

Summary of Biological and Contaminant Investigations Related to Stream Water Quality and Environmental Setting in the Upper Colorado River Basin, 1938–95

By JEFFREY R. DEACON and VERLIN C. STEPHENS

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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 a specific contamination problem; 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 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 60 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 60 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 AND VERTICAL DATUM

	Multiply	By	To obtain
	foot (ft)	0.3048	meter
	inch per year (in/yr)	25.4	millimeter per year
	mile (mi)	1.609	kilometer
	square mile (mi ²)	2.59	square kilometer

Degree Fahrenheit (°F) may be converted to degree Celsius (°C) by using the following equation:

$$^{\circ}\text{C} = 5/9 (^{\circ}\text{F} - 32)$$

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

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By Jeffrey R. Deacon *and* Verlin C. Stephens

ABSTRACT

As part of the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) program, an inventory of the biological and contaminant investigations for the Upper Colorado River Basin study unit was conducted. To enhance the sampling design for the biological component of the program, previous studies about the ecology of aquatic organisms and contaminants were compiled from computerized literature searches of biological data bases and by contacting other Federal, State, and local agencies. Biological and contaminant investigations that have been conducted throughout the basin since 1938 were categorized according to four general categories of biological investigations and two categories of contaminant investigations: algal communities, macroinvertebrate communities, fish communities, habitat characterization, contaminants in organism tissue, and contaminants in bed sediment. The studies were identified by their locations in two physiographic provinces, the Southern Rocky Mountains and the Colorado Plateau, and by the predominant land use in the area of the investigation. Studies on algal communities and contaminants in organism tissue and in bed sediment are limited throughout the basin. Studies on macroinvertebrate and fish communities and habitat characterization are the most abundant in the study unit. Natural and human factors can affect biological communities and their composition. Natural factors that affect background water-quality conditions are physiography, climate, geology, and soils. Algae, macroinvertebrates, and fish that are present in the

Southern Rocky Mountains and the Colorado Plateau physiographic provinces vary with altitude and physical environment. Green algae and diatoms are predominant in the higher altitude streams, and blue-green, golden-brown, and green algae are predominant in the lower altitude streams. Caddisflies, mayflies, and stoneflies are the dominant macroinvertebrates in the higher altitudes, whereas aquatic worms, leeches, and dragonflies are more common at lower altitudes. Cold-water species, such as trout, are present at the higher altitudes, and warmer water species, such as catfish, carp, and suckers, are predominant at the lower altitudes. Human factors that affect water-quality conditions are mining, urbanization, agriculture, and hydrologic modifications. Mining areas can be depleted of organisms or contain a low diversity of species. Acid-tolerant algae, such as certain species of green algae and diatoms, and metal-tolerant caddisflies can be present in mining areas. Urbanized areas are located in the Southern Rocky Mountains and in the Colorado Plateau and contain species characteristic of the physiographic provinces. Agricultural areas contain species, such as blue-green algae, aquatic worms, suckers, and carp, that can tolerate organic enrichment, sedimentation, and lower concentrations of dissolved oxygen.

INTRODUCTION

The National Water-Quality Assessment (NAWQA) program is a long-term program by the U.S. Geological Survey (USGS) designed to describe

the status and trends in the quality of the Nation's surface- and ground-water resources and to provide an understanding of the natural and human factors that can affect the quality of these resources (Leahy and others, 1990). The program, which consists of 60 study units, is interdisciplinary and integrates chemical, physical, and biological data to assess the Nation's water quality at local, regional, and national levels (Meador and Gurtz, 1994). In 1991, the USGS began full implementation of the NAWQA program. The Upper Colorado River Basin (UCOL) study unit was in the second group of 20 NAWQA study units selected in 1994 for implementation of the program. The overall goals of the NAWQA program are to (1) provide a nationally consistent description of current water-quality conditions for a large part of the Nation's water resources; (2) define long-term trends in water quality; and (3) identify, describe, and explain, to the extent possible, the major factors that affect water-quality conditions and trends.

The program focuses on a broad spectrum of constituents and sampling approaches for surface water, including information on (1) biological investigations (algae, macroinvertebrate, and fish communities); (2) stream habitat characterization (Gurtz, 1994); and (3) trace-element and organic contaminants in organism tissue and bed sediment. This information is integrated, as much as possible, with the surface-water-quality data that include discharge, specific conductance, temperature, pH, dissolved oxygen and concentrations of suspended sediment, inorganic constituents (major ions, nutrients, and trace elements), radionuclides, and organic contaminants in water.

The ecology of biological communities and contaminants in organism tissue and in bed sediment are two biological components used in the NAWQA program to provide multiple lines of evidence (chemical, physical, and biological) for the assessment of water quality. By linking the various components of water quality at various spatial scales, the NAWQA program can provide the kinds of information needed to generate policies and management actions that improve the Nation's water resources (Meador and Gurtz, 1994). The resulting information then can be used to design biological sampling strategies to fill in gaps in the biological and contaminant data and to effectively address critical water-quality issues in the UCOL study unit.

Biological components are useful indicators of water quality because biota respond to a variety of natural and human environmental effects, including stresses from point and nonpoint sources, toxic effluents, enriched organic effluents, extreme flows, and habitat degradation. Biota also provide spatial and temporal information and, in many studies, are more sensitive indicators of environmental change than are other media (Gurtz, 1994). Biological communities, including algae, macroinvertebrate, and fish communities; habitat characterization; and contaminants in organism tissue and in bed sediment are factors assessed by the UCOL study unit. The first step in the implementation of the biological component of the NAWQA program for the UCOL study unit is an inventory of existing biological and contaminant information.

Purpose and Scope

This report (1) identifies sources of biological and contaminant information in the UCOL study unit; (2) broadly summarizes existing information about biological and contaminant investigations; (3) discusses gaps in biological and contaminant information for the basin; and (4) categorizes this information according to the environmental setting.

The data source for this report was a subset of references compiled from a computerized bibliographic search of 21 data bases (Bauch and Apodaca, 1995). Additional information was provided by several Federal and State agencies, including the U.S. Fish and Wildlife Service, U.S. Environmental Protection Agency, National Park Service, Bureau of Reclamation, Colorado Division of Wildlife, Colorado Water Resources Research Institute; and by local universities.

Description of Study Unit

The UCOL study unit has varied climate, geology, topography, and hydrology. The study unit has a drainage area of about 17,800 mi². The primary river in the study unit, the Colorado River, originates in the mountains of central Colorado and flows about 230 mi southwest into Utah (fig. 1). The headwaters of the Colorado River and most of its tributaries originate in the mountains that form the eastern and

southern boundaries of the study unit (Driver, 1994). The major tributaries to the Colorado River in the study unit are the Blue, Eagle, Roaring Fork, and Gunnison Rivers.

The UCOL study unit is divided almost equally into two physiographic provinces—the Southern

Rocky Mountains in the eastern part and the Colorado Plateau in the western part (Apodaca and others, 1996). The climate varies from alpine conditions in the east to semiarid in the west. Precipitation is highly variable throughout the study unit and ranges from more than 50 in/yr in the higher altitudes to less than

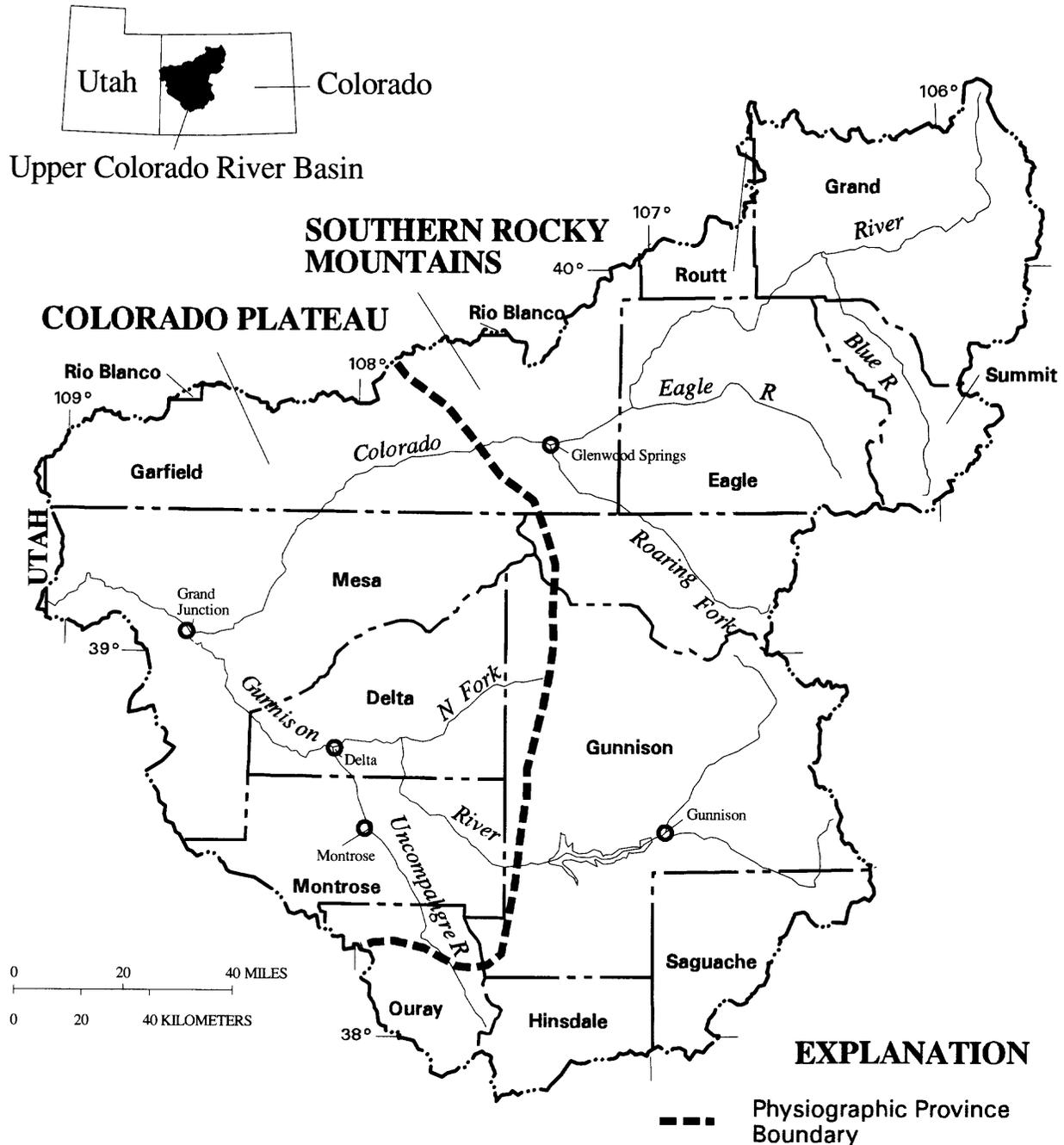


Figure 1. Location of the Upper Colorado River Basin study unit, physiographic provinces, and major streams.

