



Prepared in cooperation with Park County, Colorado

Ground-Water Quality and Potential Effects of Individual Sewage Disposal System Effluent on Ground-Water Quality in Park County, Colorado, 2001–2004

Scientific Investigations Report 2007–5220

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

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By Lisa D. Miller and Roderick F. Ortiz

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Contents

Abstract.....	1
Introduction.....	2
Purpose and Scope	2
Description of the Study Area	4
Previous Studies	4
Acknowledgments	6
Study Approach.....	6
Sample Collection and Processing	6
Analytical Methods.....	13
Quality Control	13
Data Analysis Methods.....	13
Quality of Ground Water	15
Age of Ground Water	15
Natural Factors Affecting Drinking-Water Quality in Park County.....	18
pH	18
Fluoride	18
Sulfate	18
Dissolved Solids.....	20
Radionuclides	22
Human Factors Affecting Drinking-Water Quality in Park County.....	24
Chloride.....	26
Nitrate.....	26
Bacteria	28
Summary of Drinking-Water Quality in Domestic Wells in Park County	28
Potential Effects of Individual Sewage Disposal System Effluent on Ground-Water Quality.....	30
Occurrence of Constituents Associated with Individual Sewage Disposal System Effluent in Ground-Water Samples.....	34
Potential Effects of Individual Sewage Disposal System Density and Aquifer Type on Ground-Water Quality	37
Summary.....	42
References Cited.....	45

Figures

1. Locations of the study area, domestic wells sampled by aquifer type, and all domestic wells listed in the Colorado Division of Water Resources Well Permit database (2004) in Park County, Colorado	3
2. Surficial geology of Park County, Colorado.....	5
3. (A) Estimated concentrations of tritium in precipitation near Park County, Colorado, and (B) atmospheric concentrations of CFC-11, CFC-12, and CFC-113 in air in North America.....	14
4. Explanation of a boxplot	15
5. Distribution of (A) tritium concentrations and (B) approximate recharge dates based on chlorofluorocarbon data for alluvial, crystalline-rock, sedimentary-rock, and volcanic-rock aquifers throughout Park County, Colorado, 2001–2004	16
6. Approximate ground-water recharge date based on CFC concentrations in selected wells in Park County, Colorado, 2001–2004	17

7. (A) Distribution of pH by aquifer type and (B) spatial distribution of pH in samples collected from selected domestic wells in Park County, Colorado, 2001–2004	20
8. (A) Distribution of fluoride by aquifer type and (B) spatial distribution of fluoride in samples collected from selected domestic wells in Park County, Colorado, 2001–2004	22
9. (A) Distribution of sulfate by aquifer type and (B) spatial distribution of sulfate in samples collected from selected domestic wells in Park County, Colorado, 2001–2004	24
10. (A) Distribution of dissolved solids by aquifer type and (B) spatial distribution of dissolved solids in samples collected from selected domestic wells in Park County, Colorado, 2001–2004.....	26
11. (A) Distribution of radon by aquifer type and (B) spatial distribution of radon in samples collected from selected domestic wells in Park County, Colorado, 2000–2004	28
12. (A) Distribution of uranium by aquifer type and (B) spatial distribution of uranium in samples collected from selected domestic wells in Park County, Colorado, 2000–2004	30
13. Spatial distribution of nitrite-plus-nitrate in samples collected from selected domestic wells in Park County, Colorado, 2001–2004.....	32
14. Spatial distribution of total coliform detections in samples collected from selected domestic wells in Park County, Colorado, 2001–2004.....	33
15. Number of wastewater compounds detected in samples collected from selected domestic wells in Park County, Colorado, 2001–2004.....	36
16. Distribution of nitrite-plus-nitrate concentrations in samples collected from selected domestic wells in the Bailey area in 1974 and 2001	38
17. Distribution of chloride concentrations in samples collected from selected domestic wells in the Bailey area in 1974 and 2001	38
18. Distribution of (A) potassium, (B) chloride, (C) nitrite-plus-nitrate, and (D) boron concentrations in samples collected from domestic wells in Park County, Colorado, 2001–2004, in relation to average subdivision lot size.....	39
19. Distribution of (A) potassium, (B) chloride, (C) nitrite-plus-nitrate, and (D) boron concentrations in samples collected from wells completed in the crystalline-rock aquifers in Park County, Colorado, 2001–2004, in relation to average subdivision lot size	40
20. Distribution of (A) potassium, (B) chloride, (C) nitrite-plus-nitrate, and (D) boron concentrations in samples collected from wells completed in the volcanic-rock aquifers in Park County, Colorado, 2001–2004, in relation to average subdivision lot size	41
21. Relation of nitrite-plus-nitrate concentrations in samples collected from selected domestic wells to year of individual sewage disposal system installation, Park County, Colorado.....	42

Tables

1. Ground-water-quality sites and summary of ground-water-quality data for Park County, Colorado, 2001–2004	7
2. Summary of selected ground-water-quality data for Park County, Colorado, 2000–2004	19
3. List of organic compounds identified in samples collected from domestic wells in Park County, Colorado, 2001–2004	35

Conversion Factors, Definitions, and Abbreviations

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
	Area	
acre	4,047	square meter (m ²)
square mile (mi ²)	2.590	square kilometer (km ²)
	Flow rate	
gallon per minute (gal/min)	0.06309	liter per second (L/s)
	Radioactivity	
picocurie per liter (pCi/L)	0.037	becquerel per liter (Bq/L)
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
 $^{\circ}\text{F}=(1.8\times^{\circ}\text{C})+32$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
 $^{\circ}\text{C}=(^{\circ}\text{F}-32)/1.8$

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

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).
 Altitude, as used in this report, refers to distance above the vertical datum.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius ($\mu\text{S}/\text{cm}$ at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L), micrograms per liter ($\mu\text{g}/\text{L}$), picocuries per liter (pCi/L), or picograms per kilogram (pg/kg).

Additional Abbreviations Used in This Report

BPA	Bisphenol A
CFC	Chlorofluorocarbon
CWCB	Colorado Water Conservation Board
DEET	N,N-diethyl-meta-toluamide
DS	Dissolved solids
<i>E. coli</i>	<i>Escherichia coli</i>
ISDS	Individual sewage disposal system
IQR	Interquartile range
MCL	Maximum contaminant level
4-NP	4-nonylphenol
NPDWR	National Primary Drinking Water Regulation
NSDWR	National Secondary Drinking Water Regulation
NWIS	National Water Information System
PPACG	Pikes Peak Area Council of Governments
SMCL	Secondary maximum contaminant level
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey



Ground-Water Quality and Potential Effects of Individual Sewage Disposal System Effluent on Ground-Water Quality in Park County, Colorado, 2001–2004

By Lisa D. Miller and Roderick F. Ortiz

Abstract

In 2000, the U.S. Geological Survey, in cooperation with Park County, Colorado, began a study to evaluate ground-water quality in the various aquifers in Park County that supply water to domestic wells. The focus of this study was to identify and describe the principal natural and human factors that affect ground-water quality. In addition, the potential effects of individual sewage disposal system (ISDS) effluent on ground-water quality were evaluated.

Ground-water samples were collected from domestic water-supply wells from July 2001 through October 2004 in the alluvial, crystalline-rock, sedimentary-rock, and volcanic-rock aquifers to assess general ground-water quality and effects of ISDS's on ground-water quality throughout Park County. Samples were analyzed for physical properties, major ions, nutrients, bacteria, and boron; and selected samples also were analyzed for dissolved organic carbon, human-related (wastewater) compounds, trace elements, radionuclides, and age-dating constituents (tritium and chlorofluorocarbons).

Drinking-water quality is adequate for domestic use throughout Park County with a few exceptions. Only about 3 percent of wells had concentrations of fluoride, nitrate, and (or) uranium that exceeded U.S. Environmental Protection Agency national, primary drinking-water standards. These primary drinking-water standards were exceeded only in wells completed in the crystalline-rock aquifers in eastern Park County. *Escherichia coli* bacteria were detected in one well near Guffey, and total coliform bacteria were detected in about 11 percent of wells sampled throughout the county. The highest total coliform concentrations were measured southeast of the city of Jefferson and west of Tarryall Reservoir. Secondary drinking-water standards were exceeded more frequently. About 19 percent of wells had concentrations of one or more constituents (pH, chloride, fluoride, sulfate, and dissolved solids) that exceeded secondary drinking-water standards. Currently (2004), there is no federally enforced drinking-water standard for radon in public water-supply systems, but proposed regulations suggest a maximum contaminant level of 300 picocuries per liter (pCi/L) and an alternative maximum contaminant level of 4,000 pCi/L contingent on other mitigating remedial activities to reduce

radon levels in indoor air. Radon concentrations in about 91 percent of ground-water samples were greater than or equal to 300 pCi/L, and about 25 percent had radon concentrations greater than or equal to 4,000 pCi/L. Generally, the highest radon concentrations were measured in samples collected from wells completed in the crystalline-rock aquifers.

Analyses of ground-water-quality data indicate that recharge from ISDS effluent has affected some local ground-water systems in Park County. Because roughly 90 percent of domestic water used is assumed to be recharged by ISDS's, detections of human-related (wastewater) compounds in ground water in Park County are not surprising; however, concentrations of constituents associated with ISDS effluent generally are low (concentrations near the laboratory reporting levels). Thirty-eight different organic wastewater compounds were detected in 46 percent of ground-water samples, and the number of compounds detected per sample ranged from 1 to 17 compounds. Samples collected from wells with detections of wastewater compounds also had significantly higher (p-value < 0.05) chloride and boron concentrations than samples from wells with no detections of wastewater compounds.

ISDS density (average subdivision lot size used to estimate ISDS density) was related to ground-water quality in Park County. Chloride and boron concentrations were significantly higher in ground-water samples collected from wells located in areas that had average subdivision lot sizes of less than 1 acre than in areas that had average subdivision lot sizes greater than or equal to 1 acre. For wells completed in the crystalline-rock aquifers, chloride concentrations were significantly (p-value < 0.05) higher in wells located in areas with average subdivision lot sizes less than 1 acre than in areas with average subdivision lot sizes greater than 5 acres, and boron concentrations were significantly higher in wells located in areas with average subdivision lot sizes of less than 1 acre than in areas with average subdivision lot sizes greater than 3 acres. In the volcanic-rock aquifers, wells were sampled only in areas that had average subdivision lot sizes less than 1 acre or greater than 5 acres. Potassium, chloride, and boron concentrations were significantly higher in wells located in areas that had average subdivision lot sizes of less than 1 acre than in areas with average subdivision lot sizes greater

2 Potential Effects of Individual Sewage Disposal System Effluent on Ground-Water Quality in Park County, Colorado

than 5 acres in the volcanic-rock aquifers. No significant increases in constituent concentrations were observed in wells completed in the sedimentary-rock aquifers for any lot-size category, and too few samples were collected from wells completed in the alluvial aquifers to do statistical tests.

The year of ISDS installation also was related to ground-water quality in Park County. For example, significantly higher nitrite-plus-nitrate concentrations were measured between wells with ISDS's installed in the 1970's and those installed in the 1980's. Significantly higher nitrite-plus-nitrate concentrations were not measured between wells with ISDS's installed in the 1980's and those installed in the 1990's. However, significantly higher nitrite-plus-nitrate concentrations were measured between wells with ISDS's installed in the 1990's and those installed after 1999. The lowest overall nitrite-plus-nitrate concentrations were measured in wells that had ISDS's installed after 1999, and the highest concentrations were measured in wells with ISDS's installed before 1980. Nitrate concentrations may be less in samples collected from wells with ISDS's installed after 1980 because effluent has not had enough time to move through the unsaturated zone to the ground-water table in sufficient quantities to significantly affect ground-water quality.

Concentrations of nitrite-plus-nitrate and chloride were significantly higher (p -value < 0.05) in ground-water samples collected during 2001 than in samples collected during 1974 in the Bailey area. Increases in nitrite-plus-nitrate and chloride concentrations in ground water in the Bailey area over time probably are related to a larger part of the overall recharge being from ISDS effluent either as a result of an increase in ISDS density or more time for recharge from ISDS effluent to reach the ground-water table.

Many of the wells sampled in Park County probably have a mixture of water from several parts of the aquifer system that may have different recharge areas, flow paths, and ground-water recharge dates. Because most of the development in Park County has occurred since 1990 and only about 8 percent of wells sampled for chlorofluorocarbons had ground-water recharge dates since 1990, there may not have been enough elapsed time for effluent water from ISDS's to noticeably affect sampled ground-water quality. As time passes, recharge from ISDS's may become a larger part of the ground-water resource, as a result, concentrations of chloride, boron, and other constituents associated with ISDS effluent may increase in ground water if not effectively removed by treatment processes.

Introduction

Park County, in central Colorado (fig. 1), has been one of the fastest growing counties in Colorado based on the percentage of population growth. Since 1970, the population has increased nearly eightfold (U.S. Bureau of the Census, 1982, 2004). Specifically, the population of Park County was 2,185 in 1970 and 16,949 in 2005 (U.S. Bureau of the

Census, 1982, 2006). The largest decadal population increase (7,349) occurred during the 1990's. Continued development of commuter communities and vacation homes has increased the demand on water resources and, as such, has increased the potential for contamination of ground water. Although the towns of Alma, Bailey, and Fairplay have public water-supply systems, most county residences receive their domestic water supply from individual wells. In 2000, about 89 percent of the total population of Park County received their water from individual wells (Tamara Ivahnenko, U.S. Geological Survey, oral commun., June 21, 2006). Most of these households, served by individual wells, also have individual sewage disposal systems (ISDS). Health department officials, planners, and County Commissioners in Park County are interested in obtaining current information regarding water quality in the aquifers that serve the residents of the county and in assessing the potential degradation of ground-water quality due to the increased number and density of ISDS's installed throughout the county.

Park County land-use regulations were put in place to "ensure that development in all areas of Park County provides for a water supply that is sufficient in terms of quantity, long-term dependability of supply, and quality without adversely affecting water-supply systems of neighboring uses" (Park County, 2005). To meet this goal, local entities need current information regarding the quality of ground water in Park County. Additional ground-water-quality data are needed to evaluate the effects of changing land-use and water-management practices on water resources, and to identify, describe, and explain, where possible, the major natural and human factors that affect observed water-quality conditions. In 2000, the U.S. Geological Survey (USGS), in cooperation with Park County, began a study to evaluate ground-water quality in the various aquifers in Park County that supply water to domestic wells. As part of this study, ground-water-quality samples were collected from domestic wells throughout Park County (fig. 1). Water-quality data were compiled and analyzed to provide a general assessment of present (2001–2004) ground-water quality in the various aquifers that supply water to residents of the county.

Purpose and Scope

The purpose of this report is to provide relevant data and interpretations needed by water managers and planners to assess ground-water quality in Park County. Specifically, the report provides (1) a general assessment of the quality of ground water by locale and aquifer type, and (2) an assessment of the potential effects from ISDS's on ground-water quality in the county. The report uses radionuclide data collected by the USGS in September 2000 in the Bailey area and data collected from July 2001 through October 2004, in cooperation with Park County, Colorado, to evaluate ground-water quality in the major aquifers that serve the residents of the county. In addition, selected data collected in 1974 by Klein and others (1978) also are used to determine if changes in constituent concentrations have occurred over time.

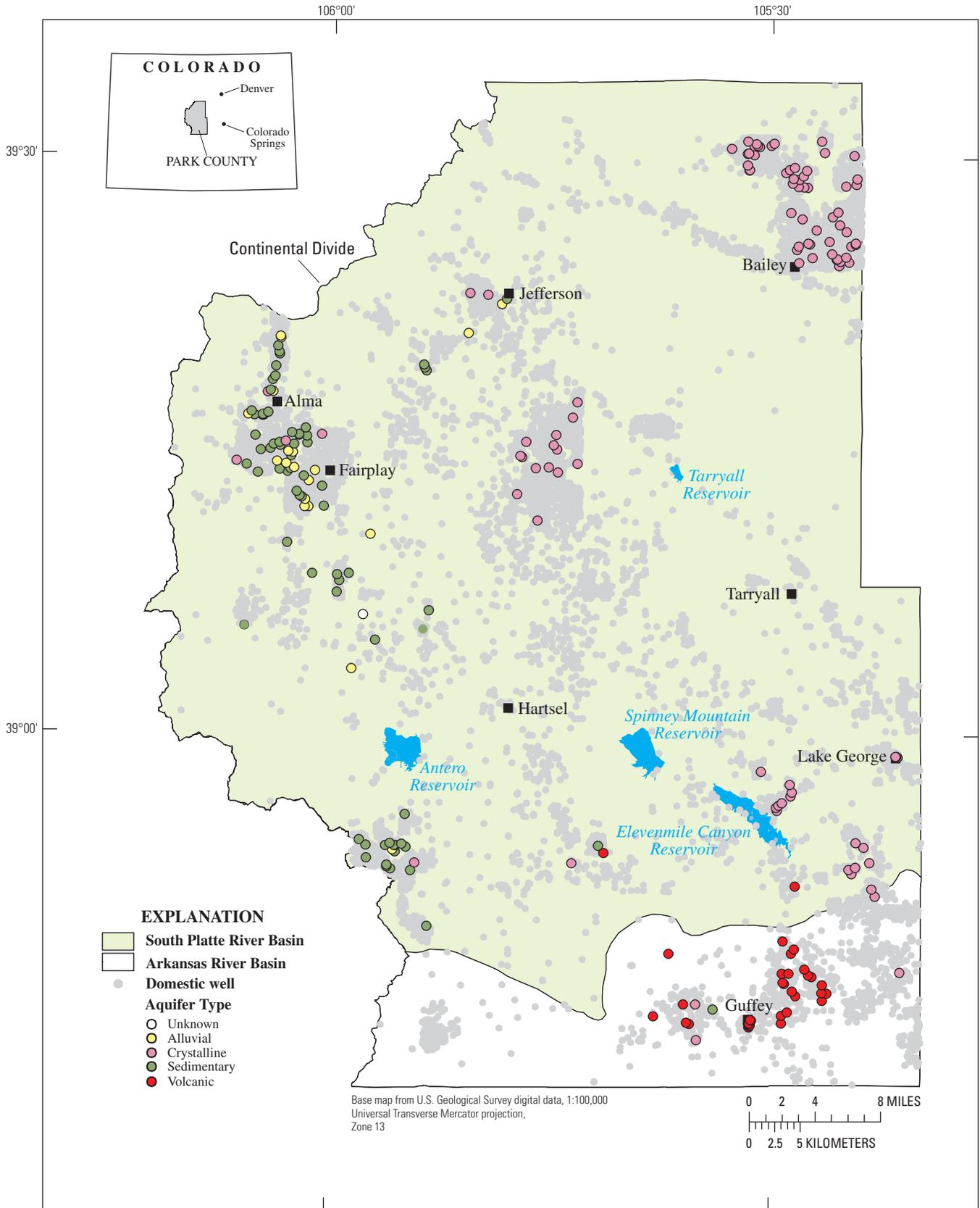


Figure 1. Locations of the study area, domestic wells sampled by aquifer type, and all domestic wells listed in the Colorado Division of Water Resources Well Permit database (2004) in Park County, Colorado.

Description of the Study Area

Park County is located on the eastern side of the Continental Divide and encompasses about 2,210 square miles (mi²) in central Colorado (fig. 1). Most of Park County is situated in the South Platte River Basin whereas a smaller area to the south is situated in the Arkansas River Basin. The terrain in Park County varies from a grass-covered plateau, encompassing much of the interior part of the county, to tree-covered mountains along the northern and western edges of the county. Land-surface altitude ranges from about 7,200 feet (ft) on the eastern edge of the county to more than 14,000 ft in the northwestern part of the county. Average annual precipitation ranges from about 10 to 40 inches and varies with altitude (Daly and Taylor, 1998). The lowest annual precipitation amounts occur in the vicinity of Hartsel (fig. 1), and the highest amounts occur along the Continental Divide in the western part of the county. Much of the precipitation in the higher attitudes is in the form of snow. On average, snow accumulates to more than 300 inches per year in the mountains north and west of Alma (Kimbrough, 2001).

Land cover in Park County is 53 percent natural herbaceous plants, grasses, and sedges (herbaceous rangeland at lower altitudes, tundra at higher altitudes); 39 percent forest (deciduous and evergreen); 5 percent alpine (mixture of tundra, snow, ice, and barren rock); 2 percent pasture or hay; and 1 percent open water (Kimbrough, 2001). Trees and shrubs also exist with the herbaceous land cover but generally account for less than 25 percent of the cover.

The estimated population of Park County in 2005 was 16,949 residents (<http://www.census.gov/popest/counties/tables/CO-EST2005-01-08.csv>, accessed May 30, 2007). This number is about eight times the number of people identified in 1970 (U.S. Bureau of the Census, 1982). Much of the population of Park County is located within subdivisions near the towns of Alma, Bailey, Fairplay, Guffey, Hartsel, and Lake George (fig. 1). Typically, house densities range from several houses per acre to a single house per many acres. Although the towns of Alma, Bailey, and Fairplay have public water-supply systems, these systems only serve a small segment of the population. In 2000, about 89 percent of the total population of Park County received their water from individual wells (Tamara Ivahnenko, U.S. Geological Survey, oral commun., June 21, 2006). The largest clusters of domestic supply wells in the South Platte Basin are located in subdivisions northeast of Bailey, near Alma and Fairplay, south of Jefferson, and southwest of Hartsel near the county line (fig. 1). Wells in the Arkansas River Basin are located primarily in the southeastern corner of the county from Guffey east to the county line (Kimbrough, 2001).

The surficial geology of Park County (fig. 2) ranges from unconsolidated alluvial deposits of Quaternary age to crystalline rocks of Precambrian age (Tweto, 1979; Klein and others, 1978). It consists of intrusive and extrusive igneous rocks and depositions of marine and terrestrial sediments. Periods of folding and faulting and erosion by glaciation and rivers collectively produced a very complex geologic setting. Detailed

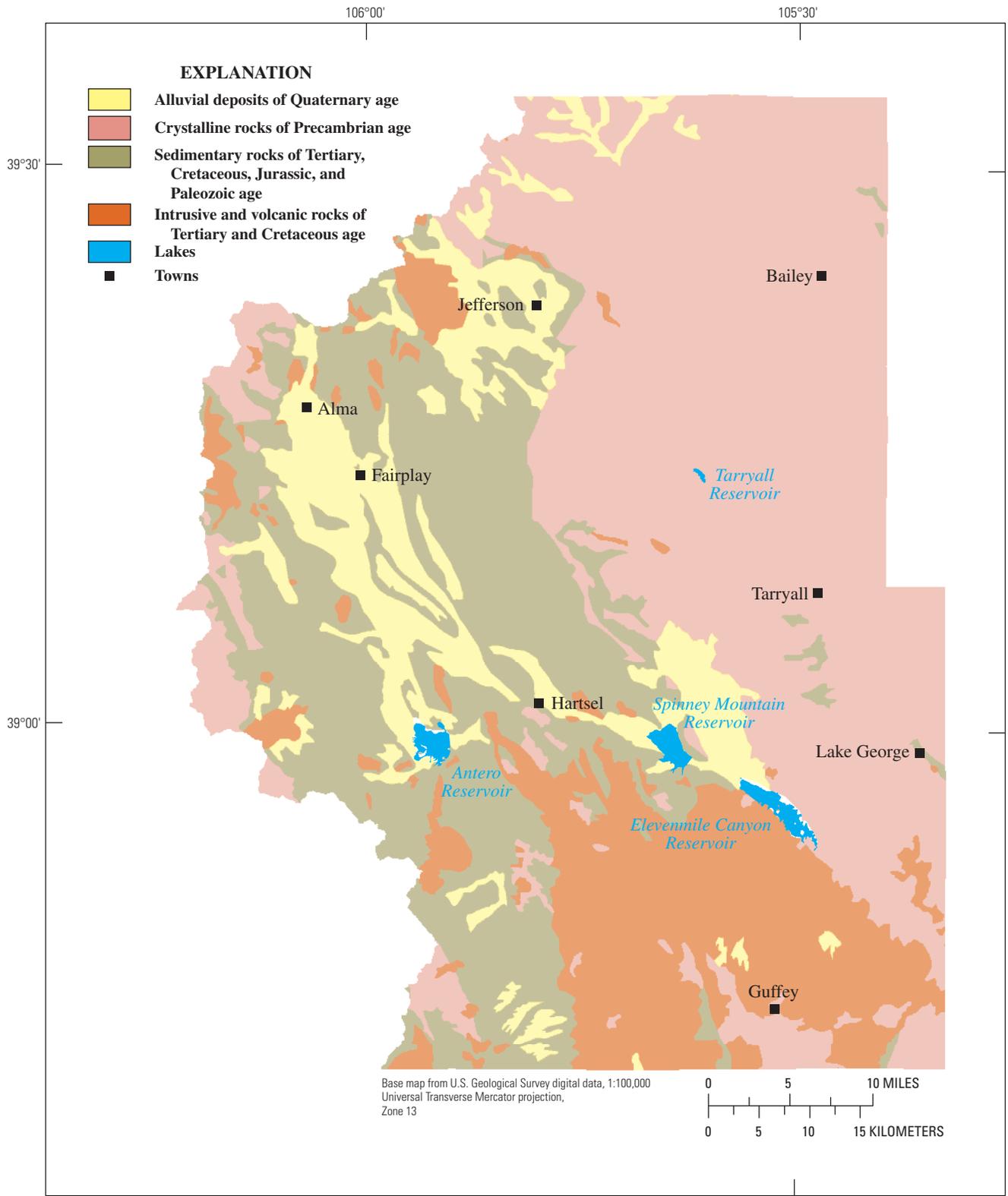
descriptions of the geology of Park County are provided by Tweto (1979) and Klein and others (1978). The four primary aquifer types in Park County are alluvial deposits of Quaternary age; crystalline-rock (metamorphic and granitic) of Precambrian age; sedimentary rock of Tertiary, Cretaceous, Jurassic, and Paleozoic age; and volcanic rock of Tertiary age (Klein and others, 1978).

