WATER-QUALITY CHARACTERISTICS OF STREAMS IN THE PICEANCE CREEK AND YELLOW CREEK DRAINAGE BASINS, NORTHWESTERN COLORADO, WATER YEARS 1977-81

By Robert L. Tobin, Helen E. Stranathan, and Kenneth J. Covay

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CONVERSION FACTORS

For readers who may prefer to use metric units rather than inch-pound units, the conversion factors for terms used in this report are listed below:

Multiply inch-pound unit	*by*	*To obtain metric unit*
acre	0.4047	hectare
acre-foot (acre-ft)	0.001233	cubic hectometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
degree Farenheit (°F)	°C=5/9(°F-32)	degree Celsius(°C)
foot (ft)	0.3048	meter
inch (in.)	25.40	millimeter
micromhos per centimeter at 25°Celsius (umhos/cm at 25°C)	1.000	microsiemens per centimeter at 25°Celsius
mile	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
tons per day (ton/d)	0.9072	metric ton per day

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ABSTRACT

Physical and chemical data from continuous recording monitors, periodic field determinations, and water samples collected at 10 sites on perennial streams and 16 sites on intermittent streams in the Piceance Creek and Yellow Creek drainage basins during the 1977-81 water years are summarized. Methods for estimating dissolved solids concentrations from measurements of specific conductance are presented.

Stream temperatures ranged from -0.5 to 35.0 degrees Celsius and were warmest near the downstream reaches of Piceance and Yellow Creeks. Minimum concentrations of dissolved oxygen were greater than 3.0 milligrams per liter in Piceance and Yellow Creeks, and concentrations of dissolved oxygen exceeded saturation during periods of active photosynthesis. Values of pH in streams ranged from 6.9 to 9.0 and were least during snowmelt runoff and greatest in low flows in the lower reaches of Piceance and Yellow Creeks. Concentrations of suspended sediment exceeded 100,000 milligrams per liter in localized runoff.

Specific conductance varied inversely with discharge. Sodium, magnesium, bicarbonate, and sulfate ions and concentration ranges of dissolved solids between 400 and 1,700 milligrams per liter were characteristic of the water quality of the perennial streams in areas of the drainage basins near the upstream reaches of Piceance and Yellow Creeks. Calcium and bicarbonate dominated the major ions, and concentrations of dissolved solids normally were less than 600 milligrams per liter in the intermittent streams during storm and snowmelt runoff.

Augmentation to Piceance and Yellow Creeks from ground-water sources in the lower reaches of both streams increased concentrations of dissolved solids several thousand milligrams per liter during medium and low flows and caused a change in water-quality type from sodium magnesium bicarbonate to a high-percentage sodium bicarbonate. Increases in dissolved concentrations of arsenic, boron, fluoride, lithium, strontium, and sulfate were related to ground-water sources or discharges from areas of energy resource development.

Nutrient concentrations ranging to several milligrams per liter of dissolved nitrogen and phosphorus, and gross alpha and beta counts of several hundred picocuries per liter were greatest in perennial and intermittent

streams during storm and snowmelt runoff. Insecticides ranging in concentrations from 0.1 to 1.5 micrograms per kilogram were detected in bed materials at several stream sites in Piceance Creek and Yellow Creek drainage basins.

INTRODUCTION

Increased demands for energy and energy independence in the United States have accelerated commercial development of natural resources in northwestern Colorado. Major resources are oil shale, coal, and natural gas. Oil-shale development is expected to be greatest in the Piceance basin (fig. 1), which contains an estimated 1 trillion barrels of recoverable oil shale (Weeks and others, 1974; Taylor, 1982).

Piceance basin is divided into four drainage basins (fig. 1): Piceance Creek and Yellow Creek drainage basins discharge north to the White River, and Roan Creek and Parachute Creek drainage basins discharge south to the Colorado River. Piceance Creek and Yellow Creeks drainage basins, hereafter referred to as Piceance Creek and Yellow Creek basins, are mostly Federal lands and contain the most extensive deposits of oil shale in Piceance basin. Oil-shale development will occur mostly on private lands in the Roan Creek and Parachute Creek drainage basins.

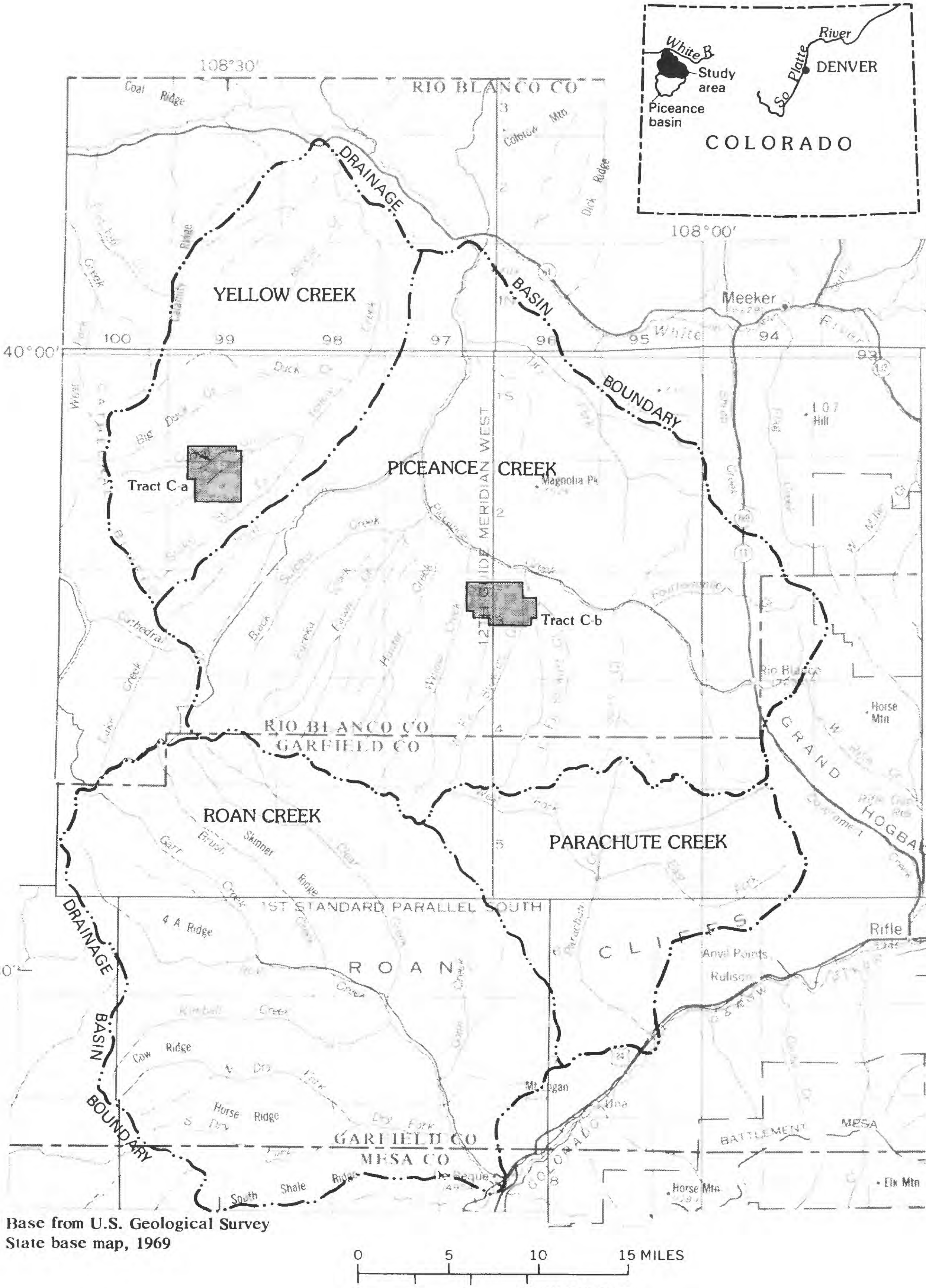
In early 1974, two leases of 5,120 acres each were awarded to two associations of oil companies for prototype development of oil shale. These two leased areas are referred to as Tract C-a and Tract C-b (fig. 1). Tract C-a is in Yellow Creek basin, and Tract C-b is in the Piceance Creek basin. As oil-shale development increases in these basins, the environmental quality of the water, land, and air will be affected. Data collected prior to major oil-shale development documents present water-quality conditions of surface flows. These data, when used in conjunction with other water-quality and biological data, can help determine the magnitude of changes in water quality that result from oil-shale development.

