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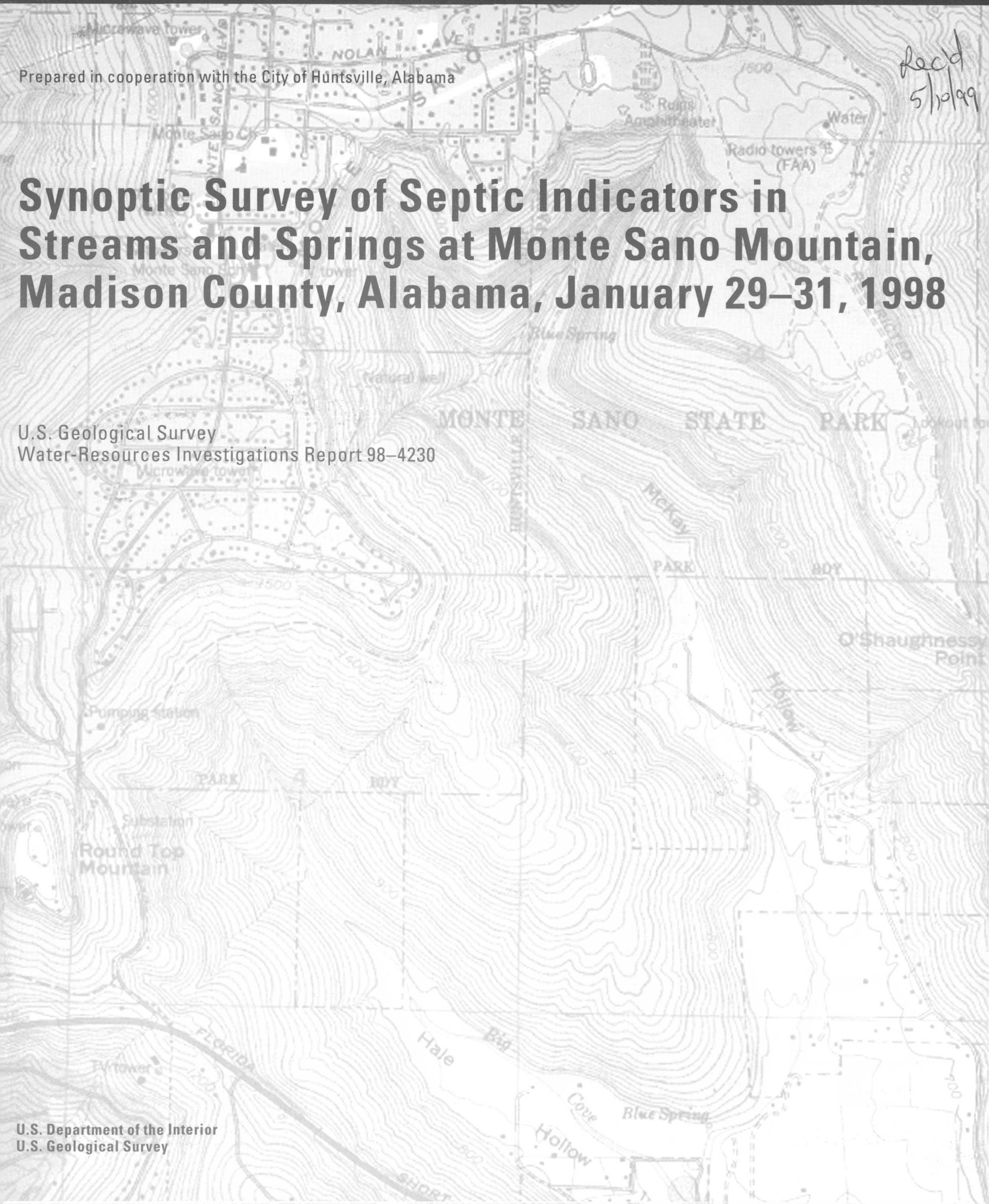
Synoptic Survey of Septic Indicators in Streams and Springs at Monte Sano Mountain, Madison County, Alabama, January 29–31, 1998

U.S. Geological Survey
Water-Resources Investigations Report 98–4230



U.S. Department of the Interior
U.S. Geological Survey

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By Ann K. McPherson and Will S. Mooty

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Montgomery, Alabama
1999

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
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CONVERSION FACTORS, VERTICAL DATUM, TEMPERATURE, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	4,047	square meter
	Volume per unit time (includes flow)	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

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.

Temperature: Temperature values can be converted by using the following equations:

$$°F = 1.8\ (°C + 32)$$
$$°C = 5/9\ (°F - 32)$$

Abbreviated water-quality units:

col/100 mL .... colony per 100 milliliters
µg/L .... microgram per liter
mg/L .... milligram per liter
µS/cm .... microsiemens per centimeter

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ABSTRACT

The U.S. Geological Survey conducted a synoptic investigation of fecal bacterial pollution in headwater streams and springs on Monte Sano Mountain. A total of 18 sites were sampled over a 3-day period in late January 1998. Fifteen of the sites were located hydrologically downgradient from residential areas on top of Monte Sano Mountain. Three additional sites were selected as background sites in unpopulated areas on Huntsville Mountain, south of Monte Sano Mountain. Sampling was conducted during a period of high baseflow after a recent storm when no surface runoff was present. Any contaminants identified in the streams and springs were likely derived from ground-water discharge because overland flow was not evident.

Four of the five sites in the Pottsville-Pennington unit (uppermost) with the highest concentration of residential land use had *Escherichia coli (E. coli)* concentrations that were more than 25 times the background level. In contrast, with the exception of one site, *E. coli* concentrations in the Bangor-Monteagle unit (middle) and Tuscumbia unit (lowermost) were at or near background levels. Caffeine also was detected in the Pottsville-Pennington unit at a site with one of the highest densities of *E. coli.* Elevated levels of nitrite plus nitrate and chloride also were identified at sites in the Pottsville-Pennington unit.

The results of this synoptic sampling event identified elevated concentrations of fecal bacteria in the Pottsville-Pennington unit at the top of the mountain. These elevated bacterial concentrations occurred in conjunction with caffeine detection and elevated levels of nitrite plus nitrate and chloride. This indicates that there is a potential water-quality problem related to discharge from the shallow ground-water system. Because the sampling sites are located in close proximity to residential development, the most probable source of the elevated fecal bacterial concentrations was septic tank effluent.

INTRODUCTION

Monte Sano Mountain is located east of the city of Huntsville in Madison County, Alabama (fig. 1). The summit of the mountain is a narrow sandstone-capped plateau that is 4 miles in length and shaped like a horseshoe (fig. 2). The valleys surrounding the mountain are underlain by limestone and exhibit karst features. A small residential community of approximately 2,100 people is located on top of the mountain in an area of 460 acres. Fecal bacteria have been detected in wells and springs on Monte Sano Mountain during previous investigations (French and Strunk, 1990; Huntsville-Madison County Health Department and City of Huntsville Department of Natural Resources and Environmental Management, 1992).

Fecal bacterial contamination of ground water is a common problem in many areas of the country—particularly in areas with fractured bedrock or solution cavities, where conduits can lead directly to deeper aquifers, or in shallow unconfined aquifers,

