Reconnaissance of Quality of Water from Farmstead Wells in Tennessee, 1989-90

By JOHN K. CARMICHAEL and MICHAEL W. BENNETT

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Multiply	By	To obtain
foot (ft)	0.3048	meter
million gallons per day (Mgal/d)	0.04381	cubic meter per second

ABBREVIATED WATER-QUALITY UNITS

mL	milliliter
mg/L	milligram per liter
µg/L	microgram per liter

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Abstract

In 1989-90, the U.S. Geological Survey, in cooperation with the Tennessee State Planning Office, conducted a statewide reconnaissance of the quality of ground water from selected farmstead wells throughout Tennessee. A network of 150 wells was established representing 93 of the 95 counties, 8 of the 9 principal aquifers, and most of the agricultural activities in the State. At each well site, water samples and general land-use data were collected. The water samples were analyzed in the field and laboratory to determine selected physical characteristics, chemical constituents, and bacterial content.

Water-quality data for fecal coliform and fecal streptococci bacteria, nitrate (as nitrogen), organic compounds, iron, manganese, and hydrogen-ion concentration (pH) were evaluated. These bacteria and chemical constituents were selected for evaluation on the basis of important aesthetic or health-related implications regarding drinking-water quality.

Statewide, samples from some of the wells representing nearly all of the principal aquifers had concentrations of bacteria or chemical constituents that exceeded drinking-water regulations. Fecal coliform bacteria were detected in samples from 39 percent of the wells statewide, and fecal streptococci bacteria were detected in 33 percent of the samples. Either or both of these bacteria were detected in only about 20 percent of the samples from wells in western Tennessee, compared to 54 percent of the wells sampled in central and eastern Tennessee. Statewide, about 15 percent of the samples containing both groups of bacteria met specific criteria for possible determination of the sources of these contaminants. Ratios of fecal coliform to fecal streptococci indicated that 64 percent of these samples showed evidence of bacterial contamination from animal sources, while 27 percent showed evidence of contamination from human sources.

Total nitrate (as nitrogen) concentrations equaled or exceeded the 10.0 milligrams per liter Primary Maximum Contaminant Level in samples from 3 percent of the wells. A relatively even statewide distribution of 20 percent of the 150 wells had nitrate (as nitrogen) concentrations exceeding 3.00 milligrams per liter, possibly indicating human influence on ground-water quality. Estimated total concentrations of organic compounds were less than 5 micrograms per liter in samples from 92 percent of the wells statewide, with median concentrations of 1.4 micrograms per liter or less in samples from seven of the eight principal aquifers. Concentrations of total-recoverable iron were equal to or exceeded the 300 micrograms per liter Secondary Maximum Contaminant Level in samples from 35 percent of the wells statewide. Concentrations of total-recoverable manganese were equal to or

exceeded the 50 micrograms per liter Secondary Maximum Contaminant Level in 25 percent of the samples. Based on values of pH determined in the field, water from 25 percent of the wells had a pH below the lower Secondary Maximum Contaminant Level limit of 6.5 with most of these occurring in western Tennessee. Water from only two wells had a pH slightly greater than the upper secondary limit of 8.5.

INTRODUCTION

Private wells supply an estimated 35 million gallons of ground water per day to approximately 700,000 people in Tennessee (S.S. Hutson, U.S. Geological Survey, oral commun., 1991). Most of these wells are in rural areas that are not served by public water-supply systems. Prior to 1989, little attention had been focused on a statewide evaluation of the quality of rural domestic drinking-water supplies. Ample documentation exists, however, that ground-water quality in some rural areas of Tennessee and other States is being degraded by natural and anthropogenic sources (Leonard, 1986; National Research Council, 1986; Vrba and Romijn, 1986; Duda and Johnson, 1987; Thackston, 1987; French and Strunk, 1988; Perry and others, 1988; Steichen and others, 1988; Mesko and Carlson, 1988; Soileau, 1988; Freshwater Foundation, 1986, 1988a, 1988b; Chandler, 1989a, 1989b; Fawcett, 1990; Hanchar, 1991; U.S. Environmental Protection Agency, 1990; Ogden and others, 1991).

The most common indicators of ground-water quality degradation associated with human or agricultural sources in rural areas are elevated concentrations of nitrate and (or) the presence of bacteria or pesticides. In many rural areas of Tennessee, data for these and other indicator constituents in ground water are lacking. In 1989-90, the U.S. Geological Survey (USGS), in cooperation with the Tennessee State Planning Office, conducted an investigation to evaluate the

quality of ground water used primarily for drinking purposes from selected farmstead wells throughout Tennessee.

Purpose and Scope

This report summarizes selected water-quality data obtained during a reconnaissance of rural domestic drinking water supplies in Tennessee. The report presents simple statistical analyses of selected bacteria and chemical constituents in ground water and offers brief explanations of observed local and regional variations. The findings are grouped by principal aquifers in the State.

A network of 150 wells (fig. 1) was established representing 93 of the 95 counties in Tennessee, eight of the nine principal aquifers, and most of the agricultural activities in the State. Wells for the network were selected from well-construction and farm-activity information provided by the University of Tennessee Agricultural Extension Service (UTAES). At each site, samples of ground water were collected for analysis in the field and at the USGS National Water Quality Laboratory for selected physical characteristics, chemical constituents, and bacteria. General land-use data also were collected. Water-quality and selected well-construction data obtained during the reconnaissance, including discussions of methods of well selection, well-construction-data acquisition, and sample collection, are presented in Bennett and others (1990).

Acknowledgments

participation in the investigation made its successful completion possible.

DESCRIPTION OF PRINCIPAL AQUIFERS AND LOCATION OF NETWORK WELLS

For the purpose of developing generalized regional hydrogeologic descriptions of the ground-water resources of Tennessee, the State has been subdivided into nine principal aquifers based on similar physiography and hydrogeology. They are named the alluvial, Tertiary sand, Cretaceous sand, Pennsylvanian sandstone, Mississippian carbonate, Ordovician carbonate, Knox, Cambrian-Ordovician carbonate, and crystalline rock aquifers (Bradley and Hollyday, 1985). For this reconnaissance, wells were selected to represent each aquifer except the Knox. The Knox aquifer was not represented because no records were obtained from the UTAES for wells completed in it. The physical characteristics of the aquifers and general quality of water obtained from them have been described by Bradley and Hollyday (1985, p. 391-396) and Broshears (1988, p. 465-472). Aquifer and well characteristics are listed in table 1. The areal and cross-sectional occurrences of the aquifers (including the Knox) and location of wells sampled are shown in figure 1.

Designation of each network well to a principal aquifer was based in most cases on the generalized areas shown in figure 1. However, a few of the wells shown were not assigned to the aquifer in which they appear to be located. In some instances, this is because the generalized aquifer boundaries of figure 1 do not show the detail of larger scale maps. In other cases, wells are completed in a principal aquifer that lies adjacent to (or beneath) the principal aquifer at land surface where the well is located. Lastly, two hand-dug wells in the flood plains of small streams in Moore and Wayne Counties were designated as alluvial wells because of their locations and shallow depths, even though the alluvial aquifer, as defined by Bradley and Hollyday, consists of flood-plain deposits associated with the Mississippi River, its tributaries, and the southern end of the Western Valley of the Tennessee River.

DATA ANALYSIS AND ASSESSMENT

Selected water-quality data collected during this reconnaissance of farmstead wells in Tennessee were used to evaluate the health-related and aesthetic quality of ground water relative to State of Tennessee drinking-water regulations. The data selected for evaluation are for fecal coliform and fecal streptococci bacteria, nitrate (as nitrogen; subsequently referred to in this report as nitrate), organic compounds, iron, manganese, and hydrogen-ion concentration (pH). Two additional constituents included in the drinking-water regulations, chloride and sulfate, also were analyzed for during the reconnaissance, but are not discussed in this report because neither constituent exceeded its recommended maximum concentration in any of the sampled wells.

Two methods were used for analysis and assessment of the selected data. First, boxplots of concentration data for each constituent grouped by principal aquifer provide a method for comparing variability (maximum-minimum range), central tendency (median), and skewness (frequency and distribution of data in relation to the median) within and among the principal aquifers. Second, maps show the statewide distribution of concentration data for each constituent. Discussion and assessment of the data for each constituent are presented in the following sections with reference to the boxplots and maps.

Analytical data for most of the selected constituents are compared to Primary or Secondary Maximum Contaminant Levels (PMCL and SMCL, respectively) adopted by Tennessee (Tennessee Department of Health and Environment, 1991). These regulations were established to prevent adverse health effects and to maintain certain aesthetic qualities of water in public use. Although the State's regulations pertain only to drinking water supplied by public and non-community

Figure 1. Locations of 150 sampled farmstead wells and areal and cross-sectional occurrences of the principal aquifers in Tennessee.

Figure 1. Locations of 150 sampled farmstead wells and areal and cross-sectional occurrences of the principal aquifers in Tennessee--Continued.

Table 1. Principal aquifers and well characteristics in Tennessee (from Bradley and Hollyday, 1985)

[ft, feet; gal/min, gallons per minute; Sources: Reports of the U.S. Geological Survey and Tennessee State agencies]

Principal aquifer name and description	Well characteristics				Remarks
	Depth (ft)		Yield (gal/min)		
	Common range	May exceed	Common range	May exceed	
Alluvial aquifer: Sand, gravel, and clay. Unconfined.	10-75	100	20-50	1,500	Large iron concentrations in some areas. Local contamination at some landfills.
Tertiary sand aquifer: A multiaquifer unit of inter-bedded sand, clay, silt and some gravel and lignite. Confined, unconfined in the outcrop area.	100-1,300	1,500	200-1,000	2,000	Includes Memphis Sand of Claiborne Group and Fort Pillow Sand of Wilcox Group. Problems with large iron concentration in some places.
Cretaceous sand aquifer: A multi-aquifer unit of interbedded sand, clay marl, and gravel. Confined, unconfined in the outcrop area.	100-1,500	2,500	50-500	1,000	Include McNairy and Coffee Sands, and Tuscaloosa Formation. Water used primarily in the outcrop area.
Pennsylvanian sandstone aquifer: A multiaquifer unit, primarily sandstone and conglomerate, interbedded with shale and some coal. Unconfined near land surface, confined at depth.	100-200	250	5-50	200	Permeability is from fractures, faults and bedding-plane openings. Principal water-bearing units are Rockcastle Sandstone and Sewanee Conglomerate. Large iron concentrations are a problem.
Mississippian carbonate aquifer: A multiaquifer unit of limestone, dolomite, and some shale. Unconfined or partly confined near land surface; may be confined at depth.	50-200	250	5-50	400	Water occurs in solution openings and bedding-plane openings. Principal water-bearing units are Ste. Genevieve (Monteagle), St. Louis and Warsaw Limestones and Fort Payne Formation. Susceptible to pollution. Water generally hard; large iron, sulfide, or sulfate concentrations problems in some areas.
Ordovician carbonate aquifer: A multiaquifer unit of limestone, dolomite, and shale. Partly confined to unconfined near land surface; confined at depth.	50-150	200	5-20	300	Principal water-bearing units are Bigby, Carters, Ridley, and Murfreesboro Limestones. Water generally hard; some large sulfide or sulfate concentrations in places. Units susceptible to contamination.
Knox aquifer: Primarily dolomite with some limestone. Does not have the structural complexity of the Cambrian-Ordovician aquifer. Confined.	700-1,200	1,400	1-10	20	A deep aquifer; occurs under most of central and western Tennessee. Away from Central Basin, water generally has large concentrations of dissolved solids.
Cambrian-Ordovician carbonate aquifer: Extremely faulted multiaquifer unit of limestone, dolomite, sandstone, and shale; structurally complex. Unconfined; confined at depth.	100-300	400	5-200	2,000	Principal water-bearing units are carbonate rocks in Chickamauga Limestone, Knox Group, and Honaker Dolomite. Water is generally hard. Brine below 3,000 feet.
Crystalline rock aquifer: A multiaquifer unit of dolomite, granite gneiss, phyllite, and metasedimentary rocks overlain by thick regolith; alluvium and colluvium in some valleys. Generally unconfined.	50-150	200	5-50	1,000	Large yields occur primarily in valleys with dolomite or deep colluvium and alluvium. Shady Dolomite is a principal aquifer. Low pH and large iron concentrations may be problems in some areas.

systems, and hence do not have legal application to wells used for domestic supply, the regulations provide an equal standard for evaluating the quality of water from farmstead wells. The analytical data for the selected constituents also are compared to other applicable water-quality data available for Tennessee.

Fecal Coliform and Fecal Streptococci Bacteria

Fecal coliform and fecal streptococci bacteria are microorganisms that live in the digestive tracts of humans and other warm-blooded animals and, thus, are components of fecal waste. The presence of these bacteria in a water supply generally indicates contamination by human and (or) animal feces. Fecal coliform and streptococci bacteria are generally not considered pathogenic, but their occurrence in water is commonly used as an indicator of the potential presence of disease-causing microorganisms.

Uncontaminated ground water does not contain fecal coliform or fecal streptococci bacteria because these microorganisms are short lived and do not reproduce in water. Thus, in most cases where they are identified, contaminated runoff or sewage waste might be assumed to migrate relatively unimpeded into a ground-water system. This occurs most frequently in areas underlain by shallow karst or fractured-bedrock aquifers where a soil cover is thin or absent, and less frequently in areas where a thick layer of soil or residuum is present or where unconsolidated sedimentary aquifers occur. Because of their morphologies and relatively large sizes [fecal coliform are rod shaped and generally 2 to 4 microns long by 0.5 microns in diameter; fecal streptococci are spherical and about 1 micron in diameter (Millipore, 1973)], downward movement of fecal coliform and streptococci bacteria in percolating water is retarded by most soil. This and other factors that delay the conveyance of bacteria into a ground-water system allow for increased mortality of these microorganisms before they reach the water table.

Contamination of wells by fecal coliform and streptococci bacteria normally occurs from localized sources, and most commonly is associated with wells that are shallow, have faulty sanitary or surface seals, are improperly constructed, or are located too close to septic systems or livestock confinement areas.

Although a drinking-water regulation has not been established for either fecal coliform or fecal streptococci bacteria, the State of Tennessee has adopted a PMCL for total coliform bacteria (includes fecal and other coliform bacteria) that is based on the presence or absence of total coliform in a sample, rather than coliform density (Tennessee Department of Health and Environment, 1991). Total-coliform tests are required to check the efficacy of water-disinfection procedures used by public and non-community systems. Under the total-coliform regulation, if one colony of fecal coliform bacteria is identified in a sample, the regulation for total coliform is exceeded.

Membrane filtration and incubation tests for fecal coliform and fecal streptococci bacteria (Britton and Greeson, 1989) were performed in the field for samples from the 150 wells. In reporting the results of these tests, samples having no detectable fecal coliform or streptococci colony growth can not be considered free of bacteria from a statistical standpoint and, thus, are reported as having less than one colony per 100 milliliter (mL) sample. The lowest measurable concentration for both bacteria is one colony per 100 mL sample and, for the purposes of this reconnaissance, was considered a positive test.

