Quality of Shallow Ground Water in Areas of Recent Residential and Commercial Development, Wichita, Kansas, 2000

NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

Water-Resources Investigations Report 02–4228

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

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By LARRY M. POPE, BRETON W. BRUCE, PATRICK P. RASMUSSEN, and CHAD R. MILLIGAN

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FOREWORD

The U.S. Geological Survey (USGS) is committed to serve the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life, and facilitates effective management of water, biological, energy, and mineral resources (http://www.usgs.gov). Information on the quality of the Nation's water resources is of critical interest to the USGS because it is so integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and that is suitable for industry, irrigation, and habitat for fish and wildlife. Escalating population growth and increasing demands for the multiple water uses make water availability, now measured in terms of quantity and quality, even more critical to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program to support national, regional, and local information needs and decisions related to water-quality management and policy (http://water.usgs.gov/nawqa). Shaped by and coordinated with ongoing efforts of other Federal, State, and local agencies, the NAWQA Program is designed to answer: What is the condition of our Nation's streams and ground water? How are the conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues and priorities. NAWQA results can contribute to informed decisions that result in practical and effective water-resource management and strategies that protect and restore water quality.

Since 1991, the NAWQA Program has implemented interdisciplinary assessments in more than 50 of the Nation's most important river basins and aquifers, referred to as Study Units (http://water.usgs.gov/nawqa/nawqamap.html). Collectively, these Study Units account for more than 60 percent of the overall water use and population served by public water supply, and are representative of the Nation's major hydrologic landscapes, priority ecological resources, and agricultural, urban, and natural sources of contamination.

Each assessment is guided by a nationally consistent study design and methods of sampling and analysis. The assessments thereby build local knowledge about water-quality issues and trends in a particular stream or aquifer while providing an understanding of how and why water quality varies regionally and nationally. The consistent, multi-scale approach helps to determine if certain types of water-quality issues are isolated or pervasive, and allows direct comparisons of how human activities and natural processes affect water quality and ecological health in the Nation's diverse geographic and environmental settings. Comprehensive assessments on pesticides, nutrients, volatile organic compounds, trace metals, and aquatic ecology are developed at the national scale through comparative analysis of the Study-Unit findings (http://water.usgs.gov/nawqa/natsyn.html).

The USGS places high value on the communication and dissemination of credible, timely, and relevant science so that the most recent and available knowledge about water resources can be applied in management and policy decisions. We hope this NAWQA publication will provide you the needed insights and information to meet your needs, and thereby foster increased awareness and involvement in the protection and restoration of our Nation's waters.

The NAWQA Program recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for a fully integrated understanding of watersheds and for cost-effective management, regulation, and conservation of our Nation's water resources. The Program, therefore, depends extensively on the advice, cooperation, and information from other Federal, State, interstate, Tribal, and local agencies, non-government organizations, industry, academia, and other stakeholder groups. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Associate Director for Water

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CONVERSION FACTORS, ABBREVIATIONS, AND DATUM

Multiply	By	To obtain
acre	4,047	square meter (m^2)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
foot (ft)	0.3048	meter (m)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
inch (in.)	2.54	centimeter (cm)
kilogram (kg)	2.205	pound (lb)
meter (m)	3.281	foot (ft)
microgram per liter (µg/L)	1.0	part per billion (ppb)
micrometer (µm)	0.00003937	inch (in.)
mile (mi)	1.609	kilometer (km)
mile per hour (mi/h)	1.609	kilometer per hour (km/h)
milligram per liter (mg/L)	1.0	part per million (ppm)
milliliter (mL)	0.0338	ounce, fluid (oz)
millimeter (mm)	0.03937	inch (in.)
picogram per kilogram (pg/kg)	1.6×10^{-14}	ounce per pound (oz/lb)
pound (lb)	0.4536	kilogram (kg)
pound per acre (lb/acre)	1.121	kilogram per hectare (kg/ha)
pound per square inch (lb/in^2)	6.895	kilopascal (kPa)
square mile (mi^2)	2.590	square kilometer (km^2)
ton	0.9072	megagram (Mg)

Temperature can be converted to degrees Celsius (°C) or degrees Fahrenheit (°F) by the equations:

$$^{o}C = 5/9\ (^{o}F-32)$$
$$^{o}F = 9/5\ (^{o}C) + 32.$$

Horizonal coordinate information is referenced to the North American Datum of 1983 (NAD 83). Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Quality of Shallow Ground Water in Areas of Recent Residential and Commercial Development, Wichita, Kansas, 2000

By Larry M. Pope, Breton W. Bruce, Patrick P. Rasmussen, *and* Chad R. Milligan

Abstract

Water samples from 30 randomly distributed monitoring wells in areas of recent residential and commercial development (1960–96), Wichita, Kansas, were collected in 2000 as part of the High Plains Regional Ground-Water Study conducted by the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) Program. The samples were analyzed for about 170 water-quality constituents that included chlorofluorocarbons, physical properties, dissolved solids and major ions, nutrients and dissolved organic carbon, trace elements, pesticide compounds, and volatile organic compounds. The purpose of this report is to provide an assessment of water quality in recharge to shallow ground water underlying areas of recent residential and commercial development and to determine the relation of ground-water quality to overlying urban land use.

Analyses of water from the 30 monitoring wells for chlorofluorocarbons were used to estimate apparent dates of recharge. Water from 18 wells with nondegraded and uncontaminated chlorofluorocarbon concentrations had calculated apparent recharge dates that ranged from 1979 to 1990 with an average date of 1986.

Water from 14 monitoring wells (47 percent) exceeded the 500-milligrams-per-liter Secondary Maximum Contaminant Level established by the U.S. Environmental Protection Agency for dissolved solids in drinking water. The Secondary Maximum Contaminant Levels of 250 milligrams per liter for chloride and sulfate were exceeded in water from one well. The source of the largest concentrations of dissolved solids and associated ions, such as chloride and sulfate, in shallow ground water in the study area probably is highly mineralized water moving out of the Arkansas River into the adjacent, unconsolidated deposits and mixing with the dominant calcium bicarbonate water in the deposits.

Concentrations of most nutrients in water from the sampled wells were small, with the exception of nitrate. Although water from the sampled wells did not have nitrate concentrations larger than the 10-milligram-per-liter Maximum Contaminant Level for drinking water, water from 50 percent of the sampled wells showed nitrate enrichment (concentrations greater than 2.0 milligrams per liter).

Most trace elements in water from the sampled wells were detected only in small concentrations, and few exceeded respective water-quality standards. Twenty percent of iron concentrations, 40 percent of manganese concentrations, 3 percent of arsenic concentrations, and 13 percent of uranium concentrations exceeded respective Maximum Contaminant Levels or Secondary Maximum Contaminant Levels.

A total of 47 pesticide compounds were analyzed in ground-water samples during this study. Water from 73 percent of the wells sampled had detectable concentrations of one or more of 8 of these 47 compounds. The herbicide atrazine or its degradation product deethylatrazine were detected most frequently (in water from 70 percent of the

sampled wells). Metolachlor was detected in water from 10 percent of the wells, and simazine was detected in water from 30 percent of the wells sampled. Other pesticides detected included dieldrin, pendimethalin, prometon, and tebuthiuron (each in water from 3 percent of the wells). All concentrations of these compounds were less than established Maximum Contaminant Levels.

A total of 85 volatile organic compounds (VOCs) were analyzed in ground-water samples during this study. Water from 43 percent of the wells had a detectable concentration of one or more VOCs. Chloroform was the most frequently detected VOC (23 percent of the wells sampled). Seven other VOCs were detected in water at frequencies of 13 percent or less in the wells sampled. Concentrations of VOCs were less than respective Maximum Contaminant Levels, except one sample with a concentration of 9.0 micrograms per liter for tetrachloroethylene (Maximum Contaminant Level of 5.0 micrograms per liter).

An analysis of hydraulic gradient, flow velocity, and residence time of the ground water indicated potential recharge areas that ranged from 0.8 to 2.8 miles upgradient of monitoring-well locations. Nineteen (63 percent) of these potential recharge areas were in agricultural areas or areas in transition from agricultural to residential and (or) commercial land use at the time water sampled from the monitoring wells was recharged to the shallow ground water. The occurrence of atrazine or deethylatrazine in water from 70 percent of the monitoring wells may indicate a historical agricultural land-use relation. This agricultural relation also may affect concentrations of other water-quality constituents of possible agricultural origin such as nitrate, which generally were in excess of background concentrations in shallow ground water.

INTRODUCTION

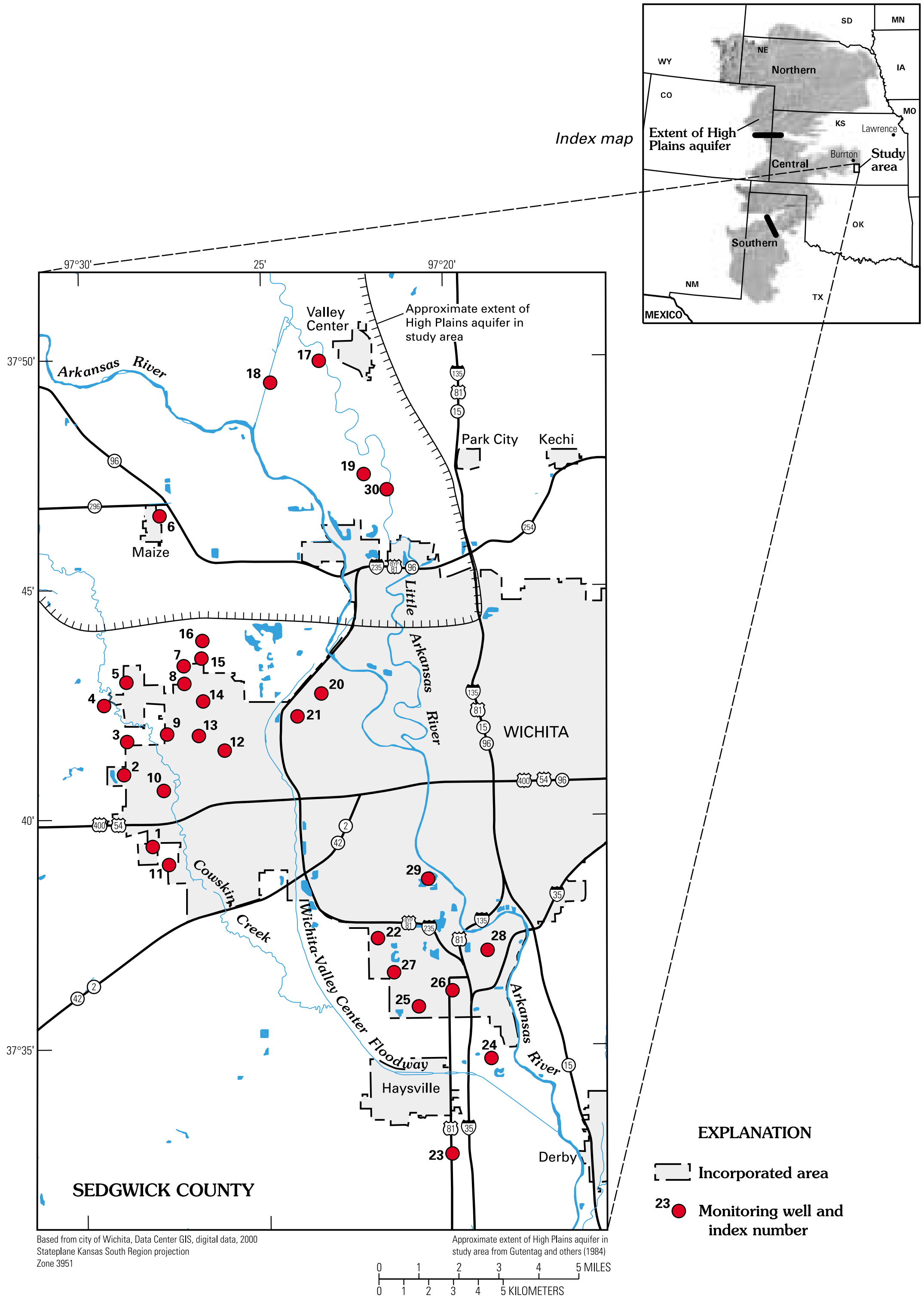
Knowledge of the quality of the Nation's water resources is important because of implications for human and aquatic health and because of substantial costs associated with land and water management, conservation, and regulation. In 1991, the U.S. Geological Survey (USGS) began full implementation of the National Water-Quality Assessment (NAWQA) Program. The long-term goals of the NAWQA Program are to describe the status and trends in the quality of the Nation's surface- and ground-water resources and to determine the natural and human-related factors affecting water quality (Gilliom and others, 1995).

The High Plains Regional Ground-Water Study began in June 1998 and represents a modification of the traditional NAWQA study design in that the ground-water resource is the primary focus of investigation (Dennehy, 2000). The High Plains aquifer is a nationally important water resource that underlies about 174,000 mi^2 in parts of eight Western States (fig. 1). About 27 percent of all irrigated land in the United States is in the High Plains, and about 30 percent of all the ground water used for irrigation in the United States is pumped from this aquifer. In addition, the aquifer system provides drinking water to 82 percent of the people who live within the aquifer boundary (Dennehy, 2000).

NAWQA ground-water studies include a component designed to assess the occurrence of water-quality constituents under areas of specific land use. The general objective of land-use studies is to assess the natural factors and human-related activities that affect the quality of recently recharged (generally less than 10 years old) shallow ground water that underlies key types of land use within each NAWQA study area. In 2000, the USGS began a ground-water-quality study of the unconsolidated deposits underlying areas of recent (1960–96) residential and commercial development in the Wichita, Kansas, area.

Studies of the potential effects of urban land use on shallow ground-water quality have two specific objectives: (1) Assess the water quality in recharge to shallow ground water underlying areas of recent residential and commercial development in large metropolitan areas, and (2) determine if ground-water-quality characteristics are related to the overlying urban land use (Squillace and Price, 1996).

Shallow depths to water, lack of a geologic barrier to slow downward migration of contaminants, and large hydraulic conductivity of unconsolidated deposits in and near the city of Wichita contribute to the potential for degradation of water quality in the High Plains aquifer by overlying land uses (Petri and others, 1964). Residential and commercial land uses and nearby agricultural land are potential sources of contaminants to the shallow ground water.



Based from city of Wichita, Data Center GIS, digital data, 2000
Stateplane Kansas South Region projection
Zone 3951

Approximate extent of High Plains aquifer in study area from Gutentag and others (1984)

Figure 1. Extent of High Plains aquifer, study area, and monitoring wells sampled as part of an assessment of shallow ground-water quality in areas of recent residential and commercial development, Wichita, Kansas.

Purpose and Scope

The purpose of this report is to provide an assessment of water quality in recharge to shallow ground water underlying areas of recent residential and commercial development, Wichita, Kansas, and to relate, to the extent possible, ground-water quality to overlying land use (fig. 2). Water samples from 30 monitoring wells installed for this study (fig. 1) were analyzed for about 170 water-quality constituents, including chlorofluorocarbons (CFCs), physical properties, dissolved solids and major ions, nutrients and dissolved organic carbon, trace elements, pesticide compounds, and volatile organic compounds (VOCs). Many of these constituents are regulated in public drinking-water supplies by the U.S. Environmental Protection Agency (USEPA). The constituents will be discussed relative to USEPA drinking-water standards as a frame of reference and in relation to natural hydrologic factors and human-related activities.

Acknowledgments

The cooperation of many individuals was essential for the completion of this study. The authors appreciate the permission granted by property owners and the city of Wichita for monitoring-well installation and collection of water samples. Appreciation also is extended to Peter McMahon (USGS) for assistance in interpretation of CFC data and Sharon Qi (USGS) for delineation of recently developed residential and commercial areas and selection of potential monitoring-well locations.

DESCRIPTION OF STUDY AREA

The study area is located in Sedgwick County, south-central Kansas (fig. 1), and includes recently developed

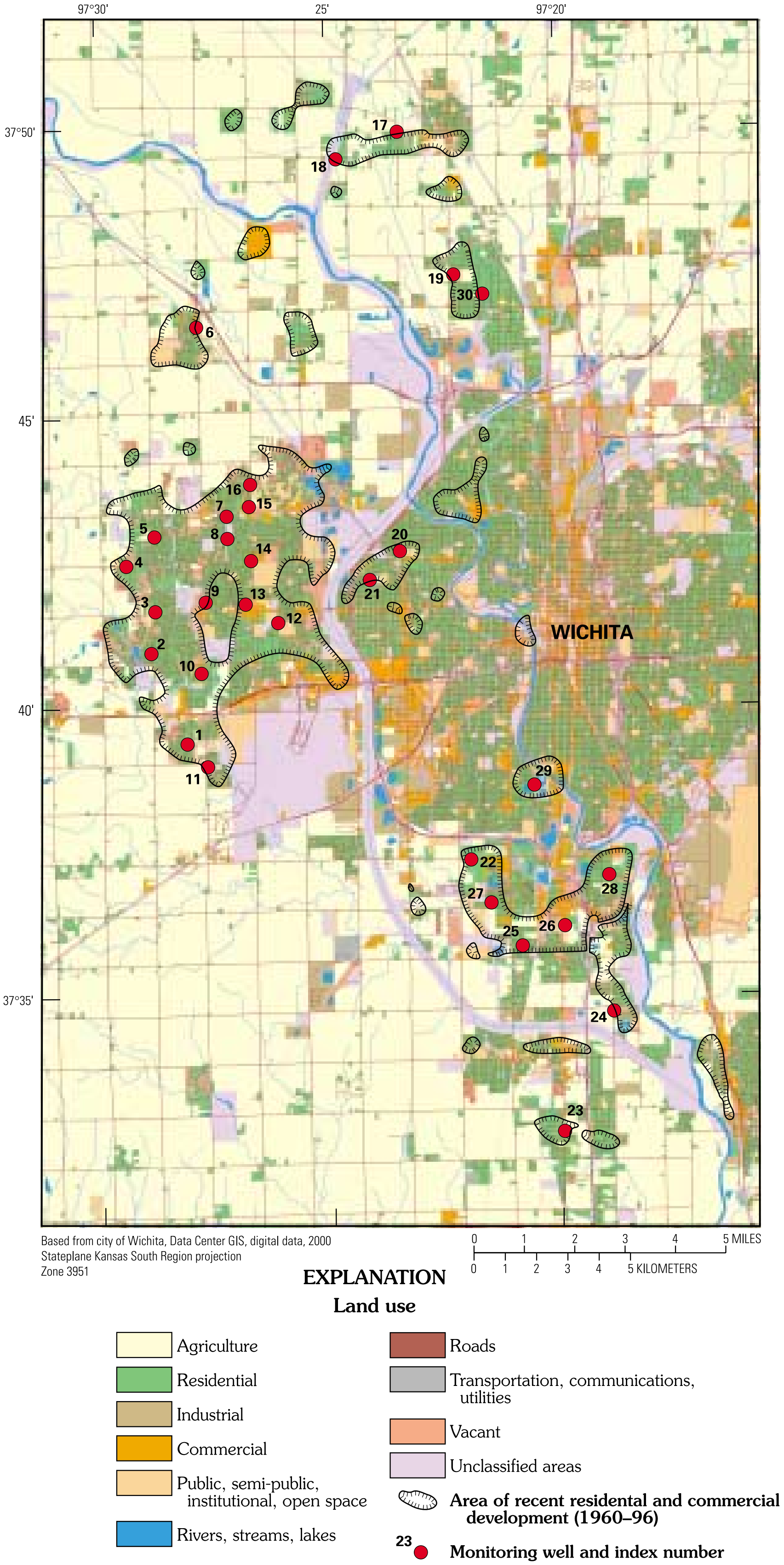


Figure 2. Land use and areas of recent residential and commercial development in study area, 1999 (modified from city of Wichita, 2000).

(1960 to 1996) residential and commercial areas of the city of Wichita and adjacent urban areas (fig. 2). The study area is located mostly within the easternmost extension of the High Plains aquifer and the alluvial and terrace deposits of the Arkansas River Valley in the Arkansas River Lowlands physiographic province (Schoewe, 1949). Land surface is flat within the Arkansas River Valley but becomes gently rolling in the uplands to the west and east of the study area. The Arkansas River and associated tributary streams generally flow south or southeast in the study area.

Climate and Precipitation

The climate in south-central Kansas is midcontinental and controlled by the movement of frontal air masses over the open inland-plains topography. Seasonal temperature and precipitation extremes are common. During the summer (June, July, August), temperatures near or above 100 $^{\circ}$F can occur. Winter months (December, January, February) are characterized by influxes of cold, dry polar air with temperatures as low as -10 $^{\circ}$F. The long-term (1961–90) average annual temperature at Wichita is 56 $^{\circ}$F. Long-term average monthly temperatures range from 29 $^{\circ}$F in January to 81 $^{\circ}$F in July. About 69 percent of the average annual precipitation of 29.33 in. falls during the warm growing season, April through September. Only about 10 percent of the average annual precipitation falls during the relatively dry winter months of December through February (National Oceanic and Atmospheric Administration, 1999). Average annual wind speeds are among the highest in the United States, exceeding 12 mi/h (Bevans, 1989). Wind direction is predominantly from the south during all seasons except winter when it is predominantly from the north.

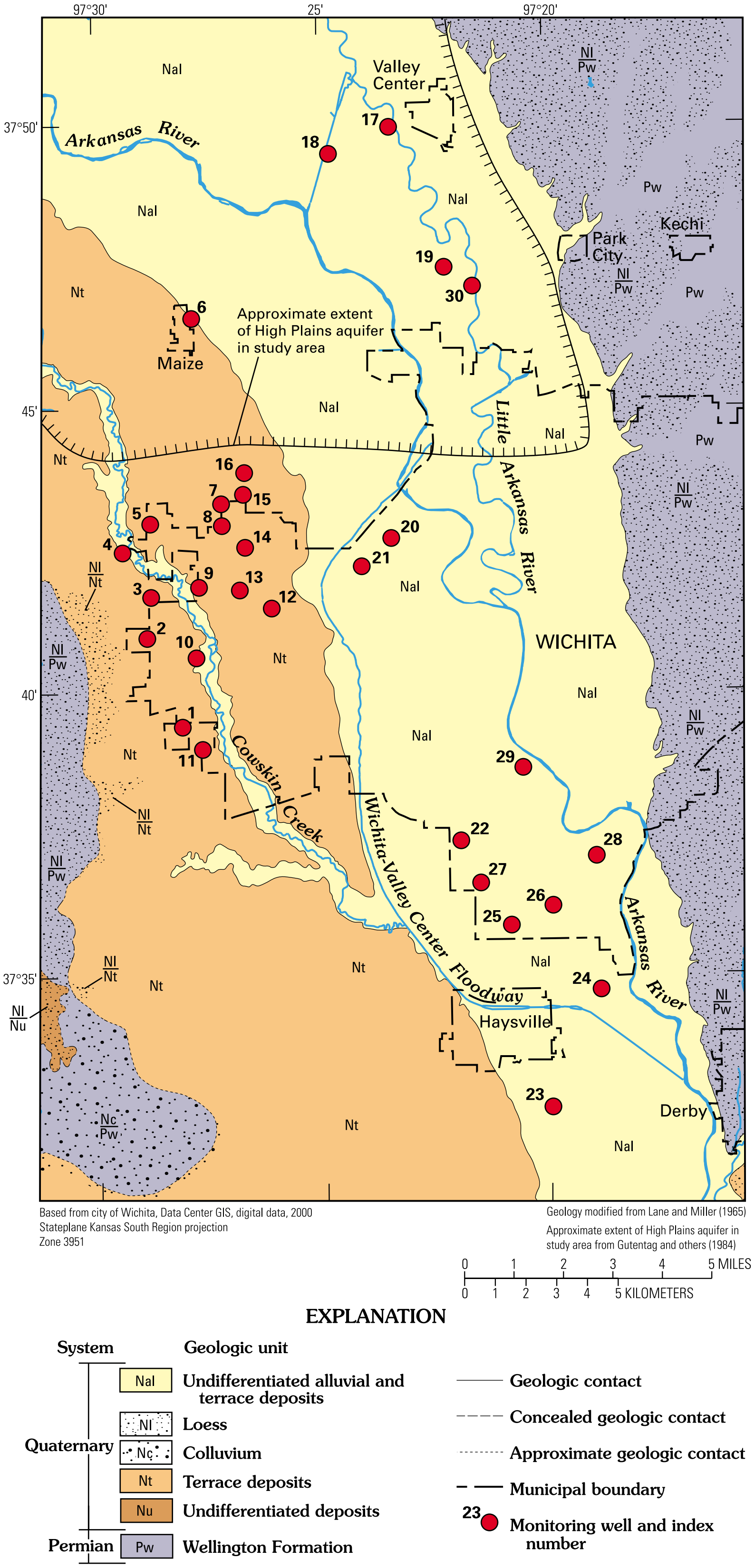
Land and Water Use

Land use in the study area is mostly associated with urban development. Residential and commercial land use occurs in areas near the 30 monitoring wells (fig. 2); however, peripherial to these urban areas are agricultural lands. Most of the area currently (2001) included in the city of Wichita has been agricultural land at some time. The growth and expansion of Wichita historically has been into agricultural areas. However, despite this urban encroachment, agriculture is still a dominant feature in Sedgwick County. In 1998, of the 640,000 acres in Sedgwick County, 86 percent (553,000 acres) was associated with the 1,570 farms in the county (Kansas Department of Agriculture and U.S. Department of Agriculture, 1999).

The current (2001) volume of ground-water withdrawn and used in the study area is not readily available; however, ground-water use information on a county-wide basis provides an approximation of water use within the study area. Of the 58,000 acre-ft of ground water withdrawn in Sedgwick County in 1997, 46 percent was used for irrigation, 24 percent for municipal use, 23 percent for industrial use, 6 percent for domestic self-supplied use, and 1 percent for a combination of recreation and stock use (Joan Kenny, USGS, written commun., 1999).

Within the study area (fig. 1), the vast majority of residents are supplied drinking water from the Wichita public-water supply. This public supply consists of about 60- to 70-percent surface water (reservoir water) with the remaining percentage coming from ground-water wells located in the Wichita well field in the High Plains aquifer located between the cities of Valley Center and Burrton (fig. 1) (Jerry Blain, city of Wichita Water and Sewer Department, oral commun., 2000). However, there are some residents who get drinking water from domestic water-supply wells completed in the alluvial and (or) terrace deposits of the Arkansas River Valley (fig. 3). Water from the alluvial deposits in the study area also is used as a supplementary public-water supply for Wichita. This supplementary ground-water supply is withdrawn from a small well field located near the confluence of the Arkansas and Little Arkansas Rivers (fig. 1) (Vernon Strasser, city of Wichita Water and Sewer Department, oral commun., 2002).

Wastewater from areas of residential and commercial development in the study area generally is discharged through municipal sanitary-sewer systems. However, some areas of onsite residential wastewater disposal (septic systems) do occur. Septic systems are used in the residential areas near monitoring wells 19 and 30 (fig. 1) (Brian Fisher, city of Wichita Department of Environmental Health, oral commun., 2002), well 23 (Dave Harper, city of Haysville, oral commun., 2002), and well 24 (Rob Younkin and La Donna Lawrenz, city of Wichita Water and Sewer Department, oral commun., 2002), and wells 17 and 18 west of Valley Center (Linda Heberling, city of Valley Center, oral commun., 2002) are in areas of past septic-system usage. The part of the study area currently (2001) affected by onsite disposal of residential wastewater is spatially limited, and similarly, the potential for adverse effects on ground-water quality from wastewater probably are limited.



Based from city of Wichita, Data Center GIS, digital data, 2000
Stateplane Kansas South Region projection
Zone 3951

Geology modified from Lane and Miller (1965)
Approximate extent of High Plains aquifer in study area from Gutentag and others (1984)

Figure 3. Surficial geology in study area.

Hydrogeologic Setting

The hydrogeologic setting of the study area has been described in detail by Williams and Lohman (1949), Petri and others (1964), and Lane and Miller (1965). A brief summary of those descriptions is presented here. Generally, unconsolidated deposits, primarily of Quaternary age, occur over bedrock in the study area (fig. 3). These deposits, both in and outside of the High Plains aquifer, consist of alluvial and terrace deposits of fine-to-coarse sand and gravel with interspersed thin layers of silt and (or) clay. Specifically, the deposits adjacent to the Arkansas River consist of fine-to-coarse sand and fine-to-very coarse gravel containing only minor amounts of silt and clay (Nal, fig. 3). The sand and gravel grade upward into clayey silt. The sand and gravel are mostly quartz fragments, but the gravel contains large amounts of pink feldspar and other minerals typical of the Rocky Mountains from which this material was eroded (Lane and Miller, 1965).

