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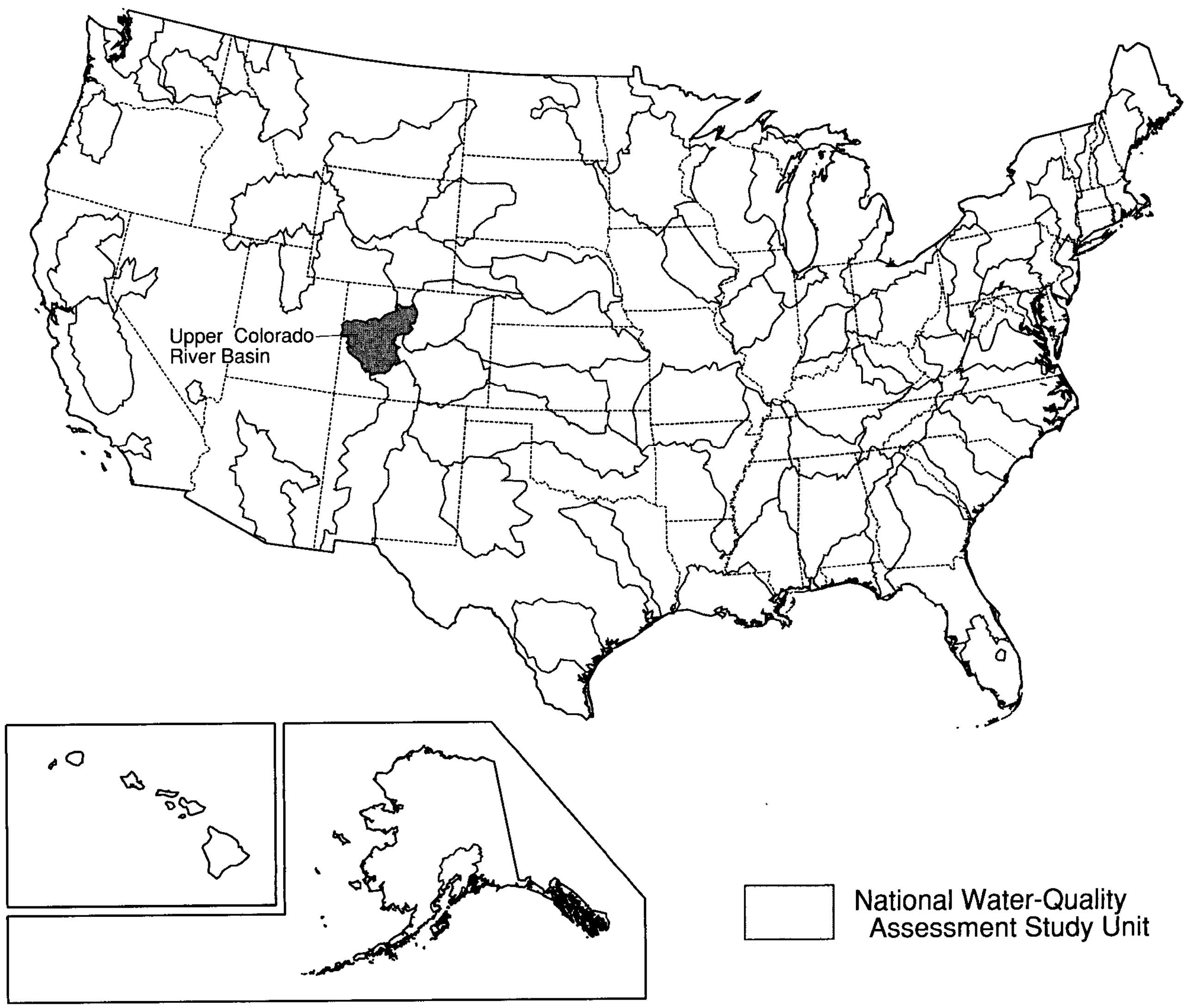
Analysis of Ground-Water-Quality Data of the Upper Colorado River Basin, Water Years 1972–92



U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 97–4240

NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

Analysis of Ground-Water-Quality Data of the Upper Colorado River Basin, Water Years 1972–92

By Lori E. Apodaca

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 97–4240

Denver, Colorado
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FOREWORD

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

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

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

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

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

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

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

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

Robert M. Hirsch

Robert M. Hirsch
Chief Hydrologist

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
foot (ft)	0.3048	meter
inch per year (in/yr)	25.4	millimeter per year
mile (mi)	1.609	kilometer
million gallons per day (Mgal/d)	0.04381	cubic meter per second
square mile (mi^2)	2.59	square kilometer

Degree Celsius (°C) may be converted to degree Fahrenheit (°F) by using the following equation:
°F = 9/5 (°C) + 32.

The following abbreviations also are used in this report:

mg/L milligram per liter
µg/L microgram per liter
MCL Maximum Contaminant Level
PMCL Proposed Maximum Contaminant Level
SMCL Secondary Maximum Contaminant Level
as N as quantified as measured nitrogen
as P as quantified as measured phosphorus

Analysis of Ground-Water-Quality Data of the Upper Colorado River Basin, Water Years 1972–92

By Lori E. Apodaca

Abstract

As part of the U.S. Geological Survey's National Water-Quality Assessment program, an analysis of the existing ground-water-quality data in the Upper Colorado River Basin study unit is necessary to provide information on the historic water-quality conditions. Analysis of the historical data provides information on the availability or lack of data and water-quality issues. The information gathered from the historical data will be used in the design of ground-water-quality studies in the basin. This report includes an analysis of the ground-water data (well and spring data) available for the Upper Colorado River Basin study unit from water years 1972 to 1992 for major cations and anions, metals and selected trace elements, and nutrients. The data used in the analysis of the ground-water quality in the Upper Colorado River Basin study unit were predominantly from the U.S. Geological Survey National Water Information System and the Colorado Department of Public Health and Environment data bases. A total of 212 sites representing alluvial aquifers and 187 sites representing bedrock aquifers were used in the analysis. The available data were not ideal for conducting a comprehensive basinwide water-quality assessment because of lack of sufficient geographical coverage.

Evaluation of the ground-water data in the Upper Colorado River Basin study unit was based on the regional environmental setting, which describes the natural and human factors that can affect the water quality. In this report, the ground-water-quality information is evaluated on the basis of aquifers or potential aquifers (alluvial, Green River Formation, Mesaverde Group, Mancos Shale, Dakota Sandstone, Morrison Formation, Entrada Sandstone, Leadville Limestone, and Precambrian) and land-use classifications for alluvial aquifers.

Most of the ground-water-quality data in the study unit were for major cations and anions and dissolved-solids concentrations. The aquifer with the highest median concentrations of major ions was the Mancos Shale. The U.S. Environmental Protection Agency secondary maximum contaminant level of 500 milligrams per liter for dissolved solids in drinking water was exceeded in about 75 percent of the samples from the Mancos Shale aquifer. The guideline by the Food and Agriculture Organization of the United States for irrigation water of 2,000 milligrams per liter was also exceeded by the median concentration from the Mancos Shale aquifer. For sulfate, the U.S. Environmental Protection Agency proposed maximum contaminant level of 500 milligrams per liter for drinking water was exceeded by the median concentration for the Mancos Shale aquifer. A total of 66 percent of the sites in the Mancos Shale aquifer exceeded the proposed maximum contaminant level.

Metal and selected trace-element data were available for some sites, but most of these data also were below the detection limit. The median concentrations for iron for the selected aquifers and land-use classifications were below the U.S. Environmental Protection Agency

secondary maximum contaminant level of 300 micrograms per liter in drinking water. Median concentration of manganese for the Mancos Shale exceeded the U.S. Environmental Protection Agency secondary maximum contaminant level of 50 micrograms per liter in drinking water. The highest selenium concentrations were in the alluvial aquifer and were associated with rangeland. However, about 22 percent of the selenium values from the Mancos Shale exceeded the U.S. Environmental Protection Agency maximum contaminant level of 50 micrograms per liter in drinking water.

Few nutrient data were available for the study unit. The only nutrient species presented in this report were nitrate-plus-nitrite as nitrogen and orthophosphate. Median concentrations for nitrate-plus-nitrite as nitrogen were below the U.S. Environmental Protection Agency maximum contaminant level of 10 milligrams per liter in drinking water except for 0.02 percent of the sites in the alluvial aquifer and 0.03 percent of the sites in the Mancos Shale. Concentrations of orthophosphate did not vary significantly among aquifers or land-use classifications.

Historic water-quality data from wells and springs helped to characterize the regional distribution of ground-water quality information in the Upper Colorado River Basin study unit. The historical ground-water data summarized in this report will be used in the design of a ground-water-quality network. Because ground-water-quality issues in the study unit are related to high dissolved solids, sulfate, selenium, and nutrients, this report discusses some of the important findings related to these issues.

INTRODUCTION

The Upper Colorado River Basin is 1 of 59 study units selected for the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) program. The NAWQA program began full implementation in 1991 to: (1) Describe water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers; (2) describe how water quality is changing over time; and (3) improve the understanding of the primary natural and human factors that affect water-quality conditions (Leahy and others, 1990). Information obtained from the selected study units would be applied in the management, regulatory, and monitoring decisions made by other Federal, State, and local agencies to better protect, use, and enhance water resources.

Assessment of the Upper Colorado River Basin study unit began in 1994 and was designed on the basis of the environmental setting, which includes the natural and human factors that affect water quality in the study unit (Apodaca and others, 1996). One of the first activities for the Upper Colorado River Basin study unit is to analyze existing water-quality data to develop a conceptual model of water-quality conditions, provide a historical perspective of the water quality in a study unit, and summarize the current understanding of various water-quality issues and relate them to the natural and human factors that affect water quality. Analysis of existing ground-water data, as related to the environmental setting, helps to describe the availability or lack of data and the water-quality issues in the basin. The information gathered will be used in the sampling design of the ground-water component of the program.

Purpose and Scope

This report provides information on the historic ground-water-quality conditions in the Upper Colorado River Basin study unit. Water-quality data from wells and springs were analyzed to characterize the regional distribution of ground-water quality in the Upper Colorado River Basin study unit. Because of limited geographic coverage of the water-quality data, it is difficult to conduct a comprehensive basinwide water-quality assessment. The water-quality data for major ions, metals and selected trace elements, and nutrients were evaluated on the basis of the environmental setting that defines the physiographic, geologic, hydrologic, land-use, and water-use characteristics of the study unit (Apodaca and others, 1996). The ground-water-quality data in this report are described on the basis of aquifers (Apodaca and others, 1996) and for alluvial aquifers on the basis of land use and depth. Changes in the concentration of a particular constituent with depth is important when evaluating the effects of surficial processes (land use) on the water quality.

An analysis of ground-water-quality data collected in the study unit from water years 1972 to 1992 by the U.S. Geological Survey and the Colorado Department of Public Health and Environment also is presented. A total of 399 well and spring sites were used in the analysis of the ground-water data collected in the study unit, with 212 sites representing alluvial aquifers and 187 sites representing bedrock aquifers. Water-quality data in the study unit were available for most of the major ions, whereas few data were available for metals, trace elements, and nutrients. This report contains: (1) A description of sources of ground-water-quality data; (2) a description of the approach used in screening the data; (3) a presentation of statistical and graphical representations of the water-quality data by major aquifers, land use, and depth; and (4) a comparison of water-quality conditions to established national water-quality criteria, where applicable. The data show the central tendencies and typical variations in the data. Information from this report will be used to select ground-water sites for additional water-quality assessment in the study unit.

Acknowledgments

The author wishes to acknowledge and thank the personnel and agencies that provided ground-water-quality information and data for the study unit: Coll Stanton of the Bureau of Reclamation; William Crick of the Colorado Department of Public Health and Environment; Bahman Hatami of the Colorado Water Conservation Board; and Donald Metzler of the U.S. Department of Energy.

DESCRIPTION OF THE UPPER COLORADO RIVER BASIN STUDY UNIT

To understand ground-water quality in the Upper Colorado River Basin, the natural and human factors in the study unit that can affect water quality need to be determined. Apodaca and others (1996) have described some of these factors that define the environmental setting of the study unit. Natural factors that can affect water-quality conditions are climate and geology. Human factors that can affect water-quality conditions are land use and water use.

The study unit has a drainage area of about 17,800 mi^2 in Colorado and Utah; all but 100 mi^2 of this area is located in Colorado (fig. 1). The area includes the upper Colorado and the Gunnison hydrologic subregions or drainage areas (U.S. Geological Survey, 1976). The study unit is divided into two physiographic provinces: the Southern Rocky Mountains in the eastern part and the Colorado Plateau in the western part (Hunt, 1974). The major river in the study unit is the Colorado River, which originates in the mountainous areas of central Colorado and flows for about 230 mi southwest into Utah. The main tributaries of the Colorado River are the Blue, Eagle, Roaring Fork, and Gunnison Rivers.

Climate in the study unit varies from alpine conditions in the east to semiarid conditions in the west primarily because of changes in land-surface altitude. Precipitation in the study unit ranges from greater than 40 in/yr in the mountainous regions near the Continental Divide to less than 10 in/yr in the western plateau regions. The Continental Divide marks the eastern and southeastern boundaries of the study unit.

Rocks underlying the study unit primarily are consolidated sedimentary units, and igneous and metamorphic rocks compose most of the higher mountainous regions (fig. 2). Aquifers in the study unit are in consolidated or unconsolidated hydrologic units. Some of the important aquifers or potential aquifers in western Colorado, in order of increasing age of the formations, are valley-fill alluvial deposits, Green River Formation, Mesaverde Group, Mancos Shale, Dakota Sandstone, Morrison Formation, Entrada Sandstone, Leadville Limestone, and Precambrian crystalline rocks (U.S. Geological Survey, 1985; Chaney and others, 1987; Apodaca and others, 1996). Ground-water resources in the study unit have not been extensively developed, and information as to the extent of these aquifers is sparse. However, domestic water in rural areas is supplied almost entirely from ground-water sources (Colorado Department of Public Health and Environment, 1994). The most productive wells are completed in alluvial aquifers consisting of unconsolidated sand and gravel in stream or terrace deposits. The locations of some of the more prominent alluvial aquifers and alluvial deposits in the study unit are shown in figure 3.