In analyzing water for fecal coliform and fecal streptococci bacteria, several sample volumes are usually tested so that the number of colonies that might develop during incubation are within prescribed ideal counting ranges. For fecal coliform, this range is from 20 to 60 colonies and for fecal streptococci, from 20 to 100 colonies per 100 mL sample (Britton and Greeson, 1989). Where colonies of either bacteria develop in numbers outside these ranges, values are reported
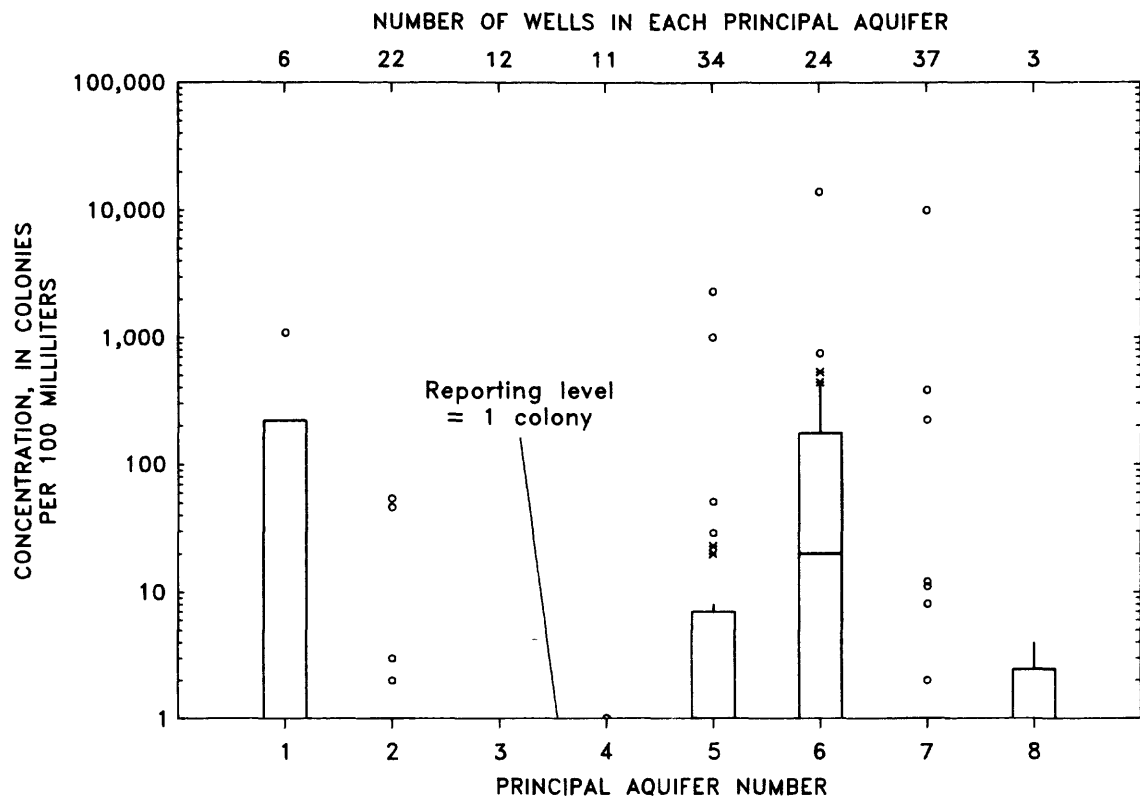
prefixed with a "K" or a "B" to denote a non-ideal count. In analyzing the bacterial data collected during this reconnaissance, non-ideal fecal coliform and streptococci colony counts are assumed to represent valid positive tests where blank samples (samples of sterile buffered water used to rinse filtering equipment prior to sampling to test equipment sterilization) showed no bacterial growth.

Boxplots of bacteria concentrations indicate that the range for fecal coliform in samples from 149 of the 150 wells (no coliform data for one well) was from less than (<)1 to 14,000 colonies per 100 mL sample (fig. 2a). The range for fecal streptococci in samples from all 150 wells was from <1 to 13,000 colonies per 100 mL sample (fig. 3a). Fecal coliform bacteria occurred in samples from 39 percent (58 of 149 wells) of the wells, and fecal streptococci bacteria occurred in 33 percent (50 of 150 wells) of the samples. A total of 28 percent (41 of 149 wells) of the samples tested positive for both types of bacteria, while 45 percent (67 of 150 wells) tested positive for either or both bacteria. On a regional level, either or both bacteria were detected in 20 percent of the samples from wells in western Tennessee while 54 percent of the wells in central and eastern Tennessee tested positive. The number and percentage of wells in each principal aquifer testing positive for bacteria are listed in table 2.

Studies of surface-water pollution have shown that it may be possible to relate the probable source of bacterial contamination to humans or other animals based on the density ratio of fecal coliform to fecal streptococci (FC/FS) (Millipore, 1975, p. 11; Geldreich and Kenner, 1969). Commonly, a dominance in the ratio of colonies of fecal coliform to streptococci in a water sample indicates contamination from a human source [FC/FS ratio of greater than (>) 2.0 but less than or equal to ($\leq$) 4.0 suggests a predominance of human waste in mixed pollution, whereas a FC/FS ratio of >4.0 is strong evidence of human waste]. Conversely, a dominance in the ratio of colonies of

fecal streptococci to fecal coliform indicates contamination from an animal source [FC/FS ratio of >0.7 but <1.0 suggests a predominance of livestock or poultry wastes in mixed pollution, whereas a FC/FS ratio of <0.7 is strong evidence of livestock or poultry waste]. A fecal coliform to streptococci ratio between 1.0 and 2.0 indicates an area of uncertain interpretation likely resulting from a mixture of human and animal waste. For interpretation of data using these methods to be valid, the following conditions must be met (Millipore, 1975, p. 11): (1) the fecal streptococci density should be greater than 25 colonies per 100 mL sample [although 23 of 150 (about 15 percent) of the sampled wells met this condition, only 22 can be used because no coliform data are available for 1 of these wells]; (2) the range of pH of the source water must be between 4.00 and 9.00 pH units (condition met by all wells); (3) fecal coliform is the only coliform count that yields a valid ratio (condition met by all wells); (4) samples collected should not be more than 24 hours downstream from the source of pollution [no data for sampled wells on transit time of water and bacteria from source(s) to well]; and (5) samples for each bacteria should be collected from the same source at the same time (condition met by all wellls). Data from about 15 percent of the wells satisfy all of the conditions except for condition 4. Although application of ratios to surface-water investigations has shown some quantitative significance, meaningful application of bacterial ratios to ground-water studies has not been documented. Bacterial ratios are presented in this report as a possible, but not proven, indicator of whether the fecal contamination is from human or animal sources.

In analyzing those data that meet the conditions specified, the bacterial ratios of 64 percent (14 of 22 wells) of the wells sampled indicate possible contamination from animal sources, whereas 27 percent (6 of 22 wells) of the wells indicate possible contamination from human sources. The other two wells had ratios that were inconclusive. Thus, with the inherent limitation of not knowing

NUMBER OF WELLS IN EACH PRINCIPAL AQUIFER

6   22   12   11   34   24   37   3

100,000

10,000

1,000

Reporting level
= 1 colony

100

CONCENTRATION, IN COLONIES PER 100 MILLILITERS

10

1

1   2   3   4   5   6   7   8

PRINCIPAL AQUIFER NUMBER

EXPLANATION

o   OBSERVATION GREATER THAN 3 X IQR FROM BOX

x   OBSERVATION GREATER THAN 1.5 X IQR FROM BOX

WHISKER (See explanation below)

75TH PERCENTILE

MEDIAN (50th percentile)

25TH PERCENTILE

INTERQUARTILE RANGE (IQR)

WHISKER (Length equals last observation within 1.5 X IQR from box)

PRINCIPAL AQUIFERS

1 – Alluvial

2 – Tertiary sand

3 – Cretaceous sand

4 – Pennsylvanian sandstone

5 – Mississippian carbonate

6 – Ordovician carbonate

7 – Cambrian– Ordovician carbonate

8 – Crystalline rock

(Aquifer names from Bradley and Hollyday, 1985)

Figure 2a. Boxplots of concentrations of fecal coliform bacteria for 149 of 150 sampled wells grouped by principal aquifer. (Data from Bennett and others, 1990.)

Figure 2b. Statewide distribution of concentrations of fecal coliform bacteria for 149 of 150 sampled wells.

Mississippian
carbonate

Pennsylvanian
sandstone

Cambrian—Ordovician
carbonate

0 10 20 30 40 50 MILES

0 10 20 30 40 50 KILOMETERS

EXPLANATION

220● WELL LOCATION AND NUMBER OF
FECAL COLIFORM COLONIES PER
100 MILLILITERS

κ NON—IDEAL COLONY COUNT

Hydrology modified from Bradley and Hollyday, 1985
Data from Bennett and others, 1990

Figure 2b. Statewide distribution of concentrations of fecal coliform bacteria for 149 of 150 sampled wells--Continued.

NUMBER OF WELLS IN EACH PRINCIPAL AQUIFER

| 6 | 22 | 12 | 11 | 34 | 25 | 37 | 3 |

CONCENTRATION, IN COLONIES PER 100 MILLILITERS

Reporting level = 1 colony

PRINCIPAL AQUIFER NUMBER

EXPLANATION

○   OBSERVATION GREATER THAN 3 X IQR FROM BOX

✳   OBSERVATION GREATER THAN 1.5 X IQR FROM BOX

WHISKER (See explanation below)

75TH PERCENTILE

INTERQUARTILE RANGE (IQR) — MEDIAN (50th percentile)

25TH PERCENTILE

WHISKER (Length equals last observation within 1.5 X IQR from box)

PRINCIPAL AQUIFERS

1 — Alluvial

2 — Tertiary sand

3 — Cretaceous sand

4 — Pennsylvanian sandstone

5 — Mississippian carbonate

6 — Ordovician carbonate

7 — Cambrian-Ordovician carbonate

8 — Crystalline rock

(Aquifer names from Bradley and Hollyday, 1985)

Figure 3a. Boxplots of concentrations of fecal streptococci bacteria for 150 sampled wells grouped by principal aquifer. (Data from Bennett and others, 1990.)
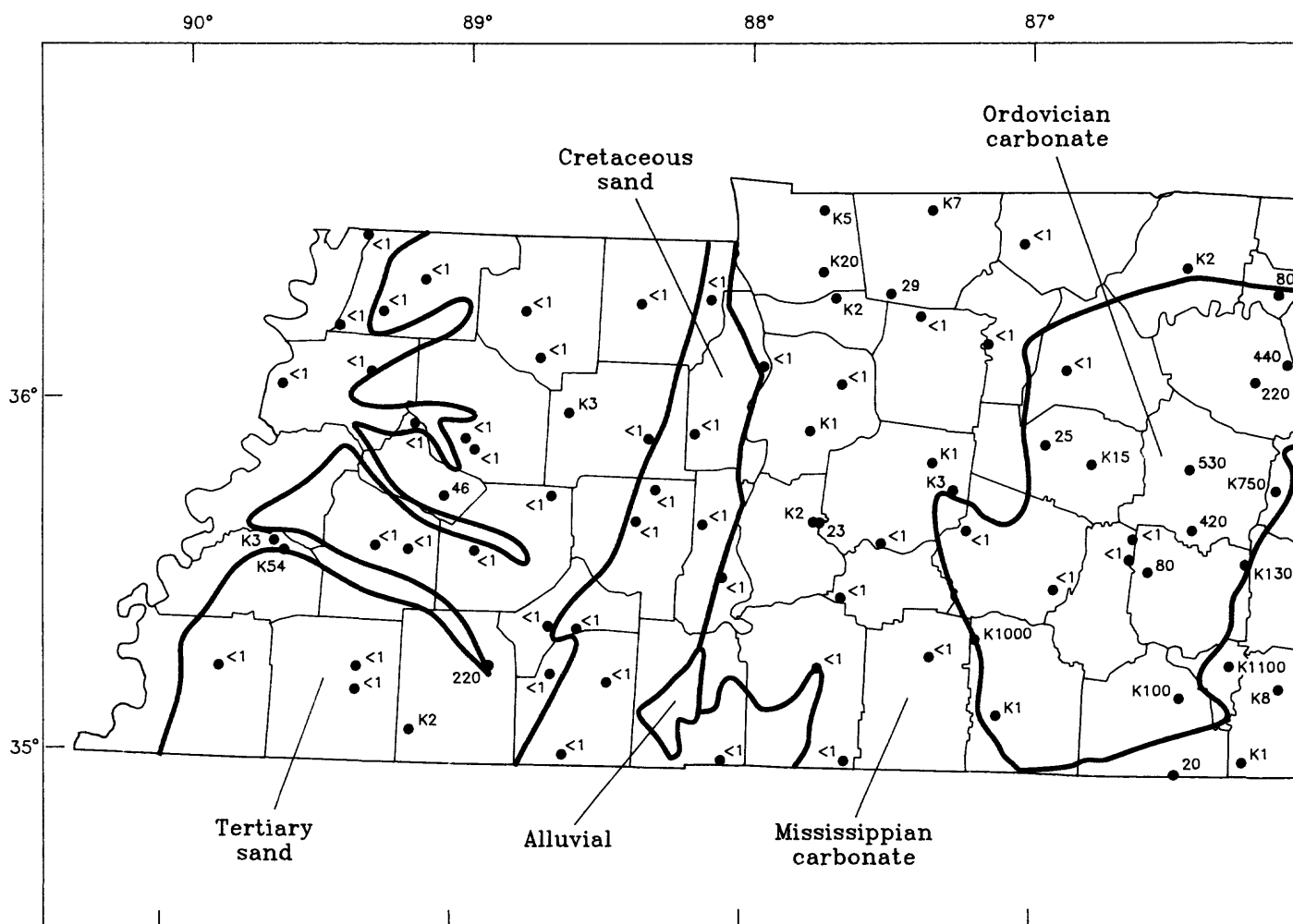
Table 2. Number and percentage of wells in each principal aquifer testing positive for fecal coliform, fecal streptococci, both, and either bacteria

[positive test indicated by growth of at least one bacterial colony per 100 millimeter sample]

Principal aquifer	Fecal Coliform		Fecal Streptococci		Fecal coliform and fecal streptococci		Fecal coliform and (or) fecal streptococci	
	Number of wells	Percent	Number of wells	Percent	Number of wells	Percent	Number of wells	Percent
Alluvial	2 of 6	33	1 of 6	17	1 of 6	17	2 of 6	33
Tertiary sand.	5 of 22	23	1 of 22	5	0 of 22	0	6 of 22	27
Cretaceous sand.	0 of 12	0	0 of 12	0	0 of 12	0	0 of 12	0
Pennsylvanian sandstone.	2 of 11	18	1 of 11	9	1 of 11	9	2 of 11	18
Mississippian carbonate.	18 of 34	53	11 of 34	32	9 of 34	26	19 of 34	56
Ordovician carbonate.	18 of 24	75	18 of 25	72	17 of 24	71	19 of 25	76
Cambrian-Ordovician carbonate.	12 of 37	32	17 of 37	46	12 of 37	32	17 of 37	46
Crystalline rock.	1 of 3	33	1 of 3	33	1 of 3	33	1 of 3	33
Totals	58 of 149	39	50 of 150	33	41 of 149	28	67 of 150	45

the time taken for water and bacteria to move from source to well, the data indicate that the possible source of the fecal coliform and fecal streptococci bacteria detected in water from the majority of this group of wells may be from poultry or livestock. Land-use data collected during the reconnaissance indicate that livestock or animal-product production is either the primary agricultural activity or a significant component of the agricultural activity practiced on about 85 percent of the farms where wells were sampled.

Median concentrations of fecal coliform and fecal streptococci bacteria for six and seven, respectively, of the eight principal aquifers were equal to the reporting level (figs. 2a and 3a). Median values of fecal coliform concentrations calculated for the Mississippian and Ordovician
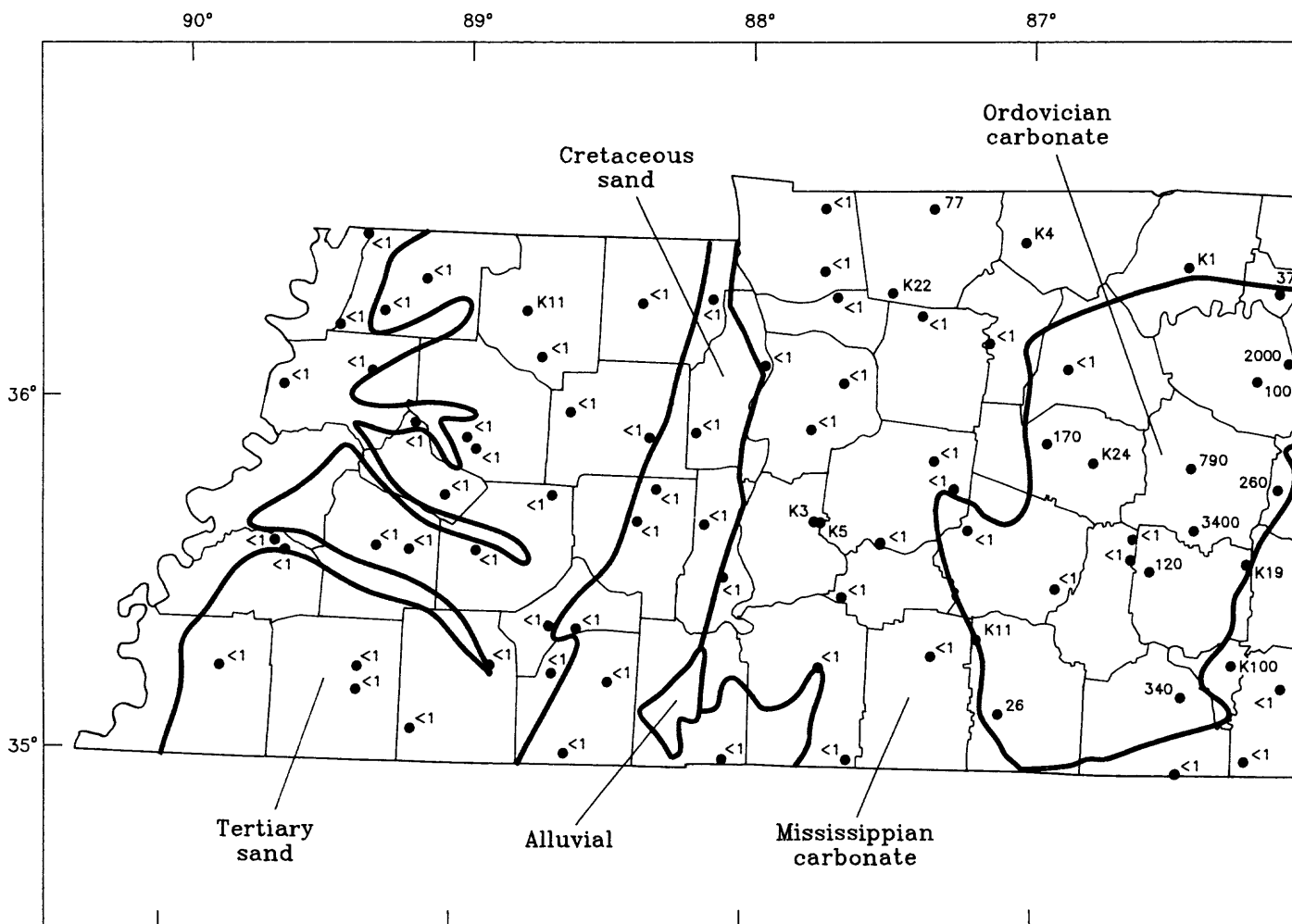
Figure 3b. Statewide distribution of concentrations of fecal streptococci bacteria for 150 sampled wells.

