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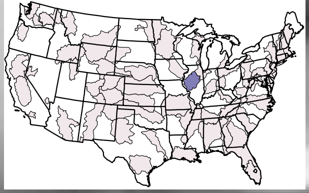
Water-Resources Investigations Report 99–4152

Contribution from the National Water-Quality Assessment Program



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

Analysis of Nutrients, Selected Inorganic Constituents, and Trace Elements in Water from Illinois Community-Supply Wells, 1984–91

By Kelly L. Warner

Water-Resources Investigations Report 99–4152

Urbana, Illinois
2000

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

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FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for specific contamination problems; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional- and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the U.S. Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 59 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 59 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch

Robert M. Hirsch
Chief Hydrologist

CONTENTS

CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
Length		
foot (ft)	0.3048	meter
Area		
square mile (mi^2)	2.590	square kilometer
Flow rate		
million gallons per day (Mgal/d)	0.04381	cubic meter per second

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

°C = (°F - 32) / 1.8

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

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Abbreviations used in this report:

IEPA	Illinois Environmental Protection Agency
LIRB	lower Illinois River Basin
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MRL	method reporting limit
NAWQA	National Water-Quality Assessment
SMCL	Secondary Maximum Contaminant Level
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey

Analysis of Nutrients, Selected Inorganic Constituents, and Trace Elements in Water from Illinois Community-Supply Wells, 1984–91

By Kelly L. Warner

Abstract

The lower Illinois River Basin (LIRB) study unit is part of the National Water-Quality Assessment program that includes studies of most major aquifer systems in the United States. Retrospective water-quality data from community-supply wells in the LIRB and in the rest of Illinois are grouped by aquifer and depth interval. Concentrations of selected chemical constituents in water samples from community-supply wells within the LIRB vary with aquifer and depth of well. Ranked data for 16 selected trace elements and nutrients are compared by aquifer, depth interval, and between the LIRB and the rest of Illinois using nonparametric statistical analyses. For all wells, median concentrations of nitrate and nitrite (as Nitrogen) are highest in water samples from the Quaternary aquifer at well depths less than 100 ft; ammonia concentrations (as Nitrogen), however, are highest in samples from well depths greater than 200 ft. Chloride and sulfate concentrations are higher in samples from the older bedrock aquifers. Arsenic, lead, sulfate, and zinc concentrations are appreciably different between samples from the LIRB and samples from the rest of Illinois for ground water from the Quaternary aquifer. Arsenic concentration is highest in the deep Quaternary aquifer. Chromium, cyanide, lead, and mercury are not frequently detected in water samples from community-supply wells in Illinois.

1. INTRODUCTION AND ACKNOWLEDGMENT

THE LOWER ILLINOIS RIVER BASIN STUDY UNIT IS PART OF THE NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

The National Water-Quality Assessment program includes studies of most major aquifer systems in the United States.

In 1991, the U.S. Geological Survey (USGS) began the full-scale National Water-Quality Assessment (NAWQA) program. The long-term goals of the NAWQA program are to describe the status of and trends in the quality of a large, representative part of the Nation's surface- and ground-water resources and to identify the major natural and human factors that affect the quality of these resources. In addressing these goals, the program will produce a wealth of water-quality information that will be useful to policy makers and water managers at the National, State, and local levels.

The NAWQA program emphasis is on regional-scale water-quality issues. The program will not diminish the need for smaller-scale studies and monitoring currently designed and implemented by Federal, State, and local agencies to meet specific needs. The NAWQA program, however, will provide a large-scale framework for understanding the regional and national water-quality conditions that cannot be acquired from small-scale programs and studies.

Study-unit investigations of more than 50 hydrologic systems that include parts of most major river basins and aquifer systems throughout the Nation are the building blocks of the national assessment. The study units range in size from 1,000 to more than 60,000 mi^2 and represent 60–70 percent of the Nation's water use and population served by public water supplies. Twenty study-unit investigations were started in 1991, 16 additional investigations were started in 1994, and 15 more began in 1997. The lower Illinois River Basin (LIRB) was selected by the USGS as 1 of 16 study units to begin investigation in 1994.

The LIRB study unit includes 18,000 mi^2 of central and western Illinois (fig. 1–1.). The LIRB extends from the downstream end of the 11,000 mi^2 upper Illinois River Basin at Ottawa, Ill., to the confluence of the Illinois and Mississippi Rivers at Grafton, Ill. Major rivers in the LIRB include 240 river miles of the main stem of the Illinois River and the Vermilion (1,330 mi^2 drainage area), Mackinaw (1,140 mi^2 drainage area), Spoon (1,860 mi^2 drainage area), Sangamon (5,420 mi^2 drainage area), and La Moine (1,350 mi^2 drainage area) Rivers.

The major aquifers in the LIRB are composed of rocks of Quaternary and Pennsylvanian-Mississippian age. Many of the major aquifers are sand and gravel, or till of Quaternary age (Quaternary aquifer) in buried bedrock valleys. Streams in central Illinois commonly are underlain by buried bedrock valleys, such as the lower Illinois buried bedrock valley (fig. 1–3.). The Quaternary aquifers supply about 90 percent of the ground water used for community supply.

The LIRB is mostly in the Till Plains Section of the Central Lowland physiographic province (Warner, 1998). The four subsections of the Till Plains are the Bloomington Ridged Plains, Galesburg, Springfield, and Kankakee (fig. 1–2.). The Galesburg and Springfield Plains are hydrogeologically similar. Both plains are covered by Illinoian glacial deposits. Buried bedrock valleys are confined to the Illinois River valley and some small tributaries. Most wells in these plains are less than 150 ft deep, and the tills do not yield large amounts of water. The Bloomington Ridged Plain is covered by Wisconsinan glacial deposits. Glacial deposits in the Bloomington Ridged Plain are up to 500 ft thick in some areas. Three major buried bedrock valleys are filled with thick Wisconsinan and Illinoian deposits (fig. 1–3.). Wells in the areas of buried bedrock valleys average 200 to 300 ft in depth. The sequence of tills and sand lenses in the Bloomington Ridged Plain is thicker than in the other plains.

The author acknowledges the statistical support of David Frothingham and Cathy Nguyen and spatial data support of David Fazio, U. S. Geological Survey. The Illinois Environmental Protection Agency is acknowledged, specifically David McMillan, for help in collecting and reviewing the data.

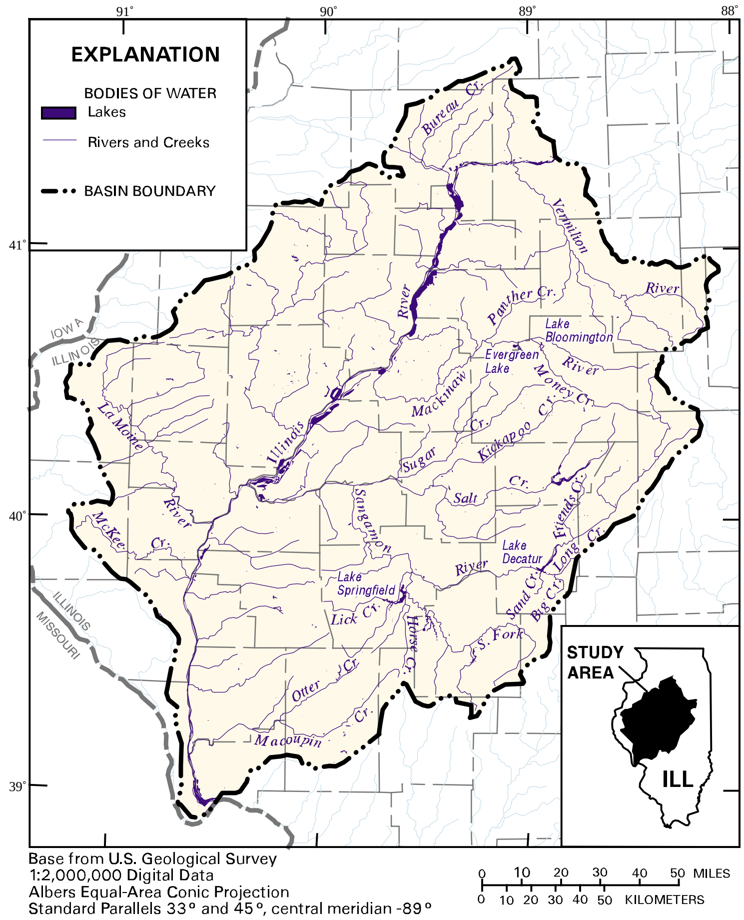

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Figure 1–1. Location of the lower Illinois River Basin.

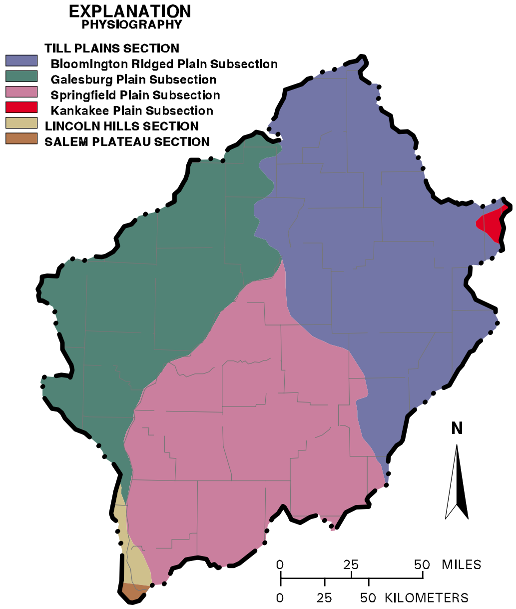

Figure 1–2. Physiography in the lower Illinois River Basin (modified from Willman and others, 1975).

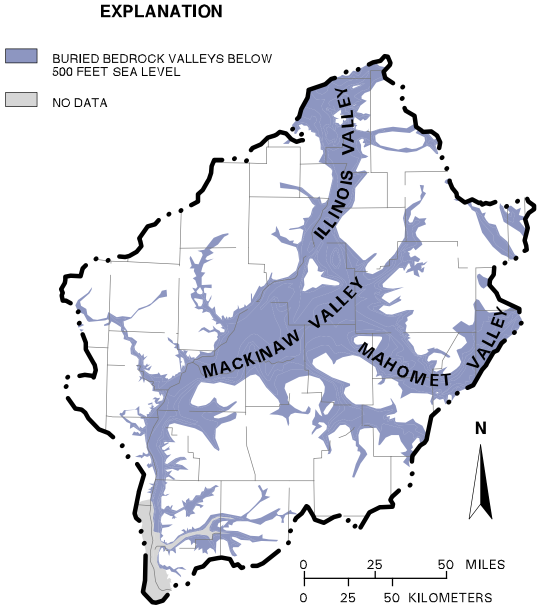

Figure 1–3. Major bedrock valleys in the lower Illinois River Basin (modified from Herzog and others, 1994).

2. WELL SELECTION AND CHARACTERISTICS

COMMUNITY-SUPPLY WELLS DEFINED BY SIX AQUIFER GROUPS AND SEVEN DEPTH INTERVALS

Water quality of community-supply wells within the lower Illinois River Basin is compared with water quality of community supplies for the rest of Illinois.

From 1984 to 1991, the USGS, in cooperation with the Illinois Environmental Protection Agency (IEPA), collected untreated ground water from community-supply wells in Illinois. The IEPA laboratories analyzed all samples in accordance with U.S. Environmental Protection Agency (USEPA) standards for the Clean Water Act data collection (U.S. Environmental Protection Agency, 1986). The analysis of these data is the framework for the design of a basinwide water-quality monitoring network of the UIRB. The distribution of 16 inorganic constituents in ground water from community-supply wells were evaluated statistically. Results of the analysis of the first water sample collected at each well by the IEPA or USGS are stored in the USGS National Water Information System (NWIS) and used in this study. Inorganic constituents discussed in this report are ammonia, nitrate and nitrite, chloride, sulfate, arsenic, boron, chromium, copper, cyanide, iron, lead, manganese, mercury, selenium, silver, and zinc. All analyses were performed on whole water samples and analytical results are expressed as total concentrations. Some constituents have more than one method reporting limit (MRL). Wells are widely distributed in counties within the LIRB.

In 1984, the IEPA and USGS began sampling untreated and unfiltered water from community-supply wells. As part of a pilot network to assess ground-water quality in community-supply wells, the USGS sampled 100 wells quarterly from 1984–85. (Voelker, 1986). Approximately 2,000 additional wells were sampled by IEPA from 1985 to 1987 (Voelker, Oberg, and Grober, 1988) in order of priority assigned by the Illinois State Water Survey (ISWS) (O’Hearn and Schock, 1984). The priority was based on potential yield of the aquifer and susceptibility of the aquifer to contamination. An additional 516 wells were sampled from 1988 to 1991.

Water-quality data from 2,616 community-supply wells sampled by IEPA and USGS prior to 1991 are stored in the USGS water-quality data base. Approximately 2,400 well logs had information on depth of well and aquifer. A subset of more than 600 of these wells are in the LIRB (fig. 2–1.) and 1,800 are outside the LIRB. The first sample from each well analyzed for at least 5 inorganic constituents was selected to represent the inorganic water quality of the aquifer at the well site. This representative sample was selected to minimize the bias associated with statistics for wells with multiple analyses. For the 16 constituents, the water quality within the LIRB is compared with the water quality of the rest of Illinois. Concentrations of inorganic constituents are summarized by aquifer and by seven arbitrarily defined intervals of depth.

Quality assurance included the IEPA Laboratory participation in the USGS’s analytical evaluation program. During the period 1984–91, there were changes in most of the laboratory methods that resulted in multiple MRL’s (table 2–1.). The IEPA Laboratory analyzed standard reference samples for trace constituents, major constituents, nutrients, and mercury. All analyses since 1988 had standard deviations from 0 to 1.01 from a known concentration, which indicates satisfactory quality assurance for the laboratory. Quality assurance on the data-collection process changed during the period from 1984 to 1991. Prior to 1990, quality-assurance samples were collected at least once during a field trip but, after review of the analytical data, were not retained for future redundant analysis. The quality-assurance procedures used since 1990 include the analyses of blind samples and trip blanks with no incidence of contamination. These quality-assurance data are being retained for future reference.

The wells are divided into six general aquifer groups on the basis of the age of the rocks in which wells are completed: undefined, Quaternary, Mississippian-Pennsylvanian, Silurian-Devonian, Cambrian-Ordovician, and multiple aquifers (table 2–2.). Wells that are screened in more than one aquifer are included in the “multiple” group. Wells that have no geologic log are included in the “undefined” group. A similar age and material classification of aquifers was used by the ISWS for a ground-water quality summary of Illinois (Gibb and O’Hearn, 1980). The age-related aquifer classification also has been used by the ISWS for water-use reports (Kirk, 1987) and the USGS (Avery, 1995).

In the tables of this report, the division of well samples into the Quaternary and “other” aquifers is included to indicate the differences between glacial drift (Quaternary) and bedrock aquifers. The Quaternary, in the tables, is identical to the Quaternary aquifer group previously defined. The previously defined Mississippian-Pennsylvanian, Silurian-Devonian, Cambrian-Ordovician, and multiple aquifer groups are combined and referred to as “other” aquifers—all wells that are known to tap bedrock aquifers.

Sample analyses are arbitrarily grouped into seven categories by well depth, representing 50-ft intervals to the depth of 300 ft (table 2–3.) and a group of wells deeper than 300 ft. The total depth of wells was reported in driller’s logs and in ISGS reports. Although screened intervals of some wells differ from total depths, for statistical purposes, well depths are used to divide the samples into intervals. Approximately 62 percent of wells are less than 300 ft deep. The distribution and correlation of inorganic concentrations in ground water for depths less than 300 ft were given more emphasis in the analysis because of the vulnerability of shallow aquifers to contamination and a network design that emphasizes the water quality of shallow wells (O’Hearn and Schock, 1984). In tables, the depth-related groups are combined into only three groups—depths less than 50 ft, depths equal to or greater than 50 ft, and wells with no reported depth information.

Table 2–1. The method reporting limits of selected water-quality constituents in the lower Illinois River Basin

[mg/L, milligrams per liter; µg/L, micrograms per liter; multiple reporting limits resulted from the use of different methods of analysis]

Water-quality constituent	Method reporting limit	Units of measure
Ammonia	0.10	mg/L
Arsenic	1.0	µg/L
Boron	50	µg/L
Chloride	1.0	mg/L
Chromium	5.0	µg/L
Copper	5.0	µg/L
Cyanide	.005	mg/L
	.010	mg/L
Iron	50	µg/L
Lead	5.0	µg/L
Manganese	5.0	µg/L
Mercury	.01	µg/L
	.005	µg/L
	.10	µg/L
Nitrate and nitrite	.10	mg/L
Selenium	1.0	µg/L
Silver	3.0	µg/L
Sulfate	10	mg/L
Zinc	50	µg/L
	100	µg/L

Table 2–2. Aquifer groups discussed in this report

Aquifer
Undefined
Quaternary
Mississippian-Pennsylvanian
Silurian-Devonian
Cambrian-Ordovician
Multiple

Table 2–3. Depth intervals below land surface for ground-water data

[ft, foot]

Depth interval (ft)
Less than 50
50–99
100–149
150–199
200–249
250–300
Greater than 300

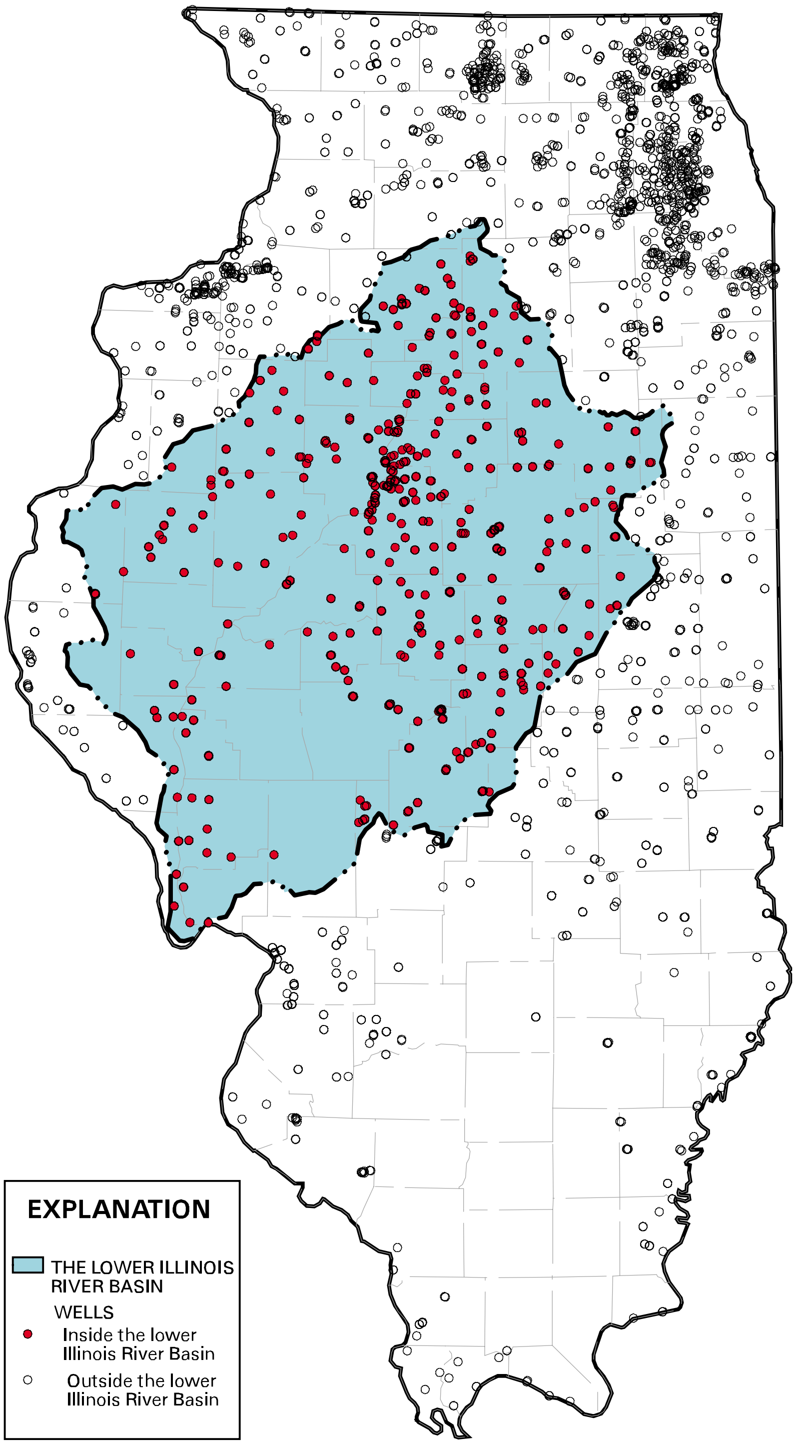

Figure 2–1. Wells sampled from 1984 to 1991.

3. WATER USE

GROUND WATER IS USED FOR DRINKING WATER AND IRRIGATION

More than one-half of the drinking water in the lower Illinois River Basin is from ground water with the largest amounts withdrawn in La Salle, Mason, Peoria, and Tazewell Counties.

The largest freshwater withdrawals in Illinois, excluding the Chicago area, are in the LIRB. In 1988, the total freshwater use for the LIRB, including surface and ground water, was 4,100 Mgal/d (Avery, 1995). Surface water is used mostly for thermoelectric power. Ground water is used mostly for community supply and irrigation (Avery, 1995). Other uses of ground water, in order of most to least use, include self-supplied industrial, self-supplied domestic, self-supplied livestock, and self-supplied commercial and mining. Avery (1995) defined these use categories and computed the water-use rates for each.

The highest ground-water use is in La Salle, Mason, Peoria, and Tazewell Counties (fig. 3–1.). Mason and Tazewell Counties have high ground-water use because of irrigation. The largest withdrawals in the State for irrigation are in Mason (100 Mgal/d) and Tazewell (29 Mgal/d) Counties. These counties irrigate crops of corn, soybean, and many specialty crops. Ground-water use in Peoria and La Salle Counties is mostly for community supply (60 percent) and commercial facilities (30 percent).

More than one-half of the drinking water in the LIRB is from ground water. In 1988, the total community-supply delivery was 190 Mgal/d, of which 108 Mgal/d or 57 percent was for domestic use. In addition to community supplies, 25 percent of the population in counties within the LIRB use self-supplied ground water. The Quaternary aquifer supplies 90 percent of the population served by community supply. In 1988, the community-supply withdrawals, by county, in the LIRB were greatest for Peoria (19 Mgal/d), Tazewell (14 Mgal/d) and La Salle (11 Mgal/d) Counties (Avery, 1995). More than 5 Mgal/d of ground water is used for community supply in McLean and Scott Counties. A large amount of ground-water use for community supply in Champaign County is outside of the LIRB.

The 1986 water use for Standard Metropolitan Statistical Areas (SMSA), which include the largest cities in the LIRB, is summarized in Kirk (1987). Peoria and Normal use ground water for primary water supply. Decatur, Bloomington, and Springfield mostly use surface-water sources. Lake Decatur supplies the city of Decatur on the Sangamon River; Big Creek, Long Creek, Friends Creek, and Sand Creek are tributaries. Ground water from sand and gravel aquifers is pumped into Friends Creek to maintain the water supply in Lake Decatur.