Reported well yields from domestic wells are variable in Park County ranging from about 0.01 to about 140 gallons per minute (gal/min) with an average reported well yield of about 7.5 gal/min (Colorado Division of Water Resources, 2004). The variability in reported well yields depends on factors such as the aquifer properties and well construction. Reported well yields for wells sampled as part of this study ranged from about 0.3 to 96 gal/min with an average reported well yield of about 8.0 gal/min (Colorado Division of Water Resources, 2004).

Previous Studies

In the mid-1970's, the USGS completed a reconnaissance water-resources appraisal (surface water, ground water, and water quality) of Park County (Klein and others, 1978). This work was done in cooperation with the Colorado Water Conservation Board (CWCB) and the Pikes Peak Area Council of Governments (PPACG). Klein and others (1978) determined that, in general, ground water in the unconsolidated alluvial deposits, consolidated sedimentary rocks, and Precambrian crystalline rocks was of suitable quality for domestic supplies with several exceptions. Specifically, dissolved fluoride concentrations in several areas exceeded the Colorado Department of Health's (1971) recommended limits for drinking water. In particular, Klein and others (1978) indicated that water from wells completed in the Pikes Peak Granite north of Bailey tended to have a greater percentage of exceedances of Colorado Department of Health's recommended fluoride limits for drinking water than water from wells completed in other geologic formations. In addition, chemical analysis of water from the Precambrian crystalline rocks in northeast Park County indicated that some wells had elevated concentrations of nitrate.

In 2001, the USGS completed a retrospective assessment of water resources for Park County. As part of this effort, surface- and ground-water resource data from 1962–1998 were compiled and analyzed by Kimbrough (2001). This report indicated that (1) ground-water contamination may be occurring in some aquifers and may be associated with population growth and the resulting increase in ISDS's, and (2) broad-scale geographic and seasonal distribution of current ground-water-quality conditions in Park County were not available. In 2004, the ground-water quality in the alluvial, crystalline-rock, sedimentary-rock, and volcanic-rock aquifers in Park County was assessed in three separate USGS fact sheets (Brendle, 2004; Ortiz, 2004a, 2004b). The fact sheets provided a preliminary assessment of the potential effects of ISDS density on ground-water quality. Brendle (2004) and



Geology modified from Green (1992)

Figure 2. Surficial geology of Park County, Colorado.

Ortiz (2004a, 2004b) used private well density as a surrogate for ISDS density, because (1) lots that have a house and a well also have an ISDS, and (2) records for wells were more easily accessible. Brendle (2004) determined that, for wells completed in the crystalline-rock aquifers in the vicinity of Bailey, concentrations of nitrate, chloride, and boron tended to be higher in areas with higher ISDS densities than in areas with lower ISDS densities. Ortiz (2004a) determined that for wells completed in the volcanic-rock aquifers in the vicinity of Guffey, concentrations of chloride and boron tended to be higher in areas with higher ISDS densities than in areas with lower ISDS densities.

Acknowledgments

The authors thank the many residents of Park County who permitted access to and sampling from their wells. The authors also thank Tom Eisenman, Director of Park County Environmental Health Department, for his support and assistance in study design and selection of areas to be sampled; and Brenda Green, Park County, for compiling ISDS data for the Park County sample sites. These data greatly enhanced the ability to evaluate the potential effects of ISDS's on ground-water quality.

Study Approach

The general study approach was to identify and prioritize specific sampling areas within the alluvial, crystalline-rock, sedimentary-rock, and volcanic-rock aquifers in Park County and to collect water samples from domestic wells within these areas to characterize the spatial distribution of the ground-water quality in the four major aquifers. The focus of the study was to identify and describe the principal natural and human factors that affect ground-water quality and evaluate the relation of selected ground-water-quality contaminants with ISDS density, aquifer rock type, geography, and other hydrologic factors.

Well completion data were available for 223 of the 224 wells sampled (Colorado Division of Water Resources, 2004). For the purpose of this study, a well was identified by the aquifer-rock type within the open interval of the well. Nineteen wells were completed in the alluvial aquifers, 99 in the crystalline-rock aquifers, 70 in the sedimentary-rock aquifers, and 35 in the volcanic-rock aquifers. The surficial geology as shown in figure 2 does not necessarily correspond to the aquifer-rock type of all wells sampled; some wells penetrate rock types other than those identified as surficial based on location and (or) well depth. For example, several wells west of Jefferson (fig. 1) were completed in the crystalline rock even though the surficial geology (fig. 2) shows only sedimentary and alluvial rocks in this area.

The overall sampling plan, in part, was designed to allow an evaluation of whether the density of development (proximity of wells and ISDS's) was a significant factor in potential degradation of ground-water quality. The closeness

of neighboring wells and ISDS's varies depending on the size of the lots in each development. Hypothetically, there is a greater potential for degradation of ground-water quality as houses are built closer to each other and as the density of ISDS's increases.

Ground water from domestic wells (that is general residential with lawn/garden irrigation and domestic animal/livestock watering wells and residential household-use only wells) installed in the major aquifers in Park County was sampled from July 2001 through October 2004 as part of this study. During 2001 and 2002, the wells were sampled once each in the summer and fall to determine if there were detectable variations in water quality with time. Statistical tests indicated no significant differences between these samples, so only the fall samples were used in the data analysis in this report (Brendle, 2004). Radionuclide data collected by the USGS in the Bailey area also were included in this analysis, because radionuclide data were not collected in the Bailey area in 2001 (during this study).

Almost all wells were sampled for physical properties (water temperature, pH, and specific conductance), selected major ions, nutrients, bacteria, and boron (table 1). Selected wells also were sampled for dissolved organic carbon, specific human-related (wastewater) compounds, trace elements, radionuclides, and age-dating constituents (tritium and chlorofluorocarbons). The samples analyzed for human-related (wastewater) compounds were collected from most wells sampled in 2001 and from selected wells in 2002, 2003, and 2004. The presence of specific human-related compounds such as fecal indicators, caffeine, detergent metabolites, cholesterol, and pharmaceuticals or elevated concentrations of bacteria or chemicals in ground waters might indicate contamination of ground water from ISDS's.

All data are stored in the USGS National Water Information System (NWIS) database to aid in assessing current water-quality conditions and future trend and change analysis. Data used in this analysis can be obtained on the Web at URL <http://nwis.waterdata.usgs.gov/co/nwis/qwdata> (search on Park County, data type ground water, and the date range of September 1, 2000, through October 10, 2004).

Sample Collection and Processing

Ground-water samples were collected for analysis of physical properties, major ions, nutrients, dissolved organic carbon, and bacteria following procedures described in the USGS National Field Manual (Wilde and others, 1998). Wastewater compounds were collected using methods described in Brown and others (1999). Samples for radon were collected and processed using the standard method for radon in drinking water (ASTM International, 2006). Uranium samples were collected and processed following methods described by Faires (1993). Procedures used to collect and analyze samples for chlorofluorocarbons (CFC) are given in Busenberg and Plummer (1992) and Plummer and Busenberg (1999), and those for determination of tritium are given in Ekwurzel and others (1994) and Ludin and others (1998).

Table 1. Ground-water-quality sites and summary of ground-water-quality data for Park County, Colorado, 2001–2004

[USGS, U.S. Geological Survey; PP, physical properties; MI, major ions; N, nutrients; Bact, bacteria; B, boron; DOC, dissolved organic carbon; WW, wastewater organics; TE, selected trace elements; Rn, radon; U, Uranium; AD, age dating; --, data not available; ALLV, alluvial; CRY, crystalline; SEDT, sedimentary; VOLC, volcanic]

USGS site number	Sampling date (mm/dd/yy)	Well depth (feet below land surface)	Apparent aquifer type	PP	MI	N	Bact	B	DOC	WW	TE	Rn	U	AD
384411105345301	8/7/2003	150	CRYS	X	X	X	X	X	X					
384451105312101	8/2/2003	205	VOLC	X	X	X	X	X	X	X				X
384456105311601	8/11/2003	300	VOLC	X	X	X	X	X	X	X		X	X	
384457105311901	8/11/2003	130	VOLC	X	X	X	X	X	X	X		X	X	
384458105311601	7/31/2003	180	VOLC	X	X	X	X	X	X	X				
384500105352301	8/8/2003	250	VOLC	X	X	X	X	X	X					
384502105312301	8/9/2003	200	VOLC	X	X	X	X	X		X				
384503105311901	7/30/2003	140	VOLC	X	X	X	X	X	X	X		X	X	
384504105290701	8/1/2003	460	VOLC	X	X	X	X	X						
384504105353401	8/8/2003	150	VOLC	X	X	X	X	X						
384512105311001	7/30/2003	140	VOLC	X	X	X	X	X				X	X	
384513105311301	7/31/2003	75	VOLC	X	X	X	X	X						X
384513105311701	8/11/2003	120	VOLC	X	X	X	X	X	X	X		X	X	
384523105374801	8/7/2003	260	VOLC	X	X	X	X	X						
384528105290801	8/1/2003	240	VOLC	X	X	X	X	X	X					X
384538105284501	8/4/2003	180	VOLC	X	X	X	X	X				X	X	
384547105334601	10/6/2004	150	SEDT	X	X	X	X	X	X	X		X	X	X
384601105354701	8/9/2003	180	VOLC	X	X	X	X	X						
384602105345701	8/11/2003	160	CRYS	X	X	X	X	X	X			X	X	
384615105262201	8/6/2003	--	VOLC	X	X	X	X	X						X
384629105281101	7/30/2003	320	VOLC	X	X	X	X	X	X					
384637105260501	8/2/2003	203	VOLC	X	X	X	X	X	X	X				X
384639105262501	8/5/2003	128	VOLC	X	X	X	X	X				X	X	
384644105282401	8/9/2003	400	VOLC	X	X	X	X	X						
384703105262201	8/1/2003	62	VOLC	X	X	X	X	X	X	X				
384707105285701	7/30/2003	450	VOLC	X	X	X	X	X	X	X		X	X	
384711105290301	7/31/2003	325	VOLC	X	X	X	X	X						
384729105270501	8/4/2003	300	VOLC	X	X	X	X	X				X	X	X
384734105271901	8/4/2003	320	VOLC	X	X	X	X	X				X	X	
384738105290501	8/7/2003	420	VOLC	X	X	X	X	X						
384739105283901	8/9/2003	250	VOLC	X	X	X	X	X						
384743105210901	8/1/2003	600	CRYS	X	X	X	X	X						
384752105273401	8/4/2003	340	VOLC	X	X	X	X	X				X	X	
384839105364701	10/6/2004	20	VOLC	X	X	X	X	X	X	X		X	X	X
384841105283001	8/6/2003	250	VOLC	X	X	X	X	X						X
384855105281801	8/5/2003	280	VOLC	X	X	X	X	X				X	X	
384920105290401	8/5/2003	150	VOLC	X	X	X	X	X				X	X	
385001105531301	9/27/2004	220	SEDT	X	X	X	X	X						
385140105225001	7/22/2003	380	CRYS	X	X	X	X	X						

Table 1. Ground-water-quality sites and summary of ground-water-quality data for Park County, Colorado, 2001–2004.—Continued

[USGS, U.S. Geological Survey; PP, physical properties; MI, major ions; N, nutrients; Bact, bacteria; B, boron; DOC, dissolved organic carbon; WW, wastewater organics; TE, selected trace elements; Rn, radon; U, Uranium; AD, age dating; --, data not available; ALLV, alluvial; CRY5, crystalline; SEDT, sedimentary; VOLC, volcanic]

USGS site number	Sampling date (mm/dd/yy)	Well depth (feet below land surface)	Apparent aquifer type	PP	MI	N	Bact	B	DOC	WW	TE	Rn	U	AD
385203105230301	7/22/2003	260	CRYS	X	X	X	X	X						
385210105281501	8/5/2003	155	VOLC	X	X	X	X	X				X	X	
385250105242401	7/19/2003	240	CRYS	X	X	X	X	X						
385254105542201	9/21/2004	478	SEDT	X	X	X	X	X	X			X	X	X
385258105554301	9/24/2004	240	SEDT	X	X	X	X	X						
385303105243701	7/21/2003	--	CRYS	X	X	X	X	X	X					
385305105555901	9/27/2004	100	SEDT	X	X	X	X	X	X			X	X	X
385310105241001	7/21/2003	230	CRYS	X	X	X	X	X	X					
385310105555901	9/23/2004	202	SEDT	X	X	X	X	X						
385318105540501	9/21/2004	107	CRYS	X	X	X	X	X	X	X		X	X	X
385319105432601	10/6/2004	220	CRYS	X	X	X	X	X	X			X	X	X
385325105231101	7/22/2003	500	CRYS	X	X	X	X	X						
385332105572301	9/20/2004	80	SEDT	X	X	X	X	X						
385351105552501	9/23/2004	140	SEDT	X	X	X	X	X		X				
385352105411501	10/1/2004	150	VOLC	X	X	X	X	X						
385358105553601	9/21/2004	145	ALLV	X	X	X	X	X						
385406105544201	9/22/2004	88	SEDT	X	X	X	X	X		X				
385411105552301	9/27/2004	120	SEDT	X	X	X	X	X		X				
385411105553001	9/22/2004	180	SEDT	X	X	X	X	X	X	X		X	X	
385411105560501	9/20/2004	260	SEDT	X	X	X	X	X						
385412105572501	9/22/2004	340	SEDT	X	X	X	X	X	X			X	X	
385413105233501	7/21/2003	150	CRYS	X	X	X	X	X				X	X	
385415105413701	10/1/2004	100	SEDT	X	X	X	X	X						X
385416105545901	9/22/2004	120	SEDT	X	X	X	X	X						
385418105554701	9/20/2004	120	SEDT	X	X	X	X	X						
385427105240901	7/21/2003	320	CRYS	X	X	X	X	X	X	X		X	X	
385429105575201	9/23/2004	405	SEDT	X	X	X	X	X	X			X	X	X
385549105544701	9/23/2004	260	SEDT	X	X	X	X	X						
385607105293001	7/14/2003	180	CRYS	X	X	X	X	X	X	X		X	X	X
385616105293301	7/16/2003	160	CRYS	X	X	X	X	X	X					
385623105292301	7/15/2003	200	CRYS	X	X	X	X	X				X	X	
385631105291001	7/18/2003	150	CRYS	X	X	X	X	X	X	X				X
385651105283301	7/17/2003	100	CRYS	X	X	X	X	X						X
385704105282901	7/17/2003	175	CRYS	X	X	X	X	X						
385727105283701	7/16/2003	150	CRYS	X	X	X	X	X	X	X				
385808105303501	7/17/2003	168	CRYS	X	X	X	X	X	X	X				
385854105211701	7/18/2003	180	CRYS1	X	X	X	X	X	X					
385856105212301	7/18/2003	149	CRYS1	X	X	X	X	X	X					
385857105212601	7/22/2003	190	CRYS1	X	X	X	X	X				X	X	

Table 1. Ground-water-quality sites and summary of ground-water-quality data for Park County, Colorado, 2001–2004.—Continued

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USGS site number	Sampling date (mm/dd/yy)	Well depth (feet below land surface)	Apparent aquifer type	PP	MI	N	Bact	B	DOC	WW	TE	Rn	U	AD
390322105582901	9/28/2004	40	ALLV	X	X	X	X	X	X	X		X	X	X
390451105565401	10/1/2004	92	SEDT	X	X	X	X	X						
390526105533801	9/28/2004	180	SEDT	X	X	X	X	X	X			X	X	
390533106054901	9/24/2004	205	SEDT	X	X	X	X	X						
390610105574501	8/8/2002	4	--	X	X	X		X						
390625105531601	9/28/2004	160	SEDT	X	X	X	X	X	X			X	X	
390719105593201	10/4/2002	197	SEDT	X	X	X	X	X						X
390756105592301	9/29/2004	128	SEDT	X	X	X	X	X		X				
390813105593101	9/26/2002	160	SEDT	X	X	X	X	X	X					
390817106011401	10/8/2002	120	SEDT	X	X	X	X	X				X	X	
390819105584301	9/18/2002	135	SEDT	X	X	X	X	X	X					
390953106025801	9/26/2002	--	SEDT	X	X	X	X	X	X					
391022105571701	10/4/2004	60	ALLV	X	X	X	X	X						
391107105455501	9/16/2004	280	CRYs	X	X	X	X	X				X	X	
391144106013201	9/19/2002	150	ALLV	X	X	X	X	X						
391144106014801	9/25/2002	140	ALLV	X	X	X	X	X						X
391147106002901	9/24/2002	200	SEDT	X	X	X	X	X				X	X	
391207106014501	9/23/2002	165	ALLV	X	X	X	X	X				X	X	
391215106020001	9/24/2002	160	SEDT	X	X	X	X	X				X	X	
391218106020801	9/19/2002	140	SEDT	X	X	X	X	X						
391229105471901	9/17/2004	380	CRYs	X	X	X	X	X						
391233106022101	9/18/2002	160	SEDT	X	X	X	X	X	X					
391250106003701	9/25/2002	155	SEDT	X	X	X	X	X	X	X				
391306106013101	9/24/2002	130	ALLV	X	X	X	X	X	X	X		X	X	
391320106015201	9/28/2002	198	SEDT	X	X	X	X	X				X	X	X
391331106050001	9/23/2002	123	SEDT	X	X	X	X	X				X	X	
391334106025901	7/10/2002	183	SEDT	X	X	X	X	X						
391338105443301	10/5/2004	350	CRYs	X	X	X	X	X						
391338106010701	10/1/2002	--	ALLV	X	X	X	X	X						X
391340106033101	9/23/2002	220	SEDT	X	X	X	X	X			X	X	X	
391344106024701	9/19/2002	160	SEDT	X	X	X	X	X	X					
391346106023101	9/23/2002	80	ALLV	X	X	X	X	X	X	X				
391351105460301	9/15/2004	240	CRYs	X	X	X	X	X	X	X		X	X	X
391354105451001	9/13/2004	280	CRYs	X	X	X	X	X						
391356106054701	9/20/2002	102	SEDT	X	X	X	X	X						
391400106030401	9/29/2004	98	ALLV	X	X	X	X	X						
391405105431201	9/16/2004	600	CRYs	X	X	X	X	X						
391405106034101	10/8/2002	160	ALLV	X	X	X	X	X				X	X	
391407106062701	9/20/2002	110	CRYs	X	X	X	X	X	X	X	X			

Table 1. Ground-water-quality sites and summary of ground-water-quality data for Park County, Colorado, 2001–2004.—Continued

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USGS site number	Sampling date (mm/dd/yy)	Well depth (feet below land surface)	Apparent aquifer type	PP	MI	N	Bact	B	DOC	WW	TE	Rn	U	AD
391423106024501	10/10/2002	115	SEDT	X	X	X	X	X	X					
391425105465901	9/16/2004	255	CRYS	X	X	X	X	X		X				
391428105470701	9/15/2004	200	CRYS	X	X	X	X	X	X			X	X	
391434106023701	9/25/2002	115	ALLV	X	X	X	X	X				X	X	X
391437106025701	10/7/2002	75	ALLV	X	X	X	X	X				X	X	
391440106044901	10/10/2002	150	SEDT	X	X	X	X	X				X	X	
391445106041001	9/30/2002	130	SEDT	X	X	X	X	X	X					
391450105443701	9/15/2004	302	CRYS	X	X	X	X	X						
391455106032801	10/8/2002	140	SEDT	X	X	X	X	X						
391458106035701	10/9/2002	100	SEDT	X	X	X	X	X	X			X	X	
391500106023301	10/14/2002	195	SEDT	X	X	X	X	X						
391503105445001	9/17/2004	420	CRYS	X	X	X	X	X						
391504106013801	9/27/2002	220	SEDT	X	X	X	X	X	X					
391504106033201	10/14/2002	180	SEDT	X	X	X	X	X				X	X	X
391509106030701	10/5/2002	108	CRYS	X	X	X	X	X	X			X	X	
391513105464401	9/14/2004	485	CRYS	X	X	X	X	X	X			X	X	X
391525106014001	10/5/2002	252	SEDT	X	X	X	X	X				X	X	
391526106051301	10/7/2002	140	SEDT	X	X	X	X	X	X			X	X	
391527106021301	7/25/2002	125	SEDT	X	X	X	X	X						
391530106021301	10/14/2002	175	SEDT	X	X	X	X	X	X		X	X	X	
391531106003901	10/4/2004	126	CRYS	X	X	X	X	X						
391535105444101	9/14/2004	550	CRYS	X	X	X	X	X	X			X	X	
391536106024201	10/5/2002	175	SEDT	X	X	X	X	X						
391550106014501	9/28/2002	305	SEDT	X	X	X	X	X	X	X				
391629105433301	9/14/2004	100	CRYS	X	X	X	X	X	X	X		X	X	
391629106043801	10/4/2002	130	SEDT	X	X	X	X	X			X			
391629106044401	9/27/2002	120	SEDT	X	X	X	X	X	X	X	X			
391629106051601	10/11/2002	110	SEDT	X	X	X	X	X	X		X			
391632106044301	9/28/2004	100	SEDT	X	X	X	X	X		X				
391632106054201	10/10/2002	--	ALLV	X	X	X	X	X						
391638106042001	7/23/2002	105	SEDT	X	X	X	X	X						
391641106052901	10/3/2002	80	SEDT	X	X	X	X	X			X			X
391717105431501	9/16/2004	300	CRYS	X	X	X	X	X		X				
391742106042301	10/3/2002	50	CRYS	X	X	X	X	X			X	X	X	
391743106040101	10/9/2002	70	ALLV	X	X	X	X	X	X					
391747106041101	10/1/2002	140	SEDT	X	X	X	X	X	X					X
391820106040201	10/2/2002	--	SEDT	X	X	X	X	X				X	X	
391831106035301	9/28/2002	155	SEDT	X	X	X	X	X	X					
391852105533401	9/30/2004	100	SEDT	X	X	X	X	X		X				

Table 1. Ground-water-quality sites and summary of ground-water-quality data for Park County, Colorado, 2001–2004.—Continued

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USGS site number	Sampling date (mm/dd/yy)	Well depth (feet below land surface)	Apparent aquifer type	PP	MI	N	Bact	B	DOC	WW	TE	Rn	U	AD
391902105534101	9/29/2004	100	SEDT	X	X	X	X	X	X	X		X	X	X
391903106034901	10/7/2002	165	SEDT	X	X	X	X	X						
391911105534501	9/29/2004	80	SEDT	X	X	X	X	X		X				
391940106033401	9/26/2002	110	SEDT	X	X	X	X	X	X					
391947106033701	10/2/2002	195	SEDT	X	X	X	X	X	X	X				
392006106034101	9/27/2002	151	SEDT	X	X	X		X	X	X				
392031106033101	9/30/2002	50	ALLV	X	X	X	X	X	X					X
392035106033301	10/2/2002	--	ALLV	X	X	X	X	X	X		X			
392050105504301	9/30/2004	18	ALLV	X	X	X	X	X	X			X	X	X
392222105482701	9/30/2004	38	ALLV	X	X	X	X	X						X
392237105480601	9/30/2004	140	SEDT	X	X	X	X	X		X				
392250105492301	9/13/2004	125	CRYS	X	X	X	X	X						
392255105503801	9/13/2004	155	CRYS	X	X	X	X	X						
392427105252501	9/11/2001	221	CRYS	X	X	X	X	X						
392435105280901	9/13/2001	400	CRYS	X	X	X	X	X		X				
392437105244401	*9/10/2001	603	CRYS	X	X	X	X	X		X				
392439105251901	9/11/2001	452	CRYS	X	X	X		X		X				
392447105253501	9/11/2001	400	CRYS	X	X	X	X	X		X				
392448105253201	9/11/2001	275	CRYS	X	X	X	X	X		X				
392452105271401	9/12/2001	340	CRYS	X	X	X	X	X		X				
392453105245501	9/11/2001	575	CRYS	X	X	X	X	X		X				
392504105255401	9/12/2001	752	CRYS	X	X	X	X	X		X				
392517105281801	9/14/2001	295	CRYS	X	X	X	X	X		X				
392526105281101	9/13/2001	600	CRYS	X	X	X	X	X		X				
392527105243701	9/10/2001	183	CRYS	X	X	X	X	X		X				
392532105241801	9/10/2001	203	CRYS	X	X	X	X	X		X				
392533105272601	9/13/2001	220	CRYS	X	X	X	X	X		X				
392536105241701	9/18/2001	405	CRYS	X	X	X	X	X		X				
392536105273201	9/13/2001	200	CRYS	X	X	X	X	X		X				
392542105260501	9/12/2001	702	CRYS	X	X	X	X	X		X				
392613105245401	9/10/2001	250	CRYS	X	X	X	X	X		X				
392618105265801	9/12/2001	400	CRYS	X	X	X	X	X		X				
392633105252301	9/10/2001	220	CRYS	X	X	X	X	X		X				
392652105275601	9/13/2001	100	CRYS	X	X	X	X	X		X				
392659105255201	9/25/2001	100	CRYS ¹	X	X	X	X	X		X				
392712105284301	9/17/2001	270	CRYS	X	X	X	X	X		X				
392714105253001	9/12/2001	103	CRYS	X	X	X	X	X		X				
392830105273501	9/19/2001	700	CRYS ¹	X	X	X	X	X		X				
392832105275001	9/19/2001	400	CRYS ¹	X	X	X	X	X		X				

Table 1. Ground-water-quality sites and summary of ground-water-quality data for Park County, Colorado, 2001–2004.—Continued

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USGS site number	Sampling date (mm/dd/yy)	Well depth (feet below land surface)	Apparent aquifer type	PP	MI	N	Bact	B	DOC	WW	TE	Rn	U	AD
392833105281301	9/21/2001	700	CRYS ¹	X	X	X	X	X		X				
392834105245801	9/14/2001	275	CRYS ¹	X	X	X	X	X		X				
392840105241501	9/14/2001	503	CRYS ¹	X	X	X	X	X		X				
392843105283601	9/18/2001	680	CRYS ¹	X	X	X	X	X		X				
392855105280901	7/23/2001	130	CRYS ¹	X	X	X	X							
392857105241201	9/25/2001	125	CRYS ¹	X	X	X	X	X		X				
392857105283301	9/18/2001	283	CRYS ¹	X	X	X	X	X		X				
392905105275301	9/20/2001	124	CRYS ¹	X	X	X	X	X		X				
392916105290501	9/17/2001	265	CRYS ¹	X	X	X	X	X		X				
392923105273901	9/20/2001	203	CRYS ¹	X	X	X	X	X		X				
392923105313501	9/20/2001	250	CRYS ¹	X	X	X	X	X		X				
392925105313301	9/21/2001	200	CRYS ¹	X	X	X	X	X		X				
392926105284801	9/17/2001	200	CRYS ¹	X	X	X	X	X		X				
392933105282901	9/17/2001	550	CRYS ¹	X	X	X	X	X		X				
392939105314101	9/25/2001	400	CRYS ¹	X	X	X	X	X		X				
393010105242401	9/18/2001	324	CRYS ¹	X	X	X	X	X		X				
393011105311501	9/17/2001	85	CRYS ¹	X	X	X	X	X		X				
393014105314201	9/19/2001	500	CRYS ¹	X	X	X	X	X		X				
393017105313601	9/17/2001	305	CRYS ¹	X	X	X	X	X		X				
393019105262601	9/14/2001	340	CRYS ¹	X	X	X	X	X						
393030105324701	9/20/2001	320	CRYS ¹	X	X	X	X	X		X				
393037105305201	9/18/2001	480	CRYS ¹	X	X	X	X	X		X				
393039105311501	9/18/2001	400	CRYS ¹	X	X	X	X	X		X				
393040105310201	9/20/2001	310	CRYS ¹	X	X	X	X	X		X				
393041105300501	9/21/2001	175	CRYS ¹	X	X	X	X	X		X				
393046105310701	9/19/2001	385	CRYS ¹	X	X	X	X	X		X				
393047105295201	9/19/2001	180	CRYS ¹	X	X	X	X	X		X				
393054105263801	9/15/2001	240	CRYS ¹	X	X	X	X	X		X				
393054105314101	9/24/2001	450	CRYS ¹	X	X	X	X	X		X				
*392527105243701	10/12/2002	183	CRYS											X
*392533105272601	10/15/2002	220	CRYS											X
*392830105273501	10/15/2002	700	CRYS ¹											X
*392939105314101	10/11/2002	400	CRYS ¹											X
*393030105324701	10/14/2002	320	CRYS ¹											X

*Well resampled for age-dating constituents.