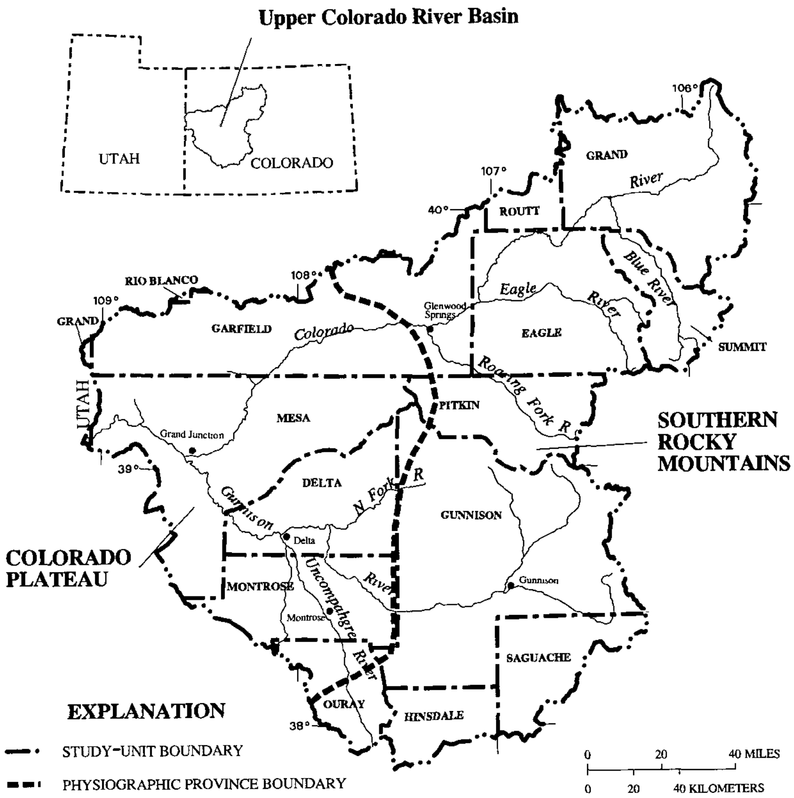

Figure 1. Location of the Upper Colorado River Basin study unit and physiographic provinces (Gallant and others, 1989).

About 85 percent of the land use in the study unit is designated as rangeland or forest (fig. 4). Agriculture (crops and livestock) and mining (mineral and energy) traditionally have been the most important economic activities in the study unit. A majority of the metal mining in the basin is located in the forested areas. However, the economy in the study unit has been greatly enhanced by tourism, which is a year-round activity. Urban and built-up land use is one of the smaller land uses in the study unit. Population in 1990 in the study unit was about 234,000 and predominantly was located in rural communities (Bureau of Census, 1990). The largest population center is near Grand Junction, Colo., in the western part of the study unit.

Water used in the study unit is predominantly surface water. Ground-water sources accounted for less than 1 percent of the water used (D.W. Litke, U.S. Geological Survey, written commun., 1995). The principal water use in the study unit is for irrigation, which accounts for about 97 percent of the offstream water use. The remaining 3 percent includes, in order of decreasing water use: livestock, domestic, power, industrial, commercial, and mining. Estimated offstream water use in the study unit during 1990 totaled about 3,500 Mgal/d (D.W. Litke, U.S. Geological Survey, written commun., 1995).

Water quality in the study unit is affected by all the components of the environmental setting such as climate, geology, land use, and water use. Water-quality issues in the study unit include: high concentrations of dissolved solids and trace elements from natural sources; high concentrations of nutrients, dissolved solids, trace elements, and pesticides from nonpoint- and point-agricultural sources; acidic water and metal contaminants from metal-mining activities; and nutrients and organic compounds from increasing urban development (Apodaca and others, 1996). Previous studies in the study unit have focused on the salinity (dissolved solids) and selenium concentrations in the ground water (Warner and others, 1985; Butler and others, 1994; Butler and others, 1996).

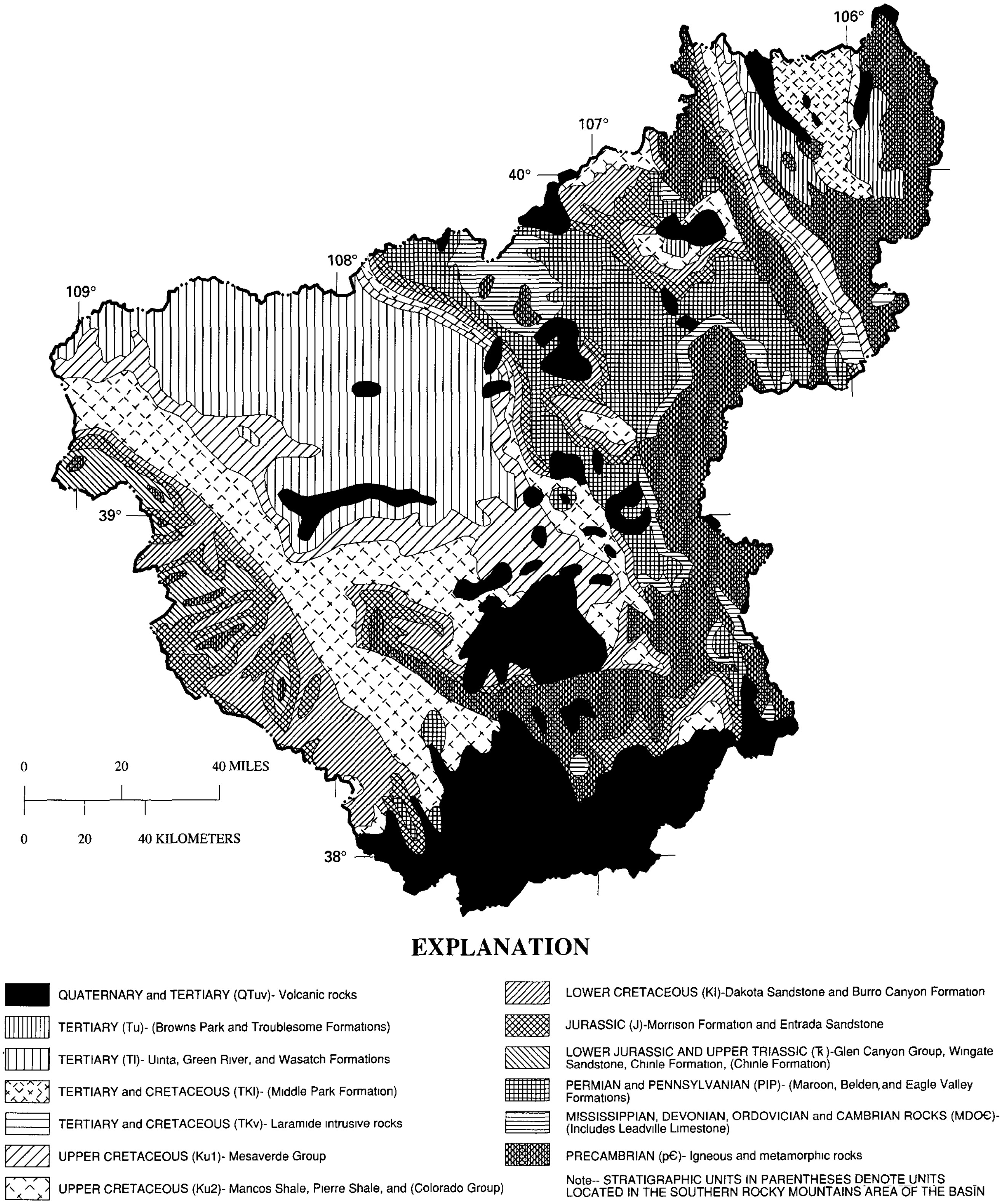

Figure 2. Generalized bedrock geology of the Upper Colorado River Basin study unit (modified from Schruben and others, 1994; Tweto, 1979).

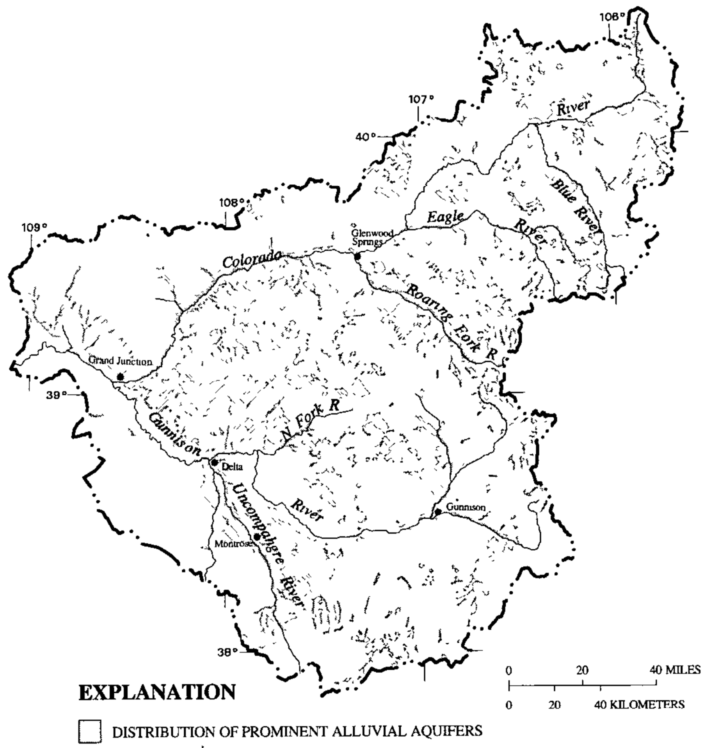

Figure 3. Locations of prominent alluvial aquifers in the Upper Colorado River Basin study unit (Tweto, 1979; Green, 1992).

SOURCES OF AVAILABLE GROUND-WATER-QUALITY DATA

Ground-water data have been collected in the study unit by a number of organizations for a variety of projects, each project with its specific study designs and sampling procedures. Some of the organizations include the Bureau of Reclamation; Colorado Department of Public Health and Environment (CDPHE); Colorado Division of Water Resources, Office of the State Engineer; U.S. Department of Energy; and U.S. Geological Survey. To obtain information on ground-water-quality data in the study unit, Federal, State, and local government agencies were contacted directly to locate these data.

The available data were not ideal for conducting a comprehensive basinwide water-quality assessment because of lack of sufficient geographical coverage. Most of the available data were from the western part of the study unit. Ground-water-quality data for alluvial and bedrock aquifers were extremely sparse in the Southern Rocky Mountains physiographic province, especially upstream from the Roaring Fork River in the northeastern part of the study unit (figs. 5 and 6). Also, the information obtained from the various agencies was inconsistent as to constituents analyzed and in sampling techniques; therefore these data sets could not be combined. The data presented in this report are not necessarily a complete collection of water-quality data for the study unit because more intensive localized studies may have been carried out; however, the intent of the report is to provide an overview of ground-water quality in the study unit based on evaluation of data available in digital form.

The primary source of ground-water-quality data for this report was the U.S. Geological Survey's National Water Information System (NWIS) data base (water years 1972–92; 172 sites representing alluvial aquifers and 187 sites representing bedrock aquifers) (figs. 5 and 6). Additional ground-water-quality information was obtained from the CDPHE. That data set represented 40 alluvial-aquifer well sites sampled in 1992 in the western part of the study unit (fig. 5).

