL SPRING	Cco
46WS 20	39 06 58	78 01 12	-	555	LEWIS(DONOVAN) SPRING	Cco
46XS 2	39 10 37	78 02 10	100	560	DRY MARSH/RUTHERFORD SPRING	Orr
46XS 3	39 08 12	78 01 11	400	600	HORSEPEN SPRING	Ost
46XS 4	39 08 08	78 00 29	-	625	ROSEMONT SPRING	Cco
47WS 9	39 05 38	77 58 43	50	418	SPRINGSBURY SPRING	Cwb
47WS 10	39 06 57	77 59 43	-	540	LLEWELLYN FARM SPRING	Cco
47WS 11	39 07 10	77 57 38	-	460	HILL AND DALE SPRING	Cwb
47XS 1	39 08 40	77 55 04	10	460	ARTHUR WEISS' SPRING	Ct
47XS 7	39 08 45	77 55 51	-	480	SPRINGFIELD SPRING	Ce
47XS 2	39 09 06	77 56 04	200	485	MORGAN SPRING	Ce
47XS 8	39 07 37	77 59 24	-	550	MILTON VALLEY SPRING	Cco
47XS 9	39 08 08	77 59 02	-	555	SMALLWOOD SPRING	Cco
47XS 10	39 08 53	77 58 41	-	575	SMITHY SPRING	Cco
47XS 11	39 10 02	77 58 54	-	590	TRAPP HILL SPRING	Cco
47XS 12	39 11 58	77 58 48	-	605	DORSEY SPRING	Ost
47XS 13	39 11 07	77 56 14	-	530	FAIRFIELD SPRING	Cco
01636330	39 03 47	77 56 17	150	635	GIULIANI SPRING	Ca

Appendix B.--Records of selected wells in Clarke County, Virginia

[Yields are in gallons per minute (gal/min); altitudes are in feet above sea level; source of information: D=Driller, O=Owner; dash indicates no data]

Explanation of symbols:

Omb - Martinsburg Formation
Ooe - Oranda and Edinburg Formations
Oln - Lincolnshire Formation and New Market Limestone
Opr - Pinesburg Station Dolomite
Orr - Rockdale Run Formation
Ost - Stonehenge Limestone

Cco - Conococheague Formation
Ce - Elbrook Formation
Cwb - Waynesboro Formation
Ct - Tomstown Formation
Ca - Antietam Formation
Ch - Harpers Formation
Cw - Weverton Formation
Cc - Catoctin Formation

Local identifier explanation:

Prefix	Quadrangle name
46X	Stephenson
47X	Berryville
48X	Round Hill
45W	Stephens City
46W	Boyce
47W	Ashby Gap
48W	Bluemont
46V	Linden

Local identifier		Latitude (degrees minutes seconds)	Longitude (degrees minutes seconds)	Depth, feet	Yield, gal/min	Casing depth, feet	Casing diameter, inches	Name or owner	Altitude, feet	Formation	Installation date	Source of information
47X	1	39 08 51	77 58 24	365	360	60	8	TOWN OF BERRYVILLE-SOUTH WELL	580	Cco	01/01/1956	D
47X	4	39 09 18	77 55 30	255	5	45	-	MITCHELL, T.	565	Cco	01/01/1956	D
47X	5	39 08 00	77 59 32	160	25	24	6	LEAKE, H.	570	Cco	01/01/1953	D
47X	6	39 08 37	77 56 35	348	25	100	6	GRAFTON SCHOOL	570	Cco	01/01/1953	D
46W	1	39 04 59	78 05 04	85	40	-	-	FARM RESTAURANT	590	Opr	-	-
48X	9	39 07 34	77 52 22	450	20	100	6	RETREAT GOLF CLUB	720	Ca	01/26/1973	D
47X	7	39 10 01	77 58 18	162	30	27	-	FOWLER, W.	460	Ca	04/20/1973	D
47X	8	39 11 13	77 59 29	295	10	19	6	MCDONALD, E.	642	Ca	01/05/1973	D
45W	6	39 03 11	78 08 11	-	20	53	6	DEPT. OF CORRECTIONS	660	Omb	08/15/1973	D
47W	50	39 04 50	77 57 22	260	25	15	6	RIVER PARK WATER SYSTEM	390	Ct	01/01/1955	D
45W	7	39 03 09	78 08 31	700	-	100	-	DEPT. OF CORRECTIONS	685	Omb	01/01/1973	D
46X	32	39 09 53	78 03 38	135	30	-	-	JONES, MICHAEL R.	585	Oln	09/01/1972	O

Appendix B.--Records of selected wells in Clarke County, Virginia--Continued

46X	33	39 09 19	78 04 49	100	30	-	-	HAMILTON, STEVE	650	Omb	01/01/1975	D
46X	34	39 09 12	78 04 39	100	40	-	-	HEADLEY, MACK S.	650	Omb	01/01/1955	O
46X	35	39 09 55	78 03 39	225	12	30	6	FUNK, O.M.	591	Oln	01/01/1967	O
46X	36	39 10 00	78 03 38	198	2	-	-	LLOYD, DAVID	592	Oln	01/01/1972	O
46X	37	39 10 02	78 03 38	300	6	-	4	CAYLOR, J.W.	594	Opr	01/01/1974	O
46X	38	39 08 59	78 04 32	200	-	-	-	GARVER, LAWRENCE J.	656	Omb	10/01/1974	O
46X	39	39 08 59	78 04 26	90	-	-	-	ANDERSON, J.M.	642	Oln	01/01/1951	O
46W	2	39 01 30	78 06 16	375	50	-	2	JONES, A.	610	Ost	01/01/1965	O
47X	9	39 07 57	77 54 49	140	12	53	6	BOLDEN, W.	560	Cco	12/01/1974	O
47X	10	39 09 49	77 57 29	110	200	99	6	BROY, W.	560	Cco	-	O
46X	40	39 11 47	78 03 10	315	23	24	6	KERNS, FRANK O.	600	Oln	08/04/1976	D
46W	3	39 01 54	78 01 13	325	40	20	6	WILSON, W.C.	590	Orr	01/01/1953	O
46W	6	39 03 32	78 05 54	136	50	29	6	THOMPSON, W.	585	Orr	-	O
46W	7	39 04 13	78 02 22	335	12	18	6	HESTER, F.	590	Orr	-	O
47X	11	39 07 38	77 54 10	805	3	54	6	RITZENBERG	485	Cwb	01/01/1968	O
47X	12	39 07 36	78 00 00	226	3	131	6	MURRAY, J.	530	Cwb	-	O
47X	13	39 08 00	77 59 41	112	10	46	6	CARTER, T.	530	Cco	01/01/1973	O
47X	14	39 11 50	77 59 00	74	30	34	-	BURNER, L.	530	Cwb	01/01/1970	O
47W	51	39 07 29	77 54 56	40	-	-	-	S.M. PERRY QUARRY INC.	585	Ct	01/01/1959	O
47X	15	39 11 48	77 59 00	80	-	17	-	BURNER, L.	560	Cco	-	-
47X	17	39 07 33	77 58 37	183	3	16	-	JONES	635	Cco	-	-
47X	18	39 08 29	77 54 30	110	10	66	-	POTTER, D.	640	Cco	01/01/1975	O
47X	19	39 09 28	77 55 22	158	1	19	-	KERNS, C.	583	Cco	10/01/1977	O
47X	20	39 10 12	77 58 20	166	4	54	6	BROY, R.	630	Ost	-	D
47X	21	39 07 31	77 59 52	389	6	13	-	GOODE, R.	658	Ost	01/01/1948	O
46W	15	39 03 18	78 04 42	240	100	51	6	LEE, E.B.	585	Ost	08/01/1974	O
46X	41	39 08 40	78 00 44	135	-	-	6	BAKER, HUGH	638	Ost	01/01/1964	O
46X	42	39 09 10	78 04 39	100	-	-	6	HEADLEY, MACK S.	642	Omb	01/01/1960	O
46X	43	39 08 08	78 02 39	130	-	-	6	ASHBY, CLAUDE	575	Opr	12/01/1976	O
46W	16	39 05 49	78 02 45	550	2	13	6	YOWELL, N.	510	Cwb	01/01/1966	O
47W	52	39 02 10	77 58 38	150	20	-	6	VAN KEUREN, E.	682	Ch	01/01/1977	O
47W	53	39 04 25	77 55 23	200	6	-	6	LEE, S.	715	Ch	01/01/1975	O
47W	54	39 03 42	77 56 21	175	30	-	6	THOMAS, W.H.	678	Ch	01/01/1964	O
47W	55	39 02 42	77 57 39	175	11	-	6	LLOYD, GRAYSON	768	Ch	01/01/1971	O
47X	22	39 07 35	77 59 56	400	2	27	6	POTTER, J.	550	Ce	09/22/1977	D
46W	17	39 03 04	78 06 29	250	1	9	6	PAYNE, E.	572	Ce	01/01/1965	O
46W	18	39 05 32	78 06 30	-	-	-	-	LOST CORNER RESTAURANT	590	Ost	01/01/1966	O
46W	20	39 02 33	78 06 58	505	5	50	6	DIGGES, JOHN A.	595	Cco	01/01/1941	O
46W	21	39 06 51	78 03 06	105	30	-	6	GARVER, JERME	600	Ce	01/01/1965	O
46W	22	39 06 12	78 02 25	450	3	-	6	CARTER, DAN	630	Ost	01/01/1957	O
46W	23	39 00 45	78 02 34	120	3	-	-	TRENARY, R.C.	615	Orr	01/01/1970	O
46W	24	39 02 29	78 02 03	575	60	-	6	WHITE, B.J.	650	Orr	01/01/1948	O
46W	25	39 05 54	78 02 34	180	40	-	-	YOWELL, W.L.	650	Orr	01/01/1913	O
46W	26	39 02 40	78 04 20	37	10	-	-	LEE, E.B., JR.	630	Oln	01/01/1966	O
46W	27	39 03 08	78 02 34	250	7	-	6	JAMES, J.W.	620	Orr	01/01/1964	O

