GEOHYDROLOGY AND GROUND-WATER QUALITY AT SELECTED SITES IN MEADE COUNTY, KENTUCKY, 1987-88

By D.S. Mull, A. Gilliam Alexander, U.S. Geological Survey, and
Paul E. Schultz, Meade County Health Department

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Factors for Converting Inch-Pound Units to International System of Units (SI)

The inch-pound units used in this report may be converted to metric (International System) units by the following factors:

Multiply inch-pound units	By	To obtain metric unit
inch (in.)	25.4	millimeter (mm)
feet (ft)	0.305	meters (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
gallon per minute (gal/min)	0.06309	liters per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
foot per second (ft/s)	0.305	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
square foot per second (ft^2/s)	0.09290	square meter per second (m^2/s)
micromhos per centimeter at 25° Celsius (μmhos/cm at 25° C)	1.000	microsiemens per centimeter at 25° Celsius (μS/cm at 25° C)

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32)/1.8$$

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

Meade County in north-central Kentucky is about 305 square miles in size, and is underlain by thick beds of limestone and dolomite which are the principal sources of drinking water for about 18,500 residents. About half the area contains mature, karst terrane with abundant sinkholes, springs, and caves. Because of this karst terrane, ground water is susceptible to rapid changes in water quality and contamination from human sources. As a result of concern over possible contamination, the U.S. Geological Survey, in cooperation with the Lincoln Trail District Health Department, conducted a study to characterize the quality of the ground water in Meade County.

Thirty-seven wells and 12 springs were selected as sampling points to characterize ground-water quality in the area. Water was analyzed for major anions and cations, nitrates, trace elements, and organic compounds. Water from selected sites was also analyzed for fecal species of coliform streptococci bacteria and total coliform content. Six wells and two springs were sampled intermittently to define the seasonal variations in water quality.

Except for fluoride and lead, the water quality was within the range expected for carbonate aquifers. Elevated concentrations of fluoride occurred throughout the study area and exceeded Federal drinking-water standards at 14 sites. The fluoride content was significantly higher in water from wells than in water from springs. Concentrations of detectable lead ranged from 10 to 50 micrograms per liter and had a median value of 7.5 micrograms per liter. Only one sample exceeded the U.S Environmental Protection Agencies Maximum Contaminant Level of 50 micrograms per liter.

Dissolved solids ranged from 100 to 2,200 milligrams per liter and the median value was 512 milligrams per liter. Hardness ranged from 20 to 1,100 milligrams per liter and the median value was 290 milligrams per liter.

Selenium was detected in only one sample, but the concentration of 29 micrograms per liter was more than twice the Maximum Contaminant Level established by the U.S. Environmental Protection Agency.

Organic compounds detected by the Gas Chromatographic/Flame Ionization Detection scans, did not indicate evidence of concentrations in excess of the current Federal drinking-water standards. Analysis for specific organic compounds indicated that the presence of these compounds was associated with agricultural chemicals, usually pesticides. The variation in the presence and concentration of organic compounds seemed to correlate with precipitation and the use of agricultural chemicals during the growing season.

Total coliform content exceeded drinking-water standards in water from all 12 springs and in 18 wells. Also, water from all springs and two wells contained fecal species of coliform or streptococci bacteria. Fecal coliform/fecal streptococci ratios indicate that three springs are occasionally contaminated by human waste and six contain fecal pollution from other warm-blooded animals, probably livestock.

Statistical analysis of the ground water quality data indicates that the variance of the concentrations of fluoride and chloride may be attributed to the site type. There was strong correlation between hardness and dissolved solids, hardness and sulfate, and sulfate and dissolved solids. No apparent relations were detected between water quality and the geographic location of sampling sites. However, seasonal variations were detected in the concentrations of dissolved solids, hardness, and iron. Concentrations generally decreased with rain storms which indicates the effect of recharge from surface runoff on ground-water quality.

INTRODUCTION

In the primarily rural area of Meade County, Kentucky, about 47 percent of the population relies on private wells or springs for their water needs. Ground water is especially vulnerable to contamination because much of the county is a typical karst terrane, where the aquifers are recharged directly through sinkholes that collect and drain surface runoff. In 1982, an outbreak of hepatitis, which caused one death and resulted in the illness and hospitalization of hundreds, was traced to widespread use of untreated water from a contaminated karst spring. This event, coupled with increasing dependence on ground water for individual water supplies, has heightened awareness about potential health hazards related to the quality of ground water in Meade County.

Ground water represents a potential source of safe, dependable drinking water for the residents of Meade County. However, information on its quality is needed to develop, use, and protect this resource. Other than a few isolated analyses, relatively little information is available to assess the safety and character of ground water throughout the county. Because nearly 3,800 homes in Meade County have private water supplies (U.S Census Bureau, 1982), information on ground-water quality is critical. In the spring of 1987, the U.S. Geological Survey, in cooperation with the Lincoln Trail District Health Department, began a 1-year study of the quality of ground water in Meade County, Kentucky.

Location and Extent of Study Area

Meade County includes an area of 305 square miles in north central Kentucky (fig. 1) and is bordered on the north and northwest by the Ohio River. Brandenburg, the county seat and one of two major population centers, is about 48 miles southwest of Louisville, Kentucky. The municipality of Muldraugh, at the extreme eastern edge of the county, is the second major population center. Smaller population centers include the communities of Battletown, Doe Valley, Ekron, Flaherty, Guston, and Payneville.

Purpose and Scope

The primary purpose of this report is to describe the quality of the ground-water resource of Meade County, and to identify areas of ground-water contamination. As part of this effort, selected chemical and bacteriological constituents are compared to Federal and State drinking water standards and criteria.

Water samples were collected by the Meade County Health Department at 49 sites that are used as private sources of drinking water. These sites were chosen for their accessibility for sampling and to give a spatial distribution of sampling sites in the study area. Except for three sites in Breckinridge County chosen for spatial distribution, all sampling sites were in Meade County. Only wells constructed according to the techniques specified in Kentucky's Water Well Drillers Certification Program, (section 401 KAR 6:300 and 6:310) Regulations of July 1985 were selected for sampling to ensure that direct infiltration of surface runoff into the wells would be limited. Buttermilk Falls Spring is not used as a primary water source, but was included in the sampling program because many people continue to haul water from the spring for domestic use. Although Federal drinking-water standards and State domestic water-supply criteria were used to evaluate the quality of ground water in the study area, a determination of water suitability for specific uses, including human consumption, is not within the scope of this project.

Acknowledgments

Appreciation is expressed to the many individuals who contributed information on their wells and allowed access to their property and dwellings for the purpose of collecting water samples. Without their cooperation this investigation would not have been possible. The authors also thank Paul Schultz, Meade County Registered Sanitarian, who contacted homeowners to obtain permission to sample privately owned springs or wells and conducted all sampling necessary for the completion of this project. The authors are also grateful to Angelo I. George, Consultant, who granted frequent use of his extensive library on the karst hydrogeology of north central Kentucky.

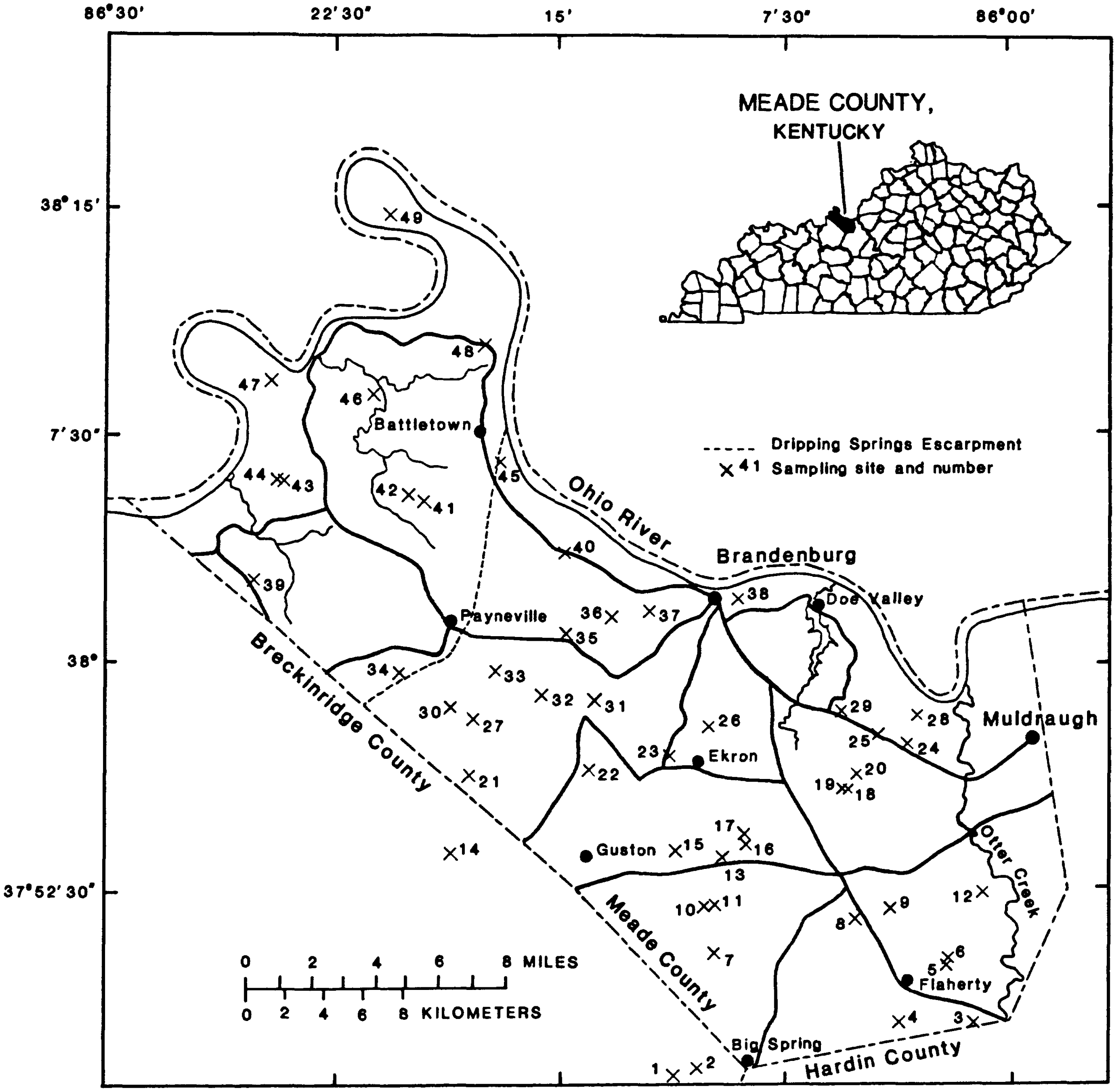


Figure 1.--Location and extent of study area.

DESCRIPTION OF STUDY AREA

Physiography

Meade County lies within the Mississippian Plateaus region of Kentucky which is part of the Interior Low Pleateaus physiographic province (Fenneman, 1938). Much of the county is a karstic plain of low local relief named the Pennyroyal (Sauer, 1927, p.21). The Pennyroyal is a gently rolling broad upland that slopes to the southwest reflecting the dip of the underlying bedrock. The region is underlain by soluble limestone, and is characterized by typical karst features such as sinkholes, caves, springs, and a marked absence of surface streams. Existing surface streams are relatively short, have steep gradients, and drain into the subsurface. Altitudes on the Pennyroyal range from about 700 feet above sea level in the east to about 600 feet in the west. Scattered hills and ridges rise as much as 200 feet above the plain.

Northwestern Meade County consists of a high plateau that is separated from the sinkhole plain to the east by the Dripping Springs escarpment (fig. 1). This escarpment is an eastward-facing cuesta that rises about 180 feet above the level of the plain. The plateau is underlain by sandstones, shales, and siltstones. Streams draining across the edge of the escarpment have produced a relatively rugged surface where valleys are narrow and deeply incised. Local relief can be as great as 250 feet. Ridges are generally flat topped and karstic features are rare except in valley bottoms. Altitudes at the edge of the escarpment are about 800 feet but the plateau surface declines approximately 100 feet toward the western edge of the county.

Precipitation

Precipitation is the ultimate source of ground water in Meade County. The chemical and physical character of precipitation and the resulting runoff affect the quality of water in a karst aquifer system.

No precipitation-recording stations exist in Meade County. The National Oceanic and Atmospheric Administration (NOAA) precipitation-recording station closest to the study area is in central Breckinridge County about 21 miles southwest of Brandenburg. Data from this station were used to detect relations between precipitation and ground-water flow and water-quality fluctuations.

Seasonal and spatial variation in precipitation occurs in the study area. In neighboring Hardin County, precipitation in a 1-month period varied more than 4 inches between two stations approximately 5.5 miles apart (Mull and Lyverse 1984, p. 10). This difference is likely attributable to isolated thundershowers. Precipitation may cause local variations of concentrations of constituents in the ground water.

Water Use

In 1980, the population of Meade county was 22,854, a 22 percent increase from the 1970 figure of 18,796 (U.S. Department of Commerce, 1982). Approximately 75 percent of the population is concentrated in the eastern and southeastern parts of the county adjacent to Fort Knox and the Brandenburg area. Only 344 families listed farming as their primary occupation during the 1980 census, which accounts for approximately one-third of 1,570 farms (C. Ritchie, Agricultural Stabilization and Conservation Service, oral commun., 1988). The area includes 67,500 acres of crop and pasture land, about one third of the county's 305 square miles.

Approximately 50 percent of the water used in Meade County was supplied by municipal or privately owned public water-supply facilities in 1980. The largest facility is the Brandenburg Water Company, with a treatment capacity of 475,000 gallons per day. The Brandenburg facility obtains water from wells drilled in the nearby alluvium of the Ohio River. The city of Brandenburg, population 1,831, is the major user of water from this source, accounting for approximately 350,000 gallons per day (Gary Wine, Supervisor, Brandenburg Water Company, oral commun., 1988).

The Meade County Water District (MCWD) purchases approximately 70,000 gallons of water per day from the Brandenburg Water Company. The MCWD is the most rapidly expanding public water-supply utility in the county, and it presently has more than 30 miles of water lines that serve 370 users.

Doe Valley, a residential community of 280 homes, obtains water from Doe Valley Lake, a spring-fed, man-made impoundment. Capacity of the treatment plant is 180,000 gallons per day, and daily consumption from January thru June of 1988 averaged 100,000 gallons per day (Kentucky Division of Water, Monthly Operating Reports, B. Argabright, Doe Valley, Inc., oral commun., 1988).

The city of Muldraugh, population 1,900, purchases water from Fort Knox which obtains water from wells tapping the Ohio River alluvium in Hardin County about 17 miles upstream from Brandenburg. Daily consumption averages 125,000 gallons per day. (A. Carlburg, Muldraugh City Hall, oral commun., 1988).

Other suppliers in the county include the Flaherty Water Company, supplying the city of Flaherty with 40,000 gallons per day, and Hardin County Water District Number 1, supplying 52,000 gallons per day to 245 users.

Considerable progress has been made in supplying treated water to residents of Meade County during the 1980's. This development has been primarily concentrated in the eastern part of the county. Presently, there are no public-water supplies available to residents in the western part of the county, where several large rural communities are located.

In 1985, about 90 percent of the residents not served by public supplies used wells or springs for drinking water. The daily withdrawal for this purpose is estimated at about 830,000 gallons (Sholar, 1988, p. 11).

In most cases individual wells yield sufficient water for domestic and stock use. Construction costs may limit the use of drilled wells in the western part of the county due to increased depth to ground water.

About 10 percent of Meade County residents rely on rain-fed cisterns for a primary source of water. Virtually all of the 800 plus homes utilizing cisterns are in the western part of the county.

Only the communities of Brandenburg, Muldraugh, and Doe Valley, have sewage-treatment facilities. Other Meade County residents use private on-site sewage systems for the disposal of domestic sewage. Typically these sewage-treatment systems consist of a septic tank and a drainfield. Unless properly designed, installed, and maintained, these systems may be a source of contamination to ground water in the area. Hundreds of Meade County residents contracted hepatitus by drinking contaminated water from the Buttermilk Falls Spring. Personnel from the Meade County Health Center conducted a dye-trace study which confirmed the subsurface connection between a private septic system and the spring. As a result of this incident, Meade County established stringent ordinances to ensure proper construction and installation of all septic systems in accordance with State guidelines. In addition, public education efforts have helped to discourage the practice of discharging untreated sewage into sinkholes.

GEOHYDROLOGY

Geology

Because nearly all ground-water samples in the study area were collected from depths of 300 feet or less, only the near-surface geology is discussed in this report. In addition, this discussion will only include rocks that comprise the principal bed-rock aquifer underlying the study area. More detailed geologic descriptions of the area are in reports by Plebuch, Faust, and Townsend (1985); Brown and Lambert (1963); and McFarlan (1943). Also, detailed stratagraphic columns, lithologic descriptions, and structural features are shown on the 7-1/2 minute geologic quadrangle maps of the area which are listed in the references.

Limestones in Meade County are of Early and Late Mississippian age and comprise, from younger to older, the Chesterian, Meramecian, and Osagean Series. The youngest rocks exposed at the surface are in the Chesterian Series and occur on the ridge-tops in the western part of Meade County (Amos, 1970, 1971, 1972, and 1976). Progressively older rocks in the Meramecian and Osagean Series crop out at the surface in an easterly direction across the County. Osagean Series rocks are only exposed in the incised valley of Otter Creek near the eastern edge of Meade County. In the following discussion, rock units are described in the sequence they would be penetrated during drilling, that is from youngest to oldest. Their stratigraphic relations are shown in figure 2.

SYSTEM	SERIES	FORMATION			
MISSISSIPPIAN	Chesterian	Upper	Buffalo Wallow Formation	Kinkaid Limestone Mem.	Leitchfield Formation
				Vienna Ls. Mem.	
			Tar Springs Formation		
		Lower	Glen Dean Limestone		
			Hardinsburg Sandstone		
			Golconda Formation	Haney Limestone Member	
				Big Clifty Sandstone Member	
				Beech Creek Ls. Mem.	Girkin Limestone
			Elwren Sandstone		
			Reelsville Limestone		
			Sample Sandstone		
			Beaver Bend and Paoli Limestones	Ss. Mem. of Mooretown Fm.	
	Meramecian	▨ Ste. Genevieve Limestone			
		▨ St. Louis Limestone			
		▨ Salem Limestone			
		Harrodsburg Limestone			
	Osagean	Borden Formation	Muldraugh Member		
			Holtsclaw Siltstone Member		
			Nancy Member		
			Kenwood Siltstone Member		
			New Providence Shale Member		

Modified from R. C. McDowell, 1981

EXPLANATION

▨ Principal aquifer

Figure 2.--Stratigraphic column for west-central Kentucky and formations of the principal aquifer in Meade County.

Residual Mantle or Residuum

In most of Meade County, Lower and Upper Mississippian carbonate bedrock is overlain by an unconsolidated, residual mantle. The mantle is derived from the underlying bedrock and consists of reddish silt and clay with fragments of chert and limestone. The mantle ranges from less than 5 to as much as 60 feet in thickness.

Lower Chesterian Rocks

The Lower Chesterian limestones include, in descending order, the Glen Dean Limestone, Haney Limestone Member and Beech Creek Limestone Member of the Golconda Formation, Reelsville Limestone, Beaver Bend and Paoli Limestones (fig. 2). Most of these limestones occur in the northwestern part of Meade County at or above the level of local streams. The Paoli Limestone is the Lower Chesterian limestone most likely to be connected hydraulically to the limestones that comprise the principal aquifer in Meade County. The Paoli Limestone is a dark-gray to light-tan, compact to crystalline, oolitic limestone that ranges in thickness from 0 to 80 feet.

Ste. Genevieve Limestone

The Ste. Genevieve Limestone crops out east of the Dripping Springs Escarpment where typical karst landforms such as caves, springs, and sinkholes are common. The formation ranges in thickness from 25 to 180 feet and consists of light-gray to almost white, massive to thin-bedded limestone. The limestone generally weathers light gray. Abundant well-developed oolites in zones as thick as 10 feet occur in the upper part of the unit. Locally, the limestone is crossbedded and interbedded with medium-gray dolomite. Beds of greenish-gray fine-grained sandstone and siltstone up to 10 feet in thickness occur in the upper part of the unit. Joints, fractures, and well-developed solution channels are common.

