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Microbiological and Chemical Quality of Ground Water used as a Source of Public Supply in Southern Missouri—Phase II, April–July, 1998

Water-Resources Investigations Report 00–4260

Prepared in cooperation with the
Missouri Department of Natural Resources,
Division of Environmental Quality,
Public Drinking Water Program

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

Cover Photograph: Water tower at the city of Crane's well number 1, Christiana Avenue and Main Street

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Rolla, Missouri
2000

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For additional information write to:

District Chief
U.S. Geological Survey, WRD
1400 Independence Road
Mail Stop 100
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ABSTRACT

The protection of public health through quality public ground-water systems is the responsibility of the U. S. Environmental Protection Agency and the State of Missouri, through the Missouri Department of Natural Resources, Public Drinking Water Program. Approximately 95 percent of the public-water supplies in Missouri use ground water as their source of drinking water through more than 3,700 public wells. Karst terrain, intensive agricultural operations, extensive numbers of on-site sewage systems, and poor well construction can lead to chemical and microbiological contamination of the contributing aquifers. Site-specific studies and routine regulatory monitoring have produced information on the overall quality and potability of the State's public-drinking-water supplies, but little is known about the presence of viruses.

The U.S. Geological Survey, in cooperation with the Missouri Department of Natural Resources, sampled 109 public-water supplies to characterize the physical, chemical, bacterial, and viral conditions in southern Missouri. During April to July 1998, these wells were sampled for nutrients, total organic carbon, optical brighteners, indicator bacteria, enteric viruses, and ribonucleic acid and somatic coliphages. These constituents indicate possible surface contamination of the sampled aquifer. Selection of the wells to be sampled depended on the age of the well (pre-1970), land use, geohydrology, and well construction.

None of the physical or chemical constituents measured or analyzed exceeded Missouri's Drinking Water Standards set by the Public Drinking Water Program of the Missouri Department of Natural Resources. The majority of ammonia plus organic nitrogen, nitrite, and phosphorus concentrations were below the laboratory's minimum reporting levels. There were a greater number of detects above the minimum reporting level with respect to the nitrite plus nitrate, ammonia, orthophosphate, and total organic carbon concentrations. Analyses included comparing and contrasting the data by grouping according to well age and construction, karst type, geohydrology, soil type, and land use. There was little variation in well construction between selected wells. The results indicated several groupings of similar and dissimilar concentrations, most expected because of hydrological, physical, or land use differences. Dissolved oxygen values indicated distinct variation in the different groupings. There were significant differences in dissolved oxygen values between the secondary and non-karst areas, the Ozark confined and Ozark unconfined geohydrologic groups, and between agricultural and other land uses. In groupings by soil and geohydrology, the Missouri bootheel region differed with respect to ammonia, total organic carbon, and phosphorus when compared with the other groups.

Less than 10 percent of the wells sampled tested positive for bacterial contamination. *E. coli* was the most frequently detected bacterium. The public wells at Monett and West Plains, Missouri,

had plates with colonies too numerous to count for all three indicator bacteria. Further analyses by rRNA (**r**ibosomal **R**ibo**N**ucleic **A**cid) hybridization techniques determined that much of the bacteria present were from ruminant and human sources. No enteric viruses were detected in the 109 samples. Both ribonucleic acid and somatic coliphage were detected at two wells. One additional well had ribonucleic acid coliphage and another had somatic coliphage for a total of four wells with coliphage selects.

INTRODUCTION

The U.S. Environmental Protection Agency (USEPA) and the Missouri Department of Natural Resources, Public Drinking Water Program (MDNR-PDWP) have the responsibility to address public ground-water systems to assure the protection of public health. Section 1412(b)(1)(A) of the Safe Drinking Water Act requires that National Primary Drinking Water Regulations be established for contaminants that may have detrimental effects on public health. This requirement, along with an additional requirement under Section 1412(b)(8) that specifies that the USEPA develop regulations for the use of disinfectants for ground-water systems as needed, has prompted the development of a Ground Water Rule (GWR). The GWR is a method to prioritize drinking-water supplies by their vulnerability to be contaminated by pathogenic microorganisms. In Missouri, residents and commercial operations are greatly dependent on ground water as a clean source of drinking water. Approximately 95 percent of the public-water supplies in Missouri use ground water as their source of drinking water through more than 3,700 public wells. Karst terrain, intensive agricultural operations, extensive numbers of on-site sewage systems, and poor well construction can lead to chemical and microbiological contamination of the contributing aquifers. State resource managers are concerned about the impact of these conditions on the microbiological and chemical quality of the ground water in the State. Currently (1999), much is known about the status of bacterial contamination of the public-water supplies through studies and monitoring efforts, but little is known about viral contamination or the effects of leaking septic systems on the contributing aquifers. Virus populations fluctuate with the natural conditions of aquifers, which tend to make their detection a hit-or-miss opportunity.

Since the early 1900's, drinking water disinfection has been used to decrease the risks of waterborne pathogens. Widespread outbreaks of typhoid fever, cholera, and other bacterial diseases prompted the need to disinfect drinking-water supplies. Enteric viruses have caused epidemics, even when the drinking water has met all of the water-quality standards for coliform bacteria, turbidity, and chlorine residuals. Results from a recent study of gastroenteritis suggested that drinking water was responsible for one-quarter to one-third of all such illnesses reported, even though the drinking water met all required standards (Sobsey, 1995). Animal or human sewage or pasture runoff can contain detrimental microorganisms such as *E. Coli*, *Salmonella*, and enteric viruses, and can cause gastroenteritis.

Enteric viruses are indicators of materials associated with the digestive tract such as sewage. Viruses are composed of genetic material that survive and reproduce by attacking or invading other living cells. As they take over another cell, they destroy the original cell's genetic material and replace it with its own. This ability enables the viruses to survive and flourish. Coliphages are viruses that infect coliform bacteria specifically. Two types of coliphages are RNA (ribonucleic acid) coliphage (also know as Male Specific), and somatic coliphage. These coliphages differ in how they infect the host bacteria. The RNA coliphage infects the bacteria cells by entering through the sex pili; the somatic coliphage enters the cells through the cell wall.

The U.S. Geological Survey (USGS), in cooperation with the MDNR-PDWP, has completed two phases of a study to characterize the bacterial and viral conditions in the ground water of southern Missouri. The first phase (Phase I) of the study is documented in Davis and Witt (1999). The data from the two sampling periods of the Phase I study indicate that microbiological contamination of public-water-supply wells drilled after 1970 is not widespread in the Ozark Plateaus. A small percentage (10 to 14) of the wells sampled in Phase I are contaminated by potentially pathogenic viruses or other pathogen indicator organisms. Also, results from the two periods of sampling varied considerably. More than a single sampling opportunity is needed to definitively address the presence or lack of viruses in the drinking-water-supply aquifers.

The objectives of the Phase II study were to determine if the chemical and microbiological quality of the ground water is affected by land use, soil, geohydrology, karst type, well construction or well age; to use optical brighteners as an indicator of onsite sewage migration to the sampled aquifer; the effectiveness of the USEPA Ground Water Disinfection Rule (GWDR) Vulnerability Assessment Plan (VAP) (U.S.Environmental Protection Agency, written commun., 1998) to categorize wells into vulnerability classes; and the type of microbiological contamination in affected wells.

The purpose of this report is to describe the study and to present the data, analyses, and conclusions derived from the data collected for this study. This report includes a description of the study area and sampling network, design, and methods. Also included are discussions of the chemical and physical data, the use of optical brighteners as a detection method, microbiological data, and the usefulness of the VAP in southern Missouri.

During this second phase (Phase II) of the study, 109 public-water-supply wells were sampled to characterize the physical, chemical, bacterial, and viral conditions in southern Missouri (table 1, at the back of this report). These wells were sampled from April to July 1998 for nutrients, total organic carbon, optical brighteners, indicator bacteria, enteric viruses, and RNA and somatic coliphages. The presence of these constituents indicate possible surface contamination of the sampled aquifer. Selection of the wells to be sampled depended on well age, land use, geohydrology, and well construction. Phase II studied older wells, drilled before 1970, to determine if age and construction would contribute to susceptibility to surface contamination.

DESCRIPTION OF STUDY AREA

The study area is located in the southern one-half of Missouri and consists of parts of three major physiographic provinces (fig. 1). The Ozark Plateaus is the dominant physiographic province in southern Missouri. The Mississippi Alluvial Plain physiographic section of the Coastal Plain Province is located in the southeastern part of the State (Missouri "bootheel"). The Osage Plains physiographic section of the Central Lowland province is located in the western part of the State. These three provinces encompass diverse topography, geology, and hydrology.

The Ozark Plateaus province is the largest in the study area and consists of three distinct physiographic sections—the Springfield Plateau, the Salem Plateau, and the St. Francois Mountains. Topography in the province ranges from nearly level to steeply rugged hills. The stream drainage patterns are radial and tend to follow geologic features such as faults and joints in the rocks. The Ozark Plateaus province is riddled with karst features such as cave systems, sinkholes, and natural tunnels. These features are formed by the dissolution of carbonate rocks along faults and fractures. The karst features allow effective interconnection between the land surface and ground water.

The Mississippi Alluvial Plain physiographic section lies in the southeastern part of the study area. This section has a flat to gently rolling terrain of unconsolidated sediments. The stream drainages mostly are a complex network of channelized streams and ditches that drain swampy areas. The rich unconsolidated sediments and drained swampland lend this region to large-scale agricultural activities.

The Osage Plains physiographic section lies in the western and northwestern part of the study area. The topography of this section is mostly gently rolling hills and broad, shallow valleys.

Geology

The Ozark Plateaus province is an area of diverse geology. The province is in an area of geologic uplift that rises above surrounding lowlands (Imes and Emmett, 1994). Lithologies include igneous and sedimentary rocks with secondary mineralization, fracturing, and faulting of the rock units. Layers of mostly dolomite and limestone sedimentary rocks of Paleozoic age overlie the basement crystalline rocks of Precambrian age. Some areas have sandstones and shales as the uppermost strata (Adamski and others, 1994).

The Salem Plateau is an area where Ordovician and Upper Cambrian rocks are exposed. These units are composed predominantly of dolomites, cherty dolomites, sandstones, and limestones (Caplan, 1960). The geologic units of Cambrian and Ordovician age range in thickness from less than 50 feet (ft) to greater than 4,000 ft thick, and average about 2,000 ft thick (Adamski and others, 1994).

The Springfield Plateau generally coincides with the area where Mississippian-aged rocks are exposed. The predominant rocks of Mississippian age are fine to coarse-grained limestones and cherty limestones

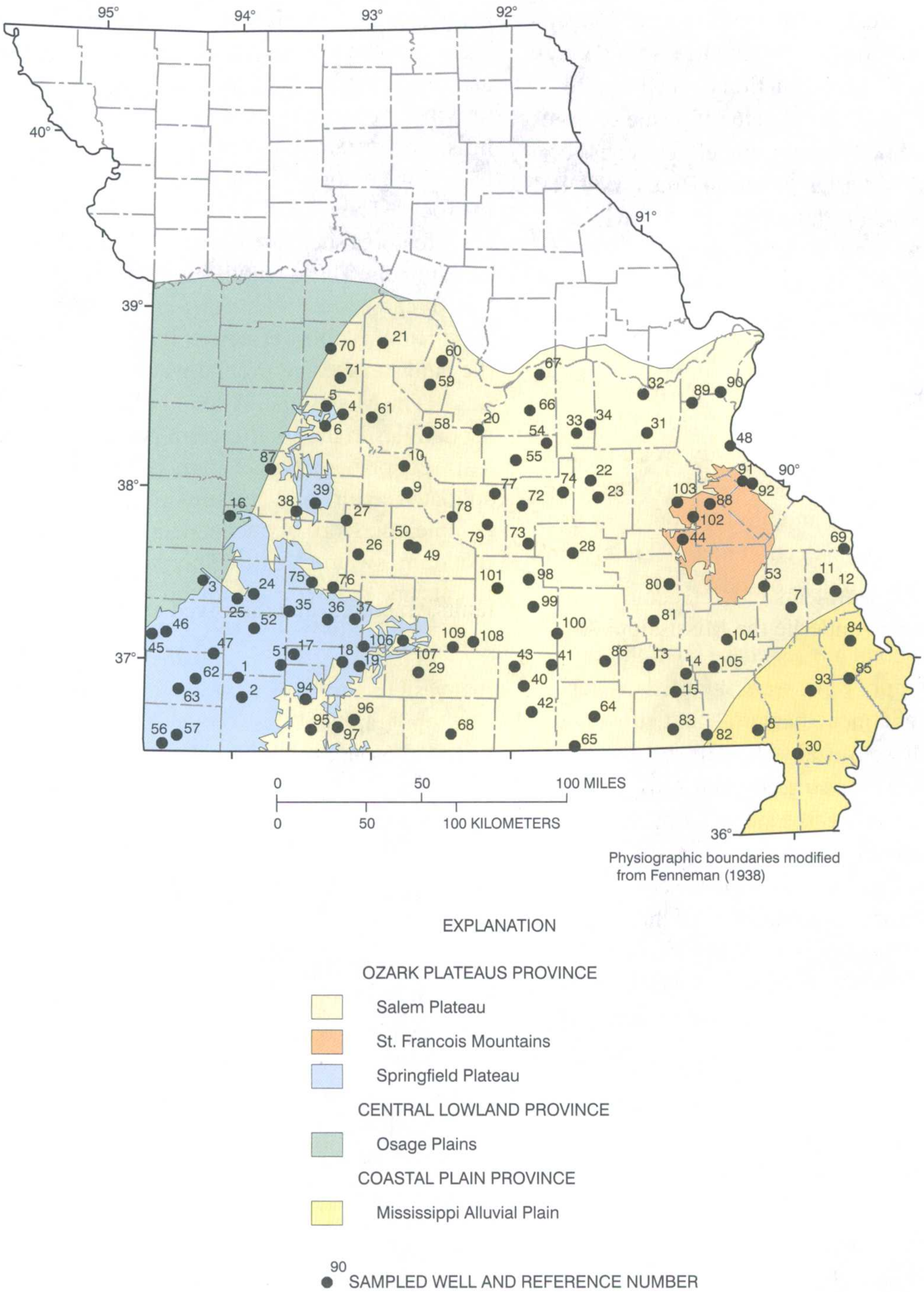

Figure 1. Location of study area, physiographic divisions, and sampled wells.

(Adamski and others, 1994). These rocks also are extensively mineralized. Lead and zinc sulfide, pyrite, lead and zinc carbonates, and zinc silicate deposits are present in the rocks of southwestern Missouri (Kiilsgaard and others, 1967). The Mississippian unit ranges from 200 to 500 ft thick (McFarland and others, 1979).

The St. Francois Mountains are a geologic remnant of resistant Precambrian igneous rocks. These peaks were left when the Cambrian sediments eroded away (Imes and Emmett, 1994). These igneous rocks underlie the Ozark Plateaus and outcrop in the eastern part. Although these rocks outcrop in the St. Francois Mountains, they can be overlain by as much as 5,000 ft of sedimentary rock elsewhere in the Ozark Plateaus. The igneous rocks in this area mainly are silica-rich granite and rhyolite with silica-poor intrusions. These igneous rocks contain commercially viable quantities of certain trace elements such as lead, iron, manganese, and silver (Kisvarsanyi, 1981).

Unconsolidated sediments of Cretaceous through Quaternary age underlie the Mississippi Alluvial Plain. This plain was formed by both structural and erosional activity. Faults form the boundary between the unconsolidated sediments and the sedimentary rocks of Paleozoic age. Faulting has allowed a thick deposit of unconsolidated sediments to lie on older sedimentary rocks that have subsided. These sediments consist mostly of unconsolidated sands, gravels, and clays (Fenneman, 1938).

The Osage Plains is underlain by soft shales, limestones, and sandstones of late Mississippian to Pennsylvanian age (Adamski and others, 1994). There are some resistant beds of sandstone and limestone that form rare east-facing escarpments (Fenneman, 1938). The rocks of Pennsylvanian age range from 40 to 700 ft thick. Uranium-bearing shales and bituminous coal beds are present in this section (Coveney and others, 1987; Robertson and Smith, 1981). In some areas, these units produce oil and gas (Anderson and Wells, 1967).

Geohydrology

The study area consists of the following eight geohydrologic units (extents of exposed parts shown in figure 2) from lowest to highest: Basement confining unit, St. Francois aquifer, St. Francois confining unit, Ozark aquifer, Ozark confining unit, Springfield Plateau aquifer, Western Interior Plains confining system, and the Mississippi Embayment (the unconsolidated unit in southeastern Missouri). The Western Interior Plains confining system is located in the western part of the study area; the Mississippi Embayment and its associated aquifers are located in the southeastern part of the study area. The Ozark Plateaus aquifer system consists of the St. Francois aquifer, St. Francois confining unit, Ozark aquifer, Ozark confining unit, and the Springfield Plateau aquifer. Geohydrologic units of the Ozark Plateaus are classified based on two characteristics; the general hydraulic properties of the rock unit, and the hydraulic relation of that unit to the adjacent units (Imes and Emmett, 1994). The aquifers in this study area can be described as being confined or unconfined. An aquifer is confined where a confining unit overlies it and is unconfined where a confining unit does not overlie it. In this area, it is estimated that about 25 percent of the precipitation is directly recharged into the ground-water system. The system of faults, fractures, and dissolved carbonate-rock conduits, in combination with thin soils and subsoils of the Ozarks, contribute to rapid recharge of the ground-water system. Most of the information included in this section is from Imes and Emmett, 1994.

The study area is underlain mostly by the Ozark Plateaus aquifer system, which is predominately a freshwater system surrounded by neighboring saline ground-water flow systems. The Ozark Plateaus aquifer system is mainly composed of carbonate rocks that are developed into extensive karst areas. There are three types of karst located in the Ozark Plateaus aquifer system, the primary, secondary, and the low density or nonkarst (fig. 3). Primary karst type generally is defined as an area with greater than 10 sinkholes per 100 square miles (mi^2), secondary karst as an area with less than 10 sinkholes per 100 mi^2, and the low density or nonkarst area as less than one sinkhole per 100 mi^2 (Harvey, 1980; Imes and Emmett, 1994). These karst areas cause the Ozark Plateaus aquifer system to be susceptible to ground-water contamination because surface pollutants can be quickly transported into the aquifer system through a series of faults, fractures, and dissolved-carbonate-rock conduits. Recharge into the Ozark Plateaus aquifer system is almost entirely from direct infiltration of precipitation. The flow pattern of this system is mostly topographically controlled with local exceptions near major faults and associated fractures.

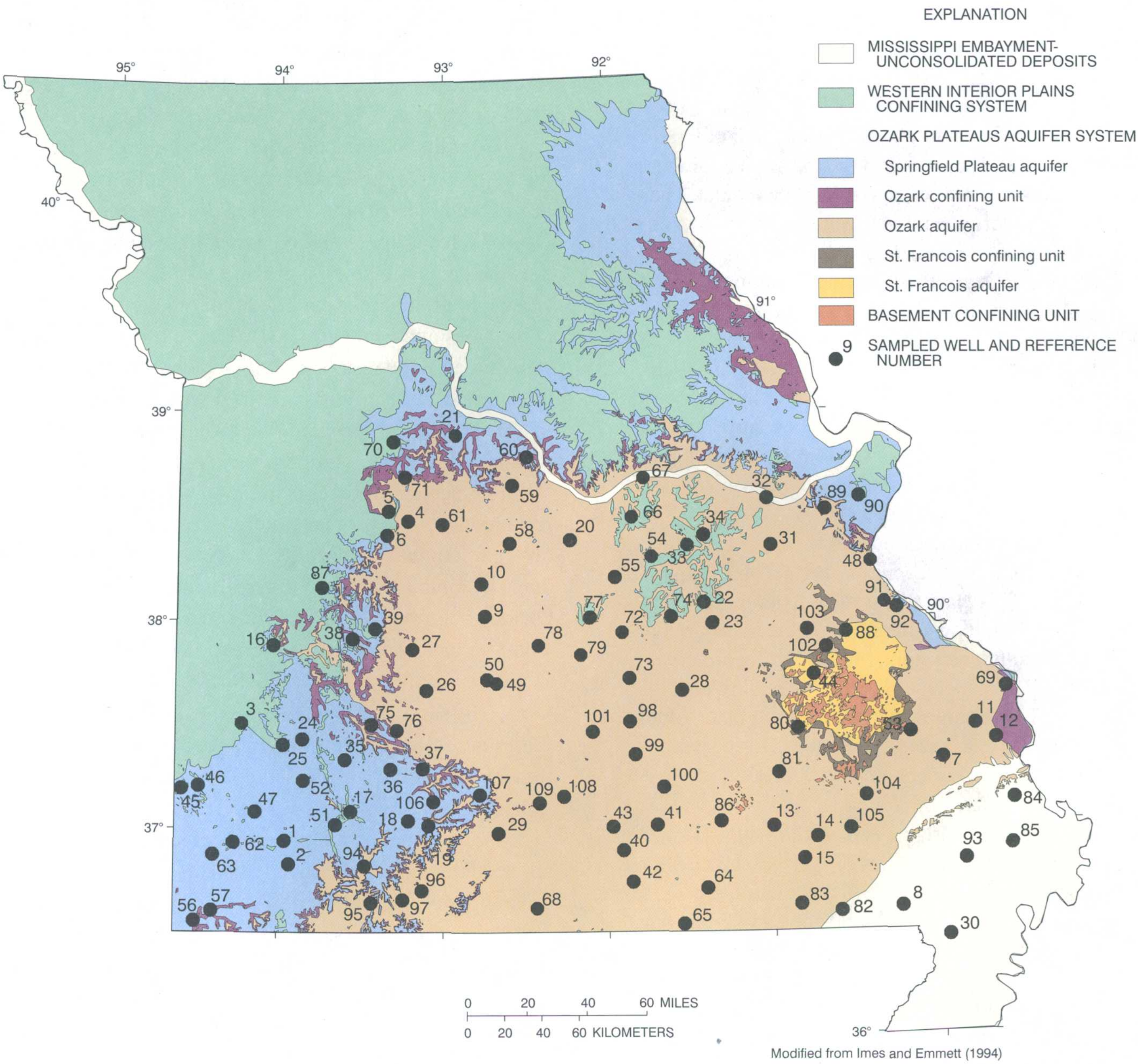

Figure 2. Location of geohydrologic units and sampled wells.