Appendix B.--Records of selected wells in Clarke County, Virginia--Continued

46W	28	39 03 56	78 05 14	210	12	-	6	SYPE, JOE, JR.	635	Orr	01/01/1962	-
46W	29	39 06 15	78 04 51	160	20	-	6	SELL, ROBERT G.	640	Orr	01/01/1972	O
46W	32	39 05 14	78 05 46	70	-	-	6	MCINTIRE, P.T.	630	Orr	01/01/1977	D
46W	33	39 04 23	78 07 05	65	-	-	4	SHILEY, A.L.	630	Orr	-	O
46W	34	39 04 42	78 07 03	600	-	-	6	SHILEY, A.L.	630	Orr	01/01/1958	O
46W	35	39 03 55	78 05 59	400	-	-	6	BUCKLEY, M.S.	625	Orr	-	O
46W	36	39 04 13	78 06 31	275	8	-	6	BUCKLEY, M.S.	625	Orr	-	O
46W	37	39 05 22	78 05 53	260	45	-	-	DOUGLAS MCINTIRE	625	Orr	-	O
46W	38	39 03 27	78 06 22	125	7	-	6	R G BUCKLEY #1	520	Cwb	01/01/1946	O
47X	23	39 09 55	77 57 28	500	8	10	6	J.G.GARDNER	550	Ce	01/01/1964	O
47W	56	39 02 09	77 59 32	72	10	-	8	WADE H SCOTT	470	Ch	01/01/1958	O
45W	8	39 03 34	78 07 55	260	4	-	6	CHARLES W KELLER	645	Ost	01/01/1971	O
45W	9	39 03 35	78 07 47	115	25	-	2	MRS H E JEFFREY	650	Ost	01/01/1968	O
45W	10	39 03 34	78 07 51	300	30	-	6	NORMAN RITTER	650	Ost	01/01/1968	O
46W	39	39 03 27	78 06 25	115	7	-	8	R G BUCKLEY #3	620	Cco	-	O
46W	40	39 03 01	78 00 35	125	3	-	6	JOSEPH MYER	620	Orr	01/01/1970	O
46W	41	39 03 03	78 06 29	90	8	-	8	MRS R SLOAN	650	Orr	01/01/1974	O
46X	44	39 10 18	78 01 20	75	3	-	6	P JENKINS	610	Ost	01/01/1958	O
46X	45	39 10 09	78 01 27	125	10	-	8	HARRY MCDONALD	610	Ost	01/01/1970	O
46W	42	39 03 31	78 06 32	400	15	-	8	R G BUCKLEY	650	Orr	10/28/1977	D
46W	43	39 04 56	78 05 21	320	10	29	6	P.T. MCINTIRE-COBB FARM	625	Orr	01/01/1958	O
46W	44	39 05 31	78 04 54	300	15	-	8	SHIRLEY GRUBBS	635	Orr	07/01/1978	O
45W	11	39 03 24	78 08 11	450	35	105	6	DOC-FIELD UNIT #7-WELL #4	640	Ost	08/20/1980	D
47W	57	39 05 40	77 59 54	88	2	-	6	STELLA D MOORE	545	Ce	-	-
47W	60	39 06 34	77 55 26	-	-	-	6	FLOYD OWENS	565	Ce	01/01/1976	D
47W	62	39 06 09	77 58 46	465	2	65	6	J O MCDANIEL	542	Ce	-	O
47W	63	39 06 31	77 58 58	204	14	4	6	GORDON LEVI	545	Ce	01/01/1953	O
48W	8	39 05 59	77 51 23	96	4	-	6	R ROBY	1,760	CpCc	-	-
47W	66	39 05 48	77 55 57	200	4	-	6	V O MANN	395	Ch	08/01/1977	O
47W	67	39 01 37	77 58 38	210	60	-	6	BLUE RIDGE RESTAURANT	660	CpCc	01/01/1962	O
46X	46	39 10 26	78 01 13	150	-	-	6	GEORGE RUST	609	Opr	01/01/1973	O
46X	47	39 10 47	78 01 06	360	-	-	6	PAUL HASH	630	Opr	01/01/1972	O
46X	48	39 11 22	78 00 36	245	8	-	6	JOHN KACKLEY	622	Opr	01/01/1965	O
46X	49	39 13 16	78 00 26	150	-	-	6	ROBERT MAY	556	Opr	09/01/1975	O
46X	50	39 13 38	78 00 46	390	2	-	-	BRUCE ENDERS	550	Opr	01/01/1973	O
46X	51	39 13 21	78 01 59	275	11	-	6	R D CALDWELL	555	Ooe	05/03/1978	O
47W	68	39 04 35	77 56 52	225	10	-	-	GEORGE CHILCOTT (WILLOW LAKE	475	Ce	02/16/1967	O
47W	69	39 03 08	77 58 00	218	5	-	-	KENNETH HERRON	925	Ch	01/01/1976	O
47W	70	39 04 32	77 59 04	430	17	-	-	FRANCIS C ENDICOTT	535	Cwb	01/01/1971	O
46X	52	39 10 17	78 01 17	290	14	-	2	W A ARTHUR	612	Opr	01/01/1968	O
46W	45	39 05 24	78 05 41	125	35	-	8	JOHN FRIES	630	Cco	03/01/1981	O
46W	46	39 02 20	78 05 56	620	3	-	-	GREENWOOD FARMS CORP	620	Cco	01/01/1810	O
46W	47	39 02 42	78 04 50	30	-	-	-	STUART LARRICK	550	Ce	01/01/1942	O