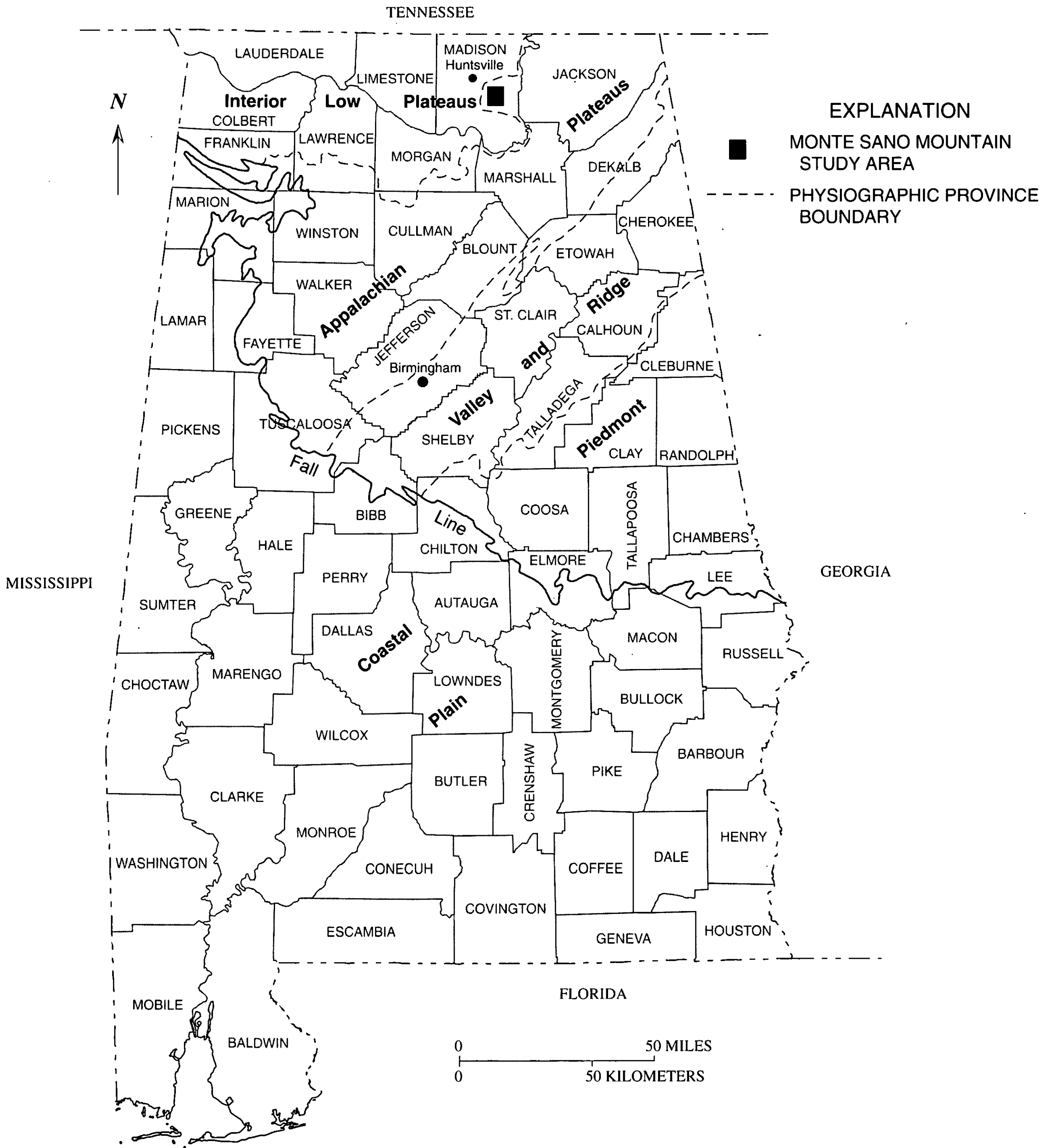

Figure 1. Location of Monte Sano Mountain study area and physiographic provinces in Alabama.

where contamination can seep directly into the ground-water system. The most common sources of fecal bacterial contamination include septic system failure, feedlot or field runoff, manure application on fields, and municipal sludge application. Septic system failure was presumed to be the most likely cause at Monte Sano Mountain, because standard septic systems are utilized by the current residents and no fields or feedlots are present on top of the mountain. However, fecal-coliform bacteria can have nonfecal and nonhuman sources. Additional information specifically linking the bacterial contamination to septic tank effluent was needed.

This investigation was conducted by the U.S. Geological Survey (USGS) as part of a cooperative program with the City of Huntsville, Alabama. The

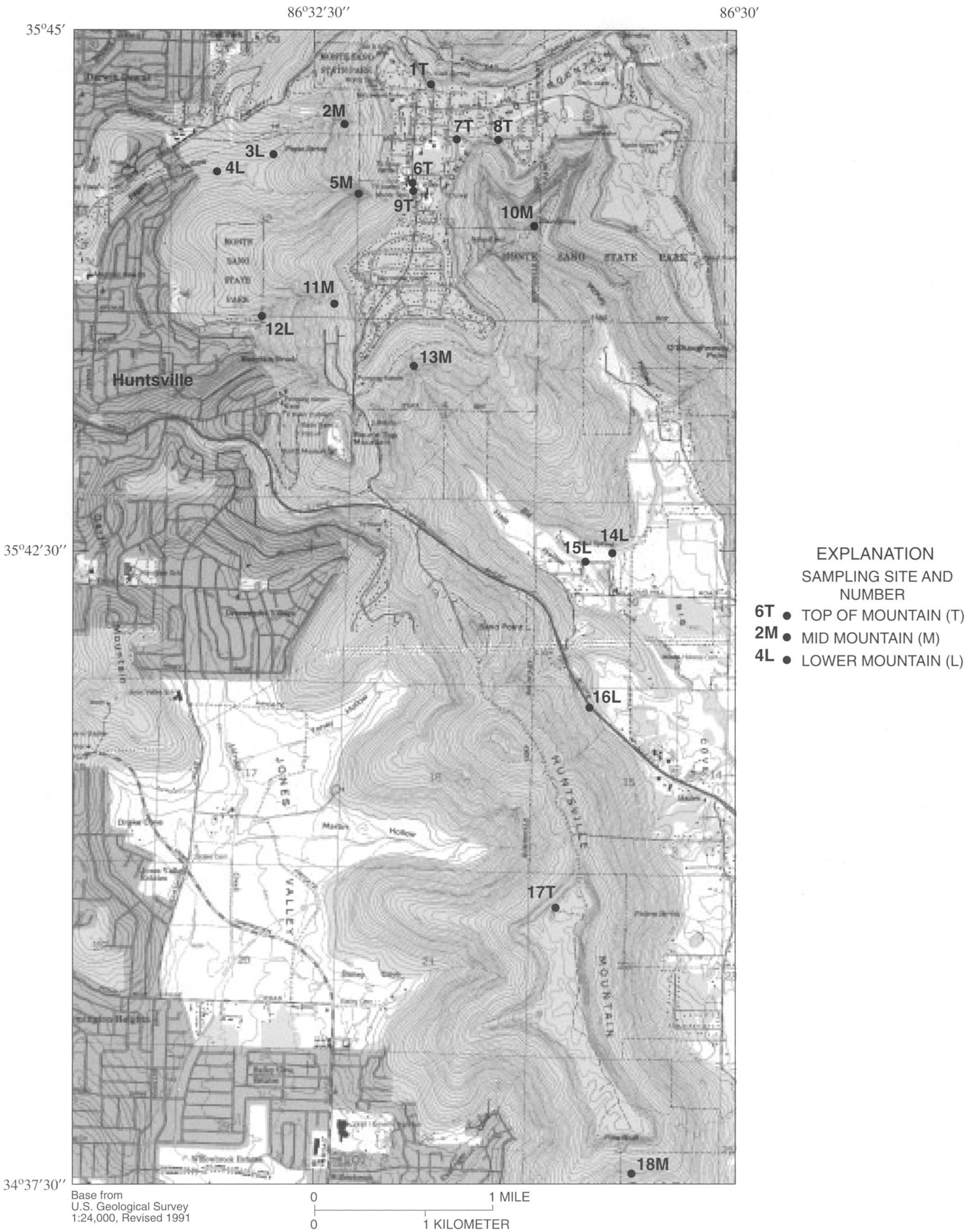

Figure 2. Location of sampling sites at Monte Sano and Huntsville Mountains, Madison County, Alabama.

purpose of this investigation was to further define the extent of previously established fecal bacterial contamination in ground water and surface water in the Monte Sano Mountain area near Huntsville, Alabama, and to identify the degree to which faulty septic tanks may have served as the fecal bacterial source. The results of this study provide valuable information about techniques that are applicable to many other areas of the country.

Purpose and Scope

This report presents the results of a synoptic survey of septic indicators in streams and springs on Monte Sano Mountain. Water samples were collected at 18 locations during high baseflow conditions in a synoptic sampling event during January 29–31, 1998. The samples were analyzed for fecal bacteria, including fecal-coliform bacteria and the more human-specific bacteria, *E. coli*, as well as for chemical compounds that are indicative of septic effluent including caffeine, detergents, and nutrients.

Background

Fecal-coliform bacteria are considered indicator organisms. Although fecal-coliform bacteria generally are not considered to be pathogenic, their presence may indicate that waterborne, disease-causing organisms exist in a water supply. The presence or absence of indicator organisms is used to evaluate the microbiological quality of water because current techniques to analyze for pathogens are either quantitatively unreliable or difficult to perform (Viessman and Hammer, 1993).

Difficulty arises when attempting to determine whether the source of the indicator organisms is human or nonhuman. Some species of fecal-coliform bacteria occur naturally in soils and other types are derived from the feces of humans and warm-blooded animals (Bickford, Lindsey, and Beaver, 1996). In 1986, the United States Environmental Protection Agency (USEPA) recommended that *E. coli* be used in place of fecal-coliform bacteria as an indicator of fecal contamination in waters used for recreation. This recommendation was based on studies that showed a strong correlation between the number of swimming-associated, gastrointestinal illnesses and the concentration of *E. coli* (Francy, Myers, and Metzker, 1993). *E. coli* is a form of coliform bacteria that is endemic to the gastrointestinal tract of warm-blooded animals and is of definite fecal origin when found in water.

Chemical indicators also may be used in combination with bacterial indicators. The most common indicators of ground-water quality degradation associated with human sources include elevated levels of nitrate and the presence of bacteria. Ethylenediaminetetraacetic acid (EDTA), methylene blue active substances (MBAS), caffeine, chloride, and phosphorus are additional compounds frequently used as chemical indicators.

