Water-Quality Data Analysis of the Upper Gunnison River Watershed, Colorado, 1989–99

By Jason J. Gurdak, Adrienne I. Greve, and Norman E. Spahr

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FOREWORD

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

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

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

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

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

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

Robert M. Hirsch
Associate Director for Water

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
acre	0.4049	hectare
acre-foot (acre-ft)	1,233	cubic meter
cubic foot (ft^3)	0.02832	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second (ft^3/s)	28.32	liter per second
foot (ft)	0.3048	meter
foot per second (ft/s)	0.3048	meter per second
pound (lb)	0.4536	kilogram
square mile (mi^2)	2.59	square kilometer

Degrees Fahrenheit (^oF) may be converted to degrees Celsius (^oC) by using the following equation:
$^oC = 5/9\ (^oF - 32)$.

Degrees Celsius (^oC) may be converted to degrees Fahrenheit (^oF) by using the following equation:
$^oF = 9/5\ (^oC) + 32$.

Additional Abbreviations or Terms

BOD, Biochemical Oxygen Demand
CDPHE, Colorado Department of Public Health and Environment
ft, feet
LOWESS, Locally Weighted Scatterplot Smoothing
L, liter
MCL, Maximum Contaminant Level
mg/L, milligrams per liter
mi^2, square mile
mL, milliliter
mg/m^2, milligrams per square meter
NPS, National Park Service
NTU, nephelometric turbidity unit
NWIS, U.S. Geological Survey National Water Information System
PEL, Probable Effect Level
pCi/L, picocuries per liter
s, second
STORET, U.S. Environmental Protection Agency Storage and Retrieval database
SDWR, Secondary Drinking Water Regulation
TVS, Table Value Standard
USEPA, U.S. Environmental Protection Agency
USFS, U.S. Forest Service
USGS, U.S. Geological Survey
VOC, Volatile Organic Compound
µg/L, micrograms per liter
µS/cm, microsiemens per centimeter at 25 degrees Celsius
WY, water year (October 1 to September 30) [WY 1980 = October 1, 1979, to September 30, 1980]
>, greater than
≅, approximately equal to

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Abstract

Water-quality data from October 1969 to December 1999 for both surface water and ground water in the upper Gunnison River watershed were retrieved and compiled from the U.S. Geological Survey National Water Information System and the U.S. Environmental Protection Agency Storage and Retrieval databases. Analyses focused primarily on a subset of these data from October 1989 to December 1999. The upper Gunnison River watershed is located west of the Continental Divide in the Southern Rocky Mountains physiographic province.

Surface-water-quality data were compiled for 482 sites in the upper Gunnison River watershed. Most values of surface-water temperature, dissolved oxygen, and pH were within Colorado Department of Public Health and Environment (CDPHE) in-stream standards. Calcium bicarbonate type water was the most spatially dominant water type in the basin.

Nutrients were most commonly sampled along the Slate River and East River near Crested Butte and along the Gunnison River from the confluence of the East and Taylor Rivers to the western edge of the watershed. Median ammonia concentrations were low, with many concentrations less than laboratory reporting levels. All nitrate concentrations met the CDPHE in-stream standard of 10 milligrams per liter. More than 30 percent of stream sites with total phosphorus data (23 of 61 sites) had concentrations greater than the U.S. Environmental Protection Agency (USEPA) recommendation for controlling eutrophication.

Ammonia concentrations at a site on the Slate River near Crested Butte had a statistically significant upward trend for the 1995–99 period. The Slate River near Crested Butte site is located immediately downstream from the towns of Crested Butte and Mount Crested Butte and may reflect recent population growth or other land-use changes. However, the rate of change of the trend is small (0.017 milligram per liter per year).

Although a multiple comparison test showed nitrate concentrations were statistically different between agriculture and forest sites and between agriculture and urban land-use classified sites, median concentrations were low among all land-use settings. Median concentrations of total phosphorus were greatest in rangeland areas and least in urban areas. No significant differences were identified for median concentrations of total phosphorus in agriculture and forest land-use areas.

Median concentrations of arsenic, lead, mercury, selenium, and silver were low or below reporting levels throughout the watershed. Aluminum, cadmium, copper, lead, manganese, and zinc concentrations were elevated near the town of Crested Butte and on Henson Creek upstream from Lake City, which may be explained by upstream areas of historical mining. Samples for six trace elements exceeded standards: cadmium, copper, lead, manganese, silver, and zinc. A downward trend (3 micrograms per liter per year) was identified for the dissolved iron concentration at a site on the Gunnison River at County Road 32 downstream from the city of

Gunnison. Streambed-sediment samples from areas affected by historical mining also had elevated concentrations of some trace elements.

Chlorophyll-*a* concentrations in samples from Blue Mesa Reservoir and streams in the Crested Butte and Gunnison areas were typical of unenriched to moderately enriched conditions. Median concentrations of 5-day biochemical oxygen demand concentrations for sites between Crested Butte and Blue Mesa Reservoir were less than 2 milligrams per liter. Occasional high (greater than 200 counts per 100 milliliters) concentrations for fecal coliform were determined at selected sites within the study area. However, median concentrations were less than 100 counts per 100 milliliters except for the Squaw Creek and Cimarron River areas in the western part of the watershed.

Ground-water-quality data have been collected by the U.S. Geological Survey from 99 wells. Many wells were completed in aquifers composed of Holocene-age valley fill and alluvium. Most field properties were within the USEPA Secondary Drinking Water Regulations (SDWR) range for treated drinking water, except for 2 (of 40) pH samples. Calcium bicarbonate was the predominant water type in nearly all aquifers except for the aquifers composed of volcanic rock, which had more sodium and sulfate mixed water types. Wells with sulfate concentrations exceeding the SDWR of 250 milligrams per liter were completed in aquifers composed of volcanic rock near Lake City. Dissolution and oxidation of sulfide minerals in these aquifers may explain the elevated sulfate concentrations in ground water at these locations.

Nutrient concentrations in ground water were generally low, and median concentrations for ammonia, nitrite, and dissolved phosphorus were below reporting levels. All nitrate concentrations in the samples were below the USEPA drinking-water maximum contaminant level of 10 mg/L. No statistical difference was found in nitrate concentrations among the four land-use classifications (agriculture, forest, rangeland, and urban).

Trace elements in ground water were generally below the USEPA SDWR. Three iron samples exceeded the USEPA SDWR of 300 micrograms per liter at two wells located near the city of Gunnison and at a well south of the town of Powderhorn near the Cebolla River. Nine of 39 manganese samples exceeded the USEPA SDWR of 50 micrograms per liter and were collected from aquifers composed of Holocene-age valley fill and alluvium near Gunnison and Crested Butte and in one well near the Cebolla River. Radon gas is a natural radioactive decay product of uranium. All 39 radon samples collected from ground water in the watershed exceeded the proposed USEPA drinking-water maximum contaminant level of 300 picocuries per liter and ranged from 426 to 3,830 picocuries per liter.

INTRODUCTION

The upper Gunnison River, located in south-central Colorado (fig. 1), drains approximately 3,965 mi^2. The East and Taylor Rivers drain an area west of the Continental Divide, converge upstream from the city of Gunnison, and form the Gunnison River, which flows into the Wayne N. Aspinall Unit of the Colorado River Storage Project (Blue Mesa, Morrow Point, and Crystal Reservoirs) and the Curecanti National Recreation Area. Currently (2001), the Curecanti National Recreation Area, along with the Crested Butte Mountain Resort, attracts a large number of recreational visitors to the upper Gunnison River watershed, which historically was dominated by ranching and mining.

Population growth and changes in land-use practices have the potential to affect both water quality and quantity in the upper Gunnison River watershed. In 1995, the U.S. Geological Survey (USGS), in cooperation with local sponsors—City of Gunnison, Colorado River Water Conservation District, Crested Butte South Metropolitan District, Gunnison County, Mount Crested Butte Water and Sanitation District, National Park Service, Town of Crested Butte, and Upper Gunnison River Water Conservancy District—established a water-quality-monitoring program in the upper Gunnison River watershed to characterize current water-quality conditions and to assess the effects of increased

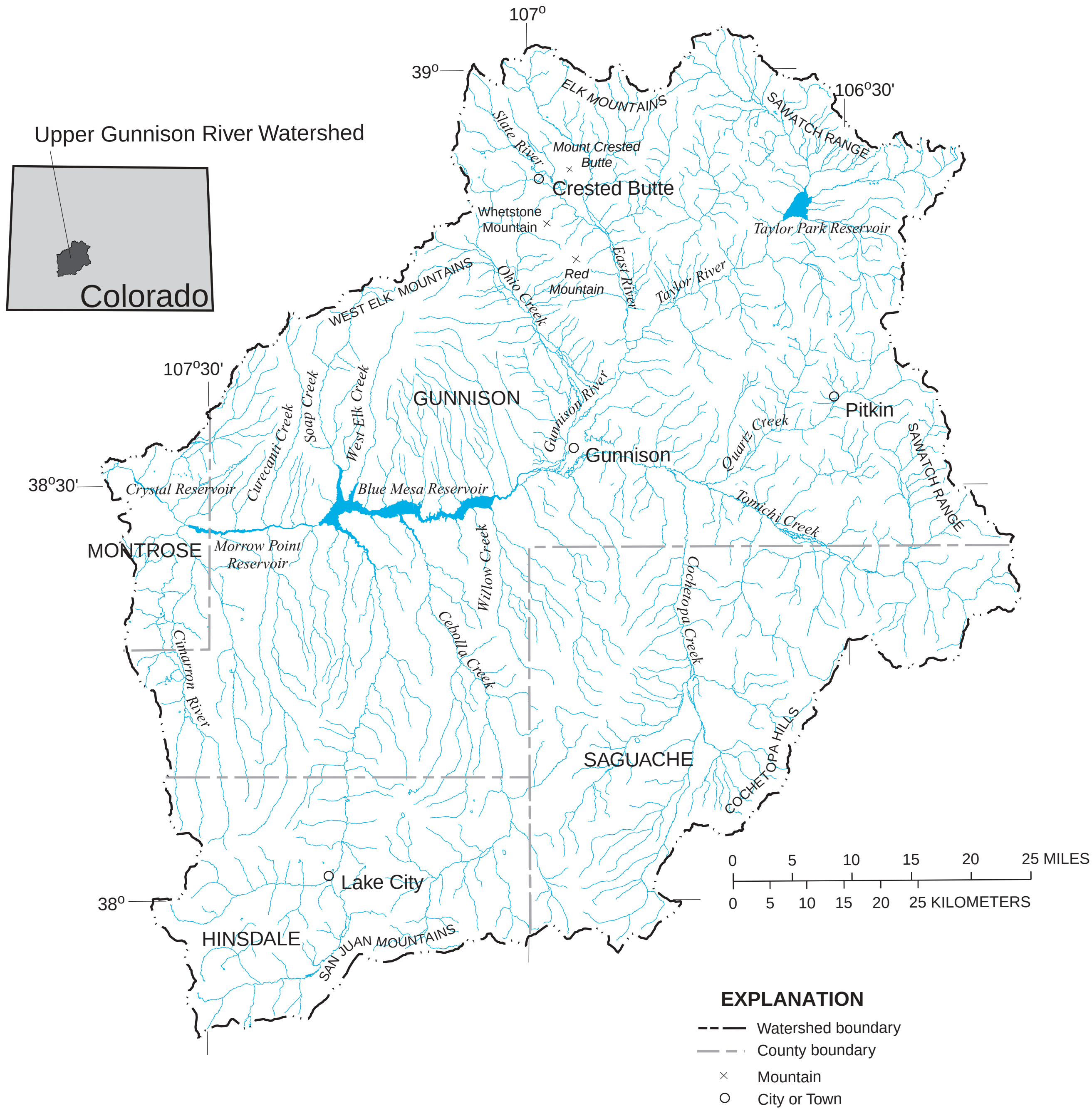


Figure 1. Location of the upper Gunnison River watershed study area.

urban development and other land-use changes on water quality. In order to evaluate the outcome of the water-quality monitoring program initiated in 1995, identify spatial and temporal gaps within the available water-quality data, evaluate the needed focus of future water studies, and ultimately aid in making informed land-use decisions in the watershed, the local sponsors expressed a need for a compilation and analysis of existing water-quality data. In 1999, the USGS, in cooperation with the local sponsors, initiated a retrospective analysis of water quality in the upper Gunnison River watershed.

Purpose and Scope

This report presents the results of the compilation and analysis of available water-quality data for the upper Gunnison River watershed. The retrospective water-quality analysis was limited to water-quality data in an electronic (computerized database) format and included only samples gathered from October 1969 to December 1999. These water-quality data were gathered and reported by the USGS, U.S. Environmental Protection Agency (USEPA), Colorado Department of Public Health and Environment (CDPHE), National Park Service (NPS), U.S. Forest Service (USFS), Colorado Department of Natural Resources, and the Bureau of Reclamation.

For selected water-quality properties and constituents in the watershed, this report presents a data summary, spatial distribution evaluation, comparison to Federal and State standards, and analyzes relations between land-use practices and water quality. Where the length of record was sufficient, trend analysis was conducted to identify changes in water quality over time. To assess the effects of land use on water quality, sites were grouped according to current land-use practices adjacent to each site, and water-quality data were compared among land-use classification groups.

Acknowledgments

The authors thank Matt Malick (National Park Service), Nancy Bauch, Bob Boulger, and Paul von Guerard (all U.S. Geological Survey) for assistance with compilation of water-quality data. Acknowledgments also are extended to Tyler Martineau and Tony Ranalli for technical reviews, Carol Anderson and Mary Kidd for editorial reviews, Joy Monson for manuscript and layout, and Sharon Powers Clendening for graphic design.

STUDY AREA

The upper Gunnison River watershed is located west of the Continental Divide in the southern Rocky Mountains of Colorado. The watershed is primarily within Gunnison County, with smaller sections located in Saguache, Hinsdale, and Montrose Counties. The headwaters are in the Elk and West Elk Mountains to the north and in the San Juan Mountains, Cochetopa Hills, and Sawatch Range to the south and east (fig. 1). Major tributaries in the upstream portion of the watershed are the Slate River, East River, Taylor River, Ohio Creek, Tomichi Creek, and Cochetopa Creek. Other tributaries (such as Cebolla Creek, Lake Fork Gunnison River, and the Cimarron River) drain into the reservoirs of the Wayne N. Aspinall Unit of the Colorado River Storage Project west of Gunnison. The Aspinall Unit reservoirs include Blue Mesa, Morrow Point, and Crystal and are in the Curecanti National Recreation Area. The maximum elevation and outlet elevation of the watershed are 14,265 and 6,526 ft, respectively. The watershed area-weighted average annual precipitation is 23 inches (Colorado Climate Center, 1984).

Forest and rangeland are the dominant land uses in the watershed (fig. 2). About 57 percent of the watershed is forested and about 32 percent is used as rangeland (table 1). Barren land or tundra is the next largest land-use category, comprising about 7.79 percent. Urban and built-up lands comprise only 6 mi^2 (0.14 percent) of the watershed (Fegeas and others, 1983; refined by Hitt, 1995).

Communities were first established in the upper Gunnison River watershed during the mid- to late 1800's as a result of the boom in silver mining. By the end of the 1800's, the silver mining boom had ended, leaving only towns that had other industries on which to base their economies. Crested Butte and Gunnison were able to rely on ranching, industry brought by the railroad and coal mining, and beginning in 1911, Western State College in Gunnison (Vandenbusche, 2000).

Today, there are many small towns and communities in the watershed, but only two areas have populations numbering in the thousands: the city of Gunnison (1999 population of 5,498) and the town of Crested Butte, including the surrounding upper East River valley (1999 population of 2,274) (Colorado Department of Local Affairs, 2000). Although the resident population is relatively small, the region attracts a large number of visitors. The largest tourist draws in the watershed are the Curecanti National Recreation Area and Crested Butte Mountain Resort, which together attract more than 1.5 million visitors

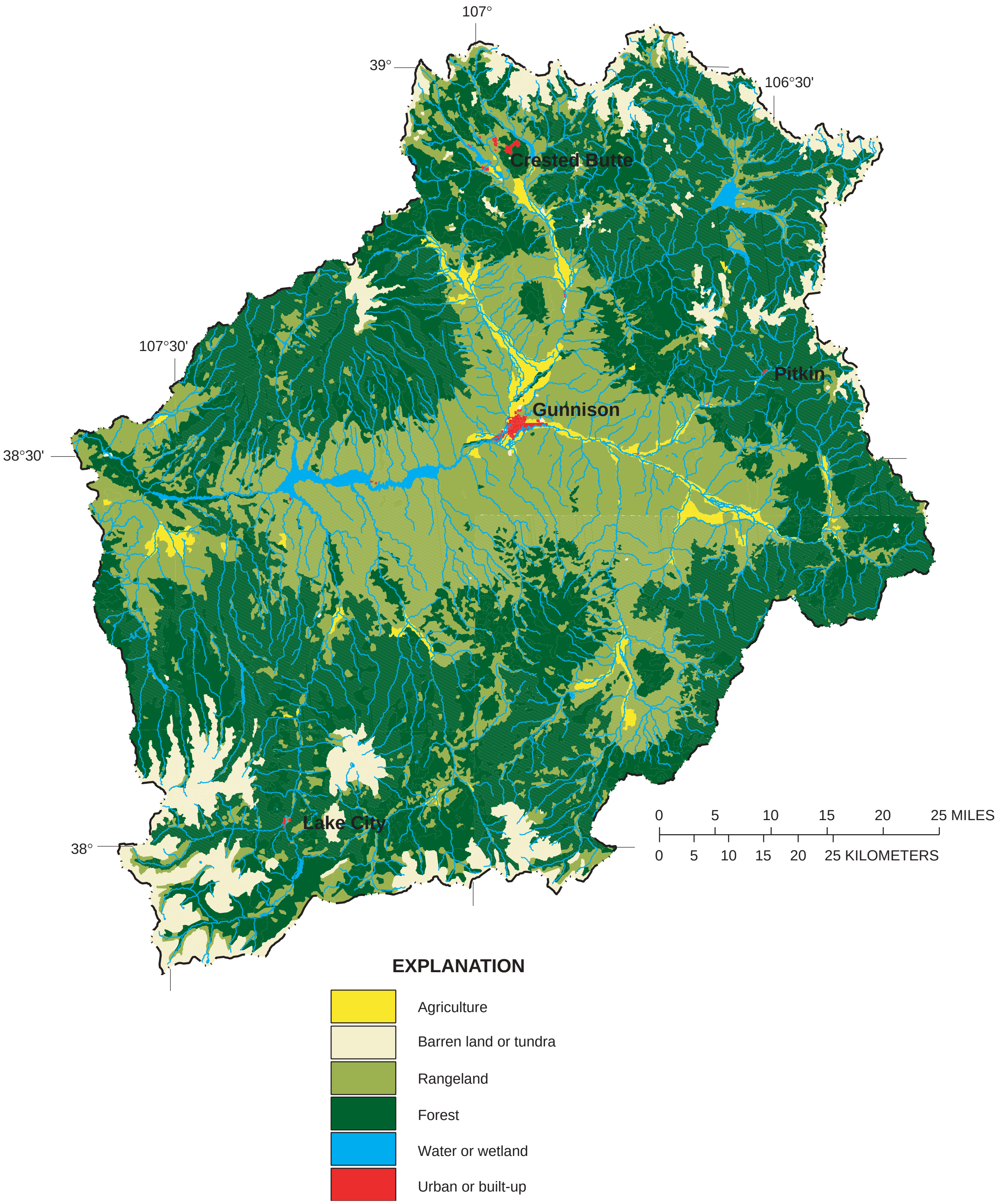


Figure 2. Land use in the upper Gunnison River watershed, 1990.

yearly (National Park Service, 2000; Gunnison County Chamber of Commerce, 2000). Tourism is the largest industry in Gunnison County, followed by education (Western State College) and ranching (Gunnison County Chamber of Commerce, 2000). Between 1990 and 1999, the population of Gunnison had a modest increase from 4,636 to 5,498 (18 percent increase); however, during the same period, the combined population of Crested Butte and Mount Crested Butte increased from 1,214 to 2,274 (87 percent increase) (Colorado Department of Local Affairs, 2000). Recently, plans were announced to construct 163 new homes in Crested Butte (Colorado Department of Labor and Employment, 2000).

Table 1. Land use for the upper Gunnison River watershed

[Fegeas and others, 1983; refined by Hitt, 1995; mi^2, square miles]

Land use	Area (mi^2)	Percentage of study area
Agriculture	92.3	2.33
Barren land or tundra	308.8	7.79
Forest	2,258.8	56.97
Mining	0.7	0.02
Rangeland	1,272.8	32.10
Water or wetland	25.8	0.65
Urban or built-up	5.7	0.14

Hydrology

The USGS has operated 21 streamflow-gaging stations within the upper Gunnison River watershed at some time during the period of October 1969 to December 1999 (fig. 3). Some gages were discontinued at the end of WY 1970 and, therefore, have only 1 year of data within the period of study. During WY 1999, 13 gages were in operation, covering the major drainages in the watershed. Typical of the southern Rocky Mountains, the annual discharge pattern is dominated by spring snowmelt (fig. 3). A substantial increase in discharge is common beginning in April, peaking in May or June, and decreasing in July and August (sites 103 and 45) (fig. 3). The remainder of the year has relatively constant flow. Exceptions to the snowmelt-dominated hydrograph, recorded downstream from the Taylor and Crystal Reservoirs (sites 97 and 50), reflect controlled releases from upstream reservoirs (fig. 3).

Surface water that is not used consumptively in the watershed drains to the three reservoirs of the Aspinall Unit. The operation of the three reservoirs—Blue Mesa, Morrow Point, and Crystal—is controlled by the Bureau of Reclamation, whereas recreation in the Curecanti National Recreation Area is controlled by the National Park Service. Together, the reservoirs have a storage capacity of 1,083,126 acre-ft (Bureau of Reclamation, 1999). Blue Mesa Reservoir is the largest and most upstream of the three reservoirs, followed in size and downstream location by Morrow Point and Crystal Reservoirs. Based on data from 1979 to 1999, Blue Mesa Reservoir has a maximum storage capacity of 940,700 acre-ft, a surface area of 9,180 acres at full pool, and an average residence time of 202 days, whereas Morrow Point and Crystal Reservoirs, respectively, have maximum storage capacities of 117,190 and 25,236 acre-ft, surface areas of 817 and 301 acres at full pool, and average residence times of 36 and 4.5 days (capacity and surface-area data from Bureau of Reclamation [1999]; residence times from Nancy Bauch, U.S. Geological Survey, and Matt Malick, National Park Service, written commun., 2001).

Geology

Rocks of Precambrian age to unconsolidated alluvium of Quaternary age underlie the upper Gunnison River watershed (fig. 4). The oldest rocks are in the eastern one-half (western flank of the Sawatch Range) and central portions of the watershed. Sedimentary rocks are exposed in central and northern locations, ranging from Paleozoic to Cretaceous in age (Green, 1992; Tweto, 1979). Erosion has exposed these sedimentary rocks as the primary feature forming many of the mountain sides and stream drainages in the central part of the watershed. Many of the taller mountains, like those in the Sawatch Range, are formed by Precambrian granite as well as by younger, Tertiary-age basalt caprock (Red Mountain) and laccolith intrusions (Mount Crested Butte and Whetstone Mountain). Tertiary igneous rocks, including ash flows, tuff, breccia, conglomerates, basalt, and other intrusive bodies, are the dominant rock types in the southern one-half and much of the northwestern sections of the watershed. The youngest formations include unconsolidated alluvium and glacial and landslide deposits of Quaternary age. The

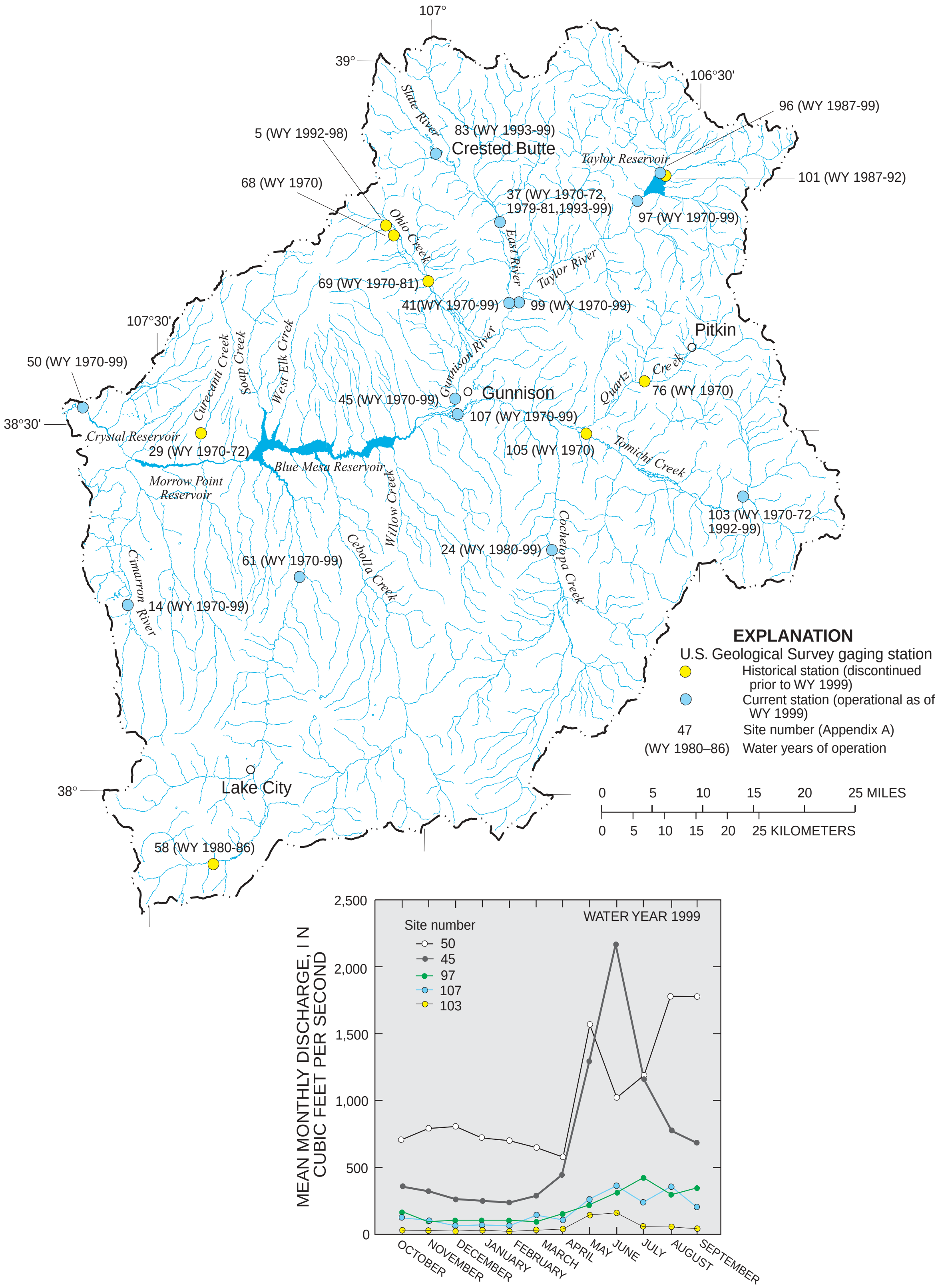


Figure 3. Location of selected U.S. Geological Survey streamflow-gaging stations and mean monthly discharge (water year 1999) for selected stations.