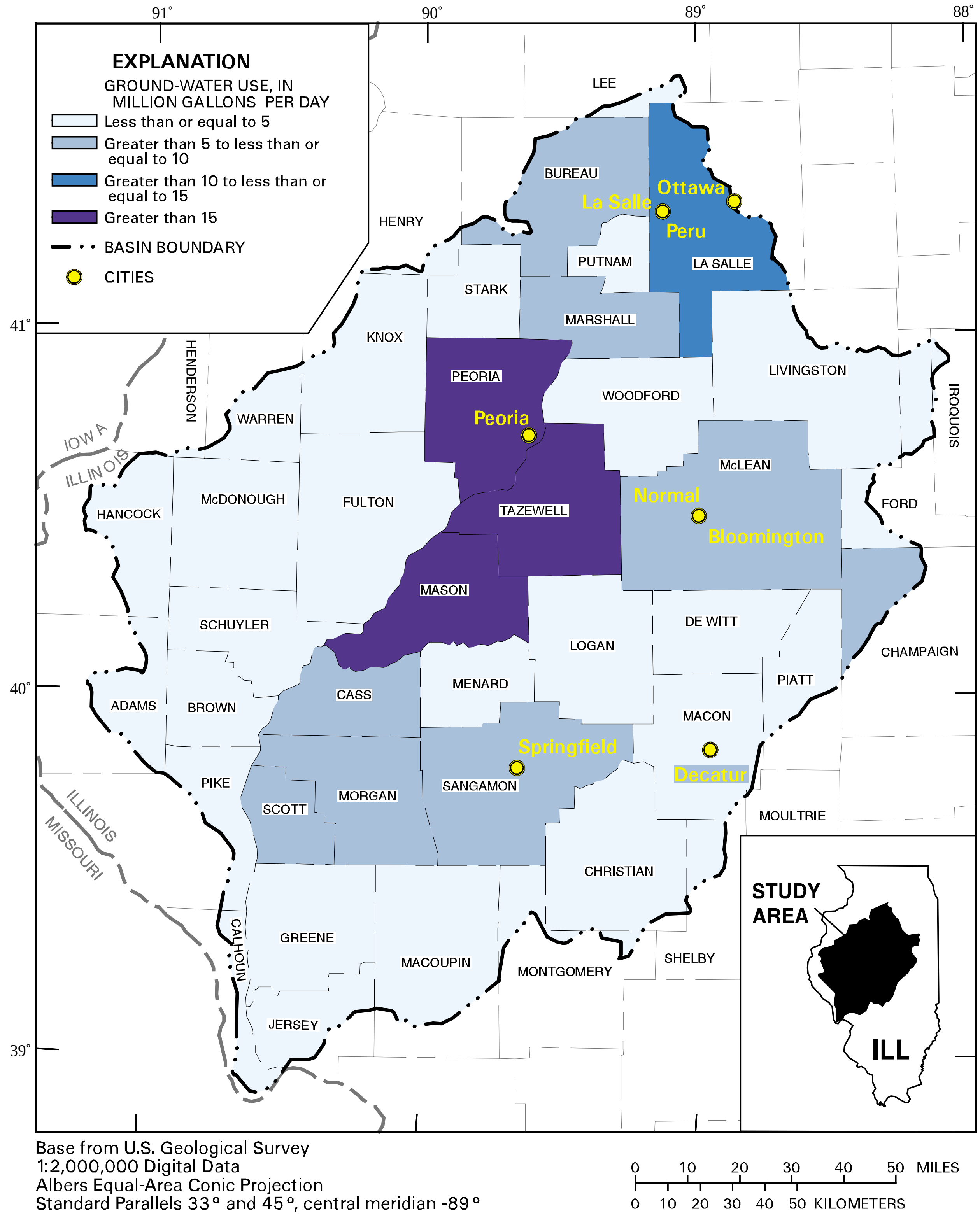

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Figure 3–1. Total ground-water use, by county, in the lower Illinois River Basin (weighted by percent area of each county within the lower Illinois River Basin).

4. STATISTICAL ANALYSES OF DATA

STATISTICAL APPROACH USED FOR DATA ANALYSIS

Statistical analysis of each constituent was done by nonparametric tests on ranked data and using exploratory analysis.

Censored data—those data below the MRL—comprise more than 50 percent of the observations for 10 of the16 constituents evaluated in this report. The lack of concentrations above the MRL makes it impossible to calculate a simple mean and standard deviation and determine the distribution of the data. Percentiles were used to characterize the distribution of the data. Parametric tests that use parameters such as the mean and standard deviation to summarize data and compute test statistics were avoided because a normal distribution of the data is assumed in these tests. Instead, values were ranked from lowest to highest for each constituent, and nonparametric tests were used on these rankings for the statistical analysis because nonparametric tests do not assume a normal distribution. When nearly 50 percent or more of the data are censored, even nonparametric tests cannot detect differences in central values (Helsel and Hirsch, 1992). If more than 80 percent of the values are below the detection limit, the statistics are not reliable, and method reporting limits are given.

The statistical analyses used in this study begin with the null hypothesis—that the data sets being compared are identical in the specified attribute, such as data distribution. A test statistic then is computed according to the equations of the particular test. Associated with each test statistic is a probability (p-value) of obtaining the computed test statistic or one even less likely by chance alone. If the p-value is less than the significance level chosen ($p \leq 0.05$), then the null hypothesis is rejected, leading to the conclusion that there is at least one difference among two or more of the data sets; this difference is statistically significant because the probability of it occurring by chance alone is small. It is possible for a test to incorrectly indicate a difference when there is actually no difference among the data sets being compared. The significance level represents the risk level or the acceptable probability of making this mistake and is usually set at 0.05 (Helsel and Hirsch, 1992, p. 106). Thus, a significance level of 0.05 indicates a 5 percent chance that the conclusion, no difference between samples, will be erroneous.

The Wilcoxon rank-sum test, also known as the Mann-Whitney test, was used to compare concentrations between two independent data sets, such as samples from the Quaternary aquifer and those from other aquifers. The purpose of applying this test is usually to determine whether the two groups come from the same population, same median and other percentiles, or alternatively whether they differ only in location, central value, or median (Helsel and Hirsch, 1992). This test is the nonparametric analog to the 2-sample *t*-test and is 95 percent as powerful as the *t*-test; however, when the assumptions of the t-test are violated, as in the case of dissimilar variances, the Wilcoxon rank-sum test is much more powerful than the *t*-test (Zar, 1984).

Comparisons of concentrations among three or more independent data sets requires the Kruskal-Wallis test, which is in essence an analysis of variance (ANOVA) procedure applied on the ranking of the data. The Kruskal-Wallis test is 95 percent as effective as the parametric single-factor ANOVA test or more effective for data with dissimilar variances or non-normal distributions (Zar, 1984). The Kruskal-Wallis test assumes the null hypothesis—that all samples have identical distributions, for example, normal or lognormal. If the null hypothesis is rejected, then at least one sample differs from the rest. In practice, the Kruskal-Wallis test usually is performed for a more specific purpose—to determine whether all groups have the same median or whether at least one median is different. This form requires that all other characteristics of the data distributions, such as spread or skewness, be identical, although not necessarily in the original units (Helsel and Hirsch, 1992).

Spearman's rank correlation procedure was used to identify monotonic (but not necessarily linear) correlations among constituents, providing a measure of the intensity of association between two variables. Spearman's correlation coefficient (r) is the linear correlation coefficient computed on the ranks of data instead of actual values. This coefficient ranges from –1 to +1; a negative coefficient indicates that the higher ranks of one variable are related to the lower ranks of the other variable. The closer the absolute value of r is to 1, the greater is the correlation between the two variables. A small r value, however, can still be significant, depending on the associated p-value. If this p-value is less than the significance level (p=0.05), then the null hypothesis of no correlation (or r=0) is rejected, and the correlation coefficient computed is considered statistically significant. Spearman's rank correlation is 91 percent as effective as the parametric form (Zar, 1984).

In ranking the data, values below the same MRL were given averaged, equivalent ranks; for example, five observations below the MRL would each have a rank of three (the average of ranks one to five), whereas the next observation lying above the MRL would be ranked sixth. For constituents with multiple MRL's, censored data with lower MRL's had lower ranks than those with higher MRL's. Other studies have ranked all censored data for a constituent equally, using the maximum MRL (Helsel and Hirsch, 1992).

In this study, percentiles (when falling between values) were interpolated and calculated by the following equation from Helsel and Hirsch (1992, p. 451):

$$P_j = X_{(n+1)} \bullet j ,$$

where

n is the number of observations of X_i, and
j is the fraction of data less than or equal to the percentile value P_j.

For example, the second observation in a data set of seven points would constitute the 25th percentile, the value not exceeded by 25 percent of the data, because (7+1)∗0.25=2.

SAS, a commercial statistical software package, was used for statistical computations in this study. Because censored values

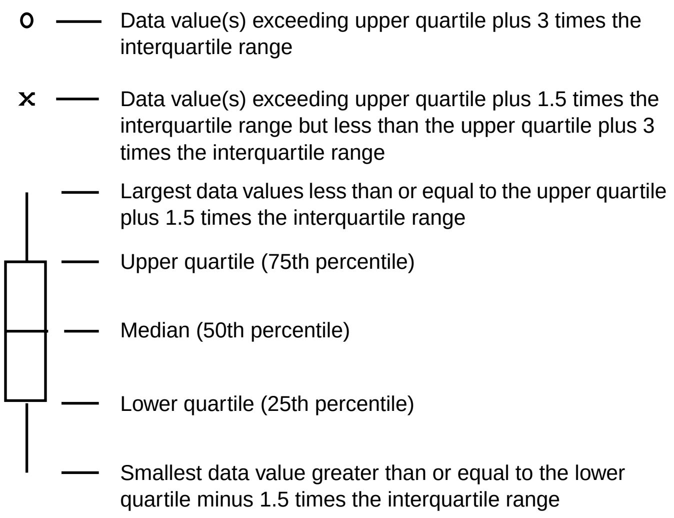

Figure 4–1. General boxplot and definitions of features.

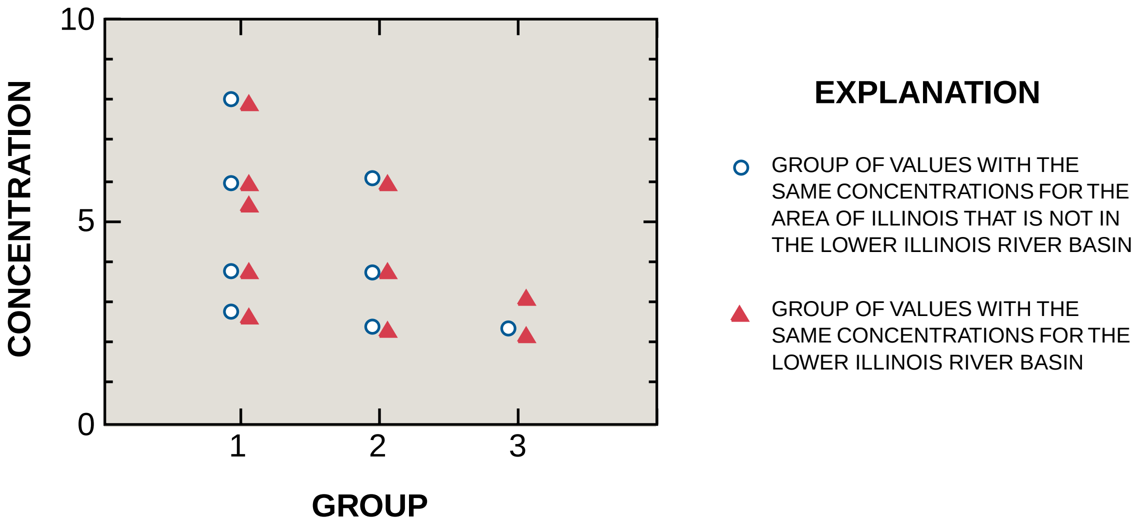

Figure 4–2. General dot chart for ground-water-quality data.

STATISTICAL APPROACH USED FOR DATA ANALYSIS

Statistical analysis of each constituent was done by nonparametric tests on ranked data and using exploratory analysis.

make up at least 15 percent of the data for 15 of the 16 constituents examined, the program mdl3.exe (written by Dennis Helsel of the USGS) was used to estimate the mean and standard deviation from log-probability regression. The 25th, 50th, and 75th percentiles were estimated from the lognormal maximum likelihood estimate (MLE) technique (Helsel and Hirsch, 1992). In this report, the MLE generated percentiles are given in statistics tables for each constituent. Probability plot procedures are used in this technique to fit a lognormal distribution to the values above the MRL. Values below the MRL are then extrapolated to estimate the summary statistics. If extrapolated values were more than one order of magnitude below the MRL, then a value of less than the MRL was substituted in the percentiles. If more than 80 percent of the analyses were below the detection limit, then the MLE technique is not reliable and the MRL is given for the percentiles. For example, 55 percent of the arsenic values for samples from the Quaternary aquifer were above the MRL, so the MLE technique was used to determine percentiles. Only 13 percent of the arsenic values for samples from other aquifers were above the MRL; therefore, the MRL was substituted for the percentiles.

Simple substitution methods, such as substituting the MRL or one-half its value for measurements below the MRL, were not used in estimating the mean because studies have shown that such methods performed poorly in comparison with other methods. The results of substitution methods also are biased—either low or high depending on the substitution values, which are arbitrary (Helsel and Hirsch, 1992).

Boxplots and dot charts are graphical presentations of the data. The boxplots represent the rank-sum test results and show the 25th, 50th, and 75th percentiles as calulated using robust log-probability regression (fig. 4–1.). Boxplot percentiles (log-probability regression) may be slightly different than percentiles (MLE) given in the statistics tables in this report because of differences in methods of interpolation. Side-by-side boxplots are convenient for determining differences in medians and similarity in spreads. Modified dot charts are high precision bar charts that show position along an aligned (common datum) scale (Helsel and Hirsch, 1992). Each dot symbol represents a group of data at that value. Therefore, one dot symbol may represent multiple analytical values. Because of the number of censored values, only noncensored data are displayed on the dot charts.The dot charts were paired to conveniently compare LIRB results with the rest of Illinois results (fig. 4–2.).

High concentrations of constituents were plotted on maps of the LIRB. High concentrations are defined as either exceeding the USEPA Maximum Contaminant Level (MCL), Maximum Contaminant Level Goal (MCLG), or Secondary Maximum Contaminant Level (SMCL); or IEPA Class I or Class II groundwater standards (table 4–1.).

Table 4–1. Selected Federal and Illinois ground-water-quality standards and maximum contaminant levels

[USEPA, U.S. Environmental Protection Agency; IEPA, Illinois Environmental Protection Agency; mg/L, milligrams per liter; –, no standard; p, proposed standard; t, regulated at the tap]

Water-quality constituent	USEPA maximum contaminant level (mg/L)	USEPA maximum contaminant level goal (mg/L)	USEPA secondary maximum contaminant level (mg/L)	IEPA class I ground-water standard (mg/L)	IEPA class II ground-water standard (mg/L)
Ammonia	–	–	–	–	–
Nitrate and nitrite	10	10	–	–	–
Chloride	–	–	250	–	–
Sulfate	500p	500p	250	400	400
Arsenic	.05	–	–	.05	.2
Boron	–	–	–	2	2
Chromium	.1	.1	–	.1	1
Copper	–	1.3t	1	.65	.65
Cyanide	.2	.2	–	.2	.6
Iron	–	–	.3	5	5
Lead	.015t	1.3t	–	.0075	.1
Manganese	–	–	.05	.15	10
Mercury	.002	.002	–	.002	.01
Selenium	.05	.05	–	.05	.05
Silver	–	–	.1	–	–
Zinc	–	–	5	5	10

5. AMMONIA

AMMONIA CONCENTRATIONS INCREASE WITH DEPTH AND AQUIFER

Ammonia concentrations differ by aquifer and depth within the lower Illinois River Basin. There is significant difference in the concentrations of ammonia in the Quaternary aquifer between the lower Illinois River Basin and the rest of Illinois.

Ammonia is a nonpersistent, noncumulative toxic substance. Ammonia is toxic to aquatic organisms, however, because it reduces the oxygen-carrying capacity of the blood (McNeely, Neimanis, and Dwyer, 1979). Ammonia is not regulated by the Safe Drinking Water Act. In Illinois, the maximum total ammonia concentration allowable for general-use surface waters (those waters for which there is no specific designation) depends on water temperature and pH but at no time may exceed 15 mg/L (Illinois Environmental Protection Agency, 1990). Although there is no ground-water standard for ammonia, 15 mg/L is considered a high concentration for this report. Only 4 samples of 609 collected in the LIRB for this study had concentrations above 15 mg/L (fig. 5–1.). In the rest of Illinois, 9 samples of the 1,891 collected had ammonia concentrations over 15 mg/L.

In most natural waters, ammonia is present primarily in its ionized form (NH4+) with a very small percentage of neutral ammonia (NH3); the sum of both concentrations constitutes total ammonia. A high percentage of the nitrogen in fertilizers applied in Illinois occurs as (or converts to) NH4+, which sorbs strongly to mineral surfaces and organic matter rather than leaching (University of Illinois, 1994). Bacteria and fungi contribute ammonia to the soil by converting the nitrogen in organic matter to ammonia (ammonification). Other natural and anthropogenic sources of ammonia include the hydrolysis of urea, microbial reduction of nitrite or nitrate under anaerobic conditions and biological fixation of atmospheric nitrogen (N2), precipitation, sewage effluent, paper mills, metal refineries, and a variety of industrial and cleaning operations (Canadian Council of Resource and Environment Ministers, 1992). Ammonia may be lost from the soil by plant uptake, erosion, volatilization, or microbial conversion to nitrate (nitrification).

In the LIRB, the concentrations of ammonia in 73 percent of the analyses were above the MRL (0.10 mg/L), and the range of concentrations was from less than 0.10 to 20 mg/L (table 5–1.). There is a significant difference in ammonia concentration by aquifer and depth. Nonparametric statistical techniques indicated a significant difference among aquifer groups (fig. 5–2.). The other aquifers had higher median concentrations (1.1 mg/L) and concentrations at the 25th percentile (0.80 mg/L) than did the Quaternary aquifer (0.49 and 0.08 mg/L, respectively).

Ninety-seven percent of ammonia values for samples from the other aquifers were above the MRL (0.10 mg/L) compared with 69 percent of the ammonia values for the Quaternary aquifer. Maximum concentrations in ground water decrease with increasing aquifer age; the highest values and greatest variability are in the Quaternary aquifer. Other aquifers tend to lie deeper, where there are few or no plant roots to remove ammonia and where possibly low oxygen levels limit nitrification. There is a significant difference ($p \leq 0.05$) in ammonia concentrations by depth interval. The samples from wells deeper than 300 ft had more detections of ammonia, but the wells from 200 to 300 ft had the highest median concentrations (0.79 to 0.95 mg/L). The highest ammonia concentrations in the LIRB samples (based on the mean, and the 75th and 90th percentiles) were from the eastern part of the study area in proximity to the Mahomet buried bedrock valley (fig. 1–3.). Within the LIRB, ammonia is correlated with arsenic, boron, fluoride, iron, and nitrate and nitrite and has a correlation coefficient greater than 0.50 and a significance level of $p \leq 0.05$.

Comparison of ammonia concentrations in ground water in the LIRB with ammonia concentrations in ground water outside the LIRB shows some differences. Ammonia concentrations are higher in the other aquifers of the LIRB than in corresponding aquifers outside the LIRB, as suggested by higher values for the mean; median; and 25th, 75th, and 90th percentiles in the LIRB. Nonparametric techniques indicated a significant difference between the LIRB and the rest of Illinois for aquifers older than the Quaternary. Ammonia concentrations in water from the Quaternary aquifers are not statistically different between the LIRB and the rest of Illinois. Median concentrations and percentage of samples above the MRL, including all samples, are similar for the LIRB and the rest of Illinois. In the area outside of the LIRB, ammonia and boron is the only correlation greater than 0.50 and has a significance level of $p \leq 0.05$.

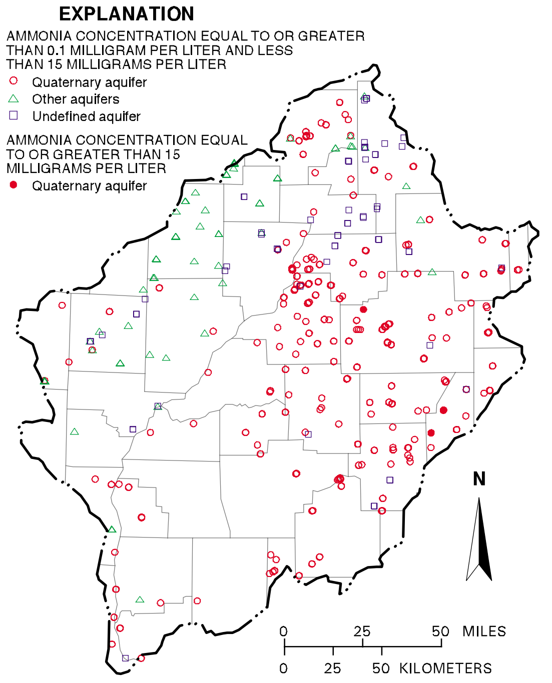

Figure 5–1. Ammonia concentrations in ground water above the reporting limit for Quaternary or other aquifers, and concentrations in undefined aquifers in the lower Illinois River Basin.

Table 5–1. Summary statistics for ammonia within and outside the lower Illinois River Basin

[N, number of observations; narl, number of observations above the method reporting limit; percentiles and maximums are in milligrams per liter; other aquifers include wells open to multiple aquifers and bedrock aquifers]

Aquifer or depth interval	N	narl	Pecentile			Maximum
			25	50 (median)	75	
Lower Illinois River Basin						
Overall	609	443	0.12	0.74	1.7	20
Quaternary aquifers	472	324	.08	.49	2.1	20
Other aquifers	62	60	.80	1.1	1.6	5.6
Undefined aquifers	75	59	.17	1.1	1.5	8.2
Depths less than 50 feet	73	32	.02	.08	.37	5.2
Depths 50 feet or greater	527	404	.12	.83	2.1	20
Unreported depths	9	7	.30	2.1	4.1	8.2
Rest of Illinois						
Overall	1,885	1,406	0.12	0.41	0.85	60
Quaternary aquifers	543	360	.07	.44	1.6	60
Other aquifers	910	746	.18	.43	.66	11
Undefined aquifers	432	300	.09	.32	.70	23
Depths less than 50 feet	79	35	.02	.08	.48	9.1
Depths 50 feet or greater	1,772	1,350	.11	.42	.88	60
Unreported depths	34	21	.06	.26	.73	3.0

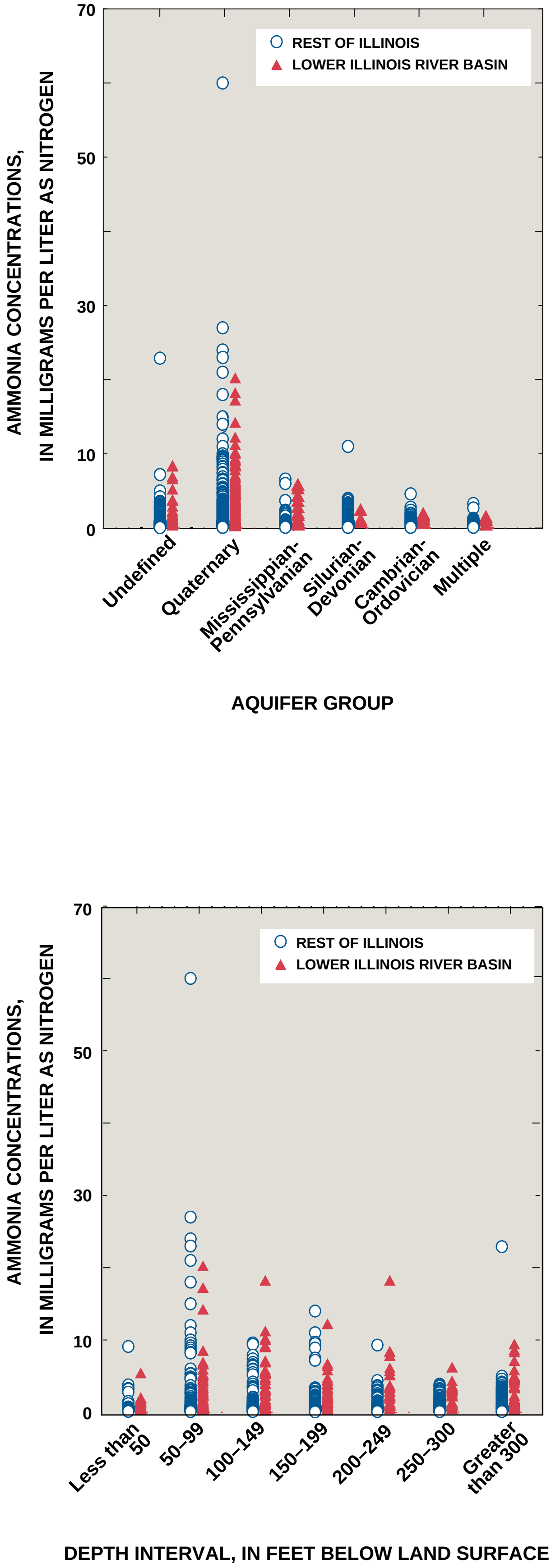

Figure 5–2. Distribution of ammonia concentrations in ground water by aquifer group and depth interval.