86°   85°   84°   83°   82°

Mississippian
carbonate

Pennsylvanian
sandstone

91
K20
100
73
360
K1100
K1
21
25
K1700

Cambrian—Ordovician
carbonate

K3
K2
K3
K3
K3
K2
K3
K13000
K3
54
K2
950
88

K9
260
K1

K1   K2

0   10   20   30   40   50 MILES

0 10 20 30 40 50 KILOMETERS

EXPLANATION

54● WELL LOCATION AND NUMBER OF
     FECAL STREPTOCOCCI COLONIES
     PER 100 MILLILITERS

K   NON—IDEAL COLONY COUNT

Hydrology modified from Bradley and Hollyday, 1985
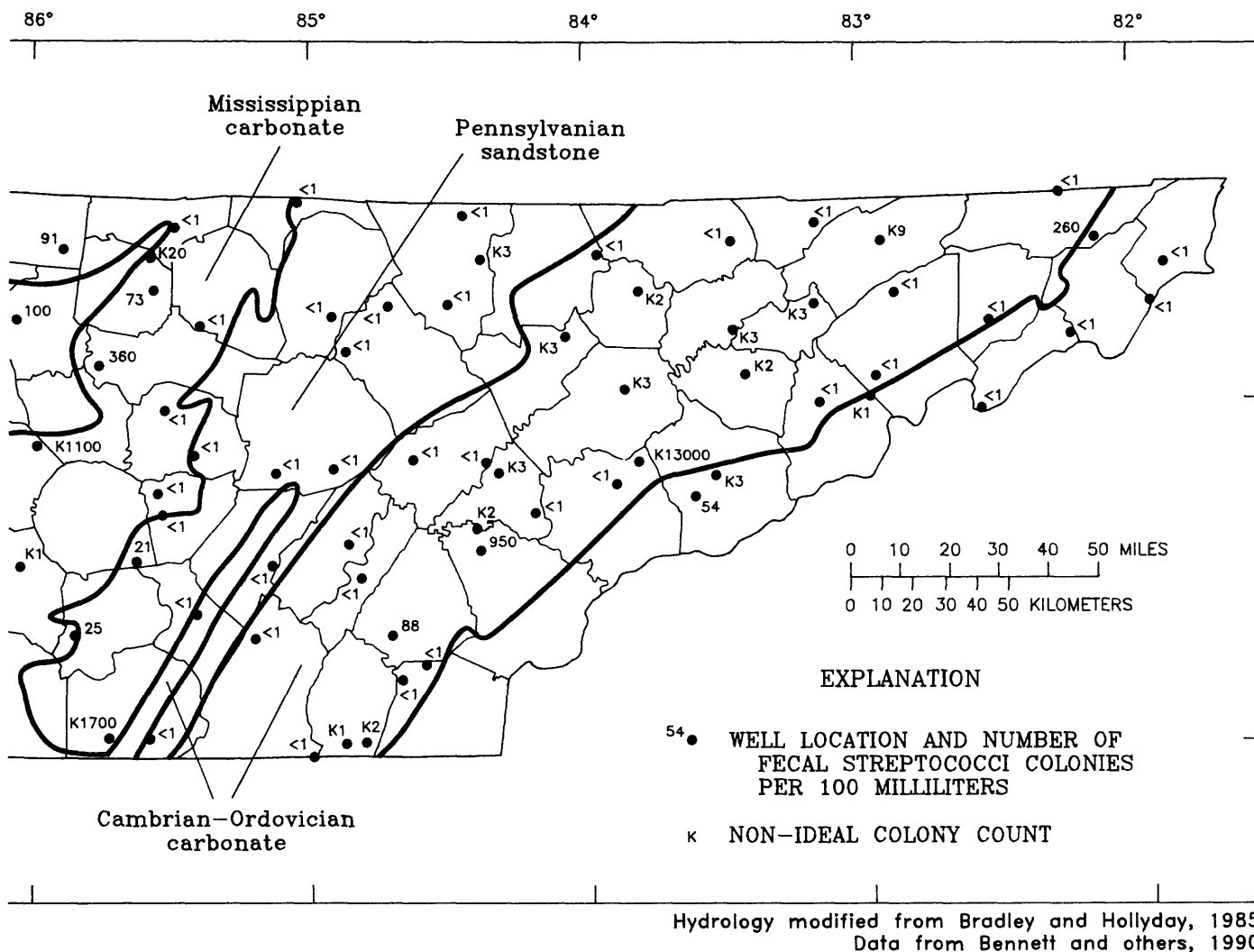Data from Bennett and others, 1990

Figure 3b. Statewide distribution of concentrations of fecal streptococci bacteria for 150 sampled wells--Continued.

carbonate aquifers (fig. 2a) were 1 and 20 colonies per 100 mL sample, respectively. A median value for fecal streptococci concentration of 37 colonies per 100 mL sample was calculated for the Ordovician carbonate aquifer (fig. 3a). Additionally, the wells completed in the Ordovician carbonate aquifer had more positive tests for one or both bacteria (19 of 25 wells or 76 percent; table 2) than any of the other aquifers. This likely is the result of relatively rapid movement of bacteria-contaminated water into the subsurface from a combination of karst topography, thin soils, and relatively shallow depths to water in most areas of Tennessee underlain by the Ordovician carbonate aquifer. Thus, rural ground-water contamination by fecal coliform and fecal streptococci bacteria appears to occur most frequently in the central part of the State (figs. 2 and 3).

Although the detection of either fecal coliform or fecal streptococci bacteria generally was highly variable among the other principal aquifers (table 2), a pattern in the data is evident. As in the Ordovician carbonate aquifer, the next highest numbers of positive samples occurred in water from the other dominantly carbonate aquifers, whereas the lowest number of positive samples occurred in water from the dominantly siliciclastic aquifers. These data indicate that rural domestic wells withdrawing water from the primarily unconsolidated, dominantly siliciclastic sedimentary aquifers in the western part of the State (alluvial, and Tertiary and Cretaceous sand aquifers) and the Pennsylvanian sandstone aquifer in the east-central part of the State are less likely to test positive for fecal coliform and fecal streptococci bacteria than wells in the primarily consolidated, dominantly carbonate bedrock aquifers in central and eastern Tennessee.

Variability in concentrations of fecal coliform and fecal streptococci bacteria also is larger for samples from wells in the dominantly carbonate aquifers than in the siliciclastic aquifers (figs. 2a and 3a). Concentration ranges for the Mississippian, Ordovician, and Cambrian-Ordovician

carbonate aquifers span from slightly greater than three to slightly greater than four orders of magnitude (figs. 2a and 3a). Variability in concentrations of fecal coliform and fecal streptococci bacteria in the other aquifers ranges from no positive tests in samples from the Cretaceous sand aquifer to less than about two orders of magnitude in the alluvial, Tertiary sand, and Pennsylvanian sandstone aquifers (figs. 2a and 3a). Furthermore, the variability in fecal coliform and fecal streptococci concentrations in samples from these latter three aquifers results from only a few positive tests for either bacteria in all wells sampled (figs. 2a and 3a). The small variability in fecal coliform and fecal streptococci concentrations for the crystalline rock aquifer likely results from having only three wells in the sample population. Overall, the variability in fecal coliform and fecal streptococci bacteria concentrations among samples from the principal aquifers also supports the conclusion that wells in central and eastern Tennessee have a greater potential for bacterial contamination than those in the western part of the State. The variability also indicates, however, that contamination of rural ground water by fecal bacteria in all areas of the State probably results from conditions or factors that are local and somewhat unique to each well. These factors, which include well construction and age, hydrogeology, and land use in the immediate vicinity of the well head, influence the vulnerability of the aquifer at a site.

Nitrate

Most nitrate in ground water is usually derived from soil and is considered a final oxidation product of nitrogenous organic material. Almost all forms of nitrogen in the soil zone are eventually converted to nitrate by chemical or biological processes. However, some of this nitrate in the soil might be reduced to nitrogen gas by the process of denitrification or taken up by plants and used for metabolic functions. Nitrate that has not been converted to nitrogen gas or taken up by biota is neither sorbed by soil or aquifer materials nor

precipitated as a mineral, and therefore, is soluble and can be mobile in ground water.

Concentrations of nitrate (as nitrogen; subsequently referred to as nitrate in this report) in most natural ground waters normally are small (a few milligrams per liter or less), and where elevated, might indicate anthropogenic activities. Sources of nitrate in ground water include nitrate and ammonia fertilizers, sewage waste from septic tanks and treatment plants, animal waste from feedlots and pastures, decaying vegetation and animals, legume plants, nitrate-bearing minerals, precipitation and surface runoff, and refuse dumps and landfills. The State of Tennessee has adopted a PMCL of 10.0 milligrams per liter (mg/L) for nitrate in finished drinking water served by public and non-community systems (Tennessee Department of Health and Environment, 1991). Concentrations exceeding this value are associated with methemoglobinemia, or cyanosis, a disease that occurs most commonly in infants ("blue-baby" disease) as the result of bacterial conversion of nitrate to nitrite in the digestive tract.

From an analysis of concentrations of nitrate in samples from 7,796 wells in the southeastern United States (Madison and Brunett, 1985), a 3.00 mg/L concentration was established as a threshold value, below which nitrate concentrations were considered background and above which the quality of ground water was considered to be influenced by human activities. This threshold value is used for evaluation of the nitrate data collected during the reconnaissance to identify the number of wells in each aquifer potentially demonstrating ground-water quality degradation. It should be noted, however, that natural or background nitrate concentrations in Tennessee and elsewhere are highly variable and are dependent on many local and regional factors.
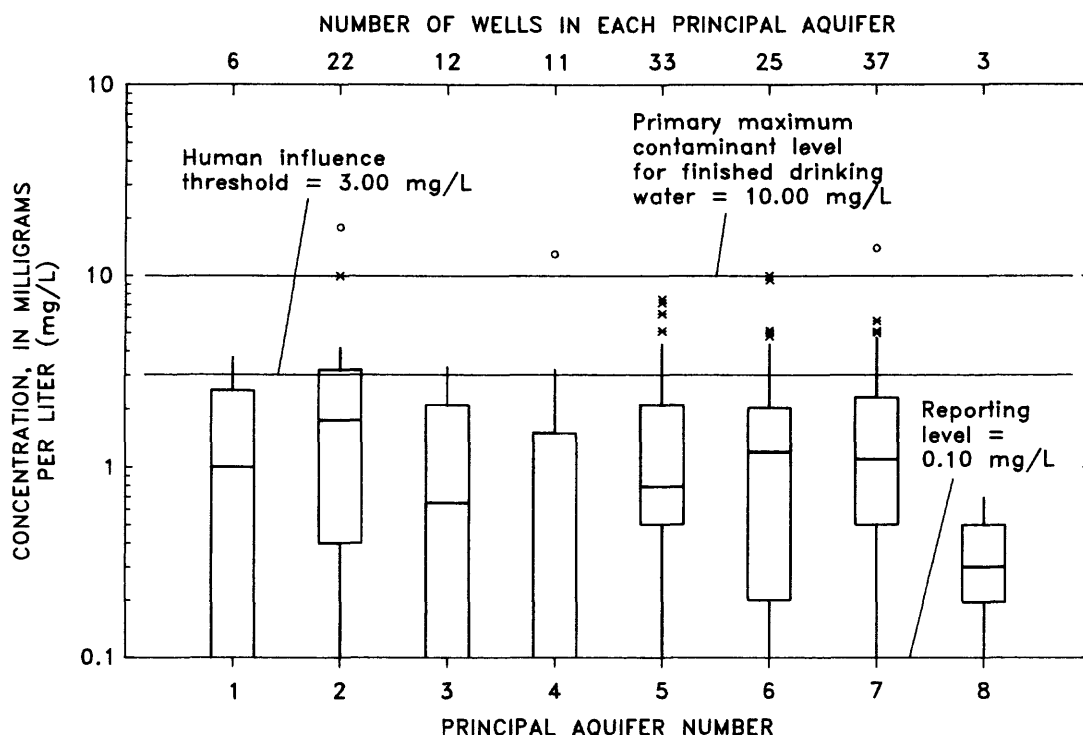
Concentrations of total nitrate normally reported by the USGS do not result from specific analyses of water for nitrate (Fishman and Friedman, 1989). Rather, they are calculated values obtained by subtracting the concentration of total nitrite in a water sample from the concentration of total nitrite plus nitrate. These calculations can only be performed when the results of both analyses are equal to or greater than their respective reporting levels (0.01 mg/L for nitrite and 0.1 mg/L for nitrite plus nitrate).

Data collected from 149 of the 150 wells (no nitrogen-species data for one well) show that concentrations of total nitrite were < 0.01 mg/L in samples from 119 wells and concentrations of total nitrite plus nitrate were < 0.1 mg/L in samples from 28 wells (results of both analyses below reporting level in samples from 25 wells). Thus, laboratory concentration data are not available for these wells. To enable evaluation of nitrate data collected during this reconnaissance, concentrations of total nitrate reported for these samples were calculated assuming that most nitrogen in the form of total nitrite plus nitrate was present in the samples as nitrate. Computed concentrations of total nitrate for samples from the 149 wells are listed in table 2 in Bennett and others (1990).

Boxplots of total nitrate data for the sampled wells indicate that concentrations ranged from < 0.1 to 18.0 mg/L (fig. 4a). Statewide, concentrations of nitrate equal to or exceeding the 10.0 mg/L PMCL were identified in samples from five of the wells (3 percent): two wells in the Tertiary sand aquifer, (10.0 and 18.0 mg/L); one well in the Pennsylvanian sandstone aquifer (13.0 mg/L); one well in the Ordovician carbonate aquifer (10.0 mg/L); and one well in the Cambrian-Ordovician carbonate aquifer (14.0 mg/L) (figs. 4a and 4b). The concentrations of nitrate in samples from these five wells might be elevated because all five are shallow (100 feet deep or less), and are located within 150 feet or less of septic tanks and (or) fertilized cropland.