Purpose and Scope

The purpose of this report is to describe and summarize the water chemistry of streams in Piceance Creek and Yellow Creek basins. The study generally was limited to the five water years 1977-81 in order to provide a coordinated data base with an intensive study of benthic invertebrates at six sampling sites in Piceance Creek basin (Covay and others, 1984). Data from October 1975 to September 1976 (1976 water year) were included, however, when they effectively supplemented the data base.

Selected data sets originally presented in U.S. Geological Survey reports (1977-82) are summarized for 26 sampling sites, hereafter referred to as site(s), from perennial and intermittent streams (fig. 2 and table 1) and include:

1. Continuous water-discharge data;
2. Continuous water-quality monitor data and periodic field determinations consisting of temperature, specific conductance, pH, and dissolved oxygen;



Base from U.S. Geological Survey
State base map, 1969

Figure 1.--Major drainage basins of the Piceance basin.

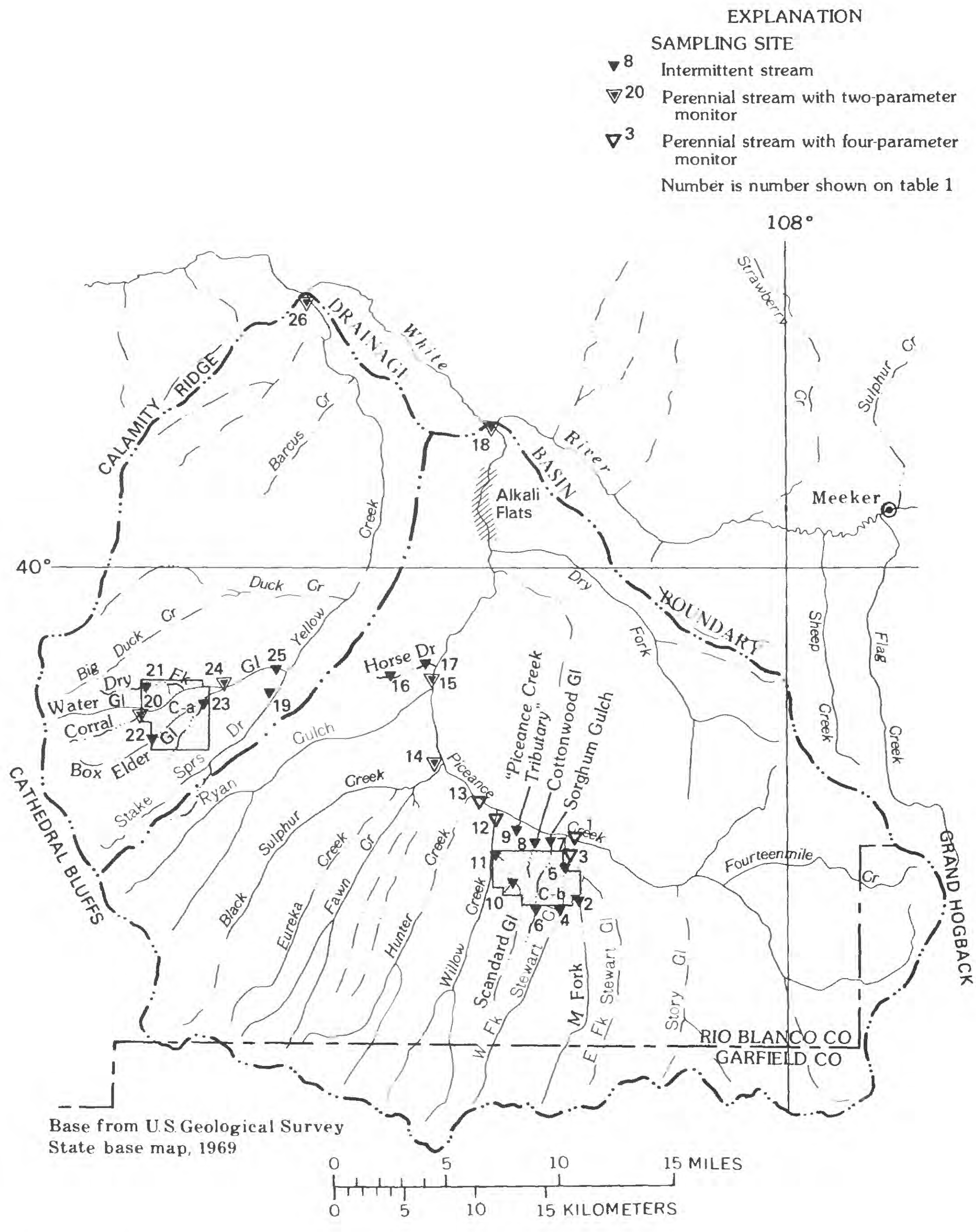


Figure 2.--Sampling sites for perennial and intermittent streams in Piceance Creek and Yellow Creek basins, water years 1977-81.

Table 1.--*Data collection sites in Piceance Creek and Yellow Creek basins, water years 1977-81*

Site number from figure 2	U.S. Geological Survey streamflow-gaging station		Stream type (I=intermittent; P=perennial)
	Number	Name	
		PICEANCE CREEK BASIN	
1	09306007	Piceance Creek below Rio Blanco	P
2	09306015	Middle Fork Stewart Gulch near Rio Blanco	I
3	09306022	Stewart Gulch above West Fork, near Rio Blanco	P
4	09306025	West Fork Stewart Gulch near Rio Blanco	I
5	09306028	West Fork Stewart Gulch at mouth, near Rio Blanco	I
6	09306033	Sorghum Gulch near Rio Blanco	I
7	09306036	Sorghum Gulch at mouth, near Rio Blanco	I
8	09306039	Cottonwood Gulch near Rio Blanco	I
9	09306042	Piceance Creek Tributary near Rio Blanco	I
10	09306050	Scandard Gulch near Rio Blanco	I
11	09306052	Scandard Gulch at mouth, near Rio Blanco	I
12	09306058	Willow Creek near Rio Blanco	P
13	09306061	Piceance Creek above Hunter Creek, near Rio Blanco	P
14	09306175	Black Sulphur Creek near Rio Blanco	P
15	09306200	Piceance Creek below Ryan Gulch, near Rio Blanco	P
16	09306202	Horse Draw near Rangely	I
17	09306203	Horse Draw at mouth, near Rangely	I
18	09306222	Piceance Creek at White River	P
		YELLOW CREEK BASIN	
19	09306230	Stake Springs Draw near Rangely	I
20	09306235	Corral Gulch below Water Gulch, near Rangely	P
21	09306237	Dry Fork near Rangely	I
22	09306240	Box Elder Gulch near Rangely	I
23	09306241	Box Elder Tributary near Rangely	I
24	09306242	Corral Gulch near Rangely	P
25	09306244	Corral Gulch at 84 Ranch	I
26	09306255	Yellow Creek near White River	P

3. Daily suspended-sediment concentrations collected by automatic-pumping samplers;
4. Water-chemistry analyses from samples collected periodically at all 26 sites in the Piceance Creek and Yellow Creek basins.