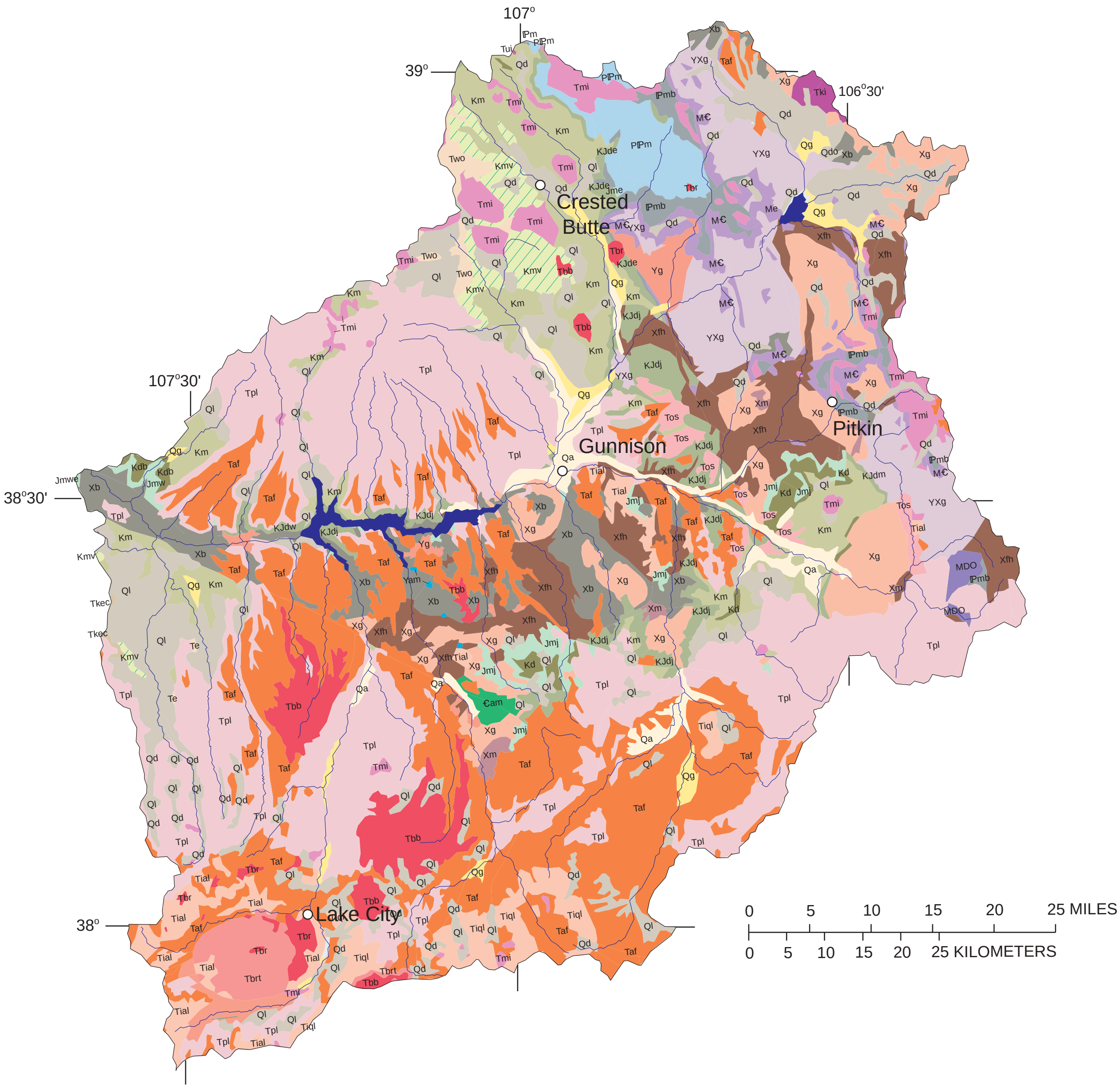


Figure 4. Geology of the upper Gunnison River watershed.

most common of these unconsolidated features are landslide deposits, present largely in the western portions of the watershed. The two largest glacial drift features, of the Pinedale and Bull Lake Glaciations, are located northeast of Taylor Park Reservoir. The two youngest formations within the unconsolidated surficial deposits of Quaternary age, modern alluvium and gravels and alluvium, are present in most major drainages.

METHODS OF DATA ANALYSIS

Methods of water-quality data analysis for the upper Gunnison River watershed consisted of retrieving all available water-quality data, in electronic format, collected from October 1969 to December 1999; performing quality-assurance measures; and presenting summary statistics, temporal and spatial trends, and comparisons to Federal and State standards.

EXPLANATION

Unconsolidated surficial deposits of Quaternary age

Qa	Modern alluvium
Qg	Gravels and alluvium
Qd	Glacial drift of Pinedale and Bull Lake Glaciations
Qdo	Older glacial drift
Ql	Landslide deposits

Sedimentary rocks of Tertiary age

Tos	Oligocene rocks
Two	Wasatch Formation
Te	Eocene prevolcanic rocks

Igneous rocks of Tertiary age

Tbb	Basalt flows and tuff, breccia, and conglomerate
Tbr	Rhyolitic intrusive rocks and flows
Tbrt	Ash-flow tuff of late-volcanic bimodal suite
Taf	Ash-flow tuff of main volcanic sequence
Tial	Intra-ash-flow andesitic lavas
Tiql	Intra-ash-flow quartz latitic lavas
Tpl	Pre-ash-flow andesitic lavas, breccias, tuffs, and conglomerates
Tui	Upper Tertiary intrusive rocks of 20 Ma
Tmi	Upper Tertiary intrusive rocks of 20 – 40 Ma

Sedimentary and igneous rocks of early Tertiary and Late Cretaceous age

Tkec	Telluride conglomerate
Tki	Laramide intrusive rocks

Sedimentary rocks of Cretaceous age

Kd	Dakota Sandstone
Kmv	Mesaverde Group, undivided
Km	Mancos Shale
Kdb	Dakota Sandstone and Burro Canyon Formation

Sedimentary rocks of Cretaceous and Jurassic ages

KJdm	Dakota and Morrison Formations
KJdj	Dakota, Burro Canyon, Morrison, and Junction Creek Formations
KJdw	Dakota, Burro Canyon, Morrison, and Wanakah Formations
KJde	Dakota, Burro Canyon, Morrison, Wanakah, and Entrada Formations

Sedimentary rocks of Jurassic age

Jmj	Morrison Formation and Junction Creek Sandstone
Jmw	Morrison Formation and Wanakah Formation
Jme	Morrison Formation and Entrada Sandstone
Jmwe	Morrison, Wanakah, and Entrada Formations

Sedimentary rocks of Permian and Pennsylvanian age

Pℙm	Maroon Formation

Sedimentary rocks of Pennsylvanian age

ℙm	Minturn Formation
ℙb	Belden Formation
ℙmb	Minturn and Belden Formations

Sedimentary rocks of Pre-Pennsylvanian Paleozoic age

MꞒ	Leadville, Gilman, Dyer, Parting, Fremont, Harding, Manitou, Dotsero, Peerless, and Sawatch Formations
MDO	Leadville, Gilman, Dyer, Parting, Fremont, Harding, and Manitou Formations

Igneous rocks of Cambrian age

Ꞓam	Alkalic and mafic intrusive rocks in small plutons, and diabase dikes

Metamorphic rocks of Precambrian age

Xb	Biotite gneiss, schist, and migmatite
Xfh	Felsic and hornblende gneisses

Igneous rocks of Precambrian age

Yg	Granitic rocks of 1,400 Ma
Yam	Alkalic and mafic rocks in small plutons, and diabase and gabbro dikes
Xg	Granitic rocks of 1,700 Ma
Xm	Mafic rocks of 1,700 Ma
YXg	Granitic rocks of 1,400 and 1,700 Ma

MA, mega-annum

Figure 4. Geology of the upper Gunnison River watershed—Continued.

Data Sources

The data analyzed in this report were collected by Federal and State agencies: USGS, USEPA, CDPHE, NPS, USFS, and the Bureau of Reclamation. The data set consists of water-quality and water-quantity information for surface and ground water. Data were obtained in electronic format from the USGS National Water Information System (NWIS) and the USEPA Storage and Retrieval (STORET) databases.

Data for 779 sites were retrieved from NWIS and STORET: 680 surface-water sites (including lakes and reservoirs) and 99 ground-water sites. Approximately 727 different constituents or properties were included in the retrieval. Substantially fewer than 727 constituents were analyzed and presented in this report. These were field properties (water temperature, pH, dissolved oxygen, and specific conductance), major ions, nutrients, trace elements, streambed sediment, suspended sediment, chlorophyll, biochemical oxygen demand, and fecal coliform. The period of record varied for water-quality sites, many of which had limited data, often only one sample. Many USGS surface-water-quality sites also measured instantaneous discharge, daily discharge, and stream stage. There were substantially fewer ground-water sites than surface-water sites with water-quantity data. Ground-water-level data were compiled for 37 wells in the basin.

Data Quality Assurance

Prior to analysis, several quality-assurance measures were taken. The initial quality-assurance measures were used to identify gross errors in the data. The USEPA has established typical ranges for many constituents and properties, which have been used as a quality-assurance guideline for data entered into STORET since 1983 (National Park Service, 1998). All data obtained from STORET and NWIS were checked using these guidelines. Data values also were checked to ensure that they fit into the context of other concentrations identified in a given sample. Dissolved concentrations were checked to be less than or equal to total concentrations when both total and dissolved concentrations were reported for a given sample. An ion balance was calculated for each sample with adequate data, which provided an effective method to check the accuracy of major dissolved constituent concentrations. An ion balance is a charge balance of a water sample, commonly calculated in milliequivalents per liter.

Concentration of cations in milliequivalents ≅
Concentration of anions in milliequivalents
Cations: calcium, magnesium, sodium, potassium
Anions: sulfate, chloride, fluoride, carbonate

A water-quality value identified as suspect by any data-quality-assurance measure was evaluated individually, taking into account the collection location, time of year, and other samples gathered at, or near, the site. In several cases, a value outside the range of STORET guidelines was actually determined to be correct. This determination was most common at sites located at the outlet of a particular abandoned mine in which trace-element concentrations were above the typical maximum value defined by STORET. At the conclusion of the data-quality-assurance measure, eight data values were deleted and one was corrected.

Data Compilation and Comparison

Methods described by Mueller and others (1995) were used to combine equivalent nitrogen and phosphorus species. Equivalent nitrogen and phosphorus species were combined because nutrient data were collected and reported by different agencies that use different laboratory methods and sampling and reporting conventions. For example, within the entire data set, nitrate nitrogen data were reported as dissolved nitrate as nitrogen, dissolved nitrate as nitrate, and total nitrate as nitrogen. Thus, nutrient species are summarized in this report as follows: ammonia as nitrogen (hereinafter referred to as “ammonia”), nitrite as nitrogen (hereinafter referred to as “nitrite”), nitrate as nitrogen (hereinafter referred to as “nitrate”), dissolved orthophosphate as phosphorus (hereinafter referred to as “orthophosphate”), total phosphorus for surface-water analysis, and dissolved phosphorus for ground-water analysis. At pH 9.24, the transformation of aqueous ammonia, NH_3, to ammonium ion, NH_4^+, is half complete, so in most natural water (pH lower than 9.24), ammonia nitrogen would primarily be in the ammonium ion form (Hem, 1992). Aqueous ammonia (hereinafter referred to as “un-ionized ammonia”) was computed using pH, water temperature, concentration of ammonium ion, and an equilibrium constant. The CDPHE has not established in-stream water-quality standards for the ammonium ion but has established an in-stream chronic standard for aqueous ammonia (un-ionized ammonia).

Major-ion concentrations were compiled to develop water types for water-quality sampling sites. Water types were calculated based on the percentage of milliequivalents of the major ions present within each sample. For those samples that exhibit a predominant water type, the cation and anion that makes up more than 50 percent of the total milliequivalents of cations and anions are identified. A number of samples had mixed water types, when no single cation or anion constitutes 50 percent or more of the totals (Hem, 1992). The cations and anions of a mixed water type are identified in order from highest to lowest in total percentage to their respective sums of cations and anions.

After compilation, the water-quality data were compared to standards (or guidelines) and land-use classifications. Stream-water-quality data were compared to CDPHE in-stream water-quality standards, which are based on the stream reach classifications: cold-water aquatic life, recreation, water supply, and agriculture. A number of the trace elements have Table Value Standards (TVS), which are site-specific in-stream standards calculated using stream hardness. TVS equations use a stream hardness value calculated from the "lower 95th-percent confidence limit of the mean hardness value at the periodic low-flow criteria determined from a regression analysis of site-specific data" (Colorado Department of Public Health and Environment, 1999). In this study, the annual low-flow period was defined as October through March. When there were more than five hardness values at a given sampling site during the low-flow period, the lower 95th-percent confidence limit of the mean hardness value was used in the TVS equation. If fewer than five samples were available during the low-flow period, the mean of the low-flow hardness values was used in the TVS equation. If there were no hardness samples available for the low-flow period, all hardness values were used and a lower 95th-percent confidence limit of the mean was determined (for five or more available non-low-flow samples). If fewer than five non-low-flow samples were available, the mean hardness of non-low-flow samples was used in the TVS equation.

The CDPHE has set chronic and acute in-stream standards for trace elements. According to the CDPHE (Colorado Department of Public Health and Environment, 1999), "chronic represents the level that protects 95 percent of the genera from chronic effects of metals that may include the following: demonstrable abnormalities and adverse effects on survival, growth, or reproduction," and "acute represents half the concentration that is lethal to 50 percent of the test organisms in a 96-hour period." For a given constituent, acute standards are usually higher than the chronic standards.

Ground-water-quality data were compared to the USEPA maximum contaminant levels (MCL's) and Secondary Drinking Water Regulations (SDWR). The USEPA MCL's are enforceable standards for public water-supply systems but are not enforceable for individual domestic wells. SDWR's are nonmandatory standards established to manage esthetic qualities (taste, odor, color) for public water supplies. Comparisons of ground-water-quality data in the upper Gunnison River watershed to USEPA MCL's are offered only as a point of reference.

Land-use classifications for water-quality sampling sites were determined based on comparison of site location to the land-use distribution map (fig. 2) and by incorporating recent changes (typically urban development) from upstream and surrounding land-use practices. Four land-use classifications were used: agriculture, forest, rangeland, and urban or built up.

Temporal Trend Analysis

Trend analyses were performed using the seasonal Kendall test (Helsel and Hirsch, 1993) for sites having at least 5 years of quarterly data, a period of record ending within the last decade, and less than 50 percent censored data (below laboratory reporting level). This analysis measured the monotonic relation between constituent concentration and time. Because the analysis is rank-based, it is resistant to the effects of small sample size, censored data, and non-normal population distributions. A positive correlation was identified if the constituent concentration increased more often than it decreased over time. In this report, a trend was determined to be present when the p-value of the statistical test was less than the decision level (alpha-level) of 0.05. The smaller the p-value, the stronger the evidence for rejection of the null hypothesis (Helsel and Hirsch, 1993). For this report, a p-value below 0.05 is sufficient evidence for rejection of the null hypothesis which states that no relation between concentration and time is present. Where instantaneous discharge data were available, flow-adjusted concentrations were used in the Kendall’s tau analysis using a locally weighted scatterplot smoothing (LOWESS). A detailed discussion of Kendall’s tau and its application is included in Helsel and Hirsch (1993).

Due to data availability, several of the trend analyses were conducted over a short time period, 5 to 10 years. In many cases, longer time periods may be required to identify a trend, particularly trends that are small in magnitude. In order to identify a trend, the change in concentration with time must be larger than the variability inherent in a given data set. Thus, trends may be present that are not identified due to the variability in the data. Conversely, trends that are identified over a 5-year period may not continue over a longer period, such as 10 years.

SURFACE-WATER QUALITY

Surface-water-quality data were collected and compiled at 482 sites located on streams and rivers in the upper Gunnison River watershed. Numerous agencies, over varying periods of record, collected a variety of water-quality data at these 482 sites. The USGS and NPS collected surface-water-quality data at the most sites, having sampled 192 and 168 sites, respectively. During the 1990’s, data were collected at 118 sites, whereas during the 1980’s and 1970’s, data were collected at 151 and 324 sites, respectively. More than one-half (255) of the sites had only one water-quality sample collected. During the 1970’s, 217 sites had only one water-quality sample collected, and during the 1990’s, 20 sites had only one water-quality sample collected. In comparison, during the entire period of study, 6.4 percent (31) of the total sites had more than 100 samples collected. Water-quality data for the upper Gunnison River watershed are summarized in table 2. Specific sites discussed or shown in figures are listed in Appendix A. Field properties were collected at nearly all surface-water sites, and major ions, nutrients, and trace elements also were commonly collected.

Field Properties

Temperature affects the life cycles and activity of biota in an aquatic environment (Allan, 1996) and the rate and equilibria of chemical reactions. Surface-water temperature in the upper Gunnison River watershed ranged between –0.7° and 22°C from October 1989 to December 1999 (table 2). Spatially, median water temperatures usually were lower in headwater areas compared to areas farther downstream. The highest median water temperatures were measured on the main stem of the Gunnison River, downstream from the city of Gunnison, and at the mouth of several other tributaries to the Aspinall Unit. Only 11 samples had water temperatures exceeding the CDPHE in-stream standard of 20°C. These measurements were made during summer periods at two sites on Tomichi Creek (104 and 107) and one site on Cochetopa Creek (24). One water-temperature measurement at site 104 and eight water-temperature measurements at site 107 exceeded 20°C; however, all were 22°C or less. Two exceedances at site 24 were recorded and both water-temperature measurements were 20.5°C. Differences in temperature with respect to land use are not presented because differences can be attributed to other factors such as shading, stream gradient, elevation, season, and streamflow rather than land use.

Dissolved oxygen is important in maintaining healthy stream biota as oxygen is necessary for the survival of many aquatic organisms. During the 1990’s, no site in the watershed had a median dissolved-oxygen concentration less than the minimum CDPHE standard of 6 mg/L. Dissolved-oxygen concentrations were typically near saturation. Differences in dissolved-oxygen concentration among sites can be attributed to differences in physical variables such as temperature and reaeration rather than land-use practices. Six stream-water-quality sites had adequate dissolved-oxygen data to support a flow-adjusted seasonal Kendall’s tau test for temporal trend analysis; however, no trends were identified, as shown in table 3.

Acidic or basic streams can affect biotic communities by reducing numbers of species and individual organisms (Allan, 1996). Few pH values were outside the range defined by CDPHE in-stream standards (6.5 to 9.0); three pH values were more acidic than standards, and only two values were more basic. The sites with pH below 6.5 were located on Henson

Table 2. Summary of the number of analyses, minimum, median, and maximum concentrations for surface-water-quality samples in the upper Gunnison River watershed

[No., number; mg/L, milligrams per liter; ° C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; µg/L, micrograms per liter; NTU, nephelometric turbidity units; mg/m^2, milligrams per square meter; mL, milliliter; <, less than; --, not available]

Property or constituent (reporting units)	No. of analyses/ No. of censored values, 1970–99	October 1989 to December 1999					
		No. of analyses/ No. of censored values	No. of sites	Minimum value	Median value	Maximum value	In-stream-segment standards[1]
Field properties							
Temperature (°C)	10,567/6	5,248/4	134	–0.7	10.54	22	20
Oxygen, dissolved (mg/L)	5,828/1	2,393/0	122	2.6	8.88	16.64	6.0
pH, field (standard units)	3,345/83	1,614/0	115	3.43	7.9	9.4	6.5–9.0
Specific conductance (µS/cm)	7,158/5	2,589/0	90	24	175	921	--
Turbidity (NTU)	1,181/0	174/0	15	0.1	1.5	35	--
Alkalinity (mg/L as $CaCO_3$)	404/0	367/0	30	16	79	175	--
Major ions							
Bicarbonate, dissolved (mg/L as HCO_3)	207/0	207/0	20	21	95	182	--
Calcium, dissolved (mg/L)	917/0	444/0	31	6.2	26.5	60	--
Chloride, dissolved (mg/L)	536/18	377/14	29	<0.1	0.89	4.4	--
Chloride, total (mg/L)	469/2	0/0	--	--	--	--	250
Fluoride, dissolved (mg/L)	688/123	378/4	30	<0.1	0.15	0.5	--
Magnesium, dissolved (mg/L)	753/3	444/0	31	0.51	5.1	13	--
Potassium, dissolved (mg/L)	668/1	378/0	30	0.19	0.9	5.6	--
Silica, dissolved (mg/L)	622/0	378/0	30	2.8	6.8	22	--
Sodium, dissolved (mg/L)	722/0	378/0	30	0.6	3.7	10	--
Sulfate, dissolved (mg/L)	549/16	377/0	29	4.3	17	53	
Sulfate, total (mg/L)	1,020/70	258/41	33	5	18	260	250
Dissolved solids (mg/L)	557/0	359/0	28	27	112	218	--
Nutrients							
Ammonia (mg/L as N)	2,330/1,119	1,228/657	100	<0.002	0.009	0.7	--
Nitrate (mg/L as N)	2,550/908	1,190/413	99	<0.005	0.07	2.55	10, 100
Nitrite, dissolved (mg/L as N)	858/563	775/561	56	<0.001	0.01	0.03	0.02, 0.05
Orthophosphate, dissolved (mg/L as P)	2,736/600	2,028/562	85	<0.001	0.008	0.143	--
Phosphorus, total (mg/L as P)	3,357/748	2,258/380	117	<0.001	0.05	4.05	--
Un-ionized ammonia (computed as mg/L)	734/0	427/0	56	0.000003	0.0003	0.008	0.02, 0.05
Trace elements							
Aluminum, dissolved (µg/L)	322/169	256/162	38	Greater than 50 percent of data censored Reporting levels of 50, 15, and 5		3,900	--
Arsenic, dissolved (µg/L)	227/112	56/51	23	Greater than 50 percent of data censored Reporting levels of 1		5	--
Cadmium, dissolved (µg/L)	775/618	498/428	59	Greater than 50 percent of data censored Reporting levels of 1, 0.3, 0.25, and 0.14		19	Footnote 2

Table 2. Summary of the number of analyses, minimum, median, and maximum concentrations for surface-water-quality samples in the upper Gunnison River watershed—Continued

[No., number; mg/L, milligrams per liter; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; µg/L, micrograms per liter; NTU, nephelometric turbidity units; mg/m^2, milligrams per square meter; mL, milliliter; <, less than; --, not available]

Property or constituent (reporting units)	No. of analyses/ No. of censored values, 1970–99	October 1989 to December 1999					
		No. of analyses/ No. of censored values	No. of sites	Minimum value	Median value	Maximum value	In-stream-segment standards[1]
Trace elements—Continued							
Copper, dissolved (µg/L)	904/611	521/394	62	Greater than 50 percent of data censored Reporting levels of 5, 4, and 1		4,700	Footnote 2
Chromium, dissolved (µg/L)	302/218	10/9	9	Greater than 50 percent of data censored Reporting level of 1		2	Footnote 2
Iron, dissolved (µg/L)	1,097/298	465/115	71	<3	[4]14	14,000	Footnote 3
Iron, total (µg/L)	407/14	252/0	23	10	220	6,400	Footnote 3
Lead, dissolved (µg/L)	880/690	495/455	56	Greater than 50 percent of data censored Reporting levels of 1 and 5		19	Footnote 2
Manganese, dissolved (µg/L)	1,307/410	736/155	74	<1	[5]10	1,200	Footnote 3
Manganese, total (µg/L)	379/88	248/35	23	<3	30	430	--
Mercury, dissolved (µg/L)	284/263	194/194	35	All data censored Reporting levels of 0.2 and 0.1			--
Nickel, dissolved (µg/L)	251/132	9/8	10	Greater than 50 percent of data censored Reporting levels of 10 and 1		1.3	Footnote 2
Silver, dissolved (µg/L)	377/337	268/265	51	Greater than 50 percent of data censored Reporting levels of 1, 0.32, and 0.2		0.2	Footnote 2
Selenium, dissolved (µg/L)	284/224	187/183	40	Greater than 50 percent of data censored Reporting levels 8, 5, and 1		2.8	--
Uranium, natural dissolved (µg/L)	333/32	61/28	37	<1	1	630	Footnote 3
Zinc, dissolved (µg/L)	950/433	547/280	64	Greater than 50 percent of data censored Reporting levels of 25, 20, 10, 8, and 3		2,100	Footnote 2
Suspended sediment							
Suspended sediment (mg/L)	385/0	385/0	40	0	48	205	--
Other parameters							
Stream chlorophyll-*a* (mg/m^2)	34/0	34/0	17	0.1	2.4	70	--
Biochemical oxygen demand (mg/L)	661/0	163/0	12	0.0	0.8	3.2	--
Fecal coliform (counts/100 mL)	3176/0	1070/0	79	0	7	3,500	Footnote 3

[1]In-stream-segment standards from Colorado Department of Public Health and Environment, Water Quality Control Commission, 1999.
[2]Table value standard, which varies with hardness (see Colorado Department of Public Health and Environment, Water Quality Control Division, 1999).
[3]Standard varies by stream reach (see Colorado Department of Public Health and Environment, Water Quality Control Division, 1999).
[4]Median calculation omitted sites that utilized a reporting level of 100.
[5]Median calculation omitted sites that utilized a reporting level of 50 micrograms per liter.