A few wells in all but the crystalline rock aquifer produced water containing concentrations of total nitrate greater than the 3.00 mg/L human-influence threshold (figs. 4a and 4b). The aquifers, number of wells (and percentage) in each,

NUMBER OF WELLS IN EACH PRINCIPAL AQUIFER

6   22   12   11   33   25   37   3

Human influence
threshold = 3.00 mg/L

Primary maximum
contaminant level
for finished drinking
water = 10.00 mg/L

Reporting
level =
0.10 mg/L

CONCENTRATION, IN MILLIGRAMS
PER LITER (mg/L)

PRINCIPAL AQUIFER NUMBER

EXPLANATION

○   OBSERVATION GREATER THAN 3 X
     IQR FROM BOX

×   OBSERVATION GREATER THAN 1.5
     X IQR FROM BOX

WHISKER (See explanation
below)

75TH PERCENTILE

INTERQUARTILE
RANGE (IQR) ——— MEDIAN (50th percentile)

25TH PERCENTILE

WHISKER (Length equals last
observation within 1.5 X IQR
from box)

PRINCIPAL AQUIFERS

1 — Alluvial

2 — Tertiary sand

3 — Cretaceous sand

4 — Pennsylvanian
    sandstone

5 — Mississippian
    carbonate

6 — Ordovician
    carbonate

7 — Cambrian—
    Ordovician
    carbonate

8 — Crystalline rock

(Aquifer names
from Bradley and
Hollyday, 1985)

Figure 4a. Boxplots of concentrations of total nitrate (as nitrogen) for 149 of 150 sampled wells grouped by principal aquifer. (Data from Bennett and others, 1990).

and concentrations are listed in table 3. The Tertiary sand and Mississippian, Ordovician, and Cambrian-Ordovician carbonate aquifers had a greater percentage of wells that exceeded the 3.00 mg/L threshold; however, these four aquifers also had more wells sampled than the other four aquifers (fig. 4a). Overall, concentrations of nitrate were less than the 3.00 mg/L threshold in about 80 percent (119 of 149 wells) of the sampled wells.
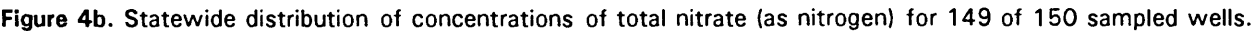
Median calculations for the eight principal aquifers generally show little variation in nitrate concentration (fig. 4a). Medians range between 0.30 mg/L (crystalline rock aquifer) and 1.75 mg/L (Tertiary sand aquifer), but five of the eight aquifers have similar medians ranging from 0.65 to 1.20 mg/L (Cretaceous sand, 0.65; Mississippian carbonate, 0.79; alluvial, 1.00; Cambrian-Ordovician carbonate, 1.10; and Ordovician carbonate, 1.20; fig. 4a). The median for the nitrate data collected from wells completed in the Pennsylvanian sandstone aquifer (fig. 4a) was below the 0.1 mg/L reporting level because more than 50 percent of the samples had nitrate concentrations below detection. The range in medians from 0.65 to 1.20 mg/L might represent an expected estimate of concentrations of total nitrate in natural ground water produced by private wells in rural areas of Tennessee. A 1987 study of 100 private wells in McMinn County, Tennessee, identified a mean concentration of nitrate of < 1.00 mg/L (French and Strunk, 1988). A 1989 study of ground-water quality from 50 rural domestic wells conducted in Bedford County, Tennessee, by the Tennessee Valley Authority identified a median concentration of nitrite plus nitrate of 0.11 mg/L (Tennessee Valley Authority, unpublished data, 1989). Results of several studies conducted by the Center for Management, Utilization, and Protection of Water Resources at Tennessee Technological University showed a mean concentration of nitrate of 1.33 mg/L for 108 ground-water samples collected from wells and springs in central and eastern Tennessee (Ogden and others, 1991) These data are in general agreement with data collected during this reconnaissance.

Variability in concentrations of total nitrate was relatively large for samples from each of the principal aquifers (figs. 4a and 4b). Concentration ranges for all of the aquifers except the crystalline rock aquifer span from about one and one-half to two orders of magnitude (fig. 4a). An estimate of the variability in concentrations of nitrate for the crystalline rock aquifer is restricted by limited data. The large variability indicates that numerous local factors affect nitrate concentrations in ground water from farm wells in Tennessee.
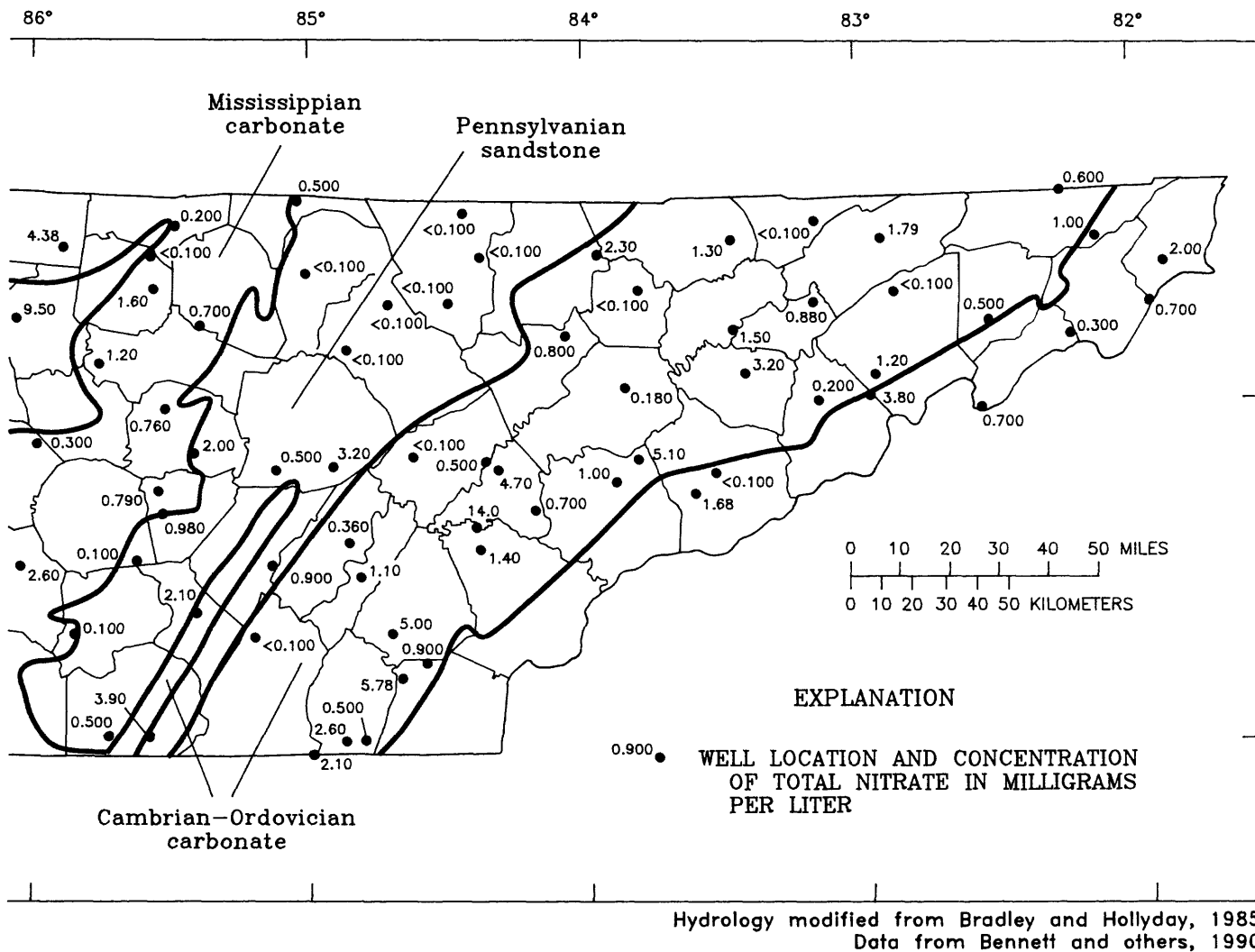
Organic Compounds

Samples collected from the 150 wells were analyzed for organic compounds by gas chromatography coupled with flame-ionization detection (GC/FID) (Wershaw and others, 1987). Analysis of water by this method is used to semi-quantitatively determine the presence of and estimate the total concentration of organic compounds. Although the method does not identify specific compounds, it detects the presence of many synthetic and natural organic compounds. Thus, the main use of GC/FID analysis is to provide a relatively inexpensive screening of water samples for total concentrations of organic compounds. If warranted, quantitative analyses then can be performed by gas chromatography coupled with mass spectrometry (GC/MS) or other methods to identify individual compounds.

Three analytical values are reported by the USGS laboratory for each GC/FID analysis: the estimated total concentration of all organic compounds detected, the number of peaks detected (usually representing individual compounds), and the number of peaks possibly identifiable by GC/MS. Estimated total concentrations reported are used for data analysis in this report because these values provide the most meaningful representation of potential organic-contaminant concentrations. It should be kept in mind, however, that not all compounds detected in water samples by GC/FID methods can be considered contaminants because, as noted previously, this

Ordovician
carbonate

Cretaceous
sand

0.080
2.20
18.0
<0.100
4.20   3.60
0.800   <0.100
3.75   3.30
2.30   <0.100
2.20   3.60
<0.100   0.300   2.10   2.10
2.50   2.70   0.900
3.20
<0.100   2.50   1.40
0.900   0.400   2.50   <0.100
1.20   10.0
1.20   <0.100

5.10
2.70
0.300   2.00
0.500   5.09
<0.100   7.49   7.17
<0.100   1.50   4.80   <0.100
1.39   4.38
0.600   0.300
10.0   0.400   1.80
0.500   0.400   1.66
6.29   5.16   0.290
<0.100
0.300   <0.100   <0.100
1.70   0.800   1.80
0.100   3.40
0.100   1.90
2.04   2.10
0.100   1.30   0.690
0.400
0.800

36°

35°

Tertiary
sand

Alluvial

Mississippian
carbonate

Figure 4b. Statewide distribution of concentrations of total nitrate (as nitrogen) for 149 of 150 sampled wells.

Figure 4b. Statewide distribution of concentrations of total nitrate (as nitrogen) for 149 of 150 sampled wells--Continued.

Table 3. Number and percentage of wells in each principal aquifer producing samples with concentrations of total nitrate (as nitrogen) exceeding the 3.00 milligrams per liter human-influence threshold

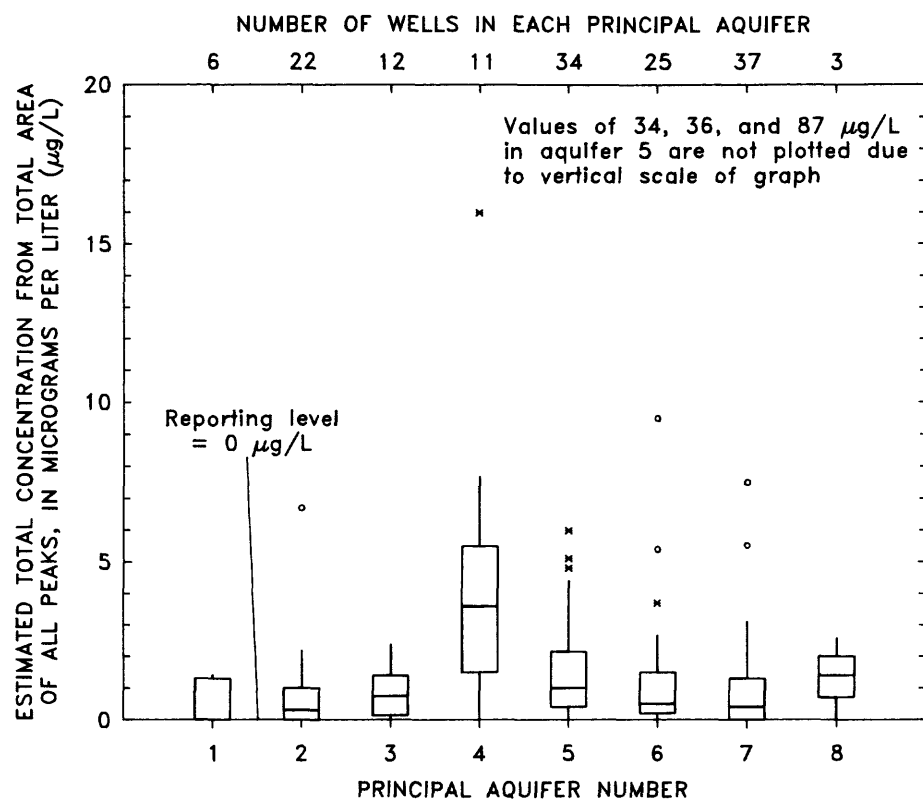| Principal aquifer	Number of wells	Percent of total wells in principal aquifer	Percent of total of 149 wells	Concentrations, in milligrams per liter
Alluvial	1 of 6	16.7	0.7	3.75
Tertiary sand.	6 of 22	27.3	4.0	3.20, 3.60, 3.60, 4.20, 10.0, 18.0
Cretaceous sand.	1 of 12	8.3	.7	3.30
Pennsylvanian sandstone.	2 of 11	18.2	1.3	3.20, 13.0
Mississippian carbonate.	6 of 33	18.2	4.0	3.40, 4.38, 5.10, 6.29, 7.17, 7.49
Ordovician carbonate.	6 of 25	24.0	4.0	4.38, 4.80, 5.09, 5.16, 9.50, 10.0
Cambrian-Ordivician carbonate.	8 of 37	21.6	5.4	3.20, 3.80, 3.90, 4.70, 5.00, 5.10, 5.78, 14.0
Crystalline rock.	0 of 3	0	0	
Total	30 of 149		˜20	

analytical method also is sensitive to some organic materials that occur naturally in water.

Boxplots of estimated total concentrations of organic compounds for the sampled wells indicate that the concentrations ranged from 0 to 87 micrograms per liter (μg/L) (fig. 5a). Note in figure 5a, however, that except for a few outlier values representing samples from wells in the Tertiary sand, Pennsylvanian sandstone, and Mississippian, Ordovician, and Cambrian-Ordovician carbonate aquifers, estimated total concentrations of organic compounds were <5 μg/L in most samples from each of the eight principal aquifers (concentrations <5 μg/L in 92 percent of all samples).

Samples from 10 wells contained detectable organic compounds in total estimated concentra-

tions > 10 μg/L in the initial GC/FID analysis (Bennett and others, 1990, p. 14-18). Seven of these wells were selected and resampled for GC/FID analyses to confirm first-round results. Concentrations from second-round analyses were <5 μg/L in samples from five of the wells. These results suggest that concentrations observed in the first-round samples may have been related to temporal variations in water chemistry, or contamination of the samples in the field or laboratory. Estimated concentrations in second-round samples from the other two wells decreased from 140 to 9.5 μg/L, and from 22 to 16 μg/L.

Median estimated total concentrations of organic compounds were generally small in samples from wells in most of the principal aquifers (fig. 5a). In seven of the eight aquifers, median concentrations were 1.4 μg/L or less. The

NUMBER OF WELLS IN EACH PRINCIPAL AQUIFER

6   22   12   11   34   25   37   3

ESTIMATED TOTAL CONCENTRATION FROM TOTAL AREA OF ALL PEAKS, IN MICROGRAMS PER LITER (μg/L)

20

Values of 34, 36, and 87 μg/L in aquifer 5 are not plotted due to vertical scale of graph

15

10

Reporting level = 0 μg/L

5

0

1   2   3   4   5   6   7   8

PRINCIPAL AQUIFER NUMBER

EXPLANATION

o   OBSERVATION GREATER THAN 3 X IQR FROM BOX

×   OBSERVATION GREATER THAN 1.5 X IQR FROM BOX

WHISKER (See explanation below)

75TH PERCENTILE

INTERQUARTILE RANGE (IQR)

MEDIAN (50th percentile)

25TH PERCENTILE

WHISKER (Length equals last observation within 1.5 X IQR from box)