Appendix B.--Records of selected wells in Clarke County, Virginia--Continued

45W	12	39 02 21	78 08 24	70	20	-	6	C J BRUMBACK	635	Ost	01/01/1979	O
46W	48	39 01 34	78 03 01	325	-	-	-	DAVID G MACDONALD	570	Cco	-	-
46W	49	39 01 36	78 06 08	255	20	-	8	THADDEUS BROWN	570	Cco	01/01/1977	O
46W	50	39 04 59	78 01 14	375	8	-	8	I L NEVILLE	580	Cco	01/01/1977	O
46W	51	39 05 15	78 02 53	320	100	81	6	BOYCE, VIRGINIA	520	Cco	01/01/1953	O
46W	52	39 04 12	78 02 13	225	2	30	6	M.JACKSON,JR.	540	Cco	-	-
46W	53	39 05 13	78 05 35	405	70	-	6	JAMES H KIRKPATRICK	590	Orr	-	-
48X	10	39 07 31	77 50 37	710	5	40	6	R H FOSTER-ROCKWOOD RIDGE FA	1265	CpCc	-	-
46W	54	39 04 29	78 02 32	260	6	62	6	MILLW.REC.CTR	585	Ce	-	-
48X	11	39 08 05	77 52 05	750	45	-	-	SHEN RETREAT-CLUB HOUSE	420	Ca	-	-
48X	12	39 08 15	77 51 13	450	10	-	-	SHEN RETREAT-RIVERVIEW NEAR	655	Ca	-	-
46X	53	39 10 15	78 03 33	100	40	35	6	JAMES HELSLEY	595	Orr	-	-
47X	24	39 07 52	77 54 43	170	5	22	6	C.DUKE	560	Ce	-	-
45W	13	39 03 43	78 08 17	56	-	-	-	SHENANDOAH VALLEY AUCTION	710	Omb	-	-
47W	71	39 06 10	77 55 32	-	-	-	-	WATERMELON PARK	390	Ch	-	-
46W	55	39 01 49	78 00 57	112	11	-	-	W CONROY WILSON #2	620	Orr	-	-
45W	14	39 03 33	78 08 28	300	-	-	-	DOUBLE TOLLGATE RESTAURANT	700	Omb	-	-
48X	13	39 07 54	77 52 24	450	10	-	-	SHEN RETREAT-TIMBER LANE	460	Ca	-	-
46W	56	39 04 48	78 03 14	200	50	-	-	MILLWOOD COUNTRY CLUB	585	Cco	-	-
46X	54	39 10 19	78 01 00	70	-	-	-	BLUE RIDGE DAY CARE CENTER #	620	Ost	-	-
46W	57	39 06 25	78 04 18	300	5	-	6	JAMES LONGERBEAM	680	Cco	-	-
46X	55	39 10 35	78 03 49	84	-	-	-	OSCAR M CARR-HOUSE	625	Omb	01/01/1912	O
46X	56	39 10 37	78 03 48	150	-	40	6	OSCAR M CARR-BARN	625	Omb	01/01/1954	O
46X	57	39 10 13	78 01 24	250	10	-	8	SANDY GOLDIZEN	630	Ost	01/01/1976	O
46X	58	39 10 22	78 01 19	102	8	-	-	TRIPLE J GROCERY	590	Ost	01/01/1960	O
46X	59	39 09 19	78 03 54	200	25	63	6	DR RAYNER JOHNSON	590	Omb	05/20/1977	D
46X	60	39 08 21	78 02 27	200	40	42	6	DAVID L DIXON	550	Opr	04/04/1978	D
46X	61	39 14 33	78 02 22	250	6	23	6	RALPH L SHIRLEY	490	Ost	06/10/1978	D
46W	58	39 06 19	78 04 23	280	-	13	6	JAMES H ROYSTON	640	Orr	-	-
46X	62	39 11 38	78 01 54	525	-	-	-	TOM CATHER	590	Ost	05/01/1976	O
46X	63	39 11 39	78 03 17	420	-	-	6	PAUL CALL	600	Oln	01/01/1973	O
46W	59	39 03 45	78 00 06	500	-	-	-	CHARLES BURWELL	550	Ct	-	-
46W	60	39 00 21	78 00 53	530	6	191	6	NORTHERN VA YOUTH CAMP	450	Ct	-	-
46X	64	39 11 57	78 03 05	360	200	-	6	HAVEN WOLFE SR	580	Opr	01/01/1979	O
46X	65	39 08 29	78 01 58	250	3	-	6	EDGAR PINE	575	Opr	01/01/1965	O
47W	72	39 03 23	77 59 17	115	15	-	-	W R FURR	515	Cwb	-	-
47W	73	39 03 33	77 59 38	600	15	-	-	BURWELL-LENNEP TRUST FOUNDTI	510	Cwb	-	-
46W	61	39 00 55	78 02 49	205	20	47	6	BETHEL	540	Cco	-	-