Table 3. Seasonal Kendall trend-analysis results for dissolved oxygen and pH in the upper Gunnison River watershed

Site name and number (Appendix A)	Period of record	Number of samples	Flow adjustment	p-Value	Trend direction	Median value
	Dissolved oxygen (milligrams per liter)					
Slate River near Crested Butte, 83	1994–98	30	Yes	1.0	None	10.3
East River below Cement Creek near Crested Butte, 37	1994–99	85	Yes	0.68	None	9.7
East River at Almont, 41	1991–99	51	Yes	0.24	None	9.7
Taylor River at Almont, 99	1994–99	31	Yes	0.48	None	9.6
Tomichi Creek at Gunnison, 107	1991–99	40	Yes	0.73	None	9.3
Gunnison River below Gunnison Tunnel, 50	1995–99	68	Yes	0.11	None	9.8
	pH (standard units)					
Slate River above Oh-Be-Joyful Creek near Crested Butte, 78	1995–99	26	No	1.0	None	7.8
Slate River above Coal Creek near Crested Butte, 79	1995–99	36	No	0.68	None	7.6
Slate River near Crested Butte, 83	1995–99	39	No	0.89	None	7.6
Slate River above the East River near Crested Butte, 88	1995–99	30	No	0.59	None	7.6
East River below Gothic, 33	1995–99	32	No	1.0	None	8.1
East River above Crested Butte, 34	1995–99	30	No	0.86	None	8.0
East River above Slate River near Crested Butte, 36	1995–99	34	No	1.0	None	8.2
East River below Cement Creek near Crested Butte, 37	1994–99	86	No	0.57	None	8.3
East River at Almont, 41	1991–99	52	No	0.71	None	8.3
Taylor River at Almont, 99	1994–99	31	No	0.06	None	8.1
Tomichi Creek at Gunnison, 107	1991–99	42	No	1.0	None	8.2
Gunnison River near Gunnison, 45	1995–99	28	No	1.0	None	8.2
Gunnison River at County Road 32 below Gunnison, 47	1995–99	53	No	0.67	None	8.1
Gunnison River below Gunnison Tunnel, 50	1995–99	67	No	0.55	None	8.0

Creek and Palmetto Gulch in the Lake City area (sites 52, 55, and 72—Appendix A). These sites are upstream from Lake City in a subbasin affected by historical mining, which can be reflected in the more acidic pH values. The two sites with single values greater than pH 9.0 were located on the Cimarron River (pH of 9.05, site 15—Appendix A) and Cebolla Creek at Hot Springs Ranch (pH of 9.4, site 7). Sufficient data for trend analysis were available for 14 sites in the basin (table 3); no trends were identified.

Specific conductance is a measure of the ability of water to conduct an electric current. In natural water, specific conductance commonly is related to the concentration of dissolved solids (Hem, 1992). At least one specific-conductance measurement was made at 605 sampling sites since 1970. At sites with a minimum of five samples since 1970, specific conductance ranged from 41.5 to 3,200 µS/cm. Only seven sampling sites had a median specific-conductance value greater than 500 µS/cm. Four of the sites were near hot springs (sites 8, 11, 12, and 108—Appendix A), and the remaining three sites were near Crested Butte (sites 22 and 86) or on Squaw Creek near Cimarron (site 90). At sites with at least five measurements since October 1989, median specific conductance ranged from 49 to 848 µS/cm (fig. 5). Only one site, Squaw Creek above Cimarron (site 90), had a median specific conductance greater than 500 µS/cm. Higher specific-conductance values are probably related to the geology and soils in the Squaw Creek–Cimarron areas.

Major Ions

Major ions summarized in this report are common constituents dissolved in most natural water and include bicarbonate, calcium, chloride, fluoride, magnesium, potassium, silica, sodium, and sulfate.

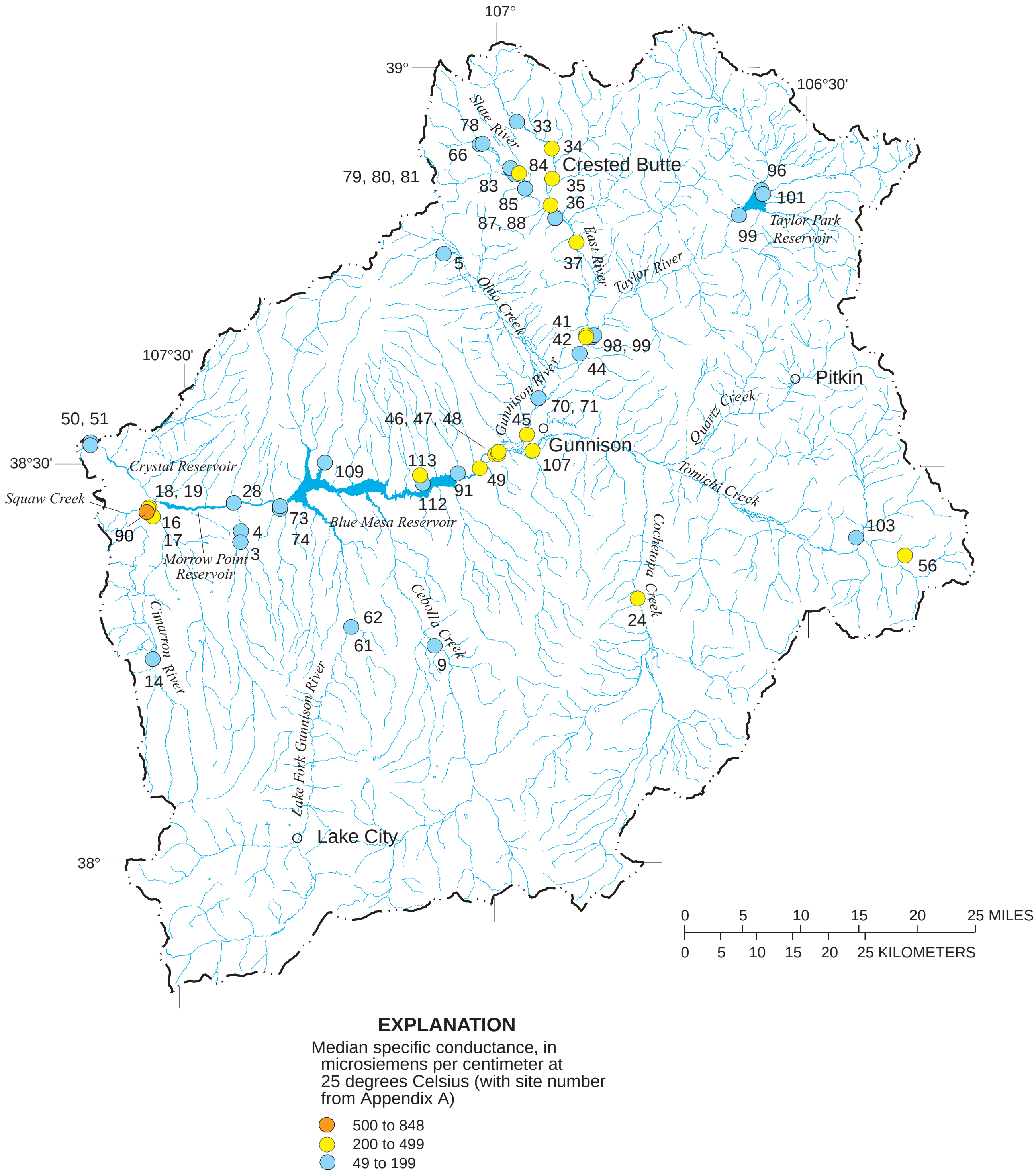


Figure 5. Spatial distribution of median specific conductance, October 1989 to December 1999.

Unless specifically stated otherwise, ion concentrations discussed in this section refer to dissolved concentrations. These major ions are dissolved in water as a result of interactions among surface and ground water, geology, soils, aquifer material, and human activities.

In most stream reaches, the dominant ions in solution are the cation calcium and anion bicarbonate. During spring runoff (May–June), recently melted snow dilutes solute concentrations and produces water ionically similar to precipitation. Other natural and anthropogenic factors that may affect water quality are often masked during spring runoff. Calcium-bicarbonate type water was the most spatially dominant from July to April (nonspringtime runoff conditions) and was present in nearly all the reaches sampled. A calcium-bicarbonate type water reflects weathering of underlying geology and soil material. Calcium-sulfate type water is found exclusively in Henson Creek and the Lake Fork of the Gunnison River, upstream from Lake City, and is attributed to the weathering of sulfate-bearing rocks associated with historical mining. Other water types in the basin (calcium sodium mixed, carbonate; magnesium-carbonate; calcium magnesium mixed, sulfate; sodium-carbonate; sodium, carbonate sulfate mixed; and sodium-sulfate) are less common than calcium-carbonate and calcium-sulfate water samples and reflect the weathering of underlying geologic material.

The CDPHE has established two in-stream standards for major ions in the upper Gunnison River watershed, 250 mg/L for both total chloride and total sulfate (Colorado Department of Public Health and Environment, 1999). Total chloride concentrations were well within in-stream standards, and only one total sulfate concentration (260 mg/L) exceeded the standard (table 2) and was measured at Indian Creek near Sargents (site 56—Appendix A). Total concentrations are determined from nonfiltered samples and contain both dissolved and particulate matter.

Hardness of water was computed from the sum of calcium and magnesium concentrations expressed as calcium carbonate ($CaCO_3$). Calcium and magnesium commonly are the result of weathering of the underlying rocks and soils in a region. In the upper Gunnison River watershed, the hardness was generally low. Since WY 1990, the range of median $CaCO_3$ concentrations was between 21 and 240 mg/L. During the entire period of study, less than 30 percent of the sampling sites in the watershed had median hardness values greater than 100 mg $CaCO_3$/L. There were large gaps in the spatial coverage of hardness data. However, based on the available information, sites located closer to headwaters in the watershed had the lowest hardness values, except Indian Creek in the upper Tomichi subbasin (sites 56 and 57). The highest hardness values were at sites classified as mining and rangeland. Increased hardness in water near mined areas may be due to increased weathering rates of rocks, which generally have more surface area exposed to water and oxygen after being mined. Forested sites had the lowest hardness values; 16 of 20 forested sites had a hardness less than 60 mg $CaCO_3$/L. The higher hardness concentrations in the rangeland areas are probably associated with underlying geology rather than land-use practices.

Nutrients

Nutrients (ammonia, nitrate, nitrite, phosphorus, and orthophosphate) in surface water can originate from various sources and are essential to most aquatic life; however, excessive nitrogen and phosphorus concentrations can produce an overgrowth of algae, which can lead to degraded aquatic habitat and a lower dissolved-oxygen concentration. In addition, excessive nitrogen concentrations are toxic to fish when in the form of un-ionized ammonia. Excessive nitrate concentrations also can be toxic to humans, causing methemoglobinemia in infants (Klaassen, 1996). Concentrations of nutrients originate from both natural and anthropogenic sources. The major factors causing excessive nutrient concentrations are human activities, including the combustion of fossil fuels, application of fertilizers, phosphate detergents, discharge of effluent from wastewater-treatment facilities, and seepage from septic systems and animal feedlots. Natural sources of nutrients include erosion of rocks and soils containing phosphorus minerals, decomposition of organic matter, and atmospheric deposition.

Nutrient samples were collected at surface-water sites in most stream reaches within the watershed. Summary statistics for these nutrients are listed in table 2. Phosphorus data were collected at more sites and more frequently than other nutrient data. Nitrite and orthophosphate have been excluded from the analysis of spatial distribution and temporal trends due to the large number of nitrite and orthophosphate concentrations reported as less than a laboratory reporting level (censored values) (table 2).

Spatial Distribution and Comparison to State Standards

Spatial distribution of nutrient concentrations and comparison to CDPHE in-stream standards were evaluated for sites with five or more samples since WY 1990. Most sites sampled for nutrients were located along the Slate River and East River near Crested Butte and along the Gunnison River from the confluence of the East and Taylor Rivers to the western edge of the watershed. Fewer sites with nutrient data were located from upstream reaches of the watershed (Lake Fork of the Gunnison River, Cebolla Creek, Ohio Creek, Tomichi Creek, Quartz Creek, and Cochetopa Creek).

Spatial distributions of median concentrations for ammonia, nitrate, and total phosphorus are illustrated in figures 6, 7, and 8, respectively. Median ammonia concentrations were relatively low, and many of the sampling sites had more than 50 percent censored data. Sites with the highest median ammonia concentrations were on the Cimarron River, near the confluence with the Gunnison River (fig. 6). Reasons for the higher concentrations in this area are unknown. Similar to ammonia, many sites in the upstream reaches of the watershed that were sampled for nitrate concentrations had more than 50 percent censored data. Of the sites having less than 50 percent censored nitrate concentration data, three sites had median concentrations (0.44, 0.25, and 0.24 mg/L) greater than 0.21 mg/L (fig. 7, sites 90, 85, and 87). Sites sampled for total phosphorus had fewer median values that were below censoring levels than sites sampled for either ammonia or nitrate. Sites along the Slate and East Rivers near Crested Butte had lower total phosphorus median values than sites in areas farther downstream in the watershed, particularly along the Gunnison River and its tributaries, downstream from Gunnison (fig. 8). Sites with total phosphorus median values greater than 0.15 mg/L were on the Gunnison River downstream from Crystal Reservoir, Squaw Creek, and the Cimarron River, Cochetopa Creek, and the Gunnison River downstream from Gunnison.

CDPHE in-stream water-quality standards for selected stream reaches are based on water-use classifications in the upper Gunnison River watershed (Colorado Department of Public Health and Environment, 1999). In-stream standards for nitrite, nitrate, and un-ionized ammonia vary spatially (according to stream reach) within the watershed. For example, in selected tributaries of the Gunnison River, an in-stream standard for nitrite was established at 0.02 mg/L, whereas the remainder of the watershed was set at 0.05 mg/L for nitrite concentration. No in-stream standards for nitrite were exceeded in the watershed. Three stream reaches have nitrate in-stream standards of 100 mg/L, and the standard for the remainder of the stream reaches is set at 10 mg/L. All nitrate concentrations were below 10 mg/L. All computed un-ionized ammonia concentrations were well below the chronic standard of 0.02 mg/L, and the maximum concentration was an order of magnitude below the standard.

The CDPHE has not established in-stream standards for total phosphorus; however, for controlling eutrophication, the USEPA has recommended that concentrations of total phosphorus be less than 0.1 mg/L in rivers and less than 0.05 mg/L in rivers that directly enter lakes and reservoirs (U.S. Environmental Protection Agency, 1986). More than 30 percent of stream sites in the watershed (23 of 61 sites) had median total phosphorus concentrations greater than the USEPA recommendations. These sites are located on the Cimarron River and tributaries (sites 15, 16, 17, 19, and 90); tributaries to Blue Mesa, Morrow Point, Crystal Reservoirs (sites 4, 6, 7, 9, 28, 73, 74, 91, 92, 94, 109, 112, and 113); the Gunnison River downstream from Gunnison (46, 49, and 51); Mill Creek (tributary to Ohio Creek, site 65); and Cochetopa Creek (site 23).

Temporal Trends

Temporal trend analyses were conducted for ammonia, nitrate, and total phosphorus at sites that met the statistical requirements discussed in the "Temporal Trend Analysis" section. These statistical requirements were met at two sites containing ammonia data, eight sites containing nitrate data, and four sites containing total phosphorus data. Sites with nitrite, orthophosphate, and un-ionized ammonia data did not meet statistical requirements.

At sites analyzed for temporal trends, the period of record was either 5 or 6 years of data, beginning in the mid-1990's and ending in 1999 (table 4). Neither nitrate nor total phosphorus had statistically significant trends at any site. However, at the Slate River near Crested Butte (site 83), ammonia concentrations had a statistically significant upward trend, with a p-value of 0.016 (table 4). The smaller the p-value, the stronger the evidence for rejection of the null hypothesis (Helsel and Hirsch, 1993), which states that no

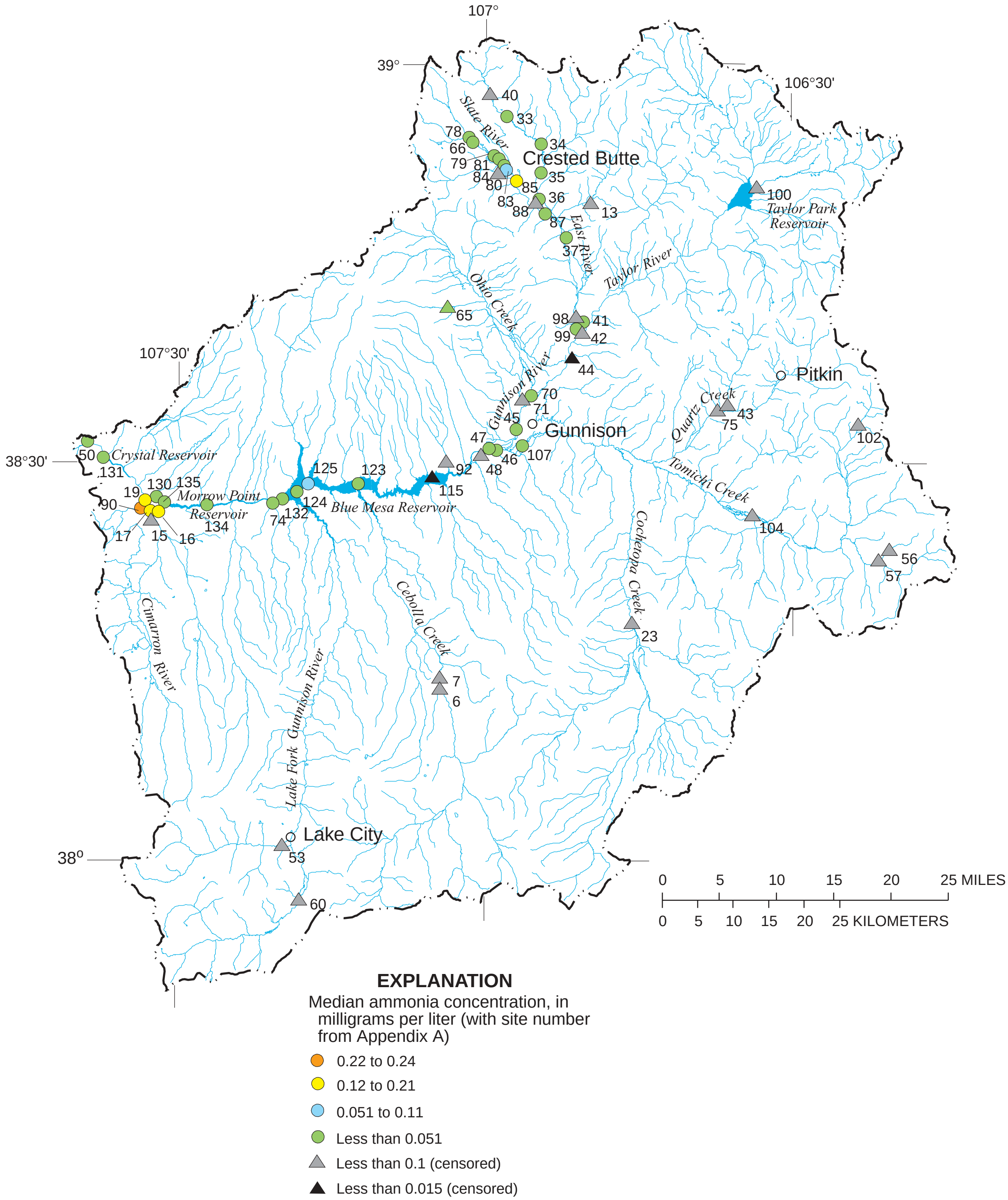


Figure 6. Spatial distribution of median ammonia concentrations, October 1989 to December 1999.

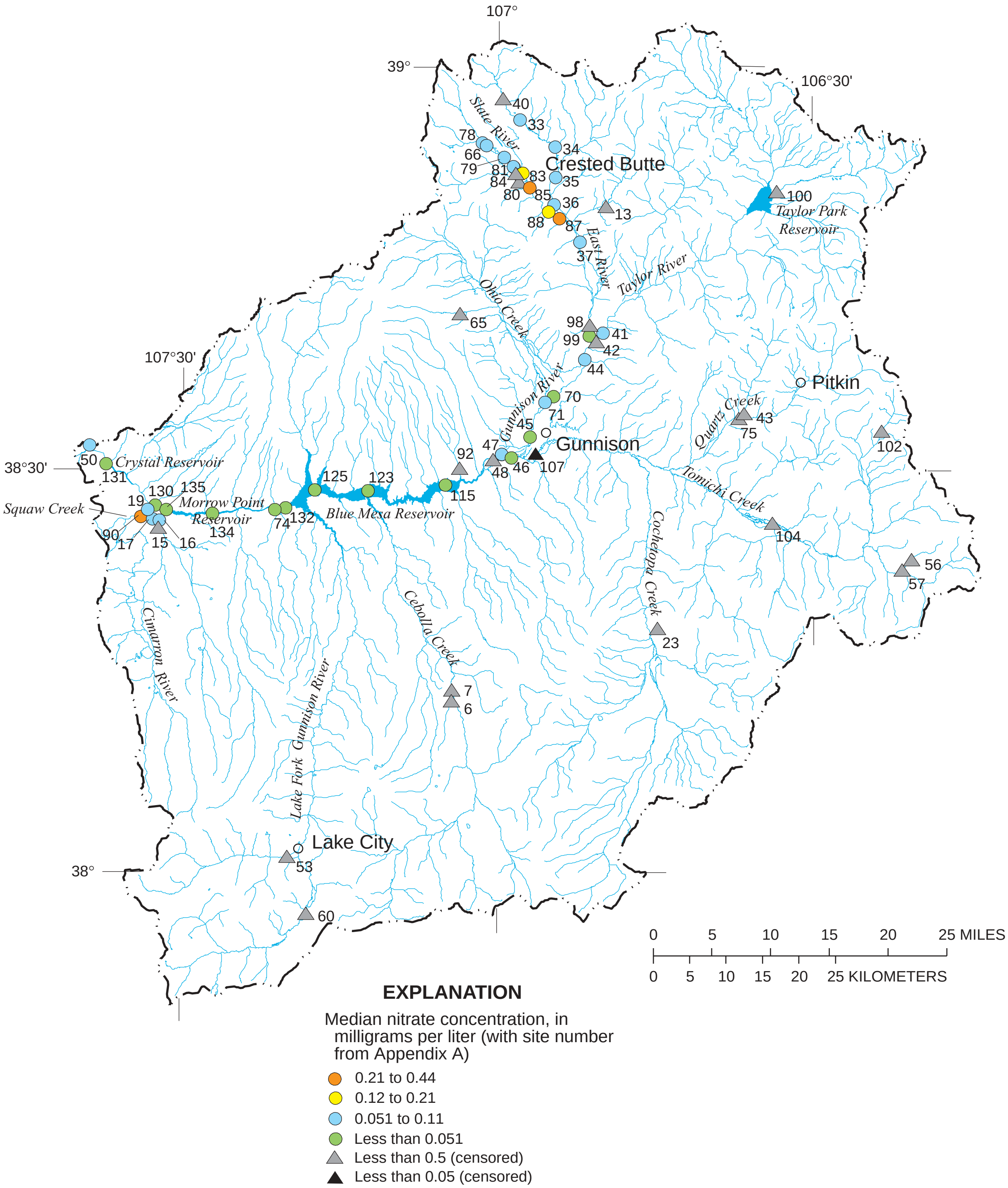


Figure 7. Spatial distribution of median nitrate concentrations, October 1989 to December 1999.

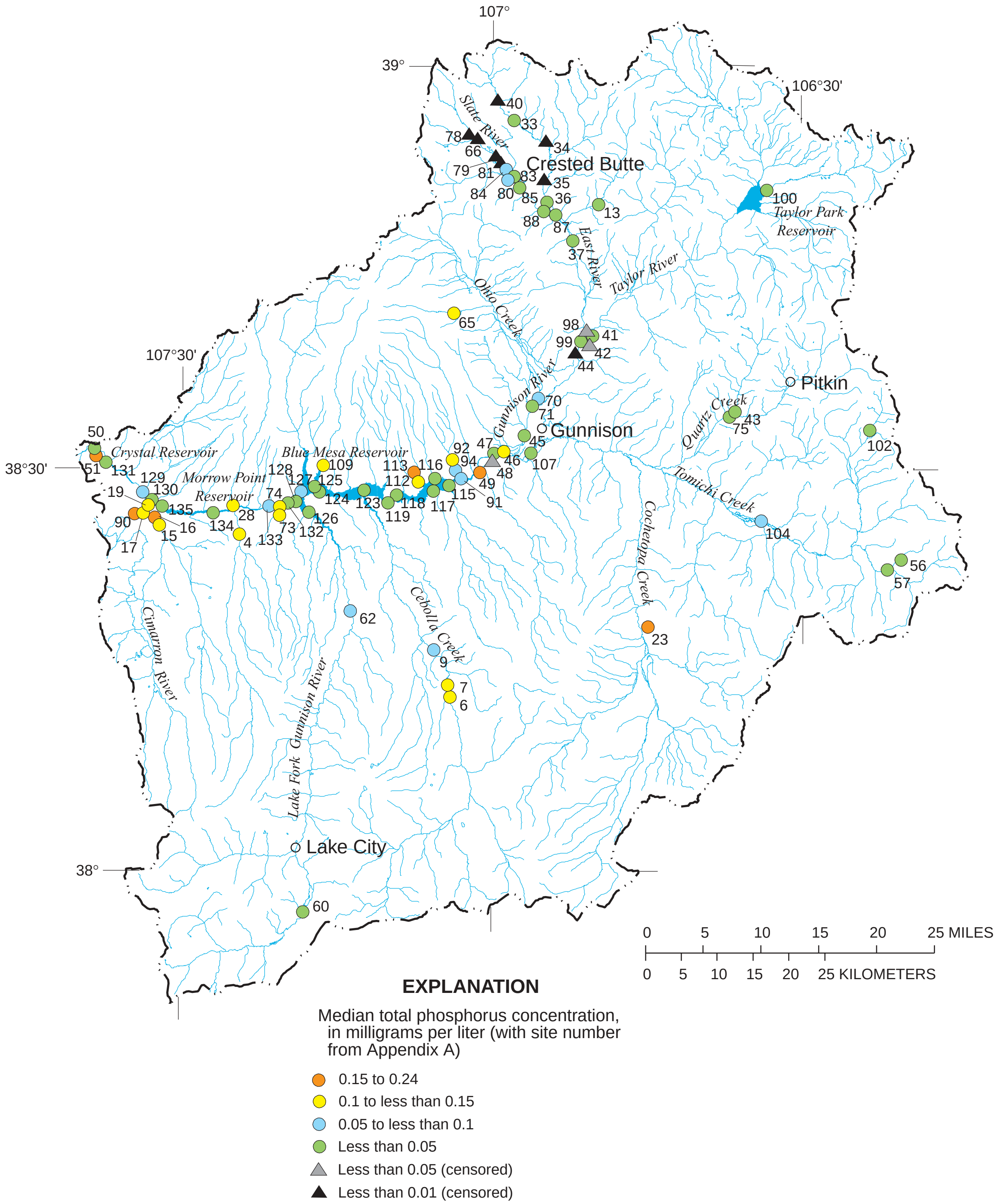


Figure 8. Spatial distribution of median total phosphorus concentrations, October 1989 to December 1999.

relation between concentration and time is present. The Slate River near Crested Butte site is located immediately downstream from the towns of Crested Butte and Mount Crested Butte and may reflect recent population growth or other land-use changes in the area. The rate of change of the trend is small (0.017 mg/L/year). Un-ionized ammonia concentrations at this site are relatively low and well below CDPHE in-stream standards, presenting no apparent environmental concern.