PRINCIPAL AQUIFERS

1 — Alluvial

2 — Tertiary sand

3 — Cretaceous sand

4 — Pennsylvanian sandstone

5 — Mississippian carbonate

6 — Ordovician carbonate

7 — Cambrian— Ordovician carbonate

8 — Crystalline rock

(Aquifer names from Bradley and Hollyday, 1985)
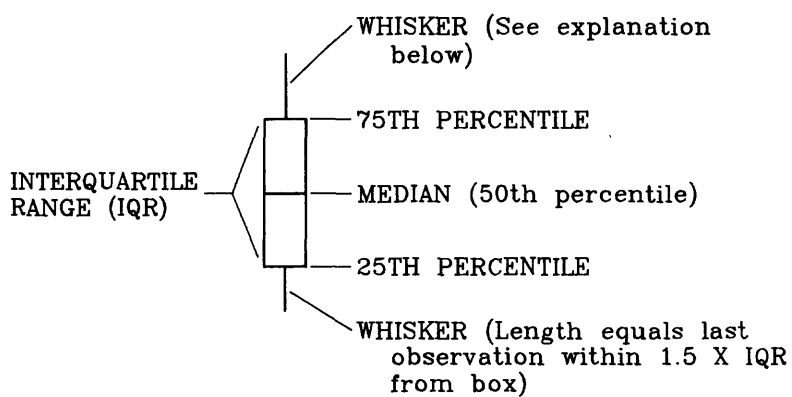
Figure 5a. Boxplots of estimated total concentrations of organic compounds for 150 sampled wells grouped by principal aquifer. (Data by Bennett and others, 1990.)
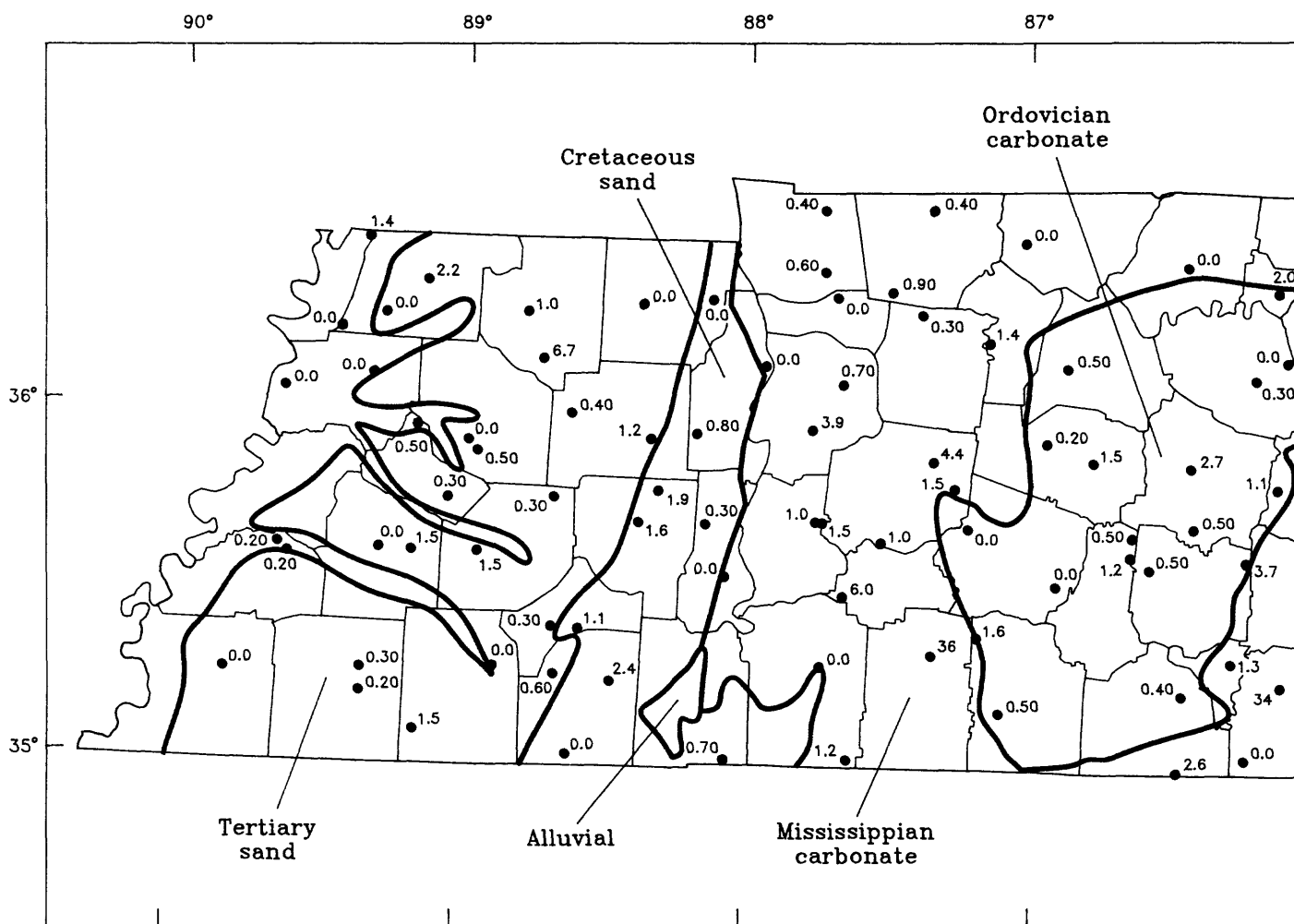
90° 89° 88° 87°

Ordovician
carbonate

Cretaceous
sand

1.4
2.2
0.0 0.0 1.0 0.0 0.40 0.40
0.0 0.0
0.60 0.0
6.7 0.90
0.0 0.0 0.30 1.4
0.0 0.0 0.0
0.40 0.70 0.50 0.0
36° 1.2 0.80 3.9 0.30
0.50 0.0
0.50 4.4 0.20 1.5 2.7
0.30 1.5 1.1
0.30 1.9 0.30 1.0 1.5 1.0 0.50
1.6 1.5 0.0 0.50
0.0 1.5 0.0 0.0 0.50
0.20 1.5 6.0 1.2 0.50 3.7
0.20 0.30 1.1 1.6
0.0 36 0.40 1.3
0.0 2.4 0.0 0.50 34
0.30 0.60 1.2
0.20 0.0
35° 1.5 0.0 0.70 1.2 2.6 0.0

Tertiary
sand

Alluvial

Mississippian
carbonate

Figure 5b. Statewide distribution of estimated total concentrations of organic compounds for 150 sampled wells.

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Farmstead Wells in Tennessee, 1989-90
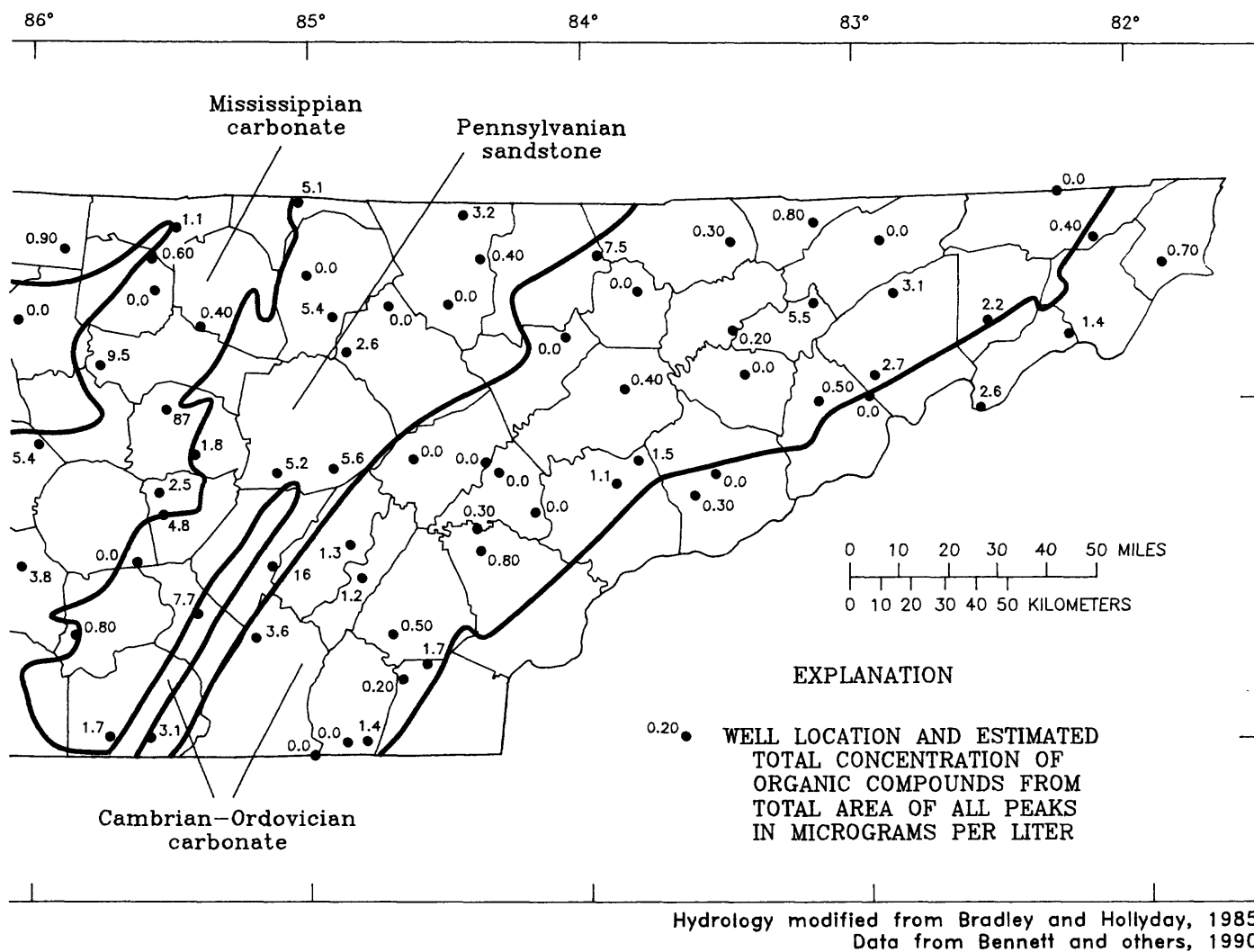
Figure 5b. Statewide distribution of estimated total concentrations of organic compounds for 150 sampled wells--Continued.

generally small concentrations of organic compounds in many of the wells sampled suggests that geologic differences within and between most of the aquifers has little influence on the concentrations of organic compounds detectable by this analytical method. However, this may not be true of the Pennsylvanian sandstone aquifer, where the median concentration of 3.6 μg/L (fig. 5a) indicates that geologic or other factors might affect the concentrations of organic compounds in water from this aquifer. A possible reason is that coal and other carbonaceous material present in these rocks of Pennsylvanian age is a source of the organic compounds detected.

The variability of estimated total concentrations of organic compounds detected by GC/FID generally is small for each of the principal aquifers (fig. 5a). Variability in all of the aquifers except the Pennsylvanian sandstone and Mississippian carbonate aquifers is one order of magnitude or less, with samples from the alluvial, Cretaceous sand, and crystalline rock aquifers varying by only about one fourth of an order of magnitude (fig. 5a). The small variability observed in these three aquifers might result from the limited number of wells sampled in each aquifer. Variability in samples from the Tertiary sand, Pennsylvanian sandstone, and Mississippian, Ordovician, and Cambrian-Ordovician carbonate aquifers ranges from slightly greater than one half to slightly less than two orders of magnitude. However, this range in concentrations is defined by relatively few samples from these five aquifers (fig. 5a). The generally small variability in most of the GC/FID data is further illustrated by 67 percent of the data being $\leq$2.2 μg/L [approximately the value denoting the upper end of the box (75th percentile) for the Mississippian carbonate aquifer] in all of the aquifers except the Pennsylvanian sandstone aquifer (fig. 5a). In this aquifer, only 27 percent of the data were $\leq$2.2 μg/L (fig. 5a).

Samples from some of the wells in each of the eight principal aquifers contained trace concentrations of organic compounds that were detectable by GC/FID analysis. It is important to keep in mind, however, that not all organic compounds detected by GC/FID analysis are considered contaminants. Other quantitative analytical methods must be performed to identify the specific organic compounds present in ground water.

Iron

Iron is the second most common element in the Earth's crust and occurs generally in small concentrations in all natural ground waters. Under most conditions, iron in ground water precipitates upon exposure to air, forming an insoluble reddish-brown oxyhydroxide that stains plumbing and laundry. Large concentrations of iron in ground water also might cause well and plumbing encrustation problems, and for these reasons, are an objectionable impurity in ground water.

The concentration of iron in ground water is related to many factors, such as temperature, pH, reduction-oxidation (redox) potential, and the amount and form of iron-bearing minerals in the aquifer material. Metallic well components such as casing, screen, and pump columns also might affect the concentration of iron in ground water delivered to the surface, especially where ground water is acidic.

The State of Tennessee has adopted a SMCL of 300 μg/L for the concentration of iron in finished drinking water served by public and non-community systems (Tennessee Department of Health and Environment, 1991). This SMCL was established primarily for maintenance of the aesthetic quality of drinking water because few problems with staining are associated with water containing iron concentrations $\leq$ 300 μg/L.

Analyses of total-recoverable iron (Fishman and Friedman, 1989) were performed on unfiltered water samples from the 150 wells. Because the

objective of this reconnaissance was to assess the quality of ground water from selected farmstead wells used primarily for domestic supply, and because water from these wells is not ordinarily filtered prior to use, analyses were performed for total-recoverable iron rather than dissolved iron. Results from these analyses provide more accurate data on the potential amount of iron available for consumption by users.
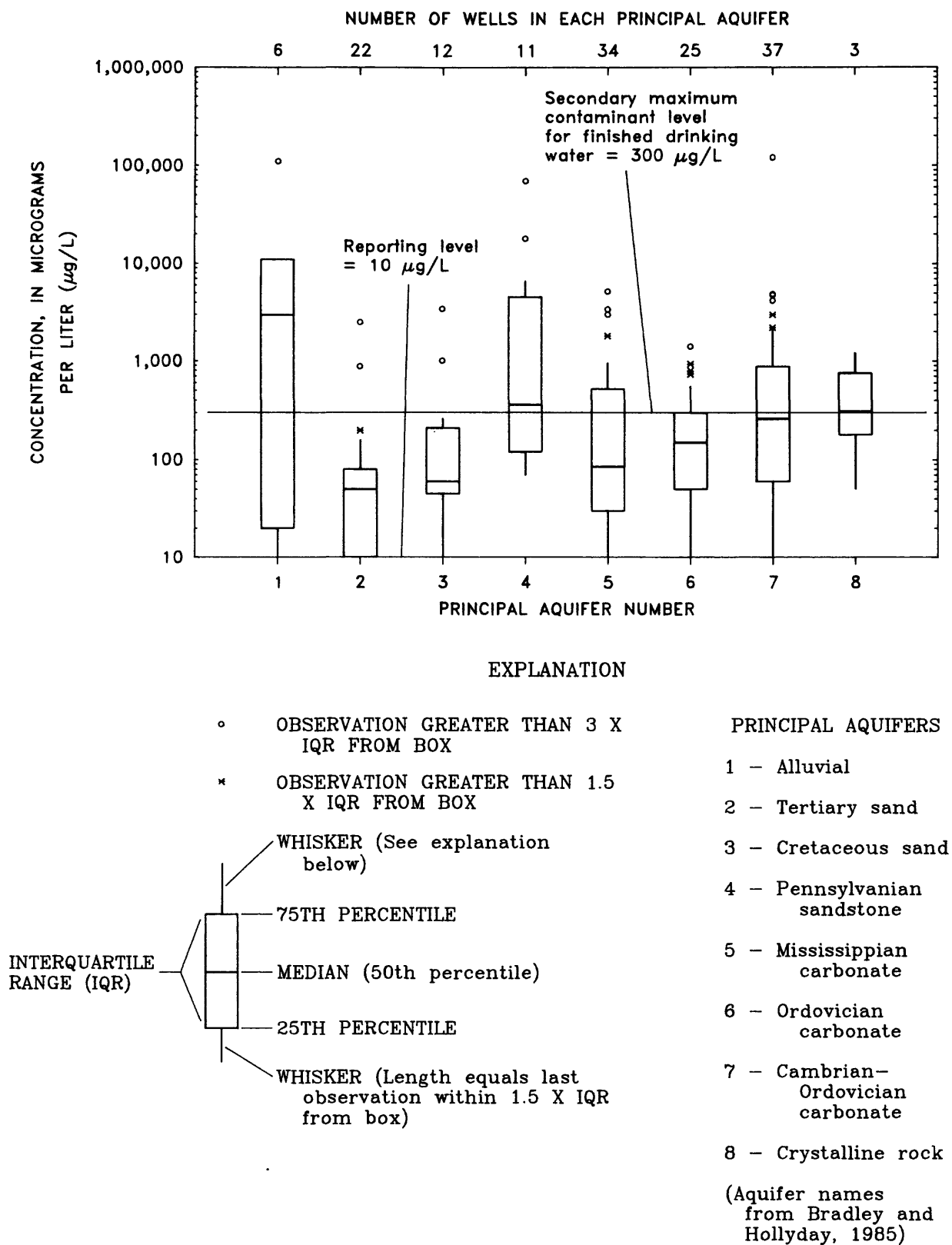
Boxplots of total-recoverable iron for the sampled wells indicate concentrations ranged from < 10 to 120,000 μg/L (fig. 6a). Overall, samples from 35 percent (52 of 150 wells) of the wells contained concentrations of iron equal to or exceeding the 300 μg/L SMCL. About 82 percent (42 of 51 wells, no casing data for one well) of these wells are constructed with metallic casing, suggesting an influence on iron concentrations. Concentrations of iron from a few wells in the alluvial, Pennsylvanian sandstone, and Cambrian-Ordovician carbonate aquifers (figs. 6a and 6b) were in excess of about 10,000 μg/L. These concentrations might represent some contribution of iron that was desorbed or solubilized by digestion of material suspended in the samples upon preservation in the field with nitric acid and (or) pretreatment at the laboratory with hydrochloric acid prior to analysis. The very large concentrations of iron in samples from two of the wells in the Pennsylvanian sandstone aquifer (18,000 and 69,000 μg/L) and from one well in the Cambrian-Ordovician carbonate aquifer (120,000 μg/L) (figs. 6a and 6b) strongly indicate relation to corrosion of metallic casing used in each well. The well which produced water containing 120,000 μg/L of iron is cased with wrought iron and is relatively old (installed in 1952).