10 in/yr in the lower altitudes of the western valleys. Temperature in the study unit ranges from -30 to 110°F. The geology primarily consists of rocks of Precambrian age, stratified sedimentary rocks, and alluvial deposits. The topography in the eastern part of the study unit consists of north-northwest-trending mountains that range in altitude from 11,000 to more than 14,000 ft. The western part of the study unit generally consists of high plateaus with altitudes ranging from 5,500 to 8,500 ft, bordered by steep cliffs along valleys. The altitude of the valleys near the Colorado-Utah State line is about 4,300 ft.

Predominant land uses in the UCOL study unit are mining, urbanization, and agriculture. Past and present mining activities have included the extraction of metals (copper, gold, lead, molybdenum, nickel, silver, vanadium, and zinc) and energy fuels (coal, gas, oil, and uranium). Urbanization is one of the smaller land uses in the mostly rural areas of the study unit. A number of urban areas are associated with growth resulting from the expansion of the ski industry and from energy development in the 1980's (Apodaca and others, 1996). Agriculture is the traditional land use in the Colorado Plateau and includes production of crops such as alfalfa, fruits, grains, hay, and vegetables.

Hydrologic modifications occur throughout the study unit. The principal water use in the UCOL study unit is irrigation, which accounts for about 97 percent of the offstream-water use. The remaining 3 percent is accounted for by the following, in order of decreasing water use: livestock, domestic, power, industrial, commercial, and mining (Apodaca and others, 1996).

Acknowledgments

The authors thank April Kobayashi and Joyce Dickey, USGS, for their assistance in retrieval of information. The authors also thank the members of the UCOL NAWQA Liaison Committee for their cooperation in providing information and data about the basin. We would especially like to thank Richard Krueger from the U.S. Fish and Wildlife Service, Barbara Horn from the Colorado Division of Wildlife, and Lynn Cudlip from the National Park Service for providing information and data for this report.

INVENTORY OF BIOLOGICAL AND CONTAMINANT INVESTIGATIONS OF STREAMS

One-hundred-twenty-six biological and contaminant investigations that relate to water quality in the UCOL study unit were grouped into six categories corresponding to the biological components of the NAWQA program: algae, macroinvertebrates, fish, habitat characterization, contaminants in organism tissue, and contaminants in bed sediments. Information about each biological and contaminant component is essential to understand water quality in the study unit. Biological and contaminant investigations in the study unit are listed by the category of investigation and their locations in the two physiographic provinces (table 1). Information about the predominant land use, water-chemistry data, and general description and locations of biological or contaminant investigations also are listed in table 1. Studies that had land-use information from sampling sites on streams that were unaffected by human activity or conducted to establish baseline data were defined as background. Studies that had sampling sites in more than one land-use category (for example, in mining, urban, and agricultural land uses) were defined as mixed land-use studies. Studies that had stream reaches directly affected by various water uses or by hydrologic modification, such as dams and canals, also were categorized in the land-use column (Hyd) in table 1. Several of the studies were not applicable (NA) to a predominant land use, but contained pertinent, generalized information about biological characteristics of the study unit. If an investigation had water-chemistry data collected in addition to the biological and contaminant data, an X was placed in the "Water-chemistry data" column in table 1. This information was provided because integration of biological and water-chemistry data can be a useful tool in water-quality analysis and because integrated information is a major component of the NAWQA program.

An important aspect of the NAWQA program is to understand the effects of land use on water quality. The objectives of the studies listed in table 1 might not relate to the effects of land use on water quality; but, the inventory of these studies according to land use can help in the overall water-quality sampling design of the UCOL study unit and in filling in some of the gaps in biological data. Data collected during many of the investigations were from both physiographic

Table 1. Literature citations indexed by type of biological or contaminant investigation, physiographic province, and predominant land use in the Upper Colorado River Basin study unit

[Mixed, more than one type of land use (mining, urban, agriculture); Hyd, water use or hydrologic modification; NA, not applicable to a predominant land use or sampling sites in figs. 2-7.]

Citation no. (figs. 2-7)	Reference citation	Type of biological or contaminant investigation							Physiographic province			Pre-dominant land use	Water-chemistry data	General description and location of biological or contaminant investigation
		Algal communities	Macro-invertebrate communities	Fish communities	Habitat characterization	Contaminants in organism tissue	Contaminants in bed sediment	Southern Rocky Mountains	Colorado Plateau					
1	Anderson (1994)			X	X				X	X	Mixed		Management action plan for potential reintroduction of Colorado squawfish and razorback sucker; sites on Colorado River from Glenwood Springs to Grand Junction	
2	Andrews (1970)			X						X	NA		Life history study of the fathead minnow	
3	Apley (1982)	X	X			X			X		Mining	X	Effects of Powderhorn gas and oil operation; sites on Deldorado, North Beaver, Road Beaver, and Cebolla Creeks (streams south of Blue Mesa Reservoir)	
4	Archer and others (1985)			X						X	Mixed		Information on endangered and threatened fish; sites on Colorado River from Grand Junction to the Utah State line	
5	Bauman and others (1977)		X						X		NA		Basinwide information on stoneflies of the Rocky Mountains	
6	Bechtel and Ecology Consultants, Inc. (1975)	X	X	X						X	Background		Baseline survey on aquatic life of Parachute Creek	
7	Behnke (1985)			X					X	X	Hyd		Fisheries impact analysis for year-round flow depletion from the Gunnison River; sites on Gunnison River from Blue Mesa Reservoir to confluence of Uncompahgre River	

Table 1. Literature citations indexed by type of biological or contaminant investigation, physiographic province, and predominant land use in the Upper Colorado River Basin study unit—Continued

[Mixed, more than one type of land use (mining, urban, agriculture); Hyd, water use or hydrologic modification; NA, not applicable to a predominant land use or sampling sites in figs. 2-7.]

Citation no. (figs. 2-7)	Reference citation	Type of biological or contaminant investigation					Physiographic province			Pre-dominant land use	Water-chemistry data	General description and location of biological or contaminant investigation
		Algal communities	Macro-invertebrate communities	Fish communities	Habitat characterization	Contaminants in organism tissue	Contaminants in bed sediment	Southern Rocky Mountains	Colorado Plateau			
8	Behnke (1986)		X	X	X			X	X	Hyd		Potential effects of reduced winter flows on fisheries in the Gunnison River; sites on Gunnison River from Blue Mesa Reservoir to confluence with North Fork of the Gunnison
9	Behnke and Benson (1980)		X	X	X			X	X	NA		Information on endangered and threatened fish; no physical sampling sites
10	Burdick (1992)		X	X	X			X	X	NA		Information on restoration of the razorback sucker; no physical sampling sites
11	Burdick (1995)		X	X	X			X	X	Mixed		Fish population information; sites on the Gunnison River from confluence with Colorado River upstream to North and South Fork confluence of Gunnison River
12	Burdick and Kaeding (1990)		X	X	X			X	X	NA		Information on the recovery of the Colorado squawfish; no physical sampling sites
13	Bureau of Land Management (1976)		X	X	X			X	X	NA		Status of endangered and threatened fish; no physical sampling sites
14	Burkhard (1967)		X	X	X			X	X	Background		Effects of channelization on the trout fishery of Tomichi Creek
15	Burkhard (1977)		X	X	X			X	X	Background		Information on fish populations; sites on the Taylor River

Table 1. Literature citations indexed by type of biological or contaminant investigation, physiographic province, and predominant land use in the Upper Colorado River Basin study unit—Continued

[Mixed, more than one type of land use (mining, urban, agriculture); Hyd, water use or hydrologic modification; NA, not applicable to a predominant land use or sampling sites in figs. 2-7.]

Citation no. (figs. 2-7)	Reference citation	Type of biological or contaminant investigation					Physiographic province			General description and location of biological or contaminant investigation		
		Algal communities	Macroinvertebrate communities	Fish communities	Habitat characterization	Contaminants in organism tissue	Contaminants in bed sediment	Southern Rocky Mountains	Colorado Plateau		Predominant land use	Water-chemistry data
16	Burkhard and Lytle (1978)		X	X	X			X	X	Hyd		Effects of Colorado River storage project on fish and wildlife resources; sites on Colorado River between Glenwood Springs and De Beque and on West Divide, Dry Hollow, Cache, and Battlement Creeks
17	Burkhard and others (1979)		X	X	X				X	Background		Fish and wildlife analysis for the Grand Mesa watershed; sites on the Gunnison River and Grand Mesa Lakes
18	Butler and others (1991)					X			X	Agriculture	X	Irrigation drainage effects; sites in lower Gunnison and Uncompahgre River Basins
19	Butler and others (1994)					X		X	X	Agriculture	X	Irrigation drainage effects; sites in the Grand Valley and lower Gunnison, and Uncompahgre River Basins
20	Campbell-Osmundson (1989)					X			X	Mixed		Heavy metal analysis and comparison--Colorado squawfish and rainbow trout; Hotchkiss National Fish Hatchery
21	Carlson and Muth (1989)			X				X	X	NA		Basinwide information on historical distribution of fish
22	Colburn (1981)	X				X		X		Mining	X	Aquatic insects as measures of trace elements; sites on Slate River and on Coal Creek
23	Colorado Department of Health (1975)	X						X		Background	X	Baseline data for upper Gunnison River Basin; sites on Taylor, East, Slate, and Gunnison Rivers and on Tomichi, Quartz, Hensen, Cement, Los Pinos, and Ohio Creeks

Table 1. Literature citations indexed by type of biological or contaminant investigation, physiographic province, and predominant land use in the Upper Colorado River Basin study unit—Continued

[Mixed, more than one type of land use (mining, urban, agriculture); Hyd, water use or hydrologic modification; NA, not applicable to a predominant land use or sampling sites in figs. 2-7.]