¹Well completed in the Pikes Peak Granite.

Analytical Methods

Water samples were analyzed for various chemical groups including major ions, nitrogen species, phosphorus species, and radiochemical constituents following procedures outlined by Fishman (1993) and Faires (1993). Additionally, water samples at selected wells were analyzed for an extensive list of organic chemicals that are assumed to be indicative of contamination from ISDS effluent using methods described by Zaugg and others (2002). Analyses of the aforementioned constituents were done at the USGS National Water Quality Laboratory in Denver, Colorado. Tritium samples were analyzed at the USGS Isotope Research Laboratory in Menlo Park, California. CFC samples were analyzed at the USGS Chlorofluorocarbon Laboratory in Reston, Virginia.

Quality Control

Quality-control samples collected in the field included 18 blank and 19 replicate samples. About 14 percent (37 of 261) of the water-quality samples collected during this study (2001–2004) were quality-control samples. Field blanks were collected and analyzed to test for sample bias from contamination. Field blanks are discussed in detail in the following paragraphs. Replicate samples were collected to estimate variability in the environmental data. Replicate samples showed little variability in environmental data. Spike samples were not collected during this study. However, mean percent recoveries for laboratory spikes from 2001–2004 for the wastewater compounds ranged from 4 to 106 percent with a mean percent recovery of 81 percent (Quality control data provided by the National Water Quality Laboratory, U.S. Geological Survey, written commun., 2007).

Calcium, magnesium, sulfate, nitrite-plus-nitrate, dissolved organic carbon, and boron were detected in one or more field blanks usually at or below the laboratory reporting level. Concentrations of calcium, magnesium, and sulfate in the environmental samples were at least one order of magnitude higher than concentrations in blank samples; therefore, concentrations of these constituents in field blanks were small relative to the concentrations in environmental samples and did not affect reported environmental concentrations. Concentrations of nitrite-plus-nitrate and dissolved organic carbon in field blanks were reported below the laboratory reporting levels. Nitrite-plus-nitrate was detected only in 1 of the 11 field blanks analyzed for nitrite-plus-nitrate, whereas organic carbon was detected in 2 of the 4 field blanks analyzed for organic carbon. Because nitrite-plus-nitrate was detected in only one sample (collected during 2001), reported environmental concentrations of nitrite-plus-nitrate probably are not substantially affected by contamination. Environmental samples with reported concentrations of dissolved organic carbon near the laboratory reporting level may be periodically affected by trace amounts of sample contamination. Trace quantities of organic carbon in field blanks did

not substantially affect the assessment of environmental data collected, because multiple lines of evidence were used to determine if human activities have an effect on ground-water quality in Park County. Potential sources of organic carbon in field blanks may include plasticizers in tubing or bottles and (or) blank water used to collect samples.

Wastewater compounds, including 4-nonylphenol (4-NP), acetophenone, benzophenone, DEET, diethoxynonylphenol, isophorone, methyl salicylate, phenol, and tris(2-butoxyethyl) phosphate, were detected in one or more field blanks usually at or below the laboratory reporting level. However, acetophenone and methyl salicylate were not detected in environmental samples. Potential sources of wastewater compounds in blanks could be field personnel (fragrances, DEET), the field environment (dust, fumes), sample bottles, sample transport, or the laboratory environment, or the blank water used for field blanks may have contained the compounds. DEET, diethoxynonylphenol, methyl salicylate, and tris(2-butoxyethyl) phosphate only were detected once (one of eight) in field blanks, and 4-NP, benzophenone, and isophorone only were detected twice (two of eight) in field blanks. Trace quantities of these compounds in field blanks did not substantially affect the assessment of environmental data collected. The most frequently detected wastewater compound in field blanks that also was detected in environmental samples was phenol. Phenol was detected in three out of eight field blanks. Zaugg and Leiker (2006) suggest that phenol sample data should be interpreted cautiously because of the frequent detections in field and laboratory blank samples at concentrations that are important relative to reported environmental concentrations. In total, phenol was detected in 26 environmental samples. In 20 of the 26 samples, 1 or more additional wastewater compounds also were detected. This indicates that the presence of phenol in these samples is probably not the result of field or laboratory contamination but that phenol may be present in the ground water in some areas of Park County. Consequently, the trace quantities of phenol that were sporadically detected in blank samples were determined not to affect the assessment of environmental data collected.

Data Analysis Methods

To determine the approximate time elapsed since recharge (apparent recharge date of the ground water) and thus the potential for a given sample to be affected by development, ground-water samples were collected from selected wells in the alluvial, crystalline-rock, sedimentary-rock, and volcanic-rock aquifers throughout Park County and analyzed for tritium and CFC's. Tritium is used as an age-dating tracer because atmospheric nuclear bomb testing beginning in 1954 produced relatively large concentrations of tritium in the atmosphere (Kendall and McDonnell, 1998). Concentrations of tritium greater than 10 picocuries per liter (pCi/L), or about 30 tritium units (TU), indicate that at least a part of the recharge to the ground-water system occurred after 1954

(Kendall and McDonnell, 1998). Concentrations of tritium do not definitively yield the apparent recharge date of the water in a sample but must be used with other age-dating chemicals such as CFC's to refine the recharge date estimate. Commercial production of CFC's began in 1930. CFC's gradually replaced older refrigerants in cooling devices. After the mid-1940's, CFC's became the preferred aerosol propellants and were widely used as solvents, degreasers, and as blowing agents for plastic foam (Plummer and others, 2006). Concentrations of tritium and CFC's in the atmosphere over time are shown in figures 3A and 3B. Concentrations of CFC's in the atmosphere have increased steadily from the 1940's through the early 1990's (fig. 3B). To determine the apparent ground-water recharge date based on CFC concentrations, ground water is assumed to be in solubility equilibrium with the air in the unsaturated zone (the zone between the land surface and the water table) at the time of recharge (Plummer and others, 2006). The apparent ground-water recharge date can be estimated by comparing the calculated partial pressures of CFC's in solubility equilibrium with the water sample with the historical CFC concentrations in local air (Plummer and others, 2006). Ground-water samples were analyzed for CFC-11, CFC-12, and CFC-113. Multiple CFC compounds (CFC-11, CFC-12, and CFC-113) are analyzed to aid in determining the apparent ground-water recharge date of a sample because each CFC compound has a unique concentration over time (fig. 3B).

CFC-based recharge dates were determined assuming no dilution by mixing or delay by interaction with aquifer materials, which are common processes for constituents moving with ground water. Because water that is pumped from a well is a mixture of the waters from all the flow lines reaching the discharge point, water samples from wells with relatively narrow open (screened) intervals will tend to have apparent recharge dates that are less affected by mixing than those samples from wells with large open intervals. Open intervals in wells sampled in Park County ranged from about 10 to about 300 ft based on available well-log data. Because of the large open intervals in many of the wells sampled, apparent ground-water recharge dates probably have been affected by mixing of water of different ages. Apparent ground-water recharge dates, based on CFC concentrations, for Park County samples were determined by the USGS Chlorofluorocarbon Laboratory in Reston, Virginia.

The maximum, minimum, median, and 10th, 25th, 75th, and 90th percentile values were computed for each constituent analyzed with the exception of the wastewater compounds, because of the small number of detections per constituent. These basic descriptive statistics were done for radionuclide data using data collected from September 2000 through October 2004, and basic descriptive statistics for the remaining constituents were done using data collected from July 2001 through October 2004.

Boxplots were generated to show simple graphical summaries of selected data sets (that is constituents) and to compare data sets based on ISDS density, aquifer type, and year of ISDS installation. Boxplots are useful because the variability

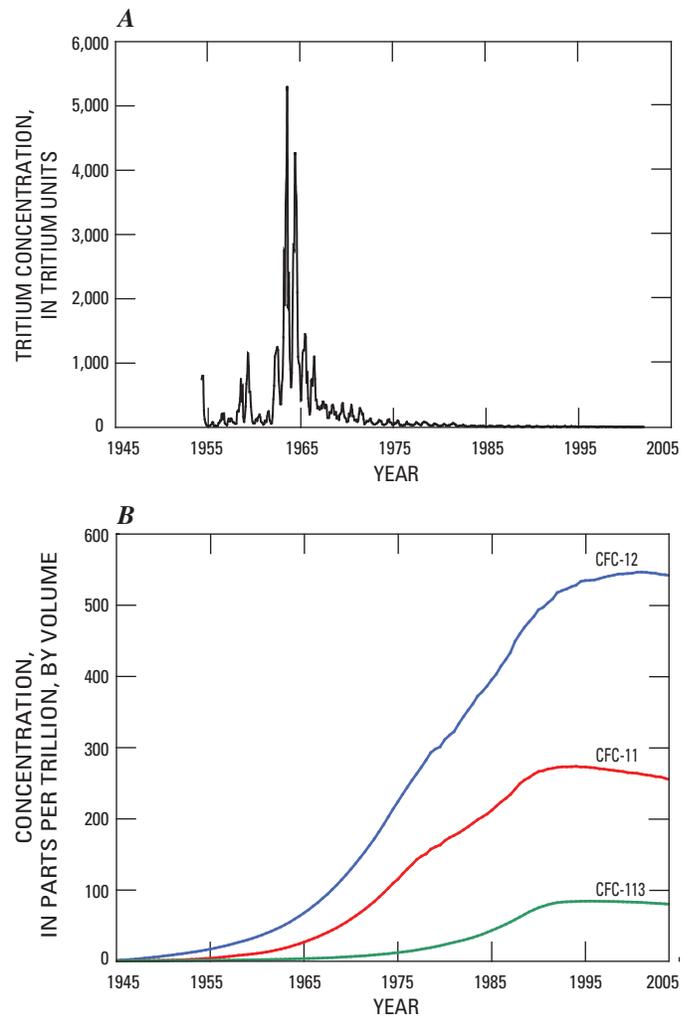


Figure 3. (A) Estimated concentrations of tritium in precipitation near Park County, Colorado (International Atomic Energy Agency, 2004), and (B) atmospheric concentrations of CFC-11, CFC-12, and CFC-113 in air in North America (http://water.usgs.gov/lab/software/air_curve/, accessed February 22, 2007).

between data sets, unusual values, and selected summary statistics are easily observed. The horizontal line within the box represents the median value (50 percent of the data are larger than this value and 50 percent of the data are less than this value). The lower horizontal line of the box is the 25th percentile or lower quartile (25 percent of the data are less than this value). The upper horizontal line of the box is the 75th percentile or upper quartile (75 percent of the data are less than this value). The interquartile range (IQR) contains the values between the 25th and 75th percentiles and is the difference between the 25th and 75th percentiles. The bottom of the vertical line on the boxplot is the smallest value within 1.5 times the IQR of the box. The top of the vertical line on the boxplot is the largest value within 1.5 times the IQR of the box. Outside values are greater than 1.5 times the IQR from the box and outlier values are greater than 3 times the IQR from the box. An example of a boxplot is shown in figure 4.

Data, collected as part of this study, were compared to U.S. Environmental Protection Agency (USEPA) primary and secondary drinking-water standards (U.S. Environmental Protection Agency, 1999b, 2002a) to assess the general quality of the ground water in the study area for domestic use. However, the primary and secondary drinking-water standards only apply to public water systems that provide water to at least 15 connections or 25 persons at least 60 days out of the year (most cities and towns, schools, businesses, campgrounds, and shopping malls are served by public water systems).

National Primary Drinking Water Regulations (NPDWR's or primary standards) are legally enforceable standards that apply to public water systems. Primary standards protect public health by limiting the levels of contaminants in drinking water. National Secondary Drinking Water Regulations (NSDWR's or secondary standards) are nonenforceable guidelines regulating contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water. The USEPA recommends secondary standards to water systems but does not require systems to comply (<http://www.epa.gov/safewater/contaminants/index.html#listsec>, accessed June 27, 2006).

To explore the potential human effects, particularly effects of ISDS's, on ground-water quality the occurrence/co-occurrence of selected constituents (that is nitrate, ammonia, chloride, total coliform, *E. coli*, boron, and wastewater compounds) associated (in part) with ISDS effluent were examined. The relations between these constituents and ISDS density, average lot size in surrounding area, aquifer type, year of ISDS installation, and other data were evaluated using the nonparametric Wilcoxon Mann-Whitney test (SYSTAT Software, Inc., 2004). Nonparametric analysis allows the user

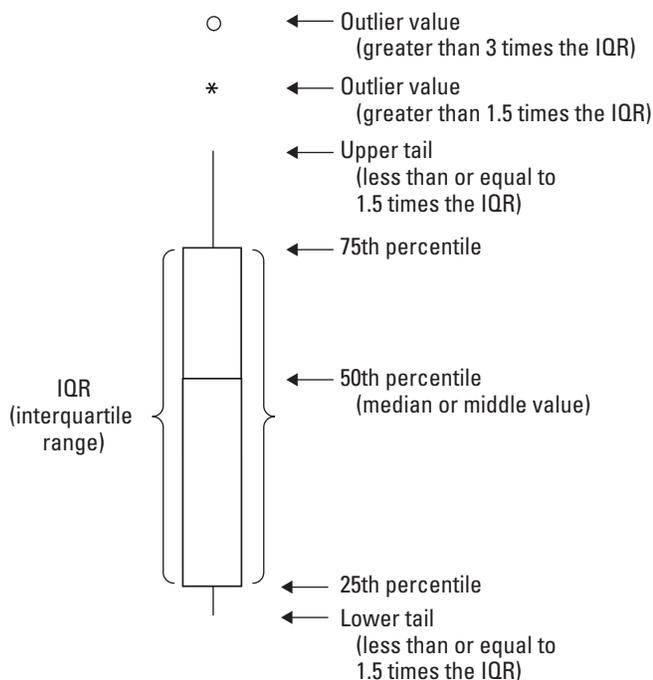


Figure 4. Explanation of a boxplot.

to analyze data without assuming an underlying distribution. The Wilcoxon Mann-Whitney test is a nonparametric test used to compare two populations (data sets). Specifically, it is used to test the null hypothesis that two data sets have identical distribution functions against the alternative hypothesis that the two distribution functions differ only with respect to location (median), if at all. For the purpose of this study, the null hypothesis is the statistical hypothesis that there is no difference in constituent concentrations between data sets. The p-value is the probability of wrongly rejecting the null hypothesis (no difference between data sets) if it is in fact true. Small p-values indicate that the null hypothesis is unlikely to be true. In other words, small p-values indicate that differences between the two data sets likely exist. Differences between data sets were determined to be significant when the p-value was 0.05 or smaller.

Quality of Ground Water

A focus of this study was to identify and describe the principal natural and human factors that affect ground-water quality throughout Park County. Knowledge of the approximate time elapsed since recharge (age of ground water) helps to understand the processes that affect ground-water quality and the potential for ground water to be affected by human activities such as wastewater discharge (ISDS effluent) and runoff from urban areas. The longer the water is in contact with soils and aquifer material, the more time there is for dissolution of minerals and time for sorption and ion exchange processes. In addition, if samples represent recharge to the aquifer that occurred prior to development, effects of ISDS's will not be detected in ground-water-quality samples. Therefore, it may not be possible to determine if ISDS's are affecting or will affect ground-water quality in the future. If samples represent recharge that has occurred since development, however, the effects of ISDS's on ground-water quality may be observed.

Age of Ground Water

Samples from selected wells throughout Park County were analyzed for tritium and CFC's to determine the approximate time elapsed since recharge. Tritium concentrations greater than 10 pCi/L in a sample indicate that at least some part of the recharge to the ground-water system occurred after 1954 (Kendall and McDonnell, 1998). Tritium concentrations were greater than 10 pCi/L in about 75 percent of the samples collected from wells in Park County. The highest tritium concentrations in precipitation were measured during the early to mid-1960's (fig. 3A). Tritium concentrations for Park County (fig. 3A) were estimated using data collected throughout North America (International Atomic Energy Agency, 2004). Ground-water recharge was assumed to be mostly from snowmelt; as a result, only tritium concentrations in precipitation

from October through March (winter months) were used to estimate annual tritium values for Park County. Current (2004) concentrations of tritium in precipitation in Park County probably are between 6 and 10 pCi/L (International Atomic Energy Agency, 2004). Consequently, tritium concentrations between 6 and 10 pCi/L may indicate ground-water recharge dates prior to about 1960 or more recent recharge since about the mid-1990's. Only one sample, collected from a well in the volcanic-rock aquifer, had a tritium concentration between 6 and 10 pCi/L. Overall the highest tritium concentrations were measured in wells completed in the alluvial and crystalline-rock aquifers, and the lowest concentrations were measured in wells completed in the sedimentary and volcanic-rock aquifers (fig. 5A).

Based on CFC data, ground-water recharge dates in Park County range from the mid-1940's to modern water. In other words, the ground-water recharge age (based on CFC data) is between zero and about 60 years old (fig. 5B and fig. 6). Based on CFC and tritium data, wells completed in the sedimentary-rock aquifers tended to have older waters than wells completed

in the other aquifer-rock types (alluvial, crystalline, and volcanic) (fig. 5B) indicating that one or more of the following conditions occur: (1) infiltration of water through the sedimentary rocks is slower than other formations, (2) the ground-water flow paths are longer, or (3) that ground-water flow velocities are slower.

Many of the wells sampled in Park County probably have a mixture of water from several parts of the aquifer system that may have different recharge areas, flow paths, and ground-water recharge dates. Given that most of the development in Park County has occurred since 1990 and only about 8 percent of wells (3 of 38) sampled for CFC's had ground-water recharge dates since 1990 (fig. 6), there may not have been enough time elapsed for effluent water from ISDS's to noticeably affect sampled ground-water quality. About 47 percent of wells sampled for age-dating constituents and wastewater compounds had detectable quantities of wastewater compounds. However, concentrations of wastewater compounds were generally low (near the laboratory reporting level). Detections of wastewater compounds in ground water indicate that these compounds are

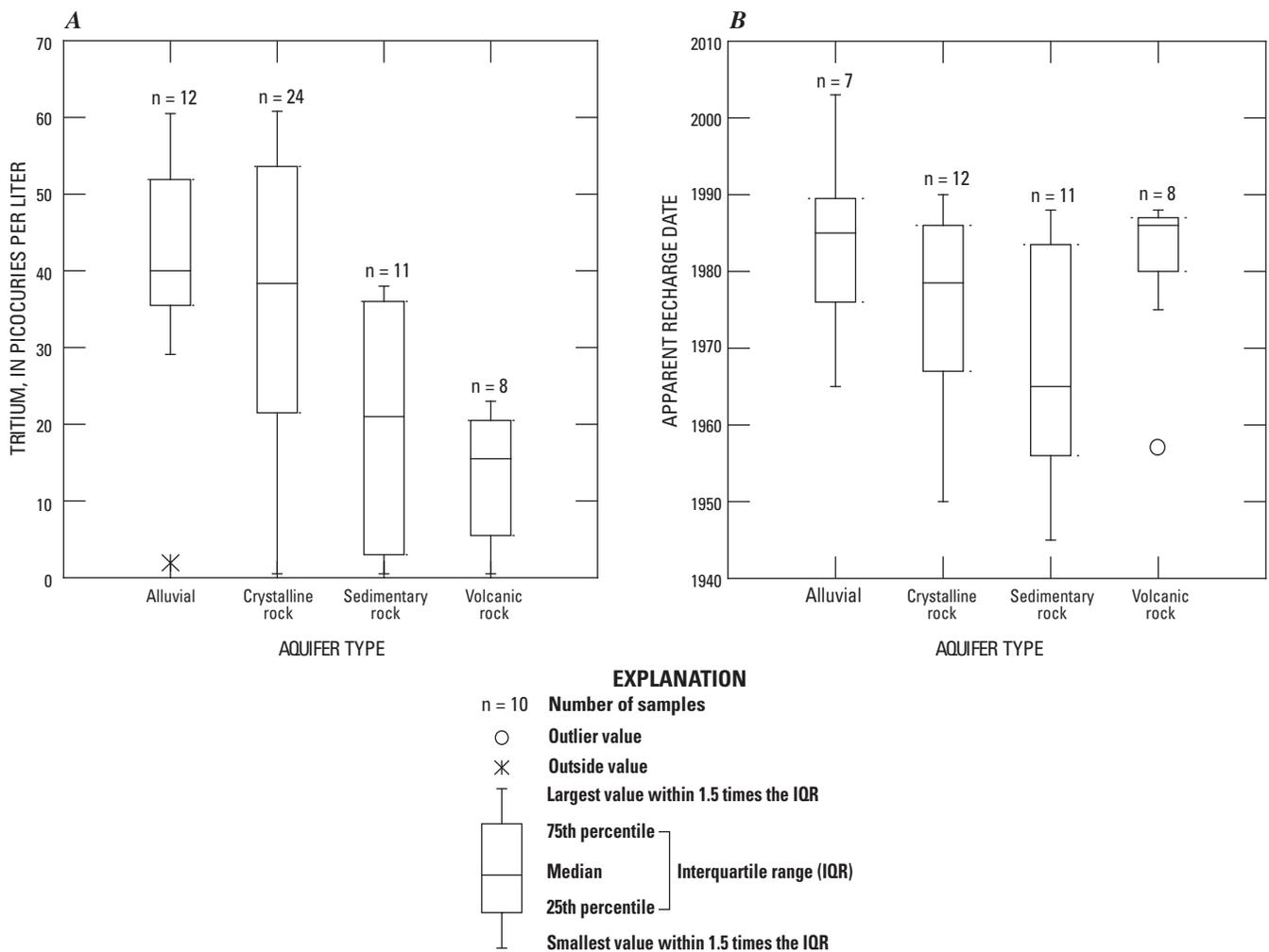
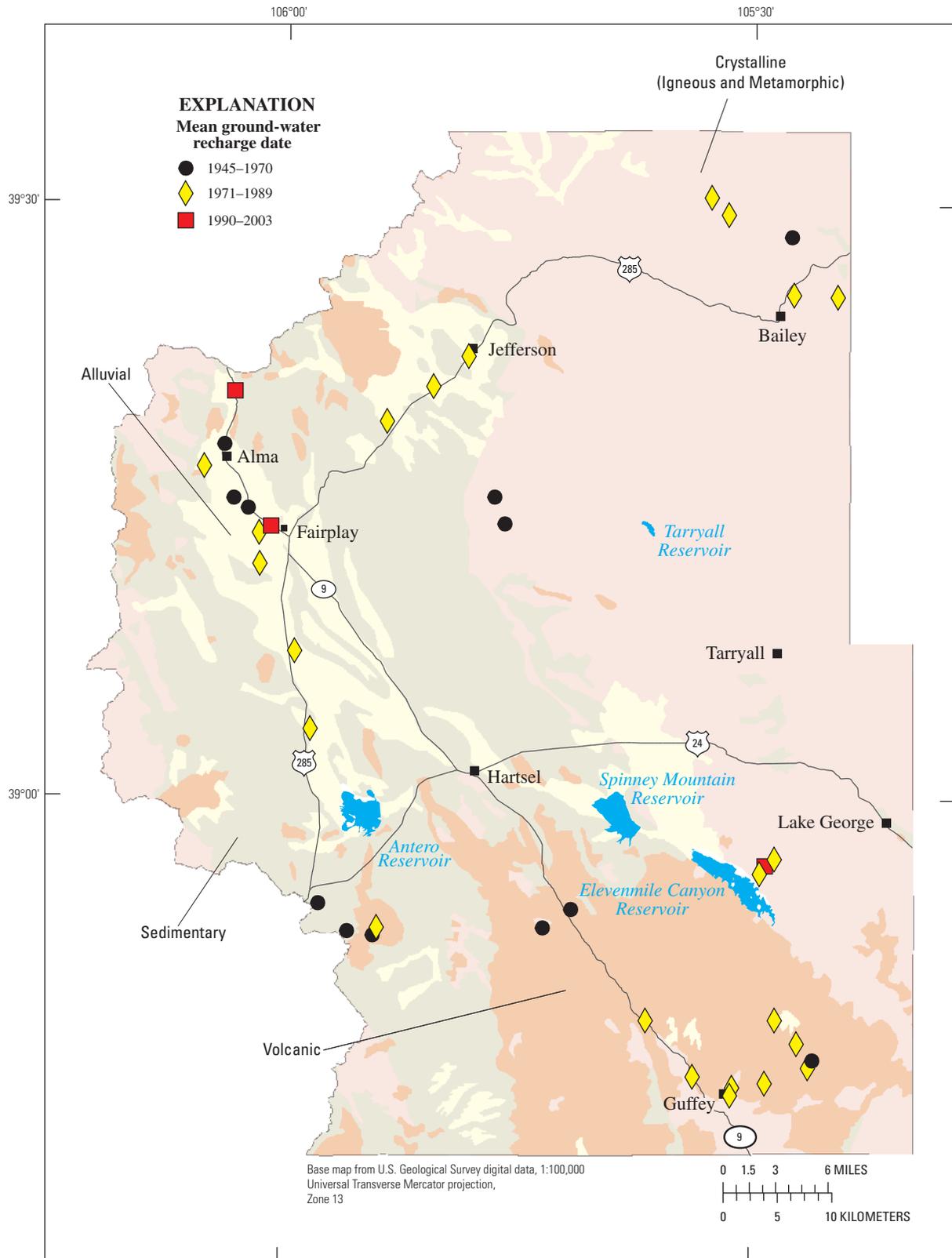


Figure 5. Distribution of (A) tritium concentrations and (B) approximate recharge dates based on chlorofluorocarbon data for alluvial, crystalline-rock, sedimentary-rock, and volcanic-rock aquifers throughout Park County, Colorado, 2001–2004.