In the Pennsylvanian sandstone aquifer, large concentrations of iron might develop where ground water contacts sandstone or shale containing pyrite or other minerals rich in iron compounds (Broshears, 1988, p. 468). The large concentration of iron (110,000 μg/L) in a sample from one well in the alluvial aquifer (figs. 6a and 6b) cannot be explained as being an artifact of metallic casing

because this well was completed with polyvinyl chloride (PVC) casing and screen. However, concentrations of iron as large as 24,000 μg/L have been identified locally in ground water from the Mississippi River alluvial aquifer in the Memphis area (Brahana and others, 1987, p. 10). These locally large iron concentrations probably are related to chemical reactions between iron-bearing sediments and water in the alluvial aquifer.

Concentrations of total-recoverable iron for samples from wells in each of the principal aquifers generally can be aggregated into two groups based on median values (fig. 6a). In general, the Tertiary and Cretaceous sand, and the Mississippian and Ordovician carbonate aquifers produced samples with smaller median concentrations of iron (150 μg/L or less) relative to the other four aquifers (medians of 260 μg/L or greater) (fig. 6a). Furthermore, 65 percent or more of the samples from wells in these aquifers (91 percent for the Tertiary sand aquifer) contained concentrations of iron less than or equal to the 300 μg/L SMCL (fig. 6a). For the alluvial, Pennsylvanian sandstone, Cambrian-Ordovician carbonate, and crystalline rock aquifers, at least 49 percent of the samples had concentrations of iron equal to or greater than the SMCL (fig. 6a). Median concentrations of iron shown in the boxplots (fig. 6a) generally agree with median values calculated from existing iron data for the principal aquifers in Tennessee as reported by Adams and others (1986, p. 118).

Variability in concentrations of total-recoverable iron generally is large for samples from wells in each of the principal aquifers (fig. 6a), suggesting that elevated concentrations are localized problems (fig. 6b) and probably are related to factors such as aquifer mineralogy, ground-water pH (or acidity), and (or) well-construction materials. Concentration ranges for nearly all of the aquifers span at least two orders of magnitude, with data for the alluvial and the Cambrian-Ordovician carbonate aquifers varying by more than four orders of magnitude (fig. 6a).

Figure 6a. Boxplots of concentrations of total-recoverable iron for 150 sampled wells grouped by principal aquifer. (Data from Bennett and others, 1990.)

A wide range in iron concentrations was not measured in samples from the crystalline rock aquifer because of the limited number of data.

Manganese

Manganese is an important metallic element, and occurs generally in small concentrations in all natural ground waters. Under most conditions, manganese in ground water precipitates on exposure to air, forming black oxides that can stain plumbing and laundry and might cause well and plumbing encrustation problems. For these reasons, excessive amounts of manganese are objectionable in ground water.

The concentration of manganese in ground water is related to many factors, such as temperature, pH, redox potential, and the amount and form of manganese-bearing minerals in the aquifer material. Metallic casing, screen, and pump columns also might affect the concentration of manganese in ground water delivered to the surface, especially where ground water is acidic.

The State of Tennessee has adopted a SMCL of 50 μg/L for manganese concentrations in finished drinking water served by public and non-community systems (Tennessee Department of Health and Environment, 1991). This SMCL was established primarily for maintenance of the aesthetic quality of drinking water because few problems with staining are associated with water having manganese concentrations $\leq$ 50 μg/L.

Analyses of total-recoverable manganese (Fishman and Friedman, 1989) were performed on unfiltered water samples from the 150 wells. Like the analyses for iron, results from this method provide more accurate data on the amount of manganese potentially available for consumption by users because, in most cases, the water is not filtered prior to use.

Boxplots of total-recoverable manganese data for the sampled wells indicate that concentrations

ranged from < 10 to 4,800 μg/L (fig. 7a). Overall, samples from 25 percent (37 of 150 wells) of the wells contained concentrations of manganese equal to or exceeding the 50 μg/L SMCL. Concentrations of manganese in excess of about 1,000 μg/L were measured in samples from a few wells in the alluvial, Pennsylvanian sandstone, and Cambrian-Ordovician carbonate aquifers (figs. 7a and 7b). These concentrations might represent naturally occurring dissolved manganese plus additional manganese that was desorbed or solubilized from material suspended in the samples upon preservation in the field with nitric acid and (or) pretreatment of the samples at the laboratory with hydrochloric acid prior to analysis. The large concentration of manganese (4,800 μg/L) in one well in the Cambrian-Ordovician carbonate aquifer (figs. 7a and 7b) also might be related to its metal (wrought iron) well casing. In the Pennsylvanian sandstone aquifer, however, large concentrations of manganese might develop where ground water contacts sandstone, shale, or coal beds that contain minerals rich in manganese. The large concentrations of manganese (1,300 and 2,800 μg/L) in two wells in the alluvial aquifer (fig. 7b) cannot be explained as being artifacts of metallic casing because one well is completed with PVC casing and screen and the other is hand dug and concrete lined. Concentrations of manganese as large as 2,300 μg/L have been reported in ground water from the Mississippi River alluvial aquifer in Lauderdale County, Tennessee (Parks and others, 1985, p. 31). As is the case for iron, these locally high concentrations of manganese probably are related to chemical reactions between manganese-bearing sediments and water in the alluvial aquifer. In general, wells producing large concentrations of manganese also produced large concentrations of iron (figs. 6b and 7b).

Concentrations of total-recoverable manganese for samples from wells in each of the principal aquifers generally can be aggregated into two groups based on median values (fig. 7a). In general, samples from wells in the Tertiary and Cretaceous sand; Mississippian, Ordovician, and Cambrian-Ordovician carbonate; and the crystalline rock aquifers had smaller median concentrations of
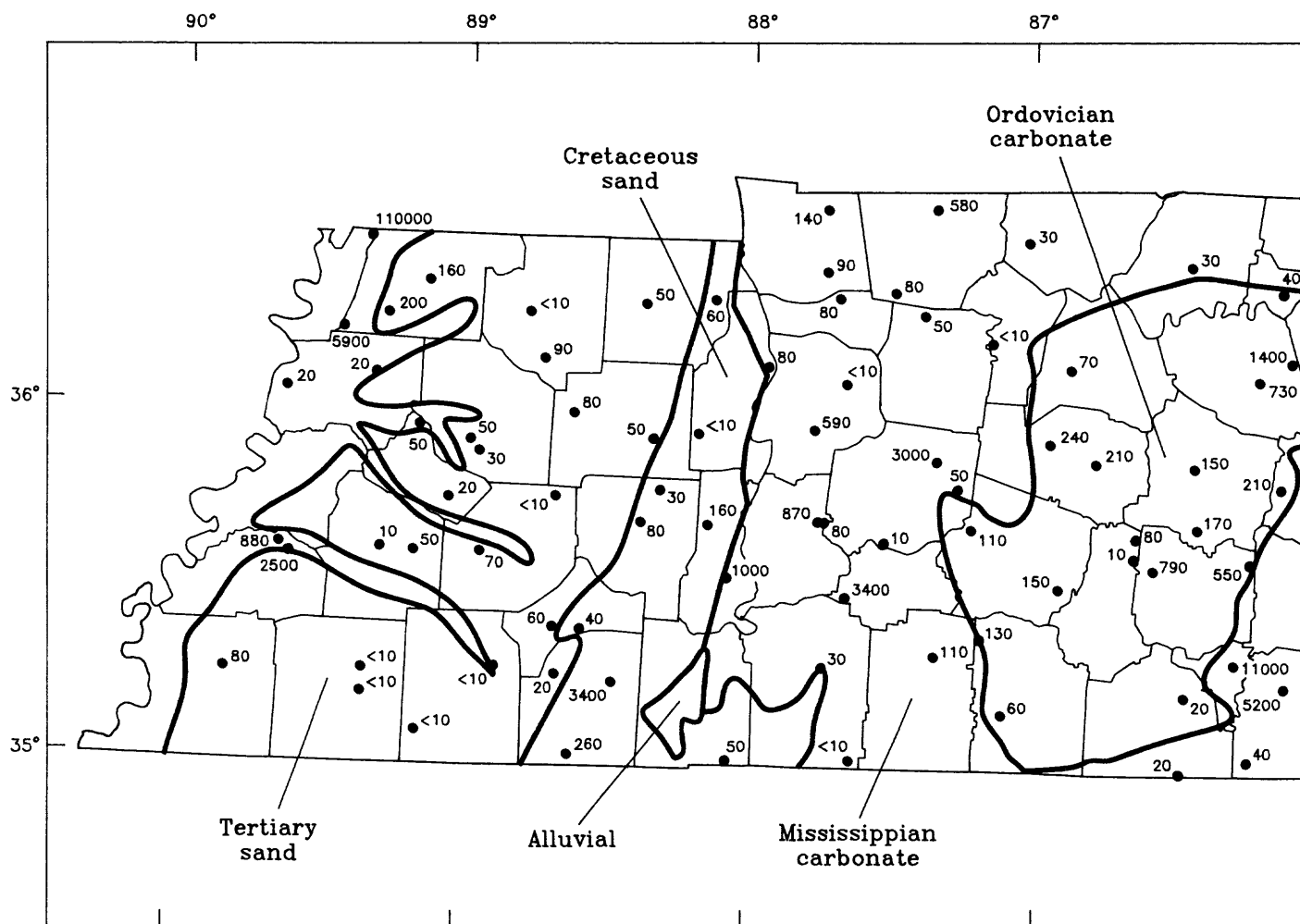
Figure 6b. Statewide distribution of concentrations of total-recoverable iron for 150 sampled wells.
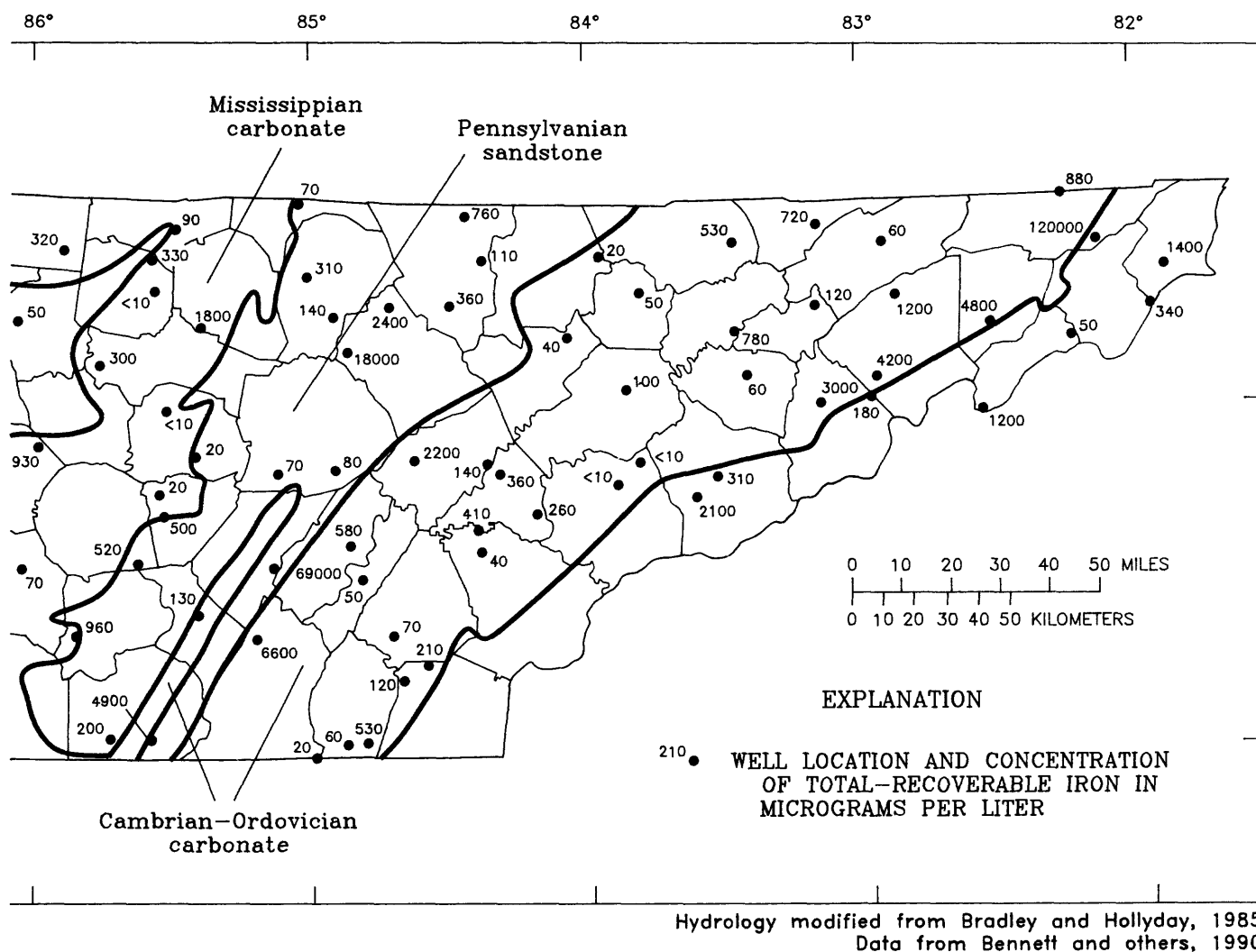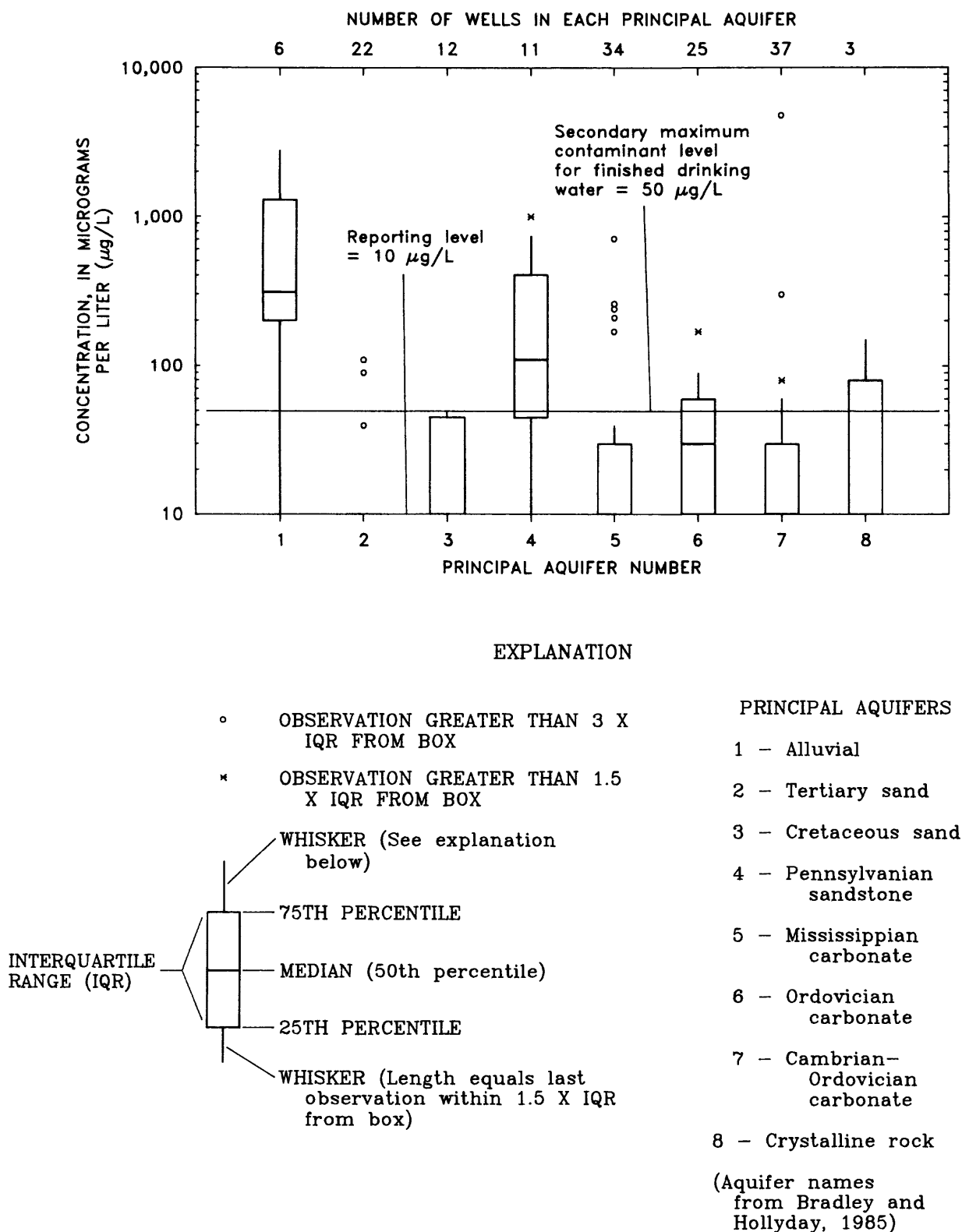
Figure 6b. Statewide distribution of concentrations of total-recoverable iron for 150 sampled wells--Continued.