Previous Investigations

Fecal-coliform contamination of ground water in the Monte Sano area was reported in 1986 during an investigation by Tennessee Valley Authority (TVA) and the Huntsville-Madison County Health Department (HMCHD). One hundred wells were surveyed in Madison County, Alabama. Thirty percent of these wells tested positive for fecal-coliform bacteria with an average concentration of 5.4 colonies per 100 milliliter (col/100 mL) (French and Strunk, 1990).

In 1987 and 1988, TVA conducted a survey of springs and streams on Monte Sano Mountain to examine the effects of septic tank leachate on ground water. Fecal-coliform concentrations in springs and streams on the mountain averaged 160 col/100 mL and 234 col/100 mL, respectively. *E. coli* concentrations in springs and streams on the mountain averaged 196 col/100 mL and 252 col/100 mL, respectively (French and Strunk, 1990).

Additional studies were conducted by the HMCHD and the City of Huntsville Department of Natural Resources and Environmental Management (HDNREM) in 1990 and 1991. Water samples were collected from seven wells and three springs on and around Monte Sano Mountain over a period of 12 months. Fecal-coliform contamination was found in the wells 42 percent of the time and in the springs 100 percent of the time. Fecal-coliform levels averaged 7.6 col/100 mL in the wells and 78 col/100 mL in the springs, respectively. Malfunctioning septic tanks were considered to be the most probable source of the contamination because of the absence of additional fecal bacterial sources (Huntsville-Madison County Health Department and City of Huntsville Department of Natural Resources and Environmental Management, 1992).

Additional sampling also was conducted during July and August 1997 by Southeastern Analytical Services, Inc. Samples were collected from two springs and three streams on the mountain. Fecal-coliform concentrations at Cold Springs and Fagan Springs ranged from 8 col/100 mL to 25 col/100 mL. Fecal-coliform concentrations in the streams ranged from 8 col/100 mL to 15 col/100 mL. Fecal-coliform concentration at the outfall near the fire station could not be determined because the colonies were too numerous to count (Southeastern Analytical Services, Inc., 1997).

Description of Study Area

Monte Sano Mountain (fig. 1) lies within the Cumberland Plateau section of the Appalachian Plateau physiographic province (Sapp and Emplaincourt, 1975). The mountain is a narrow sandstone-capped plateau with a summit that has a maximum altitude (feet above sea level) of approximately 1,600 feet (ft). The valleys surrounding the mountain are at an altitude of about 700 ft.

Huntsville has a temperate climate. Summers are characterized by warm, humid weather with frequent thunderstorms. Monthly mean temperatures range from 38.8 degrees Fahrenheit (°F) in January to 79 °F in July (National Oceanic and Atmospheric Administration, 1997). The average date for the last occurrence of freezing temperature is late March, and the average date of the first freeze is late October or early November. Annual rainfall averages about 57 inches (in.) per year of which approximately 43 percent occurs during the winter months between December and March. Precipitation amounts for the drier months of fall are appreciably less than for the relatively wet season in winter.

A small residential population of approximately 2,100 people is located on top of the mountain. The community consists of approximately 840 homes and encompasses an area of about 460 acres on the western half of the mountain. Six commercial facilities also are located on top of the mountain and include a school, television station, fire station, two churches, and a State park. Monte Sano State Park, established in 1938, occupies an area of 2,140 acres on the eastern side of the mountain.

The remaining land use in the study area is characterized by thickly forested areas on the steeply sloping sides of the mountain. Hiking trails are located all over the mountain. The valleys surrounding the mountain contain both pasture and farmland as well as sections of residential development. Hay and cotton are the predominant crops grown in the valleys.

Soils on Monte Sano Mountain are classified as residuum, alluvium, and colluvium. Soils on top of the mountain are primarily thin, silty sands with the majority of residuum being fine sand. Permeability of these soils in some areas is described as moderate to rapid, which suggests a high infiltration capacity. Thickness varies, but averages 3.8 ft (OMI, Inc., 1997).

Geology

Monte Sano Mountain is underlain by bedrock of Mississippian to Pennsylvanian age. The rock formations exposed along Monte Sano Mountain include, in ascending order, the Tuscumbia Limestone, Monteagle Limestone, Hartselle Sandstone/Pride Mountain Formation, Bangor Limestone, Pennington Formation, and the Pottsville Formation (Thomas, 1972; OMI, Inc., 1997). The lithology and stratigraphic sequence of these geologic units are illustrated in figures 3 and 4.

Series	Age	Geologic unit	Altitude (feet)	Lithology
Paleozoic	Pennsylvanian	Pottsville Formation	>1,500	Sandstone, shale, and coal
	Mississippian	Pennington Formation	1,420–1,500	Shale and limestone
		Bangor Limestone	1,100–1,420	Limestone, dolomite, and shale
		Hartselle Sandstone/ Pride Mountain Formation	1,060–1,100	Four sandstone units separated by shale
		Monteagle Limestone	800–1,060	Limestone and shale
		Tuscumbia Limestone	<800	Limestone with small amounts of chert

Figure 3. Lithology of major geologic units on Monte Sano Mountain, Alabama (modified from Doyle and others, 1975).

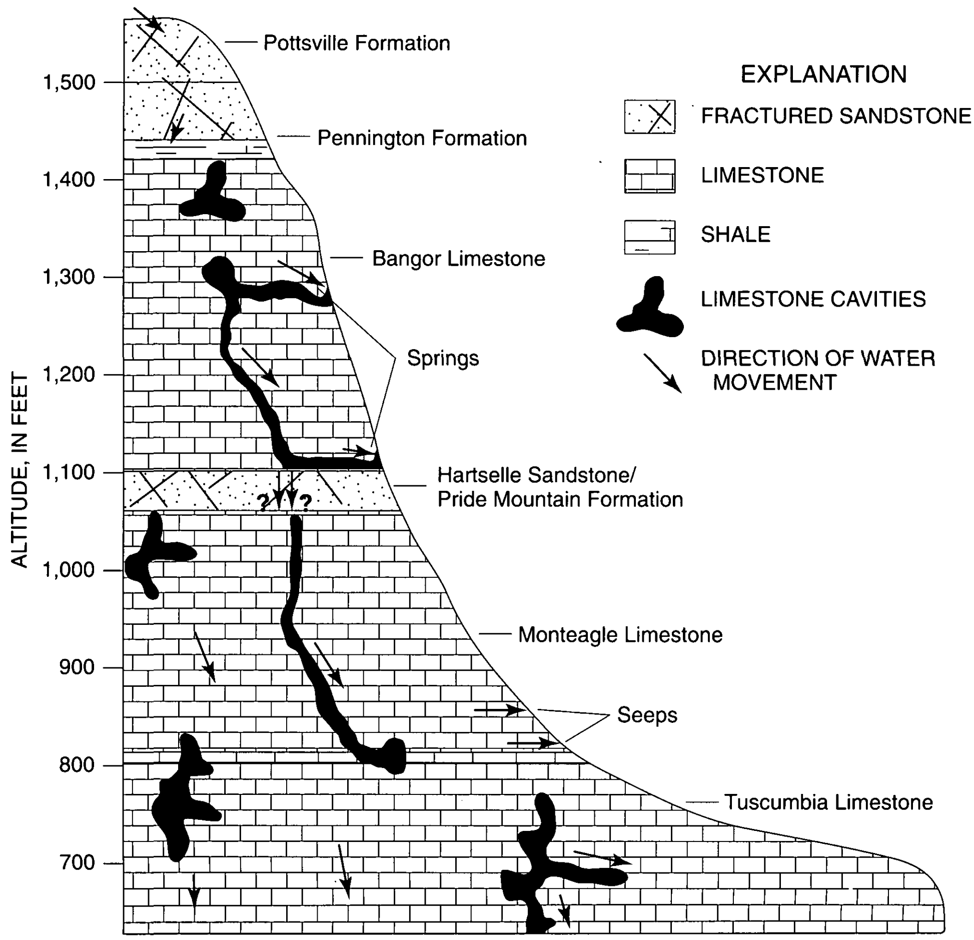

Figure 4. Generalized geologic cross section of Monte Sano and Huntsville Mountains, Madison County, Alabama (modified from Doyle and others, 1975).

The Tuscumbia Limestone is composed of highly fossiliferous limestone that is cherty in nature and is generally found below an altitude of 800 ft. The Tuscumbia Limestone is overlain by the Monteagle Limestone.

The Monteagle Limestone generally is present between an altitude of 800 and 1,060 ft. Near the top of the formation, the limestone is thinly bedded and separated by beds of shale ranging in thickness from 2 in. to 5 ft. The Monteagle Limestone is overlain by the Pride Mountain Formation.

The Pride Mountain Formation consists of one to three sandstone units separated by gray, clay shale. The Pride Mountain Formation is overlain by the Hartselle Sandstone (Thomas, 1972). The Hartselle Sandstone generally is composed of light colored, fine-grained quartoze sandstone. The Pride Mountain Formation and the Hartselle Sandstone generally are present at altitudes between 1,060 to 1,100 ft. Both formations gradually thin and pinch out between the Monteagle Limestone and the Bangor Limestone. These formations are overlain by the Bangor Limestone.