The Basement confining unit forms the base of the Ozark Plateaus aquifer system. There are no known aquifers below this confining unit. The Basement confining unit is primarily igneous rocks that are nearly impermeable and yield no significant amount of water.

The St. Francois aquifer is the lowermost water-bearing unit in the study area. This aquifer is water-bearing dolomite, sandstone, and siltstone overlaying the Basement confining unit. The St. Francois aquifer is exposed and used as a domestic and public supply of water in the St. Francois Mountains in southeast Missouri and is rarely used outside of this outcrop area. Beyond the outcrop area, the aquifer dips steeply into the subsurface and is buried beneath younger water-yielding rocks.

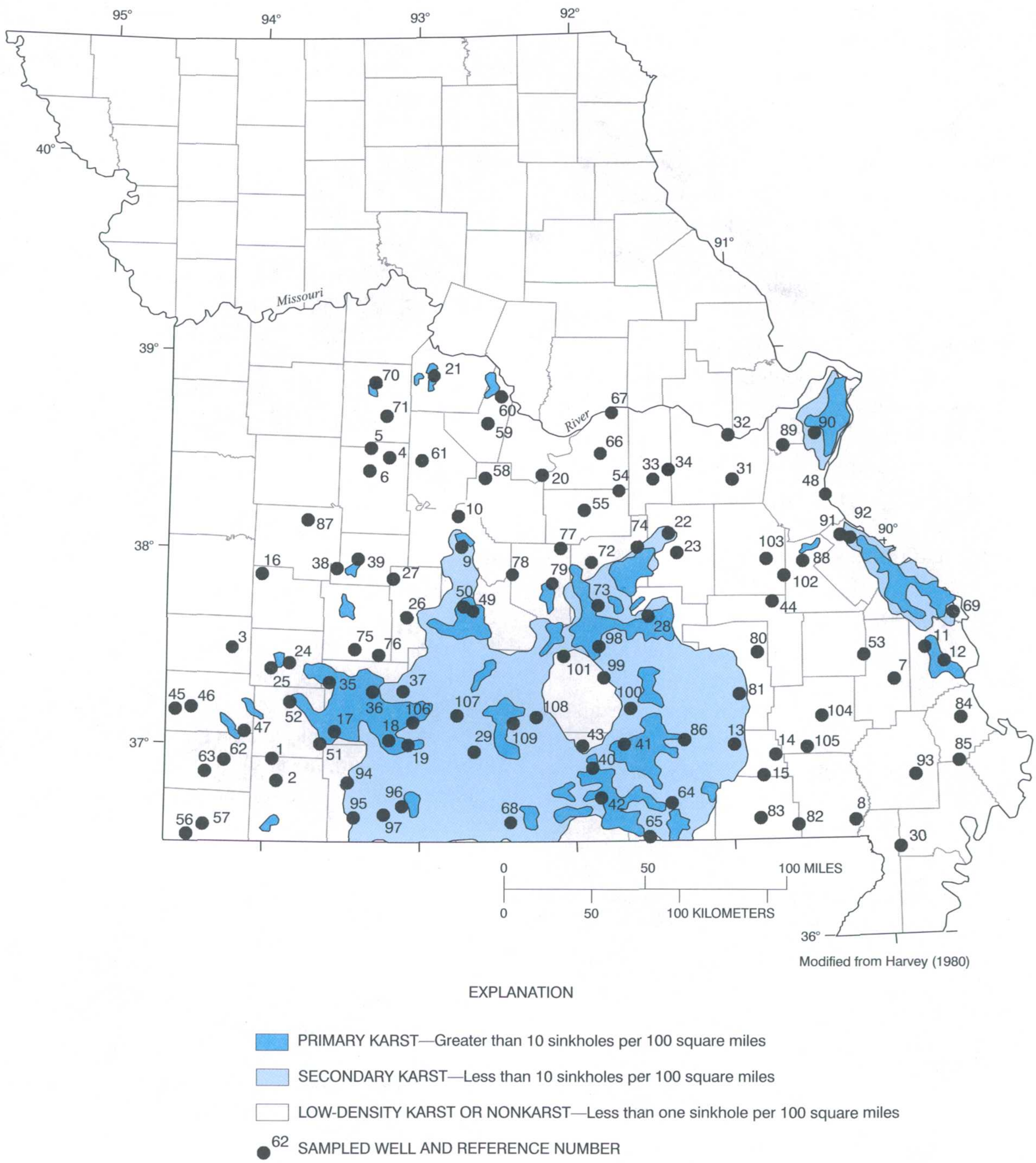

Figure 3. Location of sampled wells relative to karst and nonkarst areas.

The St. Francois confining unit retards the flow of ground water between the St. Francois aquifer and the overlying Ozark aquifer. This semipermeable unit is composed of dolomite, limestone, shale, and siltstone. The unit is missing in the St. Francois Mountains, but is nearly continuous in the subsurface from the outcrop area throughout the rest of the study area.

The Ozark aquifer is the thickest unit and is used the most as a source of domestic and public-water supply of all the aquifers in the study area. The Ozark aquifer is a sequence of water-bearing dolomite, limestone, sandstone, chert, and shale and is broken by numerous faults, bedding planes, and fracture systems. Dolomite is the predominate rock present. Dissolution of the carbonate rocks and karst development are the main processes that result in the varying permeability of the aquifer. The outcrop area of the Ozark aquifer is approximately the same as the Salem Plateau physiographic section and is broken by numerous faults, bedding planes, and fracture systems.

The Ozark confining unit restricts ground-water flow between the Ozark and Springfield Plateau aquifers. This confining unit is not present in the Salem Plateau physiographic section. This unit is slightly permeable, is composed of shale and limestone, and is the upper-most confining unit in the Ozark Plateaus aquifer system. The effectiveness of the Ozark confining unit as a barrier between the Ozark and the Springfield Plateau aquifers differs greatly from one location to another.

The Springfield Plateau aquifer forms the uppermost geohydrologic unit in the Ozark Plateaus aquifer system and is used mostly for private, rural wells. The Springfield Plateau aquifer rarely is used for public-water supply because of small yields. The Springfield Plateau aquifer is composed mostly of limestone with some chert intermixed. The Springfield Plateau aquifer outcrops in the Springfield Plateau physiographic section.

The Western Interior Plains confining system is a thick—as much as 20,000 ft—and expansive geohydrologic unit that extends from western Missouri to the Rocky Mountains. This system generally prevents vertical and lateral movement of water. Although the Western Interior Plain confining system actually is an aggregation of confining units and aquifers, wells located in this system are of limited use because of small yields, and are employed mostly for domestic or stock use.

The Mississippi Embayment is located in the southeastern part of the study area. This unit consists of unconsolidated deposits that form several layers including the alluvium, Wilcox Group, and McNairy Formations. The alluvium can be as much as 250 ft thick and supplies both domestic- and public-water-supply uses. Wells producing from the alluvium have very high yields. The thickness of the Wilcox Group can be up to 1,400 ft of unconsolidated or loosely consolidated sand and clay. The Wilcox Group is mostly used for public water supply. The McNairy Formation is made up of sand, sandy clay, and clay. The McNairy Formation is characterized by high artesian pressure and low hardness, and is used mostly for public water supply (Luckey and Fuller, 1980).

Land Use and Population

Land use in the study area is mostly forest, pasture, cropland, and livestock production (fig. 4). St. Louis, Springfield, Cape Girardeau, Joplin, and Poplar Bluff are the largest urban areas located in the study area. Historical and present-day mining is found in the Old Lead Belt, the Viburnum Trend, and the Tri-State mining areas.

Woodlands of oak and hickory deciduous trees, interspersed with pines, are located in the Ozark Plateaus province. These forests generally occupy the hilltops and steep valley walls, and the river valleys mostly are used for pasture and hay crops. Forest product industries in the Ozark Plateaus include lumber, flooring, staves, furniture, firewood, and chips for paper production. Row crops are grown in the Osage Plain and in the Mississippi Alluvial Plain. The major crops grown in the Osage Plain are soybeans, sorghum, corn, and wheat. The major crop in the Mississippi Alluvial Plain is rice.

Livestock production is located mostly in the Ozark Plateaus province. Poultry, dairy and beef cattle, and swine are the dominant livestock raised in this area. The 1997 Agricultural Census lists Missouri as one of the top three states for beef cattle and feeder pig production and one of the top six states for cattle and calves, hogs and pigs, and horses and ponies inventory, and number of turkeys sold (U.S. Department of Agriculture, 1997). Southwest Missouri and the northwestern part of the study area also have a large number of poultry operations. Recently, numerous confined animal-feeding operations (CAFOs) have begun in southern Missouri (fig. 5). CAFOs, if not managed properly,

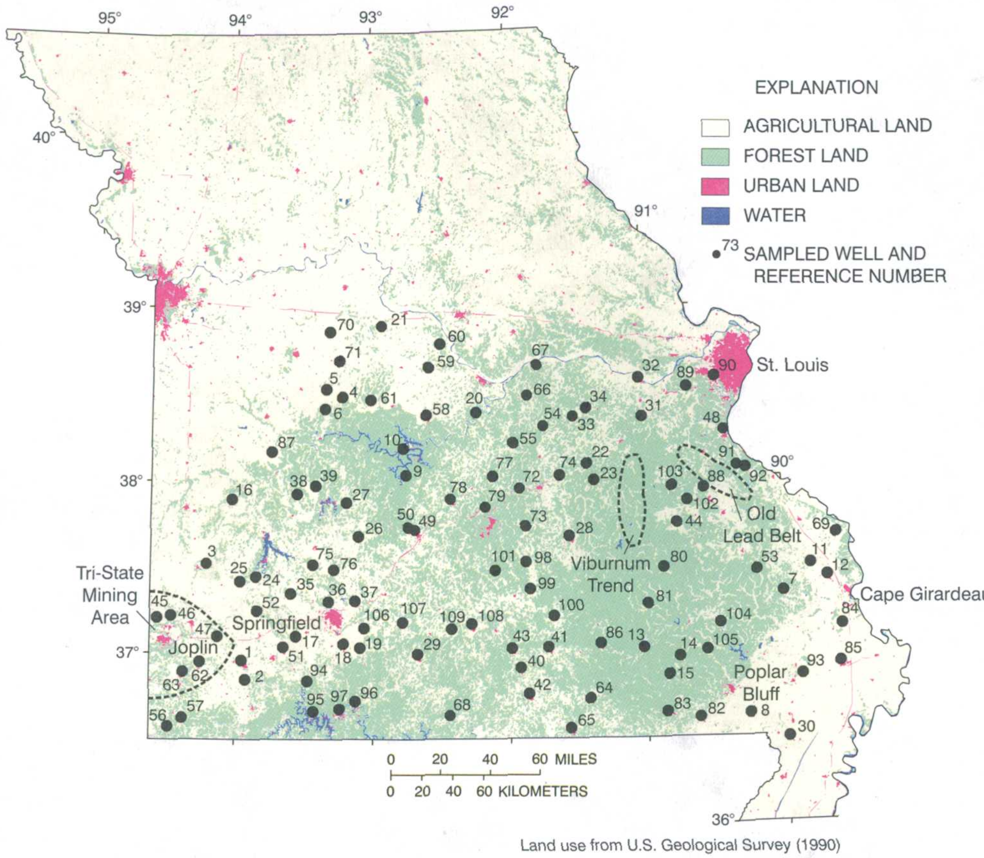

Figure 4. Land use and sampled wells.

have the capability of affecting the water resources and the public health of the surrounding area by contributing excess amounts of nutrients and bacteria to the receiving system. As illustrated in figure 4, CAFOs are a major land use in the study area.

The region studied is predominately rural with urban centers interspersed throughout. The largest city, St. Louis, is located in the extreme northeastern part of the study area (metropolitan area population is approximately 2.5 million). Other large urban centers are Springfield (population 140,494) and Joplin (population 40,961) in the southwest, and Cape Girardeau (population 34,438) and Poplar Bluff (population 16,996) in the southeast part of the study area (U.S. Census Bureau, 1999). Most of the municipalities and rural water-supply districts in the study area obtain drinking water from ground-water sources. Counties near recreational areas in the southwestern part of the State show the greatest growth in population from 1980 to 1990 (fig. 6). These areas also coincide with large concentrations of CAFOs.

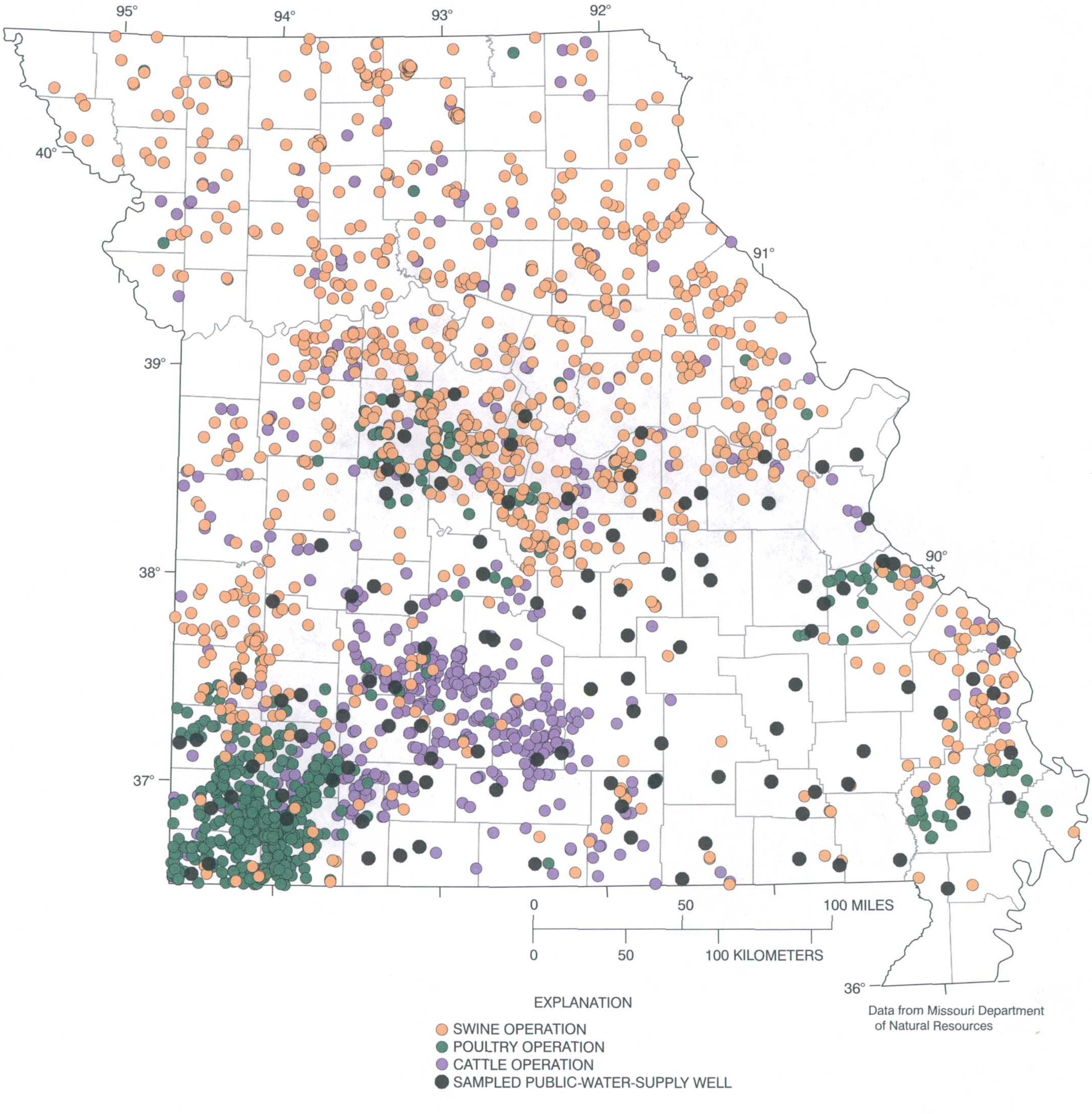

Figure 5. Location of confined animal-feeding operations and sampled wells.

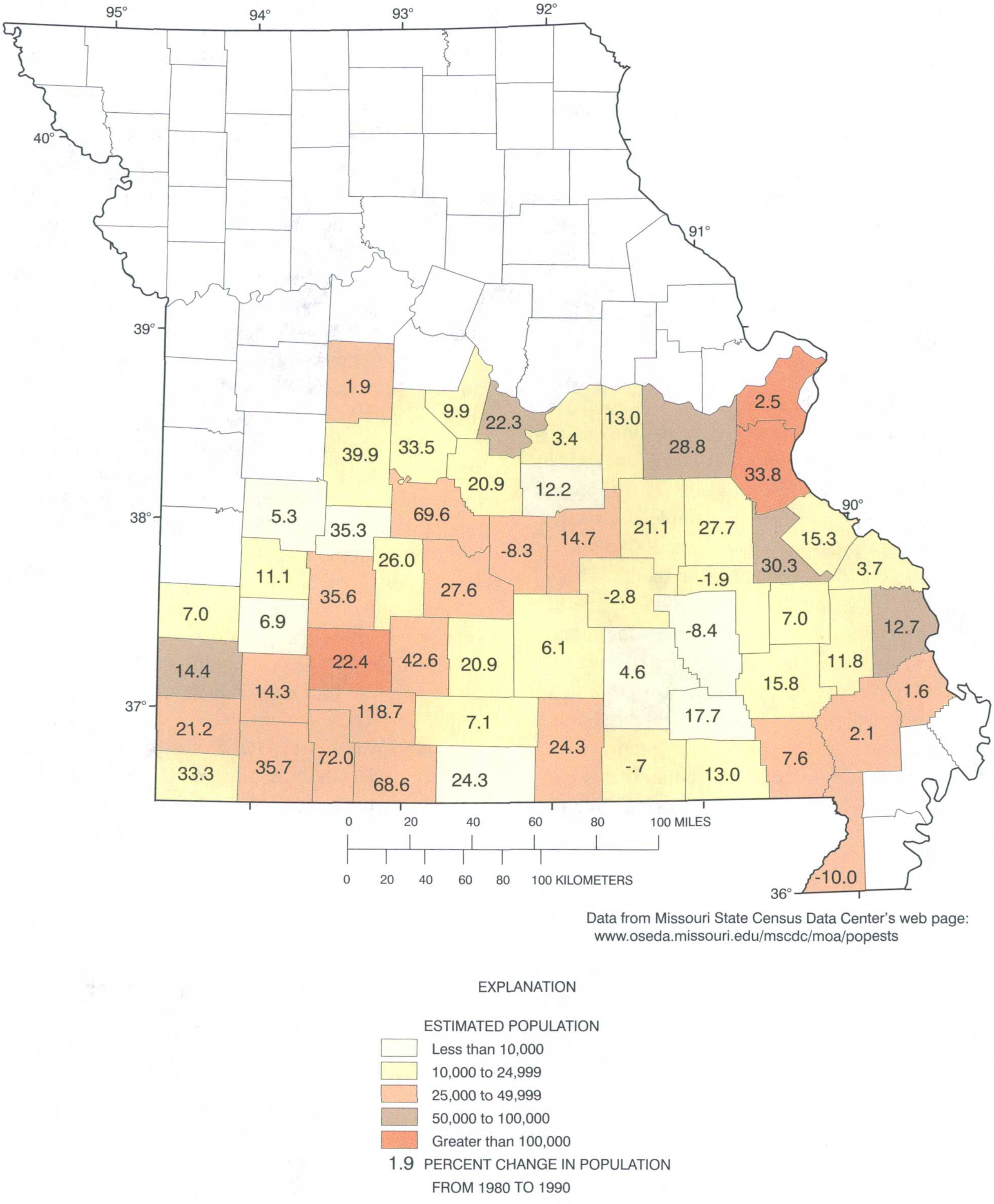

Figure 6. Estimated county population in 1998, and the change in population from 1980 to 1990.

Climate

The study area is located in a temperate climate. The mean annual air temperature ranges from 56 ^{o}F (degrees Fahrenheit) in the northeastern part of the study area to 60 ^{o}F in the southwestern part. The mean monthly temperature usually is lowest in January and highest in July. The mean annual precipitation is about 38 in/yr (inches per year) in the northern part of the study area and about 48 in/yr near the southern part. Precipitation generally is greatest from April to June, and least during December, January, and February (Dugan and Peckenpaugh, 1985).

During the sampling period, precipitation ranged from 50 to 300 percent of normal in the study area (fig. 7). Most of the samples collected in April and May were collected during periods of normal precipitation. During June, however, 11 samples were collected when precipitation ranged from 200 to 300 percent or more above normal for the month. The southwestern part of the state received only 50 percent of normal precipitation during this time. One sample collected in July was collected in an area that received 200 percent of normal precipitation. It is possible for greater than normal precipitation to affect the character of the sampled aquifer. Increased precipitation may flush greater quantities of surface contaminants into the aquifer than would occur during normal precipitation.

Soils

In Missouri, the mantle has been covered in the past by less than 2 to 20 ft of loess material. In the Ozark Plateaus province of Missouri, the deposits of loess material are thin and have eroded in many areas. Loess is a silty, mineralogically rich, fertile parent material deposited by wind mostly during the time of glaciation. The loess materials are now dominant in only small areas of the Ozarks Plateaus province. The thin loess material and the climatic conditions of the Ozark Plateaus province have resulted in highly weathered soils of poor fertility in most places. The wells sampled for this study are situated in different soil associations and physiographies. The major soil areas of the study area are the Northern Missouri Loess and Loess-Till Landscape, Southern Missouri Residual and Loess-Residual Landscape, and the Alluvial Valley Landscape (fig. 8). This soil information is gathered from Scrivner and others, 1966, and Allgood and others, 1979.

