Water Quality at Basic Fixed Sites in the Upper Colorado River Basin National Water-Quality Assessment Study Unit, October 1995–September 1998

By Norman E. Spahr, Robert W. Boulger, and Richard J. Szmajter

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FOREWORD

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

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

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

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

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

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

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

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

Robert M. Hirsch
Chief Hydrologist

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
acre	4,047	square meter
mile	1.609	kilometer
square mile	259	hectare
square mile	2.590	square kilometer
acre-foot per year	1,233	cubic meter per year
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

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

$$°F = 1.8\ (°C + 32)$$

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

Elevation, as used in this report, refers to distance above or below sea level.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm).

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

Water year is the 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends. Thus, the 12-month period ending September 30, 1996, is water year 1996.

Water Quality at Basic Fixed Sites in the Upper Colorado River Basin National Water-Quality Assessment Study Unit, October 1995–September 1998

By Norman E. Spahr, Robert W. Boulger, *and* Richard J. Szmajter

Abstract

The Upper Colorado River Basin study unit of the U.S. Geological Survey National Water-Quality Assessment Program consists of the Colorado River watershed upstream from near the Colorado-Utah State line. The basin is about equally divided between the Southern Rocky Mountains and the Colorado Plateau physiographic provinces. Data were collected at pairs of indicator sites for mining, increasing urban development, and agricultural land use. Reference basic fixed sites were established in each physiographic province to provide baseline or background information in areas where anthropogenic influences are minimal.

Water-quality data collection began at three of the sites in water year 1995. Full implementation of data collection at the 14-site network began in October 1996 and continued through September 1998. Six hundred and sixty water-quality samples were collected at the network sites.

Snowmelt runoff dominates the hydrology in most of the basin, but water management for irrigation, storage, and transmountain diversions substantially changes annual runoff characteristics in some areas. Streamflow during water years 1995 and 1997 was generally greater than long-term average conditions. During water year 1996, streamflow also was above average at many sites but not to the extent as seen during 1995 or 1997. Water year 1998 streamflows typically were near or slightly below the long-term average. Extreme low-flow conditions generally did not occur at the sites during the data-collection period.

Dissolved nitrate and total phosphorus concentrations at the background site within the Southern Rocky Mountain physiographic province typically were low (hundreths of milligrams per liter). Concentrations in areas of urban development and areas in the lower parts of the basin generally were in the tenths of milligrams per liter and in some agricultural areas were in the milligram per liter range. Median dissolved-solids concentrations at sites in the Southern Rocky Mountains were typically less than 200 milligrams per liter. Small tributaries in the Colorado Plateau and agricultural areas had dissolved-solids concentrations in the thousands of milligrams per liter range. Trace-element concentrations were high, at times, in areas of mining land use. Median zinc concentration for the French Gulch near Breckenridge site was 2,700 micrograms per liter.

Comparison of measured concentrations to Colorado State instream standards showed that concentrations of dissolved oxygen, pH, nitrate, and ammonia were within instream standards at all sites. Concentrations of cadmium and zinc at the site on French Gulch (a mining-affected site) often were greater than the State instream standard.

INTRODUCTION

Investigation began on the Upper Colorado River Basin study unit (UCOL) of the U.S. Geological Survey (USGS) National Water-Quality Assessment

(NAWQA) Program in 1994. The long-term goals of the NAWQA Program are to describe the current water-quality conditions for a large part of the Nation's freshwater streams and rivers, to describe how water quality is changing over time, and to improve understanding of the primary natural and human factors that affect water-quality conditions (Leahy and others, 1990). The UCOL encompasses 17,843 square miles in two major physiographic provinces, the Southern Rocky Mountains and the Colorado Plateau. The environmental setting and description of the UCOL were presented by Apodaca and others (1996). A network of surface-water sites (fig. 1) was established in the UCOL as part of the occurrence and distribution phase of the NAWQA design. This network is composed of the basic fixed sites, the basic building blocks of the NAWQA Program, and is described by Spahr and others (1996). The occurrence and distribution phase of NAWQA characterizes the broad-scale geographic and seasonal distributions of water-quality conditions in relation to major point and nonpoint contaminant sources and natural or background conditions (Gilliom

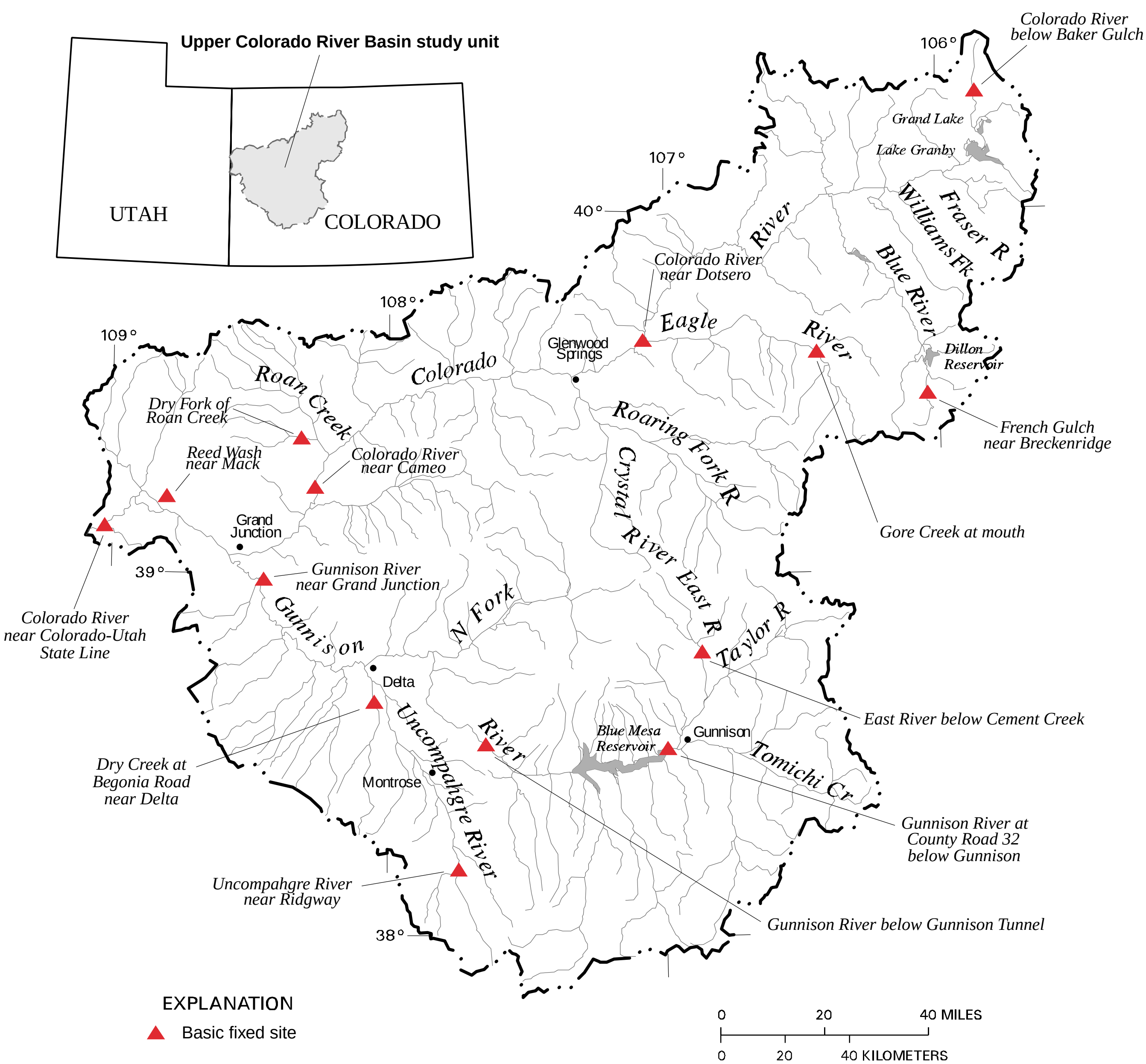

Figure 1. Study unit and location of basic fixed sites.

and others, 1995). Water-quality sampling began at three of the network sites in water year 1995. Full implementation of network sampling began in water year 1996 and continued through water year 1998.

Purpose and Scope

The purpose of this report is to describe selected water-quality data at 14 basic fixed sites in the UCOL network. This report presents the occurrence and distribution of water quality at each of the basic fixed sites. Streamflow, field measurements, nutrients, and major-ion chemistry of surface water are presented for 3 basic fixed sites during 1995–98 and for the remaining 11 basic fixed sites during 1996–98.

Data Collection

Monthly samples were collected at each of the 14 basic fixed sites during the data-collection period by using field procedures outlined in Shelton (1994). Additional samples were collected at each site during periods of extreme streamflows or at streamflows where water-quality samples previously had not been collected. During each site visit, onsite measurements were made and water samples collected for subsequent laboratory analysis at the U.S. Geological Survey central laboratory in Arvada, Colorado. A list of the onsite measurements and laboratory-analyzed constituents are given in table 1. The minimum reporting level (MRL) for each measurement also is listed in table 1. A minimum reporting level is the smallest measured concentration of a constituent that can be reliably reported using a given analytical or measurement method. Minimum reporting levels may change based on changes in laboratory methods or reliability; therefore, more than one MRL may be listed in table 1. Trace-element samples were collected during each visit for only the French Gulch near Breckenridge and Uncompahgre River near Ridgway sites. In this report, "dissolved" means that the water sample was passed through a 0.45-micrometer filter onsite prior to shipment to the laboratory for analysis. All data are available from the USGS National Water Information System (NWIS) data base and are published in the U.S. Geological Survey annual Water-Data Reports (1996, 1997, 1998, 1999).

Acknowledgments

The authors acknowledge the effort provided by Jeffrey Foster, David Hartle, and Dennis Smits, who collected most of the data. Their conscientious efforts during data collection provided representative samples and an excellent set of data for analysis. Thanks are also extended to Joy Monson for manuscript preparation, Mary Kidd for editing, Sharon Powers for illustrations assistance, and Loretta Ulibarri for technical advice on illustration layout.

Cooperators that assisted the UCOL NAWQA and the Colorado District Programs with data collection at specific basic fixed sites are listed below:

Basic fixed site and station number	Cooperator
Colorado River below Baker Gulch, station 09010500	Colorado River Water Conservation District Northern Colorado Water Conservation District
French Gulch near Breckenridge, station 09046530	Colorado Department of Public Health and Environment Summit County
Gore Creek at mouth, station 09066510	Eagle River Water and Sanitation District Town of Vail Upper Eagle Regional Water Authority
Colorado River near Cameo, station 09095500	Bureau of Reclamation
East River below Cement Creek, station 09112200	City of Gunnison Colorado River Water Conservation District Crested Butte South Metropolitan District Gunnison County Mount Crested Butte Water and Sanitation Town of Crested Butte Upper Gunnison River Water Conservancy District
Gunnison River at County Road 32 below Gunnison, station 383103106594200	City of Gunnison Colorado River Water Conservation District Gunnison County Upper Gunnison River Water Conservancy District National Park Service
Gunnison River below Gunnison Tunnel, station 09128000	National Park Service
Uncompahgre River near Ridgway, station 09146200	Bureau of Reclamation
Gunnison River near Grand Junction, station 09152500	Bureau of Reclamation
Reed Wash near Mack, station 09153290	Bureau of Reclamation
Colorado River near Colorado-Utah State line, station 09163500	Bureau of Reclamation

Table 1. Data collected at each basic fixed site

[Dissolved indicates that the sample water was passed through a 0.45-micrometer filter prior to analysis; MRL, minimum reporting level]

Activity	Constituent	Units	MRL
Onsite measurements	Discharge	cubic feet per second	0.01
	Water temperature	degrees Celsius	0.1
	Dissolved oxygen	milligrams per liter	0.1
	Specific conductance	microsiemens per centimeter at 25 degrees Celsius	1
	pH	standard units	0.1
	Alkalinity	milligrams per liter	1
Laboratory analyses	Major constituents and metals		
	Calcium, dissolved	milligrams per liter	0.02
	Chloride, dissolved	milligrams per liter	0.1
	Fluoride, dissolved	milligrams per liter	0.1
	Iron, dissolved	micrograms per liter	3
	Magnesium, dissolved	milligrams per liter	0.01
	Manganese, dissolved	micrograms per liter	1
	Potassium, dissolved	milligrams per liter	0.1
	Residue on evaporation	milligrams per liter	10
	Silica, dissolved	milligrams per liter	0.01
	Sodium, dissolved	milligrams per liter	0.2
	Sulfate, dissolved	milligrams per liter	0.1
	Nutrients		
	Ammonia nitrogen, dissolved	milligrams per liter	0.015 and 0.02
	Nitrite nitrogen, dissolved	milligrams per liter	0.01
	Nitrite plus nitrate nitrogen, dissolved	milligrams per liter	0.05
	Organic plus ammonia nitrogen, dissolved	milligrams per liter	0.2 and 0.1
	Organic plus ammonia nitrogen, total	milligrams per liter	0.2 and 0.1
	Orthophosphate phosphorus, dissolved	milligrams per liter	0.01
	Phosphorus, dissolved	milligrams per liter	0.01
	Phosphorus, total	milligrams per liter	0.01
	Organic carbon		
	Suspended	milligrams per liter	0.1
	Total	milligrams per liter	0.1 and 0.2
	Trace elements (French Gulch and Uncompahgre River sites only)		
	Aluminum, dissolved	micrograms per liter	1
	Antimony, dissolved	micrograms per liter	1
	Arsenic, dissolved	micrograms per liter	1
	Barium, dissolved	micrograms per liter	1
	Beryllium, dissolved	micrograms per liter	1
	Cadmium, dissolved	micrograms per liter	1
	Chromium, dissolved	micrograms per liter	1
	Cobalt, dissolved	micrograms per liter	1
	Copper, dissolved	micrograms per liter	1
	Lead, dissolved	micrograms per liter	1
	Molydbenum, dissolved	micrograms per liter	1
	Nickel, dissolved	micrograms per liter	1
	Selenium, dissolved	micrograms per liter	1
	Silver, dissolved	micrograms per liter	1
	Uranium, dissolved	micrograms per liter	1
	Zinc, dissolved	micrograms per liter	1
	Suspended sediment	milligrams per liter	1
Data logger	Water temperature, hourly for one of the years of data collection	degrees Celsius	0.1

WATER QUALITY

Selected results of the data collection and chemical analyses for each of the 14 basic fixed sites are presented in the following sections. Each site is represented with a discussion of water-quality conditions at the site and three pages of graphic representations of the data analysis. The first two pages of graphics are similar for all sites, and the last page shows the distribution of selected water-quality constituents in relation to streamflow or time. The first page of illustrations begins with a map of the basic fixed site showing the major stream network and the land-use/land-cover classifications (U.S. Geological Survey, 1990). The land-use/land-cover classifications are, in most instances, based on Anderson level I designations (Anderson and others, 1976). Modifications to urban land-use data were accomplished through the use of 1990 census track data (K.J. Hitt, U.S. Geological Survey, written commun., 1996). Knowledge of land use and land cover assists in the understanding of natural and anthropogenic factors that influence water quality.

The graph at the bottom of the first page of illustrations is a cumulative frequency curve of daily mean water temperatures. The daily mean temperatures are based on hourly measurements made using electronic data loggers. Water temperature is important as one of the physical conditions that describe the overall ecology of a stream. Data only are available for about 1 year; therefore, this graph is presented as a cumulative distribution and not as a probability graph. The plot shows the different percentiles of the available water-temperature data. For example, the median daily mean temperature is represented by the temperature corresponding to the 50-percent frequency point. The maximum and minimum daily mean temperatures are apparent from this graph. Because the graph is based on about 1 year of data, the approximate number of days that the average water temperature was greater than or equal to a given temperature can be determined from the temperature frequency curve. For example, if the frequency corresponding to 10°C is 14 percent, about 51 days had average water temperatures equal to or greater than 10°C (0.14×365 days). Along with the frequency curve is a plot of the hourly water temperature for 1 day. This graph shows a typical summer diurnal water-temperature change at the given site.

Many factors contribute to the observed concentrations of chemical constituents in water. As Hem (1992, p. 180) stated in reference to dissolved solids, "The concentration of dissolved solids in the water of a stream is related to many factors, but it seems obvious that one of the more direct and important factors is the variable volume of liquid water from rainfall available for dilution and transport of weathering products." Three graphs are presented on the second page of illustrations to describe the streamflow and the distribution of water-quality samples with respect to streamflow. Annual streamflow for the study period is described by use of a bar chart at the top of the second page of illustrations. The streamflow for each water year of the study period is represented by one bar in the graph. Historical data, when available, also are provided for the period prior to data collection for this study. The presented historical data begin in water year 1970 because this date is subsequent to the filling and development of most of the major reservoir systems within the study unit. A comparison of the study data-collection period to the historical data indicates in general terms whether the study data-collection period had above, below, or near normal runoff. Year-to-year variation in streamflow, as well as the streamflow for any given year, is readily discernible from this graph.

Shown in the middle of the second page of illustrations is the daily mean streamflow hydrograph for the data-collection period and an overlay of the historical mean daily streamflow (when available). The dates and instantaneous streamflow for the water-quality samples also are presented on this graph. Because the instantaneous streamflow is used in measuring the water-quality samples, occasionally these points do not fall on the line representing the daily mean discharge. This graph provides a comparison of the daily values, magnitude, and timing of the annual peak streamflows with respect to the long-term data. The distribution of water-quality samples with respect to time also is represented. For many sites, the water-quality samples are color coded to indicate on the annual hydrograph when the sampling occurred (rising limb or falling limb/base flow). Samples collected after the streamflow increased from winter base-flow conditions but prior to the annual peak were considered rising-limb samples and all other samples were considered falling limb/base flow.

The flow-duration curve for the sampling site is at the bottom of the second page of graphics. A flow-duration curve is a cumulative frequency curve that, in this instance, shows the percentage of time that a given daily mean streamflow is expected to be equaled or exceeded. For example, the streamflow corresponding to the 50-percent probability of exceedance represents the median streamflow for the site and is expected to be exceeded 50 percent of the time. Where historical streamflow data are available, the duration curve is based on the historical period beginning in water year 1970 and continuing up to the beginning of data collection for this study. Shorter periods of record are used for some sites. The streamflows at which water-quality samples were collected also are represented on the duration curve. This provides a visual representation of the distribution of water-quality samples across the various streamflows expected at the site. At many sites, the concentrations of water-quality constituents vary with streamflow, and this graph shows what streamflow conditions have associated water-quality data. In addition, major-ion bar charts also are displayed for two of the water-quality samples. These bar charts represent the major cations on the left bar and the major anions on the right bar of each chart. Comparison of the bar charts provides information on how the major-ion distribution changes with streamflow. The general classification of water also can be determined in the bar chart. For example, a calcium-bicarbonate water would have a bar chart with the lengths of the calcium (cation) and the bicarbonate (anion) sections of the bars representing more than 50 percent of the total length of the bar.

The third page of illustrations presents the distribution of selected water-quality constituents at the various sites. Concentrations of selected constituents are shown in relation to discharge or time.

Colorado River below Baker Gulch, Station 09010500

The Colorado River below Baker Gulch site is within the boundary of Rocky Mountain National Park and represents a background reference site for the Southern Rocky Mountains physiographic province. A reference site is a site where there are minimal effects on water quality from land-use changes. The drainage basin is about 53 square miles and has elevations ranging from 8,750 to 12,940 feet. Areal average annual precipitation is about 33 inches (Colorado Climate Center, 1984). The stream reach in which this site is located is designated as outstanding waters (Colorado Department of Public Health and Environment, 1996). This classification requires that no degradation in stream quality is allowed. The watershed upstream from the site mostly is composed of forest, tundra, and meadows (fig. 2); a few cabins are located within the basin. Water temperatures reflect the high elevation and the long-duration snowpack upstream from the site. Mean daily water-temperature data for water year 1997 was 3.6°C and the median was 0.4°C. Diurnal changes in temperature ranged from 0°C in the winter season to about 9°C during the snowmelt runoff period. Hourly water-temperature data for a typical summer day are shown in figure 2.

Annual streamflow (fig. 3*A*) for 1970–94 averages 46,660 acre-feet with considerable year-to-year variation. A transmountain diversion (Grand River Ditch) upstream from the site diverts an annual average of about 18,000 acre-feet of water into the South Platte River Basin. Data collection for the UCOL NAWQA began at this site in water year 1995. Annual streamflows for water years 1995–97 were greater than the long-term mean, but 1998 streamflow was slightly less than the long-term mean. The hydrology at the site is dominated by snowmelt runoff with peak flows occurring in May or June (fig. 3*B*). Fifty-six water-quality samples were collected for the UCOL NAWQA at this site beginning in January 1995 and ending in September 1998. All portions of the flow-duration curve, with the exception of extreme low flows, are represented with water-quality samples (fig. 3*C*). Extreme low flows (greater than 80 percent probability of being exceeded) did not occur during the data-collection period. As the streamflow increases, the concentration of the major ions is diluted; this is illustrated by the change in the bar charts representing the major ions for samples collected at moderate flow (bar chart on the right) and at higher flow (bar chart on the left) (fig. 3*C*). The water at this site typically is a calcium-bicarbonate type (calcium and bicarbonate are the dominant ions).

Selected water-quality constituent concentrations and properties are plotted relative to streamflow in figure 4. Several of the water-quality constituents at this site show a pronounced hysteresis between concentrations observed during the rising and falling limbs of the annual hydrograph. Hysteresis, in this example, is defined by the concentrations on the rising limb typically being greater than those at the same streamflow on the falling limb/base flow. Suspended-sediment concentrations were low (median of 2 mg/L). The major ions followed a typical dilution type curve when concentrations were plotted relative to streamflow as represented by the dissolved-solids plot in figure 4.

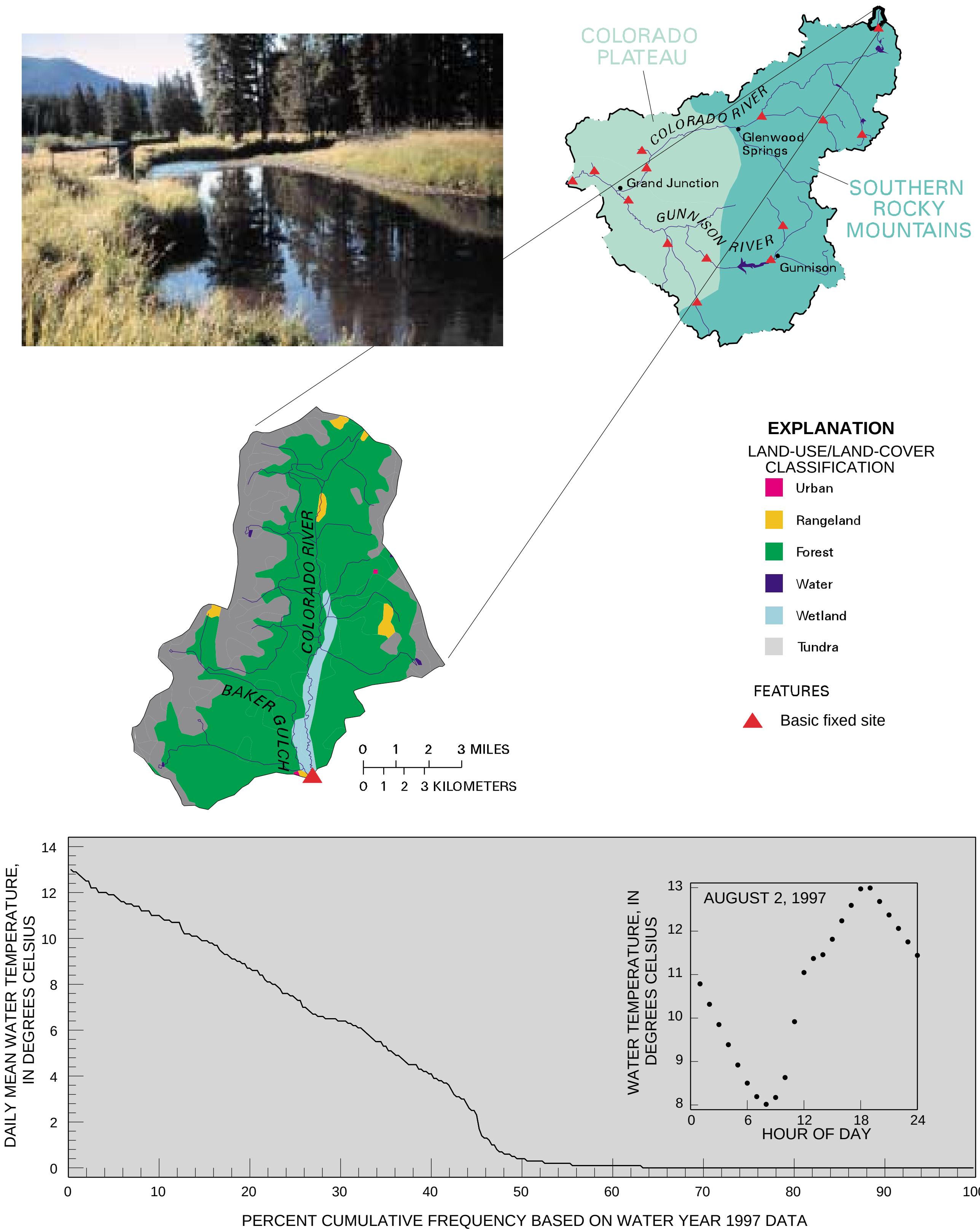

Figure 2. Photograph showing topography of basin, map showing location and land use/land cover of basin, and graphs showing frequency curve of daily mean water temperature and typical summer diurnal temperature for Colorado River below Baker Gulch, station 09010500. Photograph by Norman Spahr.

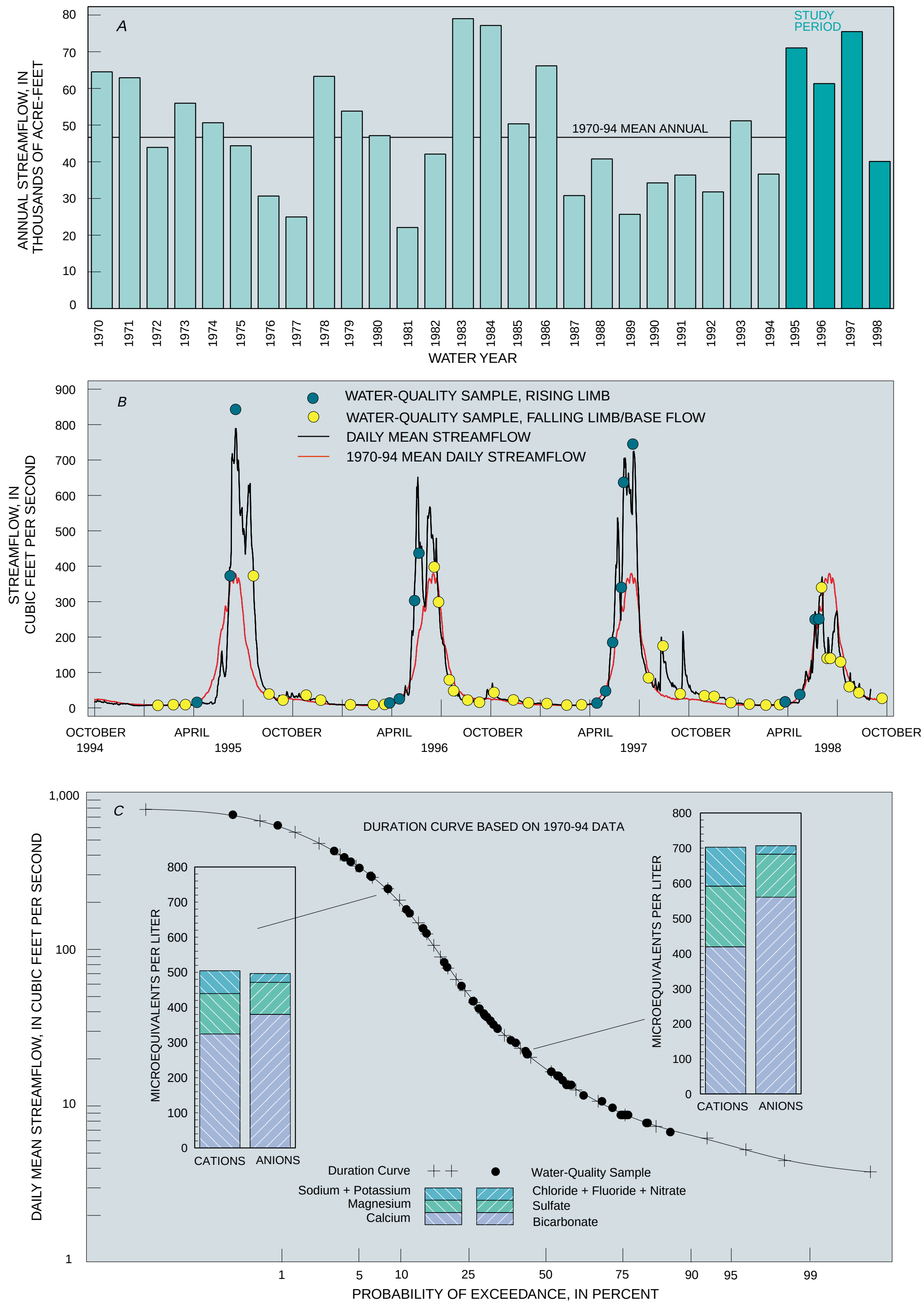

Figure 3. (*A*) Historical and study period annual streamflow, (*B*) daily mean streamflow and time distribution of water-quality samples, and (*C*) flow-duration curve with streamflow distribution of water-quality samples and examples of major-ion chemistry for Colorado River below Baker Gulch, station 09010500.