Note: Wells may be completed in rock type other than the surficial geology shown on this figure.

Figure 6. Approximate ground-water recharge date based on CFC concentrations in selected wells in Park County, Colorado, 2001–2004.

not being completely removed by ISDS's or the unsaturated zone. Because roughly 90 percent of domestic water used is assumed to be recharged by ISDS's (Van Slyke and Simpson, 1974), detections of wastewater compounds in ground water in Park County are not surprising. As time passes, it is likely that recharge from ISDS's may become a larger part of the ground-water resource.

Natural Factors Affecting Drinking-Water Quality in Park County

Ground-water quality in Park County is affected by natural factors resulting from the interaction of water with the soil and mineralogy of the various geologic formations as it infiltrates to the water table in addition to human factors. Ground-water samples were analyzed for many constituents as part of this study (2001–2004); however, the following discussion is limited to those constituents that exceeded national primary and (or) secondary drinking-water standards (U.S. Environmental Protection Agency, 1999b, 2002a) most likely as a result of natural geologic factors. Secondary drinking-water standards for pH, fluoride, sulfate, and dissolved solids (DS) and primary drinking-water standards for fluoride and uranium were equaled or exceeded in one or more samples collected from domestic wells in Park County (table 2). Concentrations of radon-222 (referred to as radon hereafter) in some wells exceeded the proposed drinking-water regulations (U.S. Environmental Protection Agency, 1999a). The occurrence and sources of pH, fluoride, sulfate, DS, uranium, and radon in ground-water samples are discussed in the following paragraphs.

pH

Only about 2 percent (5 of 224) of pH values measured were outside of the national secondary drinking-water regulation's secondary maximum contaminant level (SMCL) range for pH of 6.5 to 8.5 established by the U.S. Environmental Protection Agency (2006, 1999b). Values of pH less than 6.5 standard units were measured only in wells in the Pikes Peak Granite (crystalline-rock aquifer) in the vicinity of Bailey (fig. 7B). However, not all samples from wells in the Pikes Peak Granite were less than 6.5: pH values ranged from 5.9 to 8.4 standard units in samples from these wells (fig. 7A, B). Low pH values in some wells may indicate that ground-water flow (or perhaps recharge) is more rapid and has less contact time with geologic units, in certain areas of the Pikes Peak Granite. This may occur because of thinner soils and (or) a higher percentage of fractures to transport water. In these areas, the pH of the ground water may be closer to the pH of the precipitation that recharges the aquifer. The pH in precipitation in Colorado typically ranges from about 4.7 to 5.9 standard units (National Atmospheric Deposition Program, 2007). A pH of 8.7 was measured in one well in the volcanic-rock aquifer near Guffey (fig. 7B). High pH in certain types of volcanic rocks has been well documented in parts of the Western United States and Argentina (Welch, 2001; Spencer, 2002).

When pH decreases to less than 6.5, water becomes more corrosive and has a bitter metallic taste. Corrosion of pipes, distribution lines, and well casings becomes more substantial at a pH of less than 6.5. Values of pH greater than 8.5 can cause aesthetic problems such as a soda taste, slippery feel, buildup of scale on pipes and fixtures that can lead to lower water pressure, and deposits on dishes, utensils and laundry basins.

Fluoride

The USEPA has set primary and secondary drinking-water standards for fluoride of 4.0 and 2.0 mg/L, respectively. Only one well, completed in the Pikes Peak Granite, near Lake George, exceeded the primary drinking-water standard for fluoride of 4.0 milligrams per liter (mg/L). Concentrations of fluoride in about 12 percent (27 of 224) of the samples exceeded the secondary drinking-water standard of 2.0 mg/L (fig. 8A, B). Long-term exposure to drinking-water concentrations of fluoride greater than 4.0 mg/L may result in serious bone disorders (U.S. Environmental Protection Agency, 2002a). Excess fluoride exposures at concentrations greater than 2.0 mg/L during the formative period prior to tooth eruption may cause tooth discoloration and (or) pitting.

Fluoride (or fluorine) occurs in igneous and sedimentary rock. Concentrations of fluoride measured in wells in Park County ranged from less than 0.2 to 4.0 mg/L (fig. 8A, B and table 2). Generally the highest fluoride concentrations were measured in samples collected from wells completed in the crystalline-rock aquifers, and the lowest concentrations were measured in samples collected from wells completed in the alluvial aquifers. Ground water containing fluoride concentrations exceeding 1 mg/L occurs in many places in the United States, in a wide variety of geologic settings. Specifically, Hawley and Wobus (1977) determined fluorine was abundant in minerals in the Pikes Peak Granite, located primarily in eastern Park County. Fluoride concentrations were greater than 1 mg/L in about 97 percent (34 of 35) of samples collected (during this study) from wells completed in the Pikes Peak Granite, and about 71 percent (25 of 35) were equal to or greater than 2.0 mg/L (fig. 8). All samples with fluoride concentrations equal to or greater than 2.0 mg/L were collected from wells completed in the crystalline-rock aquifers near Bailey and Lake George (fig. 8B); 93 percent of these samples were collected from wells completed in the Pikes Peak Granite. Concentrations of fluoride in wells completed in the alluvial, sedimentary-rock, and volcanic-rock aquifers generally were less than 0.5 mg/L.

Sulfate

Sulfates are a combination of sulfur and oxygen and are part of naturally occurring minerals in some soil and rock formations that contain ground water. Sulfur is widely distributed in reduced form in igneous and sedimentary rocks as metallic sulfides. When sulfide minerals undergo weathering in contact with aerated water, the sulfur is oxidized to sulfate ions that go

Table 2. Summary of selected ground-water-quality data for Park County, Colorado, 2000–2004.

[CFC, chlorofluorocarbon; <, less than; °C, degrees Celsius; µS/cm, microsiemens per centimeter; cols/100 mL, colonies per 100 milliliters; mg/L, milligrams per liter; pCi/L, picocuries per liter; µg/L, micrograms per liter; gal/min, gallons per minute; picograms per kilogram, pg/kg; CaCO₃, calcium carbonate; E, estimated value; M, constituent measured but not quantified; --, not applicable]

Constituent or property	Number of analyses	Minimum	Concentration or value at indicated percentile					Maximum	Standard or guideline ¹
			10%	25%	50%	75%	90%		
Physical properties									
pH, standard units	224	5.9	6.8	7.2	7.5	7.8	8.0	8.7	² 6.5–8.5
Specific conductance, µS/cm	224	86	185	233	340	483	731	3,070	--
Water temperature, °C	224	4.5	5.7	7.0	8.7	10.0	11.0	14.8	--
Dissolved oxygen, mg/L	196	0	0.3	0.8	3.9	6.2	7.8	9.7	--
Major ions and dissolved solids, in mg/L									
Bicarbonate, dissolved	215	4	75	127	184	254	319	623	--
Calcium, dissolved	165	6.17	26.1	33.6	44.8	60.3	87.9	684	--
Chloride, dissolved	224	0.28	1.01	1.80	3.59	6.84	12.8	873	² 250
Fluoride, dissolved	224	<0.2	<0.2	0.2	0.3	0.8	2.2	4.0	² 2.0 and ³ 4.0
Magnesium, dissolved	165	0.56	4.43	6.52	15.5	27.0	48.0	195	--
Potassium, dissolved	165	<0.16	0.62	0.87	1.24	2.01	3.92	8.05	--
Sodium, dissolved	165	0.73	2.49	4.05	9.74	17.9	39.5	219	--
Sulfate, dissolved	220	2.4	5.8	10.2	18.0	36.3	105	1,760	² 250
Dissolved solids	158	49	124	158	202	299	496	2,810	² 500
Nutrients and organic carbon, in mg/L									
Ammonia	224	<0.04	<0.04	<0.04	<0.04	<0.04	E 0.02	2.04	--
Nitrate	6	0.21	0.21	0.24	0.53	0.79	1.40	1.47	³ 10
Nitrite plus nitrate	224	<0.06	<0.06	E 0.04	0.34	1.18	3.54	25.7	--
Nitrite	224	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.28	³ 1
Orthophosphate	224	<0.02	<0.02	<0.02	<0.02	E 0.01	0.06	0.34	--
Phosphorus	223	<.006	<.006	<.006	E 0.004	0.017	0.062	0.37	--
Organic carbon	70	0.2	0.3	0.5	0.7	1.2	1.7	7.5	--
Bacteria, in colonies/100 mL									
<i>Escherichia coli</i>	220	<1	<1	<1	<1	<1	<1	1	zero
Total coliform	220	<1	<1	<1	<1	<1	1	E 340	zero
Trace elements, in µg/L									
Aluminum, dissolved	9	<20	<20	<20	<20	<20	<20	<20	² 50 to ² 200
Arsenic, dissolved	9	<2	<2	<2	<2	<2	2.6	3	³ 10
Boron, dissolved	223	<13	6.1	11	16	26	61	574	--
Cadmium, dissolved	9	<8	<8	<8	<8	<8	<8	<8	³ 5
Copper, dissolved	9	<6	<6	<6	<6	5.2	11	13	² 1,000 and ³ 1,300
Iron, dissolved	9	<10	<10	<10	75	334	648	810	² 300
Manganese, dissolved	9	<2	<2	<2	7.8	16	26	30.8	² 50
Zinc, dissolved	9	<24	<24	<24	<24	<24	197	317	² 5,000
Other constituents or properties									
Alkalinity, mg/L as CaCO ₃	215	3	61	104	152	209	262	511	--
Hardness, mg/L as CaCO ₃	165	19	87	120	180	252	400	2,500	--
Radon, pCi/L	⁴ 77	40	314	805	1,670	3,952	6,854	19,200	--
Uranium, µg/L	⁴ 80	<1	<1	1.85	2.93	6.12	11.2	48	³ 30
Well depth, feet below land surface	217	4	100	130	180	296	444	752	--
Well yield, gal/min	207	0.3	2	4	7	10	15	96	--

¹U.S. Environmental Protection Agency drinking water standards.²Secondary drinking water standard (U.S. Environmental Protection Agency, 1999b).³Primary drinking water standard (U.S. Environmental Protection Agency, 2002a).⁴Samples collected in the Bailey area in 2000 were included in the analysis.

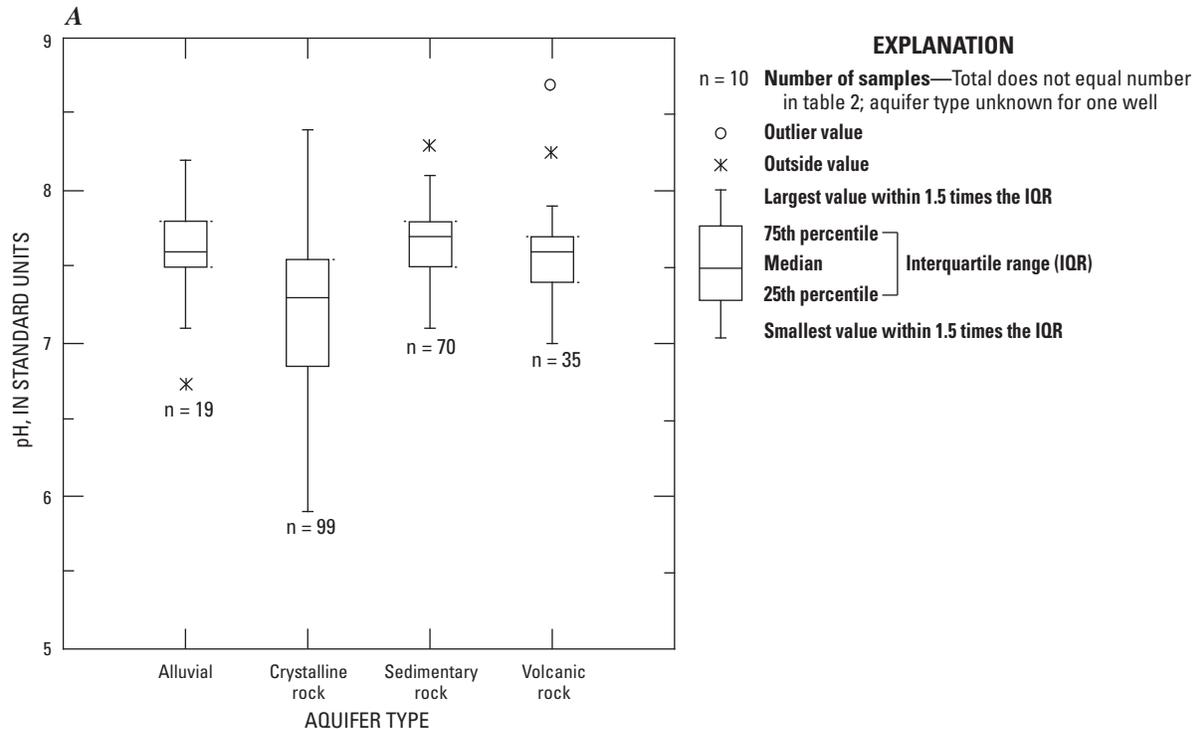


Figure 7 (above and facing page). (A) Distribution of pH by aquifer type and (B) spatial distribution of pH in samples collected from selected domestic wells in Park County, Colorado, 2001–2004.

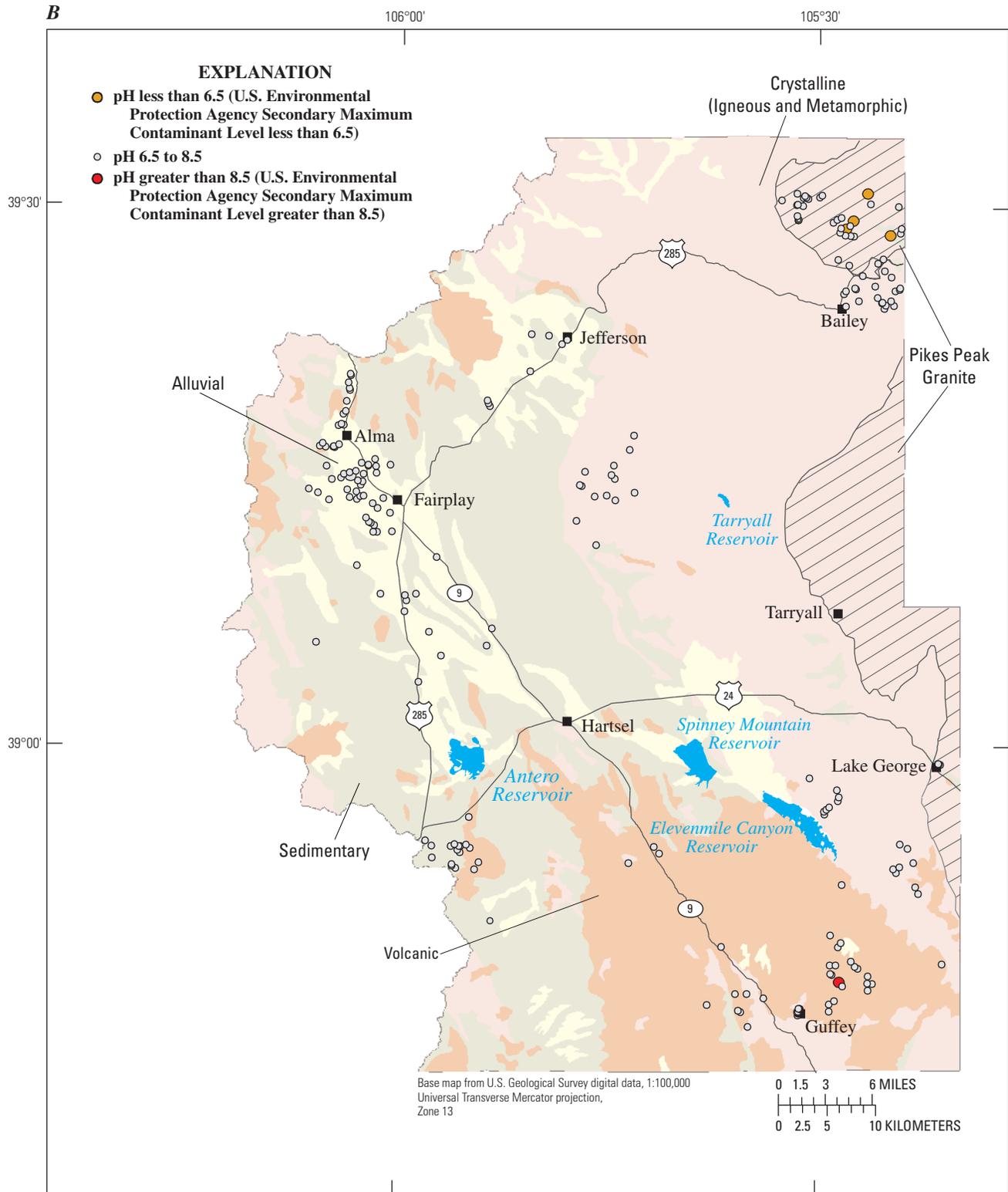
into solution in the water (Hem, 1992). In addition, the combustion of coal and petroleum and other industrial processes such as smelting of sulfide ores can release sulfur into the atmosphere (Hem, 1992). Sulfate in drinking water currently (2004) has a SMCL of 250 mg/L based on aesthetic effects (that is taste and odor).

Sulfate minerals can cause scale buildup in water pipes similar to other minerals and may be associated with a bitter taste in water. Sulfate can make cleaning clothes difficult. Using chlorine bleach in sulfur water may reduce the cleaning power of detergents. Health concerns regarding sulfate in drinking water have been raised because of reports of diarrhea associated with the ingestion of water containing high levels of sulfate. Available data indicate that people may acclimate rapidly to the presence of sulfates in their drinking water. However, groups within the general population, such as infants, may be at greater risk from the laxative effects of sulfate when they experience an abrupt change from drinking water with low sulfate concentrations to drinking water with high sulfate concentrations (U.S. Environmental Protection Agency, 1999c). According to panelists at the Health Effects from Exposure to Sulfate Workshop sponsored by the Centers for Disease Control and Prevention on September 28, 1998 (U.S. Environmental Protection Agency, 1999d), there is not enough scientific evidence on which to base a regulation for sulfate in drinking water, but panelists favored a health advisory in places where drinking water has sulfate levels greater than 500 mg/L.

Sulfate concentrations ranged from 2.4 to 1,760 mg/L, and the median concentration was 18 mg/L (table 2). The highest concentrations of sulfate generally were measured in samples collected from wells in the sedimentary-rock aquifers near the Park County line southwest of Hartsel and between Alma and Fairplay (figs. 9A, B). The lowest sulfate concentrations were measured in samples collected from wells completed in the crystalline-rock aquifers (fig. 9A, B). Sulfate concentrations measured in samples from wells completed in the crystalline-rock aquifers were generally less than 50 mg/L. Most of the samples that exceeded the SMCL of 250 mg/L for sulfate also exceeded the SMCL of 500 mg/L for DS. Concentrations in about 5 percent of the samples (12 of 220) exceeded the SMCL of 250 mg/L, and concentrations in about 4 percent of the samples (8 of 220) were greater than 500 mg/L, more than twice the SMCL (figs. 9A, B).

Dissolved Solids

DS consist of inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates) and some small amounts of organic matter that are dissolved in water. High concentrations of DS can give water a murky appearance and detract from the quality of taste of the water. In drinking water, DS originate from natural sources, sewage, urban runoff, and chemicals used



Note: Wells may be completed in rock type other than the surficial geology shown on this figure.

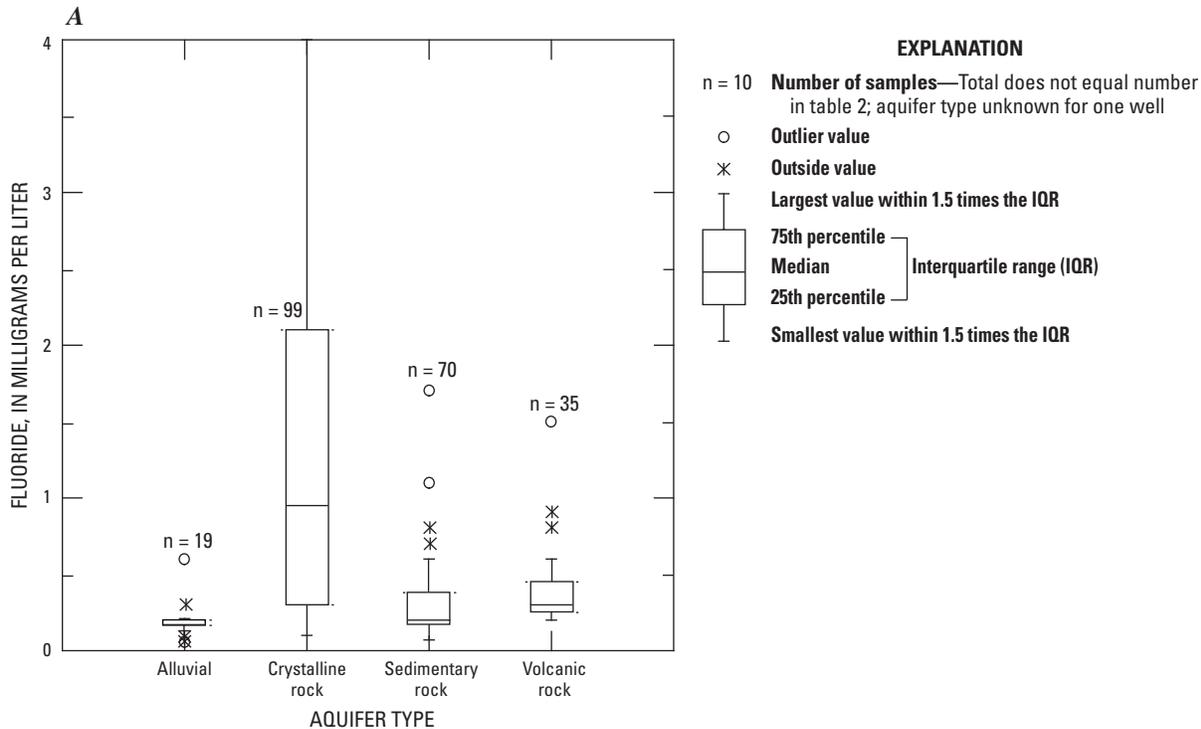


Figure 8 (above and facing page). (A) Distribution of fluoride by aquifer type and (B) spatial distribution of fluoride in samples collected from selected domestic wells in Park County, Colorado, 2001–2004.

in the water-treatment process, and the nature of the piping or hardware used to convey the water. Estimates of DS were made for samples collected from the Bailey area in 2001 when DS concentrations were not available using a linear regression relation developed between DS and specific conductance data from 43 wells sampled during 2000 in the Bailey area ($DS = [0.55 * \text{specific conductance}] + 12.41$, coefficient of determination (r^2) = 0.99, standard error = 6.8). The 55 estimated values were not used to compute the summary statistics presented in table 2 but are shown in figure 10 and included in the following discussion.