NUMBER OF WELLS IN EACH PRINCIPAL AQUIFER

Figure 7a. Boxplots of concentrations of total-recoverable manganese for 150 sampled wells grouped by principal aquifer. (Data from Bennett and others, 1990.)

manganese (30 µg/L or less) than samples from wells in the other two aquifers (110 µg/L or greater) (fig. 7a). Furthermore, 67 percent or greater (100 percent for the Cretaceous sand aquifer) of the samples from wells in these six aquifers contained concentrations of manganese less than or equal to the 50 µg/L SMCL (fig. 7a). For the alluvial and Pennsylvanian sandstone aquifers, at least 73 percent of the wells produced samples with concentrations of manganese greater than the SMCL (fig. 7a). Median concentrations of manganese shown in the boxplots (fig. 7a) are essentially equal to median values calculated from existing manganese data for the principal aquifers in Tennessee (Adams and others, 1986, p. 119).

Variability in concentrations of total-recoverable manganese generally is large for samples from wells in each of the principal aquifers (fig. 7a), indicating that elevated concentrations of manganese, like iron, are localized problems (fig. 7b). Concentration ranges for four of the eight aquifers span from slightly less than two (Mississippian carbonate aquifer) (fig. 7a) to nearly three orders of magnitude (Cambrian-Ordovician carbonate aquifer). Concentrations of manganese in samples from wells in the other three aquifers varied from less than one (Cretaceous sand aquifer) to slightly greater than one order of magnitude (Ordovician carbonate aquifer) (fig. 7a). The least variation is in the Tertiary sand aquifer, where samples from 18 of 22 wells (82 percent) contained concentrations of manganese ≤ 10 µg/L. This might be related to the low solubility of siliceous minerals that are the dominant component of the matrix of this aquifer.

Hydrogen-Ion Concentration (pH)

The free hydrogen-ion concentration, expressed as pH, is a measure of the relative acidity or alkalinity of a water. By definition, water is neutral when, at a temperature of 25 degrees C, it has a pH of 7.00 units. Values of pH progressively lower than 7.00 indicate increasing acidity, while values progressively higher than 7.00 indicate increasing alkalinity. The pH of water is commonly used as a measure of its effect on metal surfaces, because as pH increases, the corrosive activity of the water normally decreases. However, excessively alkaline waters also can be corrosive to some metals. The pH of water is one of the most important factors determining the solubility of many constituents found in ground water (Hem, 1985).

The range in pH of most natural ground water in the United States is from about 6.00 to about 8.50 (Hem, 1985, p. 64). Important factors that control the pH of natural ground water are the pH of precipitation; the rate, method, and medium through which recharging water enters an aquifer; and the chemical composition of the aquifer matrix through which the ground water circulates. Other factors, including well depth, construction materials, and hydraulic characteristics, also might influence the pH of ground water that is pumped from wells.

The State of Tennessee has adopted a SMCL range of 6.50 to 8.50 for the pH of finished drinking water served by public and non-community systems (Tennessee Department of Health and Environment, 1991). This SMCL was established primarily for maintenance of the aesthetic quality of drinking water because a pH within this range helps to reduce the corrosive effects of water on distribution lines and home plumbing.

Measurements of pH were performed in the field and laboratory for samples collected from the 150 wells; however, only field values of pH are presented in this report. Exposure to the atmosphere can change the pH of ground water. Therefore, measurements performed in the field at the time of sample collection generally are considered to be the most accurate determination of pH.

Boxplots indicate that pH ranged from 4.29 to 8.95 (fig. 8a), with the minimum and maximum values occurring in samples collected from the Pennsylvanian sandstone aquifer. The relatively
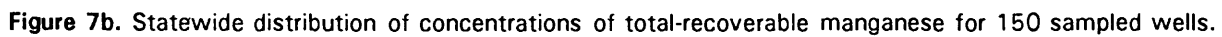
Figure 7b. Statewide distribution of concentrations of total-recoverable manganese for 150 sampled wells.
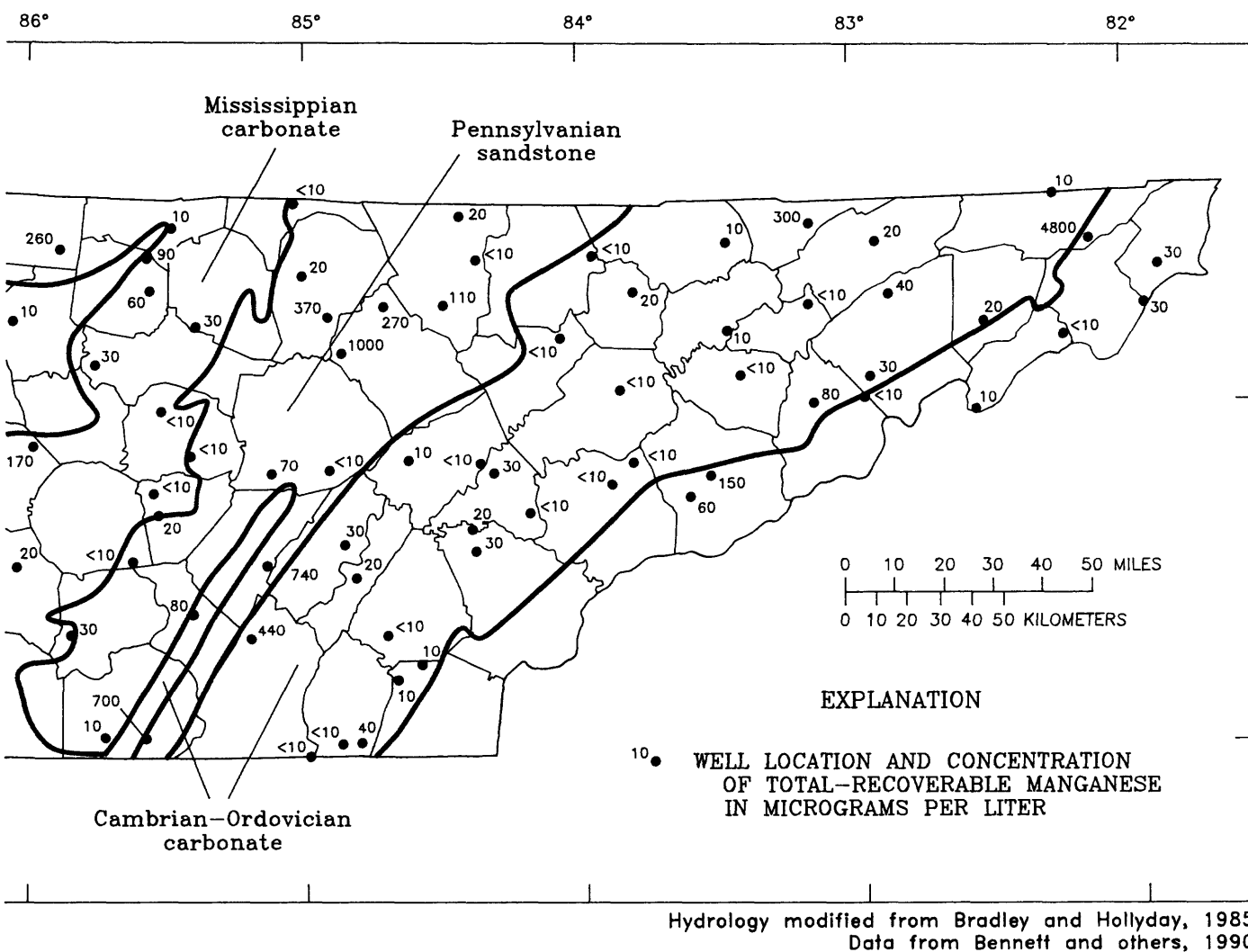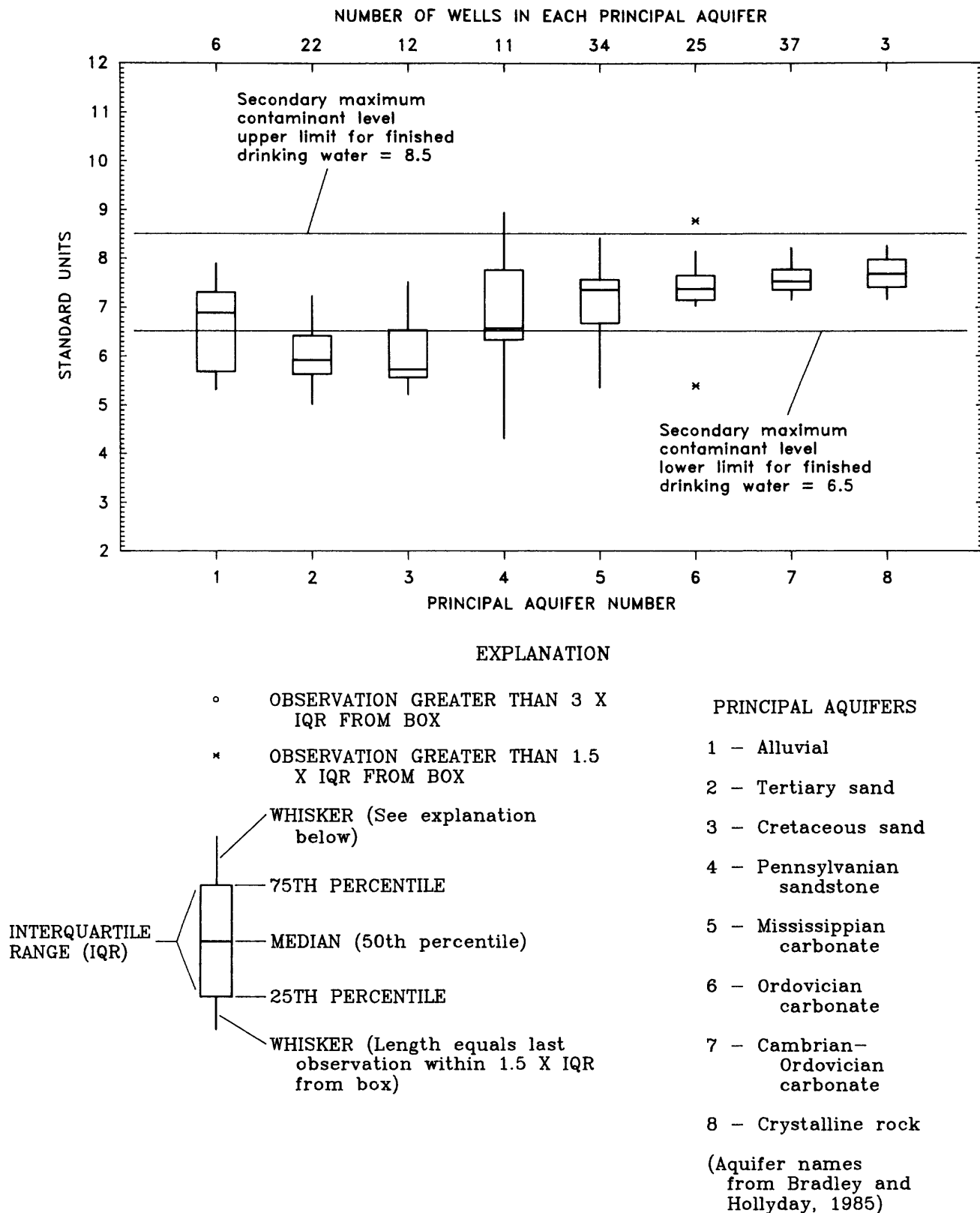
Figure 7b. Statewide distribution of concentrations of total-recoverable manganese for 150 sampled wells--Continued.

Figure 8a. Boxplots of pH for 150 sampled wells grouped by principal aquifer. (Data from Bennett and others, 1990.)

wide range in pH of water samples from wells in this aquifer is, to some extent, related to the lithologic heterogeneity of the aquifer, which contains coal and other carbonaceous deposits in some areas, and also to the relatively wide range in depths of the wells sampled (40-183 feet).

Values of pH measured for each of the principal aquifers generally can be aggregated into two groups based on median values. In general, samples from wells in the alluvial, Tertiary and Cretaceous sand, and the Pennsylvanian sandstone aquifers had lower pH values (medians of 6.88 or less) than water from the other four aquifers (medians of 7.36 or greater) (fig. 8a). This is the result of a reduced capacity of the dominantly siliceous alluvial, Tertiary and Cretaceous sand, and Pennsylvanian sandstone aquifers to neutralize relatively low pH recharge water. Samples from wells in the other four aquifers generally exhibited higher pH values, probably because of an increased buffering capacity from the dominantly carbonate composition of these aquifers. Median pH values shown in the boxplots (fig. 8a) also generally agree with median values calculated from existing pH data for the principal aquifers in Tennessee (Adams and others, 1986, p. 117).

Water samples from wells in the principal aquifers that are rich in carbonate minerals generally were less variable in pH and were more alkaline than water samples from wells in the aquifers rich in silicate minerals (fig. 8a). This is evidenced in the boxplots of pH data for the Ordovician and Cambrian-Ordovician carbonate aquifers, and the crystalline rock aquifer, where 93, 100, and 100 percent of the pH data, respectively, are within the SMCL range (fig. 8a). Although variability in the pH of samples from the Mississippian carbonate aquifer is larger than that of the other carbonate aquifers, samples from this aquifer were mostly neutral, with 85 percent of the data within the SMCL range (fig. 8a). The small number of wells sampled in the alluvial (six wells) and crystalline rock (three wells) aquifers likely are insufficient to estimate the true range in pH of water from these aquifers. Overall, the variability

in pH data for samples from each of the eight aquifers is similar to historic pH data for the principal aquifers in Tennessee (Adams and others, 1986, p. 121-124).

Problems might occur where relatively low pH (pH < 6.50) ground waters are supplied by private wells to homes equipped with metal plumbing, particularly those homes in which lead solder was used in plumbing. Samples from 25 percent (38 of 150 wells) of the wells had a pH < 6.50. From the data, areas in Tennessee where low pH potential exists are primarily restricted to the western part of the State, where the alluvial and the Tertiary and Cretaceous sand aquifers are used as sources for domestic supply (fig. 8b). However, in some local areas underlain by the Mississippian carbonate and the Pennsylvanian sandstone aquifers, relatively low pH ground water also might create a problem for leaching of metals from household plumbing systems. The pH data shown in the boxplots (fig. 8a) also indicate that, statewide, little potential appears to exist for problems associated with ground water having a pH greater than the upper SMCL limit because only two samples with a pH greater than 8.50 were collected (figs. 8a and 8b).

SUMMARY AND CONCLUSIONS

In 1989-90, the U.S. Geological Survey, in cooperation with the Tennessee State Planning Office, conducted a statewide reconnaissance of the quality of ground water from selected farmstead wells throughout Tennessee. A network of 150 wells was established representing 93 of the 95 counties in Tennessee, as well as eight of the nine principal aquifers, and most of the agricultural activities in the State. At each well site, water samples and general land-use data were collected. The water samples were analyzed in the field and laboratory to determine selected physical characteristics, chemical constituents, and bacterial content.