Appendix B.--Records of selected wells in Clarke County, Virginia--Continued

46W	62	39 03 03	78 03 31	260	12	103	-	MILLWOOD	630	Orr	-	-
46W	63	39 02 32	78 00 01	285	8	43	-	BERRYS	630	Orr	-	-
46X	66	39 12 25	78 02 15	240	26	-	6	GARY L FOLTZ	580	Opr	01/01/1976	O
46X	67	39 11 06	78 02 03	123	60	-	-	LEROY RIVERA	525	Opr	05/16/1972	O
46X	68	39 08 27	78 02 23	120	17	-	-	RICHARD BARTLES	590	Opr	01/01/1979	O
46X	69	39 12 29	78 01 56	320	20	53	6	JOHN HARDESTY	595	Ost	10/18/1977	D
46X	70	39 12 16	78 02 38	500	6	33	6	GERALD BORG	600	Omb	09/20/1977	D
46W	64	39 07 30	78 00 06	155	8	36	6	J.GERKINS	620	Cwb	-	-
46W	65	39 04 54	78 04 50	253	10	-	6	H.GLASCOCK	650	Ch	-	-
46W	65	39 03 57	78 04 15	63	-	-	84	A.WILSON	470	Cwb	-	-
47X	25	39 07 49	77 54 22	112	20	25	6	G.MYERS	540	Cwb	-	-
47W	74	39 05 55	77 59 45	125	40	47	6	JAY HILLERSON	480	Ce	07/12/1983	D
48W	9	39 07 10	77 51 56	210	10	-	-	VILLAGE MARKET #1	695	Ch	-	-
48W	10	39 07 12	77 51 55	250	12	50	6	VILLAGE MARKET #2	690	Ch	-	-
48W	11	39 07 09	77 51 58	300	5	26	6	LAWRENCE LONGERBEAM	690	Ch	-	-
48W	12	39 07 03	77 51 58	200	-	60	6	LAWRENCE LONGERBEAM	690	Ch	-	-
48W	13	39 07 12	77 51 53	96	6	-	6	MAXWELL D. MCCLAUGHRY	700	Ch	-	-
48W	14	39 07 08	77 52 02	325	3	46	6	HENRY SIXMA	670	Ch	-	-
48W	15	39 07 10	77 51 55	144	6	40	6	C.W. LLOYD	700	Ch	-	-
48W	16	39 07 08	77 51 56	100	9	25	6	PRESTON HUGHES	695	Ch	-	-
48W	17	39 07 14	77 52 05	100	5	-	6	ALLEN COCKEY	650	Ch	-	-
46X	71	39 12 55	78 02 07	500	5	20	6	GARY FOLTZ	580	Orr	08/01/1984	D
46W	66	39 05 16	78 04 46	95	20	60	6	B.M.PAYNE	580	Cco	-	-
46W	67	39 03 20	78 01 58	158	6	100	6	E.ALGER	430	-	-	-
46X	72	39 10 44	78 01 03	135	50	20	-	KENNETH SNOW	630	-	05/22/1984	D
46X	73	39 10 42	78 01 05	285	15	20	-	PAUL SNOW	630	-	05/22/1984	D
48X	14	39 07 54	77 51 34	125	25	54	-	THE RETREAT	580	Ca	-	-
47W	79	39 07 18	77 55 44	-	-	-	-	BERRYVILLE	570	-	-	-
45W	1	39 03 41	78 08 14	400	2	52	6	VA.POWER	680	-	07/15/1964	D
46X	4	39 10 51	78 01 57	260	12	53	6	R.ORNDOFF	585	-	12/15/1967	DO
46X	14	39 09 50	78 03 39	166	50	34	6	H.THOMAS	600	-	05/13/1966	D
46X	5	39 10 33	78 03 08	80	-	40	6	C.FISCHEL	560	-	08/01/1968	O
46X	6	39 09 58	78 02 00	190	20	18	6	H.MCDONALD	585	-	02/01/1959	O
46X	17	39 10 19	78 01 16	575	1	33	6	T.M.LLOYD	620	-	02/18/1969	D
46W	68	39 02 34	78 06 57	500	4	50	6	J.C.DIGGS	620	Cco	09/30/1966	-
46W	68	39 03 19	78 05 38	140	100	93	6	SMITH-MACKAY	631	Ost	02/08/1966	D
46W	69	39 06 17	78 00 57	230	120	39	6	R.CARPER	490	Ce	09/01/1968	D
46W	69	39 03 46	78 01 50	470	3	13	6	E.BANKS	590	Orr	11/17/1961	O
46W	70	39 06 20	78 00 34	136	20	14	6	G.ESTEP	625	Orr	04/29/1969	D
46W	71	39 03 06	78 00 50	128	30	117	6	R.JOHNSON	530	Ce	04/23/1962	D
46W	72	39 07 06	78 00 17	370	5	46	6	C.GRUBBS	615	Ost	12/28/1965	D
46W	72	39 05 41	78 03 29	119	20	37	6	G.KERNS	575	Cco	10/01/1968	D
46W	73	39 01 49	78 02 38	125	300	18	6	B.WALKER	575	Cco	09/26/1965	D

Appendix B.--Records of selected wells in Clarke County, Virginia--Continued

46W	73	39 05 33	78 01 21	285	6	14	-	J.W.BANKS	545	Cwb	05/26/1964	D
46W	74	39 05 02	78 01 53	286	4	53	6	T.BANKS	615	Cco	05/02/1966	D
46W	75	39 02 06	78 06 54	236	12	147	6	J.H.MACKAY	510	Cwb	09/23/1966	D
46W	75	39 04 34	78 00 24	373	50	21	6	R.C.PLATER	575	Cco	03/15/1966	D
46W	76	39 04 17	78 02 20	410	6	9	6	R.KENT	-	Orr	07/31/1967	D
46W	77	39 05 26	78 04 33	105	40	17	6	R.C.MORGAN	630	Cco	12/14/1964	D
46W	78	39 03 23	78 06 17	400	3	-	8	R G BUCKLEY #4	630	Cco	12/14/1966	D
46W	79	39 03 25	78 06 23	400	6	-	6	R G BUCKLEY #2	-	Cco	03/09/1966	D
46W	80	39 07 07	78 03 06	186	-	-	6	BYRON TIMBERLAKE	-	Orr	05/13/1965	D
46W	81	39 02 43	78 05 31	400	8	-	2	R G BUCKLEY	580	Ost	03/31/1967	D
46W	82	39 01 29	78 06 14	110	6	-	6	HOWARD E HERBALL	612	Orr	01/27/1966	D
46W	83	39 03 24	78 06 14	250	4	-	-	R G BUCKLEY #5	-	Ost	01/14/1966	D
46W	84	39 03 23	78 06 14	200	3	-	6	R G BUCKLEY #6	605	Orr	05/18/1965	D
46W	85	39 06 27	78 00 46	204	2	27	-	A.LANHAM	-	Orr	02/25/1967	D
46X	11	39 12 07	78 00 04	120	20	18	-	R.BARKER	630	-	03/07/1959	D
47X	26	39 11 33	77 57 08	186	15	51	6	E.VONPIPPIN	-	-	10/29/1965	D
47X	27	39 08 33	77 58 40	300	40	37	8	DOUBLEDAY & CO #1	540	Ce	03/02/1965	D
47X	28	39 08 45	77 58 27	400	460	46	-	DOUBLEDAY & CO #2	610	Cco	10/11/1963	DO
47X	29	39 08 56	77 58 19	230	70	52	6	TOWN OF BERRYVILLE-NORTH WELL	565	Ce	01/03/1968	D
47X	30	39 07 53	77 52 36	-	30	100	6	SHENANDOAH RETREAT	605	Cco	02/12/1963	D
47X	31	39 07 43	77 52 37	-	45	-	7	SHENANDOAH RETREAT	640	Opr	06/20/1968	D
47X	32	39 09 24	77 57 58	275	30	-	8	MILLER	520	Ct	05/09/1965	D
47X	33	39 09 23	77 58 01	140	-	-	6	SOLDIERS REST FARM	600	Cco	02/14/1966	D
47X	34	39 08 27	77 54 30	200	10	-	6	JOHN GARDNER	560	Cco	08/11/1967	D
46X	8	39 09 00	78 00 34	185	24	40	6	SWIFT	640	-	08/02/1968	D
45W	2	39 03 09	78 08 17	-	-	-	-	DEPT. OF CORRECTIONS	-	-	-	-
46W	86	39 04 20	78 02 14	595	4	75	6	MILLW.EP.CH.	650	-	-	-
46X	9	39 11 54	78 00 33	60	-	-	-	W. MILLESON	620	-	-	-
47W	80	39 07 30	77 53 33	200	75	-	6	L.MAY	640	-	01/01/1969	D
46W	87	39 04 14	78 02 12	260	3	29	6	W.REID	-	Orr	01/01/1966	-
46W	88	39 03 56	78 02 13	110	100	53	6	GILLFIELD CH.	-	Ost	05/16/1966	D
46W	89	39 05 33	78 00 44	400	3	-	6	STAELIN	-	Orr	06/06/1966	D
46W	90	39 05 56	78 04 33	140	35	42	6	ChAMBERLAIN	-	Orr	05/14/1965	D
46W	91	39 03 13	78 01 31	100	20	20	6	R FRYE	-	Orr	05/12/1966	D
46W	92	39 03 58	78 04 16	230	50	69	6	A.WILSON	-	Cco	05/02/1967	D
46W	93	39 01 32	78 06 11	127	25	-	8	ROBERT LEE	-	Ce	03/28/1967	D
46W	94	39 05 42	78 03 54	149	35	30	6	BOYCE ELEMENTARY SCHOOL	-	Ce	11/30/1964	D
46W	95	39 05 45	78 03 59	126	20	-	6	D W NAFF	-	Orr	08/24/1966	D
46W	150	39 02 56	78 06 51	130	20	52	6	E.M.AREY	-	Cco	08/02/1966	D
46W	151	39 03 05	78 06 33	219	15	79	6	B.M.E.PAYNE	-	Orr	08/18/1966	D
46W	152	39 05 29	78 03 41	550	3	8	6	E.TOWNSLEY	-	Cco	10/29/1959	D
46W	153	39 05 17	78 01 30	186	12	32	6	H.C.BERRY	-	Cco	02/10/1966	D
46W	154	39 05 18	78 03 53	113	2	34	6	A.JACKSON	-	Cco	03/01/1966	D