Sand and gravel in the unconsolidated deposits adjacent to the Arkansas River form the principal ground-water reservoir in and near Wichita and are the source of most of the ground water used. Saturated thickness of the sand and gravel ranges from less than 40 ft near Haysville (fig. 1) to about 180 ft near Maize (Hansen, 1987).

Recharge to the unconsolidated deposits is mainly by local precipitation with an annual average recharge of about 3 in. (Hansen, 1987). Annual fluctuations in the water table of 2 to 4 ft are common; however, fluctuations of as much as 10 ft are not unusual. The water table is 30 ft or less below land surface in most of the study area and generally slopes southeastward (parallel to the Arkansas River) at 5 to 7 ft/mi (Petri and others, 1964). Properly constructed wells in the Quaternary-age unconsolidated deposits of the Arkansas River Valley may yield as much as 1,500 gal/min or more (Lane and Miller, 1965).

METHODS OF INVESTIGATION

The study design to investigate ground-water quality in areas of recent residential and commercial development, Wichita, Kansas, followed the NAWQA protocols described by Squillace and Price (1996). These protocols defined or referenced procedures for (1) site selection, (2) monitoring-well installation, (3) sample collection and analysis, and (4) collection of ancillary data to define aquifer and land-use characteristics.

Site Selection and Well Installation

Selection of sites for installation of monitoring wells was a multiple-step process. First, target areas of recently developed residential and commercial land use were delineated. These target areas generally were defined as the intersection of the alluvial aquifer and areal extent of recently developed residential and commercial land uses in the study area. Second, the target areas were refined by excluding (1) areas within 1,000 m of heavy industries such as manufacturing or construction facilities, refineries of raw materials, transportation centers, or airports, and (2) areas where at least 75 percent of a 500-m buffer around potential well sites would not be in the target area. These target areas are outlined and identified in figure 2 as areas of recent residential and commercial development. Third, potential well sites were selected using an equal-area, randomized, grid-based computer program (Scott, 1990). This program was used to select 30 primary well-installation sites each with one or two secondary locations within the refined target areas. The secondary locations were identified in the event that a well-installation site could not be located within 250 m of the primary location. The computer program also provided at least a 750-m separation distance between all well locations. The locations of the 30 monitoring wells installed for the land-use study described in this report are shown in figure 1.

The installation of monitoring wells followed procedures outlined by Lapham and others (1995). All 30 monitoring wells were installed between March 24 and April 28, 2000, using a 4.25-in. inside-diameter hollow-stem auger. Well casings were 2-in. diameter, flush-threaded, schedule-40 polyvinyl chloride (PVC) pipe. Well screens also were constructed of schedule-40 PVC and were 5 ft in length with mill-slot perforation openings (0.01 in. wide). The filter pack (packing material around the well screen) consisted of silica sand above which about a 2-ft thick layer of bentonite pellets was installed. An annular seal of bentonite grout was emplaced above the bentonite pellets to within about 3 ft of land surface where a surface seal of concrete was installed. Selected well-construction details are listed in table 1. All drilling equipment was steam cleaned between monitoring-well installation sites.

All monitoring wells installed for this land-use study were completed at depths (below land surface) of 47 ft or less (table 1). Completion depths were determined by depth to water. One of the purposes of well construction was to ensure suitability for future (10 or more years) sampling for water-quality trend analysis. Therefore, the placement of the well screen relative to possible future water-level declines was an important consideration. Generally, the goal at well installation was to place the top of the well screen about 5 ft below the current (2000) water level. The top of well screens for all 30 monitoring wells were installed at a median depth below current (2000) water levels of about 6 ft. Depths to water ranged from about 4 to 35 ft, with a median depth of about 16 ft.

After installation, water levels in the monitoring wells were allowed to “recover” for about 2 weeks before development. Well development is a procedure to enhance flow of water to the well, to remove sediment that are artifacts of well installation, and to yield water representative of the aquifer being sampled. Well development mitigates artifacts associated with drilling such as changes in aquifer permeability, sediment distribution, and ground-water chemistry (Lapham and others, 1995). For the land-use study described in this report, well development consisted of pumping with a portable, low-volume submersible pump at three depth intervals in the water column. These intervals, near the top, middle, and bottom of the water column, were pumped until turbidity readings in the discharged water from each interval were less than 10 NTU (nephelometric turbidity units). Turbidity is a measure of the clarity of the water. The water levels in the monitoring wells again were allowed to “recover” for 2 weeks before water-quality samples were collected.

Table 1. Selected well-construction details for monitoring wells installed in areas of recent residential and commercial development, Wichita, Kansas

[BLS, below land surface]

Monitoring-well index number (fig. 1)	U.S. Geological Survey identification number	Date of installation (month-day-year)	Depth of completed well, BLS (feet)	Depth to water, BLS, at time of sampling (feet)	Screened interval, BLS (feet)
1	373925097280701	04–07–00	34	20.31	29–34
2	374058097285301	03–28–00	37	26.10	32–37
3	374141097284801	03–29–00	38	23.32	33–38
4	374229097292501	04–04–00	24	10.30	19–24
5	374300097284701	03–28–00	34	22.79	29–34
6	374637097275001	03–24–00	14	3.71	8.5–13.5
7	374321097271401	04–08–00	33	20.69	28–33
8	374257097271201	03–24–00	32	19.38	27–32
9	374152097274101	04–04–00	45	34.40	39–44
10	374037097274701	04–11–00	27	17.39	22–27
11	373901097274001	04–25–00	28	16.13	23–28
12	374129097260701	04–06–00	44	35.23	39–44
13	374149097265101	04–05–00	35	18.78	25–30
14	374233097264201	04–12–00	47	34.86	42–47
15	374330097264401	04–10–00	41	29.88	36–41
16	374353097264201	04–28–00	40	29.96	35–40
17	374957097232501	04–10–00	26	15.58	21–26
18	374929097244501	04–09–00	39	27.65	34–39
19	374728097221301	03–24–00	25	13.22	19.5–24.5
20	374242097232701	03–26–00	32	15.56	27–32
21	374212097240701	03–25–00	26	14.60	21–26
22	373721097220001	04–12–00	23	9.43	18–23
23	373240097200101	04–26–00	19	8.45	14–19
24	373443097185501	04–26–00	19	7.51	14–19
25	373553097205401	04–07–00	17	7.95	12–17
26	373613097195701	04–27–00	26	16.30	21–26
27	373637097213301	04–27–00	17	6.24	12–17
28	373705097185901	04–26–00	17.5	5.49	12.5–17.5
29	373839097203501	04–27–00	24	13.60	19–24
30	374708097213601	04–08–00	25	16.10	20–25

Sample Collection and Analysis

Sediment samples were collected for determination of pH, organic-carbon content, and particle-size analysis during the installation of each of the 30 wells described in this report. These samples were collected with a split-spoon sampler (Wilson, 1995) at two depths. One sample was collected in the unsaturated zone about half-way between the land surface and the estimated water level (Bevans, 1989). The other sample was collected in the saturated zone at about the depth of the well screen. These samples were used to evaluate potential water-quality interactions associated with the movement of recharge water through the sediment.

The 30 monitoring wells were sampled once from May 15 to June 8, 2000, for this assessment of shallow ground-water quality. Ground-water samples were collected and processed in a mobile water-quality laboratory. Ground water was pumped from the wells using a portable, low-volume submersible pump. All materials in contact with the water sample consisted of either stainless steel or Teflon.

Sampling protocols followed during this study are described in detail in Koterba and others (1995). To minimize the risk of sample contamination, all sample collection and preservation took place in dedicated environmental chambers consisting of clear polyethylene bags supported by tubular PVC frames. Sampling equipment extending from the permanent sampling point near the wellhead to the sampling chamber inside the mobile laboratory was decontaminated thoroughly between each sample collection using a progression of nonphosphate detergent wash, tapwater rinse, methanol rinse, and final deionized-water rinse. Polyethylene bags forming the sample and preservation chambers were replaced between each sample collection.

Sampled wells were first purged of standing water. During the initial pumping period, measurements of specific conductance, pH, water temperature, and dissolved oxygen were monitored every 5 minutes in a closed-cell, flow-through chamber until stable readings were obtained. Turbidity also was measured every 5 minutes using a portable turbidity meter. Once stable readings of these physical properties were obtained, water flow inside the laboratory was redirected to the clean sampling chamber where sample water was collected immediately for analysis. Constituents analyzed in water samples collected from each well are listed in table 13 in the “Supplemental Information” section at the back of this report.

Samples for the analysis of chlorofluorocarbons (CFCs) were collected in triplicate using a procedure described by Busenberg and Plummer (1992) that prevents exposure of the samples to air (a potential source of CFC contamination). The sampling procedure uses a closed water-transport path between the sampling pump through refrigeration-grade copper tubing to a valve system that allows filling and flushing of 62-mL borosilicate ampoules with water, creating a headspace with CFC-free ultrapure nitrogen, and permanently sealing the ampoule neck by heat fusion. Samples were analyzed at the USGS Chlorofluorocarbon Laboratory in Reston, Virginia, by gas chromatography to a detection limit of about 0.3 pg/kg of water. Results of CFC analyses are subsequently used in the calculation of potential dates at which the water sampled was recharged to the aquifer.

Samples to be analyzed for major ions, nutrients, and trace elements were filtered through a 0.45-µm pore-size disposable-capsule filter and collected in precleaned plastic bottles that were rinsed onsite with filtered ground water. Samples to be analyzed for concentrations of major cations and trace elements were preserved to less than pH 2.0 standard units using ultrapure nitric acid. A filtered, unpreserved sample was collected for major anion analysis. Additionally, a filtered sample was collected for onsite titration of carbonate alkalinity. An unfiltered sample for laboratory measurements of specific conductance and pH was filled directly in the sampling chamber and was not preserved. Nutrient samples were filtered (0.45-µm pore size) into onsite-rinsed brown plastic bottles and were chilled on ice, with no preservation, and were delivered to the laboratory within 24 hours for analysis.

To avoid contact between water sampled for dissolved organic carbon (DOC) and any methanol-rinsed sampling equipment (a possible source of DOC contamination), DOC samples were collected directly from the pump discharge tube close to the wellhead. The sample was processed through a stainless-steel, pressure-filtration funnel equipped with a 0.45-µm pore-size silver filter. Trace concentrations of silver imparted by the filter served as a biocidal preservative for the DOC sample. Water samples were forced through the silver filter using purified nitrogen gas at a pressure not exceeding 15 lb/in^2. As with other organic samples, the water was collected in a cleaned and baked amber glass bottle and immediately chilled on ice and were delivered to the laboratory within 24 hours for analysis.

Water samples collected for pesticide analyses were passed through a methanol-rinsed, stainless-steel filter chamber containing a cleaned and baked 0.7-µm pore-size glass-fiber filter. All samples analyzed for organic constituents were collected in amber-colored glass bottles and immediately chilled on ice and were delivered to the laboratory within 24 hours for analysis. Unfiltered water for analysis of VOCs was collected in precleaned 40-mL septum vials with no headspace and preserved to less than pH 2.0 standard units using one to five drops of specially prepared 1:1 hydrochloric acid.

Analysis of all water-quality samples was performed at the USGS National Water-Quality Laboratory (NWQL) in Lakewood, Colorado, according to methods listed in table 2. Results of these analyses are listed in table 4 in the section on “Age Dating” and in table 14 in the “Supplemental Information” section at the back of this report.

Quality-Control Data

Quality-control data to test sample collection, processing, and analysis were collected at a frequency of about 30 percent of the environmental ground-water samples collected from wells. Quality-control samples included field-blank samples, replicate environmental samples, and field matrix-spike samples. Field-blank samples were used to verify that decontamination procedures were adequate and that onsite and laboratory protocols and sample shipment did not contaminate the samples. Replicate environmental samples were used

Table 2. Laboratory analysis methods for analyzed water-quality constituents

[USGS, U.S. Geological Survey; UV, ultraviolet; C, carbon; GC/MS, gas chromatography/mass spectrometry]

Constituent or constituent group	Analysis method	Method reference
Chlorofluorocarbons	Purge and trap gas chromatography with an electron capture detector	Busenberg and Plummer (1992)
Major ions (USGS schedule 2750)	Atomic absorption spectrometry	Fishman (1993)
Nutrients (USGS schedule 2752)	Various methods	Fishman (1993)
Dissolved organic carbon (USGS schedule 2085)	UV-promoted persulfate oxidation and infrared spectrometry	Brenton and Arnett (1993)
Trace elements (USGS schedule 2703)	Inductively coupled plasma mass spectrometry	Faires (1993)
Pesticides (USGS schedule 2001)	Solid-phase extraction using a C–18 cartridge and GC/MS	Zaugg and others (1995)
Volatile organic compounds (USGS schedule 2020)	Purge and trap capillary-column GC/MS	Connor and others (1998)

to assess the combined effects of onsite and laboratory procedures on measurement variability. Field matrix-spike samples were analyzed to test for bias and variability from ground-water matrix interference or degradation of constituent concentration during sample processing, storage, and analysis.

Field-blank samples were analyzed for concentrations of major ions, nutrients and dissolved organic carbon, trace elements, pesticide compounds, and VOCs. The source solution for field-blank samples was specially prepared organic-free or inorganic-free water provided by the USGS NWQL for the NAWQA Program. Field-blank solution was passed through all sampling equipment, and samples were collected using the same protocols as for environmental samples.

Aluminum and zinc were each detected in two of three field-blank samples at mean concentrations of 10 and 4 μg/L, respectively. Barium and strontium were each detected in one field-blank sample at concentrations of 1 and 2 μg/L, respectively. None of the other trace elements, dissolved solids and major ions, nutrients, pesticide compounds, or VOCs listed in table 13 (in the "Supplemental Information" section at the back of this report) were detected at concentrations greater than the analytical method reporting limit. The analytical results of field-blank samples indicate that the decontamination procedures used during this study were adequate and that onsite and laboratory contamination of environmental samples was minimal.

Three sets of replicate environmental samples were collected sequentially during this study for all analyses except pesticide compounds and VOCs. Replication of pesticide compounds and VOCs was accomplished during the field matrix-spiking process wherein replicate environmental samples were injected (spiked) with known concentrations of selected pesticide compounds or VOCs.

Analytical variation between reported concentrations of replicate environmental samples was calculated for the major ions, nutrients, dissolved organic carbon, and trace elements listed in table 13. The variation, as a percentage, between constituent concentrations of replicate environmental samples was calculated with the equation:

$$\text{variation} = \frac{|A - B|}{A + B} \times 100\,, \qquad (1)$$

where A is concentration from one replicate analysis, and
B is concentration from the other replicate analysis.

Analytical variation was not calculated if one or both measured concentrations for a replicate pair were less than analytical method reporting limits.

Mean percentage variation between replicate analyses was less than 5 percent for all constituents except fluoride (7 percent), ammonia (6 percent), ammonia plus organic nitrogen (10 percent), orthophosphate (10 percent), dissolved organic carbon (15 percent), aluminum (13 percent), strontium (11 percent), and zinc (14 percent). Generally, however, the results of replicate environmental sample analyses indicate an acceptable degree of laboratory precision and reproducibility.

Analytical recovery bias and variability were assessed for the pesticides listed in table 13 using analyses of three field matrix-spike samples collected during this study. Replicate environmental samples were spiked with known amounts of pesticides and analyzed according to methods listed in table 2. Percentage recoveries were calculated with the equation:

$$\text{percentage recovery} = \frac{FMS}{CS + PS} \times 100\,, \qquad (2)$$

where FMS is the analytically determined concentration in the field matrix-spike sample,

CS is the calculated spike concentration, and

PS is the analytically determined concentration in the primary environmental sample.

Mean percentage recoveries for pesticides listed in table 13 generally ranged from 26 percent (disulfoton) to 179 percent (carbaryl) with a mean percentage recovery for all 47 pesticide compounds of 102 percent. Most mean percentage recoveries (64 percent of the pesticides listed in table 13) were between 90 and 110 percent and included pesticide compounds that might be used in an urban environment and potentially may occur in shallow ground water. These potentially urban-related pesticides and percentage recoveries included atrazine (109 percent), dieldrin (99 percent), metolachlor (109 percent), pendimethalin (93 percent), prometon (105 percent), and simazine (99 percent). Two additional urban-related pesticide compounds, deethylatrazine (a degradation product of atrazine) and tebuthiuron, had mean percentage recoveries of 75 and 124 percent, respectively. These data indicate that sample processing and analytical methods provided a reasonable approximation of expected pesticide concentrations for most of the pesticide compounds listed in table 13.

Percentage recoveries for VOCs generally were less than those for pesticides. Mean percentage recoveries for the VOCs (table 13) ranged from 47 percent (3-chloropropene, 2,2-dichloropropane, and methyl iodide) to 106 percent (2-butanone). The average mean percentage recovery for all 85 VOCs was 66 percent, meaning that data in this report may underestimate true concentrations and frequencies of detection of VOCs by an average of 34 percent.

Ancillary Data

Ancillary data were collected for all wells from which water-quality data were obtained. The ancillary data included selected features or conditions of the sampling site, the well, the subsurface at the well, and the landscape and land-management activities in the vicinity of the well. These data subsequently become part of the NAWQA National Data Base Archive. Nationally consistent and quantitative methods for the collection, documentation, and compilation of ancillary data for this study are presented in Koterba (1998).

Ancillary data were divided into two parts and maintained in separate databases. Site, well, and subsurface data are a part of the USGS National Water Information System—Ground-Water Site Inventory (GWSI) database. Land-use, land-management, and other required landscape data are a part of a new Land-Use and Land-Cover Field Sheet (LULCFS) database of the NAWQA Program.

The required GWSI data for NAWQA wells are listed in Koterba (1998, table 1, p. 5–8). These data include precise location information, well-construction details, and descriptions of the hydrogeologic unit and lithologic materials in which the well is installed.

Data requirements for the LULCFS database were designed to document land-surface activities that might affect ground-water quality. These data characterize potential point sources of ground-water contamination and areally extensive land-use practices with possible nonpoint-source effects. Nonpoint-source activities might include large areal applications of water or chemicals such as used in agricultural areas, or extensive industrial, commercial, or residential urban environments. These data generally were recorded onsite at the time of water-sample collection through observations of the area surrounding the well site.

SEDIMENT CHARACTERISTICS

Sediment characteristics such as pH, organic-carbon content, and particle size may affect shallow ground-water quality by promoting or mitigating the movement of some water-quality constituents to the water table. Sediment pH has a substantial effect on the solubility (dissolution) of minerals and nutrients and, ultimately, transport to the aquifer. Most minerals and nutrients have larger solubilities in acid soils (pH less than 7.0 standard units) than in neutral or slightly alkaline soils (pH of 7.0 standard units or larger) (Hem, 1985). Also, MTBE (methyl tert-butyl ether), an oxygenate added to gasoline to reduce air pollution and commonly found in shallow ground water in many urban areas, is degraded in sediment with a pH of 5.5 standard units or less and small organic-carbon content (Squillace and Price, 1996). Therefore, absence of MTBE in shallow ground water may be related to sediment characteristics instead of a lack of distribution in the urban environment.

Sediment pH values (table 15 in the “Supplemental Information” section at the back of this report) were near neutral (pH value of 7.0 standard units) to alkaline (pH value greater than 7.0 standard units) at all 30 monitoring-well sites (fig. 1). pH values ranged from 6.8 to 8.4 standard units with a median value of 7.6 standard units. Therefore, pH was not small enough to promote the larger solubilities of most minerals and nutrients and degradation of some organic compounds in water recharged at the locations of the 30 monitoring wells.

Organic carbon can serve as adsorption sites for chemicals such as nutrients (Lefroy and Craswell, 1997) and pesticides (Van Es, 1990). The amount of organic carbon in sediment determines its potential for chemical adsorption. Sediment with large organic-carbon content has a small potential for chemical leaching and, therefore, mitigates the movement of some water-quality constituents to the water table. Organic-carbon content of 1 percent (dry weight) is considered small (Pepper and others, 1996). Organic-carbon content of sediment or soils derived primarily from weathering of bedrock usually ranges from 0 to 4 percent but may be as large as 20 to 30 percent (Bauder, 1999).

Organic-carbon content in the sediment from the 30 monitoring-well sites (fig. 1) was small (table 15). Organic-carbon content ranged from less than 0.02 percent at many well locations to 0.5 percent at well 4 (table 15, fig. 1). These small percentages probably indicate that chemical adsorption of water-quality constituents in water recharged through sediment at the monitoring-well sites would be minimal and that the movement of constituents to the shallow water table would not be impeded.

Sediment particle size can affect water quality in an underlying aquifer by increasing or decreasing the ability of water and associated water-quality constituents to percolate through the material rather than run off over the land surface. Coarse-textured material (large percentage of sand and (or) gravel) generally has large potential for leaching contaminants to ground water and small potential for surface-runoff loss to streams and lakes (Van Es, 1990).

Sediment particle sizes (table 15) at most of the 30 monitoring-well sites (fig. 1) were sand size or larger (larger than 0.062 mm in diameter). Overall, the percentage of silt- and (or) clay-size particles (less than 0.062 mm in diameter) for all 30 monitoring-well sites was small (median of 3.4 percent). Most of the silt- and (or) clay-size particles were associated with the unsaturated zone (upper sampling interval) at each monitoring-well site. Samples collected in this zone had a median percentage of silt and (or) clay of 23.4 percent. In contrast, the median percentage of silt and (or) clay in the saturated zone (below the water level) was 1.6 percent. Part of the difference in silt and (or) clay median percentages between the saturated and unsaturated zones may be attributed to sediment sampling procedures. Water draining from the split-spoon sampler from samples collected in the saturated zone might have carried off some fine sediment particles. However, this phenomenon could not be solely responsible for the large difference in median percentages between saturated and unsaturated zone samples. Data in table 15 indicate that sediment in the study area generally is coarse-textured and probably has a large potential for leaching contaminants to ground water.

AQUIFER PROPERTIES

Information on aquifer properties such as hydraulic conductivity, hydraulic gradient, porosity of aquifer material, and flow velocity can help explain quality of ground water. These aquifer properties, when combined with apparent recharge ages of ground water, can provide insight into potential ground-water recharge areas and land-use-related water-quality effects.

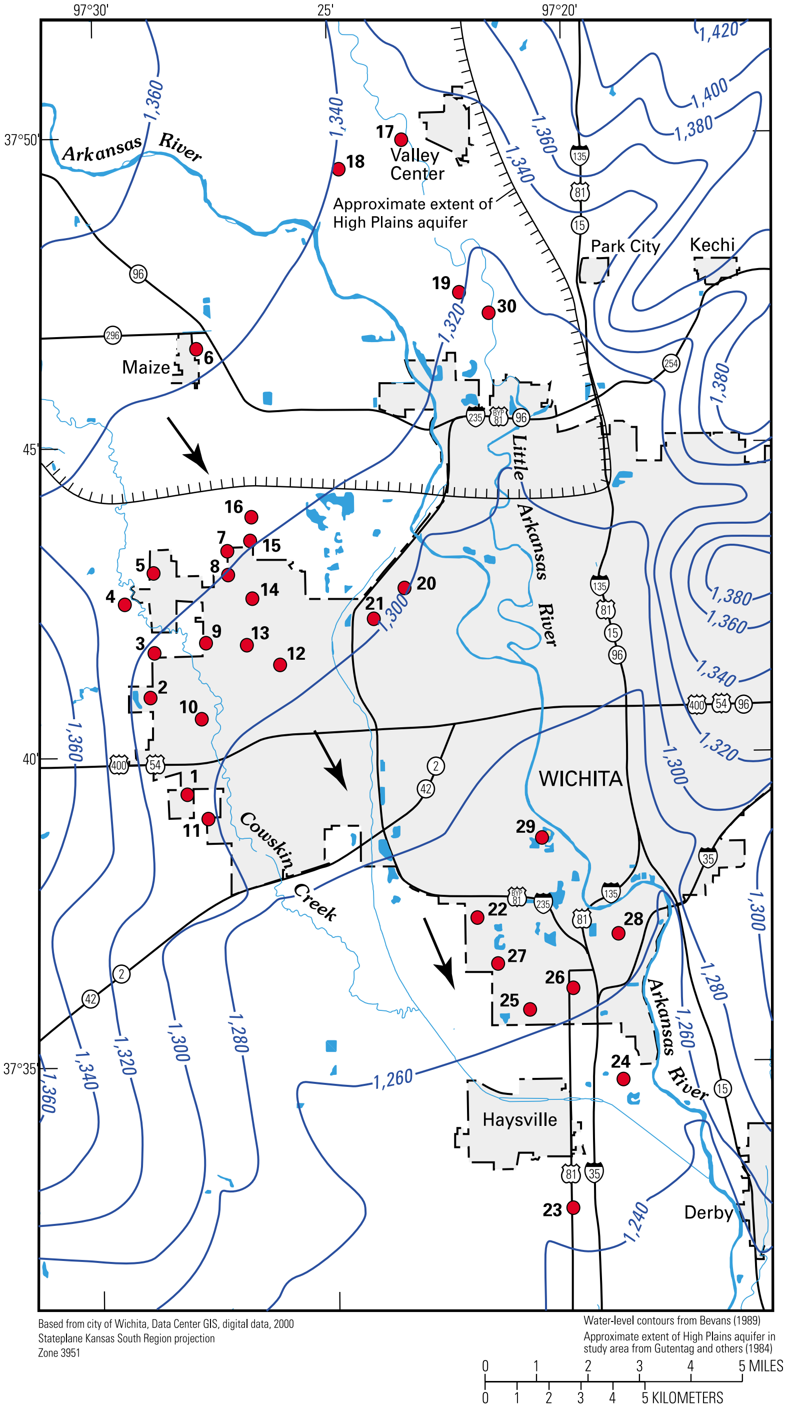
Hydraulic conductivity is the capacity of a rock (consolidated or unconsolidated material) to transmit water (Heath, 1983) and is usually expressed in units of length per time, such as feet per day but should not be misconstrued as an indication of the velocity of ground water. Values of hydraulic conductivity have a large range (as much as 12 orders of magnitude) and generally increase with increasing porosity (voids or openings in a rock). Generally, in unconsolidated deposits, such as sand and gravel, the larger the particle size of the deposited material, the larger the hydraulic conductivity (Bouwer, 1978).

Most of the water-bearing unconsolidated deposits in the Wichita study area consist of sand- and gravel-size particles (greater than 0.062 mm in diameter; table 15 at the back of this report). Estimates of hydraulic conductivity for these deposits have been made in previous ground-water investigations in and near the study area (Spinazola and others, 1985; Myers and others, 1996). Average hydraulic conductivity values of 350 and 750 ft/d were estimated for the terrace deposits (Nt, fig. 3) west of the Arkansas River alluvium and alluvial and terrace deposits (Nal, fig. 3) along the Arkansas River, respectively.

Hydraulic gradient is defined as the change in hydraulic head per unit of distance measured in the direction of steepest change (Heath, 1983). The hydraulic gradient in an unconfined aquifer is the slope of the water table. The slope of the water table determines direction of ground-water flow and is a component in calculating ground-water flow velocity.

The hydraulic gradient for most of the area where monitoring wells were installed for the study described in this report is about 0.001 with the possible exception of the area where monitoring wells 1 and 11 are located, where the ground-water flow direction is not definitely known (fig. 4). Generally, the direction of ground-water flow in the area of the monitoring wells is from the northwest to the southeast.

Most water-bearing material (consolidated or unconsolidated rocks) consists of mineral particles surrounded by open spaces. The porosity of a water-bearing material may be expressed as the ratio



Based from city of Wichita, Data Center GIS, digital data, 2000
Stateplane Kansas South Region projection
Zone 3951

Water-level contours from Bevans (1989)
Approximate extent of High Plains aquifer in study area from Gutentag and others (1984)

EXPLANATION

▭ **Incorporated area**

—1,360— **Water-level contour**—Shows altitude at which water would have stood in tightly cased wells, December 1985 or January 1986. Contour interval 20 feet. Datum is North American Vertical Datum of 1988 (NAVD 88)

→ **Approximate direction of ground-water flow**

23 ● **Monitoring well and index number**

Figure 4. Ground-water levels and approximate direction of ground-water flow in unconsolidated deposits in study area, December 1985–January 1986.

(dimensionless) of the volume of openings in a rock to the total volume of the rock (Heath, 1983). Ground water moves into, through, or is stored in these openings. Porosity, therefore, is an important determination in describing other ground-water characteristics such as flow velocity (Nielson, 1991). Porosity of unconsolidated deposits depends on the range in grain size (sorting) and on the shape of the rock particles but not on their size. Fine-grained materials tend to be better sorted and thus tend to have the largest porosity (Heath, 1983). For example, porosity of clay typically ranges from 0.40 to 0.70, whereas porosity of sand ranges from 0.15 to 0.48 and for gravel, from 0.25 to 0.40 (Nielson, 1991). On the basis of the information for sediment samples collected from the saturated zone (deeper of the paired samples from each well location) presented in table 15, an average porosity of 0.30 was estimated for the alluvial aquifer in the study area.