St. Louis Limestone

The St. Louis Limestone underlies the Ste. Genevieve Limestone, but the two formations are difficult to differentiate in poor exposures. The Lost River Chert of Elrod (1899) is considered to separate the Ste. Genevieve from the underlying St. Louis Limestone in this report. Locally the zone representing the Lost River Chert may appear as float consisting of rough-weathered blocks and slabs of chert at the land surface. In outcrop, this zone may be from 3 to 10 feet in thickness and is characterized by chert, abundant coarse fossil fragments, and silicified limestone.

The St. Louis Limestone ranges from 100 to 375 feet in thickness and consists of medium to light-gray limestone and light-yellowish-gray dolomitic limestone. The lithology is variable with beds grading laterally into other types in short distances. Medium to light-gray vitreous chert is common throughout the unit. Beds of medium to dark-gray shale, 3 to 12 inches thick occur in the middle and lower part of the unit. The lowest part of the unit may contain gypsum in thin seams and vug fillings. A core hole, about 3 miles south of Ekron, penetrated about 50 feet of interbedded limestone, gypsum, and anhydrite in the lower part of the St. Louis Limestone (Kepferle and Peterson, 1964).

The St. Louis Limestone is poorly exposed because of deep weathering and it forms a mature karst topography with abundant sinkholes. This unit is the source of several large karst springs, such as Buttermilk Falls Spring near Brandenburg.

Salem Limestone

The Salem Limestone underlies the St. Louis Limestone but crops out only in the incised stream valleys of Otter Creek and the Ohio River. The base of the unit is exposed only in the valley of Otter Creek. The Salem Limestone is about 75 to 140 feet thick, medium- to dark-gray, medium- to coarse-grained, and is clastic and oolitic. It is interbedded with fine-grained argillaceous limestone and shale, and crossbedding is abundant and characteristic of this unit. Chert occurs as nodules and fossil-fragmental blocks. The formation contains abundant fossils and gypsum- and quartz-filled geodes as much as 2 feet in diameter. The Salem Limestone is an aquitard that forms a regional cave and spring zone near the contact of the Salem Limestone with the overlying units (George, 1987).

Structure

Major structural features of Meade County include the regional westward dip of strata and a system of faults in the southern part of the county. Faults and structural contours are shown on 7-1/2 minute geologic quadrangle maps which are listed in the references.

Meade County lies on the western flank of the Cincinnati arch, a major north-south trending structural high extending from central Kentucky into southeastern Ohio. In general, the rocks dip to the west away from the crest of the arch at an average of about 30 feet per mile (Brown and Lambert, 1963, p.14). Local changes in dip have created conditions favorable for the accumulation of oil and gas in places (Palmer, 1978; Withington and Sable, 1969; and Swadley, 1963).

There is relatively little faulting in Meade County. However, several faults extend into the county from the south in the area of Big Spring and Guston (Peterson, 1964 and Palmer, 1978). These are probably related to the

Rough Creek fault system, an east-west zone of intense faulting about 30 miles southwest of Meade County (McDowell and others, 1981). The vertical displacement along the faults ranges from 40 to 100 feet.

Bedrock in the study area typically contains vertical jointing, which according to the geologic quadrangle maps, commonly occur in sets displaying a northwest or northeast trend (Kepferle, 1967; Swadley, 1963; Peterson, 1964; and Kepferle and Sable, 1977). Joints can be several feet wide at the top of the bedrock and diminish to hairline cracks at depth and may be open or soil-filled near the surface. Though present in all rock types in the county, jointing is most evident in limestones where the circulation of ground water has caused enlargement. Solutionally enlarged joints can direct surface runoff into the complex ground-water flow system.

Occurrence and Movement of Ground Water

Ground water in Meade County occurs in both unconsolidated sediments and consolidated bedrock. Unconsolidated sediments, which include gravels, sands, and silts, can store and transmit water to underlying bedrock or receive water from bedrock. When sufficiently large in areal extent and located at relatively high altitudes, as in upland or high terrace deposits, unconsolidated sediments can be a significant source of recharge to bedrock. Unconsolidated sediments at lower altitudes, such as river valleys, are partially recharged by ground water from the surrounding bedrock and may form small local aquifers. Extensive deposits of unconsolidated sediments, which occur along large perennial streams such as the Ohio River, form regional aquifers that are a major source of ground water.

Water in the residuum and alluvial deposits along major streams, including the Ohio River, occurs in intergranular (primary) openings and in conduits or pipe-like (secondary) openings. Though the tendency is to assume that all water in unconsolidated material occurs in primary openings, Mull and others (1988, p. 8) report numerous voids and the presence of conduit-like openings in unconsolidated material overlying bedrock in the Elizabethtown area, Kentucky. Quinlan and Aley (1987) report that the movement of ground water in macropores (root channels, cracks or fissures, animal burrows, and textural transitions) is commonly several orders of magnitude more rapid than that in the adjacent unconsolidated sediment.

Movement of water through intergranular openings in unconsolidated materials is typically only a few feet per year. Because of this, water-quality commonly improves as water moves through the soil horizon as a result of filtration and other physical, chemical, and biological processes. However, the presence of conduit systems in the soil horizon and at greater depth in unconsolidated sediments, provides the possibility of rapid ground-water movement. Associated with this accelerated rate of movement is a decrease in the potential for water-quality improvement. The potential also exists for contaminants to enter the ground-water flow system through these conduit systems.

The principal aquifer, as defined in this report, consists of the relatively thick and extensive beds of limestone of the Ste. Genevieve and St. Louis Limestones. However, additional limestones are included as part of the principal aquifer in Meade County because they may be an important source of water locally. The presence of this limestone bedrock is responsible for the karst terrane that characterizes much of study area. The limestones are relatively impervious except where fractures (secondary openings) have been solutionally enlarged by circulating ground water. This circulation of water dissolves calcium carbonate and enlarges openings to allow rapid movement of ground water. The enlarged openings may be vertical or horizontal and range in size from a fraction of an inch to several feet as is typical of many caves in the county. The abundance of caves is characteristic of the dissolution ability of circulating ground water. George (1985, p. 21) reports the presence of 212 caves in Meade County, 43 of which have been mapped.

Ground water moves in response to hydraulic gradients from points of recharge to points of discharge. Characteristically, recharge points are in the uplands and discharge points are in stream valleys. The configuration of the potentiometric surface (water table) in the principal aquifer in Meade County is shown by means of contours in figure 3. The contours show average summer conditions based on water-level measurements from ground-water wells (Plebuch and others, 1985). The general direction of ground-water flow can be estimated by drawing flow lines perpendicular to the potentiometric contours. Flow lines would show that the general direction of ground-water movement in Meade County is toward the Ohio River. However, the direction of ground-water flow at a specific site may differ because the water must follow available routes whose orientation is dependent on the development of secondary openings and local structure including dip of the rocks and the presence and nature of faulting.

There are generally two types of ground-water flow in Meade County, diffuse (slow, laminar flow) and conduit (rapid, turbulent flow). The relation between diffuse flow, conduit flow, and other components of the hydrologic cycle in karst terrane is shown in the generalized block diagram of figure 4 (Gunn, 1986).

Diffuse flow occurs in the primary openings of unconsolidated sediments and bedrock and is a major component of ground-water recharge, especially where extensive deposits of unconsolidated sediments overlie bedrock. Diffuse flow may occur where openings have not been enlarged sufficiently to allow conduit flow, such as near the boundary of ground-water basins and in the uppermost zone of bedrock near contacts with overlying residuum.

Conduit flow occurs in solutionally enlarged conduits which are referred to as secondary openings. Water can enter conduits through discrete points such as sinkholes and sinking streams, and also through the concentration of diffuse flow in the subsurface. Conduit flow is significant because of the potential to rapidly introduce and transmit water throughout the aquifer system. Thus, contaminants disposed of on the surface or in sinkholes may enter the ground-water flow system and rapidly impact ground-water quality.

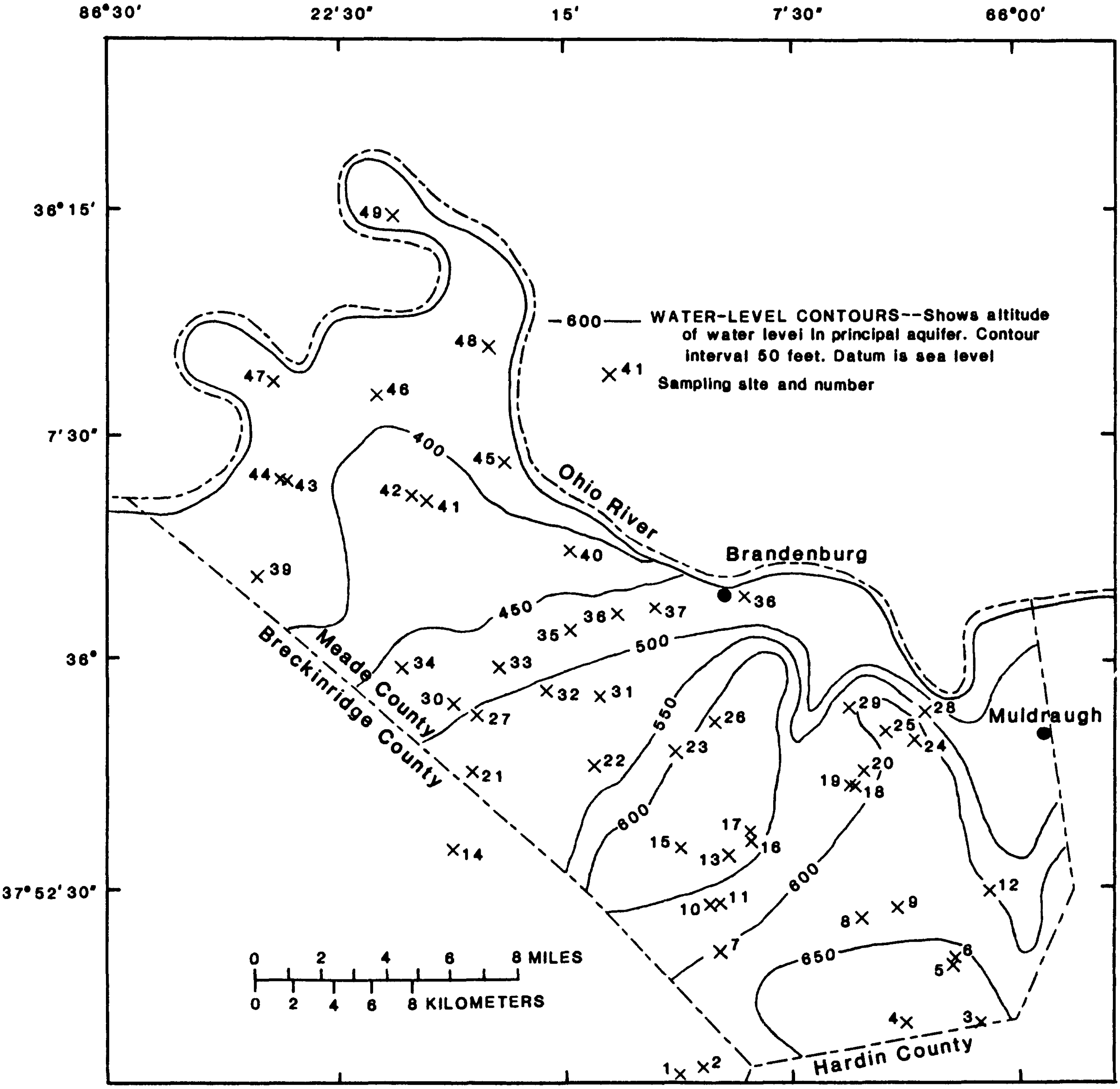
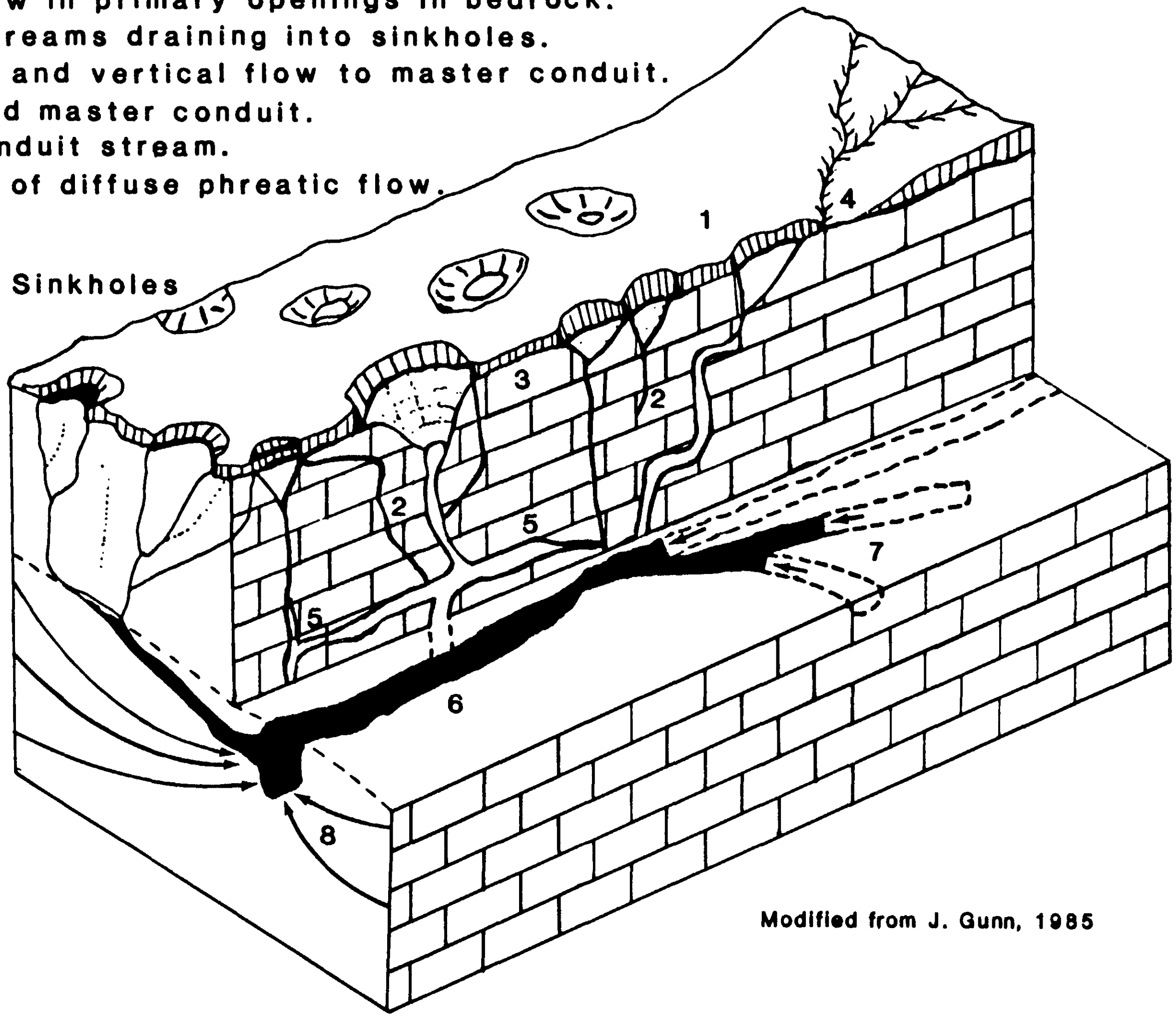


Figure 3.--Configuration of the potentiometric surface and ground water sampling sites.

EXPLANATION

1. Diffuse flow through soil, residuum, or unconsolidated surficial material.
2. Flow through enlarged vertical conduits.
3. Diffuse flow in primary openings in bedrock.
4. Surface streams draining into sinkholes.
5. Horizontal and vertical flow to master conduit.
6. Water-filled master conduit.
7. Vadose conduit stream.
8. Flow lines of diffuse phreatic flow.



Modified from J. Gunn, 1985

Figure 4.--Components of ground-water flow in a maturely karsted aquifer.

In a mature karst terrane, such as occurs in much of Meade County, sinkholes are abundant and virtually all sinkholes act as a vertical input point for water draining to the subsurface. In the subsurface, master conduits concentrate the direct input from the lesser conduits of sinkholes and sinking streams. These master conduits are dendritic or trellised, develop along horizontal and vertical openings, and form trunk conduits or channels. Virtually every sinkhole acts as a sink for surface runoff. Runoff is most frequently delivered to the subsurface by way of vertical shafts. Vertical shafts range from 60 to 130 feet in depth and drain to master conduits that lead to major resurgences (springs) which serve as natural discharge points for the trunk conduits (George, 1972, p. 3). Flow in master conduits is typically turbulent, highly variable in temperature, and relatively flashy in response to precipitation. These are characteristics frequently observed for most of the large springs in the sinkhole-plain part of Meade County. For a more detailed discussion of the occurrence and movement of ground water in karst terrane, the reader is referred to recent books by White (1988), and Ford and Williams (1989).

METHODS OF INVESTIGATIONS

Sampling-Site Selection Criteria

Forty-nine sites, consisting of 37 wells and 12 springs and were selected as ground-water sampling sites during this investigation (table 1). Only wells or springs that were used as a primary source of drinking water were sampled. Although it is not officially used as a water supply, Buttermilk Falls Spring which issues from a hillside along a public road, was selected for sampling because it was suspected of causing a hepatitus outbreak in 1982-83 and many homeowners and an occasional water hauler continue to use water from this spring.

Only wells completed since July 1985 were sampled. Since 1985, all water well drillers have been required to comply with the Kentucky Well Drillers Certification Program Regulations which specify well-construction and completion techniques and practices. The specification most relevant to ground-water sampling is the requirement that well casings be of sufficient length and adequately sealed to prevent infiltration of surface water into the well. The Regulations also require that the well bore and water in the well are disinfected after drilling and pump installation operations are complete. Thus, water samples collected from these wells were more likely to be representative of water from the formation and were less likely to be contaminated by local surface runoff.

A well was included only if water could be collected from a spigot or hydrant that would sustain the heat used to sterilize the fixture before collecting a water sample for bacteriological analysis. Also, a site was selected only if untreated water could be collected. If treatment devices were present, the water was routed around the device for an appropriate period of time before samples were collected.

Table 1.--Ground-water sampling sites in Meade County

[Depth of well or casing, in feet]

Site number	Owner or name	Site type	Lat-itude	Long-itude	Depth of well	Depth of casing	Primary aquifer
1	Floyd Wheeler	Well	374746	861128	140	100	Ste. Genevieve
2	Bert Jackson	Well	374757	861042	155	43	Ste. Genevieve
3	Ron Burnett	Well	374903	860134	95	84	St. Louis
4	Dale Thompson	Well	374905	860403	180	--	St. Louis
5	David Harper	Well	375035	860227	140	--	Ste. Genevieve-St.Louis
6	Ron Kidner	Well	375045	860223	187	140	Ste. Genevieve-St.Louis
7	Allen Hicks	Spring	375057	861009			Ste. Genevieve
8	Charles Jones	Spring	375148	860528			Ste. Genevieve
9	Timmy Pack	Well	375204	860417	230	210	St. Louis
10	Paul Jones	Spring	375210	861028			Ste. Genevieve
11	Gorden Board	Well	375212	861007	151	135	Ste. Genevieve-St.Louis
12	Warren Harding	Well	375229	860116	160	120	St. Louis
13	Hayden Hack	Well	375325	860952	221	20	St. Louis
14	J.D. Tobin	Well	375335	861845	260	200	St. Louis
15	Louis Latondress	Spring	375337	861124			Ste. Genevieve
16	Bob Andre	Well	375347	860906	140	120	St.Louis-Salem
17	Ronnie Henry	Well	375402	860909	155	20	St. Louis
18	Franklin McCoy	Spring	375511	860542			Beaver Bend
19	John Oliver	Well	375512	860552	169	40	Ste. Genevieve-St.Louis
20	Randy Rider	Well	375533	860524	199	160	St.Louis-Salem
21	John Cox	Well	375535	861809	300	200	St. Louis
22	Kennah Basham	Well	375543	861412	345	309	St.Louis-Salem
23	William Moran	Well	375604	861135	100	--	St. Louis
24	Tony Pack	Well	375620	860344	107	68	St. Louis
25	Roger Laws	Well	375634	860442	87	--	St. Louis
26	Jesse Jones	Well	375648	861020	125	86	St. Louis
27	Dave Dugan	Well	375700	861801	395	--	St. Louis
28	Morgan Cave	Spring	375703	860323			St. Louis
29	Bill Nelson	Well	375711	860556	76	--	St. Louis
30	Bernard Greenwell	Spring	375718	861846			Reelsville
31	Steve Collins	Well	375729	861402	257	--	St. Louis
32	Jeff Mattingly	Well	375737	861546	227	20	St. Louis
33	William Beavin	Well	375813	861718	300	200	St. Louis
34	Mark Fackler	Well	375813	862027	230	60	St. Louis
35	Tom Weitcha	Well	375912	861458	122	--	St. Louis
36	Joe Bryant	Well	375937	861329	227	180	Ste. Genevieve-St.Louis
37	Jim English	Well	375947	861215	281	124	St. Louis
38	Buttermilk Falls	Spring	380006	860922			St. Louis
39	Johnny Vessels	Well	380037	862516	407	260	Ste. Genevieve-St.Louis
40	Bruce Conover	Well	380118	861502	350	264	St. Louis
41	Bill Benock	Spring	380241	861940			Haney
42	R.W. Chandler	Well	380251	862010	500	160	Ste. Genevieve-St.Louis
43	Grady Johnson	Well	380314	862419	59	40	Ste. Genevieve
44	Nate Keith	Spring	380317	862432			Glen Dean
45	Oolite Springs	Spring	380342	861710			Ste. Genevieve
46	Robert Stansbury	Well	380530	862122	187	137	Ste. Genevieve-St.Louis
47	Alfred Hartley	Spring	380551	862447			Glen Dean
48	Kenny Jenkins	Well	380645	861743	542	260	Ste. Genevieve-St.Louis
49	Orville Swift	Well	381012	862052	307	100	St. Genevieve

The availability of wells completed since 1985 did not permit optimum distribution of sampling sites. Fewer wells are drilled in the northwestern part of the county because this area is sparsely populated and the principal aquifers occur at greater depth than in the central and eastern parts of the county. Thus, the sampling sites tend to be concentrated in the central and eastern part of the county. Three of the sites were selected a short distance beyond the Meade County boundary in Breckinridge County to enhance the spatial distribution of sampling sites in that particular area.