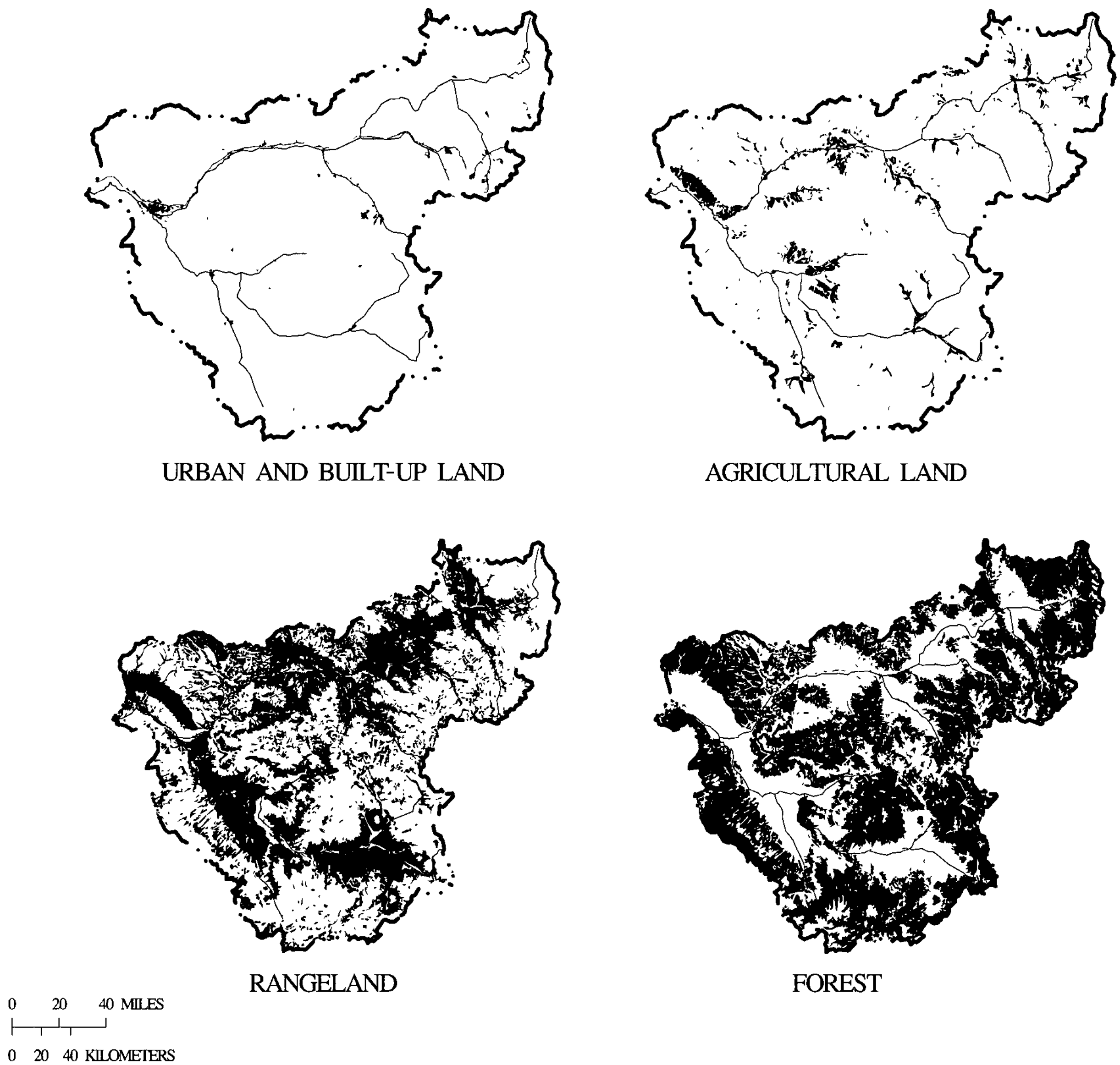

Figure 4. Major land uses in the Upper Colorado River Basin study unit (Anderson and others, 1976).

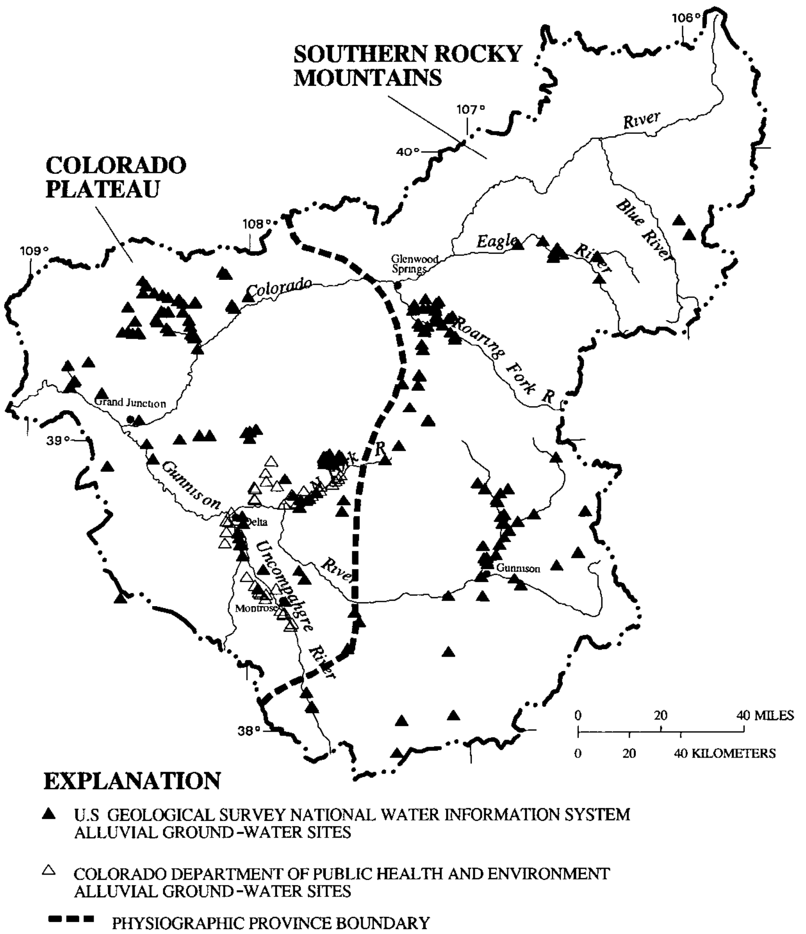

Figure 5. Locations of selected ground-water-quality sites for alluvial aquifers in the Upper Colorado River Basin study unit, water years 1972–92.

DATA-SELECTION CRITERIA AND SCREENING PROCEDURES

Analyses of concentrations of major cations and anions, metals and selected trace elements, and nutrients were from filtered (dissolved) samples. For well and spring sites that had more than one analysis, the mean value was used in the data interpretation. A large percentage of the metal, trace-element, and nutrient data contained analytical values less than detection (censored data), and many sites lacked these constituents. If a site contained only one value that was less than the detection level for a particular constituent, the censored value was used in the data interpretation. Also, if data from well sites had more than one analysis with censored and uncensored data, a mean value then was calculated using the censored values and uncensored values.

For the nonparametric statistical calculations, all values less than the analytical reporting level were treated with equal ranking. Summary statistics of the data for a particular constituent with multiple detection limits were calculated using robust log-probability regression (Helsel and Cohn, 1988). This method combines the observed data and the data below the detection value, assuming a distributional shape, in order to compute estimates of the summary statistics (Helsel, 1990). An advantage to this method is that transform biasing of the data is eliminated as the summary statistics are calculated using the original data. Data were quality assured by examining the differences between the total-cation and total-anion concentrations. Differences between total-cation and total-anion concentrations of greater than 10 percent were excluded from this analysis of ground-water-

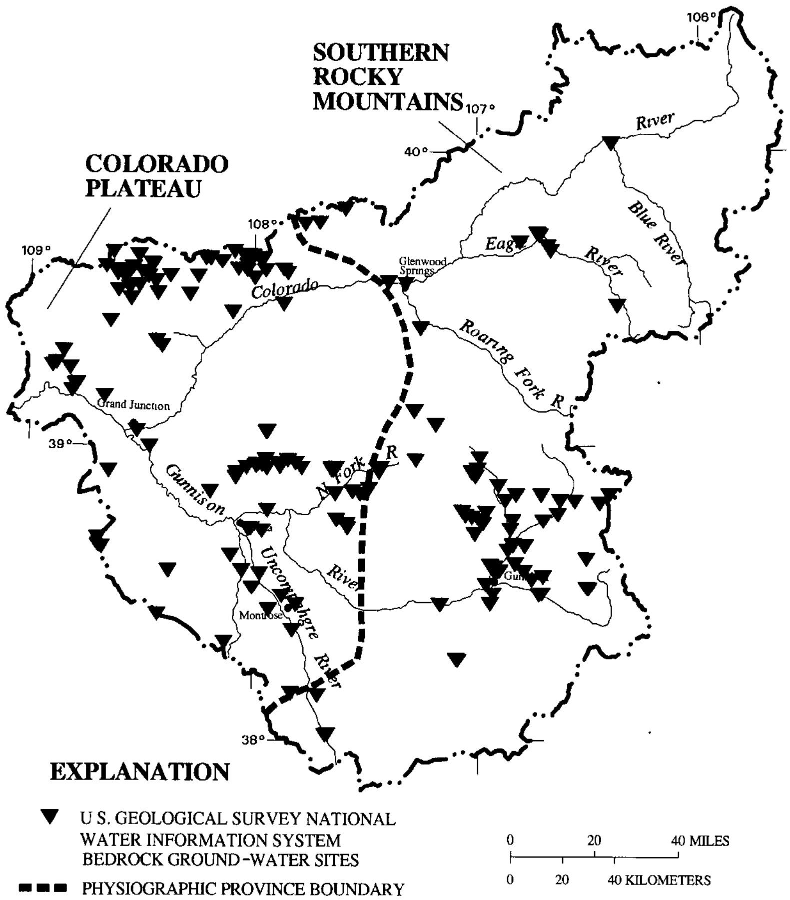

Figure 6. Locations of selected ground-water-quality sites for bedrock aquifers in the Upper Colorado River Basin study unit, water years 1972–92.

quality data. Data from wells and springs were used in the data interpretation if the aquifer information was available.

The data in this report are presented by aquifer and by land use and depth. For alluvial aquifers, land use was obtained by converting the ground-water-quality data files of the site locations to Geographic Information System (GIS) data files. The data coverage was overlaid on the GIS land-use coverage to correlate site location to a specific land use (agricultural, forest, rangeland, or urban and built-up) (fig. 4). Changes in concentration of selected water-quality constituents were related to a well depth of no more than 140 ft, because the thickness of the alluvial deposits in the study unit rarely exceeds 200 ft, and most often is less than 100 ft (Brooks and Ackerman, 1985).

Concentrations of selected constituents examined in this report were compared to the primary (MCL), secondary (SMCL), and proposed (PMCL) U.S. Environmental Protection Agency maximum contaminant levels established for drinking water (U.S. Environmental Protection Agency, 1996). MCL's are health related and legally enforceable, whereas SMCL's apply to the aesthetic qualities of water and are recommended levels. PMCL's are proposed levels that are not currently enforceable. The Food and Agriculture Organization of the United States (FAO) has developed guidelines that determine acceptable water-quality criteria for water used in the irrigation of crops (Kandiah, 1987). The concentrations of selected constituents evaluated in this report also were compared to these FAO guidelines for irrigation water.

GROUND-WATER QUALITY

Ground-water-quality data, including properties (specific conductance, pH, water temperature, dissolved oxygen, hardness, alkalinity, and dissolved solids) and constituents (major cations and anions, metals and selected trace elements, and nutrients) are statistically summarized by aquifer in table 1 and by land-use classification (agricultural, forest, rangeland, and urban and built-up) in table 2. Piper or trilinear diagrams are presented to indicate the predominant cation and anion concentrations for each aquifer (fig. 7). These diagrams are useful for visually indicating differences in major-ion chemistry in the ground water.

Boxplots were used as a nonparametric statistical method to indicate variations between aquifers and land-use classifications (figs. 8 and 9). This statistical method required few assumptions about the statistical properties of the data sets and was suitable for use with small data sets that may not be normally distributed. Boxplots graphically represent the median or 50th percentile (the center line of the box), interquartile range (the part of the box representing the range between the 25th and 75th percentile), and the 10th and 90th percentiles (the lines to the boundary points of the boxplot). If analytical values fall outside the 10th and 90th percentile, they are represented on the boxplots as points above and below these percentile values on the boxplots. Because ground-water-quality issues in the study unit are related to high dissolved solids, sulfate, selenium, and nutrients in the study unit, boxplots have been constructed to indicate differences in dissolved solids, sulfate, selenium, and nitrate-plus-nitrite as N (hereafter referred to as nitrate) between aquifers (fig. 8) and land-use classifications (fig. 9). Also, the ability to assess the concentrations of additional trace elements and nutrients in the ground water was constrained by the available data.

If there were less than 10 analyses for a constituent from a particular aquifer or land-use classification, the constituent was not graphically represented on the boxplots. The Morrison Formation and the Entrada Sandstone aquifers have insufficient data to classify the water quality in these aquifers and were not graphically represented. For the shallow alluvial ground-water wells and springs, dissolved solids, selenium, and nitrate were plotted to examine changes in concentration with depth (fig. 10). Springs have a depth of zero in figure 10.

Major Cations and Anions

Description of Ground-Water-Quality Data

In the study unit, water from most of the wells and springs sampled has major cation and anion data (calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, and fluoride) and dissolved-solids concentrations to evaluate the water quality and chemistry of the major aquifers. Major cation and anion data predominantly are available for the Colorado Plateau physiographic province (fig. 1). In tables 1 and 2, concentrations of major cations and anions and dissolved solids have been summarized as well as water-quality properties such as specific conductance, pH, water temperature, dissolved oxygen, hardness, and alkalinity.

Water Composition of Major Aquifers

Water composition in the aquifers of the study unit varies widely as a result of differences in the underlying and surrounding geology (fig. 7). Water composition can be changed by dissolution of minerals or through cation-anion exchange as ground water moves from recharge areas to discharge areas. Trilinear diagrams are a means of generally indicating similarities and differences in the composition of water from certain geologic and hydrologic units (Freeze and Cherry, 1979). Percentages of the total milliequivalents per liter of the predominant cations (lower left triangle) and anions (lower right triangle) are shown in figure 7. The center diagram shows the combined cation and anion composition of the water, which is a third point derived from projecting the data from the cation and anion plots. Aquifers in the basin that are in the alluvium, the Green River Formation, the Mesaverde Group, and the Dakota Sandstone have water compositions that predominantly are calcium bicarbonate. Alluvial aquifers that are possibly associated with or overlying the Mancos Shale in the western part of the study unit also have a composition of calcium sulfate. In addition, the Green River Formation has a water composition of magnesium bicarbonate. Aquifers in the Mancos Shale and the Leadville Limestone have water compositions of predominantly calcium sulfate; however, much of the water in the Mancos Shale is sodium sulfate type. Calcium bicarbonate water composition also is present in the Mancos Shale and the Leadville Limestone aquifers. The aquifer in the Precambrian rocks has a water composition of calcium bicarbonate; the composition data for water in this aquifer were tightly clustered and had good correlation among ionic species.