The rate of movement of ground water (flow velocity) is an important characteristic in studies of ground-water quality because, when used with estimated age of the ground water, location of potential recharge areas can be estimated. The land-use characteristics of these recharge areas may help in the evaluation of water-quality characteristics of the water samples collected from the 30 monitoring wells (fig. 1).

Ground-water flow velocity is a function of hydraulic conductivity, hydraulic gradient, and porosity and can be calculated with the equation (Heath, 1983, p. 25):

$$v = \frac{K}{n} \bullet \left(\frac{dh}{dl}\right) , \qquad (3)$$

where v is ground-water flow velocity, in feet per day;

K is the hydraulic conductivity, in feet per day;

n is the porosity of the aquifer material, dimensionless; and

$\frac{dh}{dl}$ is the hydraulic gradient, dimensionless.

Ground-water flow velocities at each of the 30 monitoring wells (fig. 1) were calculated using either a hydraulic conductivity of 350 or 750 ft/d (refer to previous discussion of hydraulic conductivity), a hydraulic gradient of 0.001, and a porosity of 0.30. Ground-water flow velocities at the 30 monitoring wells were estimated at either 1.2 or 2.5 ft/d (table 3).

AGE DATING

Age dating of ground water (time elapsed since recharged to the aquifer) can provide information useful in the determination of ground-water residence time, potential recharge areas, and, subsequently, potential land-use effects on ground-water quality. Chlorofluorocarbons (CFCs) have been used as environmental tracers and as age-dating tools for young ground water (water recharged within the past 50 years) (Busenberg and Plummer, 1992; Busenberg and others, 1993; Dunkle and others 1993; Cook and others, 1995; Szabo and others, 1996; Plummer and others, 1998, 2001). Ground-water age dating (calculation of an apparent recharge date) with CFC–11 (trichlorofluoromethane, $CFCl_3$), CFC–12 (dichlorodifluoromethane, CF_2Cl_2), and CFC–113 (trichlorotrifluoroethane, $C_2F_3Cl_3$) is possible because (1) the concentrations of CFCs in the atmosphere over the past 50 years have been measured or reconstructed, (2) the solubilities of CFCs in water are known, and (3) the concentrations of CFCs in air and young water are large enough to be measured (Plummer and Friedman, 1999).

CFCs were first manufactured in 1928 as a replacement for the toxic gases ammonia (NH_3), methyl chloride (CH_3Cl), and sulfur dioxide (SO_2) that were used as refrigerants beginning in the 1800s. CFCs are nontoxic, nonflammable, and inert under ordinary environmental conditions. These characteristics made CFCs ideal for use as propellants for many household and personal-care products sold in aerosol cans. By the 1950s, CFCs were used extensively in automobile air-conditioning systems. The pervasive use of CFCs in industrial, commercial, and household applications has resulted in a widespread distribution of CFCs in the atmosphere (Lovelock and others, 1973; Elkins, 1999).

Concentrations of CFCs in the atmosphere have increased steadily from the middle 1940s to the early 1990s (Cook and Solomon, 1997) but started to level off beginning about 1993 as a result of earlier legislation restricting production and use of CFCs (Elkins, 1999). Age dating with CFCs is possible because precipitation will absorb an amount of CFCs that is proportional to the atmospheric concentration (Thompson and Hayes, 1979). Thus, the occurrence of CFCs in the atmosphere established the potential for CFCs to enter ground water via recharge. Calculations combining known historical atmospheric concentrations of CFCs with Henry's law solubilities for CFCs determined by Warner and Weiss (1985) provide the basis for

Table 3. Estimated aquifer properties at monitoring-well sites in areas of recent residential and commercial development, Wichita, Kansas

Monitoring-well index number (fig. 1)	Hydraulic conductivity (feet per day)	Hydraulic gradient (dimensionless)	Porosity (dimensionless)	Ground-water velocity (feet per day)
1	350	0.001	0.3	1.2
2	350	.001	.3	1.2
3	350	.001	.3	1.2
4	350	.001	.3	1.2
5	350	.001	.3	1.2
6	350	.001	.3	1.2
7	350	.001	.3	1.2
8	350	.001	.3	1.2
9	350	.001	.3	1.2
10	350	.001	.3	1.2
11	350	.001	.3	1.2
12	350	.001	.3	1.2
13	350	.001	.3	1.2
14	350	.001	.3	1.2
15	350	.001	.3	1.2
16	350	.001	.3	1.2
17	750	.001	.3	2.5
18	750	.001	.3	2.5
19	750	.001	.3	2.5
20	750	.001	.3	2.5
21	750	.001	.3	2.5
22	750	.001	.3	2.5
23	750	.001	.3	2.5
24	750	.001	.3	2.5
25	750	.001	.3	2.5
26	750	.001	.3	2.5
27	750	.001	.3	2.5
28	750	.001	.3	2.5
29	750	.001	.3	2.5
30	750	.001	.3	2.5

estimation of CFCs in water recharged in equilibrium with air between about 1940 and 1990 (Plummer and others, 1993).

The use of CFCs for age dating young ground water has certain limitations. Contamination of ground water with CFCs appears to be the greatest limitation to CFC age dating particularly in urban environments where CFCs are pervasive. CFCs from sources such as air-conditioning systems, propellants in aerosol cans, plastics, and sewage effluents from domestic septic systems can potentially contaminate recharge water with CFC concentrations greater than those possible from equilibrium with atmospheric air. Estimation of apparent recharge dates is not possible for samples in which all three CFCs (CFC–11, –12, –113) are contaminated in a single sample. However, in samples where all three CFCs in a sample are not contaminated, concentration data for one or more uncontaminated CFCs may provide a reliable apparent recharge date.

One of the underlying assumptions in using CFCs as a dating tool is that the concentrations of CFCs in ground water remain relatively unchanged during the residence time in the aquifer system. However, CFCs may degrade under certain physical conditions. For instance, CFCs have been shown to undergo microbial degradation in anaerobic (low concentrations of dissolved oxygen) water (Plummer and others, 1998). Analysis of ground-water samples with degraded CFC concentrations would produce erroneously old recharge dates. According to Plummer and Busenberg (2000), CFC degradation is usually not detected in ground water until sulfate-reducing conditions develop. Evaluation of terminal electron-accepting conditions in the aquifer was beyond the scope of this study. Thus, CFC degradation was considered possible in water samples with concentrations of dissolved oxygen less than or equal to 0.5 mg/L, in which case an average apparent recharge date was not reported.

Results of CFC analyses of water samples from the 30 monitoring wells (fig. 1) and calculated apparent recharge dates (table 4) indicate that the recharge ages of the collected samples ranged from about 1979 (monitoring well 2) to about 1990 (monitoring wells 5, 15, and 30) with an average apparent recharge age of about 1986 (calculated on the basis of dates from 18 monitoring wells). Apparent recharge dates listed in table 4 are averages of the highlighted (shaded) reported CFC dates from the three

Table 4. Apparent dates of recharge calculated from analyses of chlorofluorocarbons (CFCs) for and concentrations of dissolved oxygen in water samples from 30 monitoring wells installed in areas of recent residential and commercial development, Wichita, Kansas, 2000

[Recharge dates are based on measured CFC concentrations, an average recharge elevation of 1,300 feet, and an average recharge temperature of 14.1 ^{o}C. Shading indicates those dates used to calculate apparent recharge dates for each well. mg/L, milligrams per liter; <, less than; contam., contaminated; --, not determined]

Monitoring-well index number (fig. 1)	Reported CFC recharge dates			Apparent recharge date[1]	Dissolved-oxygen concentration (mg/L)
	CFC–11	CFC–12	CFC–113		
1	<1945	1984.0	<1955	1984	5.1
	1950.0	1984.5	<1955		
	1949.0	1983.0	<1955		
2	1983.0	1975.5	1978.5	1979	2.9
	1983.0	1975.0	1978.0		
	1983.0	1975.5	1978.5		
3	Contam.	Contam.	1983.5	1986	4.1
	Contam.	1988.5	1984.0		
	Contam.	1988.0	1985.0		
4	1955.5	Contam.	<1955	--	.3
	1957.0	Contam.	<1955		
	1956.0	Contam.	<1955		
5	Contam.	Contam.	1989.5	1990	5.6
	Contam.	Contam.	1990.0		
	Contam.	Contam.	1990.0		
6	1952.5	1968.5	<1955	--	.1
	1953.0	1969.0	<1955		
	1952.5	1967.5	<1955		
7	Contam.	Contam.	Contam.	1986	.9
	Modern	1986.0	1985.0		
	Modern	1987.5	1984.5		
8	Contam.	1989.5	1988.0	1987	2.7
	Contam.	Contam.	1986.0		
	Contam.	Contam.	1986.0		
9	Modern	Modern	1988.5	1989	5.6
	Modern	Modern	1989.5		
	Modern	Modern	1988.5		
10	Contam.	Contam.	1989.0	1989	3.6
	Contam.	Contam.	1989.0		
	Contam.	Contam.	1989.5		
11	1975.5	1981.0	1982.5	1980	3.8
	1976.0	1979.0	1982.0		
	1976.0	1980.5	1984.0		
12	Contam.	Contam.	1986.0	1986	3.2
	Contam.	Contam.	1985.5		
	Contam.	Contam.	1986.0		

Table 4. Apparent dates of recharge calculated from analyses of chlorofluorocarbons (CFCs) for and concentrations of dissolved oxygen in water samples from 30 monitoring wells installed in areas of recent residential and commercial development, Wichita, Kansas, 2000—Continued

Monitoring-well index number (fig. 1)	Reported CFC recharge dates			Apparent recharge date[1]	Dissolved-oxygen concentration (mg/L)
	CFC–11	CFC–12	CFC–113		
13	Contam.	Contam.	1985.5	1985	2.6
	Modern	Contam.	1984.5		
	Modern	Contam.	1984.5		
14	Contam.	Contam.	1984.0	1984	4.2
	Contam.	Contam.	1983.5		
	Contam.	Contam.	1983.5		
15	Contam.	1994.5	1987.0	1990	4.5
	Contam.	1993.0	1987.5		
	Contam.	1991.5	1987.5		
16	1985.5	1989.5	1987.5	1987	6.1
	1985.5	1988.5	1987.0		
	1986.0	1988.0	1987.5		
17	1965.0	Contam.	1976.0	--	.2
	1964.0	Contam.	1966.5		
	1964.5	Contam.	1970.0		
18	1976.5	Contam.	1974.5	--	.5
	1976.5	Contam.	1969.0		
	1976.5	Contam.	1971		
19	Contam.	1984.5	1986.0	1984	2.8
	Contam.	1982.0	1984.0		
	Contam.	1984.0	1986.0		
20	1973.5	1987.0	1984.0	1986	1.7
	1972.0	1988.5	1984.0		
	1971.5	1987.5	1983.5		
21	1966.0	1970.0	<1955	--	<.1
	1966.0	1969.5	<1955		
	1966.0	1970.0	<1955		
22	1956.0	1959.5	<1955	--	<.1
	1950.5	1960.0	<1955		
	1948.5	1960.0	<1955		
23	<1945	1988.5	1981.5	1988	5.5
	<1945	1987.5	1978.5		
	<1945	1988.0	1976.0		
24	<1945	1975.0	<1955	--	<.1
	1950.0	1974.5	<1955		
	1951.5	1974.5	<1955		
25	1966.0	1983.0	1972.0	--	.1
	1966.0	1981.0	1969.5		
	1966.0	1982.0	1970.0		

Table 4. Apparent dates of recharge calculated from analyses of chlorofluorocarbons (CFCs) for and concentrations of dissolved oxygen in water samples from 30 monitoring wells installed in areas of recent residential and commercial development, Wichita, Kansas, 2000—Continued

Monitoring-well index number (fig. 1)	Reported CFC recharge dates			Apparent recharge date[1]	Dissolved-oxygen concentration (mg/L)
	CFC–11	CFC–12	CFC–113		
26	<1945	1949.0	<1955	--	0.2
	<1945	1945.0	<1955		
	1965.0	1962.0	<1955		
27	1948.5	1984.0	<1955	--	.2
	<1945	1981.5	<1955		
	<1945	1982.5	<1955		
28	1953.0	1973.5	<1955	--	.1
	1953.5	1974.0	<1955		
	1959.5	1974.0	<1955		
29	1952.5	1961.0	<1955	--	.1
	1953.0	1961.5	<1955		
	1953.5	1962.0	<1955		
30	Contam.	Contam.	Modern	1990	6.8
	Contam.	Contam.	1990.5		
	Contam.	Contam.	1990.0		

[1] Average of shaded reported CFC recharge dates.

replicated samples analyzed for each well. Not all of the possible reported dates were used to calculate average dates because some CFC concentrations were considered contaminated, others were considered degraded because of anaerobic conditions (concentration of dissolved oxygen less than 0.5 mg/L), and others appeared to be unusually old such as at monitoring well 1. Recharge dates reported as “modern” (less than 10 years old) in table 4 may indicate recent recharge but were not quantifiable.

The average reported recharge date (1964) of the 12 samples (table 4) with dissolved-oxygen concentrations less than or equal to 0.5 mg/L was 22 years older than the average apparent recharge date (1986) for the other 18 samples, which indicates that CFC degradation probably did occur in the anaerobic parts of the aquifer. Only “non-less-than” dates (table 4) were used to calculate the average reported recharge date for the 12 anaerobic samples.

QUALITY OF SHALLOW GROUND WATER

Shallow ground water in the Wichita area is used to a limited extent as a domestic drinking-water supply and as a supplementary public supply. The USEPA has established drinking-water standards for physical properties and chemical constituents that may have adverse effects on human health or that may affect the odor, appearance, or desirability of water (U.S. Environmental Protection Agency, 2000a). A Maximum Contaminant Level (MCL) is the maximum permissible concentration for a contaminant in drinking water that is delivered to any user of a public-water system. A Secondary Maximum Contaminant Level (SMCL) is a nonenforceable USEPA guideline regarding aesthetic effects of drinking water. A lifetime Health Advisory Level (HAL) is a nonenforceable USEPA guideline for the concentration of a chemical in drinking water that is not expected to cause adverse noncarcinogenic effects over a lifetime of exposure. Shallow ground-water quality in areas of recent residential and commercial development in Wichita, Kansas, is discussed in the following sections in relation to these USEPA standards and in relation to natural hydrologic factors and human-related activities.

Physical Properties

Physical properties were measured in water from each of the 30 monitoring wells (fig. 1) sampled during this study (table 14 at the back of this report). Measurements made at the time of sample collection included specific conductance, pH, water temperature, turbidity, dissolved oxygen, and alkalinity. A statistical summary and USEPA standards for physical properties in water from 30 monitoring wells sampled during this study are presented in table 5.

Water from most wells had specific conductance values less than 1,000 µS/cm (microsiemens per centimeter at 25 °C). Water from eight wells (6, 13, 20, 21, 24, 25, 28, 29) had specific conductance values greater than 1,000 µS/cm. Specific conductance values for these eight wells ranged from 1,020 to 2,590 µS/cm. The eight wells generally are located near and along the west side of the Arkansas River (fig. 1). Specific conductance describes the ability of water to conduct an electrical current and provides an indication of ion concentrations or dissolved solids. As specific conductance of the water increases, so does the ion concentration (Hem, 1985).

The pH of water from all except three sampled wells was within the USEPA SMCL range of 6.5 to 8.5 standard units in drinking water. The exceptions were water from wells 8 and 15 (pH of 6.4 standard units) and well 16 (pH of 6.3 standard units). pH values less than 7.0 are indicative of acidic water, and values greater than 7.0 are indicative of alkaline water.

The turbidity (cloudiness) of water from most wells was low, which generally indicates not only an acceptable aesthetic appeal and a lack of obvious contamination but also that the wells were developed properly and that samples were representative of the aquifer water. However, water from well 10 had a turbidity of 8.8 nephelometric turbidity units (NTU) (table 14) and was the only well where the water exceeded the USEPA drinking-water standard of 5.0 NTU. The second largest turbidity was 3.4 NTU in water from well 17. The relatively large turbidity in water from well 10 probably was an artifact of recent installation and infrequent pumping. Turbidity has no health effects but can interfere with disinfection and provide a medium for microbial growth.

Water from the wells had a median dissolved-oxygen concentration of 2.6 mg/L (table 5). Water from three wells (21, 22, 24) had no detectable dissolved oxygen (less than 0.1 mg/L). Water from nine other wells had dissolved-oxygen concentrations of 0.5 mg/L or less (table 14). Most of the wells (7 of 12) with water under anaerobic conditions (0.5 mg/L or less of dissolved oxygen) were clustered in a relatively small area north of Haysville between the Wichita-Valley Center Floodway and the Arkansas River (fig. 5).

Oxygen enters ground water through recharge of oxygen-enriched water that percolates down through the unsaturated zone where it may react with oxidizable material encountered along the flow path of the water. The principal reacting materials are organics and reduced inorganic minerals such as pyrite and siderite (Hem, 1985). The small dissolved-oxygen concentrations in water from many of the wells sampled during this study may represent natural and localized, oxygen-demanding (reducing) conditions in the unsaturated zone or may be an indication of contamination from the distribution or disposal of organic material associated with human activities.

Human-related organic material can originate from urban sources such as leachate from domestic septic systems and sanitary landfills, the use of land for sewage disposal, refuse dumps for disposal of organic compounds, the burial of containers with organic

Table 5. Statistical summary and U.S. Environmental Protection Agency (2000a) drinking-water standards for physical properties in water from 30 monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000

[µS/cm, microsiemens per centimeter at 25 °C; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; SMCL, Secondary Maximum Contaminant Level; --, not applicable; <, less than]

Physical property (unit of measurement)	Number of samples	Concentration or measurement			Drinking-water standard
		Minimum	Median	Maximum	
Specific conductance (µS/cm)	30	352	766	2,590	--
pH (standard units)	30	6.3	7.0	7.4	6.5–8.5 (SMCL)
Water temperature (°C)	30	14.7	16.2	18.9	--
Turbidity (NTU)	30	.20	.70	8.8	5.0 (SMCL)
Dissolved oxygen (mg/L)	30	<.1	2.6	6.8	--
Alkalinity, water whole, field (mg/L as $CaCO_3$)	30	68	265	570	--

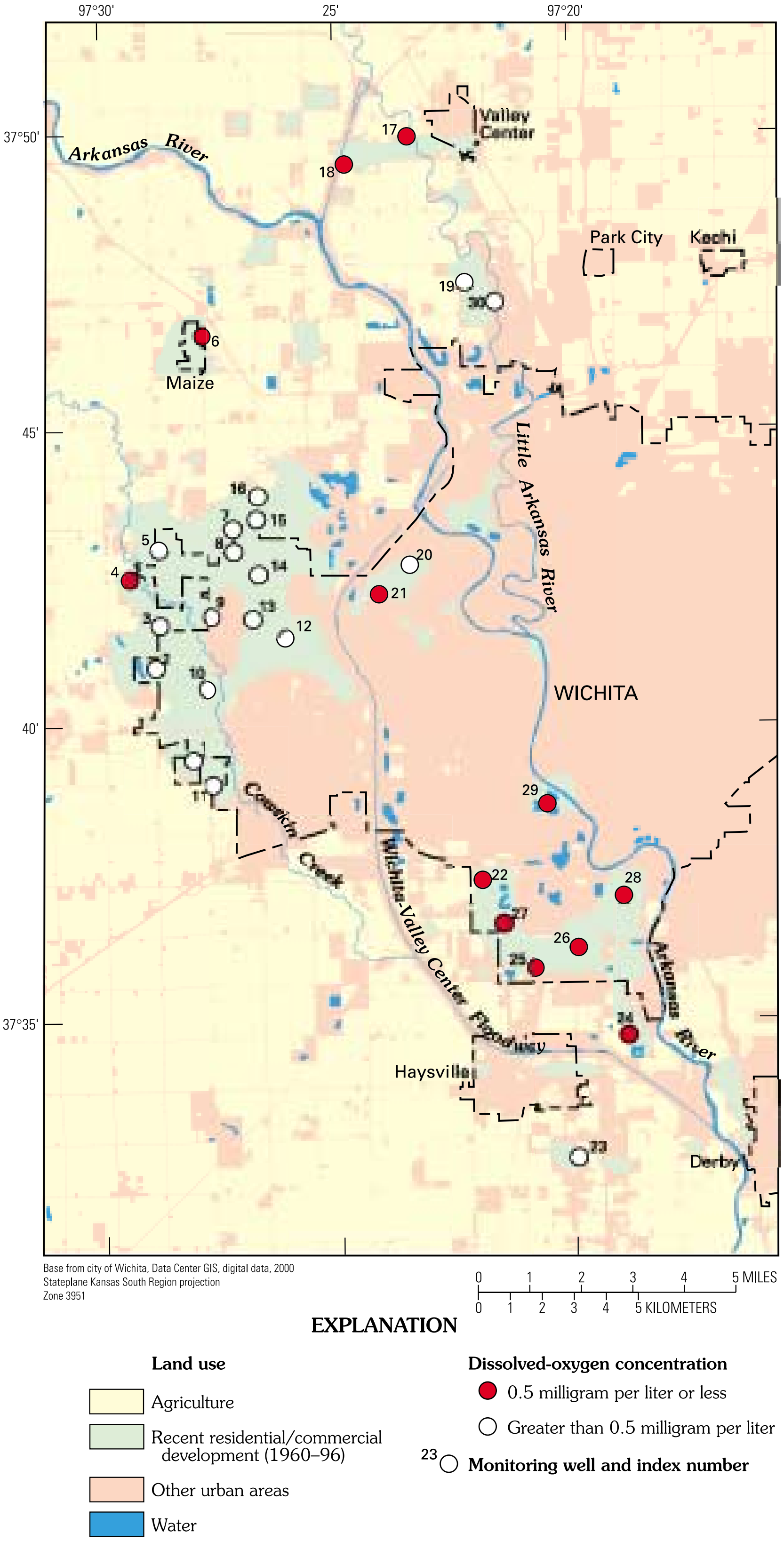


Figure 5. Occurrence of anaerobic conditions (dissolved-oxygen concentration of 0.5 milligram per liter or less) in shallow ground water from monitoring wells in areas of recent residential and commercial development, 2000.

compounds, leakage from liquid-waste storage ponds, accidental spills along roads and highways, and the use of pesticides. Additional sources of organic material may include artifacts of past agricultural activities such as crop production, distribution of animal manure, and confined animal-feeding operations. Other types and sources of oxidizable material include synthetic fertilizers used on residential lawns, parks, golf courses, or around commercial areas.

Although the percentage of organic carbon in the unconsolidated, sediment collected at the 30 well sites was small (table 15 at the back of this report), larger percentages of organic carbon may be associated with surficial soils (depths less than about 5 ft) in the study area. The surficial soils were not sampled for this study, and the organic-carbon content of these soils are not readily available from other sources. However, it is expected that organic-carbon content of the soil profile would be larger in the surficial soils than in the deeper sediment sampled during this study because of proximity to organic materials such as plant residues, waste products, pesticides, and others sources of organic contamination. Freeze and Cherry (1979, p. 245) summarized the concept of oxygen depletion in recharge water, "It is reasonable to expect that the consumption of oxygen in the soil zone will vary depending on numerous factors, such as the soil structure, porosity and permeability, nature and depth distribution of organic matter, frequency of infiltration events, depth to water table, and temperature." They further stipulated that in areas of appreciable dissolved oxygen in shallow ground water in sandy deposits that it "...is probably a result of low contents of organic matter in the soil and rapid rates of infiltration through the soil."

Alkalinity as $CaCO_3$ (calcium carbonate) in water is a measure of the acid-buffering capacity of a filtered water sample. Alkalinity as $CaCO_3$ ranged from 68 to 570 mg/L with a median concentration of 265 mg/L in the ground-water samples collected (table 5). Water with excessive alkalinity as $CaCO_3$ may have a distinctive unpleasant taste, and irrigation water with excessive alkalinity may increase the pH of the soil solution, leach organic material, decrease permeability of the soil, and impair plant growth (Hem, 1985).

Dissolved Solids and Major Ions

Dissolved solids are an important indicator of water quality and, in uncontaminated ground water, are the result of natural dissolution of rocks and minerals. Dissolved solids also are an important indicator of the suitability of water for drinking, irrigation, and industrial use. Although drinking water containing more than 500 mg/L dissolved solids (USEPA SMCL) is undesirable, such water is used in many areas where less mineralized water is not available. Water containing more than 1,000 mg/L dissolved solids is likely to contain enough of some constituents to cause noticeable taste or otherwise make the water undesirable or unsuitable for use. Dissolved solids in irrigation water may adversely affect plants directly by the development of high osmotic conditions in the soil solution and by the presence of phytoxins.

The major constituents of dissolved solids in shallow ground-water samples collected from areas of recent residential and commercial development in Wichita were the cations (positively charged ions) calcium, magnesium, potassium, silica, and sodium and the anions (negatively charged ions) bicarbonate, bromide, chloride, fluoride, and sulfate. A statistical summary and USEPA drinking-water standards (where applicable) for dissolved solids and major ions in water from 30 monitoring wells sampled during this study are presented in table 6. Method reporting limits, sample concentrations and median values, and associated drinking-water standards for dissolved solids and major ions are presented in figure 6.

Concentrations of dissolved solids in water from the 30 monitoring wells sampled ranged from 229 (well 16) to 1,630 mg/L (well 6) (tables 6 and 14, fig. 6). The distribution of dissolved-solids concentrations in water is shown in figure 7. The median dissolved-solids concentration was 492 mg/L, only slightly less than the 500-mg/L SMCL established by the USEPA (U.S. Environmental Protection Agency, 2000a). Water from 14 wells (47 percent) exceeded the SMCL for dissolved solids (fig. 7).

The distribution of dissolved solids in shallow ground water in areas of recent residential and commercial development was similar to that determined for the Wichita area by Lane and Miller (1965) and Bevans

Table 6. Statistical summary and U.S. Environmental Protection Agency (2000a) drinking-water standards for dissolved solids and major ions in water from 30 monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000

[SMCL, Secondary Maximum Contaminant Level; MCL, Maximum Contaminant Level; --, not applicable]

Dissolved solids or major ion	Number of samples	Concentration (milligrams per liter) Minimum	Median	Maximum	Drinking-water standard (milligrams per liter)
Dissolved solids	30	229	492	1,630	500 (SMCL)
Calcium	30	33	88	180	--
Magnesium	30	3.4	15	50	--
Potassium	30	1	3	13	--
Silica	30	11	19.5	34	--
Sodium	30	14	58	320	--
Bicarbonate	30	83	320	700	--
Bromide	30	.06	.16	.47	--
Chloride	30	11	64	390	250 (SMCL)
Fluoride	30	.1	.3	1.1	4 (MCL) 2 (SMCL)
Sulfate	30	5.6	54	310	250 (SMCL)

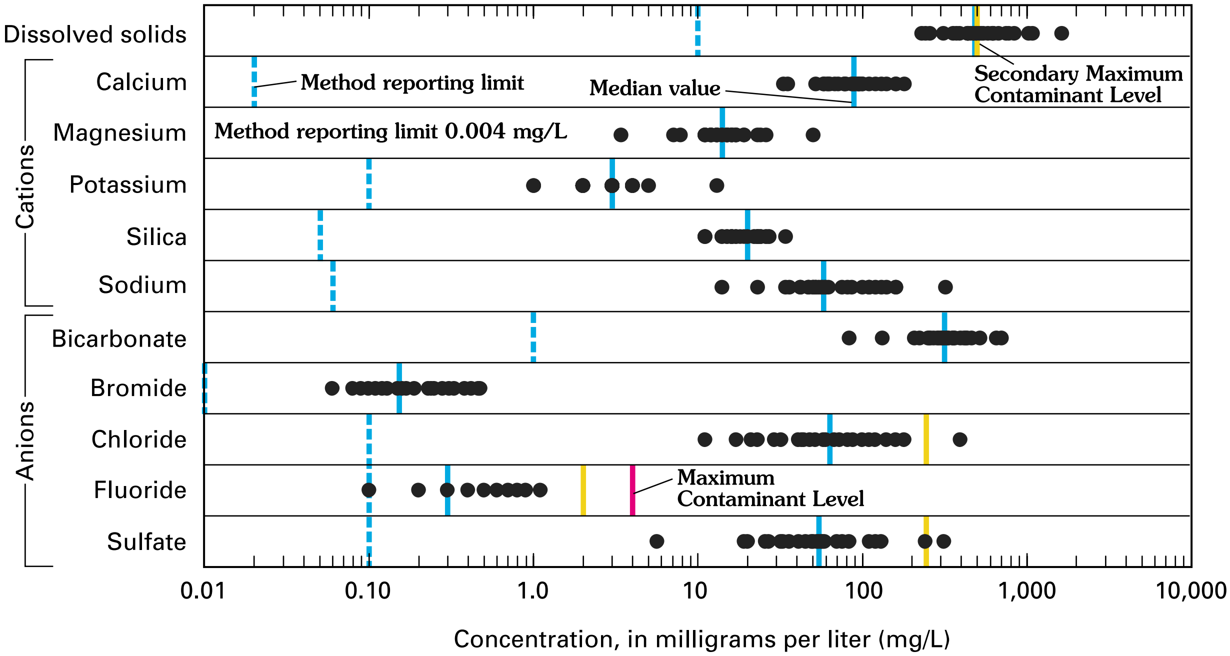


Figure 6. Method reporting limits, sample concentrations and median values, and drinking-water standards for dissolved solids and major ions detected in shallow ground water from 30 monitoring wells in areas of recent residential and commercial development, 2000 (drinking-water standards from U.S. Environmental Protection Agency, 2000a).