The Northern Missouri Loess and Loess-Till Landscape is divided into two categories: the Prairie and Prairie-Forest Transition Natural Vegetation and the Forest Natural Vegetation. The Prairie and Prairie-Forest Transition Natural Vegetation category is found north of the Missouri River and is not found in this study area. The Forest Natural Vegetation category is found only along the river hills of the Missouri River in the study area. Five of the wells sampled were completed below the Menfro-Winfield-Weldon soil association. The Menfro-Winfield-Weldon soils are a deep, moderately permeable loess material.

The Southern Missouri Residual and Loess-Residual Landscapes are divided into two categories: the Prairie and Prairie-Forest Transition Natural Vegetation, and the Forest Natural Vegetation. Most of the wells (98) sampled for this study fall into these soil landscapes. These are the soils of the Ozark Plateaus province and the Osage Plains section of southern Missouri. The Gerald-Craig-Eldon and Newtonia-Baxter Lebanon-Nixa-Clarksville and Hobson-Clarksville and the Clarksville-Fullerton-Talbott are the most common soils found at the sampled wells.

The Alluvial Valley Landscapes are divided into two categories: the Missouri and Upper Mississippi Rivers, and the Southeastern Missouri. Six of the wells sampled for this study were completed below the Southeastern Missouri category. Bosket, Calhoun, Dubbs, Dundee, Forrestdale, and Sharkey are the main soil types that characterize the Southeastern Missouri category.

SAMPLING DESIGN AND METHODS

The sampling design of the study was to randomly choose public supply wells that met selection criteria for the study. These wells were sampled in the spring of 1998 for viruses, bacteria, nutrients, carbon, and optical brighteners. Select bacterial samples were further analyzed for possible sources of the bacteria.

Well Selection

The USGS and MDNR-PDWP selected 109 public-supply wells to be sampled for this study. Criteria for selecting these wells were the availability of

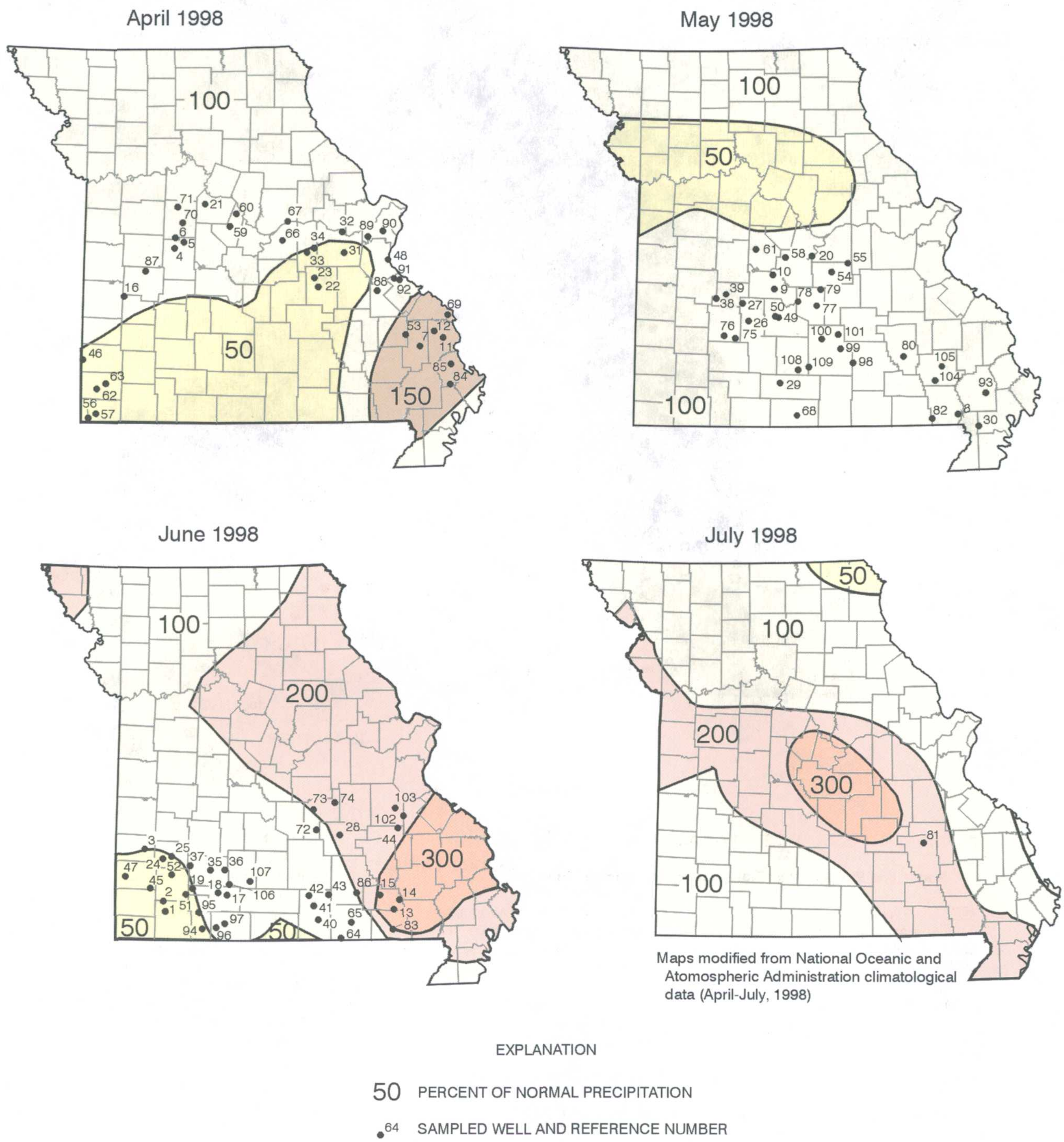

Figure 7. Percentage of normal precipitation during sampling period, 1998.

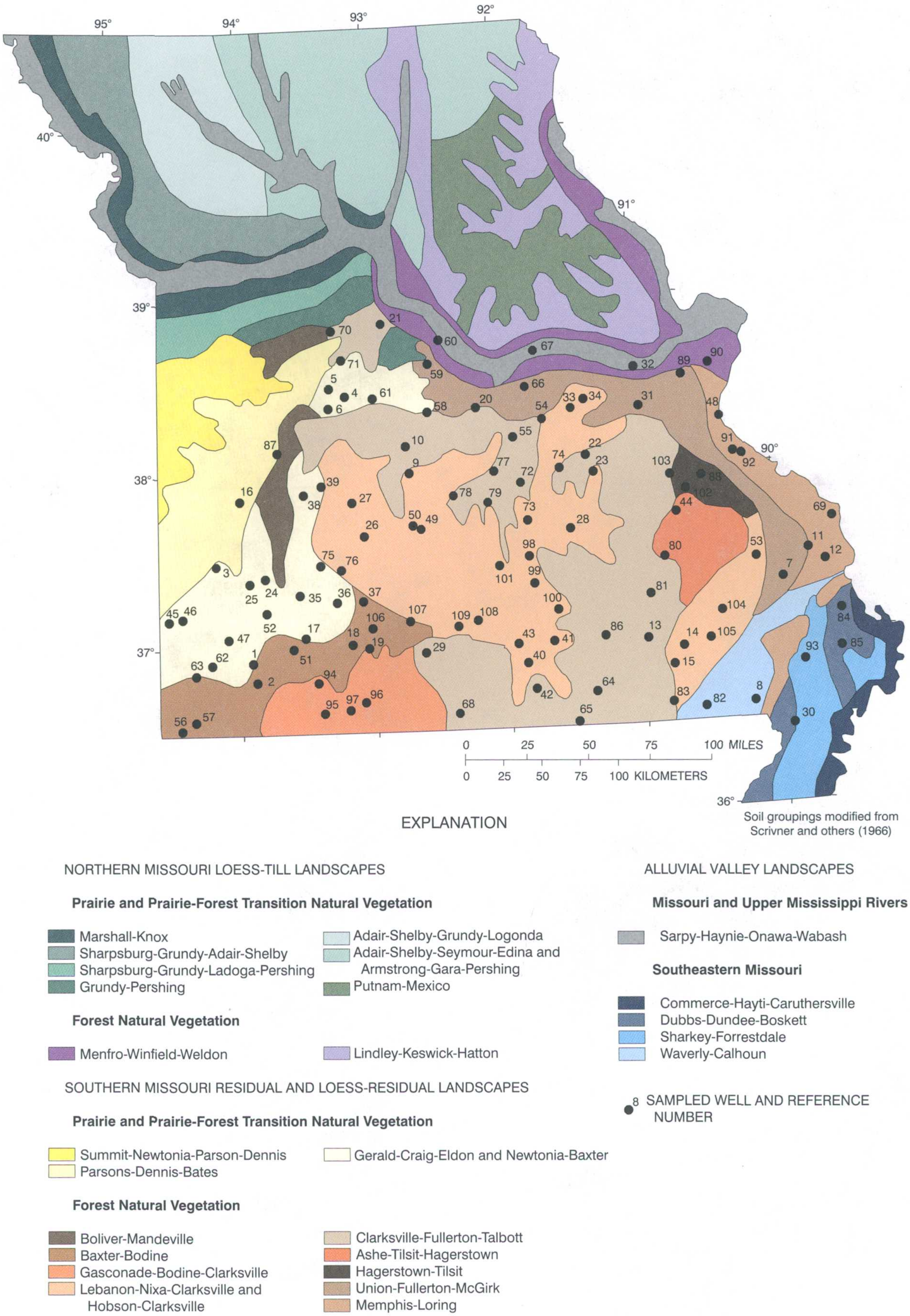

Figure 8. General soil groupings in Missouri.

well-construction, well-maintenance, usage, and geologic records. These wells were selected to represent possible effects of well age, well construction, land use, and geohydrology (table 2, at the back of this report) on the quality of the water, and to uniformly extend coverage over the study area.

Wells that were drilled during or before 1970 were targeted for this study. Although there was great variability in age (29 to 99 years old), well construction (casing material, depth, and sealing) did not vary substantially. Most of the wells were cased with steel, and a few were cased with iron pipe or concrete. The land uses of concern included areas with dense populations of CAFOs, on-site sewage systems, urban, agricultural, and forested areas. Most of the wells sampled were located in or on the outskirts of cities and towns and few were exclusively located in a rural setting. Of the 109 wells, 33 were located in forested areas, 41 in agricultural areas, 2 in urban areas, 14 in mixed agricultural and forested areas, 1 in mixed urban, agricultural and forest, 9 in mixed urban and forested areas, and 9 in mixed urban and agricultural land use areas.

Wells also were selected to represent the five major sources of ground water located in the study area. These aquifers are the alluvial aquifer (3 wells), McNairy and (or) Wilcox aquifer (4 wells), confined Ozark aquifer (32 wells), unconfined Ozark aquifer (60 wells), and the St. Francois aquifer (5 wells). There were five additional wells sampled that draw from multiple aquifers. Of the wells sampled, the shallowest wells were located in the alluvial and McNairy and (or) Wilcox aquifers, and the deepest wells were located in the unconfined Ozark aquifer. Well depths ranged from 21 to 2,217 ft. Wells also were selected to represent the three karst types – primary, secondary, and low density or non karst – present in the Ozark Plateaus aquifer system (fig. 8). For this study, 25 wells were sampled in the primary karst area, 20 wells in the secondary karst area, and 64 wells in the low density or nonkarst area.

Sampling and Analysis Method

The 109 selected wells were each sampled once from April through July 1998. These wells were sampled during the wet weather season to increase the possibility of capturing any viruses, bacteria, optical brighteners, or other sampled constituents moving through the aquifer system. There is greater interaction between the land surface and the ground water during the wet weather season.

The wells were sampled from the tap at the wellhead or the tap nearest to the wellhead before in-line chlorination or other treatment was performed. Although being an active well was one of the well selection criteria, if a well had been temporarily shut down, the sample was not collected until the well had pumped long enough to have stable specific conductance and temperature readings (usually about 10 to15 minutes). Before sampling, the tap was sterilized by spraying with an 0.1-percent chlorine solution, and rinsing with deionized water. A pre-sterilized virus filter apparatus with an optical brightener attachment (fig. 9), without the virus filter inserted, was connected to the well tap. The well was then pumped for 10 to 15 minutes with flow diverted through the apparatus into a 5-gal (gallon) bucket that emptied into a nearby drain. Specific conductance and temperature measurements were made with an Orion model 122 meter from flowing water in the bucket until each stabilized. Once the specific conductance and temperature stabilized, specific conductance, temperature, pH, alkalinity, color, and dissolved oxygen were measured and recorded on the field notes. Measurements were conducted according to procedures described by Wilde and Radtke (1998). Dissolved oxygen values were determined by the use of a Chemetrics direct reading vacuum vial at the tap. Sample water also was collected at the tap for immediate field processing and bacterial analysis. Samples for chemical analysis were collected from the tap in two 125-mL (milliliter) brown high density polyethylene bottles and a 125-mL amber glass bottle, then packaged, chilled, and sent to the USGS National Water-Quality Laboratory (NWQL) in Denver, Colorado. A pre-sterilized 1-L (liter) polyethylene bottle was used to collect water for RNA hybridization analysis. The sample water for RNA hybridization was kept chilled until the presence or absence of indicator bacteria was determined. If any of the indicator bacteria had readings greater than 10 col/100 mL (10 colonies per 100 milliliters) of sample, the 1-L bottle was shipped overnight to the USGS laboratory in Nashville, Tennessee for further analysis. A Hach color test kit was used to determine the color of the sample collected at the tap. If the reading was five or more color units, a sample was collected to send to NWQL. A polyethersulfone (PES) filter was then inserted into the optical brightener filter holder and flow was diverted through it to another 5-gal bucket. After 3 to 5 gal of well water had passed through the filter (about 40 minutes), it was removed, wrapped in aluminum foil, and chilled until

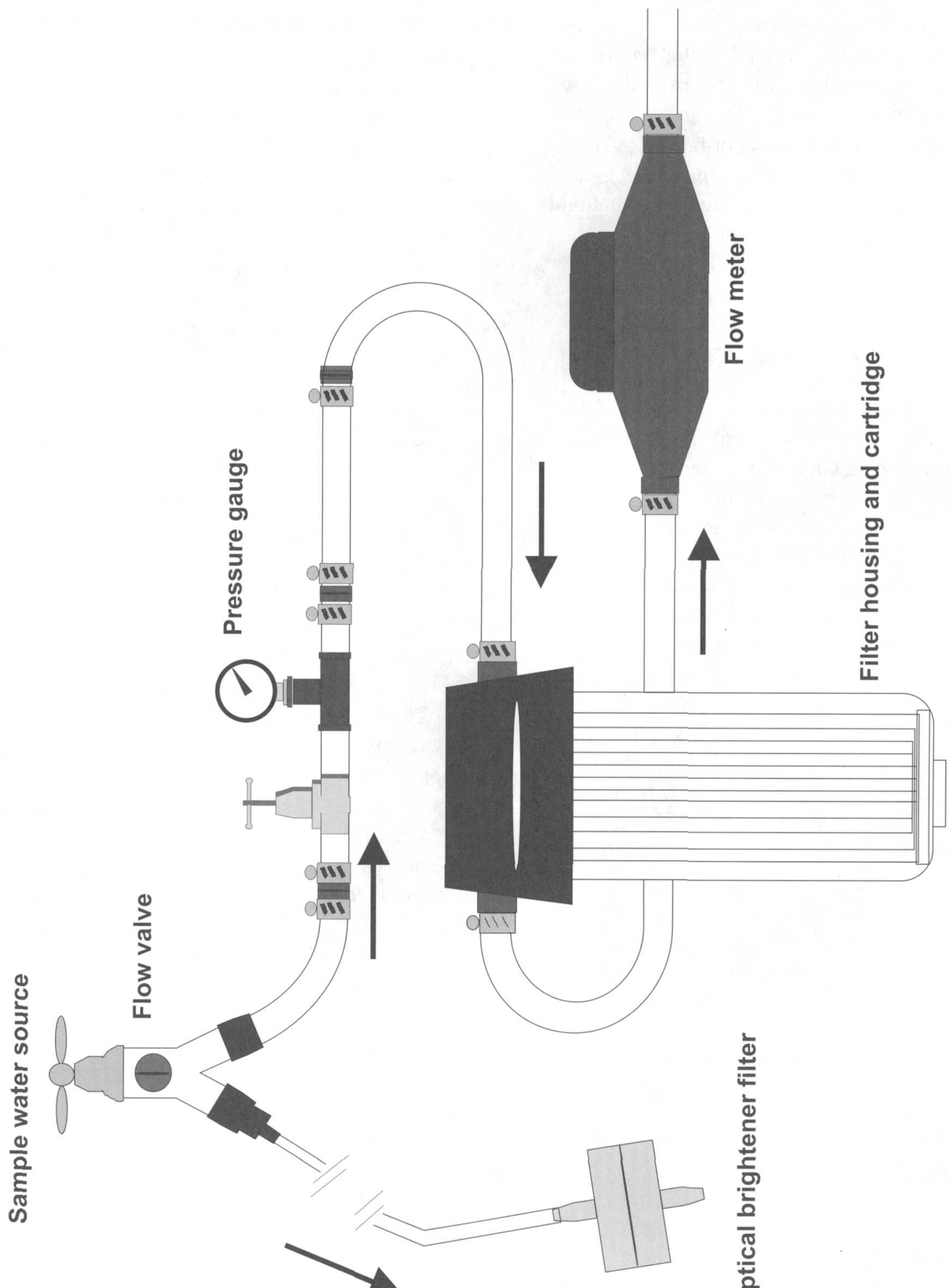

Figure 9. Virus filter apparatus with optical brightener attachment.

analyzed with a scanning spectroflourophotometer to determine the presence of optical brighteners (procedure modified from Fay and others, 1995).

After flushing the virus filter holder apparatus with about 20 gal of well water, a 1-MDS filter was inserted into the filter holder to sample for enteric viruses. About 60 to 80 gal of well water were processed through the 1-MDS filter at a rate of approximately 1.5 gal/min (gallons per minute). After disconnecting the virus filter holder apparatus from the well system, the filter holder was drained and the filter was double bagged and stored on ice until shipped to the analyzing laboratory. The virus samples were collected following the procedures described in the USEPA Information Collection Requirements (ICR) rule for the collection of samples for protozoa and enteric viruses (U.S. Environmental Protection Agency, 1995a). All samples represented untreated, natural water from the sampled aquifer.

Water samples were collected and analyzed for nitrate plus nitrite, nitrite, ammonia, ammonia plus organic nitrogen, phosphorus, orthophosphate, total organic carbon, and color. These constituents may serve as an indication of land surface contamination present in the aquifers. The NWQL, in accordance with procedures described in Fishman and Friedman (1989) and Fishman (1993) performed all chemical analyses. Ten quality control samples were collected at 10 wells during the sampling period. Four blank and six replicate quality-control samples were collected to monitor for contamination of the sample. Blank samples were collected to monitor for contamination by field procedures, equipment, and conditions. Replicate samples were collected to monitor analytical accuracy. Nutrients and TOC were analyzed in the field blanks and replicate samples. Most constituent concentrations were below the method reporting level (MRL) in the 4 field blanks with the following exceptions: (1) total ammonia detected in 2 field blanks [MRL 0.05 milligrams per liter (mg/L); detect concentrations ranged from 0.059 to 0.065 mg/L]; (2) total nitrite detected in one field blank [MRL 0.01 mg/L; detected 0.012 mg/L]; (3) total phosphorus detected in one field blank [MRL 0.01 mg/L; detected 0.014 mg/L]; and (4) total orthophosphorus detected in one field blank [MRL 0.01 mg/L; detected concentration 0.011 mg/L]. Nutrient and total organic carbon concentrations in the replicate samples were comparable and well within laboratory analytical error.

The USGS field crew, according to procedures described in Myers and Wilde (1997), analyzed the sample water collected in the 500-mL polyethylene bottle for fecal indicator bacteria. Fecal indicator bacteria are cultured because they typically are not disease-causing organisms, though they can indicate the presence of several disease- causing waterborne pathogens from the wastes of warm-blooded animals. *Escherichia Coli* (*E. coli*) bacteria detected in water is direct evidence of fecal contamination from warm-blooded animals and indicates the possible presence of pathogens (Dufour, 1977). The presence of these indicator bacteria indicates a potential public health risk. Fecal coliform, fecal streptococci, and *E. coli* were the fecal indicator bacteria cultured. Each type of bacteria was cultured using a 100-mL sample. Blank plates were run with each set of samples to check for contamination of the equipment and reagents used in the process.