6. NITRATE AND NITRITE

NITRATE CONCENTRATIONS VARY BY AQUIFER AND DEPTH INTERVAL

There is a difference in nitrate concentration by aquifer and depth interval within the lower Illinois River Basin. There is no significant difference in nitrate concentrations in the Quaternary samples and other aquifer samples between the lower Illinois River Basin and the rest of Illinois.

High levels of nitrate (NO_3^-) or nitrite (NO_2^-) in drinking water can reduce the oxygen carrying capacity of blood and lead to anoxia or death, particularly in infants (Canadian Council of Resource and Environment Ministers, 1992). Most cases of methemoglobinemia, also known as blue baby syndrome, are associated with water containing more than 10 mg/L of nitrate as nitrogen (Canadian Council of Resource and Environment Ministers, 1992). The MCL's and MCLG's are both 10 mg/L for nitrate, 1 mg/L for nitrite, and 10 mg/L for nitrate and nitrite as nitrogen (U.S. Environmental Protection Agency, 1996). In this study, total nitrate and nitrite is referred to as nitrate because most of the total is nitrate. Although nitrite is considerably more toxic than nitrate, nitrite concentration in water usually is low because it is easily converted to nitrate in the presence of oxygen. The IEPA Class I standard for potable resource ground water is 10 mg/L, and the Class II standard for general resource ground water is 100 mg/L. Eleven of the 610 samples had nitrate and nitrite above 10 mg/L (fig. 6–1). In the LIRB, all 11 measurements exceeding the MCL for nitrate were in the Quaternary aquifer at depth intervals less than 150 ft.

As part of the nitrogen cycle, microorganisms convert ammonium to nitrite and then to nitrate, which is the form of nitrogen most easily absorbed by plants. Nitrate may be lost from the soil by microbial conversion to nitrogen gas (N2) in the absence of oxygen, or by leaching into ground water. Thus, high nitrate concentrations are possible in deep ground water. Natural and anthropogenic sources of nitrate include igneous rocks, volcanic emissions, organic matter, animal excrement, atmospheric deposition, chemical fertilizers, leakage from septic tanks, sewage effluent, and industrial discharges (McNeely, Neimanis and Dwyer, 1979).

In the LIRB, the concentrations of nitrate in 36 percent of the analyses were above the MRL (0.10 mg/L), and the range of concentrations were from .1 to 29 mg/L (table 6–1.). There is a significant difference in nitrate concentration between the Quaternary aquifer group and other aquifers, among aquifer groups, and among various depth intervals (fig. 6–2.). In the LIRB, the range of nitrate concentrations is smaller in the other aquifers than in the Quaternary aquifer. Over 90 percent of the concentrations are at the MRL (0.10 mg/L) in the other aquifers. The median concentration of nitrate was at the MRL for all aquifers, but the median concentration was greater than 0.10 mg/L for depth intervals less than 100 ft. The percentage of samples with concentrations above the MRL for depths less than 50 ft (61 percent) is almost twice that for depths greater than 50 ft (33 percent). The lack of nitrate in the depth interval greater than 300 ft indicates the presence of confining layers that impede nitrate from leaching deeper into the ground water or denitrification. There is no noticeable spatial trend of nitrate concentrations in ground water, but there are a number of nitrate detections near the Illinois River south of Peoria. Spearman's correlation coefficient is highest between nitrate and ammonia (0.65), and nitrate and iron (0.53) with a high probability of significance. There also is a high probability of significance that nitrate is correlated with arsenic, boron, selenium, and sulfate, but the correlation is low (from 0.30 to 0.40).

Statistical tests show that nitrate concentrations are not significantly different between the LIRB and the rest of Illinois for the Quaternary or other aquifers. For the rest of Illinois, the eight observations exceeding 10 mg/L of nitrate occur in the Quaternary aquifer and the other aquifers, at various depths. In the rest of Illinois, there is a significant difference by aquifer group and depth interval. The Quaternary has a higher percentage of values above the MRL than the other aquifers, although the median is 0.1 mg/L for both. In the rest of Illinois, nitrate correlates highest with ammonia (0.46) or fluoride (0.39).

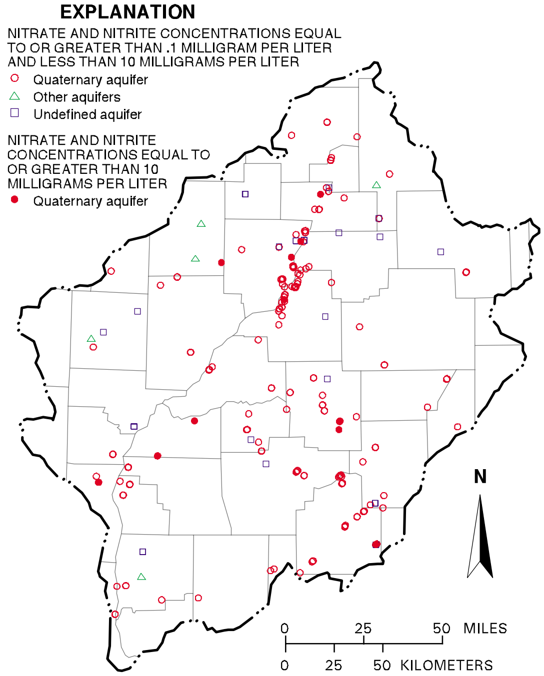

Figure 6–1. Nitrate and nitrite concentrations above the method reporting limit for Quaternary, other aquifers, and undefined aquifers in the lower Illinois River Basin.

Table 6–1. Summary statistics for nitrates and nitrites within and outside the lower Illinois River Basin

[N, number of observations; narl, number of observations above the method reporting limit; percentiles and maximums are in milligrams per liter; <, less than; gray cells are interpolated values; other aquifers include wells open to multiple aquifers and bedrock aquifers]

Aquifer or depth interval	N	narl	Percentile			Maxi-mum
			25	50 (median)	75	
Lower Illinois River Basin						
Overall	610	222	<0.01	0.03	0.39	29
Quaternary aquifers	473	191	.01	.05	1.3	29
Other aquifers	62	5	<.10	<.10	<.10	5.0
Undefined aquifers	75	26	<.01	.03	.84	8.0
Depths less than 50 feet	72	44	.04	.25	3.9	14
Depths 50 feet or greater	529	175	<.01	.02	.28	29
Unreported depths	9	3	<.01	.02	2.9	5.0
Rest of Illinois						
Overall	1,889	496	<0.01	0.01	0.12	20
Quaternary aquifers	543	199	<.01	.04	.78	18
Other aquifers	912	167	.10	.10	.10	14
Undefined aquifers	434	130	<.01	.02	.17	20
Depths less than 50 feet	79	44	.03	.20	3.0	9.4
Depths 50 feet or greater	1,776	436	<.01	.01	.1	20
Unreported depths	34	16	.01	.08	1.1	9.4

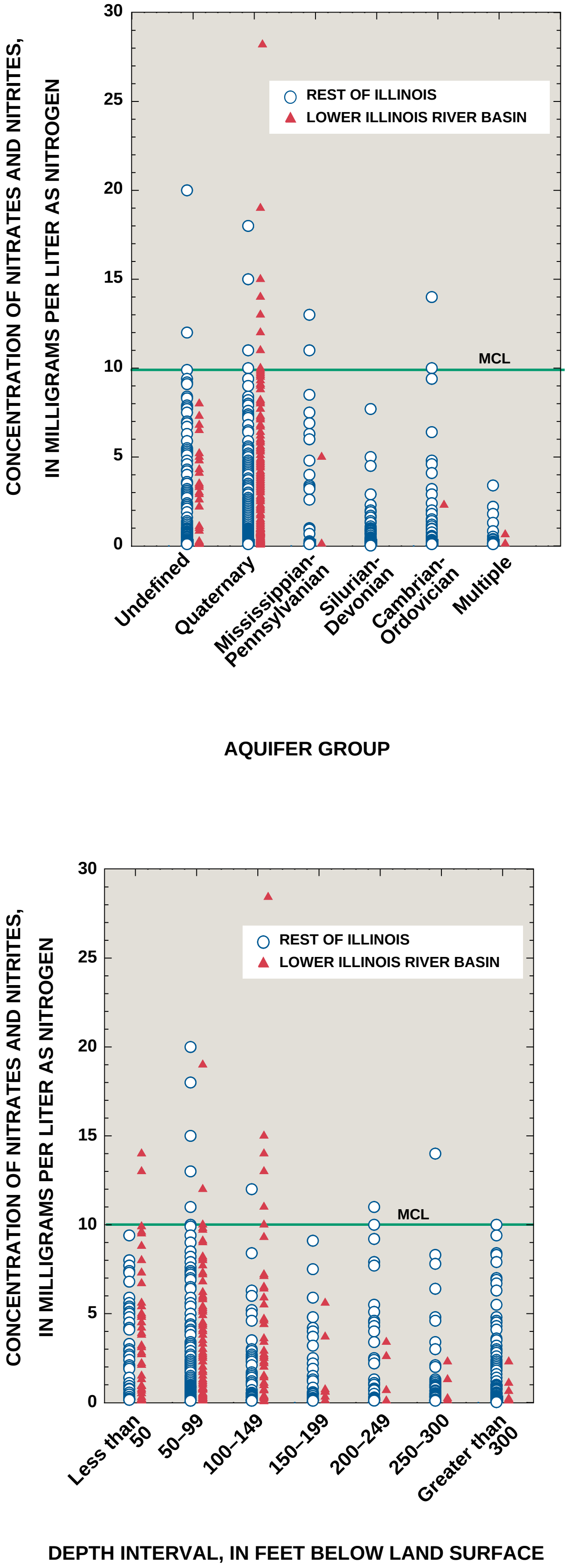

Figure 6–2. Distribution of nitrate and nitrite concentrations in ground water by aquifer group and depth interval.
(U.S. Environmental Protection Agency Maximum Contaminant Level is 10 milligrams per liter.)

7. CHLORIDE

CHLORIDE CONCENTRATIONS ARE SIGNIFICANTLY HIGHER FOR AQUIFERS OLDER THAN THE QUATERNARY

There is a difference in chloride concentration by aquifer and depth within the lower Illinois River Basin. There is a significant difference in chloride concentrations in the older aquifers between the lower Illinois River Basin and the rest of Illinois.

The primary concern associated with chloride is the undesirable taste it may leave in drinking water. Unlike chlorine (Cl_2), chloride (Cl^-) is not toxic to humans and is important in the osmotic activity of extracellular fluid. In the environment, chloride ions are very mobile and relatively unreactive because they do not appreciably enter into oxidation or reduction reactions, do not form salts of low solubility, are not significantly adsorbed on mineral surfaces, and are not biochemically active (Hem, 1985). Because of their large size, however, chloride ions may be held back by the minute pore size of clay or shale as water seeps through these layers (Hem, 1985). The USEPA SMCL is 250 mg/L. The IEPA Class I standard for potable resource ground water and Class II standard for general resource ground water for chloride are both 200 mg/L. There are 58 samples with chloride concentrations above 200 mg/L in the LIRB (fig. 7–1.). Concentrations are highest in the Cambrian-Ordovician aquifer where the median concentration (300 mg/L) exceeded IEPA Class I standard for potable resource ground water and Class II standard for general resource ground water and the USEPA SMCL.

Chloride is widely distributed in the environment and occurs most commonly as sodium chloride (NaCl), which is table salt; calcium chloride ($CaCl_2$), which is used as road salt; and potassium chloride (KCl) (Canadian Council of Resource and Environment Minister, 1992). Although chloride levels in the atmosphere generally are low, except near coastal areas and salt mines, concentrations may reach 19,300 mg/L in seawater and 200,000 mg/L in brines (Canadian Council of Resource and Environment Minister, 1992). Chlorides also may be leached from sedimentary rocks, particularly evaporites. The Wapsipinicon Limestone of Devonian age and the St. Louis Limestone of Mississippian age are present in the LIRB and contain anhydrite and gypsum beds (Willman and others, 1975). Anthropogenic sources of chloride include road salt, irrigation drainage, effluents from chemical industries, oil well operations, and sewage. It has been estimated that 25 to 50 percent of the applied road salt can enter ground water (Canadian Council of Resource and Environment Minister, 1992).

In the LIRB, the concentrations of chloride in 97 percent of the chloride analyses were above the MRL (1.0 mg/L), and the range of concentrations was from 1.0 to 1,700 mg/L (table 7–1.). There is a statistically significant difference in chloride concentration by aquifer and depth within the LIRB (fig. 7–2.). In the LIRB, median chloride concentrations are much higher in the other aquifers (164 mg/L) than in the Quaternary aquifer (16 mg/L). These concentrations may be related to the presence of brine deep in the bedrock of the LIRB. Statistical tests also show a significant difference in chloride concentrations among depth intervals. Median chloride concentrations are highest for samples from wells greater than 300 ft deep. No spatial pattern of chloride concentrations in ground water was discerned. There is a significantly high correlation (0.58) between chloride and sulfate. There are significant ($p \leq 0.05$) correlations between chloride and iron, arsenic, and boron; however, the coefficients for these correlations are less than 0.50.

A significant difference in chloride concentration for the other aquifers between the LIRB and the rest of Illinois was determined. The median chloride concentration in the other aquifers in the rest of Illinois is much lower. In contrast to the LIRB, chloride levels for the rest of Illinois were not significantly different between the other aquifers and the Quaternary aquifer; however, there are significant differences by aquifer group. The percentage of observations exceeding the 200 mg/L standard was much higher for the other aquifers in the LIRB (41 percent) than in the rest of Illinois (4.5 percent). The rest of Illinois had the highest median concentration in the less than 50-ft interval. There is a significant difference by depth interval for the rest of Illinois. In the rest of Illinois, chloride significantly correlates with sulfate (0.45).

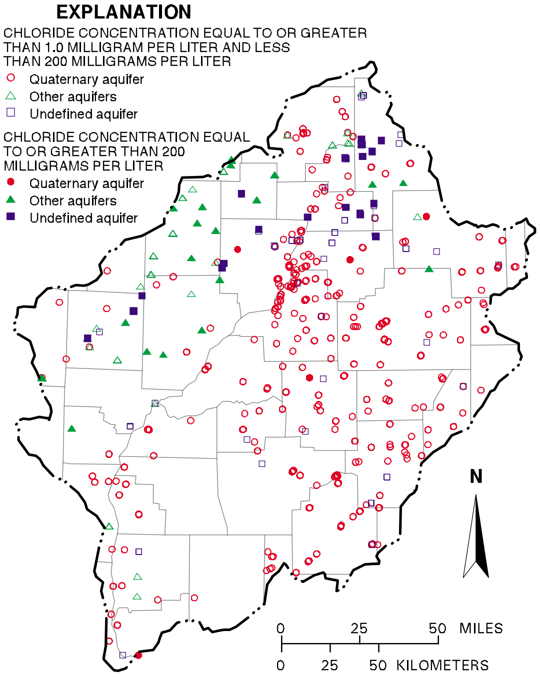

Figure 7–1. Chloride concentrations above the method reporting limit for Quaternary, other aquifers, and undefined aquifers in the lower Illinois River Basin.

Table 7–1. Summary statistics for chloride within and outside the lower Illinois River Basin

[N, number of observations; narl, number of observations above method reporting limit; percentiles and maximums are in milligrams per liter; other aquifers include wells open to multiple aquifers and bedrock aquifers]

Aquifer or depth interval	N	narl	Percentile 25	Percentile 50 (median)	Percentile 75	Maximum
Lower Illinois River Basin						
Overall	613	594	6.0	18	53	1,700
Quaternary aquifers	475	456	5.0	16	34	450
Other aquifers	63	63	14	110	330	890
Undefined aquifers	75	75	6.9	30	300	1,700
Depths less than 50 feet	74	74	16	22	46	410
Depths 50 feet or greater	530	511	5.4	18	56	1,700
Unreported depths	9	9	4.6	18	42	290
Rest of Illinois						
Overall	1,889	1,739	3.1	14	37	820
Quaternary aquifers	542	505	5.3	16	30	820
Other aquifers	911	841	3.3	15	47	540
Undefined aquifers	436	393	2.3	7.3	28	540
Depths less than 50 feet	79	79	14	22	39	420
Depths 50 feet or greater	1,776	1,627	3	13	37	820
Unreported depths	34	33	3.1	15	34	110

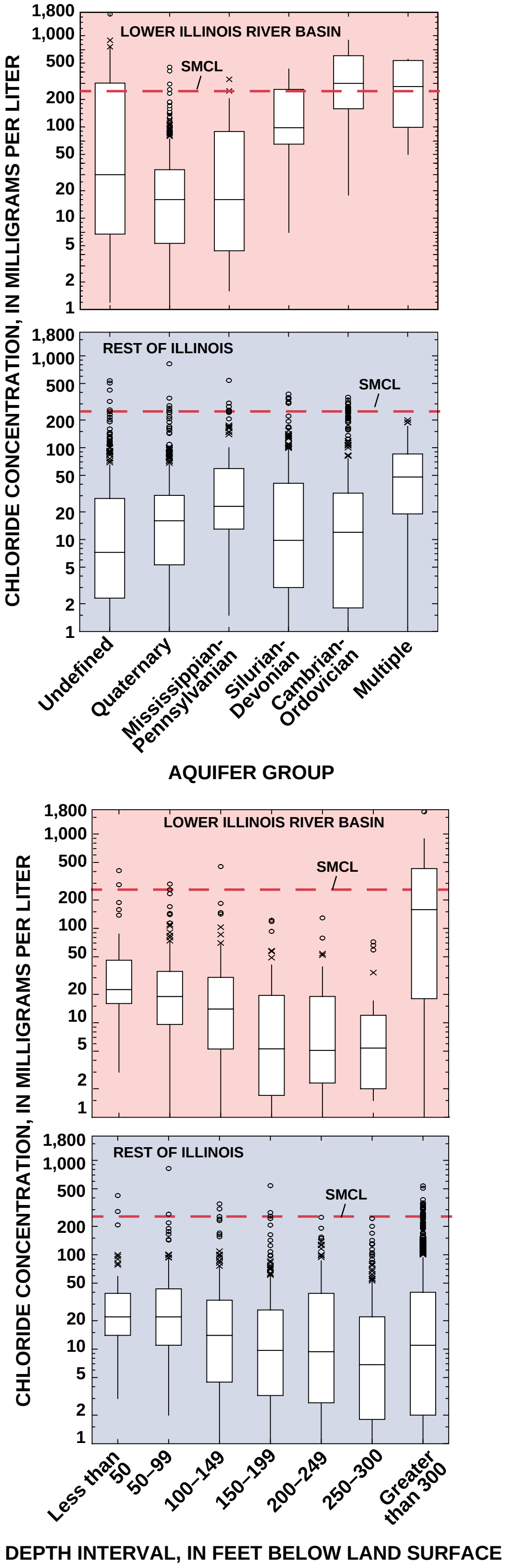

Figure 7–2. Distribution of chloride concentrations in ground water by aquifer group and depth interval.

(See figure 4–1. for explanation of boxplots. U.S. Environmental Protection Agency Secondary Maximum Contaminant Level is 250 milligrams per liter.)

8. SULFATE

SULFATE CONCENTRATIONS ARE HIGHEST IN THE OLDER THAN QUATERNARY AQUIFERS

There is a difference in sulfate concentration by aquifer and depth interval within the lower Illinois River Basin. There is a significant difference in sulfate concentration in the Quaternary aquifer between the lower Illinois River Basin and the rest of Illinois.

Sulfate (SO_4^{-2}) occurs in combination with various ions, forming compounds that can cause gastrointestinal irritation or produce an unpleasant taste in water. Among these compounds, sodium sulfate has one of the lower taste-thresholds at 200–500 mg/L (American Waterworks Association, 1990). At concentrations from 150 to 500 mg/L, some sulfate compounds may cause diarrhea, which can lead to dehydration in infants and young children (McNeely, Neimanis and Dwyer, 1979). This effect is temporary; however, residents in areas with high sulfate levels adapt easily with no ill effects (American Waterworks Association, 1990). The IEPA Class I standard for potable resource ground water and the Class II standard for general resource ground water for sulfate, except when due to natural causes, are 400 mg/L (Illinois Environmental Protection Agency, 1990). The USEPA proposed MCL is 500 mg/L and SMCL is 250 mg/L (U.S. Environmental Protection Agency, 1996). The MRL for sulfate is 10 mg/L. Thirty of 613 samples in the LIRB had concentrations greater than 400 mg/L and most were from the older aquifers (fig. 8–1.).

In water, sulfur occurs primarily as sulfate in the presence of oxygen. Under anaerobic conditions, bacteria reduces sulfate to sulfide, most commonly hydrogen sulfide, which has a rotten egg odor. Sulfide concentrations in ground water usually are low because metal sulfides have low solubility (Canadian Council of Resource and Environment Minister, 1992). Sulfate is produced naturally by volcanic emissions; the weathering of sedimentary rocks; and bacterial oxidation of sulfur-containing compounds such as hydrogen sulfide, metal sulfides, and organo-sulphur compounds. Anthropogenic sources of sulfur include mine-drainage wastes; coal combustion; and industrial discharges from tanneries, paper mills, textile plants, and metal-working industries (McNeely, Neimanis and Dwyer, 1979). Rock containing pyrite (iron sulfide) can be oxidized to release sulfur, with microorganisms acting as a catalyst and mediating oxidation. Sulfur oxidation is the source of the acidic water that drains many mined areas (Fetter, 1993).

In the LIRB, the concentrations of sulfate in 69 percent of the sulfate analyses were above the MRL, and the range of concentrations were from 10 to 1,500 mg/L (table 8–1.). Median sulfate concentrations in the LIRB are higher in the older aquifers than in the Quaternary aquifer, with the exception of the Mississippian-Pennsylvanian aquifers, which have lower values for the median and quartiles (fig. 8–2.). Within the LIRB, there is a significant difference between the Quaternary and other aquifer groups and by depth interval. The samples from wells in the Quaternary aquifer that are 50 ft or less in depth had a median concentration of 69 mg/L, whereas aquifers older than the Quaternary and greater than 300 ft deep had median concentrations of 150 mg/L. Median sulfate concentrations are highest in water from wells less than 50 ft below land surface, although samples from ground water deeper than 300 ft had the maximum concentration. Water from wells with elevated sulfate concentrations show the same spatial pattern as those with elevated chloride concentration. There is a significant correlation ($p \leq 0.05$) between sulfate and chloride (0.58), arsenic (0.57), ammonia (0.47), and iron (0.46) concentrations in ground water in the LIRB.

There is a significant difference in sulfate concentration in the Quaternary aquifer group between the LIRB and the rest of Illinois. Concentrations of sulfate in the rest of Illinois were highest in the Silurian-Devonian aquifers. These high concentrations may be due to the distribution of the Silurian-Devonian aquifers, which are more widely used in the northern part of the State. Sulfate concentration is not significantly different by depth in the rest of Illinois. Correlations within the rest of Illinois between sulfate concentrations and other constituents are similar to those found in the LIRB.

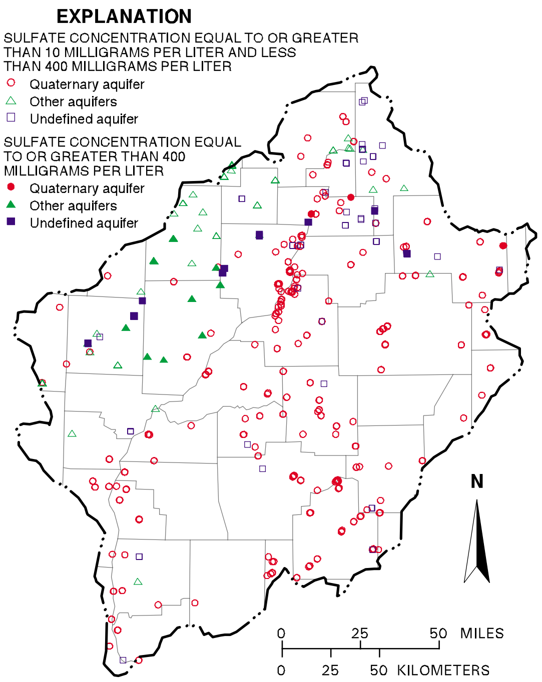

Figure 8–1. Sulfate concentrations above the method reporting limit for Quaternary, other aquifers, and undefined aquifers in the lower Illinois River Basin.