(1989). Water from wells closest to the Arkansas River generally had the largest dissolved-solids concentrations (fig. 7). Water with dissolved-solids concentrations less than 500 mg/L generally came from wells farthest west of the Arkansas River in the Cowskin Creek area.

The largest dissolved-solids concentrations determined during this study probably are related to highly mineralized water moving out of the Arkansas River into the shallow, unconsolidated deposits along the river. This movement may occur naturally when the river stage is higher than the ground-water table or may be locally enhanced by pumpage of water for municipal, industrial, and irrigation purposes (Lane and Miller, 1965). The source of highly mineralized water in the Arkansas River probably is from saline ground water discharged from Permian rock along the Arkansas River about 60 mi northwest of Wichita and, to a lesser extent, from brine disposal related to salt and oil production near Burrton in western Harvey County (Bevans, 1989).

Calcium bicarbonate water is the dominant ground-water type in areas of recent residential and commercial development (fig. 8). However, this water type may be modified locally by the mixing of sodium chloride type water along the western side of the Arkansas River. Sodium chloride type water generally is present in alluvium and terrace deposits that occur along the western side of the Arkansas River north of Kansas Highway 96 (fig. 1). The source of this sodium chloride type water is the Arkansas River (Bevans, 1989).

Associated with the variability in or mixing of water types, the concentrations of chloride (390 mg/L) and sulfate (310 mg/L) in water from well 6 both exceeded the 250-mg/L SMCLs for these constituents. Both of these concentrations were larger than concentrations in water from the other wells (fig. 6, table 14). The probable source of the relatively large concentration of chloride may be the infiltration of sodium chloride water from the Arkansas River into adjacent alluvium and terrace deposits. Although there are natural sources of chloride in the study area to produce the concentrations in shallow ground water determined during this study, the discharge of human, animal, or industrial wastes and irrigation return flows may add chloride to ground water. The relatively large concentration of sulfate may be from the oxidation of pyrite and other sulfides (common in sedimentary rocks) in well-oxygenated water or the dissolution of evaporite deposits such as gypsum (calcium sulfate).

Few, if any, human-health effects are associated with chloride or sulfate in the concentration range determined during this study; however, concentrations

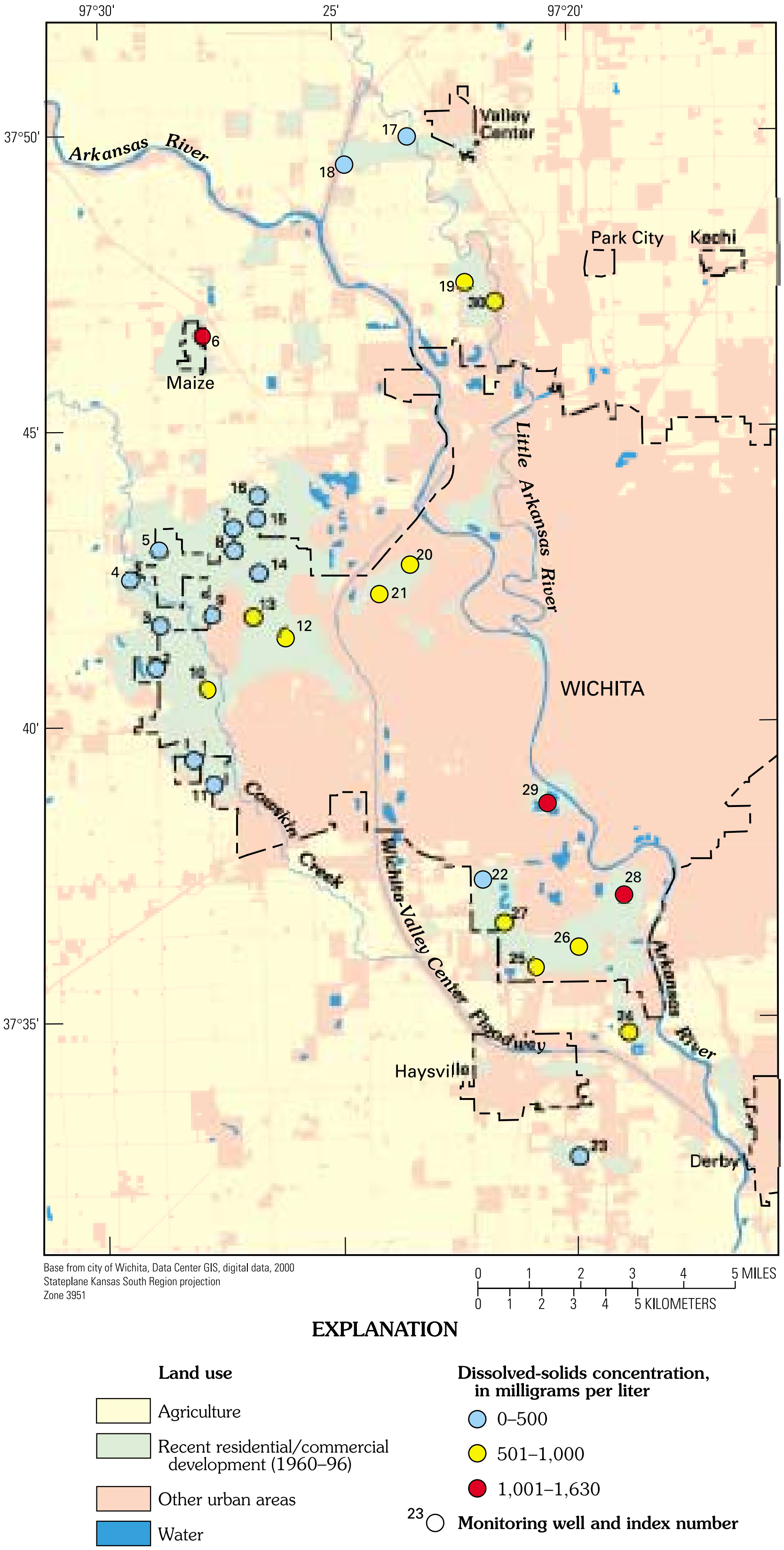


Figure 7. Distribution of dissolved-solids concentrations in shallow ground water from monitoring wells in areas of recent residential and commercial development, 2000.

larger than 250 mg/L may produce an objectionable taste in drinking water. Chloride may impart a salty taste to drinking water and may accelerate the corrosion of metals used in water-supply systems. Sulfate in drinking water may impart a bitter taste and act as a laxative on unacclimated users (Hem, 1985).

Nutrients and Dissolved Organic Carbon

Sources of nutrients in urban areas include synthetic fertilizers used for lawns and landscape areas, failing septic systems, municipal and industrial waste distribution, spills of nitrogen- or phosphorus-containing organic material, and domestic animal waste. Precipitation can be a source of nutrients (National Atmospheric Deposition Program, 2000) as a result of the burning of fossil fuels and gasoline or from lightning-induced chemical conversion of atmospheric nitrogen gas to nitrous oxides. Leachate from these various sources can infiltrate the soil profile to shallow ground water.

Most nutrient sources in Kansas, however, are associated with agricultural production. Synthetic fertilizer use in Kansas more than tripled from 1965 to 1998, from about 640,000 to about 2,100,000 tons (Kansas Department of Agriculture and U.S. Department of Agriculture, 1999). Farm livestock also produce large quantities of nitrogen- and phosphorus-rich organic waste (urine and manure) that contribute to nonpoint sources of nutrients.

Human health-based regulations have been established for nitrate concentrations in drinking water because of the potential adverse health effects on infants. Consumption of drinking water with nitrate concentrations larger than 10 mg/L can cause methemoglobinemia (blue-baby syndrome) in infants, a sometimes fatal illness related to the impairment of the oxygen-carrying ability of the blood (U.S. Environmental

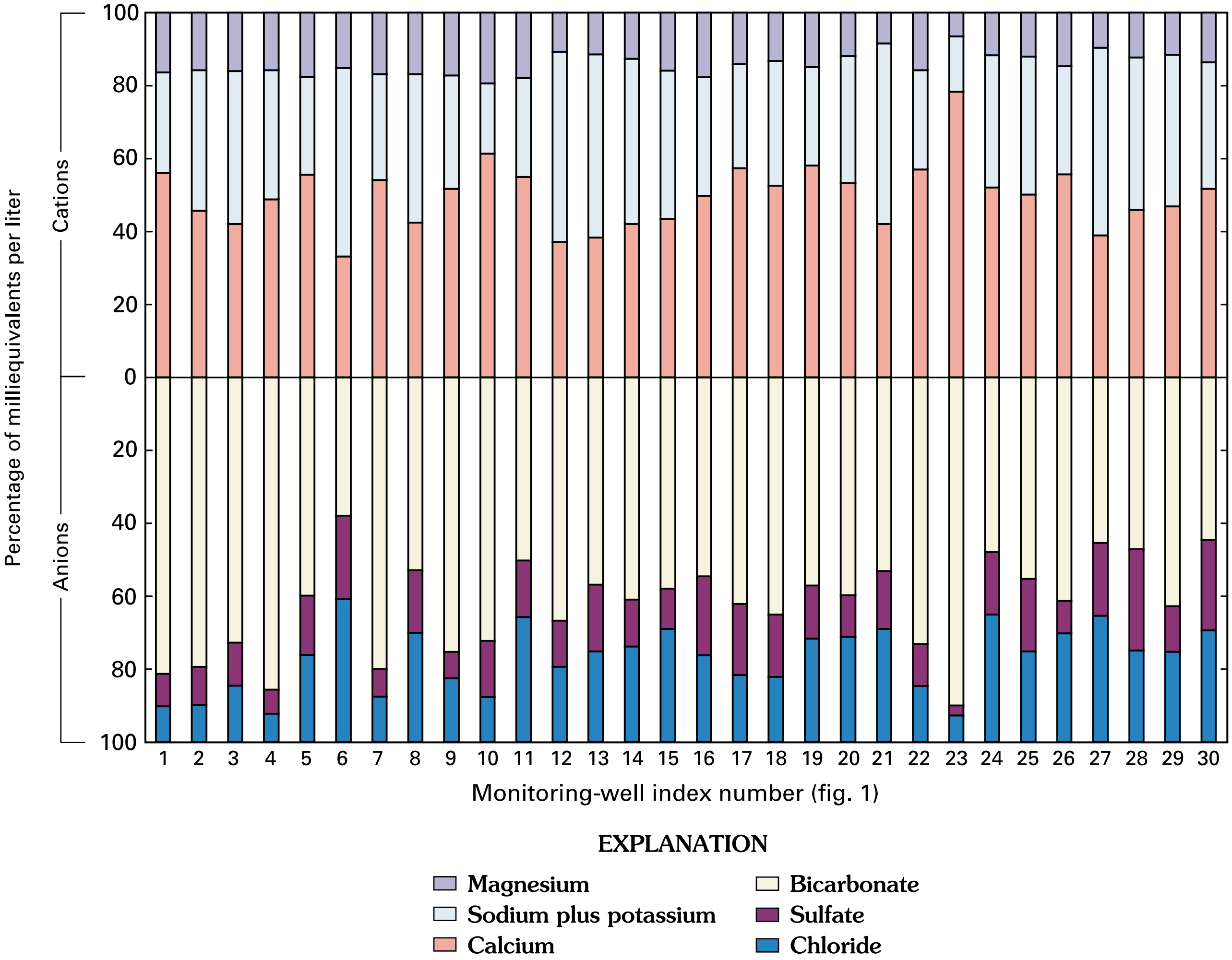


Figure 8. Major ion composition of shallow ground water from monitoring wells in areas of recent residential and commercial development, 2000.

Protection Agency, 1986). Accordingly, a MCL of 10 mg/L of nitrate as nitrogen has been established by the USEPA and implemented in the State by the Kansas Department of Health and Environment (1994).

Nitrite and nitrate are inorganic ions produced during various stages of the nitrogen cycle. In most oxygenated water, nitrate is the predominate ion because of rapid oxidation of nitrite (Reid and Wood, 1976, p. 235). Nitrite and nitrate usually occur in relatively small concentrations in uncontaminated water, and concentrations in the range of several milligrams per liter indicate contamination from human activities. Mueller and Helsel (1996) estimated a national average background concentration of nitrate in ground water of 2.0 mg/L as nitrogen; nitrate concentrations larger than 2.0 mg/L may be indicative of contamination from human-related activities.

Concentrations of most nutrients in water from the 30 wells sampled during this study were small (table 14 at the back of this report). Concentrations of ammonia as nitrogen ranged from less than 0.02 mg/L (not detected) in water from 20 wells (fig. 9; table 7) to 0.18 mg/L (well 22, table 14). Of the 10 wells with detectable concentrations of ammonia, water from seven (wells 4, 22, 24–28) were under anaerobic conditions (fig. 5). With the exception of monitoring well 4, wells 22 and 24–28 were in the cluster of wells with anaerobic water north of Haysville. Generally, ammonia is more common in ground water under reducing (anaerobic) conditions because the lack or small concentrations of dissolved oxygen stimulates the denitrification process. Denitrification refers to the biological reduction (loss of oxygen) of nitrate (NO_3^-) to ammonia (NH_3) or the ammonium ion (NH_4^+). In the absence of dissolved oxygen, heterotrophic bacteria in

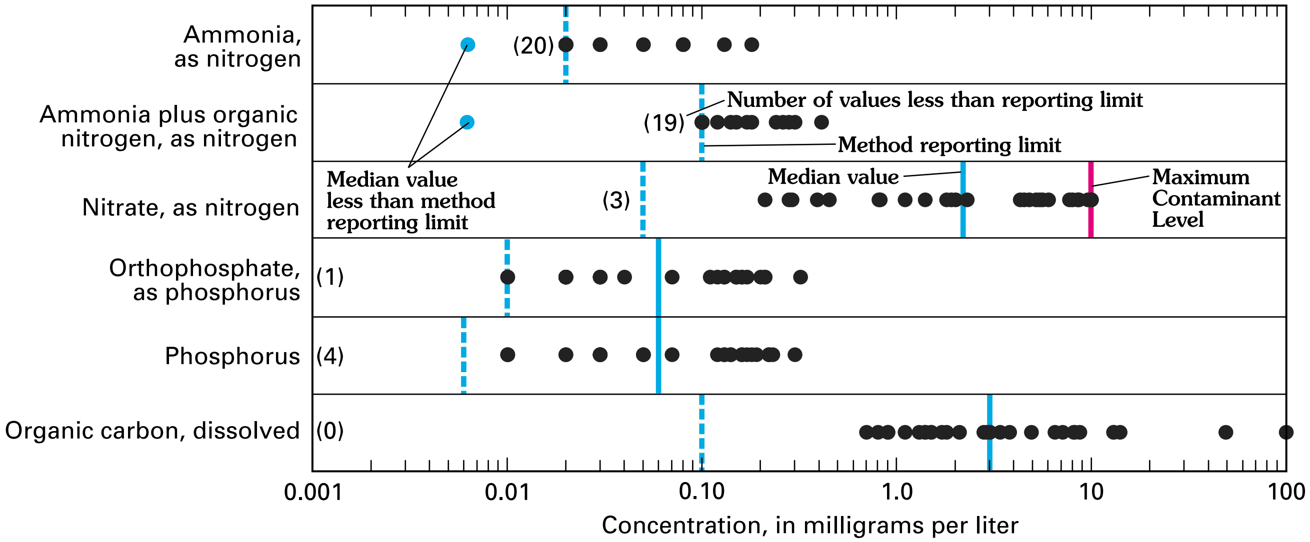


Figure 9. Method reporting limits, sample concentrations and median values, and drinking-water standards for nutrients and dissolved organic carbon detected in shallow ground water from 30 monitoring wells in areas of recent residential and commercial development, 2000 (drinking-water standards from U.S. Environmental Protection Agency, 2000a).

Table 7. Statistical summary and U.S. Environmental Protection Agency (2000a) drinking-water standards for selected nutrients in water from 30 monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000

[<, less than; --, not applicable; MCL, Maximum Contaminant Level]

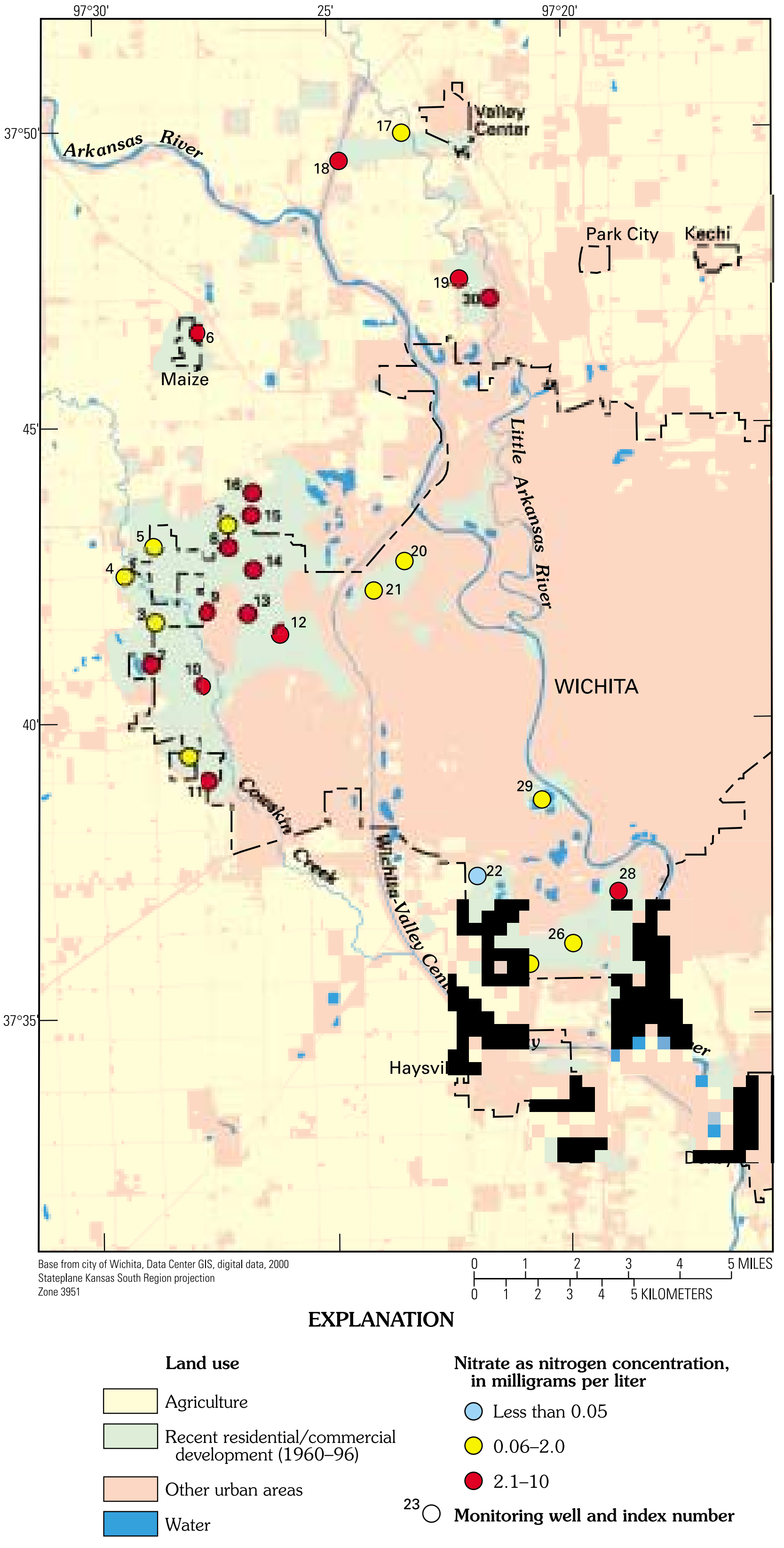
Nutrient	Number of samples	Concentration (milligrams per liter)			Drinking-water standard (milligrams per liter)
		Minimum	Median	Maximum	
Ammonia, as nitrogen	30	<0.02	<0.02	0.18	--
Ammonia plus organic nitrogen, as nitrogen	30	<.10	<.10	.41	--
Nitrate, as nitrogen	30	<.05	2.2	10	10 (MCL)
Phosphate, ortho, as phosphorus	30	<.01	.06	.32	--
Phosphorus	30	<.006	.06	.30	--
Organic carbon, dissolved	30	.7	3.0	100	--

soil and water may use nitrate as an oxygen source during respiration (Canter, 1997).

Little organic nitrogen (carbon compounds containing nitrogen such as proteins, peptides, amino acids, and nucleic acids) was detected in water from wells in the study area. Most of the detections of organic nitrogen [(ammonia + organic nitrogen) - ammonia, table 14] were from wells with water under anaerobic conditions. Of the 11 detections of organic nitrogen (wells 6, 8, 13, 22, 24–30), eight were in anaerobic water. Generally, the metabolism of organic compounds is an oxidation process, and the lack of oxygen will inhibit the rate of this process.

Concentrations of nitrite plus nitrate nitrogen (hereinafter referred to as nitrate or nitrate, as nitrogen) in water from the 30 wells sampled during this study varied throughout the study area (fig. 10). Concentrations of nitrate ranged from less than 0.05 (wells 22, 24, 27) to 10 mg/L (wells 12, 30) with a median concentration of 2.2 mg/L. Although water from none of the wells sampled during this study had concentrations greater than the 10-mg/L drinking-water MCL, water from 15 wells (50 percent) showed enrichment when compared to a 2.0-mg/L national background nitrate concentration (Mueller and Helsel, 1996). This enrichment probably is the result of human-related activities.

The 2.2-mg/L median nitrate concentration determined for water from the 30 monitoring wells sampled during this study was slightly larger than the



Base from city of Wichita, Data Center GIS, digital data, 2000
Stateplane Kansas South Region projection
Zone 3951

Figure 10. Distribution of nitrate as nitrogen concentrations in shallow ground water from monitoring wells in areas of recent residential and commercial development, 2000.

1.6-mg/L median concentration determined from a national study of shallow ground water beneath urban land (Nolan and Stoner, 2000). About one-half (53 percent) of shallow ground-water studies in urban and agricultural areas in the United States reported median nitrate concentrations in well water larger than the national background concentration of 2.0 mg/L (U.S. Geological Survey, 1999). Of the urban studies, 40 percent had median nitrate values larger than the national background concentration.

Most phosphorus in water from wells in the study area occurs as orthophosphate (fig. 9). Orthophosphate constituted a median percentage of 94 percent of the total phosphorus concentration in water from the 30 wells sampled in the study area. Orthophosphate (PO_4^{-3}) together with condensed forms of phosphate that include metaphosphate ($P_2O_6^{-2}$), pyrophosphate ($P_2O_7^{-4}$), and tripolyphosphate ($P_3O_{10}^{-5}$) constitute the major inorganic forms of phosphorus in natural water (Patnaik, 1997). However, the condensed phosphates are unstable in water and in time revert to orthophosphate (Hem, 1985). Concentrations of orthophosphate ranged from less than 0.01 (well 28) to 0.32 mg/L (well 1).

Most uncontaminated ground water has only small concentrations of dissolved organic carbon (DOC). In the absence of organic contamination such as leachate from landfills or spills or leaks from areas of oil and gas production, the source of DOC in ground water likely would be the end products of the biochemical cycle in the soil profile above the aquifer. These end products, generally, are humic and fulvic acids associated with the biological degradation and decay of soil-organic material or organic amendments (manure) applied to the soil. If present in large enough quantities, however, organic solutes composing DOC may form complexes that affect trace-element solubility, participate in redox reactions, and affect both physical and chemical properties of solid-liquid or liquid-gas interfaces (Hem, 1985). No drinking-water-quality standard has been established for DOC.

Concentrations of DOC were small in water from most of the 30 wells sampled during this study (fig. 9, table 7). Generally, concentrations less than 10 mg/L are representative of natural aquifer ranges (Nielsen, 1991, p. 545). However, two relatively large concentrations of 49 and 100 mg/L were measured in water from well 1 and well 16, respectively. The potential contamination evident in water from wells 1 and 16 is probably a localized issue and may originate as leachate from septic systems, waste disposal, or spills.

Trace Elements

Trace elements normally occur in natural water in small concentrations even though some trace elements are naturally abundant. For instance, although aluminum is the second-most abundant element (behind silica) in igneous and sedimentary rocks of the Earth’s crust, it rarely occurs in solution in natural water in concentrations greater than a few hundred micrograms per liter (Hem, 1985). The occurrence in ground water of most of the trace elements listed in table 13 (at the back of this report) typically results from natural physical and chemical processes. Physical processes include those associated with the mineral composition and origin, transport, and deposition of the aquifer material. Chemical processes include the action of water, oxygen, carbon dioxide, and other acidic components that cause the chemical breakdown or dissolution of minerals containing trace elements (Bricker and Jones, 1995, p. 1–20). Generally, the occurrence and chemical speciation of trace elements in ground water are determined by (1) hydrogen ion availability (defined by pH); (2) the presence and concentrations of inorganic ligands such as carbonate, sulfate, sulfide, and chloride; (3) the presence and concentrations of organic complexing agents (primarily humic and fulvic acids); (4) free electron availability (reducing or oxidizing conditions); and (5) the ionic strength and cation distribution of the water (Allard, 1995, p. 151–176).

Human activities may affect trace-element concentrations in shallow ground water. For instance, organic and inorganic compounds of copper have been used extensively in agricultural pesticide sprays, and their wide dispersal in cropland areas has the potential to enrich copper concentrations in shallow ground water. However, the source and distribution of trace elements probably are more dominant in urban areas where trace elements such as aluminum, chromium, copper, iron, lead, nickel, and zinc are used as structural or decorative components of buildings, exterior structures and trim work, in automobiles, and as protective coverings or coatings against corrosion and oxidation. Large quantities of some trace elements have been released with effluent discharge from industrial activities, the burning of fossil fuels, and dispersed in automobile exhaust as a result of their addition to gasoline in the refining process. This potentially wide environmental distribution of trace elements creates the possibility for dissolution of some of these elements in water that, ultimately, may recharge a shallow aquifer.

Most trace elements in water from the 30 wells sampled were detected only in small concentrations that were less than established MCLs (table 8, fig. 11). Antimony, beryllium, cadmium, lead, and silver were not detected. Chromium (two detections) and cobalt (seven detections) were detected infrequently. Aluminum, copper, molybdenum, selenium, and zinc were detected more frequently, but none of the detected concentrations were larger than established or proposed drinking-water standards. Barium and nickel were detected in water from all 30 wells, but none of the detected concentrations exceeded drinking-water standards.

Of the 30 monitoring wells sampled, concentrations of iron in water from six wells (20 percent) were larger than the 300-µg/L USEPA SMCL established for drinking water (fig. 11). Concentrations of iron in water from these six wells ranged from 630 (well 28) to 3,700 µg/L (well 24) (table 14 at the back of this report), probably associated with reducing conditions. Under reducing conditions, iron generally occurs in ground water in the ferrous iron (Fe^{+2}) oxidation state, largely as the result of the reduction (loss of oxygen) of ferric oxyhydroxides (Bricker and Jones, 1995). Iron also is present in organic wastes and in plant debris in soil, and microbial activities may affect the occurrence of iron in water. Iron is an essential element in the metabolism of plants and animals. However, if present in excessive amounts, iron forms red oxyhydroxide precipitates that strain laundry and plumbing fixtures and, therefore, is an objectionable impurity in domestic and industrial water supplies (Hem, 1985). The occurrence of iron in water from wells sampled during this study probably is from natural sources.