Land-Use Comparison

Distribution of ammonia, nitrate, and total phosphorus concentration by agriculture, forest, rangeland, and urban land-use classifications is shown in figure 9. Most nutrient data were collected at urban sites, followed by rangeland sites.

Because the nutrient data were not normally distributed, nonparametric statistics were used to determine differences among land-use groups. Statistical comparison of the median concentrations between the land-use groups was accomplished using an unbalanced analysis of variance and Tukey's multiple comparison test on the rank-transformed data (Helsel and Hirsch, 1993). Nitrate and total phosphorus were found to be different among agriculture, forest, rangeland, and urban land-use classified sites. Ammonia was not compared among the groups because more than 50 percent of the ammonia data was censored. Results of the multiple comparison test are represented by letters adjacent to the median values on the boxplots in figure 9. Plots with different letters adjacent to the medians (defined as multiple comparison groups) are statistically different at

Table 4. Seasonal Kendall trend-analysis results for selected nutrient species in the upper Gunnison River watershed

[No., number; mg/L, milligrams per liter; --, not available]

Site name and number (Appendix A)	Period of record	Number of samples/ No. of censored values	Flow adjustment	p-Value	Trend direction	Magnitude of trend slope (mg/L per year)	Median concentration (mg/L)
Ammonia							
Slate River near Crested Butte, 83	1995–99	36/2	Yes	0.02	Upward	0.017	0.08
East River below Cement Creek near Crested Butte, 37	1994–99	80/37	Yes	0.84	None	--	0.01
Nitrate							
Slate River above Coal Creek near Crested Butte, 79	1995–99	34/2	Yes	0.32	None	--	0.10
Slate River near Crested Butte 83	1995–99	36/0	Yes	0.67	None	--	0.12
Slate River above East River near Crested Butte, 88	1995–99	30/1	Yes	0.77		--	0.13
East River above Crested Butte, 34	1995–99	28/2	Yes	0.48	None	--	0.09
East River below Cement Creek near Crested Butte, 37	1994–99	79/5	Yes	0.69	None	--	0.09
East River at Almont, 41	1994–99	37/8	Yes	0.22		--	0.08
Gunnison River at County Road 32 below the City of Gunnison, 47	1995–99	51/12	Yes	0.67	None	--	0.06
Gunnison River below Gunnison Tunnel, 50	1995–99	63/12	Yes	0.90	None	--	0.06
Total phosphorus							
East River below Cement Creek near Crested Butte, 37	1995–99	74/30	Yes	0.88	None	--	0.01
East River at Almont, 41	1995–99	32/15	Yes	0.89	None	--	0.01
Gunnison River at County Road 32 below the City of Gunnison, 47	1995–99	51/7	Yes	0.24		--	0.03
Gunnison River below Gunnison tunnel, 50	1995–99	65/19	Yes	0.54	None	--	0.02

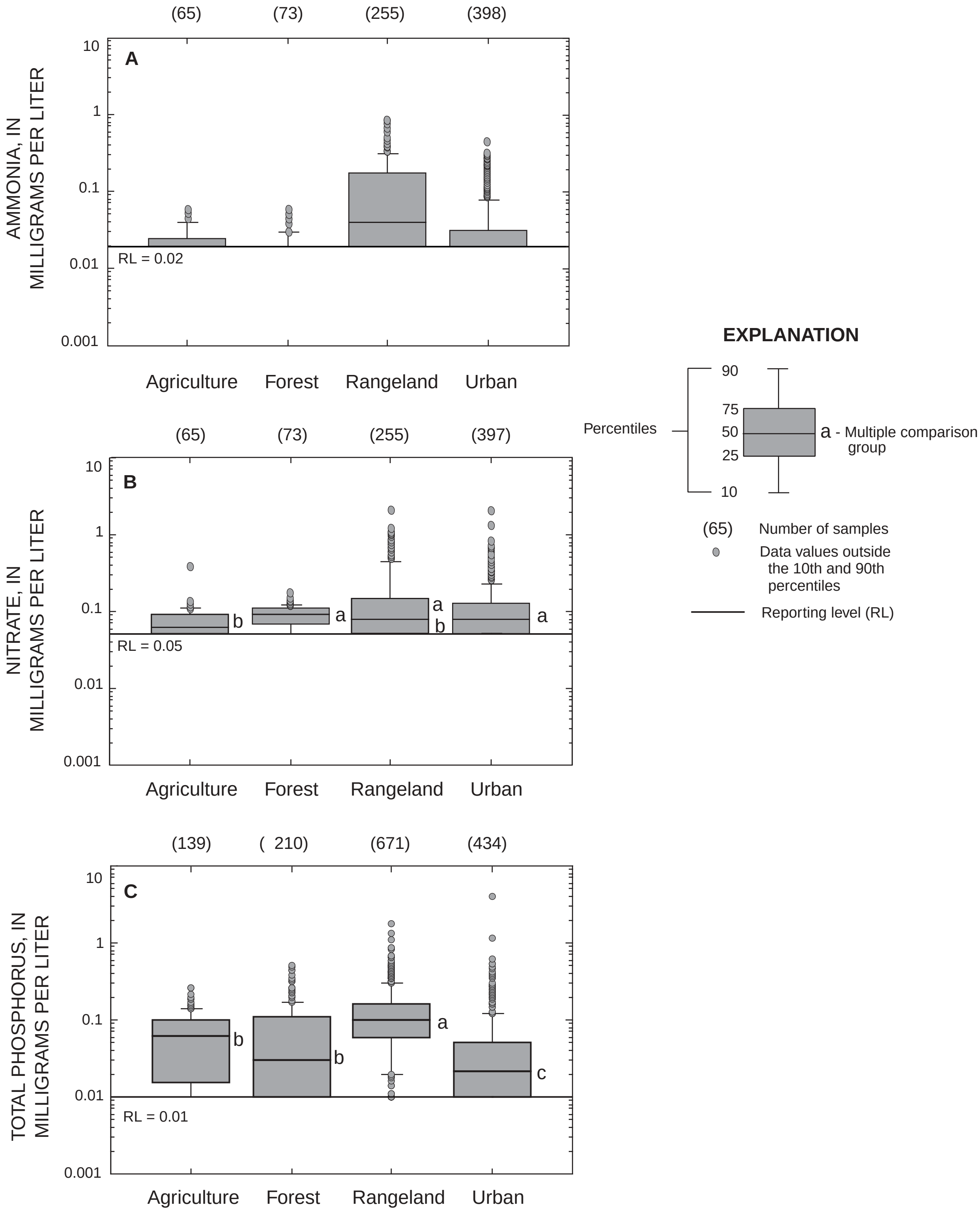


Figure 9. Distribution of (A) ammonia, (B) nitrate, and (C) total phosphorus concentrations by land-use classification for surface water, October 1989 to December 1999.

an alpha level of 0.05. In figure 9, multiple comparison groups with the same letters are not statistically different. If two letters are given (for example, ab), then the median is not statistically different from other groups with either of the letters (Mueller and others, 1995). The Tukey test showed nitrate concentrations were significantly different between agriculture and forest and between agriculture and urban land-use classifications (fig. 9). No significant differences were identified between agriculture and rangeland (fig. 9). Although differences were identified between median nitrate values of some land uses, the median nitrate concentrations were low for all land-use classifications. Median concentrations of total phosphorus were greatest in rangeland and least in urban classifications. The multiple comparison test identified no differences for median total phosphorus concentrations between agriculture and forest classifications (fig. 9). Specific reasons for the higher concentrations in rangeland sites are unknown. However, most concentrations of ammonia and nitrate were less than the 0.1 and 0.6 mg/L national background concentrations (Mueller and others, 1995). With the exception of rangeland sites, most concentrations of total phosphorus were below the national background concentration of 0.1 mg/L (Mueller and others, 1995).

Trace Elements

Many trace elements are required, in small amounts, by plant and aquatic life. However, in larger concentrations, trace elements can be harmful to plants and animals and, in sufficient concentrations, to humans. Trace elements are most often defined as those elements that occur in concentrations below 1 mg/L and are normally reported in micrograms per liter (μg/L). Unless specifically stated otherwise, trace-element concentrations discussed in this section refer to dissolved concentrations.

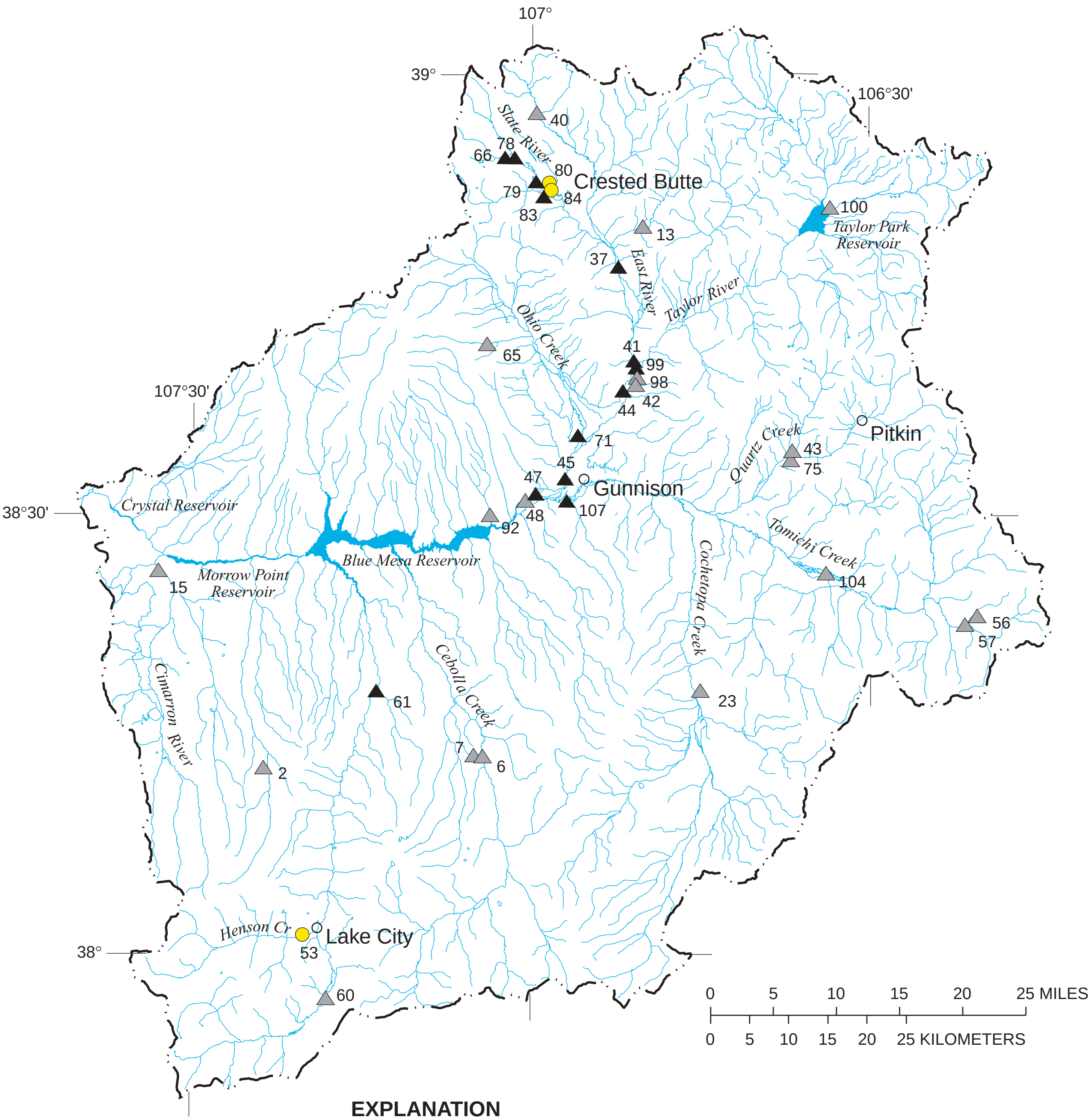
Trace elements enter the water column through both natural and anthropogenic sources. In the absence of anthropogenic influence, the types and relative concentrations of trace elements in surface water are related directly to the geology of a region. In the upper Gunnison River watershed, mining and urban areas have the potential to increase trace-element contributions to surface water. Active and historical mining exposes the underlying formations to water and air, resulting in increased physical and chemical weathering that alters the chemistry of the water contacting the exposed formation. Trace elements in urban areas are associated with industrial waste and processes, transportation, such as roads and vehicles, and many items used and found in homes, such as paint, piping, and plastics.

Of the 73 trace elements in the data set (WY 1970 to December 1999), many had too few samples to support statistical analyses. For example, 23 trace elements had fewer than 20 samples, over 30 years and 611 sites. Since WY 1990, 837 samples at 99 sampling sites included at least one trace-element concentration. Selection of trace elements for analysis was based on sites with five or more samples or the availability of CDPHE water-quality standards. The selected trace elements were aluminum, arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, uranium, and zinc.

Spatial Distribution and Comparison to State Standards

The spatial distribution of trace-element samples was not evenly distributed within the watershed. The Slate, East, and Gunnison Rivers from Crested Butte to the city of Gunnison had more trace-element sampling sites than any other stream reach in the watershed. Since WY 1990, there were between 15 and 35 sites with five or more samples for most trace elements. Adequate data for analysis for arsenic and uranium were available at two sites. No sites had adequate data for analysis of chromium and nickel.

The distribution of median concentrations for cadmium, silver, and zinc (figs. 10, 11, and 12) is representative of the sampling locations and spatial distribution of concentrations for other trace elements in the watershed. Median concentrations of arsenic, lead, mercury, selenium, and silver were low or censored throughout the basin. Concentrations of aluminum, cadmium, copper, lead, manganese, and zinc had elevated concentrations near the town of Crested Butte and on Henson Creek upstream from Lake City. These were the only two areas in which elevated trace-element concentrations were consistently detected, and both are located downstream from historical mining areas.



EXPLANATION

Median cadmium concentration, in micrograms per liter (µg/L) (with site number from Appendix A)

- 0.3 to 1.0
- Median less than 1.0 (censored)
- Median less than 0.3 (censored)

Figure 10. Spatial distribution of median cadmium concentrations, October 1989 to December 1999.

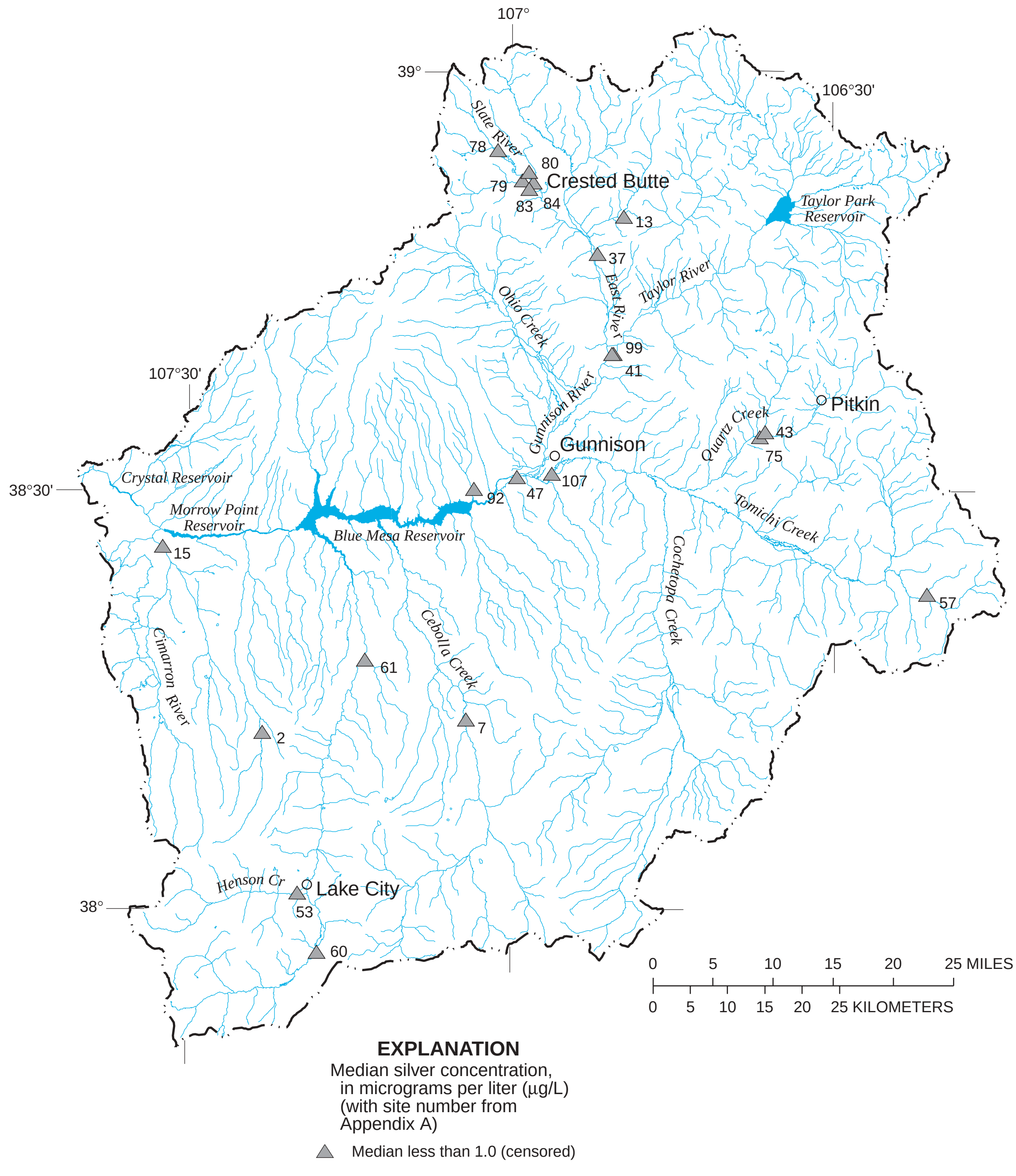


Figure 11. Spatial distribution of median silver concentrations, October 1989 to December 1999.

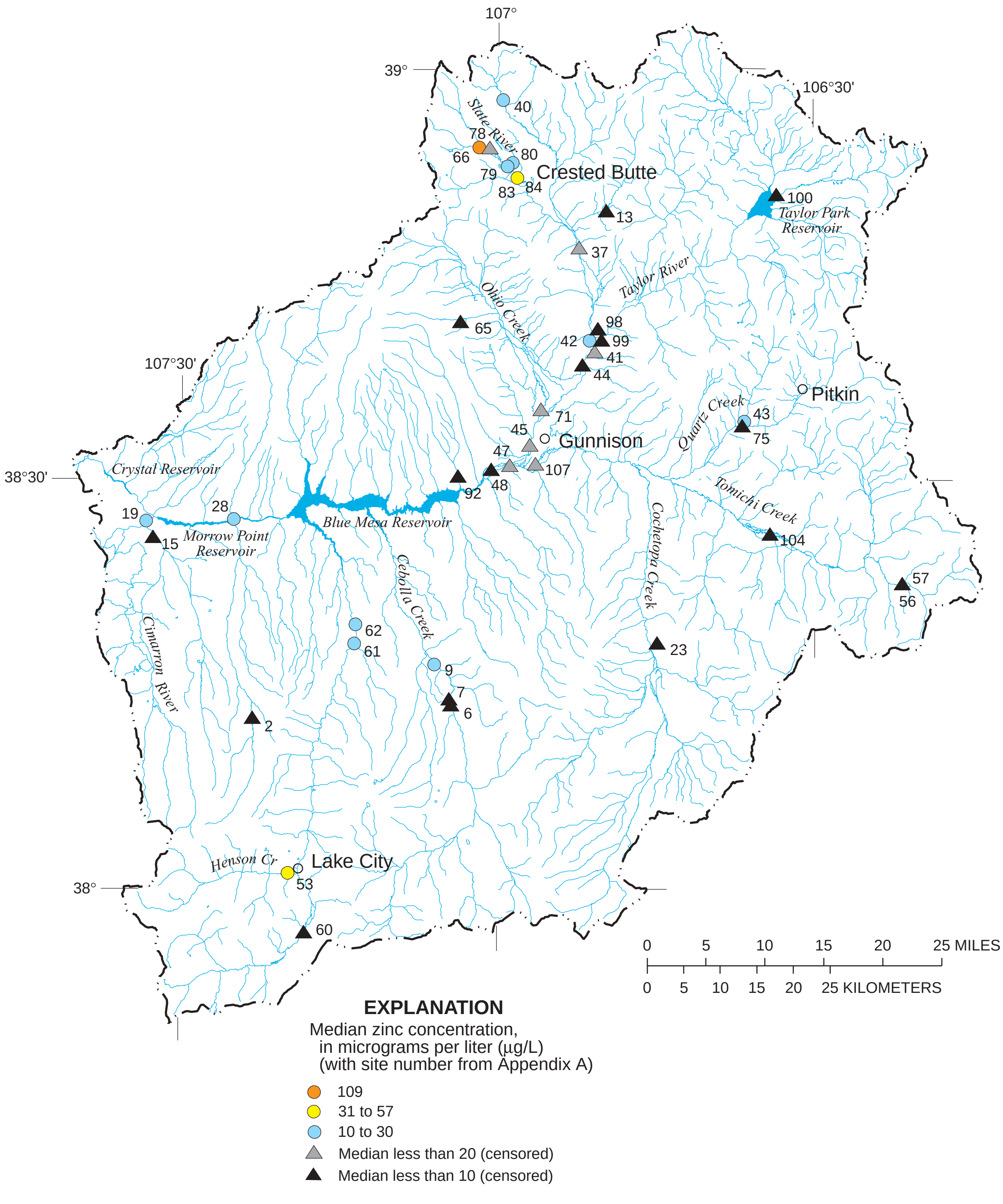


Figure 12. Spatial distribution of median zinc concentrations, October 1989 to December 1999.

Due to changes in standards and improvements in constituent minimum reporting levels, only data collected since WY 1990 were compared to CDPHE standards. Trace-element concentrations exceeded standards for six elements: cadmium, copper, lead, manganese, silver, and zinc (table 5). Manganese concentrations exceeded standards more often than any other constituent. Sites near Crested Butte and on Henson Creek upstream from Lake City had several trace elements in exceedance of CDPHE standards (fig. 13).

Temporal Trends

Temporal trend analysis was conducted on sites with at least 5 years of data, a period of record that ended within the last decade, and had less than 50 percent of the data censored. If instantaneous discharge data were not collected and a site was colocated with a USGS gage, the mean daily streamflow was used for flow adjustment. In some cases, the water-quality data record was longer than the streamflow record. A trend analysis was conducted without flow adjustment over the entire data record, and a second analysis was conducted with flow adjustment over the period of record that also had streamflow data. Results of the trend tests are listed in table 6. A downward trend (3 μg/L per year) was identified for dissolved iron concentration at the site on the Gunnison River at County Road 32 downstream from the city of Gunnison, site 47 (fig. 14). Dissolved iron concentrations at this site were low; the highest detected concentration was 120 μg/L, which is below the 300-μg/L CDPHE standard. The cause of this trend was difficult to identify due to the lack of data from upstream sites and from other tributaries, such as Tomichi Creek. A site on the East River downstream from the confluence with Cement Creek (site 37) also was evaluated for trend in dissolved iron; however, no trend was identified.

Streambed Sediment

Streambed-sediment samples have been collected at several locations. In 1977, the USEPA collected streambed-sediment samples at five sites near Gunnison and south of Blue Mesa Reservoir. The U.S. Forest Service collected samples in 1982 and 1991 near Sargents and Taylor Reservoir. Samples have been collected at 11 sites by the USGS during 1995–99 in the Crested Butte and Lake City areas. Results for selected trace elements from the 1995–99 samples are compared to the Canadian Sediment Quality Guidelines Probable Effect Level (PEL) (Canadian Council of Ministers of the Environment, 1999) in figure 15. The PEL defines the concentration level above which adverse effects to aquatic biota are predicted to occur frequently. The streambed-sediment results are similar to the water-sample trace-element results in that concentrations tend to be greater in areas downstream from historical mining (Crested Butte and Lake City). Concentrations in the lower parts of the basin are less than the Canadian PEL's.

Suspended Sediment

Measured suspended-sediment concentrations within the study area were generally low and typical of areas in the southern Rocky Mountains. Within the upper areas of the watershed, the snowmelt runoff periods are generally the only time when sediment concentrations are greater than a few milligrams per liter. Median concentrations at sites with four or more samples during October 1994 to December 1999 are shown in figure 16. The Cimarron River below Squaw Creek (site 18) in the western area of the basin was the only site with a median concentration greater than 20 mg/L. The higher concentration in this area is probably related to the geology and the more easily erodible soils. Five sites had sufficient data for trend analysis of flow-adjusted suspended-sediment concentrations. Trends in suspended-sediment concentration were not determined at any site. Results of the trend tests are listed below.