Appendix B.--Records of selected wells in Clarke County, Virginia--Continued

46W	155	39 03 35	78 06 06	218	7	42	6	S.JACKSON	-	Orr	02/10/1966	D
46W	156	39 07 30	78 03 04	200	15	25	6	R.E.DOLE	-	Ost	03/10/1966	D
46W	156	39 05 40	78 03 18	195	30	32	6	P.KAGEY	560	Cco	07/28/1959	D
46W	157	39 05 55	78 02 32	178	45	101	6	W.YOWELL	580	Cco	09/04/1965	D
46W	158	39 06 12	78 02 34	165	5	43	6	C.L.CARPENTER	575	Cco	04/03/1967	D
46W	159	39 05 44	78 03 36	465	60	40	6	H.F.HUFF	510	Cco	06/07/1967	D
46W	160	39 05 18	78 03 52	47	20	26	5	J.ROBERTS	630	Orr	12/27/1965	D
46W	161	39 05 21	78 03 50	105	30	7	6	L.MASON	640	Ost	09/30/1965	D
46W	162	39 04 19	78 02 27	125	12	37	6	A.BURNS	640	Cco	08/26/1966	D
46W	163	39 04 16	78 02 26	280	3	12	6	M.MAGRUDER	550	Cco	11/15/1966	D
46W	164	39 04 14	78 02 19	102	3	8	-	J.HAWKINS	600	Orr	01/01/1770	O
46W	165	39 05 37	78 03 18	380	2	5	6	A.GALLOWAY	590	Orr	06/09/1958	D
46W	166	39 06 15	78 01 38	500	2	36	6	R.SHAFER,JR.	560	Cco	01/23/1965	D
46W	167	39 05 35	78 03 22	111	30	22	6	P.ASHBY	470	Ce	05/24/1958	D
46W	168	39 04 01	78 06 10	400	-	-	-	M.S.BUCKLEY	530	Ce	03/29/1967	D
46W	169	39 07 04	78 02 52	177	20	10	6	T.ASH	615	Cco	11/05/1966	D
46W	170	39 07 07	78 00 16	140	40	60	-	D.ROADLEY	635	Orr	02/01/1967	D
46W	171	39 07 05	78 00 19	150	100	58	6	J.BOOTH	620	Cco	01/01/1835	D
46W	171	39 04 59	78 05 16	28	5	-	48	PAYNE	515	Cco	06/18/1969	-
46W	172	39 04 50	78 03 02	247	15	88	6	S.SINGHAS	570	Cco	03/10/1967	D
47X	35	39 08 08	77 55 57	225	-	-	6	KENNETH S SHENKS	610	-	07/25/1959	DO
47X	36	39 11 16	77 55 11	370	-	-	6	JAMES WOLF	620	-	03/31/1959	DO
47X	37	39 09 03	77 54 42	380	-	-	6	RAYMOND RATCLIFFE	620	-	11/07/1959	-
47X	38	39 09 52	77 57 34	150	13	-	6	JAMES B SHULL	480	-	01/12/1961	DO
47X	39	39 12 31	77 57 28	70	-	-	6	DAVID C CHILDS	570	-	12/07/1966	D
47X	40	39 11 10	77 58 25	110	-	-	6	CLIFFORD SHIRLEY	565	-	05/20/1959	D
47X	41	39 12 09	77 56 38	146	-	-	6	MRS I D AULD	480	-	03/12/1969	D
47X	42	39 11 08	77 59 12	68	-	-	6	NELSON ALEXANDER	535	-	11/07/1961	D
47X	43	39 09 17	77 55 34	250	4	-	6	T J MITCHELL	620	-	05/09/1966	D
47X	44	39 09 18	77 55 37	400	12	49	6	WILLIAM FRANKLIN	595	-	02/19/1959	DO
47X	45	39 12 41	77 58 14	86	-	-	6	JOHNSON BROS	600	-	12/15/1967	DO
47X	46	39 08 39	77 56 34	383	25	-	6	GRAFTON SCHOOL	580	-	03/20/1959	DO
47X	47	39 08 22	77 56 12	185	5	55	6	WEBBTOWN	450	-	06/14/1968	D
47X	48	39 07 38	77 54 10	400	6	53	6	RITZENBERG	480	-	-	DO
47X	16	39 09 34	77 57 42	230	75	13	6	J.GALLOWAY	580	-	04/01/1966	DO
46X	19	39 07 41	78 02 51	115	50	26	6	D.LEVI	610	-	11/04/1966	D
46X	20	39 10 15	78 01 20	185	30	21	6	J.LEVI	620	-	06/18/1969	D
46X	21	39 10 31	78 03 17	85	20	35	6	C.FISHEL	570	-	11/26/1968	D
46X	22	39 10 49	78 01 33	151	60	39	6	R.H.ORNDOFF	590	-	12/29/1965	DO
46X	23	39 10 18	78 01 13	155	16	64	6	E.WEIR	620	-	02/17/1969	D
46X	25	39 10 24	78 01 29	250	3	41	6	S.DENT	600	-	07/25/1966	D
46X	26	39 10 12	78 01 24	402	1	35	-	M.HINKLE	625	-	11/25/1959	D
46X	27	39 10 12	78 00 50	550	24	35	6	T.JONES	635	-	02/08/1957	D
46X	28	39 09 47	78 01 55	120	7	4	6	G.NESSELRODTE	600	-	02/17/1959	DO