Table 8. Statistical summary and U.S. Environmental Protection Agency drinking-water standards for selected trace elements in water from 30 monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000

[<, less than; --, not applicable; MCL, Maximum Contaminant Level; SMCL, Secondary Maximum Contaminant Level; HAL, lifetime Health Advisory Level]

Trace element	Number of samples	Concentration (micrograms per liter) Minimum	Median	Maximum	Drinking-water standard (micrograms per liter)
Aluminum	30	<1	10	22	--
Antimony	30	<1	<1	<2	[1]6 (MCL)
Arsenic	30	<.9	<.9	13	[2]10 (MCL)
Barium	30	72	175	350	[1]2,000 (MCL)
Beryllium	30	<1	<1	<2	[1]4 (MCL)
Cadmium	30	<1	<1	<2	[1]5 (MCL)
Chromium	28	<.8	<.8	1	[1]100 (MCL)
Cobalt	30	<1	<1	10	--
Copper	30	<1	<1	3	[1]1,300 (MCL)
Iron	30	<10	<10	3,700	[1]300 (SMCL)
Lead	30	<1	<1	<2	[1]15 (MCL)
Manganese	30	<1	30	1,000	[1]50 (SMCL)
Molybdenum	30	<1	2	12	--
Nickel	30	1	3	11	[1]100 (HAL)
Selenium	30	<.7	2	11	[1]50 (MCL)
Silver	30	<1	<1	<2	[1]100 (SMCL)
Uranium, natural	30	<1	2	76	[3]30 (MCL)
Zinc	30	<1	3	9	[1]5,000 (SMCL)

[1] U.S. Environmental Protection Agency (2000a).

[2] U.S. Environmental Protection Agency (2001a).

[3] U.S. Environmental Protection Agency (2000b).

Water from 12 monitoring wells (40 percent) sampled had concentrations of manganese larger than the USEPA SMCL of 50 µg/L (fig. 11, table 14). Concentrations of manganese in water from these 12 wells ranged from 61 (well 9) to 1,000 µg/L (well 4). As was the case with iron, the occurrence of excess concentrations of manganese in shallow ground-water samples was associated mostly with reducing environments. Water from only three wells (1, 9, 11) with concentrations of manganese larger than the SMCL had substantial dissolved-oxygen concentrations (larger than 3.5 mg/L). For the other nine wells, dissolved-oxygen concentrations were equal to or less than 0.3 mg/L. Under reducing conditions, manganese may be released (dissolved) from organic and manganese complexes or from manganese oxides. Manganese is an undesirable impurity in water supplies because of a tendency to deposit black manganese dioxide stains (Hem, 1985). The occurrence of manganese in ground water in the study area is probably from natural sources. A previous investigation of ground water in Sedgwick County concluded that most concentrations of manganese in ground water that exceeded the SMCL are from alluvium and terrace deposits, which may indicate that the manganese is derived from organic matter in the soil and then is leached by percolation of

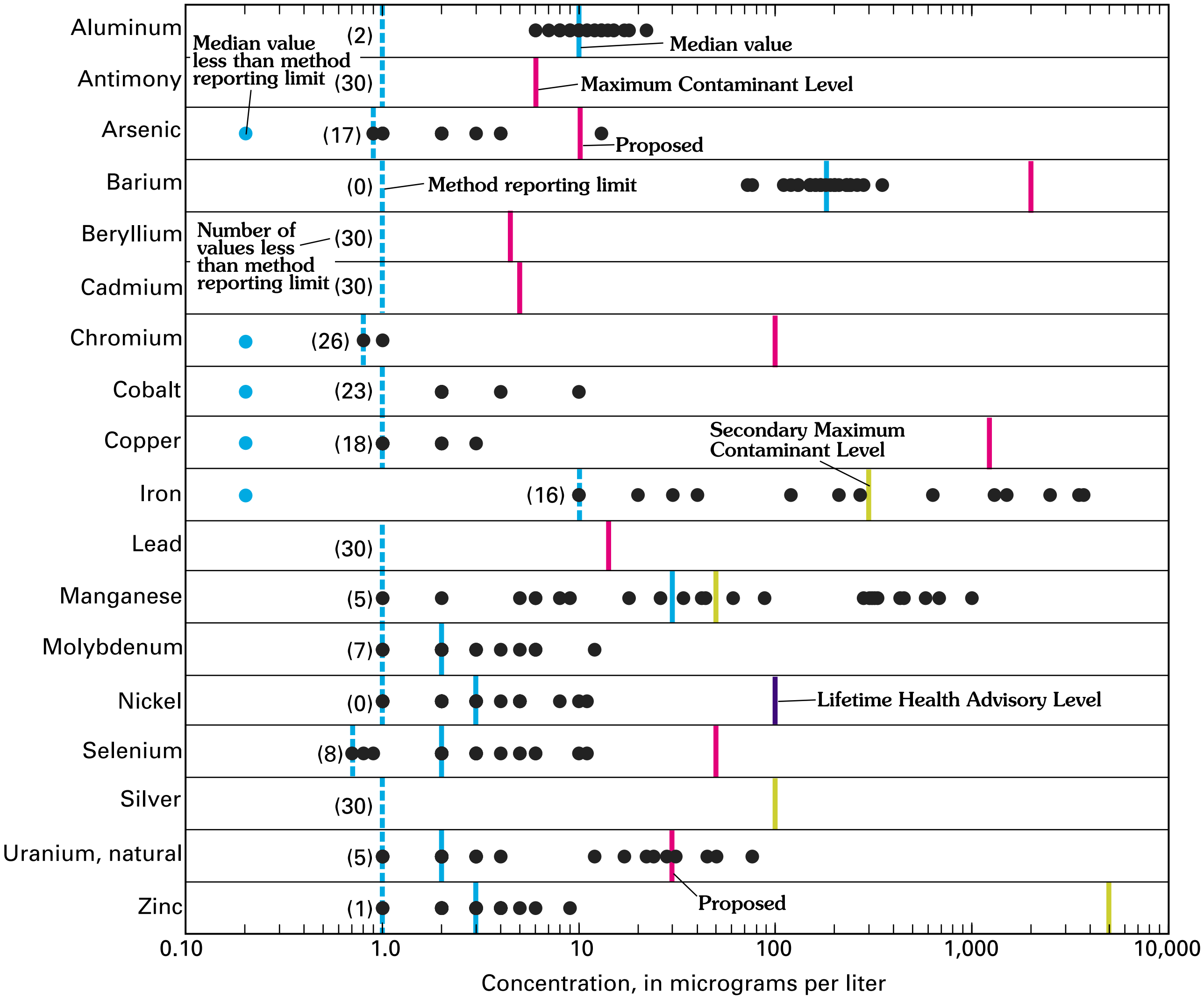


Figure 11. Method reporting limits, sample concentrations and median values, and drinking-water standards for selected trace elements in shallow ground water from 30 monitoring wells in areas of recent residential and commercial development, 2000 (drinking-water standards from U.S. Environmental Protection Agency, 2000a, 2000b, 2001a).

precipitation (or irrigation) through the unconsolidated sand and gravel into the ground water (Bevans, 1989).

In addition to the concentrations of iron and manganese that exceeded SMCLs, the concentrations of arsenic in water from one monitoring well (well 4) and uranium in water from four monitoring wells (fig. 11, table 14) exceeded their proposed MCLs of 10 µg/L (U.S. Environmental Protection Agency, 2001a) and 30 µg/L (U.S. Environmental Protection Agency, 2000b), respectively. The 13-µg/L arsenic concentration in water from well 4 probably was the result of reducing conditions (dissolved-oxygen concentration 0.3 mg/L) in the ground water at this site. Potential health effects from excessive arsenic concentrations in drinking water include cardiovascular disease, diabetes, anemia, and an increased risk of cancer (U.S. Environmental Protection Agency, 2001a).

Concentrations of uranium that exceeded the proposed MCL ranged from 31 (well 1) to 76 µg/L (well 6). Reducing conditions were evident in all but well 1 of the four wells with uranium concentrations that exceeded the proposed MCL. No known human-related source of uranium exists in the study area. Therefore, the occurrence of uranium in shallow ground water probably results from natural sources.

Exposure to radionuclides such as uranium in drinking water results in an increased risk of cancer (U.S. Environmental Protection Agency, 2000b). This increased risk is the result of “ionizing radiation” from radioactive particles (alpha particles) emitted by the decay of uranium-238. Alpha particles may ionize atoms in cells of living tissue that could damage chromosomes and lead to unnatural cellular reproduction. In addition to this potential "radiotoxicity," damage to the kidneys may occur through exposure to uranium itself ("chemical toxicity").

Some sources of trace elements in shallow ground water from areas of recent residential and commercial development could originate from human-related activities. However, the generally small concentrations that were measured for most trace elements probably reflect natural sources.

Pesticides

Pesticides are a group of compounds used to control unwanted plants or animals. Pesticides are applied to lawns, rights-of-way, and gardens in urban areas and to cropland in rural areas. The widespread use of pesticides creates the potential for the movement of pesticides or their degradation products into shallow, unconfined aquifers. The presence of pesticide compounds in ground water is a human-health concern for those using ground water as a drinking-water supply. In sufficiently large concentrations and (or) prolonged exposure, pesticides can cause human-health problems ranging from kidney and nerve damage to leukemia and other cancers (U.S. Environmental Protection Agency, 1989).

A total of 47 pesticide compounds from several classes of herbicides and insecticides that included triazine, organochlorine, organonitrogen, organophosphorus, and carbamate compounds and three pesticide degradation products (table 13 at the back of this report) were analyzed for this study. Of the 30 wells sampled, water from 22 (73 percent) had detectable concentrations of one or more of 8 of the 47 compounds (fig. 12, table 14). A statistical summary and

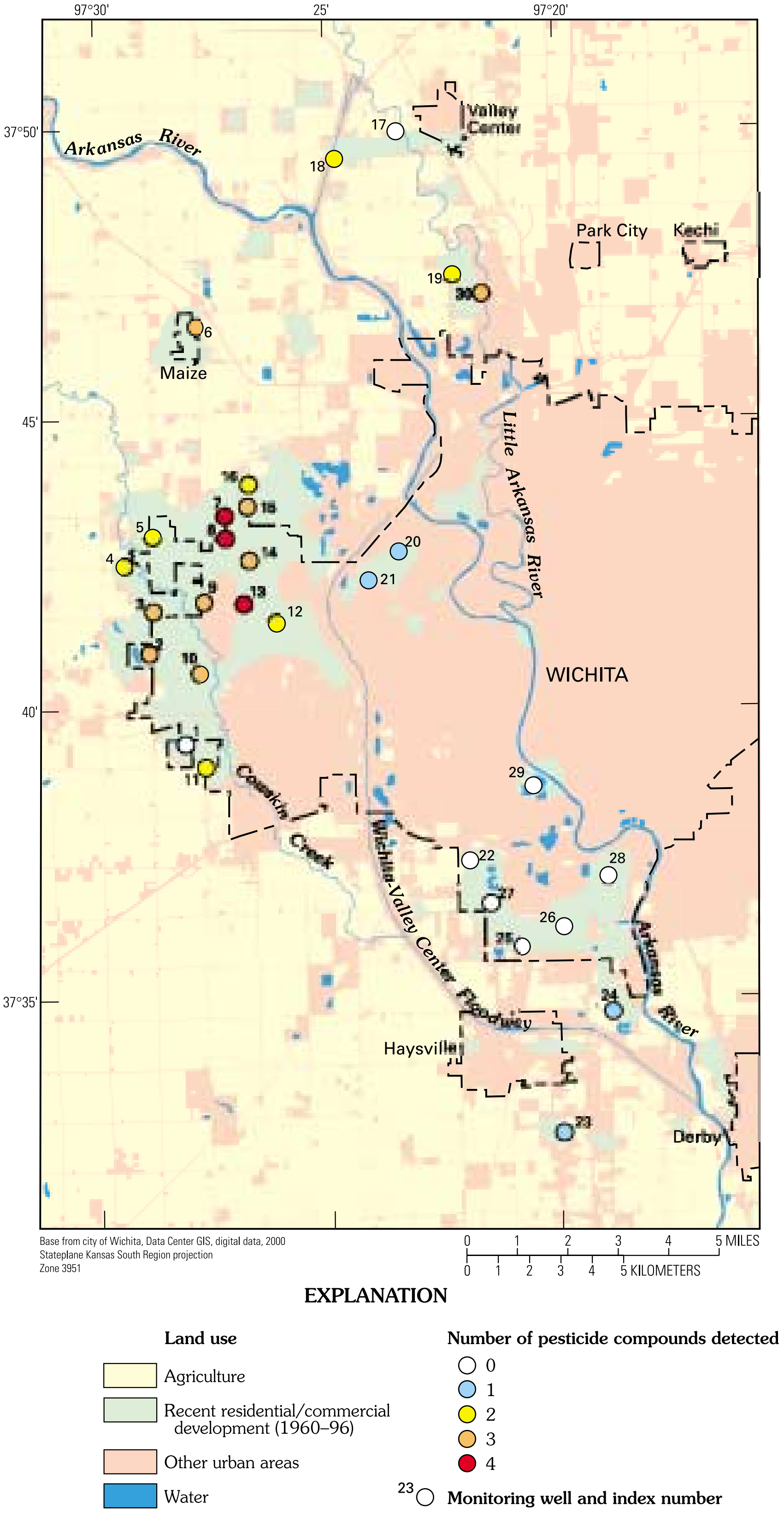


Figure 12. Number of pesticide compounds detected in shallow ground water from monitoring wells in areas of recent residential and commercial development, 2000.

Table 9. Statistical summary and U.S. Environmental Protection Agency (2000a) drinking-water standards for pesticide compounds detected in water from 30 monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000

[MCL, Maximum Contaminant Level; HAL, lifetime Health Advisory Level; <, less than; --, not applicable; E, estimated]

Pesticide compound	Number of samples	Number of detections	Concentration (micrograms per liter) Minimum	Median	Maximum	Drinking-water standard (micrograms per liter)
Atrazine	30	19	<0.001	0.006	0.14	3.0 (MCL)
Deethylatrazine	30	19	<.002	E.006	E.08	--
Dieldrin	30	1	<.001	<.001	.01	--
Metolachlor	30	3	<.002	<.002	.008	100 (HAL)
Pendimethalin	30	1	<.004	<.004	.006	--
Prometon	30	1	<.018	<.018	.06	100 (HAL)
Simazine	30	9	<.005	<.005	.07	4.0 (MCL)
Tebuthiuron	30	1	<.01	<.01	.05	500 (HAL)

USEPA drinking-water standards (where applicable) for these eight detected pesticide compounds are presented in table 9. The herbicide atrazine or its degradation product deethylatrazine were detected most frequently (water from 21 wells, 70 percent); other detected pesticides included the insecticide dieldrin (in water from one well) and the acetanilide herbicide metolachlor (in water from three wells), the organonitrogen herbicides pendimethalin and tebuthiuron (in water from one well each), and the triazine herbicides prometon (in water from one well) and simazine (in water from nine wells, 30 percent) (table 9).

Atrazine was detected in water at concentrations ranging from 0.005 (wells 6 and 16) to 0.14 µg/L (wells 7 and 18), and deethylatrazine was detected in water at estimated concentrations ranging from 0.002 (well 6) to 0.08 µg/L (well 16). The occurrence of atrazine and deethylatrazine in shallow ground water generally was restricted to the western and northern part of the study area. Atrazine or deethylatrazine was not detected in water from the cluster of monitoring wells (wells 22, 24–29) in the southern part of Wichita (north of Haysville), in water from well 17 west of Valley Center in the northern part of the study area, or in water from well 1 in the western part of the study area (fig. 13).

All detected concentrations of atrazine and simazine were less than their MCLs of 3.0 and 4.0 µg/L, respectively (U.S. Environmental Protection Agency, 2000a); MCLs have not been established for the other detected pesticide compounds. However, nonenforceable lifetime Health Advisory Levels (HALs) have been established for metolachlor (100 µg/L), prometon (100 µg/L), and tebuthiuron (500 µg/L) (U.S. Environmental Protection Agency, 2000a). All detected concentrations for these pesticide compounds were less than respective HALs. Although concentrations of detected pesticide compounds were small (relative to established MCLs and HALs), the synergistic effects on human health of these concentrations and long-term exposure to multiple pesticide compounds are unknown.

Volatile Organic Compounds

Volatile organic compounds (VOCs) are a group of relatively low molecular-weight hydrocarbons characterized by the ability to volatilize at low environmental temperatures, high aqueous solubility, mobility, resistance to degradation, and the potential for some to have carcinogenic effects. The use or production of these compounds in industrial, manufacturing, and agricultural activities is the greatest potential source for VOC contamination of ground-water resources.

VOCs are by-products or components in the production of food, drugs, paints and varnishes, deodorants, pesticides, fumigants, glues and adhesives, rubber, cleaning agents, degreasers, disinfectants, dyes, perfumes, and many other materials. One of the major sources of VOCs is as components in fuels and motor oil. Because of the diverse uses and distribution of VOCs, the potential for ground-water contamination is greatest in industrial or commercial areas as a result of improper disposal of industrial waste, accidental chemical spills, leaking gasoline storage tanks, or seepage from toxic-waste dumps or landfills. Additionally, the land application of some pesticides creates the potential for movement of associated VOCs to shallow, unconfined aquifers in urban and agricultural areas.

The presence of VOCs in ground water may pose a human-health concern for those using ground water as a drinking-water supply. In sufficiently large concentrations and (or) prolonged exposure, VOCs can cause kidney and nerve damage, leukemia, and other cancers (U.S. Environmental Protection Agency, 2001c).

Water samples from 30 monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, were analyzed for 85 VOCs (table 13 at the back of this report). Of the 30 wells sampled, 13 samples (43 percent) had detectable concentrations of one or more VOCs (fig. 14, table 14 at the back of this report). A total of eight different VOCs were detected in water from these wells (table 10). Median concentrations for all eight VOCs were less than respective analytical method reporting limits. Chloroform, however, was the most frequently detected VOC (table 10). Chloroform was detected in water from seven wells (1, 5, 8, 11–14; 23 percent). Detected concentrations of chloroform ranged from an estimated 0.07 (wells 5 and 11) to 1.7 µg/L (well 13) and were less than the 80-µg/L MCL for drinking water. Other VOCs detected included 1,1,1-trichloroethane (in two samples), bromodichloromethane (in two samples), tetrachloroethylene (in four samples), toluene (in one sample), trichloroethylene (in two samples), cis-1,2-dichloroethylene (in two samples), and tert-Butyl methyl ether (also known as methyl tert-Butyl ether, MTBE) (in two samples).

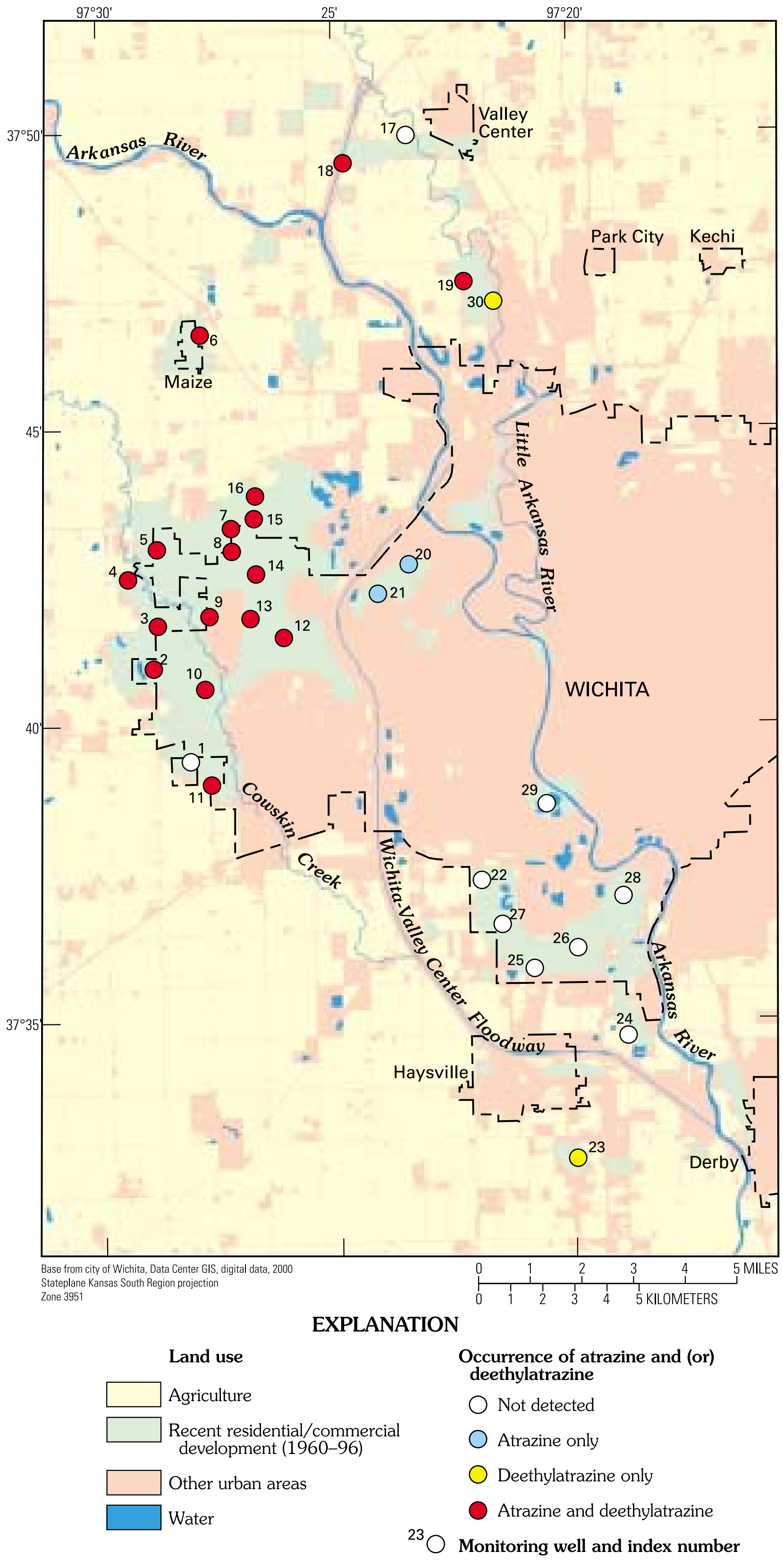


Figure 13. Occurrence of the herbicide atrazine and (or) its degradation product deethylatrazine in shallow ground water from monitoring wells in areas of recent residential and commercial development, 2000.

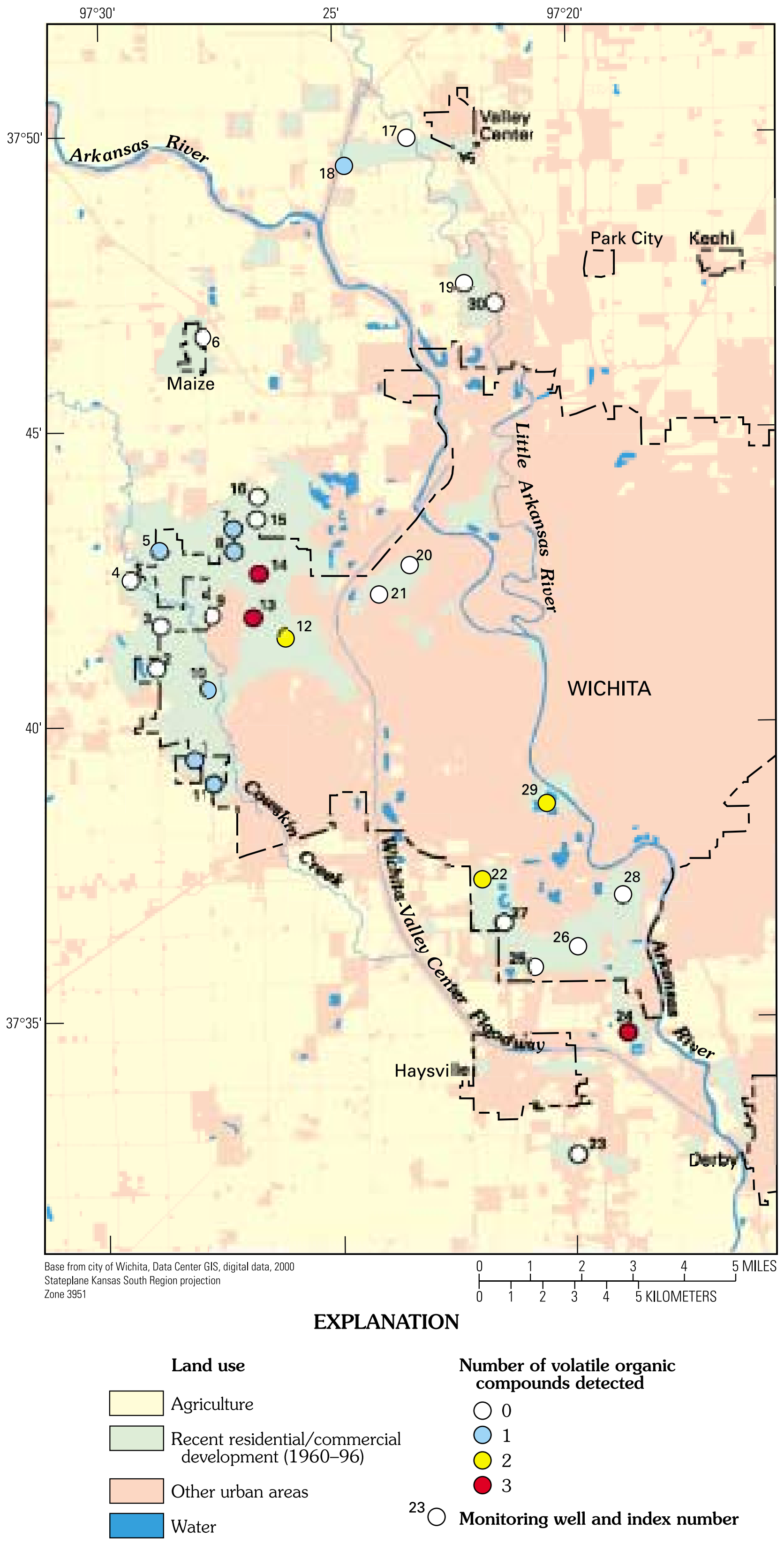


Figure 14. Number of volatile organic compounds detected in shallow ground water from monitoring wells in areas of recent residential and commercial development, 2000.

With the exception of the 9.0-µg/L concentration of tetrachloroethylene in water from well 10 (table 14), all concentrations of VOCs detected in the shallow ground-water samples collected during this study were less than established MCLs. The 9.0-µg/L concentration of tetrachloroethylene was 80 percent larger than its 5.0-µg/L MCL.

The VOCs detected in ground-water samples collected during this study have many and varied uses. Bromodichloromethane and chloroform are trihalomethane (THM) compounds that probably are formed when drinking-water sources are chlorinated during the disinfection process. The chlorination process halogenates naturally occurring organic substances (mainly fulvic and humic acids; Rook, 1977) in the source water to produce THMs. The formation of THMs is the result of the action of chlorine (OCl^-) on the fulvic and humic acids (Thurman, 1985). The bromide-substituted VOCs such as bromodichloromethane are thought to result from parallel bromination reactions initiated by the action of chlorine on background concentrations of bromide ions, which is present in most natural water (Boyce and Hornig, 1983). The occurrence of THMs in shallow ground water may be the result of using chlorinated drinking water as an irrigation source for lawns and gardens and (or) the reaction of residual chlorine in the irrigation water with naturally occurring soil fulvic and humic acids.

Tetrachloroethylene and trichloroethylene are used in dry-cleaning operations and as solvents for fats, greases, and waxes. The VOCs 1,1,1-trichloroethane and cis-1,2-dichloroethylene are used in the degreasing of metals and as constituents in solvents and glues and household products for stain removal. Toluene is a component of gasoline and a solvent for paints and coatings, lacquers, and adhesives (Verschueren, 1996). The occurrence of these compounds in shallow ground water may result from extensive

Table 10. Statistical summary and U.S. Environmental Protection Agency (2000a) drinking-water standards for volatile organic compounds detected in water from 30 monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000

[MCL, Maximum Contaminant Level; <, less than; E, estimated; --, not applicable]

Volatile organic compound	Number of samples	Number of detections	Concentration (micrograms per liter) Minimum	Median	Maximum	Drinking-water standard (micrograms per liter)
1,1,1-Trichloroethane	30	2	<0.032	<0.032	E0.06	200 (MCL)
Bromodichloromethane	30	2	<.048	<.048	.12	80 (MCL)
Chloroform	30	7	<.052	<.052	1.7	80 (MCL)
Tetrachloroethylene	30	4	<.1	<.1	9.0	5.0 (MCL)
Toluene	30	1	<.05	<.05	.15	1,000 (MCL)
Trichloroethylene	30	2	<.038	<.038	.26	5.0 (MCL)
cis-1,2-Dichloroethylene	30	2	<.038	<.038	E.08	70 (MCL)
tert-Butyl methyl ether (MTBE)	30	2	<.17	<.17	.47	--

use in an urban environment and methods of disposal or improper handling.