RNA Hybridization Microprobe Techniques

RNA hybridization techniques were used to identify specific bacterial sources, such as cattle, poultry, or humans. If 10 or more colonies per 100 mL of sample developed from the fecal indicator bacteria culture, a 1-L bottle of well water was sent to the laboratory for a 16S rRNA (ribosomal ribonucleic acid) oligonucleotide hybridization probe. RNA hybridization probes can identify fecal bacteria unique to a host species, which identifies the source of the bacteria. This RNA probe uses the sequences of unique nucleic acid on the ribosomal RNA present in particular bacteria species to identify the host animal (Amann and others, 1995). The oligonucleotide probes used in this study include the Universal sequence, *E. coli*, *Entercoccus faecalis*, *Salmonella* sp., *Bacteroides vulgatus*, *Fibrobacter succinogenes*, and a negative control. The Universal sequence attaches to a rRNA sequence common to all bacteria. The *E. coli* attaches to *E. coli* sequences and confirms the traditional plate method. The *Entercoccus faecalis* attaches to the fecal streptococcus sequence and confirms the traditional plate method. Additionally, higher numbers of *Entercoccus faecalis* are found in non-human wastes, although this is not a conclusive test for other warm-blooded animals. *Salmonella* sp. attaches to several different *Salmonella* species, and could indicate poultry or non-healthy-human wastes. *Bacteroides vulgatus* attaches to anaerobic bacteria associated with humans and is indicative of human wastes being present. *Fibrobacter succinogenes* commonly are detected in cattle. The negative controls were not probed with any oligonucleotide and are viewed as a negative control (T. Byl, USGS, written commun., 1997). On arrival at the laboratory, the water sample containing the unknown bacteria was treated to extract a cleaned bacteria pellet. The bacteria pellet was then resuspended in phosphate buffer and an ethanol solution and stored at 4 °C (degrees Celsius) until testing. For testing, the bacterial pellet was centrifuged at a 5,740 g-force to re-pelletize the bacteria, and then resuspended in a phosphate buffer to remove the ethanol. A 5-µg/L (microgram per liter) aliquot of the resuspended bacteria was air-dried, heat-fixed, and gram-stained onto a microscope slide. Observations of staining and bacterial shapes were noted, when possible, to add strength to interpretations. Then the sample was incubated at 90 °C to relax the ribosomes and to make the nucleic acids more accessible to the probes. After relaxing the RNA, the bacteria were incubated in a broth containing the fluorescent-tagged oligonucleotides. The oligonucleotide probes enter the bacterial cells and bind to their complementary sequence. The slides were then viewed using an epiflourescent microscope that illuminates the flourescing cells. The flourescing cells can be counted to provide a bacterial quantity per known amount of sample water. If a complementary sequence is not present in the bacterial cell, the unbound oligonucleotide will be flushed out of the cell during a series of rinses (T. Byl, USGS, written commun., 1997).

The enteric virus and coliphage sample was collected by running 50 to 80 gal of untreated well water at 1 to 1.5 gal/min through the 1-MDS filter. The filter was then double bagged, iced, and sent by overnight mail to the analyzing laboratory. The University of New England (UNE) at Biddeford, Maine analyzed the samples for enteric virus and coliphages using procedures outlined in the USEPA ICR rule (U.S. Environmental Protection Agency, 1995b, 1996). At the UNE laboratory, viruses were extracted from the filter in a beef broth, concentrated, and prepared for inoculation. Part of the extract was used to determine the presence of enteric viruses; another part was used to determine the presence of coliphage. The part retained for enteric virus analysis was inoculated on an African Buffalo Green monkey kidney cell media. Buffalo Green monkey kidney cells are a continuous cell line and are highly susceptible to many enteric viruses (Dahling and Wright, 1986; Dahling and others, 1984). After incubation, each culture was examined microscopically for the appearance of cytopathic effects or changes in cell morphology. Then the most probable number (MPN) of infectious total culturable viruses per liter with a 95 percent confidence level was determined. The presence of somatic coliphage and RNA (male specific) coliphage were detected by plaque assay. These coliphage assays use tryptone agar and incubation to develop the cultures. After incubation, the number of plaques are counted and recorded. Each of these procedures-- enteric virus, somatic coliphage, and RNA coliphage--use a positive and a negative control for quality assurance. The positive control ensures that the viruses can be recovered by using the intended method, and the negative control is used to verify sterile procedure, equipment, and reagents.

PHYSICAL AND CHEMICAL QUALITY

The physical properties and chemical constituents analyzed at the sampled wells demonstrated variable differences when compared by karst areas, geohydrology, soils, and land use. A statistical summary of the data is presented in table 3, which lists the minimum, maximum, and median concentrations along with the 10th, 25th, 75th, and 90th percentiles. As presented in table 4, at the back of this report, the majority of some constituent concentrations, such as ammonia plus organic nitrogen, nitrite, and phosphorus were below MRL's. There were a greater number of detections above MRL's with respect to the nitrite plus nitrate, ammonia, orthophosphate, and total organic carbon concentrations. No physical or chemical concentrations were greater than the Missouri drinking water standards (Missouri Department of Natural Resources, 1996).

Further analysis on the data was done by classifying the wells by type; karst, geohydrology, soil, well age, or land use. Once the wells were classified, the data groups were tested for significant differences in distribution by using the nonparametric Kruskal-Wallis analysis of variance (ANOVA) (Helsel and Hirsch, 1992, p. 163) test. The data groups are significantly different if the probability (p-value) is less than 0.05 percent. A p-value of less than 0.05 indicates that there is a less than five percent chance that the observed difference is by chance. If a statistically significant difference was detected, these differences were further analyzed by applying Tukey's multiple comparison test

(Helsel and Hirsch, 1992, p. 196) to the rank transformed data. Then, if warranted, the data were graphically displayed using boxplots. Some data groupings resulted in sets of less than 10 wells. Data sets of 10 or less values are a nonideal for confident statistical testing.

Analyzing the data by well age and construction characterization did not indicate any significant differences in the physical and chemical constituents. Well construction did not differ substantially from well to well. Most all wells were constructed in a similar manner and were cased with steel. Also, many wells had incomplete well construction records that made analysis difficult. Drill dates for the wells sampled ranged from 1900 to 1970, with a median year at 1951. Five wells were of undetermined age. The data was grouped by the years; 1900 to 1919, 1920 to 1939, 1940 to 1959, and 1960 to 1970. All groups consisted of 11 or more wells. The p-value for all constituents tested were greater than 0.12, indicating that there is no significant differences detected.

The data analyzed by karst-type groups demonstrated that there were no significant differences between karst-type groups in regard to the nitrite plus nitrate, nitrite, ammonia, phosphorus, orthophosphate, and pH values. Graphical representation of the dissolved oxygen concentrations by karst type illustrate that higher concentrations appear to occur in the primary and secondary karst areas (fig. 10). Dissolved oxygen concentrations tended to be highest in the secondary karst areas. Tukey's multiple comparison test indicated that the dissolved oxygen concentrations in the secondary and non-karst areas were significantly different from each other (p=0.007), but that neither was significantly different from the primary karst area concentrations.

Grouping by aquifer type resulted in less than 10 wells in most groups, which is nonideal for confident statistical comparison. The confined Ozark and the unconfined Ozark aquifer type each have an adequate number of samples for statistical testing. Analyses of the data group by aquifer type showed no significant difference in the nitrite, nitrite plus nitrate, ammonia, orthophosphate, and phosphate concentrations between the two groups.

Significant differences in dissolved oxygen concentrations were detected between the confined Ozark and the unconfined Ozark aquifer types (fig. 11). The unconfined Ozark aquifer had mean dissolved oxygen concentrations three times that of the confined Ozark group. Displaying nitrogen as ammonia concentrations graphically illustrates the occurrence of larger concentrations near the perimeter of the exposed part of the Ozark aquifer (fig. 12). Two alluvial wells in the Mississippi Embayment, reference numbers 93 and 8, also have larger concentrations.

Grouping sampled wells by soil landscapes resulted in two soils landscapes with less than 10 wells. The Alluvial Valley and the Northern Missouri Loess and Loess-Tilled Forest Natural Vegetation had six and five wells respectively. Comparing the data by soil landscape revealed that the constituent concentrations were similar for most constituents. Soil landscapes did not exhibit detectable effects on the nitrite plus nitrate, nitrite, orthophosphate, total organic carbon, pH, and dissolved oxygen concentrations. Phosphorus and ammonia concentrations were similar for all soil landscapes with the exception of the Alluvial Valley Landscape, which had six sampled wells and is not adequate for conclusive statistical interpretation (fig. 13).

Of the seven land use groupings, four had less than 10 wells and were inadequate for accurate statistical analysis. Although some groups had few wells, analysis of the data indicated that the concentrations were similar among groups for the nitrite plus nitrate, ammonia, phosphorus, and orthophosphorous constituents, and pH values, but there were substantial differences for a few parameters. Dissolved oxygen and alkalinity were statistically different when grouped by land-use type. Further analysis by Tukey's method indicated that dissolved oxygen concentrations were significantly different between the forest and urban/agricultural land uses; and the forest and agricultural land uses; the forest land use had greater mean value (fig. 14). The alkalinity values were notably different between the urban/forest and agricultural, urban/forested and urban/agricultural, and agricultural and forested land-use types; the urban/forest had a greater mean value (fig. 14).

MICROBIOLOGICAL QUALITY

Microbiological samples were collected at all wells in the study. Less than 10 percent of the sampled wells had bacterial contamination, 3.7 percent of the wells tested positive for coliphages, and none of the wells tested positive for enteric viruses (table 5, at the back of this report). Of the wells sampled, 38 percent (41) were chlorinated and 62 percent (68) were not chlorinated before distribution to the customers.

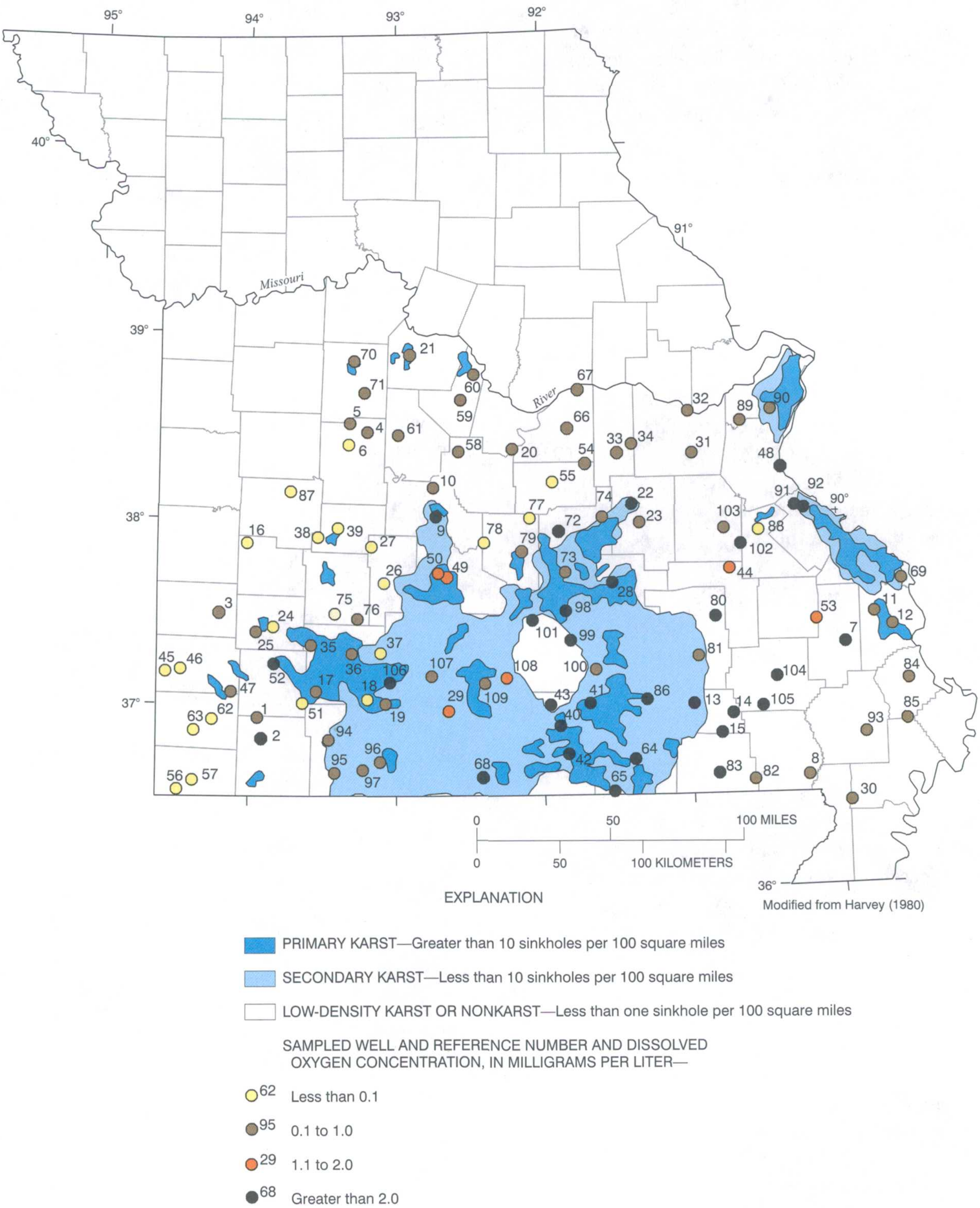

Figure 10. Dissolved oxygen concentrations in relation to karst and nonkarst areas.

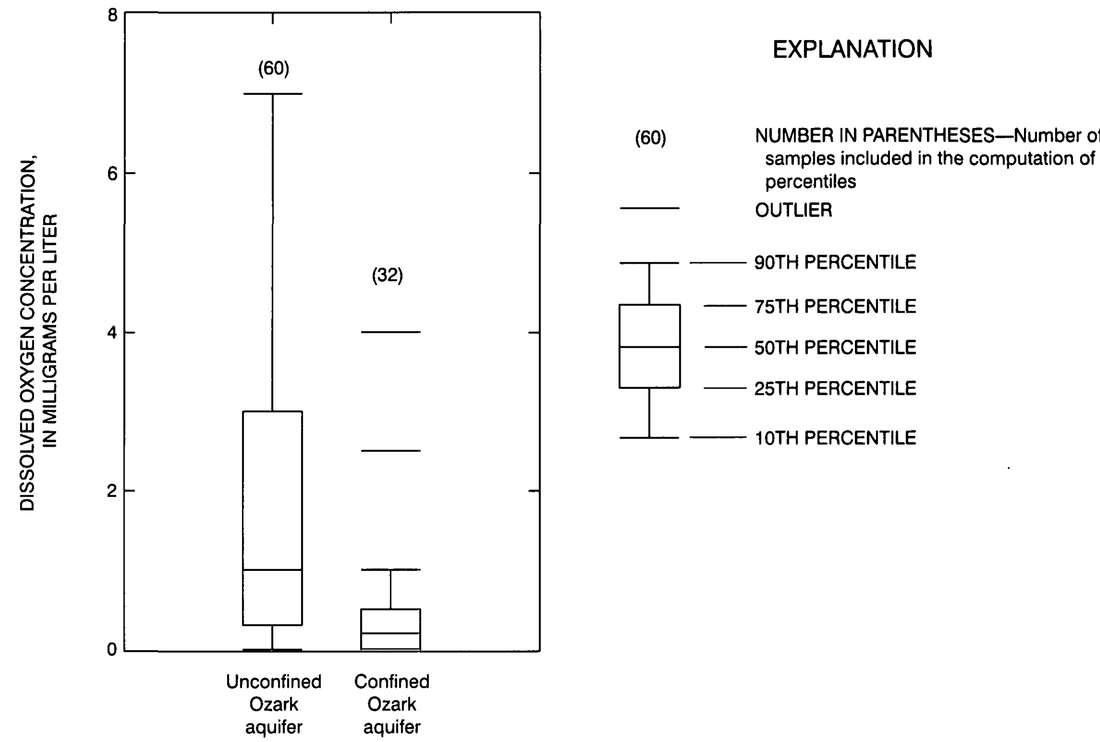

Figure 11. Distribution of dissolved oxygen concentration data within the unconfined Ozark and the confined Ozark aquifers.

E. coli was detected at nine wells and was the most detected bacterium sampled. The public-water-supply wells at Monett (reference number 2) and West Plains (reference number 40), had plate counts too numerous to count. Fecal streptococci was detected at seven wells, and also had plate counts too numerous to count at the Monett (reference number 2) and West Plains (reference number 40) wells. Fecal coliform was detected at eight wells, including too-numerous-to-count plates at the Monett and West Plains wells. There are no statistically significant correlations between the physical characteristics studied and the location of the bacteria detected. Bacteria were detected at all karst types; in the confined Ozark, unconfined Ozark, St. Francois, and alluvial aquifers, and in areas of agricultural, forested, urban, and mixed land use. Most of the *E. coli* (6 of 9), fecal streptococci (5 of 7), and fecal coliform (6 of 8) detections were in samples from the unconfined Ozark aquifer. Although 55 percent of the wells sampled were located in the unconfined Ozark aquifer, the frequency of bacteria detections in this aquifer, compared to the other aquifers sampled, appears to be large.

Samples from five wells that had bacteria counts greater than 10 colonies per 100 mL of sample were sent to the laboratory for 16S rRNA oligonucleotide hybridization probe tests. Water samples from Marquand (reference number 53), Cape Girardeau Public Water Supply District No. 2 (reference number 12), Lebanon (reference number 50), Monett (reference number 2), and West Plains (reference number 40) were analyzed for specific human- or livestock-related bacteria.

The RNA hybridization probe tests conducted on the sample from the city of Marquand's well number 1 (reference number 53) indicated that fecal bacteria (*E. coli*, *E. faecalis*, and *Salmonella*) were present. Tests for human and ruminant contamination were inconclusive. The lack of a positive Bacteroides detection indicates that the source of bacteria probably was from animals rather than humans.

The RNA hybridization probe tests conducted on the sample from the Cape Girardeau Public Water Supply District No. 2, well number 1 (reference number 12), indicated that fecal bacteria (*E. coli* and *Salmo*-

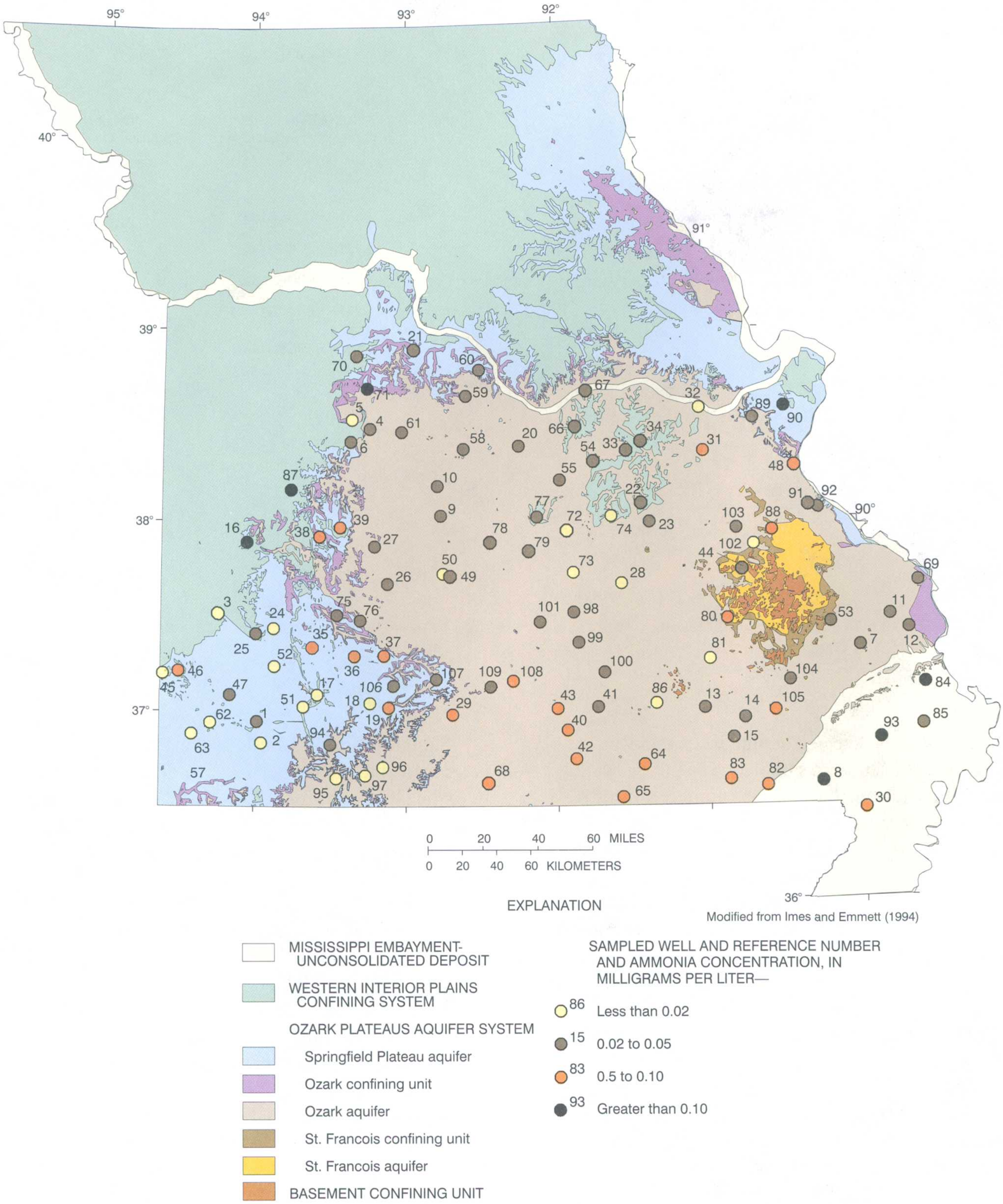

Figure 12. Nitrogen, as ammonia, concentrations in relation to the geohydrologic unit.