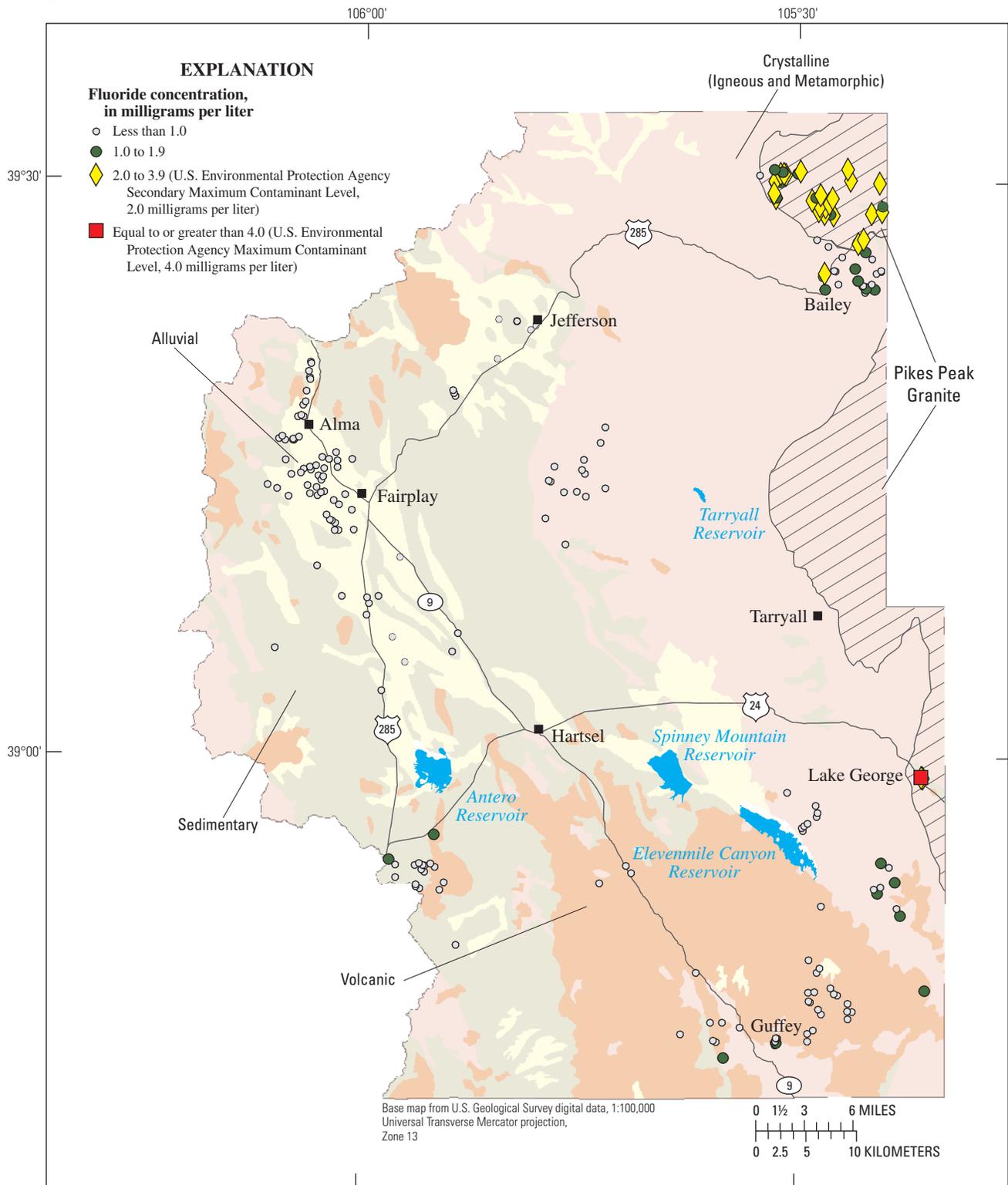
Elevated concentrations of DS in Park County ground-water samples probably are mostly from natural sources. However, some elevated concentrations of DS in the Bailey and Guffey areas may result from contamination by ISDS's, because chloride and nitrate concentrations in these ground-water samples were considerably higher than concentrations in samples collected from surrounding wells. Concentrations of DS measured in samples ranged from 49 to 2,810 mg/L, and the median DS concentration was 202 mg/L (fig. 10A and table 2). In general, DS concentrations were lowest in samples collected from wells completed in the crystalline-rock aquifers and highest in wells completed in the sedimentary-rock aquifers (figs. 10A, B). The SMCL of 500 mg/L for DS was exceeded in about 7 percent of samples (16 of 214), mostly in samples collected from wells completed in the sedimentary-rock aquifer (fig. 10). DS concentrations in about 4 percent of the samples (9 of 214) were greater than 1,000 mg/L (twice the SMCL).

Radionuclides

Radionuclides are radioactive elements such as radium and uranium. Radioactive elements sampled as part of this study included radon (radon-222) and uranium. Radon-222 (produced by the decay of radium-226) is the main radon isotope of environmental importance because it has a longer half-life (3.8 days) than other radon isotopes (Hem, 1992). Radon-222 is commonly called radon when referring to radon in homes. Radon is an invisible and odorless gas that forms from the radioactive decay of uranium and thorium naturally present in rocks and soils. Because radon is a gas, it can easily move through soil and cracks in building slabs or basement walls and concentrate in a building's indoor air. Although soil is the primary source, the use of household water that contains radon contributes to elevated indoor radon levels. Most of the cancer risk from radon in drinking water arises from the transfer of radon into indoor air, and exposure through inhalation, although some risk exists from ingesting water that contains radon. The National Academy of Sciences (1999) recommends that the USEPA continues to use 10,000 pCi/L in water to 1 pCi/L in air as the best estimate of the transfer of radon in drinking water to radon in indoor air (through showering, cooking, and other household water uses). The recommended maximum radon concentration for indoor air is 4 pCi/L (U.S. Environmental Protection Agency, 2005).

Currently (2004), there is no federally enforced drinking-water standard for radon in public water-supply systems, but proposed regulations indicate a maximum contaminant level

B



Note: Wells may be completed in rock type other than the surficial geology shown on this figure.

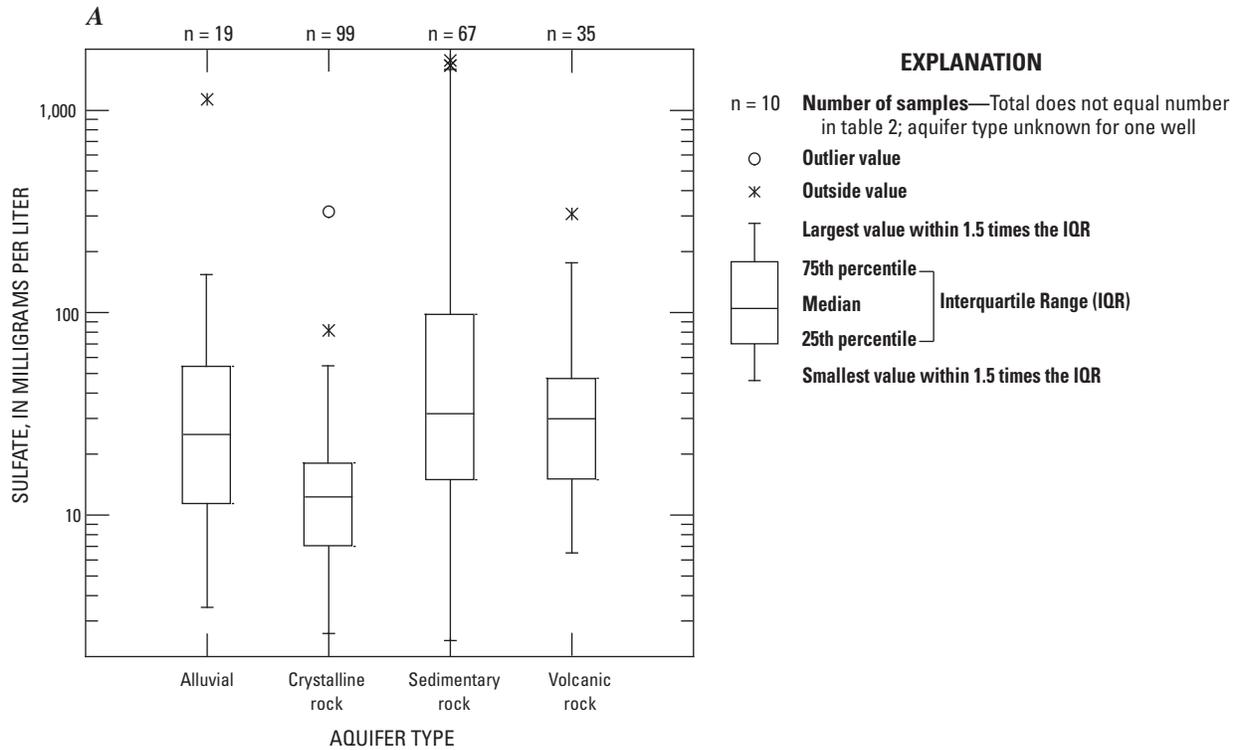


Figure 9 (above and facing page). (A) Distribution of sulfate by aquifer type and (B) spatial distribution of sulfate in samples collected from selected domestic wells in Park County, Colorado, 2001–2004.

(MCL) for radon (radon-222) of 300 pCi/L and an alternative MCL of 4,000 pCi/L contingent upon other mitigating remedial activities (U.S. Environmental Protection Agency, 1999a). Under the proposed regulations, the USEPA would encourage States and (or) managers of public water systems, to develop programs to address the health risks from radon in indoor air and require public water systems to reduce radon levels in drinking water to 4,000 pCi/L or less. If States and (or) public water systems do not develop programs to aid in reducing radon in indoor air, public water systems would be required to have radon levels in drinking water of 300 pCi/L or less. The proposed standards will apply only to public water systems that regularly serve 25 or more people and that use ground water or mixed ground and surface water. These standards will not apply to systems that rely on surface water where radon levels in the water are very low. They also will not apply to private wells, because the USEPA does not regulate them (U.S. Environmental Protection Agency, 1999a).

Radon concentrations in ground-water samples in Park County ranged from 40 to 19,200 pCi/L (table 2 and fig. 11A, B). Radon concentrations in about 91 percent of ground-water samples (70 of 77) collected from domestic wells throughout Park County were greater than or equal to 300 pCi/L, and about 25 percent (19 of 77) were greater than or equal to 4,000 pCi/L. Generally, the highest radon concentrations were measured in samples collected from wells completed in the crystalline-rock aquifers, and the lowest concentrations were measured in samples collected from wells completed in

the volcanic-rock aquifers (fig. 11A). The spatial distribution of radon concentrations in ground-water samples collected throughout Park County is shown in figure 11B.

Primary drinking-water standards have been established for uranium because of increased risk of cancer and kidney toxicity (U.S. Environmental Protection Agency, 2006). The current (2004) MCL for uranium (30 micrograms per liter [µg/L]) in drinking water was exceeded in two samples collected from wells completed in the crystalline-rock aquifer. Uranium concentrations in ground-water samples ranged from less than 1.0 to 48 µg/L (table 2 and fig. 12A, B). Similar to radon, the highest uranium concentrations generally occurred in samples collected from wells completed in the crystalline-rock aquifers, and the lowest concentrations generally occurred in samples collected from wells completed in the volcanic-rock aquifers (fig. 12A, B). The spatial distribution of uranium concentrations in ground-water samples collected throughout Park County is shown in figure 12B.

Human Factors Affecting Drinking-Water Quality in Park County

Effluent from ISDS's, runoff from parking lots and roadways, and use of chemicals (solvents for cleaning, motor oil, and paint) around the home or in industrial processes can affect ground-water quality. The following discussion is limited to those constituents that exceeded national primary and (or) secondary drinking-water standards (U.S. Environmental

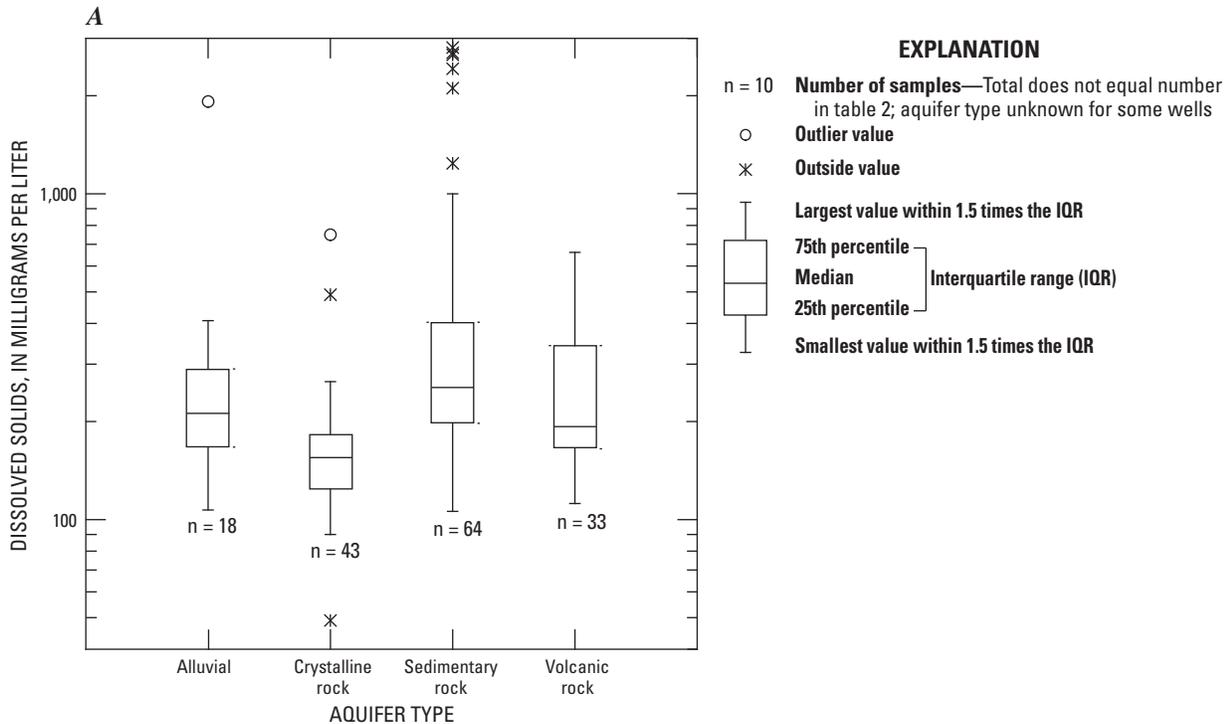


Figure 10 (above and facing page). (A) Distribution of dissolved solids by aquifer type and (B) spatial distribution of dissolved solids in samples collected from selected domestic wells in Park County, Colorado, 2001–2004.

Protection Agency, 2002a) in Park County ground-water samples most likely as a result of human factors. The USEPA secondary drinking-water standards for chloride and primary drinking-water standards for nitrate (shown as nitrite-plus-nitrate in table 2), total coliform, and *E. coli* were exceeded in one or more samples collected from domestic wells in Park County (table 2).

Chloride

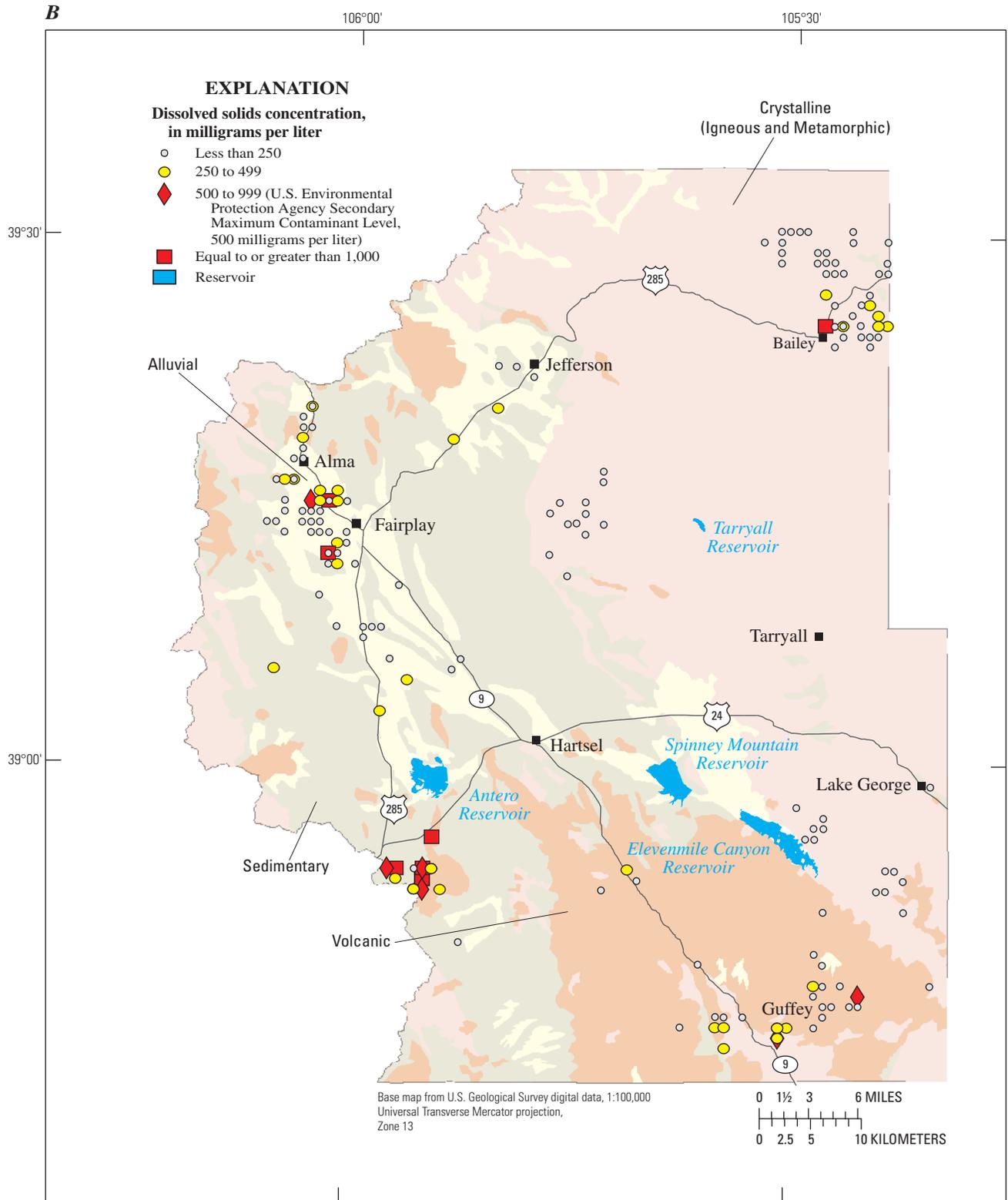
High levels of chloride tend to indicate contamination by human activities including use of road salts, discharges from water softeners, human-waste disposal, and other activities. Chloride may be naturally present in various rock types (Hem, 1992). However, higher concentrations of chloride generally exist in ISDS effluent than in natural ground water. Chloride is a conservative chemical species that generally does not degrade in natural ground water, is not readily removed through natural soil treatment, and travels faster than other less conservative chemicals in unsaturated zone and aquifer systems (Heatwole and others, 2005).

Concentrations of chloride in ground-water samples ranged from 0.28 to 873 mg/L; 75 percent of measured concentrations were less than about 7 mg/L and 90 percent were less than about 13 mg/L (table 2). The highest overall chloride concentrations were measured in wells completed in the crystalline-rock aquifers (median chloride concentration in crystalline-rock aquifer wells was 5.16 mg/L), and the lowest concentrations in wells completed in the alluvial

aquifers (median chloride concentration in alluvial aquifer wells was 1.66 mg/L). The SMCL of 250 mg/L for chloride was exceeded in only one sample collected from a well in the crystalline-rock aquifer near Bailey. (This well also had an elevated nitrite-plus-nitrate concentration of 11.1 mg/L that also exceeded the 10 mg/L MCL for nitrate.) All other measured chloride concentrations were at least an order of magnitude less than the SMCL.

Nitrate

Nitrate concentrations at or above the primary drinking-water standard of 10 mg/L generally are attributed to human sources. In Park County, elevated nitrate concentrations most likely are caused by wastewater effluent from ISDS's. Most ground-water samples were not analyzed for nitrate independently but for nitrite and nitrite-plus-nitrate. Nearly all nitrite concentrations were reported as less than the reporting level of 0.008 mg/L, which is below the primary standard of 1 mg/L reported as nitrogen. Because nitrite concentrations were small, comparisons to the nitrate standard were done using nitrite-plus-nitrate data. The maximum nitrite-plus-nitrate concentration was 25.7 mg/L (table 2), which exceeds the MCL of 10 mg/L for nitrate (reported as nitrogen). Concentrations of nitrite-plus-nitrate in about 2 percent (4 of 224) of samples equaled or exceeded the MCL for nitrate (fig. 13). All four of these wells were in the crystalline-rock aquifer near Bailey (fig. 13). The highest nitrite-plus-nitrate concentrations were measured in ground-water samples collected from wells near



Note: Wells may be completed in rock type other than the surficial geology shown on this figure.

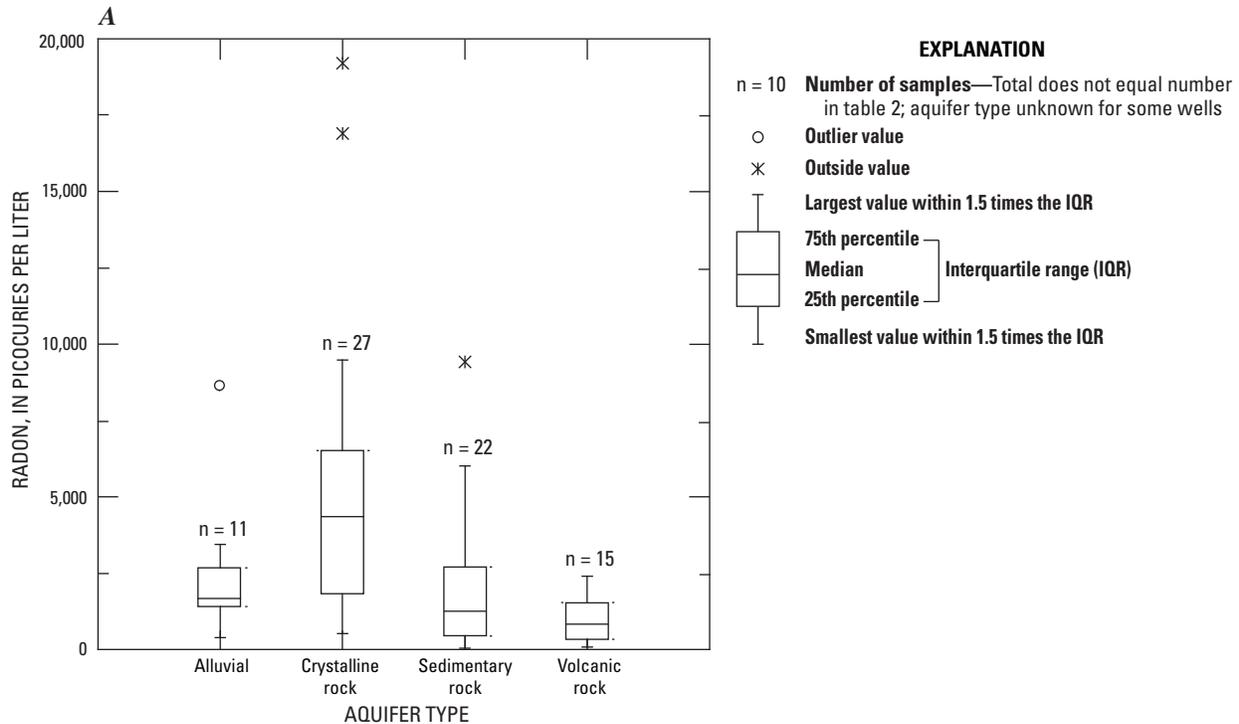


Figure 11 (above and facing page). (A) Distribution of radon by aquifer type and (B) spatial distribution of radon in samples collected from selected domestic wells in Park County, Colorado, 2000–2004.

Bailey and Guffey (fig. 13). The median nitrite-plus-nitrate concentration for samples collected throughout Park County during this study was 0.34 mg/L, which is well below the drinking-water standard for nitrate (table 2). Nitrate concentrations in drinking water are important because ingestion of nitrate by infants can cause low oxygen levels in the blood, a potentially fatal condition (U.S. Environmental Protection Agency, 2006).