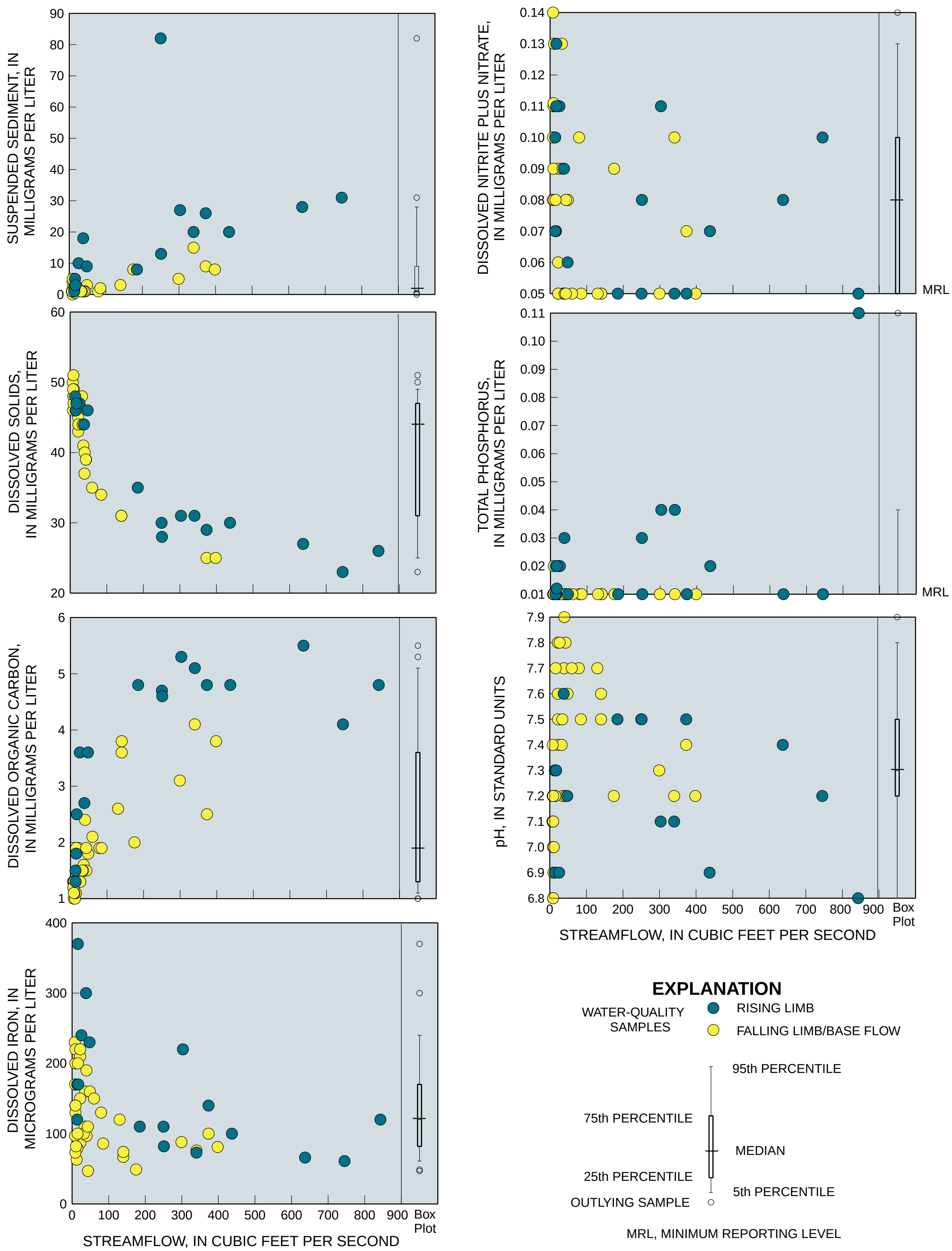

Figure 4. Distribution of selected water-quality constituents and properties relative to streamflow for Colorado River below Baker Gulch, station 09010500.

This resulted from base-flow concentrations being diluted by snowmelt runoff water. Suspended-sediment and dissolved organic-carbon concentrations increased with increasing streamflow, which resulted from the increased capacity of greater streamflows to transport material from source areas within the watershed. Dissolved iron concentrations reflect geologic sources of iron and the reducing environment of the large wetland areas in the basin. Nitrite plus nitrate concentrations were low (typically less than 0.15 mg/L) and showed no general relation to streamflow. Most total phosphorus concentrations were less than the laboratory minimum reporting level. Streamwater pH typically was circumneutral (values about 7). Ranges of concentrations for constituents not shown in figure 4 are listed below.

Constituent	Minimum	Median	Maximum
	(milligrams per liter, < less than)		
Suspended organic carbon	<0.1	0.2	0.9
Dissolved ammonia	<0.2	<0.2	0.06
Dissolved nitrite	<0.01	<0.01	0.02
Dissolved ammonia plus organic nitrogen	<0.2	<0.2	0.2
Dissolved phosphorus	<0.01	<0.01	0.03
Dissolved orthophosphate	<0.01	<0.01	0.02
Dissolved oxygen	7.5	9.3	11.0

Water-quality conditions at this site should typify background conditions in the Southern Rocky Mountains physiographic province. Concentrations of ions were fairly dilute; sediment and nutrient (nitrogen and phosphorus) concentrations were low.

French Gulch near Breckenridge, Station 09046530

French Gulch is located northeast of Breckenridge, Colorado, in the Southern Rocky Mountains physiographic province and has a drainage area of about 11 square miles. This drainage was one of two selected to represent mining effects on water quality for the UCOL NAWQA basic-fixed-site network. The sampling site is located just upstream from the mouth and about 2 miles downstream from an extensive historical mining area (fig. 5). Locations of mine shafts and dredge tailings in figure 5 are from USGS 7.5-minute topographic maps. Placer and lode mining occurred in the basin from around 1850 until the 1960's. Mine drainage contributes high concentrations of certain metals to the surface water of French Gulch (Kimball and others, 1999).

Hourly water-temperature data were collected during water year 1997. Daily mean water temperature was 3.4°C and the median was 2.6°C. The cumulative frequency curve for daily mean water temperature is shown in figure 5. Diurnal temperature variations range from near 0°C in the winter to about 5°C during snowmelt runoff. Typical summer diurnal temperature variation is shown in figure 5; the maximum daily temperature occurred around midday.

Annual streamflow for the study period is shown in figure 6*A*. Historical data are not available for this site because the site was established for the UCOL NAWQA Program. Annual streamflow during water year 1998 was substantially lower than the previous 2 years. The daily mean streamflow hydrograph and the time distribution of water-quality samples are shown in figure 6*B*. Forty-eight water-quality samples were collected at the site, beginning in October 1995 and ending in September 1998. The annual snowmelt runoff peak dominates the hydrology at this site. A flow-duration curve representing the 3 years of available data is shown in figure 6*C*. Median daily streamflow was 4 ft^3/s. The streamflow associated with the water-quality samples also is shown on the flow-duration curve. All portions of the flow-duration curve are represented with water-quality samples. The bar charts with the flow-duration curve present the distribution of the major ions at about the 50th- and 10th-percentile streamflows. As the streamflow increased (a lower probability of exceedance), the concentrations of the major ions decreased (snowmelt dilution). The water at these two flows is a calcium-sulfate type water (calcium is the major cation and sulfate the major anion).

Selected water-quality constituent concentrations and properties are plotted relative to streamflow in figure 7. Sediment concentrations in French Gulch typically are low (less than 10 mg/L) with the exception of samples collected just prior to the beginning of the snowmelt runoff. The three high-concentration samples represent the late March period for each of the 3 water years and are all at about 2 ft^3/s. These samples were collected just prior to the beginning of the snowmelt runoff period. Dissolved solids, a surrogate for major ions, showed a snowmelt dilution effect (lower concentrations at higher streamflows). Hysteresis is evident in the dissolved solids/streamflow

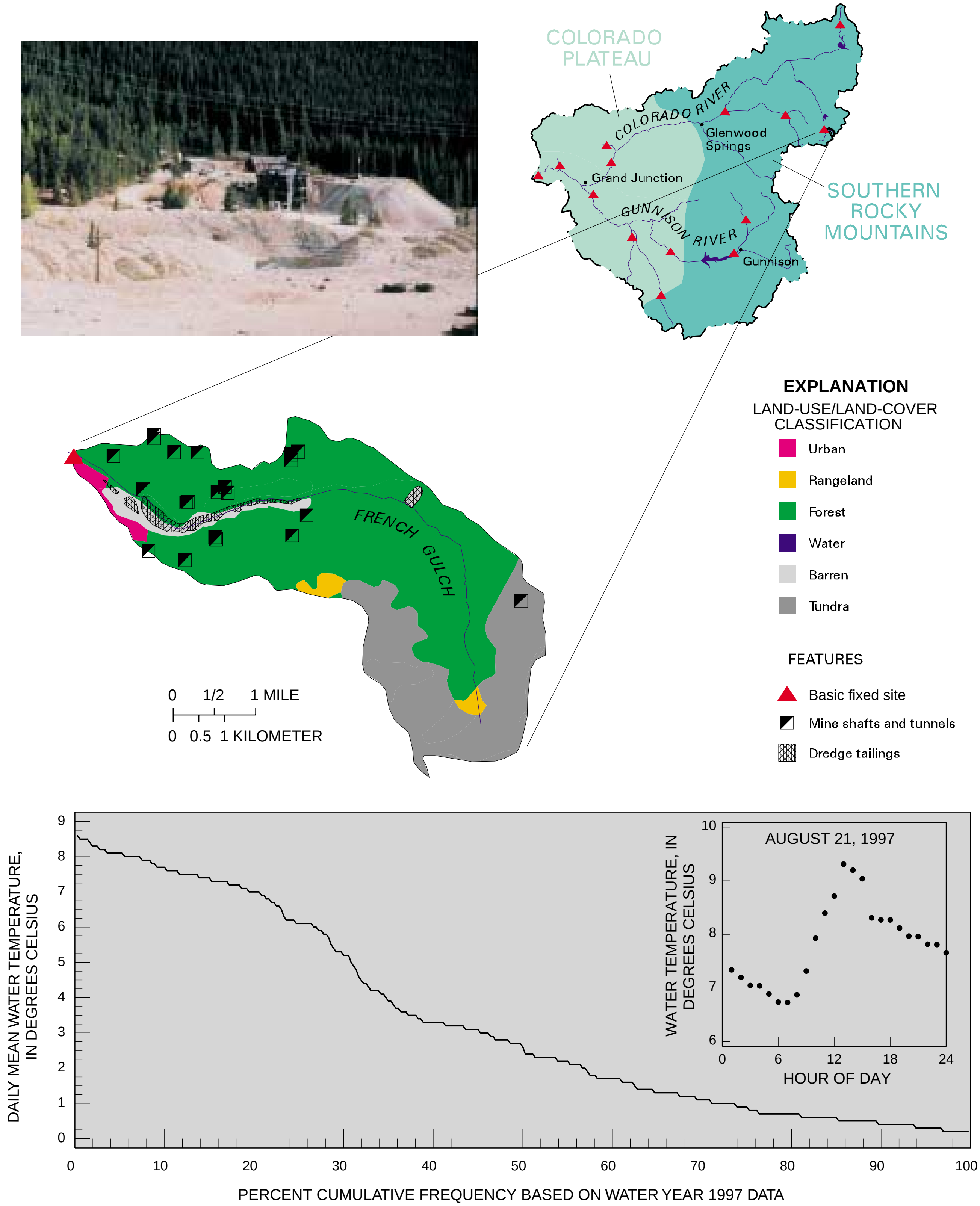

Figure 5. Photograph showing mined area within the basin, map showing location and land use/land cover of basin, and graphs showing frequency curve of daily mean water temperature and typical summer diurnal temperature for French Gulch near Breckenridge, station 09046530. Photograph by Jeffrey Bails.

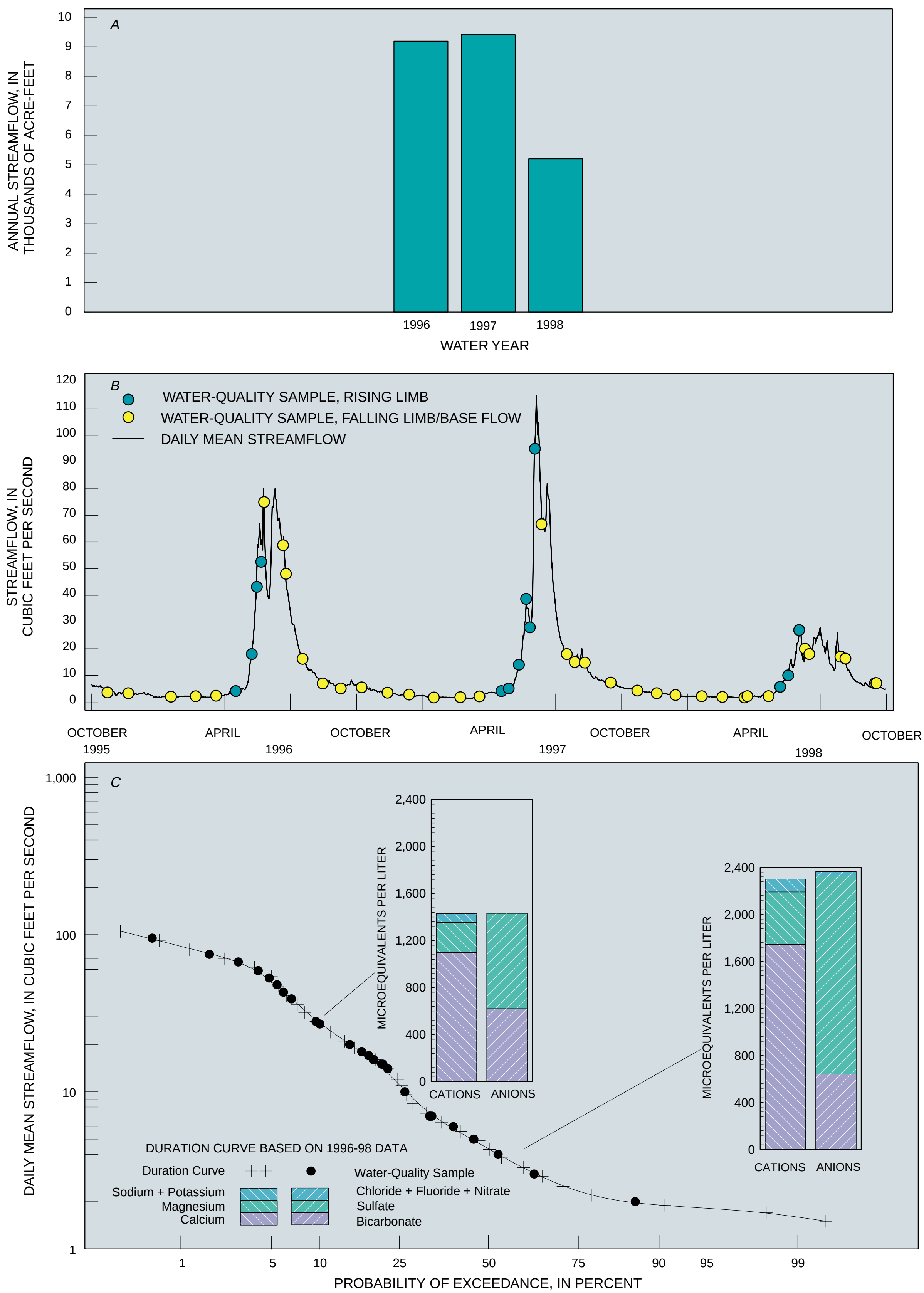

Figure 6. (*A*) Study period annual streamflow, (*B*) daily mean streamflow and time distribution of water-quality samples, and (*C*) flow-duration curve with streamflow distribution of water-quality samples and examples of major-ion chemistry for French Gulch near Breckenridge, station 09046530.

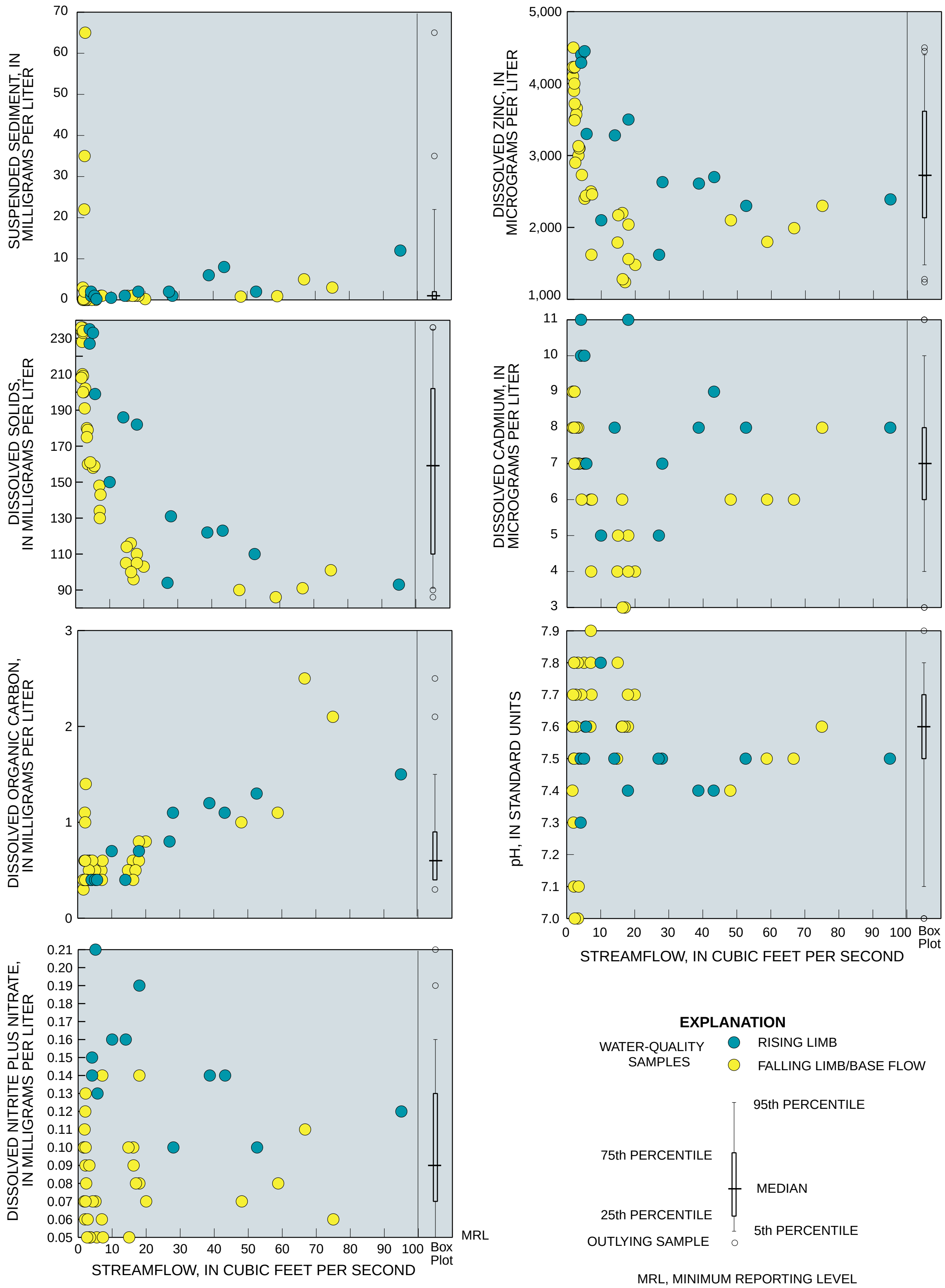

Figure 7. Distribution of selected water-quality constituents and properties relative to streamflow for French Gulch near Breckenridge, station 09046530.

relation with concentrations for the rising-limb samples being greater than the falling-limb/base-flow samples for a given streamflow. Dissolved organic-carbon (DOC) concentrations increased with increasing streamflow. The three samples that had DOC concentrations greater than the main group of samples at about 2 ft^3/s corresponded to the three sediment samples discussed above.

Nutrient concentrations in French Gulch tend to be low. No nitrite concentrations were measured greater than the MRL (minimum reporting level) of 0.01 mg/L. The majority of the ammonia and ammonia plus organic nitrogen concentrations were less than the MRL. Nitrate concentrations ranged from less than 0.05 to 0.21 mg/L (fig. 7), and concentrations on the rising limb were somewhat greater than those on the falling limb/base flow of the annual snowmelt runoff cycle. All nitrate concentrations were below the instream standard of 10 mg/L. Only a few samples had any phosphorus (total, dissolved, or orthophosphate) concentrations greater than the MRL of 0.01 mg/L. Dissolved zinc and cadmium concentrations are elevated at this site due to historical mining in the basin. Dissolved zinc concentrations tended to decrease with increasing streamflow, whereas dissolved cadmium concentrations did not show the pronounced dilution effect and simply varied around a median concentration of about 7 µg/L. The amended chronic instream standard at this site for zinc is 1,980 µg/L, and for cadmium it is 4 µg/L (Colorado Department of Public Health and Environment, 1996). For many samples, concentrations for dissolved zinc and dissolved cadmium were greater than the instream standards. The pH of the water in French Gulch at the sampling site tends to be neutral with a median value of 7.6 standard units.

Gore Creek at Mouth, Station 09066510

The site on Gore Creek at the confluence with the Eagle River was one of two sites selected to represent areas with increasing urban development within the UCOL. The site was established for the NAWQA Program, so limited historical data are available. The town and ski area of Vail are located within the basin and along with the Interstate 70 corridor and represent the major anthropogenic factors defining water quality in Gore Creek (fig. 8). The drainage area is 102 square miles and has elevations ranging from 7,730 to more than 13,000 feet. Average precipitation within the basin is 33.6 inches (Colorado Climate Center, 1984). The frequency curve for water year 1997 water temperature is shown at the bottom of figure 8. Median water temperature during water year 1997 was 4.3°C and the mean was 5.0°C. Diurnal changes in temperature ranged from 0°C in the winter season to a maximum about 8°C during snowmelt runoff. Temperature change during a typical summer day is shown in figure 8; the maximum daily temperature occurs in the late afternoon.

The streamflow gage was installed for the UCOL study in the fall of 1995. Historical streamflow data for the site are unavailable. Annual streamflow for water years 1996–98 is shown in figure 9*A*. Streamflow for water year 1998 was significantly less than the previous 2 years. Water-quality sampling began in October 1995 and continued through September 1998, resulting in 59 samples. The hydrograph of daily mean streamflow and the time distribution of water-quality samples are shown in figure 9*B*. Streamflow at the site is dominated by the annual snowmelt runoff, and peak streamflows occurred in the spring of each year. The flow-duration curve of daily mean streamflow was developed using data from water years 1996–98 and is shown in figure 9*C*. The streamflows associated with the water-quality samples also are shown with the duration curve. Water-quality samples are available to represent all flow conditions. The bar charts representing major ions for two example samples also are shown with the duration curve. The dilution of the major ions during periods of snowmelt runoff is apparent from the change in the lengths of the bars between the two separate samples (the bar chart on the left represents snowmelt conditions). The stream water is classified as a calcium-bicarbonate type water for these two samples.

Selected water-quality constituents are displayed relative to streamflow or time in figure 10. Sediment concentrations typically were less than 5 mg/L during low flow and increased with increasing streamflow. Concentrations on the rising limb of the annual snowmelt hydrograph usually were greater than those on the falling limb. The plot of dissolved solids and streamflow define the effect of snowmelt dilution on major-ion concentrations. A weak hysteresis between rising- and falling-limb samples is evident for dissolved solids. Dissolved organic carbon increased with increasing streamflow, and rising-limb concentrations were greater than falling-limb/base-flow concentrations at similar discharges.

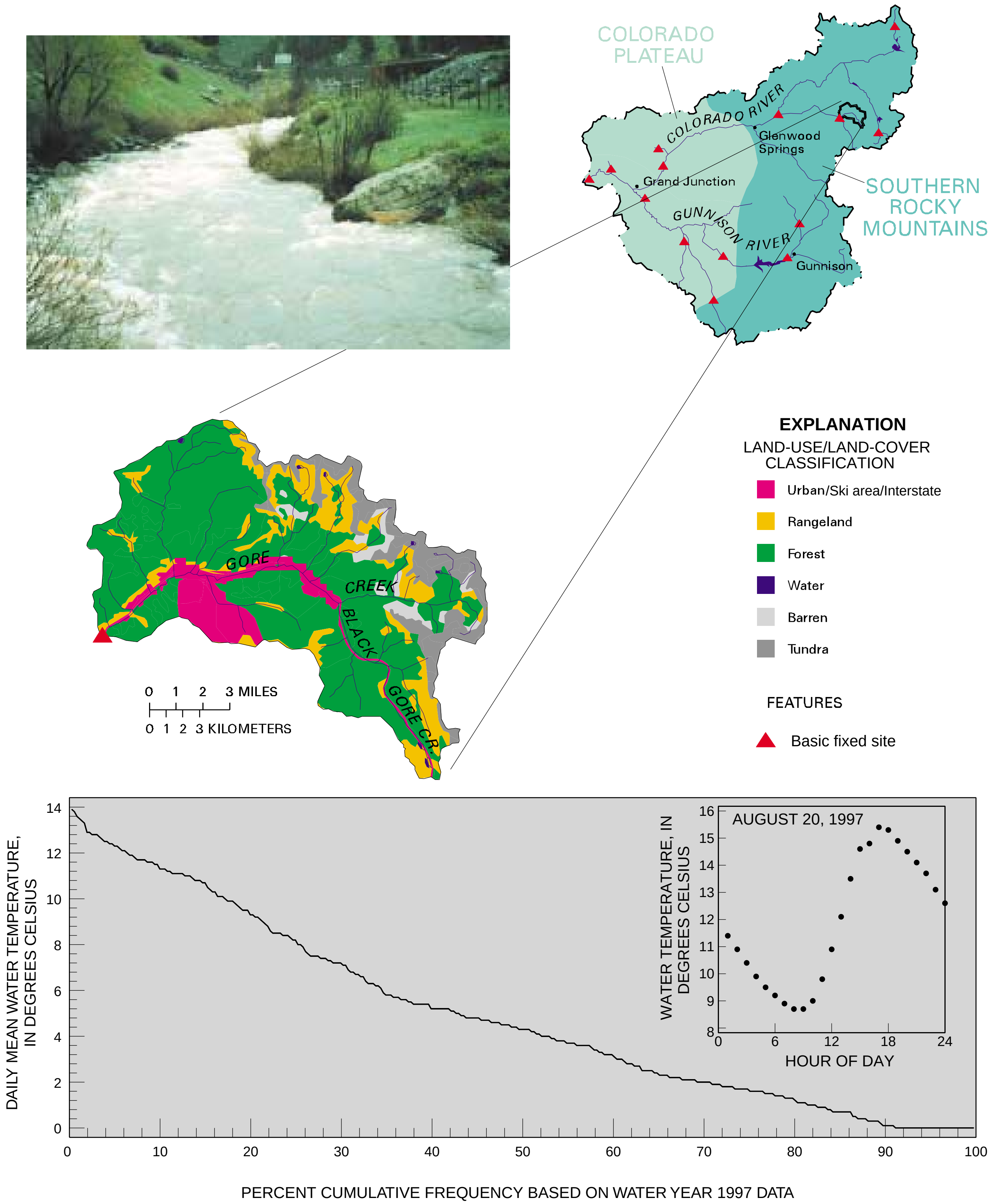

Figure 8. Photograph showing Gore Creek, map showing location and land use/land cover of basin, and graphs showing frequency curve of daily mean water temperature and typical summer diurnal temperature for Gore Creek at mouth, station 09066510. Photograph by Norman Spahr.

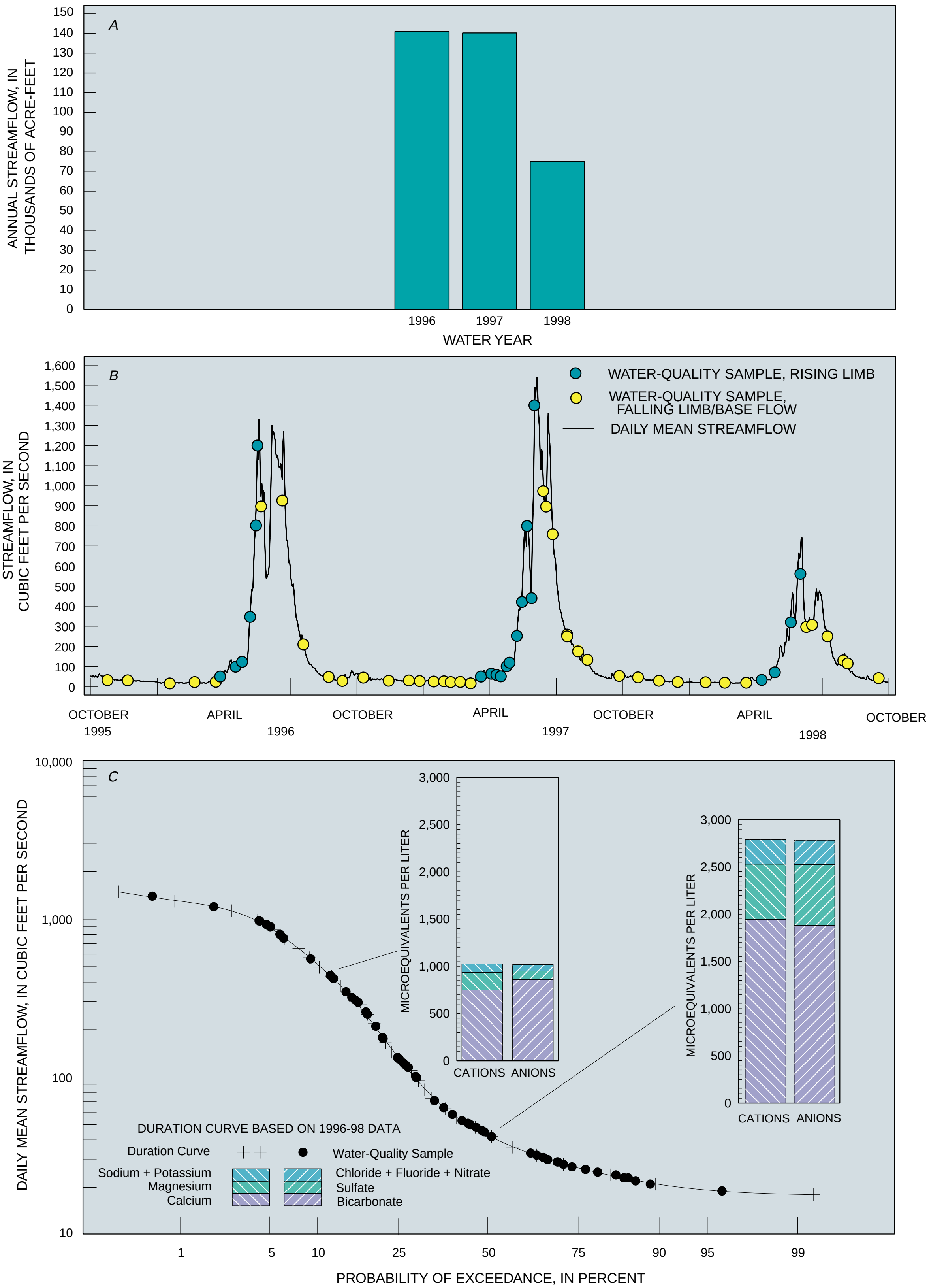

Figure 9. (*A*) Study period annual streamflow, (*B*) daily mean streamflow and time distribution of water-quality samples, and (*C*) flow-duration curve with streamflow distribution of water-quality samples and examples of major-ion chemistry for Gore Creek at mouth, station 09066510.