Site name and number (Appendix A)	Period of record	Flow adjustment	p-Value	Trend direction	Suspended sediment, median concentration (mg/L)
Slate River above Oh-Be-Joyful Creek, 78	1995–99	Yes	0.19	None	1.5
Slate River above Coal Creek, 79	1995–99	Yes	0.24	None	1.5
East River below Cement Creek, 37	1995–99	Yes	0.21	None	5.0
East River at Almont, 41	1995–99	Yes	0.54	None	5.0
Gunnison River at County Road 32, 47	1995–99	Yes	0.48	None	7.5

Table 5. Exceedances of Colorado Department of Public Health and Environment in-stream water-quality standards for dissolved trace elements in the upper Gunnison River watershed, October 1989 to December 1999

[No., number; conc., concentration; μg/L, micrograms per liter; <, less than]

Site name and number (Appendix A)	No. of samples/ No. of censored values	Range of conc. (μg/L)	CDPHE standard (μg/L) (chronic/acute)	No. of samples over the standards (chronic/acute)
Cadmium				
Oh-Be-Joyful Creek above Slate River near Crested Butte, 66	10/5	<1–1.6	0.47/1.1	5/2
Slate River near Crested Butte, 83	6/5	<1–1.2	0.72/2.0	1/0
Slate River below Crested Butte, 84	58/24	<0.25–1.1	0.72/2.0	2/0
Big Blue in Wilderness Area, 2	5/4	<0.25–2.2	0.60/1.6	1/1
Steuben Creek North of Blue Mesa Reservoir, 92	10/9	<0.25–0.4	0.35/0.72	1/0
Henson Creek above Lake City, 53	10/3	<0.25–0.97	0.90/0.16	2/7
Copper				
Oh-Be-Joyful Creek above Slate River near Crested Butte, 66	10/0	1.9–4.6	4.5/6.2	1/0
Slate River above Coal Creek, 80	18/17	<4–30	6.7/9.5	1/1
Slate River below Crested Butte, 84	58/54	<4–8	7.2/10.3	1/0
Sc01308603ac00–Rm Biological Laboratory, 32	1/0	184	16/24	1/1
East River below Cement Creek near Crested Butte, 37	25/16	<1–15	13.7/20.9	1/0
Upper Tomichi Creek above Whitepine, 102	4/0	5–11	10.8/16.1	1/0
Cebolla Creek at USGS gage, 6	6/4	<4–5	4.6/6.2	1/0
Cimarron River below Little Cimarron, 15	10/6	<4–8	7.1/10	1/0
Henson Creek above Lake City, 53	10/8	<4–15	1.1/1.2	2/2
Henson Creek above North Fork Henson, 52	1/0	7	6.2/8.7	1/0
Lead				
Oh-Be-Joyful Creek above Slate River near Crested Butte, 66	10/0	3–9.1	8/16	1/0
Slate River below Crested Butte, 84	58/53	<1–5	1.7/38	3/0
Gold Creek above Ohio, 43	9/6	<1–2	1.9/43	1/0
Cebolla Creek at USGS Gage, 6	6/5	<1–2	0.81/16	1/0
Henson Creek above Lake City, 53	10/1	<1–5	3.0/1.0	1/9
Manganese				
Slate River at Highway 135 at Crested Butte, 81	7/0	23–150	50 (chronic)	4
Slate River near Crested Butte, 83	18/0	15–158	50 (chronic)	9
Slate River below Crested Butte, 84	57/5	13–150	50 (chronic)	30
Slate River above Baxter Gulch at Highway 135 near Crested Butte, 85	7/0	46–84	50 (chronic)	4
Slate River above East River near Crested Butte, 88	6/0	4–70	50 (chronic)	1
Mill Creek at West Elk Wilderness Trailhead, 65	5/0	12–51	50 (chronic)	1
East River Below Cement Creek near Crested Butte, 37	81/10	<1–54	50 (chronic)	1
Marshall Creek near Sargents, 63	1/0	78	50 (chronic)	1
Tomichi Creek at Highway 114, 104	8/0	19–62	57 (chronic)	2
Tomichi Creek at Gunnison, 107	21/0	15–90	57 (chronic)	4
Stewart Creek at La Garita Wilderness Area, 95	4/0	28–99	50 (chronic)	2
Cebolla Creek, 9	17/0	9–52	50 (chronic)	1
Willow Creek West of Lake Fork, 111	1/0	67	50 (chronic)	1
Cimarron Creek below Squaw Creek, 19	18/0	10–100	50 (chronic)	1
Henson Creek above Lake City, 53	10/0	6–97	50 (chronic)	2
Silver				
East River at Almont, CO, 41	29/28	<0.2–0.2	0.11/2.9	1/0
Little Cimarron below Firebox Canyon, 20	1/0	0.2	0.01/0.29	1/0

Table 5. Exceedances of Colorado Department of Public Health and Environment in-stream water-quality standards for dissolved trace elements in the upper Gunnison River watershed, October 1989 to December 1999—Continued

[No., number; conc., concentration; µg/L, micrograms per liter; <, less than]

Site name and number (Appendix A)	No. of samples/ No. of censored values	Range of conc. (µg/L)	CDPHE standard (µg/L) (chronic/acute)	No. of samples over the standards (chronic/acute)
	Zinc			
Slate River above Oh-Be-Joyful Creek near Crested Butte, 78	14/10	<3–61	60/67	1/0
Slate River near Crested Butte, 83	6/0	31–455	65/72	1/1
Slate River below Crested Butte, 84	57/3	<8–310	65/72	21/17
Sc01308603ac00–Rm Biological Laboratory, 32	1/0	180	141/156	1/1
Gold Creek above Ohio, 43	9/0	9–110	69/77	1/1
Cebolla Creek at Hot Springs Ranch, 7	11/7	<8–51	40/44	1/1
Cimarron River below Little Cimarron, 15	10/8	<8–160	64/71	1/1
Henson Creek above Lake City, 53	10/0	14–190	110 (acute)	3 (acute)

Biology and Other Characteristics

Biological data available for analysis are limited and have been published in other reports. Deacon and Stephens (1996) summarize historical biological investigations for the Upper Colorado River Basin. Stephens and Deacon (1998) present data on fish tissue and organic compounds in streambed sediment for the Upper Colorado River Basin including three sites within the study area. Habitat and fish community are discussed for three sites in the study area in Deacon and Mize (1997) and Deacon and others (1999). Algal biomass in the Slate and East Rivers during winter conditions are investigated in Spahr and Deacon (1998). Algal and invertebrate data from the East River are compared to other sites in the Upper Colorado River Basin in Spahr and others (2000). Data for other types of water-quality indicators are available for selected areas in the basin. Chlorophyll, biochemical oxygen demand, and fecal coliform data have been collected in the basin and are discussed in the following sections.

Chlorophyll-*a*

Chlorophyll-*a* is a measure of the photosynthetic pigments and is used to estimate or indicate algal biomass. Data are available for lakes and streams in the study area.

Blue Mesa Reservoir Chlorophyll-*a*

Most of the lake chlorophyll data in the study area were collected from Blue Mesa Reservoir by the National Park Service. Samples were collected at several sites in the reservoir during 1975 and 1983 to 1985. Four sites in Blue Mesa Reservoir have been sampled several times each year for the 1988 through 1996 period. Concentrations at these four sites vary by season and year. Summary statistics and results of trend tests for these four Blue Mesa Reservoir sites are given below.

Site name and number (Appendix A)	Period of record	p-Value	Trend direction	Chlorophyll-*a* minimum, median, and maximum concentration (µg/L)
Iola, 116	1988–96	0.04	Downward	0.85, 4.92, 16.4
Sunnyside, 117	1988–96	0.03	Downward	1.49, 5.13, 49.1
Haystack Gulch, 118	1988–96	0.92	None	0.18, 4.34, 27.3
Lake Fork Arm, 126	1988–96	1.0	None	0.21, 3.08, 17.7

Median concentrations were low, and according to Likens (1975), values in the 0- to 3-µg/L range are typical of oligotrophic lakes (lakes with low productivity and supplies of nutrients) and values in the 2- to 15-µg/L range are typical of mesotrophic lakes (lakes with moderate productivity and supplies of nutrients). Reasons for the downward trend at the Sunnyside and Iola sites are unknown. The trends are not statistically strong (the p-values are close to 0.05), and if the 1988 data (which had greater concentrations than subsequent years) are removed from the time series, these sites no longer show a statistically significant trend.

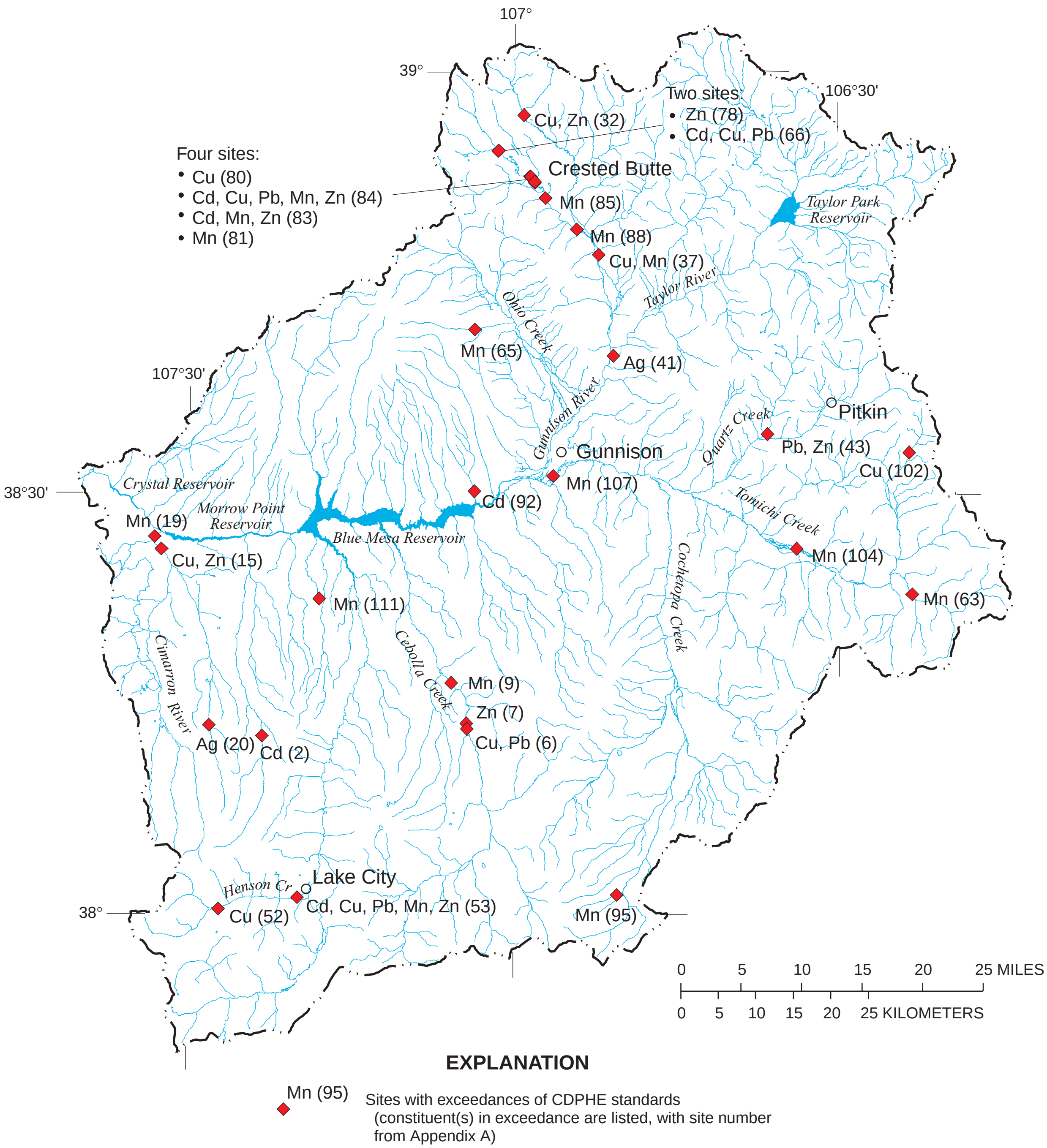


Figure 13. Exceedances of Colorado Department of Public Health and Environment in-stream water-quality standards for dissolved trace elements, October 1989 to December 1999 (Ag, silver; Cd, cadmium; Cu, copper; Mn, manganese; Pb, lead; Zn, zinc).

Table 6. Seasonal Kendall trend-analysis results for selected dissolved trace elements in the upper Gunnison River watershed

[No., number; µg/L, micrograms per liter]

Site name and number (Appendix A)	Period of record	No. of samples/ No. of censored values	Flow adjustment	p-Value	Trend direction	Median concentration (µg/L)
		Aluminum				
East River below Cement Creek near Crested Butte, 37	1995–99	19/8	Yes	1.0	None	11
		Cadmium				
Slate River below Crested Butte, 84	1994–98	30/12	Yes	0.48	None	0.3
		Iron				
East River below Cement Creek near Crested Butte, 37	1995–99	74/16	Yes	0.69	None	11
Gunnison River at County Road 32 below the city of Gunnison, 47	1995–99	46/1	Yes	0.01	Downward	28
		Manganese				
East River below Cement Creek near Crested Butte, 37	1995–99	66/6	Yes	0.12	None	5
Slate River below Crested Butte, 84	1990–98	48/0	No	0.44	None	54
Slate River below Crested Butte, 84	1994–98	29/0	Yes	0.76	None	54
Gunnison River at County Road 32 below the city of Gunnison, 47	1995–99	46/0	Yes	0.26	None	15
		Uranium				
Indian Creek near Sargents, 56	1979–92	73/1	No	1.0	None	160
		Zinc				
Slate River below Crested Butte, 84	1988–98	73/7	No	0.75	None	51
Slate River below Crested Butte, 84	1994–98	29/0	Yes	0.26	None	52

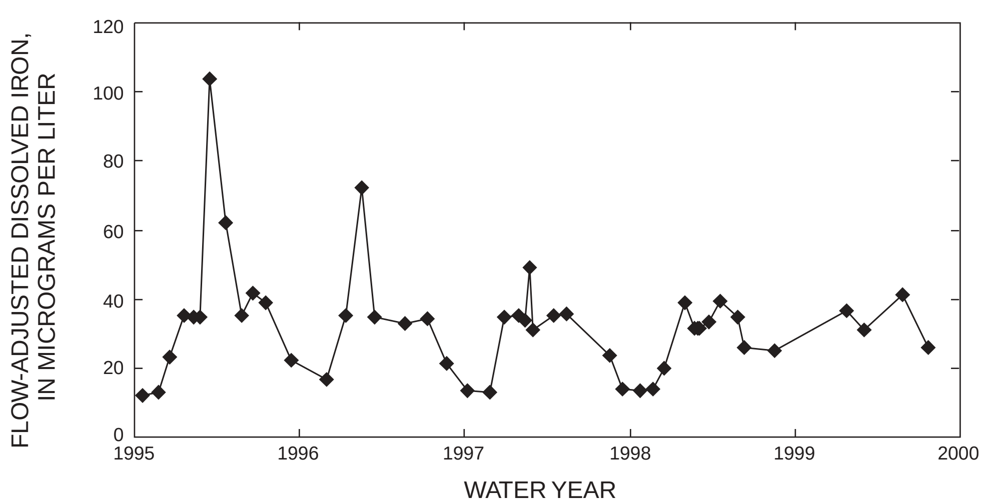


Figure 14. Flow-adjusted dissolved iron concentration at site 47 (Gunnison River at County Road 32), October 1995 to December 1999.

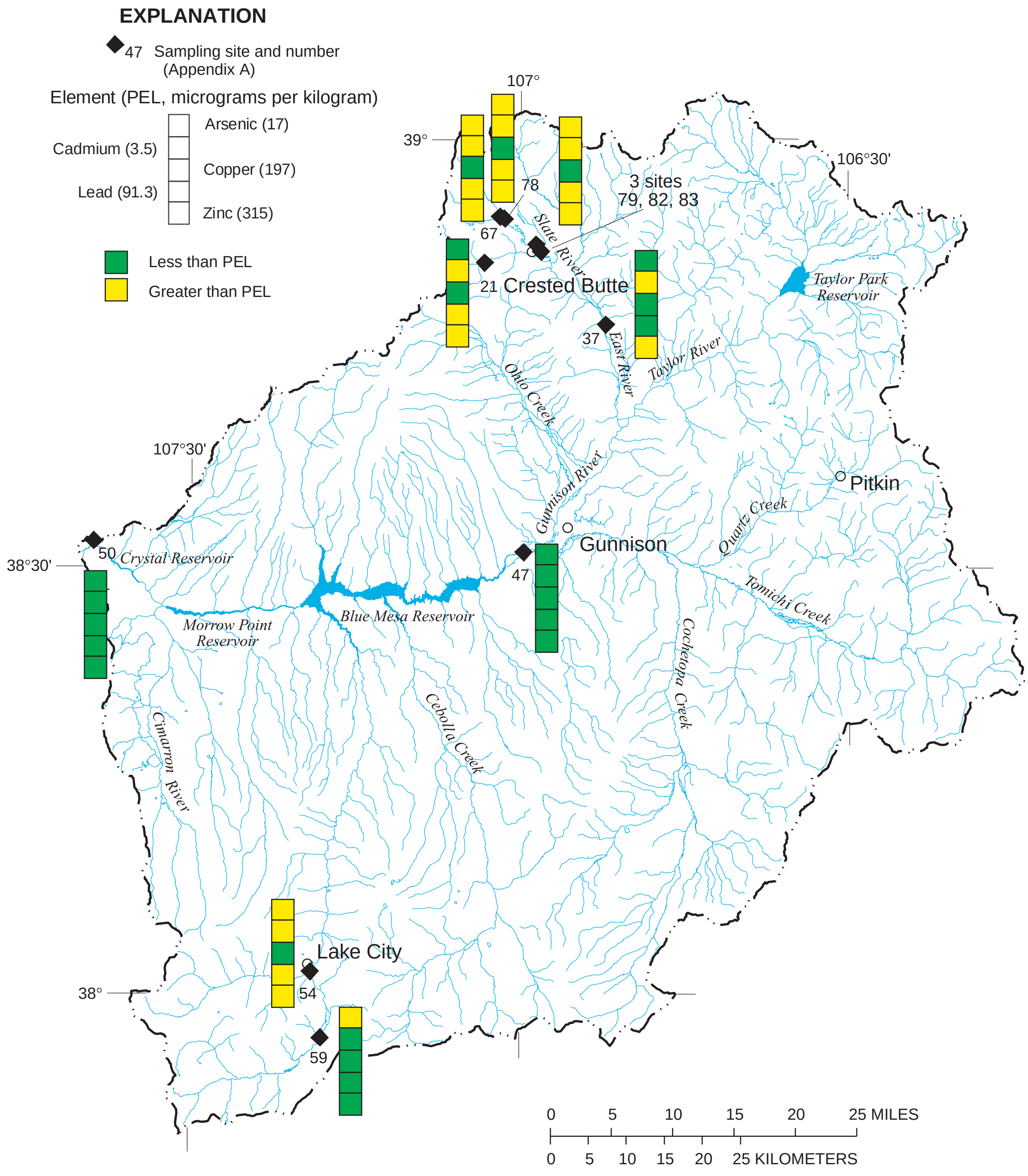


Figure 15. Spatial distribution of streambed-sediment samples, October 1995 to August 1999, and comparison of selected trace-element concentrations to the Canadian Sediment Quality Guidelines Probable Effect Level (PEL).

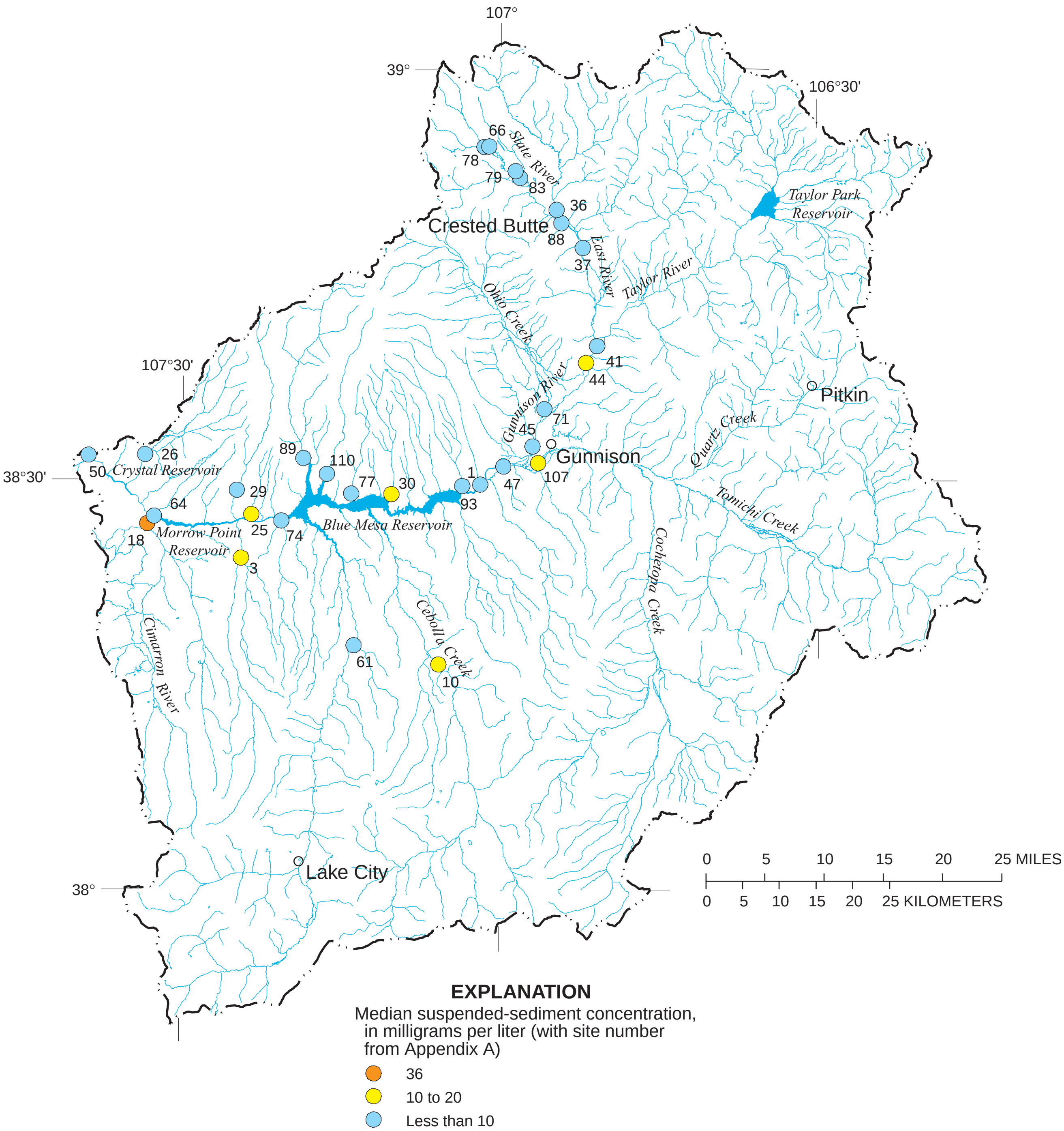


Figure 16. Spatial distribution of median suspended-sediment concentrations, October 1994 to December 1999.

Stream Chlorophyll-*a*

Samples for stream periphyton chlorophyll-*a* have been collected in the Crested Butte, Gunnison, and Tomichi Creek areas of the watershed. Data are limited with only one to five samples per site from December 1996 to September 1998. Figure 17 shows the spatial distribution and median concentrations for the available data. Concentrations below 3 mg/m^2 are typically considered unenriched, and concentrations from 3 to 20 mg/m^2 are considered moderately enriched (Biggs, 1996). Greater concentrations of chlorophyll-*a* indicate greater algal biomass. The abundance of algae increases when nutrient concentrations, light conditions, velocity, and other factors are favorable (Porter and others, 1993). Insufficient data were available for trend testing or land-use comparisons for periphyton chlorophyll-*a*.

Biochemical Oxygen Demand

Biochemical oxygen demand (BOD) is a measure of the oxygen used during a given period (for example, 5 days) for the biochemical degradation of organic material plus the oxygen used to oxidize inorganic matter. BOD is primarily used as a measure of waste loading. The BOD data discussed in this section are 5-day BOD concentrations in milligrams per liter. The data were collected at several sites during the 1970's and 1980's by the CDPHE and the USEPA. Data for the 1990's have been collected at 12 sites by the USGS in cooperation with local sponsors. Concentrations are typically low, and for the 1990's data, range from 0 to 3.2 milligrams per liter (table 2). Median concentrations for sites with five or more samples during the 1990's are shown in figure 18. Median concentrations in the Crested Butte to Gunnison area were less than 2 mg/L. As a point of reference, concentrations in a wastewater-dominated stream could be in the 10- to 20-milligrams-per-liter range or greater. Insufficient biochemical oxygen demand data were available for trend testing or land-use comparisons.

Fecal Coliform

Fecal coliforms are those organisms in the coliform bacteria group that are present in the feces and intestines of warm-blooded animals (Britton and Greeson, 1987). Fecal coliforms are considered indicator bacteria for the presence of fecal pollution. More than 3,000 fecal coliform samples have been collected at 125 sites since 1970. Sixty-seven sites had five or more samples during the 1990's, and the spatial distribution of median concentrations for these sites is shown in figure 19. With the exception of the Cimarron River and Squaw Creek area in the western part of the basin, median concentrations of fecal coliform were low (less than 100 counts per 100 milliliters). Sites with low median concentrations occasionally had higher concentrations. Table 7 lists the sites and number of samples that exceed 200 counts per 100 milliliters. This concentration was used for comparison because the CDPHE in-stream standard for fecal coliform is 200 counts per 100 milliliters based on the geometric mean of representative stream samples. Again, with the exception of the Cimarron River and Squaw Creek areas, high concentrations were infrequent. Sufficient data were available at nine sites to test for trends in fecal coliform data. Results of the trend tests are listed below. The East River at Almont was the only site with a statistically significant trend in fecal coliform concentrations. Reasons for the downward trend are unknown. Mining and forest classified sites have slightly lower median concentrations than sites classified as urban, rangeland, or agriculture. Statistically, there were no differences in median concentrations of urban, rangeland, or agriculture sites (medians of 9, 14, and 10 counts per 100 milliliters, respectively).