Sampling Schedule and Laboratory Analyses

To characterize the ground-water quality in Meade County, samples were collected and analyzed for an extensive list of physical, chemical, and bacteriological parameters. All ground-water samples were analyzed in the field for temperature, specific conductance, and pH.

One water sample was collected at 47 of the 49 sites and analyzed for various physical parameters, major anions and cations, nitrates, trace elements, trihalomethanes, polychlorinated biphenyls, chlorinated pesticides, phenols, chlorphenoxy herbicides, and other volatile organic compounds. Repeat samples were collected from eight sites to address the seasonal variations in water quality. The analytical work was performed by Watercheck Division, National Testing Laboratory, Inc., in Ypsilanti, Michigan. Results of these analyses are shown in table 2.

Water samples were also collected at about monthly intervals from selected sites and analyzed for organic compounds using a Gas Chromatographic Flame Ionization Detector (GC/FID) scan. The GC/FID scan is not quantitative, but is a general screening method used to determine the presence of organic compounds. This analysis was considered to be the most efficient and cost effective way of determining contamination of ground water due to the presence of organic compounds. Although the GC/FID scan can not be used to identify specific organic compounds, results of the scan can be used to calculate concentration ranges for organics in water and determine other related characteristics such as seasonality. GC/FID scans were performed by the U.S. Geological Survey, Quality-Water Service Unit in Ocala, Florida. The results of these analyses are given in table 3.

A major component of the water-quality investigation included analyses of the bacterial content of the water. Samples for these analyses were collected from 45 of the 49 sites, once in the spring and once in the fall. In addition, tests were also performed for total coliform content in the spring and the fall for each of the 49 sites. The eight sites that were monitored periodically for seasonal variations in chemical quality were also monitored for seasonal variations in total coliform densities. Analysis for total coliform bacteria was conducted by the Kentucky Cabinet for Human Resources, Frankfort, Kentucky. Analyses for fecal coliform and fecal streptococci were performed by Beckmar Environmental Laboratory in Louisville, Kentucky. Results of all bacterial analysis are shown in table 4.

Table 2.--Water-quality data

[Turbidity in nephelometric turbidity units; alkalinity and hardness as calcium

				INORGANICS AND TRACE ELEMENTS												
				Milligrams per liter								Micrograms per liter				
Site number	Site Type	Date sampled	Turbidity	Nitrate	Hardness	Alkalinity	Dissolved solids	Sodium	Chloride	Sulfate	Fluoride	Arsenic	Barium	Iron	Nickel	Silver
1	Well	3-25-87	0.1	<1	240	180	450	5	<10	30	2	<2	<30	<20	30	<2
		6-14-87	.2	<1	220	175	440	3	<10	32	3.9	<2	<30	80	<20	<2
		10-06-87	.2	<1	290	190	528	4	20	24	4	<2	<30	50	<20	<2
		1-11-88	.2	<1	270	170	240	4	<10	20	4.5	<2	<30	60	<20	<2
		1-28-88	.3	<1	200	160	240	3	<10	<20	5	<2	<30	110	<20	<2
		2-29-88	.2	<1	220	190	270	3.9	25	20	7	<2	<30	120	<20	<2
2	Well	4-14-87	.1	<1	230	190	430	<1	<10	<20	1.1	<2	<30	<20	21	<2
3	Well	4-14-87	.2	<1	250	238	490	4	<10	<20	1.5	<2	<30	112	<20	<2
4	Well	8-05-87	.4	<1	210	160	381	1	10	<20	.6	<2	<30	40	<20	<2
5	Well	4-02-87	.3	<1	490	197	700	9	5	<20	1.6	<2	<30	120	<20	<2
6	Well	4-02-87	.3	1	390	264	450	7	10	20	.4	<2	<30	660	<20	<2
7	Spring	10-08-87	.2	<1	220	190	447	3	10	24	.5	<2	<30	30	<20	<2
9	Well	8-18-87	.2	<1	100	210	332	1	20	<20	2.4	<2	<30	50	<20	<2
11	Well	4-01-87	.1	<1	320	225	580	3	5	20	2	<2	<30	40	<20	<2
12	Well	3-24-88	.2	<1	310	250	640	4	<10	70	1.3	<2	<30	21	<20	<2
		6-14-87	.2	<1	390	220	710	2	<10	94	4	<2	<30	80	<20	<2
		10-06-87	.2	<1	330	230	630	2	20	48	4	<2	<30	60	<20	<2
		1-11-88	.2	<1	280	200	300	2	<10	<20	1.3	<2	<30	30	<20	<2
		1-28-88	.1	<1	300	210	315	2	<10	65	3.5	<2	<30	150	<20	<2
		2-22-88	.2	<1	320	210	330	3	<10	90	5	<2	<30	40	<20	<2
13	Well	8-18-87	.2	<1	150	280	452	2	10	20	3.4	<2	<30	50	<20	<2
14	Well	4-01-87	.3	<1	1,030	195	1,870	54	50	475	2.1	<2	<30	132	<20	<2
15	Spring	4-20-87	.3	<1	330	220	600	<1	<10	<20	<.1	<2	<30	40	31	<2
16	Well	8-18-87	2.1	1	230	270	502	1	<10	<20	3	<2	<30	290	<20	<2
17	Well	4-14-87	.3	<1	310	300	620	<1	2	<20	.2	<2	<30	80	63	5
18	Spring	4-20-87	.2	1	330	230	590	<1	<10	30	<.1	<2	<30	<20	<20	<2
19	Well	3-13-87	16	<1	320	230	620	3	<10	50	2.3	<2	<30	180	40	<2
		6-14-87	3.9	<1	370	290	750	2	<10	65	4	<2	<30	400	<20	<2
		10-07-87	1.7	<1	360	300	712	2	10	40	4	<2	<30	510	<20	<2
		1-11-88	2.7	<1	400	310	330	2	<10	50	3.2	<2	<30	480	<20	<2
		1-28-88	.8	<1	390	300	360	2	<10	45	3.5	<2	<30	410	<20	<2
		2-22-88	.9	<1	300	280	390	2	<10	55	4.5	<2	<30	600	<20	<2
20	Well	9-17-87	1.5	<1	340	300	690	6	10	34	7	<2	<30	180	<20	<2
21	Well	8-18-87	.4	<1	190	250	469	2	<10	27	4.4	<2	<30	50	<20	<2
22	Well	4-16-87	3.7	<1	1,100	204	2,200	17	10	890	2.2	<2	<30	90	37	5
23	Well	10-02-87	.9	<1	290	250	605	7	30	28	4	<2	<30	140	<20	<2
24	Well	8-05-87	.2	<1	270	230	534	4	10	20	2.7	<2	<30	50	<20	<2
25	Well	4-16-87	.2	<1	260	220	490	6	<10	<20	<.1	<2	<30	40	<20	<2
26	Well	8-18-87	<.1	<1	180	230	413	3	<10	<20	.5	<2	<30	100	<20	<2
27	Well	4-01-87	1.1	<1	350	177	660	5	5	120	2	<2	<30	70	<20	<2
28	Spring	8-05-87	3.2	<1	230	240	520	5	20	25	.2	<2	<30	200	<20	<2
29	Well	8-05-87	.3	<1	300	250	580	3	<10	27	3	<2	<30	70	<20	<2

from springs and wells

carbonate; dissolved solids as sodium chloride; <, less than; *, detected in duplicate sample]

							ORGANICS								
							Micrograms per liter								
Zinc	Cadmium	Lead	Chromium	Copper	Manganese	Selenium	Toluene	Methylene chloride	Trichlorofluoromethane	1,2-Dichlorobenzene	1,4-Dichlorobenzene	Trichloroethylene	Styrene	Xylene	2-Nitrophenol
100	<2	36	<4	<4	7	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
120	<2	27	<4	31	<4	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
120	<2	<10	<4	14	<4	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
110	3	<10	<4	4	<4	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
100	<2	<10	<4	10	9	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
100	<2	<10	<4	47	20	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
120	<2	<10	<4	48	<4	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
80	<2	<10	<4	<4	6	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
220	<2	<10	<4	9	<4	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
290	<2	<10	<4	8	70	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
210	<2	<10	<4	19	20	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
5	3	<10	<4	<4	<4	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
230	<2	<10	<4	14	20	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
20	<2	27	<4	9	<4	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
150	<2	44	<4	4	<4	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
140	<2	33	<4	7	5	<2	1.5	5.5	4.6	<.5	<.5	<2	9.9	12.9	<6
190	<2	<10	<4	13	<4	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
270	3	18	<4	10	5	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
250	3	<10	<4	12	6	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
170	<2	<10	<4	7	6	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
480	<2	<10	<4	8	7	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
231	12	46	<4	11	20	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
8	5	37	<4	<4	<4	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
200	<2	<10	<4	10	10	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
40	7	44	10	21	150	<2	<.5	<.5	<5	<.5	<.5	2.8	<.5	<.5	<6
20	<2	40	5	<4	40	29	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
90	<2	18	<4	11	30	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
270	<2	38	<4	8	60	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	12	<6
260	3	<10	<4	11	50	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
230	4	15	<4	8	51	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
230	<2	<10	<4	24	60	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
240	3	<10	<4	12	50	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
140	3	<10	<4	6	20	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
480	<2	<10	<4	<4	5	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
370	6	39	<4	8	20	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
220	<2	<10	<4	15	20	<2	<.5	<.5	<5	.5	<.5	<2	<.5	<.5	<6
140	<2	13	<4	<4	5	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
30	<2	26	<4	<4	10	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
650	<2	<10	<4	5	20	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
320	<2	38	<4	30	10	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
10	<2	13	<4	<4	7	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
90	<2	13	<4	9	5	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6

Table 2.--Water-quality data

[Turbidity in nephelometric turbidity units; alkalinity and hardness as calcium

				INORGANICS AND TRACE ELEMENTS													
				Milligrams per liter									Micrograms per liter				
Site number	Site Type	Date sampled	Turbidity	Nitrate	Hardness	Alkalinity	Dissolved solids	Sodium	Chloride	Sulfate	Fluoride		Arsenic	Barium	Iron	Nickel	Silver
30	Spring	3-23-87	.2	2	410	280	950	65	70	120	<.1		<2	<30	210	<20	<2
31	Well	4-15-87	.4	<1	320	208	620	3	<10	86	3.5		<2	<30	100	26	<2
32	Well	4-15-87	.1	<1	270	232	630	<1	<10	<20	1.1		<2	<30	30	<20	<2
33	Well	9-17-87	5	<1	300	210	555	2	10	34	5.6		<2	<30	580	<20	<2
34	Well	4-20-87	.3	<1	282	240	530	<1	<10	<20	.2		<2	<30	64	29	<2
35	Well	9-17-87	6	<1	780	170	1150	16	30	150	7		<2	<30	330	<20	4
36	Well	4-15-87	.6	<1	340	228	650	4	<10	65	.8		<2	<30	250	26	<2
37	Well	3-23-87	.2	<1	280	240	530	2	<10	<20	.5		<2	<30	35	<20	<2
		6-14-87	.3	<1	260	240	505	2	<10	<20	1.5		<2	<30	80	<20	<2
		10-02-87	.3	<1	290	260	562	2	10	<20	1		<2	<30	120	<20	<2
		1-06-88	4.6	<1	190	250	270	2	<10	<20	1.2		<2	<30	230	<20	4
		1-25-88	.2	<1	220	240	270	2	<10	<20	1.2		<2	<30	80	<20	<2
		3-01-88	.3	<1	310	250	270	1.4	<10	<20	1		<2	<30	30	<20	<2
38	Spring	3-16-87	5	<1	240	180	480	5	10	20	<.1		<2	<30	120	24	11
		6-14-87	5.4	1	200	220	450	3	15	23	.1		<2	<30	370	<20	<2
		10-06-87	.4	<1	290	280	594	4	20	<20	.2		<2	<30	40	<20	<2
		1-06-88	1.2	<1	240	220	270	4	20	<20	<.1		<2	<30	70	<20	<2
		1-25-88	4	<1	230	200	270	3	<10	<20	<.1		<2	<30	360	<20	<2
		2-29-88	.4	4	170	220	300	3.1	<10	<20	<.1		<2	<30	50	<20	<2
39	Well	10-02-87	.4	<1	390	570	1100	70	30	38	.6		<2	<30	80	<20	4
40	Well	4-16-87	.5	<1	610	192	970	14	10	140	1.2		<2	<30	70	26	<2
41	Spring	9-17-87	.7	<1	370	180	702	21	60	71	<.1		<2	<30	100	<20	<2
42	Well	4-15-87	.2	<1	430	200	780	16	<10	120	3.1		<2	<30	70	31	<2
43	Well	10-02-87	.2	<1	300	240	592	7	20	25	5		<2	<30	90	<20	<2
44	Spring	6-14-87	12.4	<1	180	110	321	2	<10	31	<.1		<2	<30	570	<20	<2
		10-02-87	.7	<1	280	250	605	5	20	51	<.1		<2	<30	200	<20	<2
		1-11-88	.7	<1	210	150	240	4	<10	40	<.1		<2	<30	60	<20	<2
		1-28-88	.7	<1	160	120	180	4	<10	20	<.1		<2	<30	140	<20	<2
		3-04-88	10	<1	50	40	100	2.3	<10	<20	<.1		<2	<30	620	<20	<2
45	Spring	4-01-87	1	<1	270	62	380	2	5	31	<.1		<2	<30	50	<20	<2
46	Well	3-24-87	.4	<1	430	180	730	6	<10	110	2.1		<2	<30	140	<20	<2
		6-14-87	4.7	<1	450	180	810	4	<10	170	4		<2	<30	280	<20	<2
		10-02-87	5	<1	480	230	823	5	20	88	5.2		6	<30	410	<20	<2
		1-13-88	8	<1	360	180	420	4	<10	80	4.5		<2	<30	430	<20	<2
		1-25-88	.2	<1	450	170	350	4	<10	170	4.5		<2	<30	480	<20	<2
		3-04-88	3	<1	400	150	475	4.7	<10	200	4.5		<2	<30	510	<20	<2
47	Spring	3-25-87	.3	5	150	100	300	6	10	30	<.1		<2	<30	70	20	<2
48	Well	4-01-87	.2	<1	500	234	1030	14	5	160	2.1		<2	<30	40	<20	<2
49	Well	3-24-87	1.9	<1	280	280	600	12	<10	20	.8		<2	<30	140	<20	<2
		6-14-87	11	<1	320	260	615	6	<10	28	4		<2	<30	330	<20	<2
		10-02-87	.2	<1	290	260	597	5	20	22	5		<2	<30	80	<20	<2
		1-11-88	.4	<1	280	260	300	6	<10	<20	3		<2	<30	190	<20	<2
		1-25-88	.2	<1	270	260	300	7	20	<20	2.8		<2	<30	120	<20	<2
		2-29-88	.3	<1	300	280	300	6.8	30	<20	2.5		<2	<30	120	<20	<2

from springs and wells--Continued

carbonate; dissolved solids as sodium chloride; <, less than; *, detected in duplicate sample]

							ORGANICS								
Micrograms per liter															
Zinc	Cadmium	Lead	Chromium	Copper	Manganese	Selenium	Toluene	Methylene chloride	Trichlorofluoromethane	1,2-Dichlorobenzene	1,4-Dichlorobenzene	Trichloroethylene	Styrene	Xylene	2-Nitrophenol
10	<2	49	<4	<4	6	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
170	5	17	<4	<4	10	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
250	<2	26	<4	<4	5	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
230	<2	<10	<4	7	6	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
23	7	37	<4	11	10	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
20	4	28	5	8	10	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
240	5	35	<4	30	10	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
250	<2	32	<4	11	20	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
300	<2	15	<4	<4	<4	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
220	<2	<10	<4	8	6	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
240	4	16	<4	18	6	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
230	<2	<10	<4	5	<4	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	30.1
200	<2	<10	<4	65	<4	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
10	<2	50	<4	5	10	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
10	<2	18	<4	7	5	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
7	<2	<10	<4	19	<4	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
10	4	<10	<4	6	<4	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
10	<2	<10	<4	7	9	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
20	<2	<10	<4	7	5	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
190	3	16	<4	8	10	<2	<.5	<.5	<5	<.5	<.5	<2	.3*	1.5*	<6
620	5	35	<4	19	8	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
6	<2	<10	<4	5	5	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
830	5	35	<4	<4	8	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
100	<2	<10	<4	13	6	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
10	<2	21	<4	8	8	<2	<.5	<.5	<5	<.5	1	<2	<.5	<.5	<6
30	3	<10	<4	6	5	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
40	<2	<10	<4	5	<4	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
10	<2	<10	<4	8	8	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
20	<2	<10	<4	<4	9	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
<4	<2	35	<4	18	<4	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
260	<2	28	<4	<4	10	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
310	<2	35	<4	8	50	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
220	<2	<10	<4	24	200	<2	<.5	<.5	<5	<.5	<.5	<2	.3	.6	<6
290	<2	10	<4	7	40	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
320	3	<10	<4	6	20	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
280	<2	10	<4	19	30	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
10	<2	28	<4	4	20	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
570	<2	35	<4	<4	10	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
320	<2	38	<4	5	6	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
370	<2	33	<4	6	5	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
670	<2	<10	<4	15	4	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
1,500	3	<10	<4	8	4	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
1,100	<2	<10	<4	11	<4	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6
620	<2	<10	<4	7	5	<2	<.5	<.5	<5	<.5	<.5	<2	<.5	<.5	<6

Table 3.--Gas chromatograph/flame ionization detection scans for organic constituents in water from selected springs and wells

[Concentrations in micrograms per liter; RRT, relative retention times]