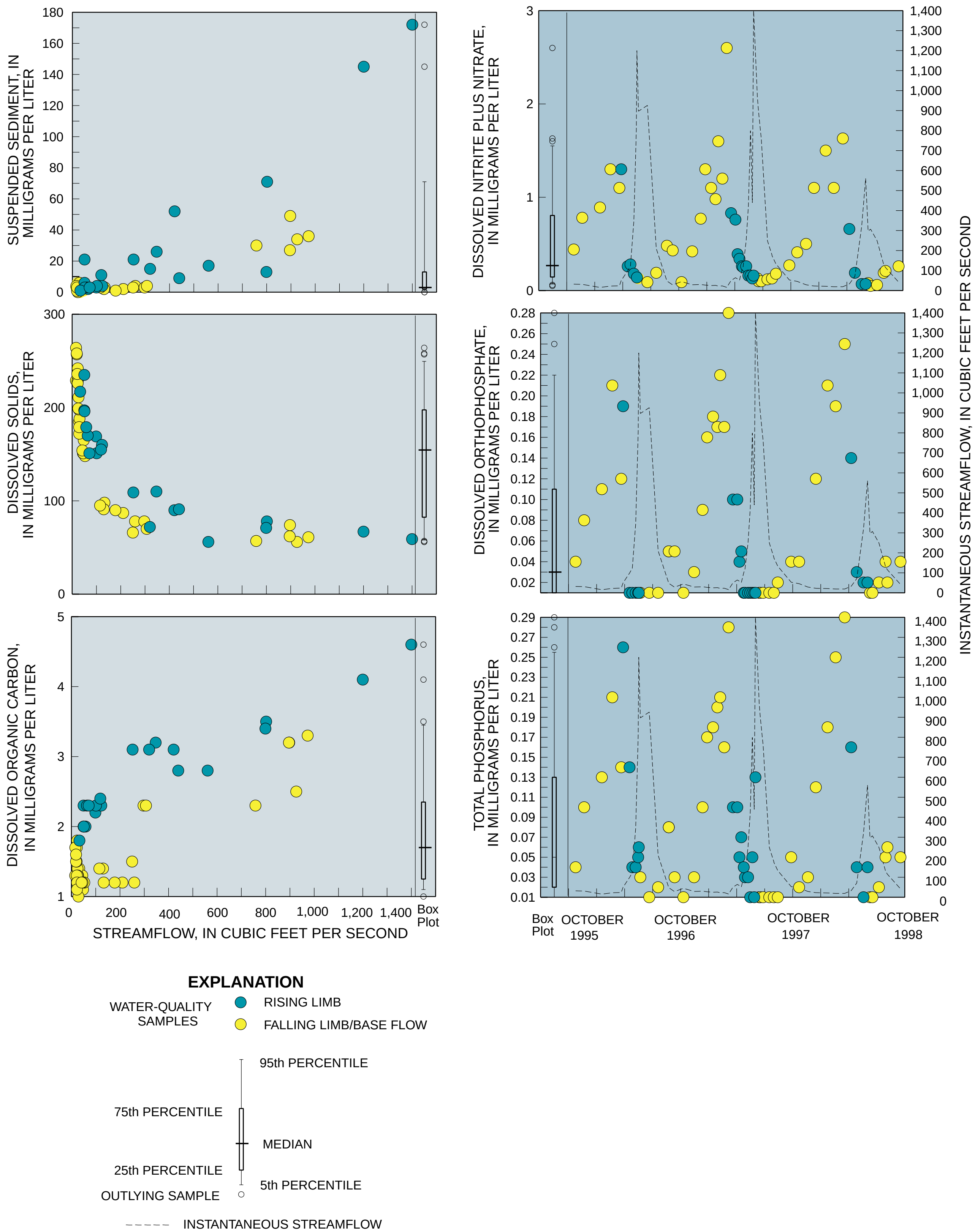

Figure 10. Distribution of selected water-quality constituents relative to streamflow and time for Gore Creek at mouth, station 09066510.

Nutrient concentrations at the Gore Creek site are not monotonically related to discharge. Concentrations of selected nutrients are plotted relative to time on the right side of figure 10. The streamflow also is plotted as a dashed line in these graphs. Nitrite plus nitrate, orthophosphate, and total phosphorus concentrations peaked each winter just prior to the beginning of snowmelt runoff. Concentrations were diluted by snowmelt and remained low until the following autumn. Ranges of concentrations for constituents not displayed in figure 10 are listed below.

Constituent	Minimum (milligrams per liter; <, less than)	Median	Maximum
Suspended organic carbon	<0.2	0.3	3.8
Dissolved ammonia	<0.02	<0.02	0.05
Dissolved nitrite	<0.01	<0.01	0.03
Dissolved ammonia plus organic nitrogen	<0.2	<0.2	0.2
Dissolved phosphorus	<0.01	0.03	0.26
Dissolved oxygen	8.8	10	13
pH (standard units)	7.6	8.5	9.5

None of the samples contained concentrations of nitrite, nitrate, or ammonia in excess of the State instream water-quality standards. All dissolved-oxygen concentrations were greater than the instream standard of 6 milligrams per liter. Three measurements of pH exceeded the upper instream standard of 9.0, but none were less than the lower standard of 6.5. Nutrient concentrations were greatest during the winter extreme low-flow conditions. The water quality of Gore Creek portrays streams that are not effluent dominated in urban areas within the Southern Rocky Mountains.

Colorado River near Dotsero, Station 09070500

This site is on the Colorado River downstream from the confluence with the Eagle River (fig. 11) and was selected as an integrator site for the UCOL network. Integrator sites generally are large basins with many different land uses/land covers and integrate the many factors affecting water quality. This site is located near the change from the Southern Rocky Mountains to the Colorado Plateau physiographic province (fig. 11). Drainage area upstream from the gage is about 4,394 square miles; elevations range from about 6,130 to more than 14,000 feet. Annual precipitation ranges from about 11 to more than 60 inches with an areal average of about 25.3 inches.Vegetation types at lower elevations in the basin are pinyon juniper and sagebrush rangeland; forested areas are present at higher elevations. Urban areas are developed along the Interstate 70 corridor from Dillon, west through the basin and in the Fraser River Basin (Winter Park to Granby areas).

The cumulative frequency curve for water year 1997 water-temperature data is shown in the figure 11 graph. Median daily temperature (50 percent value on the curve) was 7.0°C with a minimum of 0°C and a maximum of 17.3°C. The mean daily water temperature for 1997 was 7.4°C. Diurnal temperature changes ranged from 0° to 4°C with the maximum occurring during the snowmelt runoff. Hourly values for a typical summer day also are shown on the graph in figure 11.

Streamflow data have been collected at the site since 1940. Annual streamflows since 1970 are shown in figure 12*A*. Streamflow during the first 2 years of UCOL data collection was greater than the long-term annual mean and the 1998 streamflow was slightly lower. Streamflow at this site represents about 33 percent of the volume that leaves the UCOL study unit. The daily streamflow hydrograph is shown in figure 12*B* along with the time distribution of water-quality samples. Data collection for UCOL began in October 1995 and continued through September 1998, resulting in 44 water-quality samples. Annual snowmelt runoff dominates the hydrology at this site. The flow-duration curve based on 1970–95 data and the streamflow distribution of water-quality samples are shown in figure 12*C*. With the exception of extremely low flows, which did not occur during the sampling period, all flow conditions are represented with water-quality samples. Major ions are described for two samples in the bar charts within the flow-duration curve graph. Snowmelt runoff dilution is obvious by a comparison of the bar charts (lower concentrations in the bar chart on the left). Sulfate represents a greater percentage of the anions during low flow than during the snowmelt runoff period (the percentage of the anion bar represented by sulfate is larger in the bar chart on the right). The water during high flow is a calcium-bicarbonate type and during low flow is a mixed type with calcium and bicarbonate-sulfate.

Selected water-quality constituent concentrations and properties are plotted relative to streamflow in figure 13. Suspended-sediment and dissolved organic-carbon concentrations increased

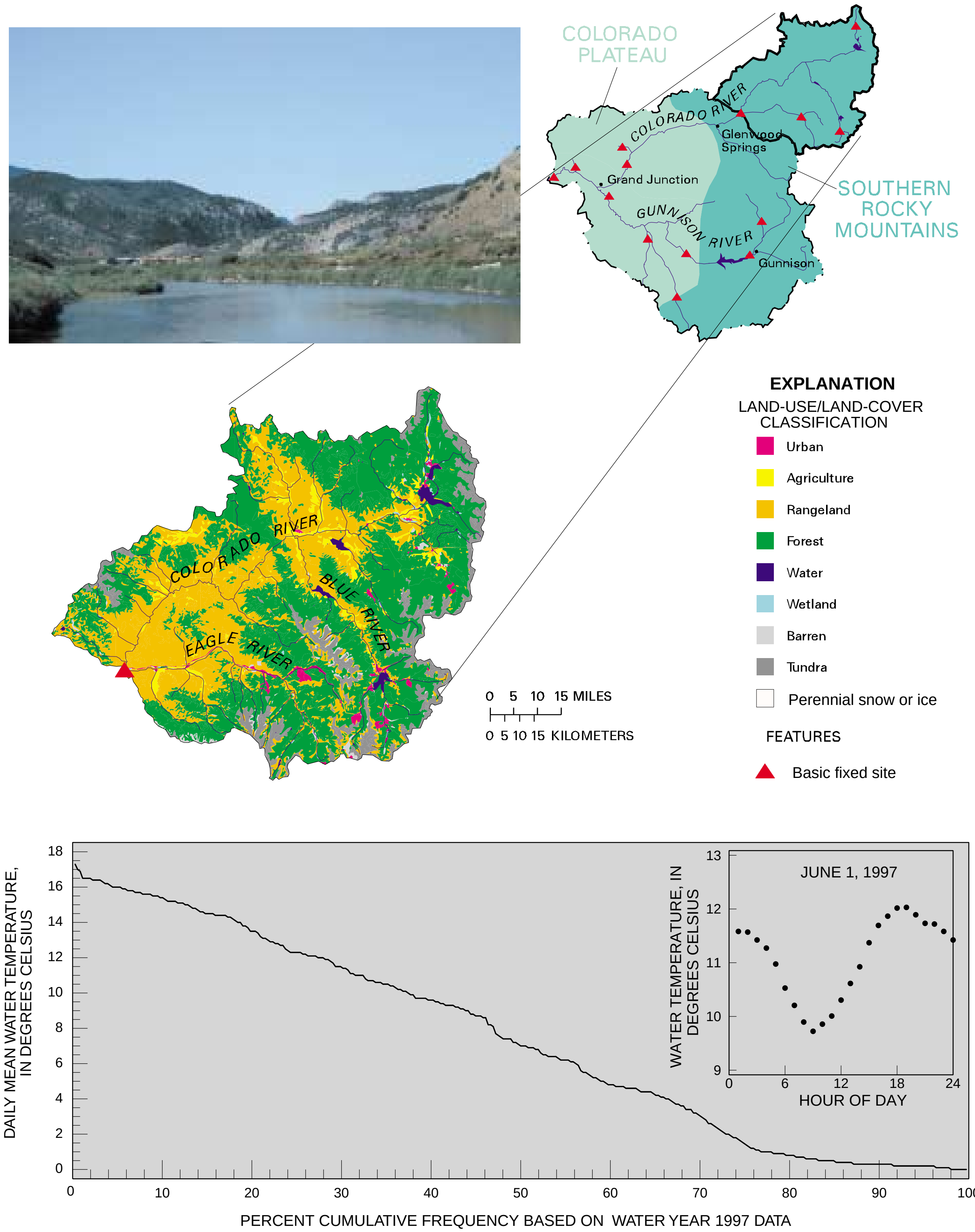

Figure 11. Photograph showing area near site, map showing location and land use/land cover of basin, and graphs showing frequency curve of daily mean water temperature and typical summer diurnal temperature for Colorado River near Dotsero, station 09070500. Photograph by Norman Spahr.

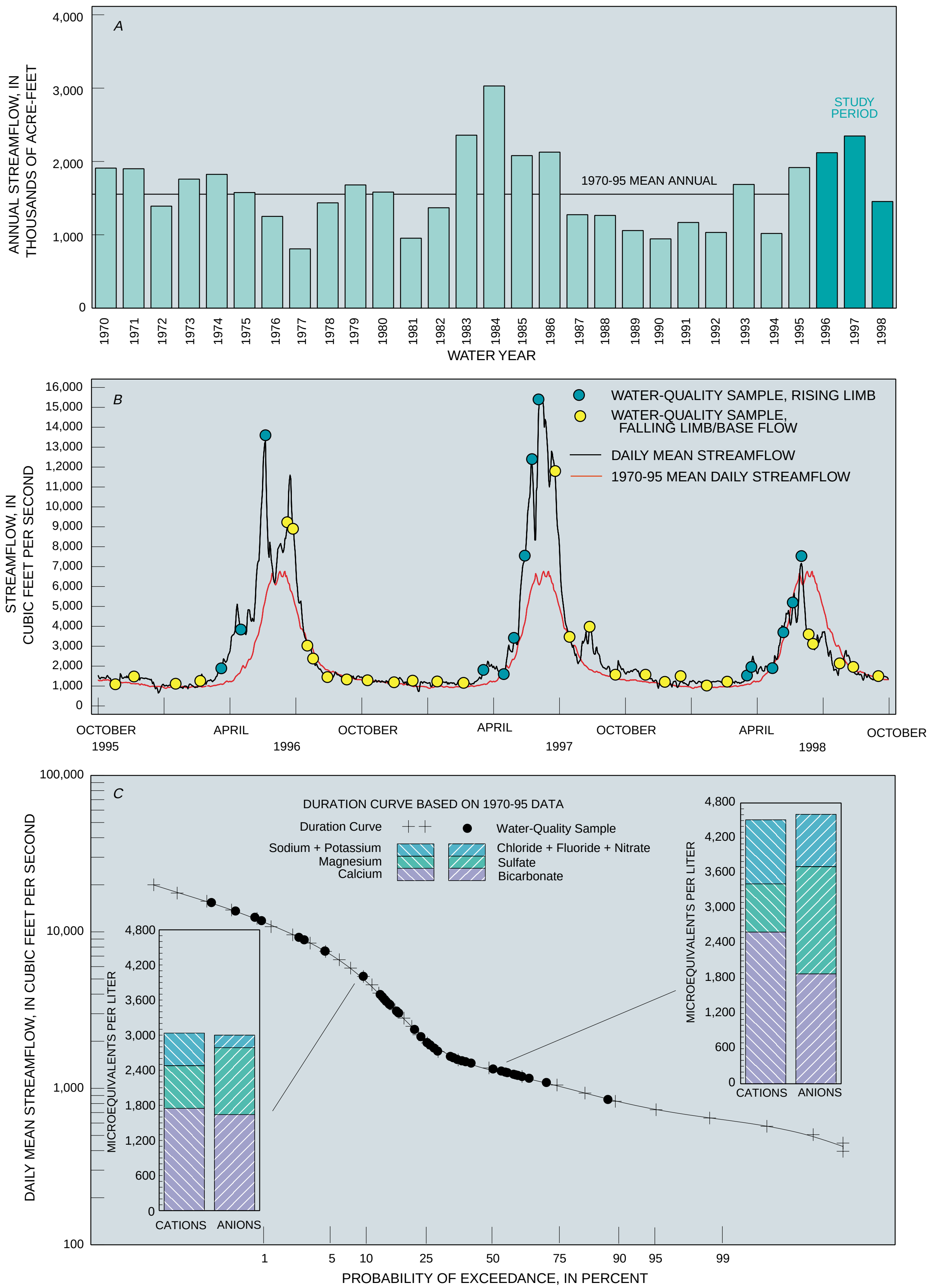

Figure 12. (*A*) Historical and study period annual streamflow, (*B*) daily mean streamflow and time distribution of water-quality samples, and (*C*) flow-duration curve with streamflow distribution of water-quality samples and examples of major-ion chemistry for Colorado River near Dotsero, station 09070500.

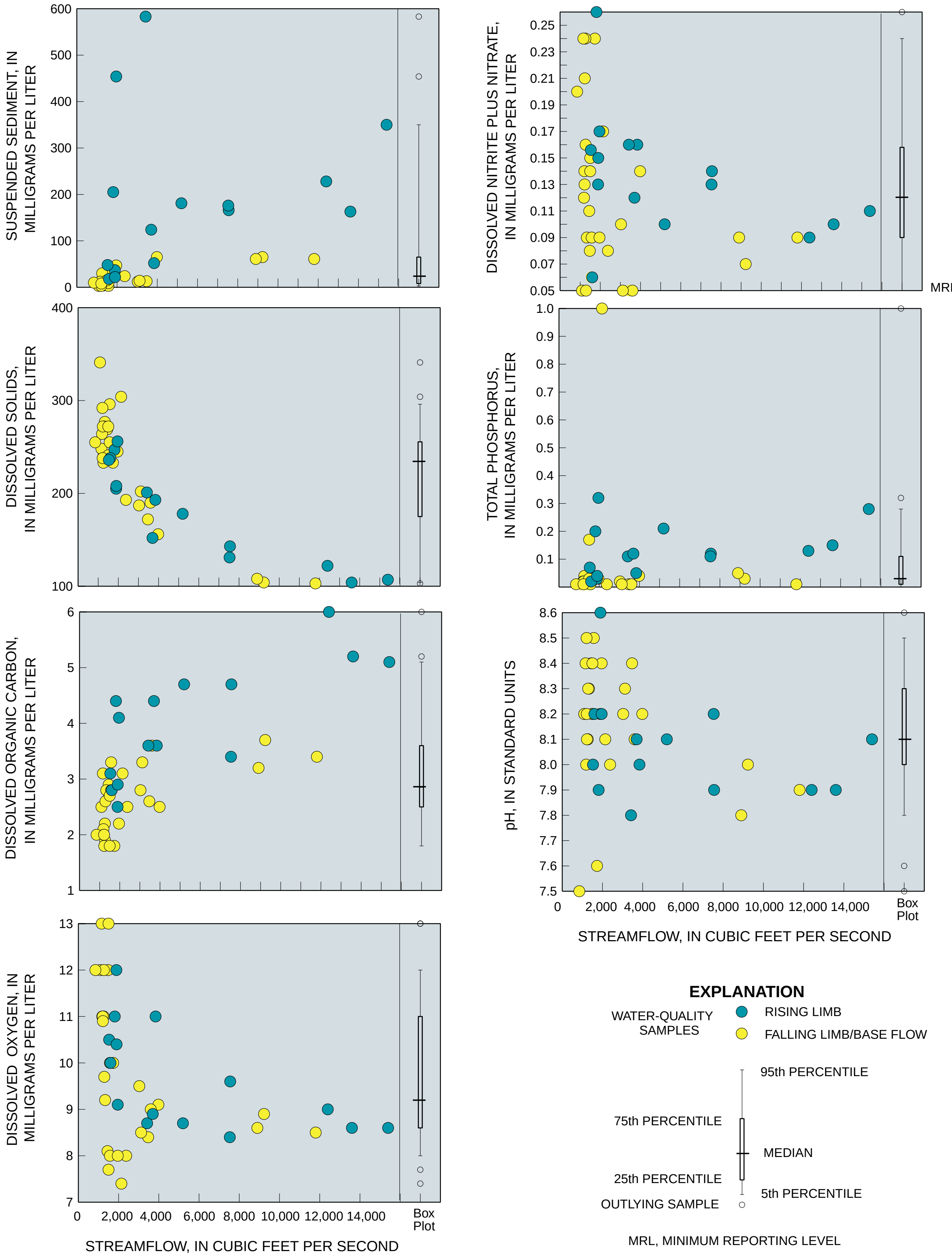

Figure 13. Distribution of selected water-quality constituents and properties relative to streamflow for Colorado River near Dotsero, station 09070500.

with increasing streamflow; concentrations on the rising limb of the annual snowmelt runoff event typically were greater than concentrations at similar streamflows on the falling limb/base flow. The two samples with very high suspended-sediment concentrations (454 and 583 mg/L) at relatively low streamflows were samples that were collected just at the beginning of snowmelt runoff. Major-ion concentrations, as represented by dissolved solids, showed a snowmelt dilution effect and did not exhibit a great deal of hysteresis. Dissolved oxygen varied around a median of 9.2 mg/L, probably as a result of changing water temperature. Nitrite plus nitrate concentrations were low (less than 0.05 to 0.26 mg/L) and did not show a strong relation to streamflow. With few exceptions, concentrations of total phosphorus generally were less than 0.2 mg/L and also did not display any relation to streamflow. Ranges of concentrations for constituents not displayed are given below.

Constituent	Minimum	Median	Maximum
	(milligrams per liter; <, less than)		
Suspended organic carbon	0.2	0.5	15
Dissolved ammonia	<0.02	<0.02	0.08
Dissolved nitrite	<0.01	<0.01	0.02
Dissolved ammonia plus organic nitrogen	<0.2	<0.2	0.4
Dissolved phosphorus	<0.01	<0.01	0.05
Dissolved orthophosphate	<0.01	<0.01	0.04

At this site, concentrations of dissolved oxygen, nitrite, nitrate, ammonia, and pH were within the State instream standards. Water quality at this site is an integration of many natural and anthropogenic factors.

Dry Fork of Roan Creek, Station 09095300

The site on Dry Fork was selected as a reference site for the Colorado Plateau physiographic province. Vegetation in the basin is mostly sage and pinyon-juniper with some rangeland (photograph and map, fig. 14). The agriculture areas typically are hay meadows. Drainage area is 97 square miles, and the average precipitation is about 16.7 inches.

The frequency curve for daily mean water temperature for water year 1997 is shown on the graph in figure 14. Data for May and part of June could not be used in the frequency curve due to sensor malfunction. The median water temperature was 4.1°C and the mean was 7.2°C. Diurnal temperature changes ranged from 0°C in the winter to 18.5°C in July. The large diurnal changes are due to low streamflow and the hot, arid summer climate typical of this area.

This site was established for the UCOL Program, so historical streamflow and water-quality data are unavailable. The annual streamflow for the 3 years of data collection is shown in figure 15*A*. Annual streamflow is low (mean of 3,330 acre-feet) at this site; the water year 1998 streamflow was much greater than the previous 2 years due to larger snowmelt runoff and higher sustained base-flow conditions. The hydrograph of daily streamflows and the time distribution of water-quality samples are shown in figure 15*B*. The hydrology in water year 1996 was dominated by low flows with one rainfall-runoff event. In 1997 and 1998, there was a combination of snowmelt runoff and rainfall-runoff events. Water-quality sampling began in October 1995 and continued through September 1998, resulting in 42 samples. The flow-duration curve for the 3 years of data collection is shown in figure 15*C* along with the streamflow distribution of water-quality samples. Median daily streamflow is 2.9 ft^3/s and the streamflow seldom exceeds 10 ft^3/s. Water-quality samples are well distributed across the streamflows represented in the flow-duration curve. The bar charts on the flow-duration curve represent the major-ion chemistry for two flow conditions. Because the streamflow is not completely dominated by snowmelt runoff, there is not a continuous dilution along the duration curve. Some samples collected during higher streamflow than the example at the 50th percentile have a greater concentration of major ions. The two samples plotted were chosen simply to give a representation of major-ion concentrations. The dominant ions are sodium, magnesium, and sulfate, resulting in a sodium-sulfate or a sodium and magnesium-sulfate water type in the two samples.

Selected water-quality constituent concentrations and properties relative to streamflow are shown in figure 16. Sediment concentrations were fairly large at this site (median concentration of 184 mg/L), and with any increase in streamflow, the sediment concentration can increase substantially. During low streamflows there is a great deal of variability in the dissolved-solids concentrations (1,000 to almost 3,000 mg/L). Dissolved solids were diluted during

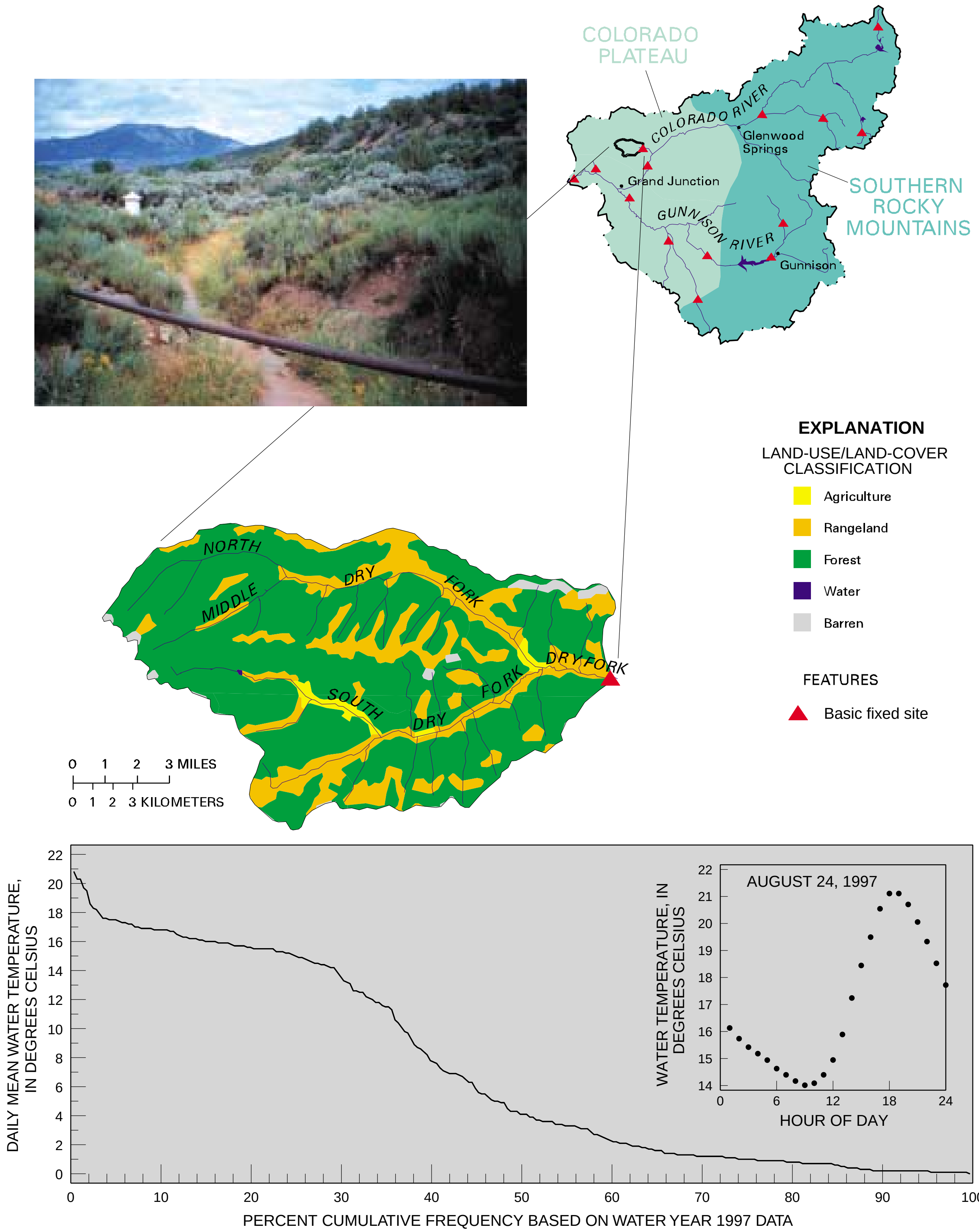

Figure 14. Photograph showing station, map showing location and land use/land cover of basin, and graphs showing frequency curve of daily mean water temperature and typical diurnal temperature for Dry Fork of Roan Creek, station 09095300. Photograph by Jeffrey Deacon.