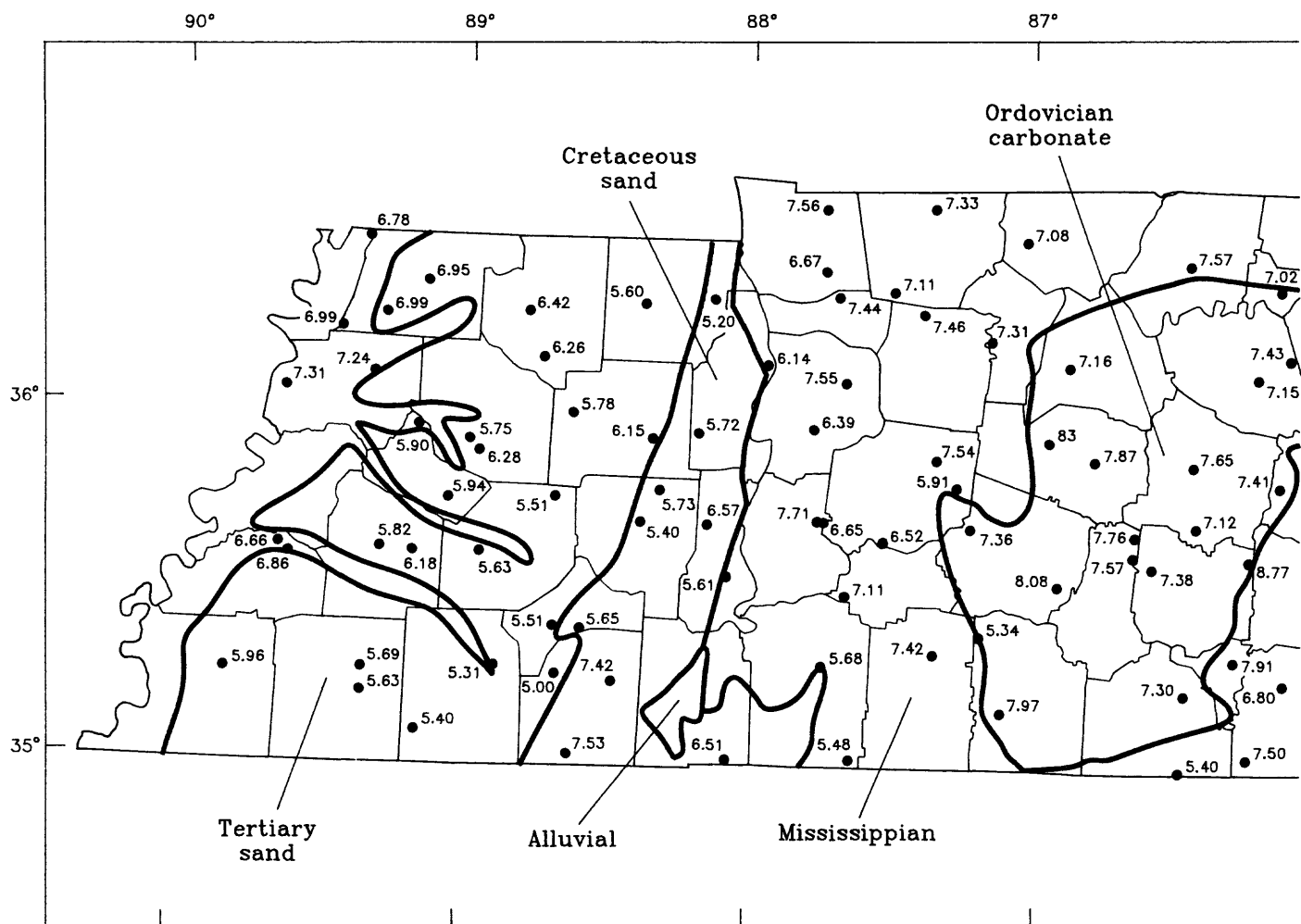Water-quality data for fecal coliform and fecal streptococci bacteria, nitrate (as nitrogen), organic

Figure 8b. Statewide distribution of pH for 150 sampled wells.

Mississippian
carbonate

Pennsylvanian
sandstone

7.15

7.58

7.51
7.30
7.38
7.82
7.56
7.21
7.85
7.82
7.48
7.60
7.03
7.15
7.60
4.29
7.53
7.10
7.73
8.95
8.21
7.41
7.14
7.59
7.52
7.22
8.27
7.76
6.26
7.52
7.49
7.22
8.15
7.79
7.74
7.31
7.53
7.79
7.79
6.41
7.73
7.21
7.22
7.15
7.50
7.85
7.93
7.68
8.42
7.36
7.79
7.13
8.01
7.15
7.74
6.67
7.92
5.30
6.48
7.52
6.57
7.38
7.82
7.69
7.45
7.21
7.78
7.91 7.21
7.77

0   10   20   30   40   50 MILES

0 10 20 30 40 50 KILOMETERS

EXPLANATION

7.79● WELL LOCATION AND pH IN
STANDARD UNITS

Cambrian—Ordovician

Hydrology modified from Bradley and Hollyday, 1985
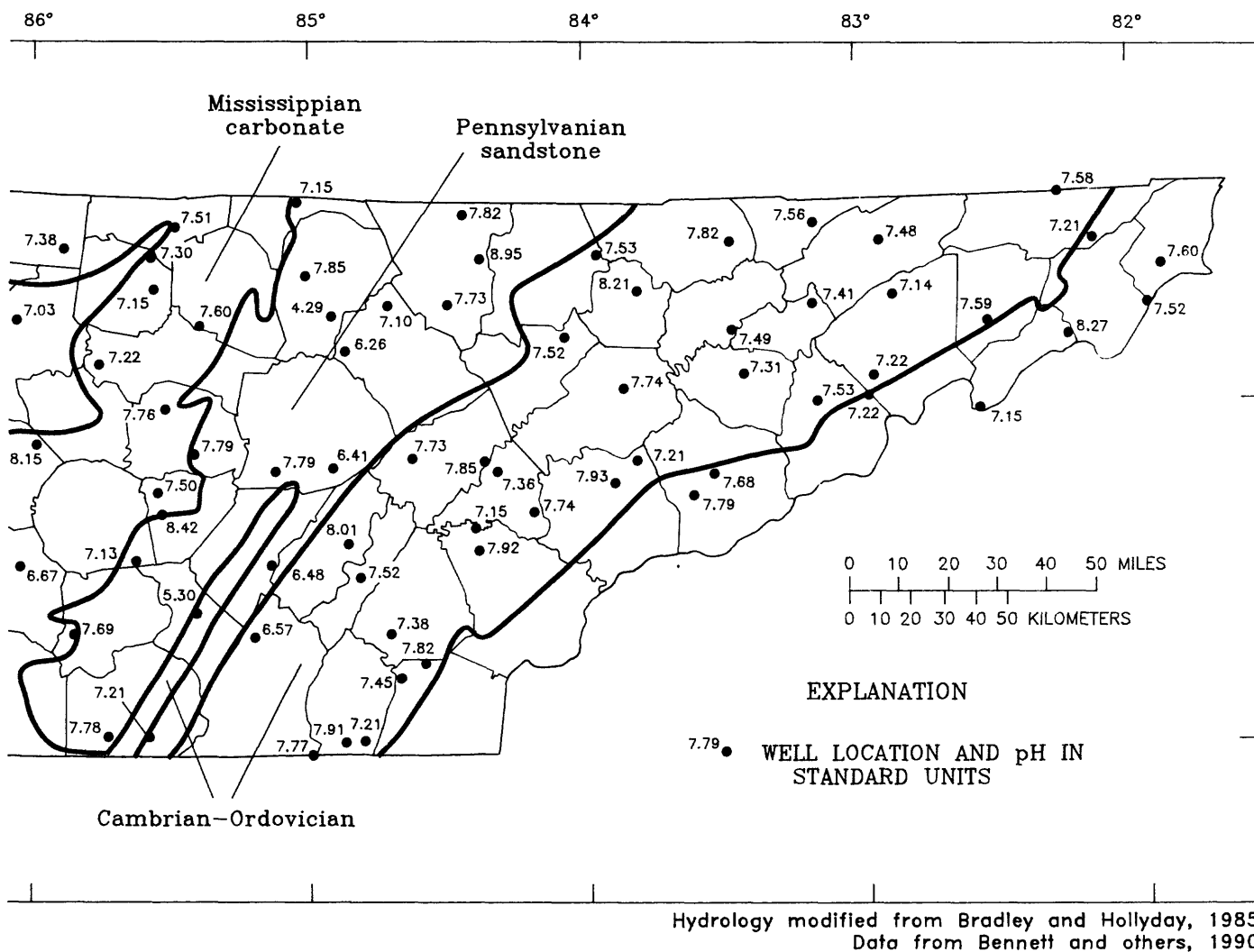Data from Bennett and others, 1990

Figure 8b. Statewide distribution of pH for 150 sampled wells--Continued.

compounds, iron, manganese, and hydrogen-ion concentration (pH) were selected from a list of other reconnaissance analytes for evaluation and discussion. These seven bacteria and chemical constituents were selected on the basis of important aesthetic or health-related implications regarding drinking-water quality. The water-quality data were grouped according to eight of the nine principal aquifers in Tennessee and were analyzed for local and regional variation within and among these aquifers.

Positive tests for fecal coliform bacteria (indicating exceedence of the Primary Maximum Contaminant Level adopted by the State of Tennessee for total coliform bacteria) occurred in 39 percent of the wells sampled. Thirty-three percent of the wells sampled tested positive for fecal streptococci bacteria. Both types of bacteria were detected in samples from 28 percent of the wells, and samples from 45 percent of the wells tested positive for either or both bacteria. On a regional level, 20 percent of the samples from wells in western Tennessee tested positive for either or both bacteria compared to 54 percent of the samples from wells in the central and eastern parts of the State. From interpretation of the ratios of fecal coliform to streptococci densities in about 15 percent of the samples, 64 percent of these wells indicate possible bacterial contamination from animal sources, whereas 27 percent indicate possible contamination from human sources.

Bacteria data indicate that wells withdrawing water from the primarily unconsolidated aquifers in the western part of the State and the Pennsylvanian sandstone aquifer in the east-central part of the State are less likely to test positive for fecal coliform or fecal streptococci bacteria than the consolidated bedrock aquifers in central and eastern Tennessee. However, the data also indicate that in all rural areas of the State, contamination of wells by fecal bacteria probably results from local conditions or factors, including well construction and age, hydrogeology, and land use in the immediate vicinity of the well head.

Concentrations of total nitrate (as nitrogen) equal to or exceeding the 10.0 mg/L Primary Maximum Contaminant Level were measured in samples from 3 percent (5 of 149 wells) of the wells statewide. Concentrations of total nitrate (as nitrogen) were below 3.00 mg/L, a threshold value above which ground-water quality might be influenced by human activities, in water from about 80 percent of the wells statewide. Although median concentrations of nitrate for water from the principal aquifers ranged from 0.30 to 1.75 mg/L, medians for five of the aquifers were within the relatively narrow range of 0.65 to 1.20 mg/L.

Relatively large variability of total nitrate concentrations in samples from each of the principal aquifers indicates that numerous local factors affect nitrate concentrations. Instances where concentrations of nitrate in ground water exceeded the Primary Maximum Contaminant Level were isolated and appear to be related to factors such as well depth and proximity to sources of nitrogen.

Total concentrations of organic compounds in samples collected from the wells were estimated by gas chromatography coupled with flame-ionization detection and were below 5 μg/L in 92 percent of the wells. Samples from the Pennsylvanian sandstone aquifer had a higher median concentration than samples from the other aquifers, indicating that coal and other carbonaceous material might affect the concentrations of organic compounds in ground water from this aquifer.

Concentrations of total-recoverable iron were equal to or exceeded the 300 μg/L Secondary Maximum Contaminant Level in 35 percent (52 of 150 wells) of the wells sampled. Concentrations greater than about 10,000 μg/L in samples from a few wells in the alluvial, Pennsylvanian sandstone, and Cambrian-Ordovician carbonate aquifers might represent additional dissolved iron resulting from the solution of material suspended in the samples. Based on median concentrations, wells in the Tertiary and Cretaceous sand, and the Mississippian carbonate aquifers, generally had smaller

concentrations of iron (medians of 150 μg/L or less) than the alluvial, Pennsylvanian sandstone, Cambrian-Ordovician carbonate, and crystalline aquifers (medians of 260 μg/L or greater). Although iron concentrations in ground water exceeding the Secondary Maximum Contaminant Level appear localized, the data indicate that water from the alluvial and Pennsylvanian sandstone aquifers has greater potential to cause iron-related problems than water from the other principal aquifers.

Concentrations of total-recoverable manganese were equal to or exceeded the 50 μg/L Secondary Maximum Contaminant Level in 25 percent (37 of 150 wells) of the wells sampled. Concentrations greater than about 1,000 μg/L in samples from a few wells in the alluvial, Pennsylvanian sandstone, and Cambrian-Ordovician carbonate aquifers might represent additional dissolved manganese resulting from the solution of material suspended in the samples. In general, samples having a large concentration of manganese also had a large concentration of iron. Based on median concentrations, ground water from the Tertiary and Cretaceous sand; Mississippian, Ordovician, and Cambrian-Ordovician carbonate; and the crystalline rock aquifers generally had smaller concentrations of manganese (medians of 30 μg/L or less) than ground water from the alluvial and Pennsylvanian sandstone aquifers (medians of 110 μg/L or greater). Although manganese concentrations in ground water exceeding the Secondary Maximum Contaminant Level appear localized, greater potential for manganese-related problems, as is true for iron, occurs in areas where water is derived from the alluvial and Pennsylvanian sandstone aquifers.

Field values of pH for the sampled wells ranged from 4.29 to 8.95 units, with both the minimum and maximum values occurring in samples collected from the Pennsylvanian sandstone aquifer. Based on median pH values, the alluvial, Tertiary and Cretaceous sand, and the Pennsylvanian sandstone aquifers produced water with lower pH values (medians of 6.88 or less) than the other four aquifers (medians of 7.36 or

greater). Samples from the aquifers rich in carbonate minerals also generally exhibited less variability in pH and were more alkaline than those from the aquifers rich in silicate minerals. Samples from 28 percent (38 of 150 wells) of the wells had a pH < 6.50. From the data, relatively low pH ground water (pH < 6.50) occurs most frequently in the alluvial and the Tertiary and Cretaceous sand aquifers, and to a lesser extent, locally in the Mississippian carbonate and Pennsylvanian sandstone aquifers. Low pH ground water provides potential for the leaching of lead and other metals from household plumbing systems. Data collected during this reconnaissance indicate that, statewide, little potential exists for problems associated with ground water having a pH greater than the upper Secondary Maximum Contaminant Level limit because samples from only two wells had a pH greater than 8.50.

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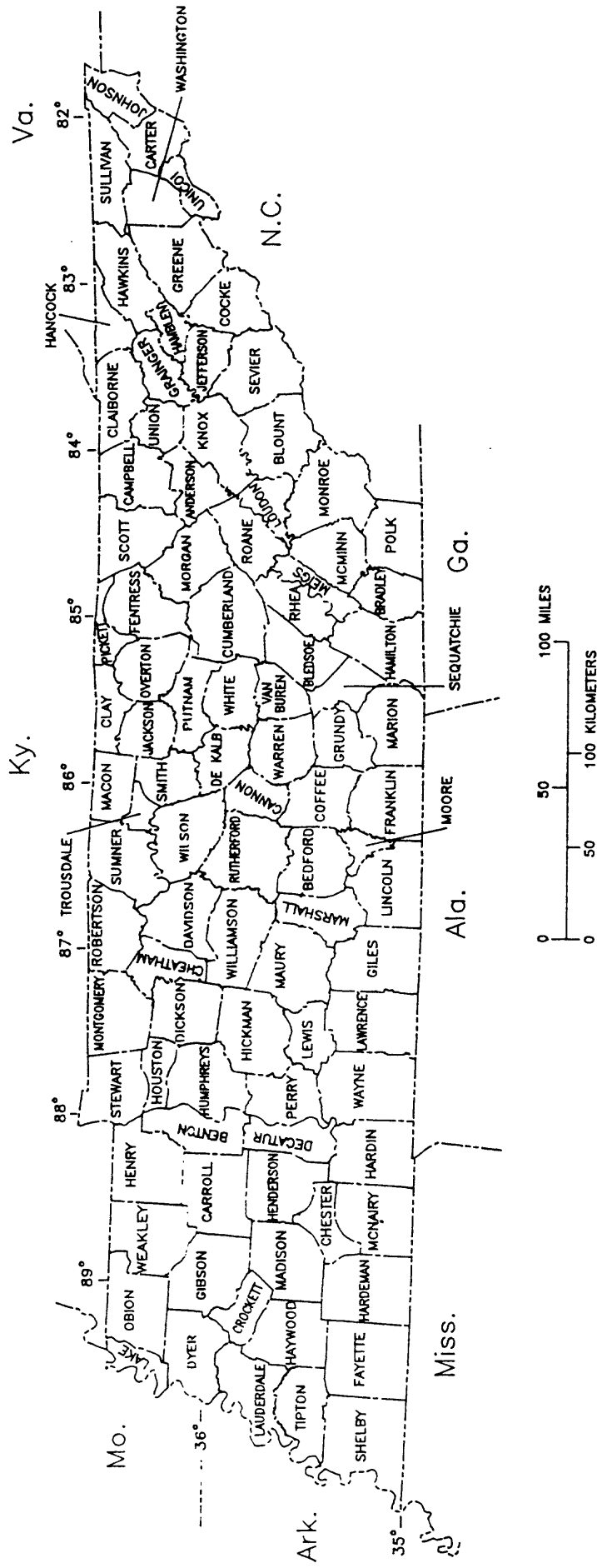
Location of Tennessee Counties