Site number	Site type	Date sampled	RRT	Concentration range
1	Well	3-25-87	0	0
		4-30-87	0	0
		5-28-87	.37	1-5
		6-14-87	0	0
		8-04-87	0	0
		8-27-87	.36	5-10
		8-27-87	1.33	5-10
		8-27-87	1.37	10-20
		8-27-87	1.41	5-10
		10-06-87	0	0
		10-29-87	0	0
		12-03-87	0	0
		1-11-88	0	0
		1-28-88	0	0
		2-29-88	0	0
12	Well	3-24-88	0	0
		4-30-88	0	0
		5-28-88	0	0
		6-14-87	.61	1-5
		6-14-87	.63	1-5
		8-27-87	.36	5-10
		8-27-87	1.33	5-10
		8-27-87	1.38	20-30
		8-27-87	1.67	1-5
		10-06-87	0	0
		10-29-87	0	0
		12-03-87	0	0
		1-11-88	0	0
		1-28-88	0	0
		2-22-88	0	0
19	Well	4-30-87	0	0
		5-28-87	.37	1-5
		5-28-87	.48	1-5
		6-14-88	0	0
		8-04-87	1.47	1-5
		8-27-87	.36	5-10
		8-27-87	1.33	5-10
		8-27-87	1.38	20-30
		10-06-87	0	0
		10-29-87	0	0
		12-03-87	0	0
		1-11-88	0	0
		1-28-88	0	0
		2-22-88	0	0
37	Well	3-23-87	0	0
		4-28-87	0	0
		5-28-87	.37	1-5
		5-28-87	.47	1-5
		5-28-87	.69	1-5
		5-28-87	.93	1-5
		5-28-87	1.18	1-5
		5-28-87	1.40	1-5
		5-28-87	1.44	1-5
		6-14-87	0	0
		8-03-87	1.47	1-5
		9-02-87	.36	5-10
		9-02-87	1.16	1-5
		9-02-87	1.33	5-10
		9-02-87	1.37	10-20
		9-02-87	1.41	1-5
		10-01-87	0	0
		10-27-87	0	0
		12-02-87	0	0
		1-06-88	0	0
		1-25-88	0	0
		2-29-88	0	0
38	Spring	3-16-87	.59	5-10
		4-28-87	0	0
		5-28-87	.37	1-5
		5-28-87	.47	1-5
		5-28-87	.69	1-5
		5-28-87	.93	1-5
		5-28-87	1.40	1-5
		6-14-87	1.05	1-5
		6-14-87	1.51	1-5
		8-04-87	0	0
		9-02-87	.35	5-10
		9-02-87	1.33	5-10
		9-02-87	1.38	20-40
		9-02-87	1.41	1-5
		10-06-87	0	0
		10-29-87	0	0
		12-02-87	0	0
		1-06-88	0	0
		1-25-88	0	0
		2-29-88	0	0
44	Spring	4-28-87	0	0
		5-28-87	.37	1-5
		5-28-87	1.06	1-5
		5-28-87	1.51	1-5
		6-14-87	.63	1-5
		6-14-87	1.72	1-5
		8-04-87	0	0
		9-02-87	.36	5-10
		9-02-87	1.33	5-10
		9-02-87	1.37	10-20
		9-02-87	1.41	1-5
		10-01-87	0	0
		10-27-87	0	0
		12-02-87	0	0
		1-11-88	0	0
		1-28-88	0	0
		3-03-88	0	0
46	Well	3-24-87	0	0
		4-28-87	0	0
		5-28-87	.37	1-5
		5-28-87	.46	1-5
		5-28-87	.47	1-5
		5-28-87	.93	1-5
		5-28-87	1.40	1-5
		6-14-87	.63	1-5
		6-14-87	1.72	1-5
		8-04-87	0	0
		9-01-87	.36	5-10
		9-01-87	.61	1-5
		9-01-87	1.33	1-5
		9-01-87	1.38	5-15
		9-01-87	1.41	1-5
		10-01-87	0	0
		10-27-87	1.73	10-20
		12-03-87	0	0
		1-13-88	0	0
		1-25-88	0	0
		3-03-88	0	0
49	Well	3-24-87	0	0
		4-30-87	1.51	5-10
		5-28-87	.37	1-5
		5-28-87	.48	1-5
		5-28-87	1.40	1-5
		6-14-87	0	0
		9-01-87	.35	5-10
		9-01-87	.48	1-5
		9-01-87	1.33	5-10
		9-01-87	1.38	10-20
		9-01-87	1.41	1-5
		10-01-87	0	0
		10-27-87	0	0
		12-02-87	0	0
		1-11-88	0	0
		1-25-88	0	0
		2-29-88	0	0

Table 4.--Bacteriological and physical characteristics of ground water

[Bacteriological data in number of colonies per 100 milliliter; temperature in degrees Celsius; specific conductance in microsiemens per centimeter at 25 degrees Celsius; pH in standard units; **, organisms too numerous to count; cg, confluent growth; --, no analysis]

			BACTERIA			PHYSICAL CHARACTERISTICS			
Site number	Site type	Date sampled	Total coliform	Fecal coliform	Fecal streptococci	Water temperature	Air temperature	Specific conductance	pH
1	Well	3-25-87	0	--	--	13.5	--	410	7.74
		4-30-87	**	--	--	14.5	28.5	400	7.67
		5-28-87	**	--	--	15	31	400	7.54
		6-14-87	**	--	--	15.5	31	380	7.95
		8-04-87	0	--	--	15.5	28	400	7.26
		8-27-87	**	--	--	15.5	32	415	7.73
		10-06-87	**	--	--	14	16	420	7.79
		10-29-87	**	--	--	13.5	8	405	7.7
		12-03-87	0	--	--	13	13	420	7.88
		1-11-88	0	--	--	12	0	445	7.23
		1-28-88	0	--	--	12.5	7.5	430	7.89
		2-29-88	0	--	--	12.5	2.5	420	8.29
2	Well	4-14-87	0	0	0	13.5	--	395	7.61
		11-24-87	0	0	0	13.5	13.5	390	7.98
3	Well	4-14-87	cg	0	0	14.5	--	400	7.58
		11-23-87	0	0	0	13	11	410	7.92
4	Well	5-20-87	--	0	0	16	30	300	7.5
		8-05-87	--	0	0	16	29	550	7.61
		11-16-87	0	0	0	14	23	305	8.14
5	Well	4-02-87	**	0	0	12.5	--	740	7.47
		11-16-87	**	0	0	14	23	800	7.75
6	Well	4-02-87	**	16	37	12.5	--	480	7.34
		11-16-87	0	0	0	14	23	495	7.61
7	Spring	4-23-87	**	0	0	13.5	19	490	7.69
		10-08-87	**	3	7	12.5	12	415	8.49
8	Spring	4-23-87	**	53	38	15	27	520	7.27
		1-12-88	**	560	730	3.5	7	435	8.33
		1-13-88	--	0	0	3	2	415	8.07
9	Well	3-30-87	0	--	--	13.5	--	412	7.59
		4-27-87	0	0	0	15.5	28.5	440	7.51
		8-18-87	0	0	0	15.5	32.5	440	7.23
10	Spring	4-23-87	**	68	71	11.5	19	570	7.09
		1-12-88	**	16	22	9	9	480	7.7
11	Well	4-01-87	0	0	0	15	--	460	7.51
		11-23-87	0	0	0	14	14	425	7.82
12	Well	3-24-87	0	--	--	13	--	600	7.49
		4-30-87	**	--	--	15	28	560	7.4
		5-28-87	0	--	--	16	33	600	7.42
		6-14-87	0	--	--	16.5	32	590	7.75
		8-04-87	cg	--	--	16.5	32	580	7.02
		8-27-87	0	--	--	18	32	600	7.34
		10-06-87	0	--	--	14	16	560	7.62
		10-29-87	0	--	--	14	8	575	7.57
		12-03-87	**	--	--	12	13.5	650	7.72
		1-06-88	--	--	--	12.5	.15	495	--
		1-11-88	0	--	--	9	2	520	7.58
		1-28-88	0	--	--	10.5	8.5	550	7.77
		2-22-88	0	--	--	12	15	575	8.1
13	Well	3-30-87	**	0	0	13	--	570	7.32
		8-18-87	--	--	--	16	27	500	7.15
		11-23-87	0	0	0	14	14	485	7.74
14	Well	4-01-87	cg	0	0	11.5	--	1,630	7.37
		11-24-87	**	0	0	12.5	13	1,700	7.62

Table 4.--Bacteriological and physical characteristics of ground water--Continued

[Bacteriological data in number of colonies per 100 milliliter; temperature in degrees Celsius; specific conductance in microsiemens per centimeter at 25 degrees Celsius; pH in standard units; **, organisms too numerous to count; cg, confluent growth; --, no analysis]

			BACTERIA			PHYSICAL CHARACTERISTICS			
Site number	Site type	Date sampled	Total coliform	Fecal coliform	Fecal streptococci	Water temperature	Air temperature	Specific conductance	pH
15	Spring	4-20-87	**	0	30	11.5	--	525	7.45
		11-24-87	**	30	70	11	13	520	8.61
16	Well	3-30-87	0	0	0	14	--	480	7.39
		8-18-87	--	--	--	16	28.5	480	7.58
		11-23-87	0	0	0	13.5	15	480	7.75
17	Well	4-14-87	0	0	0	14.5	--	560	7.27
		11-18-87	0	0	0	13.5	12	560	7.51
18	Spring	4-20-87	**	5	6	11.5	--	465	7.74
		10-22-87	**	0	0	12.5	17	495	7.76
19	Well	3-13-87	0	0	0	13.5	--	650	7.59
		4-30-87	**	--	--	15	28	625	7.32
		5-28-87	0	--	--	15.5	29	648	7.35
		6-14-87	0	--	--	15	33	600	7.88
		8-04-87	0	--	--	--	--	--	--
		8-27-87	0	--	--	15.5	31	610	7.53
		10-06-87	0	--	--	14	16.5	640	7.39
		10-29-87	0	--	--	13	9	640	7.22
		12-03-87	0	--	--	13	13	600	7.49
		1-28-88	0	--	--	13	8.5	650	7.41
		2-22-88	0	--	--	13.5	11	625	7.77
20	Well	3-30-87	**	0	0	13	--	550	7.56
		9-17-87	**	0	0	15.5	25	530	--
21	Well	8-18-87	--	--	--	15.5	30	500	7.27
		11-25-87	0	0	0	14	--	500	7.75
		3-14-88	0	0	4	--	--	--	--
22	Well	4-16-87	0	0	0	15	--	1,600	--
		11-10-87	0	0	0	13	11	1,450	7.66
23	Well	5-20-87	--	0	0	16	32	510	7.41
		10-02-87	--	--	--	14	--	505	7.29
		11-10-87	cg	0	0	13.5	5	495	7.8
		3-14-88	**	--	--	--	--	--	--
24	Well	3-30-87	0	0	0	13.5	--	412	7.59
		8-05-87	--	--	--	16	32	440	7.32
		11-18-87	0	0	0	13.5	10.5	410	7.74
25	Well	4-16-87	**	0	0	15.5	--	418	--
		10-22-87	0	0	0	14	13	420	7.58
26	Well	3-30-87	cg	0	0	14	--	398	7.43
		8-18-87	--	--	--	15	32.5	390	7.63
		11-25-87	0	0	0	13.5	21	420	7.71
27	Well	4-01-87	0	0	0	14.5	--	548	7.6
		11-19-87	**	0	0	15.5	13.5	595	7.82
28	Spring	4-23-87	**	23	13	12	20	420	7.25
		8-05-87	--	--	--	13	22	475	7.5
		10-22-87	**	120	0	11.5	15	480	8.39
		11-18-87	**	110	120	11.5	11	480	8.47
29	Well	4-21-87	0	0	0	14	--	465	7.7
		8-05-87	--	--	--	16	31.5	480	7.39
		10-22-87	0	0	0	13	12	445	7.65
30	Spring	3-23-87	**	0	4	13.5	--	890	7.56
		11-19-87	**	10	500	13	12	1,000	7.98

Table 4.--Bacteriological and physical characteristics of ground water--Continued

[Bacteriological data in number of colonies per 100 milliliter; temperature in degrees Celsius; specific conductance in microsiemens per centimeter at 25 degrees Celsius; pH in standard units; **, organisms too numerous to count; cg, confluent growth; --, no analysis]

			BACTERIA			PHYSICAL CHARACTERISTICS			
Site number	Site type	Date sampled	Total coliform	Fecal coliform	Fecal streptococci	Water temperature	Air temperature	Specific conductance	pH
31	Well	4-15-87	0	0	0	14.5	--	580	6.57
		11-25-87	0	0	0	14	23	575	7.91
32	Well	4-15-87	0	0	0	15.5	--	430	6.66
		11-10-87	0	0	0	13.5	11	430	7.97
33	Well	4-21-87	cg	0	0	16.5	--	480	7.87
		9-17-87	cg	0	0	15.5	27	458	--
34	Well	4-20-87	0	0	0	13	--	440	7.25
		11-19-87	0	0	0	12.5	5	390	7.95
35	Well	4-21-87	**	0	0	16	--	1,400	7.4
		9-17-87	**	0	0	15.5	25	1,210	--
36	Well	4-15-87	**	0	0	14.5	--	570	6.62
		10-27-87	0	--	--	--	--	--	--
		11-19-87	**	0	0	14	2	500	7.65
37	Well	3-23-87	cg	0	0	13.5	--	460	7.43
		4-28-87	0	--	--	14.5	20	455	7.43
		5-28-87	cg	--	--	15.5	34	470	7.4
		6-14-87	**	--	--	15.5	31	460	7.79
		8-03-87	**	--	--	16.5	34	455	7.1
		9-02-87	0	--	--	15.5	27	460	7.74
		10-01-87	0	--	--	14.5	23	460	7.7
		10-27-87	0	--	--	13.5	13	455	7.54
		12-02-87	0	--	--	13.5	7	405	7.65
		1-06-88	0	--	--	12	13	485	7.42
		1-25-88	0	--	--	9.5	9	440	7.76
		2-29-88	cg	--	--	14	9	470	8.28
38	Spring	3-16-87	**	113	59	13	--	492	7.56
		4-28-87	**	--	--	13.5	20	480	7.41
		5-27-87	**	0	--	12.9	34	510	6.98
		6-14-87	**	--	--	13	22	480	6.31
		8-03-87	**	--	--	14.5	34	435	7.02
		9-02-87	**	--	--	13	10	630	8.24
		10-06-87	**	--	--	13.5	20	560	8.07
		10-29-87	**	--	--	12.5	14	510	8.31
		12-02-87	**	--	--	11	9.5	495	8.45
		1-06-88	**	--	--	12.5	14	495	8.34
		1-25-88	**	--	--	11.5	7.5	445	7.95
		2-29-88	**	--	--	11.5	0	480	9.24
39	Well	4-28-87	0	0	0	15	21	1,000	6.99
		10-02-87	--	--	--	16	--	1,050	6.73
		11-25-87	0	0	0	14.5	24	980	7.3
40	Well	4-16-87	**	0	0	14.5	--	1,000	--
		1-27-88	0	0	0	12	3	1,010	7.66
41	Spring	3-18-87	**	28	8	--	--	--	--
		9-17-87	**	124	58	15.5	28.5	650	8
42	Well	4-15-87	0	0	0	16.5	--	800	6.61
		10-08-87	0	0	0	15	12.5	760	7.64
43	Well	3-09-87	0	--	--	--	--	--	--
		5-20-87	--	0	0	14.5	30	440	7.52
		10-02-87	--	--	--	13.5	22.5	460	7.27
		11-16-87	0	0	0	13	26	460	7.85

Table 4.--Bacteriological and physical characteristics of ground water--Continued

[Bacteriological data in number of colonies per 100 milliliter; temperature in degrees Celsius; specific conductance in microsiemens per centimeter at 25 degrees Celsius; pH in standard units; **, organisms too numerous to count; cg, confluent growth; --, no analysis]

			BACTERIA			PHYSICAL CHARACTERISTICS			
Site number	Site type	Date sampled	Total coliform	Fecal coliform	Fecal strepto-cocci	Water temp-erature	Air temp-erature	Specific conduct-ance	pH
44	Spring	3-18-87	**	40	6	10.3	--	300	7.35
		4-28-87	**	--	--	11	--	295	7.24
		5-28-87	**	--	--	11.5	24	420	6.9
		6-14-87	**	--	--	11.5	21	300	6.32
		8-04-87	**	--	--	13	24	440	7.05
		9-01-87	**	--	--	14.5	24.5	560	7.93
		10-01-87	**	--	--	13.5	20	420	8.45
		10-27-87	**	--	--	13.5	12	440	8.21
		12-02-87	**	--	--	10	10.5	420	8.59
		1-11-88	**	--	--	9	5	380	8.65
		1-28-88	**	--	--	9.5	2	345	8.58
		3-03-88	--	--	--	10	--	180	7.96
45	Spring	4-01-87	**	0	0	10.5	34	380	7.96
		10-08-87	**	730	73	11	13.5	340	8.57
46	Well	3-24-87	0	--	--	13	--	710	7.64
		4-07-87	0	--	--	--	--	--	--
		4-28-87	**	--	--	15.5	19.5	700	7.53
		5-28-87	cg	--	--	16	--	700	7.44
		6-14-87	**	--	--	15.5	25	710	7.55
		8-04-87	0	--	--	16	25	710	7.23
		9-01-87	0	--	--	15.5	24	740	7.72
		10-01-87	0	--	--	14.5	20	760	7.67
		10-27-87	**	--	--	14.5	11.5	695	7.72
		12-03-87	**	--	--	13.5	8.5	720	7.7
		1-13-88	**	--	--	12	2	725	7.69
		1-25-88	0	--	--	12	8	740	7.69
		3-04-88	0	--	--	13	--	750	8.14
47	Spring	3-25-87	**	--	--	15	--	320	7.02
		1-27-88	**	0	250	9.5	3	365	8.16
48	Well	4-01-87	**	0	0	14	--	800	7.4
		10-08-87	**	0	0	16.5	14.5	840	7.6
49	Well	3-24-87	0	--	--	13.5	--	525	7.5
		4-30-87	0	--	--	14.5	24	510	7.44
		5-28-87	**	--	--	15.5	--	525	7.29
		6-14-87	0	--	--	16.5	25	540	7.54
		8-04-87	--	--	--	15.5	32	635	7.1
		9-01-87	0	--	--	15.5	27	490	7.64
		10-01-87	0	--	--	15.5	20	520	7.37
		10-27-87	0	--	--	14	10	520	7.52
		12-02-87	0	--	--	13	10.5	565	7.38
		1-11-88	0	--	--	13	0.6	540	7.54
		1-25-88	0	--	--	11	0.4	495	7.59
		2-29-88	0	--	--	11.5	5	520	8.07

Sampling Procedures

Procedures adopted for sampling the quality of ground water during this investigation generally can be divided into two categories: (1) procedures for collecting samples, and (2) procedures for the preparation and handling of bottles and containers used to collect and store the sample prior to analysis.

Collecting Samples

To obtain a valid sample, each well was pumped until the water from the sample collection point (faucet) was representative of water in the aquifer. All water in the well bore, pipes, and tanks of the water-delivery system was displaced with water from the aquifer before the sample was collected. The condition of equilibrium between the aquifer and water from the well was determined by the field measurements of temperature, specific conductance, and pH, and by pumping the well to replace at least two volumes of water initially standing in the well bore and water-delivery system.

The quantity of water to be pumped and the time required for sufficient pumping to displace the desired quantity of water was based on well depth and diameter, length of the column of water in the well bore, the size of the pressure or storage tank, and open-flow rate from the faucet. Most water-systems sampled stored about 110 gallons and the open-flow rate at an outside faucet was about 10 gallons per minute. Thus, the required volume of water could be discharged in about 22 minutes.

At the start of pumping and at 5-minute intervals during pumping, temperature, pH, and specific conductance of the discharged water were measured. Temperature was measured with a calibrated laboratory thermometer, pH was measured with a Beckman 21 meter, and specific conductance was measured with a Beckman RB-3 meter. Each meter was calibrated at the beginning of each day. Stabilization was assumed when values did not change for three consecutive measurements and a minimum of two volumes of water was displaced from the water-delivery system. The last measurement during the stabilization process was recorded as the sample value for temperature, specific conductance, and pH (table 4).

Flushing and flame sterilization of the mouth of the faucet were used to ensure the sterility of the faucet when collecting water samples for coliform determinations from wells. The sample for coliform determination was the last sample to be collected at each site. This permitted maximum flushing during the stabilization process and the collection of other samples. A portable butane torch was then used to sterilize the faucet before the sample was collected.

The collection of a representative sample of water flowing from a spring was simplified because pumping was not required to obtain an equilibrated sample. Nearly all water was collected from a discharge pipe leading from the mouth of the spring and in most cases contained all water flowing from the spring. A few springs did not have discharge pipes and were sampled directly from the spring mouth. To avoid potential contamination from sediment or other particulate matter, sample containers did not contact the pipe or bottom of the spring. Field measurements for temperature, pH, and specific conductance were made to confirm that conditions in the spring were stable. This was especially important when sampling after heavy rains in April and May 1987.

Handling Samples and Containers

All water samples were collected in glass bottles except for samples collected for total coliform bacteria. These samples were collected in sterile plastic twirl packs.

Glass bottles used for water samples were divided on the basis of pretreatment and whether the water sample required the addition of a preservative. Untreated bottles and caps were rinsed with the water being sampled. When sampling from the mouth of a spring without the use of a discharge pipe, the bottle was lowered from the water surface to the bottom and returned to the surface at a rate sufficient to allow filling of the bottle during the completion of one transit.