Table 1. Statistical summary of ground-water-quality data for selected sites in the Upper Colorado River Basin study unit by aquifer, water years 1972–92

[Number in parentheses adjacent to the water-quality property or constituent is the data parameter code from the U.S. Geological Survey National Water Information System (NWIS); ----, no data; <, less than]

Aquifer	Number of analyses	Value at indicated percentile				
		10th	25th	50th (median)	75th	90th
Specific conductance, in microsiemens per centimeter at 25 degrees Celsius (00095)						
Alluvium	212	202	385	677	1,365	3,248
Green River Formation	53	498	573	658	902	1,267
Mesaverde Group	34	323	426	904	1,480	3,861
Mancos Shale	32	214	495	3,110	5,178	7,779
Dakota Sandstone	29	196	314	469	1,650	3,076
Morrison Formation	7	434	445	584	1,283	1,432
Entrada Sandstone	5	290	365	450	554	----
Leadville Limestone	11	201	338	744	1,775	13,540
Precambrian	15	50	96	206	461	650
pH-field (00400)						
Alluvium	208	6.7	7.0	7.3	7.7	7.9
Green River Formation	53	7.5	7.6	7.8	8.1	8.5
Mesaverde Group	34	7.1	7.3	7.5	8.1	8.3
Mancos Shale	32	6.8	7.0	7.2	7.7	8.0
Dakota Sandstone	29	6.4	6.6	7.3	7.7	8.0
Morrison Formation	7	7.1	7.2	7.3	7.4	8.0
Entrada Sandstone	5	7.3	7.5	7.6	8.1	----
Leadville Limestone	9	6.6	7.1	7.5	7.6	7.9
Precambrian	15	7.0	7.3	7.5	7.8	8.0
Water temperature, in degrees Celsius (00010)						
Alluvium	171	5.0	7.0	10	12	16
Green River Formation	53	5.9	6.9	9.0	11	13
Mesaverde Group	33	6.0	10	14	16	20
Mancos Shale	31	6.2	9.9	12	13	19
Dakota Sandstone	29	5.5	7.4	11	16	18
Morrison Formation	7	6.6	9.5	14	40	48
Entrada Sandstone	5	5.5	7.4	10	17	----
Leadville Limestone	11	5.0	7.0	27	43	51
Precambrian	15	3.0	5.1	7.0	10	17
Dissolved oxygen, in milligrams per liter (00300)						
Alluvium	15	.10	.20	1.5	6.5	7.8
Green River Formation	0	----	----	----	----	----
Mesaverde Group	0	----	----	----	----	----
Mancos Shale	14	.29	.60	.95	1.8	2.7
Dakota Sandstone	0	----	----	----	----	----
Morrison Formation	0	----	----	----	----	----
Entrada Sandstone	0	----	----	----	----	----
Leadville Limestone	0	----	----	----	----	----
Precambrian	0	----	----	----	----	----
Hardness, total as $CaCO_3$, in milligrams per liter (00900)						
Alluvium	200	82	170	305	590	1,409
Green River Formation	53	100	240	270	331	468
Mesaverde Group	34	10	34	115	190	381
Mancos Shale	33	118	248	1,950	2,400	2,560
Dakota Sandstone	29	44	95	170	250	502
Morrison Formation	7	22	38	98	238	240
Entrada Sandstone	5	6.0	92	130	170	----
Leadville Limestone	11	111	178	270	883	1,106
Precambrian	15	28	40	98	228	270

Table 1. Statistical summary of ground-water-quality data for selected sites in the Upper Colorado River Basin study unit by aquifer, water years 1972–92—Continued

[Number in parentheses adjacent to the water-quality property or constituent is the data parameter code from the U.S. Geological Survey National Water Information System (NWIS); ----, no data; <, less than]

Aquifer	Number of analyses	Value at indicated percentile				
		10th	25th	50th (median)	75th	90th
Alkalinity, total as $CaCO_3$, in milligrams per liter (00410)						
Alluvium	155	75	150	243	338	421
Green River Formation	33	186	238	270	283	425
Mesaverde Group	12	49	139	180	260	367
Mancos Shale	19	119	140	213	346	442
Dakota Sandstone	22	24	98	174	485	738
Morrison Formation	5	204	225	239	313	----
Entrada Sandstone	4	----	131	143	156	----
Leadville Limestone	8	81	118	157	232	509
Precambrian	15	13	40	93	214	247
Dissolved solids, in milligrams per liter (70301)						
Alluvium	197	119	246	474	1,085	2,932
Green River Formation	53	294	357	412	569	846
Mesaverde Group	33	188	232	568	857	2,302
Mancos Shale	33	192	488	3,745	5,235	7,644
Dakota Sandstone	29	114	202	331	1,083	2,300
Morrison Formation	7	244	245	350	779	908
Entrada Sandstone	5	169	207	219	298	----
Leadville Limestone	11	121	187	470	1,528	7,988
Precambrian	15	30	62	142	284	398
Calcium, dissolved as Ca, in milligrams per liter (00915)						
Alluvium	212	25	47	80	154	391
Green River Formation	53	17	56	64	73	87
Mesaverde Group	34	3.1	7.4	22	48	68
Mancos Shale	33	32	67	340	485	530
Dakota Sandstone	29	12	25	48	76	131
Morrison Formation	7	7.2	9.5	16	77	82
Entrada Sandstone	5	2.0	28	40	42	----
Leadville Limestone	11	29	66	75	339	374
Precambrian	15	5.7	10	31	58	77
Magnesium, dissolved as Mg, in milligrams per liter (00925)						
Alluvium	212	4.8	11	27	57	127
Green River Formation	53	9.0	20	26	36	65
Mesaverde Group	34	.69	2.7	8.5	17	40
Mancos Shale	33	2.8	20	195	283	434
Dakota Sandstone	29	2.8	7.4	11	22	41
Morrison Formation	7	1.0	3.2	8.6	13	15
Entrada Sandstone	5	.30	5.1	7.0	15	----
Leadville Limestone	11	2.4	7.3	8.7	12	48
Precambrian	15	1.0	2.9	4.4	19	23
Sodium, dissolved as Na, in milligrams per liter (00930)						
Alluvium	212	3.5	8.5	28	104	293
Green River Formation	53	22	30	45	85	192
Mesaverde Group	34	7.8	26	140	370	904
Mancos Shale	33	6.3	23	330	765	1,520
Dakota Sandstone	29	2.1	6.4	14	250	696
Morrison Formation	7	1.9	3.0	99	27	319
Entrada Sandstone	5	11	11	16	63	----
Leadville Limestone	11	1.1	1.5	53	110	2,472
Precambrian	15	1.7	3.6	4.9	13	21

Table 1. Statistical summary of ground-water-quality data for selected sites in the Upper Colorado River Basin study unit by aquifer, water years 1972–92—Continued

[Number in parentheses adjacent to the water-quality property or constituent is the data parameter code from the U.S. Geological Survey National Water Information System (NWIS); ----, no data; <, less than]

Aquifer	Number of analyses	Value at indicated percentile				
		10th	25th	50th (median)	75th	90th
Potassium, dissolved as K, in milligrams per liter (00935)						
Alluvium	207	1.0	1.5	2.2	4.1	9.9
Green River Formation	53	.35	.50	.73	1.2	2.3
Mesaverde Group	34	.78	1.3	2.6	7.2	13
Mancos Shale	33	1.1	2.6	9.3	14	17
Dakota Sandstone	29	1.2	2.3	4.3	9.6	24
Morrison Formation	7	1.5	2.0	4.9	7.2	8.1
Entrada Sandstone	5	.80	1.0	1.8	4.2	----
Leadville Limestone	11	.32	.58	5.0	9.3	71
Precambrian	15	.40	.70	1.1	4.2	5.9
Bicarbonate, as $CaCO_3$, in milligrams per liter (00440)						
Alluvium	165	120	198	300	408	510
Green River Formation	27	280	303	330	365	517
Mesaverde Group	11	57	160	210	268	362
Mancos Shale	18	136	170	240	350	527
Dakota Sandstone	20	27	120	200	625	900
Morrison Formation	5	250	273	290	383	----
Entrada Sandstone	4	----	160	175	190	----
Leadville Limestone	8	99	145	190	280	623
Precambrian	15	16	50	110	265	300
Sulfate, dissolved as SO_4, in milligrams per liter (00945)						
Alluvium	212	7.4	22	110	438	1,513
Green River Formation	53	20	32	75	123	328
Mesaverde Group	34	2.6	5.7	22	98	183
Mancos Shale	33	23	152	2,300	3,438	4,790
Dakota Sandstone	29	6.8	13	69	140	452
Morrison Formation	7	1.0	6.8	43	101	204
Entrada Sandstone	5	20	36	43	52	----
Leadville Limestone	11	5.0	5.1	93	881	950
Precambrian	15	3.7	4.8	7.2	13	32
Chloride, dissolved as Cl, in milligrams per liter (00940)						
Alluvium	212	1.0	2.4	7.5	16	44
Green River Formation	53	1.6	2.9	3.8	5.4	9.8
Mesaverde Group	34	1.8	3.5	9.5	18	94
Mancos Shale	33	.88	3.7	27	213	262
Dakota Sandstone	29	1.1	1.9	4.1	22	140
Morrison Formation	7	1.0	2.0	16	151	196
Entrada Sandstone	5	1.7	1.8	2.1	4.4	----
Leadville Limestone	11	.16	.50	14	32	3,865
Precambrian	15	.50	.60	2.8	6.9	11
Fluoride, dissolved as F, in milligrams per liter (00950)						
Alluvium	179	.10	.20	.30	.70	1.1
Green River Formation	52	.10	.10	.20	.30	1.3
Mesaverde Group	34	.10	.20	.45	2.6	3.1
Mancos Shale	33	.10	.20	.55	.89	2.6
Dakota Sandstone	29	.10	.18	.50	1.3	2.3
Morrison Formation	7	.10	.13	1.4	3.7	3.9
Entrada Sandstone	5	.10	.18	.30	.80	----
Leadville Limestone	11	.10	.13	1.1	2.6	2.9
Precambrian	15	.10	.10	.20	.90	1.4

Table 1. Statistical summary of ground-water-quality data for selected sites in the Upper Colorado River Basin study unit by aquifer, water years 1972–92—Continued

[Number in parentheses adjacent to the water-quality property or constituent is the data parameter code from the U.S. Geological Survey National Water Information System (NWIS); ----, no data; <, less than]

Aquifer	Number of analyses	Value at indicated percentile				
		10th	25th	50th (median)	75th	90th
Aluminum, dissolved as Al, in micrograms per liter (01106)						
Alluvium	64	10	18	100	100	250
Green River Formation	20	10	10	10	25	78
Mesaverde Group	12	10	20	20	35	92
Mancos Shale	3	----	93	100	107	----
Dakota Sandstone	1	----	----	150	----	----
Morrison Formation	0	----	----	----	----	----
Entrada Sandstone	0	----	----	----	----	----
Leadville Limestone	1	----	----	100	----	----
Precambrian	0	----	----	----	----	----
Arsenic, dissolved as As, in micrograms per liter (01000)						
Alluvium	112	<1.0	<1.0	2.0	3.0	5.0
Green River Formation	42	<1.0	2.8	5.3	7.0	13
Mesaverde Group	17	<1.0	<1.0	2.0	4.3	5.8
Mancos Shale	16	<1.0	<1.0	<1.0	1.0	2.0
Dakota Sandstone	13	<1.0	<1.0	<1.0	4.8	113
Morrison Formation	0	----	----	----	----	----
Entrada Sandstone	4	----	2.0	5.5	8.0	----
Leadville Limestone	3	----	1.8	4.0	10	----
Precambrian	5	<1.0	<1.0	<1.0	2.8	----
Barium, dissolved as Ba, in micrograms per liter (01007)						
Alluvium	74	15	25	50	89	101
Green River Formation	39	52	89	100	200	300
Mesaverde Group	13	49	72	100	425	2,260
Mancos Shale	2	----	----	102	----	----
Dakota Sandstone	4	----	25	43	78	----
Morrison Formation	0	----	----	----	----	----
Entrada Sandstone	1	----	----	60	----	----
Leadville Limestone	1	----	----	140	----	----
Precambrian	0	----	----	----	----	----
Boron, dissolved as B, in micrograms per liter (01020)						
Alluvium	151	20	40	100	220	560
Green River Formation	50	25	30	40	100	321
Mesaverde Group	29	30	58	360	813	1,760
Mancos Shale	25	60	261	440	612	917
Dakota Sandstone	15	20	53	110	960	1,750
Morrison Formation	0	----	----	----	----	----
Entrada Sandstone	1	----	----	240	----	----
Leadville Limestone	7	28	66	150	192	680
Precambrian	6	20	20	45	50	122
Cadmium, dissolved as Cd, in micrograms per liter (01025)						
Alluvium	75	1.0	1.8	7.0	10	10
Green River Formation	24	.01	.03	.11	.39	1.8
Mesaverde Group	13	.07	.16	.38	1.0	2.6
Mancos Shale	7	<1.0	<1.0	<2.0	2.0	2.0
Dakota Sandstone	5	<1.0	<1.0	<1.0	<2.0	----
Morrison Formation	0	----	----	----	----	----
Entrada Sandstone	1	----	----	<1.0	----	----
Leadville Limestone	0	----	----	----	----	----
Precambrian	0	----	----	----	----	----

Table 1. Statistical summary of ground-water-quality data for selected sites in the Upper Colorado River Basin study unit by aquifer, water years 1972–92—Continued

[Number in parentheses adjacent to the water-quality property or constituent is the data parameter code from the U.S. Geological Survey National Water Information System (NWIS); ----, no data; <, less than]