Citation no. (figs. 2-7)	Reference citation	Type of biological or contaminant investigation					Physiographic province			Pre-dominant land use	Water-chemistry data	General description and location of biological or contaminant investigation
		Algal communities	Macro-invertebrate communities	Fish communities	Habitat characterization	Contaminants in organism tissue	Contaminants in bed sediment	Southern Rocky Mountains	Colorado Plateau			
24	Colorado Department of Health (1976)	X	X			X	X	X	X	Mixed	X	Water quality of the Colorado River; 23 sites between Dotsero and Utah State line
25	Colorado Division of Wildlife (1975)		X	X	X			X	X	Background		Fish and wildlife analysis for the Dallas Creek watershed; sites on Uncompangre River and on Dallas, Pleasant Valley, and Cow Creeks
26	Cope (1977)			X				X		NA		Index to fishery publications
27	Cudlip (1992)		X					X		Background	X	Baseline data for upper Gunnison Basin; sites on Taylor, East, Slate, and Gunnison Rivers and on Tomichi, Quartz, and Cochetopa Creeks
28	Cudlip and others (1987)	X	X	X				X		Hyd	X	Blue Mesa Reservoir water quality; sites on Blue Mesa Reservoir and tributaries
29	Dufford and others (1987)	X							X	Hyd		Responses of algae to regulation; sites on Colorado, Williams Fork, Blue, and Fryingpan Rivers and on Rifle Creek
30	Everhart and Seaman (1971)			X				X		NA		Basinwide information on fish
31	Feast (1954)			X				X		Hyd		Fish management investigations; sites on Grand Lake, Shadow Mountain, and Granby Reservoirs

Table 1. Literature citations indexed by type of biological or contaminant investigation, physiographic province, and predominant land use in the Upper Colorado River Basin study unit—Continued

[Mixed, more than one type of land use (mining, urban, agriculture); Hyd, water use or hydrologic modification; NA, not applicable to a predominant land use or sampling sites in figs. 2-7.]

Citation no. (figs. 2-7)	Type of biological or contaminant investigation				Physiographic province			Pre-dominant land use	Water-chemistry data	General description and location of biological or contaminant investigation		
	Reference citation	Algal communities	Macro-invertebrate communities	Fish communities	Habitat characterization	Contaminants in organism tissue	Contaminants in bed sediment				Southern Rocky Mountains	Colorado Plateau
32	Federal Water Pollution Control Administration (1968)		X	X				X	X	Mixed	X	Effects of municipal and industrial waste on aquatic life; sites on Colorado, Eagle, Roaring Fork, Gunnison, Uncompahgre, North Fork of the Gunnison, Cimarron, and Slate Rivers and on Tenmile Creek
33	Finnell (1961-63)			X	X			X		Hyd		Fish management investigations; sites on Granby Reservoir
34	Flinckinger and others (1973)		X	X					X	Mixed		Macroinvertebrate and fish information; sites on the Colorado River near Rifle
35	Four Corners Environmental Research Institute (1976)	X		X				X	X	Mixed	X	Effects of municipal and industrial waste on aquatic life; sites on Colorado, Eagle, Roaring Fork, Gunnison, Uncompahgre, North Fork of the Gunnison, Cimarron, and Slate Rivers and on Tenmile Creek
36	Goettl (1970)		X	X				X		Mining	X	Effects of mineral mining; sites on Lake Fork of the Gunnison River and on Hensen and Tenmile Creeks
37	Goettl and Davies (1975)							X		Mining	X	Effects of mineral mining; sites on Williams Fork River and on Tenmile Creek
38	Goettl and Davies (1978)							X		Mining	X	Effects of mineral mining; sites on Williams Fork River
39	Goettl and Davies (1979)							X		Mining	X	Effects of mineral mining; sites on Williams Fork River

Table 1. Literature citations indexed by type of biological or contaminant investigation, physiographic province, and predominant land use in the Upper Colorado River Basin study unit—Continued

[Mixed, more than one type of land use (mining, urban, agriculture); Hyd, water use or hydrologic modification; NA, not applicable to a predominant land use or sampling sites in figs. 2-7.]

Citation no. (figs. 2-7)	Reference citation	Type of biological or contaminant investigation					Physiographic province			General description and location of biological or contaminant investigation		
		Algal communities	Macroinvertebrate communities	Fish communities	Habitat characterization	Contaminants in organism tissue	Contaminants in bed sediment	Southern Rocky Mountains	Colorado Plateau		Predominant land use	Water chemistry data
40	Goettl and Sinley (1970)		X	X		X		X		Mining	X	Effects of mineral mining; sites on Lake Fork of the Gunnison River and on Hensen and Tenmile Creeks
41	Goettl and others (1972)					X		X		Mining	X	Effects of mineral mining; sites on Lake Fork of the Gunnison River and on Tenmile Creek
42	Hawkins and Nesler (1991)			X				X	X	NA		Basinwide information on nonnative fishes
43	Haynes and others (1984)		X	X	X				X	Mixed		Information on the distribution of larval Colorado squawfish; sites on Colorado and Gunnison Rivers near Grand Junction
44	Haynes and Muth (1982)		X	X	X				X	Mixed		Habitat requirements for the Colorado squawfish and humpback chubs; sites on Colorado River from Loma to Utah State line
45	Haynes and Muth (1984)		X	X	X				X	Mixed		Habitat requirements for the Colorado squawfish and humpback chubs; sites on Colorado River from Loma to Utah State line
46	Haynes and others (1985)		X	X	X				X	Mixed		Habitat requirements for the Colorado squawfish and humpback chubs; sites on Colorado River from Loma to Utah State line
47	Haynes and others (1982)		X	X	X			X	X	NA		Life history of the reddsider shiner; no physical sampling sites
48	Hickman (1983)		X	X	X				X	NA		Effects of habitat alteration on endangered fishes; no physical sampling sites

Table 1. Literature citations indexed by type of biological or contaminant investigation, physiographic province, and predominant land use in the Upper Colorado River Basin study unit—Continued

[Mixed, more than one type of land use (mining, urban, agriculture); Hyd, water use or hydrologic modification; NA, not applicable to a predominant land use or sampling sites in figs. 2-7.]

Citation no. (figs. 2-7)	Reference citation	Type of biological or contaminant investigation							Physiographic province			General description and location of biological or contaminant investigation
		Algal communities	Macroinvertebrate communities	Fish communities	Habitat characterization	Contaminants in organism tissue	Contaminants in bed sediment	Southern Rocky Mountains	Colorado Plateau	Predominant land use	Water-chemistry data	
49	Holden (1968)			X					X	Mixed		Information on roundtail chubs; site on Colorado River near De Beque
50	Holden (1977)			X	X				X	NA		Habitat requirements of juvenile Colorado squawfish; no physical sampling sites
51	Holden and others (1981)	X	X	X	X				X	Urban		Information on aquatic biology; sites on Gunnison River near Delta and on Salt Creek near Mack
52	Holden and Stalmaker (1975)			X	X				X	NA		Basinwide information on fish distribution
53	Horn (1990)		X	X				X		Mining	X	Effects of Eagle Mine on water quality; sites on Eagle River from headwaters to town of Edwards and on Homestake, Two Elk, and Cross Creeks
54	Horn and Woodling (1991)		X	X				X		Mining	X	Effects of Eagle Mine on water quality; sites on Eagle River from headwaters to town of Edwards and on Homestake, Two Elk, and Cross Creeks
55	Hurlbut (1990)		X			X		X		Mining	X	Effects of heavy metals on macroinvertebrate communities; sites on Peru and Deer Creeks
56	Joseph and others (1977)			X	X			X	X	NA		Status of endangered and threatened fishes; no physical sampling sites
57	Kaeding and Osmundson (1989)			X	X				X	Hyd		Flow recommendations for Colorado squawfish habitat; sites on Colorado River between Palisade and confluence of Gunnison River (15-mile reach)

Table 1. Literature citations indexed by type of biological or contaminant investigation, physiographic province, and predominant land use in the Upper Colorado River Basin study unit—Continued

[Mixed, more than one type of land use (mining, urban, agriculture); Hyd, water use or hydrologic modification; NA, not applicable to a predominant land use or sampling sites in figs. 2-7.]

Citation no. (figs. 2-7)	Reference citation	Type of biological or contaminant investigation							Physiographic province			General description and location of biological or contaminant investigation
		Algal communities	Macroinvertebrate communities	Fish communities	Habitat characterization	Contaminants in organism tissue	Contaminants in bed sediment	Southern Rocky Mountains	Colorado Plateau	Pre-dominant land use	Water-chemistry data	
58	Kidd (1977)		X	X				X	Background			Information on endangered and threatened fish; sites on the Colorado and Gunnison Rivers
59	Kinnear and Vincent (1967)			X	X			X	Background			Information on fish and fish habitat; sites on the Gunnison River in the Black Canyon of the Gunnison National Monument
60	Kittel and others (1994)				X			X	NA			Basinwide information on riparian vegetation
61	Knight (1965)		X		X			X	Background			Studies on stoneflies; sites on the South Fork of the Gunnison River and tributaries
62	Knight and Argyle (1962)		X		X			X	Background	X		Water quality of stream entering Blue Mesa Reservoir; sites on Soap Creek
63	Krueger (1988)					X			Mixed			Colorado squawfish heavy metal analysis; site on Colorado River at Grand Junction
64	Krueger and others (1991)					X		X	Mixed			Contaminants in fish tissue; sites on Colorado River near Palisade, near Loma, and near Utah State line
65	Kunkle and others (1983)					X		X	Background			Metal concentrations in fish; sites on Gunnison River between Gunnison and Blue Mesa Reservoir
66	Kurey (1985)					X			Mixed			Organochlorine contaminants in fish; sites on canals and creeks in the Grand Valley
67	Lemons (1954)			X				X	Mixed			Aquatic life surveys of the Colorado River near Grand Junction
68	Maddux and others (1993)			X	X			X	NA			Information on critical habitat for endangered fish; no physical sampling sites

Table 1. Literature citations indexed by type of biological or contaminant investigation, physiographic province, and predominant land use in the Upper Colorado River Basin study unit—Continued

[Mixed, more than one type of land use (mining, urban, agriculture); Hyd, water use or hydrologic modification; NA, not applicable to a predominant land use or sampling sites in figs. 2-7.]

Citation no. (figs. 2-7)	Reference citation	Type of biological or contaminant investigation					Physiographic province			Pre-dominant land use	Water-chemistry data	General description and location of biological or contaminant investigation	
		Algal communities	Macro-invertebrate communities	Fish communities	Habitat characterization	Contaminants in organism tissue	Contaminants in bed sediment	Southern Rocky Mountains	Colorado Plateau				
69	Mars (1979a)		X	X				X			Urban	X	Water quality of Fraser River; six sites on Fraser River between Winter Park and confluence with Colorado River
70	Mars (1979b)		X	X				X			Urban	X	Water quality of Gore Creek; five sites on Gore Creek between golf course bridge and DOWDS Junction
71	Martin and Prestel (1991)		X	X				X			Mining	X	Effects of Eagle Mine on water quality; sites on Eagle River from headwaters to town of Edwards and on Homestake, Two Elk, and Cross Creeks
72	McAda (1977)			X	X						NA		Life-history study on three species of native Colorado River suckers; no physical sampling sites
73	McAda and others (1994)			X	X						Mixed		Recovery implementation of endangered fish; sites on Colorado River between Grand Junction and Utah State line
74	McAda and Kaeding (1989)			X	X						Hyd		Relations between river discharge and fish; sites on Colorado River between Palisade and Utah State line
75	McAda and Kaeding (1991a)			X	X			X			NA		Effects of the Aspinall Unit projects on endangered fish; no physical sampling sites
76	McAda and Kaeding (1991b)			X	X						Mixed		Information on movements of Colorado squawfish; sites on Colorado River between Palisade and Utah State line
77	McAda and Wydoski (1980)			X	X						NA		Life history of the razorback sucker; no physical sampling sites

Table 1. Literature citations indexed by type of biological or contaminant investigation, physiographic province, and predominant land use in the Upper Colorado River Basin study unit—Continued

[Mixed, more than one type of land use (mining, urban, agriculture); Hyd, water use or hydrologic modification; NA, not applicable to a predominant land use or sampling sites in figs. 2-7.]