Appendix B.--Records of selected wells in Clarke County, Virginia--Continued

46X	29	39 08 57	78 00 36	140	7	55	6	H.JOHNSON	640	-	11/16/1966	D
46X	30	39 09 00	78 00 35	170	30	17	6	I.BARB	640	-	09/19/1968	D
46X	31	39 11 23	78 00 39	242	8	24	-	J.KACKLEY	630	-	11/25/1964	D
46X	18	39 09 49	78 02 48	100	-	-	6	C.EMMART	-	-	-	O
48X	2	39 08 41	77 51 37	270	7	55	-	DAVID ALEXANDER	480	Ch	04/22/1981	D
47W	1	39 04 26	77 55 43	305	15	75	-	ANDRES ARANGO	700	Ch	07/29/1985	D
46W	132	39 03 35	78 05 52	270	50	22	-	TIM BANDYK	630	Orr	03/02/1983	D
46W	133	39 05 07	78 01 28	305	1	44	-	DOWNING BANKS	550	Cco	05/24/1982	D
46X	74	39 07 34	78 05 43	320	50	60	-	JAMES HEITMANCIK	643	Omb	12/05/1985	D
47W	2	39 06 43	77 58 45	505	4	46	-	BATTERTON, COL. R.J.	540	Ce	08/15/1979	D
46X	75	39 10 34	78 04 18	405	12	56	-	BAYLISS, R.W.	595	Ooe	03/22/1982	D
47X	49	39 11 11	77 58 35	205	17	77	-	BELL, CAP	660	Cco	09/29/1982	D
48W	1	39 06 43	77 52 15	300	3	87	-	BELL, RATCLIFFE	645	Ch	10/06/1980	D
46W	134	39 04 12	78 05 39	500	3	152	-	BOREL, ALAIN	630	Orr	06/03/1981	D
48X	3	39 08 33	77 51 27	425	4	28	-	BORRMANN, DONALD	580	Ch	01/18/1979	D
46W	135	39 05 36	78 03 54	455	12	20	-	BROWN, SHIRLEY CLARK	590	Orr	09/18/1984	D
46X	76	39 13 06	78 02 22	500	1	20	-	BURNER, HENRY	560	Orr	09/24/1980	D
47W	3	39 01 49	77 56 25	305	5	67	-	BURTON, KEN	1,565	CpCc	08/17/1983	D
47W	4	39 04 24	77 58 56	265	10	97	-	CHAMBERLAYNE, PYE	520	Cwb	04/23/1979	D
46X	13	39 10 09	78 03 37	265	5	21	-	COCKRELL, AUGUSTUS	595	Orr	07/18/1979	D
47W	5	39 01 18	77 59 30	285	5	95	-	COX, WILLIAM	495	Cwb	10/27/1980	D
47W	6	39 07 14	77 57 33	205	10	47	-	CRAWFORD, KENNETH	500	Cwb	11/03/1981	D
47W	7	39 07 12	77 57 33	305	15	36	-	CRAWFORD, KENNETH	740	Ch	12/01/1981	D
47X	50	39 09 47	77 53 26	345	15	72	-	CROSS, WILLIAM	480	Cwb	11/08/1983	D
47W	8	39 07 07	77 56 32	265	12	42	-	DART, NANCY	500	Cwb	06/01/1981	D
47X	51	39 08 26	77 56 22	165	10	47	-	DELOZIER, CHARLES	550	Ce	03/16/1983	D
47W	9	39 06 20	77 52 33	305	50	80	-	EASLEY, ROBERT	700	Ch	05/15/1980	D
47W	10	39 06 12	77 57 46	505	3	67	-	EBENEZER METHODIST CHURCH	430	Cwb	11/19/1980	D
47W	11	39 01 24	77 59 17	365	6	53	-	ELLISON, DOUG	800	Ch	05/30/1981	D
46X	77	39 09 26	78 02 26	205	12	42	-	EMMART, CARLTON	595	Orr	06/19/1985	D
47W	12	39 01 55	77 59 03	225	5	55	-	ERICKSON, KEN	620	Ch	08/05/1982	D
47W	13	39 07 10	77 52 42	245	3	33	-	ESTEP, GEORGE	590	Ch	02/27/1979	D
48X	4	39 08 35	77 51 26	205	8	53	-	FANNING, JOHN D.	540	Ch	11/07/1984	D
47W	14	39 02 08	77 54 12	425	1	25	-	FARRIS, CHARLES	1,330	CpCc	06/11/1981	D
48X	5	39 08 41	77 51 31	285	20	60	-	FERGUSON, JAMES	560	Ch	10/08/1982	D
47W	15	39 04 29	77 56 52	400	2	74	-	FEWELL, STANLEY	560	Ch	08/27/1984	D
46W	136	39 01 47	78 02 44	400	15	86	-	FITZPATRICK, JOHN	570	Cco	07/16/1981	D
48X	6	39 07 35	77 50 45	425	2	37	-	FOSTER, R.H.	1,250	CpCc	05/16/1979	D
48W	2	39 07 26	77 51 10	425	0	20	-	FOSTER, R.H.	875	Ch	05/16/1979	D
48W	3	39 07 26	77 50 57	605	9	27	-	FOSTER, R.H.	1,075	Ch	05/16/1979	D
46X	15	39 10 43	78 02 00	500	1	21	-	FOX, DELBERT	595	Orr	12/01/1981	D
45W	3	39 03 39	78 08 11	445	3	78	-	FREEMAN, RICHARD	665	Orr	09/24/1980	D
46W	137	39 06 18	78 00 35	145	50	145	-	GALLOWAY, JAMES	-	-	08/13/1981	D
47W	16	39 04 47	77 57 24	240	100	63	-	GILLIONS, WILLIAM	420	Ct	11/11/1982	D

Appendix B.--Records of selected wells in Clarke County, Virginia--Continued

48X	7	39 08 37	77 51 27	125	25	55	-	GIVENS, DOROTHY	520	Ch	08/04/1980	D
47X	52	39 07 31	77 52 58	485	20	63	-	GORDON, DOROTHY	770	C	11/20/1980	D
47W	17	39 04 09	77 56 23	365	10	68	-	HALES, CARL	670	Ch	05/06/1982	D
46W	138	39 04 26	78 02 04	375	100	40	-	HAMILTON, LLOYD	570	Cco	05/10/1982	D
47X	54	39 09 18	77 58 00	265	1	21	-	HEFLIN, NORMAN	550	Cco	06/27/1979	D
48W	4	39 04 52	77 52 30	285	8	58	-	HIGGINS, JANINE	1,735	Ch	11/10/1982	D
47X	55	39 07 44	77 57 39	425	25	26	-	HOWELL, THOMAS	500	Ce	10/02/1981	D
46X	16	39 10 50	78 01 56	125	20	30	-	HAYES, DONALD	595	Orr	05/09/1983	D
47X	56	39 10 48	77 59 17	105	15	20	-	HUYETTE, LOUISE	-	Orr	09/02/1983	D
47X	57	39 10 48	77 59 12	225	5	3	-	HUYETTE, LOUISE	640	Cco	08/13/1979	D
46X	78	39 10 28	78 02 18	405	2	60	-	KACKLEY, CHARLES	565	Orr	02/02/1983	D
47W	18	39 05 20	77 54 39	305	7	84	-	KEESLING, JAMES	620	Ch	07/11/1979	D
46W	139	39 01 02	78 00 25	305	8	47	-	KENNEDY	455	-	10/09/1979	D
46X	79	39 07 48	78 03 10	385	0	26	-	LEVI, DONALD	620	Orr	08/31/1981	D
47W	19	39 02 25	77 58 48	285	6	105	-	LEWIS, JAMES	725	Ch	07/15/1981	D
47W	20	39 06 02	77 57 30	265	5	56	-	LICHLITER, DURWARD	480	Cwb	05/02/1981	D
47W	21	39 01 06	77 57 56	190	10	76	-	LICHLITER, JUNIOR	945	CpCc	06/24/1985	D
47W	22	39 06 13	77 59 12	205	50	92	-	LINSTER, HARRY	500	Ce	10/14/1981	D
47W	23	39 04 48	77 54 58	505	2	114	-	LOHR, BENEDICT	880	Cw	05/27/1979	D
46X	80	39 08 27	78 02 20	165	15	42	-	LONGERBEAM, DAVID	640	Orr	06/18/1985	D
47W	24	39 03 14	77 57 05	205	15	35	-	LYONS, ROBERT	680	Ch	08/25/1981	D
46W	140	39 01 00	78 02 37	305	10	70	-	MACDONALD, ARNOLD	-	-	06/24/1983	D
46W	141	39 02 46	78 00 16	285	8	144	-	MARSHALL, DOUGLAS	510	Cwb	06/28/1984	D
46W	142	39 05 00	78 03 08	205	6	19	-	MASON, DAN	550	Cco	11/02/1979	D
47W	25	39 05 54	77 57 01	325	10	106	-	MCAFEE, DON	455	Ct	10/22/1982	D
47W	26	39 05 53	77 56 56	125	50	109	-	MCAFEE, DON	455	Cwb	09/23/1982	D
46W	143	39 01 07	78 00 04	205	30	84	-	MCARTOR, WALTER	765	Ch	07/20/1979	D
46X	81	39 11 45	78 00 14	145	30	71	-	MCCOMBIE, BOB	630	Orr	05/18/1979	D
47W	27	39 03 14	77 54 07	295	100	34	-	MCDANIEL, GARY	1,695	CpCc	09/10/1982	D
46W	144	39 06 09	78 00 13	145	30	38	-	MCDONALD, J.L.	565	Ce	08/13/1981	D
47X	58	39 12 01	77 59 55	160	20	36	-	MCDONALD, J.L.	650	Orr	08/23/1978	D
47W	28	39 05 40	77 56 13	465	3	46	-	MEEKS, R.B.	380	-	10/03/1983	D
46W	145	39 03 29	78 01 01	285	15	47	-	MILLER, FREDRICK	635	Orr	07/11/1980	D
47X	59	39 08 30	77 58 25	110	15	69	-	MELVIN, DON	530	Cwb	10/19/1983	D
46W	146	39 03 39	78 05 32	185	30	50	-	MICHAEL, RONALD	615	Cco	06/19/1985	D
47W	29	39 06 21	77 54 02	365	25	42	-	MINCHIN	505	Ch	08/30/1985	D
46W	147	39 03 36	78 06 04	165	12	62	-	MT. OLIVE CHURCH	710	Ch	03/23/1982	D
46X	82	39 11 14	78 03 28	355	50	66	-	MYER, A. FRED	570	Ooe	08/01/1985	D
46X	83	39 13 05	78 00 08	235	50	45	-	NICHOLSON, GEOFFREY	585	Orr	11/01/1979	D
46W	148	39 00 05	78 01 14	530	7	91	-	NORTHERN VIRGINIA YOUTH CAMP	-	-	04/21/1981	D
47W	30	39 04 14	77 58 31	425	4	101	-	PENNIMAN, THOMAS	540	Ct	10/30/1980	D
46W	149	39 02 03	78 02 37	50	31	-	-	W.E. POOLE	540	Ce	05/22/1984	D
47X	60	39 13 25	77 58 48	250	3	21	-	RACER, RAY	-	-	05/16/1979	D
46W	96	39 03 41	78 02 30	385	30	64	-	REID, FREDDIE	560	Ce	06/21/1985	D