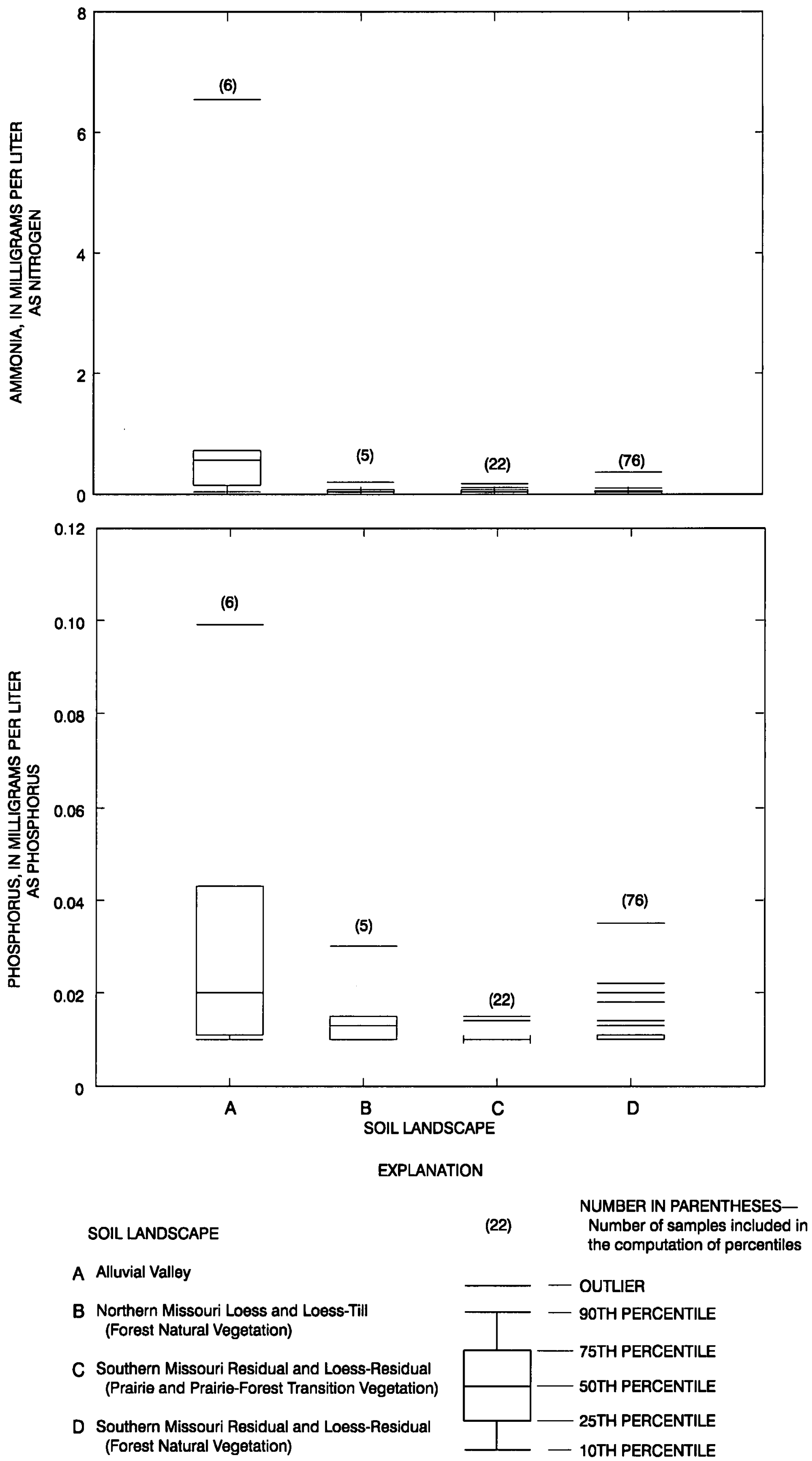

Figure 13. Distribution of ammonia and phosphorus data within each soil landscape.

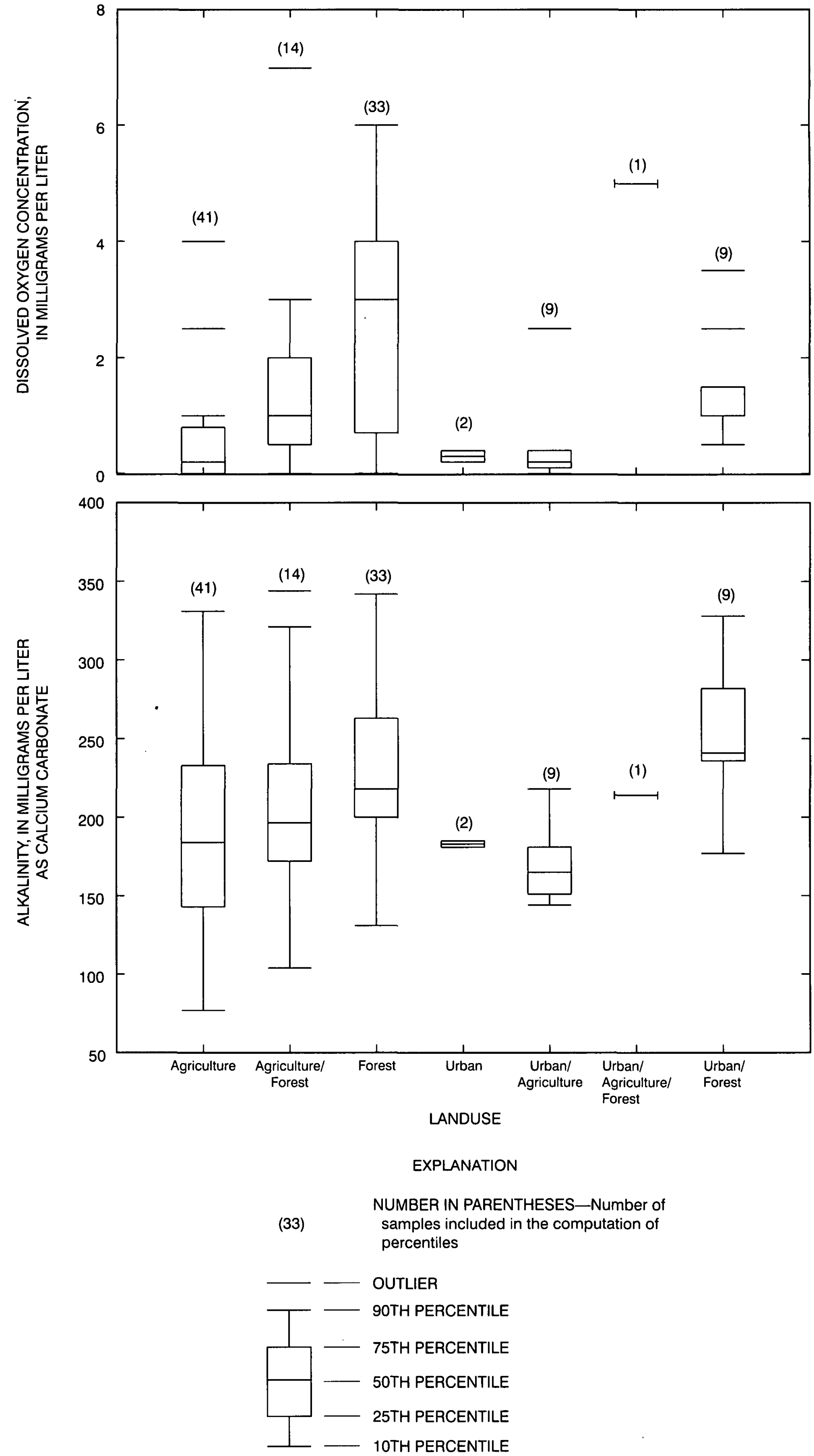

Figure 14. Distribution of alkalinity and dissolved oxygen concentration data within each land-use type.

nella) were present. Ruminant bacteria also were present but the tests were inconclusive for human effects.

RNA hybridization probe tests on the sample from the city of Lebanon's North well (reference number 50) indicate that fecal bacteria (*E. coli*, *Salmonella*, Bacteroides, and ruminants) were present. The Lebanon sample was positive for ruminant and human bacteria indicating several sources of contamination were possible. The sources of this contamination were not investigated for this study.

There were too many bacteria to count in the sample from the city of Monett's West County well (reference number 2). The laboratory observed naturally or pre-stained bacteria fluoresce in the negative-control samples, making it difficult to interpret the other positive tests. The fluorescing bacteria could be a natural fluorescence by a cellular component such as phosphorus minerals in the cell, or chlorophyll molecules. Another possible explanation is that the bacteria could have been pre-stained in the aquifer by a dye study or some other fluorescing molecule (optical brighteners), although tests conducted by this study did not detect fluorescing molecules in the aquifer. The tests conducted indicated that fecal bacteria (*E. coli*, Bacteroides, and ruminants) were present and were positive for ruminant and human bacteria.

RNA hybridization probe tests conducted on the sample from the city of West Plain's Cherry Street well (reference number 40) indicated that fecal bacteria (*E. coli*, *Salmonella*, Bacteroides, and ruminants) were present. These tests indicated that the sources of bacteria may include animals and humans. The sample from West Plains also had fluorescing cells, possibly chlorophyll, and a large, multicellular round ball, like the green algae Volvox, present (T. Byl, USGS, written commun., 1998).

Samples from each well were processed and analyzed for the presence of RNA (male specific) and somatic coliphages. Coliphages were detected at four public-supply wells (table 4). The public-supply wells sampled at Monett (fig. 1, reference number 2) and West Plains (fig. 1, reference number 40) had large counts of both types of coliphage. The well at Monett had counts of 4,754 RNA and 8,897 somatic coliphages per 100 L. The well at West Plains had counts of 613 RNA and 8,862 somatic coliphages per 100 L. These counts are considerably larger than what typically is developed from samples analyzed by the UNE laboratory (J.M. Vaughn, University of New England, oral commun., 1998). RNA coliphage was detected in the city of Chamois well (fig. 1, reference number 67), although no bacteria colonies were detected at this well. The city of Lebanon's North well (fig. 1, reference number 50) had detection of somatic coliphages.

OPTICAL BRIGHTENER ANALYSIS

Private water and sewage systems can contribute to the microbiological contamination of public water supplies in karst aquifers. Poorly constructed wells and septic systems can allow surface contaminants to reach ground-water supplies and can create public health hazards by introducing potentially harmful microorganisms. Because septic sewage systems rely on the percolation of wastewaters in the soil horizons, thin soils and karst topography can be an avenue for these wastes to impact ground-water supplies. Many households use laundry detergents with optical brighteners such as cyanuric chloride/diaminostilbene disulfonic acid, a whitener for cotton and other cellulosic material. As households do laundry, optical brighteners are added to their septic system as gray water. A detection of optical brighteners in the sampled water is an indication of septic system impacts on ground-water supplies. The detection of optical brighteners could be an inexpensive method of evaluating this aspect of ground-water quality.

The presence of optical brighteners was determined by methods outlined by Fay and others (1995). The Kirkwood Ranney well number 3 (reference number 90) was the only well out of the 109 sampled that indicated the presence of optical brighteners. The Kirkwood well is relatively close to a wastewater treatment facility, and is located in the floodplain of the Meramec River. The river stage was close to bankfull at the time of sampling. The wellhead also is located in a pit-type situation. The possibility exists that the optical brightener detected was residual from ground-water studies in the area. Upstream (west) from the Ranney well is a ground-water contamination situation involving trichloroethylene (TCE), which is the subject of many studies (U.S. Environmental Protection Agency, 1990). The lack of bacteria in the well-water sample indicates that the optical brightener may be from ground-water studies rather than from wastewater effects. The results from this optical brightener study were inconclusive a to the effectiveness of this method. No optical brighteners were detected at sites where bacteria were detected. The low number of bacteria detects and low volume of water sampled may have contributed to the lack of detections.

GROUND-WATER VULNERABILITY ASSESSMENT

The USEPA has developed a plan designed to provide State public-water-supply agencies a method for identifying wells within their network that are vulnerable to possible microbiological contamination (U.S. Environmental Protection Agency, written commun., 1998). This plan is called the Ground Water Disinfection Rule (GWDR) Vulnerability Assessment Plan (VAP). This plan is designed to provide a tool to predict the likelihood of contaminants migrating from their source to the withdrawal point of a well by taking into account a variety of geohydrologic conditions, the presence of microbes in the past, and well construction that affect a well's vulnerability to microbiological contaminants. The vulnerability of a well is determined through a series of decision diagrams which incorporate the findings from three categories; the results of previous microbe monitoring, ground-water sensitivity to potential contamination, and well construction. The first category, results of previous microbe monitoring, reasons that if microbe contamination has been found in the past 5 years, the well is vulnerable to contamination regardless of the findings in the other two categories. Ground-water sensitivity is defined as the ability of the natural geohydrologic system to prevent the migration of microbe contamination to the ground water supply. In the presence of contamination, a well in a highly sensitive aquifer would be vulnerable to contamination regardless of the well construction. The third category, well construction, assumes that a poorly constructed well can provide a conduit for contaminant to reach the ground water regardless of the ground-water sensitivity. After the assessment, a well is judged to have low vulnerability to contamination, high vulnerability to contamination, or unknown vulnerability (because of the lack of data). This study has applied the VAP to selected wells to determine if vulnerability can be accurately predicted using this plan in the Ozark Plateaus.

Questionnaires requesting the information needed for the assessment were sent to all public-water-suppliers chosen for this study. Of the 109 questionnaires sent, 34 were returned. The information needed to assess the vulnerability includes results of past microbe monitoring, conditions relating to ground-water sensitivity, and well construction. Gaps in required information gathered from the public water supplies were filled, if possible, by the USGS. When microbes were detected by this study, and no questionnaire was returned by the public water supplier, an attempt was made by the USGS to fill in the three data categories.

A summary of the data gathered for the application of the VAP is listed in table 6, at the back of this report. Of the 41 wells assessed, 26 were rated "high vulnerability", 11 were rated "unknown vulnerability", and 4 were rated "low vulnerability". The reason that many of the wells were of unknown vulnerability is that the information concerning the casing and grout conditions was not known. Many of the public-water-suppliers had a paucity of well data on record and were unable to completely fill out the questionnaire. This may be because of the fact that the wells were older and were less likely to have sufficient information on construction.

Ninety percent of the wells assessed using the VAP were rated as high or unknown in terms of vulnerability to contamination. On the basis of these results, along with consideration of land use (such as a large number of CAFOs (fig. 4)), bacterial contamination might be expected to be extensive in ground water of the Ozark Plateaus. Bacteria were detected at less than 10 percent of the wells sampled. Although contamination currently appears localized (for example, at Monett and West Plains), the vulnerability that is indicated by an assessment such as VAP indicates the importance of water-quality monitoring.

Comparing microbe detects from this study to the vulnerability ratings of table 6 indicates that six of the microbe detects correspond with high vulnerability, five with unknown vulnerability rating. Although the VAP was useful in predicting which wells were of low vulnerability and was collaborated by no microbe detect from this study, the overwhelming percentage of high or unknown vulnerability ratings of the wells sampled obfuscated areas of likely microbe contamination.

SUMMARY AND CONCLUSIONS

Karst terrain, intensive agricultural operations, large numbers of on-site sewage systems, and poor well construction can lead to microbiological contamination of the aquifer systems that are used to supply drinking water from the more than 3,700 public wells in Missouri. State resource managers are concerned about the impact of these conditions on the microbiological and chemical quality of the ground water in the State. Site-specific studies and routine regulatory monitoring have produced information on the overall quality and potability of the State's public-drinking-water supplies, but little is known about the presence of viruses. To address these concerns, the U. S. Geological Survey, in cooperation with the Missouri Department of Natural Resources, Public Drinking Water Program, selected and sampled 109 public-water-supply wells from April through July 1998. These wells were sampled during the wet-weather season to increase the possibility of detecting the sampled constituents. The wells sampled for this study were selected to represent older wells (pre-1970), various land uses, geohydrology, and construction to determine their effects on the chemical and microbiological quality of the ground water. A survey of optical brighteners was conducted to determine their effectiveness as an indicator of contaminant migration from onsite sewage systems to the sampled aquifer. An rRNA hybridization analysis was included in this study to identify the type of organisms that are involved in the microbiological contamination of affected wells. The effectiveness of the U. S. Environmental Protection Agency Ground Water Disinfection Rule Vulnerability Assessment Plan was determined for public wells used for this study.

Of the 109 wells sampled, approximately 55 percent (60 wells) were located in the unconfined Ozark aquifer, 29 percent (32 wells) in the confined Ozark aquifer, 5 percent (5 wells) in the St. Francois aquifer, 5 percent (5 wells) in the mixed St. Francois and unconfined Ozark aquifer, 4 percent (4 wells) in the McNairy/Wilcox aquifer, and 3 percent (3 wells) in an alluvial aquifer. Twenty-three percent (25 wells) of the wells sampled are in the primary karst area, 18 percent (20 wells) in the secondary karst, and 59 percent (64 wells) in the non-karst area. More than one-half of the wells sampled are located in soils of the Southern Missouri Residual and Loess-Residual landscape. Of the public-water supplies sampled, 62 percent (68 wells) were not chlorinated; 38 percent (41 wells) did chlorinate. There was great variability of well age, ranging from 29 to 99 years old. The well depths ranged from 21 (City of Marquand, reference number 53) to 2,217 (City of Jackson, reference number 11) ft deep. Altitude at the wellhead ranged from 240 (KK Water Supply Co., reference number 10) to 1,642 (City of Seymour, reference number 107) ft. Wells were fitted with either submersible or vertical turbine pumps. The majority of the wells were located in or on the outskirts of cities and towns; few were located in a strictly rural setting. Of the 109 wells, 38 percent (41 wells) were located in agricultural areas, 30 percent (33 wells) were in forested areas, 14 percent (15 wells) in mixed agricultural and forested areas, 8 percent (9 wells) in mixed urban and forested areas, 9 in mixed urban and agricultural land-use areas, and 2 percent (2 wells) in urban areas.

Samples from each well were analyzed for physical, chemical, and biological factors. All samples represented untreated, natural water from the sampled aquifer. The physical properties included pH, specific conductance, temperature, and dissolved oxygen. The chemical constituents included nutrients, alkalinity, total organic carbon, and color. Biological parameters consisted of *E. coli*, fecal streptococci, fecal coliform, enteric viruses, RNA and somatic coliphages, and rRNA hybridization. Quality-control samples were collected for all types of samples collected.

The physical properties and chemical constituents analyzed demonstrated differences when compared by karst areas, geohydrology, soils, and land use. The majority of ammonia plus organic nitrogen, nitrite, and phosphorus concentrations were below laboratory detection levels. There was a larger number of samples with values greater than detection limits with respect to the nitrite plus nitrate, ammonia, orthophosphate, and total organic carbon concentrations.

The data were analyzed by applying the non-parametric Kruskal-Wallis analysis of variance test and Tukey's multiple comparison test. These analyses of the physical and chemical data indicated grouping of similar and dissimilar concentrations, though no concentrations were determined to be above the Missouri Drinking Water Standards. The hydrologic, physical, and land-use differences between regions would lend itself naturally to some differences in the physical and chemical constituent concentrations measured for this study. Analyzing the data grouped by karst type demonstrated that there were no significant differences except for dissolved oxygen, which showed appreciable differences in values between the secondary and non-karst area, although both were similar to the primary karst type. The Mississippi Embayment generally had larger constituent concentrations than the other geohydrologic groups, with significant differences pertaining to ammonia and total organic carbon concentrations. Comparing the data by soil type revealed that the constituent concentrations were statistically similar among all soil types except for the Alluvial Valley Landscape, which was different in regards to phosphorus and ammonia concentrations. Analyzing the data grouped by land-use type indicated that the concentrations were statistically similar for most constituents, though dissolved oxygen and alkalinity values were statistically different in a variety of land-use combinations.

Analysis of microbiological samples demonstrated that less than 10 percent of the wells had bacterial contamination, 3.7 percent of the wells tested positive for coliphages, and none of the wells tested positive for enteric viruses. The public wells sampled at Monett and West Plains had high levels of both bacteria and coliphages.

Bacteria was detected at all karst types, in the confined Ozark, unconfined Ozark, St. Francois, and alluvial aquifers, and in areas of agricultural, forested, urban, and mixed land use. Most *E. coli* were detected in the unconfined Ozark. Five wells that had bacteria counts greater than 10 col/100 mL of sample were analyzed by rRNA hybridization techniques. These five wells had bacteria contributed from a variety of sources, predominately by ruminant and human sources. Two wells, Monett and West Plains, had indications of the presence of chlorophyll.

None of the wells sampled were determined to have enteric viruses, although four wells were determined to have RNA and/or somatic coliphages present. The wells at Monett and West Plains had large values of both coliphage types. Virus populations fluctuate with the natural conditions of aquifers, which tend to make their detection a hit-or-miss opportunity. More than a single sampling opportunity is needed to definitively address the presence or lack of viruses in the drinking-water-supply aquifers. The two sampling rounds of Phase I (Davis, 1999) and the single sampling of Phase II studies give three opportunities for viral detection, and the results seem to indicate that the presence of enteric viruses in public-drinking-water supplies are not a major health concern in the Ozark region of Missouri.

A comparison of the USEPA Ground-Water Disinfection Program –Vulnerability Assessment Plan with the results from this study was made to determine the effectiveness of the Vulnerability Assessment Plan for predicting possible well contamination in the Ozark region. Because of unknown and high vulnerability ratings of the wells by the Vulnerability Assessment Plan, 97 percent of the 39 wells assessed would fall into the high category for microbial contamination. Though this area had a high vulnerability rating, less than 10 percent of the wells sampled had bacterial contamination. This would indicate that although the Ozark region is at high risk for contamination, currently (1999), contamination problems are of a localized nature.

The overall health of the ground water used for public-water supplies in the study has been determined to meet or exceed State regulations. With the exception of localized problems, the physical, chemical, bacterial, and viral constituent values are not at a level of concern at this time. The character of the geology, hydrology, soils, and land use in the Ozark region does, however, indicate that a constant vigilance is needed to assure that surface contamination does not become a problem.