The Bangor Limestone generally is present between an altitude of 1,100 to 1,420 ft. The lower part of the Bangor Limestone consists of interbedded shales, shaley limestone, and argillaceous limestone, and the middle part consists of massively bedded limestones and dolomite. The Bangor Limestone is overlain by the Pennington Formation.

The Pennington Formation is composed of shale and limestone and generally is present between an altitude of 1,420 to 1,500 ft. The Pennington Formation is the uppermost formation of Mississippian age and is overlain by the Pottsville Formation.

The Pottsville Formation is located at the top of Monte Sano Mountain and consists of fractured sandstone, shale, and coal. The coal seams that overlie the shale are about 1.5 ft thick, and the sandstone above the coal seam generally is thinly to massively crossbedded. The Pottsville Formation generally is present between altitudes of 1,500 to 1,600 ft; it is the youngest formation on the mountain and the lowermost formation of Pennsylvanian age.

Hydrogeology

Monte Sano Mountain is underlain by three aquifers: the Pottsville Formation, the Bangor aquifer, and the Tuscumbia aquifer. The Pottsville Formation is not considered a major aquifer because it yields only small amounts of water to wells (Bossong and Harris, 1987). The Bangor aquifer includes the Bangor Limestone and the underlying Pride Mountain Formation/Hartselle Sandstone. The Tuscumbia aquifer includes the Monteagle Limestone and the Tuscumbia Limestone. The Bangor and Tuscumbia aquifers are important sources of public and domestic water supplies.

Soil cover on the Pottsville Formation is relatively thin, and the rocks are well indurated and cemented. The rocks typically have low porosity and permeability (Bossong and Harris, 1987). Ground-water flow within the Pottsville Formation is predominantly through fractures and bedding planes. Most of the sandstone springs are of the seepage type, fed by water stored in the subsoil. Most of the precipitation that falls on the outcrop area of the Pottsville Formation runs off directly due to the thin soil cover and low storage capacity of the rock. Ground-water recharge to the Bangor aquifer is limited, because shale units within the Pottsville and Pennington Formations that overlie the Bangor aquifer retard recharge to the aquifer.

The Bangor and Tuscumbia aquifers are partially confined by the overlying Pennington Formation. The principle constituent of the limestone in these aquifers is calcium carbonate, a compound that is readily soluble by dilute acids present in ground water. Within limestone aquifers, relatively small, insignificant fractures can be enlarged by solutional processes into significant cavernous features. Ground-water movement within the carbonate aquifers is predominantly through these solution features. At the base of Monte Sano Mountain, where the Tuscumbia aquifer is exposed, the aquifer is partially confined by the overlying residuum.

APPROACH AND METHODS OF STUDY

This synoptic investigation included three specific elements that were of critical importance in determining the source of bacterial and chemical indicators at Monte Sano Mountain: (1) the condition of the hydrologic system during the time of sampling; (2) the bacterial and chemical constituents that serve as indicators for septic tank effluent; and (3) the comparison of data within similar units based on land use, geology, and hydrogeology.

The hydrologic condition at the time of sampling was an important element in this investigation. Samples were collected under high baseflow conditions, following a period of increased precipitation, but when no overland flow was present. Based on the hydrologic system at Monte Sano Mountain, the recent precipitation would provide a flushing effect in the shallower soil zone where septic tanks are located. Indicators that were identified in the streams were likely derived from ground-water discharge rather than surface runoff because no overland runoff was present at the time of sampling. To reduce the effects of evapotranspiration on streamflow to a minimum, samples were collected after the first killing frost.

Innovative methods were used in this investigation to identify the origin of fecal bacterial contamination. The most common indicators of ground-water quality degradation associated with human sources include elevated concentrations of nitrate and the presence of fecal bacteria (Carmichael and Bennett, 1993). Surface-water samples were collected and analyzed for *E. coli* and fecal coliform. *E. coli* is considered to be the best indicator of fecal contamination in freshwater (Francy, Myers, and Metzker, 1993). Fecal coliform was included to provide a link between prior studies and because Federal criteria exist for this indicator. The samples also were analyzed for specific and nonspecific indicators of wastewater effluent. Specific indicators include compounds in detergents and cleansers, such as EDTA, or compounds in food and medicine, such as caffeine or 17B estradiol. Nonspecific indicators include compounds such as nitrate and chloride.

Also critical to this investigation was understanding the factors that affect water quality in the study area. Monte Sano Mountain is composed of layers of sandstone, shale, and carbonate rock. Different chemical and hydrologic processes occur in each of these rock types, causing differences in water chemistry. Chemical and bacterial data obtained from sites in a particular formation compare best to data obtained from background sites within the same formation.

To accurately classify the data, three major units were defined based on land use, geology, and hydrogeology. The Pottsville Formation and Pennington Formation, composed primarily of sandstone and shale, were combined to form the Pottsville-Pennington unit, which drains the flat top of the mountain and is dominated by residential land use. The Bangor Limestone and the Monteagle Limestone, both carbonate formations, were combined to form the Bangor-Monteagle unit, which drains the steeply sloping, forested sides of the mountain. The Tuscumbia Limestone, also carbonate, forms the Tuscumbia unit, which drains the base of the mountain and the valley floor with mixed forest and residential land use. The 18 sites have been grouped into these three units (table 1). Sites located in the Pottsville-Pennington unit are designated with a T (for top of the mountain) after the site number. Sites in the Bangor-Monteagle unit are designated with an M (for mid mountain), and sites in the Tuscumbia unit are designated with an L (for lower mountain).

Methods of study for this project were divided into the following phases: (1) field reconnaissance, (2) data collection and laboratory analysis, (3) data interpretation, and (4) quality assurance/quality control. Field reconnaissance was performed during October 20–21, 1997, to select representative sites for sampling. Eighteen sampling sites at springs and streams on and around Monte Sano Mountain were identified (fig. 2; table 1). Fifteen of the sites were located hydrologically downgradient from residential areas on top of Monte Sano Mountain. Five sites were located in each of the three major units that were defined on the basis of land use, geology, and hydrogeology. Two springs and a seep, located in unpopulated areas on Huntsville Mountain, south of Monte Sano Mountain, were selected as background sites, and each was located within one of the three units: Pottsville-Pennington unit, Bangor-Monteagle unit, or the Tuscumbia unit.

Table 1. Site description and classification based on land use and geologic units
[ft, foot]

Site number (fig. 2)	Site description	Land use	Altitude (ft)	Geologic unit
		Pottsville-Pennington unit		
17T	Background	Forest	1,500	Pottsville Formation
8T	Subdivision/Monte Sano	Residential	1,570	Pottsville Formation
7T	Subdivision/Monte Sano	Residential	1,570	Pottsville Formation
6T	Television station	Residential/commercial	1,580	Pottsville Formation
9T	Coal mine	Residential/commercial	1,580	Pottsville Formation
1T	Cold Springs	Forest	1,480	Pennington Formation
		Bangor-Monteagle unit		
18M	Background	Forest	1,250	Bangor Limestone
11M	Subdivision/landslide	Forest/residential	1,410	Bangor Limestone
13M	CCC cistern	Forest	1,200	Bangor Limestone
5M	Bluff Line Trail	Forest	1,060	Monteagle Limestone
2M	Bluff Line Trail	Forest	1,050	Monteagle Limestone
10M	Blue Springs/ravine	Forest	900	Monteagle Limestone
		Tuscumbia unit		
16L	Background	Forest	740	Tuscumbia Limestone
12L	Subdivision/Huntsville	Forest/residential	800	Tuscumbia Limestone
3L	Fagan Springs	Forest	790	Tuscumbia Limestone
4L	Owens Drive	Forest/residential	720	Tuscumbia Limestone
15L	Big Cove Creek	Residential	660	Tuscumbia Limestone
14L	Blue Springs/Dug Hill Road	Forest/residential	660	Tuscumbia Limestone

Surface-water samples were collected for bacteriological and chemical analysis during January 29–31, 1998. Data-collection procedures at the 18 sites conformed to standard USGS protocol and included equal-width-increment (EWI) sampling. EWI sampling produces a composite sample that is representative of flow in a cross section. Sample collection and processing techniques that minimize contamination of water samples (Shelton, 1994) were used. Field measurements of stream discharge, air temperature, water temperature, pH, dissolved oxygen, and specific conductance were made at the time of sampling. Alkalinity and 5-day biochemical oxygen demand (BOD_5) were measured in the field by USGS personnel. Bacterial samples were processed within 6 hours of collection by membrane filtration techniques and were analyzed for fecal coliform and *E. coli* (Britton and Greeson, 1987; Myers and Wilde, 1997). Samples were analyzed for MBAS, EDTA, nitrite, nitrate, ammonia, phosphorus, chloride, total organic carbon, and 64 additional compounds that are wastewater indicators. EDTA samples were analyzed by Quanterra Environmental Services in Arvada, Colorado. All other chemical analyses were performed by the USGS National Water Quality Laboratory in Denver, Colorado. All samples were chilled to and maintained at 4 degrees Celsius (°C) until analyzed.