Twirl packs are small plastic bags with a tear-off top and bendable strip for sealing. The bag is opened by tearing off the top and spreading the bag using tabs on each side of the bag. For filling, the bag is positioned under the faucet or pipe or carefully lowered below the water surface if sampling from the mouth of a spring. The bag is closed by rolling the plastic over the bendable strip whose ends are folded over to complete the seal. This procedure ensures the sterile integrity of the bag during the sampling process.

Water samples for the GC/FID scans required the use of glass acid-rinsed bottles and the addition of a preservative to each sample bottle. Acid rinsed bottles were not rinsed prior to filling. The bottle was filled without allowing overflow to prevent flushing or dilution of the pretreatment. The added preservative was one milliliter of liquid mercuric chloride that served as a bactericide and was contained in a glass ampoule. The contents of the ampoule were emptied into the water in the bottle after the sample was collected. Once the preservative was added to the water sample, the cap was attached and the sample was agitated to ensure adequate mixing of the preservative. Samples for GC/FID scans were chilled as soon as the sample was collected. A chest of ice was used for storage and transportation of the sample to the laboratory.

Glass bottles used to sample for volatile organics were pretreated with sodium thiosulfate and equipped with teflon lined septum caps. Because air must not be trapped in the sample to be analyzed for volatile organic compounds, the bottle was filled so that the water mounded above the lip of the bottle. The teflon liner, with the convex side down, was placed on the bottle and the cap attached. The bottle was then inspected for air bubbles. If air bubbles were present, the cap and liner were removed and more water was added to the sample and the capping process was repeated. Water in the bottle was not discarded because the dilution of the sodium thiossulfate would have resulted in an improperly treated sample.

Quality Assurance

Quality assurance is a term used to describe the programs and procedures, including, but not limited to quality control procedures, which are necessary to assure data reliability. Because the interpretation and utilization of analytical data is affected by the data's reliability, results need to be comparable no matter when or where the analyses were made and what methods or specialized techniques were followed. For these reasons, quality assurance was a major component of the investigation in Meade County. A quality assurance program for field measurements, sampling, and reporting of analytical results was adopted. The following discussion is limited to a description of the procedures for sampling that were used to evaluate the quality and reliability of water-quality data from the different laboratories used during this investigation.

To identify the quality and reliability of water-quality analyses performed by different laboratories, a quality-assurance program consisting of duplicate and split sampling was used. Approximately 10 percent of all samples were collected for the quality assurance program. The GC/FID scans were excluded from the quality-assurance program because scans are used as a screening tool and the results are not quantitative.

Duplicate water samples were collected at selected sites and delivered to the same laboratory. The duplicate sample was given a fictitious name and identification number. Results were used to evaluate the validity of the analysis and the reproducibility of results from a particular laboratory. Duplicate sampling and analyses that were part of the quality-assurance program are shown in tables 5 and 6.

In addition to duplicate sampling, split sampling also was used. Split sampling differed from duplicate sampling in that water from a site was delivered to two different laboratories for the same analysis. The commercial laboratory of Watercheck Division, and the U.S. Geological Survey National laboratory in Arvada, Colorado were used for split sample analyses. Selected constituents were used for comparison. Constituents were selected on the basis of frequency of occurrence and importance with respect to drinking-water standards. Split-sample analyses are shown in table 5. Discrepancies between the Survey and private laboratories are attributable to differing degrees of sensitivity for various methods of detection.

Table 5.--Quality-assurance analyses

[Turbidity in nephelometric turbidity units; alkalinity and hardness as calcium carbonate; dissolved solids
selected constituents by USGS Water-

			INORGANICS AND TRACE ELEMENTS													
			Milligrams per liter									Micrograms per liter				
Site Number	Site type	Date and sample	Turbidity	Nitrate	Hardness	Alkalinity	Dissolved solids	Sodium	Chloride	Sulfate	Fluoride	Arsenic	Barium	Iron	Nickel	Silver
1	Well	6-14-87	0.2	<1	220	175	440	3	<10	32	3.9	<2	<30	80	<20	<2
		duplicate	.2	<1	240	175	450	3	<10	30	4	<2	<30	90	<20	<2
		1-11-88	.2	<1	270	170	240	4	<10	20	4.5	<2	<30	60	<20	<2
		duplicate	.2	<1	210	180	240	4	<10	<20	4.5	<2	<30	60	<20	<2
12	Well	2-22-88	.2	<1	320	210	330	3	<10	90	5	<2	<30	40	<20	<2
	*	split sample	--	--	340	221	374	3.1	1.7	93	2	--	49	21	<20	<2
15	Spring	4-20-87	.3	<1	330	220	600	<1	<10	<20	<.1	<2	<30	40	31	<2
	*	split sample	--	--	--	--	--	3.7	4.5	39	--	--	--	--	--	--
18	Spring	4-20-87	.2	<1	330	230	590	<1	<10	30	<.1	<2	<30	<20	<20	<2
	*	split sample	--	--	--	--	--	2.1	1.3	39	--	--	--	--	--	--
19	Well	2-22-88	.9	<1	300	280	390	2	<10	55	4.5	<2	<30	600	<20	<2
	*	split sample	--	--	380	206	410	2.5	.7	68	1.8	--	78	660	<20	<2
34	Well	4-20-87	.3	<1	282	240	530	<1	<10	<20	.2	<2	<30	64	29	<2
	*	split sample	--	--	--	--	--	2.4	2.2	20	--	--	--	--	--	--
37	Well	1-06-88	4.6	<1	190	250	270	2	<10	<20	1.2	<2	<30	230	<20	4
	*	split sample	--	--	280	247	265	2.3	.8	7	.7	--	79	94	<20	<2
38	Spring	3-16-87	5	<1	240	180	480	5	10	20	<.1	<2	<30	120	24	11
		duplicate	5	<1	240	180	480	5	10	20	<.1	<2	<30	120	24	11
		1-06-88	1.2	<1	240	220	270	4	20	<20	<.1	<2	<30	70	<20	<2
		duplicate	.7	<1	280	230	300	4	20	<20	<.1	<2	<30	70	<20	<2
	*	split sample	--	--	270	199	305	4.5	11	16	.2	--	43	18	<20	<2
39	Well	10-02-87	.4	<1	390	570	1,100	70	30	38	.6	<2	<30	80	<20	<2
		duplicate	.3	<1	380	560	1,100	72	30	39	.7	<2	<30	60	<20	3
49	Well	3-24-87	1.9	<1	280	280	600	12	<10	20	.8	<2	<30	140	<20	<2
		duplicate	.3	<1	300	280	620	8	<10	20	.8	<2	<30	<20	<20	<2

from selected springs and wells

as sodium chloride; analysis by Watercheck Division , National Testing Laboratories, Inc., except where noted; Quality Laboratory, Arvada, Colorado]

							ORGANICS								
							Micrograms per liter								
Zinc	Cadmium	Lead	Chromium	Copper	Manganese	Selenium	Toluene	Methylene chloride	Trichlorofluoromethane	1,2-Dichlorobenzene	1,4-Dichlorobenzene	Trichloroethylene	Styrene	Xylene	2-Nitrophenol
120	<2	27	<4	31	<4	<2	<.5	<5	<5	<.5	<.5	<2	<.5	<.5	<5
110	<2	25	<4	<4	<4	<2	<.5	<5	<5	<.5	<.5	<2	<.5	<.5	<5
110	3	<10	<4	4	<4	<2	<.5	<5	<5	<.5	<.5	<2	<.5	<.5	<5
120	<2	<10	<4	<4	<4	<2	<.5	<5	<5	<.5	<.5	<2	<.5	<.5	<5
170	<2	<10	<4	7	6	<2	<.5	<5	<5	<.5	<.5	<2	<.5	<.5	<5
180	<2	<10	<4	<4	1	--	--	--	--	--	--	--	--	--	--
8	5	37	<4	<4	<4	<2	<.5	<5	<5	<.5	<.5	<2	<.5	<.5	<5
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
20	<2	40	5	<4	40	29	<.5	<5	<5	<.5	<.5	<2	<.5	<.5	<5
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
240	3	<10	<4	12	50	<2	<.5	<5	<5	<.5	<.5	<2	<.5	<.5	<5
280	<2	<10	<4	<4	62	--	--	--	--	--	--	--	--	--	--
23	7	37	<4	11	10	<2	<.5	<5	<5	<.5	<.5	<2	<.5	<.5	<5
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
240	4	16	<4	18	6	<2	<.5	<5	<5	<.5	<.5	<2	<.5	<.5	<5
260	<2	<10	<4	<4	5	--	--	--	--	--	--	--	--	--	--
10	<2	50	<4	5	10	<2	<.5	<5	<5	<.5	<.5	<2	<.5	<.5	<5
10	<2	50	<4	5	10	<2	<.5	<5	<5	<.5	<.5	<2	<.5	<.5	<5
10	4	<10	<4	6	<4	<2	<.5	<5	<5	<.5	<.5	<2	<.5	<.5	<5
8	4	<10	<4	6	5	<2	<.5	<5	<5	<.5	<.5	<2	<.5	<.5	<5
19	<2	18	<4	<4	2	--	--	--	--	--	--	--	--	--	--
2	3	16	<4	8	10	<2	<.5	<5	<5	<.5	<.5	<2	<.5	<.5	<5
2	3	<10	<4	9	20	<2	<.5	<5	<5	<.5	<.5	<2	0.3	1.5	<5
320	<2	38	<4	5	6	<2	<.5	<5	<5	<.5	<.5	<2	<.5	<.5	<5
350	<2	22	<4	<4	40	<2	<.5	<5	<5	<.5	<.5	<2	<.5	<.5	<5

Table 6.--Quality-assurance analyses of bacteria from selected springs and wells

[Colonies per 100 milliliters; **, organisms too numerous to count; --, no analysis]

Site number	Site type	Date sampled	Total coliform	Fecal coliform	Fecal strepto-cocci
7	Spring	4-23-87	**	--	--
		duplicate	**	--	--
		10-08-87	**	3	7
		duplicate	**	3	5
10	Spring	4-23-87	**	68	71
		duplicate	**	53	38
12	Well	3-24-87	0	--	--
		duplicate	0	--	--
19	Well	6-14-87	0	--	--
		duplicate	0	--	--
21	Well	3-14-88	0	0	0
		duplicate	0	0	0
27	Well	11-19-87	**	0	0
		duplicate	0	0	0
30	Spring	3-23-87	**	0	4
		duplicate	**	0	0
36	Well	4-15-87	**	--	--
		duplicate	0	--	--
		11-19-87	**	0	0
		duplicate	**	0	0
38	Spring	3-16-87	**	113	59
		duplicate	**	--	--
		4-28-87	**	--	--
		duplicate	**	--	--
		1-06-88	**	--	--
		duplicate	**	--	--
46	Well	12-03-87	**	--	--
		duplicate	**	--	--
		1-25-88	0	--	--
		duplicate	0	--	--
49	Well	3-24-87	0	--	--
		duplicate	0	--	--

GROUND-WATER QUALITY IN MEADE COUNTY

Water Quality Criteria

Sites sampled during this investigation are sources of drinking water for county residents. Federal drinking-water standards and State domestic water supply criteria were chosen to evaluate the quality of ground water in Meade County.

Federal drinking-water standards, established by the U.S. Environmental Protection Agency, are used to determine the suitability of finished water for public consumption. These standards are subdivided into the Maximum Contaminant Level (MCL) and the Secondary Contaminant Level (SMCL). A MCL is an enforceable standard which can be set at a feasible limit (U.S. Environmental Protection Agency, 1986a). A SMCL represents a reasonable goal, and though it is not Federally enforceable, is intended as a guideline for states in setting safe drinking water standards for contaminants which generally affect the aesthetic quality of drinking water (U.S. Environmental Protection Agency, 1986b). When a constituent exists at a level much greater than the SMCL, health implications and aesthetic degradation may exist (U.S. Environmental Protection Agency, 1988). The Kentucky domestic water supply criteria have also been included for comparison purposes. This criteria must be met before a water source can be considered for use as a treatable domestic supply (Kentucky Natural Resources and Environmental Protection Cabinet, 1985). The current Federal drinking water standards (MCL and SMCL) and the Kentucky domestic water-supply criteria are listed in table 7.

The lowest measured concentration of a particular constituent is determined by its minimum detection limit (table 8). Detection limits denoted by "less than" symbols, reflect the inability of the analysis to generate a value for a given constituent. As an example, a <0.1 milligram per liter value for fluoride does not mean that flouride is absent from the sample. Rather, it should be read that if flouride is present it is at a concentration less than 0.1 milligrams per liter.

The quality of ground water in Meade County is influenced by natural and man-related factors. Natural influences include the quality of precipitation, the geologic source of water, and the length of time the water is in contact with the the surrounding rock. Many of man's activities also affect the quality of ground water such as the use of agricultural chemicals, salt on highways in winter, and disposal of storm-water runoff. The influence of both natural and man-related activities on ground-water quality can be determined by various measurements and analyses of physical, chemical, and bacteriological characteristics and constituents.

In general, the quality of ground water from carbonate rocks in Meade County is similar to the water from similar aquifers in other parts of Kentucky. For example, hardness ranged from 50 to 1,100 mg/L in the study area and from 60 to 600 mg/L in 1,128 samples from the same aquifers in the

Table 7.--Federal drinking water standards and Kentucky domestic water supply criteria

[Concentrations in milligrams per liter except where noted; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; DWS, domestic water supply criteria]

Water quality parameter	U.S. ENVIRONMENTAL PROTECTION AGENCY		KENTUCKY
	MCL	SMCL	DWS
INORGANICS AND TRACE ELEMENTS			
Arsenic	0.05	-	-
Barium	1	-	1
Cadmium	.01	-	-
Chloride	-	250	250
Chromium	.05	-	.05
Copper	-	1	1
Fluoride	4	2.0	1
Iron	-	0.3	-
Lead	.05	-	.05
Manganese	-	.05	.05
Mercury	.002	-	-
Nitrate	10		10
Selenium	.01	-	.01
Silver	.05	-	0.05
Sulfate	-	250	250
Zinc	-	5	-
Dissolved solids	-	500	750
pH (standard units)	-	6.5-8.5	-
ORGANICS			
Benzene	.005	-	-
Carbon tetrachloride	.005	-	-
2,4 D	.1	-	-
1,2-Dichlorobenzene	.075	-	-
1,2-Dichloroethane	.005	-	-
1,1-Dichloroethylene	.007	-	-
Endrin	.002		
Lindane	.004	-	-
Methoxychlor	.001	-	-
1,1,1-Trichloroethane	.2	-	-
Total trihalomethanes	.1	-	-
Toxaphene	.005	-	-
Trichloroethylene	.005	-	-
Silvex 2,4,5-TP	.01	-	-
Vinyl Chloride	.002	-	-
BACTERIA (colonies per 100 milliliters)			
Total coliform	1-4	-	-
Fecal coliform	-	-	2,000

Table 8.--Summary of selected ground water quality data from springs and wells

[Concentrations in micrograms per liter except where noted; temperature in degrees Celcius, specific conductance as microsiemens per centimeter at 25 degrees Celsius; values less than detection limit set equal to zero; na, no applicable standard; MCL, maximum contaminant level; SMCL; secondary maximum contaminant level; DWS, domestic water supply criteria]

Water-quality parameter	Number of observations	Number of detections	Minimum detection limit	Minimum detection	Maximum detection	Mean	Standard deviation	Median	Percentage of samples not meeting indicated standard or criteria		
									MCL	SMCL	DWS
PHYSICAL CHARACTERISTICS											
Water temperature	189	189	0	3	18	13.56	2.03	13.5		na	
Dissolved solids	86	86	20	100	2,200	550	310	512	0	52	13
Specific conductance	189	189	0	180	1,700	557.2	224.41	495		na	
Alkalinity (mg/L)	86	86	5	40	570	222	63	226		na	
pH (standard units)	182	182	0	6.31	9.24			7.6	0	4.2	0
Turbidity (NTU)	86	86	0.1	.1	16	1.7	2.94	.3		na	
INORGANICS AND TRACE ELEMENTS											
Major Anions and Cations											
Chloride (mg/L)	86	39	10	2	70	11	12	5	0	0	0
Fluoride (mg/L)	86	70	.1	.1	7	2.2	2	2	27	64	78
Sodium (mg/L)	86	80	1	1	70	6.5	11.6	4		na	
Sulfate (mg/L)	86	58	20	20	890	57.9	111	26	0	2.3	2.3
Hardness (mg/L)	86	86	20	50	1,100	319	156	290		na	
Nutrients											
Nitrate (mg/L)	86	7	1	1	5	.6	.7	.5	0	0	0
Metals and Trace Elements											
Arsenic	86	1	2	6	6	1	.5	1	0	0	0
Barium	86	0	30	0	30	15	0	15	0	0	0
Cadmium	86	24	2	3	12	2	2	1	1.2	0	0
Chromium	86	3	4	5	10	2.2	1	2	0	0	0
Copper	86	69	4	4	65	10.7	10.7	8	0	0	0
Iron	86	83	20	30	660	169	169	100	0	20	0
Lead	86	43	10	10	50	17	14.5	7.5	1.2	0	1.2
Manganese	86	68	4	4	200	16.9	29.1	7	0	10	10
Mercury	86	0	.2	0	.2	.1	0	.1	0	0	0
Nickel	86	13	20	20	63	13	8.9	10		na	
Selenium	86	1	2	29	29	1.3	3.0	1	1.2	0	1.2
Silver	86	6	2	4	11	1.4	1.3	1	0	0	0
Zinc	86	85	4	5	1,500	220	244	195	0	0	0
ORGANICS											
Trihalomethanes											
Chloroform	86	0	2	0	2	1	0	1		na	
Bromoform	86	0	4	0	4	2	0	2		na	
Bromodochorimethane	86	0	2	0	2	1	0	1		na	
Dibromochloromethane	86	0	4	0	4	2	0	2		na	
Total Trihalomethanes	86	0	2	0	2	1	0	1	0	0	0
Volatiles											
Carbon tetrachloride	86	0	5	0	5	2.5	0	2.5	0	0	0
1,2-Dichloroethane	86	0	2	0	2	1	0	1	0	0	0
Toluene	86	1	.5	1.5	1.5	.3	1.4	.3		na	
Benzene	86	0	.5	0	.5	.3	0	.3	0	0	0
Chlorobenzene	86	0	.5	0	.5	.3	0	.3		na	
Chloroethane	86	0	2	0	2	1	0	1		na	
Ethylbenzene	86	0	.5	0	.5	.3	0	.3		na	
Methylene Chloride	86	1	5	5.5	5.5	.3	.6	.3		na	
Tetrachloroethylene	86	0	4	0	4	2	0	2		na	
Dichlorofluoromethane	86	0	5	0	5	2.5	0	2.5		na	
Trichlorofluoromethane	86	1	5	4.6	4.6	2.5	.3	2.5		na	
1,1-Dichloroethane	86	0	2	0	2	1	0	1		na	
1,1-Dichloroethylene	86	0	2	0	2	1	0	1	0	0	0
1,1,1-Trichloroethane	86	0	5	0	5	2.5	0	2.5	0	0	0
1,1,2-Trichloroethane	86	0	2	0	2	1	0	1		na	
1,1,2,2-Tetrachloroethane	86	0	2	0	2	1	0	1		na	

Table 8.--Summary of selected ground water quality data from springs and wells--Continued

[Concentrations in micrograms per liter except where noted; temperature in degrees Celcius, specific conductance as microsiemens per centimeter at 25 degrees Celsius; values less than detection limit set equal to zero; na, no applicable standard; MCL, maximum contaminant level; SMCL; secondary maximum contaminant level; DWS, domestic water supply criteria]

Water-quality parameter	Number of observations	Number of detections	Minimum detection limit	Minimum detection	Maximum detection	Mean	Standard deviation	Median	Percentage of samples not meeting indicated standard or criteria		
									MCL	SMCL	DWS
ORGANICS--Continued											
Volatiles--Continued											
1,2-Dichlorobenzene	86	1	.5	.5	.5	.3	.03	.3	0	0	0
1,2-Dichloropropane	86	0	2	0	2	1	0	1		na	
Trans-1,2-Dichloroethylene	86	0	2	0	2	1	0	1		na	
1,3-Dichlorobenzene	86	0	.5	0	.5	.3	0	.3		na	
1,4-Dichlorobenzene	86	1	.5	1	1	.3	.08	.3		na	
Chlorethyvinylether	86	0	3	0	3	1.5	0	1.5		na	
Vinyl chloride	86	0	1	0	1	.5	0	.5	0	0	0
Trichloroethylene	86	1	2	2.8	2.8	1	.2	1	0	0	0
Styrene	86	2	.5	.3	9.9	.4	1.04	.3		na	
Xylene	86	2	.5	1.5	12.9	.6	1.8	.3		na	
Dibromochloropropane	86	0	5	0	5	2.5	0	2.5		na	
PCB and Chlorinated Pesticides											
Hexachlorobenzene	86	0	5	0	5	2.5	0	2.5		na	
Lindane	86	0	4	0	4	2	0	2	0	0	0
Chlordane	86	0	20	0	20	10	0	10		na	
Endrin	86	0	.1	0	.1	.05	0	.05		na	
Toxaphene	86	0	5	0	5	2.5	0	2.5	0	0	0
Heptachlor	86	0	2	0	2	1	0	1		na	
Methoxychlor	86	0	50	0	50	25	0	25	0	0	0
PCB	86	0	4	0	4	2	0	2		na	
Phenols											
Phenol	86	0	5	0	5	2.5	0	2.5		na	
2-Chlorophenol	86	0	5	0	5	2.5	0	2.5		na	
2-Nitrophenol	86	1	6	30.1	30.1	3.3	2.9	3		na	
2,4-Dichlorophenol	86	0	6	0	6	3	0	3		na	
2,4-Dimethylphenol	86	0	8	0	8	4	0	4		na	
2,4-Dinitrophenol	86	0	50	0	50	25	0	25		na	
2,4,6-Trichlorophenol	86	0	8	0	8	4	0	4		na	
4-Nitrophenol	86	0	30	0	30	15	0	15		na	
Pentachlorophenol	86	0	80	0	80	40	0	40		na	
Chlorphenoxy Herbicides											
2,4-D	86	0	1	0	1	.5	0	.5		na	
Silvex 2,4,5-TP	86	0	.5	0	.5	.3	0	.3	0	0	0
BACTERIA (colonies per 100 milliliters)											
Total coliform	178	178	0	0	too numerous to count				61	0	0
Fecal coliform	89	89	0	0	730	19.48	99.83		30	0	0
Fecal strep.	89	89	0	0	730	23.75	99.07			na	

Mississippian Plateau Region of the state. The dissolved solids ranged from 100 to 2,200 mg/L in the study area and 150 to 1,100 mg/L in 906 samples from similar carbonate rocks in the state (Moody and others, 1988, p. 266).