Site name and number (Appendix A)	Period of record	Flow adjustment	p-Value	Trend direction	Fecal coliform, median concentration (counts per 100 mL)
East River below Cement Creek, 37	1993–99	No	1.0	None	5
East River at Almont, 41	1991–99	No	0.002	Downward	6
Slate River below Crested Butte, 84	1979–98	No	0.4	None	23
Tomichi Creek at Gunnison, 107	1991–99	No	0.4	None	45
Iola, 116	1986–96	No	1.0	None	1
Sunnyside, 117	1986–96	No	0.2	None	1
Haystack Gulch, 118	1986–96	No	0.4	None	0
Old Highway 50 Beach, 120	1986–96	No	0.3	None	1
Cimarron Creek below Squaw Creek, 19	1986–96	No	0.1	None	105

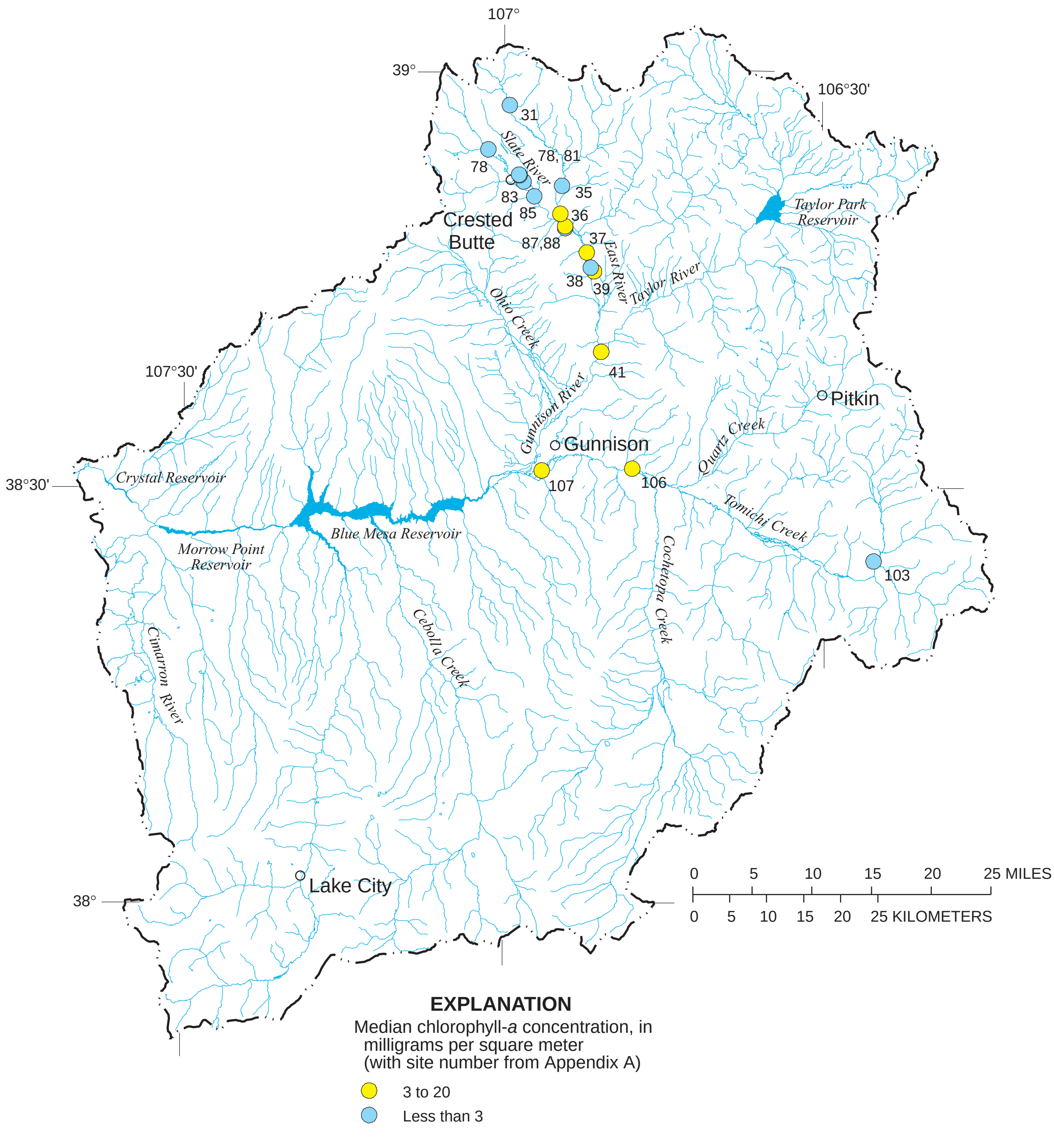


Figure 17. Spatial distribution of median chlorophyll-*a* concentrations, December 1996 to September 1998.

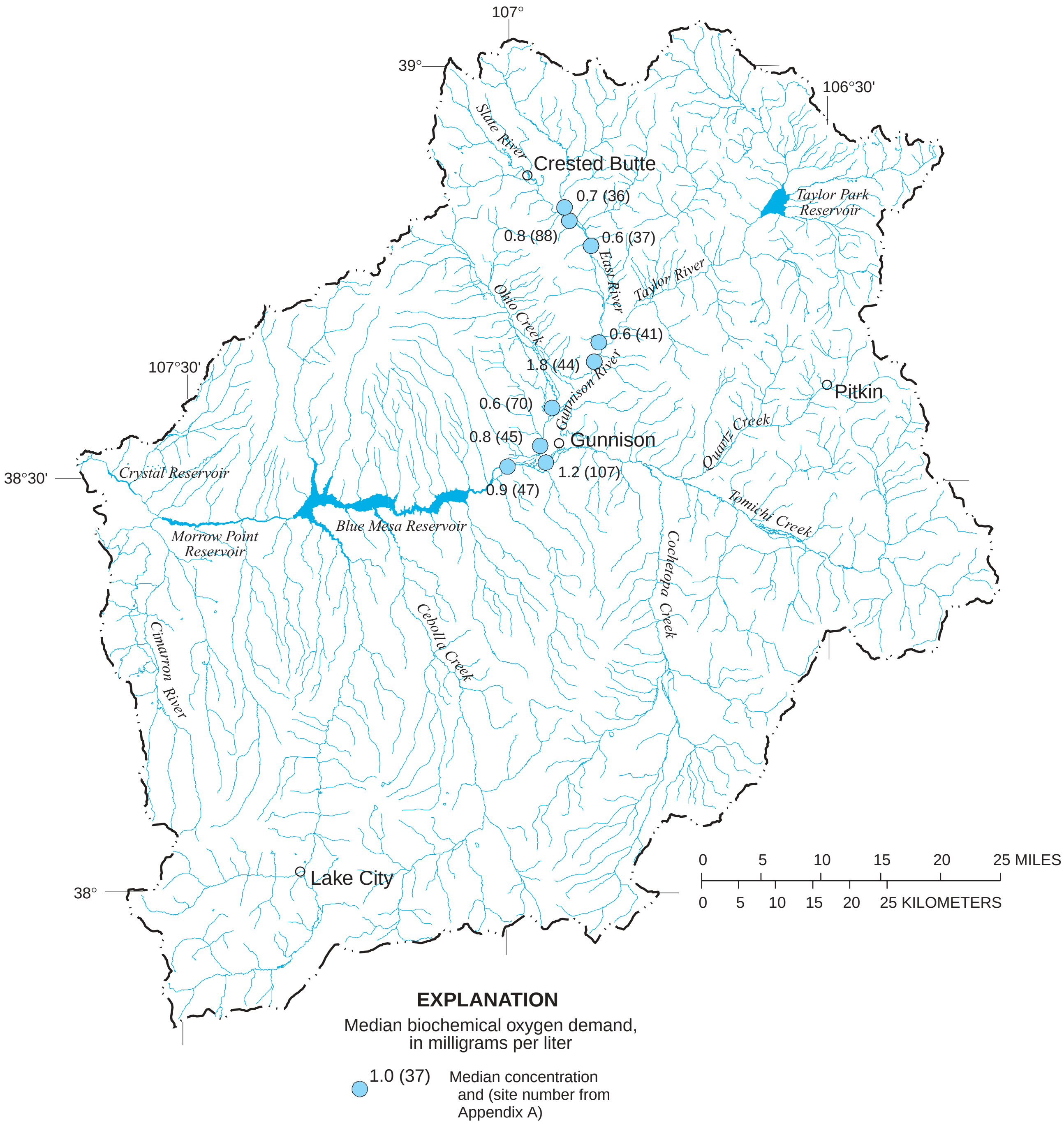


Figure 18. Spatial distribution of median biochemical oxygen demand concentrations, July 1995 to October 1999.

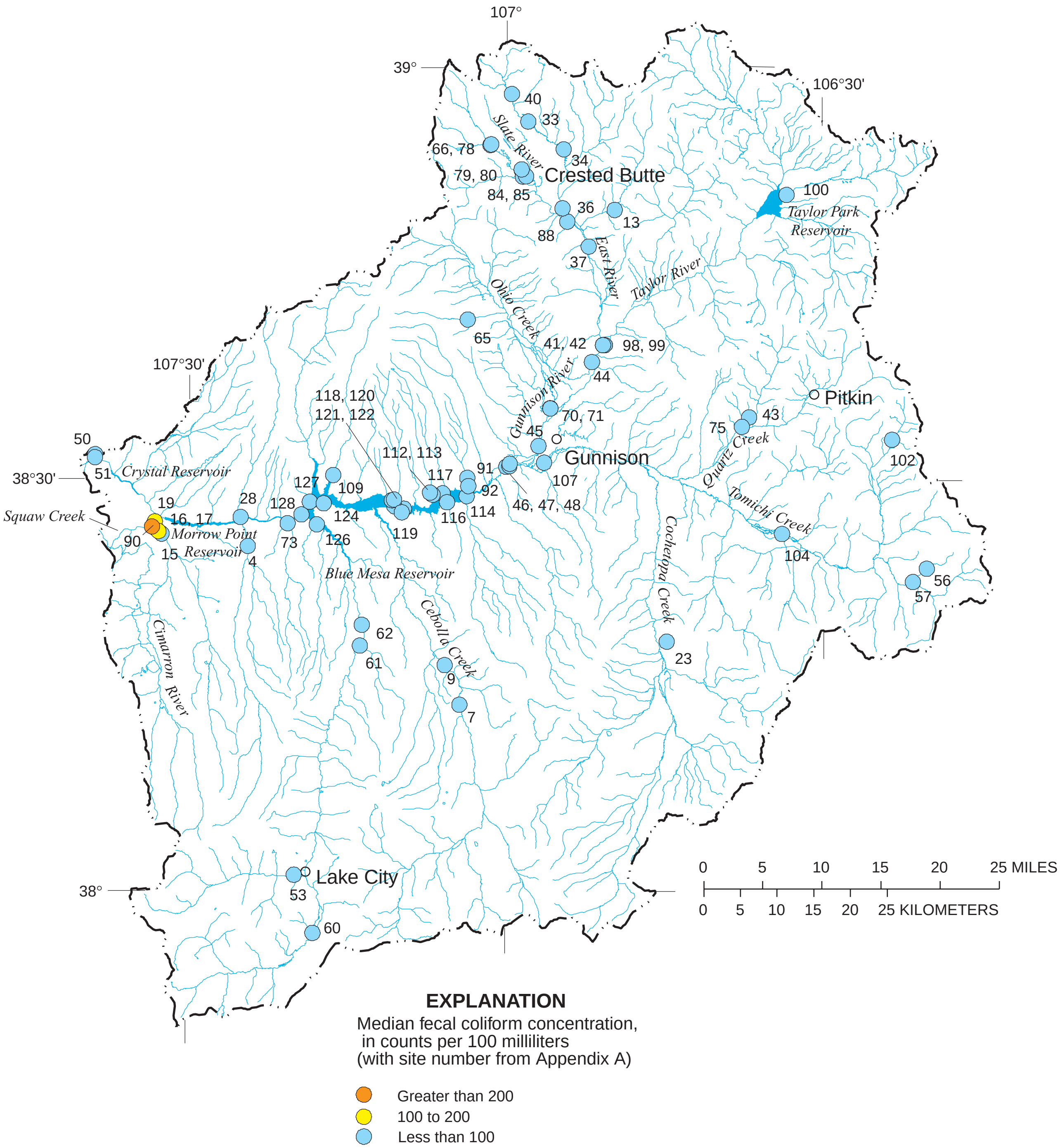


Figure 19. Spatial distribution of median fecal coliform concentrations, October 1989 to December 1999.

Table 7. Sites and number of samples with fecal coliform concentrations greater than 200 counts per 100 milliliters in the upper Gunnison River watershed, October 1989 to December 1999

Site name and number (Appendix A)	Total number of samples collected	Range of concentrations (counts per 100 milliliters)	Number of samples greater than 200 counts per 100 milliliters
East River above Crested Butte, 34	30	1–200	1
East River at Almont, 41	48	1–210	1
Slate River near Crested Butte, 83	32	1–340	3
Slate River below Crested Butte, 84	43	1–2,300	5
Slate River above East River, 88	31	1–420	1
Ohio Creek above mouth, 70	6	1–270	1
Ohio Creek above mouth, 71	8	2–250	1
Indian Creek near Sargents, 56	23	3–430	1
Cochetopa Creek above Dome Lakes, 23	6	3–230	1
Tomichi Creek at Gunnison, 107	39	1–230	2
Gunnison River at Riverway, 46	35	0–2,000	2
Steuben Creek north of Blue Mesa, 92	7	0–475	1
Upper North Willow, 113	21	0–3,500	9
Cebolla Creek at USGS gage, 6	4	0–230	1
Cebolla Creek, 9	22	0–255	1
Iola Beach, 114	46	0–3,500	2
Old Highway 50 beach, 120	50	0–1,500	1
Bay of Chickens East, 121	47	0–3,500	5
Bay of Chickens West, 122	48	0–3,500	4
Blue Creek, 4	6	2–207	1
McIntyre Gulch, 127	24	0–345	1
Cimarron Creek above Benney's, 16	24	0–3,500	11
Cimarron Creek above Squaw Creek, 17	24	0–3,500	11
Cimarron Creek below Squaw Creek, 19	57	0–3,500	22
Squaw Creek above Cimarron Creek, 90	24	0–3,500	16
Crystal Creek, 27	3	60–3,500	1

GROUND-WATER QUALITY

Many wells were completed in aquifers composed of valley fill and alluvium of Holocene age, which included more than 50 percent (55 of 99 wells) of the total wells and all wells that were constructed in the 1990's. Aquifers composed of valley fill and alluvium tend to be relatively shallow and unconfined and are located in and near stream valleys, primarily near Crested Butte, Lake City, and Gunnison (fig. 20). Seventeen wells were completed in consolidated sandstone of varying age and are scattered throughout the watershed. Four wells were completed in volcanic rocks of varying age and are located primarily in the southwestern part of the watershed, near Lake City (fig. 20). Seven wells were completed in igneous and metamorphic rocks of Cambrian age and are located in central and northern areas (fig. 20). Well-completion data are provided in Appendix B; however, data were not available for 15 wells that were completed during the mid-1970's. Specific sites discussed or shown in figures are listed in Appendix B.

Ground-water-quality data were collected by the USGS from all 99 wells, 71 of which have historical ground-water-quality data from the mid-1970's and early 1980's. The water-quality data from the remaining 28 wells were collected in 1996 and 1997 as part of the USGS National Water-Quality Assessment (NAWQA) Program. Many of these wells were installed following NAWQA protocols designed to limit possible contamination (Lapham and others, 1995).

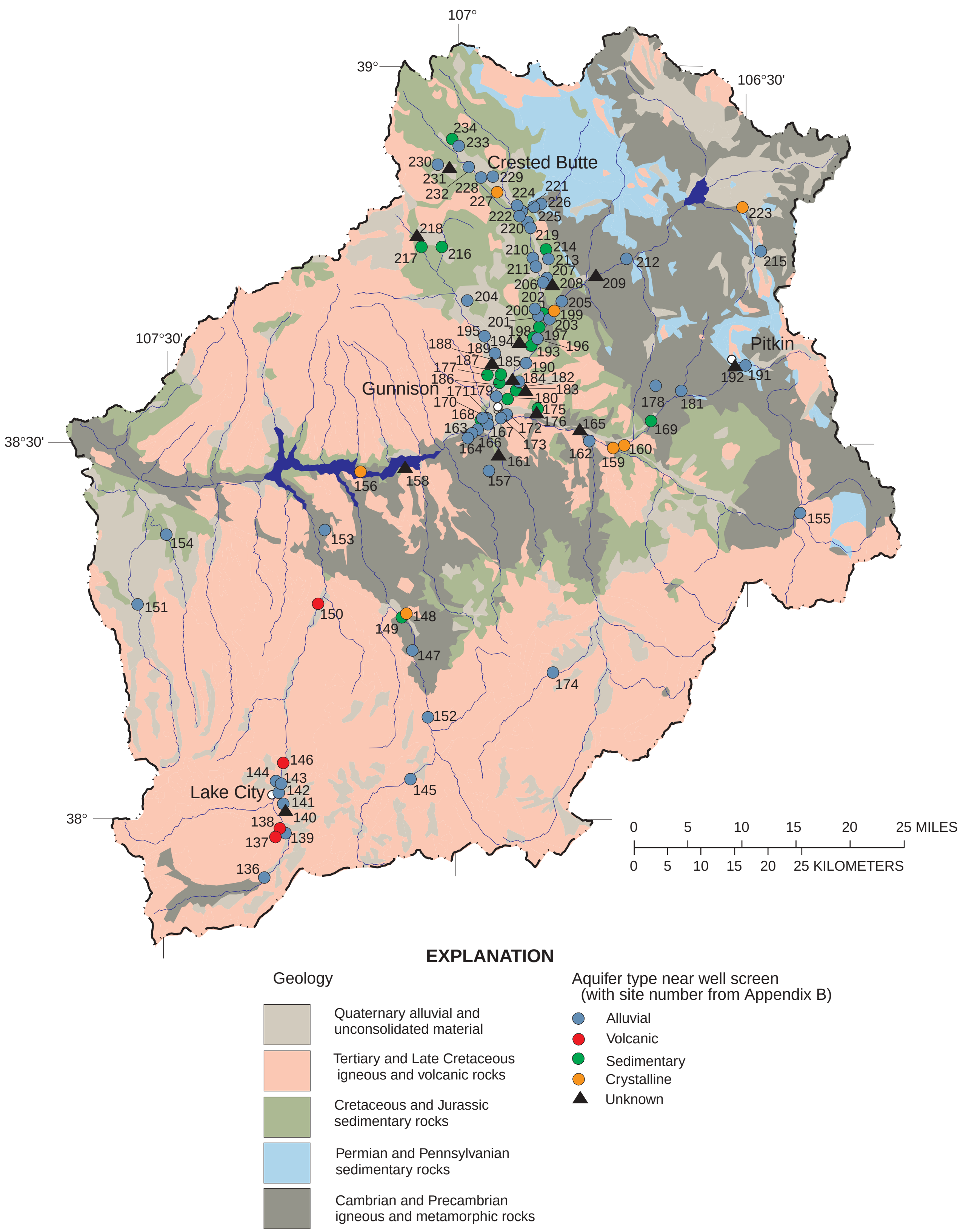


Figure 20. Spatial distribution of wells according to aquifer type, 1970 to 1999.

Water-quality sampling for field properties (water temperature, pH, dissolved oxygen, alkalinity, specific conductance, and turbidity) were collected at nearly all wells sampled in the 1990's, whereas data from wells sampled before 1990 contained less dissolved oxygen, alkalinity, or turbidity data (table 8). Major-ion data were collected at nearly all historically sampled wells and wells sampled in the mid-1990's. Nutrient (ammonia, nitrate, nitrite, dissolved phosphorus, and orthophosphate) data were collected in all wells sampled in the 1990's, but only nitrate and orthophosphate data were available for the historical well-water samples. Trace-element data were available for all wells sampled in the 1990's, but only iron and manganese data were consistently available for the historical wells.

Field Properties

Physical properties were measured at nearly all wells in the 1990's, and summary statistics are presented in table 8. Water temperature ranged from 4.3° to 13.8°C, with a median of 10.1°C (table 8). Five of the 37 (13 percent) well-water samples had dissolved-oxygen concentrations of less than 1 mg/L. The range of pH values in the well-water samples was 6.2 to 7.8, with a median value of 7.2. Two of the 40 samples (at sites located just west of Lake City, site 144—Appendix B, and north of Gunnison, site 179) had pH values below the USEPA SDWR range (6.5 to 8.5) for treated drinking-water (U.S. Environmental Protection Agency, 2000).

Major Ions and Dissolved Solids

The following major ions were analyzed in ground-water samples from the watershed: bicarbonate, bromide, calcium, chloride, fluoride, magnesium, potassium, silica, sodium, and sulfate (table 8). The USEPA has established the SDWR's for chloride, fluoride, and sulfate (table 8). All chloride samples met the SDWR of 250 mg/L. All chloride concentrations in ground water were at least one order of magnitude lower than 250 mg/L except for three samples collected at site 232, which had concentrations of 100, 140, and 200 mg/L. The well at this site is located in the town of Crested Butte and is constructed in a aquifer composed of Holocene-age valley fill and alluvium. Elevated chloride concentrations may be attributed to anthropogenic activity and may cause the drinking water to taste salty if concentrations are above 250 mg/L (Apodaca and Bails, 2000).

The maximum fluoride concentration sampled in ground water during the 1990's was 1.3 mg/L, which was below the USEPA SDWR of 2.0 mg/L. Four historical fluoride samples, collected from the mid-1970's, exceeded 2.0 mg/L. Two of these wells (located east and north of Gunnison, sites 175 and 187) are completed in sedimentary rocks (Brushy Basin Member and Dakota Sandstone). There are no well-completion data available for the other two wells (located south and east of Gunnison, sites 161 and 176). No natural or hydrogeologic cause is apparent for these elevated concentrations of fluoride.

All sulfate concentrations, except for one well (site 129) with a concentration of 230 mg/L, were nearly one order of magnitude smaller than the SDWR of 250 mg/L. This well and four historically sampled wells (sites 137, 138, 146, and 194) with sulfate concentrations exceeding 250 mg/L were completed in volcanic-rock aquifers near Lake City. Dissolution and oxidation of sulfide minerals in the volcanic-rock aquifers may explain the elevated sulfate concentrations in ground water at these locations.

Calcium and magnesium are dominant cations in most ground water, and both ions contribute to the hardness of water. Calcium generally is a product of the dissolution of carbonate minerals and limestone, whereas magnesium is more commonly produced from the dissolution of igneous and metamorphic rocks that contain ferromagnesian minerals (Hem, 1992). Ground-water samples throughout the watershed tended to have higher calcium than magnesium concentrations.

Two of 39 dissolved-solids concentrations in ground-water samples exceeded the SDWR of 500 mg/L (table 8). These two dissolved-solids concentrations were collected from site 232 in Crested Butte. Because all dissolved-solids samples collected during the 1990's were from wells constructed in aquifers composed of alluvium, a comparison among aquifer types was performed on samples collected from 1970 to 1999 (fig. 21). Due to the small number of ground-water samples from wells completed in volcanic and cystalline rock, a multiple comparison test of the medians among aquifer types was not done. Three of the four dissolved-solids concentrations from aquifers composed of volcanic rock were nearly one order of magnitude greater than ground-water samples collected from other aquifer types. The volcanic lithology of these aquifers are generally ash flow, tuff, and breccia, which tend to dissolve in ground water.