Fecal bacterial data obtained during the data-collection phase of the investigation were compared to established State and Federal standards and criteria for fecal bacterial levels to determine if a potential problem exists. Standards and criteria have been defined by the Federal government and the State of Alabama which set guidelines for bacterial concentrations according to water use (table 2). The USEPA has set a drinking-water standard of 0 col/100 mL for fecal coliform and *E. coli*. The USEPA and the Alabama Department of Environmental Management (ADEM) have established criteria for recreational water use that includes both primary body contact and secondary body contact. Primary body contact involves full-body contact such as swimming, canoeing, and scuba diving. Secondary body contact involves such activities as wading.

Criteria are based on the geometric mean of five samples taken within a 30-day timeframe. Only one sample was collected at each site during the synoptic sampling event. Therefore, it is not possible to ascertain that a definite water-quality problem exists based on the synoptic data.

The fecal bacterial levels and chemical concentrations at sites that represented residential land use also were compared to background sites to determine if residential land use could be associated with significantly elevated levels of the selected indicators. Sites were grouped together according to the major unit they drained and compared graphically.

Quality assurance and quality control measures were practiced throughout the study according to established USGS guidelines. The effectiveness of sterilization procedures for bacterial analyses was checked by processing a sterile water blank at each sampling site. A trip blank for chemical analyses also was submitted to the National Water Quality Laboratory in Denver to verify that no contamination occurred during sampling.

SEPTIC INDICATORS

Results of the investigation have been classified into separate sections: (1) bacterial indicators, (2) chemical indicators, and (3) discussion. Data are presented in graphical and tabular form and are grouped according to the appropriate unit based on land use, geology, and hydrogeology (table 1). Data from sites within a specific unit were compared to data obtained from background sites in the corresponding unit.

General water chemistry varied between units as seen by differences in alkalinity, pH, and specific conductivity (table 3). Specific conductivity ranged from 30 microsiemens per centimeter (µS/cm) at the top of the mountain (17T) to 501 µS/cm at the base of the mountain (16L). Alkalinity ranged from 8 milligrams per liter (mg/L) $CaCO_3$ (9T) to 226 mg/L $CaCO_3$ (12L), and pH ranged from 6.4 (9T) to 8.5 (4L). In general, specific conductivity and alkalinity were lowest at sites in the Pottsville-Pennington unit and increased at sites in the Bangor-Monteagle and Tuscumbia units due to the carbonate structure of the limestone.

Table 2. State and Federal standards and criteria for bacterial concentrations and selected organic contaminants in surface water

[col/100 mL, colony per 100 milliliters; µg/L, microgram per liter; >, greater than; mg/L, milligram per liter; PAH, polycyclic aromatic hydrocarbon]

Bacteria	Description and source	Drinking-water standard (col/100 mL)	Primary body contact (col/100 mL)	Secondary body contact (col/100 mL)	Aquatic toxicity (col/100 mL)
Fecal coliform	Bacteria derived from human and warm-blooded animal feces, but can occur in soils.	[a]0	[b]200 [d]400	[b]1,000 [d]2,000	[c]2,000
E. coli (*Escherichia coli*)	Bacteria derived predominantly from human and warm-blooded animal feces.	[a]0	[b]126 [d]235	none [d]576	none
Organic constituent	**Description and source**	**Drinking-water standard (µg/L unless noted)**	**Primary body contact**	**Secondary body contact**	**Aquatic toxicity (µg/L)**
MBAS (Methylene blue active substances)	Synthetic and natural anionic surfactants. Source is predominantly from domestic sewage effluent.	[e,f]500	none	none	[f]250
LAS (Linear alkylbenzenesulfonate)	Specific synthetic anionic surfactants. Source is domestic sewage effluent.	none	none	none	[f]25
EDTA (Ethylenediaminetetraacetic acid)	Synthetic chemical derived predominantly from domestic sewage and industrial effluents.	none	none	none	>1,000
Nitrate (NO_3)	Elevated levels of this nutrient commonly indicate sewage effluent or agricultural effects.	10 mg/L	none	none	none
Nitrite (NO_2)	Elevated levels of this nutrient commonly indicate sewage effluent or agricultural effects.	1 mg/L	none	none	none
TOC (Total organic carbon)	All natural and synthetic organic compounds.	none	none	none	none
Caffeine	Component of beverages, food products, and medications. Source is domestic sewage effluent.	none	none	none	none
Benzo[*a*]pyrene	Sources of this PAH include sewage effluent, fires, and asphalt.	[g,h].2	none	none	none

[a]Actual standard of the U.S. Environmental Protection Agency (1994) is that no more than one sample per month (sampled daily) may be positive for total coliforms, of which fecal coliform and *E. coli* are a subgroup.

[b]Bacterial concentration is the geometric mean of not less than five samples taken over a 30-day period.

[c]Fish and Wildlife criteria established by Alabama Department of Environmental Management (1994).

[d]Bacterial density that cannot be exceeded in 10 percent of the samples collected over a 30-day period.

[e]U.S. Environmental Protection Agency, 1994.

[f]Barber and others, 1995.

[g]U.S. Environmental Protection Agency, 1996.

[h]World Health Organization proposed a guideline limit of 0.01 µg/L for drinking water in 1984 (Dojlido and Best, 1993).

Table 3. Summary of selected field water-quality properties and bacterial and chemical constituents for streams and springs on and around Monte Sano Mountain, January 29–31, 1998

[ft, foot; ft^3/s, cubic foot per second; µS/cm, microsiemens per centimeter; mg/L, milligram per liter; °C, degrees Celsius; col/100 mL, colony per 100 milliliters; MRL, minimum reporting limit; µg/L, microgram per liter; MBAS, methylene blue active substances; EDTA, Ethylenediaminetetraacetic acid; TOC, total organic compound; <, analytes which have not been detected (followed by the MRL determined during the provisional method detection limit study); E, definite detection, estimated quantity below MRL; —, no data]

Site number (fig. 2)	Site description	Field water-quality properties									Bacterial constituents		Chemical constituents							
		Altitude (ft)	Discharge (ft^3/s)	Specific conductivity (µS/cm)	pH	Alkalinity (mg/L $CaCO_3$)	Air temperature (°C)	Water temperature (°C)	Dissolved oxygen (mg/L)	Dissolved oxygen, percent saturation	*E. coli* (col/100 mL)	Fecal coliform (col/100 mL)	Nitrogen, nitrite plus nitrate dissolved (mg/L as N) MRL=0.05	Nitrogen, ammonia dissolved (mg/ L as N) MRL = 0.02	Phosphorus total (mg/L as P) MRL =0.010	Chloride dissolved (mg/L as Cl) MRL=0.1	Caffeine (µg/L) MRL=0.08	MBAS (mg/L) MRL=0.02	EDTA (mg/L) MRL=0.05	TOC (mg/L) MRL=0.1
	Pottsville-Pennington unit																			
17T	Background	1,500	0.02	30	6.8	9	9.3	9.7	6.6	61	[a]<2	[b]<2	0.171	<0.02	0.019	0.99	<0.08	<0.02	<0.05	0.3
8T	Subdivision/top of mountain	1,570	.09	109	6.6	28	14.0	12.3	9.5	94	170	250	1.180	<.02	<.010	5.20	E.024	<.02	<.05	1.2
7T	Subdivision/top of mountain	1,570	.08	149	7.2	51	14.2	11.8	8.8	86	160	380	.961	<.02	<.010	5.60	<.08	<.02	<.05	1.4
6T	Television station	1,580	.01	290	7.1	117	12.0	11.0	7.6	73	8	12	1.400	.034	<.010	11.00	<.08	<.02	<.05	1.3
9T	Coal mine	1,580	.02	99	6.4	8	9.1	12.9	7.5	75	50	48	1.630	<.02	<.010	—	<.08	<.02	<.05	.6
1T	Cold Springs	1,480	.23	182	7.6	52	6.2	11.2	10.5	101	53	9	2.050	<.02	<.010	5.30	<.08	<.02	<.05	1.0
	Bangor-Monteagle unit																			
18M	Background	1,250	.16	133	8.0	59	11.6	13.2	10.3	103	5	20	.059	<.02	<.010	1.10	<.08	<.02	<.05	.9
11M	Subdivision/landslide	1,410	.02	155	7.9	76	14.7	9.2	7.7	71	5	8	1.660	<.02	<.010	6.50	<.08	<.02	<.05	1.3
13M	CCC cistern	1,200	.03	169	7.6	107	5.7	11.6	8.9	87	—	—	1.610	<.02	<.010	5.30	<.08	<.02	<.05	.7
5M	Bluff Line Trail	1,060	.05	311	7.9	141	18.2	9.3	10.2	94	8	10	.966	<.02	<.010	2.70	<.08	<.02	<.05	.9
2M	Bluff Line Trail	1,050	.03	317	8.0	138	14.2	12.0	9.5	94	8	10	1.540	<.02	<.010	5.40	<.08	<.02	<.05	1.2
10M	Blue Springs/ravine	900	.25	277	8.3	130	2.7	11.9	9.3	88	6	8	1.010	<.02	<.010	2.00	<.08	<.02	<.05	.8
	Tuscumbia unit																			
16L	Background	740	.01	501	8.3	139	10.5	13.1	9.6	94	3	4	.217	<.02	<.010	1.40	<.08	<.02	<.05	1.3
12L	Subdivision/Huntsville	800	.03	414	8.4	226	.7	6.4	12.0	103	1,100	3,100	<.05	<.02	<.010	1.60	<.08	<.02	<.05	1.3
3L	Fagan Springs	790	.73	387	7.8	189	2.2	11.6	9.8	95	6	16	.923	<.02	<.010	3.90	<.08	<.02	<.05	1.5
4L	Owens Drive	720	.72	392	8.5	196	4.7	8.0	10.6	95	4	10	.710	<.02	<.010	3.30	<.08	<.02	<.05	1.4
15L	Big Cove Creek	660	.01	230	7.6	113	6.0	5.9	10.4	86	7	10	.057	<.02	<.010	2.60	<.08	<.02	<.05	.9
14L	Blue Springs/Dug Hill Road	660	3.48	320	7.6	157	4.8	13.0	8.2	80	10	16	.704	<.02	<.010	2.10	<.08	<.02	<.05	.7