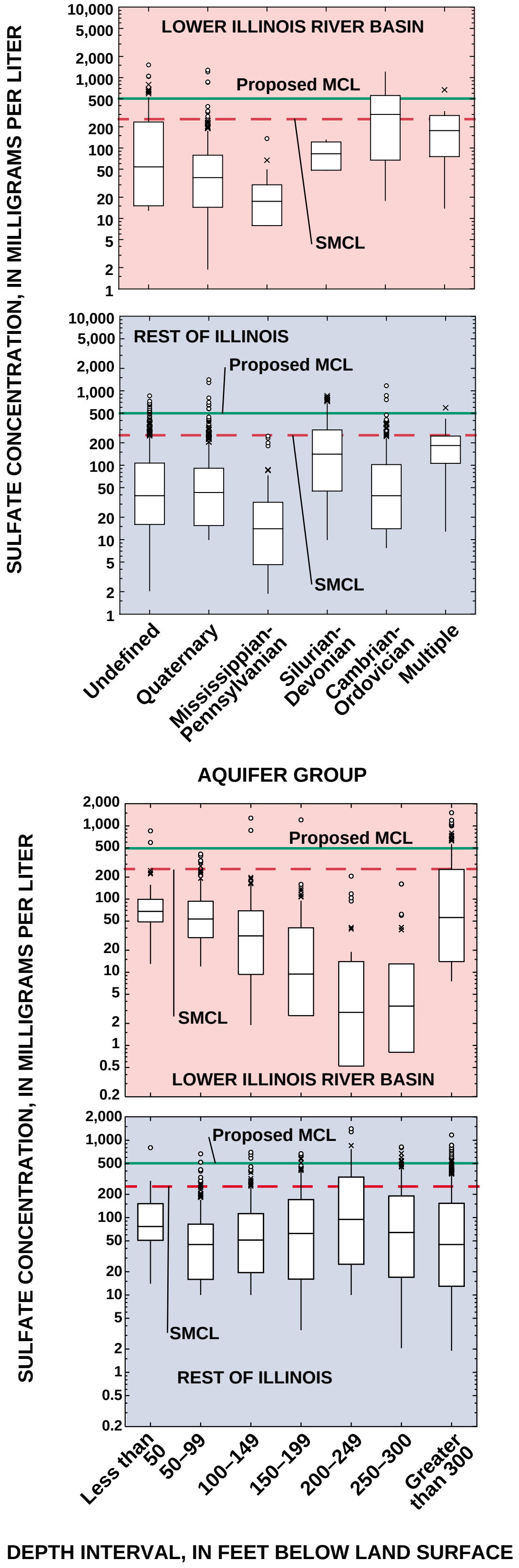

Figure 8–2. Distribution of sulfate concentrations in ground-water samples by aquifer group and depth interval.

(See figure 4–1. for explanation of boxplots. The U.S. Environmental Protection Agency proposed Maximum Contaminant Level is 500 milligrams per liter (mg/L) and the Secondary Maximum Contaminant Level is 250 mg/L.)

Table 8–1. Summary statistics for sulfate within and outside the lower Illinois River Basin

[N, number of observations; narl, number of observations above method reporting limit; percentiles and maximums are in milligrams per liter; gray cells are interpolated values; other aquifers include wells open to multiple aquifers and bedrock aquifers]

Aquifer or depth interval	N	narl	Percentile 25	Percentile 50 (median)	Percentile 75	Maximum
Lower Illinois River Basin						
Overall	612	422	9.4	46	95	1,500
Quaternary aquifers	474	308	8.2	39	79	1,300
Other aquifers	63	55	22	110	310	1,200
Undefined aquifers	75	59	14	54	230	1,500
Depths less than 50 feet	74	73	49	68	99	860
Depths 50 feet or greater	529	344	7.3	38	94	1,500
Unreported depths	9	5	3.6	42	290	520
Rest of Illinois						
Overall	1,888	1,535	16	53	140	1,400
Quaternary aquifers	542	395	12	43	91	1,400
Other aquifers	910	780	19	80	200	1,200
Undefined aquifers	436	360	16	39	110	860
Depths less than 50 feet	79	79	51	77	150	800
Depths 50 feet or greater	1,775	1,427	15	51	140	1,400
Unreported depths	34	29	19	53	110	440

9. ARSENIC

ARSENIC CONCENTRATIONS ARE HIGHEST IN THE DEEP QUATERNARY AQUIFER

There is a difference in arsenic concentration by aquifer and depth interval within the lower Illinois River Basin. There is a significant difference in arsenic concentration in the Quaternary and older aquifers between the lower Illinois River Basin and the rest of Illinois.

Arsenic has been classified as a human carcinogen (group A) by the USEPA. Although arsenic is found in many foods and may be a dietary requirement, excessive amounts of arsenic causes cardiac damage and acute gastrointestinal damage. Chronic doses may lead to vascular disorders, such as blackfoot disease (American Waterworks Association, 1990), and the accumulation of arsenic in body tissues can result in symptoms of severe poisoning. The trivalent form of arsenic, arsenite (AsO_3^{3-}), is more toxic than the pentavalent form, arsenate (AsO_4^{3-}), because arsenite is more effectively bioaccumulated (McNeely, Neimanis and Dwyer, 1979). Organo-arsenic compounds generally are less toxic than inorganic arsenic (American Waterworks Association, 1990). Common analytical procedures, however, report only total arsenic concentrations. Long-term use of water with 210 µg/L total arsenic has been reported as poisonous (Hem, 1985). High concentrations of arsenic also may reduce crop yield by destroying chlorophyll. IEPA Class I standard for potable resource ground water and Class II standard for general resource ground water for arsenic are, respectively, 50 and 200 µg/L, and the USEPA MCL is 50 µg/L. In the LIRB, 16 of the 613 samples had arsenic concentrations above 50 µg/L (fig. 9–1.).

Inorganic forms of arsenic prevail in most natural waters and may bind to colloidal humic matter where organic content is high. Total dissolved arsenic in ground water, as used in this report, is usually a combination of arsenite and arsenate. Arsenite is found mostly in reducing conditions, in absence of hydrogen sulfide. Arsenite is the most toxic and mobile form of arsenic and is found in association with iron in the soluble ferrous state (Fetter, 1993). Arsenic associated with sulfate indicates oxidized sulfide minerals and an oxidized form of arsenic, arsenate. Under strongly reducing conditions, if iron and hydrogen sulfide are present, then arsenic sulfide would coprecipitate with iron sulfide (Fetter, 1993). Arsenate constitutes the stable form of arsenic in aerobic water, whereas arsenite dominates under anaerobic conditions. Arsenate tends to adsorb on or coprecipitate with hydrous iron oxides, aluminum hydroxide, and clay. Arsenite has a strong affinity for sulfur, readily adsorbing on and coprecipitating with other metal sulfides (Canadian Council of Resource and Environment Minister, 1992). These affinities may partly explain the correlations found between arsenic and other constituents in the study. Arsenic enters the environment from pesticides, coal combustion, the smelting of nonferrous metal ores, embalming fluid, volcanic gasses, geothermal water, and the weathering of arsenic minerals, which are widely distributed, particularly those arsenic minerals formed by sulfide, iron, and nickel (Canadian Council of Ministers of the Environment, 1992; Fetter, 1993). In the 1930's, poison pesticide baits utilizing arsenic were used in the Midwest to counter grasshopper infestation. Poison baits were buried and later showed up in a water supply in concentrations of 21,000 µg/L (21 mg/L) (Fetter, 1993).

In the LIRB, the concentrations of arsenic in 48 percent of the analyses were above the MRL (1.0 µg/L), and the range of concentrations was from 1 to 110 µg/L (table 9–1.). The median concentration for all aquifers is at the MRL (1.0 µg/L). Application of the Kruskal-Wallis test indicates significant difference in arsenic concentrations between the Quaternary and older aquifers. The Quaternary aquifer has a median concentration of arsenic above the MRL at depths greater than 150 ft. The highest concentration of arsenic was from wells in the Quaternary aquifer (fig. 9–2.). The percent of values above the MRL decreased with increasing aquifer age. There are significant differences among depth intervals. Arsenic concentrations are higher for depths from 150 to 300 ft deep. Spatially, there are more detections of arsenic in ground water east of the Illinois River in the proximity of the buried Mahomet Valley. There are significant correlations ($p \leq 0.05$) between arsenic and sulfate (–0.59), iron (0.56), fluoride (0.47), boron (0.40), and chloride (–0.26) for the Quaternary aquifer and the older aquifers of the LIRB. In the Quaternary aquifer, arsenic correlates with ammonia (0.68) and nitrate (0.51).

There is a significant difference in arsenic concentrations for the Quaternary and older aquifers between the LIRB and the rest of Illinois. For the rest of Illinois, the Quaternary aquifer that are deeper than 300 ft below land surface and the older aquifers shallower than 540 ft deep have median arsenic concentrations above the MRL. There is a significant difference in arsenic concentrations by aquifer group and depth intervals for the rest of Illinois. In the rest of Illinois, results from Spearman's rank correlation procedure did not show a strong correlation between arsenic and sulfate, fluoride, boron, or chloride, but there is a significant correlation between arsenic and iron (0.49) or manganese (0.32).

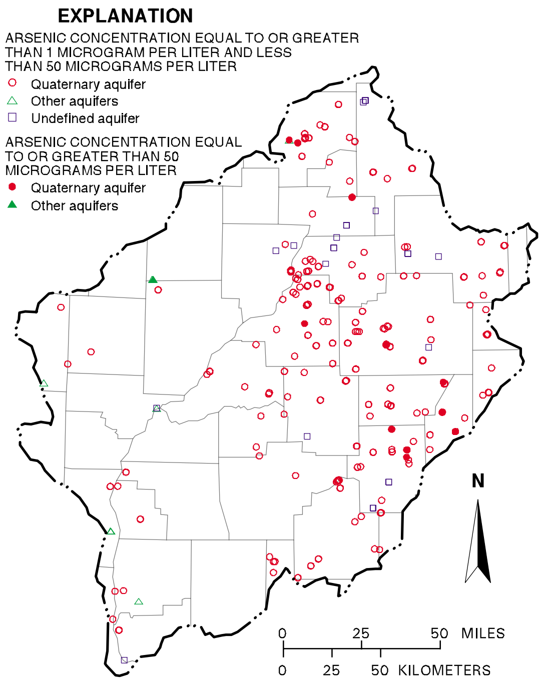

Figure 9–1. Arsenic concentrations above the method reporting limit for Quaternary, other aquifers, and undefined aquifers in the lower Illinois River Basin.

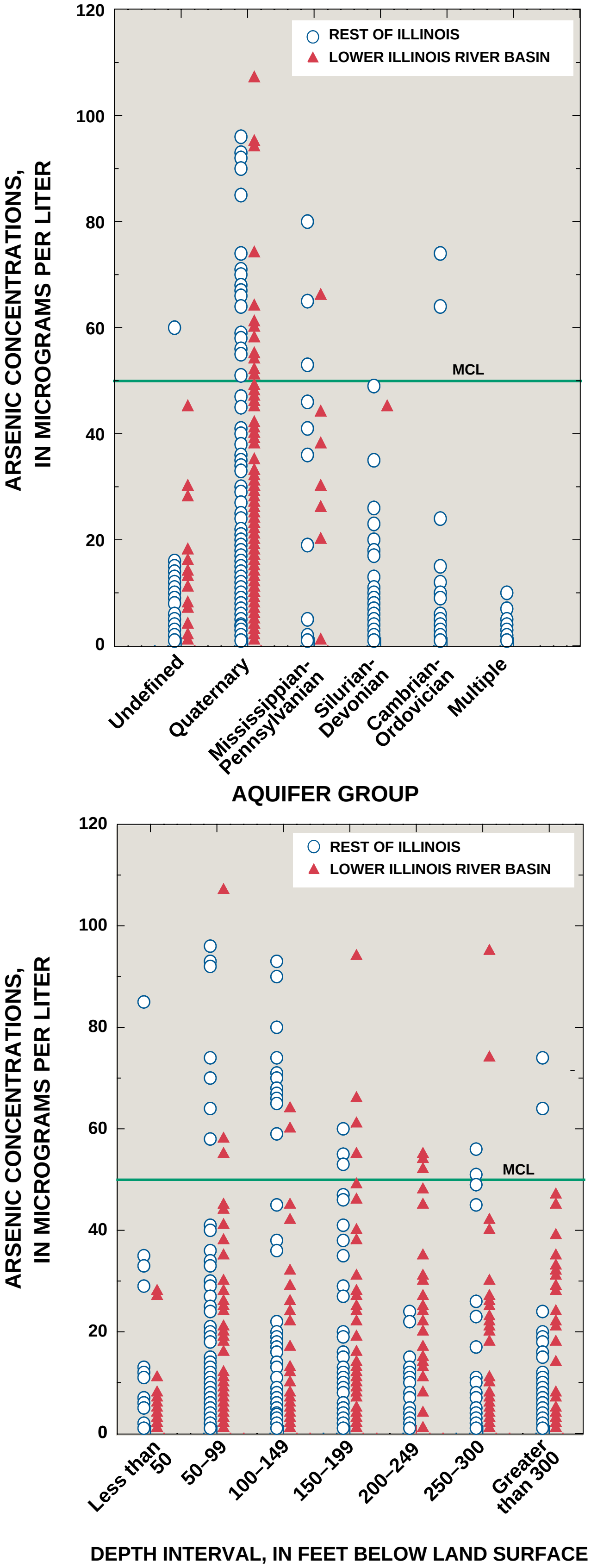

Figure 9–2. Distribution of arsenic concentrations in ground water by aquifer group and depth interval.

(U.S. Environmental Protection Agency Maximum Contaminant Level is 50 micrograms per liter.

Table 9–1. Summary statistics for arsenic within and outside the lower Illinois River Basin

[N, number of observations; narl, number of observations above the method reporting limit; percentiles and maximums are in micrograms per liter; <, less than; gray cells are interpolated values; other aquifers include wells open to multiple aquifers and bedrock aquifers]

Aquifer or depth interval	N	narl	Percentile			Maximum
			25	50 (median)	75	
Lower Illinois River Basin						
Overall	613	293	0.18	0.95	7.5	110
Quaternary aquifers	475	262	.32	1.5	10	110
Other aquifers	63	8	<1.0	<1.0	<1.0	66
Undefined aquifers	75	23	.06	.29	1.0	45
Depths less than 50 feet	74	29	.20	.63	2.0	28
Depths 50 feet or greater	530	259	.19	1.0	8.3	110
Unreported depths	9	5	.29	1.0	29	51
Rest of Illinois						
Overall	1,891	616	0.09	0.37	1.5	96
Quaternary aquifers	543	267	.22	.96	5.0	96
Other aquifers	912	221	.07	.26	.92	80
Undefined aquifers	436	128	.16	.44	1.2	60
Depths less than 50 feet	79	24	.06	.28	1.0	85
Depths 50 feet or greater	1,778	589	.10	.39	1.6	96
Unreported depths	34	3	<1.0	<1.0	<1.0	2.0

10. BORON

BORON CONCENTRATIONS ARE SIGNIFICANTLY DIFFERENT BETWEEN THE QUATERNARY AND OLDER AQUIFERS

There is a difference in boron concentration by aquifer group and depth interval within the lower Illinois River Basin. There is a significant difference in boron concentration in the other aquifers between the lower Illinois River Basin and the rest of Illinois.

Boron does not appear to accumulate in human tissues, but large doses can cause digestive difficulties and affect the central nervous system (McNeely, Neimanis and Dwyer, 1979). Although boron is essential to plant growth in trace amounts, concentrations as high as 1 mg/L may be toxic to some plants, such as citrus crops (Hem, 1985). Boron concentrations range from generally less than a few hundred micrograms per liter in surface and ground water to 48,000 µg/L in brines and hot springs (Hem, 1985). Both IEPA Class I and Class II standards for boron in ground water are 2,000 µg/L, and there is no USEPA MCL. Four of the 613 samples had boron concentrations above 2,000 µg/L (fig. 10–1.).

Elemental boron is not found in nature and little is known about the environmental chemistry of boron compounds. The more important boron solutes are unlikely to adsorb extensively to mineral surfaces because the surfaces tend to be anionic or uncharged (Hem, 1985). Boric acid (H_3BO_3) is probably the predominant boron species in fresh water because it is moderately soluble and does not readily dissociate. Boron is derived naturally from volcanic activity; soil leaching; and the weathering of igneous and sedimentary rocks, particularly granites, pegmatite, gabbros, and serpentine rocks. Anthropogenic sources include domestic sewage, agricultural runoff, and industrial discharges because of the use of boron in water softeners, cleaning agents, pesticides, and a variety of industrial operations (Canadian Council of Resource and Environment Minister, 1992).

In the LIRB, the concentrations of boron in 71 percent of the analyses were above the MRL (50 µg/L), and the range of concentrations was from 50 to 2,100 µg/L (table 10–1.). In the LIRB, there is a significant difference between aquifer groups and depth intervals (fig. 10–2.). All samples from Silurian or older aquifers had boron concentrations above the MRL of 50 µg/L. The Kruskal-Wallis test showed a significant difference in boron concentrations between the Quaternary aquifer and the older aquifers. The median boron concentration was much higher for the older aquifers (802 µg/L) than the Quaternary aquifer (130 µg/L).

In the LIRB, the Kruskal-Wallis test indicated a significant difference in boron concentration by depth interval. Boron concentrations increased with increasing depth. Median boron concentrations were lowest in samples from wells within 50 ft of the land surface and highest in samples from wells with depths greater than 300 ft. Approximately 85 percent of samples from the older aquifers were from wells greater than 300 ft deep. These samples had the highest median concentration of 940 µg/L. In the LIRB, there is no spatial pattern of boron concentration in ground water. There is a significant correlation ($p \leq 0.05$) of boron with fluoride (0.73), ammonia (0.56), manganese (–0.46), nitrite/nitrate (0.38), chloride (0.31), selenium (0.19), and arsenic (0.13) in the LIRB.

The boron concentration in water samples from the rest of Illinois are significantly different from the LIRB for the older aquifers but similar for the Quaternary aquifer. For the Quaternary aquifer, boron concentrations in ground water in the LIRB and the rest of Illinois had comparable values for the mean, percentiles, and the percentage of values above the MRL but had substantially lower values for the other aquifers in the rest of Illinois. There are significant differences by aquifer group and depth interval in the rest of Illinois. There are not as many samples from other aquifers within the LIRB (63) compared with the rest of Illinois (908). The relative scarcity of samples from other aquifers in the LIRB may account for some of the differences in statistical test results. There are significant correlations ($p \leq 0.05$) of boron with fluoride (0.70) and ammonia (0.58) in the rest of Illinois.

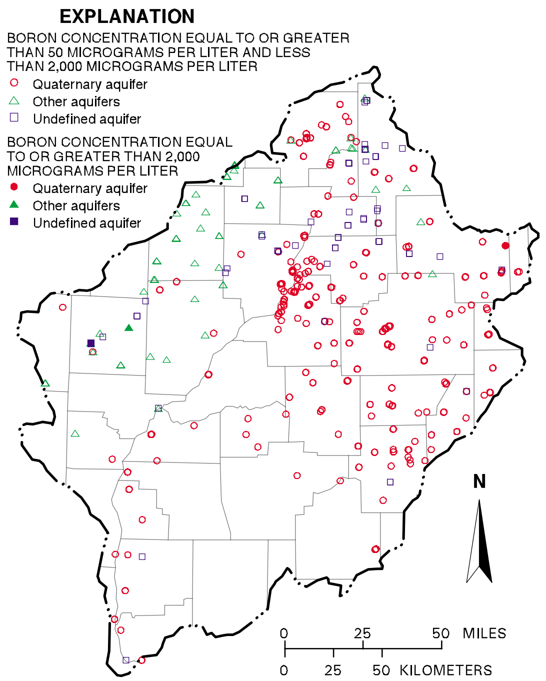

Figure 10–1. Boron concentrations above the method reporting limit for Quaternary, other aquifers, and undefined aquifers in the lower Illinois River Basin.

Table 10–1. Summary statistics for boron within and outside the lower Illinois River Basin

[N, number of observations; narl, number of observations above method reporting limit; percentiles and maximums are in micrograms per liter; gray cells are interpolated values; other aquifers include wells open to multiple aquifers and bedrock aquifers]

Aquifer or depth interval	N	narl	Percentile 25	Percentile 50 (median)	Percentile 75	Maximum
Lower Illinois River Basin						
Overall	613	438	50	170	390	2,100
Quaternary aquifer	475	324	44	130	290	2,100
Other aquifers	63	57	390	802	1,100	2,000
Undefined aquifers	75	57	61	400	790	2,100
Depths less than 50 feet	74	39	22	51	120	1,400
Depths 50 feet or greater	530	391	58	200	400	2,100
Unreported depths	9	8	140	450	740	1,400
Rest of Illinois						
Overall	1,879	1,354	53	180	440	2,300
Quaternary aquifer	540	346	33	89	330	2,300
Other aquifers	908	724	77	270	540	1,600
Undefined aquifers	431	284	39	110	350	1,500
Depths less than 50 feet	78	27	10	28	72	500
Depths 50 feet or greater	1,767	1,306	58	200	460	2,300
Unreported depths	34	21	36	150	380	840

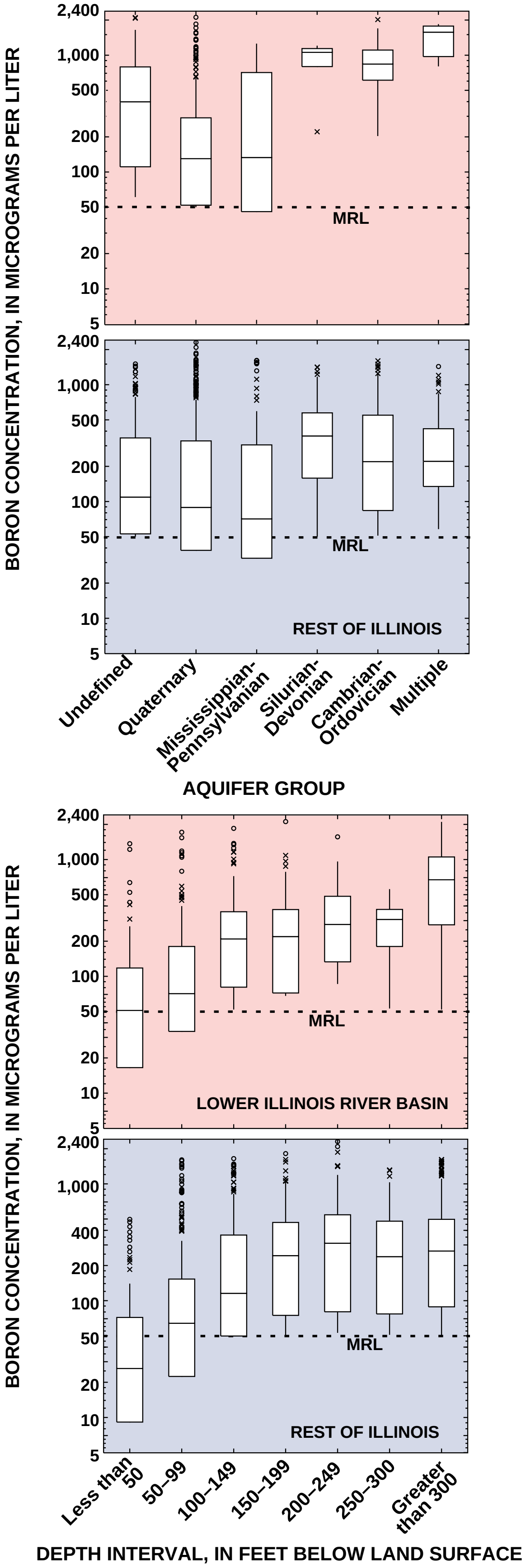

Figure 10–2. Distribution of boron concentrations in ground water by aquifer group and depth interval.

(See figure 4–1. for explanation of boxplots. Method reporting limit is 50 micrograms per liter.)

11. CHROMIUM

CHROMIUM CONCENTRATIONS ARE LOW

There are no significant differences in chromium concentration by aquifer group or depth interval within the lower Illinois River Basin. There is a significant difference in chromium concentration in the older than Quaternary aquifers between the lower Illinois River Basin and the rest of Illinois.