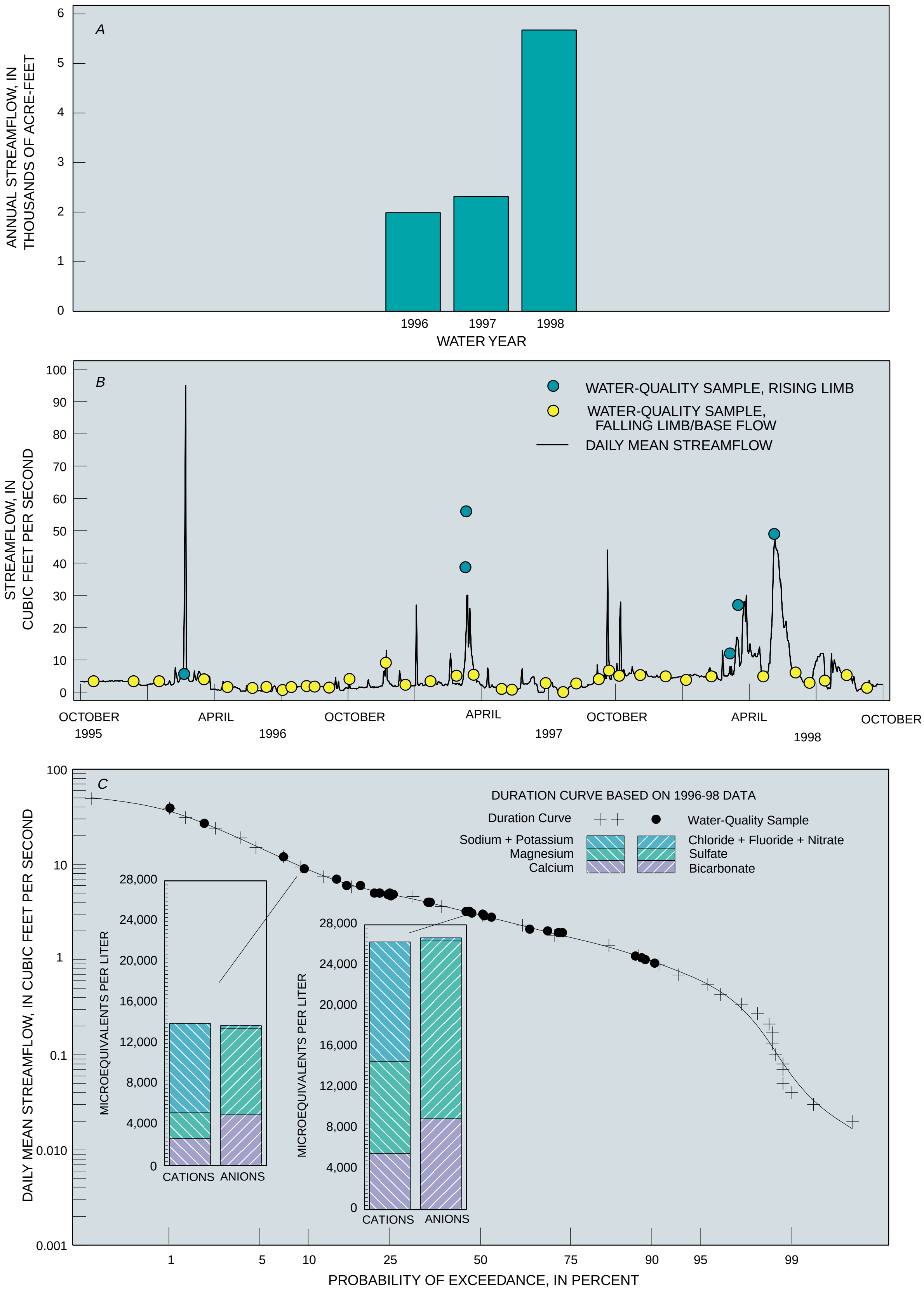

Figure 15. (*A*) Study period annual streamflow, (*B*) daily mean streamflow and time distribution of water-quality samples, and (*C*) flow-duration curve with streamflow distribution of water-quality samples and examples of major-ion chemistry for Dry Fork of Roan Creek, station 09095300.

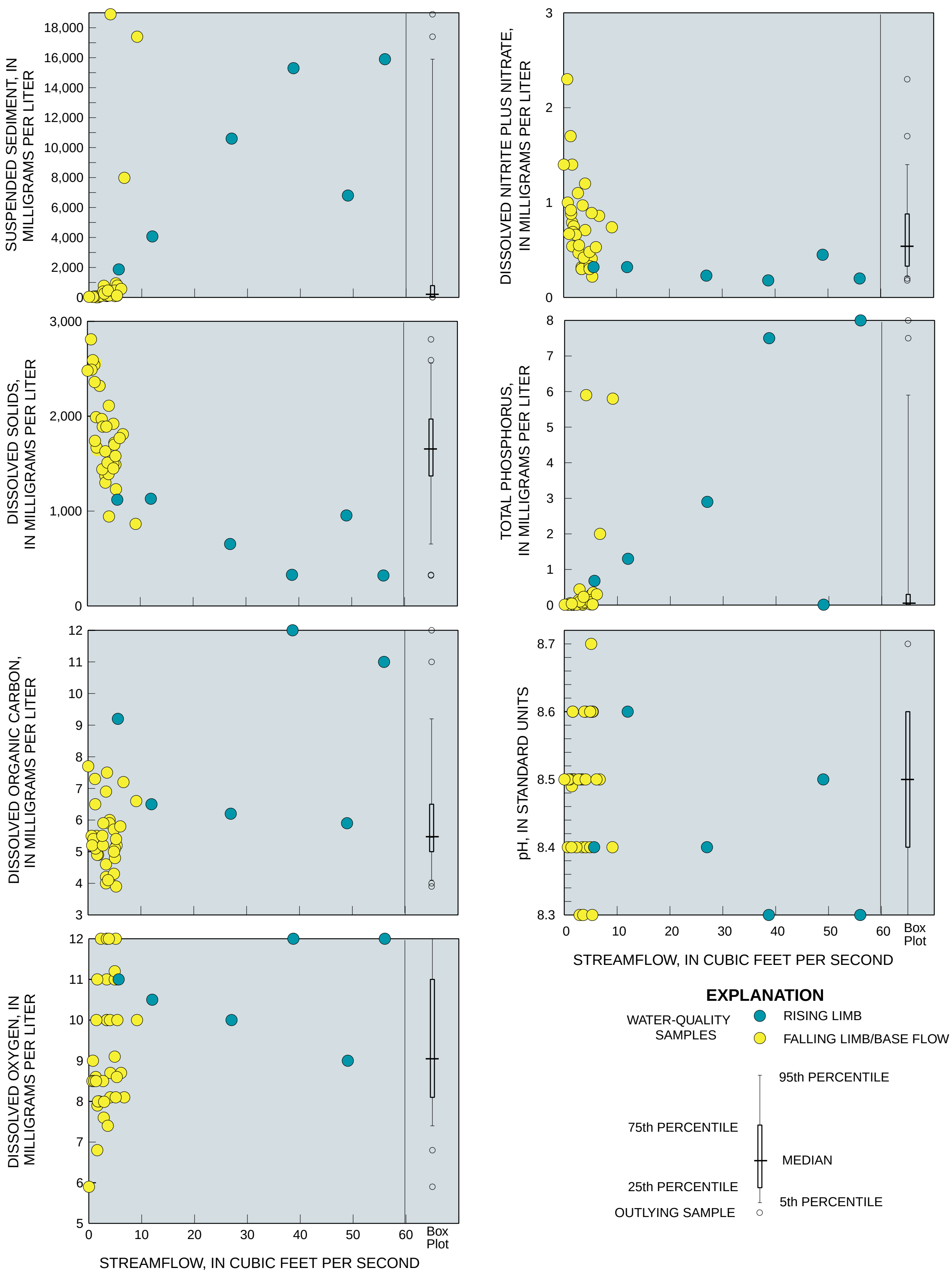

Figure 16. Distribution of selected water-quality constituents and properties relative to streamflow for Dry Fork of Roan Creek, station 09095300.

higher streamflows. Dissolved organic-carbon concentrations did not show any strict relation to streamflow but varied around a median of 5.4 mg/L. Nitrite plus nitrate concentrations show a dilution-type relation to streamflow, but there is a lot of variability at lower streamflows. At times, high concentrations of total phosphorus (6–8 mg/L) were detected. Measured values for pH and concentrations of dissolved oxygen, ammonia, nitrite, and nitrate were within the State instream water-quality standards. Concentration ranges for constituents not shown on the graphs are as follows:

Constituent	Minimum	Median	Maximum
	(milligrams per liter; <, less than; >, greater than)		
Suspended organic carbon	0.2	0.8	>33
Dissolved ammonia	<0.02	<0.02	0.14
Dissolved nitrite	<0.01	<0.01	0.04
Dissolved ammonia plus organic nitrogen	<0.2	0.3	0.7
Dissolved phosphorus	<0.01	<0.01	0.09
Dissolved orthophosphate	<0.01	0.01	0.07

This site is considered typical of many small tributaries in the arid plateau area. Base-flow concentrations of the major ions were large. Any increase in streamflow was accompanied by large increases in sediment and other constituents that relate to particulate matter in the water, such as total phosphorus and suspended organic carbon.

Colorado River near Cameo, Station 09095500

This site on the Colorado River is a NAWQA integrator site representing the Colorado River Basin upstream from the major agricultural areas and the confluence with the Gunnison River (fig. 17). The basin is a mix of land uses; forest and rangeland are predominant (fig. 17). Precipitation ranges from about 8 inches in the downstream areas to more than 60 inches in the mountains, and the average is 24.7 inches. The drainage area is 8,050 square miles.

Continuous water-temperature and specific-conductance data are collected at this site for other USGS programs. The frequency distribution for daily mean water temperature for water year 1997 is shown on the graph in figure 17. Water temperature was fairly uniformly distributed around a median value of 9.4°C and a mean of 9.5°C. Diurnal temperature varied from 0°C in January to about 4°C during snowmelt runoff and early summer periods. A typical graph of the hourly temperature change for August also is shown in figure 17; maximum temperature occurred around 1900 hours.

Streamflow data have been collected at this site since 1933. The annual streamflow from 1970 to 1998 is shown in figure 18*A*. Streamflow was greater than the long-term mean for the first 2 years of project data collection and was about equal to the mean for the third year. Streamflow at this site represents about 60 percent of the volume leaving the UCOL study unit. The hydrograph of mean daily streamflows and the time distribution of water-quality samples are shown figure 18*B*. The hydrograph illustrates how much above the average water year 1997 was from the long-term mean. Water-quality sampling began in October 1995 and continued through September 1998, resulting in 42 samples. The hydrology at the site is dominated by the annual snowmelt runoff. Peak flows typically occur in late May or early June; however, the 1996 peak occurred approximately 2 weeks earlier. The flow-duration curve based on the 1970 to 1995 data along with the streamflow distribution of water-quality samples is shown in figure 18*C*. With the exception of extremely low streamflows, which did not occur during the study period, all streamflows are well represented with water-quality samples. The bar charts along with the flow-duration curve show the effects of snowmelt dilution on the major-ion chemistry of two representative samples. At higher streamflows (the bar chart on the left), calcium and bicarbonate represent the majority of the ions present. During lower streamflows, relative percentages of sulfate and chloride increase (bar chart on the right) and result in a mixed water type.

Selected constituents and properties are plotted relative to streamflow in figure 19. Median sediment concentration was 61 mg/L but can be thousands of milligrams per liter during the rising limb of the annual snowmelt runoff peak. Dissolved solids have a very well-defined relation to streamflow, with little or no hysteresis between the rising- and falling-limb/base-flow samples. Dissolved organic carbon increased with increasing streamflow, and the

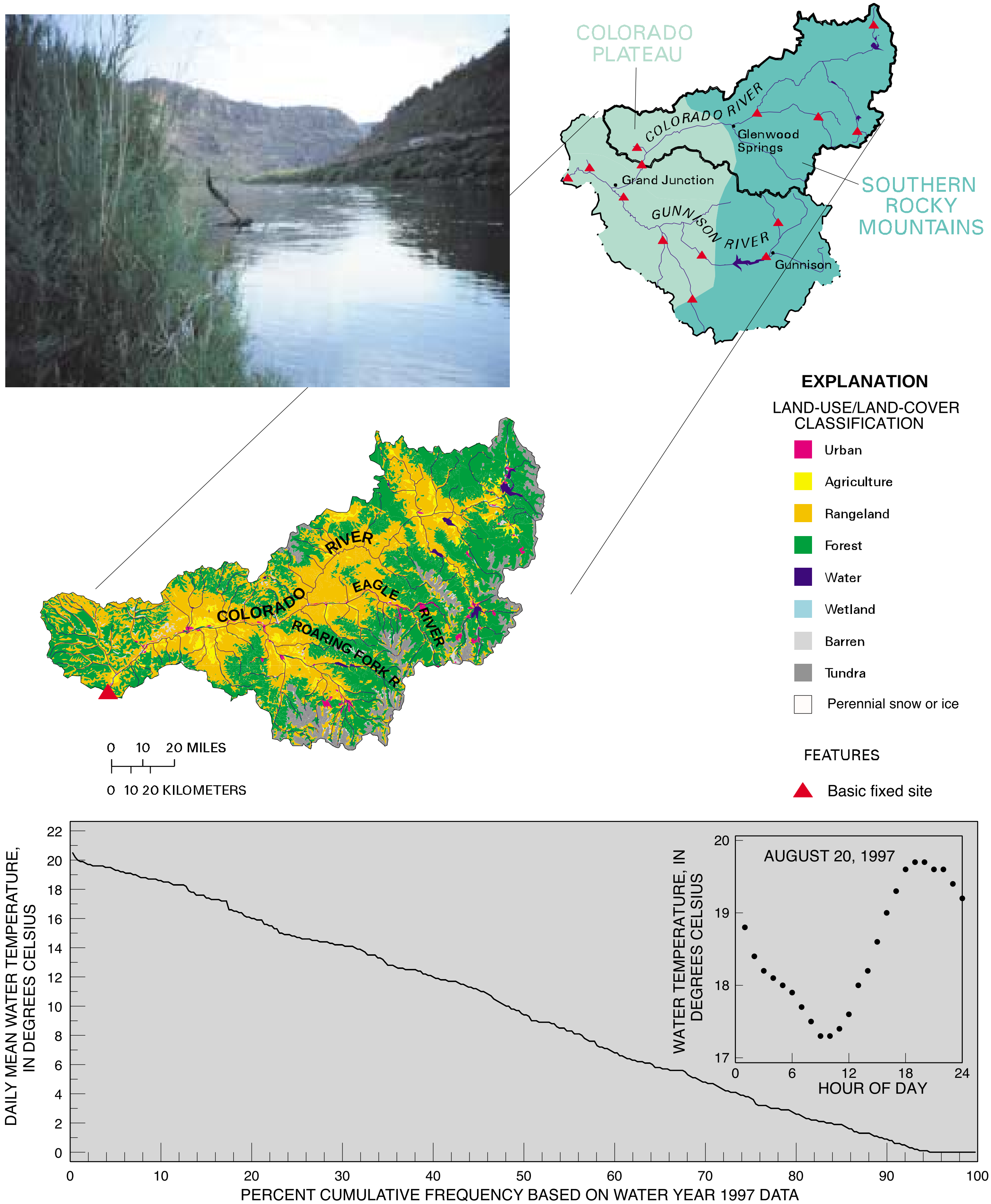

Figure 17. Photograph showing area near site, map showing location and land use/land cover of basin, and graphs showing frequency curve of daily mean water temperature and typical summer diurnal temperature for Colorado River near Cameo, station 09095500. Photograph by Jeffrey Deacon.

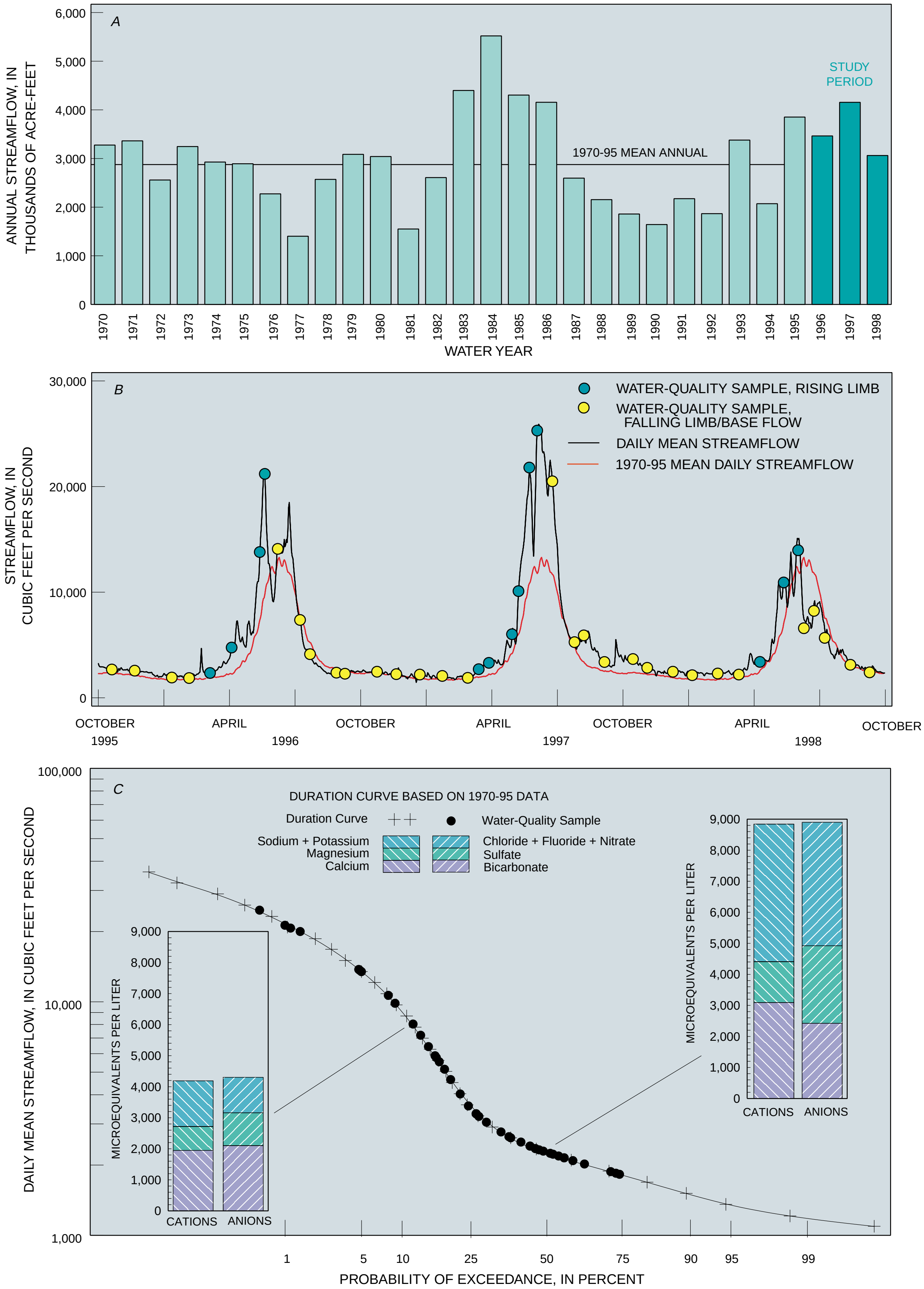

Figure 18. (*A*) Historical and study period annual streamflow, (*B*) daily mean streamflow and time distribution of water-quality sample, and (*C*) flow-duration curve with streamflow distribution of water-quality samples and examples of major-ion chemistry for Colorado River near Cameo, station 09095500.

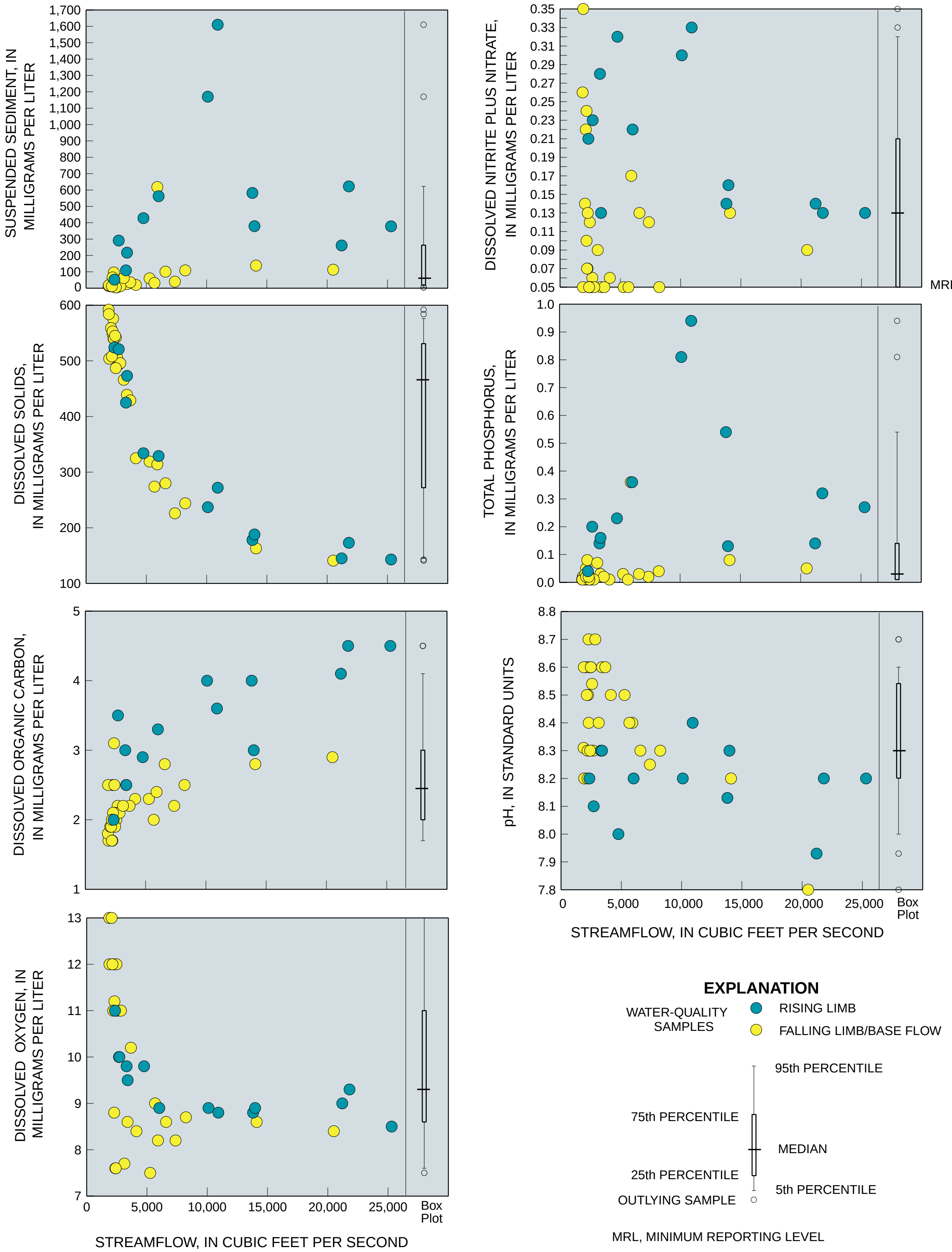

Figure 19. Distribution of selected water-quality constituents and properties relative to streamflow for Colorado River near Cameo, station 09095500.

rising-limb samples had greater concentrations than those on the falling limb/base flow. Total phosphorus had a median concentration of 0.03 mg/L, and greater concentrations occurring during the rising limb. Ranges of concentrations for constituents not plotted are listed below.

Constituent	Minimum	Median	Maximum
	(milligrams per liter; <, less than; >, greater than)		
Suspended organic carbon	0.2	0.5	>10
Dissolved ammonia	<0.02	0.025	0.14
Dissolved nitrite	<0.01	<0.01	0.04
Dissolved ammonia plus organic nitrogen	<0.2	<0.2	0.3
Dissolved phosphorus	<0.01	<0.01	0.04
Dissolved orthophosphate	<0.01	0.01	0.03

Measured values for pH were within the State instream water-quality standard of 6.5 to 9.0. All concentrations of dissolved oxygen were greater than the 5-mg/L instream standard. Nitrite and nitrate concentrations were all less than the 0.05- and 10-mg/L instream standards. All un-ionized ammonia concentrations computed from ammonia, pH, and temperature were below the chronic instream standard of 0.06 mg/L.

The integration of many factors affect the water-quality conditions at this site. Areas within the Colorado Plateau can produce large amounts of sediment during snowmelt and rainfall events, which results in the periodic large suspended-sediment concentrations at this site. Concentrations of other constituents such as total phosphorus and suspended organic carbon, usually associated with suspended sediment, also were greater during these periods.

East River below Cement Creek, Station 09112200

The East River site was one of two sites selected for study to represent areas of increasing urban development and recreation land use within the UCOL. Increasing urban development is occurring within the basin in the Crested Butte and Mount Crested Butte areas. During the winter, the basin has large increases in population due to winter recreational activities. The basin has an area of 238 square miles and is located in the Southern Rocky Mountains physiographic province (fig. 20). Land use/land cover is mostly forest with urban areas near Crested Butte and some rangeland and agriculture (hay meadows). Elevations range from about 8,000 to more than 14,000 feet. Precipitation ranges from about 20 to more than 50 inches with an average of 33.2 inches.

The cumulative frequency curve for mean daily temperature for water year 1997 is shown in the graph in figure 20. June and part of July data are missing due to equipment malfunction, so the frequency curve is not as smooth as it would be with complete data in the 6°–10°C range. Median water temperature was 3.8°C with a minimum of 0°C and a maximum daily mean of 13.9°C. Diurnal temperature changes ranged from 0°C in the winter to more than 8°C during snowmelt runoff and summer periods.

Streamflow data have been collected at this site during several periods (1970–72, 1980–81, 1994–98). Annual streamflow for available data is shown in figure 21*A*. A hydrograph of daily streamflow is shown in figure 21*B* along with the time distribution of water-quality samples. Snowmelt runoff dominated the hydrology at this site with peak streamflows occurring in the spring. Timing and magnitude of the snowmelt runoff are evident in the graph. Routine water-quality sampling began in October 1995 and continued through September 1998, resulting in 46 samples. One sample was collected during peak flow in 1995 because that year had one of the larger snowpacks in recent history.

A flow-duration curve was computed using the available historical information and is presented in figure 21*C*. The streamflow distribution of water-quality samples also is shown in this graph. All flow conditions are represented with water-quality samples. Major-ion chemistry is presented in the bar charts for two representative samples. The result of snowmelt dilution is evident by the decrease in the overall length of the bars between the chart on the right and the chart on the left. Calcium and bicarbonate are the dominant ions at both of these flow conditions.

Selected water-quality constituent concentrations and properties are plotted relative to streamflow or time in figure 22. Except for periods of the rising limb of the snowmelt runoff peak, sediment concentrations were low (median concentration of 5 mg/L). The one sample at 241 mg/L was collected during the peak-flow conditions in 1995. Dissolved solids had a smooth inverse relation to streamflow with minimal scatter and little difference between rising-limb and

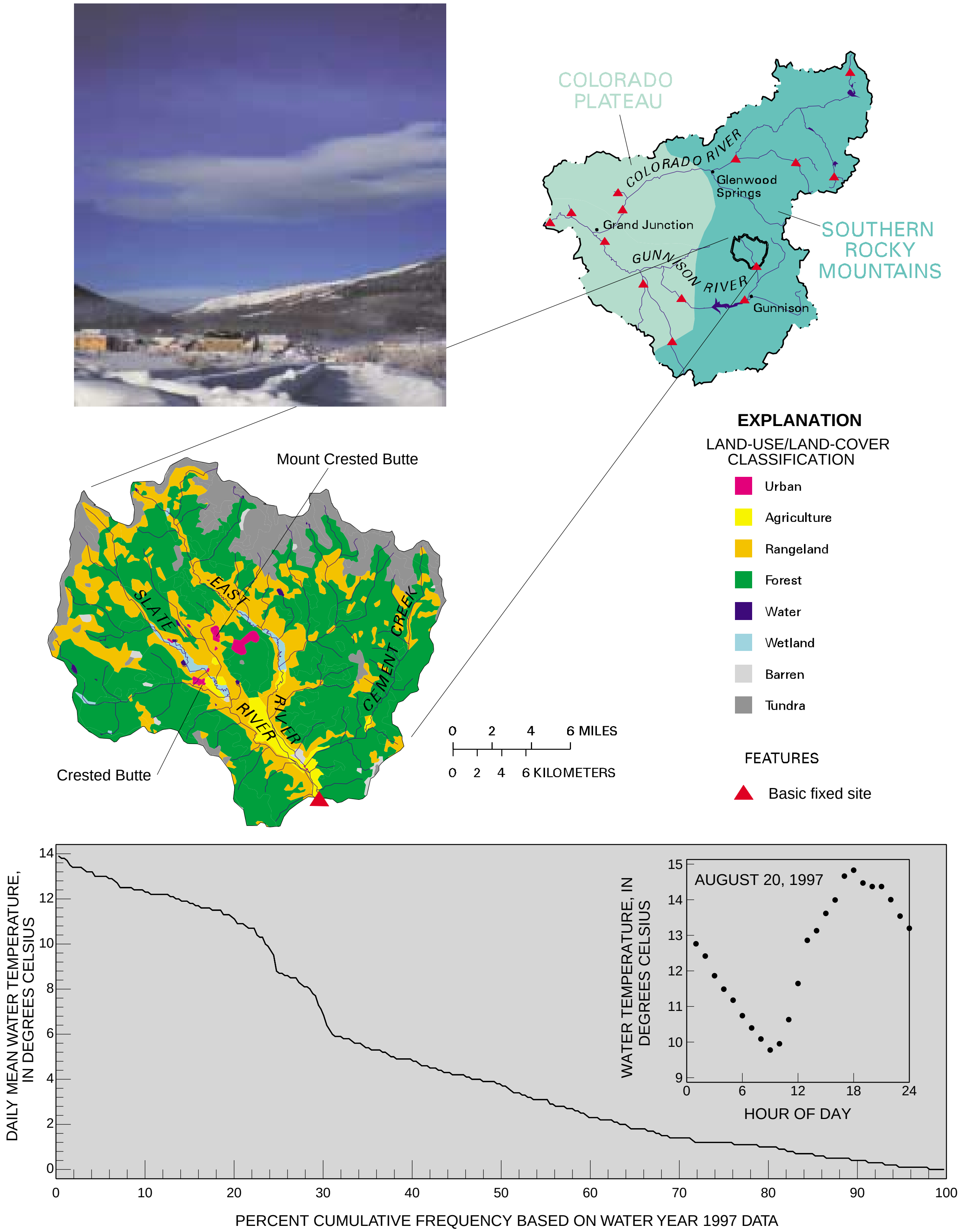

Figure 20. Photograph showing basin topography, map showing location and land use/land cover of basin, and graphs showing frequency curve of daily mean water temperature and example of diurnal temperature for East River below Cement Creek, station 09112200. Photograph by Norman Spahr.