The source and significance of each constituent or characteristic that was measured during this investigation is briefly discussed in the following text. Where applicable seasonal relationships have been noted. In addition, selected references are included that provide more detailed information on each topic.

Physical Properties

Dissolved Solids

One of the most frequently measured (and cited) characteristics of ground-water quality is dissolved solids (residue at 180°C). Dissolved solids consist of inorganic salts and small amounts of organic matter. Equivalent terminology is "filterable residue." These dissolved constituents can be either positively charged (cations) or negatively charged (anions). The principal cations are sodium, potassium, calcium, and magnesium; principal anions include the carbonates, chlorides, sulfates, and nitrates.

The dissolved solids content of potable drinking water usually ranges from 20 to 1,000 mg/L (U.S. Environmental Protection Agency, 1976, p. 205). Excess dissolved solids are objectionable in drinking water because of possible physiological effects, unpalatable mineral taste, and higher costs due to corrosion or the necessity for additional treatment. The physiological effects directly associated with high concentrations of dissolved solids include laxative effects, principally from sodium sulfate and magnesium sulfate, and the adverse effects of sodium on certain patients with cardiac disease and women with toxemia due to pregnancy (U.S. Environmental Protection Agency, 1976, p. 205).

Kentucky has established 750 mg/L as the criteria for dissolved solids concentrations in a treatable domestic water supply. The range of dissolved solids concentrations for samples collected was from 100 to 2,200 mg/L. The median value for dissolved solids for 86 samples was 512 mg/L. The concentrations of dissolved solids ranged from 240 to 2,200 mg/L in water from wells and 100 to 1,030 mg/L in water from springs. The higher concentration of dissolved solids in water from wells could be because of the longer contact time between the water and the geologic materials in the aquifer.

The dissolved solids content is not constant but fluctuates with seasonal hydrologic conditions. Repeat samples from the same well at sites 1, 12, 19, 37, 46, and 49 (see table 2) were generally lower in dissolved solids content during wet weather when more water was recharging the ground-water system. The lower dissolved solids content during periods of recharge was probably due to the dilution effect of recharge to the ground-water system and the shorter residence time of the water (and thus contact-time with rocks) necessary for the dissolution of various constituents.

Review of the spatial distribution of values of dissolved solids content did not show any discernable pattern across Meade County.

Specific Conductance

Specific conductance is a measure of the ability of water to conduct an electric current which is related to the quantity and types of ionized substances in water. Therefore, specific conductance can be used as an indicator of dissolved solids which is a general measure of water quality. The larger the specific conductance value, the larger the concentration of dissolved solids. Values for dissolved solids are generally related to specific conductance by a factor of 0.6. However, this factor ranged from 0.45 to 1.44 in Meade County.

Specific conductance is a simple and relatively inexpensive method of monitoring water quality. As with dissolved solids, the values for specific conductance were higher in water from wells than from springs and vary with seasonal hydrologic conditions (see table 4). There was no pattern to the spatial distribution of values for specific conductance which ranged from 180 to 1,700 μS/cm. The median value for specific conductance was 495 μS/cm. As with all values listed in table 4, the values of specific conductance provide a base level for measuring future quality changes in water from spring and wells in the study area.

Turbidity

Turbidity is the measurement of the interference of light passage through water due to insoluble particles which may scatter or absorb rays. One nephelometric turbidity unit (NTU) is equivalent to the interference effect of a suspension of 1 mg of silica, of specified particle size, in one liter of water (Viessman and Hammer, 1985).

Turbidity may be caused by a variety of suspended materials ranging in size from colloidal to coarse dispersions. In rivers and streams, turbidity is due to the overland transport of unconsolidated material that is carried into the streams by surface runoff. Turbidity may also be caused by plantonic organisms, dust, and waste-water discharge (Krenkel and Novotny, 1980). In typical karst terrane, such as underlies much of Meade County, turbidity in water from springs or wells is generally caused by unconsolidated material that has entered the ground-water system from the land surface.

High turbidity is undesirable not only for aesthetic reasons, but in some instances, turbidity can actually reduce the effectiveness of water purification techniques by protecting micro-organisms (Krenkel and Novotny, 1980). Although turbidity in ground water is generally most noticeable following heavy rains, an occurrence of muddy water from a pumped well during a relatively dry period has been documented (Mull and Lyverse, 1984, p.48). In this case, heavy pumping of a well used for public supply for the city of Elizabethtown had caused lower water levels and turbulence which dislodged sediment in the ground-water flow system and resulted in turbid discharges from the well. The same effect can be seen in domestic water-supply wells, especially when water levels are lowered to the vicinity of the pump intake during periods of relatively high water use.

For 86 water samples checked during this investigation, turbidity ranged from 0.1 to 16 NTU and the median value was 0.3 NTU. In general, the higher values were for samples collected after periods of heavy rains and probably indicate rapid recharge of karst aquifers by surface runoff into sinkholes and other openings. Some of the highest levels of turbidity were recorded following intense summer rains in June 1987. One of the highest turbidity values was 12 NTU in water from a spring (site 44) sampled June 14, 1987.

pH, Alkalinity and Acidity

The measure of hydrogen-ion activity in an aqueous solution is expressed as pH. A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote an alkaline (basic) condition; values lower than 7.0 indicate an acidic condition. Most ground waters in the United States have pH values ranging from about 6.0 to 8.5, but water having lower pH is not uncommon in thermal springs or in areas affected by acid mine drainage.

Because degasification (such as loss of carbon dioxide), precipitation (such as calcium carbonate), and other chemical and physical reactions may cause the pH of a water sample to change significantly within several hours or even minutes after a water sample is collected, a field measurement of pH is required for valid results. Values of field determinations of pH are included in table 4 and summarized in table 8. The values of pH ranged from 6.31 to 9.24 in 182 determinations. The median value of pH was 7.6. The SMCL range of 6.5 to 8.5 pH units has been established by the U.S. Environmental Protection Agency (1986b). For the 182 samples taken, this pH standard was exceeded in 4.2 percent of the samples.

Alkalinity is the measure of the change in the pH of a water sample when a strong acid is added. Alkalinity represents the total constituents in water that tend to elevate the pH above a value of 4.5 and is commonly expressed as milligrams per liter of calcium carbonate. Alkalinity is a measure of the buffering capacity of the water, and because pH has a direct effect on organisms and the toxicity of certain pollutants in the water, the buffering capacity is important to water quality (U.S. Environmental Protection Agency, 1986c).

The principal solutes that contribute to alkalinity are dissolved from rocks during the passage of water. In most ground water, alkalinity is produced by the dissolved carbon dioxide species, bicarbonate, and carbonate. The principal source of carbon dioxide species is the carbon dioxide gas fraction of the atmosphere, or the atmospheric gases present in the soil and residuum between the land surface and the water table (Hem, 1985, p. 108).

Problems caused by excess alkalinity are generally related to industrial or agricultural use. Usually alkalinity must exceed 600 mg/L before it causes problems in water used for irrigation. Excess alkalinity can cause problems for swimmers by altering the pH of the lacrimal fluid around the eye, causing irritation. Alkalinity resulting from naturally occurring materials is not considered a health hazard in drinking water supplies. Maximum levels up to approximtely 400 mg/L as calcium carbonate are not considered a problem to human health (U.S. Environmental Protection Agency, 1986c). Alkalinity in 86 samples ranged from 40 to 570 mg/L, and the mean and median values were 222 and 226 mg/L, respectively. These values are fairly typical of ground water from sedimentary rocks containing a high ratio of carbonates as in the study area.

Major Anions and Cations

Chloride

Chloride is usually present in all natural waters. The major source of chloride in ground water in Meade County are sedimentary rocks, particularly the evaporites. High levels of chloride are usually due to industrial waste, sewage effluent, leaching of soils by irrigation, and by brines related to oil production. Water with naturally occurring high chloride content generally occurs at depths greater than reached by domestic wells throughout Meade County. The fresh-saline water interface map of Kentucky (Hopkins, 1966) shows the presence of high chloride (saline) water at altitudes ranging from about 250 feet to 450 feet above sea level for Meade County. Most wells in the county tap aquifers ranging from 200 to 600 feet above sea level.

At concentrations greater than 250 mg/L, chlorides can be detected by taste, which is objectionable to many people. In high concentrations, chloride may increase the corrosion of water-utility equipment and household plumbing fixtures. The SMCL for chloride is 250 mg/L although water sources containing as much as 2,000 mg/L of chloride are used for domestic purposes in some area of the country without the development of adverse effects (Sawyer and McCarty, 1978, p.401).

Based on the analyses of 86 samples collected during this investigation, chloride content is not a problem in ground water from Meade County. Chloride concentrations were less than 70 mg/L in all samples and were less than the detection limit of 10 mg/L in many samples. The median value was 5 mg/L. The two highest concentrations of chloride, 60 and 70 mg/L, were detected in water from springs at sites 30 and 41, respectively. Water from only one well (site 14) contained chloride in concentrations as high as 50 mg/L. This suggests that the springs may receive water with elevated levels of chloride from a relatively shallow source rather than from the deeper aquifers that supply water to the wells.

Fluoride

The mineral fluorite, which has a rather low solubility and occurs in both igneous and sedimentary rocks, is a common source of fluoride. Mineral particles that contain fluoride are common and widespread constituents of sedimentary rocks.

Concentrations of fluoride in ground water are usually less than 1.0 mg/L. However, ground water containing fluoride concentrations exceeding 1.0 mg/L occurs in many places in the United States, in a wide variety of geologic terranes (Hem, 1985, p. 120).

Fluoride has potential beneficial effects in the structure of bones and teeth, but excessive fluoride in drinking water produces objectionable dental fluorosis. This is the most common harmful effect caused by the excessive intake of fluoride (U.S. Environmental Protection Agency, 1972, p. 66). The MCL for fluoride of 4.0 mg/L was exceeded in 27 percent of the samples taken during this study. Samples with fluoride concentrations greater than the limit of detection ranged from 0.1 to 7 mg/L, and the median value was 2.0 mg/L. The Kentucky domestic water supply criteria of 1.0 mg/L of fluoride was exceeded in 78 percent of the samples.

The elevated concentrations of fluoride in Meade County are generally consistent with the findings of Sprinkle and others (1983, p. 25). They reported that the fluoride content, in 1,698 ground-water samples throughout Kentucky from rocks similar to those underlying Meade County, ranged from 0.0 to 7.4 mg/L. However, the median value of fluoride in those samples was only 0.2 mg/L. In the absence of a known source of fluoride contamination, the elevated levels of fluoride are assumed to be indicative of the natural mineral content of the rocks underlying Meade county.

Sodium

Sodium is a common constituent in the environment and is abundant in both igneous and sedimentary rocks. In sediments, sodium may occur as unaltered mineral grains, as a component of cementing materials, or as crystals of readily soluble sodium salts deposited with the sediments or left by saline water that entered at some time after deposition (Hem, 1985, p. 100). Sodium salts are highly soluble, and their concentrations in natural waters show considerable variation, regionally and locally. In addition to natural sources of sodium salts, anthropogenic sources are sewage, industrial effluents, and deicing compounds. The reuse of water for irrigation commonly leaves a residual that is much higher in sodium concentration than was the original water. Removal of sodium is costly and is not common in public water supply treatment.

Sodium intake may be restricted by physicians for persons suffering from hypertension, edema associated with congestive cardiac failure, renal disease, cirrhosis of the liver, and women with toxemias of pregnancy. Diets for these individuals permit 20 mg/L sodium in drinking water and water used for cooking (Environmental Protection Agency, 1972, p. 88). The sodium intake from sources other than water recommended for very restricted diets is 500 mg/day.

The MCL for sodium has not been established. The U.S Environmental Protection Agency believes that the available data do not support any particular level for sodium in drinking water and that the potential problems related to intake of sodium in drinking water vary greatly from person to person (Environmental Protection Agency, 1976b, p. 124). Sodium concentrations ranged from less than 1 to 70 mg/L in the study area. The median value was 4 mg/L which was similar to the median value (5 mg/L) reported by Sprinkle and others (1983, p.24) for similar rocks in the Mississippian Plateau region of Kentucky. The highest concentrations of sodium, 54, 65, 70 mg/L were detected in water from wells 13 and 39 and spring 30, respectively.

Sulfate

Sulfate occurs in certain igneous rock minerals, but the most extensive occurrences are in evaporite sediments. Gypsum (calcium sulfate) makes up a considerable amount of many evaporite sequences and occurs in the lower part of the St. Louis Limestone and the upper part of Salem Limestone as scattered nodules or thin beds interbedded with limestone and anhydrites (McGrain, 1964). Locally, high concentrations of sulfate in ground water may reflect the abundance of gypsum and anhydrites. Another source of sulfate is the oxidation of pyrite, an iron sulfide, which is a common mineral in the thin shale beds that occur in the study area. The weathering of iron sulfide yields sulfate ions that are readily soluble in the water. High sulfate concentrations can also be attributed to industrial and waste disposal processes and to the combustion of high-sulfur coal.

The presence of sulfate ion in drinking water can result in a cathartic effect. Both sodium sulfate and magnesium sulfate are well-known laxatives. Peterson (1951) determined that waters containing more than 750 mg/L of sulfate showed a laxative effect and those with less than 600 mg/L generally did not. The laxative effect was commonly noted by newcomers or casual users of water high in sulfates.

Sulfate was detected in 58 samples in concentrations ranging from 20 to 890 mg/L. The SMCL for sulfate, 250 mg/L, was exceeded in 2.3 percent of the 86 samples. The median concentration of sulfate was 26 mg/L. However, based on the values for the mean and the standard deviation, 57.9 and 111 mg/L respectively, relatively high values of sulfate are present in ground water in Meade County.

Water Hardness

Hardness is an evaluation of certain chemical properties of water based on its observed ability to form insoluble compounds with soap. Because most of the observed effects with soap are due to the presence of calcium and/or magnesium, hardness is generally defined in terms of these two constituents but the term hardness may also include other divalent cations (Hem, 1985, p. 158).

Because the property of hardness can not be attributed to a single cation, some convention has to be used to express concentrations in quantitative terms. This is usually accomplished by reporting hardness as an equivalent concentration of calcium carbonate, sometimes called "total hardness". When hardness exceeds the alkalinity the excess is termed "noncarbonate hardness" (Hem, 1985, p. 159).

The following classification system for hardness has been suggested by Dufor and Becker (1964, p.27):

Hardness range (in mg/L of calcium carbonate)	
0-60	Soft
61-120	Moderately hard
121-180	Hard
>180	Very hard

For domestic use, hardness in water is usually not objectionable until it exceeds the 100 mg/L level. However, hardness often greatly exceeds this level in areas where water comes in contact with limestone, especially in the case of gypsiferous formations (Hem, 1985, p. 159). This may be the case in the study area. Values for hardness in 86 samples ranged from 50 to 1,100 mg/L. The median value for hardness was 290 mg/L which suggests that there is a high probability of getting hard or very hard water from any well tapping bedrock in Meade County. Water from wells is more likely to be hard or very hard than water from springs because of the longer contact time between water and the rock materials and the frequent occurrence of gypsiferous minerals in the deeper part of the aquifers.

Nitrate

Natural sources of nitrogenous substances include precipitation, dustfall, nonurban runoff, biological fixation, and mineralization of organic matter in soil. Human sources of nitrogenous substances include runoff from urban areas and livestock feedlots, effluent from municipal wastewater and septic tank leach fields, discharges from automobile exhausts and other combustion processes, drainage from fertilized agricultural lands, and industrial wastewaters.

Nitrogen becomes part of biological matter through the bacteria and algae that can fix atmospheric nitrogen into organic compounds and nitrates. Nitrogen-fixing plants known as legumes, such as clover, alfalfa, soy beans, and locust trees, form root nodules where nitrogen-fixing bacteria live. Overall, two gases (molecular nitrogen and nitrous oxide) and five forms of nongaseous, combined nitrogen (amino and amide groups, ammonium, nitrite, and nitrate) are important in the nitrogen cycle. The amino and amide groups are in soil organic matter and are constituents of plant and animal protein. The ammonium ion is either released from proteinaceous organic matter or urea, or is synthesized in industrial processes involving atmospheric nitrogen fixation. The nitrite ion is formed from the nitrate or the ammonium ions by certain nitrogen fixing bacteria, in soil, water, sewage, and the digestive tract. The nitrate ion is formed by the complete oxidation of ammonium ions by soil or water microorganisms, and nitrite is an intermediate product of this nitrification process (Environmental Protection Agency, 1976a, p. 107).

Intake of nitrates constitutes a hazard to warm-blooded animals when conditions are favorable for reduction to nitrite. In the gastrointestinal tract, nitrate can be reduced to nitrite which then reaches the bloodstream and reacts directly with hemoglobin to impair oxygen transport (Environmental Protection Agency, 1976). The reaction of nitrite with hemoglobin can be hazardous in infants under 3 months of age. Serious and occasionally fatal poisonings in infants have occurred following ingestion of untreated well waters containing nitrate concentrations in excess of 10 mg/L (Environmental Protection Agency, 1986c).

In the study area, nitrate occurred in excess of the detection level of 1 mg/L in only 7 samples. Values ranged from 1 to 5 mg/L and in no instance was the MCL level of 10 mg/L exceeded. These few occurrences of nitrate are probably related to agricultural activities.

Trace Elements

Concentrations of a variety of constituents occur naturally in ground waters in trace amounts only. Certain trace elements such as arsenic, cadmium, lead, mercury, and selenium can be highly toxic to humans and other biota. However, low concentrations of some trace elements, such as copper and zinc, are beneficial and may be essential to life. Some trace elements, such as iron and manganese, can cause problems such as the buildup of scale deposits and staining of laundry or plumbing fixtures.

Trace elements enter natural water systems by normal weathering of minerals, but significant localized inputs may result from man's activities. When the rate of input of trace elements or related compounds into a water system exceeds the natural rate of cycling, contamination or adverse ecological effects may result. Urban runoff commonly contains significant concentrations of lead, zinc, and copper from automotive exhaust. Other man-induced sources of significant ground-water contamination by trace elements includes domestic waste waters, industrial plating wastes, paints, biocides, and fertilizers.