Chromium is present primarily in its trivalent (Cr^{3+}) and hexavalent (Cr^{6+}) form in aqueous systems. Whereas, Cr^{3+} is nontoxic and nutritionally essential, Cr^{6+} is toxic, causing liver and kidney damage, internal hemorrhage, and respiratory disorder, as well as chronic and subchronic effects such as dermatitis and skin ulceration (American Waterworks Association, 1990). The USEPA has classified chromium as a human carcinogen (group A) because Cr^{6+} has been shown to cause cancer in humans and animals by inhalation exposure. Chromium also is toxic to aquatic organisms and will bioaccumulate. The 1992 Canadian Water Quality Guidelines (Canadian Council of Resource and Environment Minister, 1992) suggest chromium limits of 20 μg/L to protect fish and 2 μg/L to protect aquatic life, in general. The USEPA MCL and the IEPA Class I standard for potable resource ground water for chromium are 100 μg/L. In this study, chromium concentrations constitute total chromium. There are no detections above 100 μg/L and very few concentrations above the MRL of 5.0 μg/L (fig. 11–1.).

Hexavalent chromium is soluble and not significantly sorbed by soils or particulate matter (Canadian Council of Resource and Environment Minister, 1992). Under anaerobic conditions or in the presence of oxidizable substances, usually organic molecules, Cr^{6+} will be reduced to Cr^{3+}, which tends to sorb on particulate matter or precipitate out of solution (Canadian Council of Resource and Environment Minister, 1992; McNeely, Neimanis and Dwyer, 1979). Dissolved chromium concentrations often are low in aqueous systems, particularly in well aerated waters with little organic matter. Federal surveys from 1969 to 1980 show mean chromium concentrations of 10 μg/L for surface water and 16 μg/L for ground water (American Waterworks Association, 1990).

Chromium enters the environment naturally through weathering, although chromite (the predominant chromium-bearing mineral) is highly resistant to weathering. Anthropogenic sources of chromium include metal-plating operations; combustion of fossil fuels; tanning; old mining operations; and the manufacturing of ceramics, paints, dyes, and paper (American Waterworks Association, 1990; Canadian Council of Resource and Environment Minister, 1992).

In the LIRB, the concentrations of chromium in 1 percent of the analyses were above the MRL, and the range of concentrations was from 5 to 40 μg/L (table 11–1.). There is a difference in the range of concentrations between the Quaternary and older aquifers, although the median for all aquifers is at the MRL (5.0 μg/L). This difference also is reflected in the percentage of concentrations greater than the MRL, which is lowest for the Quaternary aquifer. The maximum concentration of 40 μg/L was from a sample in the older aquifer at a depth greater than 300 ft below land surface (fig. 11–2.). Although there are differences in ranges of concentrations, there is no significant difference among aquifer groups in the LIRB. There is a significant difference between the Quaternary aquifer and other aquifers. Within the LIRB, there is not a significant difference in chromium concentration by depth interval. Chromium detections in ground water do not appear to have a spatial pattern and, thus, may be a result of local land-use effects. The largest Spearman correlation coefficient with significance ($p \leq 0.05$) is between chromium and silver (0.32).

Chromium concentrations generally were low in the LIRB and the rest of Illinois. Only 7 and 10 percent of the observations in the rest of Illinois and within the LIRB, respectively, have chromium detections. The mean and 25th and 75th percentiles are equivalent for the LIRB and the rest of Illinois. Unlike the LIRB, chromium concentrations within the rest of Illinois did not differ significantly between the Quaternary aquifer and the other aquifers. There is no significant difference between the LIRB and the rest of Illinois for the Quaternary aquifer, but there are differences between the two areas by depth interval of the sampled wells. The percentage of values above the MRL was higher for the older aquifers of the LIRB than in the rest of Illinois, 22 and 6 percent, respectively. The largest Spearman correlation coefficient with significance in the rest of Illinois is between chromium and silver (0.29).

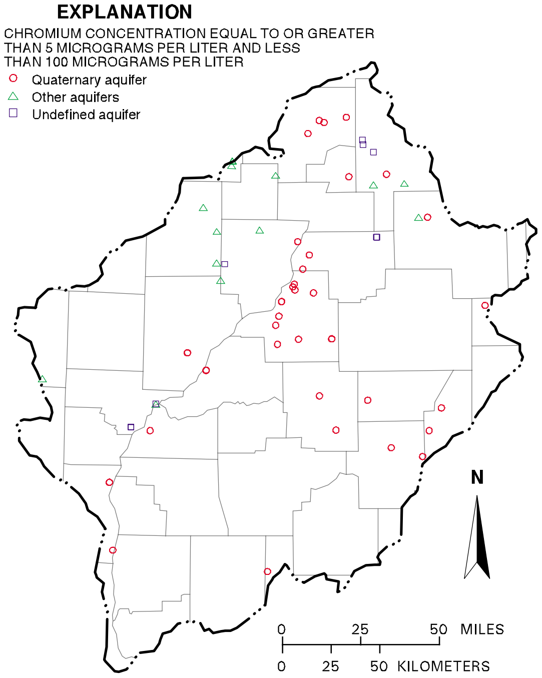

Figure 11–1. Chromium concentrations above the method reporting limit for Quaternary, other aquifers, and undefined aquifers in the lower Illinois River Basin.

Table 11–1. Summary statistics for chromium within and outside the lower Illinois River Basin

[N, number of observations; narl, number of observations above method reporting limit; percentiles and maximums are in micrograms per liter; <, less than; gray cells are interpolated values; other aquifers include wells open to multiple aquifers and bedrock aquifers]

Aquifer or depth interval	N	narl	Percentile 25	Percentile 50 (median)	Percentile 75	Maximum
Lower Illinois River Basin						
Overall	613	62	<5.0	<5.0	<5.0	40
Quaternary aquifers	475	39	<5.0	<5.0	<5.0	22
Other aquifers	63	14	1.4	2.5	4.5	40
Undefined aquifers	75	9	<5.0	<5.0	<5.0	9
Depths less than 50 feet	74	4	<5.0	<5.0	<5.0	22
Depths 50 feet or greater	530	57	<5.0	<5.0	<5.0	40
Unreported depth	9	1	<5.0	<5.0	<5.0	7
Rest of Illinois						
Overall	1,880	128	<5.0	<5.0	<5.0	36
Quaternary aquifers	541	45	<5.0	<5.0	<5.0	36
Other aquifers	908	63	<5.0	<5.0	<5.0	30
Undefined aquifers	431	20	<5.0	<5.0	<5.0	32
Depths less than 50 feet	78	5	<5.0	<5.0	<5.0	7
Depths 50 feet or greater	1,768	120	<5.0	<5.0	<5.0	36
Unreported depths	34	3	<5.0	<5.0	<5.0	6

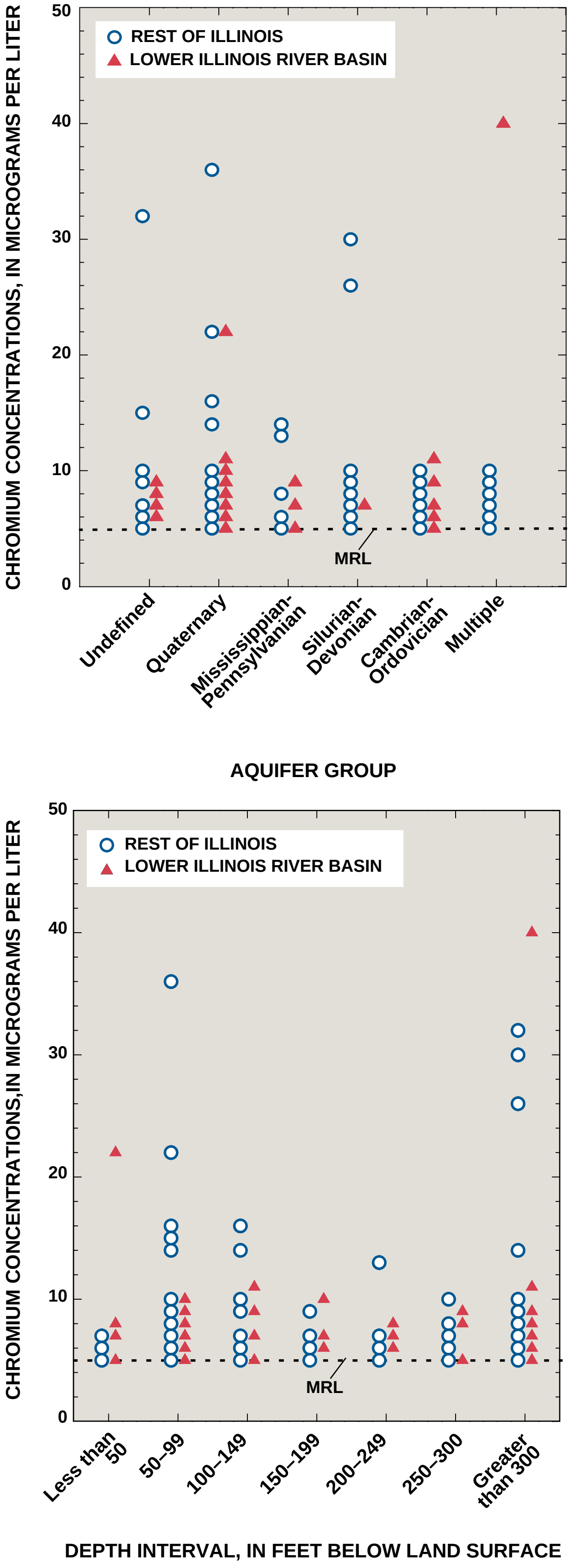

Figure 11–2. Distribution of chromium concentrations in ground water by aquifer group and depth interval.
(Method reporting limit is 5.0 micrograms per liter.)

12. COPPER

COPPER CONCENTRATIONS DO NOT VARY SIGNIFICANTLY BY DEPTH INTERVAL OR AQUIFER

There is no difference in copper concentration by aquifer or depth interval within the lower Illinois River Basin. There is no significant difference in copper concentration in the Quaternary and older aquifers between the lower Illinois River Basin and the rest of Illinois.

Copper (Cu) is not known to be toxic to man at moderate levels, but water becomes distasteful to drink at concentrations of copper between 1,000 to 5,000 µg/L (Canadian Council of Resource and Environment Ministers, 1992). Lack of copper in the diet has been associated with iron deficiency and reproductive abnormalities. Very large doses of copper over time may result in liver and renal damage or anemia (American Waterworks Association, 1990). The IEPA Class I standard for potable resource ground water and the IEPA Class II standard for general resource ground water, except due to natural causes, are 650 µg/L. The recommended USEPA MCLG is 1,300 µg/L at the tap for copper and the SMCL is 1,000 µg/L. Water from five wells had concentrations of copper above 650 µg/L (fig. 12–1.).

Copper may occur in solution in either the Cu^{2+} or Cu oxidation stage. The redox conditions in oxygenated water and the tendency of Cu ions to disproportionate favor the more oxidized form (Hem, 1985). Water with lower concentrations of copper are readily explainable as results of coprecipitation by oxides or adsorption on mineral surfaces (Hem, 1985). Copper is a common heavy metal constituent of natural water, but little copper in water is of natural origin because most copper minerals are relatively insoluble (McNeely, Neimanis, and Dwyer, 1979). It is estimated that anthropogenic sources of copper to aquatic environments provide 33 to 60 percent of the total annual global input (Canadian Council of Resource and Environment Ministers, 1992). Copper is common in the earth’s crust as stable sulfide minerals.

In the LIRB, the concentrations of copper in 28 percent of the analyses were above the MRL (5.0 µg/L), and the range of concentrations was from 5 to 2,700 µg/L (table 12–1.). There is no significant difference, in median concentration of copper, between the Quaternary and older aquifers or among individual aquifer groups. The median concentration is below the MRL for all aquifers. The range of concentrations for the LIRB was from 5 to 2,700 µg/L with the highest concentrations in the Quaternary aquifer (fig. 12–2.). The Kruskal-Wallis test showed no significant difference in concentration of copper between depth intervals. The median concentration for all depth intervals was less than 5 µg/L, which is the MRL. The spatial distribution of copper concentrations above the MRL does not show a pattern. Water samples from a cluster of wells near Peoria in the Quaternary aquifer have copper concentrations above the MRL, but this cluster probably represents the greater density of wells in the area. The highest Spearman correlation coefficient with significance is between copper and lead (0.40).

Copper concentrations in the rest of Illinois are similar to the LIRB. Further Kruskal-Wallis tests show no significant difference between the LIRB and the rest of Illinois in copper concentrations by depth interval or aquifer group. In the rest of Illinois, the highest Spearman correlation coefficient with significance is lead (0.32).

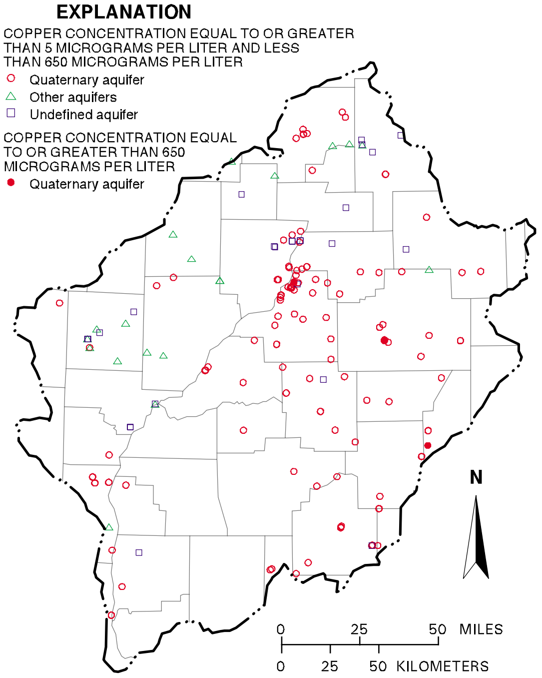

Figure 12–1. Copper concentrations above the method reporting limit for Quaternary, other aquifers, and undefined aquifers in the lower Illinois River Basin.

Table 12–1. Summary statistics for copper within and outside the lower Illinois River Basin

[N, number of observations; narl, number of observations above method reporting limit; percentiles and maximums are in micrograms per liter; gray cells are interpolated values; other aquifers include wells open to multiple aquifers and bedrock aquifers]

Aquifer or depth interval	N	narl	Percentile 25	Percentile 50 (median)	Percentile 75	Maximum
Lower Illinois River Basin:						
Overall	613	174	0.25	1.2	6.0	2,700
Quaternary aquifers	475	129	.22	1.1	6.0	2,700
Other aquifers	63	19	.27	1.3	6.0	650
Undefined aquifers	75	26	.52	2.2	9.0	190
Depths less than 50 feet	74	26	.53	2.0	6.0	1,400
Depths 50 feet or greater	530	145	.21	1.1	6.0	2,700
Unreported depths	9	3	.58	2.2	13	68
Rest of Illinois:						
Overall	1,880	421	.31	1.1	4.2	1,300
Quaternary aquifers	541	124	.31	1.2	4.4	340
Other aquifers	908	206	.31	1.2	4.3	1,100
Undefined aquifers	431	91	.28	1.0	3.8	1,300
Depths less than 50 feet	78	26	.63	2.2	7.3	420
Depths 50 feet or greater	1,768	384	.29	1.1	4.0	1,300
Unreported depths	34	11	.63	2.2	9.3	110

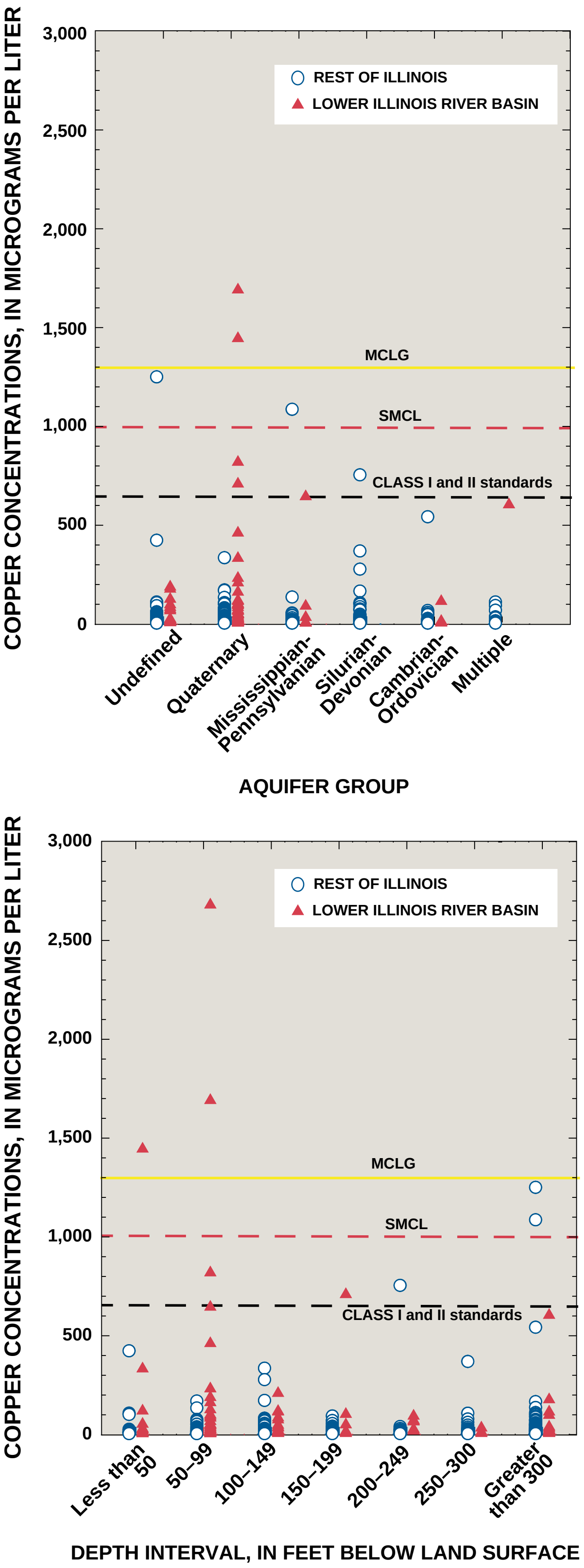

Figure 12–2. Distribution of copper concentrations in ground water by aquifer group and depth interval.

(U.S. Environmental Protection Agency Maximum Contaminant Level Goal is 1,300 micrograms per liter (µg/L) and Secondary Maximum Contaminant Level is 1,000 µg/L. Illinois Environmental Protection Agency Class I and Class II standards are 650 µg/L.)

13. CYANIDE

CYANIDE DETECTED IN ONLY TWO GROUND-WATER SAMPLES

There is not a statistical difference in cyanide concentration by aquifer or depth interval within the lower Illinois River Basin because less than 1 percent of analyses had a detection of cyanide. There is no significant difference in cyanide concentration in the Quaternary and other aquifers between the lower Illinois River Basin and the rest of Illinois because less than 1 percent of analyses had a detection of cyanide.

Cyanide in drinking water may cause damage to the thyroid and nervous system (U.S. Environmental Protection Agency, 1994). Cyanide combines with cell cytochrome; prevents oxygen transport; and is readily absorbed from the lungs, intestines, and skin (American Waterworks Association, 1990). The toxicity of cyanide varies, depending on its chemical form. Although high doses can be fatal, low, chronic amounts may be detoxified in the liver (American Waterworks Association, 1990). Cyanide concentrations generally are low in drinking water. A 1970 USEPA survey of 969 community water-supply systems throughout the nation showed the maximum cyanide concentration of 0.008 mg/L (U.S. Department of Health, Education, and Welfare, 1970). Because cyanide is biodegradable and readily forms compounds with metal ions (such as copper and iron), large-scale distribution is unlikely (McNeely, Neimanis and Dwyer, 1979). The IEPA Class I and Class II standards for cyanide in ground-water resources are 0.2 and 0.6 mg/L, respectively. The USEPA MCL is 0.2 mg/L. Cyanide was detected in two samples at concentrations below the MCL (fig. 13–1.).

Cyanides, defined by the presence of a carbon-nitrogen group (CN), occur in a variety of chemical forms, from the simple ion (CN-) and undissociated form (HCN) to salts (for example, sodium cyanide and potassium cyanide) to organic and metal complexes. The cyanide ion has a strong affinity for many metal ions but is not strongly adsorbed or retained in soils because of the ion's negative charge. Some metallocyanide complexes, such as iron-cyanide, may dissociate as a result of sunlight when pH is less than 8.0 (Canadian Council of Resource and Environment Ministers, 1992). In waters at pH below 8.0, HCN generally will be the predominate dissolved form. Cyanide is generated primarily from industrial operations, such as electroplating, metal cleaning, steel plants, and oil refineries. Concentrations in effluent can range from an average of 3 mg/L for electroplating to 30–60 mg/L for steel mills.

In the LIRB, the concentrations of cyanide in less than 1 percent of the analyses were above the MRL (0.005 or 0.01 mg/L) and, therefore, no statistical tests were performed on these data. The range of concentrations was from 0.005 to 0.03 mg/L (table 13–1.). The only two samples above the MRL were taken from the Quaternary aquifer in 1986 (fig. 13–2.). The first sample was from ground water (0.01 mg/L) in Christian County at a depth of 42 ft, and the second sample (0.03 mg/L) was from ground water in Champaign County at a depth of 270 ft. Statistical tests for correlation are not useful with only two detections of cyanide.

In the rest of Illinois, 28 (1 percent) of the samples were above the MRL, whereas 78 percent were less than 0.01 mg/L and 21 percent were less than 0.005 mg/L. Although concentrations ranged up to 0.10 mg/L, most were below the MRL.

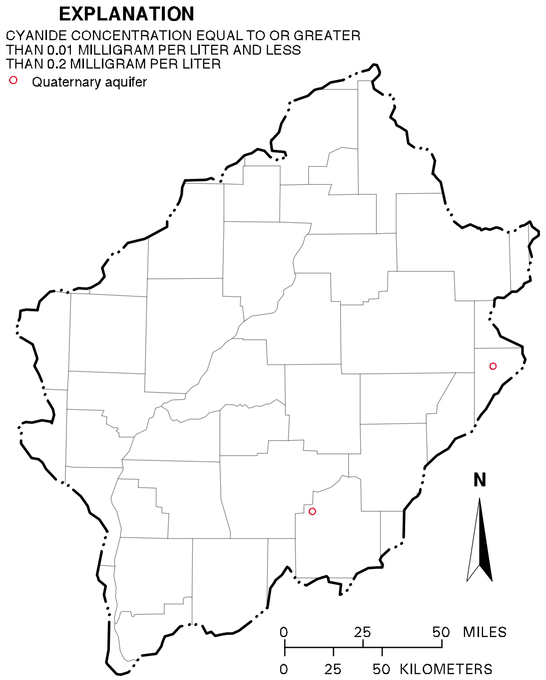

Figure 13–1. Cyanide concentrations above the method reporting limit for Quaternary, other aquifers, and undefined aquifers in the lower Illinois River Basin.