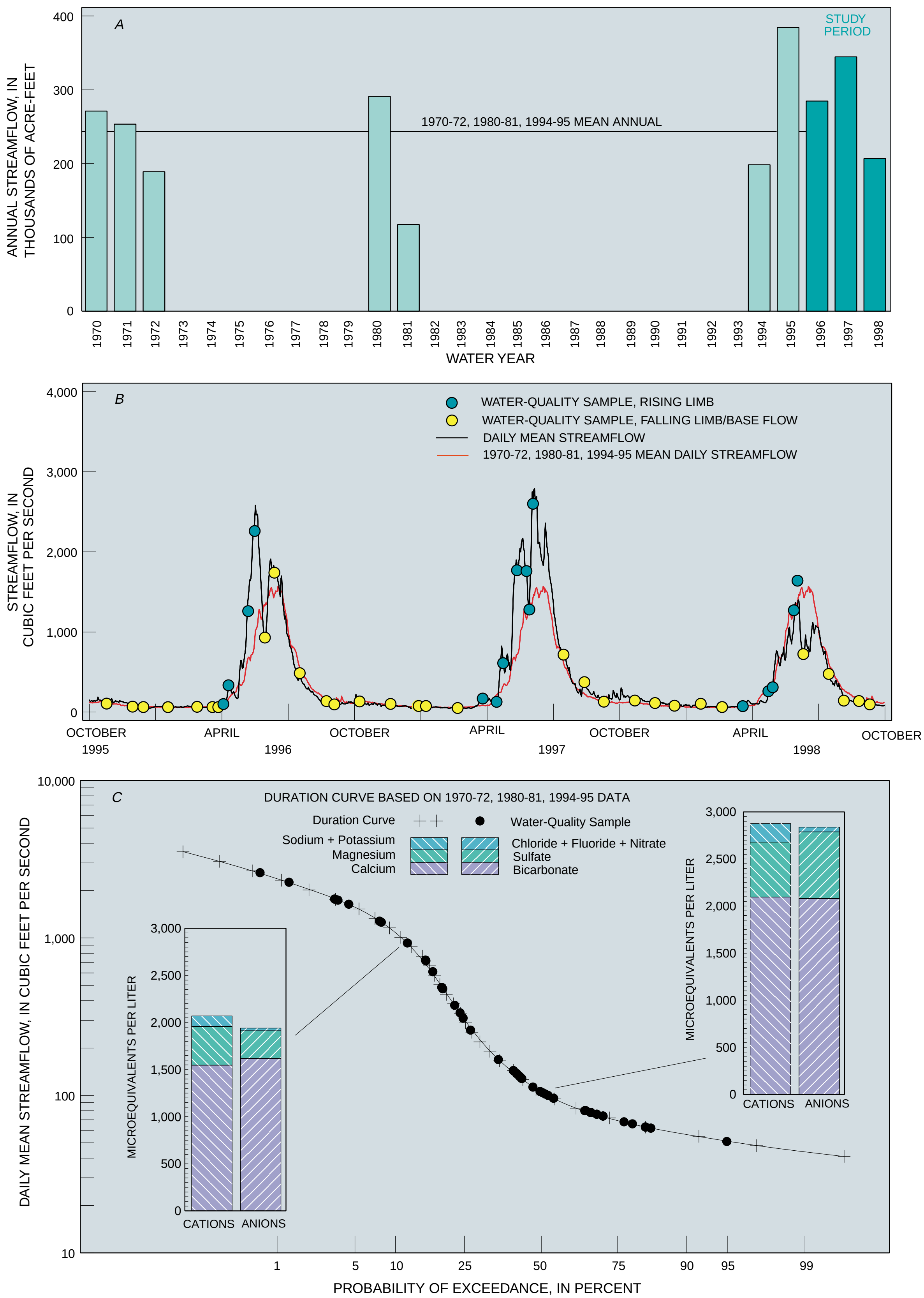

Figure 21. (*A*) Historical and study period annual streamflow, (*B*) daily mean streamflow and time distribution of water-quality samples, and (*C*) flow-duration curve with streamflow distribution of water-quality samples and examples of major-ion chemistry for East River below Cement Creek, station 09112200.

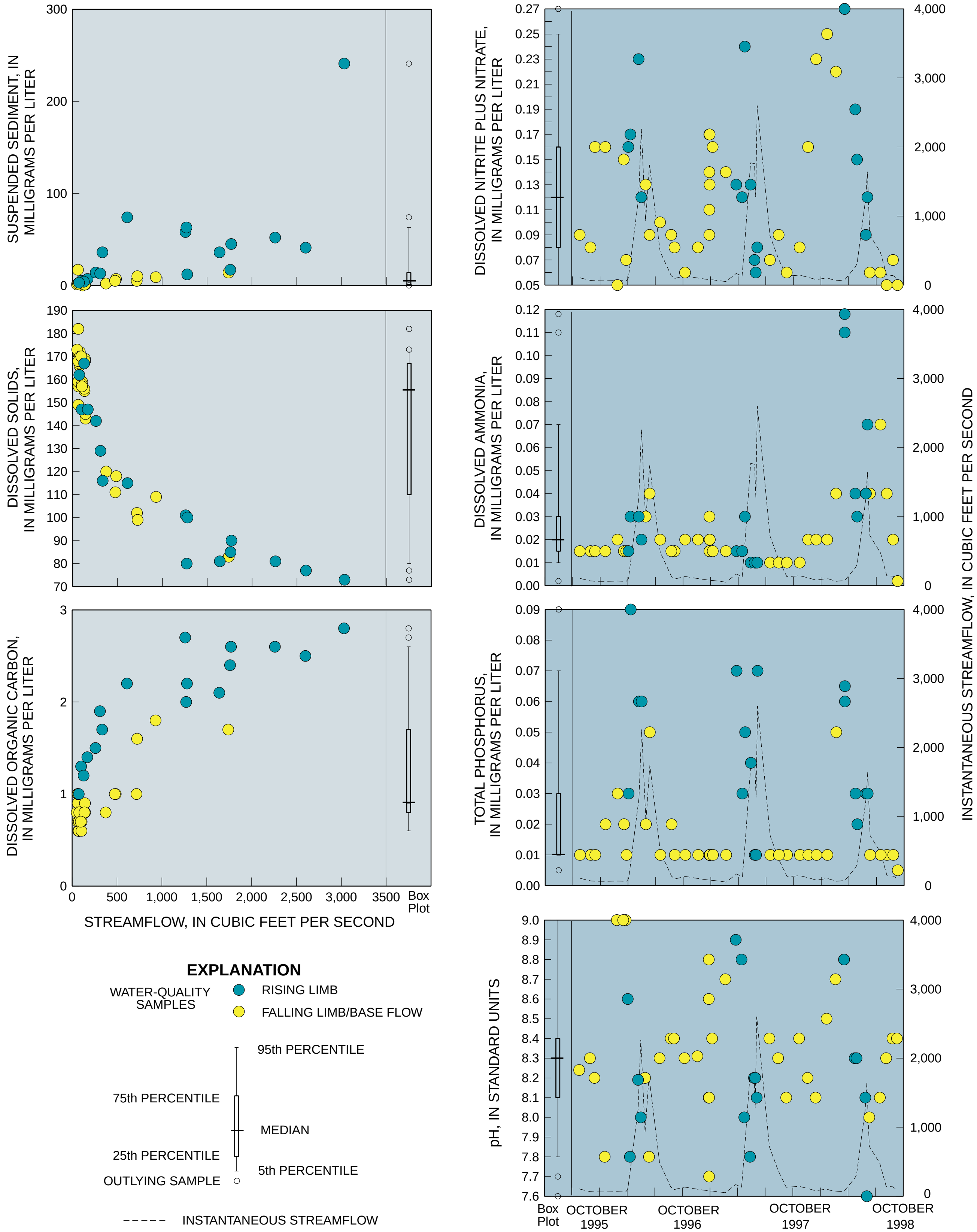

Figure 22. Distribution of selected water-quality constituents and properties relative to streamflow or time for East River below Cement Creek, station 09112200.

falling-limb/base-flow samples at similar streamflow. Dissolved organic-carbon concentrations increased with increasing streamflow and displayed hysteresis, with rising-limb samples having greater concentrations than falling-limb/base-flow samples at similar streamflows. Nitrite plus nitrate, ammonia, and total phosphorus did not have strong relations to streamflow, but the changes in concentrations with time are repetitive. Concentrations for these elements tended to peak just prior to the snowmelt runoff period, decreased with the onset of snowmelt, and then began to increase again the following winter. The dashed lines on the time-distribution plots are streamflow and assist in the visualization of the temporal changes of constituent concentrations. Ranges of concentrations for constituents not shown in figure 22 are listed below.

Constituent	Minimum (milligrams per liter; <, less than)	Median	Maximum
Suspended organic carbon	0.6	1	2.8
Dissolved nitrite	<0.01	<0.01	0.02
Dissolved ammonia plus organic nitrogen	<0.2	<0.2	0.2
Dissolved phosphorus	<0.01	<0.01	0.04
Dissolved orthophosphate	<0.01	<0.01	0.04
Dissolved oxygen	7.1	9.5	13

All measurements of dissolved oxygen were greater than the 6.0-mg/L State instream standard. Values of pH were within the State instream standards of 6.5 to 9.0. Nitrite and nitrate concentrations did not exceed the respective State instream standards of 0.05 and 10 mg/L. Concentrations of un-ionized ammonia calculated from ammonia, pH, and temperature did not exceed the chronic State instream standard of 0.02 mg/L.

Nutrient concentrations were greatest during the winter extreme low-flow conditions. The water quality of the East River portrays streams that are not effluent dominated in developing areas of the Southern Rocky Mountains.

Gunnison River at County Road 32 below Gunnison, Station 383103106594200

This site was selected, in cooperation with the National Park Service, to characterize the water quality of the Gunnison River upstream from the Curecanti National Recreation Area. The site is downstream from the city of Gunnison and just upstream from Blue Mesa Reservoir (fig. 1) and the Curecanti National Recreation Area. The drainage area is 2,128 square miles and elevations range from about 7,570 to more than 14,000 feet. A mixture of land use/land cover (fig. 23) is found, including substantial rangeland and agriculture (hay meadows) in the Tomichi Basin, urban areas of Gunnison and Crested Butte, and forested areas along the upper basin divide. The Gunnison River is formed at the confluence of the Taylor and East Rivers. Tomichi Creek enters the Gunnison River about 1.5 miles upstream from the sampling site.

The frequency curve of daily mean water temperature collected during 1997 and 1998 is shown on the graph in figure 23. Two years were used in this graph due to missing data caused by sensor malfunction. Median temperature was 5.8°C. Diurnal temperature changes range from 0°C in the winter to about 7°C during snowmelt runoff and the summer months.

Streamflow-gaging stations near the mouth of Tomichi Creek and just upstream from Tomichi Creek on the Gunnison River provide the daily streamflow data for this site. No major tributaries enter the river between the sampling site and these gaging stations. Daily streamflow from the two gages are summed to generate the daily streamflow for the sampling site. All daily streamflows in figures 24 and 25 are based on the computed values. Streamflow measured at the sampling site during water-quality sampling was compared to the sum of the streamflow at the gages, and the mean difference was 7.5 percent. Historical and study-period annual streamflows are shown in figure 24*A*. Streamflow in water years 1995 and 1997 were substantially larger than the long-term mean. Daily streamflow hydrograph and the time distribution of water-quality samples are shown in figure 24*B*.

The annual snowmelt runoff peak dominates the hydrology at this site. Water-quality sampling began at this site in January 1995 and continued through September 1998, resulting in 41 samples. The flow-duration curve and discharge distribution of the water-quality samples are shown in figure 24*C*. Water-quality samples are well distributed throughout the duration curve with the exception of flows with an exceedance probability of greater than 90 percent. Extremely low streamflows did not occur during the study period. Major-ion chemistry is presented for two representative flows as bar charts along

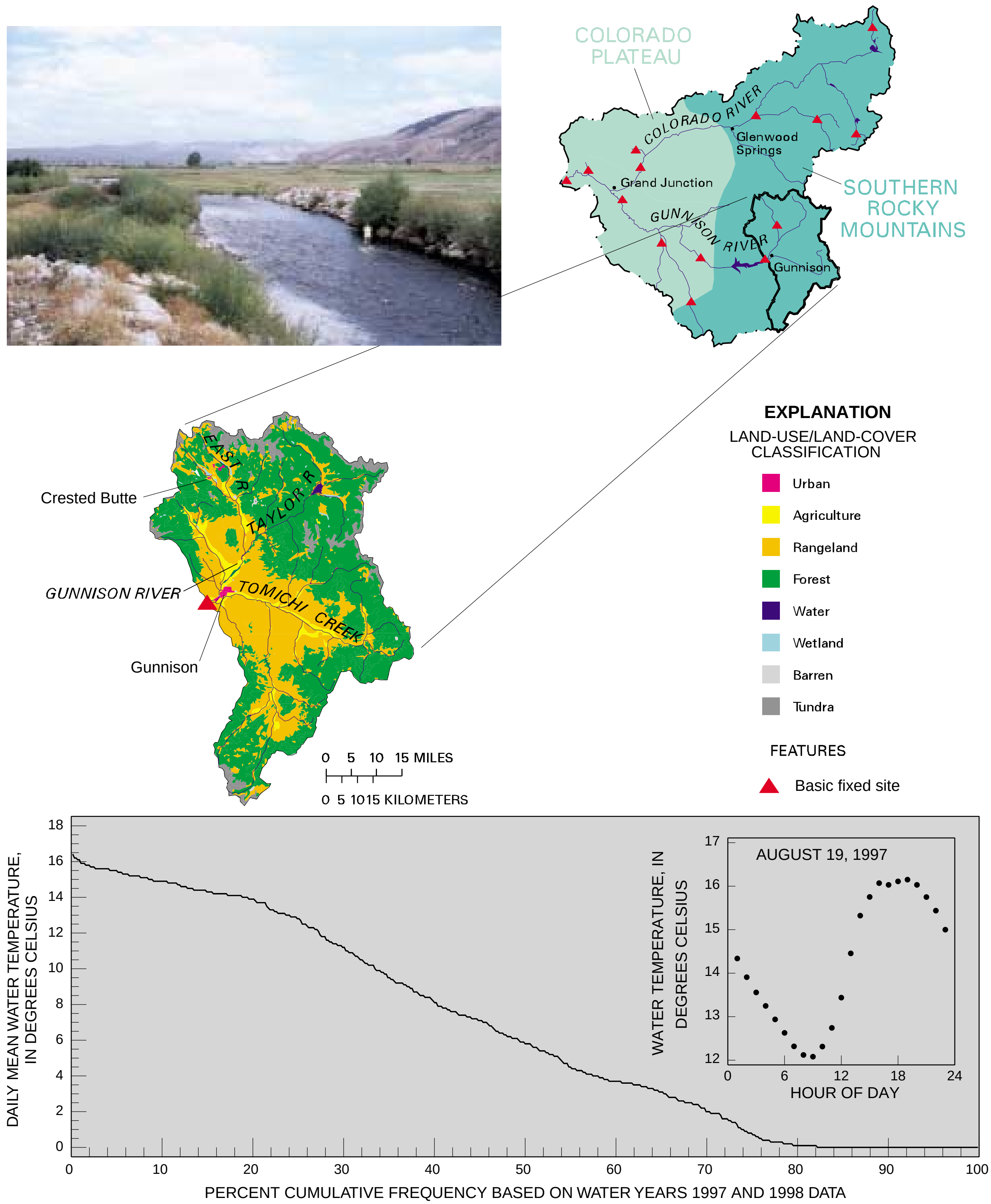

Figure 23. Photograph showing lower Tomichi Creek, map showing location and land use/land cover of basin, and graphs showing frequency curve of daily mean water temperature and example of diurnal temperature for Gunnison River at County Road 32 below Gunnison, station 383103106594200. Photograph by Norman Spahr.

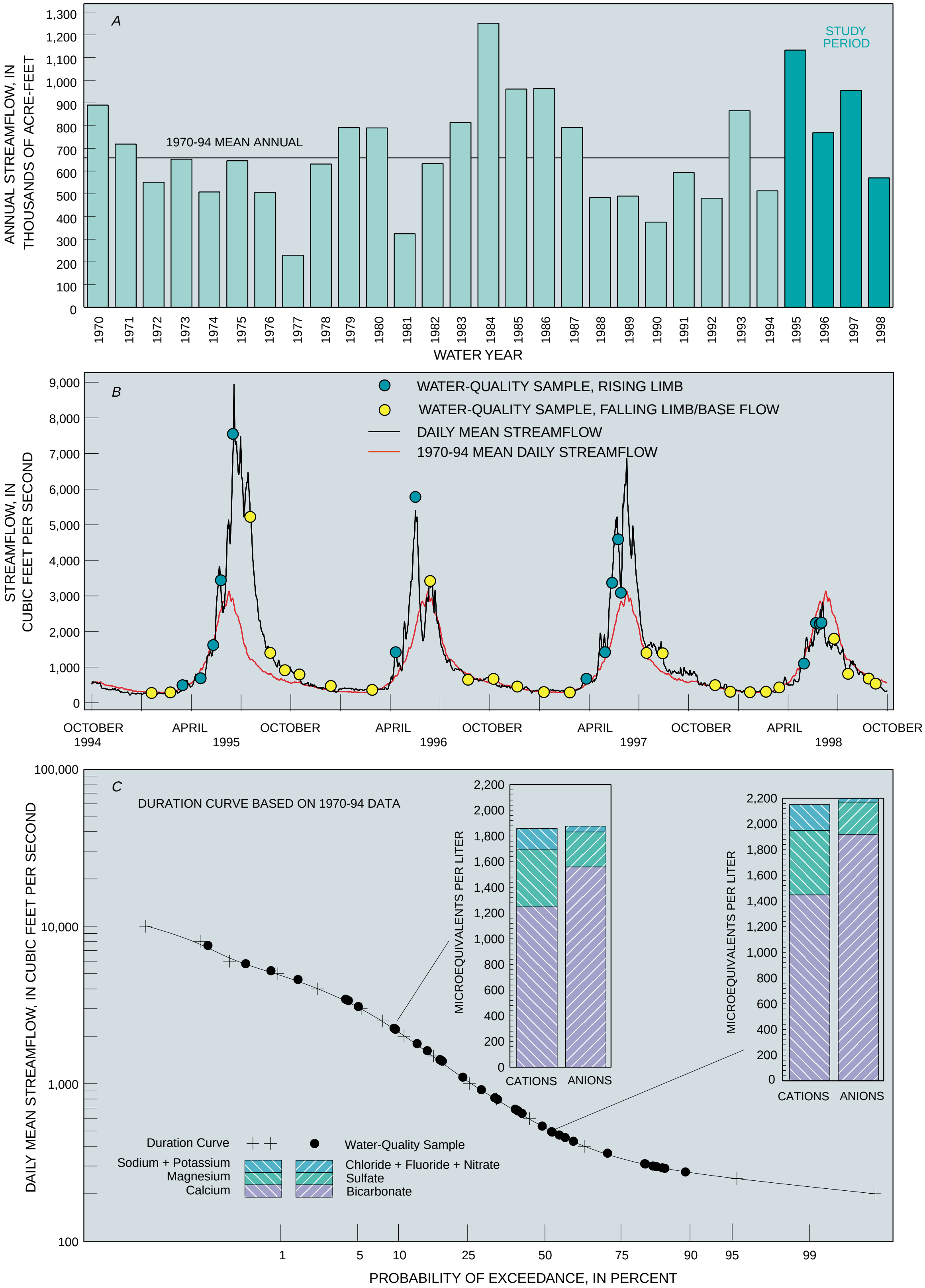

Figure 24. (*A*) Historical and study period annual streamflow, (*B*) daily mean streamflow and time distribution of water-quality samples, and (*C*) flow-duration curve with streamflow distribution of water-quality samples and examples of major-ion chemistry for Gunnison River at County Road 32 below Gunnison, station 383103106594200 (streamflows based on sum of streamflows at Gunnison River near Gunnison and Tomichi Creek near Gunnison).

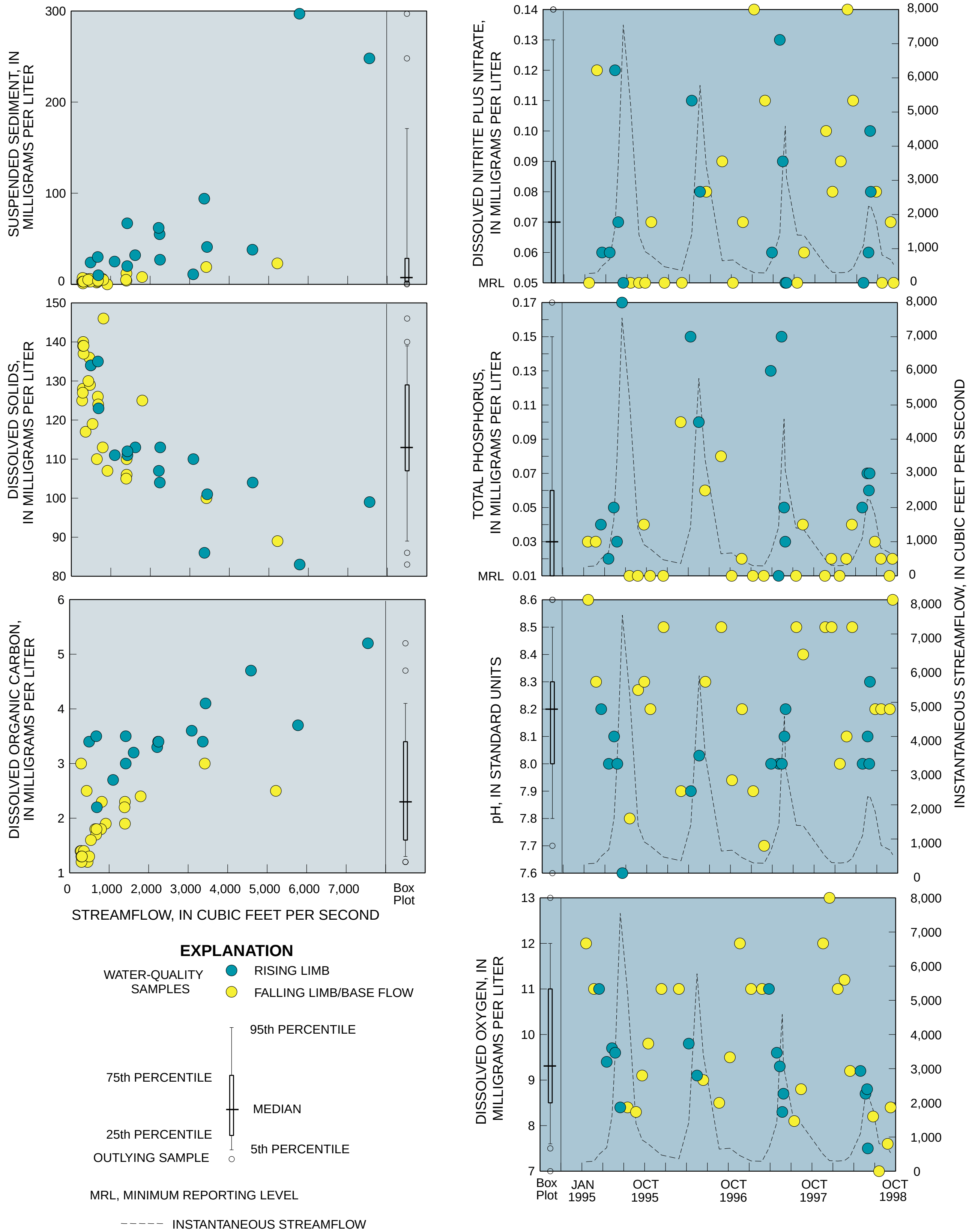

Figure 25. Distribution of selected water-quality constituents and properties relative to streamflow or time for Gunnison River at County Road 32 below Gunnison, station 383103106594200.

with the duration curve. Some snowmelt dilution of the major-ion concentrations occurred as streamflow increased (compare the length of the bars on the right chart to the length of the bars on the left chart). The water at this site is classified as a calcium-bicarbonate type (because those are the dominant ions).

Selected constituents and properties are plotted relative to streamflow or time in figure 25. Except during high streamflow, sediment concentrations typically were low (median of 7.5 mg/L). The snowmelt dilution of dissolved solids is shown by the decrease in concentration with increasing streamflow. Dissolved organic-carbon concentrations increased with streamflow, and rising-limb samples had greater concentrations than falling-limb/base-flow samples at similar flow. Nitrogen and phosphorus concentrations did not have strong relations to streamflow at this site. The time plots of nitrite plus nitrate show that often the peak concentrations occurred prior to the snowmelt runoff peak flows. Concentrations then were diluted by snowmelt and began to rise again the following winter. Total phosphorus concentrations were greatest just before or during peak flows. pH and dissolved oxygen fluctuated about median values of 8.2 and 9.3, respectively. Ranges of constituents not shown graphically are given below.

Constituent	Minimum	Median	Maximum
	(milligrams per liter; <, less than)		
Suspended organic carbon	0.2	0.4	3.0
Dissolved ammonia	<0.02	<0.02	0.07
Dissolved nitrite	<0.01	<0.01	0.02
Dissolved ammonia plus organic nitrogen	<0.2	<0.2	0.3
Dissolved phosphorus	<0.01	<0.01	0.04
Dissolved orthophosphate	<0.01	0.01	0.03

All measurements of dissolved oxygen and pH were within the State instream standards. All nitrite and nitrate concentrations were below the 0.05- and 10-mg/L instream standards, respectively. Un-ionized ammonia concentrations computed using ammonia, pH, and temperature were below the 0.02-mg/L instream standard. Water quality in the Gunnison River at this site is representative of mixed land-use and high-elevation basins. Some nitrogen is present during winter periods, and some phosphorus is present prior to and during snowmelt.

Gunnison River below Gunnison Tunnel, Station 09128000

This site was selected and water-quality samples collected, in cooperation with the National Park Service, to characterize the water quality of the Gunnison River leaving the Curecanti National Recreation Area and entering the Black Canyon of the Gunnison National Park. Drainage area upstream from the site is 3,965 square miles. There are multiple land uses and land covers (fig. 26) within the basin, but the major features defining hydrology and water quality are the three reservoirs (Blue Mesa Reservoir, Morrow Point Reservoir, and Crystal Lake) upstream.

Daily mean water temperature measured for water year 1998 is shown as a frequency curve on the graph in figure 26. Water year 1998 data were used because of a sensor malfunction during 1997. Median temperature was 6.9°C, and the mean was 6.7°C. Diurnal temperature changes are small (maximum of 2°C) due to the upstream reservoirs. An example of the hourly temperature change is shown in figure 26.

Streamflow data have been collected at this site since 1903. Annual streamflow from 1970 to 1998 is shown in figure 27*A*. Streamflow during water years 1995, 1996, and 1997 was greater than the long-term annual mean. The daily streamflow hydrograph and time distribution of water-quality samples are shown in figure 27*B*. The regulation of the streamflow is apparent by the abrupt changes in streamflow. Water-quality sampling began at this site in December 1994 and continued through September 1998, resulting in 55 samples. Using the 1970–94 data, a flow-duration curve was computed and is presented with the streamflow distribution of water-quality samples in figure 27*C*. Low flows did not occur during the sampling period; therefore, water-quality samples at flows lower than the 70th percentile were not collected. Major-ion chemistry is presented for two representative flows as bar charts in figure 27*C*. There was little change in the major-ion chemistry between the sample representing moderate flow (bar chart on the right) and the sample representing higher flow (bar chart on the left). The water is a calcium-bicarbonate type at these two flow conditions (calcium and bicarbonate are the dominant cation and anion).

Selected constituents and properties are plotted relative to streamflow and time in figure 28. Suspended-sediment concentrations are low (median

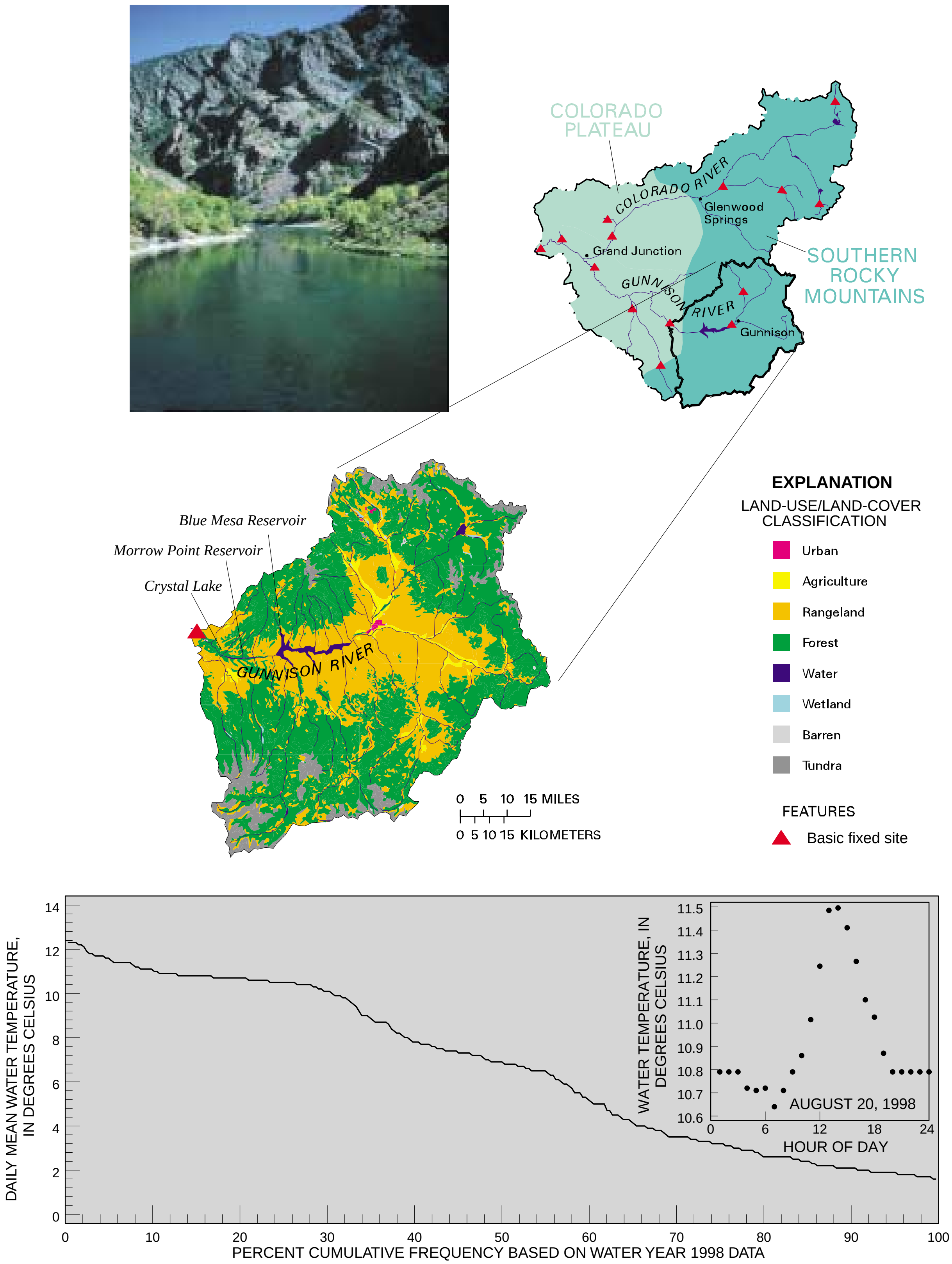

Figure 26. Photograph showing site, map showing location and land use/land cover of basin, and graph showing frequency curve of daily mean water temperature and typical summer diurnal temperature for Gunnison River below Gunnison Tunnel, station 09128000. Photograph by Jeffrey Deacon.