MTBE has been used as an octane enhancer in gasoline in the United States since the late 1970s. MTBE is the most widely used fuel oxygenate. In 1995, 8.0 billion kg (almost 9 million tons) were produced in the United States (American Chemical Society, 1996). The occurrence of MTBE in shallow ground water probably results from gasoline spills or leaking storage tanks.

RELATION TO LAND USE

The general objective of NAWQA land-use studies is to assess the natural factors and human-related activities that affect the quality of recently recharged shallow ground water that underlies key types of land use in each NAWQA study area. The assumption of these types of studies is that the overlying land use is related to the quality of the shallow ground water being locally recharged. To verify that a relation exists between overlying land use and water quality, the direction of ground-water flow (hydraulic gradient) and its velocity, age at which water was recharged, and potential recharge areas can be examined.

Ground-water flow direction in the study area is from the northwest to the southeast (fig. 4) and, generally, is parallel to the Arkansas River. Flow velocity was estimated previously (table 3) at 2.5 ft/d in the alluvial and terrace deposits (Nal, fig. 3) along the Arkansas River and 1.2 ft/d in the terrace deposits (Nt, fig. 3) west of the Arkansas River alluvium. The age at which sampled water was recharged was calculated through analyses of CFC concentrations (table 4).

Potential recharge areas for the water sampled from 30 monitoring wells during this study were determined by first calculating the distance to those potential areas. These distances (in miles) (table 11) were calculated by multiplying the ground-water residence time (in years) by flow velocity (in feet per day; table 3) by 365.25 (days per year) by a unit conversion factor of 0.000189. Ground-water residence time was calculated by subtracting apparent recharge dates from 2000 (year of sampling). The average apparent recharge date (1986) of reported CFC-determined dates (table 4) was used as an estimated recharge date for water from monitoring wells with contaminated or otherwise unreliable CFC results. Distances to potential recharge areas for the 30 monitoring wells sampled in this study (table 11) ranged from 0.8 (wells 5 and 15) to 2.8 mi (well 19) upgradient of the well locations (fig. 4).

Land use in potential recharge areas was determined by locating areas upgradient (northwest) of the monitoring-well locations (fig. 4) using the distances indicated in table 11 and then determining the land use of these areas at the apparent or estimated time of recharge. The size of these potential recharge areas was arbitrarily selected to be an area with a radius of 1,000 ft around a point measured the calculated distances upgradient from monitoring-well locations. Dominant land use in these areas at the time of recharge (table 12) was determined from a combination of

Table 11. Apparent or estimated date of recharge, residence time, flow velocity, and distance to potential recharge areas (from well locations) for shallow ground water from 30 monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000

Monitoring-well index number (fig. 1)	Apparent or (estimated)[1] recharge date	Residence time (years)	Flow velocity (feet per day)	Distance to potential recharge areas (miles)
1	1984	16	1.2	1.3
2	1979	21	1.2	1.7
3	1986	14	1.2	1.2
4	(1986)	14	1.2	1.2
5	1990	10	1.2	.8
6	(1986)	14	1.2	1.2
7	1986	14	1.2	1.2
8	1987	13	1.2	1.1
9	1989	11	1.2	.9
10	1989	11	1.2	.9
11	1980	20	1.2	1.7
12	1986	14	1.2	1.2
13	1985	15	1.2	1.2
14	1984	16	1.2	1.3
15	1990	10	1.2	.8
16	1987	13	1.2	1.1
17	(1986)	14	2.5	2.4
18	(1986)	14	2.5	2.4
19	1984	16	2.5	2.8
20	1986	14	2.5	2.4
21	(1986)	14	2.5	2.4
22	(1986)	14	2.5	2.4
23	1988	12	2.5	2.1
24	(1986)	14	2.5	2.4
25	(1986)	14	2.5	2.4
26	(1986)	14	2.5	2.4
27	(1986)	14	2.5	2.4
28	(1986)	14	2.5	2.4
29	(1986)	14	2.5	2.4
30	1990	10	2.5	1.7

[1] Estimated as the average of apparent recharge dates for 18 wells (table 4).

Table 12. Apparent or estimated recharge dates and land use of potential recharge areas at date of recharge for shallow ground-water samples from 30 monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000

Monitoring-well index number (fig. 1)	Apparent or (estimated)[1] recharge date	Land use of potential recharge areas
1	1984	Agricultural
2	1979	Agricultural
3	1986	Agricultural
4	(1986)	Agricultural
5	1990	Agricultural
6	(1986)	Agricultural
7	1986	Agricultural
8	1987	Agricultural
9	1989	Transitional[2]
10	1989	Transitional[2]
11	1980	Transitional[2]
12	1986	Residential/commercial
13	1985	Residential/commercial
14	1984	Agricultural
15	1990	Agricultural
16	1987	Agricultural
17	(1986)	Agricultural
18	(1986)	Agricultural
19	1984	Agricultural
20	1986	Sand pit
21	(1986)	Agricultural
22	(1986)	Residential/commercial
23	1988	Residential/commercial
24	(1986)	Residential/commercial
25	(1986)	Residential/commercial
26	(1986)	Residential/commercial
27	(1986)	Residential/commercial
28	(1986)	Residential/commercial
29	(1986)	Residential/commercial
30	1990	Agricultural

[1] Estimated as the average of apparent recharge dates (table 4).

[2] In transition from agricultural to residential/commercial land use.

sources that included (1) USGS 7.5-minute topographic maps photographically updated in 1982, (2) digital land-use data (city of Wichita, Kansas, 2000), (3) dates of sewer-main installation (LaDonna Lawrenz and Kerry Gibson, city of Wichita Water and Sewer Department, oral commun., 2002), (4) casting dates on street curbs and side walks, (5) information from area residents, and (6) author knowledge and onsite inspection of the areas.

Agricultural land use was the dominant land use of potential recharge areas (table 12) for 16 (53 percent) of the 30 monitoring wells in areas of recent residential and commercial development (fig. 1). Residential and (or) commercial land use was the dominant land use of potential recharge areas for 10 (33 percent) of the wells, and potential recharge areas for three (10 percent) of the wells were believed to be in a transitional state of development from agricultural to residential and (or) commercial land use. The potential recharge area for one well (well 20) was believed to be in an area of extensive sand-dredging (sand-pit) operations. The results presented in table 12 provide possible explanations for previously discussed ground-water-quality characteristics, such as pesticides and VOC concentrations, for some of the 30 monitoring wells in areas of recent residential and commercial development.

One or more pesticide compounds were detected in water from 22 (73 percent) of the 30 monitoring wells in areas of recent residential and commercial development (fig. 12). Atrazine or deethylatrazine were detected in water from 21 (70 percent) of the 30 monitoring wells (fig. 13). These pesticide detection rates for shallow ground water in the Wichita area are substantially larger than the 49-percent detection rate of one or more compounds reported nationally in shallow ground water in urban areas (U.S. Geological Survey, 1999). Therefore, the possibility of the occurrence of some pesticide compounds, particularly atrazine and deethylatrazine, being an artifact of past agricultural use was investigated.

Atrazine has been the most extensively used herbicide in corn and grain-sorghum production in Kansas for the past 40 years. It is applied annually to about 79 percent of the corn and 82 percent of the grain sorghum (Devlin and others, 2000). In urban areas, atrazine has been used for nonselective weed control on industrial or noncropped land (U.S. Environmental Protection Agency, 1989) and for selective weed control on warm-season turfgrasses such as bermuda and zoysia (Fagerness and others, 2001). Historically, however, approximately 95 percent of the atrazine applied in the United States is used in corn and grain-sorghum production, predominately in the Mississippi River Basin where about 82 percent of the Nation's corn acreage is planted (CIBA-GEIGY Corporation, 1992).

Author discussions with professional lawn-care specialists in the Wichita area indicated that, although atrazine has been used historically in turfgrass application, it has not been used extensively or intensively applied in the Wichita area. The majority of atrazine use has been on bermuda and zoysia grass in the southern part of the study area (the area near monitoring wells 22–29; fig. 1). Furthermore, in recent years, cool-season grasses such as fescue and blue grass have become popular in the developing areas of west Wichita (the area near monitoring wells 1–16, 20, 21). These grasses are intolerant of atrazine. Additionally, Sedgwick County has not used atrazine in controlling weeds along roadways for about 20 years (Joseph O. Brunk, Sedgwick County Noxious Weed Department, oral commun., 2002). Historical use of atrazine by or in the city of Wichita was not available, but much of the atrazine used may have been associated with golf-course maintenance, all of which are downgradient of well locations.

Atrazine or deethylatrazine was detected mainly in shallow ground water recharged through agricultural areas or in areas of transition from agricultural to residential and (or) commercial land use (water from monitoring wells 1–11, 14–19, 21, 30; table 12). Water recharged through agricultural areas contained a detectable concentration of atrazine or deethylatrazine in 89 percent of the samples (fig. 13, table 12). For the purpose of this discussion, water recharged through areas in transition from an agricultural to a residential and (or) commercial land use (monitoring wells 9–11) was considered to be agriculturally affected.

In contrast to the 89-percent detection rate of atrazine or deethylatrazine in shallow ground water recharged through agricultural areas, these chemicals were detected in only 30 percent (fig. 15) of shallow ground water (water from monitoring wells 12, 13, 22–29) recharged through residential and (or) commercial areas (fig. 13, table 12) even though these wells had some of the shallowest depths to water in the study area (table 1). Because shallow ground water from 70 percent of the wells with water recharged through residential and (or) commercial areas was under anaerobic (reducing) conditions (dissolved-oxygen concentrations 0.5 mg/L or less) (fig. 5), the smaller detection rate of atrazine or deethylatrazine may be the result of these reducing conditions and not the result of differences in land use.

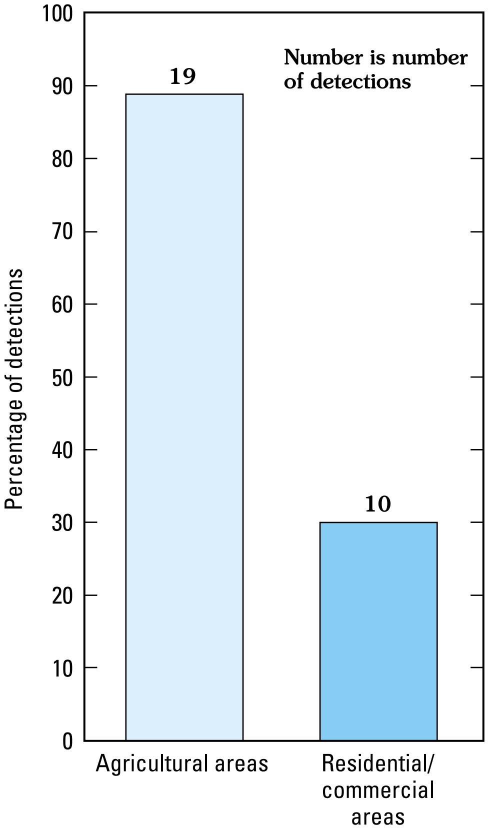


Figure 15. Comparison of percentage of detection of atrazine or deethylatrazine in shallow ground water recharged through 19 areas of agricultural and 10 areas of residential and (or) commercial land use in Wichita study area.

Literature describing anaerobic degradation of atrazine is not extensive; however, available literature (Gu and others, 1992; DeLaune and others, 1997; Papiernik and Spalding, 1997; Larsen and others, 2001) indicates that degradation of atrazine or deethylatrazine is no more frequent or rapid in soils or ground water under anaerobic conditions than under aerobic conditions. Therefore, the absence of atrazine or deethylatrazine in the majority of water from wells where the source of recharge was through residential and (or) commercial areas probably reflects limited use of atrazine in these areas. Furthermore, the major source of these chemicals in shallow ground water of the study area probably was the result of agricultural use. The possibility that the occurrence of agricultural herbicides in shallow ground water in urban areas may be an artifact of past or nearby agricultural use also was discussed by Barbash and others (1999, p. 23).

VOCs were detected in water recharged through both agricultural areas and residential and (or) commercial areas. At least one VOC was detected in 42 percent of water samples from monitoring wells recharged through agricultural or transitional areas (tables 12 and 14) with chloroform the most frequently detected (26 percent). Other VOCs detected in water recharged through agricultural areas included 1,1,1-trichloroethane, bromodichloromethane, tetrachloroethylene, toluene, and MTBE (table 14). Similarly, at least one VOC was detected in 50 percent of water samples recharged through residential and (or) commercial areas (table 12); however, chloroform was not the single-most frequently occurring VOC. Tetrachloroethylene was detected in 30 percent, and chloroform, trichloroethylene, and cis-1,2-dichloroethylene each were detected in 20 percent of the water samples recharged through residential and (or) commercial areas (tables 12 and 14). Other VOCs detected in these water samples included 1,1,1-trichloroethane, bromodichloromethane, and MTBE (table 14).

The frequency of occurrence of at least one VOC in water recharged through agricultural areas and residential and (or) commercial areas was similar, 42 and 50 percent, respectively. When detected, twice as many VOCs (on average) were detected in water recharged through residential and (or) commercial areas than in water recharged through agricultural areas.

The occurrence of chloroform in water from monitoring wells in residential and commercial areas where chlorinated drinking water was used to irrigate lawns was discussed in the section on “Volatile Organic Compounds.” Chloroform could have been formed by the action of chlorine (OCl^-) on naturally occurring fulvic and humic acids in the soil. However, when chloroform occurrences in water from monitoring wells were evaluated relative to potential recharge areas (table 12), chloroform detections occurred mostly (71 percent) in water recharged through agricultural or transitional land uses (wells 1, 5, 8, 11, 14; fig. 1). Chlorinated municipal drinking-water use in agricultural areas for irrigation is unlikely.

The occurrence of chloroform in water recharged through agricultural areas may be the result of one or a combination of the following: (1) the atmospheric distribution of chloroform from nearby urban areas, (2) the use of some pesticides that contain chloroform as an artifact of their manufacturing process, or (3) chloroform may have entered the shallow ground-water system and mixed with recharge from agricultural areas as it flowed under areas of residential or commercial land use where chlorinated municipal water was used for lawn and garden irrigation. As of 1993, Wichita was one of the five major chloroform manufacturing centers in the United States with an estimated annual production capacity of 145 million lb (Agency for Toxic Substances and Disease Registry, 1997). This production capacity may increase atmospheric concentrations of chloroform relative to non-production areas. Chloroform is used in the production of some pesticides (Verschueren, 1996). The possibilities of mixing of water from different land-use recharge areas would complicate the evaluation of land-use effects on the quality of shallow ground water in areas of recent residential and commercial development.

SUMMARY AND CONCLUSIONS

Knowledge of the quality of the Nation’s water resources is important because of implications for human and aquatic health and because of substantial costs associated with land and water management, conservation, and regulation. In 1991, the U.S. Geological Survey (USGS) began full implementation of the National Water-Quality Assessment (NAWQA) Program. The long-term goals of the NAWQA Program are to describe the status and trends in the quality of the Nation’s surface- and ground-water resources and to determine the natural and human-related factors affecting water quality.

The High Plains Regional Ground-Water Study was begun in June 1998 and represents a modification of the traditional NAWQA study design in that the ground-water resource is the primary focus of investigation. The High Plains aquifer is a nationally important water resource that underlies about 174,000 mi^2 in parts of eight Western States. About 27 percent of irrigated land in the United States is in the High Plains, and about 30 percent of all the ground water used for irrigation in the United States is pumped from this aquifer. In addition, the aquifer system provides drinking water to 82 percent of the people who live within the aquifer boundary.

NAWQA ground-water studies include a component designed to assess the occurrence of water-quality constituents under areas of specific land use. The general objective of land-use studies is to assess the natural factors and human-related activities that affect the quality of recently recharged (generally less than 10 years old) shallow ground water that underlies key types of land use within each NAWQA study unit. In 2000, the USGS began a ground-water-quality study of the unconsolidated (alluvial and terrace) deposits underlying areas of recent residential and commercial land use in Wichita, Kansas.

Studies of the potential effects of urban land use on shallow ground-water quality have two specific objectives: (1) Assess the water quality in recharge to shallow unconsolidated aquifers underlying areas of recent residential and commercial development in large metropolitan areas, and (2) determine whether or not ground-water-quality characteristics could be related to the overlying urban land use.

Water samples from 30 monitoring wells installed in areas of recent residential and commercial development in the Wichita area were analyzed for about 170 water-quality constituents, including chlorofluorocarbons, physical properties, dissolved solids and major ions, nutrients and dissolved organic carbon, trace elements, pesticide compounds, and volatile organic compounds (VOCs). Many of these constituents are regulated in public drinking-water supplies by the U.S. Environmental Protection Agency (USEPA). Depths to the water table in the sampled wells ranged from about 4 to 35 ft with a median depth of about 16 ft.

Analyses of water from the 30 monitoring wells for chlorofluorocarbons were used to calculate apparent dates of recharge. Water from 18 wells with nondegraded and uncontaminated chlorofluorocarbon concentrations had calculated apparent recharge dates that ranged from 1979 to 1990 with an average date of 1986.

Physical properties were measured in water from each of the 30 monitoring wells sampled during this study. Water from most wells had specific conductance values less than 1,000 µS/cm. Water from eight wells had specific conductance values greater than 1,000 µS/cm. Specific conductance values for these eight wells ranged from 1,020 to 2,590 µS/cm. The pH of water from all sampled wells was within the Secondary Maximum Contaminant Level (SMCL) range of 6.5 to 8.5 standard units with the exception of water from three wells that had pH values of 6.3 or 6.4 standard units. The turbidity of water from most wells was low. However, one well had a turbidity of 8.8 NTU, which exceeded the USEPA drinking-water standard of 5.0 NTU. Low turbidity indicates acceptable aesthetic quality, a lack of obvious contamination, and that wells were developed properly and the samples were representative of the aquifer water. Water from the wells had a median dissolved-oxygen concentration of 2.6 mg/L. Water from three wells had no detectable dissolved oxygen (less than 0.1 mg/L). Water from nine other wells had dissolved-oxygen concentrations of 0.5 mg/L or less. Alkalinity as $CaCO_3$ ranged from 68 to 570 mg/L with a median concentration of 265 mg/L.

Concentrations of dissolved solids in water from the 30 sampled wells ranged from 229 to 1,630 mg/L with a median concentration of 492 mg/L, only slightly less than the 500-mg/L SMCL established by the USEPA. Water from 47 percent of the wells exceeded the SMCL for dissolved solids.

Generally, the data collected for this study indicate that calcium bicarbonate water is the dominant ground-water type in areas of recent residential and commercial development. However, this water type may by modified locally by the mixing of sodium chloride type water possibly from infiltration of sodium chloride in water from the Arkansas River. The SMCLs (250 mg/L) for chloride and sulfate were exceeded in water from one well.

Concentrations of most nutrients in water from the 30 wells were small, with the exception of nitrate as nitrogen. Concentrations of nitrate as nitrogen ranged from less than 0.05 to 10 mg/L with a median concentration of 2.2 mg/L. Water from 50 percent of the wells had nitrate enrichment relative to a national background nitrate concentration of 2.0 mg/L. This enrichment probably is due to human-related activities such as fertilizers used for lawns and landscape areas, failing septic systems, municipal and industrial waste distribution, spills of nitrogen-containing organic material, domestic animal waste, and past agricultural use.

Concentrations of DOC were small in water from most of the 30 wells sampled. However, two wells yielded water with relatively large concentrations (49 and 100 mg/L).

Most detected trace elements in water from the 30 sampled wells occurred only in small concentrations and were less than established Maximum Contaminant Levels (MCLs) or Health Advisory Levels (HALs). The trace elements antimony, beryllium, cadmium, lead, and silver were not detected in water from any of the sampled wells. Infrequent detections of chromium (two detections) and cobalt (seven detections) occurred. Aluminum, copper, molybdenum, selenium, and zinc were detected more frequently, but none of the detected concentrations exceeded established or proposed drinking-water standards. In contrast, barium and nickel were detected in water from all 30 wells, but none of the detected concentrations exceeded drinking-water standards. Concentrations of iron in water from 20 percent of the sampled wells exceeded the 300-µg/L USEPA SMCL. Concentrations of iron in water from these wells ranged from 630 to 3,700 µg/L. Concentrations of manganese in water from 40 percent of the sampled wells were larger than the 50-µg/L USEPA SMCL. Concentrations of manganese in water from these wells ranged from 61 to 1,000 µg/L. In addition to the concentrations of iron and manganese that exceeded SMCLs, one sample contained an arsenic concentration (13 µg/L) and four samples contained uranium concentrations (31 to 76 µg/L) that exceeded their respective proposed MCLs of 10 and 30 µg/L. Most of the occurrences of large iron, manganese, arsenic, and uranium concentrations were associated with well locations where water was under reducing (anaerobic) conditions.

Some sources of trace elements in shallow ground water from areas of recent residential and commercial development may have originated from human-related activities. However, the generally small concentrations that were measured for most trace elements probably reflect natural sources.

A total of 47 pesticide compounds from several classes of herbicides and insecticides that included triazine, organochlorine, organonitrogen, organophosphorus, and carbamate compounds and three pesticide degradation products were analyzed in ground-water samples. Of the 30 well samples, water from 22 (73 percent) had detectable concentrations of one or more of 8 of the 47 compounds. The herbicide atrazine or its degradation product deethylatrazine were detected the most frequently (in 21 samples, 70 percent). Metolachlor was detected in water from three wells, and simazine was detected in water from nine wells; other detected pesticides included dieldrin, pendimethalin, prometon, and tebuthiuron (in water from one well each). All detected concentrations for these pesticides were less than respective MCLs or HALs; however, the synergistic effects of these concentrations and potential long-term exposure to multiple pesticide compounds in drinking water on human health are unknown. Although some of the pesticides detected during this study may be used in urban areas, the pervasive occurrence of herbicides such as atrazine and its degradation product deethylatrazine probably is an artifact of past or nearby agricultural use.

Water samples were analyzed for 85 volatile organic compounds (VOCs). Of the 30 wells sampled, water from 13 (43 percent) had detectable concentrations of one or more VOCs. Chloroform was the most frequently detected VOC (in 23 percent of samples). The occurrence of chloroform may be the result of chlorinated drinking water used in lawn and garden irrigation. Other VOCs detected included 1,1,1-trichloroethane (in two samples), bromodichloromethane (in two samples), tetrachloroethylene (in four samples), toluene (in one sample), trichloroethylene (in two samples), cis-1,2-dichloroethylene (in two samples), and MTBE (in two samples). The occurrence of MTBE probably results from gasoline spills or leaking storage tanks. The occurrence of other VOCs may be the result of their residential and commercial applications as cleaners, solvents, or degreasers. All VOC concentrations were less than respective MCLs except a 9.0-µg/L concentration of tetrachloroethylene that was larger than its 5.0-µg/L MCL.

Potential recharge areas were determined for the 30 monitoring wells by analysis of hydraulic gradient, flow velocity, and residence time of the ground water. Potential recharge areas ranged from 0.8 to 2.8 mi upgradient of monitoring-well locations. Nineteen (63 percent) of these potential recharge areas were in agricultural areas or areas in transition from agricultural to residential and (or) commercial land use at the time water sampled from the monitoring wells was recharged to the shallow ground water. Ten monitoring wells (33 percent) had recharge areas in the targeted land use (residential and commercial areas). The occurrence of atrazine or deethylatrazine in water from 70 percent of the monitoring wells may indicate a historical agricultural land-use relation to shallow ground-water quality in areas of recent residential and commercial development. This agricultural relation also may affect concentrations of other water-quality constituents of possible agricultural origin such as nitrate, which generally were in excess of background concentrations in shallow ground water.

Twice as many VOCs (on average) were detected in water recharged through residential and (or) commercial areas than in water recharged through agricultural areas. The occurrence of chloroform in water recharged through agricultural areas may indicate the potential for mixing of recharge water from residential or commercial areas. This mixing may occur as recharge from agricultural areas flows under existing residential or commercial areas and could complicate the identification of relations between shallow groundwater quality and land-use characteristics.

REFERENCES CITED

Agency for Toxic Substances and Disease Registry, 1997, Toxicological profile for chloroform: Atlanta, Georgia, U.S. Department of Health and Human Services, Public Health Service, accessed April 4, 2002, at URL http://www.atsdr.cdc.gov/toxprofiles/tp6.html

Allard, Bert, 1995, Groundwater, *in* Salbu, Brit, and Steinnes, Eiliv, eds., Trace elements in natural waters: Boca Raton, Florida, CRC Press, p. 151–176.

American Chemical Society, 1996, Facts and figures for the chemical industry, 1. Production by the U.S. chemical industry: Chemical and Engineering News, June 24, 1996, p. 40–46.

Barbash, J.E., Thelin, G.P., Kolpin, D.W., and Gilliom, R.J., 1999, Distribution of major herbicides in ground water of the United States: U.S. Geological Survey Water-Resources Investigations Report 98–4245, 57 p.

Bauder, Jim, 1999, When is organic matter built up or used up?: Missoula, Montana State University, accessed May 10, 2001, at URL http://www.montana.edu/wwwpb/ag/ baudr178.html.

Bevans, H.E., 1989, Water resources of Sedgwick County, Kansas: U.S. Geological Survey Water-Resources Investigations Report 88–4225, 119 p.

Bouwer, Herman, 1978, Groundwater hydrology: New York, McGraw-Hill, 480 p.

Boyce, S.D., and Horning, J.F., 1983, Reaction pathways of trihalomethane formation from the halogenation of dihydrooxyaromatic model compounds for humic acid: Environmental Science and Technology, v. 17, no. 4, p. 202–211.

Brenton, R.W., and Arnett, T.L. 1993, Methods of analysis by the U.S. Geological Survey National Water-Quality Laboratory—determination of dissolved organic carbon by UV-promoted persulfate oxidation and infrared spectrometry: U.S. Geological Survey Open-File Report 92–480, 12 p.

Bricker, O.P., and Jones, B.F., 1995, Main facts affecting the compositions of natural waters, *in* Salbu, Brit, and Steinnes, Eiliv, eds., Trace elements in natural waters: Boca Raton, Florida, CRC Press, p. 1–20.

Busenberg, E., and Plummer, L.N., 1992, Use of chlorofluorocarbons ($CC1_3F$ and $CC1_2F_2$) as hydrologic tracers and age-dating tools—the alluvium and terrace system of central Oklahoma: Water Resources Research, v. 28, no. 9, p. 2257–2283.

Busenberg, E., Weeks, E.P., Plummer, L.N., and Bartholomay, R.C., 1993, Age dating ground water by use of chlorofluorocarbons ($CC1_3F$ and $CC1_2F_2$), and distribution of chlorofluorocarbons in the unsaturated zone, Snake River plain aquifer, Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations Report 93–4054, 47 p.

Canter, L.W., 1997, Nitrates in groundwater: Boca Raton, Florida, CRC Press, 263 p.

CIBA-GEIGY Corporation, 1992, A review of surface-water monitoring for atrazine in the Chesapeake Bay watershed (1976–1991): Greensboro, North Carolina, CIBA-GEIGY Corporation Technical Report 3–92, 3 p.

City of Wichita, Kansas, 2000, Wichita city land-use boundaries: City of Wichita-Data Center GIS, accessed April 17, 2001, at URL http://www.wichitgov.org/GIS/main.html

Connor, B.F., Rose, D.L., Noriega, M.C., Murtagh, L.K., and Abney, S.R., 1998, Methods of analysis by the U.S. Geological Survey National Water-Quality Laboratory—determination of 86 volatile organic compounds in water by gas chromatography/mass spectrometry, including detections less than reporting limits: U.S. Geological Survey Open-File Report 97–829, 78 p.

Cook, P.G., and Solomon, D.K., 1997, Recent advances in dating young groundwater—chlorofluorocarbons, $^3H/^3He$ and ^{85}Kr: Journal of Hydrology, v. 191, no. 1–4, p. 245–265.

Cook, P.G., Solomon, D.K., Plummer, L.N., Busenberg, E., and Schiff, S.L., 1995, Chlorofluorocarbons as tracers of groundwater transport processes in a shallow, silty sand aquifer: Water Resources Research, v. 31, no. 3, p. 425–434.

DeLaune, R.D., Devai, I., Mulbah, C., Crozier, C., and Lindau, C.W., 1997, The influence of soil redox conditions on atrazine degradation in wetlands: Agriculture, Ecosystems and Environment, v. 66, no. 1, p. 41–46.