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TABLES

Table 1. Identification and drill date for the sampled wells
[PWS-ID, Public Water Supply Identification Number]

Reference number (fig. 1)	County	Public-water-supply system	Local name	PWS-ID	USGS identification number	Facility type	Drill date
1	Barry	Purdy	Well No. 2	5010667	364854093550801	City	1967
2	Barry	Monett	West County	5010537	365534093564601	City	1965
3	Barton	Barton County Consolidated Public Water Supply District No. 1	East Well	5024023	372929094122701	Water District	1967
4	Benton	Lincoln	Under water tower	3010469	382323093195801	City	1950
5	Benton	Cole Camp	City Park Well No. 1	3010180	382726093121601	City	1946
6	Benton	Ionia	Well No. 1	3010400	383023093192201	City	1960
7	Bollinger	Marble Hill - South	Ward Well	4010483	371808089584701	City	1941
8	Butler	Qulin	Well No. 1	4010670	363544090144901	City	1965
9	Camden	Camdenton	Rodeo Grounds	3010130	380010092441901	City	1961
10	Camden	KK Water Supply	Well No. 1	3036050	380802092425501	Subdivision	1967
11	Cape Girardeau	Jackson	Well No. 2	4010404	372307089393801	City	1926
12	Cape Girardeau	Cape Girardeau County Public Water Supply District No. 2	Well No. 1	4024097	372729089464401	Water District	1966
13	Carter	Grandin	Well No. 1	4010322	364950090492801	City	1964
14	Carter	Ellsinore	Old Well	4010246	365559090445301	City	1951
15	Carter	Carter County Public Water Supply District No. 1	Well No. 1	4024108	365917091002901	Water District	No Data
16	Cedar	El Dorado Springs	Well No. 3	5010241	375152094010801	City	1958
17	Christian	Sparta	Well No. 1	5010752	365953093045601	City	1960
18	Christian	Ozark	Well No. 1	5010619	370114093121901	City	1942
19	Christian	Billings	New Well	5010071	370352093332301	City	1967
20	Cole	Cole County Public Water Supply District No. 5	St. Thomas	3024164	382203092130301	Water District	1968
21	Cooper	Pilot Grove	Well No. 1	3010642	385222092544701	City	1936

Table 1. Identification and drill date for the sampled wells--Continued

[PWS-ID, Public Water Supply Identification Number]

Reference number (fig. 1)	County	Public-water-supply system	Local name	PWS-ID	USGS identification number	Facility type	Drill date
22	Crawford	Steelville	Well No. 1	6010759	375759091211801	City	1934
23	Crawford	Cuba	North of RR tracks	6010200	380348091242601	City	1930
24	Dade	Lockwood	Well No. 2	5010475	372312093572601	City	1946
25	Dade	Greenfield	Old Well No. 2	5010331	372451093502601	City	1910
26	Dallas	Buffalo	Well No. 3	5010114	373844093052801	City	1949
27	Dallas	Urbana	Well No. 1	5010807	375034093103501	City	1962
28	Dent	Salem	Well No. 2	4010721	373842091323401	City	1936
29	Douglas	Ava	EDA Well No. 3	5010040	365702092391801	City	1970
30	Dunklin	Clarkton	Well No. 2	4010170	362708089580701	City	1949
31	Franklin	St. Clair	Crest Lane	6010708	382047090583501	City	No Data
32	Franklin	Washington	Well No. 2	6010838	383334091003401	City	1927
33	Gasconade	Owensville	2nd and Monroe	6010618	382029091300501	City	1913
34	Gasconade	Rosebud	Well No. 1	6010702	382316091241201	City	1941
35	Greene	Springfield	Well No. 1	5010754	371606093183301	City	1915
36	Greene	Strafford	Well No. 1	5010768	371618093065201	City	1968
37	Greene	Ash Grove	Well No. 1	5010032	371858093350801	City	1925
38	Hickory	Weaubleau	Well No. 1	5010843	375339093322301	City	1969
39	Hickory	Wheatland	Well No. 1	5010855	375633093240901	City	1963
40	Howell	West Plains	Cherry St.	4010853	364333091511001	City	1944
41	Howell	Howell County Public Water Supply District No. 1	Well No. 1	4024264	365237091543201	Water District	No Data
42	Howell	Willow Springs	10th Street	4010862	365930091581401	City	1953
43	Howell	Mountain View	Well No. 1	4010551	365953091421601	City	1938
44	Iron	Belleview Elem. School	Well No. 1	4171180	374241090445301	School	1958
45	Jasper	Sarcoxie	Well No. 2	5010723	370401094072401	City	1948

Table 1. Identification and drill date for the sampled wells--Continued
[PWS-ID, Public Water Supply Identification Number]

Reference number (fig. 1)	County	Public-water-supply system	Local name	PWS-ID	USGS identification number	Facility type	Drill date
46	Jasper	Carl Junction	Well No. 1	5010138	371040094335601	City	1910
47	Jasper	Oronogo	West Well No. 2	5010606	371121094274901	City	1900
48	Jefferson	Herculaneum	Well No. 1	6010359	381623090230301	City	1909
49	Laclede	Laclede County Public Water Supply District No. 3	Well No. 1	5024319	373955092360601	Water District	No Data
50	Laclede	Lebanon	North	5010458	374115092403201	City	1942
51	Lawrence	Marionville	Well No. 1	5010499	370013093383301	City	1911
52	Lawrence	Miller	Well No. 2	5010525	371255093500801	City	1965
53	Madison	Marquand	Well No. 1	4010501	372546090101501	City	1968
54	Maries	Vienna	Well No. 1	3010822	381118091564601	City	1954
55	Maries	Belle	City Hall	3010054	381713091431201	City	1937
56	McDonald	Noel	Well No. 1	5010577	363239094285201	City	1903
57	McDonald	Pineville	Well No. 1	5010645	363530094224501	City	1939
58	Miller	Eldon	W Grand & N Newton	3010240	382112092351001	City	1931
59	Moniteau	California	At old tower	3010124	383746092340301	City	1910
60	Moniteau	Jamestown	Well No. 1	3010407	384556092284401	City	1954
61	Morgan	Stover	Well No. 1	3010767	382628092594201	City	1939
62	Newton	Neosho	Dewey & Finney	5010560	365138094221901	City	1937
63	Newton	Granby	Well No. 2	5010321	365437094155201	City	1940
64	Oregon	Thayer	Well No. 3	4010788	363126091325801	City	1946
65	Oregon	Alton	Well No. 1	4010012	364137091234601	City	1948
66	Osage	Linn	City Hall	3010470	382917091511101	City	1956
67	Osage	Chamois	1st Street	3010155	384031091460201	City	1923
68	Ozark	Gainesville	Well No. 1	5010297	363610092254001	City	1951

Table 1. Identification and drill date for the sampled wells--Continued
[PWS-ID, Public Water Supply Identification Number]

Reference number (fig. 1)	County	Public-water-supply system	Local name	PWS-ID	USGS identification number	Facility type	Drill date
69	Perry	Frohna	Well No. 1	4010293	373822089371001	City	1961
70	Pettis	Sedalia	South of No. 6	3010728	384004093134001	City	1905
71	Pettis	Hughesville	Well No. 1	3010386	385018093174201	City	No Data
72	Phelps	Phelps County Public Water Supply District No. 1	Well No. 1	3024465	374210091514501	Water District	1937
73	Phelps	Newburg	Well No. 1	3010887	375451091540501	City	1958
74	Phelps	St. James	Park Well	3010712	375955091362001	City	1969
75	Polk	Pleasant Hope	Well No. 1	5010650	372719093161901	City	1965
76	Polk	Morrisville	Well No. 1	5010545	372858093253401	City	1963
77	Pulaski	Waynesville	Well No. 2	3010841	374939092123001	City	1961
78	Pulaski	Richland	Downtown	3010684	375120092234001	City	1947
79	Pulaski	Dixon	Park Well	3010219	375939092055701	City	1939
80	Reynolds	Ellington	Well No. 2	4010243	371440090581501	City	1961
81	Reynolds	Centerville	Well No. 1	4010151	372609090573201	City	1968
82	Ripley	Naylor	Well No. 1	4010557	363435090363301	City	1963
83	Ripley	Ripley County Public Water Supply District No. 1 - West	West Well No. 1	4024522	363645090505601	Water District	1965
84	Scott	Sikeston	Well No. 6-Plant No. 2	4010743	365245089350401	City	1960
85	Scott	Benton	Well No. 1	4010062	370549089335001	City	1903
86	Shannon	Winona	Well No. 4	4010867	370050091192901	City	1963
87	St Clair	Lowry City	Well No. 2	5010480	380824093434201	City	1967
88	St Francois	Bonne Terre	Well No. 1	4010087	375451090324201	City	1962
89	St Louis	Eureka	Allenton Rd.	6010258	383009090391901	City	1962
90	St Louis	Kirkwood	Ranney Well	6010430	383325090270801	City	1947

Table 1. Identification and drill date for the sampled wells--Continued
[PWS-ID, Public Water Supply Identification Number]

Reference number (fig. 1)	County	Public-water-supply system	Local name	PWS-ID	USGS identification number	Facility type	Drill date
91	Ste Genevieve	Bloomsdale	Well No. 1	4010079	380130090140401	City	1966
92	Ste Genevieve	Ste. Genevieve County Public Water Supply District No. 1 - North	Well No. 1	4024544	380234090175101	Water District	1969
93	Stoddard	Essex	Well No. 001	4010255	364850089514001	City	1956
94	Stone	Reed Springs	Well No. 2	5010679	364451093225401	City	1961
95	Stone	Crane	Well No. 1	5010192	365433093340901	City	1969
96	Taney	Hollister	Esplanade	5010374	363716093130401	City	1953
97	Taney	Forsyth	Well No. 2	5010285	364111093071001	City	1946
98	Texas	Summersville	Well No. 2	4010777	371050091394601	City	1961
99	Texas	Raymondville	Well No. 1	4010674	372012091495101	City	1957
100	Texas	Texas County Public Water Supply District No. 1	Well No. 1	4024606	372647092052201	Water District	1967
101	Texas	Licking	Well No. 2	4010467	372939091514901	City	1959
102	Washington	Irondale	Well No. 1	6010401	375028090400301	City	1967
103	Washington	Potosi	Well No. 5	6010659	375538090465301	City	1966
104	Wayne	Williamsville	Well No. 1	4010861	365813090325001	City	1962
105	Wayne	Wayne County Public Water Supply District No. 1	Well No. 1	4024637	370737090265301	Water District	1970
106	Webster	Rogersville	Well No. 1	5010699	370646093030901	City	1954
107	Webster	Seymour	Well No. 1	5010734	370845092461101	City	1927
108	Wright	Norwood	Well No. 1	5010585	370631092250201	City	1954
109	Wright	Mountain Grove	Well No. 3	5010550	370812092155601	City	1947

Table 2. Selected characteristics for the public water supply systems sampled

[PWSD, public water supply district SMRALRL-F, Southern Missouri Residual and Loess-Residual Landscape – forest; GC, Gerald-Craig-Eldon and Newtonia-Baxter; PD, Parsons-Dennis-Bates; WC, Waverly-Calhoun; CF, Clarksville-Fullerton-Talbott; UF, Union-Fullerton-McGirk; LC, Lebanon-Nixa-Clarksville and Hobson-Clarksville, AVL-SM, Alluvial Valley Landscape – Southeastern Missouri; MW, Menfro-Winfield-Weldon; DD, Dubbs-Dundee-Boskett; HT, Hagerstown-Tilsit; ML, Memphis-Loring; af, agriculture and forest; u, urban; ua, urban and agriculture; a, agriculture; uaf, urban, agriculture, and forest; f, forest; uf, urban and forest; N/A, not available]

Reference number (fig. 1)	County	Public-water-supply system	Soils	Karst type	Geohydrology	Land use	Altitude, in feet above sea level	Depth of well, in feet	Pump type
1	Barry	Purdy	SMRALRL-F	Nonkarst	Confined Ozark	a	1,470	900	Submersible
2	Barry	Monett	GC	Nonkarst	Confined Ozark	a	1,300	1,535	Turbine
3	Barton	Barton County Consolidated PWSD No. 1	PD	Nonkarst	Confined Ozark	a	1,020	940	Submersible
4	Benton	Lincoln	GC	Nonkarst	Confined Ozark	a	958	600	Submersible
5	Benton	Cole Camp	GC	Nonkarst	Unconfined Ozark	a	1,049	451	Submersible
6	Benton	Ionia	GC	Nonkarst	Unconfined Ozark	a	971	550	Submersible
7	Bollinger	Marble Hill - South	SMRALRL-F	Nonkarst	Unconfined Ozark	f	420	N/A	Turbine
8	Butler	Qulin	WC	Nonkarst	McNairy	a	317	324	Turbine
9	Camden	Camdenton	CF	Secondary	Unconfined Ozark	uf	1,036	940	Turbine
10	Camden	KK Water Supply	CF	Nonkarst	Unconfined Ozark	uf	240	855	Turbine
11	Cape Girardeau	Jackson	SMRALRL-F	Primary	Unconfined Ozark	ua	450	2,217	Turbine
12	Cape Girardeau	Cape Girardeau County PWSD No. 2	SMRALRL-F	Nonkarst	Unconfined Ozark	a	636	1,200	Submersible
13	Carter	Grandin	SMRALRL-F	Nonkarst	Unconfined Ozark	f	600	775	Turbine
14	Carter	Ellsinore	SMRALRL-F	Nonkarst	Unconfined Ozark	f	720	1,360	Submersible
15	Carter	Carter County PWSD No. 1	SMRALRL-F	Secondary	Unconfined Ozark	f	600	600	Submersible
16	Cedar	El Dorado Springs	PD	Nonkarst	Confined Ozark	a	915	951	Submersible
17	Christian	Sparta	SMRALRL-F	Primary	Confined Ozark	a	1,423	1,100	Submersible
18	Christian	Ozark	SMRALRL-F	Primary	Confined Ozark	ua	1,184	1,151	Submersible
19	Christian	Billings	GC	Primary	Confined Ozark	ua	1,368	1,190	Submersible
20	Cole	Cole County PWSD No. 5	UF	Nonkarst	Unconfined Ozark	af	795	730	Submersible
21	Cooper	Pilot Grove	UF	Primary	Confined Ozark	a	855	630	Submersible

Table 2. Selected characteristics for the public water supply systems sampled--Continued

[PWSD, public water supply district SMRALRL-F, Southern Missouri Residual and Loess-Residual Landscape – forest; GC, Gerald-Craig-Eldon and Newtonia-Baxter; PD, Parsons-Dennis-Bates; WC, Waverly-Calhoun; CF, Clarksville-Fullerton-Talbott; UF, Union-Fullerton-McGirk; LC, Lebanon-Nixa-Clarksville and Hobson-Clarksville, AVL-SM, Alluvial Valley Landscape – Southeastern Missouri; MW, Menfro-Winfield-Weldon; DD, Dubbs-Dundee-Boskett; HT, Hagerstown-Tilsit; ML, Memphis-Loring; af, agriculture and forest; u, urban; ua, urban and agriculture; a, agriculture; uaf, urban, agriculture, and forest; f, forest; uf, urban and forest; N/A, not available]

Reference number (fig. 1)	County	Public-water-supply system	Soils	Karst type	Geohydrology	Land use	Altitude, in feet above sea level	Depth of well, in feet	Pump type
22	Crawford	Steelville	CF	Nonkarst	Unconfined Ozark , St. Francois	f	880	1,320	Turbine
23	Crawford	Cuba	LC	Secondary	Unconfined Ozark	f	1,042	602	Submersible
24	Dade	Lockwood	GC	Nonkarst	Confined Ozark	a	1,080	1,203	Submersible
25	Dade	Greenfield	GC	Primary	Confined Ozark	a	1,075	1,006	Turbine
26	Dallas	Buffalo	SMRALRL-F	Nonkarst	Unconfined Ozark	a	1,192	1,050	Submersible
27	Dallas	Urbana	SMRALRL-F	Nonkarst	Unconfined Ozark	a	1,085	1,090	Submersible
28	Dent	Salem	SMRALRL-F	Secondary	Unconfined Ozark, St. Francois	f	1,180	1,800	Turbine
29	Douglas	Ava	SMRALRL-F	Secondary	Unconfined Ozark	af	1,350	838	Submersible
30	Dunklin	Clarkton	AVL-SM	Nonkarst	McNairy	a	285	1,320	Turbine
31	Franklin	St. Clair	CF	Nonkarst	Unconfined Ozark, St. Francois	f	680	1,540	Submersible
32	Franklin	Washington	MW	Nonkarst	Unconfined Ozark	uf	515	982	Submersible
33	Gasconade	Owensville	LC	Nonkarst	Unconfined Ozark	af	1,035	900	Submersible
34	Gasconade	Rosebud	LC	Nonkarst	Unconfined Ozark	af	905	508	Submersible
35	Greene	Springfield	GC	Primary	Confined Ozark	u	1,130	1,404	Turbine
36	Greene	Strafford	SMRALRL-F	Secondary	Confined Ozark	ua	1,481	1,100	Submersible
37	Greene	Ash Grove	GC	Primary	Confined Ozark	a	1,040	640	Turbine
38	Hickory	Weaubleau	GC	Nonkarst	Confined Ozark	a	985	960	no data
39	Hickory	Wheatland	LC	Primary	Confined Ozark	a	1,077	860	Submersible
40	Howell	West Plains	SMRALRL-F	Primary	Unconfined Ozark	uaf	1,021	1,695	Submersible
41	Howell	Howell County PWSD No. 1	SMRALRL-F	Primary	Unconfined Ozark	af	1,250	1,250	Submersible
42	Howell	Willow Springs	SMRALRL-F	Secondary	Unconfined Ozark	ua	1,291	1,545	Submersible

Table 2. Selected characteristics for the public water supply systems sampled--Continued

[PWSD, public water supply district SMRALRL-F, Southern Missouri Residual and Loess-Residual Landscape – forest; GC, Gerald-Craig-Eldon and Newtonia-Baxter; PD, Parsons-Dennis-Bates; WC, Waverly-Calhoun; CF, Clarksville-Fullerton-Talbott; UF, Union-Fullerton-McGirk; LC, Lebanon-Nixa-Clarksville and Hobson-Clarksville, AVL-SM, Alluvial Valley Landscape – Southeastern Missouri; MW, Menfro-Winfield-Weldon; DD, Dubbs-Dundee-Boskett; HT, Hagerstown-Tilsit; ML, Memphis-Loring; af, agriculture and forest; u, urban; ua, urban and agriculture; a, agriculture; uaf, urban, agriculture, and forest; f, forest; uf, urban and forest; N/A, not available]

Reference number (fig. 1)	County	Public-water-supply system	Soils	Karst type	Geohydrology	Land use	Altitude, in feet above sea level	Depth of well, in feet	Pump type
43	Howell	Mountain View	SMRALRL-F	Primary	Unconfined Ozark	af	1,146	1,150	Submersible
44	Iron	Belleview Elem. School	SMRALRL-F	Nonkarst	St. Francois	f	560	186	Submersible
45	Jasper	Sarcoxie	GC	Nonkarst	Confined Ozark	a	1,172	1,258	Turbine
46	Jasper	Carl Junction	GC	Nonkarst	Confined Ozark	ua	895	914	Submersible
47	Jasper	Oronogo	GC	Nonkarst	Confined Ozark	ua	975	925	Submersible
48	Jefferson	Herculaneum	MW	Nonkarst	Unconfined Ozark	uf	580	473	Submersible
49	Laclede	Laclede County PWSD No. 3	SMRALRL-F	Primary	Unconfined Ozark	af	1,333	1,275	Submersible
50	Laclede	Lebanon	SMRALRL-F	Primary	Unconfined Ozark	uf	1,233	1,637	Submersible
51	Lawrence	Marionville	SMRALRL-F	Primary	Confined Ozark	a	1,355	976	Turbine
52	Lawrence	Miller	GC	Primary	Confined Ozark	a	1,302	1,075	Turbine
53	Madison	Marquand	SMRALRL-F	Nonkarst	Alluvial	af	590	21	Submersible
54	Maries	Vienna	CF	Nonkarst	Unconfined Ozark	f	888	670	Turbine
55	Maries	Belle	LC	Nonkarst	Unconfined Ozark	af	1,029	806	Submersible
56	McDonald	Noel	SMRALRL-F	Nonkarst	Confined Ozark	a	1,040	1,225	Submersible
57	McDonald	Pineville	SMRALRL-F	Nonkarst	Confined Ozark	a	880	903	Submersible
58	Miller	Eldon	GC	Nonkarst	Unconfined Ozark	a	930	850	Submersible
59	Moniteau	California	UF	Nonkarst	Unconfined Ozark, St. Francois	a	896	1,635	Submersible
60	Moniteau	Jamestown	MW	Primary	Confined Ozark	a	865	672	Submersible
61	Morgan	Stover	GC	Nonkarst	Unconfined Ozark	a	1,070	525	Submersible
62	Newton	Neosho	SMRALRL-F	Nonkarst	Confined Ozark	a	1,164	1,247	Submersible
63	Newton	Granby	GC	Nonkarst	Confined Ozark	a	1,105	1,000	Submersible
64	Oregon	Thayer	SMRALRL-F	Primary	Unconfined Ozark	f	720	550	Submersible
65	Oregon	Alton	SMRALRL-F	Secondary	Unconfined Ozark	f	787	1,200	Submersible

Table 2. Selected characteristics for the public water supply systems sampled--Continued

[PWSD, public water supply district SMRALRL-F, Southern Missouri Residual and Loess-Residual Landscape – forest; GC, Gerald-Craig-Eldon and Newtonia-Baxter; PD, Parsons-Dennis-Bates; WC, Waverly-Calhoun; CF, Clarksville-Fullerton-Talbott; UF, Union-Fullerton-McGirk; LC, Lebanon-Nixa-Clarksville and Hobson-Clarksville, AVL-SM, Alluvial Valley Landscape – Southeastern Missouri; MW, Menfro-Winfield-Weldon; DD, Dubbs-Dundee-Boskett; HT, Hagerstown-Tilsit; ML, Memphis-Loring; af, agriculture and forest; u, urban; ua, urban and agriculture; a, agriculture; uaf, urban, agriculture, and forest; f, forest; uf, urban and forest; N/A, not available]