Table 13–1. Summary statistics for cyanide within and outside the lower Illinois River Basin

[N, number of observations; narl, number of observations above method reporting limits; percentiles and maximums are in milligrams per liter; <, less than; other aquifers include wells open to multiple aquifers and bedrock aquifers]

Aquifer or depth interval	N	narl	Percentile 25	Percentile 50 (median)	Percentile 75	Maximum
Lower Illinois River Basin						
Overall	612	2	<0.01	<0.01	<0.01	0.03
Quaternary aquifers	475	2	<.01	<.01	<.01	.03
Other aquifers	63	0	<.01	<.01	<.01	<.01
Undefined aquifers	74	0	<.01	<.01	<.01	<.01
Depths less than 50 feet	74	1	<.01	<.01	<.01	<.01
Depths 50 feet or greater	529	1	<.01	<.01	<.01	.03
Unreported depths	9	0	<.01	<.01	<.01	<.01
Rest of Illinois						
Overall	1,890	28	<0.01	<0.01	<0.01	0.10
Quaternary aquifers	542	5	<.01	<.01	<.01	.02
Other aquifers	912	17	<.01	<.01	<.01	.10
Undefined aquifers	436	6	<.01	<.01	<.01	.09
Depths less than 50 feet	79	0	<.01	<.01	<.01	<.01
Depths 50 feet or greater	1,777	28	<.01	<.01	<.01	.10
Unreported depths	34	0	<.01	<.01	<.01	<.01

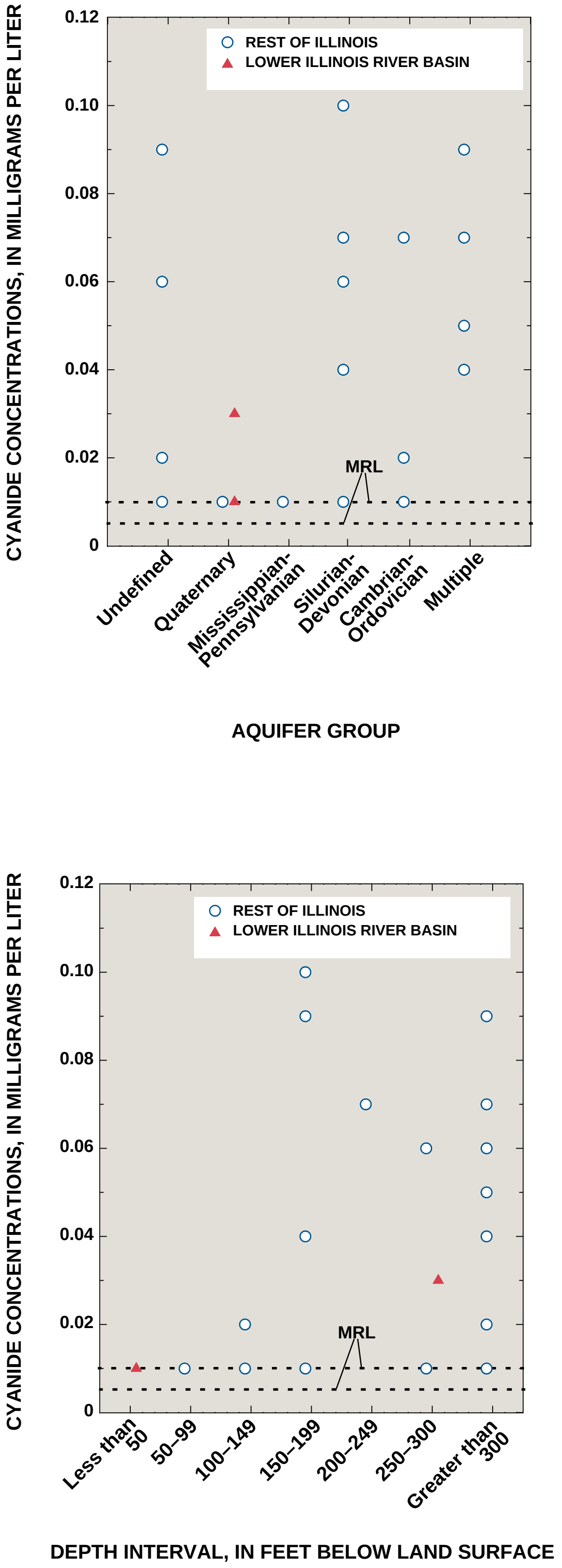

Figure 13–2. Distribution of cyanide concentrations in ground water by aquifer group and depth interval.

(Method reporting limit varies depending on analytical method, 0.005 or 0.01 milligram per liter.)

14. IRON

IRON CONCENTRATIONS ARE SIGNIFICANTLY DIFFERENT BETWEEN THE QUATERNARY AND OTHER AQUIFERS

There is a difference in iron concentration by aquifer and depth interval within the lower Illinois River Basin. There is no significant difference in iron concentration in the Quaternary and other aquifers between the lower Illinois River Basin and the rest of Illinois.

Iron in drinking water does not pose a health threat and, therefore, is not regulated under the Safe Drinking Water Act. In high enough concentrations, however, iron forms reddish-brown precipitates that encrust pipes and stain laundry and plumbing fixtures. Iron also produces an unpleasant taste in drinking water and may promote bacterial growth in pipes and service mains. Upper limits of 50 µg/L and 300 µg/L have been recommended for iron, the first for more palatable water (McNeely, Neimanis and Dwyer, 1979) and the latter to reduce staining (Hem, 1985). Although iron serves as a minor plant nutrient, concentrations exceeding 20,000 µg/L have been shown to be toxic to some plants (McNeely, Neimanis, and Dwyer, 1979.). The IEPA Class I standard for potable resource ground water and Class II standard for general resource ground water for iron are 5,000 µg/L. The USEPA SMCL level is 300 µg/L. There are 37 samples with concentrations of iron above 5,000 µg/L (fig. 14–1.).

Iron generally occurs in either its ferric (Fe^{3+}) or ferrous (Fe^{2+}) form, with each having different chemical properties. When exposed to oxygen, ferrous iron (which is present under reducing conditions and is more mobile than ferric iron) is oxidized to the ferric form, which tends to precipitate. Thus, ground water that is clear when first drawn from a well may soon turn brown from precipitating ferric hydroxide (Hem, 1985). Various microorganisms also affect the form in which iron occurs. Iron enters the environment naturally through the weathering of sulfide minerals and igneous, sedimentary, and metamorphic rocks. Anthropogenic sources of iron include coal burning, acid mine drainage, mineral processing, sewage, landfill leachates, and iron-related industries (Canadian Council of Resource and Environment Ministers, 1992). Whereas, iron concentrations usually are less than 500 µg/L in well aerated surface water, concentrations in ground water and thermal hot springs may range from 10,000 to 100,000 µg/L (Canadian Council of Ministers of the Environment, 1992). For this study, samples were analyzed for total iron concentration.

In the LIRB, the concentrations of iron in 85 percent of the analyses were above the MRL (50 µg/L), and the range of concentrations was from 50 to 21,000 µg/L (table 14–1.). The Kruskal-Wallis test indicated a significant difference in iron concentrations between the Quaternary aquifer and the other aquifers, as indicated by the substantially higher median and 25th and 75th percentiles in the Quaternary aquifer. The highest values occurred in the Quaternary and Mississippian-Pennsylvanian aquifers, and within 150 ft of the land surface (fig. 14–2.). The lowest medians were determined for aquifers other than the Quaternary and depths greater than 50 ft. The highest medians and 25th percentiles were for depths of 151–300 ft within the LIRB. Iron concentrations are significantly different among aquifer groups and among depth intervals. Ground water with iron concentrations above 5,000 µg/L are more often detected east of the Illinois River. Arsenic, ammonia, nitrate/nitrite, manganese, and sulfate each had significant ($p \leq 0.05$) correlation coefficients, exceeding 0.45, with iron.

Compared with the LIRB, iron concentrations for the rest of Illinois spanned an even greater range of values from less than 50 to greater than 45,000 µg/L. There are significant differences by aquifer group and depth interval for the rest of Illinois. Although the highest values overall were in the rest of Illinois, the median and percentiles were lower in the rest of Illinois than in the LIRB. Between the LIRB and the rest of Illinois, the Kruskal-Wallis test indicated no significant difference in iron concentrations for either the Quaternary aquifer or the other aquifers, but unlike the LIRB, the median and 75th percentile generally decreased with depth interval in the rest of Illinois. In the rest of Illinois, the highest significant ($p \leq 0.05$) correlation is between iron and arsenic (0.49) and manganese (0.69).

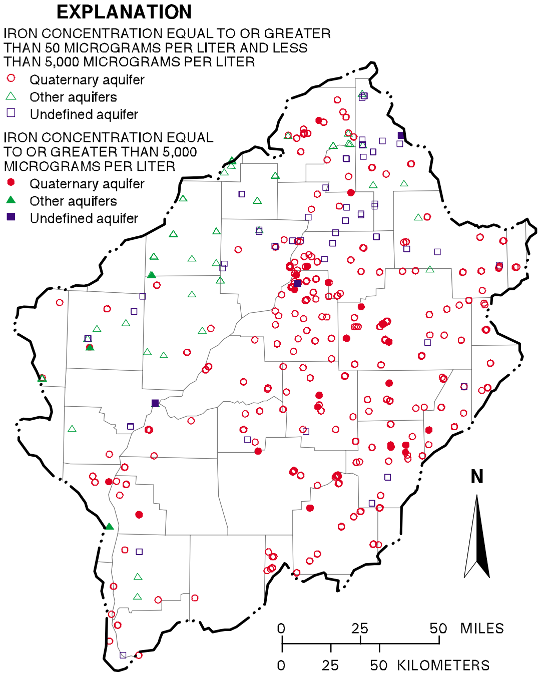

Figure 14–1. Iron concentrations above the method reporting limit for Quaternary, other aquifers, and undefined aquifers in the lower Illinois River Basin.

Table 4–1. Summary statistics for iron within and outside the lower Illinois River Basin

[N, number of observations; narl, number of observations above method reporting limit; percentiles and maximums are in micrograms per liter; gray cells are interpolated values; other aquifers include wells open to multiple aquifers and bedrock aquifers]

Aquifer or depth interval	N	narl	Percentiles			Maximum
			25	50 (median)	75	
Lower Illinois River Basin						
Overall	612	521	250	1,400	2,600	21,000
Quaternary aquifer	474	400	410	1,600	2,800	13,000
Other aquifers	63	54	120	250	1,100	21,000
Undefined aquifers	75	67	190	500	1,800	6,000
Depths less than 50 feet	74	55	75	700	2,100	21,000
Depths 50 feet or greater	529	457	290	1,500	2,600	13,000
Unreported depths	9	9	750	2,000	2,800	5,100
Rest of Illinois						
Overall	1,880	1,588	120	450	1,500	45,000
Quaternary aquifer	541	476	400	1,500	2,900	40,000
Other aquifers	907	762	96	290	820	45,000
Undefined aquifers	432	350	86	340	1,100	17,000
Depths less than 50 feet	78	59	92	1,100	3,300	40,000
Depths 50 feet or greater	1,768	1,506	120	450	1,400	45,000
Unreported depths	34	23	35	130	860	11,000

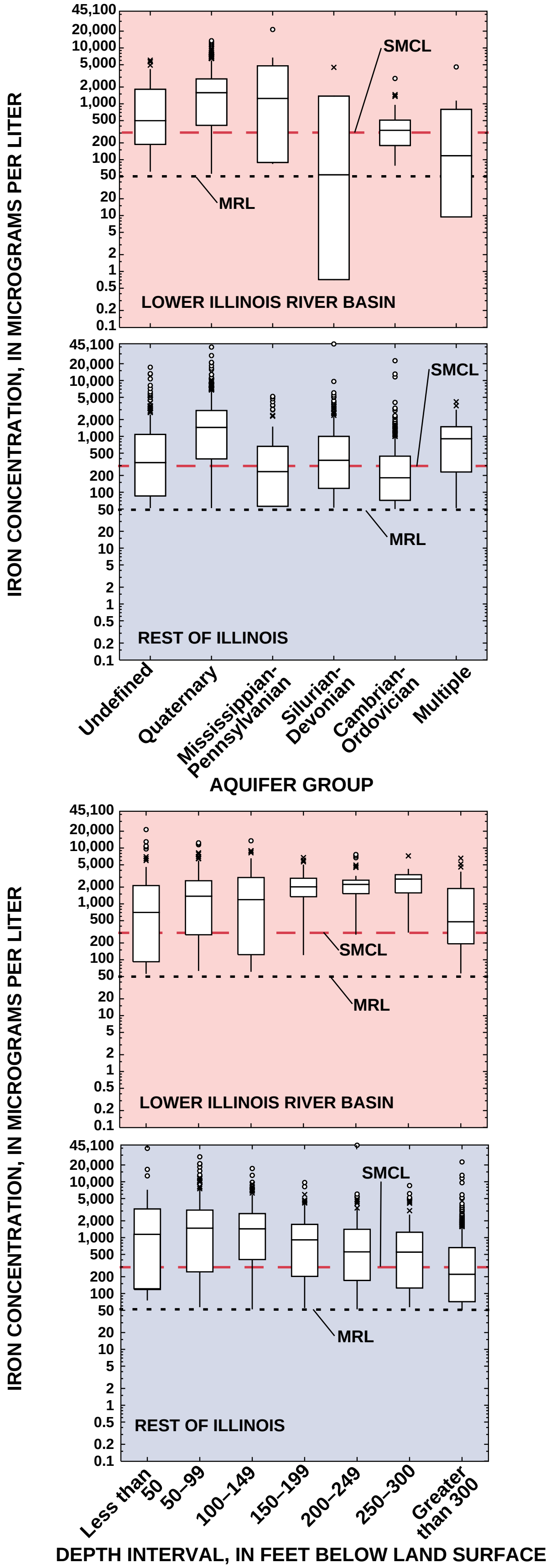

Figure 14–2. Distribution of iron concentrations in ground water by aquifer group and depth interval.

(See figure 4–1. for explanation of boxplots. Method reporting limit is 50 micrograms per liter (µg/L). U.S. Environmental Protection Agency Secondary Maximum Contaminant Level is 300 µg/L.)

15. LEAD

LEAD CONCENTRATIONS ARE LOW

There is no difference in lead concentration by aquifer or depth interval within the lower Illinois River Basin. There is a significant difference in lead concentration in the Quaternary aquifers between the lower Illinois River Basin and the rest of Illinois.

Lead exposure, as measured by blood test levels, is associated with a range of adverse health effects, including interference with heme synthesis necessary for formation of red blood cells, anemia, kidney damage, impaired reproductive function, interference with vitamin D metabolism, impaired cognitive performance, delayed neurological and physical development, and elevations in blood pressure (American Waterworks Association, 1990). Lead can have a deleterious effect on the cognitive development of infants and young children (Shannon and Graef, 1987), who absorb ingested lead more readily than do older children and young adults. Listed as a probable human carcinogen by the USEPA, lead also accumulates in aquatic organisms, including benthic bacteria, fresh water plants, invertebrates, and fish, but does not become amplified at successive levels of the food chain (Canadian Council of Resource and Environment Ministers, 1992). The IEPA Class I standard for potable ground-water resources and Class II standard for general ground-water resources are 7.5 µg/L and 100 µg/L, respectively. The USEPA MCL is 15 µg/L and the MCLG is 1,300 µg/L for lead concentrations in drinking water. There are 37 samples with concentrations above 7.5 µg/L and 7 of these samples are above 100 µg/L (fig. 15–1.).

Concentrations of dissolved lead generally are low in surface and ground water because of the tendency of lead to sorb onto sediment surfaces and form insoluble compounds with carbonates, hydroxides, sulfides, sulfates, and various oxides (Canadian Council of Resource and Environment Ministers, 1992). Lead in drinking water primarily comes from the corrosion of lead pipes and solder (American Waterworks Association, 1990), especially if water is poorly buffered or has a pH below neutrality. Although the concentrations of lead in drinking water commonly are less than 50 µg/L, concentrations can be as high as 2,600 µg/L in tap water left unused overnight in lead plumbing (Canadian Council of Resource and Environment Ministers, 1992).

Lead enters the environment naturally through the weathering of rock, particularly sulfide minerals. Anthropogenic sources, which contribute more lead to the hydrosphere than weathering, include mining, milling, smelting, and refining operations; atmospheric deposition; street runoff; and industrial and municipal wastewater discharges (Canadian Council of Resource and Environment Ministers, 1992).

In the LIRB, the concentrations of lead in 8 percent of the analyses were above the MRL (5.0 µg/L) and, therefore, statistical tests for differences among data sets are not valid. The range of concentrations was from 5 to 220 µg/L (table 15–1. and fig. 15–2.). The 25th, 50th, and 75th percentile concentrations of lead for all aquifers and specified depth intervals are at the MRL of 5 µg/L. The density of ground-water samples with detections of lead are in Peoria and Tazewell Counties near the Illinois River. In the LIRB, lead is significantly correlated with zinc (0.42) and copper (0.46), which are often found together in sulfide minerals in the carbonates of Illinois and are both constituents that may be dissolved from metal pipes and solder.

The rest of Illinois had 5 percent of observations above the MRL. The range of concentrations in the rest of Illinois was from 5 to 200 µg/L. The 25th, 50th, and 75th percentile concentrations of lead for all aquifers and depth intervals are at the MRL of 5 µg/L. Lead is not significantly correlated to other trace elements for the rest of Illinois, except for zinc (0.22) and copper (0.32), which have low correlation coefficients but high significance ($p \leq 0.05$).

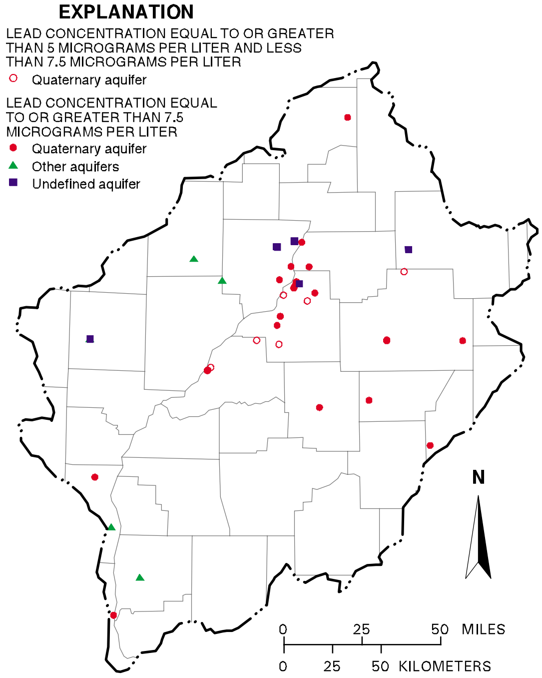

Figure 15–1. Lead concentrations above the method reporting limit for Quaternary, other aquifers, and undefined aquifers in the lower Illinois River Basin.

Table 15–1. Summary statistics for lead within and outside the lower Illinois River Basin

[N, number of observations; narl, number of observations above the method reporting limit; percentiles and maximums are in micrograms per liter; <, less than; gray cells are interpolated values; other aquifers include wells open to multiple aquifers and bedrock aquifers]

Aquifer or depth interval	N	narl	Percentile 25	Percentile 50 (median)	Percentile 75	Maximum
Lower Illinois River Basin						
Overall	613	46	<5.0	<5.0	<5.0	220
Quaternary aquifers	475	33	<5.0	<5.0	<5.0	220
Other aquifers	63	5	<5.0	<5.0	<5.0	190
Undefined aquifers	75	8	<5.0	<5.0	<5.0	190
Depths less than 50 feet	74	6	<5.0	<5.0	<5.0	200
Depths 50 feet or greater	530	37	<5.0	<5.0	<5.0	220
Unreported depths	9	3	.42	2.1	22	80
Rest of Illinois						
Overall	1,891	94	<5.0	<5.0	<5.0	200
Quaternary aquifers	543	24	<5.0	<5.0	<5.0	48
Other aquifers	912	41	<5.0	<5.0	<5.0	50
Undefined aquifers	436	29	<5.0	<5.0	<5.0	200
Depths less than 50 feet	79	3	<5.0	<5.0	<5.0	33
Depths 50 feet or greater	1,778	88	<5.0	<5.0	<5.0	200
Unreported depths	34	3	<5.0	<5.0	<5.0	62

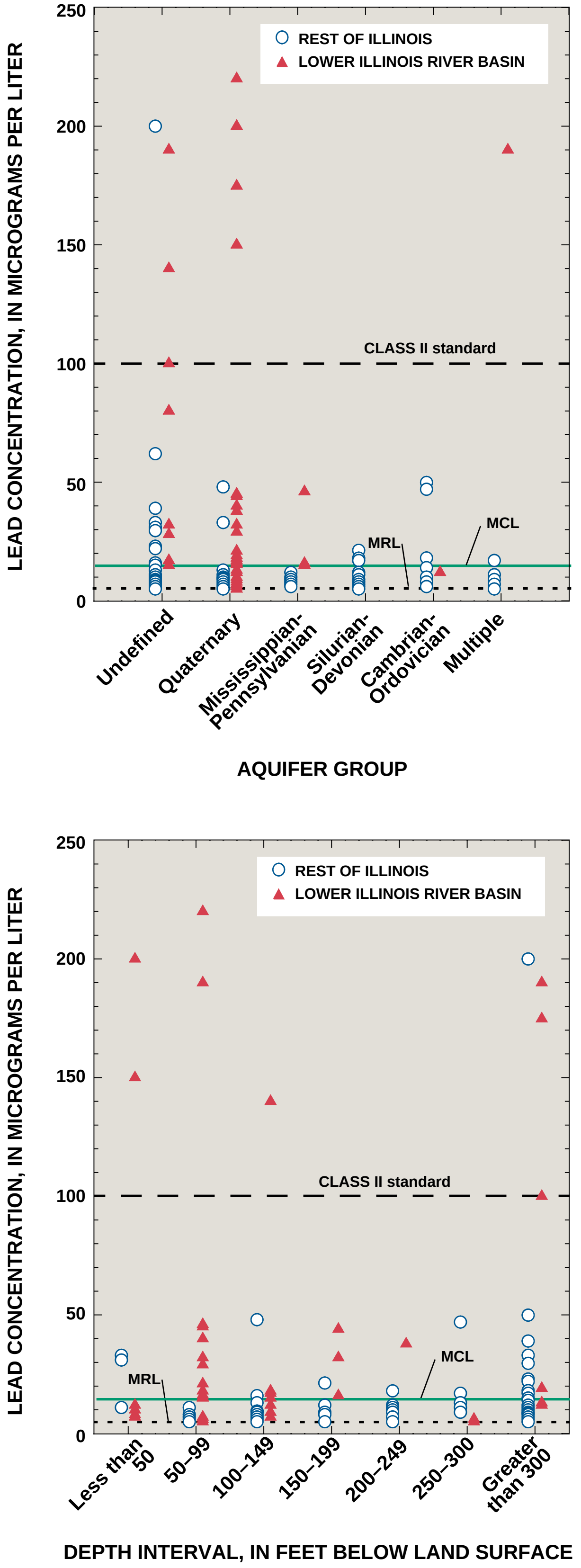

Figure 15–2. Distribution of lead concentrations in ground water by aquifer group and depth interval.

(U.S. Environmental Protection Agency Maximum Contaminant Level is 15 micrograms per liter (µg/L). Illinois Environmental Protection Agency Class II standard is 100 µg/L. Method reporting limit is 5.0 µg/L.)

16. MANGANESE

MANGANESE CONCENTRATIONS ARE HIGHEST IN THE QUATERNARY AQUIFER

There is a difference in manganese concentration by aquifer and depth interval within the lower Illinois River Basin. There is no significant difference in manganese concentration in the Quaternary and older aquifers between the lower Illinois River Basin and the rest of Illinois.

Manganese is an essential trace element for microorganisms, plants, and animals, and is unlikely to be toxic at concentrations found in natural waters. Manganese is regulated primarily for its tendency to deposit black oxide stains on laundry, cooking utensils, plumbing fixtures, and pipes. An upper limit of 10 µg/L has been recommended to minimize staining, and concentrations exceeding 200 µg/L may cause an unpleasant taste in drinking water (McNeely, Neimanis and Dwyer, 1979). The IEPA Class I standard for potable resource ground water and Class II standard for general resource ground water for manganese (Mn) are 150 and 10,000 µg/L, respectively. The USEPA SMCL is 50 µg/L. Within the LIRB, 26 percent of the 613 sample concentrations exceeded the Class I standard for potable resource ground water, whereas none exceeded the Class II standard for general resource ground water. In the LIRB, 161 analyses are above the IEPA Class I standard (150 µg/L). Ten percent of the 1,881 observations in the rest of Illinois were greater than 150 µg/L (fig. 16–1.).

In the absence of oxygen, under reducing conditions, manganese is present primarily as dissolved Mn^{+2} ions. Exposure to air will oxidize Mn^{+2} to its tetravalent form (Mn^{+4}), which tends to precipitate as manganese oxides. Manganese commonly occurs in association with iron (Canadian Council of Resource and Environment Ministers, 1992). Manganese is widely distributed in soils, sediments, and metamorphic and sedimentary rocks, which provide an appreciable natural source of Mn through weathering. The iron and steel industry and acid mine drainage, in particular, release a large portion of the manganese found in the environment (Canadian Council of Resource and Environment Ministers, 1992).