Dennehy, K.F., 2000, High Plains regional ground-water study: U.S. Geological Survey Fact Sheet 091–00, 6 p.

Devlin, D.L., Regehr, D.L., and Barnes, P.L., 2000, Managing to minimize atrazine runoff: Manhattan, Kansas State University Agricultural Experimental Station and Cooperative Extension Service, Publication MF–2208, 12 p.

Dunkle, S.A., Plummer, L.N., Busenberg, E., Phillips, P.J., Denver, J.M., Hamilton, P.A., Michel, R.L., and Coplen, T.B., 1993, Chlorofluorocarbons ($CC1_3F$ and $CC1_2F$) as dating tools and hydrologic tracers in shallow groundwater of the Delmarva Peninsula, Atlantic Coastal Plain, United States: Water Resources Research, v. 29, no. 12, p. 3837–3860.

Elkins, J.W., 1999, Chlorofluorocarbons (CFCs), *in* Alexander, D.E., and Fairbridge, R.W., eds., The Chapman and Hall encyclopedia of environmental science: Boston, Kluwer Academic Publ., p. 78–80.

Fagerness, M.J., Tisserat, N., Bauernfeind, B., and Fry, J.D., 2001, Turfgrass pesticide selection guide for professional applicators: Manhattan, Kansas State University Agricultural Experiment Station and Cooperative Extension Service, Publication MF–2466, 27 p.

Faires, L.M., 1993, Methods of analysis by the U.S. Geological Survey National Water-Quality Laboratory—determination of metals in water by inductively coupled plasma-mass spectrometry: U.S. Geological Survey Open-File Report 92–634, 28 p.

Fishman, M.J., 1993, Methods of analysis by the U.S. Geological Survey National Water-Quality Laboratory—determination of inorganic and organic constituents in water and fluvial sediments: U.S. Geological Survey Open-File Report 93–125, 217 p.

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Englewood Cliffs, New Jersey, Prentice-Hall, Inc., 604 p.

Gilliom, R.J., Alley, W.M., and Gurtz, M.E., 1995, Design of the National Water-Quality Assessment Program—occurrence and distribution of water-quality conditions: U.S. Geological Survey Circular 1112, 33 p.

Gu, J.D., Berry, D.F., Taraban, R.H., Mortens, D.C., and Walker, H.L., 1992, Biodegradability of atrazine, cyanazine, and dicamba in wetland soils: Blacksburg, Virginia, Water Resources Research Center Bulletin 172, 84 p.

Gutentag, E.D., Heimes, F.J., Krothe, N.C., Luckey, R.R., and Weeks, J.B., 1984, Geohydrology of the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Professional Paper 1400–B, 63 p.

Hansen, C.V., 1987, Estimates of freshwater storage and potential natural recharge for principal aquifers in Kansas: U.S. Geological Survey Water-Resources Investigations Report 87–4230, 100 p.

Heath, R.C., 1983, Basic ground-water hydrology: U.S. Geological Survey Water-Supply Paper 2220, 84 p.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Kansas Department of Agriculture and U.S. Department of Agriculture, 1999, Kansas farm facts: Topeka, Kansas, 114 p.

Kansas Department of Health and Environment, 1994, Kansas register: Topeka, Kansas, Secretary of State, v. 13, no. 28, p. 1050–1062.

Koterba, M.T., 1998, Ground-water data-collection protocols and procedures for the National Water-Quality Assessment Program—collection, documentation, and compilation of required site, well, subsurface, and landscape data for wells: U.S. Geological Survey Water-Resources Investigations Report 98–4107, 91 p.

Koterba, M.T., Wilde, F.D., and Lapham, W.W., 1995, Ground-water data-collection protocols and procedures for the National Water-Quality Assessment Program—collection and documentation of water-quality samples and related data: U.S. Geological Survey Open-File Report 95–399, 133 p.

Lane, C.W., and Miller, D.E., 1965, Geohydrology of Sedgwick County, Kansas: Kansas Geological Survey Bulletin 176, 100 p.

Lapham, W.W., Wilde, F.D., and Koterba, M.T., 1995, Ground-water data-collection protocols and procedures for the National Water-Quality Assessment Program—selection, installation, and documentation of wells, and collection of related data: U.S. Geological Survey Open-File Report 95–398, 69 p.

Larsen, L., Joergensen, C., and Aamand, J., 2001, Potential mineralization of four herbicides in a ground water-fed wetland area: Journal of Environmental Quality, v. 30, no. 1, p. 24–30.

Lefroy, R.D.B., and Craswell, E.T., 1997, Soil as a filter for nutrients and chemicals—sustainability aspects: International Board for Soil Research and Management, accessed May 11, 2001, at URL http://www.agnet.org/library/article/tb146.html

Lovelock, J.E., Maggs, R.J., and Wade, R.J., 1973, Halogenated hydrocarbons in and over the Atlantic: Nature, v. 241, no. 5386, p. 194–196.

Mueller, D.K., and Helsel, D.R., 1996, Nutrients in the Nation’s waters—too much of a good thing?: U.S. Geological Survey Circular 1136, 24 p.

Myers, N.C., Hargadine, G.D., and Gillespie, J.B., 1996, Hydrologic and chemical interaction of the Arkansas River and the *Equus* Beds aquifer between Hutchinson and Wichita, south-central Kansas: U.S. Geological Survey Water-Resources Investigations Report 95–4191, 100 p.

National Atmospheric Deposition Program, 2000, Isopleth maps: accessed July 23, 2002, at URL http://nadp.sws.uiuc.edu.isopleths/maps2000.html

National Oceanic and Atmospheric Administration, 1999, Climatological data annual summary, Kansas: Asheville, N.C., National Climate Center, 29 p.

Nielsen, D.M., 1991, Practical handbook of ground-water monitoring: New York, Lewis Publ., 717 p.

Nolan, B.T., and Stoner, J.D., 2000, Nutrients in ground water of the conterminous United States, 1992–1995: Environmental Science and Technology, v. 34, no. 7, p. 1156–1165.

Papiernik, S.K., and Spalding, R.F., 1997, Atrazine, deethylatrazine, and deisopropylatrazine persistence measured in situ under denitrifying conditions: Riverside, California, U.S. Department of Agriculture, Agricultural Research Service, accessed March 21, 2002, at URL http://www.nal.usda.gov/ttic/tektran/data/000008/59/0000085967.html

Patnaik, Pradyot, 1997, Handbook of environmental analysis: Boca Raton, Florida, CRC Press, 584 p.

Pepper, I.L., Gerba, C.P., and Brusseau, M.L., eds., 1996, Pollution science: New York, Academic Press, 397 p.

Petri, L.R., Lane, C.W., and Furness, L.W., 1964, Water resources of the Wichita area, Kansas: U.S. Geological Survey Water-Supply Paper 1499–I, 69 p.

Plummer, L.N., and Busenberg, E., 2000, Chlorofluorocarbons, *in* Environmental tracers in subsurface hydrology: Boston, Kluwer Academic Publ., p. 441–478.

Plummer, L.N., Busenberg, E., Boehlke, J.K., Nelms, D.L., Michel, R.L., and Schlosser, P., 2001, Groundwater residence times in Shenandoah National Park, Blue Ridge Mountains, Virginia, USA—a multi-tracer approach: Chemical Geology, v. 179, no. 1–4, p. 93–111.

Plummer, L.N., Busenberg, E., Drenkard, S., Schlosser, P., Ekwurzel, B., Weppernig, R., McConnell, J.B., and Michel, R.L., 1998, Flow of river water into a karstic limestone aquifer—2. Dating the young fraction in groundwater mixtures in the Upper Floridan aquifer near Valdosta, Georgia: Applied Geochemistry, v. 13, no. 8, p. 1017–1043.

Plummer, L.N., and Friedman, L.C., 1999, Tracing and dating young ground water: U.S. Geological Survey Fact Sheet 134–99, 4 p.

Plummer, L.N., Michel, R.L., Thurman, E.M., and Glynn, P.D., 1993, Environmental tracers for age dating young ground water, *in* Alley, W.M., ed., Regional groundwater quality: New York, Van Nostrand Reinhold, p. 255–294.

Reid, G.K., and Wood, R.D., 1976, Ecology of inland waters and estuaries: New York, D. Van Nostrand Co., 485 p.

Rook, J.J., 1977, Chlorination reaction of fulvic acids in natural waters: Environmental Science and Technology, v. 11, no. 5, p. 478–482.

Schoewe, W.H., 1949, The geography of Kansas, part 2—physical geography: Transactions of the Kansas Academy of Sciences, v. 52, no. 3, p. 261–333.

Scott, J.C., 1990, Computerized stratified random site-selection approaches for design of a ground-water-quality sampling network: U.S. Geological Survey Water-Resources Investigations Report 90–4101, 109 p.

Spinazola, J.M., Gillespie, J.B., and Hart, R.J., 1985, Ground-water flow and solute transport in the *Equus* beds area, south-central Kansas, 1940–79: U.S. Geological Survey Water-Resources Investigations Report 85–4336, 68 p.

Squillace, P.J., and Price, C.V., 1996, Urban land-use study plan for the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 96–217, 19 p.

Szabo, Z., Rice, D.E., Plummer, L.N., Busenberg, E., Drenkard, S., and Schlosser, P., 1996, Age dating of shallow groundwater with chlorofluorocarbons, tritium/helium 3, and flow path analysis, southern New Jersey coastal plain: Water Resources Research, v. 32, no. 4, p. 1023–1038.

Thompson, G.M., and Hayes, J.M., 1979, Trichlorofluoromethane in groundwater—a possible tracer and indicator of groundwater age: Water Resources Research, v. 15, no. 3, p. 546–554.

Thurman, E.M., 1985, Organic geochemistry of natural waters: Dordrecht, Netherlands, Mantinus Nijhoff/Dr. W. Junk Publ., 497 p.

U.S. Environmental Protection Agency, 1986, Quality criteria for water, 1986: U.S. Environmental Protection Agency Report 440/5–86–001, unnumbered pages.

———1989, Drinking water health advisory—pesticides: Chelsa, Michigan, Lewis Publ., 819 p.

———2000a, Drinking water standards and health advisories: Washington D.C., Office of Water, EPA 822–B–00–001, unnumbered pages.

———2000b, Final rule for (non-radon) radionuclides in drinking water: Office of Water, accessed March 11, 2002, at URL http://www.epa.gov/safewater/rads/technicalfacts.html

———2001a, Drinking water standards for arsenic: Office of Water, accessed March 11, 2002, at URL http://www.epa.gov/ogwdw000/ars/ars_rule_factsheet.html

———2001b, MTBE and underground storage tanks: Office of Underground Storage Tanks, accessed May 31, 2001, at URL http://www.epa.gov/swerust1/mtbe/index.htm

———2001c, National primary drinking water standards: Office of Water, accessed March 26, 2002, at URL http://www.epa.gov/safewater/mel.html

U.S. Geological Survey, 1999, The quality of our Nation’s waters—nutrients and pesticides: U.S. Geological Survey Circular 1225, 82 p.

Van Es, H.M., 1990, Pesticide management for water quality: Ithaca, New York, Department of Soil, Crop, and Atmospheric Sciences, Cornell University, accessed May 11, 2001, at URL http://pmep.cce.cornell.edu/facts-slides-self/facts/pestmgt-water-qual-90.html

Verschueren, Karel, 1996, Handbook of environmental data on organic chemicals: New York, John Wiley and Sons, Inc., 2064 p.

Warner, M.J., and Weiss, R.F., 1985, Solubilities of chlorofluorocarbons 11 and 12 in water and seawater: Deep Sea Research, v. 32, p. 1485–1497.

Williams, C.C., and Lohman, S.W., 1949, Geology and ground-water resources of a part of south-central Kansas, with specific reference to the Wichita municipal water supply: Kansas Geological Survey Bulletin 79, 455 p.

Wilson, Neal, 1995, Soil water and ground water sampling: Boca Raton, Florida, CRC Press, 188 p.

Zaugg, S.D., Sandstrom, M.W., Smith, S.G., and Fehlberg, K.M., 1995, Methods of analysis by the U.S. Geological Survey National Water-Quality Laboratory—determination of pesticides in water by C–18 solid-phase extraction and capillary-column gas chromatography/mass spectrometry with selected-ion monitoring: U.S. Geological Survey Open-File Report 95–181, 60 p.

SUPPLEMENTAL INFORMATION

Table 13. Water-quality constituents analyzed in shallow ground-water samples from monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000

[USGS, U.S. Geological Survey; SC, schedule; µg/L, micrograms per liter; N, nitrogen; P, phosphorus]

Constituent	Analytical method reporting limit	Constituent	Analytical method reporting limit
Dissolved solids, major ions, and selected trace elements, USGS SC2750, in milligrams per liter (unless noted)			
Dissolved solids	10	Bicarbonate	1.0
Bromide	.01	Calcium	.02
Chloride	.10	Fluoride	.1
Iron	10 µg/L	Magnesium	.004
Manganese	3.0 µg/L	Potassium	.1
Silica	.05	Sodium	.06
Sulfate	.10		
Nutrients, USGS SC2752, and dissolved organic carbon, USGS SC2085, filtered, in milligrams per liter			
Nitrogen, ammonia, as N	.02	Nitrogen, ammonia plus organic nitrogen, as N	.10
Nitrogen, nitrite, as N	.01	Nitrogen, nitrite plus nitrate, as N	.05
Phosphorus	.006	Orthophosphate, as P	.01
Carbon, organic, dissolved	.10		
Trace elements, USGS SC2703, filtered, in micrograms per liter			
Aluminum	1	Antimony	1
Arsenic	.9	Barium	1
Beryllium	1	Cadmium	1
Chromium	.8	Cobalt	1
Copper	1	Lead	1
Manganese	1	Molybdenum	1
Nickel	1	Selenium	.7
Silver	1	Uranium, natural	1
Zinc	1		
Pesticides, USGS SC2001, filtered, in micrograms per liter			
2,6-diethylaniline	.003	Acetochlor	.002
Alachlor	.002	Atrazine	.001
Azinphos-methyl	.001	Benfluralin	.002
Butylate	.002	Carbaryl	.003
Carbofuran	.003	Chlorpyrifos	.004
Cyanazine	.004	DCPA	.002
Deethylatrazine	.002	Diazinon	.002
Dieldrin	.001	Disulfoton	.017
EPTC	.002	Ethalfluralin	.004
Ethoprophos	.003	Fonofos	.003
Lindane	.004	Linuron	.002
Malathion	.005	Metolachlor	.002
Metribuzin	.004	Molinate	.004
Napropamide	.003	Parathion	.004
Parathion-methyl	.006	Pebulate	.004

Table 13. Water-quality constituents analyzed in shallow ground-water samples from monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000—Continued

Constituent	Analytical method reporting limit	Constituent	Analytical method reporting limit
Pesticides, USGS SC2001, filtered, in micrograms per liter—Continued			
Pendimethalin	0.004	Phorate	0.002
Prometon	.018	Propachlor	.007
Propanil	.004	Propargite	.013
Propyzamide	.003	Simazine	.005
Tebuthiuron	.01	Terbacil	.007
Terbufos	.013	Thiobencarb	.002
Triallate	.001	Trifluralin	.002
alpha-HCH	.002	cis-Permethrin	.005
p,p'-DDE	.006		
Volatile organic compounds, USGS SC2020, unfiltered, in micrograms per liter			
1,1,1,2-Tetrachloroethane	.03	1,1,1-Trichloroethane	.032
1,1,2,2-Tetrachloroethane	.09	1,1,2-Trichloroethane	.06
1,1,2-Trichlorotrifluoroethane	.06	1,1-Dichloroethane	.066
1,1-Dichloroethylene	.04	1,1-Dichloropropene	.026
1,2,3,4-Tetramethylbenzene	.23	1,2,3,5-Tetramethylbenzene	.2
1,2,3-Trichlorobenzene	.27	1,2,3-Trichloropropane	.16
1,2,3-Trimethylbenzene	.12	1,2,4-Trichlorobenzene	.19
1,2,4-Trimethylbenzene	.056	1,2-Dibromo-3-chloropropane	.21
1,2-Dibromoethane	.036	1,2-Dichlorobenzene	.048
1,2-Dichloroethane	.13	1,2-Dichloropropane	.068
1,3,5-Trimethylbenzene	.044	1,3-Dichlorobenzene	.054
1,3-Dichloropropane	.12	1,4-Dichlorobenzene	.05
2,2-Dichloropropane	.05	2-Butanone	1.6
2-Chlorotoluene	.042	2-Hexanone	.7
3-Chloropropene	.2	4-Chlorotoluene	.06
4-Isopropyl-1-methylbenzene	.07	4-Methyl-2-pentanone	.37
Acetone	7	Acrylonitrile	1.2
Benzene	.035	Bromobenzene	.036
Bromochloromethane	.044	Bromodichloromethane	.048
Bromoethene	.1	Bromoform	.06
Bromomethane	.26	Butylbenzene	.19
Carbon disulfide	.07	Chlorobenzene	.028
Chloroethane	.12	Chloroform	.052
Chloromethane	.5	Dibromochloromethane	.18
Dibromomethane	.05	Dichlorodifluoromethane	.27
Dichloromethane	.38	Diethyl ether	.17
Diisopropyl ether	.1	Ethyl methacrylate	.18
Ethyl tert-butyl ether	.054	Ethylbenzene	.03
Hexachlorobutadiene	.14	Hexachloroethane	.19

Table 13. Water-quality constituents analyzed in shallow ground-water samples from monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000—Continued

Constituent	Analytical method reporting limit	Constituent	Analytical method reporting limit
Volatile organic compounds, USGS SC2020, unfiltered, in micrograms per liter—Continued			
Isopropylbenzene	0.032	Methyl acrylate	1.4
Methyl acrylonitrile	.6	Methyl iodide	.12
Methyl methacrylate	.35	Naphthalene	.25
Styrene	.042	Tetrachloroethylene	.1
Tetrachloromethane	.06	Tetrahydrofuran	2.2
Toluene	.05	Trichloroethylene	.038
Trichlorofluoromethane	.09	Vinyl chloride	.11
cis-1,2-Dichloroethylene	.038	cis-1,3-Dichloropropene	.09
m- and p- Xylene	.06	n-Propylbenzene	.042
o-Ethyl toluene	.06	o-Xylene	.038
sec-Butylbenzene	.032	tert-Butyl methyl ether (MTBE)	.17
tert-Butylbenzene	.06	tert-Pentyl methyl ether	.11
trans-1,2-Dichloroethylene	.032	trans-1,3-Dichloropropene	.09
trans-1,4-Dichloro-2-butene	.7		

Table 14. Results of physical and chemical analyses of shallow ground-water samples from monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000

[μS/cm, microsiemens per centimeter at 25 °C; °C, degrees Celsius: NTU, nephelometric turbidity units; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; USGS, U.S. Geological Survey; SC, schedule; μg/L, micrograms per liter; <, less than; N, nitrogen, P, phosphorus; E, estimated; --, not analyzed]

Date, time, physical property, or constituent	Index numbers for monitoring wells (fig. 1)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Date (month/day/year)	5/22/00	5/18/00	5/21/00	5/20/00	5/19/00	5/16/00	5/23/00	5/17/00	5/19/00	6/1/00	6/1/00	5/22/00	5/21/00	5/30/00	6/2/00
Time (24 hour)	1600	1400	1000	1000	900	1400	900	900	1500	1000	1500	1000	1400	1600	1000
Physical properties															
Specific conductance (μS/cm)	739	626	579	587	690	2,590	507	724	744	851	733	839	1,070	788	425
pH (standard units)	7.2	7.0	7.0	6.8	6.6	7.1	6.8	6.4	6.7	6.9	6.6	6.9	6.8	6.9	6.4
Water temperature (°C)	17.0	16.1	17.3	15.8	17.0	14.7	16.3	17.0	16.2	17.4	16.1	16.8	16.2	18.9	17.4
Turbidity (NTU)	.70	.50	2.0	.40	.20	.40	.70	.50	.70	8.8	3.1	.50	.40	2.6	1.0
Dissolved oxygen (mg/L)	5.1	2.9	4.1	.3	5.6	.1	.9	2.7	5.6	3.6	3.8	3.2	2.6	4.2	4.5
Alkalinity, water whole, field (mg/L as $CaCO_3$)	340	250	210	270	210	530	210	170	290	340	180	270	360	240	110
Major ions and trace elements, USGS SC2750, filtered, in milligrams per liter (unless noted)															
Dissolved solids	476	389	355	372	435	1,630	310	438	441	578	492	530	746	491	256
Bicarbonate	420	310	260	330	250	650	260	210	360	420	220	330	430	290	130
Bromide	.10	.15	.12	.24	.23	.47	.17	.31	.15	.38	.42	.28	.46	.31	.16
Calcium	96	62	52	61	78	180	58	58	79	120	86	63	94	71	35
Chloride	29	23	32	17	58	390	23	68	48	41	88	60	110	73	41
Fluoride	.2	.2	.3	.3	.2	.8	.2	.2	.2	.2	.1	.3	.3	.3	.2
Iron (μg/L)	270	<10	<10	3,500	<10	<10	<10	<10	<10	<10	10	<10	<10	<10	120
Magnesium	17	13	12	12	15	50	11	14	16	23	17	11	17	13	7.8
Manganese (μg/L)	88	<1	<1	1,000	<1	320	1	6	61	9	280	8	5	1	44
Potassium	4	2	4	1	2	4	3	3	1	2	3	3	3	3	3
Silica	20	26	23	34	26	16	22	24	23	24	23	22	23	24	27
Sodium	52	59	57	50	42	320	34	62	54	42	47	100	140	86	36
Sulfate	36	32	33	20	54	310	19	53	27	70	54	50	110	49	20

Table 14. Results of physical and chemical analyses of shallow ground-water samples from monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000—Continued

Date, time, physical property, or constituent	Index numbers for monitoring wells (fig. 1)														
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Date (month/day/year)	6/2/00	5/31/00	5/31/00	5/15/00	5/17/00	5/18/00	5/23/00	6/5/00	6/6/00	5/24/00	6/6/00	6/8/00	6/7/00	6/7/00	5/24/00
Time (24 hour)	1400	1500	1000	1300	1400	1000	1500	1400	1100	1500	1500	1000	1000	1400	1000
Physical properties															
Specific conductance (µS/cm)	352	712	693	855	1,020	1,040	696	401	1,200	1,110	801	973	1,390	1,380	921
pH (standard units)	6.3	7.2	7.1	6.8	7.0	7.2	7.2	7.4	7.1	7.2	7.0	7.3	7.0	6.8	6.9
Water temperature (^{o}C)	16.9	15.8	16.1	14.7	17.1	16.0	16.1	15.3	16.4	14.7	17.6	15.8	14.7	18.4	14.9
Turbidity (NTU)	.70	3.4	1.9	.50	1.3	1.0	1.9	2.6	.30	.60	.50	2.3	.30	1.6	1.6
Dissolved oxygen (mg/L)	6.1	.2	.5	2.8	1.7	<.1	<.1	5.5	<.1	.1	.2	.2	.1	.1	6.8
Alkalinity, water whole, field (mg/L as $CaCO_3$)	68	250	220	230	320	290	300	190	350	380	290	260	420	570	210
Major ions and trace elements, USGS SC2750, filtered, in milligrams per liter (unless noted)															
Dissolved solids	229	470	434	515	616	624	454	242	836	772	541	670	1,080	1,020	618
Bicarbonate	83	300	270	280	390	350	360	240	420	460	360	320	520	700	250
Bromide	.13	.08	.11	.12	.11	.11	.06	.09	.23	.12	.33	.19	.15	.25	.09
Calcium	33	94	78	96	110	90	89	68	140	130	100	87	160	160	100
Chloride	21	52	43	82	110	120	44	11	180	120	100	140	160	160	100
Fluoride	.1	.6	.5	.5	.6	.4	.7	.2	.6	1.1	.8	1.1	.9	.5	.4
Iron (µg/L)	<10	20	<10	<10	30	40	1,300	<10	3,700	1,500	210	2,500	630	10	<10
Magnesium	7.1	14	12	15	15	11	15	3.4	19	19	16	13	26	24	16
Manganese (µg/L)	18	6	2	<1	26	34	430	42	580	310	680	330	450	300	<1
Potassium	3	3	4	2	2	3	3	2	3	4	2	3	13	5	3
Silica	27	15	15	16	16	11	17	14	16	11	17	14	11	19	18
Sodium	23	52	56	50	81	120	47	14	110	110	60	130	160	160	75
Sulfate	26	75	56	57	59	83	45	5.6	120	130	41	110	240	110	110

Table 14. Results of physical and chemical analyses of shallow ground-water samples from monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000—Continued

Date, time, physical property, or constituent	Index numbers for monitoring wells (fig. 1)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Nutrients, USGS SC2752, and dissolved organic carbon, USGS SC2085, filtered, in milligrams per liter															
Nitrogen, ammonia, as N	0.02	<0.02	<0.02	0.05	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.02	0.02	<0.02	<0.02
Nitrogen, ammonia plus organic nitrogen, as N	<.10	<.10	<.10	<.10	<.10	.41	<.10	.10	<.10	<.10	<.10	<.10	.12	<.10	<.10
Nitrogen, nitrite, as N	<.01	<.01	<.01	<.01	<.01	.06	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Nitrogen, nitrite plus nitrate, as N	1.1	4.8	1.9	1.4	1.8	4.5	2.0	8.6	5.2	7.7	8.1	10	6.0	5.4	4.3
Phosphorus	.30	.17	.22	.01	.16	.16	.23	.14	.14	.13	.13	.19	.18	.22	.12
Orthophosphate, as P	.32	.16	.21	.02	.15	.15	.21	.13	.13	.12	.15	.17	.16	.20	.11
Carbon, organic, dissolved	49	1.4	.9	2.8	.9	4.9	2.1	1.4	.8	1.3	14	1.1	1.8	3.4	8.7
Trace elements, USGS SC2703, filtered, in micrograms per liter															
Aluminum	9	10	14	10	9	22	9	15	11	8	6	10	13	12	6
Antimony	<1	<1	<1	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1
Arsenic	2	.9	<.9	13	1	<2	1	<.9	.9	1	<.9	<.9	<.9	<.9	<.9
Barium	200	170	170	240	170	150	110	150	160	350	210	190	260	180	130
Beryllium	<1	<1	<1	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cadmium	<1	<1	<1	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chromium	<.8	<.8	.8	<.8	<.8	<.8	<.8	<.8	<.8	1	<.8	<.8	<.8	<.8	<.8
Cobalt	4	<1	<1	10	<1	<2	<1	<1	<1	<1	2	<1	<1	<1	<1
Copper	<1	<1	<1	<1	<1	3	<1	<1	<1	1	<1	2	1	<1	<1
Lead	<1	<1	<1	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1
Manganese	88	<1	<1	1,000	<1	320	1	6	61	9	280	8	5	1	44
Molybdenum	3	<1	2	2	<1	6	1	<1	<1	1	<1	1	1	2	<1
Nickel	3	2	1	4	2	5	1	3	1	5	5	2	2	2	1
Selenium	5	3	2	.9	2	10	.7	2	<.7	3	5	2	3	4	<.7
Silver	<1	<1	<1	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1
Uranium, natural	31	2.3	1.5	1.4	<1	76	<1	<1	2.5	17	1.1	1.7	4.4	1.3	<1
Zinc	2	3	2	2	3	9	3	6	3	3	3	4	3	3	2

Table 14. Results of physical and chemical analyses of shallow ground-water samples from monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000—Continued