Citation no. (figs. 2-7)	Reference citation	Type of biological or contaminant investigation					Physiographic province			Pre-dominant land use	Water-chemistry data	General description and location of biological or contaminant investigation
		Algal communities	Macro-invertebrate communities	Fish communities	Habitat characterization	Contaminants in organism tissue	Contaminants in bed sediment	Southern Rocky Mountains	Colorado Plateau			
78	McKnight and Feder (1984)	X	X				X			Mining	X	Ecological effects of acid conditions; sites on Snake River and on Deer Creek
79	Miller and others (1982)			X			X		X	NA		Basinwide information on fishes of the Upper Colorado River system
80	Natural Energy Resources Company (1987)	X	X	X			X			Hyd	X	Water use effects on water quality; sites on Taylor River
81	Nehring (1980)			X			X			Background		Information on trout populations; sites on Colorado, Frying Pan, and Taylor Rivers
82	Nehring (1986)		X	X			X		X	Background		Stream fisheries investigations; sites on Blue, Colorado, Fryingpan, Gunnison, and Taylor Rivers
83	Nehring (1987)			X			X		X	Background		Stream fisheries investigations; sites on Blue, Colorado, Fryingpan, Gunnison, and Taylor Rivers
84	Nehring (1993)		X	X			X		X	Background		Stream fisheries investigations; sites on Blue, Colorado, Fryingpan, Gunnison, and Taylor Rivers
85	Nehring and Anderson (1983)		X	X			X		X	Background		Stream fisheries investigations; sites on Colorado, Eagle, Fryingpan, Gunnison, and Taylor Rivers
86	Nehring and Anderson (1993)			X		X	X			Mixed		Information on critical salmonid habitat; sites on Blue, Colorado, Fryingpan, Gunnison, and Taylor Rivers
87	Nehring and Thompson (1994)		X	X			X		X	Background		Stream fisheries investigations; sites on Blue, Colorado, Fryingpan, Gunnison, and Taylor Rivers

Table 1. Literature citations indexed by type of biological or contaminant investigation, physiographic province, and predominant land use in the Upper Colorado River Basin study unit—Continued

[Mixed, more than one type of land use (mining, urban, agriculture); Hyd, water use or hydrologic modification; NA, not applicable to a predominant land use or sampling sites in figs. 2-7.]

Citation no. (figs. 2-7)	Reference citation	Type of biological or contaminant investigation							Physiographic province			Pre-dominant land use	Water-chemistry data	General description and location of biological or contaminant investigation
		Algal communities	Macro-invertebrate communities	Fish communities	Habitat characterization	Contaminants in tissue	Contaminants in bed sediment	Southern Rocky Mountains	Colorado Plateau					
88	Nelson and Roline (1995)		X						X			Agriculture		Effects of sediment on macroinvertebrate communities; sites on North Fork of the Gunnison and Gunnison Rivers
89	Nuclear Utilities Service Corporation (1981)		X							X		Urban	X	Biology/water quality related to stream classification; sites on Slate River and on Woods and Washington Gulch Creeks
90	Olive (1953)		X	X						X		NA		Bibliography of the limnology and fishery biology of Colorado
91	Osmundson (1992)					X			X			Mining		Contaminants in biota and sediments; sites on Uncompahgre River and Ridgway Reservoir
92	Osmundson and Kaeding (1989)			X			X					Hyd		Colorado squawfish and razorback sucker (use of the 15-mile reach)
93	Osmundson and Kaeding (1991)			X			X					Hyd		Recommendations for flows of 15-mile reach; sites on Colorado River between Palisade and confluence of Gunnison River
94	Osmundson and others (1995)			X			X			X		Hyd		Relations between flow and rare-fish habitat in the 15-mile reach
95	Peckarsky (1983)		X							X		Background	X	Water quality of upper East River; sites on East River and on Copper Creek
96	Pennack (1974)		X									Mining		Information on macroinvertebrate taxa; sites on Parachute Creek and tributaries
97	Pettus (1974)			X								Mining	X	Information on trout; sites on the East and West Forks of Parachute Creek

Table 1. Literature citations indexed by type of biological or contaminant investigation, physiographic province, and predominant land use in the Upper Colorado River Basin study unit—Continued

[Mixed, more than one type of land use (mining, urban, agriculture); Hyd, water use or hydrologic modification; NA, not applicable to a predominant land use or sampling sites in figs. 2-7.]

Citation no. (figs. 2-7)	Reference citation	Type of biological or contaminant investigation						Physiographic province			General description and location of biological or contaminant investigation
		Algal communities	Macroinvertebrate communities	Fish communities	Habitat characterization	Contaminants in organism tissue	Contaminants in bed sediment	Southern Rocky Mountains	Colorado Plateau	Predominant land use	
98	Pitlick and Van Steeter (1994)				X			X	Hyd		Changes in morphology and endangered-fish habitat; sites on Colorado River between Palisade and Fruita (15- and 18-mile reaches)
99	Pratt (1938)	X	X	X			X		NA		Ecology of the trout of the Gunnison River; no physical sampling sites
100	Prestel (1992)	X	X	X			X		Mining	X	Effects of Eagle Mine on water quality; sites on Eagle River from headwaters to town of Edwards and on Homestake, Two Elk, and Cross Creeks
101	Prewitt and others (1978)		X	X	X			X	Mixed		Colorado squawfish and humpback chub population and habitat monitoring; sites on Colorado River between Palisade and Clifton
102	Richardson (1962)	X	X	X	X		X		Background	X	Stream survey of East Elk Creek; sites on East Elk Creek (stream entering Blue Mesa Reservoir)
103	Rosenland and Stevens (1988)			X			X		Background		Fisheries and aquatic management of Rocky Mountain National Park; sites on streams and lakes in Rocky Mountain National Park
104	Rosenland and Stevens (1990)			X			X		Background		Fisheries and aquatic management of Rocky Mountain National Park; sites on streams and lakes in Rocky Mountain National Park
105	Ruiter and Bishop (1984)	X	X	X				X	NA	X	Compilation and summary of water-quality and aquatic-life data reports

Table 1. Literature citations indexed by type of biological or contaminant investigation, physiographic province, and predominant land use in the Upper Colorado River Basin study unit—Continued

[Mixed, more than one type of land use (mining, urban, agriculture); Hyd, water use or hydrologic modification; NA, not applicable to a predominant land use or sampling sites in figs. 2-7.]

Citation no. (figs. 2-7)	Reference citation	Type of biological or contaminant investigation					Physiographic province			Pre-dominant land use	Water-chemistry data	General description and location of biological or contaminant investigation
		Algal communities	Macro-invertebrate communities	Fish communities	Habitat characterization	Contaminants in organism tissue	Contaminants in bed sediment	Southern Rocky Mountains	Colorado Plateau			
106	Stanford (1994)		X	X				X		Hyd	Flows to assist recovery of endangered species; sites on Colorado River between Palisade and Fruita (15- and 18-mile reaches)	
107	Stanford and Ward (1986)		X				X	X		NA	Basinwide information on fish of the Colorado system	
108	Tyus and others (1982)		X				X	X		NA	Basinwide information on fishes of the Upper Colorado River Basin	
109	U.S. Fish and Wildlife Service (1987)		X		X			X		Mixed	Recovery implementation for endangered fish; sites on Colorado River between Palisade and Fruita (15- and 18-mile reaches)	
110	U.S. Public Health Service (1963)		X					X		Mixed	Contaminants in bottom sediment; sites on Colorado River near Rifle and near Grand Junction and on Gunnison River near Gunnison	
111	Valdez and Clemmer (1982)			X				X		NA	Information on life history of the humpback and bonytail chub; no physical sampling sites	
112	Ward (1987)	X							X	Hyd	Trichoptera of regulated Rocky Mountain streams; sites on the Blue, Colorado, and Fryngpan Rivers	
113	Ward and Kondratieff (1992)	X						X		NA	Guide to mountain stream insects	
114	Ward and Stanford (1990)	X						X		Hyd	Mayflies of the Gunnison River; 11 sites on Gunnison River between headwaters and confluence with Colorado River	

Table 1. Literature citations indexed by type of biological or contaminant investigation, physiographic province, and predominant land use in the Upper Colorado River Basin study unit—Continued

[Mixed, more than one type of land use (mining, urban, agriculture); Hyd, water use or hydrologic modification; NA, not applicable to a predominant land use or sampling sites in figs. 2-7.]

Citation no. (figs. 2-7)	Reference citation	Type of biological or contaminant investigation					Physiographic province			Pre-dominant land use	Water-chemistry data	General description and location of biological or contaminant investigation
		Algal communities	Macro-invertebrate communities	Fish communities	Habitat characterization	Contaminants in organism tissue	Contaminants in bed sediment	Southern Rocky Mountains	Colorado Plateau			
115	Ward and others (1986)		X		X			X	X	NA		Basinwide information on macroinvertebrates of the Colorado River system
116	Weber (1959)		X	X	X			X		Hyd		Effects of reduced streamflow on the trout fishery; sites on Colorado River downstream from Granby Dam
117	Wick and others (1985)			X	X				X	Mixed		Colorado squawfish and humpback chub population and habitat monitoring; sites on Colorado River from Grand Junction to Loma
118	Wick and others (1986)			X	X				X	Mixed		Colorado squawfish and humpback chub population and habitat monitoring; sites on Colorado River from Grand Junction to Loma
119	Wick and others (1981)			X	X				X	Mixed		Colorado squawfish and humpback chub population and habitat monitoring; sites on Colorado River from Palisade to Clifton
120	Wick and others (1979)			X	X				X	Mixed		Colorado squawfish and humpback chub population and habitat monitoring; sites on Colorado River from Palisade to Clifton
121	Wiltzius (1978)		X	X				X	X	Hyd		Information on distribution and abundance of fishes in the Gunnison River; sites on Gunnison River from Blue Mesa Reservoir to Escalante confluence
122	Woodling (1976)		X					X		Mixed	X	Effects of mining and sewage on water quality of Slate River; six sites on Slate River and on Coal Creek

Table 1. Literature citations indexed by type of biological or contaminant investigation, physiographic province, and predominant land use in the Upper Colorado River Basin study unit—Continued

[Mixed, more than one type of land use (mining, urban, agriculture); Hyd, water use or hydrologic modification; NA, not applicable to a predominant land use or sampling sites in figs. 2-7.]