[a]*E. coli* colonies were not detected; when calculated according to USGS protocol, values are recorded as <2.
[b]Fecal-coliform colonies were not detected; when calculated according to USGS protocol, values are recorded as <2.

Bacterial Indicators

Surface-water samples were collected and analyzed for *E. coli* and fecal-coliform concentrations at each of the 18 sites. Bacterial data for the sites are presented in table 3 and figure 5. At background sites 17T and 18M, *E. coli* concentrations ranged from < 2 col/100 mL to 5 col/100 mL, and fecal-coliform concentrations ranged from < 2 col/100 mL to 20 col/100 mL. At the other sites, *E. coli* concentrations ranged from 4 col/100 mL (4L) to 1,100 col/100 mL (12L), and fecal-coliform concentrations ranged from 8 col/100 mL (10M and 11M) to 3,100 col/100 mL (12L).

Concentrations of *E. coli* and fecal coliform exceeded the drinking-water standard of 0 col/100 mL at all sites except background site 17T. Criteria for primary body contact were exceeded at sites 8T and 7T in the subdivision on top of Monte Sano Mountain in the Pottsville-Pennington unit. At sites 8T and 7T, *E. coli* concentrations were 170 col/100 mL and 160 col/100 mL, and fecal-coliform concentrations were 250 col/100 mL and 380 col/100 mL, respectively. Four of the five sites (8T, 7T, 9T, 1T) in the Pottsville-Pennington unit had *E. coli* concentrations that were more than 25 times the background level (site 17T); three of these sites (8T, 7T, 9T) also had fecal-coliform concentrations that were 25 times the background level. These sites were located in areas with the highest concentration of residential land use. In contrast, with the exception of one site (12L), *E. coli* and fecal-coliform concentrations in the Bangor-Monteagle unit and the Tuscumbia unit were at or near background levels. *E. coli* and fecal-coliform concentrations at the top of the mountain were one to two orders of magnitude greater than those at the lower elevations, with the exception of site 12L.

The highest concentrations of *E. coli* (1,100 col/100 mL) and fecal coliform (3,100 col/100 mL) were noted at site 12L. This site was located in the valley below Monte Sano Mountain in the Tuscumbia unit near a subdivision within the city of Huntsville. The criteria for recreational use at this site were exceeded for both primary and secondary body contact. It is not known why the concentrations were so high at this particular site, nor is it possible to elaborate about the origin of the bacteria without additional sampling. However, these values may be outliers that were affected by a localized source.

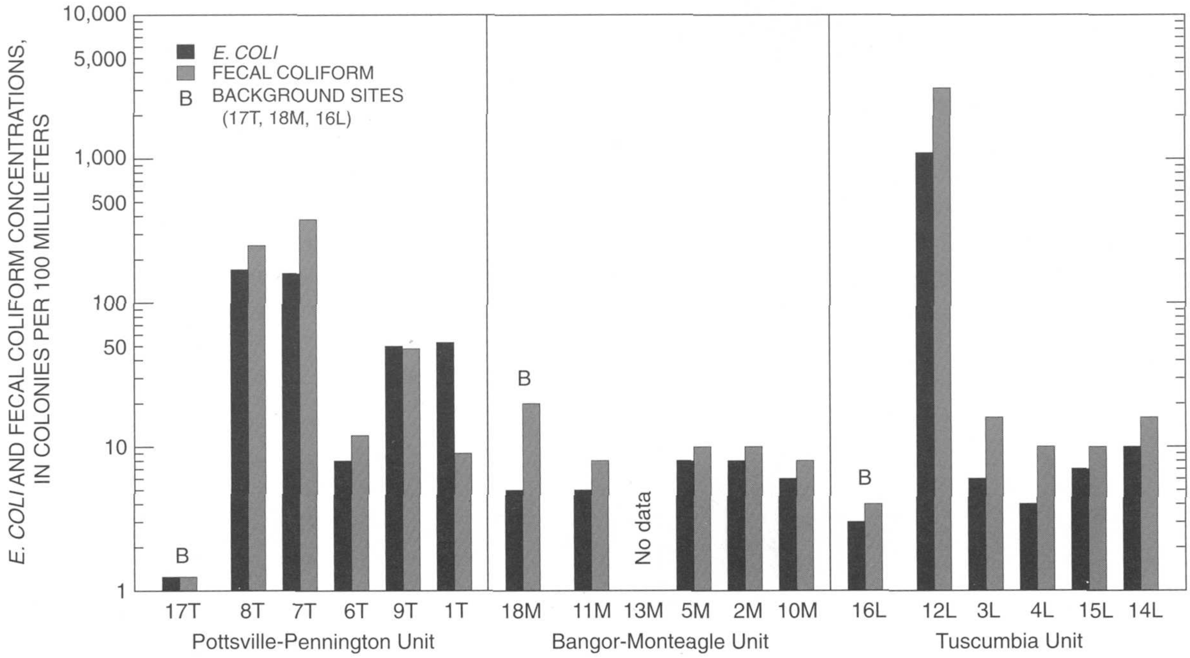

Figure 5. *E. coli* and fecal-coliform concentrations at selected sites on and around Monte Sano Mountain, Alabama, January 29–31, 1998.

Chemical Indicators

Samples were analyzed for inorganic compounds which might be present from septic tank systems, including nitrogen, chloride, and phosphorus (table 3). Samples also were analyzed for specific and nonspecific chemical indicators of wastewater effluent including MBAS, EDTA, and 64 organic compounds (table 4). Compounds listed in table 4 are highlighted if they were detected at any site.

Nutrients

Elevated levels of nitrogen can be associated with domestic sewage effluent. The two major forms of nitrogen which are usually of concern include ammonium ions and nitrate (Cantor, 1985). Nitrate and nitrite are formed from the nitrification of ammonium ions. Common sources of nitrate in ground water include nitrate and ammonia fertilizer, sewage waste from septic tanks, animal waste, and decaying vegetation (Carmichael and Bennett, 1993). High levels of nitrate and nitrite in drinking water can cause serious health problems, especially if the water is ingested by infants. Therefore, maximum contaminant levels (MCL's) of 1 milligram per liter (mg/L) and 10 mg/L have been established for nitrite and nitrate, respectively, by the USEPA (table 2).