Bacteria

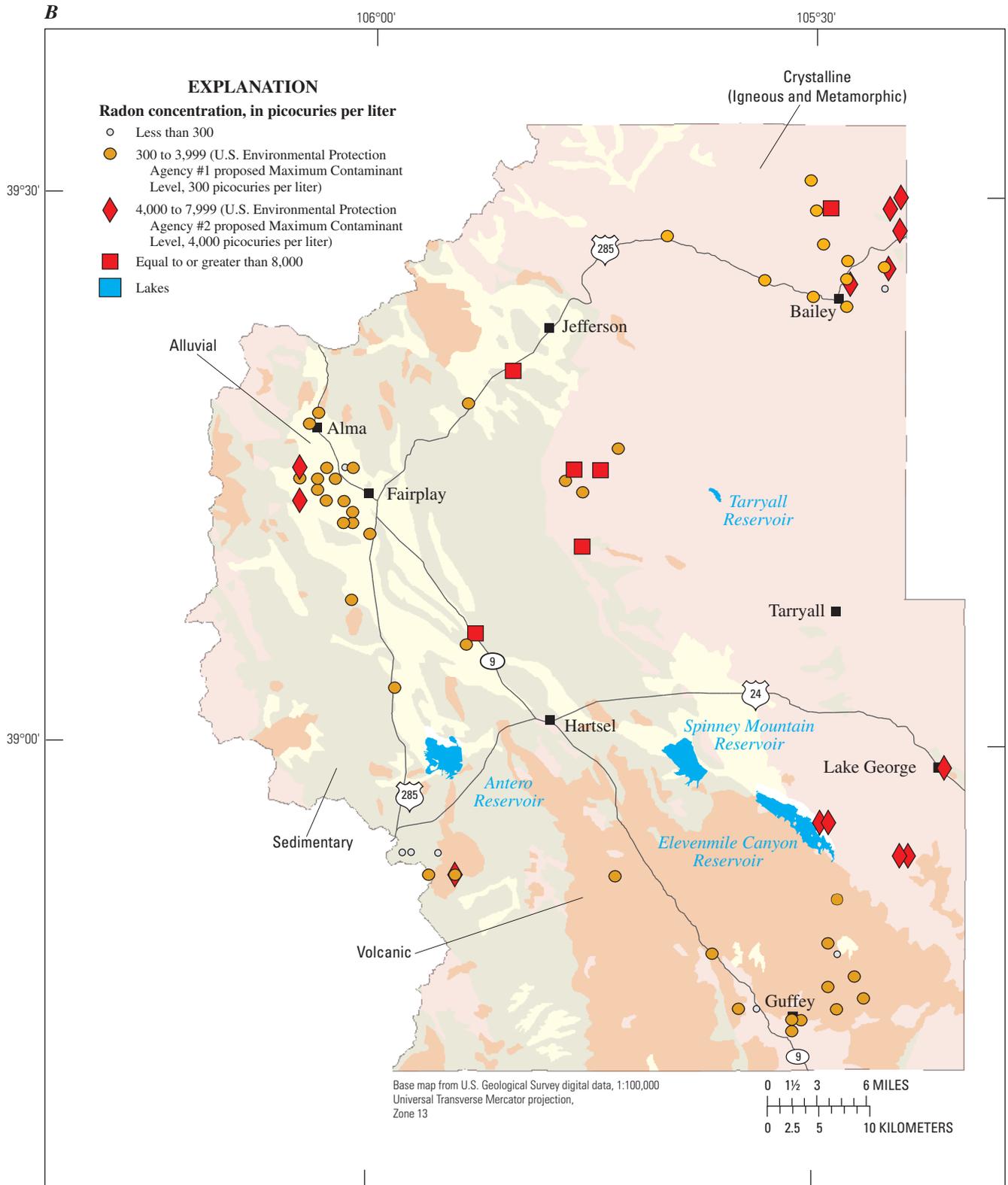
Total coliform and *E. coli* bacteria live in the intestines of warm-blooded animals and in waste material or feces excreted from the intestinal tract. The presence of total coliform and *E. coli* in water samples is used to indicate recent sewage or animal-waste contamination. Although not typically disease causing, their presence is correlated with the presence of several waterborne disease-causing organisms. A few strains of *E. coli* are pathogenic, such as *E. coli* O157:H7, but most strains are not (Wilde and others, 1998). For public water-supply systems, the USEPA requires that no more than 5.0 percent of samples collected in a month have detections of total coliform; and for water systems that collect fewer than 40 routine samples per month, no more than 1 sample can test positive for total coliform per month (U.S. Environmental Protection Agency, 2006). Because only one sample was collected and analyzed for total coliform and *E. coli* at each well during this study, a well was considered to exceed the USEPA primary drinking-water standards if bacteria were detected.

E. coli only were detected in one sample from a well near Guffey, whereas, total coliform were detected in about 11 percent (24 of 220) of wells sampled. Concentrations of total coliform in samples ranged from less than 1 colony per 100 milliliters (col/100 mL) of water to an estimated 340 col/100 mL (table 2). The highest total-coliform concentrations were measured in samples collected from wells south-east of Jefferson and west of Tarryall Reservoir (fig. 14).

In 1974, ground-water-quality samples were collected by the USGS from 80 wells throughout Park County. Total coliform concentrations in the crystalline-rock aquifer wells in the Bailey area were higher in samples collected during 1974 (Kimbrough, 2001) than in samples collected during this study (the Bailey area was sampled during 2001). Total coliform were detected in about 20 percent of the crystalline-rock aquifer wells sampled in the Bailey area in 1974 compared to 5 percent in 2001. Concentrations of total coliform in the Bailey area ranged from less than 1 to 2,000 col/100 mL in 1974 and from less than 1 to an estimated 2 col/100 mL in 2001.

Summary of Drinking-Water Quality in Domestic Wells in Park County

Overall, ground water throughout Park County is suitable for domestic use. Only about 3 percent of ground-water samples had concentrations of fluoride, nitrate, and (or) uranium that exceeded a primary drinking-water standard. These primary drinking-water standards only were exceeded



Note: Wells may be completed in rock type other than the surficial geology shown on this figure.

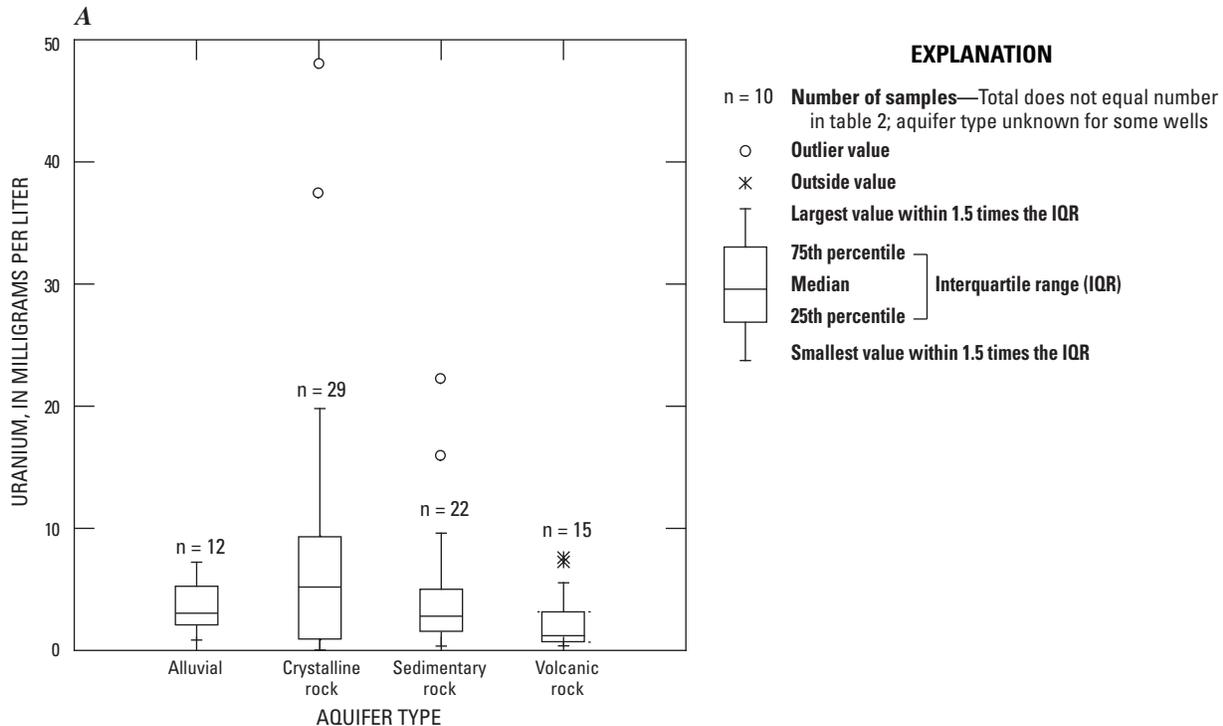


Figure 12 (above and facing page). (A) Distribution of uranium by aquifer type and (B) spatial distribution of uranium in samples collected from selected domestic wells in Park County, Colorado, 2000–2004.

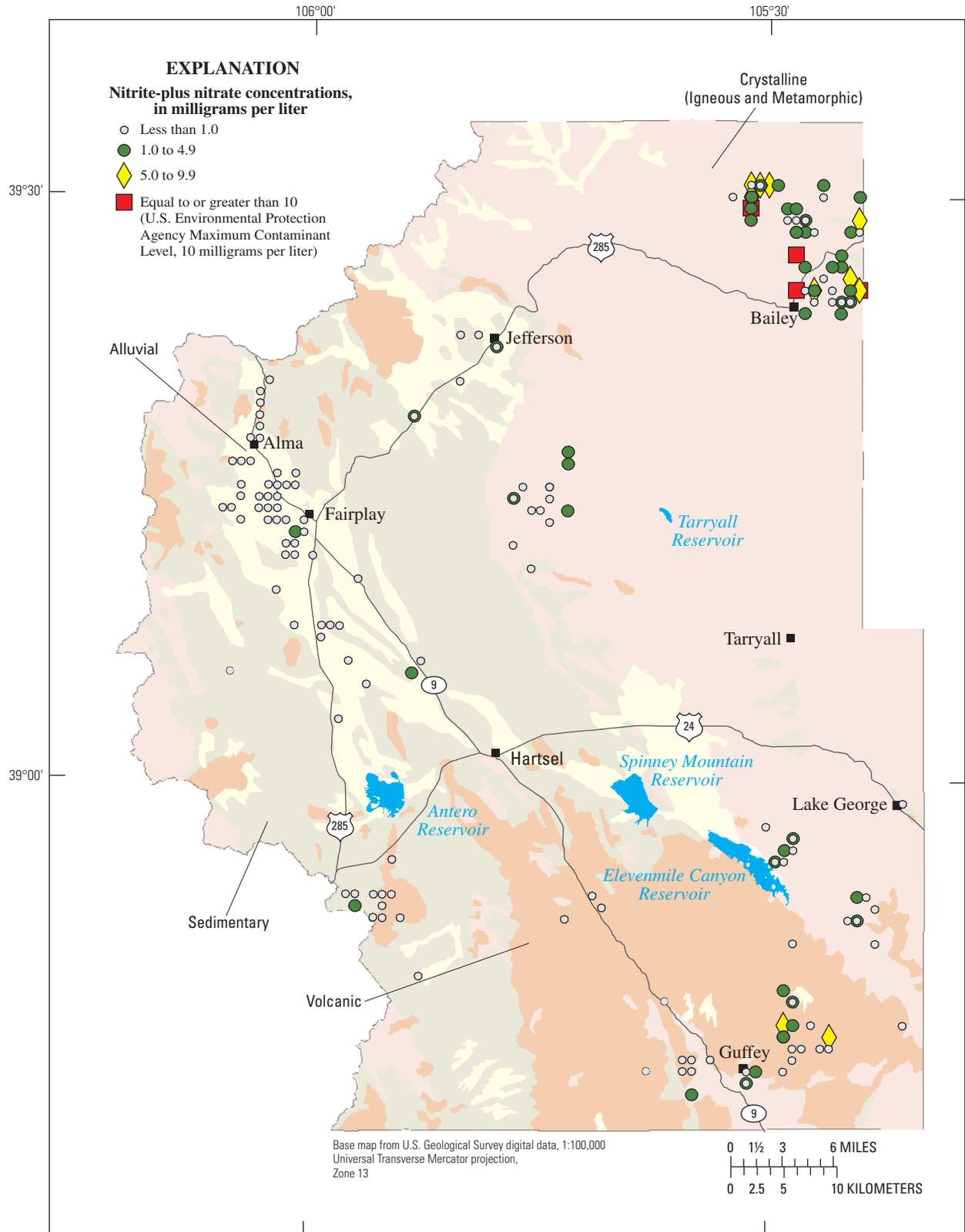
in samples collected from wells completed in the crystalline-rock aquifers. Radon concentrations in about 25 percent of the samples were greater than or equal to 4,000 pCi/L, the highest proposed maximum contaminant level for radon in drinking water. Most radon concentrations greater than 4,000 pCi/L were measured in samples collected from wells completed in the crystalline-rock aquifers; however, some high concentrations of radon (greater than 4,000 pCi/L) were measured in samples collected from wells completed in the alluvial and sedimentary-rock aquifers. Total coliform were detected in about 11 percent of samples throughout Park County. These samples were collected from wells completed in each aquifer-rock type (alluvial, crystalline, sedimentary, and volcanic). Secondary standards were exceeded more frequently than primary standards. Concentrations of one or more constituents exceeded secondary drinking-water standards in about 19 percent of samples.

Based on age-dating data, only about 8 percent of wells sampled for CFC’s had ground-water recharge dates after 1990. Because most of the development in Park County has occurred since 1990, there may not have been enough time elapsed for human activities to considerably affect sampled ground-water quality. As time passes, it is possible that recharge affected by human activities may become a larger part of the ground-water resource. As a result, concentrations and (or) frequency of detection of constituents associated with human activities may increase.

The USEPA recommends that well owners have their wells tested for pH, DS, nitrates, and total-coliform bacteria levels annually (U.S. Environmental Protection Agency, 2002b). One way to reduce the risk of contaminating nearby wells is to properly maintain the onsite ISDS. Many useful bulletins describing proper use and maintenance of septic tanks (ISDS’s) can be found on the World Wide Web at sites such as: <http://www.agnr.umd.edu/users/wye/personel/Miller/septic.html>, <http://www.soil.ncsu.edu/publications/Soilfacts/AG-439-13/>, and <http://www.montana.edu/wwwpb/pubs/mt9401.html>.

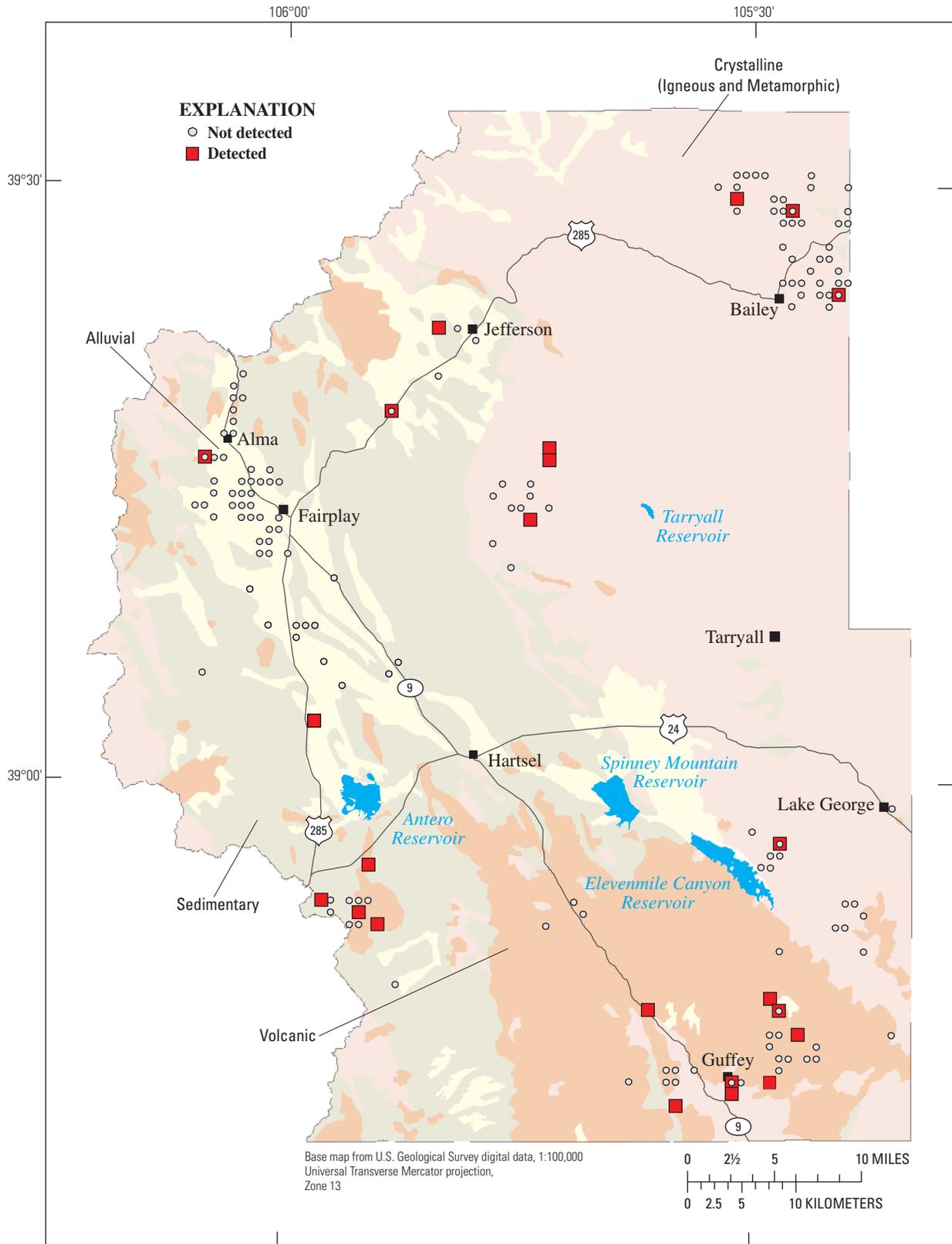
Potential Effects of Individual Sewage Disposal System Effluent on Ground-Water Quality

An ISDS can provide a source of chemicals and bacteria if the leach-field pipe is too close to the water table or if the ground-water-flow velocity is too rapid to allow for proper geochemical or physical treatment of the ISDS effluent. Chemicals from products that are used in households can enter the ground-water system as a more concentrated effluent from an ISDS (Kolpin and others, 2002) than from natural sources. Examples of products containing these chemicals include soaps that contain boron, dietary salt that contains chloride,



Note: Wells may be completed in rock type other than the surficial geology shown on this figure.

Figure 13. Spatial distribution of nitrite-plus-nitrate in samples collected from selected domestic wells in Park County, Colorado, 2001–2004.



Note: Wells may be completed in rock type other than the surficial geology shown on this figure.

Figure 14. Spatial distribution of total coliform detections in samples collected from selected domestic wells in Park County, Colorado, 2001–2004.

caffeinated beverages, pesticides, perfumes, or human waste that contains nitrite, nitrate, and ammonia. Persistent detections or elevated concentrations of bacteria also may indicate contamination from an ISDS, especially if detections of bacteria also are accompanied by detections of wastewater compounds or elevated concentrations of other chemicals.

Geochemical and physical processes occur in the subsoil—the unsaturated zone above the water table and the saturated zone below the water table that can reduce the concentrations of chemical and biological constituents in ISDS effluent. In a properly functioning ISDS, most of the potential contaminants in effluent are removed by filtration or oxidation in the unsaturated zone below the leach field and above the water table (Wilhelm and others, 1994). When effluent reaches the unsaturated zone above the water table, it flows through the pores between the particles, such as sand and gravel from the weathered sedimentary rock, that make up the subsoil. Large particles and bacteria in the effluent can be filtered by the subsoil, leaving mostly dissolved compounds in the effluent. As the effluent flows through the subsoil and is exposed to oxygen, ammonia is oxidized to form nitrate. When nitrate reaches the water table, and if dissolved organic carbon is present and dissolved oxygen is absent, the nitrate and dissolved organic carbon may be consumed by denitrifying bacteria to produce nitrogen and carbon dioxide gases. Thus, the concentration of nitrate increases beyond the leach field but then can decrease as it travels through the saturated zone (Robertson and others, 1989).

Caffeine and other organic chemicals can be degraded to other compounds by bacteria in the saturated zone in the vicinity of the leach field from which the chemicals originated. Organic chemicals can persist in ground water, however, if degrading bacteria are not present. Biological constituents in ISDS effluent that can cause disease (pathogenic organisms) include bacteria and viruses. These microorganisms have different survival rates and transport properties in the unsaturated and saturated zones below a leach field. For example, *E. coli* potentially can survive for several weeks in the subsurface if conditions are favorable (Matthess and Pekdeger, 1981). Total coliform and *E. coli* bacteria can be removed from ISDS effluent by filtration as the effluent flows through the unsaturated zone (Viraraghavan and Warnock, 1976). If the water table is close to the land surface, the unsaturated zone is thin, and more of the bacteria in the effluent potentially can reach the water table (Canter and Knox, 1985).

Occurrence of Constituents Associated with Individual Sewage Disposal System Effluent in Ground-Water Samples

Wastewater compounds were detected in 46 percent (43 of 93) of samples collected from wells in Park County. Thirty-eight different organic wastewater compounds were detected in ground-water samples (table 3); most were at low concentrations at or near the laboratory reporting levels. Only 1 (tetrachloroethylene [PCE]) of the 38 wastewater compounds

detected in ground-water samples is regulated in drinking water by the USEPA. PCE was detected in about 6 percent of samples (6 of 93); however, PCE concentrations were low. The maximum PCE concentration measured was an estimated 0.3 µg/L, which is an order of magnitude lower than the MCL for PCE of 5 µg/L (0.005 mg/L). The number of wastewater compounds detected per sample ranged from 1 to 17 compounds. The spatial distribution of wastewater compound detections and number of wastewater compounds detected at each site is shown in figure 15. Detections of wastewater compounds in ground water indicate that these compounds are not being completely removed by ISDS's or the unsaturated zone. Because ISDS's typically are not designed to remove all wastewater compounds, and roughly 90 percent of domestic water used is assumed to be recharged by ISDS's (Van Slyke and Simpson, 1974), detections of wastewater compounds in ground water in Park County are not surprising.

The most frequently detected wastewater compounds were phenol, bisphenol A (BPA), isophorone, 4-nonylphenol (4-NP), and tris (2-chloroethyl) phosphate. Wastewater compounds detected in ground-water samples, frequency of detection, and possible use or source of the compound are listed in table 3. Phenol was detected in 28 percent of the samples. Phenols are used in the formation of phenolic resins and in the manufacture of nylon and other synthetic fibers (<http://www.atsdr.cdc.gov/tfacts115.html#bookmark02>, September 17, 2007). Phenols also are used in chemicals that kill bacteria and fungi in slimes, disinfectants, antiseptics, and medicinal preparations such as mouthwash and throat lozenges. BPA was detected in 24 percent of ground-water samples analyzed for wastewater constituents. BPA is used as a plasticizer in the manufacture of polycarbonate plastic and epoxy resins that are used in baby bottles, as protective coatings on food containers, and as composites and sealants in dentistry (Calafat and others, 2005). Isophorone was detected in 9 percent of the samples. Isophorone is used as a solvent in some printing inks, paints, lacquers, and adhesives (<http://www.eco-usa.net/toxics>, June 13, 2006). In 8 percent of wells sampled, 4-NP was detected. 4-nonylphenol (4-NP) is used to make nonylphenol ethoxylates, or nonionic detergent metabolites, that are in numerous industrial, agricultural, and domestic products such as detergents and pesticide formulations (http://www.pesticideinfo.org/Docs/ref_general2.html#ChemUseType, September 17, 2007). Tris(2-chloroethyl) phosphate was detected in about 8 percent of the samples. Tris(2-chloroethyl) phosphate is used as a flame retardant in plastics, especially in flexible foams used in automobiles and furniture, and in rigid foams used for building insulation (<http://www.inchem.org/documents/iarc/vol48/48-06.html>, July 3, 2006).