Aquifer	Number of analyses	Value at indicated percentile				
		10th	25th	50th (median)	75th	90th
Chromium, dissolved as Cr, in micrograms per liter (01030)						
Alluvium	58	2.5	5.2	15	28	42
Green River Formation	13	<10	<10	<10	<10	<10
Mesaverde Group	10	1.8	8.0	10	10	397
Mancos Shale	8	.78	1.6	2.2	4.5	7.2
Dakota Sandstone	4	----	10	10	15	----
Morrison Formation	0	----	----	----	----	----
Entrada Sandstone	1	----	----	10	----	----
Leadville Limestone	1	----	----	<4	----	----
Precambrian	0	----	----	----	----	----
Copper, dissolved as Cu, in micrograms per liter (01040)						
Alluvium	77	1.0	2.0	10	10	25
Green River Formation	34	0.9	1.0	1.7	3.0	5.5
Mesaverde Group	14	1.0	2.0	5.0	9.0	25
Mancos Shale	9	1.0	1.8	3.0	5.0	12
Dakota Sandstone	5	<1.0	<1.0	2.0	3.0	----
Morrison Formation	0	----	----	----	----	----
Entrada Sandstone	1	----	----	2.0	----	----
Leadville Limestone	1	----	----	8.0	----	----
Precambrian	0	----	----	----	----	----
Iron, dissolved as Fe, in micrograms per liter (01046)						
Alluvium	207	<10	<10	30	100	276
Green River Formation	49	1.8	6.0	11	35	80
Mesaverde Group	33	16	38	77	175	632
Mancos Shale	33	<10	14	40	123	545
Dakota Sandstone	29	14	30	103	648	1,680
Morrison Formation	5	20	28	70	603	----
Entrada Sandstone	7	<10	<10	21	48	330
Leadville Limestone	11	<10	<10	20	20	60
Precambrian	15	<10	<10	20	108	690
Lead, dissolved as Pb, in micrograms per liter (01049)						
Alluvium	77	1.0	2.0	30	50	68
Green River Formation	32	1.0	2.0	3.0	5.3	8.7
Mesaverde Group	11	1.0	1.0	2.0	3.5	5.0
Mancos Shale	9	<1.0	<1.0	<1.0	<4.0	4.6
Dakota Sandstone	5	<1.0	<1.0	3.0	3.3	----
Morrison Formation	0	----	----	----	----	----
Entrada Sandstone	1	----	----	3.0	----	----
Leadville Limestone	1	----	----	<4.0	----	----
Precambrian	0	----	----	----	----	----
Lithium, dissolved as Li, in micrograms per liter						
Alluvium	28	9.5	31	40	80	720
Green River Formation	42	<10	<10	13	27	101
Mesaverde Group	1	----	----	2,800	----	----
Mancos Shale	2	----	----	208	----	----
Dakota Sandstone	0	----	----	----	----	----
Morrison Formation	0	----	----	----	----	----
Entrada Sandstone	0	----	----	----	----	----
Leadville Limestone	3	----	295	730	1,083	----
Precambrian	0	----	----	----	----	----

Table 1. Statistical summary of ground-water-quality data for selected sites in the Upper Colorado River Basin study unit by aquifer, water years 1972–92—Continued

[Number in parentheses adjacent to the water-quality property or constituent is the data parameter code from the U.S. Geological Survey National Water Information System (NWIS); ----, no data; <, less than]

Aquifer	Number of analyses	Value at indicated percentile 10th	25th	50th (median)	75th	90th
Manganese, dissolved as Mn, in micrograms per liter (01056)						
Alluvium	205	<10	<10	<10	31	280
Green River Formation	49	.72	1.5	4.3	20	87
Mesaverde Group	34	<10	<10	25	50	122
Mancos Shale	33	<10	<10	80	218	478
Dakota Sandstone	29	<10	<10	30	175	725
Morrison Formation	7	<10	<10	<10	39	48
Entrada Sandstone	5	<10	<10	<10	70	----
Leadville Limestone	11	<10	<10	20	390	960
Precambrian	15	<10	<10	<10	25	230
Molybdenum, dissolved as Mo, in micrograms per liter (01060)						
Alluvium	69	<1.0	5.8	10	12	22
Green River Formation	22	<10	<10	<10	19	31
Mesaverde Group	11	<10	<10	14	21	43
Mancos Shale	15	<1.0	1.3	4.0	8.5	45
Dakota Sandstone	1	----	----	11	----	----
Morrison Formation	0	----	----	----	----	----
Entrada Sandstone	0	----	----	----	----	----
Leadville Limestone	1	----	----	9	----	----
Precambrian	0	----	----	----	----	----
Selenium, dissolved as Se, in micrograms per liter (01145)						
Alluvium	119	<1.0	<1.0	2.0	6.0	20
Green River Formation	37	<1.0	<1.0	<1.0	2.4	5.2
Mesaverde Group	12	<1.0	<1.0	<1.0	4.0	9.7
Mancos Shale	23	<1.0	<1.0	<1.0	48	142
Dakota Sandstone	11	<1.0	<1.0	<1.0	1.8	5.2
Morrison Formation	0	----	----	----	----	----
Entrada Sandstone	3	----	<1.0	<1.0	1.8	----
Leadville Limestone	3	----	<1.0	<1.0	<1.0	-----
Precambrian	5	<1.0	<1.0	<1.0	<1.0	----
Uranium, dissolved as U, in micrograms per liter (22703)						
Alluvium	1	----	----	<0.6	----	----
Green River Formation	2	----	----	2.5	----	----
Mesaverde Group	0	----	----	----	----	----
Mancos Shale	0	----	----	----	----	----
Dakota Sandstone	1	----	----	16	----	----
Morrison Formation	0	----	----	----	----	----
Entrada Sandstone	0	----	----	----	----	----
Leadville Limestone	0	----	----	----	----	----
Precambrian	0	----	----	----	----	----
Vanadium, dissolved as V, in micrograms per liter (01085)						
Alluvium	19	1.3	2.0	4.0	8.0	10
Green River Formation	23	1.8	5.3	9.5	15	19
Mesaverde Group	5	2.0	2.0	4.0	7.3	----
Mancos Shale	15	<1.0	3.1	4.0	5.9	24
Dakota Sandstone	0	----	----	----	----	----
Morrison Formation	0	----	----	----	----	----
Entrada Sandstone	0	----	----	----	----	----
Leadville Limestone	1	----	----	<4.0	----	----
Precambrian	0	----	----	----	----	----

Table 1. Statistical summary of ground-water-quality data for selected sites in the Upper Colorado River Basin study unit by aquifer, water years 1972–92—Continued

[Number in parentheses adjacent to the water-quality property or constituent is the data parameter code from the U.S. Geological Survey National Water Information System (NWIS); ----, no data; <, less than]

Aquifer	Number of analyses	Value at indicated percentile				
		10th	25th	50th (median)	75th	90th
		Zinc, dissolved as Zn, in micrograms per liter (01090)				
Alluvium	76	4.0	9.0	15	30	60
Green River Formation	34	2.1	5.0	8.5	20	42
Mesaverde Group	13	10	18	50	87	186
Mancos Shale	9	8.7	12	30	45	90
Dakota Sandstone	6	10	20	20	110	281
Morrison Formation	0	----	----	----	----	----
Entrada Sandstone	1	----	----	20	----	----
Leadville Limestone	2	----	----	30	----	----
Precambrian	0	----	----	----	----	----
		Nitrate-plus-nitrite, as N, in milligrams per liter (00631)				
Alluvium	170	<.10	.13	.48	1.3	3.6
Green River Formation	50	<.10	.17	.75	1.5	2.6
Mesaverde Group	33	<.10	<.10	.21	.39	.77
Mancos Shale	32	<.10	<.10	1.1	3.8	6.5
Dakota Sandstone	27	<.10	<.10	.12	.30	.39
Morrison Formation	6	<.10	<.10	.24	.70	.74
Entrada Sandstone	5	<.10	<.10	<.10	.34	----
Leadville Limestone	12	<.10	<.10	.11	.40	.57
Precambrian	15	<.10	.11	.26	.54	.75
		Orthophosphate, dissolved as P, in milligrams per liter (00671)				
Alluvium	138	<.01	<.01	.02	.04	.07
Green River Formation	26	<.01	<.01	.03	.05	.10
Mesaverde Group	32	<.01	<.01	.04	.11	.25
Mancos Shale	23	<.01	<.01	.02	.02	.05
Dakota Sandstone	20	<.01	<.01	<.01	.02	.06
Morrison Formation	5	<.01	<.01	<.01	.02	----
Entrada Sandstone	4	----	<.01	<.01	.02	----
Leadville Limestone	8	<.01	<.01	.02	.03	.03
Precambrian	15	<.01	<.01	<.01	.03	.06

Table 2. Statistical summary of ground-water-quality data for selected sites in the Upper Colorado River Basin study unit by land-use classification, water years 1972–92

[Number in parentheses adjacent to the water-quality property or constituent is the data parameter code from the U.S. Geological Survey National Water Information System (NWIS); ----, no data; <, less than]

Land use (Anderson and others, 1976)	Number of analyses	Value at indicated percentile				
		10th	25th	50th (median)	75th	90th
	Specific conductance, in microsiemens per centimeter at 25 degrees Celsius (00095)					
Agricultural	91	419	613	925	2,269	3,689
Forest	34	98	219	374	940	1,718
Rangeland	61	157	289	631	1,235	2,851
Urban and built-up	20	175	380	535	795	2,196
	pH-field (00400)					
Agricultural	87	6.7	6.9	7.2	7.5	7.7
Forest	34	6.3	6.9	7.6	7.9	8.1
Rangeland	61	6.8	7.2	7.5	7.7	8.1
Urban and built-up	20	6.8	7.1	7.3	7.6	8.1
	Water temperature, in degrees Celsius (00010)					
Agricultural	65	7.5	9.9	11	14	25
Forest	31	3.0	5.0	7.5	10	12
Rangeland	56	4.1	6.3	9.0	11	15
Urban and built-up	15	6.0	6.3	8.5	11	13
	Dissolved oxygen, in milligrams per liter (00300)					
Agricultural	13	.09	.18	1.5	5.8	7.6
Forest	0	----	----	----	----	----
Rangeland	2	----	----	6.9	----	----
Urban and built-up	0	----	----	----	----	----
	Hardness, total as $CaCO_3$, in milligrams per liter (00900)					
Agricultural	82	180	250	425	1,100	2,060
Forest	34	38	90	155	340	661
Rangeland	60	62	130	280	447	1,100
Urban and built-up	18	69	210	260	390	1,183
	Alkalinity, total as $CaCO_3$, in milligrams per liter (00410)					
Agricultural	67	143	204	262	340	419
Forest	18	40	88	153	280	334
Rangeland	46	69	120	229	344	460
Urban and built-up	18	74	136	227	295	349
	Dissolved solids, in milligrams per liter (70301)					
Agricultural	82	252	384	684	2,280	3,578
Forest	32	70	122	251	649	1,234
Rangeland	59	99	187	394	896	2,174
Urban and built-up	18	118	254	310	671	2,040
	Calcium, dissolved as Ca, in milligrams per liter (00915)					
Agricultural	91	54	73	120	239	481
Forest	34	11	25	42	78	102
Rangeland	61	20	41	69	95	224
Urban and built-up	20	22	40	76	110	2,040
	Magnesium, dissolved as Mg, in milligrams per liter (00925)					
Agricultural	91	11	18	36	67	168
Forest	34	2.7	4.8	10	46	97
Rangeland	61	3.9	6.7	21	51	104
Urban and built-up	20	3.8	15	22	35	109

Table 2. Statistical summary of ground-water-quality data for selected sites in the Upper Colorado River Basin study unit by land-use classification, water years 1972–92—Continued

[Number in parentheses adjacent to the water-quality property or constituent is the data parameter code from the U.S. Geological Survey National Water Information System (NWIS); ----, no data; <, less than]

Land use (Anderson and others, 1976)	Number of analyses	Value at indicated percentile				
		10th	25th	50th (median)	75th	90th
Sodium, dissolved as Na, in milligrams per liter (00930)						
Agricultural	91	7.1	17	44	147	338
Forest	34	2.2	3.1	20	99	177
Rangeland	61	3.1	5.6	24	89	404
Urban and built-up	20	3.7	4.8	13	30	148
Potassium, dissolved as K, in milligrams per liter (00935)						
Agricultural	86	1.4	1.8	2.9	5.6	17
Forest	34	.80	1.2	1.9	2.4	3.9
Rangeland	61	.90	1.2	2.2	3.3	5.0
Urban and built-up	20	.95	1.4	2.4	4.1	8.8
Bicarbonate, as HCO_3, in milligrams per liter (00440)						
Agricultural	77	192	254	316	410	510
Forest	17	53	118	190	340	420
Rangeland	46	84	150	275	429	559
Urban and built-up	19	90	175	278	340	414
Sulfate, dissolved as SO_4, in milligrams per liter (00945)						
Agricultural	91	27	73	210	925	1,800
Forest	34	3.2	5.0	20	140	622
Rangeland	61	5.8	19	62	334	1,340
Urban and built-up	20	7.0	16	88	200	1,133
Chloride, dissolved as Cl, in milligrams per liter (00940)						
Agricultural	91	1.9	5.3	14	29	190
Forest	34	.30	1.4	3.6	4.8	11
Rangeland	61	.90	1.9	5.7	11	23
Urban and built-up	20	1.3	2.8	5.6	12	29
Fluoride, dissolved as F, in milligrams per liter (00950)						
Agricultural	71	.15	.20	.40	1.1	1.7
Forest	31	.10	.13	.20	.30	.70
Rangeland	56	.10	.20	.30	.60	.70
Urban and built-up	16	.10	.10	.20	.50	.69
Aluminum, dissolved as Al, in micrograms per liter (01106)						
Agricultural	27	57	88	100	150	250
Forest	12	2.9	7.5	19	100	150
Rangeland	15	10	10	10	100	100
Urban and built-up	6	100	100	100	150	285
Arsenic, dissolved as As, in micrograms per liter (01000)						
Agricultural	51	<1.0	<1.0	2.0	4.0	6.0
Forest	19	<1.0	<1.0	2.0	3.0	9.2
Rangeland	27	<1.0	<1.0	<1.0	2.0	3.8
Urban and built-up	12	<1.0	<1.0	1.5	3.0	5.0
Barium, dissolved as Ba, in micrograms per liter (01007)						
Agricultural	31	13	20	41	65	100
Forest	18	11	21	54	89	100
Rangeland	16	23	30	65	100	109
Urban and built-up	5	15	19	40	46	----