Table 8. Summary of the number of analyses, minimum, median, and maximum concentrations for ground-water-quality samples in the upper Gunnison River watershed

[No., number; conc., concentration; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; SDWR, secondary drinking-water regulation; MCL, maximum contaminant level; MoE, margin of exposure; NTU, nephelometric turbidity units; pCi/L, picocuries per liter; µg/L, micrograms per liter; <, less than; --, not defined]

Constituent or property (reporting units)	No. of analyses/ No. of censored values, 1970–99	No. of analyses/ No. of censored values, 1990–99	No. of sites, 1990–99	Minimum value, 1990–99	Median value, 1990–99	Maximum value, 1990–99	USEPA drinking-water standards and health advisories[1]
Field properties							
Water temperature (degrees Celsius)	109/0	39/0	28	4.3	10.1	13.8	--
Dissolved oxygen (mg/L)	37/2	37/2	27	0.1	2.4	7.3	--
Turbidity (NTU)	35/0	35/0	27	0.09	1.5	58	--
Specific conductance (µS/cm at 25 degrees Celsius)	111/0	40/0	28	100	331	1,050	--
pH (standard units)	111/0	40/0	28	6.2	7.2	7.8	6.5–8.5 (SDWR)
Alkalinity (mg/L as $CaCO_3$)	42/0	39/0	27	38	133	313	--
Major ions							
Bicarbonate, dissolved, field (mg/L as HCO_3)	10/0	10/0	9	83	168	226	--
Bromide, dissolved (mg/L)	39/14	39/14	27	<0.01	0.016	1.2	--
Calcium, dissolved (mg/L)	106/0	39/0	27	15	53	140	--
Chloride, dissolved (mg/L)	106/0	39/0	27	0.1	1.5	200	250 (SDWR)
Fluoride, dissolved (mg/L)	103/13	39/12	27	<0.1	0.16	1.3	2.0 (SDWR)
Magnesium, dissolved (mg/L)	106/0	39/0	27	1.6	7.8	21	--
Potassium, dissolved (mg/L)	106/0	39/0	27	0.24	1.7	7.4	--
Silica, dissolved (mg/L)	106/0	39/0	27	6.5	13	38	--
Sodium, dissolved (mg/L)	106/0	39/0	27	1.5	4.8	32	--
Sulfate, dissolved (mg/L)	106/0	39/0	27	3.7	17	230	250 (SDWR)
Dissolved solids (mg/L)	39/0	39/0	28	61	195	557	500 (MCL)
Hardness, total (as mg/L of $CaCO_3$)	106/0	39/0	28	44	160	440	--
Nutrients							
Ammonia (mg/L as N)	39/25	39/25	27	<0.015	<0.015	0.109	--
Nitrate (mg/L as N)	102/8	39/5	27	<0.05	0.261	4.55	10 (MCL)
Nitrite, dissolved (mg/L as N)	39/39	39/39	27	<0.01	<0.01	<0.01	1 (MCL)
Orthophosphate, dissolved (mg/L as P)	101/23	39/15	27	<0.01	0.014	0.229	--
Phosphorus, dissolved (mg/L as P)	39/22	39/22	27	<0.01	<0.01	0.228	--
Trace elements and radon							
Aluminum, dissolved (µg/L)	39/0	39/0	27	3	5.4	10	50–200 (SDWR)
Antimony, dissolved (µg/L)	39/39	39/39	27	<1	<1	<1	6.0 (MCL)
Arsenic, dissolved (µg/L)	61/46	39/32	27	<1	<1	4	10 (MCL)
Barium, dissolved (µg/L)	39/1	39/1	27	<1	73	299	2000 (MCL)
Beryllium, dissolved (µg/L)	39/39	39/39	27	<1	<1	<1	4.0 (MCL)
Boron, dissolved (µg/L)	67/14	28/1	28	6.2	24.5	89	--
Cadmium, dissolved (µg/L)	39/39	39/39	27	<1	<1	<1	5.0 (MCL)
Chromium, dissolved (µg/L)	39/7	39/7	27	<1	2.4	5.3	100 (MCL)
Cobalt, dissolved (µg/L)	39/36	39/36	27	<1	<1	2	--
Copper, dissolved (µg/L)	39/22	39/22	27	<1	<1	127	1,000 (SDWR)
Iron, dissolved (µg/L)	106/20	39/10	27	<3	5.9	7,400	300 (SDWR)
Lead, dissolved (µg/L)	41/38	39/38	27	<1	<1	1.4	--
Manganese, dissolved (µg/L)	105/40	39/12	27	<1	2.1	1,850	50 (SDWR)
Molybdenum, dissolved (µg/L)	39/24	39/24	27	<1	<1	3.7	--
Nickel, dissolved (µg/L)	39/21	39/21	27	<1	<1	3.8	--

Table 8. Summary of the number of analyses, minimum, median, and maximum concentrations for ground-water-quality samples in the upper Gunnison River watershed—Continued

[No., number; conc., concentration; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; SDWR, secondary drinking-water regulation; MCL, maximum contaminant level; MoE, margin of exposure; NTU, nephelometric turbidity units; pCi/L, picocuries per liter; µg/L, micrograms per liter; <, less than; --, not defined]

Constituent or property (reporting units)	No. of analyses/ No. of censored values, 1970–99	No. of analyses/ No. of censored values, 1990–99	No. of sites, 1990–99	Minimum value, 1990–99	Median value, 1990–99	Maximum value, 1990–99	USEPA drinking-water standards and health advisories[1]
Trace elements and radon—Continued							
Selenium, dissolved (µg/L)	61/56	39/38	27	<1	<1	11	50 (MCL)
Uranium, dissolved (µg/L)	39/21	39/21	27	<1	<1	13	30 (MCL)
Zinc, dissolved (µg/L)	39/18	39/18	27	<1	1.4	303	5000 (SDWR)
Radon-222 (pCi/L)	39/0	39/0		426	1,175	3,830	300 (MCL)
Pesticides and volatile organic compounds							
Alachlor, dissolved (µg/L)	33/33	33/33	21	<0.002	<0.002	<0.002	2.0 (MCL)
Atrazine, dissolved (µg/L)	33/33	33/33	21	<0.001	<0.001	<0.002	3.0 (MCL)
Bromacil, dissolved (µg/L)	21/20	21/20	9	<0.035	<0.035	0.050	--
Prometon, dissolved (µg/L)	33/32	33/32	21	<0.018	<0.018	0.0365	--
Benzene, total (µg/L)	33/33	33/33	21	<0.032	<0.032	<0.050	5.0 (MCL)
Toluene, total (µg/L)	33/33	33/33	21	<0.038	<0.038	< 0.060	1000(MCL)
Tricholoroethylene, total (µg/L)	33/32	33/32	21	<0.038	<0.038	0.177	5.0 (MCL)
Chloroform, total (µg/L)	33/32	33/32	21	<0.050	<0.052	0.232	80 (MCL)
Methyl *tert*-butyl ether (µg/L)	33/29	33/29	21	<0.100	<0.112	0.460	20-40 (MoE)
Tetrachloroethylene, total (µg/L)	33/33	33/33	21	<0.038	<0.038	<0.050	5.0 (MCL)
Vinyl chloride, total (µg/L)	33/33	33/33	21	<0.010	<0.112	<0.112	2.0 (MCL)
1,3-Dichlorobenzene (µg/L)	33/32	33/32	21	<0.054	<0.054	0.100	600 (MCL)
1,2,4-Trimethylbenzene, (µg/L)	33/32	33/32	21	<0.050	<0.050	0.328	--

[1]U.S. Environmental Protection Agency, 2000.

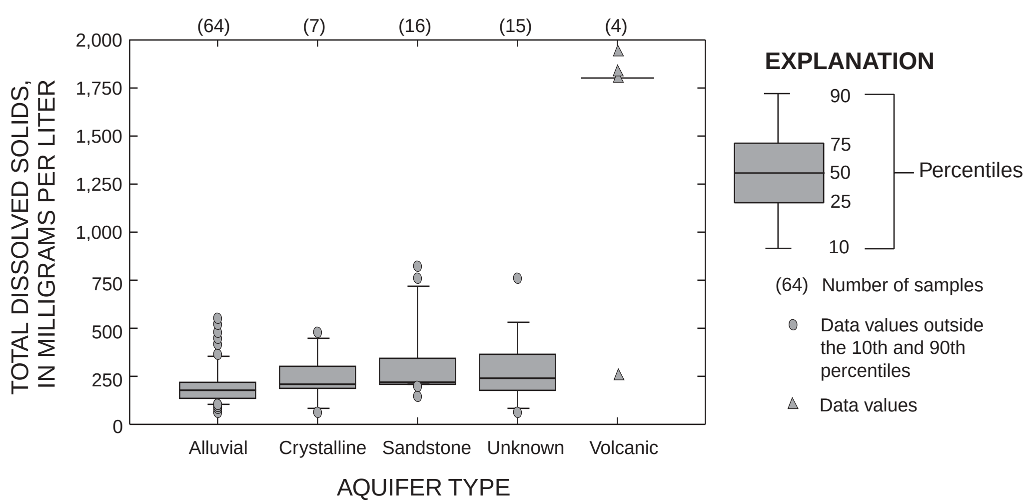


Figure 21. Distribution of dissolved-solids concentrations by aquifer type for ground-water samples, 1970 to 1999.

Water sampled from similar aquifer types generally has similar water types; 58 of the 63 samples collected in alluvial aquifers were calcium bicarbonate water type (table 9). Calcium bicarbonate was the dominant water type in nearly all aquifers except for the volcanic-rock aquifers, which had more sodium and sulfate mixed water types (table 9). Calcium and bicarbonate occur naturally in most ground water and result from the dissolution of carbonate minerals such as limestone, whereas sodium and sulfate occur more commonly from the dissolution of minerals from igneous and volcanic rock (Hem, 1992). Although relatively few samples were collected from aquifers of sedimentary rock, the predominant water type was calcium bicarbonate because many of the aquifers composed of sedimentary rock contain sandy limestone layers.

Nutrients

Elevated concentrations of nutrients, particularly nitrate, can result from the seepage of animal and human waste or nitrogen fertilizers into the ground water. Wells that can be at risk from elevated nitrate concentrations include those constructed in aquifers near land-use activities that can result in the seepage or leaching of available nitrogen (such as in rangeland, urban, and agriculture land uses). Shallow, alluvial aquifers associated with these land uses can provide the most direct and efficient route for nitrate to enter the water-table aquifer. Mueller and Helsel (1996) define background levels as having nitrate concentrations less than 2 mg/L.

Table 9. Description of dominant water types of sampled wells in the upper Gunnison River watershed

[Ca, calcium; HCO_3, bicarbonate; Cl, chloride; SO_4, sulfate; Na, sodium; Mg, magnesium; --, not available]

Geohydrologic description	Number of wells (total 99)	Predominant water type (number of samples)
	Wells completed in alluvium	
Cenozoic valley fill	1	--
Holocene flood-plain alluvium	10	Ca - HCO_3 (7)
Holocene valley fill	45	Ca - HCO_3 (51) Ca - (HCO_3 and Cl mix) (2) Ca - SO_4 (2)
	Wells completed in volcanic rock	
Tertiary System	1	Na - SO_4 (1)
Miocene Series	1	(Ca and Na mixed) - HCO_3 (1)
Oligocene Series	2	(Ca and Na mixed) - SO_4 (1) Na - (SO_4 and HCO_3 mix) (1)
	Wells completed in sedimentary rock	
Dakota Group, Cretaceous	2	Ca - HCO_3 (2)
Dakota Group, Upper Cretaceous	4	Ca - HCO_3 (2) Na - HCO_3 (1)
Mancos Shale, Upper Cretaceous	1	Ca - HCO_3 (1)
Mesaverde Group, Upper Cretaceous	2	Ca - HCO_3 (1)
Burro Canyon Formation, Upper Cretaceous	2	Ca - HCO_3 (2)
Morrison Formation, Upper Jurassic Brushy Basin Member	4	Ca - HCO_3 (3) (Ca and Na mixed) - HCO_3 (1)
Entrada Sandstone, Upper Jurassic	1	Ca - HCO_3 (1)
Morrison Formation, Upper Jurassic	1	Ca - HCO_3 (1)
	Wells completed in crystalline rock	
Precambrian Erathem	5	Ca - HCO_3 (6)
Precambrian crystalline rock	2	Ca - HCO_3 (1)
	Wells completed in unidentified lithology	
--	15	Ca - HCO_3 (9) Ca - SO_4 (2) Na - HCO_3 (2) (Ca and Na mixed) - SO_4 (1) (Ca and Na mixed) - HCO_3 (1)

Thirty-nine nutrient analyses were performed on water samples from 27 ground-water wells during the 1990's (table 8). Nutrient concentrations were generally low. Median concentrations for ammonia, nitrite, and dissolved phosphorus were below laboratory reporting levels (censored data).

All nitrate samples were below the USEPA drinking-water MCL of 10 mg/L. The highest historical (WY 1970 to 1990) nitrate concentration was 5.1 mg/L and was detected at a well (site 162) near the confluence of Cochetopa Creek and Tomichi Creek in WY 1974. The highest nitrate concentration measured in the 1990's was 4.5 mg/L in a well located at Crested Butte (site 232).

Aquifers composed of Holocene-age valley fill and alluvium were the only aquifer type to have nitrate concentrations exceeding 2 mg/L. The wells with nitrate concentrations exceeding 2 mg/L, as well as most wells completed in shallow, alluvial aquifers, are located in agriculture and urban land-use areas. The highest nitrate concentration (5.1 mg/L) was measured in 1974 at a well (site 162) in an agriculture land-use area. The next four highest nitrate concentrations (4.5, 4.1, 3.8, and 3.7 mg/L) were measured in two wells (sites 232 and 173, located in Crested Butte and Gunnison, respectively) classified as urban land use. The distribution of nitrate concentrations are represented on boxplots in figure 22. Differences were evaluated using the Kruskal-Wallis test on rank-transformed data to determine if median nitrate concentrations were significantly different among agriculture, forest, rangeland, and urban land-use classified wells. The p-value obtained from the Kruskal-Wallis test (p-value = 0.46) showed no statistical difference between median nitrate concentrations among the four land-use classifications.

Trace Elements and Radon

Summary statistics and USEPA drinking-water standards for trace elements and radon are listed in table 8. Thirteen of 18 trace elements have USEPA-established drinking-water standards or regulations; for those 13 trace elements, only a few iron and manganese concentrations from ground-water samples in the watershed exceeded the standards and regulations. Three iron samples exceeded the USEPA SDWR of 300 µg/L at two wells (sites 163 and 171) near the city of Gunnison and at a well (site 147) south of the town of Powderhorn near Cebolla Creek. All three wells were completed in aquifers composed of Holocene-age valley-fill alluvium. Elevated iron concentrations can form red oxyhydroxide precipitates that stain laundry and plumbing, creating an objectionable impurity in water supplies (Hem, 1992). Nine of 39 water samples at six sites (147, 163, 166, 171, 179, and 222) analyzed for manganese exceeded the USEPA SDWR of 50 µg/L and were collected from aquifers composed of Holocene-age valley-fill alluvium near Gunnison, Crested Butte, and in one well near Cebolla Creek. Elevated concentrations of

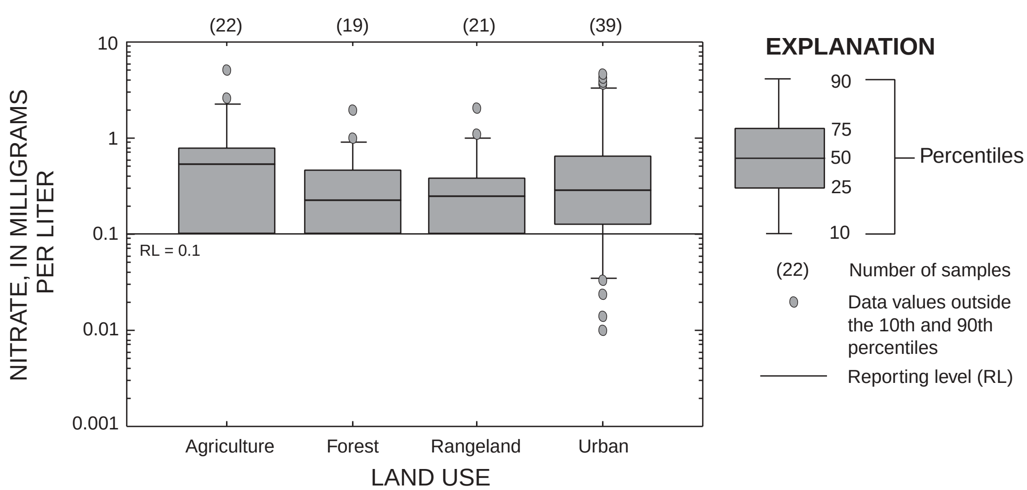


Figure 22. Distribution of nitrate concentrations by land-use classifications for ground-water samples, 1970 to 1999.

manganese can cause a brown discoloration and affect the taste of drinking water and also can deposit black-oxide stains on plumbing and laundry fixtures (Hem, 1992). Manganese sources are typically associated with minerals common to igneous and metamorphic rocks (Hem, 1992). No differences were found in median concentrations of trace elements for forest, rangeland, and urban land uses (Apodaca and Bails, 2000). Insufficient data were available for comparison of other trace-element concentrations and land use.

Radon gas is a natural radioactive decay product of uranium. Sources of radon include soil, rock, mine tailings containing uranium, and water that has passed through uranium-containing materials. Although still under review, the USEPA has established an MCL of 300 pCi/L for radon in drinking water. The national average concentration for radon in ground water was 350 pCi/L (Paulsen, 1991). All 39 radon samples collected at 27 sites (as noted in Appendix B) in the watershed exceeded the USEPA MCL and the national average. Measured concentrations ranged from 426 to 3,830 pCi/L (table 8).

Pesticides and Volatile Organic Compounds

Of the 120 pesticide samples summarized in table 8, only 2 (bromacil and prometon) had concentrations above laboratory reporting limits. Neither of the two pesticides have USEPA drinking-water standards or regulations (table 8). Bromacil is a herbicide that controls annual and perennial grasses and broadleaf weeds, and prometon is a herbicide used as a nonselective soil sterilant in non-agricultural settings. The two pesticides were detected in wells located near Gunnison—bromacil at site 179 and prometon at site 171.

Seven of 21 sites for which ground-water samples were analyzed for volatile organic compounds (VOC's) contained detectable concentrations of VOC's (table 8). The VOC's detected include trichloroethylene (site 221), chloroform (site 229), methyl *tert*-butyl ether (MTBE) (sites 171, 147, and 232), 1,3-dichlorobenzene (site 164), and 1,2, 4-trimethylbenzene (site 222). All detected VOC concentrations were below USEPA drinking-water standards. These VOC's have a varied use and source; trichloroethylene is a metal degreaser; MTBE is added to gasoline to increase the octane and reduce carbon monoxide emissions; 1,3-dichlorobenzene is common in insecticides and other fumigants; and 1,2,4-trimethylbenzene is a petroleum by-product. The wells with VOC detections are located near Gunnison and Crested Butte. A well located in Crested Butte (site 232) had four detections of MTBE, which was the most frequently detected VOC in the watershed.

SUMMARY

The retrospective water-quality analysis for the upper Gunnison River watershed was limited to water-quality data in an electronic (computerized database) format and included only samples gathered from October 1969 to December 1999. Data were obtained from the USGS National Water Information System (NWIS) and the USEPA Storage and Retrieval (STORET) databases. For selected water-quality constituents in the watershed, this report presents a data summary, temporal trend analysis, spatial distribution evaluation, comparison to State and Federal standards, and an analysis of the relation between land-use practices and water quality.

Surface-water-quality data were collected and compiled at 482 sites in the upper Gunnison River watershed. Field properties (temperature, dissolved oxygen, pH, and specific conductance) were collected at nearly all surface-water sites. Major ions, nutrients, and trace elements also were commonly collected.

Most values of surface-water temperature, dissolved oxygen, and pH were within CDPHE in-stream standard ranges. Only 11 samples had water temperatures exceeding the CDPHE in-stream standard of 20°C. These measurements were made during summer periods at two sites on Tomichi Creek and one site on Cochetopa Creek. During the 1990's, no site in the watershed had a median dissolved-oxygen concentration below the minimum CDPHE standard of 6 mg/L. Few pH values were outside the range defined by CDPHE in-stream standards (6.5 to 9.0); three pH values were more acidic and only two values were more basic than the standards. No temporal trends in pH were identified.

Calcium-bicarbonate type water was the most spatially dominant from July to April (nonspringtime runoff conditions) and was present in nearly all reaches of the watershed. Calcium-sulfate type water is present in Henson Creek and the Lake Fork of the Gunnison River, upstream from Lake City, and is attributed to the weathering of sulfate-bearing rocks associated with historical mining. Total chloride concentrations were well below in-stream standards; only one total sulfate concentration (260 mg/L) exceeded the in-stream standard and was measured at Indian Creek near Sargents.

Most sites sampled for nutrients were along the Slate River and East River near Crested Butte and along the Gunnison River from the confluence of the East and Taylor Rivers to the western edge of the watershed. Median ammonia concentrations were relatively low, and many of the sampling sites had more than 50 percent censored data. All computed un-ionized ammonia concentrations were below the chronic standard of 0.02 mg/L, and the maximum concentration was an order of magnitude below the standard. Of the sites having less than 50 percent censored nitrate concentration data, three sites had median concentrations (0.44, 0.25, and 0.24 mg/L) greater than 0.21 mg/L. All nitrate concentrations were below the CDPHE in-stream standard of 10 mg/L. More than 30 percent of stream sites in the watershed (23 of 61 sites) had median total phosphorus concentrations greater than the USEPA recommendations for controlling eutrophication. These sites are located on the Cimarron River and tributaries (5 sites); tributaries to Blue Mesa, Morrow Point, Crystal Reservoirs (13 sites); the Gunnison River downstream from Gunnison (3 sites); Mill Creek (tributary to Ohio Creek, 1 site); and Cochetopa Creek (1 site).

Temporal trends were not identified for either nitrate or total phosphorus. However, at the Slate River near Crested Butte site, ammonia concentrations had a statistically significant (alpha level of 0.05) upward trend, with a p-value of 0.016. The Slate River near Crested Butte site is located immediately downstream from the towns of Crested Butte and Mount Crested Butte and may reflect recent population growth or other land-use changes in the area. The rate of change of the trend is small (0.017 mg/L/year). Un-ionized ammonia concentrations at this site were relatively low and well below CDPHE in-stream standards, presenting no apparent environmental concern from the un-ionized species of ammonia.

Although the multiple comparison test showed nitrate concentrations were statistically different between agriculture and forest and between agriculture and urban land-use classified sites, median concentrations were low among all land-use settings and most concentrations were less than national background levels (0.6 mg/L). Median concentrations of total phosphorus were greatest in rangeland areas and least in the urban areas. No significant differences were identified for median concentrations of total phosphorus in agricultural and forested areas.

Most trace-element samples were collected on the Slate, East, and Gunnison Rivers from Crested Butte to the city of Gunnison. Median concentrations of arsenic, lead, mercury, selenium, and silver were low or censored throughout the watershed. Aluminum, cadmium, copper, lead, manganese, and zinc had elevated concentrations near Crested Butte and on Henson Creek upstream from Lake City. These were the only two areas in which elevated trace-element concentrations were consistently detected, and both are downstream from historical mining areas. Samples exceeded standards for six trace elements: cadmium, copper, lead, manganese, silver, and zinc. Manganese concentrations exceeded standards more often than any other trace element. Sites near Crested Butte and on Henson Creek upstream from Lake City had several trace-element concentrations in exceedance of CDPHE standards. A downward trend (3 µg/L per year) was identified for dissolved iron concentration in samples from a site on the Gunnison River at County Road 32 below the city of Gunnison. Dissolved iron concentrations at this site were low; the highest detected concentration was 120 µg/L, which is below the 300-µg/L CDPHE standard. Trace elements in bed sediment had spatial distributions similar to trace elements in water, and the greater concentrations were measured in samples from historical mining areas near Lake City and Crested Butte. Concentrations of selected trace elements exceeded the Canadian Probable Effect Levels in the historical mining areas. Suspended-sediment concentrations were generally low (less than 20 mg/L), and no temporal trends were detected.

Biological data available for analysis are limited. Chlorophyll-*a* concentrations in samples from Blue Mesa Reservoir and streams in the Crested Butte and Gunnison areas were typical of unenriched to moderately enriched conditions. Biochemical oxygen demand was typically low, with median concentrations in the Crested Butte to Gunnison area of less than 2 mg/L. Occasional high concentrations of fecal coliform occur in the watershed. However, with the exception of the Squaw Creek and Cimarron River area, median concentrations were less than 100 counts per 100 milliliters.

Ground-water-quality data were collected by the USGS from 99 wells. Water-quality samples for physical properties, major ions, nutrients, and trace elements were collected at nearly all wells sampled during the 1990's. Many wells were completed in aquifers composed of Holocene-age alluvium and valley fill, which include more than one-half (56 of 99 wells) of the total wells and all wells that were constructed in the 1990's.

Most field properties were within the USEPA SDWR range for treated drinking water. Calcium bicarbonate was the dominant water type in samples from nearly all wells except for samples from wells completed in volcanic rock, which had more sodium and sulfate mixed water types. All ground-water samples were lower than the SDWR for chloride. The three greatest concentrations of chloride were collected at site 232. This well is supplied by an aquifer composed of Holocene-age valley fill and alluvium and is located in the town of Crested Butte. Elevated chloride concentrations may be attributed to anthropogenic activity and may cause the drinking water to taste salty. Wells with sulfate concentrations exceeding the SDWR of 250 mg/L were completed in aquifers of volcanic rock near Lake City. Dissolution and oxidation of sulfide minerals in the aquifers composed of volcanic rock may explain the elevated sulfate concentrations in ground water at these locations. Dissolved-solids samples from 2 of 39 samples exceeded the SDWR of 500 mg/L. These samples were from site 232 in Crested Butte.

Thirty-nine nutrient analyses were performed on water samples from 27 wells during the 1990's. Nutrient concentrations were generally low, and median concentrations for ammonia, nitrite, and dissolved phosphorus were below censoring levels. All nitrate samples were below the USEPA drinking-water MCL of 10 mg/L. Wells most at risk from elevated nitrate concentrations can include those constructed in aquifers near land-use activities that result in the seepage of animal and human waste (such as in rangeland, urban, and agriculture land uses). Shallow, alluvial aquifers associated with these land uses can provide the most direct and efficient route for nitrate to enter the water-table aquifer. However, there were no statistical differences between nitrate concentrations from wells in agriculture, forest, rangeland, or urban land-use settings.

Trace elements in ground water were generally below the USEPA SDWR. Three iron samples exceeded the USEPA SDWR of 300 μg/L at two wells near Gunnison and at a well south of the town of Powderhorn near the Cebolla River. Nine of 39 manganese samples exceeded the USEPA SDWR of 50 μg/L; these samples were collected from aquifers composed of valley fill and alluvium of Holocene age near Gunnison and Crested Butte and in one well near the Cebolla River. All 39 radon samples collected from ground water in the watershed exceeded the proposed USEPA drinking-water standard (300 pCi/L MCL) and ranged from 426 to 3,830 pCi/L.

Only 2 of 120 pesticide samples (bromacil and prometon) had concentrations above censoring limits. Five of 21 sites for which ground-water samples were collected and analyzed for volatile organic compounds (VOC's) contained detectable concentrations. The VOC's detected include trichloroethylene, chloroform, methyl *tert*-butyl ether (MTBE), 1,3-dichlorobenzene, and 1,2,4-trimethylbenzene. All detected VOC concentrations met USEPA drinking-water standards.