The constituents sampled for laboratory analysis and frequency of collection during this study are generalized in table 2. All samples for laboratory analysis were collected, preserved, and analyzed in accordance with accepted procedures of the U. S. Geological Survey (Goerlitz and Brown, 1972, Greeson and others, 1977, Thatcher and others, 1977, and Skougstad and others, 1979).

Summaries, including continuous-monitor data and periodic field determinations, major ions, nutrients, trace constituents, radioactive substances, and insecticides and herbicides are presented for all sites. Although more than 50 percent of the data were collected during medium to low-flow conditions, water-quality characteristics for high and extremely low flows also are defined.

Description of Study Area

Location

The Piceance Creek and Yellow Creek basins form the northern half of Piceance basin in Rio Blanco and Garfield Counties, northwestern Colorado (fig. 2). Piceance Creek basin has a drainage area of 630 mi^2; Yellow Creek basin has a drainage area of 262 mi^2.

Piceance Creek (fig. 2) originates in the Grand Hogback northeast of Rio Blanco, Colorado. The creek flows in a northwesterly direction in its upper section and in a northerly direction in the lower section before joining the White River, 17 mi west of Meeker. Yellow Creek (fig. 2) originates in the Cathedral Bluffs of western Piceance basin and flows north to its confluence with the White River, 27 mi northwest of Meeker, Colorado.

Geology and Geomorphic Setting

The Piceance basin is part of the Colorado Plateau Province (Thornbury, 1965). During the Eocene Epoch, a large freshwater lake occupied a structural depression in northwestern Colorado and northeastern Utah. Lake and fluvial sediments, aquatic plants, and micro-organisms such as algae, fungi, and zooplankton settled in the lake to form an organically rich, sedimentary sequence of rocks. These sedimentary rocks have been described previously by Donnell (1961), Coffin, Welder, and Glanzman (1971), Dyni (1974), and Cashion and Donnell (1974). They consist of sandstones, shales, pyroclastics, and marlstones and form the Wasatch, Green River, and Uinta Formations. The Green River Formation contains the richest known deposits of organic oil shale and marlstone in the world (Donnell, 1961, and Yen and Chilingarian, 1976).

Table 2.--*Sampling schedule, Piceance Creek and Yellow Creek basins, water years 1977-81*

Constituent	Symbol	Group nomenclature	Approximate sampling frequency
Calcium----------------	Ca	Cations--------	Monthly.
Magnesium--------------	Mg	----do---------	Do.
Potassium--------------	K	----do---------	Do.
Sodium-----------------	Na	----do---------	Do.
Bicarbonate------------	HCO_3	Anions---------	Monthly.
Chloride---------------	Cl	----do---------	Do.
Fluoride---------------	F	----do---------	Do.
Sulfate----------------	SO_4	----do---------	Do.
Ammonia----------------	NH_3-N	Nutrients------	Monthly, quarterly,
Nitrite + nitrate------	NO_2+NO_3-N	----do---------	Do.
Organic nitrogen-------	Org-N	----do---------	Do.
Phosphorus-------------	P	----do---------	Do.
Arsenic----------------	As	Trace con-	Monthly, quarterly,
Barium-----------------	Ba	stituents.	semiannually.
Boron------------------	B	----do---------	Do.
Cadmium----------------	Cd	----do---------	Do.
Chromium---------------	Cr	----do---------	Do.
Copper-----------------	Cu	----do---------	Do.
Iron-------------------	Fe	----do---------	Do.
Lead-------------------	Pb	----do---------	Do.
Lithium----------------	Li	----do---------	Do.
Manganese--------------	Mn	----do---------	Do.
Mercury----------------	Hg	----do---------	Do.
Molybdenum-------------	Mo	----do---------	Do.
Selenium---------------	Se	----do---------	Do.
Strontium--------------	Sr	----do---------	Do.
Vanadium---------------	Va	----do---------	Do.
Zinc-------------------	Zn	----do---------	Do.
Gross Alpha and beta--	---------	Radioactive	Semiannually (high
Uranium---------------	U-natural	substances.	and low flows).
Radium----------------	Ra-226	----do---------	Do.
Organochlorine--------	---------	Insecticides	Semiannually (high
Organophosphorus------	---------	and herbi-	and low flows).
Chlorophenoxy acids---	---------	cides.	

A general geomorphic description of this region is presented by Frickel and others (1975) and Thornbury (1965). The topography is classified as ridge and valley and is greatly dissected (fig. 3). The ridges and valleys in Piceance Creek and Yellow Creek basins trend in a southwesterly to northeasterly direction. Drainage patterns range from trellis to parallel and seem to be structurally controlled. Surface rocks in both Piceance Creek and Yellow Creek basins consist mostly of silts and sandstones from the Uinta Formation. Surface exposures of the Green River Formation, however, commonly occur in the valleys of Yellow Creek basin where streams have eroded through the thin deposits of the overlying Uinta Formation.

Climate and Vegetation

The climate of the Piceance basin is semiarid. Precipitation during the summer consists of short-duration, high-intensity thunderstorms, often local in extent. Winter precipitation occurs mostly as snow. Precipitation tends to increase with altitude. Annual precipitation ranges from 15 in. below an altitude of 8,000 ft to 25 in. above 8,000 ft (Weeks and others, 1974, Frickel and others, 1975).

Air temperature also varies with altitude, but may be modified locally by topography. Temperature ranges from -48°F to 97°F (Frickel and others, 1975).

Vegetation distributions are related to altitude, slope orientation, and soil depth (Frickel and others, 1975). North-facing slopes retain more moisture, have better developed soils, and support a more dense plant community than do south-facing slopes. Lower elevations are characterized by pinon pine and juniper. Pines and aspen dominate at the higher elevations.

Land Use

Historically, the main activity in the Piceance basin has been agriculture and ranching. A large deer population also inhabits the area. Because of the increased demand for energy, the basin has had intense oil, gas, and oil-shale exploration. Development of two Federal oil-shale lease tracts, C-a and C-b, began during 1974, and natural vegetation has been removed in some areas. Land use could be further affected by surface mining and retorting.

Surface-Water Hydrology

Overland runoff to streams in Piceance basin results mostly from snowmelt in spring and short-duration, high-intensity thunderstorms in summer. Baseflow to streams originates principally from springs and other ground water inflow. Most streams in the Piceance Creek and Yellow Creek basins, however, are intermittent. Discharge records for many of these streams are published in the Colorado annual water resources reports (U.S. Geological Survey, 1975-82).