Trace elements in natural waters are predominantly associated with particles suspended in the water. The amounts of trace elements in solution in natural waters usually make up only a minor percentage of all the heavy metals in samples, except in the case of water with low pH.

Many trace elements, such as cadmium, copper, lead, and mercury, can be toxic to aquatic organisms when present in critical concentrations. These constituents are non-biodegradable and persist in the environment for extended periods of time. Thus, the concentration of trace elements may be magnified in the food chain.

Concern about the contamination of water by trace elements has increased during the last several years because of the increased knowledge about trace elements as a health factor. Therefore, analyses for selected trace elements were included in the analysis performed during this investigation (see table 2).

Arsenic

Arsenic occurs in nature mostly as arsenides or pyrites, but it occurs in elemental form in places. Arsenic is used in the manufacture of glass, pigments, textiles, paper, metal adhesives, ceramics, linoleum, and mirrors. Because of its poisonous action on various destructive organisms, it has been used in paints, wood preservatives, insecticides, and herbicides.

Arsenic is used as a component of agricultural chemicals, and can enter surface streams and ground water through improper waste disposal and agricultural drainage. An important factor in the natural circulation of arsenic, however, is the volatility of the element and some of its compounds.

Inorganic arsenic is absorbed readily through the gastrointestinal tract, the lungs, and to a lesser extent through the skin. It is then distributed throughout the body tissues and fluids. After cessation of continuous exposure, arsenic may be retained in the body for as long as 70 days. Concentrations as high as 1.0 mg/L of arsenic have been reported in water used for drinking, and for short periods of time have produced no apparent ill effects. However, long-term exposure to a concentration of 0.2 mg/L has been reported to be poisonous (McKee and Wolf, 1963, p. 140).

Because small amounts of arsenic can be toxic to humans, it is considered a highly undesirable impurity in drinking-water supplies. The MCL level for arsenic is 50 μg/L. Arsenic, in excess of the minimum detectable limit of 2 μg/L, was detected in only one sample (6 μg/L) from site 46, a well.

Barium

Barium is an alkaline earth metal which occurs in igneous and carbonate rocks. The mineral form of barium, barite, is fairly common in sedimentary rocks. Concentrations in many treated drinking waters and most natural waters is low. Barite is used in the production of pigments, textiles, rubbers, plastics, and in X-ray photography.

The human digestive system is extremely permeable to barium and allows rapid transfer to and from the blood stream. When ingested, barium is highly toxic with acute poisoning exerting a strong and prolonged stimulant action on cardiac, gastrointestinal, and bladder muscles. The MCL for barium is 1.0 mg/L. Barium concentrations in excess of the minimum detection level of 30 μg/L were not detected during this investigation.

Cadmium

Cadmium is rare in natural occurrence and is usually associated with zinc ores that occur in various sedimentary rocks. Cadmium is used in the manufacture of paints, alloys, and pesticides. It also is used extensively in the production of polyvinyl-chloride (PVC) materials, electrical batteries, and fluorescent and video tubes. Many of these uses tend to make cadmium available to ground water that comes in contact with buried wastes containing those products (Hem, 1985, p. 142).

The natural occurrence of cadmium in water in more than minute amounts is almost unknown. In the past, cadmium in detectable levels was usually the result of contamination from mining or industrial wastes. Most cadmium related contamination of ground water in the United States is due to discharge from electroplating plants and the breakdown of cadmium-containing products in landfills (Environmental Protection Agency, 1976b, p. 59).

According to ReVelle and ReVelle (1984, p. 221), the main effect of cadmium in the body appears as kidney disease and possibly, high blood pressure. Once in the body, cadmium can reside from 10 to 30 years before one-half the absorbed amount is lost.

The MCL for cadmium is 10 μg/L. Cadmium was detected in 24 samples during this investigation, but the MCL was exceeded in only one sample. This was from site 14 and the concentration was 12 μg/L. The median value for cadmium was 1.0 μg/L.

Chromium

Chromium is an amphoteric element existing in water in several different valence states. Natural waters contain only trace amounts of chromium because it is relatively insoluble. Chromium is used in metal plating, leather tanning, paints, dyes, explosives, ceramics, and photography. Industrial uses of chromium produces waste solutions containing chromate ions.

Concentrations of chromium in natural waters not affected by waste disposal are commonly less than 10 μg/L (Hem, 1985, p. 138). The median value for chromium in the public-water supplies for the 100 largest cities in the United States was 0.43 μg/L (Durfor and Becker, 1964, p. 78).

Acute systematic poisoning can result from high exposure to hexavalent chromium. The chronic health effects are respiratory and dermatologic. Chromium, in certain forms, is also known to be carcinogenic. The MCL for chromium is 50 μg/L. Chromium was detected at sites 17, 18, and 35, but the concentrations did not exceed 10 μg/L.

Copper

Copper occurs as a native metal and in various mineral forms such as oxides (cuprite), carbonates (malachite), and sulfides (chalcocite). Copper is essential for plants because it performs vital functions in many enzymes, and plays a major role in the synthesis of chlorophyll. It is also essential for animal metabolism because it is used for the production of hemoglobin (Environmental Protection Agency, 1976a, p. 54). Man has utilized copper since prehistoric times, and many of modern uses result in its dispersal in the environment

The consumption of water with elevated concentrations of copper is not known to have an adverse effect on humans. Prolonged oral administration of excessive amounts may result in liver damage, but water supplies seldom have sufficient copper to cause such damages (Environmental Protection Agency, 1976a, p.54). Dufor and Becker (1964) reported a median value of 8.3 μg/L for copper in treated water from the 100 largest public water-supply systems in the United States.

Sufficient data are not available for copper to establish a level which would protect against the potential toxicity of this element. Using available organoleptic data, for controlling undesirable taste and odor quality of ambient water, the estimated level is 1 mg/L (U.S. Environmental Protection Agency, 1986c). The SMCL for copper is 1.0 mg/L. Copper was detected in 69 samples ranging from less than 4 to 65 μg/L and the median concentration was 8 μg/L.

Iron

As the fourth most abundant mineral, by weight, in the earth's crust, iron is common in many rocks and soils. Iron exists in soils and minerals mainly as insoluble ferric oxide and iron sulfide (pyrite). For practical purposes, the ferric form of iron is insoluble. Iron also occurs as ferrous carbonate (siderite) which is slightly soluble. Under reducing (anaerobic) conditions, the ferric iron is reduced to ferrous iron, and solution occurs, thus increasing the iron content of ground water. Iron may be present in natural waters in various quantities, depending on the geology of the area and other chemical components of the water. A detailed discussion of the chemistry of the occurrence of iron in natural waters is presented by Hem (1985, p. 76-84).

Iron is a necessary trace element required by both plants and animals. For humans it is vital for the transportation of oxygen in the blood. Iron is an objectionable constituent in water supplies, for either domestic or industrial use. Iron content in excess of 0.3 mg/L usually causes problems of taste and staining of plumbing fixtures and it has potential toxic effects at exceedingly high concentrations. However, these concentrations rarely occur in natural waters (U.S. Environmental Protection Agency, 1976).

The SMCL for iron is 0.3 mg/L. The minimum detectable level for iron, 0.02 mg/L, was exceeded in 83 samples and ranged from 0.021 to 0.66 mg/L. The median and the mean concentrations for iron were 0.100 and 0.169 mg/L, respectively. Although some samples contained concentrations of iron in excess of the SMCL, owners did not report problems that are typically related to iron in their water.

Lead

Lead is common in sedimentary rocks, mainly as lead sulfide (galena), but also as lead carbonate (cerussite), lead sulfate (anglesite), and lead chlorophosphate (pyromorphite). Owing to its low solubility, the natural mobility of lead is low. In addition to its natural occurrence, lead and its compounds may enter natural water systems during mining, smelting, processing, and use. In particular, the combustion of leaded gasolines has caused widespread dispersion of lead throughout the environment (Hem, 1985, p. 143).

Nutritionally, lead has no known beneficial or desirable effects but tends to accumulate in the tissues of man and other animals. Like other trace elements, the toxicity of lead is greatly affected by variations in pH, hardness, organic materials, and the presence of other metals (U.S. Environmental Protection Agency, 1976a, p. 82).

The U.S. Environmental Protection Agency MCL for lead of 50 μg/L was met in one of 86 samples. However, lead concentrations exceeded the minimum detection level, 10 μg/L, in 43 samples and ranged from 10 to 50 μg/L. The median value was 7.5 μg/L. The elevated values of lead in some samples (sites 12, 14, 17, 30, and 38) suggest the need to determine the source of the lead. A potential anthropogenic source of lead in domestic water supplies is the solder used in water distribution lines.

Manganese

Manganese does not occur naturally as a metal but is seen in various salts and minerals, frequently in association with iron compounds. Small amounts commonly occur in dolomite and limestone, substituting for calcium. Black deposits of manganese oxides occur as nodules and coatings of stream gravels, especially in springs issuing from caves in the study area. Ground water may contain more than 1.0 mg/L of manganese, usually in association with high iron concentrations in acid mine drainage (Hem, 1985, p 89).

Although manganese is an essential element for both plant and animal life forms, it is an undesirable impurity in water supplies, mainly owing to deposition of black oxide stains. Manganese concentrations exceeded the detection limit of 4 μg/L in 68 samples and concentrations ranged from 4 to 200 μg/L. The median concentration of manganese was 7 μg/L. The SMCL for manganese is 50 μg/L which was exceeded in about 10 percent of the samples.

Mercury

There are several forms of mercury, ranging from elemental to dissolved inorganic and organic species, that occur in the environment. However, the naturally occurring forms of mercury are not expected in the rocks underlying Meade County. As a result of agricultural and industrial applications, mercury is distributed throughout the environment. Mercury enters natural waters in many ways, such as discharge from chlorine-caustic soda plants and pulp mills. It is used in electrical devices, thermometers, fungicides, dental fillings, drugs, and paints (ReVelle and ReVelle, 1984).

Certain microorganisms have the ability to convert inorganic and organic forms of mercury to the highly toxic methyl or dimethyl mercury. This fact has made any form of mercury potentially hazardous to the environment.

Chronic mercury poisoning results from exposure to small amounts of mercury over extended periods of time. Poisonings are generally not caused by direct ingestion of contaminated water but by eating mercury-contaminated fish and shellfish which, through biological magnification, may concentrate mercury to levels that are toxic to humans (ReVelle and ReVelle, 1984).

The MCL for mercury is 2 μg/L. In 86 water samples, mercury was not detected in excess of the minimum detection level of 0.2 μg/L.

Nickel

Nickel is a silver-white metallic element which does not occur naturally in elemental form, but is present as a constituent in various ores, minerals, and soils. Nickel is comparatively inert and is used in corrosion-resistant materials, long-lived batteries, and many electrical items such as contacts, spark plugs, and electrodes.

In general, high levels of nickel in natural fresh waters are from the natural abundance of nickel and from man-made products (Hem, 1985, p. 139). Nickel may enter waters from mine wastes, electroplating plants, and from atmospheric emissions. Nickel is considered to be relatively nontoxic to man. The toxicity to aquatic life indicates tolerances that vary widely and are influenced by species, pH, and synergistic effects (U.S. Environmental Protection Agency, 1976a, p. 105).

Drinking-water standards for nickel are not defined. However, the criterion for nickel ingested through water and contaminated aquatic organisms is 13.4 μg/L (U.S. Environmental Protection Agency, 1986c). Nickel was present in concentrations higher than the minimum detection level of 20 μg/L in 13 samples and ranged from 20 to 63 μg/L. The median value of nickel was 10 μg/L.

Selenium

Selenium is a relatively rare element, and it occurs naturally in soils derived from sedimentary rocks. It is metallic gray in crystalline form, and is obtained primarily as a byproduct of electrolytic copper refining. It is used in rectifiers, as a semiconductor, and in xerography (U.S. Environmental Protection Agency, 1986c). Selenium reaches the environment chiefly from the fly ash discharged by coal-fired power plants. Much of this selenium is in the smallest fly ash particles, which often elude capture by electrostatic precipitators (ReVelle and ReVelle, 1984).

Selenium has been regarded as one of the more dangerous chemicals reaching the aquatic environment by the U.S. Environmental Protection Agency. Biologically it is an essential element recognized as a metabolic requirement in trace amounts for animals but toxic to them when ingested in amounts ranging from about 0.1 to 10 mg/kg of food (U.S. Environmental Protection Agency, 1986c). Selenium entering streams from seleniferous irrigated soil has been reported to contain as much as 1 mg/L of dissolved selenium. This type of water is usually high in dissolved solids and is not likely to be used by humans as drinking water. In rare instances, selenium has been reported at concentrations of 9 mg/L over a 3 month period (Hem, 1985, p. 145).

Selenium was detected in a sample from only one site (site 18 which is a spring) but the concentration of 29 μg/L in the sample was in excess of the MCL of 10 μg/L.

Silver

Silver is a relatively rare metal but is commercially important in making currency, various photo-chemicals, jewelry, and in silver plating. Silver is also used as a disinfectant for water, and concentrations as low as 10 μg/L in alkaline waters are effective in removing some coliform bacteria. Silver iodide is used in seeding clouds with condensation nuclei to induce rain or snowfall. However, the amounts of silver that appears in rain or runoff that results from cloud-seeding procedures are too small to have any significant environmental effect (Hem, 1985, p. 141).

Colloidal silver consumed in dosages of several hundred milligrams per kilogram of body weight, can cause anemia and possible death. The main chronic effect in humans is permanent blue-gray discoloration of the skin and eyes. Silver is biomagnified in aquatic vertebrates, especially in the gills and internal organs of fish (U.S. Environmental Protection Agency, 1976a, p. 202).

The MCL for silver is 50 μg/L. Silver, in excess of the minimum detection level, was detected in six water samples during this investigation. Concentrations ranged from 2 to 11 μg/L, but only one sample from the spring at site 38 exceeded a concentration of 5 μg/L.

Zinc

Zinc is a fairly common element with the same abundance in crustal rocks as copper and nickel and it usually occurs as a sulfide. Zinc has only the oxidation state of Zn^{2+} and tends to be substantially more soluble in natural water than copper and nickel. Zinc is essential in plant and animal metabolism, but water is not a significant source of the element in a dietary sense (Hem, 1985, p. 142).

Zinc is widely used in industrial, manufacturing, and chemical processes. High concentrations of zinc in surface waters indicate the presence of industrial and urban pollution. Streams affected by mine drainage commonly contain 100 μg/L or more of zinc and concentrations as high as 21,000 μg/L have been reported. Almost all drinking water has detectable concentrations of zinc because it is dissolved from galvanized pipes in household plumbing (U.S. Environmental Protection Agency, 1979). Zinc is an essential element in the diets of humans and animals, but water is not the major source of dietary zinc. Concentrations in public drinking water are generally low, although soft acidic waters occasionally have zinc concentrations as high as 5 mg/L (U.S. Environmental Protection Agency, 1976a).

The SMCL for zinc is 5 mg/L. Zinc occurred in concentrations in excess of the minimum detection level of 4 μg/L in 85 samples and concentrations ranged from 5 to 1,500 μg/L. The median concentration of zinc was 195 μg/L.

Organic compounds

There has been a dramatic increase in the production and use of synthetic organic compounds in the United States over the past 50 years. Most of these substances do not occur naturally, and many are carcinogenic. Many organic compounds are stable in aqueous solutions and are difficult to remove from the environment.

In the past, analyses for specific organic compounds were not routinely included as part of water-quality determinations. However, because of the potential for organic contamination from agricultural chemicals analysis for specific, synthetic organic compounds were a major component of the water-quality determinations in this investigation.

In the late 1970's, the U.S. Environmental Protection Agency proposed a list of toxic materials termed "priority pollutants" for which it was to define effluent limitations and guidelines. The priority pollutant list was an initial effort to cope with the very difficult problems posed by synthetic organic materials in the environment (Hem, 1985, p. 154). The organic compounds analyzed in ground-water samples collected during this investigation are listed as priority pollutants by the U.S. Environmental Protection Agency. The results of the organic analyses of 86 ground-water samples are listed in table 2 and discussed below.

Trihalomethanes

Trihalomethanes (THM's) occur most frequently in treated water supplies, and are often created by the reaction of chlorine, which is used as a disinfecting agent, with naturally occurring organic substances such as humic and fulvic acids. THM's are derivatives of methane where three of the four hydrogen atoms have been replaced by three atoms of chlorine, bromine or iodine. Chloroform is the most common organic compound within this group.

The MCL for total THM's is 0.10 mg/L. None of the ground-water samples analyzed during this investigation contained THM's in excess of the minimum detection limit THM's of 2 to 4 μg/l for specific compounds in this group (see table 8).

Volatile Organic Compounds

With improving analytical techniques and instrumentation, organic chemicals in water can be identified and quantified in concentrations of a few micrograms per liter. Of the chemicals that can now be measured, several are volatile organic compounds (VOCS) suspected of being carcinogens. Another toxic effect of these compounds, other than the potential cancer risk, include varying degrees of depression of the central nervous system. VOCS are produced, used, and are the by-products of a wide variety of industrial applications and processes including production of polyvinyl chloride resins, refrigerants, dry-cleaning operations, solvents, metal degreasers, and insecticide fumigants.

Eight VOCS were detected in the 86 ground-water samples: toluene, methylene chloride, triclorofluoromethane, 1,2-dichlorobenzene, 1,4-dichlorobenzene, styrene, xylene, and trichloroethylene. One or more of these VOCS were detected in samples from sites 12, 17, 19, 23, 44, and 46 but concentrations did not exceed the MCL for these compounds established by the U.S. Environmental Protection Agency. Also, five of the VOCS detected were from one sample collected from a well at site 12.

The U.S. Environmental Protection Agency is currently considering maximum contaminant levels of zero micrograms per liter for trichloroethylene, and both forms of dichlorobenze, because of their suspected carcinogenic effects on humans (U.S. Environmental Protection Agency, 1988). With the exception of toluene, all of the volatiles detected are common ingredients in agricultural chemicals (Berg, 1986).

Polychlorinated Biphenyls

Polychlorinated biphenyls (PCBs) are synthetically produced compounds that are characterized by their chemical and thermal stability, inertness, and dielectric nature. As a group, PCBs and chlorinated insecticides are the most persistent anthropogenic compounds introduced into the environment since the lead and arsenic pesticides of the early 1900's. Although the use of many of these contaminants have been banned in the United States for more than a decade, significant residues continue to be detected (Smith and others, 1987, p. 52).

PCBs were used generally in products such as heat transfer agents, lubricants, dielectric agents, flame retardants, plasticizers, and waterproofing materials. After 1971 they were used almost exclusively as insulating or cooling agents in closed electrical systems, such as transformers and capacitors.

Once in the environment, PCBs tend to accumulate in living tissue with concentrations increasing in organisms as they move up the food chain (biological magnification). In addition, hydrophobic PCBs are highly persistent and can remain associated with sediment or tissue for many years. Because of environmental persistence and toxicity, PCBs were first regulated under provisions of the Toxic Substances Control Act of 1976 and their use was banned in 1979.

Because of wide-spread use, PCBs persistence in the environment, and potential toxicity, analyses for PCBs were included in this investigation. None of the ground-water samples contained PCB's in excess of the minimum detection level of 4 μg/L.

Chlorinated Pesticides

Pesticides are chemicals designed to combat the attacks of various pests on agriculture and horticultural crops and farm animals. These compounds are typically classified by target and include insecticides, fungicides, herbicides, and rodentcides.

Pesticides enter natural waters through many routes, including runoff, direct application in the control of weeds and mosquito larve, drift, rainfall, spills, and poor waste disposal techniques. Movement by erosion of soil particles with absorbed pesticides is one of the principal means of entry into the water (U.S. Environmental Protection Agency, 1972, p. 318).

The chlorinated hydrocarbons are one of the most important groups of the synthetic organic insecticides because of their wide use, stability in the environment, and toxicity to mammals and insects. The use of organochlorine insecticides was initiated with the discovery of DDT by Paul Muller in 1939. Following the discovery of DDT, numerous other organochlorine insecticides were developed and used. Some of these include Lindane, Chlordane, Heptachlor, Aldrin, Dieldrin, and Toxaphene (Smith, 1987). Determinations for all except Aldrin, DDT, and Dieldrin were included in analyses of organics in water samples during this investigation (see table 8).