Appendix B.--Records of selected wells in Clarke County, Virginia--Continued

46X	84	39 08 26	78 05 08	145	50	50	-	RILEY, PETER PAUL	625	Omb	03/28/1985	D
47W	31	39 07 10	77 54 51	145	100	135	-	ROBEY, ROLAND	500	Ct	03/03/1981	D
46X	85	39 07 52	78 04 53	265	50	61	-	ROBINSON, W.E.	625	Orr	06/01/1983	D
46W	97	39 03 31	78 07 20	225	80	31	-	ROSS, DONALD	640	Orr	03/11/1985	D
47X	61	39 10 21	77 58 14	105	75	22	-	ROUSS, LARRY	600	Cco	10/04/1982	D
48X	8	39 08 06	77 51 33	385	30	96	-	SENSENY SOUTH, CORP'N.	610	Ch	08/03/1984	D
46W	98	39 07 23	78 01 08	500	1	60	-	RUHL, ROBERT	630	Cco	11/15/1984	D
47X	62	39 11 11	77 58 16	165	15	95	-	SHIRLEY, REGINALD	640	Cco	04/07/1983	D
46W	99	39 06 11	78 00 16	410	20	51	-	SINGHAS, C.E.	565	Ce	02/27/1979	D
46W	100	39 06 09	78 00 18	165	50	107	-	SINGHAS, J.B.	560	Ce	09/17/1984	D
46W	101	39 01 21	78 00 04	300	6	57	-	SINGHAS, MICHAEL	850	Ch	07/03/1980	D
46X	86	39 10 19	78 01 20	500	-	-	-	SLATER, JOHN	620	Orr	-	D
46W	102	39 04 41	78 04 22	245	10	47	-	STROSNIDER, E.	560	Orr	08/26/1980	D
47W	32	39 06 01	77 57 29	300	9	23	-	SURRETTE, ROBERT	490	Ct	03/21/1985	D
47W	33	39 02 18	77 58 25	205	8	92	-	TAVENNER, RONALD	725	Ch	05/07/1982	D
46W	103	39 06 14	78 01 35	125	10	30	-	TINSMAN, WESLEY	600	Cco	03/24/1982	D
46X	87	39 10 12	78 00 53	235	50	17	-	VINCENT, ANDREW	640	Orr	09/24/1980	D
46W	104	39 00 56	78 03 18	165	6	84	-	WAGGONER, MILES	470	Cwb	05/10/1982	D
47W	34	39 05 36	77 56 01	405	2	56	-	WATKINS, GERTRUDE	500	Ch	02/09/1981	D
47W	35	39 06 10	77 52 51	265	15	43	-	WIGGLEWORTH, JAMES P.	650	Ch	09/08/1983	D
47W	36	39 03 53	77 54 29	305	20	66	-	WILEY, CARROLL	1,220	CpCc	12/13/1984	D
46X	88	39 08 20	78 02 14	485	20	21	-	WISECARVER, KENNETH	645	Orr	-	D
47W	37	39 03 01	77 58 12	300	8	65	-	WYATT, JIMMY	930	Ch	10/02/1980	D
47X	63	39 09 38	77 52 50	145	10	113	-	WYATT, ROBERT	490	Cwb	10/31/1983	D
47X	64	39 09 49	77 53 17	305	40	105	-	WYATT, ROBERT	490	Cwb	10/22/1985	D
47W	38	39 03 17	77 57 06	140	10	69	-	AIELLO, LOUIE	655	Ch	10/16/1979	D
47W	39	39 04 24	77 59 16	400	3	27	-	BARR, GEROME	510	Cwb	04/03/1981	D
47W	40	39 04 24	77 59 16	300	10	149	-	ANDERSON, RAY	510	Cwb	06/11/1981	D
46X	89	39 11 27	78 02 19	180	10	45	-	BARTLETT, DAVE	580	Orr	09/21/1978	D
46W	105	39 01 27	78 02 51	220	100	210	-	BENTSEN, SEN. LLOYD	415	Cwb	10/09/1981	D
47X	65	39 09 08	77 54 30	300	75	84	-	BASS, HOWARD	-	Cwb	11/14/1984	D
46W	106	39 07 21	78 00 11	600	15	29	-	BOWLES, WILSON	615	Cco	01/21/1983	D
47X	66	39 11 11	77 59 26	120	50	50	-	BRANNON, JAMES	640	Orr	08/09/1977	D
47X	67	39 12 21	77 57 34	260	10	55	-	BROVERY, STANLEY	650	Cco	08/10/1977	D
45W	4	39 02 20	78 08 24	60	50	42	-	BRUMBACK, CLYDE	625	Orr	09/04/1978	D
46W	107	39 04 59	78 02 12	180	20	55	-	BUGARSKI, JOSEPH	570	Cco	06/18/1985	D
47X	68	39 09 50	77 58 49	300	15	47	-	BYRD, SEN. HARRY	610	Cco	06/18/1985	D
47X	69	39 09 07	77 59 25	260	45	80	-	BYRD, SEN. HARRY	620	Cco	06/18/1985	D
47X	70	39 10 00	77 58 42	200	25	52	-	HARRY BYRD, III	610	Cco	12/17/1981	D
46X	90	39 10 17	78 00 39	400	4	41	-	CATHER, RAY	650	Orr	03/20/1982	D
47X	71	39 11 15	77 56 12	400	15	21	-	COINER, CHARLES	530	Cco	12/13/1985	D
46X	91	39 11 31	78 02 25	100	-	21	-	COMBS, GARY	-	Orr	09/16/1981	D
46W	108	39 06 58	78 05 34	160	30	60	-	DENT, PAT	650	Oln	01/23/1981	D
46X	93	39 12 43	78 00 11	130	60	25	-	DAVIS, KENNETH L.	595	Orr	10/05/1981	D