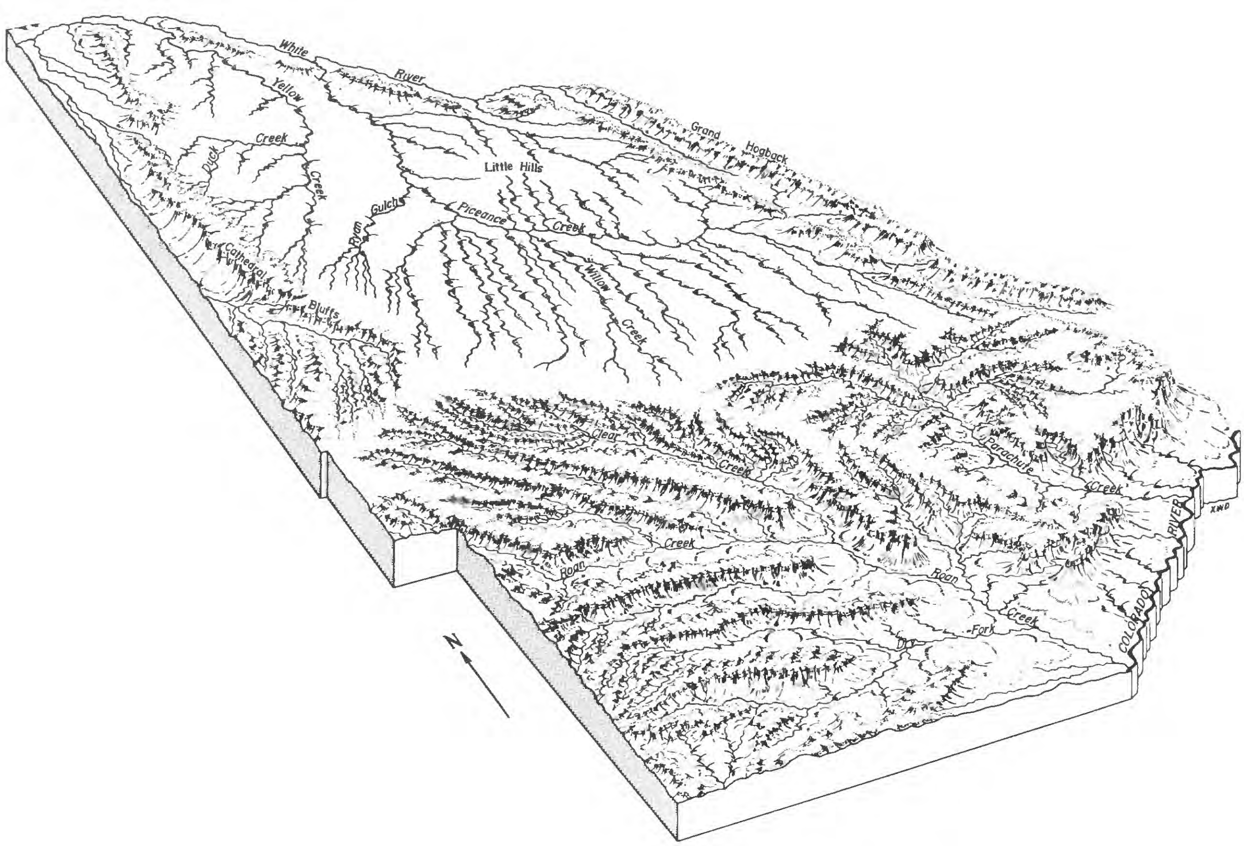


Figure 3.--Physiography of the major drainage basins in Piceance basin (from Coffin and others, 1971).

Irrigation diversions from Piceance and Yellow Creeks are common. At times, these diversions may result in zero flows at some streamflow-gaging stations. In Piceance Creek basin, more than 5,000 acres of land are irrigated; in Yellow Creek basin, 200 acres of land are irrigated. A detailed discussion of the surface-water hydrology in Piceance basin is presented in Weeks and others (1974).

Mean daily discharge for perennial flows at seven sites in Piceance Creek basin and three sites in Yellow Creek basin during the 1977-81 water years are shown in figures 4 to 6. Discharge summaries for sites 15 and 26 during the study period and period of record are presented below.

Site number and name	Mean discharge in cubic feet per second for indicated water years						
	1977	1978	1979	1980	1981	1965-81	1973-81
Site 15, Piceance Creek below Ryan Gulch.	12.7	16.0	28.7	35.4	17.3	20.1	--
Site 26, Yellow Creek near White River.	1.28	2.26	1.42	2.85	1.92	--	1.85

Stream discharges during the 1977-81 water years in Piceance and Yellow Creeks were least during the 1977 water year and greatest during the 1980 water year. The low discharges in Piceance and Yellow Creeks during the 1977 water year were a direct result of the below-normal snowpack during the winter of 1976-77. The flows in the spring-fed tributaries (fig. 5) evidently were not significantly affected by this low-precipitation period until the following year.

Beginning in mid-1978, mine-dewatering discharges from Tract C-b to Piceance Creek Tributary measured at site 9 periodically contributed to increases in streamflow in Piceance Creek. Significant increases in streamflow also occurred during the 1978-80 water years in Corral Gulch at site 24, Corral Gulch near Rangely (fig. 6). These increases in streamflow resulted from continuous mine dewatering at Tract C-a.

WATER-QUALITY CHARACTERISTICS

Physical and chemical data are complex in natural aquatic systems. Variations and interrelationships of chemical constituents in natural waters are discussed in Hem (1970) and Stumm and Morgan (1970). The criteria used to establish water-quality types for discussions of the major ions are shown in table 3. Data summaries presented in this report are based on a review of the data that have been published in annual State reports (U.S. Geological Survey, 1977-82).