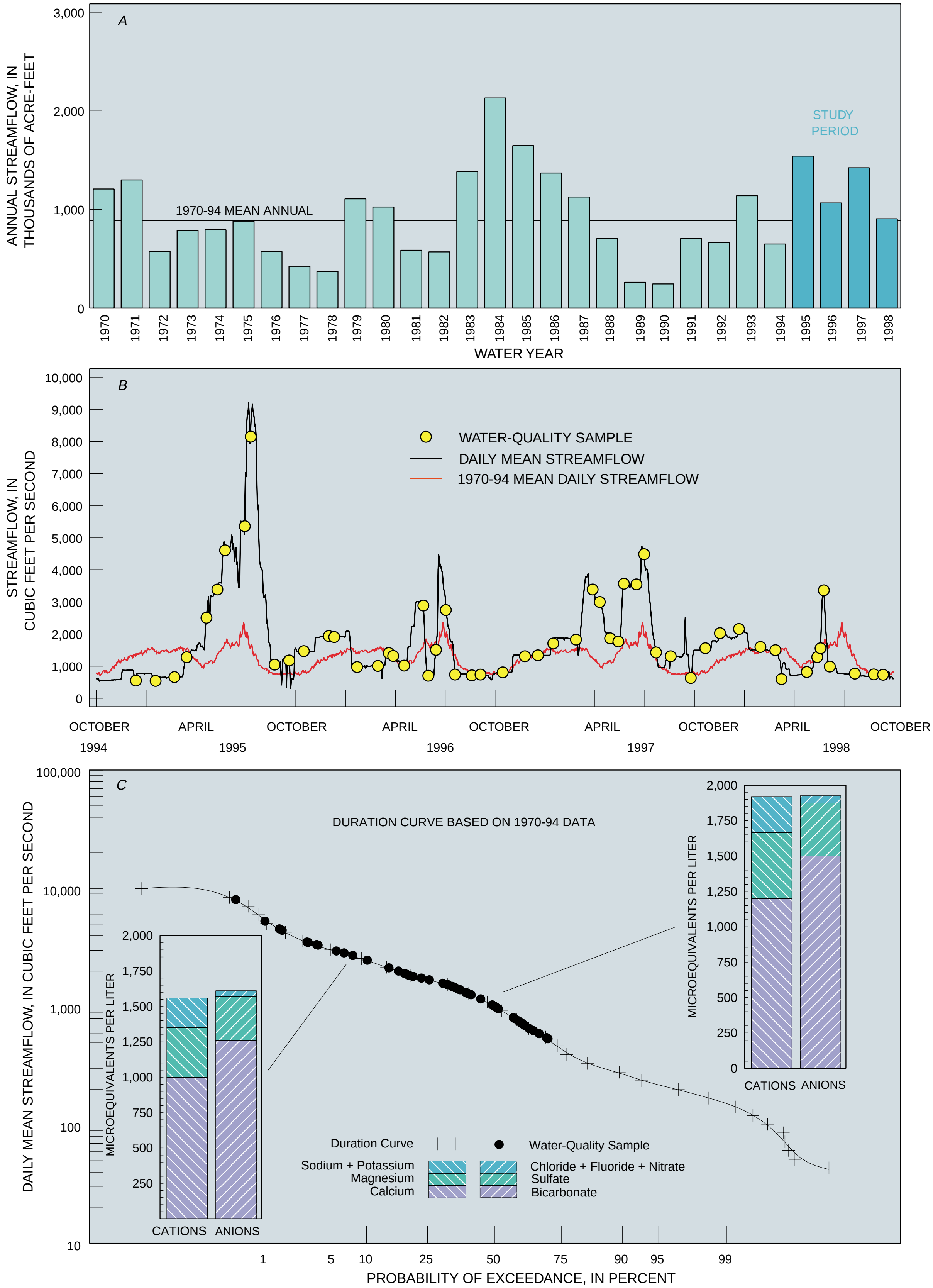

Figure 27. (*A*) Historical and study period annual streamflow, (*B*) daily mean streamflow and time distribution of water-quality samples, and (*C*) flow-duration curve with streamflow distribution of water-quality samples and examples of major-ion chemistry for Gunnison River below Gunnison Tunnel, station 09128000.

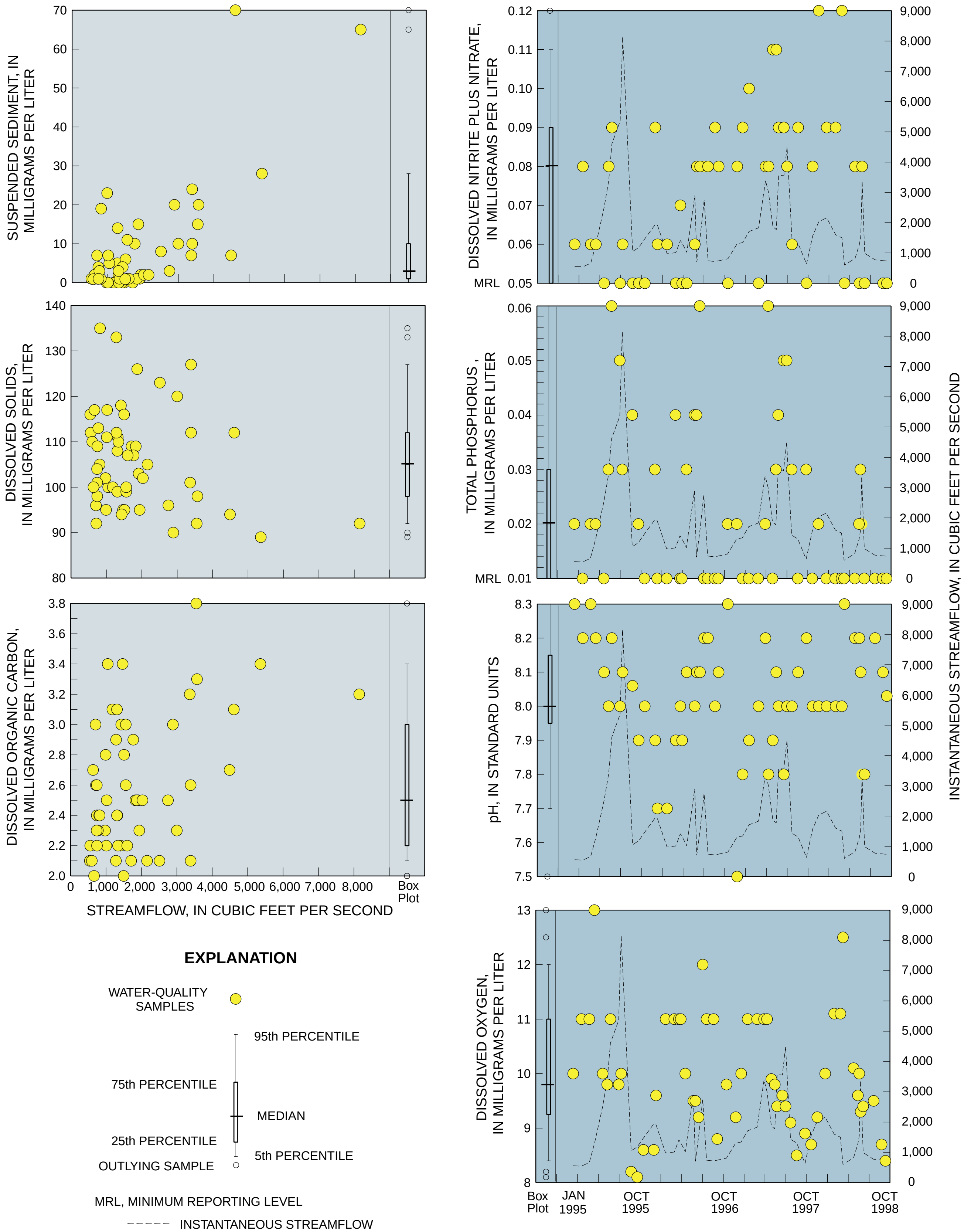

Figure 28. Distribution of selected water-quality constituents and properties relative to streamflow and time for Gunnison River below Gunnison Tunnel, station 09128000.

of 3 mg/L), as would be expected downstream from major reservoir systems. Higher streamflows had slightly more sediment. Concentrations of other constituents showed very little relation to streamflow, and many had a limited range as a result of what could be thought of as a dampening of variability due to the reservoir system upstream. Ranges of concentrations for constituents not shown in figure 28 are listed below.

Constituent	Minimum	Median	Maximum
	(milligrams per liter; <, less than)		
Suspended organic carbon	<0.2	0.2	0.7
Dissolved ammonia	<0.02	<0.02	0.04
Dissolved nitrite	<0.01	<0.01	0.02
Dissolved ammonia plus organic nitrogen	<0.2	<0.2	0.2
Dissolved phosphorus	<0.01	<0.01	0.03
Dissolved orthophosphate	<0.01	0.01	0.03

Dissolved-oxygen concentrations were greater than the 6.0-mg/L State instream standard. Values of pH were within the 6.5 to 9.0 instream standard. Nitrite and nitrate did not exceed the 0.05- and 10-mg/L instream standards, respectively. Un-ionized ammonia as computed by ammonia, pH, and temperature did not exceed the 0.02-mg/L instream standard. Water-quality conditions at this site could be described as relatively dilute with a limited amount of variability.

Uncompahgre River near Ridgway, Station 09146200

The Uncompahgre River site was one of two sites selected for study to represent areas of mining land use within the UCOL. The basin is in the southern part of the UCOL (fig. 29) and has a drainage area of 149 square miles. Precipitation ranges from about 12 to more than 50 inches with an average of 27.5 inches. Land use/land cover within the basin includes ranching, two small urban areas (Ridgway and Ouray), forest, and alpine areas, with mining being the historical predominant land use. There are hundreds of abandoned mines within the basin (fig. 29, mine locations from U.S. Geological Survey, 1997).

The frequency curve of water year 1997 daily mean water temperature is shown on the graph in figure 29. Daily water temperature is fairly evenly distributed about a median of 6.8°C and a mean of 7.4°C. Diurnal temperature changes ranged from 1°C in the winter to more than 11°C during snowmelt runoff. Typical summer hourly water temperatures for 1 day are shown in figure 29.

Streamflow data have been collected at this site since 1958. The annual streamflow from 1970 to 1998 is shown in figure 30*A*. Streamflow in 1997 was much greater than the other 2 years of data collection. Daily streamflow hydrograph and the time distribution of water-quality samples are shown in figure 30*B*. Snowmelt runoff peaks dominate the hydrology at this site. Comparing the current daily streamflow to the long-term mean shows that the water year 1996 and 1998 peaks were near average, and the water year 1997 peak was much greater than average (fig. 30*A*). Water-quality sampling began in October 1995 and continued through September 1998 (fig. 30*B*), resulting in 45 samples.

The flow-duration curve based on the 1970–95 data is shown in figure 30*C*. The streamflow distribution of water-quality samples and examples of major-ion chemistry also are shown with the duration information. Most parts of the duration curve are represented with water-quality samples except for extremely low flows (probability of exceedance greater than 90 percent), which did not occur during the study period. Snowmelt dilution effect on the major ions is evident by a comparison of the right and left bar charts representing median- and high-flow samples. The water at these two streamflows is a calcium-sulfate type (calcium and sulfate are the dominant cation and anion).

Selected constituent concentrations are plotted relative to streamflow in figure 31. Suspended-sediment concentrations typically were low (median concentration 29 mg/L) but increased with increasing discharge. Rising-limb concentrations were greater than concentrations on the falling-limb/base-flow for similar streamflow. Dissolved-solids concentrations were diluted with snowmelt runoff. Concentrations on the falling limb were greater than those on the rising limb for dissolved solids at streamflows greater than 200 ft^3/s, possibly due to contributions of dissolved solids from ground water. At low streamflows, dissolved organic-carbon concentrations increased with streamflow; then concentrations remained fairly constant at around 1 mg/L for streamflows greater than

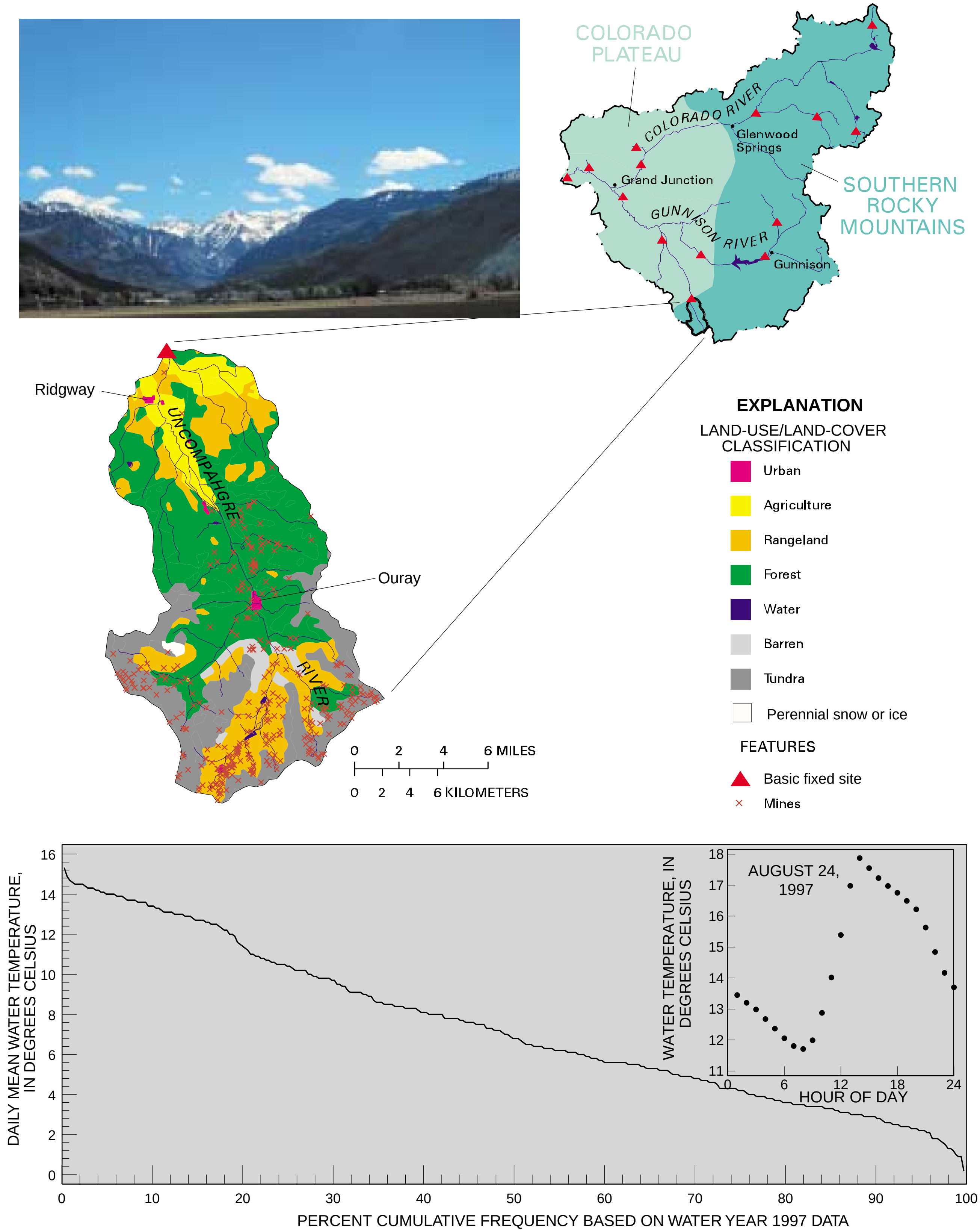

Figure 29. Photograph showing lower Uncompahgre River valley, map showing location and land use/land cover of basin, and graphs showing frequency curve of daily mean water temperature and typical summer diurnal temperature for Uncompahgre River near Ridgway, station 09146200. Photograph by Norman Spahr.

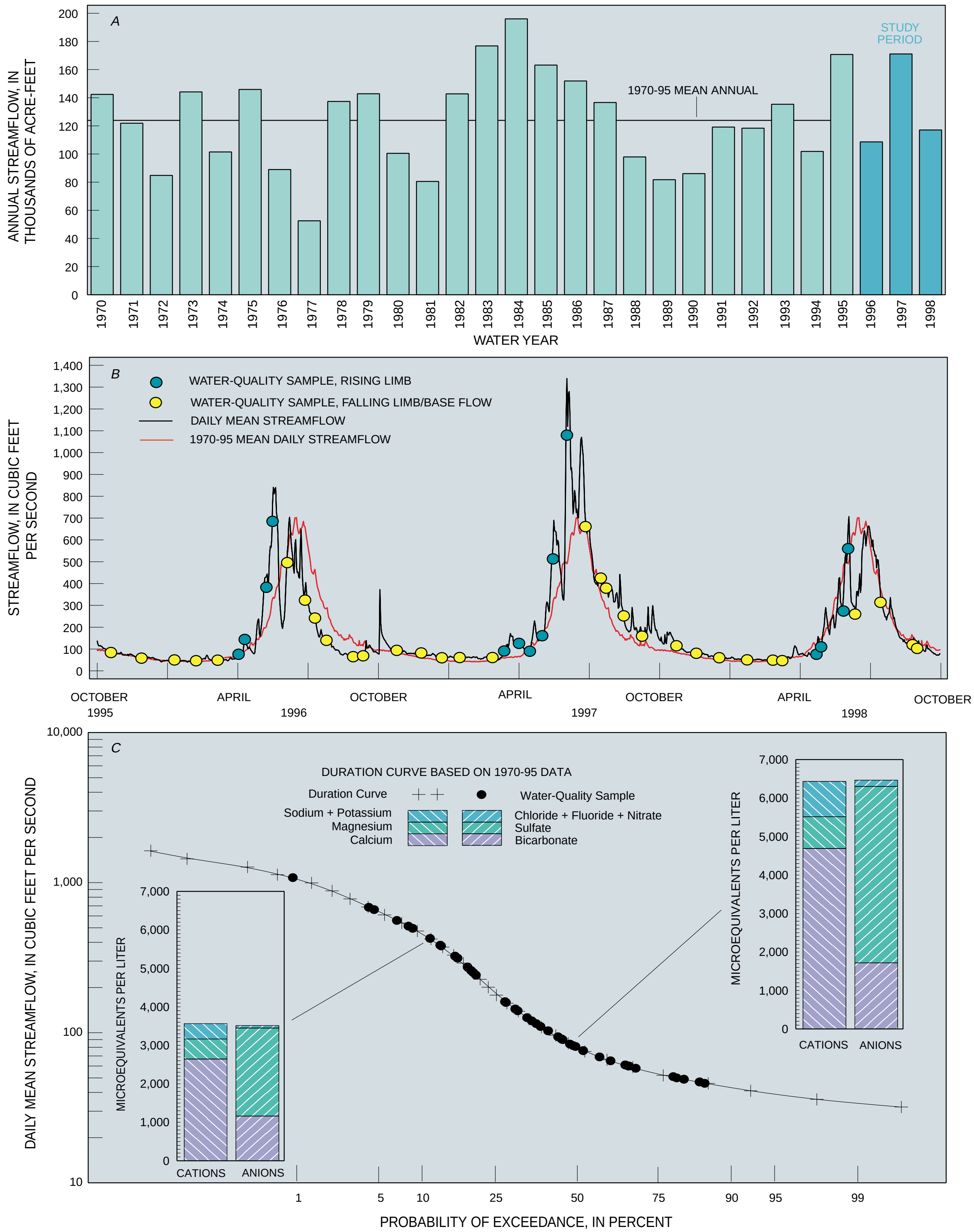

Figure 30. (*A*) Historical and study period annual streamflow, (*B*) daily mean streamflow and time distribution of water-quality samples, and (*C*) flow-duration curve with streamflow distribution of water-quality samples and examples of major-ion chemistry for Uncompahgre River near Ridgway, station 09146200.

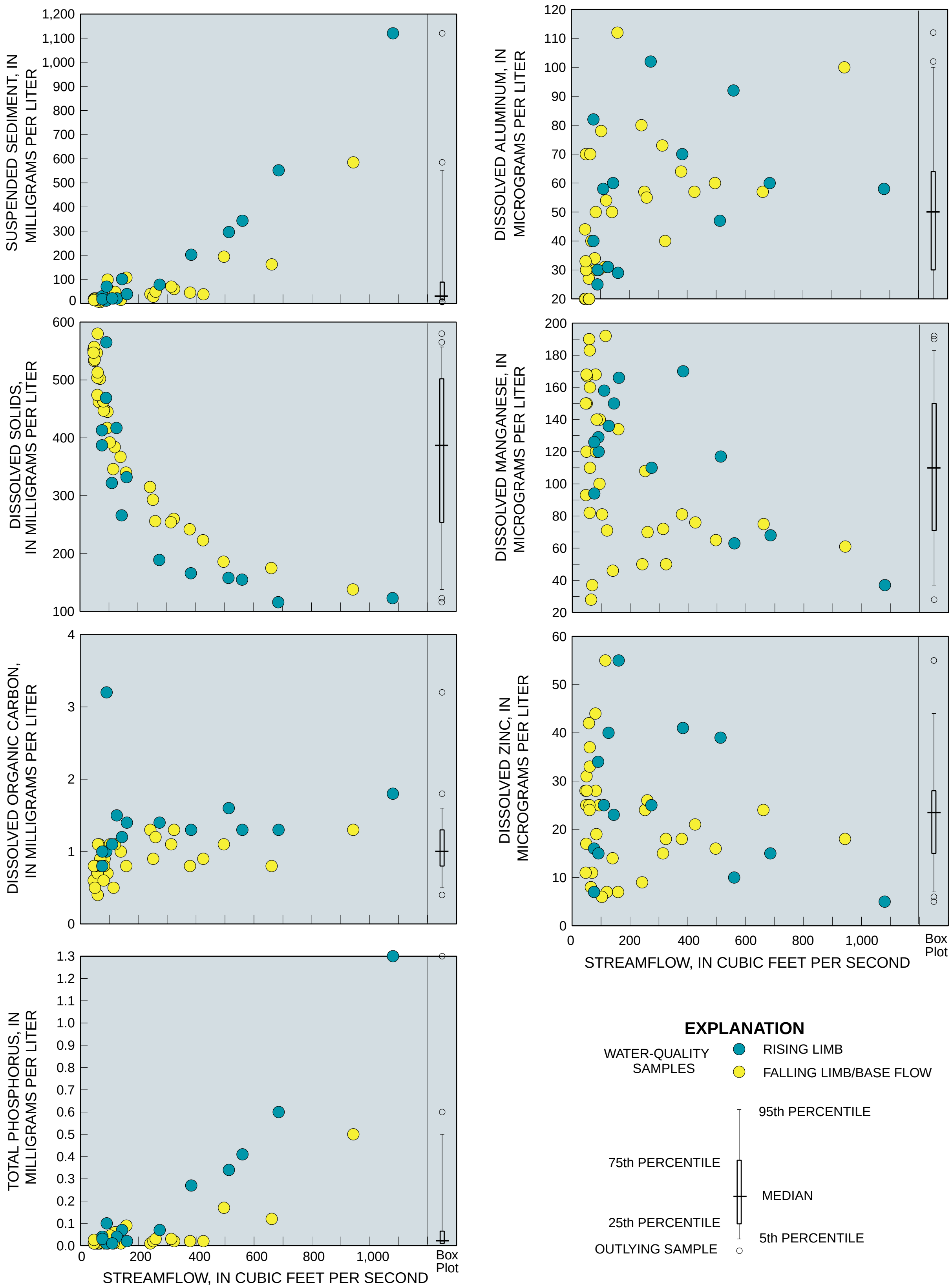

Figure 31. Distribution of selected water-quality constituents relative to streamflow for the Uncompahgre River near Ridgway, station 09146200.

200 ft^3/s. Total phosphorus, which commonly is transported with sediment, had a concentration/streamflow relation very similar to that of sediment. The relation of aluminum concentration and streamflow had a lot of scatter, and low concentrations were detected only during low streamflow. Manganese and zinc concentration/streamflow relations also had a lot of scatter but showed that high flows diluted the concentration (high concentrations were not detected at high streamflow). Concentration ranges for other constituents not shown in figure 31 are listed below.

Constituent	Minimum	Median	Maximum
	(milligrams per liter; <, less than)		
Suspended organic carbon	0.2	0.4	4.8
Dissolved ammonia	<0.02	0.03	0.06
Dissolved nitrite	<0.01	<0.01	0.03
Dissolved nitrite plus nitrate	0.09	0.13	0.21
Dissolved ammonia plus organic nitrogen	<0.02	<0.02	0.03
Dissolved phosphorus	<0.01	<0.01	0.03
Dissolved orthophosphate	<0.01	<0.01	0.02
pH (standard units)	7.3	8.0	8.4
Dissolved oxygen	7.4	9.2	12.0

Concentrations of dissolved oxygen did not fall below the State instream standard of 6 mg/L, pH values were within the instream standard of 6.5 to 9.0, and nitrite and nitrate did not exceed the respective State instream standards of 0.05 and 10 mg/L. State standards for this stream reach for manganese and zinc are 1,000 and 225 micrograms per liter, respectively, based on total recoverable samples. Concentrations for manganese and zinc in figure 31 are dissolved (the sample was filtered).

Concentrations of nutrients were low. Trace metals transported from the mining areas were detected at this site.

Dry Creek at Begonia Road near Delta, Station 09149480

The Dry Creek site was one of two sites selected to study water quality in agricultural areas within the UCOL. Dry Creek is a tributary to the Uncompahgre River with headwaters in the Uncompahgre Plateau and a drainage basin area of 175 square miles. Water is transported into and out of Dry Creek through irrigation canals and ditches. Headwater areas are composed of forest and rangeland with intensive agriculture along the downstream reaches of the basin (fig. 32). The crop pattern for 1993 (more recent data are unavailable) is shown in figure 32 to present an indication of types of crops and location of agricultural areas (Bureau of Reclamation, digital data, accessed January 14, 1999, at URL ftp://hp5.rsgis.do.usbr.gov/pub). Precipitation ranges from about 8 to more than 23 inches with an average of 14.3 inches.

Daily mean water-temperature data collected in 1997 are shown in the frequency curve on the graph in figure 32. Daily mean water temperature is fairly uniformly distributed around a median of 8.9°C and a mean of 9.6°C. Diurnal water-temperature changes ranged from 0°C in December to 9.8°C in June.

This site was established for the UCOL program so historical data are not available. Annual streamflow for the data-collection period is shown in figure 33*A*. The daily streamflow hydrograph and time distribution of the water-quality samples are shown in figure 33*B*. The annual peak streamflows are affected by a combination of snowmelt runoff and irrigation water management. The rapid changes in streamflow and the increase in streamflows in September and October are a result of irrigation-water management. Water-quality sampling began in October 1995 and continued through September 1998, resulting in 44 samples. The samples were coded into two groups, November–May and June–October, to investigate differences approximating the growing season. Using 1996–98 water-year data, the flow-duration curve was computed and is shown along with the discharge distribution of water-quality samples and examples of major-ion chemistry in figure 33*C*. All flow conditions that occurred during the data-collection period are represented by water-quality samples. The dilution of major ions between streamflows at the 50th percentile (bar chart on the right) and those at about the 10th percentile (bar chart on the left) is apparent by comparison of the bar charts representing the two streamflows. The water in both example flow conditions is a calcium-sulfate type (calcium and sulfate are the dominant cation and anion).