Table 2. Statistical summary of ground-water-quality data for selected sites in the Upper Colorado River Basin study unit by land-use classification, water years 1972–92—Continued

[Number in parentheses adjacent to the water-quality property or constituent is the data parameter code from the U.S. Geological Survey National Water Information System (NWIS); ----, no data; <, less than]

Land use (Anderson and others, 1976)	Number of analyses	Value at indicated percentile				
		10th	25th	50th (median)	75th	90th
Boron, dissolved as B, in micrograms per liter (01020)						
Agricultural	65	40	80	157	353	683
Forest	29	9.0	13	40	113	146
Rangeland	43	20	30	90	148	368
Urban and built-up	9	17	41	140	264	362
Cadmium, dissolved as Cd, in micrograms per liter (01025)						
Agricultural	33	3.9	6.1	10	10	10
Forest	16	.05	.17	.51	2.8	10
Rangeland	16	.13	.29	1.0	9.3	17
Urban and built-up	6	2.8	10	10	10	10
Chromium, dissolved as Cr, in micrograms per liter (01030)						
Agricultural	29	8.7	14	20	30	40
Forest	9	.24	.80	25	15	75
Rangeland	12	<10	<10	<10	20	44
Urban and built-up	5	10	10	15	31	----
Copper, dissolved as Cu, in micrograms per liter (01040)						
Agricultural	33	3.6	9.5	10	15	26
Forest	16	.35	.65	2.0	8.5	10
Rangeland	18	.26	.98	2.3	10	31
Urban and built-up	6	2.8	10	10	15	24
Iron, dissolved as Fe, in micrograms per liter (01046)						
Agricultural	90	<10	18	50	130	473
Forest	31	<10	<10	12	30	70
Rangeland	60	<10	<10	20	60	205
Urban and built-up	20	<10	20	40	165	220
Lead, dissolved as Pb, in micrograms per liter (01049)						
Agricultural	32	1.7	30	50	53	90
Forest	17	<1.0	<1.0	4.0	10	50
Rangeland	18	.14	.89	2.0	39	66
Urban and built-up	6	8.4	30	48	50	104
Lithium, dissolved as Li, in micrograms per liter (01130)						
Agricultural	9	29	45	80	805	1,228
Forest	7	9.6	33	40	44	529
Rangeland	10	12	33	40	60	130
Urban and built-up	----	----	----	----	----	----
Manganese, dissolved as Mn, in micrograms per liter (01056)						
Agricultural	89	<10	<10	15	83	432
Forest	31	<10	<10	<10	<10	75
Rangeland	60	<10	<10	<10	30	168
Urban and built-up	19	<10	<10	<10	20	138
Molybdenum, dissolved as Mo, in micrograms per liter (01060)						
Agricultural	36	3.1	10	10	10	16
Forest	11	1.0	1.0	10	18	28
Rangeland	14	1.0	1.5	10	20	33
Urban and built-up	5	10	10	10	16	35

Table 2. Statistical summary of ground-water-quality data for selected sites in the Upper Colorado River Basin study unit by land-use classification, water years 1972–92—Continued

[Number in parentheses adjacent to the water-quality property or constituent is the data parameter code from the U.S. Geological Survey National Water Information System (NWIS); ----, no data; <, less than]

Land use (Anderson and others, 1976)	Number of analyses	Value at indicated percentile				
		10th	25th	50th (median)	75th	90th
Selenium, dissolved as Se, in micrograms per liter (01145)						
Agricultural	58	<1.0	<1.0	2.0	7.0	24
Forest	17	<1.0	<1.0	<1.0	2.0	2.8
Rangeland	28	<1.0	<1.0	2.8	6.0	20
Urban and built-up	12	<1.0	<1.0	1.5	2.5	98
Uranium, dissolved as U, in micrograms per liter (22703)						
Agricultural	----	----	----	----	----	----
Forest	1	----	----	<0.6	----	----
Rangeland	----	----	----	----	----	----
Urban and built-up	----	----	----	----	----	----
Vanadium, dissolved as V, in micrograms per liter (01085)						
Agricultural	10	.42	.83	1.8	4.3	9.5
Forest	3	----	6.5	8.0	9.5	----
Rangeland	6	3.0	3.0	6.0	9.0	13
Urban and built-up	----	----	----	----	----	----
Zinc, dissolved as Zn, in micrograms per liter (01090)						
Agricultural	34	10	10	15	22	88
Forest	16	2.3	4.6	10	28	42
Rangeland	17	1.4	4.1	8.0	25	79
Urban and built-up	6	11	20	30	40	463
Nitrate-plus-nitrite, as N, in milligrams per liter (00631)						
Agricultural	65	<.10	.15	.81	3.1	7.7
Forest	31	<.10	<.10	.25	.52	.95
Rangeland	55	<.10	.11	.44	1.3	2.1
Urban and built-up	15	<.10	.30	.60	.92	1.6
Orthophosphate, dissolved as P, in milligrams per liter (00671)						
Agricultural	50	<.01	<.01	.02	.05	.07
Forest	21	<.01	<.01	<.01	.03	.07
Rangeland	48	<.01	<.01	.02	.04	.07
Urban and built-up	15	<.01	<.01	.02	.04	.06

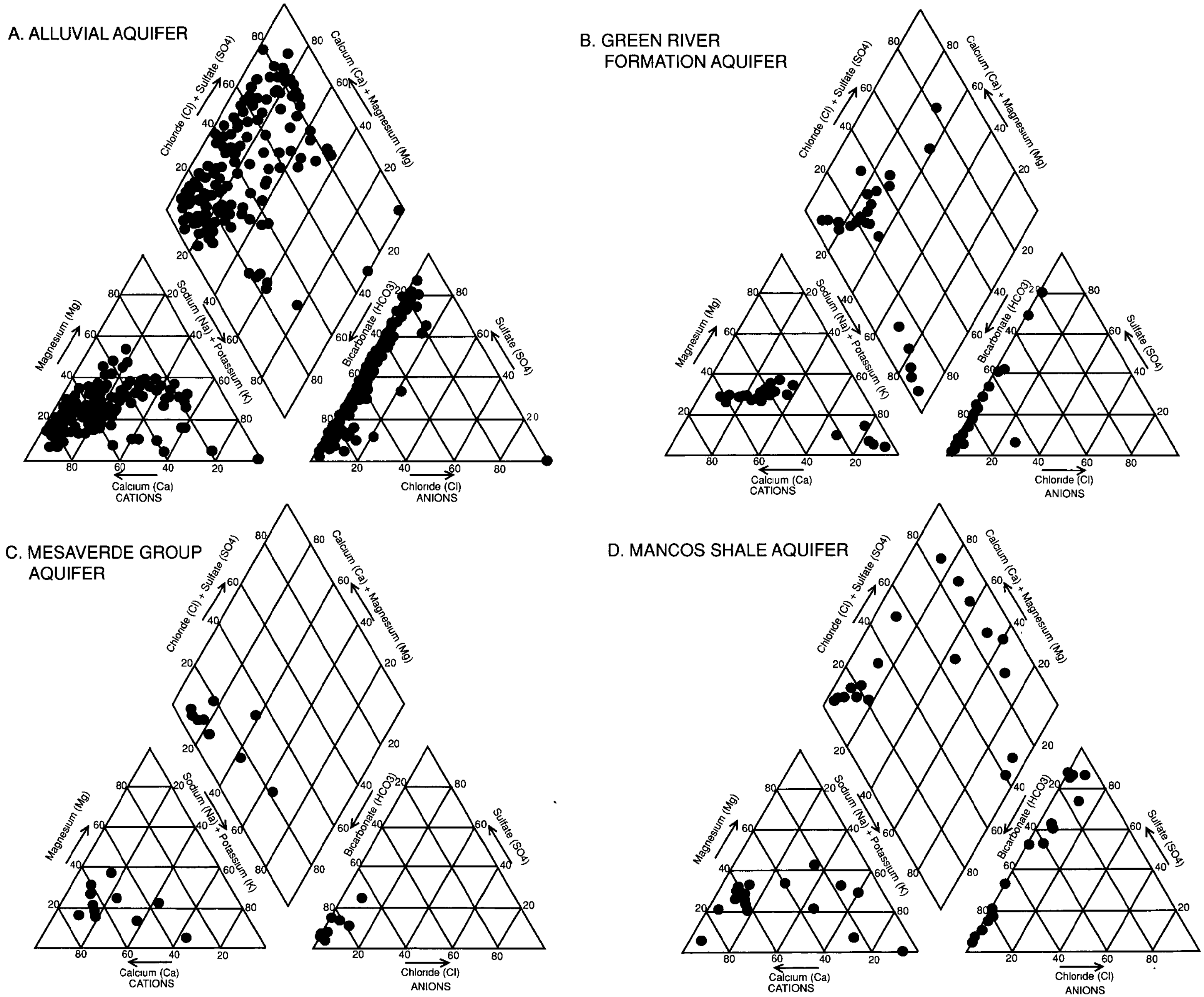

Figure 7. Ionic composition of ground water by aquifer in the Upper Colorado River Basin.

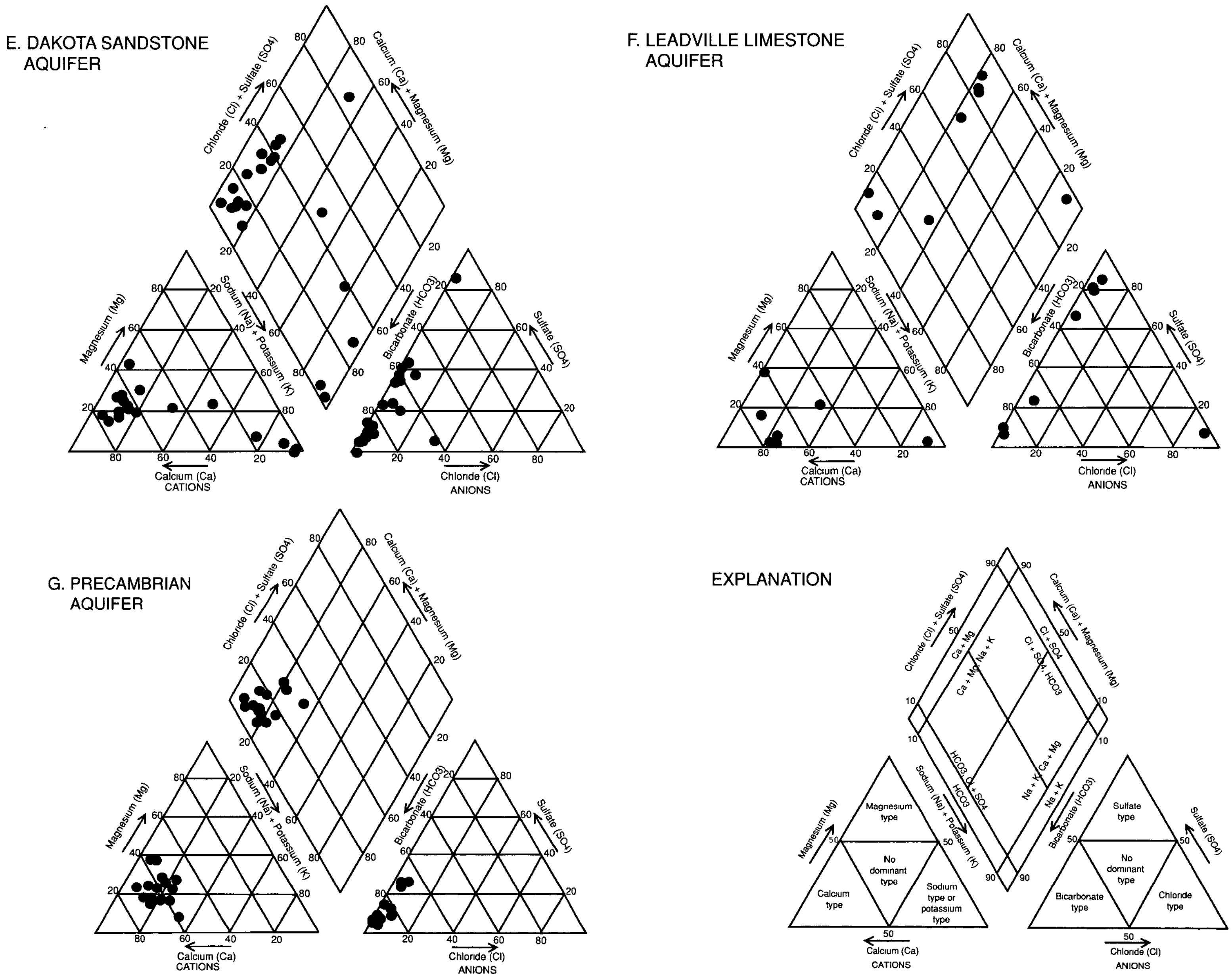

Figure 7. Ionic composition of ground water by aquifer in the Upper Colorado River Basin—Continued.