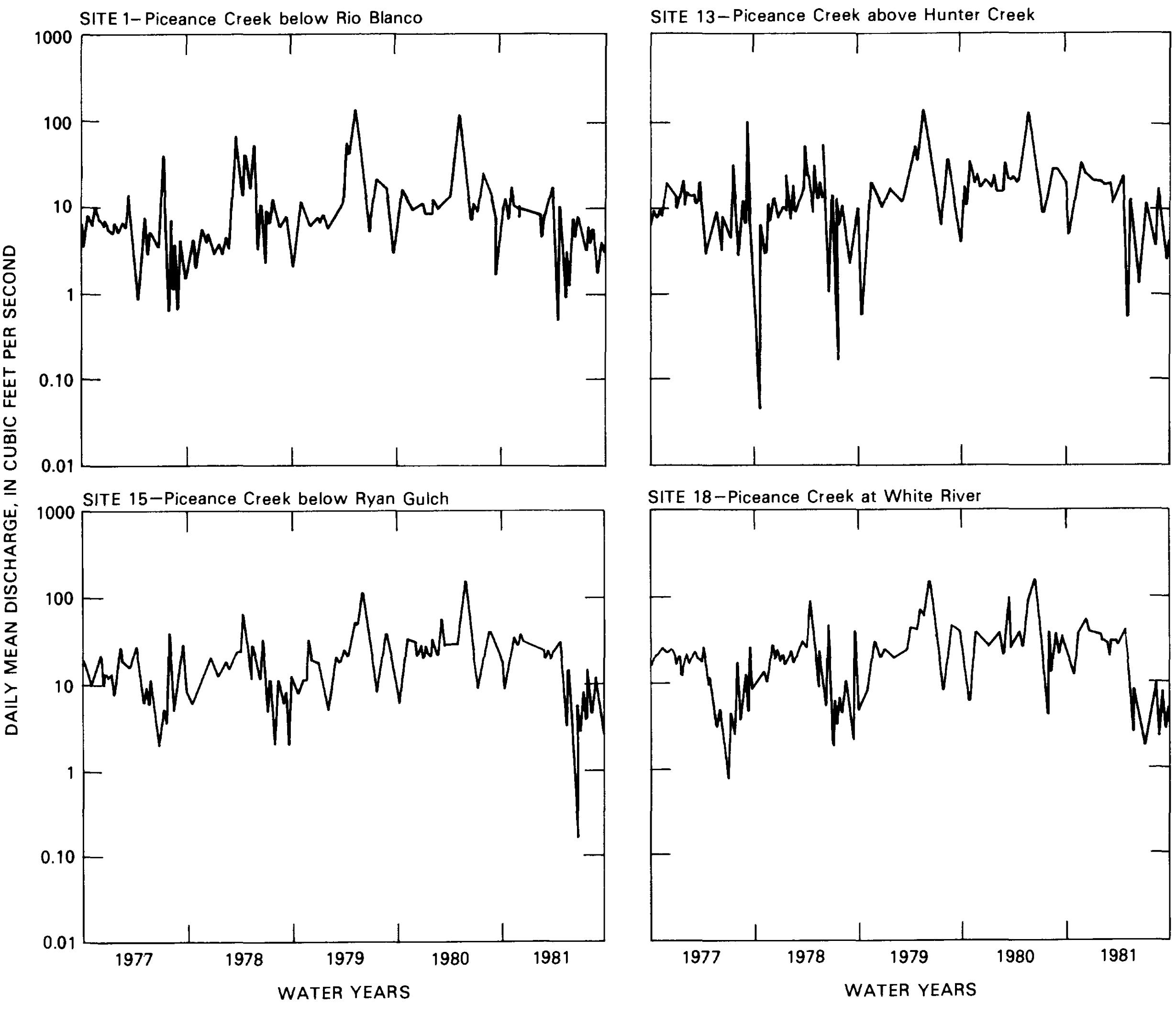


Figure 4.--Daily mean discharge at four sites on Piceance Creek, water years 1977-81.

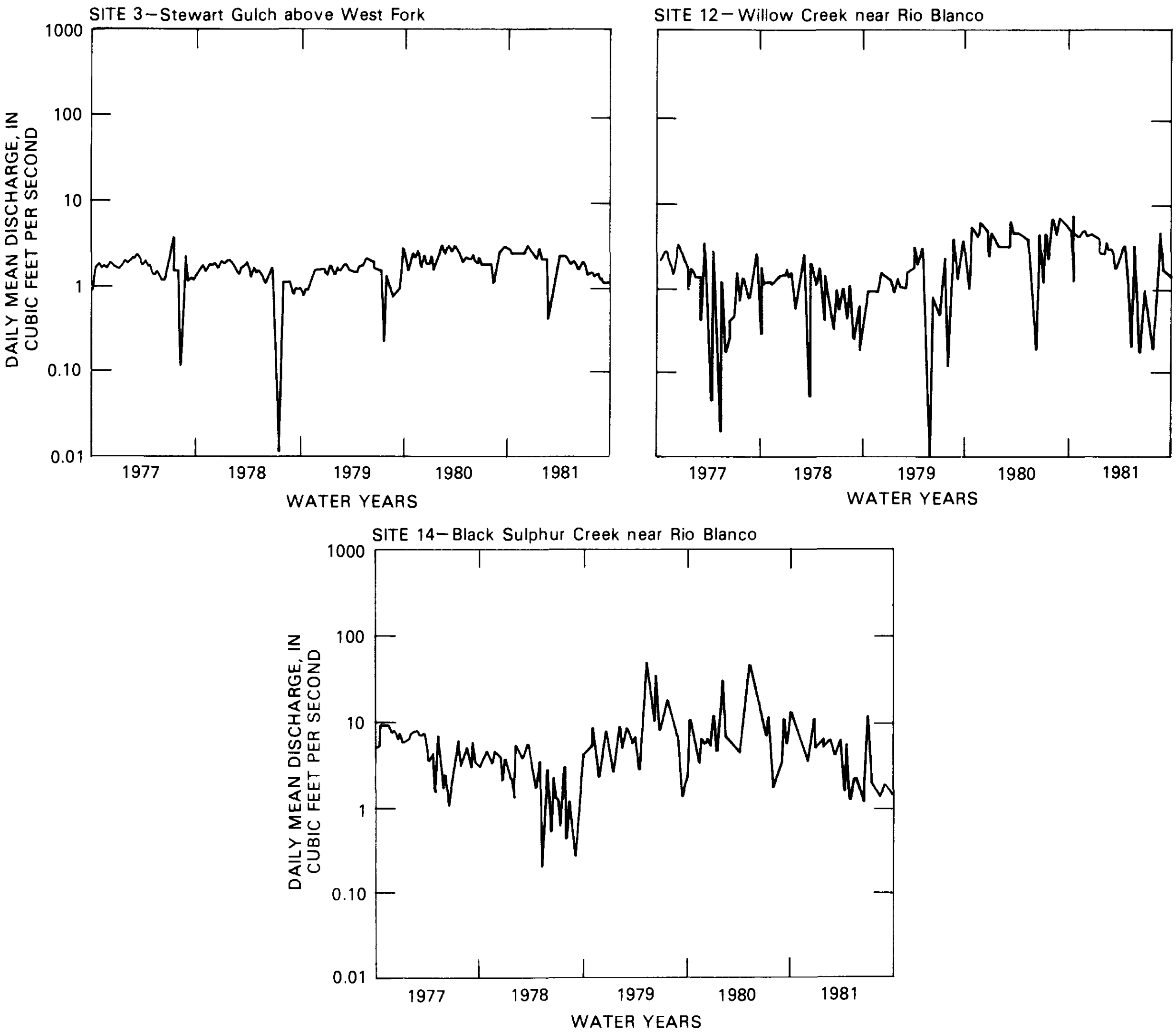


Figure 5.--Daily mean discharge at sites on three perennial tributaries to Piceance Creek, water years 1977-81.