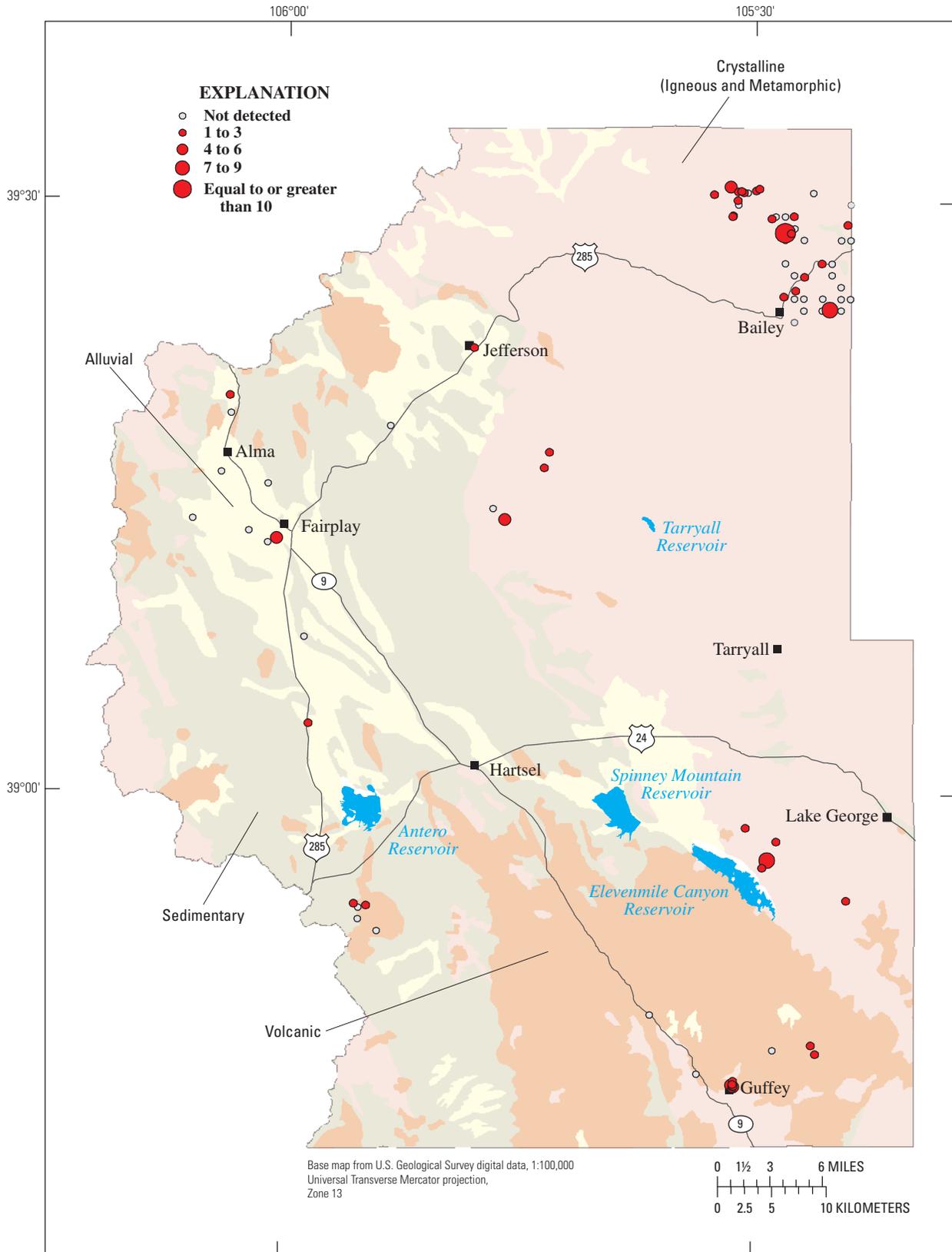
The co-occurrence of multiple constituents possibly associated with ISDS effluent (such as bacteria, wastewater compounds, and elevated concentrations of nitrate, chloride, or boron) in a single sample can provide strong evidence of contamination by an ISDS. For example, samples collected from one well in the volcanic-rock aquifer near Guffey had detectable concentrations of *E. coli* bacteria, total coliform bacteria, six wastewater compounds, and a nitrite-plus-nitrate

Table 3. List of organic compounds identified in samples collected from domestic wells in Park County, Colorado, 2001–2004.

[Possible use or source: Listings not exhaustive. Pcode, U.S. Geological Survey National Water Information System (NWIS) database parameter code; CAS number; Chemical Abstracts Service Registry Number; mg/L, milligram per liter; µg/L, microgram per liter; --, unknown; NA; not applicable]

Pcode	Compound name	CAS number	Number of samples	Number of detects	Frequency of detection (percent)	Reporting level (µg/L)	Possible use or source
34466	Phenol	108-95-2	93	26	28	0.50	disinfectants, antiseptics, medicinal preparations, synthetic fibers
62069	Bisphenol A (BPA)	80-05-7	93	22	24	1.00	plasticizer
34409	Isophorone	78-59-1	93	8	9	0.50	solvent
62085	4-Nonylphenol (total)	84852-15-3	93	7	8	5.00	nonionic detergent metabolite
62087	Tris(2-chloroethyl) phosphate	115-96-8	93	7	8	0.50	flame retardant
38260	Methylene blue active substances, unfiltered	NA	58	4	7	*0.1	surfactants or detergents
62075	Hexahydrohexamethyl cyclopentabenzopyran (HHCB)	1222-05-5	93	6	6	0.50	fragrance
62082	N,N-diethyl-meta-toluamide (DEET)	134-62-3	93	6	6	0.50	insect repellent
34476	Tetrachloroethylene (PCE)	127-18-4	93	6	6	0.50	paint and spot removers, water repellents, degreasers, glues
62088	Tris(dichloroisopropyl) phosphate	13674-87-8	93	6	6	0.50	flame retardant
34572	1,4-Dichlorobenzene	106-46-7	93	5	5	0.50	deodorant, moth repellent, fumigant
62065	Acetyl hexamethyl tetrahydro naphthalene (AHTN)	21145-77-7	93	5	5	0.50	fragrance
62084	p-Cresol	106-44-5	93	5	5	1.00	wood preservative
34443	Naphthalene	91-20-30	93	4	4	0.50	fumigant, dyes, insecticides
62092	Triphenyl phosphate	115-86-6	93	4	4	0.50	flame retardant, plasticizer
62067	Benzophenone	119-61-9	93	3	3	0.50	fixative for perfumes and soap, plasticizer
62072	Cholesterol	57-88-5	93	3	3	2.00	plant and animal steroid
62093	Tris(2-butoxyethyl) phosphate	78-51-3	93	3	3	0.50	flame retardant, plasticizer
62057	3-beta-Coprostanol	360-68-9	93	2	2	2.00	animal fecal steroid
62062	4-tert-Octylphenol	140-66-9	93	2	2	1.00	nonionic detergent metabolite
62070	Camphor	76-22-2	93	2	2	0.50	flavor, ointments, fragrance
62076	Indole	120-72-9	93	2	2	0.50	fragrance, human feces, coal tar
62078	Isopropylbenzene (cumene)	120-72-9	93	2	2	0.50	solvent, petroleum products
34288	Tribromomethane (Bromoform)	75-25-2	93	2	2	0.50	chlorination by-product, laboratory reagents
62090	Triclosan	3380-34-5	93	2	2	1.00	disinfectants in detergents, soaps, deodorants, toothpastes
62054	1-Methylnaphthalene	90-12-0	93	1	1	0.50	gasoline, diesel fuel, crude oil
62055	2,6-Dimethylnaphthalene	581-42-0	93	1	1	0.50	diesel fuel, kerosene
62056	2-Methylnaphthalene	91-57-6	93	1	1	0.50	gasoline, diesel fuel, crude oil
62058	3-Methyl-1H-indole	83-34-1	93	1	1	1.00	fragrance
62063	5-Methyl-1(H)-benzotriazole	136-85-6	93	1	1	2.00	antioxidant in antifreeze and deicers
62066	Anthraquinone	84-65-1	93	1	1	0.50	dye, insecticide, bird repellent
50305	Caffeine	58-08-2	93	1	1	0.50	stimulant, beverages, diuretic
82680	Carbaryl	63-25-2	93	1	1	1.00	insecticide
62083	Diethoxynonylphenol	--	93	1	1	5.00	nonionic detergent metabolite
61705	Diethoxyoctylphenol	--	93	1	1	1.00	nonionic detergent metabolite
62073	d-Limonene	5989-27-5	93	1	1	0.50	cleaning products, aerosol fragrance
61706	Ethoxyoctylphenol	--	93	1	1	1.00	
62091	Triethyl citrate	77-93-0	93	1	1	0.50	food additive, cosmetics, plasticizer

*Concentration of constituent in milligrams per liter.



Note: Wells may be completed in rock type other than the surficial geology shown on this figure.

Figure 15. Number of wastewater compounds detected in samples collected from selected domestic wells in Park County, Colorado, 2001–2004.

concentration of 1.43 mg/L, which was more than double the nitrite-plus-nitrate concentrations in nearby wells. The co-occurrence of these multiple constituents in one well probably indicates contamination by sewage effluent.

Chloride and boron concentrations were significantly higher (p -value < 0.05) in samples collected from wells with detections of wastewater compounds than in wells with no detections of wastewater compounds. However, nitrite-plus-nitrate concentrations were not significantly different between wells with detections of wastewater compounds and those with no detections. Heatwole and others (2005) suggested that chloride measurements (1) can serve as a precursor to contamination from other ISDS constituents (including nitrogen), (2) may help determine if contaminants in monitoring wells originate from ISDS's or other sources, and (3) can be used to estimate the relative ratio of ISDS water and aquifer water (mixing factors). Similarly, boron isotopes have been useful in determining human influences on ground water. Babcock and others (2006) developed a method using boron isotopes to track the transport and fate of recycled water following recharge into a shallow brackish aquifer. Barth and others (1996) used boron isotopes to identify contamination of ground water from a solid-waste disposal site. Higher concentrations of chloride and boron in samples from wells that have detections of wastewater compounds than in samples from wells that do not have detections of wastewater compounds indicate that recharge from ISDS effluent is affecting ground-water quality in Park County. If the overall recharge from ISDS's increases, concentrations of chloride, boron, and other constituents associated with ISDS effluent also are likely to increase.

Concentrations of nitrite-plus-nitrate (p -value = 0.0002) and chloride (p -value = 0.0006) were significantly higher in ground-water samples collected from the crystalline-rock aquifers in the Bailey area during 2001 than in 1974 (figs. 16 and 17). The median nitrite-plus-nitrate concentration measured during 1974 was 0.82 mg/L compared to 2.58 mg/L for samples collected during this study (2001) (fig. 16), and the median chloride concentration measured during 1974 was 3.4 mg/L compared to 7.75 mg/L measured during 2001 (fig. 17). Changes in nitrite-plus-nitrate and chloride concentrations in the Bailey area over time likely are related to a larger part of the overall recharge being from ISDS effluent either as a result of an increase in ISDS density or more time for recharge from ISDS effluent to reach the ground-water table.

Potential Effects of Individual Sewage Disposal System Density and Aquifer Type on Ground-Water Quality

Ground-water-quality data were grouped by average subdivision lot size, aquifer type, and year of ISDS installation to investigate the effects of ISDS density and aquifer type on ground-water quality. The average subdivision lot size and year of ISDS installation were provided by Park County for selected wells (Brenda Green, Park County, written commun., 2007). The nonparametric Wilcoxon Mann-Whitney test was

used to determine if concentrations of selected constituents, associated with ISDS effluent, were significantly different in ground-water samples based on average subdivision lot size, aquifer type, and (or) year of ISDS installation.

Throughout Park County the average subdivision lot size was used as a surrogate for ISDS density. Wells were placed into four categories based on average subdivision lot size (ISDS density): (1) average lot size less than 1 acre, (2) average lot size from 1 to 3 acres, (3) average lot size from 3 to 5 acres, and (4) average lot size greater than 5 acres. Chloride and boron concentrations were significantly higher in ground-water samples collected from wells located in areas that had average subdivision lot sizes less than 1 acre than in areas that had average subdivision lot sizes equal to or greater than 1 acre (fig. 18). Median potassium concentrations increased as average subdivision lot size decreased (fig. 18). Significantly higher (p -value < 0.05) potassium concentrations were measured only in wells located in areas that have average lot sizes less than or equal to 5 acres than in wells located in areas that have average lot sizes greater than 5 acres (fig. 18).

Wells were grouped by aquifer rock type (alluvial, crystalline-rock, sedimentary-rock, and volcanic-rock) and then by average subdivision lot size. Too few samples were collected from alluvial aquifer wells to determine if differences in constituent concentrations were present between lot-size categories. For wells completed in the crystalline-rock aquifers, median chloride and boron concentrations increased as average subdivision lot size decreased (fig. 19). However, increases in chloride concentrations were significant (p -value < 0.05) only between wells located in areas that had average subdivision lot sizes less than 1 acre and wells located in areas that had average subdivision lot sizes greater than 5 acres. Increases in boron concentrations were significant (p -value < 0.05) only between wells located in areas that had average subdivision lot sizes less than 1 acre and wells located in areas that had average subdivision lot sizes greater than 3 acres. Increases in constituent concentrations were not significant in wells completed in the sedimentary-rock aquifers for any lot-size category. One reason for this may be that (based on CFC and tritium data) ground water in the sedimentary-rock aquifers tended to be older than ground water in the other aquifer-rock types. There may not have been enough time for ISDS effluent to reach the ground-water table in sufficient quantities to noticeably affect ground-water quality. For wells completed in the volcanic-rock aquifers, potassium, chloride, and boron concentrations were significantly higher in wells located in areas that had average subdivision lot sizes of less than 1 acre than in areas that had average subdivision lot sizes greater than 5 acres (fig. 20). Significant increases in constituent concentrations may occur between other lot size categories in the volcanic-rock aquifers, but samples were collected only from wells located in areas that had average subdivision lot sizes less than 1 acre and greater than 5 acres.

Nitrate concentrations were significantly higher in wells with ISDS's installed in the 1970's than in wells with ISDS's installed in the 1980's (fig. 21). Significantly higher

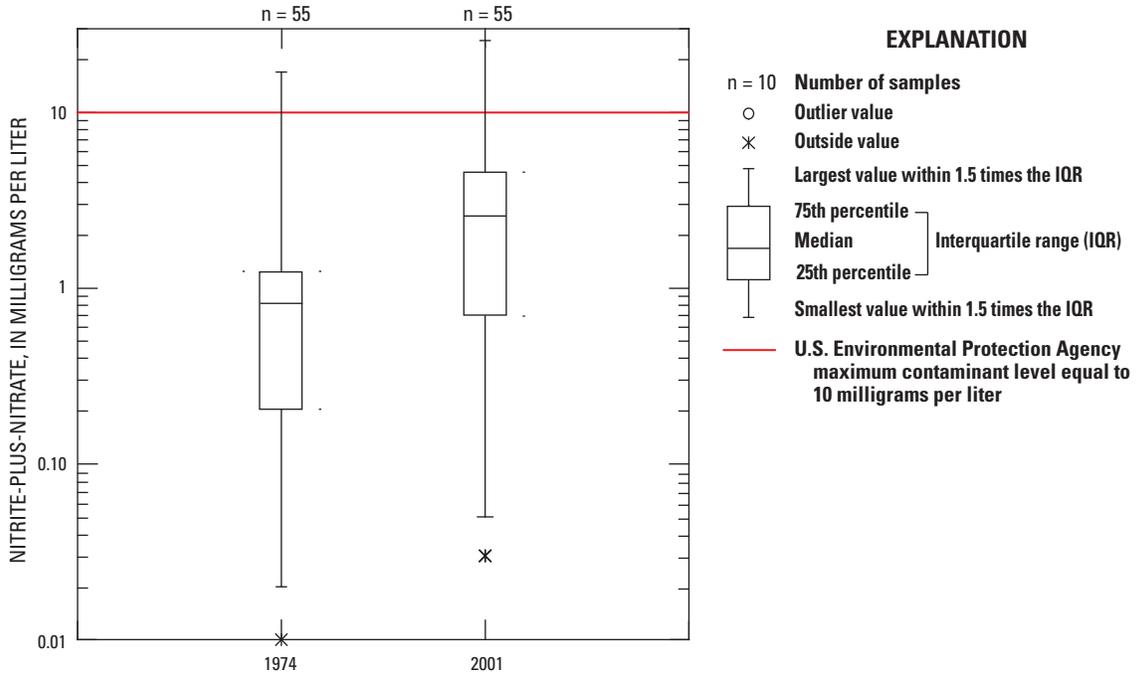


Figure 16. Distribution of nitrite-plus-nitrate concentrations in samples collected from selected domestic wells in the Bailey area in 1974 and 2001.

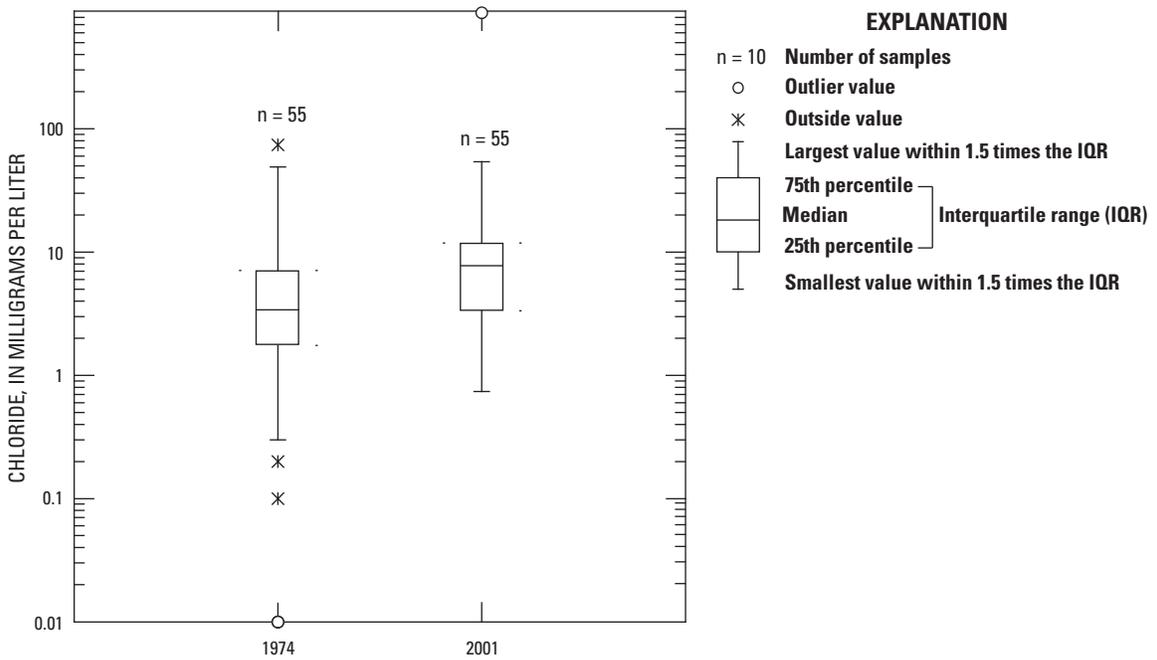
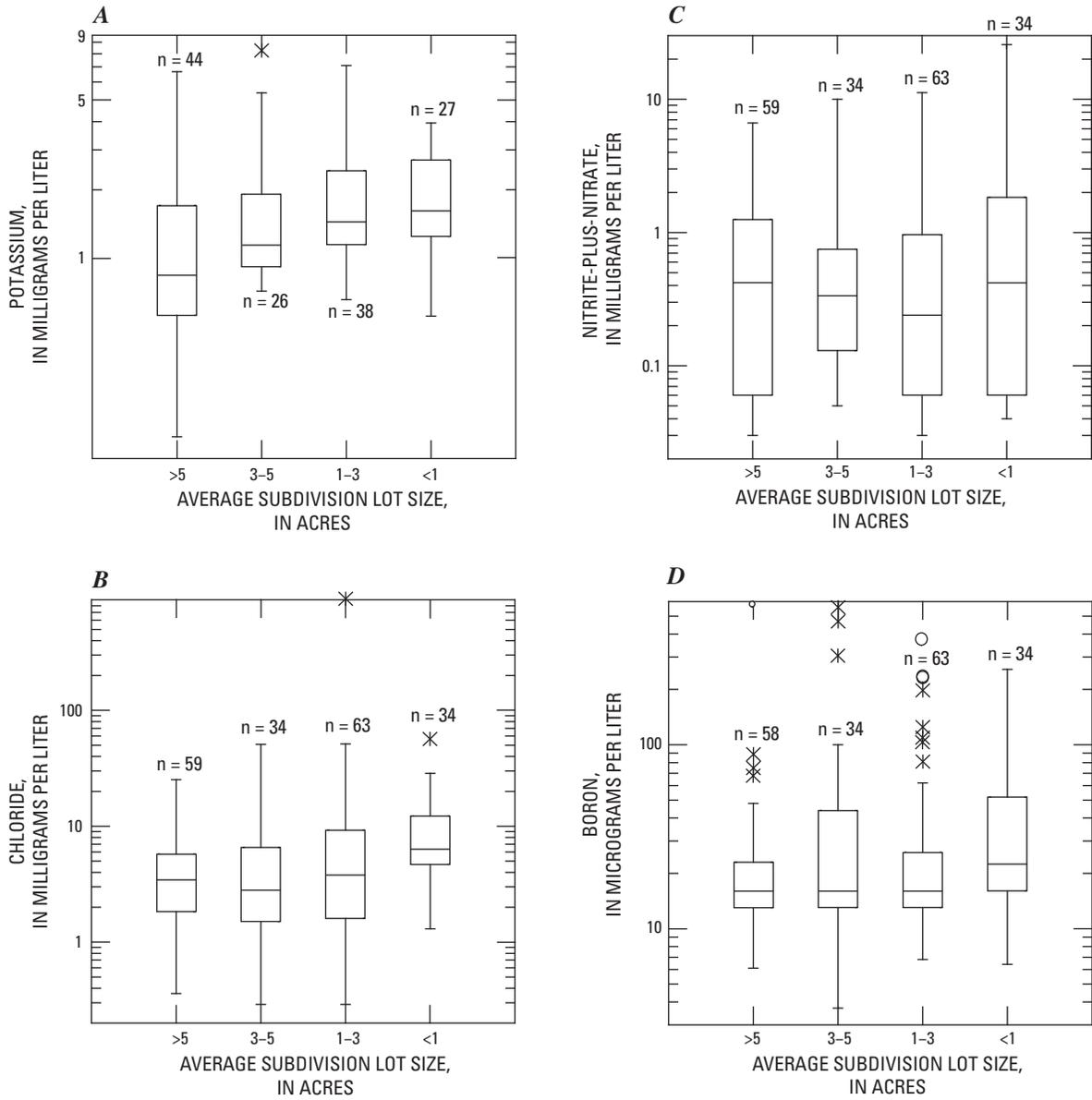


Figure 17. Distribution of chloride concentrations in samples collected from selected domestic wells in the Bailey area in 1974 and 2001.