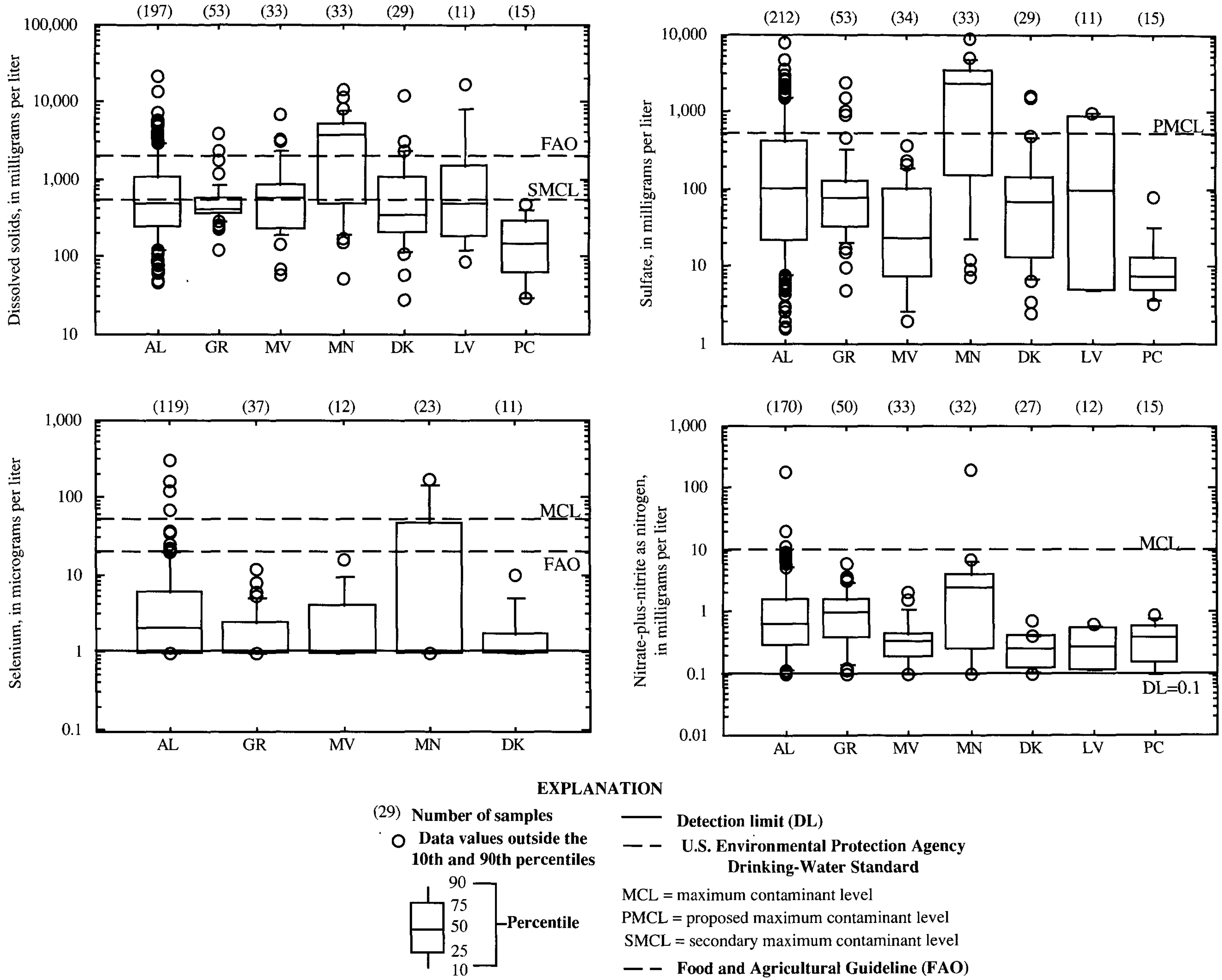

Figure 8. Concentrations of dissolved solids, sulfate, selenium, and nitrate-plus-nitrite as nitrogen in ground-water samples, by aquifer, and comparison to water-quality criteria, water years 1972–92. [AL, alluvial; GR, Green River Formation; MV, Mesaverde Group; MN, Mancos Shale; DK, Dakota Sandstone; LV, Leadville Limestone; PC, Precambrian; FAO, Food and Agricultural Guideline (Kandiah, 1987)] Contaminant levels are from the U.S. Environmental Protection Agency (1996).

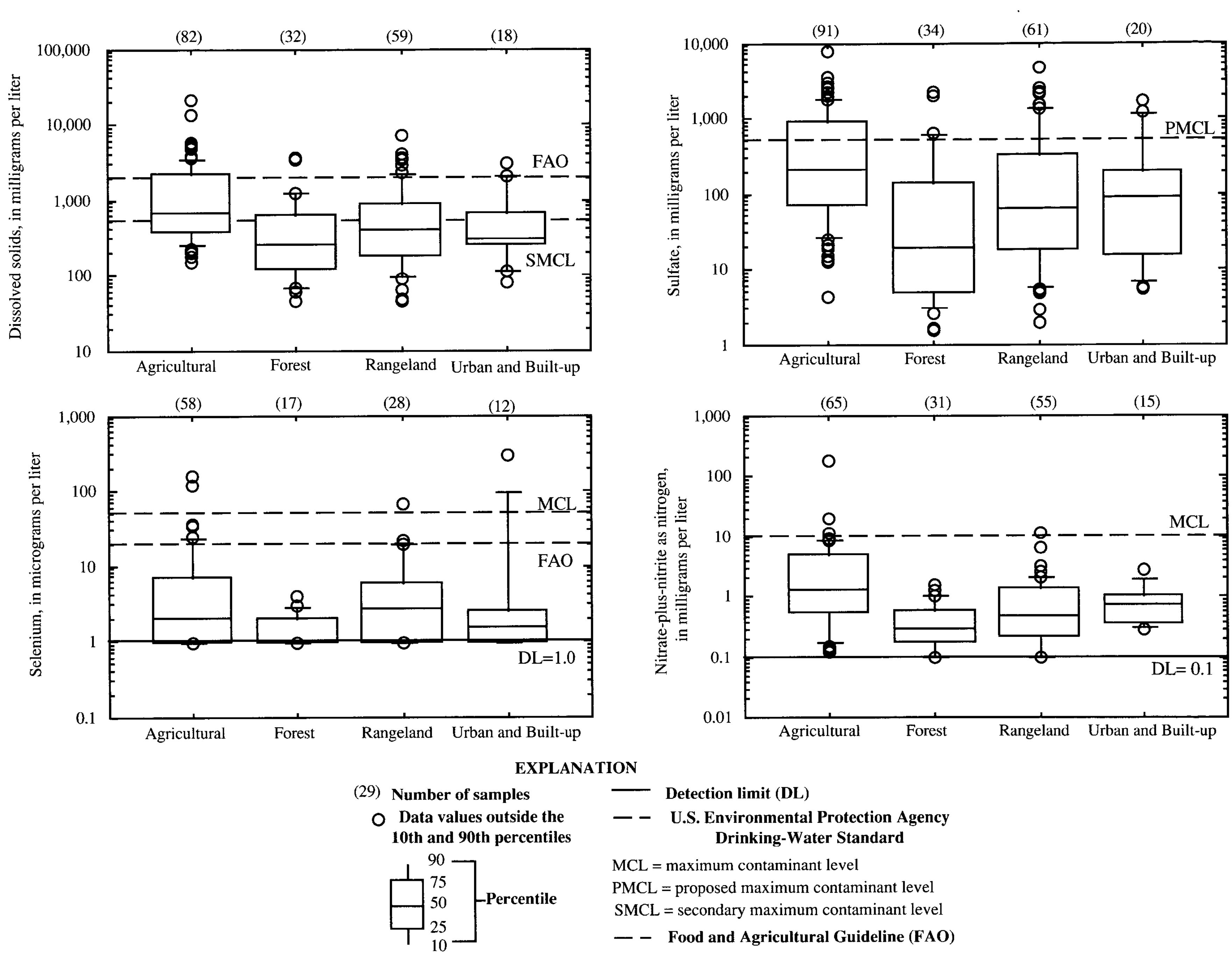

Figure 9. Concentrations of dissolved solids, sulfate, selenium, and nitrate-plus nitrite as nitrogen in ground-water samples, by land-use classification, and comparison to water-quality criteria, water year 1972–92. [FAO, Food and Agricultural Guideline (Kandiah, 1987)] Contaminant levels are from the U.S. Environmental Protection Agency (1996).

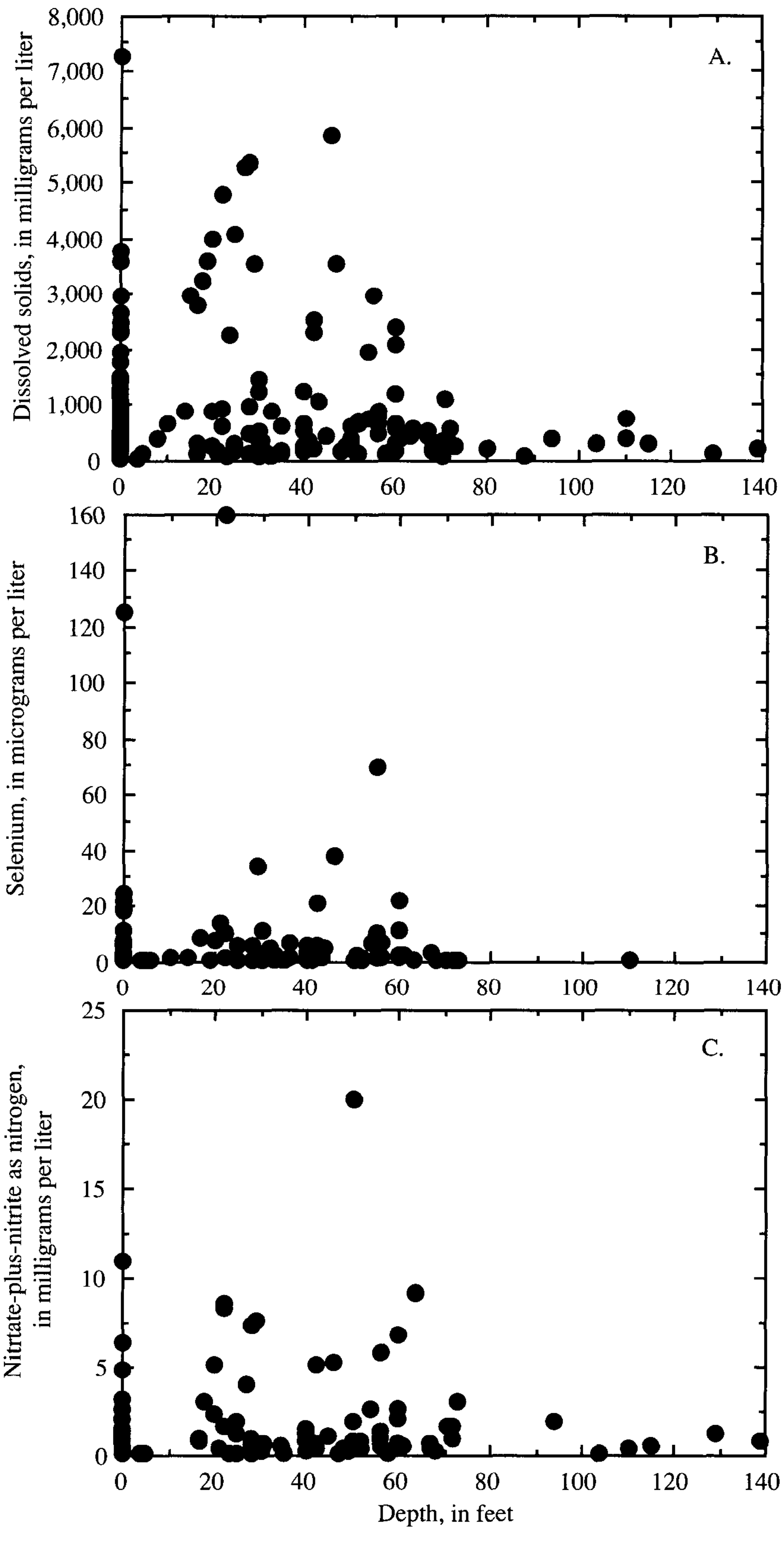

Figure 10. Relation of concentrations of dissolved solids, selenium, and nitrate-plus-nitrite as nitrogen to depth for samples collected from springs and selected wells completed in alluvial aquifers, water years 1972–92.

Concentrations in Ground Water

Major cation and anion concentrations differ among the aquifers in the study unit (table 1). Water from the Mancos Shale aquifer has the highest median concentrations of major ions, such as calcium, magnesium, sodium, potassium, sulfate, and chloride (table 1) and the highest median dissolved-solids concentration (fig. 8). For dissolved solids in drinking water, the SMCL is 500 mg/L (U.S. Environmental Protection Agency, 1996), and concentrations that exceed the FAO guideline of 2,000 mg/L (Kandiah, 1987) can adversely affect crops. The median dissolved-solids concentration of the Mancos Shale aquifer (3,745 mg/L) exceeded the SMCL criterion and the FAO guideline (fig. 8 and table 1). Dissolved-solids concentrations for the Mancos Shale exceeded the SMCL criterion for about 75 percent of the sites. Water from the alluvial, Mesaverde Group, and Leadville Limestone aquifers also had some high concentrations of dissolved solids. Percentages of sites in these aquifers that had concentrations exceeding the SMCL criterion were: alluvial 48 percent; Mesaverde Group 55 percent; and Leadville Limestone 45 percent. High dissolved-solids concentrations in the study unit result from weathering of soluble material (salts) from many of the sedimentary rocks, such as the Mancos Shale, that are in the western part of the study unit (Colorado Department of Public Health and Environment, 1994). High dissolved-solids concentrations in the Leadville Limestone aquifer, which is in the central part of the study unit, may be a result of the aquifer being in contact with evaporite deposits where water typically has a sodium chloride composition and a large sulfate concentration (Geldon, 1989).