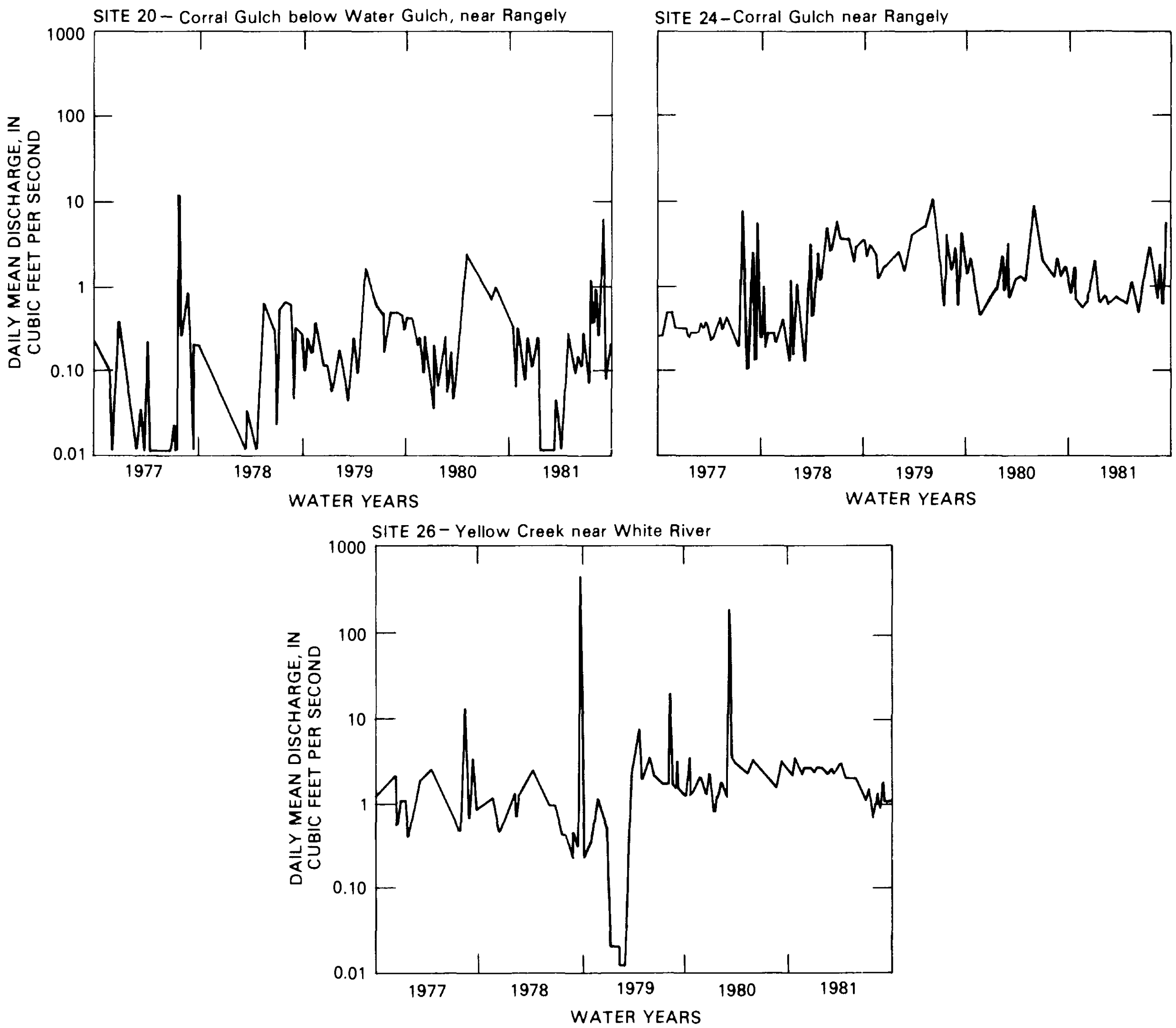


Figure 6.--Daily mean discharge at three sites on perennial streams in Yellow Creek basin, water years 1977-81.

Table 3.--*Chemical criteria used to classify water types and hardness*

Water types (modified from Piper and others, 1953, p. 26)		Hardness (modified from Durfor and Becker, 1964, p. 27)	
Milliequivalents per liter		Classification	Bivalent cations; calcium and magnesium (milligrams per liter as $CaCO_3$)
Cations	Anions		
Single cation used when it amounts to 50 percent or more of the total cations; when the above does not exist, the highest two cations are used.	Single anion used when it amounts to 50 percent or more of the total anions; when the above does not exist, the highest two anions are used.	Soft------	Less than 60.
		Moderately hard----	61-120.
		Hard------	121-180.
		Very hard-	More than 180.

Summaries are presented for both continuous-monitor data and periodic field determinations, major ions, nutrients, trace constituents, radioactive substances, and pesticides. Data were analyzed for 7 perennial streamflow sites and 11 intermittent streamflow sites in the Piceance Creek basin and 3 perennial streamflow sites and 5 intermittent streamflow sites in the Yellow Creek basin.

Continuous-recording monitors for specific conductance and temperature were maintained at all perennial streamflow sites and periodically at many of the intermittent streamflow sites.. In addition, continuous-monitoring records for dissolved oxygen and pH were maintained for site 1, Piceance Creek below Rio Blanco, and site 13, Piceance Creek above Hunter Creek, and the perennial tributaries to Piceance Creek, Stewart Gulch above West Fork, at site 3 and Willow Creek near Rio Blanco, at site 12. Data collected at sites equipped only for temperature and specific conductance are from in situ monitors. Pumping samplers were used at sites 1, 3, 12, and 13 to record data for temperature, specific conductance, pH, and dissolved oxygen. Daily suspended-sediment concentrations were collected with automatic-pumping samplers.

Although much of the alkalinity data were published as equivalent concentrations of calcium carbonate, alkalinity values in this report are shown as equivalent concentrations as bicarbonate. At all except two sites, bicarbonate was considered to be the only significant form of alkalinity. Carbonate concentrations up to several hundred milligrams per liter, however, were common near the mouths of Piceance and Yellow Creeks at sites 18 and 26. Carbonate concentrations at these sites were converted to equivalent concentrations of bicarbonate and added to the determined bicarbonate concentrations for a total alkalinity reported as bicarbonate.

Piceance Creek Basin

Temperature

During summer, water temperatures in Piceance Creek (table 4) were warmest near the mouth at site 18 (maximum = 32.0°C); cooler maximum temperatures of 26.5°C were recorded in the middle reaches of Piceance Creek at site 13 above Hunter Creek and site 15 below Ryan Gulch. The maximum daily range of temperature for Piceance Creek was 20°C at site 18; a maximum daily range of 22.0°C occurred in Piceance Creek basin in Willow Creek at site 12. At site 15, the first site upstream from site 18, the maximum daily range was 17°C. The somewhat cooler temperatures observed in the middle section of Piceance Creek resulted from flow augmentation to Piceance Creek by local springs and by the cooler, spring-fed tributaries of Stewart Gulch and Black Sulphur Creek.

Stream temperatures measured at the intermittent sites (table 5) generally were less than in the perennial streams. The temperatures were cooler because intermittent streamflow is seasonal in Piceance basin and occurs principally in spring and early summer. The 33.5°C recorded in Piceance Creek Tributary at site 9 occurred in July, 1981, during the dewatering of oil-shale mines.

Specific Conductance

Instantaneous values of specific conductance plotted against instantaneous discharge in Piceance Creek show a general inverse relationship (fig. 7). This relationship was best defined near the mouth of Piceance Creek at site 18 where chemical inputs from the drainage basin were fully integrated. During snowmelt runoff in wet years, specific conductance decreased to values less than 1,000 micromhos throughout most of Piceance Creek. Maximum values, ranging from 1,470 micromhos in the upper reaches of Piceance Creek at site 1 to 5,000 to 10,000 micromhos (table 4) at the lower reaches near White River at site 18, occurred during low-flow conditions. Although spring augmentation, irrigation diversions and returns, and oil-shale development tended to increase specific conductance in a downstream direction, the greatest increase in specific conductance in Piceance Creek resulted from inputs of high-conductance ground water downstream from site 15 below Ryan Gulch.

Variations in specific conductance in the perennial tributaries (table 4, fig. 8) were a function of spring-flow characteristics and basin activities. The minimum-maximum values of 200 to 2,050 micromhos (table 4) for the three perennial streams occurred at site 14, Black Sulphur Creek. Except for the low conductances of waters associated with snowmelt runoff, specific conductance normally ranged between 1,250 to 1,400 micromhos in the Stewart Gulch at site 3, and 1,150 to 1,500 micromhos in Willow Creek at site 12. Somewhat greater values of between 1,200 to 2,000 micromhos were recorded in Black Sulphur Creek at site 14. The tendency for specific conductance to remain within these limited ranges is due to the significant amount of augmentation to streamflow from local springs. The dissolved solids of many of these springs vary little throughout the year.