Concentrations of selected constituents are plotted relative to streamflow in figure 34. The concentration/streamflow relations show a lot of scatter and are poorly defined for some constituents, possibly due to the different sources of water

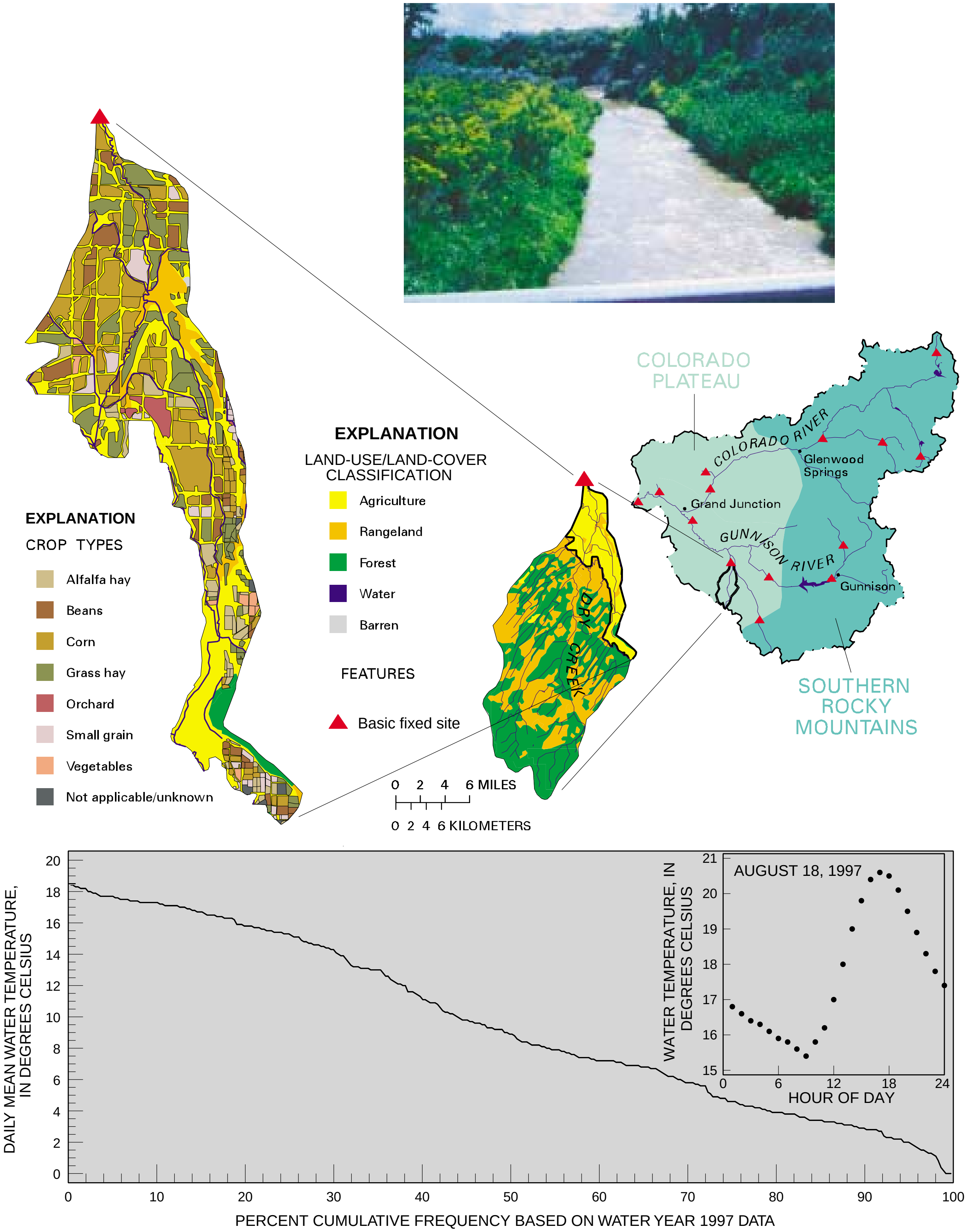

Figure 32. Photograph showing site; maps showing location, land use/land cover, and crop pattern in basin; and graphs showing frequency curve of daily mean water temperature and example of diurnal temperature for Dry Creek at Begonia Road near Delta, station 09149480. Photograph by Robert Boulger.

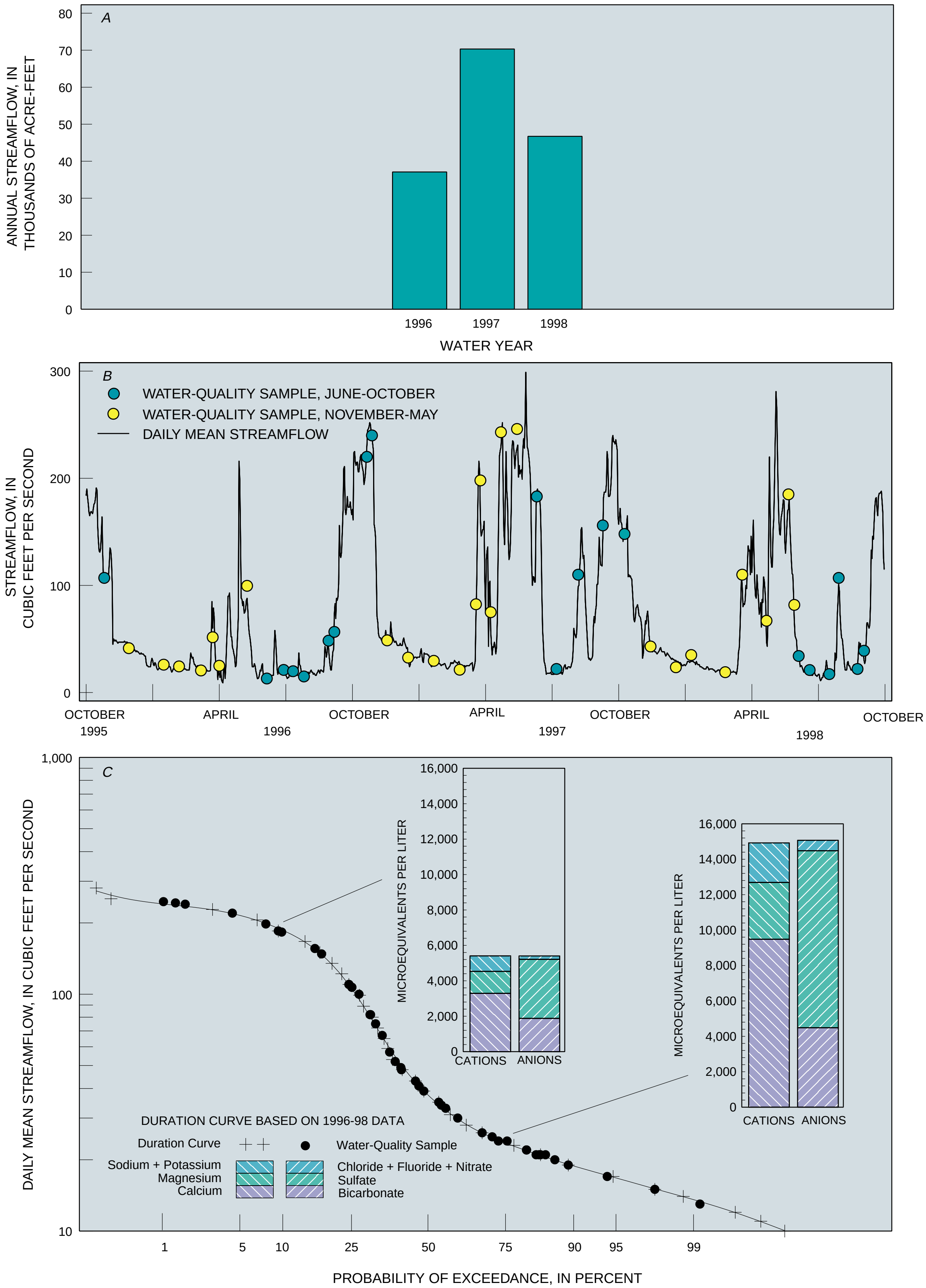

Figure 33. (*A*) Study period annual streamflow, (*B*) daily mean streamflow and time distribution of water-quality samples, and (*C*) flow-duration curve with streamflow distribution of water-quality samples and examples of major-ion chemistry for Dry Creek at Begonia Road near Delta, station 09149480.

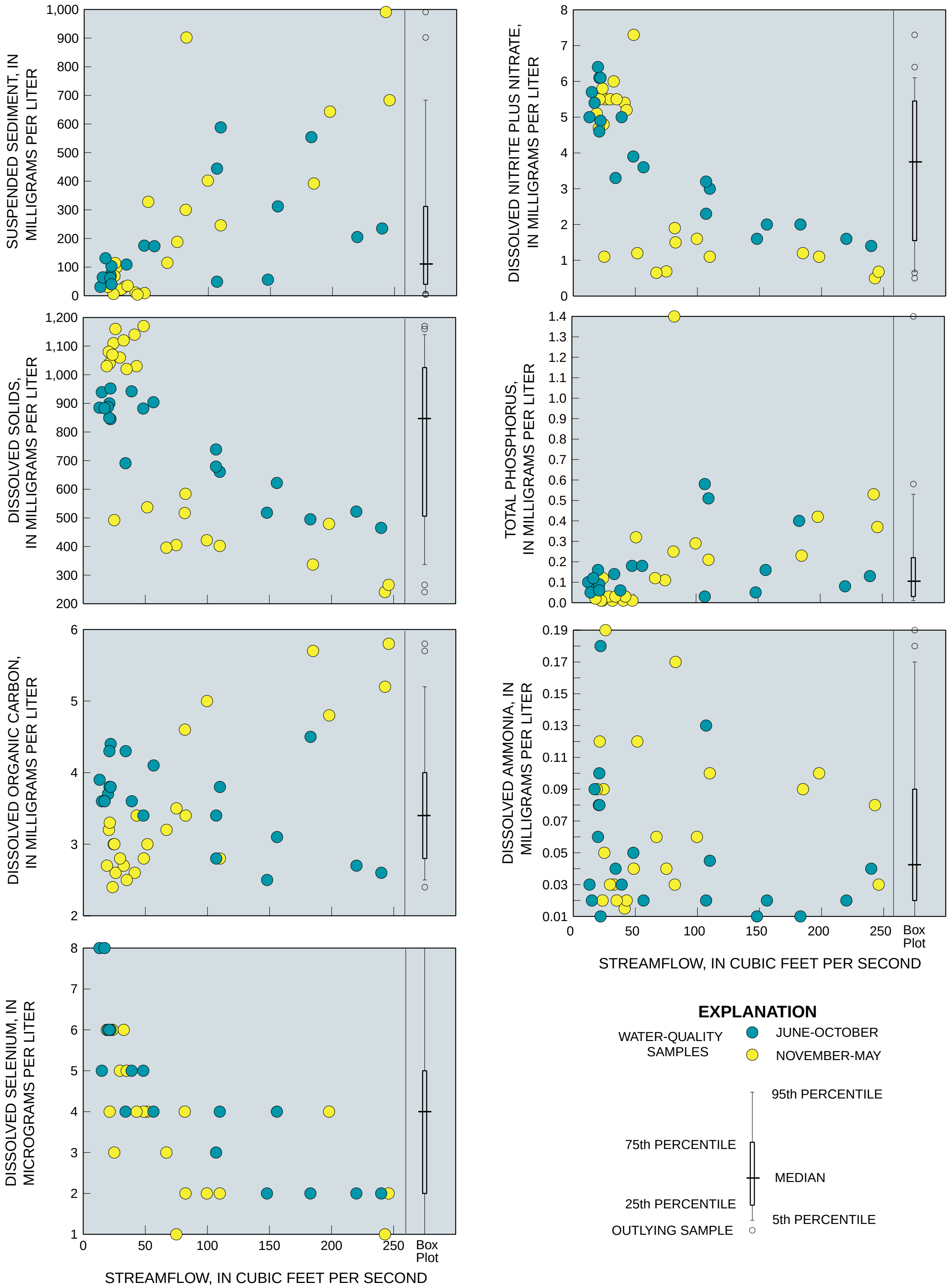

Figure 34. Distribution of selected water-quality constituents relative to streamflow for Dry Creek at Begonia Road near Delta, station 09149480.

(irrigation, natural runoff from the headwater areas, and ground water). The dissolved organic-carbon graph is a good example, with concentrations for June–October showing decreasing concentrations with increasing streamflow, while the November–May samples had increasing concentrations with increasing streamflow. Selenium concentrations can be elevated (4–8 μg/L) at lower streamflow conditions, probably as a result of the interaction of irrigation return flows and shallow ground water with Mancos Shale, which is present in the downstream parts of the basin. Nitrite plus nitrate concentrations were were relatively high at lower streamflow (5 mg/L or more). Concentrations of total phosphorus were slightly greater at higher streamflows than lower streamflows. Concentrations of ammonia varied for any given streamflow. Ranges of concentrations for other constituents are listed below.

Constituent	Minimum	Median	Maximum
	(milligrams per liter; <, less than; >, greater than)		
Suspended organic carbon	0.2	1.1	>10
Dissolved nitrite	<0.01	0.02	0.06
Dissolved ammonia plus organic nitrogen	<0.2	0.4	1.2
Dissolved phosphorus	<0.01	0.01	0.09
Dissolved orthophosphate	<0.01	0.01	0.09
pH (standard units)	8.0	8.3	8.6
Dissolved oxygen	7.4	9.9	14

Values for pH were within the State instream standards of 6.5 to 9.0, and dissolved oxygen was always greater than the 5.0-mg/L instream standard. Water quality in the agricultural areas represented by this site can be summarized as having managed streamflows, at times having high sediment and dissolved-solids concentrations (thousands of milligrams per liter), having relatively high nitrate concentrations in the milligrams per liter range, and, where Mancos Shale is present, having elevated selenium concentrations in the water.

Gunnison River near Grand Junction, Station 09152500

The Gunnison River near Grand Junction site is near the mouth of the Gunnison River (fig. 35) and was selected as an integrator site for the Gunnison River Basin. The drainage area is 7,928 square miles. Precipitation ranges from less than 10 inches near the gage to more than 50 inches in the headwaters, and the average is 21 inches. Land use, as expected in a large integrator basin, is varied. The frequency curve for daily mean water temperature for water year 1997 is shown in the figure 35 graph. Water temperature is fairly uniformly distributed about a median of 9.0°C and a mean of 10.1°C. Diurnal temperature changes ranged from about 0.4°C in the winter to 3.6°C in July and August. An example of diurnal temperature changes also is shown in figure 35.

Streamflow data have been collected at this site since 1896. Annual streamflow for water years 1970–98 is shown in figure 36*A*. Water year 1997 had much greater streamflow than average, and water years 1996 and 1998 had about average streamflow. Flow at this site represents about 40 percent of the flow leaving the study unit at the Colorado-Utah State line. The daily streamflow hydrograph and time distribution of water-quality samples are shown in figure 36*B*. Snowmelt runoff dominates the hydrology at this site, and the annual peaks occur in May or June. Water-quality sampling began for the project in October 1995 and continued through September 1998, resulting in 43 samples. One sample was collected in June 1995 during the high-flow period as it was expected that 1995 would have a much greater than normal snowmelt peak. Substantial water-quality information has been collected at this site for other programs of the U.S. Geological Survey. The flow-duration curve based on the 1970–95 data is shown along with the streamflow distribution of water-quality samples and examples of major-ion chemistry in figure 36*C*. Except for low-flow conditions, which did not occur during data collection, all flow conditions are represented with water-quality samples. Snowmelt dilution of the major-ion concentrations is apparent by comparing the lengths of the bars in the bar chart on the right to the bars in the chart on the left. Sulfate is the dominant anion; there is no dominant cation but rather a mixture of ionic species.

Selected water-quality constituents and properties are plotted relative to streamflow in the graphs in figure 37. Suspended-sediment concentrations can be high (thousands of milligrams per liter) at times. The snowmelt dilution of the major ions

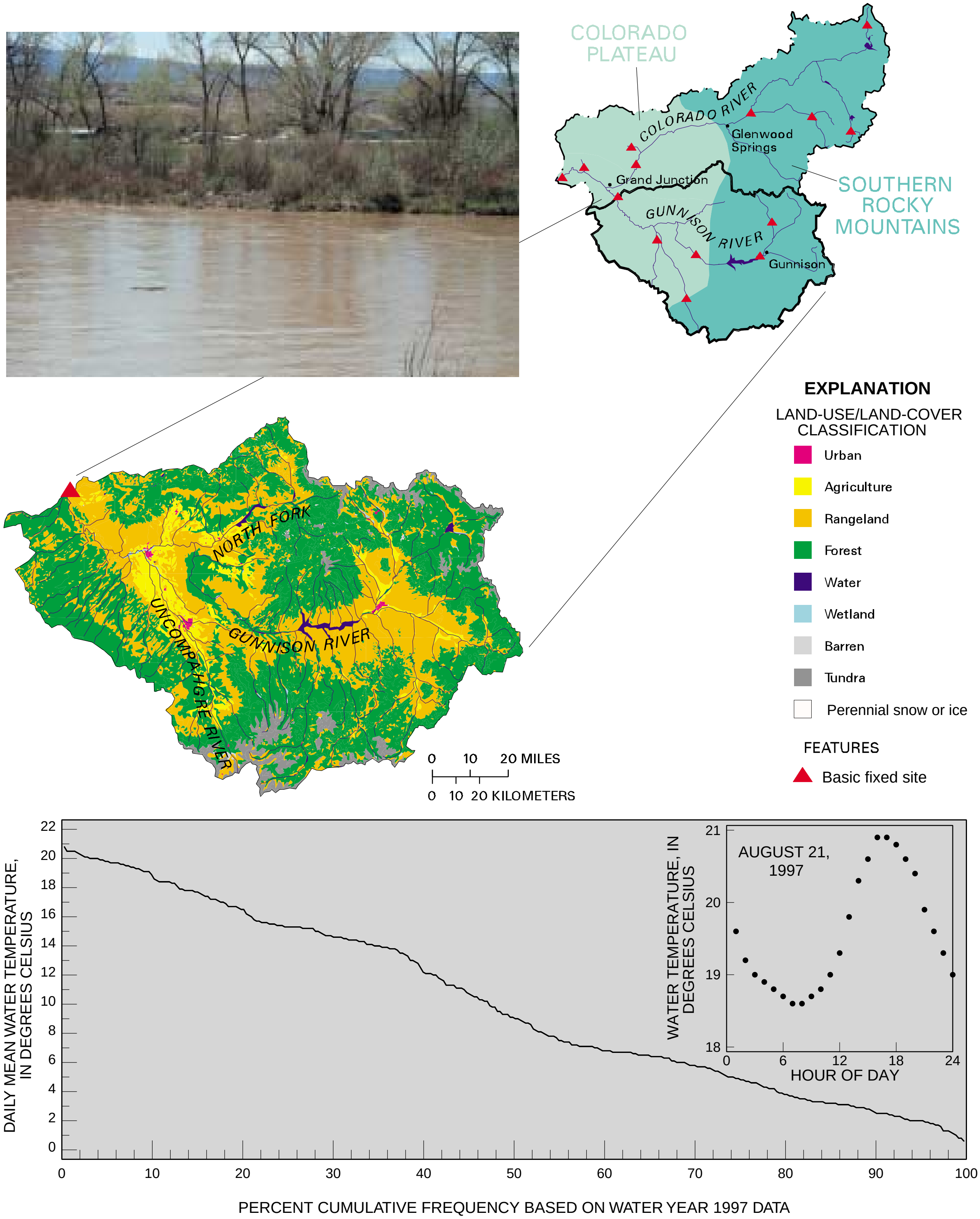

Figure 35. Photograph showing site, map showing location and land use/land cover of basin, and graphs showing frequency curve of daily mean water temperature and typical summer diurnal temperature for Gunnison River near Grand Junction, station 09152500. Photograph by Norman Spahr.

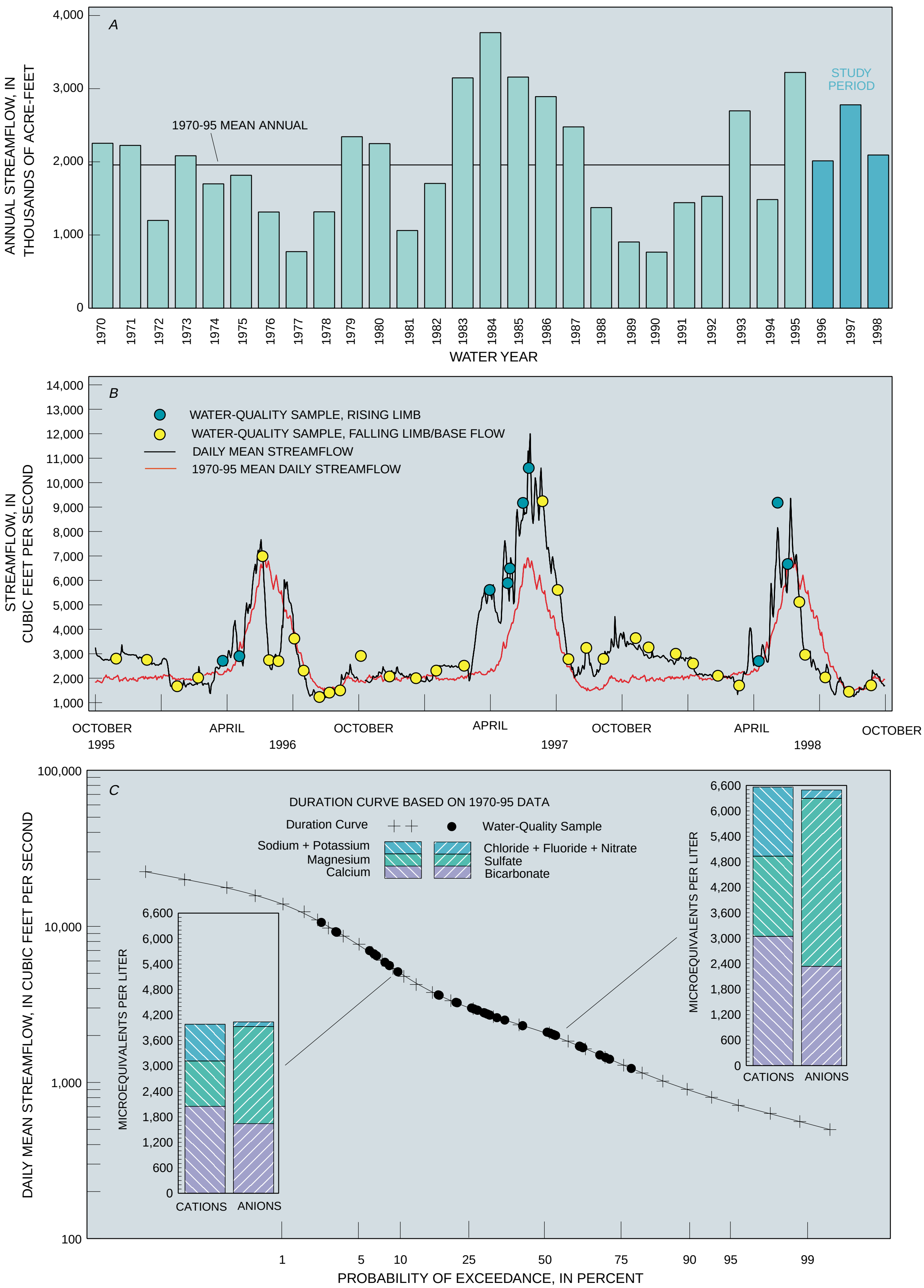

Figure 36. (*A*) Historical and study period annual streamflow, (*B*) daily mean streamflow and time distribution of water-quality samples, and (*C*) flow-duration curve with streamflow distribution of water-quality samples and examples of major-ion chemistry for Gunnison River near Grand Junction, station 09152500.

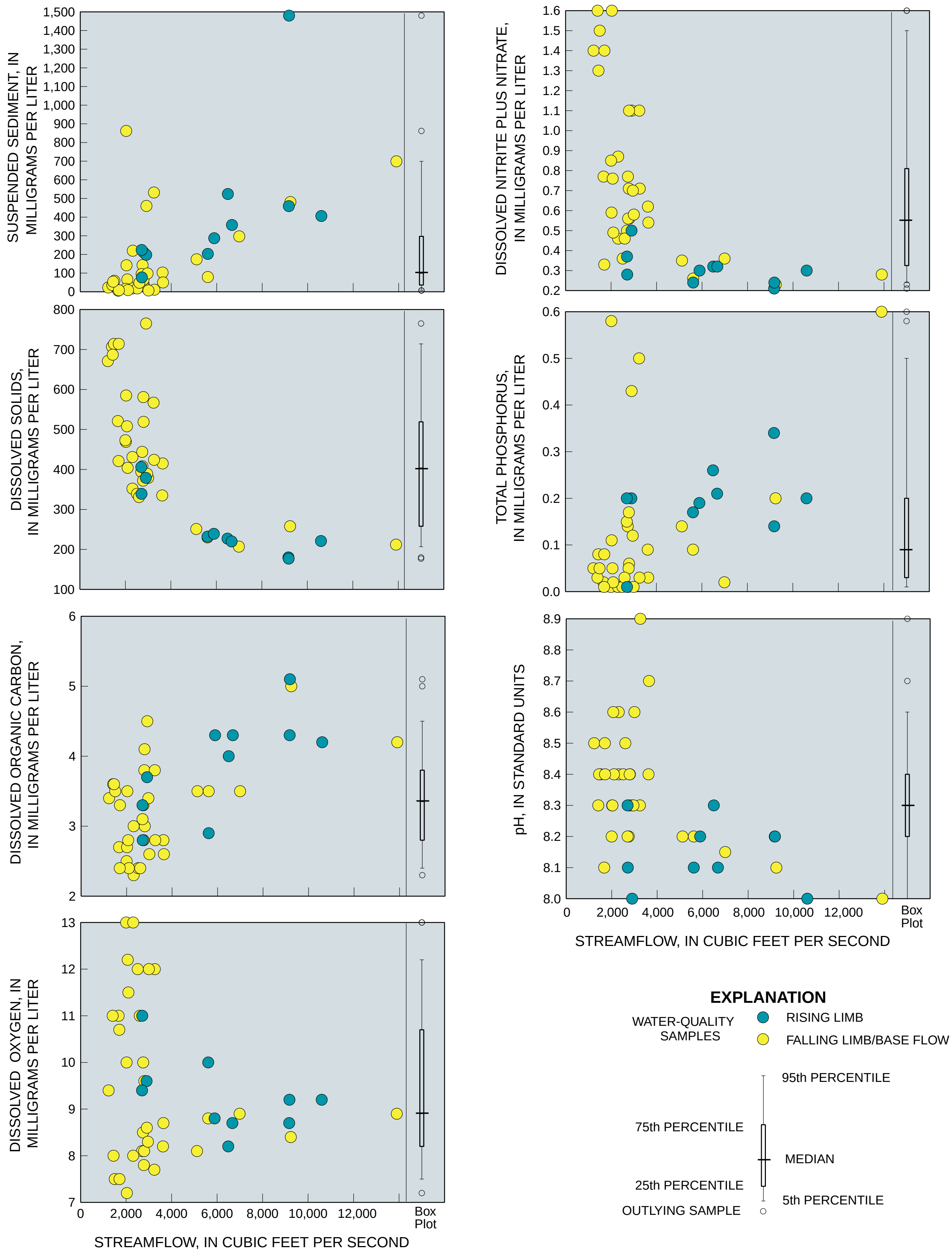

Figure 37. Distribution of selected water-quality constituents and properties relative to streamflow for Gunnison River near Grand Junction, station 09152500.

and nitrite plus nitrate is seen in the graphs. There is no hysteresis effect on concentrations between rising and falling limbs of the annual snowmelt runoff peak for water-quality constituents at this site. Ranges of concentrations for other water-quality constituents are listed below.

Constituent	Minimum	Median	Maximum
	(milligrams per liter; <, less than)		
Suspended organic carbon	0.2	0.9	13.0
Dissolved ammonia	<0.02	<0.02	0.08
Dissolved nitrite	<0.01	0.01	0.06
Dissolved ammonia plus organic nitrogen	<0.2	<0.2	0.5
Dissolved phosphorus	<0.01	0.01	0.05
Dissolved orthophosphate	<0.01	0.01	0.06

Dissolved-oxygen concentrations were greater than the 6-mg/L State instream standard. Values of pH fell within the 6.5 to 9.0 State instream standard range. Only one sample of nitrite was greater than the 0.05-mg/L instream standard, and all nitrate concentrations were less than the 10-mg/L instream standard. Un-ionized ammonia concentrations as computed from ammonia, pH, and temperature were less than the 0.02-mg/L chronic standard. During low flow, sulfate was commonly greater than the 250-mg/L State instream standard for this stream reach.

The multiple influences of land use/land cover and physiography on water quality are evident at this integrator site. The diluting effects of snowmelt are seen on the typically high concentrations of major ions. Sediment carried from smaller tributaries in the Colorado Plateau during high-flow periods contribute to the occasional large sediment concentrations detected at this site, and low-flow nitrate concentrations are in the milligram per liter range.

Reed Wash near Mack, Station 09153290

The site on Reed Wash was one of two sites selected to represent agricultural land use in the UCOL. Reed Wash is a tributary to the Colorado River in the agricultural area known as the Grand Valley, which is basically the Colorado River Valley in the Grand Junction area. The Reed Wash Basin is a small (16 square miles), intensively farmed and ranched area (fig. 38). The 1993 crop pattern (Bureau of Reclamation digital data, accessed January 14, 1999, at URL ftp://hp5.rsgis.do.usbr.gov/pub) also is shown in figure 38. Irrigated agriculture has occurred in the Grand Valley area since 1886 (Skogerboe, 1982), with irrigation networks delivering water and drainage networks routing return flows and ground water to natural and manmade drainages. Most of the irrigation water is diverted from the Colorado River. Annual precipitation is about 7.5 inches.

The frequency curve of daily mean water temperature for water year 1997 is shown in the figure 38 graph. In this arid, hot environment, water temperature can be warm (greater than 20°C). Median water temperature was 10.9°C, and the mean was 11.9°C. Diurnal temperature changes varied from 0.5°C in the winter to 8.8°C in May. An example of hourly water-temperature data is plotted in figure 38.

Streamflow data have been collected at this site since 1975. The annual streamflow for water years 1976–95 is shown in figure 39*A*. Irrigation-water management precludes a lot of year-to-year variability in streamflow. The daily streamflow hydrograph and time distribution of water-quality samples are shown in figure 39*B*. The streamflow is either low during the non-irrigation season or high when irrigation is occurring, with very abrupt changes between the two conditions. Water-quality sampling began in October 1995 and continued through September 1998, resulting in 53 samples. The flow-duration curve based on the 1976–95 data is shown in figure 39*C* along with the streamflow distribution of water-quality samples and examples of the major ions for the two different flow conditions. The shape of the duration curve also shows that the streamflow is either high or low with a very small percentage of the time being between the two conditions. Concentrations of major ions are high during low base-flow conditions and substantially less during the irrigation season (compare the bar chart on the right to the one on the left). No cation or anion is dominant in all flow conditions.