Citation no. (figs. 2-7)	Type of biological or contaminant investigation				Physiographic province			Pre-dominant land use	Water-chemistry data	General description and location of biological or contaminant investigation	
	Reference citation	Algal communities	Macro-invertebrate communities	Fish communities	Habitat characterization	Contaminants in organism tissue	Contaminants in bed sediment				Southern Rocky Mountains
123	Woodling (1977)		X	X				X	Agriculture	X	Water quality of Roan Creek; sites on Roan, Clear, Brush, Carr, Kimball, and Dry Fork Creeks
124	Woodling (1985)			X			X	X	NA		Basinwide information on little fish of Colorado
125	Woodling (1993)		X	X			X		Mining	X	Effects of Eagle Mine on water quality; sites on Eagle River from headwaters to town of Edwards and on Homestake, Two Elk, and Cross Creeks
126	Wuerthele (1976)		X				X		Mining	X	Water quality of Eagle River Basin; sites on Eagle River and on Alkali, Lake, Brush, Gypsum, Gore, Homestake, Resolution, Cross, Turkey, Elk, and Grouse Creeks

provinces and were grouped in more than one investigational category and in more than one land use.

Algal Communities

Ten investigations between 1962 and 1987 incorporated algal-community information (table 1, fig. 2). Sites in these studies were located in all predominant land-use categories and in both physiographic provinces (table 1, fig. 1). The algal data in these investigations were presented mostly as taxonomic identifications for the stream segments. The summaries of these investigations indicate that algal data are limited throughout the basin, but that algae are very useful indicators of water chemistry.

Land use can affect types, numbers, and diversity of algae. Mining areas contain different taxa than that present in agricultural areas. For instance, in the UCOL study unit, investigations done in mining areas commonly contain certain species of green algae and diatoms because of their tolerance to acidic conditions and metals. Agricultural areas commonly contain blue-green algae as the predominant species because of its tolerance to higher concentrations of nitrogen from fertilizers (Stephen Porter, U.S. Geological Survey, oral commun., 1996).

Macroinvertebrate Communities

Fifty investigations between 1938 and 1995 included macroinvertebrate-community information (table 1, fig. 3). Sites in these studies were located in a variety of land uses and in both physiographic provinces (table 1, fig. 1). These investigations presented the data as taxonomic identifications or as numbers of organisms. Some of the investigations presented both types of data. The summaries of these investigations indicate there is an abundance of information on macroinvertebrate communities throughout the UCOL study unit.

Land use can have direct effects on the composition of macroinvertebrate communities. The use of indicator species for water-quality analysis is very common in studies of macroinvertebrate communities, especially when determining the water quality from mining effects. Macroinvertebrate-community composition can be different in mining areas than in agricultural areas. Mining areas

commonly are depleted of aquatic organisms, but can contain metal-tolerant species. Agricultural areas commonly contain species, such as aquatic worms and leeches, that are tolerant of organic-carbon enrichment, sedimentation, and low dissolved-oxygen concentrations (Stephen Porter, U.S. Geological Survey, oral commun., 1996).

Fish Communities

Eighty-nine investigations summarized fish community or population information between 1938 and 1995 (table 1, fig. 4). Sites in these studies were located in a variety of land uses and in both physiographic provinces (table 1, fig. 1). The information on fish was presented as taxonomic identifications or as numbers of fish. Some of the investigations presented both types of data. The summaries of these investigations indicate that information on fish communities is extensive throughout the UCOL study unit.

Fish communities are an important issue in the UCOL study unit; the study unit contains four fishes presently listed as endangered by the U.S. Fish and Wildlife Service (USFWS) (Behnke and Benson, 1980): the Colorado squawfish (*Ptychocheilus lucius*), the humpback chub (*Gila cypha*), the bonytail chub (*Gila elegans*), and the razorback sucker (*Xyrauchen texanus*). In addition, recreational fishing in the study unit is important to many anglers.

Historically, native fauna consisted of the following minnows and suckers in addition to those fishes listed above: roundtail chub (*Gila robusta*), flannelmouth sucker (*Catostomus latipinnis*), speckled dace (*Rhinichthys osculus*), kendall warm springs dace (*Rhinichthys osculus thermalis*), and bluehead sucker (*Catostomus discobolus*) (Tyus and others, 1982). The current fauna of the Colorado River is dominated by exotic species. All of the big river fish that were native to the area, except for the speckled dace, flannelmouth sucker, bluehead sucker, and roundtail chub, face extinction. The cause of the disappearance of some of the native species is due to loss of habitat and competition from other species (Ward and others, 1986). Native fish in the upper reaches of the basin included mountain sucker (*Catostomus platyrhynchus*), mountain whitefish (*Prosopium williamsoni*), mottled sculpin (*Cottus bairdi*), and Colorado cutthroat trout (*Salmo clarki pleuriticus*).

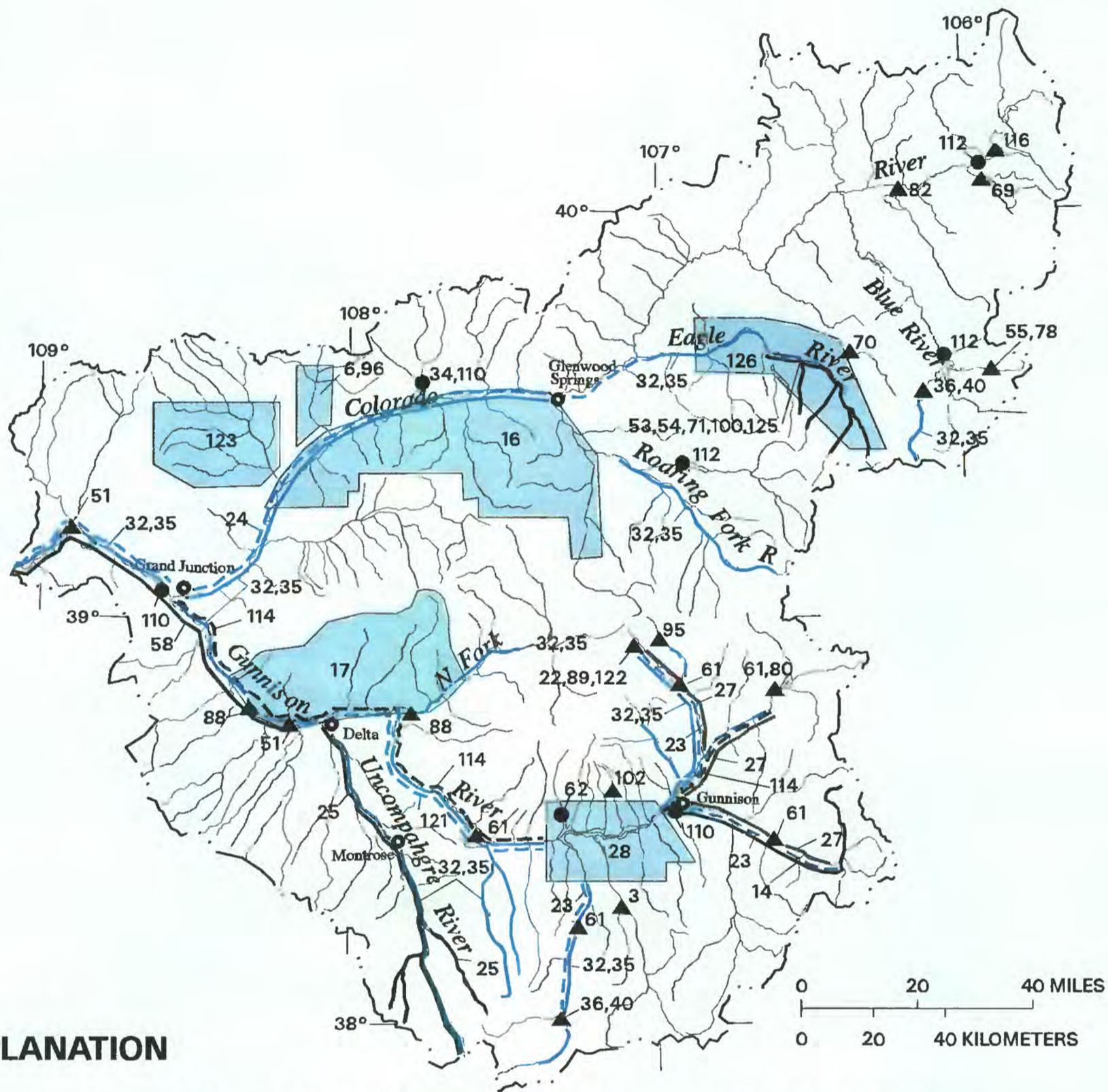


EXPLANATION

GENERAL LOCATIONS OF SITES SAMPLED FOR ALGAL – COMMUNITY INVESTIGATIONS Number designates literature citation listed in table 1

- ²⁹ SINGLE SITE SAMPLING LOCATION
- ▲³ GENERAL SITE LOCATION Includes several or many samples collected in area
- 6 EXTENSIVE STUDY AREA
- 35 } RIVER REACH SAMPLING AREAS
- 24 }

Figure 2. General locations of sites sampled for algal-community investigations.