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APPENDIXES

Appendix A. Selected surface-water sites in the upper Gunnison River Basin

[NWIS, National Water Information System; STORET, Storage and retrieval database; CDPHE, Colorado Department of Public Health and Environment; NPS, National Park Service; SW, surface water; SP, spring; LK, lake; UNLV, University of Nevada–Las Vegas Toxic Metals in Water data]

Site number for this report	Information from USGS NWIS or USEPA STORET					
	Site number as appears in database	Site names as they appear in database	Latitude	Longitude	Agency collecting data	Type of site
1	382943107015300	Beaver Creek at Beaver Creek Picnic Area	382943	1070153	USGS	SW
2	10238	Big Blue in Wilderness Area	381243	1072312	CDPHE	SW
3	382418107242600	Blue Creek at Hwy 50	382418	1072426	USGS	SW
4	CURE_BC01	Blue Creek	382509.7	1072424.8	NPS	SW
5	09113100	Castle Creek above Mouth near Baldwin, Co	384610	1070500	USGS	SW
6	10282	Cebolla Cr. @ Usgs Gage	381339	1070422	CDPHE	SW
7	10281	Cebolla Cr. @ Hot Springs Ranch	381339.5	1070422	CDPHE	SW
8	381626107055400	Cebolla Hot Springs 'A'	381626	1070554	USGS	SP
9	CURE_CB1A	Cebolla Creek	381632.3	1070546.7	NPS	SW
10	381633107054700	Cebolla Creek at Bridge SE Of Powderhorn	381633	1070547	USGS	SW
11	385006106493400	Cement Creek Warm Spring	385006	1064934	USGS	SP
12	384857106522800	Ranger Warm Spring	384857	1065228	USGS	SP
13	10121	Approx. 1/3 Mi. above Campground.	384943	1064945	CDPHE	SW
14	09126000	Cimarron River near Cimarron, Co.	381525	1073245	USGS	SW
15	10230	Cimarron River blw. Little Cimarron	382600	1073234	CDPHE	SW
16	CURE_CM12	Cimarron Ck above Benny's	382611.6	1073251	NPS	SW
17	CURE_CM08	Cimarron Ck above Squaw Ck	382627.5	1073314.4	NPS	SW
18	09127000	Cimarron River bl Squaw Creek, Nr Cimarron, Co.	382647	1073318	USGS	SW
19	CURE_CM10	Cimarron Ck below Squaw Ck	382653.6	1073312.2	NPS	SW
20	10237	Little Cimmarron blw Firebox Canyon	381328	1072804	CDPHE	SW
21	09111000	Coal Creek near Crested Butte, Co.	385123	1070319	USGS	SW
22	03032231	Crested Butte Colorado Slate R.Coal Cr.Gunnison	385220	1070020	UNLV	SW
23	10325	Cochetopa Cr. above Dome Lakes	381816.2	1064449.2	CDPHE	SW
24	09118450	Cochetopa Creek below Rock Creek Nr Parlin, Co.	382008	1064618	USGS	SW
25	382730107232900	Corral Creek at Hwy 92	382730	1072329	USGS	SW
26	383150107333300	Crystal Creek at Hwy 92	383150	1073333	USGS	SW
27	CURE_CYC1	Crystal Creek	382946.6	1073503.8	NPS	SW
28	CURE_CUR2	Curecanti Creek	382715.7	1072506.2	NPS	SW
29	09125000	Curecanti Creek near Sapinero, Co.	382916	1072452	USGS	SW
30	382900107101600	East Elk Creek at Campground abv Blue Mesa Res	382900	1071016	USGS	SW

Appendix A. Selected surface-water sites in the upper Gunnison River Basin—Continued

[NWIS, National Water Information System; STORET, Storage and retrieval database; CDPHE, Colorado Department of Public Health and Environment; NPS, National Park Service; SW, surface water; SP, spring; LK, lake; UNLV, University of Nevada–Las Vegas Toxic Metals in Water data]

Site number for this report	Information from USGS NWIS or USEPA STORET					
	Site number as appears in database	Site names as they appear in database	Latitude	Longitude	Agency collecting data	Type of site
31	385741106592900	East River above Gothic	385741	1065929	USGS	SW
32	385726106591600	Sc01308603ac00–Rm Biological Laboratory	385700	1065910	USGS	SP
33	385609106575800	East River below Gothic	385609	1065758	USGS	SW
34	385408106543600	East River above Crested Butte	385408	1065436	USGS	SW
35	09110500	East River near Crested Butte, Co.	385152	1065433	USGS	SW
36	384950106544200	East River above Slate River Nr Crested Butte	384950	1065442	USGS	SW
37	09112200	East River bl Cement Creek Nr Crested Butte, Co.	384703	1065213	USGS	SW
38	384557106515000	East River Ditch Number 1 at Highway 135	384557	1065150	USGS	SW
39	384541106513100	East River Ditch Number 1 near Spann Ranch	384541	1065131	USGS	SW
40	10118	East R. above Gothic	384506	1065922	CDPHE	SW
41	09112500	East River at Almont Co.	383952	1065051	USGS	SW
42	000078	East River at Confl. With Taylor	383952	1065051	CDPHE	SW
43	10336	Gold Cr. above Ohio	383455	1065031	CDPHE	SW
44	383838106515400	Gunnison River below Almont	383838	1065154	USGS	SW
45	09114500	Gunnison River near Gunnison, Co.	383231	1065657	USGS	SW
46	CURE_GR07	Gunnison River - Riverway	383113.2	1065940.6	NPS	SW
47	383103106594200	Gunnison River at Cnty Rd 32 below Gunnison, Co	383103	1065942	USGS	SW
48	000057	Gunnison River West Of Gunnison	383100	1070000	CDPHE	SW
49	CURE_GR4A	Gunnison River - Cooper Ranch	382958.2	1070129.3	NPS	SW
50	09128000	Gunnison River below Gunnison Tunnel, Co.	383145	1073854	USGS	SW
51	CURE_GR01	Gunnison River - Black Canyon	383132.1	1073855	NPS	SW
52	HC2	Henson Creek abv North Fork Henson	380022	1072706	CDPHE	SW
53	10246	Henson Cr. above Lake City	380113	1071953	CDPHE	SW
54	380133107190000	Hensen C at Mouth at Lake City, Co	380133	1071900	USGS	SW
55	NHC1	North Fork Henson Creek	380027	1072800	CDPHE	SW
56	000149	Indian Creek near Sargents	382832	1062127	CDPHE	SW
57	10392	Indian Cr. @ Mouth	382234	1062134	CDPHE	SW
58	09123400	Lake Fork below Mill Gulch near Lake City, Co.	375423	1072303	USGS	SW
59	375655107180400	Lakefork Gunnison abv Lake San Cristobal at 7 Rd	375655	1071804	USGS	SW
60	10248	Lake Fk. Gunnison River above Lake San Cristobal	375659	1071806	CDPHE	SW

Appendix A. Selected surface-water sites in the upper Gunnison River Basin—Continued

[NWIS, National Water Information System; STORET, Storage and retrieval database; CDPHE, Colorado Department of Public Health and Environment; NPS, National Park Service; SW, surface water; SP, spring; LK, lake; UNLV, University of Nevada–Las Vegas Toxic Metals in Water data]

Site number for this report	Information from USGS NWIS or USEPA STORET					
	Site number as appears in database	Site names as they appear in database	Latitude	Longitude	Agency collecting data	Type of site
61	09124500	Lake Fork at Gateview, Co.	381756	1071346	USGS	SW
62	CURE_LF01	Lake Fork	381927.3	1071336.5	NPS	SW
63	10390	Marshall Cr. Nr. Sargents	382117.4	1064053.6	CDPHE	SW
64	382720107324000	Mesa Creek at Footbridge abv Crystal Reservoir	382720	1073240	USGS	SW
65	10267	Mill Cr. @ West Elk Wilderness Trailhead	384143	1070341	CDPHE	SW
66	385426107013400	Oh-Be-Joyfull Cr Ab Slate River Nr Crested Butte	385426	1070134	USGS	SW
67	385437107015600	Oh-Be-Joyful C at Mo Nr Crested Butte, Co.	385437	1070156	USGS	SW
68	09113300	Ohio Creek at Baldwin, Co.	384556	1070328	USGS	SW
69	09113500	Ohio Creek near Baldwin, Co.	384208	1065952	USGS	SW
70	09113980	Ohio Creek above Mouth, Nr. Gunnison, CO	383516	1065551	USGS	SW
71	383516106555000	Ohio Creek above Mouth, near Gunnison, Co	383515	1065550	USGS	SW
72	PALMETTO3	Palmetto Gl blw Hough Mine	375833	1073447	CDPHE	SW
73	CURE_PC01	Pine Creek	382649	1072039.8	NPS	SW
74	382702107203900	Pine Creek above Morrow Point Reservoir	382702	1072039	USGS	SW
75	10335	Quartz Cr. below Ohio City	383355	1065031	CDPHE	SW
76	09118000	Quartz Creek near Ohio City, Co.	383335	1063809	USGS	SW
77	382902107140400	Red Creek above blue Mesa Reservoir	382902	1071404	USGS	SW
78	385429107013000	Slate Ri Ab Oh-Be-Joyfull Cr Nr Crested Butte	385429	1070130	USGS	SW
79	385240106583600	Slate Ri above Coal Cr near Crested Butte	385240	1065836	USGS	SW
80	000150	Slate River above Coal Creek	385238	1065836	CDPHE	SW
81	385237106583300	Slate River at Hwy 135 at Crested Butte, Co.	385237	1065833	USGS	SW
82	385231106583200	Slate R bl Coal C at Crested Butte, Co.	385231	1065832	USGS	SW
83	09111500	Slate River near Crested Butte, Co.	385210	1065810	USGS	SW
84	000151	Slate R. blw Crested Butte	384049.8	1065630.6	CDPHE	SW
85	385106106571000	Slate R Ab Baxter Gl @Hwy 135 Nr Crested Butte	385106	1065710	USGS	SW
86	03038221	Crested Butte Colorado,Slate R.Coal Cr.Gunnison	385010	1065610	UNLV	SW
87	384853106541500	Slate R at Mouth Nr Crested Butte, Co.	384853	1065415	USGS	SW
88	384852106541500	Slate River above East River near Crested Butte	384852	1065415	USGS	SW
89	383137107183600	Soap Creek at Ponderosa Campground abv Blue Mesa	383137	1071836	USGS	SW
90	CURE_SC09	Squaw Ck above Cimarron Ck	382631.5	1073328.1	NPS	SW

Appendix A. Selected surface-water sites in the upper Gunnison River Basin—Continued

[NWIS, National Water Information System; STORET, Storage and retrieval database; CDPHE, Colorado Department of Public Health and Environment; NPS, National Park Service; SW, surface water; SP, spring; LK, lake; UNLV, University of Nevada–Las Vegas Toxic Metals in Water data]

Site number for this report	Information from USGS NWIS or USEPA STORET					
	Site number as appears in database	Site names as they appear in database	Latitude	Longitude	Agency collecting data	Type of site
91	CURE_STC1	Steuben Creek	382935.6	1070335.3	NPS	SW
92	10255	Steuben Cr. North Of Blue Mesa Res.	383011	1070341	CDPHE	SW
93	382937107033500	Steuben Creek above Blue Mesa Reservoir	382937	1070335	USGS	SW
94	CURE_SC01	Steuben Creek - Access Road	382936.3	1070335.5	NPS	SW
95	10329	Stewart Cr. @ La Garita W.A.	380126	1065031	CDPHE	SW
96	09107000	Taylor River at Taylor Park, Co.	385059	1063421	USGS	SW
97	09109000	Taylor River below Taylor Park Reservoir, Co.	384906	1063631	USGS	SW
98	000058	Taylor River at Almont	383952	1065041	CDPHE	SW
99	09110000	Taylor River at Almont, Co.	383952	1065041	USGS	SW
100	10160	Texas Cr. @ Mouth	385048	1063325	CDPHE	SW
101	09107500	Texas Creek at Taylor Park, Co.	385041	1063412	USGS	SW
102	10309	Upper Tomichi Cr. above Whitepine	383256	1062329	CDPHE	SW
103	09115500	Tomichi Creek at Sargents, Co.	382442	1062520	USGS	SW
104	10301	Tomichi Cr. @ Hwy 114	382606	1063355	CDPHE	SW
105	09117000	Tomichi Creek at Parlin, Co.	382950	1064332	USGS	SW
106	383126106475600	Tomichi Ck. blw. Cochetopa Ck. Nr. Parlin, Co	383126	1064756	USGS	SW
107	09119000	Tomichi Creek at Gunnison, Co.	383118	1065625	USGS	SW
108	383050106302700	Waunita Hot Spring C	383050	1063027	USGS	SP
109	CURE_WEC1	West Elk Creek	383021.3	1071622.1	NPS	SW
110	383028107162200	West Elk Creek above Blue Mesa Reservoir	383028	1071622	USGS	SW
111	10235	Willow Cr. West Of Lake Fork	382230	1071800	CDPHE	SW
112	CURE_NW06	Lower North Willow	382857.8	1070657.2	NPS	SW
113	CURE_NW11	Upper North Willow	382906.4	1070712	NPS	SW
114	CURE_BM17	Iola Beach	382851.3	1070344.6	NPS	LK
115	382856107050000	Blue Mesa Reservoir at Iola Basin	382856	1070500	USGS	LK
116	CURE_BM05	Iola	382824.6	1070535.9	NPS	LK
117	CURE_BM04	Sunnyside	382903.4	1070600.4	NPS	LK
118	CURE_BM03	Haystack Gulch	382755.2	1070940.3	NPS	LK
119	CURE_BM19	Elk Creek Marina	382739	1070952.2	NPS	LK
120	CURE_BM14	Old Hwy 50 Beach	382806.5	1071034.7	NPS	LK

Appendix A. Selected surface-water sites in the upper Gunnison River Basin—Continued

[NWIS, National Water Information System; STORET, Storage and retrieval database; CDPHE, Colorado Department of Public Health and Environment; NPS, National Park Service; SW, surface water; SP, spring; LK, lake; UNLV, University of Nevada–Las Vegas Toxic Metals in Water data]

Site number for this report	Information from USGS NWIS or USEPA STORET					
	Site number as appears in database	Site names as they appear in database	Latitude	Longitude	Agency collecting data	Type of site
121	CURE_BM16	Bay Of Chickens East	382835.9	1071036.8	NPS	LK
122	CURE_BM15	Bay Of Chickens West	382832.7	1071048.7	NPS	LK
123	382829107122200	Blue Mesa Reservoir at Cebolla Basin	382829	1071222	USGS	LK
124	CURE_BM18	Blue Mesa Highlands	382817.3	1071715	NPS	LK
125	382831107172600	Blue Mesa Reservoir at Sapinero Basin	382831	1071726	USGS	LK
126	CURE_BM01	Lake Fork Arm	382645.3	1071753.2	NPS	LK
127	CURE_BM13	Mcintyre Gulch	382824.9	1071834.6	NPS	LK
128	CURE_BM02	Lake Fork Marina	382728	1071921.4	NPS	LK
129	CURE_CL04	Crystal Reservoir	382718.4	1073241.6	NPS	LK
130	382710107323000	Crystal Reservoir blw Morrow Point Dam Powerhous	382710	1073230	USGS	LK
131	383024107371800	Crystal Reservoir near Crystal Dam	383024	1073718	USGS	SW
132	382711107201200	Morrow Point Res blw Blue Mesa Dam Powerhouse	382711	1072012	USGS	LK
133	CURE_MPL6	Morrow Point Reservoir	382707.8	1072043.8	NPS	LK
134	382644107271000	Morrow Point Reservoir at Kokanee Bay	382644	1072710	USGS	LK
135	382702107315400	Morrow Point Reservoir near Dam Of	382702	1073154	USGS	LK

Appendix B. Characteristics of ground-water-quality sites in the upper Gunnison River watershed, 1970–99

[FP, field properties; MI, major ions; TE, trace elements; N, nutrients; R, radon]

Site number for this report	Site identification	Sample date(s)	Depth to water (feet)	Approximate age and lithologic unit near well screen	Type of data
136	375523107194601	05/16/1974	--	Holocene valley-fill sand	FP, MI,TE, N
137	375900107174001	09/23/1981	--	Tertiary System	FP, MI,TE
138	375910107174001	09/23/1981	--	Oligocene Series	FP, MI,TE
139	375920107173000	08/27/1997	--	Holocene valley-fill alluvium	FP, MI,TE, N, R
140	380018107182401	05/16/1974	--	--	FP, MI,TE, N
141	380032107180600	08/05/1997	--	Holocene valley-fill alluvium	FP, MI,TE, N, R
142	380213107183201	05/15/1974	--	Holocene valley-fill sand	FP, MI,TE, N
143	380244107181700	08/27/1997	--	Holocene valley-fill alluvium	FP, MI, TE, N, R
144	380307107181400	08/27/1997	--	Holocene valley-fill alluvium	FP, MI,TE, N, R
145	380314107043401	05/16/1974	--	Holocene valley-fill sand	FP, MI,TE, N
146	380435107175001	09/23/1981	--	Oligocene Series	FP, MI,TE
147	381339107042500	09/18/1997	--	Holocene valley-fill alluvium	FP, MI,TE, N, R
148	381620107051801	05/15/1974	--	Precambrian erathem	FP, MI,TE, N
149	381634107054701	05/15/1974	--	Upper Cretaceous Dakota Sandstone	FP, MI,TE, N
150	381700107141401	05/15/1974	--	Miocene Series	FP, MI,TE, N
151	381709107325801	05/27/1974	--	Holocene valley-fill sand	FP, MI,TE, N
152	381804107061000	09/17/1997	--	Holocene valley-fill alluvium	FP, MI,TE, N, R
153	381824107113200	09/15/1997	--	Holocene valley-fill alluvium	FP, MI,TE, N, R
154	382240107295501	05/27/1974	--	Holocene valley-fill sand	FP, MI,TE, N
155	382414106244900	08/04/1997	--	Holocene valley-fill alluvium	FP, MI,TE, N, R
156	382741107095901	05/28/1974	--	Precambrian metamorphic rock	FP, MI,TE, N
157	382758106563701	06/11/1974	--	Holocene alluvium	FP, MI,TE, N
158	382802107055001	05/28/1974	--	--	FP, MI,TE, N
159	382942106434101	06/08/1974	--	Precambrian crystalline rocks	FP, MI,TE, N
160	382954106425401	06/10/1974	--	Precambrian metamorphic rock	FP, MI,TE, N
161	382954106555401	06/12/1974	--	--	FP, MI,TE, N
162	383005106461801	06/10/1974	3.0	Holocene valley-fill sand	FP, MI, TE, N
163	383109106573400	08/05/1997	--	Holocene valley-fill alluvium	FP, MI, TE, N, R
164	383121106583000	08/28/1997	--	Holocene valley-fill alluvium	FP, MI, TE, N, R
165	383129106480001	07/27/1976	26.0	--	FP, MI, TE, N
166	383130106574100	05/08/1997	10.58	Holocene valley-fill alluvium	FP, MI, TE, N, R
		10/09/1997	6.5		FP, MI, TE, N, R
167	383150106565501	06/11/1974	2	Holocene valley-fill sand	FP, MI, TE, N
168	383150106574601	06/11/1974	--	Upper Jurassic Brushy Basin Shale Member of Morrison Formation	FP, MI, TE, N
169	383159106395001	06/10/1974	--	Upper Jurassic Brushy Basin Shale Member of Morrison Formation	FP, MI, TE, N
170	383203106570101	08/28/1976	--	Holocene alluvium	FP, MI, TE, N
171	383219106565300	05/08/1997	3.0	Holocene valley-fill alluvium	FP, MI, TE, N, R
		10/09/1997	3.0		FP, MI, TE, N, R
172	383232106550500	12/04/1996	17.7	Holocene valley-fill alluvium	FP, MI, TE, N, R
		05/07/1997	19.85		FP, MI, TE, N, R
		10/10/1997	15.9		FP, MI, TE, N, R

Appendix B. Characteristics of ground-water-quality sites in the upper Gunnison River watershed, 1970–99—Continued

[FP, field properties; MI, major ions; TE, trace elements; N, nutrients; R, radon]

Site number for this report	Site identification	Sample date(s)	Depth to water (feet)	Approximate age and lithologic unit near well screen	Type of data
173	383232106554700	05/06/1997	19.1	Holocene valley-fill alluvium	FP, MI, TE, N, R
		10/09/1997	8.6		FP, MI, TE, N, R
174	383236106513100	08/25/1997	--	Holocene valley-fill alluvium	FP, MI, TE, N, R
175	383242106515201	06/10/1974	--	Upper Jurassic Brushy Basin Shale Member of Morrison Formation	FP, MI, TE, N
176	383258106531501	06/13/1974	33.0	--	FP, MI, TE, N
177	383304106571001	06/12/1974	--	Lower Cretaceous Burro Canyon Formation	FP, MI, TE, N
178	383326106373900	08/06/1997	--	Holocene valley-fill alluvium	FP, MI, TE, N, R
179	383334106555400	12/03/1996	13.3	Holocene valley-fill alluvium	FP, MI, TE, N, R
		05/29/1997	4.06		FP, MI, TE, N, R
		10/08/1997	10.4		FP, MI, TE, N, R
180	383404106550601	08/24/1977	7.0	Cretaceous Dakota Sandstone	FP, MI, TE
181	383412106363401	06/08/1974	--	Holocene valley-fill sand	FP, MI, TE, N
182	383431106540301	02/12/1977	239	--	FP, MI, TE, N
183	383436106540701	08/19/1977	113	Cretaceous Dakota Sandstone	FP, MI, TE, N
184	383440106551501	08/26/1976	12	Holocene alluvium	FP, MI, TE, N
185	383518106553601	10/14/1976	15	--	FP, MI, TE, N
186	383522106553101	10/14/1976	157	Upper Cretaceous Dakota Sandstone	FP, MI, TE, N
187	383543106563201	10/29/1976	178	Upper Cretaceous Dakota Sandstone	FP, MI, TE, N
188	383549106561201	10/14/1976	32	--	FP, MI, TE, N
189	383555106552801	06/13/1974	--	Holocene valley-fill sand	FP, MI, TE, N
190	383623106525601	06/11/1974	3.0	Holocene valley-fill sand	FP, MI, TE, N
191	383642106304601	06/08/1974	--	Holocene valley-fill sand	FP, MI, TE, N
192	383657106305601	06/08/1974	--	--	FP, MI, TE, N
193	383754106522401	08/17/1977	33	Lower Cretaceous Burro Canyon Formation	FP, MI, TE, N
194	383800106523201	08/17/1977	134	--	FP, MI, TE, N
195	383817106562801	06/10/1974	--	Holocene valley-fill sand	FP, MI, TE, N
196	383827106515801	05/17/1974	--	Holocene valley-fill sand	FP, MI, TE, N
197	383849106515201	08/26/1976	--	Upper Jurassic Morrison Formation	FP, MI, TE, N
198	383852106515601	08/27/1976	--	Upper Cretaceous Dakota Group	FP, MI, TE, N
199	383953106502601	08/27/1976	21.0	Precambrian crystalline rocks	FP, MI, TE, N
200	383953106503000	08/07/1997	--	Holocene valley-fill alluvium	FP, MI, TE, N, R
201	384003106504401	08/26/1976	--	Holocene alluvium	FP, MI, TE
202	384014106511201	06/07/1974	--	Upper Jurassic Brushy Basin Shale Member of Morrison Formation	FP, MI, TE, N
203	384050106511500	08/07/1997	--	Holocene valley-fill alluvium	FP, MI, TE, N, R
204	384126106590200	08/26/1997	--	Holocene valley-fill alluvium	FP, MI, TE, N, R
205	384130106492201	05/17/1974	--	Holocene valley-fill gravel	FP, MI, TE, N
206	384250106511501	08/23/1977	--	--	FP, MI, TE, N
207	384255106510801	10/28/1976	14.0	Holocene alluvium	FP, MI, TE, N
208	384258106504601	06/07/1974	--	--	FP, MI, TE, N

Appendix B. Characteristics of ground-water-quality sites in the upper Gunnison River watershed, 1970–99—Continued

[FP, field properties; MI, major ions; TE, trace elements; N, nutrients; R, radon]

Site number for this report	Site identification	Sample date(s)	Depth to water (feet)	Approximate age and lithologic unit near well screen	Type of data
209	384318106470001	06/12/1974	--	--	FP, MI, TE, N
210	384418106513601	08/27/1976	--	Holocene alluvium	FP, MI, TE, N
211	384423106512001	08/27/1976	17.0	Holocene alluvium	FP
212	384446106423601	06/12/1974	15.0	Holocene valley-fill sand	FP, MI, TE, N
213	384447106503701	10/28/1976	20.0	Holocene alluvium	FP, MI, TE, N
214	384450106503601	10/28/1976	58.0	Upper Jurassic Entrada Sandstone	FP, MI, TE, N
215	384518106284201	08/23/1976	11.0	Holocene alluvium	FP, MI, TE, N
216	384531107012701	06/10/1976	15.0	Upper Cretaceous Mesaverde limestone	--
		08/16/1977	--		FP, MI, TE, N
217	384553107030601	10/13/1976	10.0	Upper Cretaceous Mesaverde limestone	FP, MI, TE, N
218	384646107035801	06/10/1974	--	--	FP, MI, TE, N
219	384720106522701	08/27/1976	--	Holocene alluvium	FP
220	384751106524401	06/07/1974	--	Holocene valley-fill sand	FP, MI, TE, N
221	384815106523000	08/26/1997	--	Holocene valley-fill alluvium	FP, MI, TE, N, R
222	384827106530200	05/14/1997	0.8	Holocene valley-fill alluvium	FP, MI, TE, N, R
		10/08/1997	1.45		FP, MI, TE, N, R
223	384849106375101	06/14/1974	17.0	Precambrian Erathem	FP, MI, TE, N
224	384851106534700	05/13/1997	1.79	Holocene valley-fill alluvium	FP, MI, TE, N, R
		10/07/1997	16.5		FP, MI, TE, N, R
225	384852106521200	08/26/1997	--	Cenozoic valley-fill alluvium	FP
226	384913106514001	06/07/1974	12.0	Holocene valley-fill sand	FP, MI, TE, N
227	385009106555101	06/06/1974	32.0	Precambrian metamorphic rock	FP, MI, TE, N
228	385123106574801	06/07/1974	--	Holocene valley-fill sand	FP, MI, TE, N
229	385124106562200	05/13/1997	4.55	Holocene valley-fill alluvium	FP, MI, TE, N, R
		10/07/1997	10.4		FP, MI, TE, N, R
230	385125106571900	08/06/1997	--	Holocene valley-fill alluvium	FP, MI, TE, N, R
231	385204107020001	08/09/1978	--	--	FP, MI, TE, N
232	385213106584700	12/05/1996	--	Holocene valley-fill alluvium	FP, MI, TE, N, R
		05/12/1997	8.6		FP, MI, TE, N, R
		10/07/1997	12.05		FP, MI, TE, N, R
233	385345107002000	08/06/1997	5.0	Holocene valley-fill alluvium	FP, MI, TE, N, R
234	385351107002501	04/29/1977	--	Upper Cretaceous Mancos Shale	FP, MI, TE, N