EXPLANATION

n = 10 **Number of samples**—Total number may not equal number of samples; average subdivision lot size unknown for some wells

○ **Outlier value**

✱ **Outside value**

— **Largest value within 1.5 times the IQR**

75th percentile } **Interquartile Range (IQR)**

Median }

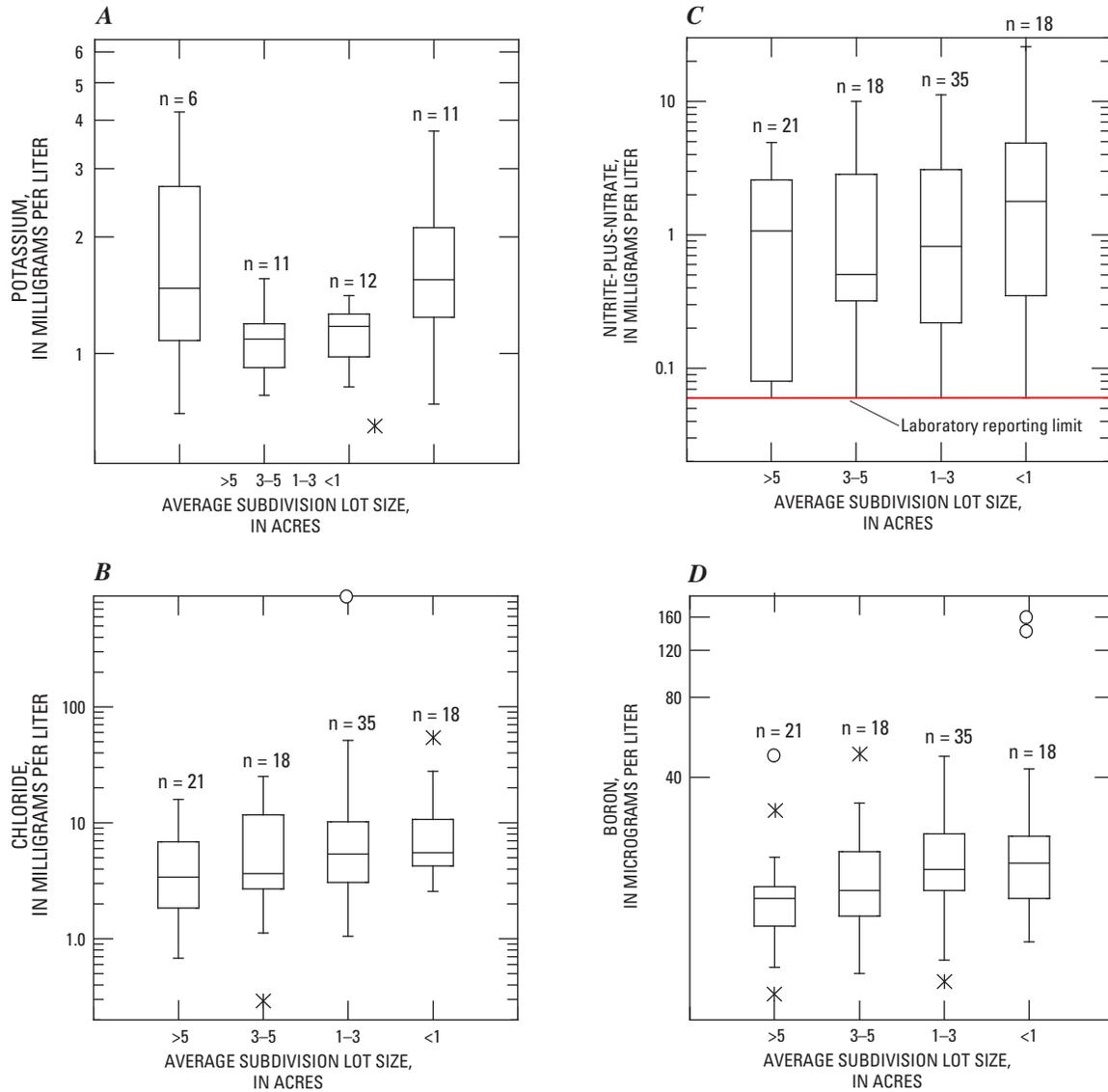
25th percentile }

— **Smallest value within 1.5 times the IQR**

< **Less than**

> **Greater than**

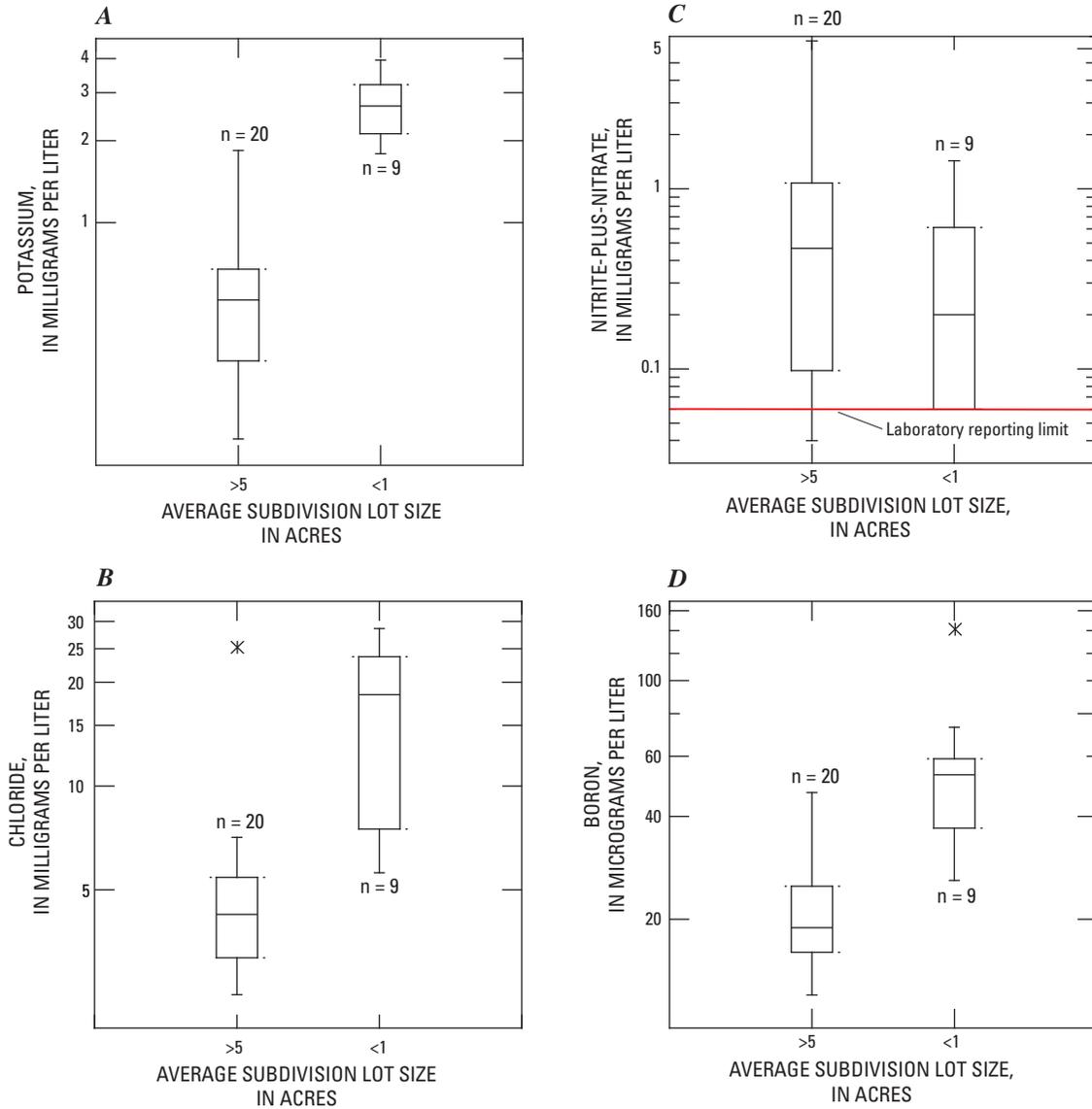
Figure 18. Distribution of (A) potassium, (B) chloride, (C) nitrite-plus-nitrate, and (D) boron concentrations in samples collected from domestic wells in Park County, Colorado, 2001–2004, in relation to average subdivision lot size.



EXPLANATION

- n = 10 **Number of samples**—Total number may not equal number of samples; average subdivision lot size unknown for some wells
- **Outlier value**
- ✱ **Outside value**
- **Largest value within 1.5 times the IQR**
- ▢ **75th percentile**
- **Median**
- ▢ **25th percentile**
- **Smallest value within 1.5 times the IQR**
- < **Less than**
- > **Greater than**

Figure 19. Distribution of (A) potassium, (B) chloride, (C) nitrite-plus-nitrate, and (D) boron concentrations in samples collected from wells completed in the crystalline-rock aquifers in Park County, Colorado, 2001–2004, in relation to average subdivision lot size.



EXPLANATION

- n = 10 **Number of samples**—Total number may not equal number of samples; average subdivision lot size unknown for some wells
- **Outlier value**
- ✱ **Outside value**
- | **Largest value within 1.5 times the IQR**
- ▭ **75th percentile**
- **Median**
- ▭ **25th percentile**
- **Interquartile Range (IQR)**
- | **Smallest value within 1.5 times the IQR**
- < **Less than**
- > **Greater than**

Figure 20. Distribution of (A) potassium, (B) chloride, (C) nitrite-plus-nitrate, and (D) boron concentrations in samples collected from wells completed in the volcanic-rock aquifers in Park County, Colorado, 2001–2004, in relation to average subdivision lot size.

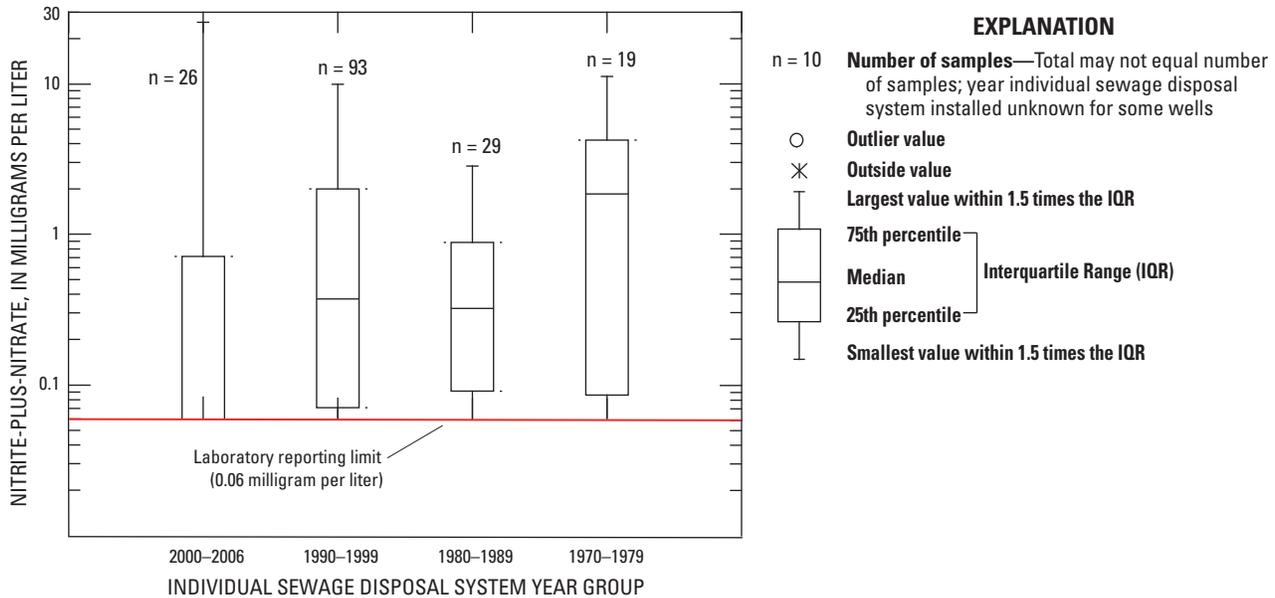


Figure 21. Relation of nitrite-plus-nitrate concentrations in samples collected from selected domestic wells to year of individual sewage disposal system installation, Park County, Colorado.

nitrite-plus-nitrate concentrations were not measured between wells with ISDS's installed in the 1980's compared to those with ISDS's installed in the 1990's (fig. 21). However, nitrite-plus-nitrate concentrations were significantly higher in wells with ISDS's installed in the 1990's than in wells with ISDS's installed from 2000 to 2006 (fig. 21). The highest nitrite-plus-nitrate concentrations were measured in wells with ISDS's installed before 1980. Nitrate concentrations may be higher in wells where ISDS's were installed before 1980 because effluent has had enough time to move through the unsaturated zone to the ground-water table in sufficient quantities to affect local ground-water quality. Other possibilities may be (1) ISDS's installed before 1980 may not be as effective at removing contaminants as those installed after 1980, or (2) ISDS's installed before 1980 are more likely to need major service or repairs than newer systems.

Ground-water-quality data collected from wells throughout Park County indicate that recharge from ISDS effluent has affected local ground-water systems; however, concentrations of constituents associated with ISDS effluent are low, and drinking-water quality is good throughout Park County with some exceptions. Data also indicate that ISDS density and year of ISDS installation are related to ground-water quality. In general, ground-water quality was least affected by ISDS's in areas that had average subdivision lot sizes greater than 5 acres, and most affected in areas that had average subdivision lot sizes less than 1 acre. Ground-water quality in wells with ISDS's installed before 1980 was most affected by ISDS effluent; and wells with ISDS's installed after 1999 were least affected by ISDS effluent.

Summary

In 2000, the U.S. Geological Survey, in cooperation with Park County, began a study to evaluate ground-water quality in the various aquifers in Park County that supply water to domestic wells. The focus of this study was to identify and describe the principal natural and human factors that affect ground-water quality. Of particular interest to health department officials, planners, and County Commissioners in Park County is the potential degradation of ground-water quality due to the increased number and density of individual sewage disposal systems (ISDS) installed throughout the county. As a result, in addition to providing a general assessment of ground-water quality in Park County, the potential effects of ISDS's on ground-water quality were evaluated.

As part of this study, ground-water-quality samples were collected from 224 existing domestic water-supply wells sampled from July 2001 through October 2004 in the alluvial, crystalline-rock, sedimentary-rock, and volcanic-rock aquifers in Park County. Almost all wells were sampled for physical properties (water temperature, pH, specific conductance, and dissolved oxygen), selected major ions, nutrients, and bacteria. Selected wells also were sampled for dissolved organic carbon, human-related (wastewater) compounds, radionuclides, and age-dating constituents (tritium and chlorofluorocarbons). The presence of specific human-related compounds such as fecal indicators, caffeine, detergent metabolites, cholesterol, and pharmaceuticals or elevated concentrations of bacteria or chemicals in ground waters were used to indicate

contamination of ground water from ISDS's. The overall sampling plan, in part, was designed to allow an evaluation of whether the density of development (proximity of wells and ISDS's) was a significant factor in potential degradation of ground-water quality.

The natural processes that affect ground-water quality and the potential for ground water to be affected by human activities such as wastewater discharge (ISDS effluent) are related to the age of the ground water. To determine the approximate time elapsed since recharge (apparent recharge date of the ground water) and thus the potential for a given sample to be affected by development, ground-water samples were collected from selected wells in the alluvial, crystalline-rock, sedimentary-rock, and volcanic-rock aquifers throughout Park County and analyzed for tritium and chlorofluorocarbons. Tritium concentrations greater than 10 picocuries per liter (pCi/L) in a sample indicate that at least some part of the recharge to the ground-water system occurred after 1954. About 75 percent of samples collected had tritium concentrations greater than 10 pCi/L. Generally, the highest tritium concentrations were measured in wells completed in the alluvial and crystalline-rock aquifers, and the lowest concentrations were measured in wells completed in the sedimentary- and volcanic-rock aquifers. Based on chlorofluorocarbon data, ground-water recharge dates in Park County range from the mid-1940's to modern water (2004). Chlorofluorocarbon and tritium data indicate that wells completed in the sedimentary-rock aquifers tended to have older waters than wells completed in the other aquifer-rock types (alluvial, crystalline, and volcanic) indicating that (1) infiltration of water through the sedimentary rocks is slower than other formations, (2) the ground-water flow paths are longer, or (3) that ground-water flow velocities are slower.

Many of the wells sampled in Park County probably have a mixture of water from several parts of the aquifer system that may have different recharge areas, flow paths, and ground-water recharge dates. Because most of the development in Park County has occurred since 1990 and only about 8 percent of wells sampled for chlorofluorocarbons had ground-water recharge dates after 1990, there may not have been enough elapsed time for effluent water from ISDS's to noticeably affect sampled ground-water quality. About 47 percent of wells sampled for age-dating constituents and wastewater compounds had detectable quantities of wastewater compounds. Detections of wastewater compounds in ground water indicate that these compounds are not being completely removed by ISDS's or the unsaturated zone. Because roughly 90 percent of domestic water used is assumed to be recharged by ISDS's, detections of wastewater compounds in ground water in Park County are not surprising.

Data collected as part of this study were compared to the U.S. Environmental Protection Agency's primary and secondary drinking-water standards to assess the general quality of the ground water in the study area for domestic use even

though the drinking-water standards only apply to public water systems. Primary drinking-water standards are legally enforceable standards that are put in place to protect public health by limiting the levels of contaminants in drinking water. Secondary drinking-water regulations are nonenforceable guidelines regulating contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water.

Ground-water quality is related to natural factors (resulting from the interaction of water with the soil and mineralogy of the various geologic formations as it infiltrates to the water table) and to human factors. Because elevated concentrations of some constituents are more related to natural factors and others are more related to human factors, constituents that exceeded drinking-water standards were grouped accordingly. Secondary drinking-water standards for pH, fluoride, sulfate, and dissolved solids, primary drinking-water standards for fluoride and uranium, and proposed drinking-water standards for radon were exceeded in one or more samples collected from domestic wells in Park County most likely because of natural factors.

Only about 2 percent of measured pH values were outside of the national secondary drinking-water regulation's secondary maximum contaminant level range for pH of 6.5 to 8.5. Values of pH less than 6.5 standard units were measured only in wells in the Pikes Peak Granite (crystalline-rock aquifer) in the vicinity of Bailey. However, not all pH values in samples from wells in the Pikes Peak Granite were low. Low pH values in some wells may indicate that ground-water flow (or perhaps recharge) is more rapid and has less contact time with geologic units, in certain areas of the Pikes Peak Granite. This lesser contact time may occur because of thinner soils and (or) a higher percentage of fractures to transport water. In these areas, the pH of the ground water may be closer to the pH of the precipitation that recharges the aquifer.

Only one sample collected from a well completed in the Pikes Peak Granite near Lake George exceeded the primary drinking-water standard for fluoride of 4.0 milligrams per liter (mg/L); however, fluoride concentrations in about 12 percent of samples throughout Park County exceeded the secondary drinking-water standard of 2.0 mg/L. All samples with fluoride concentrations equal to or greater than 2.0 mg/L were collected from wells completed in the crystalline-rock aquifers near Bailey and Lake George; 93 percent of these samples (with fluoride concentrations greater than or equal to 2.0 mg/L) were collected from wells completed in the Pikes Peak Granite.

Sulfate concentrations ranged from 2.4 to 1,760 mg/L, and the median concentration was 18 mg/L. The highest concentrations of sulfate generally were measured in wells in the sedimentary-rock aquifers near the Park County county line southwest of Hartsel and between Alma and Fairplay. Most of the wells that exceeded the secondary maximum contaminant level of 250 mg/L for sulfate also exceeded the secondary maximum contaminant level of 500 mg/L for dissolved solids.

About 5 percent of the samples had concentrations of sulfate that exceeded the secondary maximum contaminant level of 250 mg/L, and about 4 percent of these samples had sulfate concentrations greater than 500 mg/L, more than twice the secondary maximum contaminant level level.

Elevated concentrations of dissolved solids in Park County wells probably are mostly from natural sources. However, some elevated concentrations of dissolved solids in the Bailey and Guffey areas may result from contamination by ISDS's, because chloride and nitrite-plus-nitrate concentrations in these ground-water samples were considerably higher than concentrations in samples collected from surrounding wells. Concentrations of dissolved solids measured in samples ranged from 49 to 2,810 mg/L. The secondary maximum contaminant level for dissolved solids (500 mg/L) was exceeded in about 7 percent of samples, mostly in samples collected from wells completed in the sedimentary-rock aquifer. Dissolved-solids concentrations in about 4 percent of the samples were greater than 1,000 mg/L (twice the secondary maximum contaminant level).

Currently (2004), there is no federally enforced drinking-water standard for radon in public water-supply systems, but proposed regulations indicate a maximum contaminant level of 300 pCi/L and an alternative maximum contaminant level of 4,000 pCi/L (contingent upon other mitigating remedial activities to reduce concentrations of radon in indoor air). Radon concentrations in ground-water samples in Park County ranged from 40 to 19,200 pCi/L. Radon concentrations in about 91 percent of ground-water samples collected from domestic wells throughout Park County were greater than or equal to 300 pCi/L, and about 25 percent had radon concentrations greater than or equal to 4,000 pCi/L. Generally, the highest radon concentrations were measured in samples collected from wells completed in the crystalline-rock aquifers, and the lowest concentrations were measured in samples collected from wells completed in the volcanic-rock aquifers.

The current (2004) MCL for uranium of 30 micrograms per liter ($\mu\text{g/L}$) in drinking water was exceeded in two samples collected from wells completed in the crystalline-rock aquifer. Uranium concentrations in samples ranged from less than 1.0 to 48 $\mu\text{g/L}$. The highest uranium concentrations generally were measured in wells completed in the crystalline-rock aquifers, and the lowest concentrations generally were measured in wells completed in the volcanic-rock aquifers.

National secondary drinking-water standards for chloride and primary drinking-water standards for nitrate, total coliform bacteria, and *E. coli* bacteria were exceeded in one or more samples collected from domestic wells in Park County. Chloride concentrations in ground-water samples ranged from 0.28 to 873 mg/L; 75 percent of measured concentrations were less than 7 mg/L, and 90 percent were less than 13 mg/L. The secondary maximum contaminant level of 250 mg/L for chloride was exceeded in only one sample collected from a well completed in the crystalline-rock aquifer near Bailey. All other measured chloride concentrations were at least an order of magnitude less than the secondary maximum contaminant level.

Concentrations of nitrite-plus-nitrate in about 2 percent of samples equaled or exceeded the maximum contaminant level of 10 mg/L for nitrate. All of these samples were collected from wells in the crystalline-rock aquifer near Bailey. Generally, the highest nitrite-plus-nitrate concentrations in the county were measured in ground-water samples collected from wells near the towns of Bailey and Guffey. The median nitrite-plus-nitrate concentration for samples collected throughout Park County during this study was 0.34 mg/L.

E. coli bacteria were detected in one well near Guffey; whereas, total-coliform bacteria were detected in about 11 percent of wells sampled throughout Park County. Concentrations of total coliform in samples ranged from near the reporting level of 1 colony per 100 milliliters of water to an estimated 340 colonies per 100 milliliters of sample. The highest total-coliform concentrations were measured southeast of Jefferson and west of Tarryall Reservoir. Total-coliform concentrations and the frequency of detections in the crystalline-rock aquifer wells in the Bailey area were higher in samples collected during 1974 than in samples collected during this study (the Bailey area was sampled during 2001).

Overall, ground water throughout Park County is suitable for domestic drinking water. Only about 3 percent of wells had concentrations of fluoride, nitrate, and (or) uranium that exceeded a primary drinking-water standard. These primary drinking-water standards were exceeded only in wells completed in the crystalline-rock aquifers. Secondary standards were exceeded more frequently. About 19 percent of wells had concentrations of one or more constituents that exceeded secondary drinking-water standards.

Chemicals from products that are used in households can enter the ground-water system as a more concentrated effluent from an ISDS than from natural sources. Persistent detections or elevated concentrations of bacteria also may indicate contamination from an ISDS, especially if detections of bacteria also are accompanied by detections of wastewater compounds or elevated concentrations of other chemicals.

Wastewater compounds were detected in 46 percent of samples collected from wells in Park County. Thirty-eight different organic wastewater compounds were detected in ground-water samples, and most at low concentrations at or near the laboratory reporting levels. The number of wastewater compounds detected per sample ranged from 1 to 17 compounds. The most frequently detected wastewater compounds were phenol, bisphenol A, isophorone, 4-nonylphenol, and tris(2-chloroethyl) phosphate. Phenol was detected in 28 percent of the samples. Bisphenol A was detected in 24 percent of ground-water samples. Isophorone was detected in 9 percent of the samples, and 4-nonylphenol and tris(2-chloroethyl) phosphate were detected in 8 percent of samples.

The co-occurrence of multiple constituents possibly associated with ISDS effluent (such as bacteria, wastewater compounds, and elevated concentrations of nitrate, chloride, or boron) in a single sample can provide strong evidence of contamination by an ISDS. Chloride and boron concentrations were significantly higher ($p\text{-value} < 0.05$) in samples collected from wells with detections of wastewater compounds than in

wells with no detections of wastewater compounds. However, nitrite-plus-nitrate concentrations were not significantly different between wells with detections of wastewater compounds and those with no detections.

Changes in nitrite-plus-nitrate and chloride concentrations in the Bailey area over time probably are related to a larger part of the overall recharge being from ISDS effluent either as a result of an increase in ISDS density or more time for recharge from ISDS effluent to reach the ground-water table. Concentrations of nitrite-plus-nitrate (p-value = 0.0002) and chloride (p-value = 0.0006) were significantly higher in ground-water samples collected during 2001 than in 1974. The median nitrite-plus-nitrate concentration measured during 1974 was 0.82 mg/L compared to 2.58 mg/L for samples collected during this study (2001), and the median chloride concentration measured during 1974 was 3.4 mg/L compared to 7.75 mg/L measured during 2001.

Throughout Park County the average subdivision lot size was used as a surrogate for ISDS density. Chloride and boron concentrations were significantly higher in ground-water samples collected from wells located in areas that had average subdivision lot sizes less than 1 acre than in wells located in areas that had average subdivision lot sizes equal to or greater than 1 acre. Median potassium concentrations increased as average subdivision lot size decreased; however, statistically significant (p-value < 0.05) increases in potassium concentrations only occurred between wells located in areas that had average lot sizes less than or equal to 5 acres and wells located in areas that had average lot sizes greater than 5 acres.

Wells were grouped by aquifer rock type (alluvial, crystalline-rock, sedimentary-rock, and volcanic-rock) and then by average subdivision lot size. Too few samples were collected from alluvial aquifer wells to determine if differences in constituent concentrations were present between lot-size categories. For wells completed in the crystalline-rock aquifers, median boron and chloride concentrations increased as average subdivision lot size decreased. However, statistically significant (p-value < 0.05) increases in concentrations of boron were detected only between wells located in areas that had average subdivision lot sizes less than 1 acre and wells located in areas that had average subdivision lot sizes greater than 3 acres. Significant increases in chloride concentrations were detected only between wells located in areas that had average subdivision lot sizes less than 1 acre and wells located in areas that had average subdivision lot sizes greater than 5 acres. No significant increases in constituent concentrations were observed in wells completed in the sedimentary-rock aquifers for any lot-size category. In the volcanic-rock aquifers, wells were sampled only in areas that had average subdivision lot sizes less than 1 acre or greater than 5 acres. Potassium, chloride, and boron concentrations were significantly higher in wells located in areas that had average subdivision lot sizes of less than 1 acre than in areas with average subdivision lot sizes greater than 5 acres in the volcanic-rock aquifers.

Significant increases in nitrite-plus-nitrate concentrations were observed between wells with ISDS's installed in the 1970's and wells with ISDS's installed in the 1980's.

Significantly higher nitrite-plus-nitrate concentrations were not observed between wells with ISDS's installed in the 1980's and wells with ISDS's installed in the 1990's. The lowest overall nitrite-plus-nitrate concentrations were measured in wells that had ISDS's installed after 1999. Nitrite-plus-nitrate concentrations may be higher in samples collected from wells with ISDS's installed before 1980 because effluent has had enough time to move through the unsaturated zone to the ground-water table in sufficient quantities to affect ground-water quality. Other possibilities may be (1) ISDS's installed before 1980 may not be as effective at removing contaminants as those installed after 1980, or (2) ISDS's installed before 1980 are more likely to need major service or repairs.

Ground-water-quality data collected from wells throughout Park County indicate that recharge from ISDS effluent has affected local ground-water systems; however, concentrations of constituents associated with ISDS effluent are low, and drinking-water quality is good throughout Park County with some exceptions. Data also indicate that ISDS density and year of ISDS installation are related to ground-water quality. In general, ground-water quality was least affected by ISDS's in areas that had average subdivision lot sizes greater than 5 acres, and most affected in areas that had average subdivision lot sizes less than 1 acre. Ground-water quality in wells with ISDS's installed before 1980 was most affected by ISDS effluent, and wells with ISDS's installed after 1999 was least affected. As time passes, recharge from ISDS's may become a larger part of the ground-water resource; and, as a result, concentrations of nitrate, chloride, boron, and other constituents associated with ISDS effluent also are likely to increase in ground water.

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