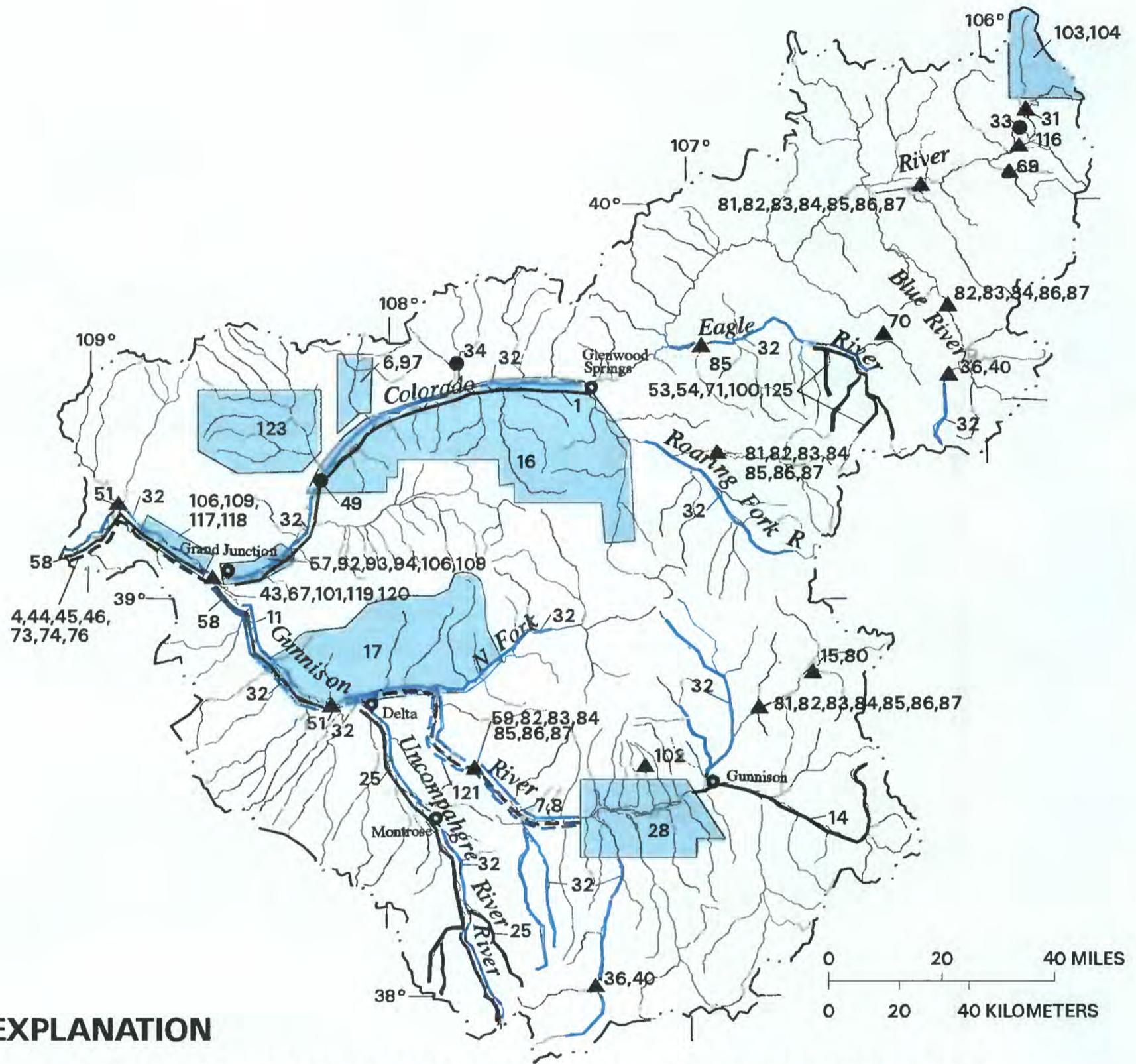
EXPLANATION

GENERAL LOCATIONS OF SITES SAMPLED FOR MACROINVERTEBRATE-COMMUNITY INVESTIGATIONS

Number designates literature citation listed in table 1

- 62 SINGLE SITE SAMPLING LOCATION
 - ▲ 61 GENERAL SITE LOCATION Includes several or many samples collected in area
 - 16 EXTENSIVE STUDY AREA
 - 25
 - 114
 - 23
 - 27
 - 32,35
- RIVER REACH SAMPLING AREAS

Figure 3. General locations of sites sampled for macroinvertebrate-community investigations.



EXPLANATION

GENERAL LOCATIONS OF SITES SAMPLED FOR FISH-COMMUNITY INVESTIGATIONS

Number designates literature citation listed in table 1

- 34 SINGLE SITE SAMPLING LOCATION
 - ▲ 51 GENERAL SITE LOCATION Includes several or many samples collected in area
 - 28 EXTENSIVE STUDY AREA
 - 25
 - 32
 - 7,8
 - 121
- } RIVER REACH SAMPLING AREAS

Figure 4. General locations of sites sampled for fish-community investigations.

Land use can have variable effects on the structure of fish communities. Intensely mined areas can be depleted of fish. Fish communities in agricultural areas most likely contain species, such as suckers, carp, and catfish, that tolerate gravel, sand, and silt substrates in slower and warmer waters. The more pristine headwater reaches and mountain streams can contain brook, brown, rainbow, and cutthroat trout.

Habitat Characterization

Fifty investigations between 1959 and 1995 included habitat-characterization information (table 1, fig. 5). Sites in these studies mostly were located in areas of hydrologic modifications and in both physiographic provinces, but primarily are limited to the Colorado Plateau (table 1, fig. 1). Habitat information from these studies mainly consisted of stream substrates, channel width, channel depth, channel morphology, and flow.

Hydrologic modifications can alter flows and degrade the necessary habitat for endangered species and fish communities. Habitat in the headwater and mountain streams is characterized by coarse substrate, such as boulders and cobbles; swift and cold water; and riparian vegetation. The lower reaches of the study unit contain fine substrates, such as gravel, sand, and silt; warm water; and less riparian vegetation.

Contaminants in Organism Tissue

Sixteen investigations between 1970 and 1994 summarized information about contaminants in tissue (table 1, fig. 6). Sites in these studies were located in a variety of land uses and in both physiographic provinces (table 1, fig. 1). Three of the studies contained information on organic and on trace-element contaminants (table 1, citation numbers 18, 19, 64). One study contained information solely on organic contaminants (table 1, citation number 66). The remaining twelve studies contained information solely on trace-element contaminants. A variety of organisms, which includes aquatic plants, macroinvertebrates, fish, and other vertebrates, was used in the studies. The summaries of these investigations indicate that the watersheds for the Fraser, Blue,

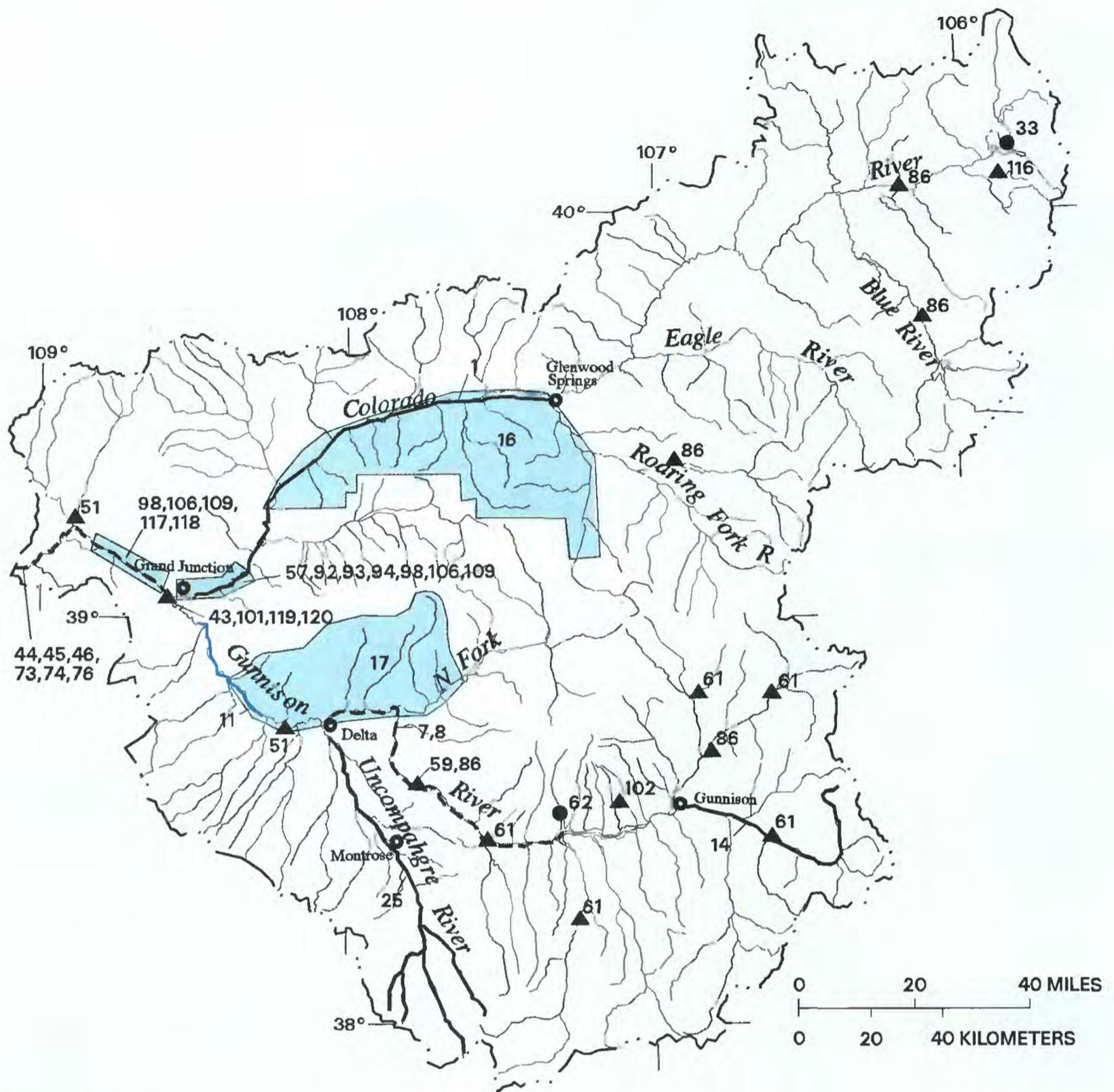
Eagle, and Roaring Fork Rivers have very limited data on contaminants in tissue.

Specific contaminant constituents can be directly related to land use and geology in the UCOL study unit. Organic-contaminant investigations were most common in agricultural areas, and trace-element contaminant investigations were most common in mining areas. Investigations solely for collection of trace-element contaminant data mostly were done in the Southern Rocky Mountains physiographic province, whereas investigations for collection of both organic-contaminant and trace-element contaminant data were done in the Colorado Plateau physiographic province, especially in the Grand and Uncompahgre Valleys.

Contaminants in Bed Sediment

Seven investigations between 1963 and 1994 included information on contaminants in bed sediment (table 1, fig. 7). Sites in these studies mostly were located in agricultural and mining areas and in both physiographic provinces (table 1, fig. 1). Five of the studies contained information on organic and on trace-element contaminants (table 1, citation numbers 3, 18, 19, 24, 110). Two studies contained information solely on trace-element contaminants (table 1, citation numbers 28, 91). The summaries of these investigations indicate that bed-sediment information is limited throughout the UCOL study unit.