In the LIRB, the concentrations of manganese in 84 percent of the analyses were above the MRL (5.0 µg/L), and the range of concentrations was from 5 to 1,500 µg/L (table 16–1.). Application of the Kruskal-Wallis test showed significant differences between aquifers and by depth interval in the LIRB (fig. 16–2.). Compared with the other aquifers within the LIRB, the highest quartiles (25th, 50th, and 75th) and percentage of concentrations above the MRL were in the Quaternary aquifer. Only the Mississippian-Pennsylvanian aquifer had comparable values for the mean, median, and maximum. Manganese concentrations are highest within 100 ft of the land surface and lowest for depths greater than 300 ft. The mean and 75th and 90th percentiles for manganese generally decreased with increasing depth interval. Ground water with manganese concentrations above 150 µg/L are most common in the southern part of the LIRB in the shallow Quaternary aquifer. Boron and iron had the highest significance values ($p \leq 0.05$) for Spearman's rank-order correlation coefficients for manganese (–0.46 and 0.47, respectively).

Comparison between the rest of Illinois and the LIRB shows that there is not a significant difference in the Quaternary or older aquifers. Among the aquifer groups in the rest of Illinois, manganese concentrations were highest in the Quaternary aquifer. Overall, the median concentration of manganese in ground water in the rest of Illinois is lower than in the LIRB. Manganese concentrations in the rest of Illinois appeared to decrease with increasing depth interval, with the highest concentrations occurring within 100 ft of the land surface. In the rest of Illinois, only iron is significantly correlated with manganese (0.69).

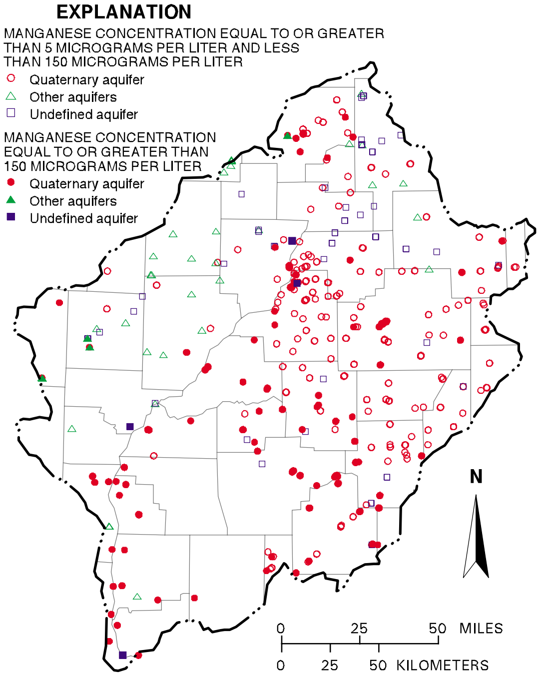

Figure 16–1. Manganese concentrations above the method reporting limit for Quaternary, other aquifers, and undefined aquifers in the lower Illinois River Basin.

Table 16–1. Summary statistics for manganese within and outside the lower Illinois River Basin

[N, number of observations; narl, number of observations above the method reporting limit; percentiles and maximums are in micrograms per liter; gray cells are interpolated values; other aquifers include wells open to multiple aquifers and bedrock aquifers]

Aquifer or depth interval	N	narl	Percentile 25	Percentile 50 (median)	Percentile 75	Maximum
Lower Illinois River Basin						
Overall	613	512	12	46	160	1,500
Quaternary aquifers	475	417	23	64	190	1,500
Other aquifers	63	37	1.8	7.0	15	1,400
Undefined aquifers	75	58	6.0	15	62	370
Depths less than 50 feet	74	58	9.8	180	370	1,400
Depths 50 feet or greater	530	447	12	42	140	1,500
Unreported depths	9	8	.19	31	88	140
Rest of Illinois						
Overall	1,881	1,498	5.7	15	45	2,200
Quaternary aquifers	541	494	27	59	180	2,200
Other aquifers	908	675	4.6	10	21	1,200
Undefined aquifers	432	329	5.0	11	36	1,100
Depths less than 50 feet	78	71	47	170	410	1,500
Depths 50 feet or greater	1,769	1,400	5.5	14	42	2,200
Unreported depths	34	27	5.0	10	.27	280

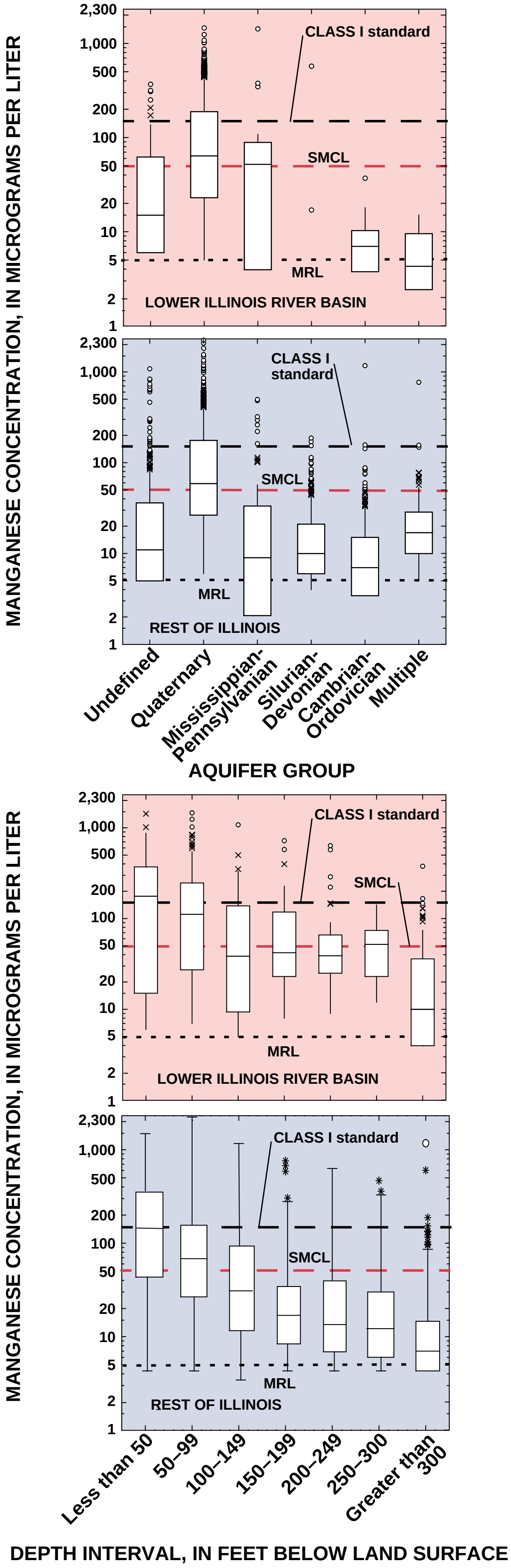

Figure 16–2. Distribution of manganese concentrations in ground water by aquifer group and depth interval.

(See figure 4–1. for explanation of boxplots. Illinois Environmental Protection Agency Class I standard is 150 micrograms per liter (µg/L). U.S. Environmental Protection Agency Secondary Maximum Contaminant Level is 50 µg/L. Method reporting limit is 5.0 µg/L.)

17. MERCURY

MERCURY CONCENTRATIONS DO NOT EXCEED 2 MICROGRAMS PER LITER

There is a difference in mercury concentration by aquifer and depth interval within the lower Illinois River Basin. There is no significant difference in mercury concentration in the Quaternary and other aquifers between the lower Illinois River Basin and the rest of Illinois.

The methylmercury ion is about 50 times more toxic to mammals than inorganic mercury salts. Mercury compounds have a long retention time in the human body (McNeely, Neimanis and Dwyer, 1979). The ingestion of mercury, particularly as part of an organic compound such as methylmercury, can result in permanent brain damage (McNeely, Neimanis, and Dwyer, 1979). The IEPA Class I standard for potable resource ground water and the Class II standard for general resource ground water for mercury, except due to natural causes, are 2 and 10 µg/L, respectively. The MCL for mercury (inorganic) is 2 µg/L. There are no samples with mercury concentrations above the MCL, Class I, or Class II standards. Overall, there are few detections—only 298 detections out of 2,485 samples.

The most stable form of mercury in most natural water systems is the free metal, Hg (aq). Concentrations of mercury in a ground-water system closed to the atmosphere are likely to be higher than concentrations in water open to the atmosphere because mercury tends to vaporize (Hem, 1985). Although mercury is rare, its natural tendency to volatilize widely disperses it. Organic complexes, such as methylmercury, ($HgCH_3$) and other similar forms, can be produced by methane-generating bacteria in contact with metallic mercury in sediments (Hem, 1985). Higher mercury concentrations in unfiltered samples, such as those collected for this study, generally are associated with unidentified solids. Concentrations of mercury in filtered samples usually are very low (Hem, 1985). Low concentrations of inorganic mercury favor the formation of dimethylmercury, whereas high concentrations favor the formation of monomethylmercury (McNeely, Neimanis, and Dwyer, 1979).

Mercury in the earth’s crust occurs only in minor quantities as the mineral cinnabar. A number of sulfide minerals, such as sphalerite, chalcopyrite, and galena, may contain mercury. Various industries have used mercury in products such as paints, electrical equipment, agricultural applications, and dental amalgams. In 1960, the use of mercury for treatment of seed grain and various other applications was banned in the United States. The burning of fossil fuels also can introduce mercury compounds to the environment (McNeely, Neimanis, and Dwyer, 1979).

In the LIRB, the concentrations of mercury in 12 percent of the analyses were above the MRL (0.005, 0.01, or 0.10 µg/L) (fig. 17–1.), and the range of concentrations was from 0.01 to 1.10 µg /L (table 17–1. and fig.17–2.). The water from wells that were open to multiple or unidentified aquifers had 56 percent of the samples above the MRL. Most detections are in the east central part of the LIRB. A low but statistically significant ($p \leq 0.05$) Spearman’s correlation coefficient between mercury and cyanide (0.31) or copper (0.26) indicates a slight correlation within the LIRB.

In the rest of Illinois, the concentrations of mercury in 12 percent of the analyses were above the MRL (0.005, 0.01, or 0.10 µg/L), and the range of concentrations was from 0.01 to 1.60 µg /L. The depth interval of less than 50 ft had a slightly higher percent (20 percent) of samples above the MRL compared with the other depth intervals, which ranged from 9 to 13 percent. The Spearman’s correlation between mercury and cyanide (0.27) or copper (0.11) is significant for the rest of Illinois.

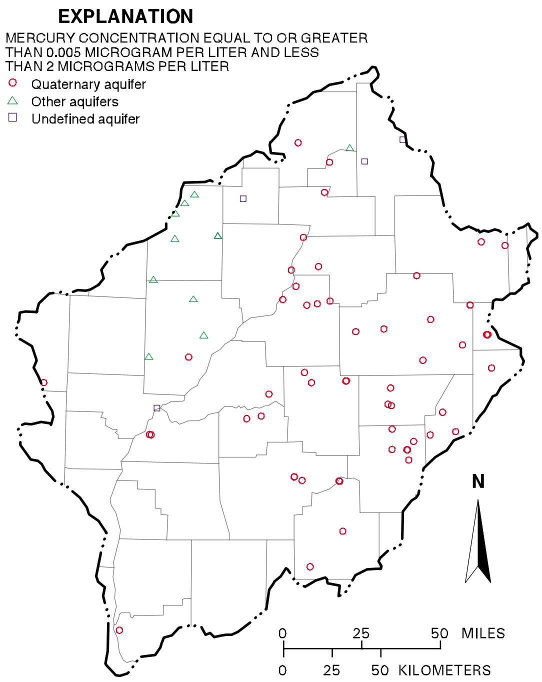

Figure 17–1. Mercury concentrations above the method reporting limits for Quaternary, other aquifers, and undefined aquifers in the lower Illinois River Basin.

Table 17–1. Summary statistics for mercury within and outside the lower Illinois River Basin

[N, number of observations; narl, number of observations above the method reporting limits; percentiles and maximums are in micrograms per liter ; other aquifers include wells open to multiple aquifers and bedrock aquifers]

Aquifer or depth interval	N	narl	Percentile 25	Percentile 50 (median)	Percentile 75	Maximum
Lower Illinois River Basin						
Overall	606	71	0.01	0.05	0.05	1.1
Quaternary aquifers	469	56	.01	.05	.05	1.1
Other aquifers	63	11	.01	.05	.05	.12
Undefined aquifers	74	14	.01	.05	.05	.18
Depths less than 50 feet	72	7	.01	.01	.05	.06
Depths 50 feet or greater	526	63	.01	.05	.05	1.1
Unreported depths	8	1	.03	.05	.05	.05
Rest of Illinois						
Overall	1,879	227	0.01	0.05	0.05	1.6
Quaternary aquifers	541	65	.01	.01	.05	.86
Other aquifers	903	90	.01	.05	.05	1.6
Undefined aquifers	435	72	.01	.05	.05	.21
Depths less than 50 feet	79	16	.01	.05	.05	.49
Depths 50 feet or greater	1,766	208	.01	.05	.05	1.6
Unreported depths	34	3	.05	.05	.05	.15

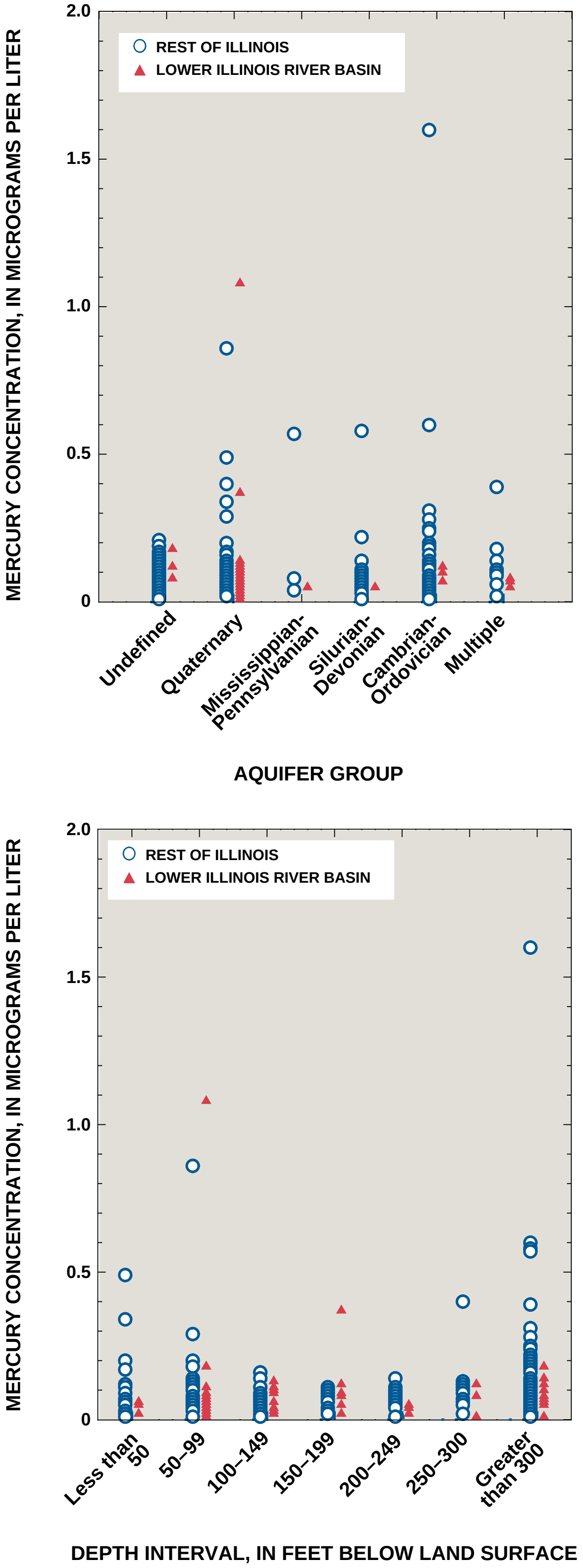

Figure 17–2. Distribution of mercury concentrations in ground water by aquifer group and depth interval.

(U.S. Environmental Protection Agency Maximum Contaminant Level is 2.0 micrograms per liter (µg/L); method reporting limits vary among 0.1, 0.01, and 0.005 µg/L depending on the analytical method.)

18. SELENIUM

SELENIUM DETECTED IN SHALLOW QUATERNARY AQUIFER

There is a difference in selenium concentration by aquifer and depth interval within the lower Illinois River Basin. There is no significant difference in selenium concentration in the Quaternary and other aquifers between the lower Illinois River Basin and the rest of Illinois.

Low levels of selenium are essential to human health. There are some correlations between reduced levels of breast cancer and heart disease at less than acute levels (Illinois State Water Survey, 1977b). Most intake of selenium is from food, which reflects the local soil conditions (American Waterworks Association, 1990). The concentration of selenium in drinking water typically is low. In 1978, USEPA surveys of the water quality of rural and community ground water showed 43 of 329 (13 percent) ground-water samples had selenium concentrations greater than 5 µg/L, and 10 of 329 samples (3 percent) had selenium concentrations greater than 10 µg/L (American Waterworks Association, 1990). The IEPA Class I and the Class II standards for selenium, except due to natural causes, are 50 µg/L. The USEPA drinking water standard MCL and MCLG also are 50 µg/L. There were many detections of selenium in the LIRB (fig. 18–1.). There were no concentrations above the standard for selenium for the LIRB or rest of Illinois in the samples collected for this study.

Dissolved selenium in the aquatic environment occurs in oxygenated water as selenite (SeO_3^{2-}) or selenate (SeO_4^{2-}) ionic species but is readily reduced to elemental and relatively insoluble Se^0 (Hem, 1985). Selenium is frequently found in large amounts in deposits of native sulfur and sulfide ores of heavy metals and in coal (Canadian Council of Resource and Environment Ministers, 1992). Selenium occurs naturally in water in trace amounts as a result of geochemical processes such as weathering of rocks and erosion of soil (Canadian Council of Resource and Environment Ministers, 1992). Selenium is found at low concentrations in the soils of Illinois. Anthropogenic sources of selenium in water include effluents from copper and lead refineries and municipal sewage (Canadian Council of Resource and Environment Ministers, 1992).

In the LIRB, the concentrations of selenium in 21 percent of the analyses were above the MRL (1.0 µg/L), and the range of selenium concentrations was from 1 to 7 µg/L (table 18–1.). In the LIRB, there are differences among aquifers and by depth interval of selenium concentrations as determined using the Kruskal-Wallis test (fig. 18–2.). There is a significant difference in concentrations between the Quaternary aquifer and older aquifers. The median concentrations for the Quaternary and older aquifers are below the MRL of 1 µg/L, but there was a larger percent of samples (24 percent) with concentrations above the MRL for the Quaternary aquifer compared with the older aquifers (3 percent). The water from wells that are less than 50 ft deep had more samples with concentrations above the MRL (34 percent) than samples from wells greater than 50 ft deep (19 percent). The concentrations of selenium in ground water over 2 µg/L are concentrated along the Illinois River upstream from the city of Peoria. Selenium concentrations were compared with other trace elements, nutrients, and inorganic constituents using the Spearman’s correlation coefficient. The correlations between selenium and nitrate (0.40) and ammonia (–0.31) had the most significance. There are small but significant ($p \leq 0.05$) correlations among selenium and iron, fluoride, arsenic, boron, and sulfate.

There is no significant difference in selenium concentrations between the LIRB and the rest of Illinois for the Quaternary and older aquifers or by depth interval. A higher percent of concentrations above the MRL were found in the samples from the LIRB (21 percent) compared with the rest of Illinois (10 percent). The median for the rest of Illinois and the LIRB is 1 µg/L, which is at the MRL.

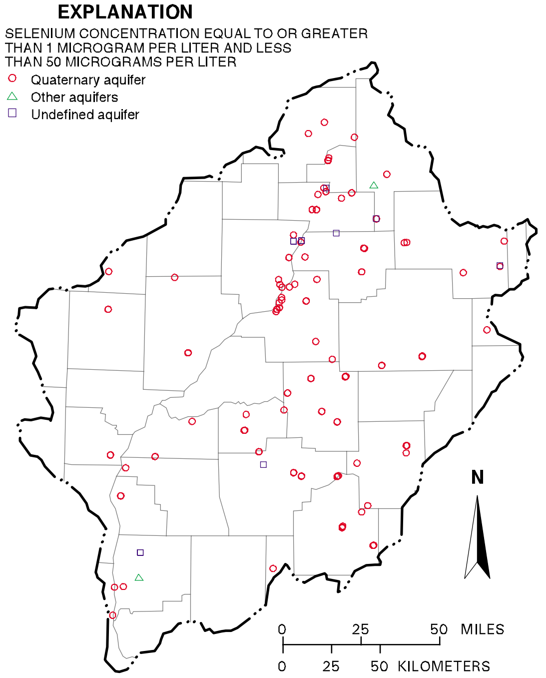

Figure 18–1. Selenium concentrations above the method reporting limit for Quaternary, other aquifers, and undefined aquifers in the lower Illinois River Basin.

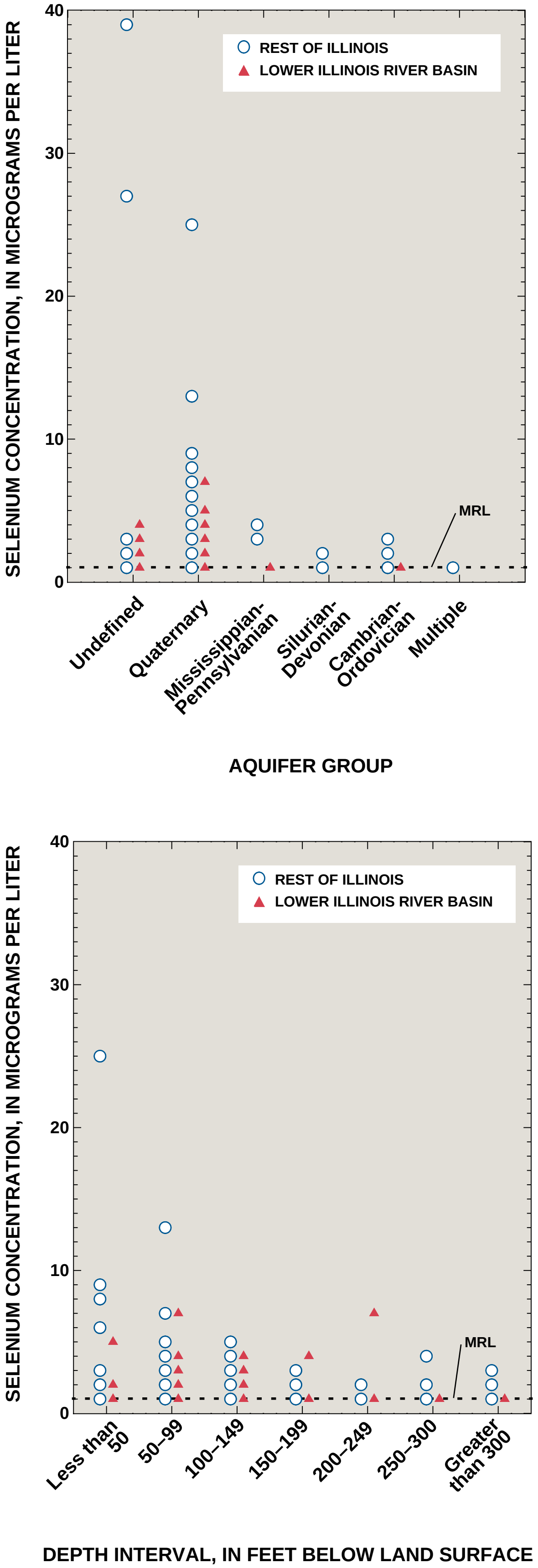

Figure 18–2. Distribution of selenium concentrations in ground water by aquifer group and depth interval.
(Method reporting limit is 1.0 microgram per liter.)

Table 18–1. Summary statistics for selenium within and outside the lower Illinois River Basin

[N, number of observations; narl, number of observations above the method reporting limit; percentiles and maximums are in micrograms per liter; <, less than; gray cells are interpolated values; other aquifers include wells open to multiple aquifers and bedrock aquifers]

Aquifer or depth interval	N	narl	Percentile 25	Percentile 50 (median)	Percentile 75	Maximum
Lower Illinois River Basin						
Overall	613	128	<1.0	<1.0	<1.0	7.0
Quaternary aquifers	475	115	.39	.60	.94	7.0
Other aquifers	63	2	<1.0	<1.0	<1.0	1.0
Undefined aquifers	75	11	<1.0	<1.0	<1.0	4.0
Depths less than 50 feet	74	25	.49	.74	1.0	5.0
Depths 50 feet or greater	530	101	<1.0	<1.0	<1.0	7.0
Unreported depths	9	2	<1.0	<1.0	<1.0	1.0
Rest of Illinois						
Overall	1,885	195	<1.0	<1.0	<1.0	39
Quaternary aquifers	542	94	<1.0	<1.0	<1.0	25
Other aquifers	908	58	<1.0	<1.0	<1.0	5.0
Undefined aquifers	435	43	<1.0	<1.0	<1.0	39
Depths less than 50 feet	78	21	.15	.39	1.0	25
Depths 50 feet or greater	1,773	172	<1.0	<1.0	<1.0	13
Unreported depths	34	2	<1.0	<1.0	<1.0	39

19. SILVER

SILVER CONCENTRATIONS VARY BY AQUIFER

There is a difference in silver concentration by aquifer within the lower Illinois River Basin. There is a significant difference in silver concentration in the older aquifers between the lower Illinois River Basin and the rest of Illinois.