Table 4.--*Summary of continuous-monitor data and field determinations for selected water-*

[°C=degrees Celsius; micromhos=micromhos per centimeter at 25°C; mg/L=milligrams

Site number and name	Water-quality characteristics	1977 water year minimum	1977 water year maximum	1977 water year maximum daily range	1978 water year minimum	1978 water year maximum	1978 water year maximum daily range
1 Piceance Creek below Rio Blanco.	Temperature (°C)	0.0	29.5	18.0	0.0	23.0	13.5
	Specific conductance (micromhos)	(960)	(1,210)	ND	565	1,470	ND
	pH (units)	7.7	8.5	ND	7.7	8.6	ND
	Dissolved oxygen (mg/L)	5.4	12.9	3.7	(6.8)	(10.8)	ND
	Suspended-sediment concentration (mg/L)	8	10,700	ND	7	9,250	ND
13 Piceance Creek above Hunter Creek.	Temperature (°C)	(0.0)	[1]26.5	[1]17.5	0.0	26.0	17.0
	Specific conductance (micromhos)	[1]793	[1]1,680	ND	550	1,580	ND
	pH (units)	[1]7.6	[1]8.7	ND	7.8	8.9	ND
	Dissolved oxygen (mg/L)	[1]4.9	[1]14.7	ND	3.1	13.6	7.9
	Suspended-sediment concentration (mg/L)	10	87,000	ND	0.0	4,110	ND
15 Piceance Creek below Ryan Gulch.	Temperature (°C)	(0.5)	(22.5)	ND	(1.5)	(21.5)	ND
	Specific conductance (micromhos)	(1,350)	(2,000)	ND	(1,150)	(2,000)	ND
	pH (units)	(8.2)	(8.8)	ND	(7.1)	(8.9)	ND
	Dissolved oxygen (mg/L)	(7.7)	(11.9)	ND	(8.4)	(12.3)	ND
	Suspended-sediment concentration (mg/L)	10	21,700	ND	9	8,100	ND
18 Piceance Creek at White River.	Temperature (°C)	(0.0)	(19.5)	ND	-.5	32.0	18.5
	Specific conductance (micromhos)	(1,900)	(4,400)	ND	628	6,870	ND
	pH (units)	(8.1)	(8.6)	ND	(7.4)	(8.8)	ND
	Dissolved oxygen (mg/L)	(6.4)	(12.7)	ND	(8.8)	(14.2)	ND
	Suspended-sediment concentration (mg/L)	14	2,600	ND	4	25,000	ND
3 Stewart Gulch above West Fork, near Rio Blanco.	Temperature (°C)	[1].5	[1]20.5	[1]13.5	[1].5	[1]20.0	[1]14.5
	Specific conductance (micromhos)	[1]635	[1]1,790	ND	(1,200)	[1]1,460	ND
	pH (units)	[1]8.0	[1]8.5	ND	7.8	8.6	ND
	Dissolved oxygen (mg/L)	[1]3.6	[1]12.6	[1]5.9	[1]2.2	[1]15.7	[1]12.4
	Suspended-sediment concentration (mg/L)	1.0	560	ND	3.0	275	ND
12 Willow Creek near Rio Blanco.	Temperature (°C)	0.0	[1]26.0	[1]19.5	0.0	28.5	21.0
	Specific conductance (micromhos)	[1]1,000	[1]1,560	ND	(1,050)	1,680	ND
	pH (units)	[1]7.6	[1]8.7	ND	7.7	8.6	ND
	Dissolved oxygen (mg/L)	[1]5.3	[1]11.6	[1]3.7	3.6	11.8	ND
	Suspended-sediment concentration (mg/L)	6	3,820	ND	0.0	998	ND
14 Black Sulphur Creek near Rio Blanco.	Temperature (°C)	0.0	23.5	18.0	.5	23.0	18.5
	Specific conductance (micromhos)	1,070	2,050	ND	870	2,020	ND
	pH (units)	(7.9)	(8.3)	ND	(7.5)	(8.3)	ND
	Dissolved oxygen (mg/L)	(7.6)	(10.4)	ND	(6.2)	(11.3)	ND
	Suspended-sediment concentration (mg/L)	14	6,400	ND	8	19,800	ND

[1]Based on incomplete record of less than 80 percent for this year.

quality characteristics for perennial streams in Piceance Creek basins, water years 1977-81

per liter; ND=not determined; ( )=data from field determinations only]

1979 water year			1980 water year			1981 water year				
minimum	maximum	maximum daily range	minimum	maximum	maximum daily range	minimum	maximum	maximum daily range	5-year range	5-year maximum daily range
0.0	22.0	13.5	[1]0.0	[1]23.0	[1]15.5	0.0	26.5	16.5	0.0-29.5	18.0
606	1,380	ND	[1]706	[1]1,310	ND	878	1,390	ND	565-1,470	ND
[1]7.5	[1]8.6	ND	7.7	8.5	ND	7.8	8.7	ND	[1]7.5-8.7	ND
[1]5.1	[1]12.3	[1]4.1	[1]6.0	[1]12.3	[1]3.9	5.4	11.7	4.7	[1]5.1-12.9	[1]4.7
8	3,920	ND	9.0	4,070	ND	8	623	ND	7-10,700	ND
[1]0.0	[1]23.5	[1]13.5	0.0	22.0	13.5	0.0	26.0	17.0	[1].0-26.5	[1]17.5
[1]700	[1]1,630	ND	664	1,830	ND	1,120	1,620	ND	550-1,830	ND
[1]7.4	[1]8.7	ND	(7.5)	8.6	ND	7.8	8.6	ND	[1]7.4-8.9	ND
[1]6.0	[1]11.7	[1]5.3	5.0	(12.8)	6.1	5.1	14.4	7.0	[1]3.1-14.7	[1]7.9
19	4,750	ND	7.0	5,760	ND	10	1,560	ND	0-87,000	ND
(0.0)	(21.0)	ND	0.0	23.5	13.5	0.0	26.5	17	.0-26.5	17
(870)	(2,000)	ND	593	1,980	ND	520	2,920	ND	520-2,920	ND
(7.6)	(8.7)	ND	(7.8)	(8.5)	ND	(7.9)	(8.4)	ND	(7.1)-(8.9)	ND
(8.1)	(13.1)	ND	(7.0)	(11.4)	ND	(5.8)	(12.5)	ND	(5.8)-(13.1)	ND
11	4,500	ND	8	4,060	ND	8	6,190	ND	8-21,700	ND
0.5	29.5	20.0	0.0	28.0	15.0	0.0	31.5	20.0	-.5-32.0	20.0
790	3,620	ND	543	5,050	ND	1,320	10,000	ND	543-10,000	ND
(7.5)	(8.7)	ND	(8.1)	(8.6)	ND	(8.1)	(8.9)	ND	(7.4)-(8.9)	ND
(7.5)	(16.2)	ND	(7.6)	(10.9)	ND	(3.6)	(12.5)	ND	(3.6)-(16.2)	ND
10	4,500	ND	13	4,080	ND	12	3,190	ND	4-25,000	ND
[1]0.5	[1]20.0	[1]12.0	1.0	18.5	ND	[1]2.5	[1]19.5	ND	[1].5-20.5	[1]14.5
[1]1,100	[1]1,410	ND	844	1,430	ND	1,190	1,390	ND	[1]635-1,790	ND
7.7	8.6	ND	7.7	8.9	ND	(7.8)	8.7	ND	7.7-8.9	ND
6.8	13.6	ND	6.4	14.6	ND	7.1	11.4	2.9	[1]2.2-15.7	[1]12.4
2.0	536	ND	4.0	237	ND	1.0	450	ND	1.0-560	ND
[1]0.0	[1]24.0	[1]19.0	0.0	22.5	16.5	0.0	29.5	22.0	.0-29.5	22.0
[1]1,050	[1]1,480	ND	[1]596	[1]1,550	ND	[1]580	[1]1,590	ND	[1]580-1,680	ND
[1]7.7	[1]8.7	ND	[1]7.4	[1]8.8	ND	7.9	8.6	ND	[1]7.4-8.8	ND
[1]6.2	[1]12.9	ND	[1]5.5	[1]12.7	[1]3.3	[1]5.9	(12.7)	[1]3.4	[1]3.6-12.9	[1]3.7
3	7,030	ND	20	753	ND	1	644	ND	0-7,030	ND
0.5	22.5	19.5	0.0	23.0	15.0	0.0	23.0	15.0	.0-23.5	19.5
950	1,960	ND	551	1,990	ND	200	1,910	ND	200-2,050	ND
(7.6)	(8.7)	ND	(7.5)	(8.4)	ND	(7.8)	(8.3)	ND	(7.5)-(8.7)	ND
(8.1)	(11.0)	ND	(7.4)	(12.8)	ND	(7.9)	(12.0)	ND	(6.2)-(12.8)	ND
13	2,000	ND	7	5,510	ND	11	2,620	ND	7-19,800	ND