Bed-sediment contamination can be directly related to land use and geology. Trace-element and organic contaminants often are more concentrated in bed sediments than in water. Trace-element analyses are the most common analyses done in the bed-sediment investigations. The National Uranium Resource Evaluation (NURE) program has an extensive data base on selected trace elements in the UCOL study unit. Investigations done on stream reaches in the headwater areas of streams were solely trace-element investigations. The lower reaches in the valleys were investigated for trace elements and organic compounds.



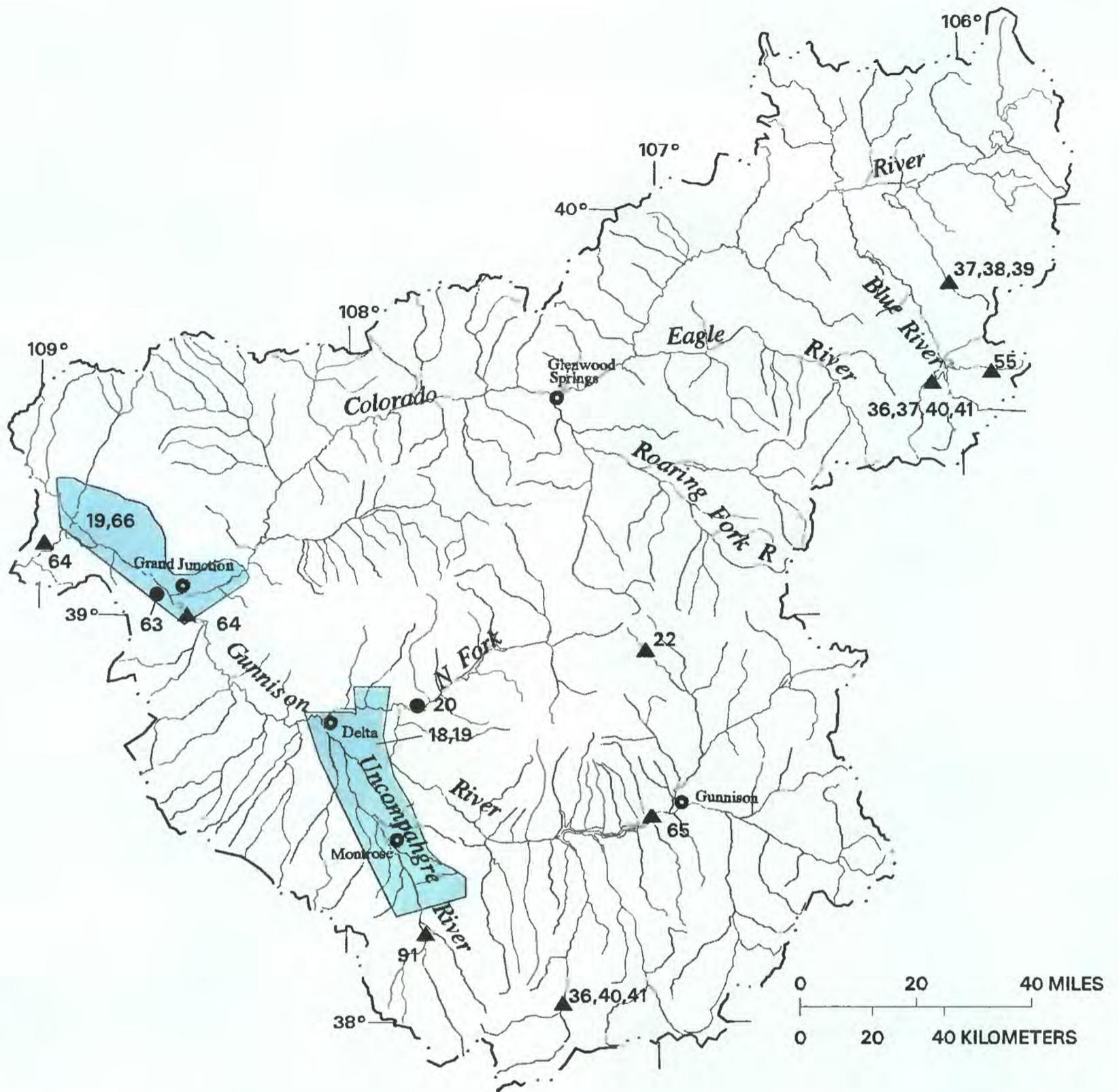
EXPLANATION

GENERAL LOCATIONS OF SITES SAMPLED FOR HABITAT-CHARACTERIZATION INVESTIGATIONS

Number designates literature citation listed in table 1

- ⁶² SINGLE SITE SAMPLING LOCATION
- ▲⁶¹ GENERAL SITE LOCATION Includes several or many samples collected in area
- ▭¹⁷ EXTENSIVE STUDY AREA
- ²⁵ } RIVER REACH SAMPLING AREAS
- ¹¹ }
- ^{7,8} }

Figure 5. General locations of sites sampled for habitat-characterization investigations.



EXPLANATION

GENERAL LOCATIONS OF SITES SAMPLED FOR CONTAMINANTS IN ORGANISM-TISSUE INVESTIGATIONS

Number designates literature citation listed in table 1

● 20

SINGLE SITE SAMPLING LOCATION

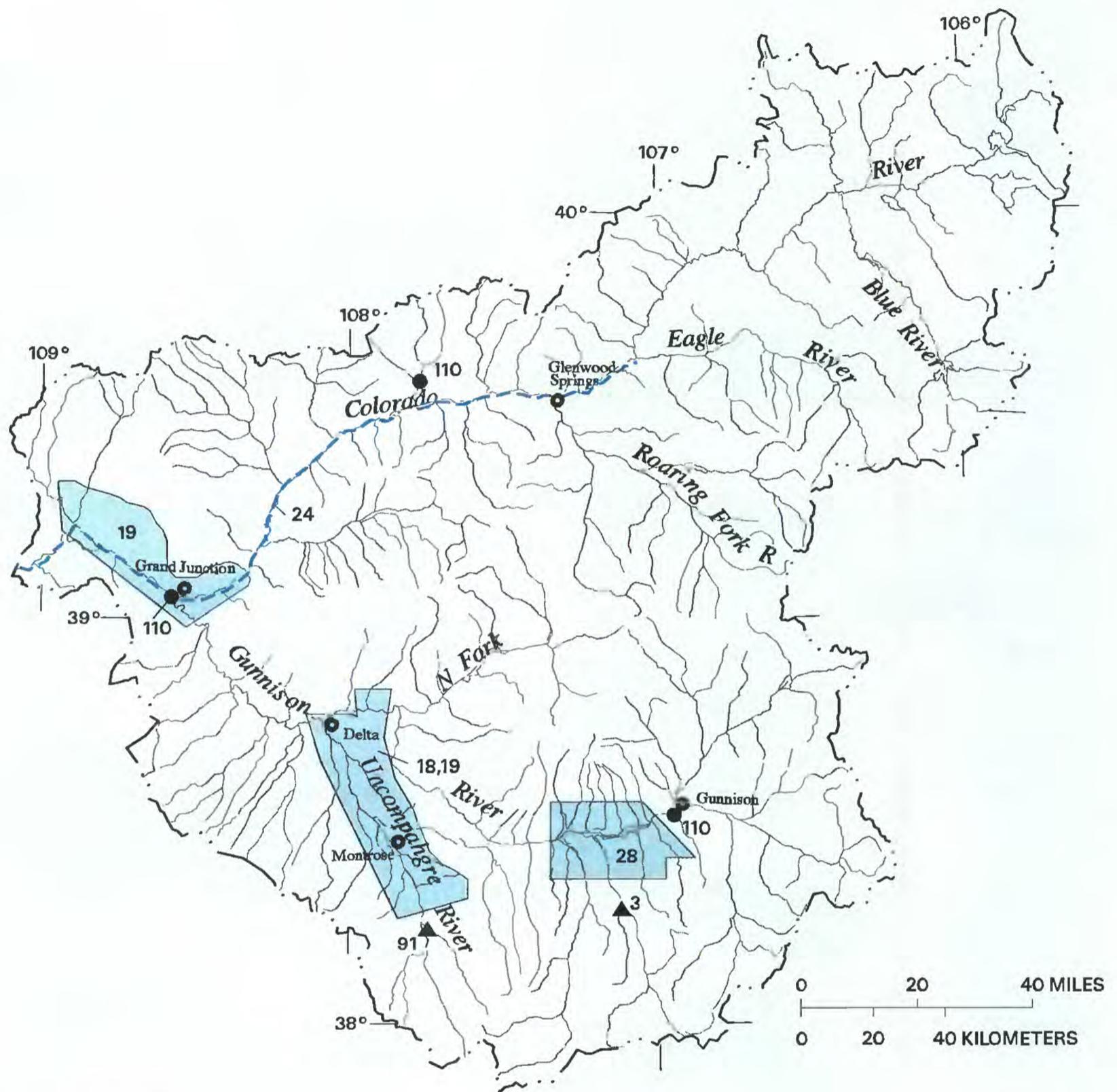
▲ 91

GENERAL SITE LOCATION Includes several or many samples collected in area

18,19

EXTENSIVE STUDY AREA

Figure 6. General locations of sites sampled for contaminants in organism-tissue investigations.



EXPLANATION

GENERAL LOCATIONS OF SITES SAMPLED FOR CONTAMINANTS IN BED-SEDIMENT INVESTIGATIONS

Number designates literature citation listed in table 1

- 110 SINGLE SITE SAMPLING LOCATION
- ▲ 91 GENERAL SITE LOCATION Includes several or many samples collected in area
- 28 EXTENSIVE STUDY AREA
- 24 RIVER REACH SAMPLING AREA

Figure 7. General locations of sites sampled for contaminants in bed-sediment investigations.

EFFECTS OF ENVIRONMENTAL SETTING ON BIOLOGICAL COMMUNITIES IN STREAMS

The environmental setting of the UCOL study unit is based on natural and human factors. Natural factors that affect water-quality conditions are physiography, climate, geology, and soils. Human factors that affect water-quality conditions are mining, urbanization, agriculture, and hydrologic modifications. Apodaca and others (1996) provided a more detailed description of the environmental setting in the UCOL study unit.

Natural Factors

The UCOL study unit provides diverse habitats for aquatic biological communities. This diversity reflects the extreme ranges of altitude, climate, vegetation, and geology in the study unit. Running-water habitats vary from cool, clear, and forested headwater reaches traversing crystalline bedrock at higher altitudes, to warm, sluggish, and saline reaches at lower altitudes that have low gradients and fine substrates.