Concentrations of nitrite plus nitrate at the background sites were significantly lower than concentrations at other sites (fig. 6A; table 3). The greatest variation was seen at sites located in the Pottsville-Pennington unit on top of Monte Sano Mountain where concentrations ranged from 0.171 mg/L at the background site (17T) to 2.05 mg/L at Cold Springs (1T). A similar pattern was noted in the Bangor-Monteagle unit. Concentrations ranged from 0.059 mg/L at the background site (18M) to 1.66 mg/L at site 11M. In the Tuscumbia unit, two sites (12L and 15L) had concentrations of nitrite plus nitrate that were lower than the background site. Concentrations ranged from <0.05 mg/L at site 12L to 0.923 mg/L at Fagan Springs (3L), as compared to 0.217 mg/L at the

Table 4. Specific and nonspecific chemical indicators of wastewater contamination

[**Highlighted** compounds were detected]

Specific indicators of wastewater contamination	Nonspecific indicators of wastewater contamination	
Methylene blue active substances/	Acenaphthene	2,6-Di *tert* butylphenol
linear alkylbenzenesulfonate	Acenaphthylene	2,6-Di *tert* para benzoquinone
Ethylenediaminetetraacetic acid	Acetophenone	Dieldrin
Nonylphenol ethoxylate 1-total	Anthracene	D-limonene
Nonylphenol ethoxylate 2-total	Atrazine	**Fluoranthene**
Nonylphenol-total	Benzaldehyde	Fluorene
Caffeine	**Benzo[*a*]anthracene**	**Indeno[1,2,3-*c,d*]pyrene**
17B-estradiol	**Benzo[*a*]pyrene**	Lindane
3B-coprostanol	**Benzo[*b*]fluoranthene**	1-Methylnaphthalene
Cholesterol	**Benzo[*g,h,i*]perylene**	2-Methylnaphthalene
	Benzo[*k*]fluoranthene	Methyl parathion
	Bis (2-ethylhexyl) adipate	Metochlor
	Bis (2-ethylhexyl) phthalate	Naphthalene
	Bisphenol A	dichlorodiphenyldichloroethylene
	2-Butoxy-phosphate ethanol	**Paracresol**
	2-(2-Butoxyethoxy) ethanol	Phenanthrene
	2-(2-Butoxyethoxy) ethyl acetate	Phenol
	Butylated hydroxytoluene	Phthalic anhydride
	Butylated hydroxyanisole	**Pyrene**
	Carbaryl	Simazine
	Chlorpyrifos	Tetrachloroethylene
	Chrysene	*trans*-Chlordane
	cis-Chlordane	Tri (2-chloroethyl) phosphate
	Dimethyl-2,3,5,6-tetrachloroterephthalate	Tri (dichlorisopropyl) phosphate
	Diazinon	Tribromomethane
	Dibenzo[*a,h*]anthracene	Tributyl phosphate
	1,2-Dichlorobenzene	1,2,4-Trimethylbenzene
	1,3-Dichlorobenzene	Triphenyl phosphate
	1,4-Dichlorobenzene	

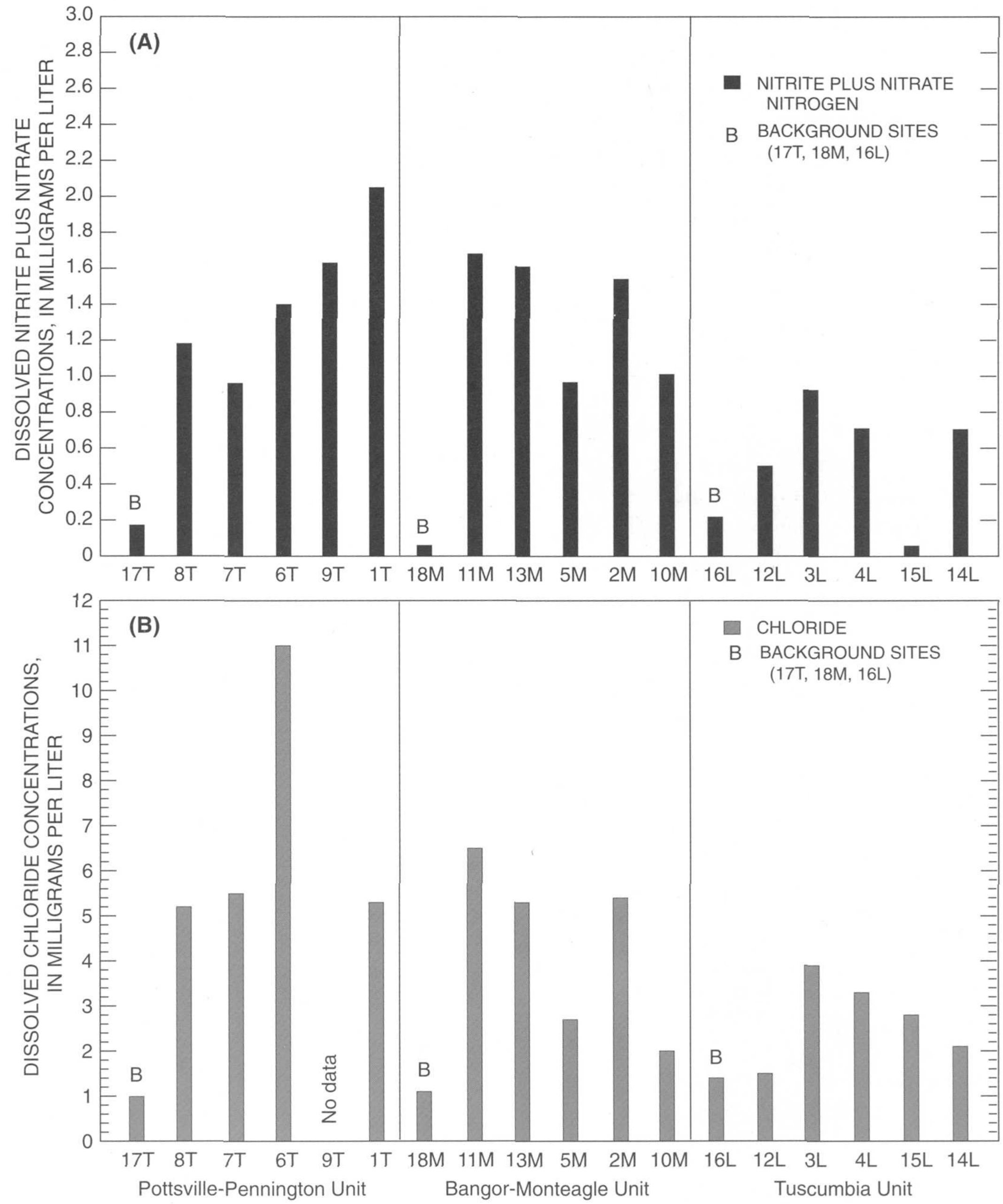

Figure 6. **(A)** Dissolved nitrite plus nitrate and **(B)** dissolved chloride concentrations at selected sites on and around Monte Sano Mountain, Alabama, January 29–31, 1998.

background site (16L). Although the MCL's for nitrate were not exceeded in the streams and springs at Monte Sano Mountain, the pattern noted between the background sites and human-influenced sites is significant because high nitrate levels are one of the most common indicators of ground-water quality degradation associated with human activity.

Levels of ammonium ions were below the minimum reporting limit (MRL) of 0.02 mg/L at all sites except for 6T, which had a concentration of 0.034 mg/L (table 3). Ammonium ions are less mobile than nitrate ions in both saturated soil and unsaturated soil (Cantor, 1985).

Phosphorus is widely distributed in rocks, minerals, plants, and animals (Dojlido and Best, 1993). Although phosphorus is a component of sewage, it is usually not transported through the soil to ground water. Phosphorus is easily retained in the underlying soils due to chemical changes and adsorption. Typically, low concentrations of phosphorus are introduced into ground water from septic tank effluent (Cantor, 1985). All concentrations of phosphorus were below the MRL (0.010 mg/L) except for a background site (17T) that had a concentration of 0.019 mg/L (table 3).

Chloride

Chloride is present in certain geologic formations as well as in precipitation (Hem, 1985). Chloride may enter a stream system from precipitation, the leaching of various rock formations, runoff from salted roads during the winter, or by the transport of ocean spray in coastal areas (Meybeck, Chapman, and Helmer, 1990). Chloride also occurs in plants and animals; human urine contains chloride (Dojlido and Best, 1993). Due to its anionic form and mobility within the water phase, chloride can be useful as an indicator of septic tank system pollution (Cantor, 1985).

Chloride levels exhibited a pattern similar to nitrite plus nitrate (fig. 6B). Levels of chloride at the background sites were significantly lower than levels at all other sites (table 3). This pattern was most pronounced in the Pottsville-Pennington unit on top of Monte Sano Mountain but is evident within the Bangor-Monteagle unit and the Tuscumbia unit as well. Chloride levels in the Pottsville-Pennington unit ranged from 0.99 mg/L at the background site (17T) to 11.0 mg/L at the television station (6T). Concentrations in the Bangor-Monteagle unit ranged from 1.1 mg/L at the background site (18M) to 6.5 mg/L at site 11M, and within the Tuscumbia unit, concentrations ranged from 1.4 mg/L at the background site (16L) to 3.9 mg/L at Fagan Springs (3L).

Caffeine

Caffeine (1,3,7-trimethylxanthine) is a stimulant chemical contained in many beverages, such as coffee and soft drinks, and in a variety of food products. Caffeine is considered a specific indicator of human sewage when present in water. Caffeine was detected at one site (8T) in a subdivision on top of Monte Sano Mountain in the Pottsville-Pennington unit (table 3). This detection is significant because site 8T also had one of the highest concentrations of *E. coli* and fecal-coliform bacteria.

MBAS, LAS, and EDTA

MBAS is an anionic surfactant, composed of synthetic LAS (linear alkylbenzenesulfonate), LAS biological metabolites and impurities, synthetic anionic surfactants, and naturally occurring compounds such as humic substances (Barber and others, 1995). There were no detections of anionic surfactants such as MBAS or LAS at any of the sites.