Reference number (fig. 1)	County	Public-water-supply system	Soils	Karst type	Geohydrology	Land use	Altitude, in feet above sea level	Depth of well, in feet	Pump type
66	Osage	Linn	UF	Nonkarst	Unconfined Ozark	af	941	1,080	Submersible
67	Osage	Chamois	MW	Nonkarst	Unconfined Ozark	a	555	300	Submersible
68	Ozark	Gainesville	SMRALRL-F	Secondary	Unconfined Ozark	f	760	860	Submersible
69	Perry	Frohna	SMRALRL-F	Nonkarst	Unconfined Ozark	a	1,010	1,092	Submersible
70	Pettis	Sedalia	GC	Nonkarst	Unconfined Ozark, St. Francois	a	780	1,531	Submersible
71	Pettis	Hughesville	UF	Primary	Unconfined Ozark	a	820	935	Submersible
72	Phelps	Phelps County PWSD No. 1	SMRALRL-F	Primary	Unconfined Ozark	f	1,203	960	Submersible
73	Phelps	Newburg	CF	Nonkarst	Ozark Unconfined	f	764	785	Turbine
74	Phelps	St. James	LC	Secondary	Ozark Unconfined	f	1,109	1,100	Submersible
75	Polk	Pleasant Hope	SMRALRL-F	Nonkarst	Ozark Unconfined	a	1,169	660	Submersible
76	Polk	Morrisville	GC	Nonkarst	Ozark Confined	a	1,155	1,000	Submersible
77	Pulaski	Waynesville	SMRALRL-F	Nonkarst	Unconfined Ozark	uf	7,75	900	Turbine
78	Pulaski	Richland	SMRALRL-F	Nonkarst	Unconfined Ozark	f	1,110	1,202	Submersible
79	Pulaski	Dixon	CF	Nonkarst	Unconfined Ozark	f	1,162	889	Submersible
80	Reynolds	Ellington	SMRALRL-F	Secondary	Unconfined Ozark	f	650	23	Submersible
81	Reynolds	Centerville	SMRALRL-F	Nonkarst	Unconfined Ozark	f	730	803	Submersible
82	Ripley	Naylor	AVL-SM	Nonkarst	Alluvial	a	305	70	Submersible
83	Ripley	Ripley County PWSD No. 1 - West	SMRALRL-F	Nonkarst	Unconfined Ozark	f	420	845	Submersible
84	Scott	Sikeston	DD	Nonkarst	Wilcox	ua	327	400	Turbine
85	Scott	Benton	DD	Nonkarst	Unconfined Ozark	a	435	1,500	Submersible
86	Shannon	Winona	SMRALRL-F	Primary	Unconfined Ozark	f	986	1,110	Submersible
87	St Clair	Lowry City	PD	Nonkarst	Confined Ozark	a	870	630	Submersible
88	St Francois	Bonne Terre	HT	Primary	St. Francois	f	958	746	Turbine
89	St Louis	Eureka	UF	Nonkarst	Unconfined Ozark	uf	475	802	Submersible

Table 2. Selected characteristics for the public water supply systems sampled--Continued

[PWSD, public water supply district SMRALRL-F, Southern Missouri Residual and Loess-Residual Landscape – forest; GC, Gerald-Craig-Eldon and Newtonia-Baxter; PD, Parsons-Dennis-Bates; WC, Waverly-Calhoun; CF, Clarksville-Fullerton-Talbott; UF, Union-Fullerton-McGirk; LC, Lebanon-Nixa-Clarksville and Hobson-Clarksville, AVL-SM, Alluvial Valley Landscape – Southeastern Missouri; MW, Menfro-Winfield-Weldon; DD, Dubbs-Dundee-Boskett; HT, Hagerstown-Tilsit; ML, Memphis-Loring; af, agriculture and forest; u, urban; ua, urban and agriculture; a, agriculture; uaf, urban, agriculture, and forest; f, forest; uf, urban and forest; N/A, not available]

Reference number (fig. 1)	County	Public-water-supply system	Soils	Karst type	Geohydrology	Land use	Altitude, in feet above sea level	Depth of well, in feet	Pump type
90	St Louis	Kirkwood	MW	Secondary	Alluvial	u	400	62	Submersible
91	Ste Genev-ieve	Bloomsdale	ML	Secondary	Unconfined Ozark	f	664	950	Submersible
92	Ste Genev-ieve	Ste. Genevieve County PWSD No. 1 - North	ML	Nonkarst	St. Francois	f	729	1,150	Submersible
93	Stoddard	Essex	AVL-SM	Nonkarst	McNairy	a	301	475	Submersible
94	Stone	Reed Springs	SMRALRL-F	Nonkarst	Confined Ozark	f	1,363	1,100	Submersible
95	Stone	Crane	SMRALRL-F	Nonkarst	Confined Ozark	af	1,242	1,660	Submersible
96	Taney	Hollister	SMRALRL-F	Secondary	Unconfined Ozark	uf	800	990	Submersible
97	Taney	Forsyth	SMRALRL-F	Secondary	Unconfined Ozark	uf	947	1,015	Turbine
98	Texas	Summersville	SMRALRL-F	Secondary	Unconfined Ozark	f	1,230	1,250	Submersible
99	Texas	Raymondville	SMRALRL-F	Secondary	Unconfined Ozark	f	1,344	850	Submersible
100	Texas	Texas County PWSD No. 1	SMRALRL-F	Secondary	Unconfined Ozark	af	1,370	1,300	Submersible
101	Texas	Licking	SMRALRL-F	Primary	Unconfined Ozark	f	1,290	903	Turbine
102	Washington	Irondale	SMRALRL-F	Nonkarst	St. Francois	f	965	1,030	Submersible
103	Washington	Potosi	CF	Nonkarst	St. Francois	f	940	1,425	Turbine
104	Wayne	Williamsville	SMRALRL-F	Nonkarst	Unconfined Ozark	a	391	650	Turbine
105	Wayne	Wayne County PWSD No. 1	SMRALRL-F	Nonkarst	Unconfined Ozark	f	430	769	Submersible
106	Webster	Rogersville	SMRALRL-F	Primary	Confined Ozark	ua	1,485	1,260	Submersible
107	Webster	Seymour	SMRALRL-F	Secondary	Confined Ozark	af	1,642	1,235	Submersible
108	Wright	Norwood	SMRALRL-F	Primary	Unconfined Ozark	af	1,519	1,199	Submersible
109	Wright	Mountain Grove	SMRALRL-F	Secondary	Unconfined Ozark	f	1,480	1,520	Submersible

Table 3. Statistical summary of values of physical properties and concentrations of chemical constituents

[°C, degree Celsius; µS/cm, microseimen per centimeter at 25 °C; mg/l, milligrams per liter; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; <, less than]

Physical property or constituent	Number of samples	Minimum	Percentiles					Maximum
			10	25	50 (median)	75	90	
Water temperature (°C)	109	12.0	14.5	15.5	16.0	17.0	18.5	24.5
Specific conductance (µS/cm)	109	157	307	354	444	522	680	1,460
pH (standard units)	109	6.9	7.2	7.5	7.6	7.7	7.8	8.2
Dissolved oxygen (mg/l)	109	0.0	0.0	0.2	0.8	2.5	4.0	7.0
Alkalinity (mg/l as $CaCO_3$)	109	77	136	165	212	252	289	344
Nitrate plus nitrite (mg/l as N)	109	<0.05	<0.05	<0.05	<0.05	0.246	1.1	3.58
Nitrite (mg/l as N)	109	<0.01	<0.01	<0.01	<0.01	<0.01	0.012	0.017
Ammonia (mg/l as N)	109	<0.02	<0.02	0.022	0.036	0.061	0.099	6.54
Ammonia plus organic nitrogen (mg/l as N)	109	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.64
Phosphorus (mg/l as P)	109	<0.01	<0.01	<0.01	<0.01	<0.01	0.014	0.099
Orthophosphorus (mg/l as P)	109	<0.01	<0.01	<0.01	<0.01	0.014	0.017	0.044
Total organic carbon (mg/l)	109	<0.1	<0.1	<0.1	0.3	0.8	1.6	5.9

Table 4. Results of physical and chemical analysis for sampled wells in the study area

[°C, degrees Celsius; Pt - Co, Platinum-Cobalt; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligams per liter; $CaCO_3$, calcium carbonate; <, less than laboratory detection levels; NA, no data]

Reference number (fig. 1)	Date	Water temperature (°C)	Color (Pt-Co units)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	pH (standard units)	Alkalinity (mg/L as $CaCO_3$)	Total organic carbon (mg/L)
1	6/10/98	17.5	<5	350	0.3	7.7	172	>0.50
2	6/11/98	16.0	<5	350	4.0	7.2	154	.1
3	6/8/98	19.0	<5	293	.2	7.9	138	.1
4	4/8/98	15.0	<5	582	.5	7.1	258	.2
5	4/8/98	13.5	<5	460	.2	7.1	215	.2
6	4/9/98	14.5	<5	461	0	7.2	217	2.9
7	4/23/98	15.0	<5	529	4.0	7.7	268	.1
8	5/20/98	16.5	<5	894	.2	8.2	184	.1
9	5/7/98	15.5	<5	541	.5	7.5	282	.4
10	5/7/98	15.5	<5	646	1.0	7.4	328	.2
11	4/21/98	19.5	<5	669	.1	7.6	218	.3
12	4/21/98	14.0	<5	291	1.0	7.5	136	.1
13	6/24/98	16.0	<5	406	3.0	7.7	212	.5
14	6/25/98	17.0	<5	371	4.0	7.6	195	.1
15	6/25/98	16.5	<5	397	6.0	7.5	207	4.4
16	4/13/98	19.0	<5	788	0	7.5	160	.3
17	6/17/98	16.5	<5	364	.6	7.7	180	.9
18	6/8/98	17.0	<5	307	0	7.9	144	.3
19	6/8/98	17.5	<5	319	.1	7.9	164	.1
20	5/5/98	15.0	<5	639	< 1.0	7.5	321	1.2

Table 4. Results of physical and chemical analysis for sampled wells in the study area--Continued

[°C, degrees Celsius; Pt - Co, Platinum-Cobalt; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligams per liter; $CaCO_3$, calcium carbonate; <, less than laboratory detection levels; NA, no data]

Reference number (fig. 1)	Date	Water temperature (°C)	Color (Pt-Co units)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	pH (standard units)	Alkalinity (mg/L as $CaCO_3$)	Total organic carbon (mg/L)
21	4/8/98	15.0	<5	569	0.5	7.5	289	0.2
22	4/27/98	15.0	<5	390	4.0	8.1	213	.4
23	4/27/98	16.0	<5	436	.5	7.8	218	.1
24	6/16/98	19.0	<5	241	0	7.8	115	1.9
25	6/11/98	19.0	<5	283	.2	7.7	135	.2
26	5/14/98	16.5	<5	415	0	7.6	210	.4
27	5/13/98	15.5	<5	564	0	7.5	282	1.5
28	6/3/98	15.5	<5	403	3.0	7.7	205	.1
29	5/27/98	17.0	<5	484	2.0	7.6	234	.2
30	5/19/98	24.5	<5	600	1.0	8.2	233	2.5
31	4/28/98	15.3	<5	421	1.0	7.8	175	.1
32	4/13/98	15.5	<5	483	1.0	7.7	241	.8
33	4/30/98	16.0	<5	487	.1	7.6	234	< .10
34	4/30/98	15.0	<5	377	.5	7.8	172	.1
35	6/16/98	17.5	<5	391	.4	7.8	185	.3
36	6/18/98	16.5	<5	319	.2	7.5	151	.4
37	6/18/98	16.0	<5	312	0	7.5	147	1.4
38	5/18/98	18.0	<5	443	0	7.7	214	.2
39	5/12/98	16.5	<5	467	0	7.7	243	.3
40	6/18/98	15.5	8	471	5.0	7.3	214	.1
41	6/18/98	15.5	<5	383	7.0	7.8	193	.8

Table 4. Results of physical and chemical analysis for sampled wells in the study area--Continued

[°C, degrees Celsius; Pt - Co, Platinum-Cobalt; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligams per liter; $CaCO_3$, calcium carbonate; <, less than laboratory detection levels; NA, no data]

Reference number (fig. 1)	Date	Water temperature (°C)	Color (Pt-Co units)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	pH (standard units)	Alkalinity (mg/L as $CaCO_3$)	Total organic carbon (mg/L)
42	6/17/98	15.5	<5	354	2.5	7.9	165	>2.0
43	6/15/98	16.0	<5	422	3.0	7.7	200	.1
44	6/30/98	16.0	<5	573	2.0	7.6	266	.3
45	4/16/98	17.5	<5	243	0	8.0	108	.1
46	6/9/98	17.5	<5	375	0	7.2	167	1.6
47	6/9/98	20.0	<5	414	.4	7.4	181	.1
48	4/15/98	15.0	<5	696	2.5	7.5	291	.2
49	5/6/98	15.0	<5	350	2.0	7.7	172	.3
50	5/14/98	16.0	<5	366	1.5	7.7	177	.7
51	6/10/98	17.5	<5	318	0	7.6	155	.1
52	6/9/98	17.0	<5	324	2.5	7.8	154	.1
53	4/23/98	12.0	<5	223	1.5	7.0	104	NA
54	5/7/98	15.5	<5	613	<1.0	7.6	287	.4
55	5/5/98	16.0	<5	375	0	7.8	143	.1
56	4/15/98	20.0	<5	528	0	7.7	126	.1
57	4/15/98	18.5	<5	331	0	7.4	116	.3
58	5/6/98	16.0	<5	490	<1.0	7.6	244	.1
59	4/7/98	16.0	<5	482	.2	6.9	221	.1
60	4/7/98	15.5	<5	451	.3	7.2	224	.8
61	5/6/98	14.5	<5	482	1.0	7.6	236	.1

Table 4. Results of physical and chemical analysis for sampled wells in the study area--Continued

[°C, degrees Celsius; Pt - Co, Platinum-Cobalt; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligams per liter; $CaCO_3$, calcium carbonate; <, less than laboratory detection levels; NA, no data]

Reference number (fig. 1)	Date	Water temperature (°C)	Color (Pt-Co units)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	pH (standard units)	Alkalinity (mg/L as $CaCO_3$)	Total organic carbon (mg/L)
62	4/14/98	19.0	<5	327	0	7.2	158	1.4
63	4/14/98	18.0	<5	300	0	7.7	132	.1
64	6/16/98	15.5	<5	609	3.5	7.4	312	1.8
65	6/17/98	16.5	<5	509	3	7.6	256	1.9
66	4/29/98	16.5	<5	457	.1	7.5	220	<.10
67	4/29/98	14.5	<5	500	.1	7.6	253	.5
68	5/27/98	15.0	<5	495	4	7.5	259	.2
69	4/20/98	16.0	<5	688	.3	7.4	306	.1
70	4/6/98	16.0	<5	451	.5	7.1	228	.5
71	4/8/98	16.0	<5	930	.2	7.0	331	.4
72	6/3/98	15.0	<5	341	4	7.5	222	1
73	6/2/98	15.7	<5	462	.6	7.6	234	.1
74	6/2/98	16.5	<5	753	.7	7.4	260	.3
75	5/19/98	16.0	<5	314	.1	7.8	173	.2
76	5/11/98	17.0	<5	290	1	8.1	143	.8
77	5/6/98	16.0	<5	475	.6	7.8	236	.4
78	5/5/98	1.07	<5	490	0	7.6	252	.1
79	5/20/98	18.0	<5	690	.1	7.5	280	4.9
80	7/16/98	17.5	<5	264	4.5	7.3	131	<.1
81	5/18/98	16.1	<5	360	.3	7.6	144	.1

Table 4. Results of physical and chemical analysis for sampled wells in the study area--Continued

[°C, degrees Celsius; Pt - Co, Platinum-Cobalt; μS/cm, microsiemens per centimeter at 25 °C; mg/L, milligams per liter; $CaCO_3$, calcium carbonate; <, less than laboratory detection levels; NA, no data]

Reference number (fig. 1)	Date	Water temperature (°C)	Color (Pt-Co units)	Specific conductance (μS/cm)	Dissolved oxygen (mg/L)	pH (standard units)	Alkalinity (mg/L as $CaCO_3$)	Total organic carbon (mg/L)
82	5/20/98	16.5	<5	522	1	6.9	108	1.3
83	6/16/98	17.0	<5	508	2	7.6	255	.1
84	4/22/98	16.0	<5	354	0.2	7.4	148	1.2
85	4/22/98	16.5	<5	622	1	7.6	279	.5
86	6/24/98	16.5	<5	347	6	7.7	202	<.1
87	4/13/98	17.0	<5	451	0	7.4	189	.1
88	4/16/98	15.5	<5	737	0	7.5	290	.1
89	4/13/98	15.0	<5	1,460	1	7.5	282	.2
90	4/14/98	14.5	<5	611	.2	7.3	181	.7
91	4/16/98	12.0	<5	486	4	7.6	263	.1
93	5/19/98	18.5	<5	1,070	.8	7.6	214	.5
94	6/10/98	17.0	<5	361	.4	7.5	182	.5
95	6/17/98	18.0	<5	315	1	7.8	156	1.3
96	6/9/98	16.9	<5	482	.5	7.5	240	.1
97	6/9/98	18.5	<5	476	1	7.5	230	.4
98	5/14/98	16.0	<5	374	3	7.7	186	.2
99	5/13/98	15.5	<5	385	3	7.8	185	.2
100	5/13/98	17.5	<5	464	.8	7.7	282	1.0
101	5/12/98	14.5	<5	411	3	7.7	217	1.6
102	6/24/98	14.5	<5	680	3	7.3	342	3.0

Table 4. Results of physical and chemical analysis for sampled wells in the study area--Continued

[°C, degrees Celsius; Pt - Co, Platinum-Cobalt; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligams per liter; $CaCO_3$, calcium carbonate; <, less than laboratory detection levels; NA, no data]

Reference number (fig. 1)	Date	Water temperature (°C)	Color (Pt-Co units)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	pH (standard units)	Alkalinity (mg/L as $CaCO_3$)	Total organic carbon (mg/L)
103	6/4/98	16.0	<5	444	0.2	7.6	200	.2
104	5/21/98	15.0	<5	157	4	7.3	77	.3
105	5/18/98	16.5	<5	339	4.5	7.8	162	1.0
106	6/15/98	14.5	<5	421	2.5	7.5	193	.8
107	6/15/98	15.5	<5	346	1.0	7.8	172	.5
108	5/26/98	16.0	<5	409	2.0	7.7	344	.3
109	5/26/98	14.5	<5	444	1.0	7.8	215	.1

Table 4. Results of physical and chemical analysis for sampled wells in the study area--Continued

[°C, degrees Celsius; Pt - Co, Platinum-Cobalt; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligams per liter; $CaCO_3$, calcium carbonate; <, less than laboratory detection levels; NA, no data]

Reference number (fig. 1)	Date	Nitrogen, ammonia (mg/L)	Nitrogen, nitrite, (mg/L)	Nitrogen, ammonia and organic (mg/L)	Nitrogen, nitrite plus nitrate (mg/L)	Phosphorus (mg/L)	Phosphorus, ortho (mg/L)
1	6/10/98	<0 .020	<0 .010	0.10	2.540	<0 .014	0.010
2	6/11/98	.034	< .010	< .10	< .050	.010	< .016
3	6/8/98	< .020	< .010	< .10	< .050	.010	.012
4	4/8/98	< .020	< .010	.10	< .057	.010	.014
5	4/8/98	.023	< .010	< .10	< .050	.010	.013
6	4/9/98	.022	< .010	< .10	< .050	.010	.016
7	4/23/98	.05	< .010	.10	< 3.580	.010	.027
8	5/20/98	.721	.0017	.64	.066	.043	.042
9	5/7/98	.041	< .010	.10	< .537	< .010	.010
10	5/7/98	.041	< .010	< .10	< .050	< .010	.010
11	4/21/98	.042	< .010	.10	< .680	.010	.015
12	4/21/98	.026	< .010	< .10	< .050	< .010	< .010
13	6/24/98	.027	< .010	.10	< .096	< .010	.010
14	6/25/98	.036	< .010	.10	< .061	< .010	< .010
15	6/25/98	.022	< .010	< .10	< .050	< .010	.010
16	4/13/98	.171	.010	< .14	.050	< .010	.010
17	6/17/98	.065	< .010	< .10	< .050	< .010	.010
18	6/8/98	< .020	< .010	< .10	< .050	.010	.015
19	6/8/98	< .020	< .010	.10	< .172	.010	.014
20	5/5/98	.037	< .010	< .10	< .050	< .010	.010

Table 4. Results of physical and chemical analysis for sampled wells in the study area--Continued

[°C, degrees Celsius; Pt - Co, Platinum-Cobalt; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligams per liter; $CaCO_3$, calcium carbonate; <, less than laboratory detection levels; NA, no data]

Reference number (fig. 1)	Date	Nitrogen, ammonia (mg/L)	Nitrogen, nitrite, (mg/L)	Nitrogen, ammonia and organic (mg/L)	Nitrogen, nitrite plus nitrate (mg/L)	Phosphorus (mg/L)	Phosphorus, ortho (mg/L)
21	4/8/98	0.075	<0 .010	<0 .10	<0.050	0.010	0.017
22	4/27/98	.024	< .010	< .10	.135	< .010	.016
23	4/27/98	.024	< .010	< .10	.283	< .010	.013
24	6/16/98	.050	.011	< .10	< .050	< .010	.010
25	6/11/98	< .020	< .010	< .10	< .050	.010	.014
26	5/14/98	.039	< .010	< .10	< .050	< .010	.010
27	5/13/98	.021	< .010	< .10	< .050	< .010	.010
28	6/3/98	< .020	< .010	.10	< 1.27	< .010	.010
29	5/27/98	.073	.012	.10	< 1.19	< .010	.010
30	5/19/98	.530	.010	< .56	.05	.026	.044
31	4/28/98	.100	< .010	< .10	< .05	< .010	.014
32	4/13/98	.020	< .010	< .10	.05	< .013	.010
33	4/30/98	.022	< .010	< .10	< .050	< .010	.014
34	4/30/98	.025	< .010	< .10	.106	< .010	.018
35	6/16/98	.072	< .010	< .10	< .050	< .010	.010
36	6/18/98	.066	.011	.10	< .076	< .010	.010
37	6/18/98	.060	.012	< .10	< .050	< .010	.010
38	5/18/98	.053	< .010	< .10	< .050	< .010	.010
39	5/12/98	.087	< .010	< .10	< .050	< .010	.010
40	6/18/98	.038	.012	.10	< .311	< .010	.010

Table 4. Results of physical and chemical analysis for sampled wells in the study area--Continued

[°C, degrees Celsius; Pt - Co, Platinum-Cobalt; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligams per liter; $CaCO_3$, calcium carbonate; <, less than laboratory detection levels; NA, no data]