Algae, macroinvertebrates, and fish present in the Southern Rocky Mountains and the Colorado Plateau physiographic provinces vary with altitude and physical habitat (table 2). The major controlling

Table 2. Major aquatic biological taxa in the Southern Rocky Mountains and Colorado Plateau physiographic provinces of the Upper Colorado River Basin study unit

Taxonomic group	Southern Rocky Mountains	Colorado Plateau
Algae ¹	Chlorophyta (green algae) Chrysophyta Bacillariophyceae (diatoms) Chrysophyceae (golden-brown algae) Cyanophyta (blue-green algae) Pyrrhophyta (dinoflagellates)	Chlorophyta Chrysophyta Bacillariophyceae Chrysophyceae Cyanophyta Euglenophyta (euglenoid algae)
Macroinvertebrates ²	Ephemeroptera (mayflies) Trichoptera (caddisflies) Diptera (true flies) Coleoptera (beetles) Odonata (dragonflies and damselflies) Plecoptera (stoneflies) Amphipoda (scuds) Oligochaeta (worms) Tricladida (flatworms) Nematoda (roundworms) Gastropoda	Ephemeroptera Trichoptera Diptera Coleoptera Odonata Megaloptera (alderflies and dobsonflies) Amphipoda Oligochaeta Decapoda (crayfish) Gastropoda (snails) Hirudinea (leeches)
Fish ³	Salmonidae (salmon and trout) Cyprinidae (minnows and carp) Catostomidae (suckers) Percidae (perches) Cottidae (sculpins) Esocidae (northern pike)	Salmonidae Cyprinidae Catostomidae Percidae Cottidae Ictaluridae (catfish) Cyprinodontidae (topminnows and killifish) Poeciliidae (mosquitofish) Centrarchidae (bass and sunfish)

¹Colorado Department of Health (1976); Apley (1982); Natural Energy Resources Company (1987).

²Federal Water Pollution Control Administration (1968); Ward and others (1986); Ward and Kondratieff (1992).

³Everhart and Seaman (1971); Woodling (1985).

factors that determine composition of biological communities are changes in water temperature, water discharge and velocity, substrate and suspended material, chemical conditions, and aquatic and riparian vegetation (Ward and Kondratieff, 1992). The differences in biological communities between the Southern Rocky Mountains and the Colorado Plateau are the result of a combination of these factors. The Southern Rocky Mountains physiographic province contains streams that have steep gradients, cobble and boulder substrates, and extended periods of ice and snow cover. The Colorado Plateau physiographic province contains the larger reaches of the Colorado River that are characterized by sand and silt substrates, warmer water, sparse vegetation, and lower gradients. Distinct biological communities are associated with the two physiographic provinces; however, overlap of species can occur in the transition zone, which is located along the division line of the two physiographic provinces. The predominant algae in the Southern Rocky Mountains are green algae and diatoms. The predominant algae in the Colorado Plateau are blue-green, golden-brown, and green algae. In the higher altitudes, caddisflies, mayflies, and stoneflies are the predominant macroinvertebrates. In the transition zone from high-altitude to low-altitude streams, caddisflies and mayflies become less predominant; stoneflies are rare; and crayfish, dobsonflies, and damselflies are more common. The lower altitudes are favorable to species, such as aquatic worms, leeches, and dragonflies. In fish communities, cold-water species, such as trout, predominate in the higher altitudes, and warm water species, such as carp, catfish, and suckers, predominate in the lower altitudes (table 2). The information in table 2 is a general summary of the major biological taxa in the physiographic provinces and does not represent all species in the UCOL study unit.

Human Factors

Human factors can adversely affect water quality, biota, and habitat as a result of point and nonpoint sources of chemical and physical constituents. Mining, urbanization, agriculture, and hydrologic modifications are the principal activities that affect water quality and available habitat in the UCOL study unit (Driver, 1994).

The environmental setting of the Southern Rocky Mountains physiographic province consists primarily of mining, urban, and recreational land uses. In many of the headwater reaches of the Colorado River and its tributaries, mining activities have severely affected aquatic life and habitat. As tributaries converge, precipitation of metals occurs as a result of dilution, which also results in direct effects on the fauna and habitat by coating the substrates of streams with toxic constituents. The Colorado Division of Wildlife has made biological assessments of the Eagle River Superfund Site and has evaluated the effects of mining on the water quality and biota of the Eagle River. These studies (table 1, citation numbers 53, 54, 71, 100, and 125) are good examples of how mining causes decreased numbers of organisms and affects community structures of macroinvertebrate and fish populations. Mining areas can be depleted of organisms or contain a low diversity of species; however, acid-tolerant algae, such as species of green algae and diatoms, and metal-tolerant caddisflies can be present in areas affected by mining (Stephen Porter, U.S. Geological Survey, oral commun., 1996).

Urbanization, recreation, and their associated effects on biological communities are important water-quality issues in the UCOL study unit. Development and construction of homes can affect water quality by increasing sedimentation that can affect macroinvertebrate life cycles and fish reproduction. Septic systems are the predominant method of sewage waste disposal for areas that are located outside sanitation districts and municipal treatment facilities of major towns and cities. Increasing development of these septic systems increases nutrient loading, which then affects the biological community. The Colorado Department of Health conducted water-quality investigations (table 1, citation numbers 69 and 70) of the Fraser River and Gore Creek watersheds, which are typical examples of areas affected by urbanization and recreation in the study unit. These studies indicate an increase in nutrients and changes in macroinvertebrate communities as the streams flow through the urbanized areas. Most roads and highways within the UCOL study unit are developed and located next to streams. Increasing urbanization and recreation have resulted in increased use and size of these roads. Sanding and salting of and stormwater runoff from these highways can adversely

affect water quality and associated biological communities.

The environmental setting of the Colorado Plateau physiographic province primarily consists of agriculture and urban land uses. Nutrients from fertilization carried from an agricultural site to a water body can cause detrimental effects on various species of flora and fauna. Different algal species are affected by changes in habitat and by availability of nutrients. Pesticides commonly used during agricultural activities can be transported to streams and can have damaging effects on the biota. Agricultural areas might contain species, such as blue-green algae, aquatic worms, and suckers, that tolerate organic enrichment, sedimentation, and lower dissolved-oxygen concentrations. The USGS and USFWS conducted investigations in the Grand Valley and in the lower Gunnison and Uncompahgre River Basins (table 1, citation numbers 18 and 19) that provided valuable information on the potential effects of irrigation return flows on water quality and biota. Results indicated that the degradation of the irrigation return flows can alter the biological communities by eliminating algae and invertebrates necessary for the aquatic food chain. Grazing is a predominant land use in the study unit, and the movement of cattle to and from water can adversely affect the riparian vegetation and can eliminate the undercut banks and aquatic and terrestrial vegetation.

One of the most important factors that affects the biological communities and ecology of the Upper Colorado River system is the extent of hydrologic modifications. Most segments of the Colorado River and its tributaries have become a series of reservoirs with tailwaters between them. Except for the remote headwaters, almost all running water in the UCOL study unit is affected by regulation (Stanford and Ward, 1986). The USFWS has evaluated the effects of flow regimes on fish habitats and populations (primarily endangered species) in several studies (table 1, citation numbers 57, 93, 106, and 109). Reservoirs essentially halt the migration of fish, but more importantly, dams and interbasin water transfers change the flow regime of streams, the temperature of the water, and the habitat of the fish community. These hydrologic modifications affect functional, chemical, and physical characteristics of the water that enters the reservoir, and these changes can alter the life cycles, diversity, types, and numbers of organisms in biological communities. Flow regimes of streams

shape the gross physical structure of the streams, such as channel morphology and substrate type; this structure, in turn, determines the quantity and quality of various habitats available for fish (Osmundson and Kaeding, 1991).

SUMMARY

The U.S. Geological Survey's National Water-Quality Assessment (NAWQA) program is a long-term, interdisciplinary program that is designed to integrate chemical, physical, and biological data to assess the Nation's ground-water and surface-water quality. The Upper Colorado River Basin (UCOL) study unit is one of 60 study units established to assess current water-quality conditions, define long-term trends, and identify major natural and human factors affecting water-quality conditions throughout the Nation. This report summarizes historical data that can be used to design biological sampling strategies to fill in gaps in the biological and contaminant data and to effectively address critical water-quality issues in the UCOL study unit.

One-hundred-twenty-six references concerning the ecology of aquatic organisms and contaminants were compiled from computerized literature searches of biological data bases and by contacting other Federal, State, and local agencies. Biological and contaminant investigations that have been conducted throughout the basin since 1938 were categorized according to four general categories of biological investigations and two categories of contaminant investigations: algal communities, macroinvertebrate communities, fish communities, habitat characterization, contaminants in organism tissue, and contaminants in bed sediment. The studies were identified by their locations in two physiographic provinces, the Southern Rocky Mountains and the Colorado Plateau, and by the predominant land use in the area of the investigation.

Studies on algae and contaminants in organism tissue and in bed sediment are very limited throughout the basin. Studies on macroinvertebrate and fish communities and habitat characterization are the most abundant.

Distinct biological communities are associated with the two physiographic provinces in the UCOL study unit. Natural and human factors can affect biological communities and their composition.

Natural factors that affect background water-quality conditions are physiography, climate, geology, and soils. Different algal species are affected by changes in habitat and by the availability of nutrients. The predominant algae in the high-altitude streams are green algae and diatoms. In the lower altitudes, blue-green, golden-brown, and green algae are predominant. Macroinvertebrate communities vary by altitude, substrate, water temperature, and concentration of dissolved oxygen. Mayflies, caddisflies, and stoneflies compose most of the species present in the high-altitude streams. In the transition zone from high-altitude to low-altitude streams, caddisflies and mayflies become less predominant; stoneflies are rare; and crayfish, dobsonflies, and damselflies are more common. Because of changes in the physical environment at lower altitudes, additional species, such as aquatic worms, leeches, and dragonflies, also are present.

Human factors that affect water-quality conditions are mining, urbanization, agriculture, and hydrologic modifications. Land uses affect biological communities and their composition. Mining areas can be depleted of organisms or contain a low diversity of species; however, acid-tolerant algae, such as green algae and diatoms, and metal-tolerant caddisflies can be present in areas affected by mining. Urbanized areas are located in the Southern Rocky Mountains and in the Colorado Plateau and contain species characteristic of the physiographic province. Agricultural areas contain species, such as blue-green algae, aquatic worms, and suckers and carp, that can tolerate organic enrichment, sedimentation, and lower concentrations of dissolved oxygen.

The sampling design for the biological component in the UCOL study unit can be enhanced with this summary of biological and contaminant information. The NAWQA program attempts to fill in some of the gaps in biological data. This historical biological summary can be used to select ecological sites, design sampling strategies, and integrate physical, chemical, and biological information for the UCOL study unit.

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