Silver (Ag) is not considered a health threat by the USEPA because silver does not impair bodily functions or cause physiological problems, and there is no evidence of carcinogenicity or mutagenicity (American Waterworks Association, 1990). Accumulations of 1 to 5 grams of silver can result in argyria (a permanent, blue-gray discoloration of the skin and organs), but no known cases of argyria from drinking water have been reported (American Waterworks Association, 1990). The IEPA Class I standard for silver is 50 µg/L, but there is no IEPA Class II standard for silver. There is no USEPA MCL or MCLG for silver, but the SMCL is 100 µg/L. There are low detections of silver (3–31 µg/L) in ground water in the LIRB (fig. 19–1.) and the rest of Illinois but no concentrations above the SMCL.

The solubility of silver is limited to less than 10 µg/L in most natural water due to pH-EH conditions (Hem, 1985). Silver occurs naturally in its elemental form and in ores, such as argentite (Ag_2S) and cerargyrite (AgCl). Silver also may be found in association with sulfur, chlorides, and ammonia salts. Silver is released into the environment by weathering; volcanic activity; and discharges from photographic, electronic, and electroplating industries. Most of the world's silver production comes as a by-product of lead-zinc, copper, and gold mining (Canadian Council of Resource and Environmental Ministers, 1992). Concentrations of silver generally are low in the aquatic environment because of low crustal abundance, precipitation as solids, and sorption to solids, particularly by manganese dioxide. Silver iodide has been used in seeding clouds with condensation nuclei to induce rainfall, but resulting concentrations of silver in rainfall are too low to have substantial effects on ground water (Hem, 1985).

In the LIRB, the concentrations of silver in 12 percent of the analyses were above the MRL (3.0 µg/L), and the range of concentrations was from 3 to 13 µg/L (fig. 19–2. and table 19–1.). The ranges of concentrations for the Quaternary and older aquifers are similar. The Quaternary aquifer had the lowest percentage of concentrations above the MRL (10 percent), whereas 17 percent for the older aquifers were above the MRL. There does not appear to be a spatial pattern of silver detections in ground water. Chromium (0.32) and copper (0.25) are significantly correlated with silver.

There is a greater range of silver concentrations in the rest of Illinois, but the 75th percentile was still at the MRL. Samples from older aquifers in the rest of Illinois had less than 1 percent silver concentrations above the MRL compared with 17 percent of silver concentrations from older aquifers above the MRL for the LIRB. There is a higher percentage of detections of silver in the water from wells less than 50 ft deep. Similar to the LIRB, there is a significant correlation of silver with chromium (0.29) and copper (0.15).

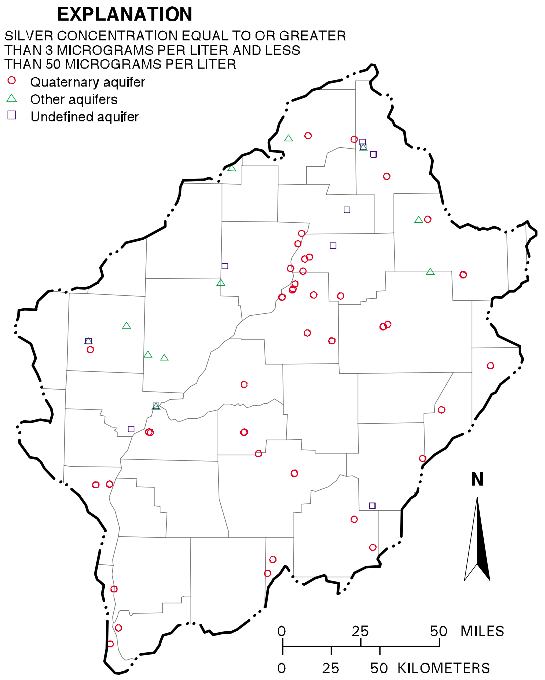

Figure 19–1. Silver concentrations above the method reporting limit for Quaternary, other aquifers, and undefined aquifers in the lower Illinois River Basin.

Table 19–1. Summary statistics for silver within and outside the lower Illinois River Basin

[N, number of observations; narl, number of observations above the method reporting limit; percentiles and maximums are in micrograms per liter; <, less than; other aquifers include wells open to multiple aquifers and bedrock aquifers]

Aquifer or depth interval	N	narl	Percentile 25	Percentile 50 (median)	Percentile 75	Maximum
Lower Illinois River Basin						
Overall	612	72	<3.0	<3.0	<3.0	13
Quaternary aquifers	474	48	<3.0	<3.0	<3.0	13
Other aquifers	63	11	<3.0	<3.0	<3.0	12
Undefined aquifers	75	13	<3.0	<3.0	<3.0	10
Depths less than 50 feet	74	7	<3.0	<3.0	<3.0	10
Depths 50 feet or greater	529	64	<3.0	<3.0	<3.0	13
Unreported depths	9	1	<3.0	<3.0	<3.0	11
Rest of Illinois						
Overall	1,880	132	<3.0	<3.0	<3.0	31
Quaternary aquifers	541	45	<3.0	<3.0	<3.0	31
Other aquifers	908	53	<3.0	<3.0	<3.0	27
Undefined aquifers	431	34	<3.0	<3.0	<3.0	19
Depths less than 50 feet	78	15	<3.0	<3.0	<3.0	13
Depths 50 feet or greater	1,768	115	<3.0	<3.0	<3.0	31
Unreported depths	34	2	<3.0	<3.0	<3.0	19

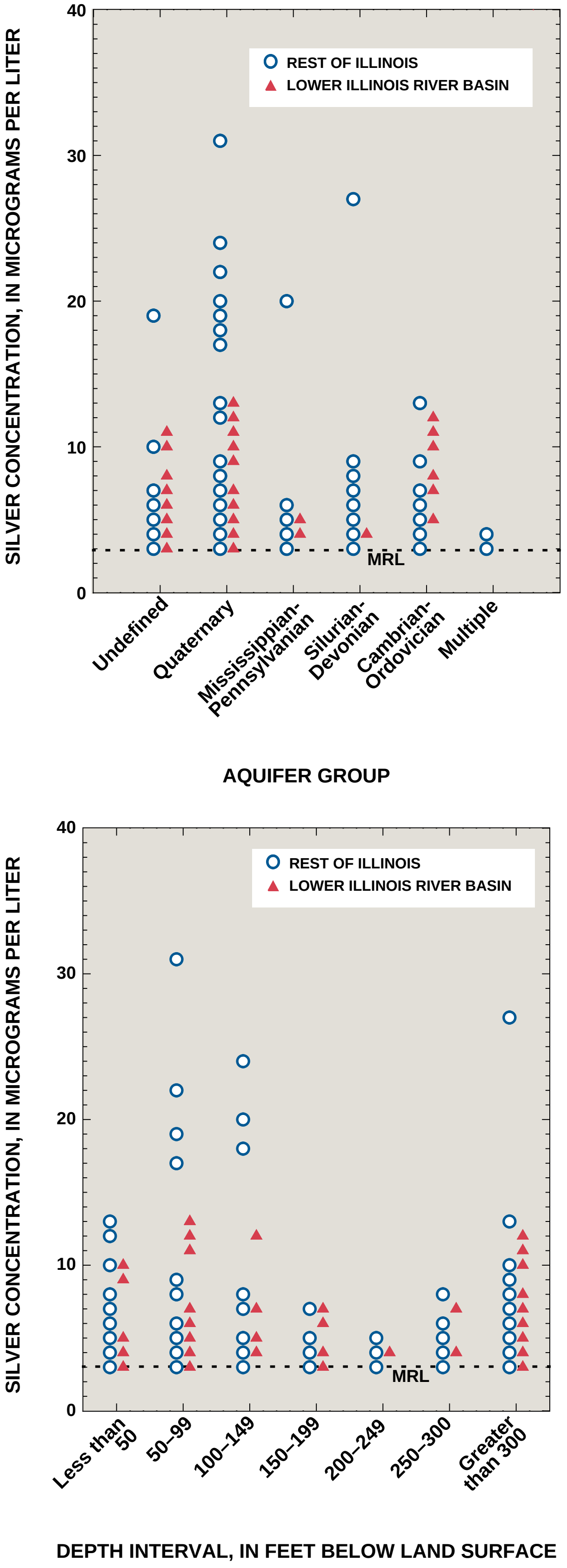

Figure 19–2. Distribution of silver concentrations in ground water by aquifer group and depth interval.
(Method reporting limit is 3.0 micrograms per liter.)

20. ZINC

ZINC CONCENTRATIONS VARY SIGNIFICANTLY BY DEPTH

There is a difference in zinc concentration by depth interval but not by aquifer group within the lower Illinois River Basin. There is a significant difference in zinc concentration in the Quaternary aquifer between the lower Illinois River Basin and the rest of Illinois.

Zinc is relatively nontoxic to man (McNeely, Neimanis, and Dwyer, 1979). There are no known health effects from excess zinc intake, but there are some adverse effects of a too low intake of zinc (American Waterworks Association, 1990). Excessive amounts of zinc are regulated on the basis of taste and smell considerations. The IEPA Class I and the Class II standards for zinc, except due to natural causes, are 5,000 and 10,000 µg/L, respectively. The USEPA SMCL is 5,000 µg/L. Two samples had zinc concentrations above the SMCL (fig. 20–1.). There were no samples above the Class I standard for samples from wells in the rest of Illinois.

Zinc is a common metal in the environment. Zinc is found in rocks as a sulfide or carbonate associated with copper-zinc and copper-lead-zinc ores (McNeely, Neimanis, and Dwyer, 1979). These ores are present in Illinois. Zinc is used in coatings to protect iron and steel; in alloys for die casting; and in brass rolled sheets and strips for dry batteries, roofing and exterior fittings on buildings, and some printing processes (Canadian Council of Resource and Environment Ministers, 1992). Zinc is used in brass and other alloys used in plumbing systems (Illinois State Water Survey, 1977a).

Zinc (Zn) has only one important oxidation state in the aqueous system (Zn^{2+}) and tends to be relatively soluble in water (Hem, 1985). The highest dissolved zinc concentration in water is possible at low pH, low alkalinity, and high ionic strength (Hem, 1985). In natural waters, zinc can be found in many forms, such as simple hydrated ions, and inorganic and organic complexes (Canadian Council of Resource and Environment Ministers, 1992). In the presence of other dissolved solids, much of the zinc will be transported in solution as hydrated cations or complex species. In the presence of suspended solids, much of the zinc will be sorbed to suspended solids and colloidal particles (Canadian Council of Resource and Environment Ministers, 1992).

In the LIRB, the concentrations of zinc in 7 percent of the analyses were above the MRL (50 or 100 µg/L), and the range of concentrations was from 50 to 16,000 µg/L (fig. 20–2. and table 20–1.). In the LIRB, 78 percent of the samples that were analyzed for zinc are from the Quaternary aquifer. The Quaternary aquifer also had the highest zinc concentration—16,000 µg/L. All aquifers have a median concentration of 50 µg/L, which is at the lowest MRL. There is no significant difference in zinc concentrations by aquifer group within the LIRB. The median concentration for zinc is at the MRL for all depth intervals. The samples from wells less than 50 ft deep in the LIRB had 16 percent detections, and wells greater than 50 ft deep had detections of zinc in only 5 percent of samples. Although the median and quartiles are the same between samples for less than 50 ft and deeper, the range of concentrations increases with increasing depth interval. The range of concentrations for the LIRB is from 50 to 16,000 µg/L, with the maximum concentrations in the Quaternary aquifer at a depth interval greater than 300 ft. There is a significant difference in zinc concentrations by depth interval for the LIRB. There is no spatial pattern of zinc concentration in ground water. Zinc is significantly correlated with lead (0.42) and copper (0.33). The correlation of zinc with cyanide and mercury is small, but there is a high probability that there is some correlation.

Zinc concentrations were significantly different in the rest of Illinois by aquifer and by depth interval. There is a significant difference between zinc concentrations in the Quaternary aquifer in the LIRB and the rest of Illinois but no significant difference for older aquifers. The correlations of zinc and other constituents in samples from the rest of Illinois show the highest correlations with copper (0.25) and lead (0.22).

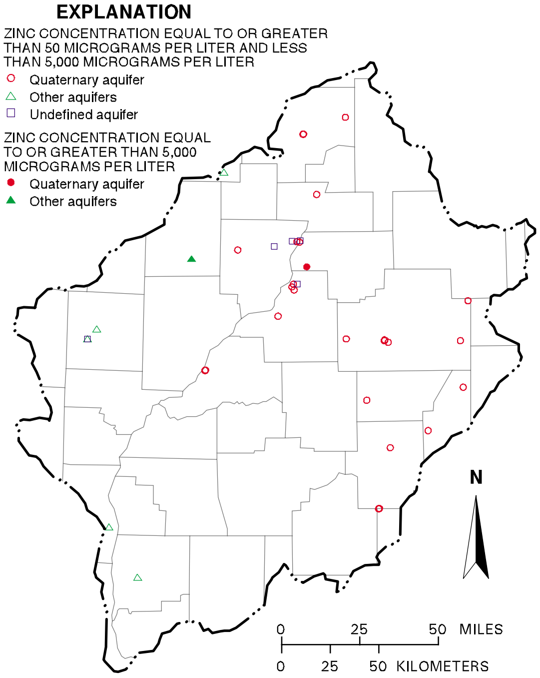

Figure 20–1. Zinc concentrations above the method reporting limit for Quaternary, other aquifers, and undefined aquifers in the lower Illinois River Basin.

Table 20–1. Summary statistics for zinc within and outside the lower Illinois River Basin

[N, number of observations; narl, number of observations above method reporting limits; percentiles and maximums are in micrograms per liter; <, less than; other aquifers include wells open to multiple aquifers and bedrock aquifers]

Aquifer or depth interval	N	narl	Percentile 25	50 (median)	75	Maxi-mum
Lower Illinois River Basin						
Overall	612	43	<50	<50	<50	16,000
Quaternary aquifers	475	32	<50	<50	<50	16,000
Other aquifers	63	6	<50	<50	<50	12,000
Undefined aquifers	74	5	<50	<50	<50	4,600
Depths less than 50 feet	74	12	<50	<50	<50	1,700
Depths 50 feet or greater	529	29	<50	<50	<50	16,000
Unreported depths	9	2	<50	<50	120	350
Rest of Illinois						
Overall	1,879	148	<50	<50	<50	4,000
Quaternary aquifers	541	25	<50	<50	<50	1,600
Other aquifers	906	79	<50	<50	<50	2,400
Undefined aquifers	432	44	<50	<50	<50	3,900
Depths less than 50 feet	78	5	<50	<50	<50	770
Depths 50 feet or greater	1,767	139	<50	<50	<50	3,600
Unreported depths	34	4	<50	<50	<50	3,900

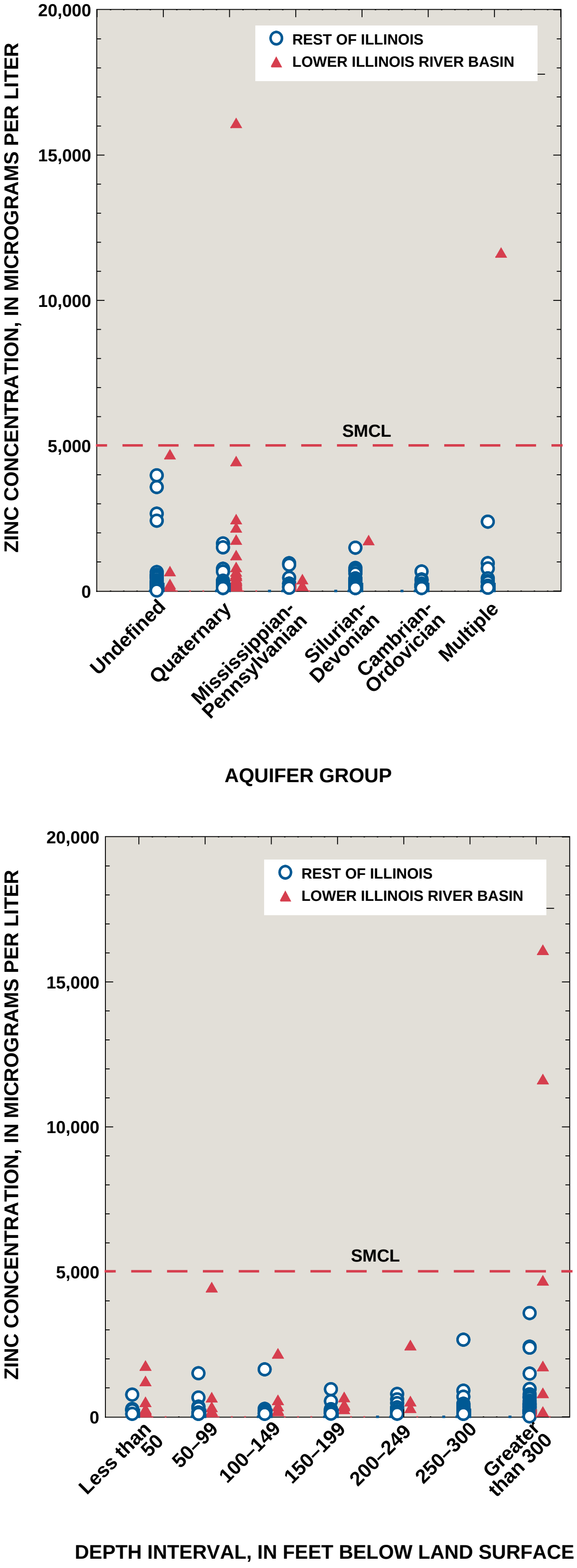

Figure 20–2. Distribution of zinc concentrations in ground water by aquifer group and depth interval.

(U.S. Environmental Protection Agency Secondary Maximum Contaminant Level is 5,000 micrograms per liter.)

21. SUMMARY AND CONCLUSIONS

The lower Illinois River Basin study unit is part of the National Water-Quality Assessment program, which includes most major aquifers in the United States. More than one-half of the drinking water in the lower Illinois River Basin is supplied from ground water. The study characterized and compared the source water quality from wells in four major aquifer groups—Quaternary, Mississippian-Pennsylvanian, Silurian-Devonian, and Cambrian-Ordovician. Water-quality data from wells that tapped undefined or multiple aquifers also were examined. The water-quality data were further characterized and compared with respect to the depth interval of the sampled wells. Similar water-quality data from wells in the area of the State outside of the lower Illinois River Basin were characterized and compared with the data from the lower Illinois River Basin.

Constituent concentrations vary in ground water in similar aquifers between the lower Illinois River Basin and the rest of Illinois (table 21–1.). There is a significant difference in lead concentrations in water from wells in the Quaternary aquifer between the lower Illinois River Basin and the rest of Illinois. Three other constituents (arsenic, sulfate, and zinc) also had significant differences in concentrations from wells in the Quaternary aquifer between the lower Illinois River Basin and the rest of Illinois. One common source for arsenic, lead, sulfate, and zinc is from mining and coal combustion. The older rocks in the lower Illinois River Basin are mined for coal. The percentage of land area within the lower Illinois River Basin with coal-bearing bedrock is greater than the area outside the lower Illinois River Basin containing coal-bearing bedrock, especially for areas where ground water is the main drinking-water source. The bedrock materials that were eroded and redeposited by Quaternary continental glaciers are a source for minerals that contain arsenic, lead, sulfate, and zinc. Leaching of these minerals combined with coal processing by-products make the Quaternary aquifer susceptible to high concentrations of these minerals. Therefore, the lower Illinois River Basin contains a source in the immediate area for arsenic, lead, sulfate, and zinc that could easily leach to the ground-water system.

The concentrations of ammonia, arsenic, boron, chloride, chromium, and silver in the aquifers other than Quaternary are significantly different between the lower Illinois River Basin and the rest of Illinois. The median concentrations for ammonia and chloride are 2 to 10 times higher for the lower Illinois River Basin. The median concentrations for chromium and silver are the same for the lower Illinois River Basin and the rest of Illinois. Approximately 10 percent of all samples analyzed are above the MRL for chromium and silver, but the percent of detections above the MRL for the lower Illinois River Basin older aquifers is higher than the rest of Illinois. Within the lower Illinois River Basin, most constituents had differences in concentrations by aquifer or depth interval (table 21–2.). Chromium, copper, and lead did not show a significant difference by aquifers or depth interval.

The differences in concentrations of three constituents—silver, sulfate, and zinc—in the lower Illinois River Basin and the rest of Illinois were significant by either depth interval or aquifer but not both. A comparison of concentration by depth interval within an aquifer indicated that the concentration of manganese, nitrate, and selenium are highest in the shallow Quaternary aquifer, whereas concentrations of arsenic are highest in the deeper Quaternary aquifer. The older aquifers did not show higher concentrations of any constituent at shallow depths. The concentrations of boron, chloride, chromium, and sulfate did increase within the older aquifers as depth increased.

Table 21–1. Significant difference in concentrations of constituents between the Quaternary and other aquifers of the lower Illinois River Basin and the rest of Illinois by means of the Wilcoxon Rank-Sum statistical test

Differences between the lower Illinois River Basin and the rest of Illinois		
Water-quality constituent	**Quaternary aquifer**	**Other aquifers**
Ammonia	No	Yes
Nitrates and nitrites	No	No
Chloride	No	Yes
Sulfate	Yes	No
Arsenic	Yes	Yes
Boron	No	Yes
Chromium	No	Yes
Copper	No	No
Cyanide	Not applicable	Not applicable
Iron	No	No
Lead	Not applicable	Not applicable
Manganese	No	No
Mercury	No	No
Selenium	No	No
Silver	No	Yes
Zinc	Yes	No

Table 21–2. Significant difference in concentrations of constituents by aquifer group and depth interval by means of the Wilcoxon Rank-Sum statistical test for the lower Illinois River Basin and the rest of Illinois

Water-quality constituent	Lower Illinois River Basin		Rest of Illinois	
	Aquifer group	Depth interval	Aquifer group	Depth interval
Ammonia	Yes	Yes	Yes	Yes
Nitrates and nitrites	Yes	Yes	Yes	Yes
Chloride	Yes	Yes	Yes	Yes
Sulfate	Yes	Yes	Yes	No
Arsenic	Yes	Yes	Yes	Yes
Boron	Yes	Yes	Yes	Yes
Chromium	No	No	No	No
Copper	No	No	No	No
Cyanide	Not applicable	Not applicable	Not applicable	Not applicable
Iron	Yes	Yes	Yes	Yes
Lead	Not applicable	Not applicable	Not applicable	Not applicable
Manganese	Yes	Yes	Yes	Yes
Mercury	Yes	Yes	Yes	Yes
Selenium	Yes	Yes	Yes	Yes
Silver	Yes	No	Yes	Yes
Zinc	No	Yes	Yes	Yes

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GLOSSARY

Class I Standard for Potable Resource Ground Water. Maximum permissible level determined by the Illinois Environmental Protection Agency for all ground water that is 10 feet or more below the land surface and meets defined geologic criteria or is within 200 or 400 feet of a potable water supply.

Class II Standard for General Resource Ground Water. Maximum permissible level determined by the Illinois Environmental Protection Agency for all ground water that is not regulated by Class I standards.

Maximum Contaminant Level (MCL). Maximum permissible level of a contaminant in water that is delivered to any user of a public water system.

Maximum Contaminant Level Goal (MCLG). A nonenforceable concentration of a drinking water contaminant that is protective of adverse human health effects and allows an adequate margin of safety.

Secondary Maximum Contaminant Levels (SMCL). A nonenforceable Federal guideline for taste, odor, color, and certain other nonaesthetic aspects of drinking water.

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