When ingested, various chlorinated hydrocarbons can cause symptoms of poisoning that are similar but differ in severity. Ingestion of small quantities causes headaches, dizziness, gastrointestinal disturbances, numbness and weakness of the extremities, apprehension, and hyperirritability. In more severe cases, there are muscular fasciculations spreading from the head to the extremities, followed eventually by spasms involving entire muscle groups, leading in some cases to convulsions and death (U.S. Environmental Protection Agency, 1972, p. 76).

Similar to PCBs, organochlorine insecticides tend to accumulate in living organisms and sediment, bio-magnify, and are highly persistent. For example, DDT has a half life of approximately 20 years. Analyses for seven organochlorine pesticides were performed on all ground-water samples collected during this investigation. Results of the analysis showed that none of the pesticides exceeded minimum detection levels which ranged from 0.1 to 50 μg/L (see table 8).

Phenols

A wide variety of organic chemicals are classed as phenolic compounds which are hydroxy derivatives of benzene and its condensed nuclei. Phenol itself, which has but one hydroxol group, is the most typical of the group and is often used as a model compound. Sources of phenolic compounds include the production of fungicides, pesticides, phenolic resins, germicides, pharmaceuticals, plastics, explosives, antiseptic throat lozenges, and skin medications.

The sorption of phenolic compounds to natural sediments and bioaccumulation is generally minor, except for the highly chlorinated phenols. In addition, phenols are removed from the environment through biodegradation and photolysis. The rate at which the various phenolic compound are removed from the environment is based on the type of functional group that is associated with the basic phenolic skeleton (Smith and others, 1987, p.98).

Entrance of phenols directly into surface-water systems may occur via wastewater discharges and indirectly via transformation products of other compounds. Because of the direct input of surface runoff into the ground-water flow system, especially in karst terrane such as is common in Meade County, surface runoff may be the source of phenols in ground water. Because of high aqueous solubility, phenols can occur in relatively high concentrations in ground water or surface streams.

Phenols may affect water quality in a variety of ways. Major aesthetic problems can exist because of their organoleptic properties. A wide range of threshold odor levels exist for the phenols and the process of water purification may also cause chlorination of these compounds which can produce persistent odor problems (U.S. Environmental Protection Agency, 1972, p. 80). Compound-specific analysis for nine phenolic compounds, listed as priority pollutants by the U.S. Environmental Protection Agency (1988), were performed on 86 ground-water samples during this investigation. Only one compound, 2-Nitrophenol, exceeded its minimum detection limit and this occurred in only one sample from a well at site 37 (see table 2).

Chlorophenoxy Herbicides

Because of the need to reduce production costs and increase productivity, there has been a general increase in the use of herbicides on crops in the United States. Most herbicides are characterized by high aqueous solubilities and high vapor pressures. Thus, herbicides do not bioconcentrate, sorb to sediments, or volatilize from solution to an appreciable extent.

Herbicides enter natural waters in a variety of ways. Terrestrial herbicides are carried into surface waters by runoff. Consequently, residues of herbicides in surface waters are related to the timing of the application relative to precipitation. In addition, aquatic herbicides are applied directly to surface waters to control aquatic vegetation. In general, herbicides are non-persistent environmental contaminants, due to the fact that their high solubilities greatly reduce solute partitioning into sediment, organic matter, or biological lipid reservoirs.

Because of the use of herbicides for agricultural purposes in Meade County, analyses for specific herbicides were performed on all ground-water samples collected during this investigation. Results of these analyses showed that none of the ground-water samples contained concentrations of the herbicides, 2,4-D or Silvex in excess of respective minimum detectable limits even though sampling periods were designed to follow heavy rains during the spring and summer periods of increased agricultural activity (see table 2).

Gas Chromatography/Flame Ionization Detector Scan Analysis

Because much of the land of the Meade County study area is devoted to agricultural use, the runoff from these lands may contain residues of pesticides and fertilizers which can lead to elevated levels of synthetic organics and nutrients in ground water.

The Gas Chromatography/Flame Ionization Detector (GC/FID) scan analysis was used to detect potential contamination of ground water from synthetic organic compounds that could be part of the agricultural runoff. Although the GC/FID scan does not detect the presence of nutrients that might originate in fertilizers, it can detect the presence of synthetic organic compounds related to the use of pesticides.

Eight sites were selected for sampling during 12 sampling intervals after runoff events. If organic compounds were detected, semi-quantitative calculations were made and reported as concentration ranges (See table 3). Though the GC/FID analysis does not identify specific organic compounds, limited qualitative interpretations can be made about the groups of organic compounds detected, thus narrowing the field of potential organic contaminants.

The GC/FID scan indicates that most detections of organics in the ground-water system occurred between late-March thru mid-October (fig. 5). The one exception to this characterization appears in the seventh sampling interval from September 14 thru October 13, 1987. Because this is typically the time of harvest, little crop or soil preparation activity was underway and the application of pesticides was thought to be limited. Also, a lack of significant precipitation prior to this sampling may have affected results.

The highest concentrations and detections of organic compounds were noted during the sixth sampling interval after several days of light to moderate rains (fig. 5). Preceding this rainfall event was an extended period of very little or no precipitation over the study area. This dry period probably enhanced the potential for contamination by organics due to the residual accumulation of some pesticides in soils. As the pesticides are applied, adhesion between the organic compound and soil particles occur. A cumulative affect for some organic compounds is possible if the interval between applications is not sufficient for dispersal or if insufficient precipitation is available after application to allow the pesticide adequate access to it's target (pesticides such as nematocides and fungicides require some precipitation to carry them further into the soil horizon). An alternative explanation for the elevated concentrations during the sixth sampling interval is that the pesticides were applied just prior to a

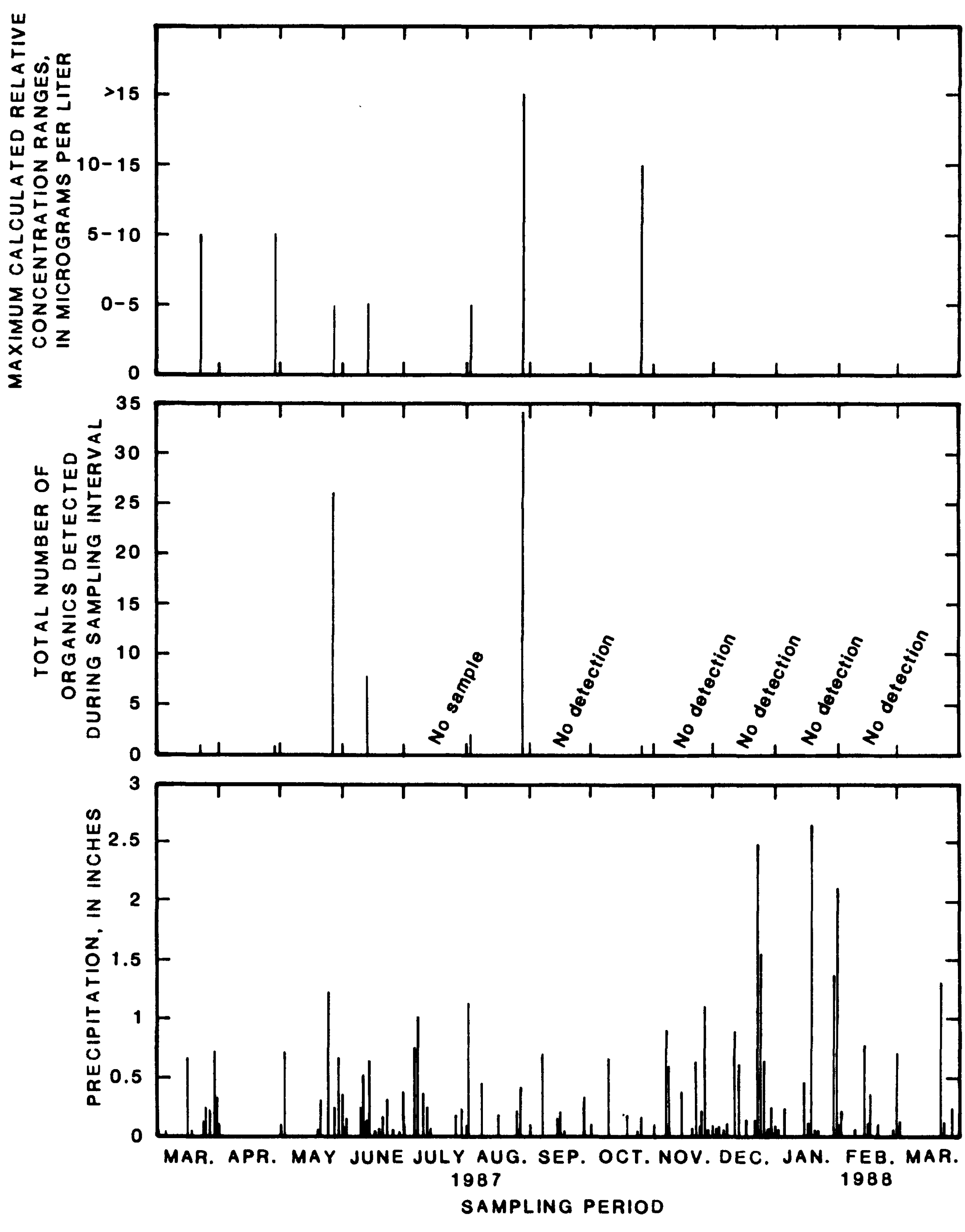


Figure 5.--Relation between occurrence and concentration of organic compounds in ground water and precipitation.

precipitation event which could cause relatively high wash-off rates and result in elevated levels of organics in surface waters recharging the karstic ground-water system. However, elevated concentrations of organics in water from all eight sampling-sites tends to weaken the validity of this explanation.

Bacteria

In addition to being chemically safe for human consumption, drinking-water supplies should be virtually free of all harmful micro-organisms. Because ground water moves primarily through enlarged pipe-like openings in karst aquifers, the introduction and relatively widespread distribution of contaminants, such as bacteria, is possible. Thus, bacterialogical pollution could become a problem in ground-water supplies in the study area. For this reason, analysis for bacteria was a major component of water-quality evaluation for this investigation and included analyses for fecal coliform, fecal streptococci, and total coliform.

Since the 1880's, the presence of coliform bacteria has been used as an indicator of the sanitary quality of water because these organisms are abundant in the digestive tracts of humans and other warm-blooded animals and are present in fecal waste. Although coliform bacteria are not directly harmful, their presence in excessive numbers may indicate the possible presence of other species of pathenogenic bacteria (U.S. Environmental Protection Agency, 1976, p. 29). However, because coliform bacteria occur in many different environmental settings, such as various types of vegetation and in soils, the presence of these organisms may not be an accurate indicator of the suitability of domestic-water supplies. There is an increasing trend toward direct detection of fecal species of coliform and streptococci which are more accurate indicators of the sanitary characteristic of a water resource.

Results of bacterialogical analysis are shown in table 4. The MCL for total coliform is four colonies per 100 mL, and 61 percent of the samples failed to meet this standard. Of the 49 sites sampled for total coliform bacteria, all of the springs and about half of the wells contained bacterial growth that was described as too numerous to count.

Fecal coliform, which comprise a portion of the total coliform group, are restricted to the intestinal tract of warm-blooded animals and are considered the primary indicator of fecal contamination in water. Because the normal habitat is the intestines of warm-blooded animals, fecal streptococci is increasingly used as an indicator of contamination. These bacteria confirm fecal pollution and provide additional information on the origin of the pollution. The ratio of fecal coliform to fecal streptococci can be used to indicate whether the source of bacteria is animal or human waste. If the ratio of fecal coliform to fecal streptococci is 4.0 or greater, the pollution is considered to be derived from human waste; if the ratio is 0.7 or less, the source of the pollution is thought to be other warm-blooded animals (Krenkel and Novotny, 1980). The ratios of fecal coliform to fecal streptococci bacteria for samples collected in this study suggests that three springs (sites 28, 44, and 45) are at times contaminated by human waste. In addition, six other sites, two wells and four springs, (sites 6, 7, 15, 21, 30, and 47) are likely contaminated, at times, by the excreta of other warm-blooded animals, probably livestock.

Water samples from 12 springs and 33 wells were analyzed for fecal indicator bacteria (coliform or streptococci). Water from all 12 springs and two of the 33 wells contained fecal contamination, at times. Although the Kentucky criterion of 2,000 fecal coliform colonies per 100 mL for treatable domestic water supplies was not exceeded in any of the samples, 30 percent of the samples failed to meet the implied federal standard for fecal species pertaining to coliform bacteria. The presence of fecal bacteria in all samples from springs may be due to septic tank systems in the area.

STATISTICAL ANALYSIS

Water-quality data collected during the study are summarized in table 8. The maximum and minimum values detected for each constituent are given along with calculated values for the mean, median, and standard deviation. These values help to characterize various water-quality constituents. For example, a large standard deviation indicates wide variability in concentrations, whereas widely differing values for the mean and median indicate skewness in the data. Sulfate has a standard deviation of 111, a mean of 59.0, and a median of 26. This indicates a wide variability in data and a skewness toward larger values.

For the purposes of statistical analysis all values were assumed to equal or exceed the detection limit so that a maximum value for mean, median, and standard deviation might be generated. Next, the analytical values reported as less than the detection limit were assumed to be zero so that minimum values for mean, median, and standard deviation could be generated. This approach showed no significant change in the mean, median, or standard deviation for any of the constituents analyzed. Therefore, only the minimum values generated for mean, median, and standard deviation are reported (see table 8).

Also listed in table 8 are the percentages of samples that exceeded specific Federal drinking-water standards and state domestic water supply criteria. These data indicate those water-quality constituents about which a water user might need to be watchful. In the case of certain metals and trace elements such as lead, for example, the data suggest the need to identify the source of a particular constituent for possible remedial action, such as removal of a source of contamination or the development of a alternative source of water.

Several types of statistical tests can be used to determine the relation between water-quality constituents. Such tests may be as simple as comparing average values of constituents in water from different aquifers to developing regression models to define relations between components.

Although detailed statistical analysis is outside the scope of this study, some simple statistical tests were applied to the data in an attempt to identify the relations between ground-water quality characteristics in Meade County. All statistical analysis used computer programs developed by the Statistical Analysis Systems Institute (Helwig and Council, 1979). Statistical tests performed for the study area used the following parameters:

1. Physical characteristics including location, site type (well or spring), well depth, casing depth, principle aquifer, and season.

2. Chemical constituents and properties including chloride, fluoride, lead, sulfate, hardness, and dissolved solids.

The F-test validates the assumption that for the data set being considered the variances between two classes are equal. This assumption must hold true before a T-test can be performed. The results of the F-test indicated that the variances of analytical results of samples from wells and springs are considered equal for all constituents and properties except lead content.

A student's t-test was performed on the remaining data to test the validity of the assumption that for the data under consideration the true means of the normally distributed data are equivalent. The results of the student's t-test indicate that this assumption was valid except for chloride and fluoride. This test result indicates that variations in the concentrations of chloride and fluoride may be attributable to the site type.

Correlation coefficients are calculated by comparing the relations between variables. Coefficients may vary from 1 to -1 (negative numbers show an inverse relation). A value of zero shows no correlation. Correlation increases as the values approach 1 or -1. Strong correlations were only noted for the following relations: hardness and dissolved solids; hardness and sulfate; and sulfate and dissolved solids. Somewhat weaker correlations seemed to exist between: hardness and casing depth; hardness and lead; sulfate and casing depth; sulfate and lead; flouride and lead (inverse); lead and dissolved solids; lead and well depth; and dissolved solids and casing depth.

Analysis of variance was conducted to determine the amount of variation in water quality constituents such as chlorides and lead (dependent variable) due to variation of type of aquifer and site type (independent variable) and random error. A 95-percent confidence level was used to determine a significant relation between the independent and dependent variable. For variance due to site type (well or spring), only fluoride and chloride met this criteria for significance. For variance due to aquifer type, only chloride met the established criteria.

Simple regression procedures were conducted to produce best linear fit models for dependent variables by adding or removing independent variables in a stepwise progression. Models using each water-quality constituent as a dependent variable were attempted. Only independent variables fitting a 95-

percent confidence interval were used. Linear models adhering to this criteria were generated for the following relations: hardness using dissolved solids as the variable; dissolved solids using hardness and sulfate as variables; and sulfate using dissolved solids as the variable.

Based on the results of these statistical analyses, the following statements can be made to characterize the water quality at sites sampled in the Meade County study area:

1. There are no apparent relations between water-quality and geographic site location.
2. Site type (well or spring) only affected the variance of fluoride and chloride, and variance due to aquifer type was only significant for chloride.
3. A correlation exists between hardness and dissolved solids, hardness and sulfate, and sulfate and dissolved solids.
4. Hardness, dissolved solids and sulfate were the only water-quality measurements to fit a simple linear regression model.
5. Weaker correlations appeared to exist between several other constituents but did not model well when put into a simple regression. However, these constituents may better fit a higher order polynomial regression which was not tested.

CHARACTERIZATION OF GROUND-WATER QUALITY

In Meade County, most ground-water flow is through conduit systems common to the karstic rocks of the St. Genevieve and St. Louis Limestones, which are the principal aquifers. Because of the karst geology, many aspects of ground-water flow in granular aquifers, such as filtration and slow rates of travel, are not generally applicable. The potential for water-quality problems due to rapid and widespread dispersal of pollutants exists throughout the karst aquifer system.

The chemical and physical quality of the ground water in the study area is within anticipated ranges for a carbonate aquifer. The water is hard or very hard and sulfate concentrations in water from some sites exceed the limit established for drinking water. Fluoride concentrations exceeded Federal drinking water standards in almost one-third of the ground-water samples analyzed. Statistical analysis indicates that the fluoride concentrations are significantly higher in water from wells than in water from springs.

Although the concentrations of lead exceeded the drinking water standards in only one sample, concentrations seemed high for a carbonate aquifer. Statistical analysis of the relation between lead and various other properties such as site type were inconclusive.

Although selenium was detected in only one of the 86 samples, the selenium concentration in that sample was more than twice the standard for drinking water. The site at which selenium was detected was sampled only once during the investigation.

Excessive concentrations of organic compounds were not detected. Specific organic compounds detected in this investigation typically are associated with pesticides and other agricultural chemicals. Though not compound specific, the GC/FID scan analysis supported this assumption by showing a correlation between the growing season and the detection of organic compounds. In general, the occurrence of detected organic compounds was associated with larger precipitation events, as indicated by comparison of the GC/FID scan data and precipitation records.

Although 18 of the 37 wells tested positive for total coliform bacteria, only two of the wells sampled contained fecal species of coliform or streptococci bacteria. However, all 12 of the springs sampled contained fecal coliform or fecal streptococci bacteria. Although the ratio between fecal coliform and fecal streptococci bacteria does not conclusively identify the source of contamination, it indicates that three of the springs may be occasionally contaminated by human waste, while several other sites may be occasionally contaminated with animal waste.

SUMMARY

1. The St. Louis and Ste. Genevieve Limestones are the principal aquifers in the study area. Alluvium and other unconsolidated sediments, may store water and recharge the underlying aquifer.

2. Because of the highly karstic aquifer system which underlies most of Meade County, ground water is susceptible to rapid changes in water quality. Water-quality enhancement by filtration and other chemical, physical, and biological processes that occur in the soil zone is probably limited in this karst aquifer system.

3. Most physical and chemical water-quality characteristics were within expected ranges and were typical of areas where limestone is the principal aquifer.

4. Concentrations of fluoride exceeded Federal standards for drinking water at 14 sites. The fluoride content in ground water was significantly higher in wells than in springs.

5. Concentrations of lead in ground water were higher than expected at many sites. However, concentrations in excess of the MCL of 50 μg/L were detected in only one sample.

6. The selenium content in one sample from site 18 was 29 μg/L, which was more than twice the MCL for selenium. Selenium was detected in only one sample.

7. Concentrations of specific organic compounds were less than the present MCL drinking-water standards at all sites. With one exception, all identified organic constituents were probably associated with agricultural chemicals.

8. The occurrence and relative abundance of synthetic organic compounds as defined by the GC/FID scans seemed to correlate with the growing season.

9. Results of analyses for total coliform bacteria indicated total coliform densities in excess of the drinking-water standards in all of the springs and 18 of the 37 wells sampled.

10. Results of the analyses for fecal bacteria indicated that the water from only two of the 33 wells analyzed contained fecal species of coliform or streptococci bacteria. However, water from all 12 springs contained fecal coliform or fecal streptococci bacteria.

11. Fecal coliform/fecal streptococci ratios suggest that three of the springs may be occasionally contaminated by human waste and that six sites may be occasionally contaminated by fecal pollution from other warm-blooded animals, probably domestic livestock.

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