Appendix B.--Records of selected wells in Clarke County, Virginia--Continued

46X	94	39 10 22	78 01 14	100	50	37	-	DOTZLER	610	Orr	09/23/1985	D
47W	41	39 04 21	77 58 40	380	2	100	-	DOVE, RONALD	525	Ct	08/28/1981	D
47W	42	39 03 37	77 56 55	400	6	115	-	DUNSMORE	670	Ch	06/14/1982	D
46W	109	39 05 54	78 01 10	160	120	130	-	EASTMEN, RICHARD	600	Cco	10/22/1979	D
46W	110	39 02 54	78 00 34	340	9	98	-	ELSEA, LLOYD	490	-	11/25/1980	D
46W	111	39 05 56	78 00 58	130	25	30	-	EWING, LOUIS	585	Cco	07/17/1984	D
46X	95	39 10 41	78 04 18	140	20	58	-	FOSTER, THURMAN	595	Ooe	03/05/1984	D
46X	96	39 12 24	78 02 11	500	100	35	-	FOLTZ, HERMAN	580	Orr	07/12/1981	D
46X	97	39 12 23	78 02 15	360	90	21	-	FOLTZ, LYNN	580	Orr	03/26/1982	D
47W	43	39 07 17	77 52 33	100	20	21	-	GUENTHER, FRANK	585	Ch	08/21/1981	D
46W	112	39 05 48	78 00 53	300	4	110	-	GEORGE GREENHALGH, JR.	575	Cco	10/23/1979	D
46W	113	39 05 58	78 01 10	160	10	63	-	HALL, DAN	585	Cco	10/17/1983	D
46X	98	39 12 27	78 01 59	100	50	28	-	HARDESTY, JACK	595	Orr	09/27/1982	D
46X	99	39 12 44	78 02 01	320	20	53	-	HARDESTY, JOHN O.	565	Orr	10/14/1977	D
46W	114	39 01 02	78 03 03	340	-	292	-	HARRISON, WILLIAM	515	-	07/07/1977	D
47X	72	39 09 49	77 58 25	250	30	21	-	HENKE, JERRY	570	Cco	01/04/1983	D
46W	115	39 05 35	78 06 01	160	100	21	-	HICKS	640	Orr	10/22/1979	D
47W	44	39 06 30	77 53 16	360	4	70	-	HORNADAY, WILLIAM P.	-	-	09/10/1984	D
48W	5	39 06 51	77 52 16	260	8	35	-	HUMMER, KENNETH	675	Ch	12/31/1982	D
46X	100	39 11 19	78 00 34	240	20	32	-	KACKLEY, JOHN D.	630	Orr	08/01/1984	D
46X	101	39 12 14	78 02 52	100	75	63	-	KOON, ROBERT W., JR.	585	Orr	12/05/1983	D
46X	102	39 12 41	78 03 32	700	5	21	-	KOON, ROBERT W.	580	Omb	10/11/1983	D
46X	103	39 14 09	78 01 31	220	40	30	-	LEE, ALBERT A.	560	Orr	05/26/1982	D
47X	73	39 07 49	77 55 34	120	60	76	-	LEMLEY, EVERETT	525	Cwb	09/16/1980	D
46W	116	39 05 56	78 03 02	100	30	28	-	LIEBOLD, RICK AND SUSAN	575	Orr	04/02/1981	D
46W	117	39 04 40	78 06 56	140	100	21	-	LLOYD, RONALD	645	Orr	06/13/1979	D
47X	74	39 09 52	77 58 57	120	30	72	-	LLOYD, ELEANOR	610	Cco	05/25/1984	D
47X	75	39 10 18	77 54 36	220	25	168	-	MACANLIS, DAVID	510	Cwb	12/23/1980	D
45W	5	39 01 22	78 07 31	140	25	42	-	MACKAY-SMITH	600	Orr	10/28/1977	D
47W	45	39 05 44	77 57 30	260	15	84	-	MASI, CHRIS	440	Cwb	08/19/1981	D
46W	118	39 06 42	78 03 00	60	75	21	-	MATSON, ROBERT A.	570	Ch	10/25/1979	D
46W	119	39 04 39	78 04 24	300	2	21	-	MCCARTY, EVA	645	Ch	07/15/1977	D
47X	76	39 09 00	77 54 30	140	60	50	-	MINEFILL	540	Cwb	07/23/1982	D
46W	120	39 00 59	78 00 42	220	30	108	-	MICHAEL, TALBERT	-	-	06/13/1983	D
46X	104	39 12 10	78 00 04	400	3	41	-	MILLESON, JOHN SR.	635	Orr	09/30/1981	D
46W	121	39 03 38	78 05 30	80	50	42	-	MOORE, CLARENCE	625	Cco	02/02/1981	D
46X	105	39 08 19	78 02 27	500	4	21	-	MORRISON, BILL	645	Orr	05/08/1979	D
46W	122	39 06 12	78 00 27	280	20	40	-	EUTSLER, RAYMOND	550	Ce	01/10/1985	D
47X	77	39 08 44	77 58 16	280	5	35	-	NICHOLS, EARL	560	Cco	04/17/1981	D
46W	123	39 05 07	78 05 05	380	5	25	-	POPE, GARY	595	Orr	08/15/1983	D
46X	106	39 10 19	78 01 03	70	150	50	-	POTTER, ELIZABETH	625	Orr	10/15/1979	D
46W	124	39 01 20	78 06 58	300	30	100	-	ROMAINE, JOAN	615	Cco	07/20/1981	D
46W	125	39 02 20	78 05 59	600	3	20	-	ROMAINE, JOAN	630	Cco	03/27/1981	D

Appendix B.--Records of selected wells in Clarke County, Virginia--Continued

46W	126	39 06 18	78 04 24	380	20	21	-	ROYSTON, JAMES	625	Orr	09/12/1977	D
48W	6	39 06 48	77 52 10	200	15	75	-	SCHILLING, BOB	665	Ch	05/28/1984	D
47W	46	39 07 01	77 55 51	380	10	280	-	SHANK, O	600	Cwb	09/08/1981	D
46W	127	39 03 57	78 05 39	160	30	42	-	SIPE, JAMES	580	Orr	08/13/1980	D
47W	47	39 04 24	77 55 18	160	30	63	-	SERKIN, STEPHEN	740	-	12/15/1983	D
48W	7	39 06 55	77 52 05	300	5	42	-	SMARR, STEVE	690	Ch	03/07/1984	D
47W	48	39 07 20	77 55 43	600	4	140	-	SOWERS, FRANK (DAIRY)	565	Cwb	12/28/1981	D
46W	128	39 05 52	78 01 00	120	30	52	-	TUPPER	595	Cco	10/25/1979	D
47X	78	39 09 56	77 58 59	150	60	23	-	VINSON, RANDY	600	Cco	01/27/1979	D
46W	129	39 05 31	78 01 01	140	-	-	-	WESTPHAL, DIETRICH	540	Cco	08/17/1983	D
46W	130	39 05 31	78 01 01	700	5	40	-	WESTPHAL, DIETRICH	540	Cco	08/22/1983	D
47W	49	39 07 08	77 55 47	330	60	326	-	WHITE, LAURA	590	Cwb	07/28/1981	D
46W	131	39 06 00	78 00 34	600	2	20	-	WILLIAMS, WILLIAM	550	Ce	06/17/1982	D
46X	10	39 11 53	78 03 18	355	200	54	-	WOLFE, HAVEN	480	Ce	02/21/1980	D
47X	79	39 10 49	77 54 31	230	5	20	-	WILLIAMS, RICHARD W.	580	Orr	10/21/1981	D
47X	80	39 11 06	77 57 18	280	30	27	-	WILSON, PAUL F.	610	Cco	10/15/1981	D

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