Date, time, physical property, or constituent	Index numbers for monitoring wells (fig. 1)														
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Nutrients, USGS SC2752, and dissolved organic carbon, USGS SC2085, filtered, in milligrams per liter															
Nitrogen, ammonia, as N	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.18	<0.02	0.08	0.03	0.08	0.13	0.03	<0.02	<0.02
Nitrogen, ammonia plus organic nitrogen, as N	<.10	<.10	<.10	<.10	<.10	<.10	.30	<.10	.15	.24	.18	.28	.26	.14	.17
Nitrogen, nitrite, as N	<.01	<.01	.01	<.01	<.01	<.01	<.01	<.01	<.01	.01	.06	<.01	.03	<.01	<.01
Nitrogen, nitrite plus nitrate, as N	9.6	.82	5.6	8.5	.45	.28	<.05	.81	<.05	.40	.21	<.05	2.3	.29	10
Phosphorus	.07	.01	.03	.03	.03	.02	<.006	.01	<.006	<.006	.02	.05	<.006	.03	.05
Orthophosphate, as P	.07	.01	.02	.02	.03	.02	.02	.03	.02	.02	.03	.01	<.01	.02	.04
Carbon, organic, dissolved	100	3.8	1.5	.7	6.5	1.5	2.9	13	3.0	3.0	7.1	8.1	13	8.2	1.7
Trace elements, USGS SC2703, filtered, in micrograms per liter															
Aluminum	7	13	10	10	13	8	18	15	11	8	8	17	<1	<1	12
Antimony	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Arsenic	<.9	<.9	<.9	<.9	<.9	<.9	4	<.9	3	2	2	4	2	<.9	<.9
Barium	150	200	200	230	230	150	120	280	240	130	230	76	72	160	240
Beryllium	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cadmium	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chromium	<.8	<.8	<.8	<.8	<.8	<.8	<.8	--	--	<.8	<.8	<.8	<.8	<.8	<.8
Cobalt	<1	2	<1	<1	<1	<1	<1	<1	<1	<1	2	<1	2	2	<1
Copper	<1	<1	<1	1	<1	1	<1	<1	1	1	1	<1	2	2	1
Lead	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Manganese	18	6	2	<1	26	34	430	42	580	310	680	330	450	300	<1
Molybdenum	<1	3	2	2	2	2	6	2	3	5	4	12	6	2	2
Nickel	1	8	2	3	3	2	2	3	5	3	5	1	11	10	3
Selenium	<.7	2	11	2	6	2	<.7	.8	<.7	<.7	<.7	<.7	6	3	3
Silver	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Uranium, natural	<1	12	3	3	22	50	2	2	2	45	2	2	28	24	3
Zinc	3	3	3	4	4	2	5	3	2	2	4	4	1	1	<1

Table 14. Results of physical and chemical analyses of shallow ground-water samples from monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000—Continued

Date, time, physical property, or constituent	Index numbers for monitoring wells (fig. 1)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Pesticides, USGS SC2001, filtered, in micrograms per liter															
2,6-diethylaniline	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Acetochlor	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Alachlor	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Atrazine	<.001	.02	.008	.006	.008	.005	.14	.05	.05	.02	.01	.007	.04	.08	.02
Azinphos-methyl	<.001	<.001	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.01	<.001	<.001
Benfluralin	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Butylate	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Carbaryl	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003
Carbofuran	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003
Chlorpyrifos	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004
Cyanazine	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004
DCPA	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Deethylatrazine	<.002	E.01	E.009	E.006	E.01	E.002	E.05	E.05	E.03	E.01	E.01	E.007	E.03	E.05	E.01
Diazinon	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Dieldrin	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	.01	<.001	<.001
Disulfoton	<.017	<.017	<.017	<.017	<.017	<.017	<.017	<.017	<.017	<.017	<.017	<.017	<.017	<.017	<.017
EPTC	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Ethalfluralin	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004
Ethoprophos	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003
Fonofos	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003
Lindane	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004
Linuron	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Malathion	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005
Metolachlor	<.002	<.002	<.004	<.002	<.002	.005	.007	.008	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Metribuzin	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004

Table 14. Results of physical and chemical analyses of shallow ground-water samples from monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000—Continued

Date, time, physical property, or constituent	Index numbers for monitoring wells (fig. 1)														
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Pesticides, USGS SC2001, filtered, in micrograms per liter															
2,6-diethylaniline	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Acetochlor	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Alachlor	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Atrazine	.005	<.001	.14	.006	.007	.01	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Azinphos-methyl	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Benfluralin	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Butylate	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Carbaryl	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003
Carbofuran	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003
Chlorpyrifos	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004
Cyanazine	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004
DCPA	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Deethylatrazine	E.08	<.002	E.05	E.02	<.002	<.002	<.002	E.003	<.002	<.002	<.002	<.002	<.002	<.002	E.006
Diazinon	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Dieldrin	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Disulfoton	<.017	<.017	<.017	<.017	<.017	<.017	<.017	<.017	<.017	<.017	<.017	<.017	<.017	<.017	<.017
EPTC	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Ethalfluralin	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004
Ethoprophos	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003
Fonofos	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003
Lindane	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004
Linuron	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Malathion	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005
Metolachlor	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Metribuzin	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004

Table 14. Results of physical and chemical analyses of shallow ground-water samples from monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000—Continued

Date, time, physical property, or constituent	Index numbers for monitoring wells (fig. 1)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Pesticides, USGS SC2001, filtered, in micrograms per liter—Continued															
Molinate	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Napropamide	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003
Parathion	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004
Parathion-methyl	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006
Pebulate	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004
Pendimethalin	<.004	<.004	<.005	<.004	<.004	<.004	<.004	<.004	<.004	.006	<.004	<.004	<.004	<.004	<.004
Phorate	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Prometon	<.018	<.018	<.018	<.018	<.018	<.018	<.018	<.018	<.018	<.018	<.018	<.018	<.018	<.018	<.018
Propachlor	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007
Propanil	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004
Propargite	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013
Propyzamide	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003
Simazine	<.005	.006	.06	<.005	<.005	<.005	.07	.04	.04	<.005	<.005	<.005	.02	.03	.01
Tebuthiuron	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Terbacil	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007
Terbufos	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013
Thiobencarb	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Triallate	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Trifluralin	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002
alpha-HCH	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002
cis-Permethrin	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005
p,p’-DDE	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006
Volatile organic compounds, USGS SC2020, unfiltered, in micrograms per liter															
1,1,1,2-Tetrachloroethane	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03
1,1,1-Trichloroethane	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	E.06	E.05	<.032
1,1,2,2-Tetrachloroethane	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09
1,1,2-Trichloroethane	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06
1,1,2-Trichlorotrifluoroethane	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06

Table 14. Results of physical and chemical analyses of shallow ground-water samples from monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000—Continued

Date, time, physical property, or constituent	Index numbers for monitoring wells (fig. 1)														
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Pesticides, USGS SC2001, filtered, in micrograms per liter—Continued															
Molinate	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Napropamide	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003
Parathion	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004
Parathion-methyl	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006
Pebulate	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004
Pendimethalin	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004
Phorate	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Prometon	<.018	<.018	<.018	<.018	<.018	<.018	<.018	<.018	<.018	<.018	<.018	<.018	<.018	<.018	.06
Propachlor	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007
Propanil	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004	<.004
Propargite	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013
Propyzamide	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003
Simazine	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	.01
Tebuthiuron	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	.05	<.01	<.01	<.01	<.01	<.01	<.01
Terbacil	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007	<.007
Terbufos	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013	<.013
Thiobencarb	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Triallate	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Trifluralin	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002
alpha-HCH	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002
cis-Permethrin	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005
p,p'-DDE	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006
Volatile organic compounds, USGS SC2020, unfiltered, in micrograms per liter															
1,1,1,2-Tetrachloroethane	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03
1,1,1-Trichloroethane	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032
1,1,2,2-Tetrachloroethane	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09
1,1,2-Trichloroethane	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06
1,1,2-Trichlorotrifluoroethane	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06

Table 14. Results of physical and chemical analyses of shallow ground-water samples from monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000—Continued

Date, time, physical property, or constituent	Index numbers for monitoring wells (fig. 1)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Volatile organic compounds, USGS SC2020, unfiltered, in micrograms per liter—Continued															
1,1-Dichloroethane	<0.066	<0.066	<0.066	<0.066	<0.066	<0.066	<0.066	<0.066	<0.066	<0.066	<0.066	<0.066	<0.066	<0.066	<0.066
1,1-Dichloroethylene	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04
1,1-Dichloropropene	<.026	<.026	<.026	<.026	<.026	<.026	<.026	<.026	<.026	<.026	<.026	<.026	<.026	<.026	<.026
1,2,3,4-Tetramethylbenzene	<.23	<.23	<.23	<.23	<.23	<.23	<.23	<.23	<.23	<.23	<.23	<.23	<.23	<.23	<.23
1,2,3,5-Tetramethylbenzene	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
1,2,3-Trichlorobenzene	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27
1,2,3-Trichloropropane	<.16	<.16	<.16	<.16	<.16	<.16	<.16	<.16	<.16	<.16	<.16	<.16	<.16	<.16	<.16
1,2,3-Trimethylbenzene	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12
1,2,4-Trichlorobenzene	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19
1,2,4-Trimethylbenzene	<.056	<.056	<.056	<.056	<.056	<.056	<.056	<.056	<.056	<.056	<.056	<.056	<.056	<.056	<.056
1,2-Dibromo-3-chloropropane	<.21	<.21	<.21	<.21	<.21	<.21	<.21	<.21	<.21	<.21	<.21	<.21	<.21	<.21	<.21
1,2-Dibromoethane	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036
1,2-Dichlorobenzene	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048
1,2-Dichloroethane	<.13	<.13	<.13	<.13	<.13	<.13	<.13	<.13	<.13	<.13	<.13	<.13	<.13	<.13	<.13
1,2-Dichloropropane	<.068	<.068	<.068	<.068	<.068	<.068	<.068	<.068	<.068	<.068	<.068	<.068	<.068	<.068	<.068
1,3,5-Trimethylbenzene	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044
1,3-Dichlorobenzene	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054
1,3-Dichloropropane	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12
1,4-Dichlorobenzene	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
2,2-Dichloropropane	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
2-Butanone	<950	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6
2-Chlorotoluene	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042
2-Hexanone	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7
3-Chloropropene	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
4-Chlorotoluene	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06

Table 14. Results of physical and chemical analyses of shallow ground-water samples from monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000—Continued

Date, time, physical property, or constituent	Index numbers for monitoring wells (fig. 1)														
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Volatile organic compounds, USGS SC2020, unfiltered, in micrograms per liter—Continued															
1,1-Dichloroethane	<0.066	<0.066	<0.066	<0.066	<0.066	<0.066	<0.066	<0.066	<0.066	<0.066	<0.066	<0.066	<0.066	<0.066	<0.066
1,1-Dichloroethylene	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04
1,1-Dichloropropene	<.026	<.026	<.026	<.026	<.026	<.026	<.026	<.026	<.026	<.026	<.026	<.026	<.026	<.026	<.026
1,2,3,4-Tetramethylbenzene	<.23	<.23	<.23	<.23	<.23	<.23	<.23	<.23	<.23	<.23	<.23	<.23	<.23	<.23	<.23
1,2,3,5-Tetramethylbenzene	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
1,2,3-Trichlorobenzene	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27
1,2,3-Trichloropropane	<.16	<.16	<.16	<.16	<.16	<.16	<.16	<.16	<.16	<.16	<.16	<.16	<.16	<.16	<.16
1,2,3-Trimethylbenzene	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12
1,2,4-Trichlorobenzene	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19
1,2,4-Trimethylbenzene	<.056	<.056	<.056	<.056	<.056	<.056	<.056	<.056	<.056	<.056	<.056	<.056	<.056	<.056	<.056
1,2-Dibromo-3-chloropropane	<.21	<.21	<.21	<.21	<.21	<.21	<.21	<.21	<.21	<.21	<.21	<.21	<.21	<.21	<.21
1,2-Dibromoethane	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036
1,2-Dichlorobenzene	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048
1,2-Dichloroethane	<.13	<.13	<.13	<.13	<.13	<.13	<.13	<.13	<.13	<.13	<.13	<.13	<.13	<.13	<.13
1,2-Dichloropropane	<.068	<.068	<.068	<.068	<.068	<.068	<.068	<.068	<.068	<.068	<.068	<.068	<.068	<.068	<.068
1,3,5-Trimethylbenzene	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044
1,3-Dichlorobenzene	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054
1,3-Dichloropropane	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12
1,4-Dichlorobenzene	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
2,2-Dichloropropane	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
2-Butanone	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	<250	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6
2-Chlorotoluene	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042
2-Hexanone	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7
3-Chloropropene	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
4-Chlorotoluene	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06

Table 14. Results of physical and chemical analyses of shallow ground-water samples from monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000—Continued

Date, time, physical property, or constituent	Index numbers for monitoring wells (fig. 1)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Volatile organic compounds, USGS SC2020, unfiltered, in micrograms per liter—Continued															
4-Isopropyl-1-methylbenzene	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07
4-Methyl-2-pentanone	<.37	<.37	<.37	<.37	<.37	<.37	<.37	<.37	<.37	<.37	<.37	<.37	<.37	<.37	<.37
Acetone	<7	<7	<7	<7	<7	<7	<7	<7	<7	<7	<7	<7	<7	<7	<7
Acrylonitrile	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2
Benzene	<.035	<.035	<.035	<.035	<.035	<.035	<.035	<.035	<.035	<.035	<.035	<.035	<.035	<.035	<.035
Bromobenzene	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036
Bromochloromethane	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044
Bromodichloromethane	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048	E.06	.12	<.048
Bromoethene	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
Bromoform	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06
Bromomethane	<.26	<.26	<.26	<.26	<.26	<.26	<.26	<.26	<.26	<.26	<.26	<.26	<.26	<.26	<.26
Butylbenzene	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19
Carbon disulfide	<.07	<.07	<.07	<.07	<.07	<.07	<.07	<.07	<.07	<.07	<.07	<.07	<.07	<.07	<.07
Chlorobenzene	<.028	<.028	<.028	<.028	<.028	<.028	<.028	<.028	<.028	<.028	<.028	<.028	<.028	<.028	<.028
Chloroethane	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12
Chloroform	.33	<.052	<.052	<.052	E.07	<.052	<.052	.17	<.052	<.052	E.07	.16	1.7	.28	<.052
Chloromethane	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
Dibromochloromethane	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18
Dibromomethane	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
Dichlorodifluoromethane	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27
Dichloromethane	<.38	<.38	<.38	<.38	<.38	<.38	<.38	<.38	<.38	<.38	<.38	<.38	<.38	<.38	<.38
Diethyl ether	<.17	<.17	<.17	<.17	<.17	<.17	<.17	<.17	<.17	<.17	<.17	<.17	<.17	<.17	<.17
Diisopropyl ether	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
Ethyl methacrylate	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18
Ethyl tert-butyl ether	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054

Table 14. Results of physical and chemical analyses of shallow ground-water samples from monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000—Continued

Date, time, physical property, or constituent	Index numbers for monitoring wells (fig. 1)														
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Volatile organic compounds, USGS SC2020, unfiltered, in micrograms per liter—Continued															
4-Isopropyl-1-methylbenzene	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07
4-Methyl-2-pentanone	<.37	<.37	<.37	<.37	<.37	<.37	<.37	<.37	<.37	<.37	<.37	<.37	<.37	<.37	<.37
Acetone	<7	<7	<7	<7	<7	<7	<7	<7	<7	<7	<7	<7	<7	<7	<7
Acrylonitrile	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2
Benzene	<.035	<.035	<.035	<.035	<.035	<.035	<.035	<.035	<.035	<.035	<.035	<.035	<.035	<.035	<.035
Bromobenzene	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036	<.036
Bromochloromethane	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044	<.044
Bromodichloromethane	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048	<.048
Bromoethene	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
Bromoform	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06
Bromomethane	<.26	<.26	<.26	<.26	<.26	<.26	<.26	<.26	<.26	<.26	<.26	<.26	<.26	<.26	<.26
Butylbenzene	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19
Carbon disulfide	<.07	<.07	<.07	<.07	<.07	<.07	<.07	<.07	<.07	<.07	<.07	<.07	<.07	<.07	<.07
Chlorobenzene	<.028	<.028	<.028	<.028	<.028	<.028	<.028	<.028	<.028	<.028	<.028	<.028	<.028	<.028	<.028
Chloroethane	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12
Chloroform	<.052	<.052	<.052	<.052	<.052	<.052	<.052	<.052	<.052	<.052	<.052	<.052	<.052	<.052	<.052
Chloromethane	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
Dibromochloromethane	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18
Dibromomethane	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
Dichlorodifluoromethane	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27	<.27
Dichloromethane	<.38	<.38	<.38	<.38	<.38	<.38	<.38	<.38	<.38	<.38	<.38	<.38	<.38	<.38	<.38
Diethyl ether	<.17	<.17	<.17	<.17	<.17	<.17	<.17	<.17	<.17	<.17	<.17	<.17	<.17	<.17	<.17
Diisopropyl ether	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
Ethyl methacrylate	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18	<.18
Ethyl tert-butyl ether	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054	<.054

Table 14. Results of physical and chemical analyses of shallow ground-water samples from monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000—Continued

Date, time, physical property, or constituent	Index numbers for monitoring wells (fig. 1)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Volatile organic compounds, USGS SC2020, unfiltered, in micrograms per liter—Continued															
Ethylbenzene	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Hexachlorobutadiene	<.14	<.14	<.14	<.14	<.14	<.14	<.14	<.14	<.14	<.14	<.14	<.14	<.14	<.14	<.14
Hexachloroethane	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19
Isopropylbenzene	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032
Methyl acrylate	<1.4	<1.4	<1.4	<1.4	<1.4	<1.4	<1.4	<1.4	<1.4	<1.4	<1.4	<1.4	<1.4	<1.4	<1.4
Methyl acrylonitrile	<.6	<.6	<.6	<.6	<.6	<.6	<.6	<.6	<.6	<.6	<.6	<.6	<.6	<.6	<.6
Methyl iodide	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12
Methyl methacrylate	<.35	<.35	<.35	<.35	<.35	<.35	<.35	<.35	<.35	<.35	<.35	<.35	<.35	<.35	<.35
Naphthalene	<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25
Styrene	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042
Tetrachloroethylene	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	9.0	<.1	.21	<.1	<.1	<.1
Tetrachloromethane	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06
Tetrahydrofuran	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2
Toluene	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
Trichloroethylene	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038
Trichlorofluoromethane	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09
Vinyl chloride	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11
cis-1,2-Dichloroethylene	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038
cis-1,3-Dichloropropene	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09
m- and p- Xylene	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06
n-Propylbenzene	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042
o-Ethyl toluene	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06
o-Xylene	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038
sec-Butylbenzene	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032
tert-Butyl methyl ether (MTBE)	<.17	<.17	<.17	<.17	<.17	<.17	.26	<.17	<.17	<.17	<.17	<.17	<.17	<.17	<.17

Table 14. Results of physical and chemical analyses of shallow ground-water samples from monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000—Continued

Date, time, physical property, or constituent	Index numbers for monitoring wells (fig. 1)														
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Volatile organic compounds, USGS SC2020, unfiltered, in micrograms per liter—Continued															
Ethylbenzene	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Hexachlorobutadiene	<.14	<.14	<.14	<.14	<.14	<.14	<.14	<.14	<.14	<.14	<.14	<.14	<.14	<.14	<.14
Hexachloroethane	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19	<.19
Isopropylbenzene	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032
Methyl acrylate	<1.4	<1.4	<1.4	<1.4	<1.4	<1.4	<1.4	<1.4	<1.4	<1.4	<1.4	<1.4	<1.4	<1.4	<1.4
Methyl acrylonitrile	<.6	<.6	<.6	<.6	<.6	<.6	<.6	<.6	<.6	<.6	<.6	<.6	<.6	<.6	<.6
Methyl iodide	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12	<.12
Methyl methacrylate	<.35	<.35	<.35	<.35	<.35	<.35	<.35	<.35	<.35	<.35	<.35	<.35	<.35	<.35	<.35
Naphthalene	<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25
Styrene	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042
Tetrachloroethylene	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	.15	<.1	<.1	<.1	<.1	.13	<.1
Tetrachloromethane	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06
Tetrahydrofuran	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2
Toluene	<.05	<.05	.15	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
Trichloroethylene	<.038	<.038	<.038	<.038	<.038	<.038	E.06	<.038	.26	<.038	<.038	<.038	<.038	<.038	<.038
Trichlorofluoromethane	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09
Vinyl chloride	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11
cis-1,2-Dichloroethylene	<.038	<.038	<.038	<.038	<.038	<.038	E.07	<.038	E.08	<.038	<.038	<.038	<.038	<.038	<.038
cis-1,3-Dichloropropene	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09
m- and p- Xylene	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06
n-Propylbenzene	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042	<.042
o-Ethyl toluene	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06
o-Xylene	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038	<.038
sec-Butylbenzene	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032
tert-Butyl methyl ether (MTBE)	<.17	<.17	<.17	<.17	<.17	<.17	<.17	<.17	<.17	<.17	<.17	<.17	<.17	.47	<.17

Table 14. Results of physical and chemical analyses of shallow ground-water samples from monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000—Continued

Date, time, physical property, or constituent	Index numbers for monitoring wells (fig. 1) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Volatile organic compounds, USGS SC2020, unfiltered, in micrograms per liter—Continued															
tert-Butylbenzene	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
tert-Pentyl methyl ether	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11
trans-1,2-Dichloroethylene	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032
trans-1,3-Dichloropropene	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09
trans-1,4-Dichloro-2-butene	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7

Table 14. Results of physical and chemical analyses of shallow ground-water samples from monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000—Continued

Date, time, physical property, or constituent	Index numbers for monitoring wells (fig. 1)														
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Volatile organic compounds, USGS SC2020, unfiltered, in micrograms per liter—Continued															
tert-Butylbenzene	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<00.06	<0.06	<0.06	<0.06	<0.06
tert-Pentyl methyl ether	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11	<.11
trans-1,2-Dichloroethylene	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032	<.032
trans-1,3-Dichloropropene	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09	<.09
trans-1,4-Dichloro-2-butene	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7

Table 15. Results of pH, organic-carbon, and particle-size analyses of sediment samples collected during installation of shallow ground-water monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000

[BLS, below land surface; mm, millimeters; <, less than; --, not applicable]

Monitoring-well index number (fig. 1)	Core-material sampling depth BLS (feet)	pH (standard units)	Organic carbon (percent)	Particle-size diameter (percent less than indicated particle size)								
				16 mm	8 mm	4 mm	2 mm	1 mm	0.5 mm	0.25 mm	0.125 mm	0.062 mm
1	14–19	7.4	<0.02	100	99.6	97.3	95.1	91.9	78.9	48.8	11.8	3.5
	30–32	7.5	<.02	100	96.7	91.9	86.1	78.3	61.5	15.3	2.5	1.0
2	15–17	7.5	<.02	100	100	99.9	99.5	98.7	92.7	38.8	5.2	.8
	35–36	7.3	<.02	100	99.3	88.9	58.7	34.1	19.4	8.7	2.3	1.1
3	12–14	7.3	<.02	--	100	99.8	99.5	98.7	95.3	65.4	11.7	1.9
	36–37	7.2	<.02	100	98.0	89.0	68.8	47.3	25.9	8.4	4.1	3.1
4	9–14	7.6	.33	100	99.6	99.4	98.9	98.1	96.9	94.3	82.7	74.1
	21–23	8.2	.50	--	100	98.7	95.6	91.0	83.8	68.2	54.2	48.7
5	13–14	7.3	.04	--	--	100	98.8	96.4	86.5	41.5	15.1	7.2
	35–36	7.7	<.02	100	97.9	90.8	76.1	53.8	25.3	8.5	3.3	1.3
6	3	8.1	.17	--	100	98.0	91.3	89.0	85.6	75.3	58.7	48.0
	11–12	8.0	<.02	--	--	100	99.9	98.9	92.7	65.9	26.4	5.5
7	16–17	7.5	<.02	100	93.0	89.3	85.9	80.4	70.7	55.4	25.6	6.9
	30–32	7.6	<.02	100	99.6	95.3	85.1	72.8	55.0	24.1	4.0	1.5
8	9–12	8.1	.08	--	--	100	99.5	97.6	86.9	62.5	38.9	23.7
	30–32	7.2	<.02	--	100	98.8	90.8	81.3	66.7	39.1	26.6	22.6
9	21–23	7.6	.09	100	99.6	99.1	97.8	95.7	90.8	79.1	66.8	57.1
	41–43	7.1	<.02	100	99.0	85.8	70.2	52.1	33.7	19.5	10.8	8.4
10	11–14	7.4	.06		100	99.5	98.0	95.3	92.8	87.0	80.2	74.3
	24–25	7.1	<.02	100	94.1	89.8	82.7	68.7	42.0	16.9	10.2	5.7
11	15–16	6.9	<.02	--	100	99.9	99.8	99.3	94.7	44.5	5.0	.9
	26–27	7.2	<.02	100	98.2	88.6	69.7	48.4	24.3	11.5	4.4	1.9
12	14–16	7.4	.03	--	100	98.3	93.7	85.5	78.0	64.6	51.9	43.1
	41–43	7.6	<.02	--	100	98.8	94.7	85.6	60.1	11.9	2.1	.5
13	10–13	7.8	.08	--	100	99.4	98.2	93.5	80.1	59.9	46.3	38.7
	30–32	7.8	<.02	100	98.3	90.0	72.4	51.9	23.2	7.8	3.2	1.6
14	13–14	8.2	.07	--	--	100	99.8	99.1	92.4	70.4	44.7	29.9
	44–46	8.1	.04	100	99.7	88.5	65.1	45.7	28.4	12.2	4.7	3.2
15	16–18	8.2	.02	--	100	99.2	97.4	94.4	90.8	81.6	56.5	30.2
	39–40	7.5	<.02	100	99.2	92.8	81.6	64.1	37.8	13.4	3.7	2.1
16	13–15	8.2	.12	100	100	99.6	96.7	87.6	76.3	62.8	48.7	40.3
	38–39	8.1	<.02	--	100	98.7	92.5	81.3	58.0	20.9	5.0	2.9
17	8–9	6.8	.30	--	100	99.9	98.5	95.7	92.9	91.3	89.7	84.1
	24–25	8.0	.08	100	95.9	89.6	80.3	68.2	42.3	18.7	10.1	7.1
18	16–17	8.4	.18	100	95.4	83.1	75.8	72.4	69.7	67.1	62.4	47.4
	35–38	7.4	<.02	100	99.3	91.5	77.8	58.4	36.6	7.2	.7	.2
19	10	7.8	.10	100	97.5	95.5	92.1	87.1	78.8	67.0	44.7	20.7
	23–25	8.1	<.02	100	97.0	86.1	65.5	43.9	25.8	11.6	6.2	4.1

Table 15. Results of pH, organic-carbon, and particle-size analyses of sediment samples collected during installation of shallow ground-water monitoring wells in areas of recent residential and commercial development, Wichita, Kansas, 2000—Continued

Monitoring-well index number (fig. 1)	Core-material sampling depth BLS (feet)	pH (standard units)	Organic carbon (percent)	Particle-size diameter (percent less than indicated particle size)								
				16 mm	8 mm	4 mm	2 mm	1 mm	0.5 mm	0.25 mm	0.125 mm	0.062 mm
20	8–9	8.1	0.05	--	100	99.3	98.1	95.3	89.5	67.6	39.6	23.2
	30–32	8.3	.03	100	98.3	89.0	68.9	49.5	29.2	12.7	3.3	1.3
21	7–9	7.3	<.02	--	--	--	100	99.7	98.9	80.6	27.1	6.8
	24–26	7.4	.05	100	99.4	95.2	82.9	67.0	45.6	20.2	4.1	1.1
22	9	7.6	.09	100	99.6	98.5	97.6	96.9	95.3	80.7	42.6	23.9
	22–23	8.4	.10	100	98.7	87.9	72.1	60.3	43.2	15.4	4.7	3.4
23	6–8	8.0	<.02	--	100	100	99.9	99.6	97.6	66.3	16.4	6.0
	17–18	8.1	.08	--	100	98.7	95.2	87.1	51.7	7.8	2.4	.9
24	5–7	8.0	.10	100	99.0	98.0	94.7	88.4	57.7	11.2	2.4	1.0
	16–18	8.2	<.02	100	96.4	88.2	77.1	58.7	34.0	8.3	2.0	1.1
25	5–6	7.8	.16	--	--	--	100	99.8	99.3	98.5	86.4	32.3
	15–16	8.0	.03	100	97.3	89.6	70.6	51.4	30.8	9.3	2.1	.8
26	6–8	8.3	.18	--	--	100	99.7	99.5	99.3	99.1	98.5	84.5
	24–25	8.2	<.02	100	97.3	90.2	77.6	65.7	50.3	17.4	1.3	.5
27	5–6	8.0	<.02	--	100	99.5	98.8	95.5	83.8	51.9	8.9	1.2
	15–16	8.2	.05	100	97.5	91.1	77.6	51.0	19.3	5.9	1.5	.5
28	5–6	7.1	<.02	100	99.1	94.0	82.7	66.0	49.0	7.6	1.0	.3
	15–16	8.0	.04	100	95.2	88.9	76.3	59.9	35.1	10.6	3.9	1.8
29	6–8	7.0	<.02	--	--	100	99.9	99.1	93.0	35.4	2.0	.3
	22–23	7.2	<.02	100	97.3	94.7	88.9	79.9	64.7	14.7	2.3	.9
30	6–9	6.8	.09	100	98.2	92.2	86.8	83.2	79.1	70.4	26.0	10.7
	23–26	7.3	.02	100	95.2	88.4	76.9	63.7	45.6	16.4	4.2	.6