The median concentration of sulfate in the Mancos Shale aquifer (2,300 mg/L) exceeded the PMCL criterion for sulfate of 500 mg/L (fig. 8 and table 1) (U.S. Environmental Protection Agency, 1996). Sulfate concentrations exceeded the PMCL criterion for about 66 percent of the sites in the Mancos Shale. High sulfate concentrations in water can result from weathering of sulfide minerals in metal-mining or coal-mining areas or from erosion and weathering of gypsum (calcium sulfate), which often is enhanced by agricultural irrigation through the use and reuse of surface and ground water (Chaney and others, 1987; Colorado Department of Public Health and Environment, 1994). At mine sites, the weathering of sulfide minerals generally is localized and affects shallow aquifers. For the Mancos Shale aquifer, a source of sulfate in the ground water can be attributed to the oxidation of pyrite by infiltrating water (irrigation water), which puts sulfate into solution (Butler and others, 1996).

Analysis of land use overlying the alluvial aquifer indicates that agricultural land use had the highest median concentration of dissolved solids (684 mg/L), and forest land use had the lowest median concentration of dissolved solids (251 mg/L) (fig. 9 and table 2). The median concentration for dissolved solids associated with agricultural land use (684 mg/L) exceeded the SMCL of 500 mg/L (U.S. Environmental Protection Agency, 1996). The FAO guideline of 2,000 mg/L for dissolved solids (Kandiah, 1987) was not exceeded by any of the median concentrations for the land-use classifications (fig. 9). In the study unit, use and reuse of surface water for agriculture is a major source of increased dissolved solids in the ground water (Butler and others, 1991). High concentrations of sulfate also are associated with agricultural land use (fig. 9 and table 2). The median concentrations of sulfate did not exceed the proposed MCL of 500 mg/L for any of the land-use classifications (U.S. Environmental Protection Agency, 1996).

Relations of dissolved-solids concentrations to depth in springs (zero or very shallow depth) and wells for alluvial aquifers generally indicate higher concentrations at shallow depths (generally less than 60 ft) than at depths greater than 60 ft (fig. 10). Increase of some elements, such as chloride and sodium, can occur in shallow aquifers from weathering of soluble salts in the bedrock or through the infiltration of surface water that contains salts (Colorado Department of Public Health and Environment, 1994). Salinity occurs mostly in shallow unconfined aquifers of agricultural regions where irrigation is used extensively (Butler and others, 1991). Alluvial aquifers along major streams are most susceptible to the effects of agricultural practices because of the shallow depth to water and unconfined aquifer conditions.

Analysis of existing water-quality data for major cations and anions indicates that the data are not regionally distributed throughout the study unit. To determine current water-quality conditions in the study unit, additional data need to be collected to identify the occurrence and distribution of the major cations and anions. For areas that use ground water as a municipal water source (predominantly in the Southern Rocky Mountains physiographic province) additional sampling of pre-existing wells is needed. The most productive wells in the NAWQA study unit are in valley-fill alluvial deposits, and additional sampling of the wells is needed because of the lack of water-quality data. Information also is needed for wells associated with a specific land use. In the Southern Rocky Mountains physiographic province, urbanization is increasing in many mountain communities, which can affect the water quality (Apodaca and others, 1996). Because of the sparse data in these areas, additional information is needed to supplement the data identified as urban and built-up land use. Also, historical water-quality data provided little information on temporal variations in ground-water quality. Another important aspect in determining current water-quality conditions is to examine seasonal variations and variations attributed to recharge on the water quality.

Metals and Selected Trace Elements

Description of Ground-Water-Quality Data

For metals and selected trace elements, concentrations are difficult to compare among aquifers and land-use classifications because of sparse data. Concentrations of most metals and trace elements, if available, were less than the detection level (censored data). The censored data for the selected trace elements ranged from a few percent to greater than 75 percent of the data. Metal and selected trace-element data primarily were from alluvial aquifers. Concentrations of metals and trace elements are summarized in tables 1 and 2, for aluminum, arsenic, barium, boron, cadmium, chromium, copper, iron, lead, lithium, manganese, molybdenum, selenium, uranium, vanadium, and zinc.

Concentrations in Ground Water

In the study unit, metal concentrations differ between aquifers and land uses. The median iron concentrations for the various aquifers did not exceed the SMCL for iron of 300 µg/L (table 1) (U.S. Environmental Protection Agency, 1996). Land use associated with alluvial aquifers indicated that the highest median iron concentrations were in agricultural (50 µg/L) and in urban and built-up (40 µg/L) land uses (table 2). Iron present in excessive amounts in drinking water forms red oxyhydroxide precipitates that stain laundry and plumbing fixtures (Hem, 1992).

Median concentration of manganese exceeded the SMCL of 50 µg/L in water from the Mancos Shale (80 µg/L) (table 1) (U.S. Environmental Protection Agency, 1996). None of the median concentrations of manganese in the four land-use classifications exceeded the SMCL of 50 µg/L (table 2) (U.S. Environmental Protection Agency, 1996). High manganese concentrations in ground water can cause a brown discoloration of the water and affect the taste of the water. The presence of high concentrations of manganese in water supplies is undesirable because of the tendency to deposit black-oxide stains (Hem, 1992).

For trace elements, selenium data were available and indicated some differences between aquifers (fig. 8) and land-use classifications (fig. 9). The highest median selenium concentration among aquifers (2.0 µg/L) was in the alluvium (table 1), which was much lower than the MCL for selenium of 50 µg/L (U.S. Environmental Protection Agency, 1996). Samples associated with rangeland (fig. 9 and table 2) had the highest median concentrations of selenium (2.8 µg/L). The MCL for selenium of 50 µg/L was exceeded in 0.02 percent of the samples for the alluvial aquifer and 22 percent of the samples for the Mancos Shale aquifer. The recommended maximum concentration for selenium in irrigation water is 20 µg/L (FAO guideline), and the median concentrations of selenium for the various aquifers and land uses were less than 20 µg/L. A correlation between high selenium concentrations and shallow depth is not as strong as for dissolved-solids concentrations using the available data (fig. 10). However, in figure 10 the data show that at depths of less than 60 ft, the selenium concentrations appear to be higher. Knowledge of the presence of selenium in ground water is important because of potential effects on animal and human health. The source of selenium and the effects of high selenium concentrations on fish and waterfowl in the study unit were summarized in a study by Butler and others (1994).

Sample sizes and ranges in concentrations of trace-element data other than selenium were too small to make any definitive statements about the aquifer or the land use. However, some natural and human factors can be identified that contribute to the occurrence of trace elements in ground-water samples collected in the study unit. The presence of trace elements can be attributed to the natural erosion processes of the hydrologic units, which include the weathering of hydrothermally altered rock in mineralized areas. A human factor associated with mining is metal-mine drainage that causes acidic water and corresponding concentrations of heavy metals, such as cadmium, copper, iron, manganese, zinc, and sometimes molybdenum (Colorado Department of Public Health and Environment, 1994). Other human factors may include acidic deposition from industrial and automotive emissions; fertilizer additions, such as copper, zinc, and sulfate; industry-related point sources; and disturbance of the land surface, which allows soluble materials to be weathered.

Because of the lack of historical data for trace elements in the study unit, additional sampling would be useful to characterize water quality on a regional scale and to relate these characteristics to land uses. For example, mining practices have affected water quality in the study unit as a result of point-source mine drainage and nonpoint-source runoff from mined areas (Apodaca and others, 1996). Many headwater streams have been affected by past mining practices; however, little information about ground-water quality in these areas is available.

Nutrients

Description of Ground-Water-Quality Data

Because data were few for most nutrient species in the study unit, dissolved nitrate-plus-nitrite as nitrogen, and dissolved orthophosphate are the only species listed in tables 1 and 2. About 6 percent of the available water-quality data was censored for nitrate, and about 30 percent was censored for orthophosphate. Most of the nutrient data were for water from alluvial aquifers in the study unit.

Concentrations in Ground Water

The median concentration of dissolved nitrate in ground water varied between selected aquifers (fig. 8 and table 1). The highest median nitrate concentration was from the aquifer in the Mancos Shale (1.1 mg/L), and the lowest was from the aquifer in the Entrada Sandstone (<0.1 mg/L); however, none of the median concentrations exceeded the 10 mg/L MCL (fig. 8 and table 1) (U.S. Environmental Protection Agency, 1996). About 0.02 percent of the concentrations in collected samples from the alluvial wells exceeded the MCL, and 0.03 percent of the concentrations from the aquifer in the Mancos Shale exceeded the MCL (U.S. Environmental Protection Agency, 1996). In a national study completed by the USGS NAWQA program, nitrate concentrations that exceed the MCL for drinking water occurred in about 21 percent of the wells that had a depth as much as 100 ft below the surface (Mueller and others, 1995).

The land use associated with the highest median concentration of nitrate is agricultural (0.81 mg/L) (fig. 9). All land-use classifications had median concentrations less than the MCL of 10 mg/L for nitrate (fig. 9 and table 2) (U.S. Environmental Protection Agency, 1996). In the national study, about 16 percent of the samples collected from wells in agricultural areas exceeded the nitrate drinking-water standard (Mueller and others, 1995). Concentrations that exceeded the MCL criteria in the study unit were less than the 16 percent determined nationally. The plot of nitrate concentration to depth (fig. 10) shows that nitrate concentrations were higher at depths less than 70 feet than at depths greater than 70 feet. The higher median nitrate concentration in shallow wells and wells in agricultural areas could indicate that there was an effect from the land surface on the nitrate concentrations in ground water in the study unit. In the agricultural land use, applications of fertilizers on cropland, especially irrigated lands, could be a source of nitrate.

There was minimal variability in median orthophosphate concentrations among aquifers and land uses (tables 1 and 2). The median concentration of orthophosphate among aquifers ranged from <0.01 to 0.04 mg/L (table 1). The median concentration of orthophosphate among land uses ranged from <0.01 to 0.02 mg/L (table 2), which indicates no variability in orthophosphate concentration between land uses.

Historical ground-water-quality data for the study unit were analyzed, but there are few data available on nutrient species. Additional information on nutrient species would aid in evaluating the factors that affect nutrient concentrations in the study unit. Identifying a particular land use associated with nutrient concentrations can be important in determining the factors that contribute to these concentrations. In addition to the application of fertilizers in the agricultural and urban areas, the use of individual septic tanks is a likely source of increased nitrate concentrations (Apodaca and others, 1996).

SUMMARY

Major ions, metals and selected trace elements, and nutrients in ground water of the Upper Colorado River Basin study unit were characterized on the basis of environmental setting. Ground-water-quality data collected for water years 1972 to 1992 were evaluated on the basis of aquifers and, for alluvial aquifers, on the basis of land use and depth. The data available for ground-water quality in the study unit were sparse. Most available data were for alluvial aquifers associated with agricultural land use in the western part of the study unit. Bedrock and alluvial well data were very sparse in the Southern Rocky Mountains physiographic province. The ground-water-quality data for this report were compiled from the U.S. Geological Survey's data base with 172 sites representing alluvial aquifers and 187 sites representing bedrock aquifers. Data for 40 sites were available from the Colorado Department of Public Health and Environment's data base.

The most prevalent ground-water-quality data from these data bases were for major cations and anions. From the differences in the major ion chemistry, similarities and differences in the water composition of the aquifers can be defined. Aquifers in the basin that are in the alluvium, the Green River Formation, the Mesaverde Group, and the Dakota Sandstone have water compositions that are predominantly calcium bicarbonate. Aquifers in the Mancos Shale and the Leadville Limestone have water compositions of predominantly calcium sulfate; however, much of the water in the Mancos Shale is sodium sulfate type. The aquifer in the Precambrian rocks has a water composition of calcium bicarbonate.

Ion concentrations for calcium, magnesium, sodium, potassium, sulfate, and chloride, as well as dissolved solids, were highest in ground water associated with the Mancos Shale aquifer. The median dissolved-solids concentration for the Mancos Shale (3,745 mg/L) exceeds the SMCL criteria for drinking water (500 mg/L) and the FAO guideline for irrigation water (2,000 mg/L). Land use associated with agriculture had the highest dissolved-solids concentrations. Median sulfate concentrations that exceeded the MCL criterion of 500 mg/L also were from the aquifer in the Mancos Shale (2,300 mg/L). Some of the high sulfate concentrations were associated with agricultural land use. Dissolved-solids concentrations were high at depths of less than 60 ft for alluvial aquifers.

Ion concentrations were not high for selected aquifers and land-use classifications, and the SMCL for iron of 300 μg/L was not exceeded. Median concentrations of manganese exceeded the SMCL of 50 μg/L in water from the Mancos Shale. None of the median concentrations of manganese were high in the four land-use classifications.

Most trace-element data were less than the detection limits, and a good comparison between aquifers for trace elements could not be made. The highest selenium concentrations were in the alluvial aquifer and were associated with rangeland. However, about 22 percent of the values for selenium in the Mancos Shale aquifer exceed the MCL of 50 mg/L. All median concentrations of selenium were below the FAO guideline of 20 mg/L. Selenium concentrations at depths of less than 60 ft appear to have higher values as indicated by the few data.

All median nitrate concentrations were less than the MCL of 10 mg/L for the aquifers. The highest median nitrate concentration was in the aquifer in the Mancos Shale, and the lowest was in the Entrada Sandstone aquifer. Nitrate concentrations exceeded the MCL of 10 mg/L in 0.02 percent of the sites associated with alluvial aquifers and in 0.03 percent of the sites associated with the Mancos Shale aquifer. Nitrate concentrations were high at shallow depths, indicating that there was an effect from the land surface on the shallow ground water. Concentrations of orthophosphate did not vary significantly among aquifers or land-use classifications.

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