EDTA is a synthetic chemical widely used as a stabilizer for bleaching agents in laundry detergents. It was not detected at any of the sites.

Polycyclic Aromatic Hydrocarbons and Paracresol

Polycyclic (or polynuclear) aromatic hydrocarbons (PAH's) are formed during combustion processes and may enter surface-water systems in a variety of ways, including atmospheric deposition, surface runoff, and soil leaching (Smith, Witkowski, and Fusillo, 1988). Several PAH's have been identified as carcinogens or mutagens. Sources of PAH's include domestic sewage, asphalt surfaces, car tires, vehicular exhaust, crude oil, and petroleum (Dojlido and Best, 1993). In general, PAH's of higher molecular weights are more resistant to biodegradation than PAH's of lower molecular weight (Smith, Witkowski, and Fusillo, 1988). Both types of PAH's were identified at Monte Sano Mountain.

PAH's were detected at four sites (1T, 12L, 3L, 15L) (table 5). The greatest number of PAH's were detected at Cold Springs (1T) and Fagan Springs (3L) where 10 different hydrocarbons were detected at each site. Specific compounds and MRL's are presented in table 5. Standards and criteria have been established for benzo[*a*]pyrene and are listed in table 2.

Paracresol is a compound that is frequently used for wood preservation (Dojlido and Best, 1993). Paracresol has also been reported in domestic sewage (Verschueren, 1983), but it tends to biodegrade quickly (Howard, 1991). Paracresol was detected in the Pottsville-Pennington unit on top of the mountain at four sites (8T, 7T, 6T, 9T) (table 5).

Total Organic Carbon

Total organic carbon (TOC) is a measure of the dissolved and particulate forms of organic carbon in a water sample. Organic material may enter a stream system from a variety of sources, both natural (decaying leaves) and human (sewage). Concentrations

Table 5. Summary of selected organic compounds detected in streams and springs on and around Monte Sano Mountain, January 29–31, 1998

[MRL, minimum reporting limit; all measurements are µg/L, micrograms per liter; <, analytes that have not been detected (followed by the MRL determined during the provisional method detection limit study); E, definite detection, estimated quantity below MRL]

Site number (fig. 2)	Site description	Paracresol MRL=0.03	Benzo[a] anthracene MRL=0.06	Chrysene MRL=0.06	Fluoranthene MRL=0.03	Pyrene MRL=0.03	Benzo[b] fluoranthene MRL=0.05
	Pottsville-Pennington unit						
17T	Background	<0.03	<0.06	<0.06	<0.03	<0.03	<0.05
8T	Subdivision/top of mountain	E.015	<.06	<.06	<.03	<.03	<.05
7T	Subdivision/top of mountain	E.011	<.06	<.06	<.03	<.03	<.05
6T	Television station	E.020	<.06	<.06	<.03	<.03	<.05
9T	Coal mine	.034	<.06	<.06	<.03	<.03	<.05
1T	Cold Springs	<.03	.061	E.055	E.020	E.020	.082
	Bangor-Monteagle unit						
18M	Background	<.03	<.06	<.06	<.03	<.03	<.05
11M	Subdivision/landslide	<.03	<.06	<.06	<.03	<.03	<.05
13M	CCC cistern	<.03	<.06	<.06	<.03	<.03	<.05
5M	Bluff Line Trail	<.03	<.06	<.06	<.03	<.03	<.05
2M	Bluff Line Trail	<.03	<.06	<.06	<.03	<.03	<.05
10M	Blue Springs/ravine	<.03	<.06	<.06	<.03	<.03	<.05
	Tuscumbia unit						
16L	Background	<.03	<.06	<.06	<.03	<.03	<.05
12L	Subdivision/Huntsville	<.03	<.06	<.06	.033	.031	<.05
3L	Fagan Springs	<.03	E.054	E.045	.039	.049	.060
4L	Owens Drive	<.03	<.06	<.06	<.03	<.03	<.05
15L	Big Cove Creek	<.03	.081	.12	<.03	<.03	.22
14L	Blue Springs/Dug Hill Road	<.03	<.06	<.06	<.03	<.03	<.05

of TOC ranged from 0.3 mg/L (17T) to 1.5 mg/L (3L) (table 3). There were no significant differences noted between concentrations at background sites or human-influenced sites. No pattern was evident upon examination of these data. All of the sites were located within forested areas.Therefore, natural sources may account for the TOC concentrations identified in the surface water.

Discussion

Several patterns have been identified from the data collected during this synoptic sampling event at Monte Sano Mountain. To interpret these data effectively, it is necessary to examine these patterns collectively. Some of the constituents that showed definite variations between the background sites and human-influenced sites at Monte Sano Mountain included *E. coli*, fecal coliform, nitrite plus nitrate, and chloride.

E. coli concentrations were more than 25 times the background level at four of the five sites located in the Pottsville-Pennington unit; fecal-coliform concentrations were more than 25 times the background level at three of the five sites in this unit. In contrast, with the exception of one site, *E. coli* and fecal-coliform concentrations in the Bangor-Monteagle unit and the Tuscumbia unit were at or near background levels. Caffeine was detected at one site in the Pottsville-Pennington unit that had the second highest *E. coli* concentration measured in this study. Concentrations of nitrite plus nitrate and chloride at human-influenced sites were significantly higher than at background sites. This pattern was most pronounced in the Pottsville-Pennington unit on top of Monte Sano Mountain near residential areas.

Caffeine was the only compound detected that is a specific indicator of septic tank effluent. The detection of caffeine in combination with the occurrence of nonspecific indicators, such as chloride, nitrite plus nitrate, PAH's, and paracresol, and the corresponding association with elevated bacteria levels, strengthens the assumption that the source of ground-water contamination is most likely septic tank effluent.

This synoptic investigation provided a one-time look at bacterial and chemical indicators in the shallow ground water on Monte Sano Mountain during a period of high baseflow with no surface runoff. Concentrations of these indicators may vary with different hydrologic conditions or seasons. As researchers become more familiar with new methodologies and analytical detection levels improve, more definite conclusions can be drawn as to the source of fecal bacterial contamination in ground water.

SUMMARY

The U.S. Geological Survey conducted a synoptic investigation of fecal bacterial pollution in headwater streams and springs on Monte Sano Mountain, a sandstone-capped plateau near Huntsville, Alabama. The investigation was designed to evaluate new methods for tracing sewage effluent and to enhance previous studies conducted by local agencies that detected fecal-coliform bacteria in ground water, streams, and springs. Surface-water samples were analyzed for fecal-coliform levels in combination with more human-specific bacterial (*E. coli*) and chemical (caffeine and detergents) indicators to better define the degree to which faulty septic tanks may have served as the fecal bacterial source.

A total of 18 sites were sampled over a 3-day period in late January 1998. Fifteen of the sites were located hydrologically downgradient from residential areas on top of Monte Sano Mountain. Three additional sites were selected as background sites in unpopulated areas on Huntsville Mountain, south of Monte Sano Mountain. Sampling was conducted during a period of high baseflow after a recent storm when no surface runoff was present. Any contaminants identified in the streams and springs were likely derived from ground-water discharge because overland flow was not evident.

To accurately analyze the data, the sites which drain Monte Sano Mountain were separated into three groups based on land use, geology, and hydrogeology. The Pottsville Formation and Pennington Formation, composed primarily of sandstone and shale, were combined to form the Pottsville-Pennington unit that drains the flat top of the mountain and has the highest concentration of residential land use. The Bangor Limestone and the Monteagle Limestone, both carbonate formations, were combined to form the Bangor-Monteagle unit, which drains the steeply sloping, forested sides of the mountain. The Tuscumbia Limestone, also carbonate, forms the Tuscumbia unit, which drains the base of the mountain and the valley floor.

Four of the five sites located in the Pottsville-Pennington unit had *E. coli* concentrations that were more than 25 times the background level. Two of those four sites had concentrations that exceeded the primary body contact level recommended in the recreational use criteria established by ADEM. In contrast, with the exception of one site, *E. coli* concentrations in the Bangor-Monteagle unit and the Tuscumbia unit were at or near background levels and well below recreational use criteria. Caffeine also was detected at one site in the Pottsville-Pennington unit that had *E. coli* concentrations near the primary body contact criteria levels. Elevated nitrite plus nitrate and chloride concentrations also were identified at sites in the Pottsville-Pennington unit.

The results of this synoptic sampling event identified elevated fecal bacterial concentrations in the Pottsville-Pennington unit that indicated a potential water-quality problem related to discharge from the shallow ground-water system. These elevated fecal bacterial concentrations occurred in conjunction with caffeine detection at one site and with elevated chloride and nitrite plus nitrate concentrations at all sites within the Pottsville-Pennington unit. These sites are located in close proximity to residential development, indicating that the most probable source of the elevated fecal bacterial concentrations was septic tank effluent.

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