Reference number (fig. 1)	Date	Nitrogen, ammonia (mg/L)	Nitrogen, nitrite, (mg/L)	Nitrogen, ammonia and organic (mg/L)	Nitrogen, nitrite plus nitrate (mg/L)	Phosphorus (mg/L)	Phosphorus, ortho (mg/L)
41	6/18/98	0.071	<0.013	0.10	<0 .447	0.010	0.010
42	6/17/98	.099	< .010	.10	1.100	< .011	.010
43	6/15/98	.065	< .012	< .10	< .050	< .010	.010
44	6/30/98	.026	< .010	.10	< 1.180	< .010	.010
45	4/16/98	.065	< .010	< .10	.050	< .010	< .010
46	6/9/98	.023	< .010	< .10	< .050	.010	.015
47	6/9/98	< .020	< .010	< .10	< .050	.010	.016
48	4/15/98	.070	< .010	.10	.061	.015	.011
49	5/6/98	.031	< .010	.10	< .123	< .010	.010
50	5/14/98	< .020	< .010	.10	< .398	< .010	.010
51	6/10/98	< .020	< .010	< .10	< .050	.010	.015
52	6/9/98	< .020	< .010	.10	< .508	.010	< .013
53	4/23/98	.032	< .010	< .10	.451	< .010	< .010
54	5/7/98	.032	< .010	.10	< .451	< .010	.010
55	5/5/98	.042	< .010	.10	< 2.000	< .010	.010
56	4/15/98	.060	< .010	< .10	.050	< .011	< .010
57	4/15/98	.058	< .010	< .10	.050	< .011	.010
58	5/6/98	.037	< .010	.10	< .059	< .010	.010
59	4/7/98	.023	< .010	< .10	< .050	.010	.013
60	4/7/98	.041	< .010	< .10	< .050	.010	.019

Table 4. Results of physical and chemical analysis for sampled wells in the study area--Continued

[°C, degrees Celsius; Pt - Co, Platinum-Cobalt; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligams per liter; $CaCO_3$, calcium carbonate; <, less than laboratory detection levels; NA, no data]

Reference number (fig. 1)	Date	Nitrogen, ammonia (mg/L)	Nitrogen, nitrite, (mg/L)	Nitrogen, ammonia and organic (mg/L)	Nitrogen, nitrite plus nitrate (mg/L)	Phosphorus (mg/L)	Phosphorus, ortho (mg/L)
61	5/6/98	0.041	<0 .010	0.10	<1.160	<0 .010	0.010
62	4/14/98	< .020	< .010	< .10	.050	< .015	.010
63	4/14/98	< .020	< .010	.10	.155	< .011	.010
64	6/16/98	.068	< .013	.10	< .246	< .010	.010
65	6/17/98	.066	< .013	.10	< 1.490	< .010	.010
66	4/29/98	.027	< .010	< .10	< .050	< .010	.013
67	4/29/98	.026	< .010	< .10	< .050	< .010	.016
68	5/27/98	.069	< .012	.10	1.070	< .035	.010
69	4/20/98	.032	< .010	< .10	< .050	.010	.013
70	4/6/98	.356	.010	< .32	< .050	.010	.015
71	4/8/98	.045	< .010	< .10	< .050	.010	.015
72	6/3/98	< .020	<.010	< .10	< .050	<.010	< .010
73	6/2/98	< .020	< .010	.10	< 1.630	< .010	.010
74	6/2/98	< .020	< .010	< .10	< .050	< .010	.010
75	5/19/98	.035	< .010	< .10	< .050	< .010	.010
76	5/11/98	.041	< .010	< .10	< .050	< .010	.010
77	5/6/98	.027	NA	< .10	< .050	< .010	.010
78	5/5/98	.035	< .010	< .10	< .050	< .010	.010
79	5/20/98	.044	< .010	.10	< .117	< .010	.010
80	7/16/98	< .020	.010	< .10	< .050	< .010	.019

Table 4. Results of physical and chemical analysis for sampled wells in the study area--Continued

[°C, degrees Celsius; Pt - Co, Platinum-Cobalt; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligams per liter; $CaCO_3$, calcium carbonate; <, less than laboratory detection levels; NA, no data]

Reference number (fig. 1)	Date	Nitrogen, ammonia (mg/L)	Nitrogen, nitrite, (mg/L)	Nitrogen, ammonia and organic (mg/L)	Nitrogen, nitrite plus nitrate (mg/L)	Phosphorus (mg/L)	Phosphorus, ortho (mg/L)
81	5/18/98	0.059	<0.010	< 0.10	0.050	0.014	0.011
82	5/20/98	6.540	< .010	< .10	.050	.014	.011
83	6/16/98	.065	< .012	.10	< .109	< .010	< .010
84	4/22/98	.034	< .010	.10	< .960	< .010	.010
85	4/22/98	.144	< .010	< .10	.050	.099	.022
86	6/24/98	< .020	< .010	.10	< .127	< .010	.010
87	4/13/98	.103	< .010	< .10	.050	< .010	.010
88	4/16/98	.078	< .010	.10	.082	.022	.013
89	4/13/98	.028	< .010	.10	.747	.020	.016
90	4/14/98	.201	.010	.17	.128	.030	.024
91	4/16/98	.021	< .010	.10	.075	< .011	< .010
92	4/15/98	.029	< .010	.10	.188	.013	.010
93	5/19/98	.598	.016	.56	.065	< .011	.010
94	6/10/98	< .020	< .010	.10	< .106	.010	.010
95	6/17/98	.036	< .012	< .10	< .050	< .010	.010
96	6/9/98	< .020	< .010	< .10	< .050	.010	.016
97	6/9/98	< .020	< .010	< .10	< .050	.010	.010
98	5/14/98	.039	< .010	.10	< .254	< .010	.010
99	5/13/98	.039	< .010	.10	< .355	< .010	.010
100	5/13/98	.023	< .010	.10	< .181	< .010	.010

Table 4. Results of physical and chemical analysis for sampled wells in the study area--Continued

[°C, degrees Celsius; Pt - Co, Platinum-Cobalt; μS/cm, microsiemens per centimeter at 25 °C; mg/L, milligams per liter; $CaCO_3$, calcium carbonate; <, less than laboratory detection levels; NA, no data]

Reference number (fig. 1)	Date	Nitrogen, ammonia (mg/L)	Nitrogen, nitrite, (mg/L)	Nitrogen, ammonia and organic (mg/L)	Nitrogen, nitrite plus nitrate (mg/L)	Phosphorus (mg/L)	Phosphorus, ortho (mg/L)
101	5/12/98	0.027	< 0.011	0.10	< 0.066	0.010	0.019
102	6/24/98	< .020	< .010	.10	< .589	< .010	.010
103	6/4/98	.030	< .010	< .10	< .050	< .010	.010
104	5/21/98	.061	< .011	.10	< .187	.010	.012
105	5/18/98	.043	< .011	.10	< .182	.010	.014
106	6/15/98	.047	< .011	.10	< 1.790	< .010	.010
107	6/15/98	.044	< .011	.10	< .170	< .010	.010
108	5/26/98	.023	< .010	.10	< 1.020	.010	.020
109	5/26/98	.082	< .010	< .10	.050	< .018	.010

Table 5. Microbiological data for the wells sampled

[RNA, ribonucleic acid; PFU/100L, plaque forming units per 100 liters; MPN/100L, most probable number per 100 liters; <, less than; TNTC, too numerous to count; PWSD, public water supply district]

Reference number (fig. 1)	County	Public water supply system	Facility type	Sampling date	Colonies per 100 milliliters of sample			RNA coliphage (PFU/100L)	Somatic coliphage (PFU/100L	Enteric virus, human, total culturable (MPN/100L)
					E. coli	Fecal streptococci	Fecal coliform			
1	Barry	Purdy	City	6/10/98	0	0	0	0	0	<1
2	Barry	Monett	City	6/11/98	TNTC	TNTC	TNTC	4,754	8,897	<1
3	Barton	Barton Co. Cons. PWSD #1	Water District	6/8/98	0	0	0	0	0	<1
4	Benton	Lincoln	City	4/8/98	0	0	0	0	0	<1
5	Benton	Cole Camp	City	4/8/98	0	0	0	0	0	<1
6	Benton	Ionia	City	4/9/98	0	0	0	0	0	<1
7	Bollinger	Marble Hill - South	City	4/23/98	0	0	0	0	0	<1
8	Butler	Qulin	City	5/20/98	0	0	0	0	0	<1
9	Camden	Camdenton	City	5/7/98	0	0	0	0	0	<1
10	Camden	KK Water Supply	Subdivision	5/7/98	0	0	0	0	0	<1
11	Cape Girardeau	Jackson	City	4/21/98	0	0	0	0	0	<1
12	Cape Girardeau	Cape Girardeau Co. PWSD #2	Water District	4/21/98	15	39	8	0	0	<1
13	Carter	Grandin	City	6/24/98	0	0	0	0	0	<1
14	Carter	Ellsinore	City	6/25/98	0	0	0	0	0	<1
15	Carter	Carter Co. PWSD #1	Water District	6/25/98	0	0	0	0	0	<1

Table 5. Microbiological data for the wells sampled--Continued

[RNA, ribonucleic acid; PFU/100L, plaque forming units per 100 liters; MPN/100L, most probable number per 100 liters; <, less than; TNTC, too numerous to count; PWSD, public water supply district]

Reference number (fig. 1)	County	Public water supply system	Facility type	Sampling date	Colonies per 100 milliliters of sample: E. coli	Fecal streptococci	Fecal coliform	RNA coliphage (PFU/100L)	Somatic coliphage (PFU/100L	Enteric virus, human, total culturable (MPN/100L)
16	Cedar	El Dorado Springs	City	4/13/98	0	0	0	0	0	<1
17	Christian	Sparta	City	6/17/98	0	0	0	0	0	<1
18	Christian	Ozark	City	6/8/98	0	0	0	0	0	<1
19	Christian	Billings	City	6/8/98	0	0	0	0	0	<1
21	Cooper	Pilot Grove	City	4/8/98	0	0	0	0	0	<1
22	Crawford	Steelville	City	4/27/98	0	0	0	0	0	<1
23	Crawford	Cuba	City	4/27/98	0	0	0	0	0	<1
24	Dade	Lockwood	City	6/16/98	0	0	0	0	0	<1
25	Dade	Greenfield	City	6/11/98	0	0	0	0	0	<1
26	Dallas	Buffalo	City	5/14/98	0	0	0	0	0	<1
27	Dallas	Urbana	City	5/13/98	0	0	0	0	0	<1
28	Dent	Salem	City	6/3/98	0	0	0	0	0	<1
29	Douglas	Ava	City	5/27/98	0	0	0	0	0	<1
30	Dunklin	Clarkton	City	5/19/98	0	0	0	0	0	<1
31	Franklin	St. Clair	City	4/28/98	0	0	0	0	0	<1
32	Franklin	Washington	City	4/13/98	0	0	0	0	0	<1
33	Gasconade	Owensville	City	4/30/98	0	0	0	0	0	<1
34	Gasconade	Rosebud	City	4/30/98	0	0	0	0	0	<1
35	Greene	Springfield	City	6/16/98	0	0	0	0	0	<1
36	Greene	Strafford	City	6/18/98	0	0	0	0	0	<1
37	Greene	Ash Grove	City	6/18/98	0	0	0	0	0	<1
38	Hickory	Weaubleau	City	5/18/98	0	0	0	0	0	<1

Table 5. Microbiological data for the wells sampled--Continued

[RNA, ribonucleic acid; PFU/100L, plaque forming units per 100 liters; MPN/100L, most probable number per 100 liters; <, less than; TNTC, too numerous to count; PWSD, public water supply district]

					Colonies per 100 milliliters of sample					
Reference number (fig. 1)	County	Public water supply system	Facility type	Sampling date	E. coli	Fecal streptococci	Fecal coliform	RNA coliphage (PFU/100L)	Somatic coliphage (PFU/100L	Enteric virus, human, total culturable (MPN/100L)
39	Hickory	Wheatland	City	5/12/98	0	0	0	0	0	<1
40	Howell	West Plains	City	6/18/98	TNTC	TNTC	TNTC	613	8,862	<1
41	Howell	Howell Co. PWSD #1	Water District	6/18/98	0	0	0	0	0	<1
42	Howell	Willow Springs	City	6/17/98	0	0	0	0	0	<1
43	Howell	Mountain View	City	6/15/98	0	0	0	0	0	<1
44	Iron	Belleview Elem. School	School	6/30/98	0	0	0	0	0	<1
45	Jasper	Sarcoxie	City	4/16/98	0	0	0	0	0	<1
47	Jasper	Oronogo	City	6/9/98	0	0	0	0	0	<1
48	Jefferson	Herculaneum	City	4/15/98	0	0	0	0	0	<1
49	Laclede	Laclede Co. PWSD #3	Water District	5/6/98	0	0	0	0	0	<1
50	Laclede	Lebanon	City	5/14/98	5	3	13	0	136	<1
51	Lawrence	Marionville	City	6/10/98	0	0	0	0	0	<1
52	Lawrence	Miller	City	6/9/98	0	0	0	0	0	<1
53	Madison	Marquand	City	4/23/98	21	3	0	0	0	<1
54	Maries	Vienna	City	5/7/98	0	0	0	0	0	<1
55	Maries	Belle	City	5/5/98	4	1	15	0	0	<1
56	McDonald	Noel	City	4/15/98	0	0	0	0	0	<1
57	McDonald	Pineville	City	4/15/98	0	0	0	0	0	<1
58	Miller	Eldon	City	5/6/98	0	0	0	0	0	<1

Table 5. Microbiological data for the wells sampled--Continued

[RNA, ribonucleic acid; PFU/100L, plaque forming units per 100 liters; MPN/100L, most probable number per 100 liters; <, less than; TNTC, too numerous to count; PWSD, public water supply district]

Reference number (fig. 1)	County	Public water supply system	Facility type	Sampling date	Colonies per 100 milliliters of sample			RNA coliphage (PFU/100L)	Somatic coliphage (PFU/100L	Enteric virus, human, total culturable (MPN/100L)
					E. coli	Fecal streptococci	Fecal coliform			
59	Moniteau	California	City	4/7/98	0	0	0	0	0	<1
60	Moniteau	Jamestown	City	4/7/98	0	0	0	0	0	<1
61	Morgan	Stover	City	5/6/98	0	0	0	0	0	<1
62	Newton	Neosho	City	4/14/98	0	0	0	0	0	<1
63	Newton	Granby	City	4/14/98	0	0	0	0	0	<1
64	Oregon	Thayer	City	6/16/98	0	0	0	0	0	<1
65	Oregon	Alton	City	6/17/98	0	0	0	0	0	<1
66	Osage	Linn	City	4/29/98	0	0	0	0	0	<1
67	Osage	Chamois	City	4/29/98	0	0	0	329	0	<1
68	Ozark	Gainesville	City	5/27/98	0	0	0	0	0	<1
69	Perry	Frohna	City	4/20/98	0	0	0	0	0	<1
70	Pettis	Sedalia	City	4/6/98	0	0	0	0	0	<1
71	Pettis	Hughesville	City	4/8/98	0	0	0	0	0	<1
72	Phelps	Phelps Co. PWSD #1	Water District	6/3/98	0	0	0	0	0	<1
73	Phelps	Newburg	City	6/2/98	0	0	0	0	0	<1
75	Polk	Pleasant Hope	City	5/19/98	0	0	0	0	0	<1
76	Polk	Morrisville	City	5/11/98	0	0	0	0	0	<1
77	Pulaski	Waynesville	City	5/6/98	0	0	0	0	0	<1
78	Pulaski	Richland	City	5/5/98	0	0	0	0	0	<1
79	Pulaski	Dixon	City	5/20/98	0	0	0	0	0	<1
80	Reynolds	Ellington	City	7/16/98	0	0	0	0	0	<1
81	Reynolds	Centerville	City	5/18/98	0	0	0	0	0	<1

Table 5. Microbiological data for the wells sampled--Continued

[RNA, ribonucleic acid; PFU/100L, plaque forming units per 100 liters; MPN/100L, most probable number per 100 liters; <, less than; TNTC, too numerous to count; PWSD, public water supply district]

					Colonies per 100 milliliters of sample					
Reference number (fig. 1)	County	Public water supply system	Facility type	Sampling date	E. coli	Fecal streptococci	Fecal coliform	RNA coliphage (PFU/100L)	Somatic coliphage (PFU/100L	Enteric virus, human, total culturable (MPN/100L)
82	Ripley	Naylor	City	5/20/98	0	0	0	0	0	<1
83	Ripley	Ripley Co. PWSD #1 - West	Water District	6/16/98	0	0	0	0	0	<1
84	Scott	Sikeston	City	4/22/98	0	0	0	0	0	<1
85	Scott	Benton	City	4/22/98	1	0	0	0	0	<1
86	Shannon	Winona	City	6/24/98	0	0	0	0	0	<1
87	St Clair	Lowry City	City	4/13/98	0	0	0	0	0	<1
88	St Francois	Bonne Terre	City	4/16/98	0	0	0	0	0	<1
89	St Louis	Eureka	City	4/13/98	0	0	0	0	0	<1
90	St Louis	Kirkwood	City	4/14/98	0	0	0	0	0	<1
91	Ste Genev-ieve	Bloomsdale	City	4/16/98	0	0	0	0	0	<1
92	Ste Genev-ieve	Ste. Genev-ieve Co. PWSD #1 - North	Water District	4/15/98	0	0	0	0	0	<1
93	Stoddard	Essex	City	5/19/98	0	0	0	0	0	<1
94	Stone	Reed Springs	City	6/10/98	0	0	0	0	0	<1
95	Stone	Crane	City	6/17/98	0	0	0	0	0	<1
96	Taney	Hollister	City	6/9/98	0	0	0	0	0	<1
97		Forsyth	City	6/9/98	0	0	0	0	0	<1
98	Texas	Summersville	City	5/14/98	1	4	1	0	0	<1
99	Texas	Raymondville	City	5/13/98	0	0	0	0	0	<1

Table 5. Microbiological data for the wells sampled--Continued

[RNA, ribonucleic acid; PFU/100L, plaque forming units per 100 liters; MPN/100L, most probable number per 100 liters; <, less than; TNTC, too numerous to count; PWSD, public water supply district]

					Colonies per 100 milliliters of sample					
Reference number (fig. 1)	County	Public water supply system	Facility type	Sampling date	E. coli	Fecal streptococci	Fecal coliform	RNA coliphage (PFU/100L)	Somatic coliphage (PFU/100L	Enteric virus, human, total culturable (MPN/100L)
100	Texas	Texas Co. PWSD #1	Water District	5/13/98	0	0	0	0	0	<1
101	Texas	Licking	City	5/12/98	0	0	0	0	0	<1
102	Washing-ton	Irondale	City	6/24/98	1	0	1	0	0	<1
103	Washing-ton	Potosi	City	6/4/98	0	0	0	0	0	<1
104	Wayne	Williamsville	City	5/21/98	0	0	4	0	0	<1
105	Wayne	Wayne Co. PWSD #1	Water District	5/18/98	0	0	0	0	0	<1
106	Webster	Rogersville	City	6/15/98	0	0	0	0	0	<1
107	Webster	Seymour	City	6/15/98	0	0	0	0	0	<1
108	Wright	Norwood	City	5/26/98	0	0	0	0	0	<1
109	Wright	Mountain Grove	City	5/26/98	0	0	0	0	0	<1

Table 6 – Total vulnerability ranking according to the USEPA Ground Water Disinfection Rule-Vulnerability Assessment Plan
[PWSD, Public Water Supply District]

Reference number (fig. 1)	Public water supply name	Vulnerability: Microbes previously detected	Vulnerability: Ground water Sensitivity	Vulnerability: Well construction	Total Vulnerability	Microbes detected in this study
1	Purdy	yes	low	acceptable	high	no
2	Monett	unknown	low	unknown	unknown	yes
6	Ionia	unknown	low	unknown	unknown	no
8	Qulin	no	low	unknown	unknown	no
12	Cape Girardeau PWSD #2	unknown	unknown	unknown	unknown	yes
17	Sparta	unknown	low	unknown	unknown	no
21	Pilot Grove	yes	low	unknown	high	no
22	Steelville	unknown	low	unknown	unknown	no
27	Urbana	no	low	acceptable	low	no
28	Salem	yes	high	acceptable	high	no
32	Washington	no	unknown	acceptable	unknown	no
34	Rosebud	no	unknown	unknown	unknown	no
39	Wheatland	unknown	low	unacceptable	high	no
40	West Plains	yes	high	unknown	high	yes
41	Howell Co.	yes	high	unknown	high	no
42	Willow Springs	no	high		high	no
44	Belleview	yes	unknown	unknown	high	no
45	Sarcoxie	yes	low	unacceptable	high	no
46	Carl Junction	no	low	acceptable	low	no
48	Herculaneum	yes	unknown	acceptable	high	no
50	Lebanon	unknown	high	acceptable	high	yes
52	Miller	no	high	unacceptable	high	no
53	Marquand	unknown	high	unacceptable	high	yes
55	Belle	unknown	unknown	unknown	unknown	yes
56	Noel	unknown	low	acceptable	low	no
60	Jamestown	unknown	high	unknown	high	no
67	Chamois	yes	high	unknown	high	yes
68	Gainesville	yes	high	acceptable	high	no
69	Frohna	yes	low	unknown	high	no
79	Dixon	no	low	acceptable	low	no
80	Ellington	no	high	unacceptable	high	no
81	Centerville	yes	unknown	unknown	high	no
85	Benton	unknown	low	unknown	unknown	yes
88	Bonne Terre	unknown	high	unknown	high	no
90	Kirkwood	unknown	high	unknown	high	no
97	Forsyth	unknown	high	unknown	high	no
98	Summersville	no	high	acceptable	high	yes
101	Licking	no	high	acceptable	high	no
102	Irondale	yes	low	acceptable	high	yes
104	Williamsville	unknown	unknown	unknown	unknown	yes
109	Mountain Grove	unknown	high	unknown	high	no

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