Concentrations of selected constituents are plotted relative to streamflow or time in figure 40. Suspended-sediment concentrations during low-flow conditions typically were less than 100 mg/L, and during high-flow, ranged from 100 to about 1,500 mg/L. During the period when the irrigation water diversion and delivery systems are first initialized in the spring, very large (thousands of milligrams per liter) sediment concentrations are

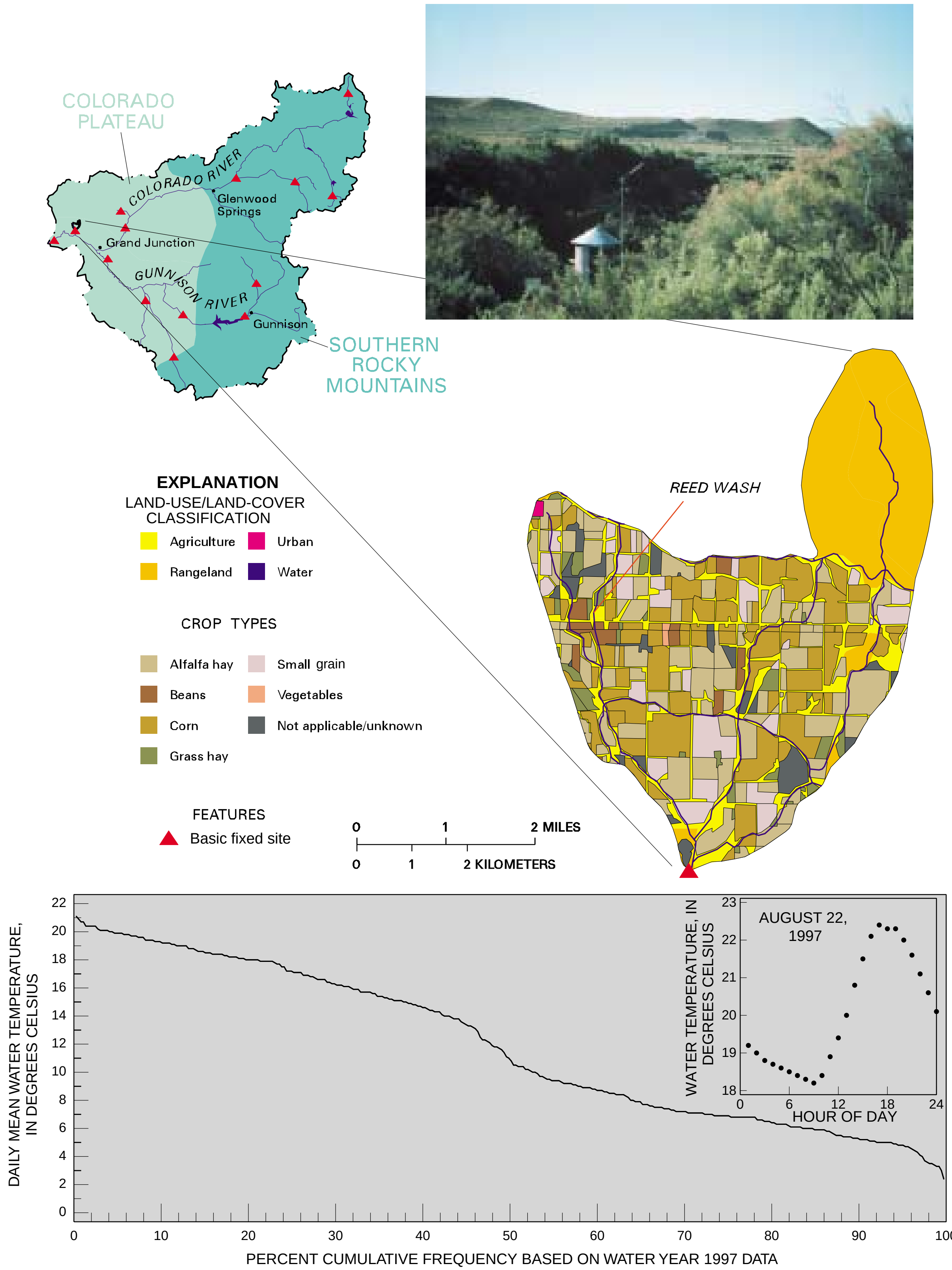

Figure 38. Photograph showing site; map showing location, land use/land cover, and crop pattern of basin; and graphs showing frequency curve of daily mean water temperature and typical summer diurnal temperature for Reed Wash near Mack, station 09153290. Photograph by Norman Spahr.

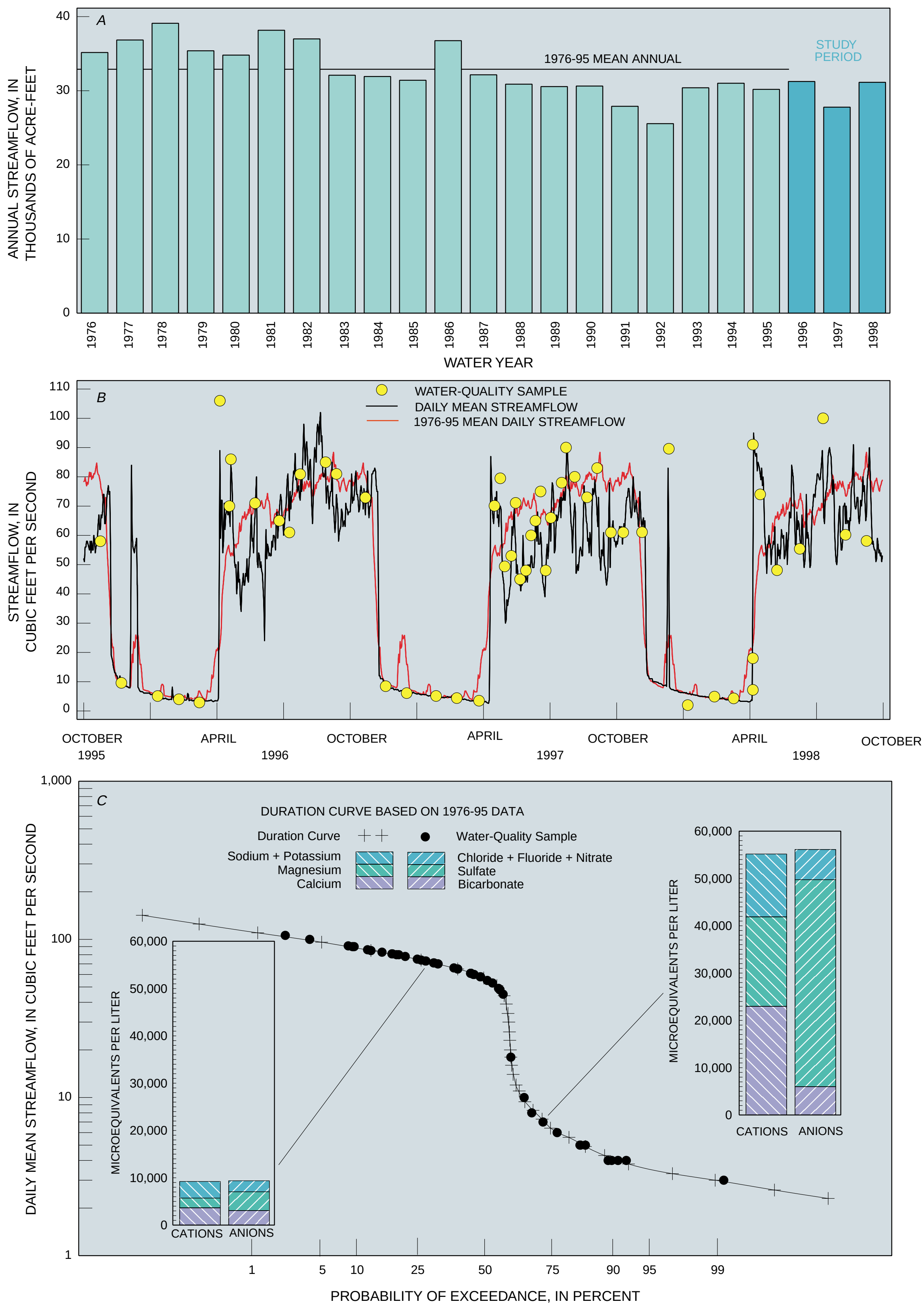

Figure 39. (*A*) Historical and study period annual streamflow, (*B*) daily mean streamflow and time distribution of water-quality samples, and (*C*) flow-duration curve with streamflow distribution of water-quality samples and examples of major-ion chemistry for Reed Wash near Mack, station 09153290.

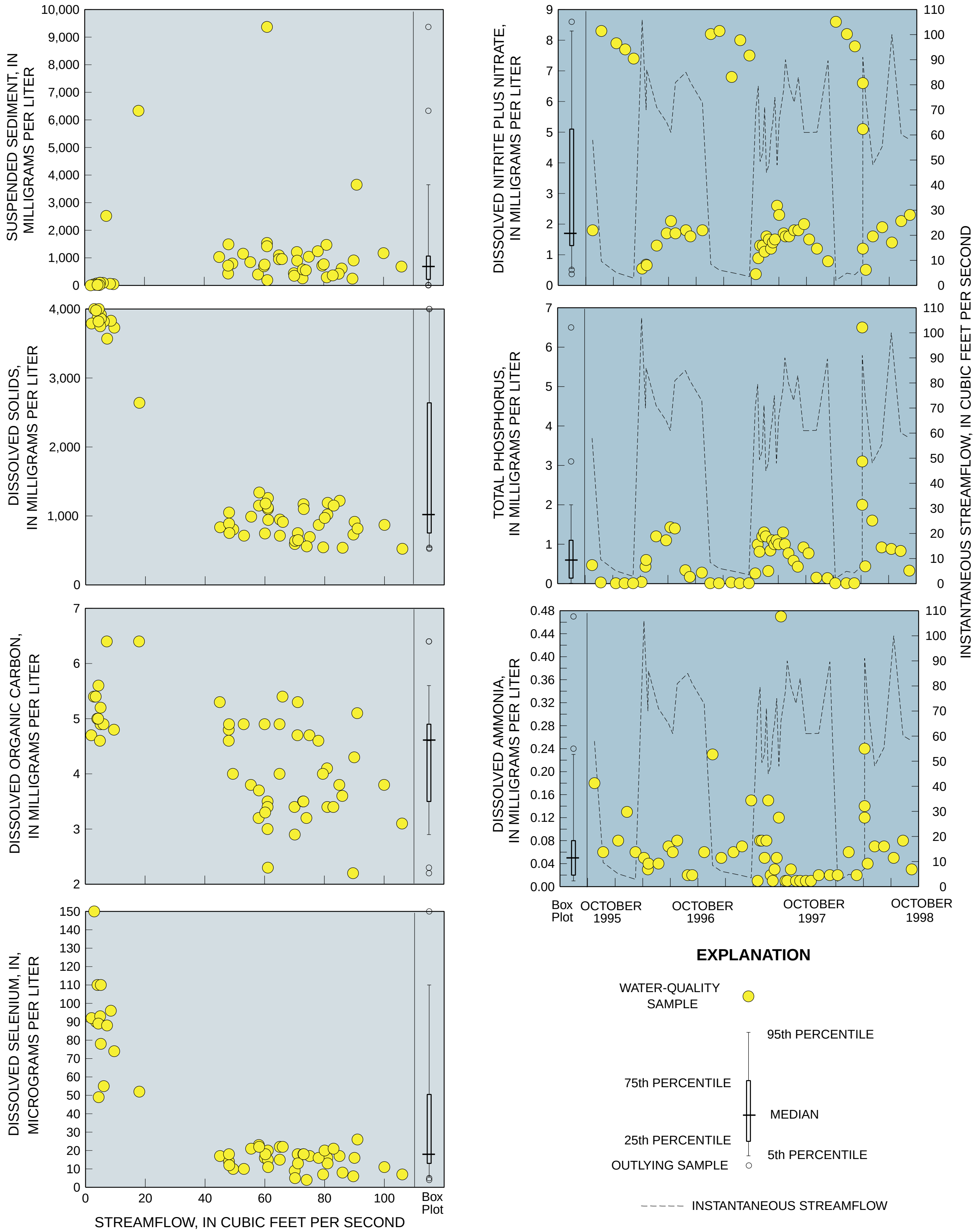

Figure 40. Distribution of selected water-quality constituents relative to streamflow and time for Reed Wash near Mack, station 09153290.

detected. Selenium concentrations during base-flow conditions exceeded 50 μg/L. The bimodal distribution of concentrations relating to the two flow conditions is evident in the graphs of figure 40. Nitrite plus nitrate concentrations were highest during the base-flow periods, whereas total phosphorus concentrations were highest during the irrigation periods. Ranges of concentrations for other constituents are as follows.

Constituent	Minimum (milligrams per liter; <, less than; >,greater than)	Median	Maximum
Suspended organic carbon	0.2	4.5	>25
Dissolved nitrite	<0.01	0.03	0.08
Dissolved ammonia plus organic nitrogen	<0.2	0.3	2
Dissolved phosphorus	<0.01	0.04	0.29
Dissolved orthophosphate	<0.01	0.05	0.28
pH (standard units)	7.7	8.0	8.3
Dissolved oxygen	7.0	8.6	13

Measured values for pH and concentrations of dissolved oxygen, ammonia, nitrite, and nitrate were within the State instream water-quality standards. Water quality in the agricultural area represented by Reed Wash can be summarized as having managed streamflow, high sediment, dissolved solids typically in the thousands of milligrams per liter range, and the potential for elevated selenium concentrations.

Colorado River near Colorado-Utah State Line, Station 09163500

The site near the State line is the integrator site for the entire study unit and defines the water quality leaving the UCOL. The site is located in the Colorado Plateau (fig. 41) in one of the many canyons along the Colorado River. Drainage area is 17,843 square miles, and elevations range from about 4,325 to 14,270 feet. Precipitation ranges from less than 10 to more than 50 inches, and the average is 22.1 inches.

Daily mean water-temperature data collected by other programs of the U.S. Geological Survey during 1997 are shown in the frequency graph in figure 41. The daily mean temperatures are fairly uniformly distributed about a median of 9.5°C and a mean of 10.5°C. Diurnal changes ranged from 0°C in December to 2.5°C in May. An example of summer diurnal changes is shown in figure 41.

Streamflow data have been collected at this site since 1951. The 1970–98 annual streamflow is shown in figure 42*A*. Annual streamflows during the study period were greater than the long-term annual mean. The daily streamflow hydrograph and the time distribution of water-quality samples are shown in figure 42*B*. It is apparent how much larger the streamflows in water year 1997 were compared to the long-term mean streamflow. The annual snowmelt runoff peak dominates the hydrology at this site. Water-quality sampling began for the project in October 1995 and continued through September 1998, resulting in 42 samples. Historical water-quality data collected by other programs are available for this site in the USGS NWIS data base. The daily mean flow-duration curve for 1970–95 is shown in figure 42*C* along with the streamflow distribution of water-quality samples and examples of the major-ion chemistry. Low-flow conditions did not occur at this site during the study period; therefore, water-quality samples could not be collected to represent the low-flow portion of the duration curve. The snowmelt dilution of major ions is apparent by comparing the bar chart on the right to the bar chart on the left in figure 42*C*. The water type at this site for the example streamflows is a mixture as no single anion or cation is dominant.

Concentrations of selected constituents and properties are plotted relative to discharge in figure 43. Concentrations on the rising limb for suspended sediment, dissolved organic carbon, and total phosphorus were commonly greater than concentrations on the falling limb/base flow of the annual peak. No hysteresis in concentrations is apparent for dissolved solids or nitrite plus nitrate; however, the snowmelt dilution of the concentrations is evident. Ranges of concentrations for other constituents are listed below.

Constituent	Minimum (milligrams per liter; <, less than)	Median	Maximum
Suspended organic carbon	0.3	1.2	6.9
Dissolved ammonia	<0.02	0.03	0.09
Dissolved nitrite	<0.01	0.01	0.06
Dissolved ammonia plus organic nitrogen	<0.2	<0.2	0.3
Dissolved phosphorus	<0.01	<0.01	0.03
Dissolved orthophosphate	<0.01	0.01	0.03

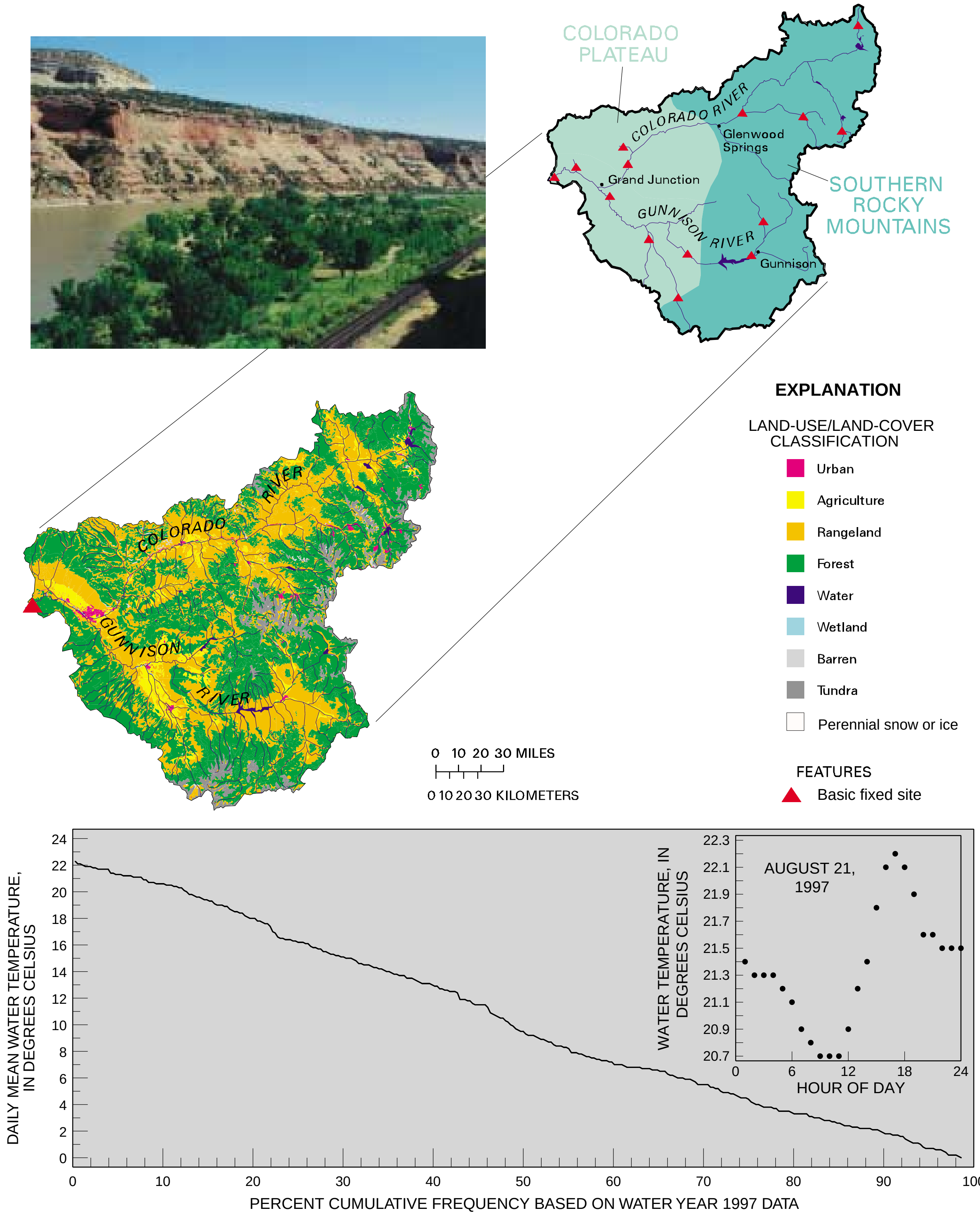

Figure 41. Photograph showing area near site, map showing land use/land cover of basin, and graphs showing frequency curve of daily mean temperature and example of diurnal temperature for Colorado River near Colorado-Utah State line, station 09163500. Photograph by Jeffrey Foster.

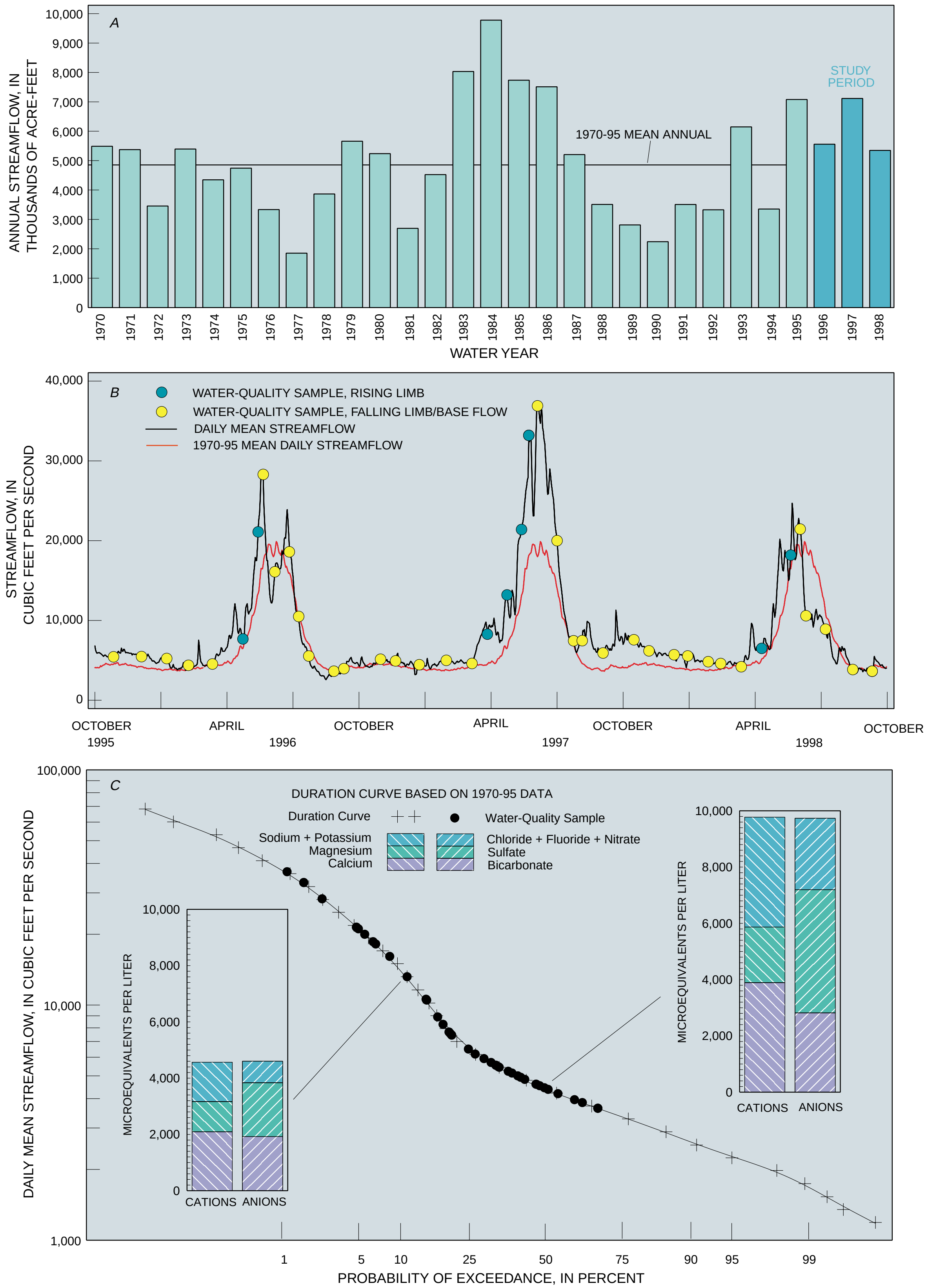

Figure 42. (*A*) Historical and study period annual streamflow, (*B*) daily mean streamflow and time distribution of water-quality samples, and (*C*) flow-duration curve with streamflow distribution of water-quality samples and examples of major-ion chemistry for Colorado River near Colorado-Utah State line, station 09163500.

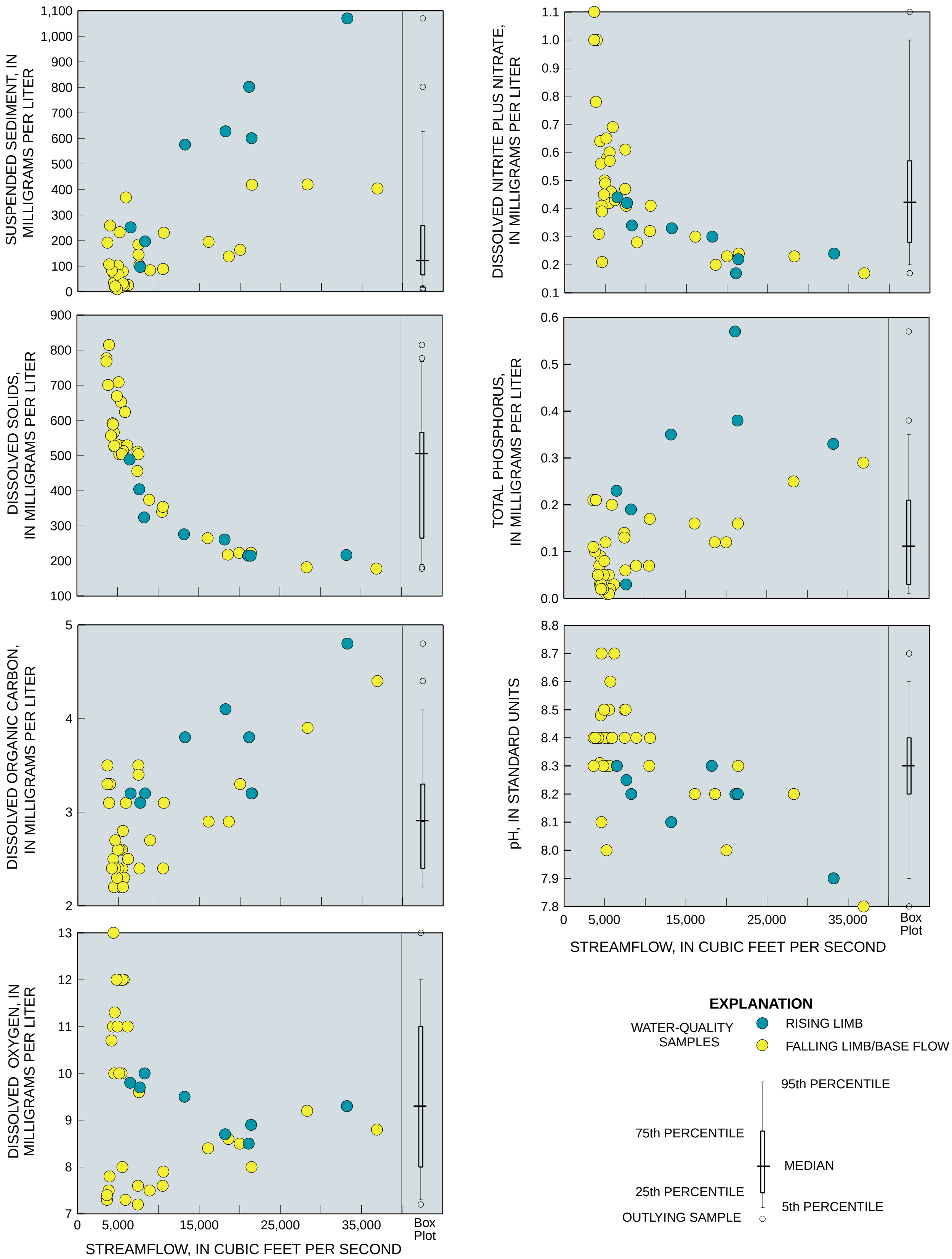

Figure 43. Distribution of selected water-quality constituents and properties relative to streamflow for Colorado River near Colorado-Utah State line, station 09163500.

Concentrations of dissolved oxygen were greater than the minimum State instream standard of 7.0 mg/L. Values of pH met the State instream standard of 6.5 to 9.0. Only one sample for nitrite (0.06 mg/L) exceeded the Sate instream standard of 0.05 mg/L. Un-ionized ammonia as computed by ammonia, pH, and temperature were less than the 0.06-mg/L chronic instream standard. Water quality at this site represents an integration of the land use/land cover, geology, and physiography of a large watershed, but the relation of concentration to streamflow for many constituents is well defined.

SUMMARY AND CONCLUSIONS

The USGS Upper Colorado River Basin National Water-Quality Assessment study unit consists of the watershed of the Colorado River upstream from the Colorado-Utah State line. The basin encompasses 17,843 square miles in two major physiographic provinces, the Southern Rocky Mountains and the Colorado Plateau. The landscape changes from alpine areas in the mountainous eastern part of the basin to arid, desertlike areas in the west. Forest and rangeland are the principal land uses/land covers in the basin. Irrigated agriculture is a dominant use in the lower Gunnison River and Grand Junction areas. Mining and ranching are historically the primary land uses in the mountainous areas, but in many places these uses are yielding to urban development and recreation land use.

Planning of the UCOL surface-water network began in 1994. Water-quality sampling began at 3 of the UCOL basic-fixed sites in water year 1995, and full implementation of sampling at all 14 network sites began in water year 1996. Data collection continued through water year 1998 and resulted in 660 samples at the 14 sites in the network. The previous sections of this report have provided descriptions, summaries, and interpretation of data on the water temperature, streamflow, and water-quality conditions for each of the network sites. Although detailed site-to-site comparisons are beyond the scope of this report, some generalized summaries can be stated.

Snowmelt runoff dominates the hydrology in most of the basin, but water management for irrigation, storage, and transmountain diversions substantially changes the annual runoff characteristics in many areas. As streamflow moved from the Southern Rocky Mountains to the Colorado Plateau and out of the basin, numerous changes to the chemistry of the water were observed. Suspended-sediment concentrations increased from one to hundreds of milligrams per liter. Dissolved solids increased from tens to hundreds of milligrams per liter, with thousands of milligrams per liter measured in tributaries in the plateau areas. The percentage of magnesium, sodium, sulfate, and chloride in the water increased from the typical calcium-bicarbonate water type of the mountains. Nitrate concentrations of hundreths of milligrams per liter in background areas of the mountains increased to tenths of milligrams per liter in urban areas, and some agricultural areas had concentrations in the milligrams per liter range. Phosphorus concentrations also increased, but to a lesser extent than nitrate. Trace elements, while typically low in many areas, can increase to thousands of micrograms per liter in areas historically mined within the basin.

In most instances, instream water-quality standards as set by the State of Colorado were met for the stream reaches studied. The greatest exception was trace-element concentrations in some mining-affected areas.

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