Table 5.--*Summary of continuous-monitor data and field determinations for selected water-quality characteristics for intermittent streams in Piceance Creek basin, water years 1977-81*

[°C=degrees Celsius; micromhos=micromhos per centimeter at 25°C; mg/L=milligrams per liter; ND=not determined]

Water-quality characteristic	5-year range for all available data, water years 1977-81				
	Site 2	Site 4	Site 5	Site 6	Site 7
Temperature (°C)	1.0-3.0	0.0-16.5	0.0-19.0	13.0	17.0
Specific conductance (micromhos)	1,430-1,900	100-1,840	100-310	910	305-2,250
pH (units)	ND	8.6	8.7	8.4	7.8-8.4
Dissolved oxygen (mg/L)	ND	10.6	10.5	8.4	ND
Suspended-sediment concentration (mg/L).	ND	0-500	0-1,800	ND	0-8,020

Water-quality characteristic	5-year range for all available data, water years 1977-81				
	Site 8	Site 9	Site 10	Site 11	Site 17
Temperature (°C)	17.0	0.0-33.5	0.0	0.0-22.0	0.0-23.5
Specific conductance (micromhos)	225-910	650-2,570	108	147-674	112-589
pH (units)	7.8-8.4	8.1-8.9	7.3	7.9	7.6-8.2
Dissolved oxygen (mg/L)	7.3	4.8-11.6	10.0	10.7	11.3
Suspended-sediment concentration (mg/L).	0-62,000	0-76,600	ND	0-49,000	0-3,790

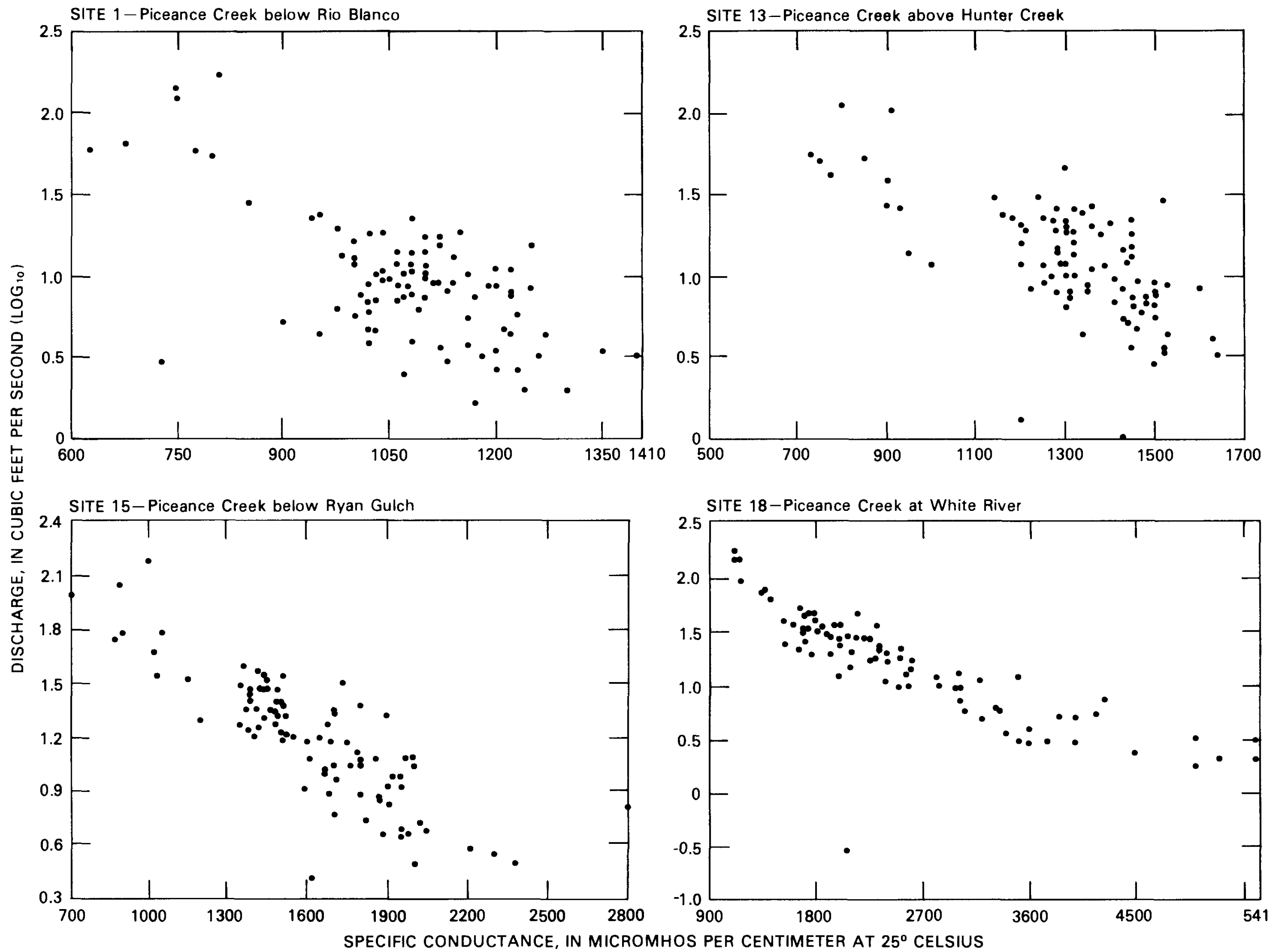


Figure 7.--Correlation of instantaneous discharge and specific conductance at four sites on Piceance Creek, water years 1977-81.

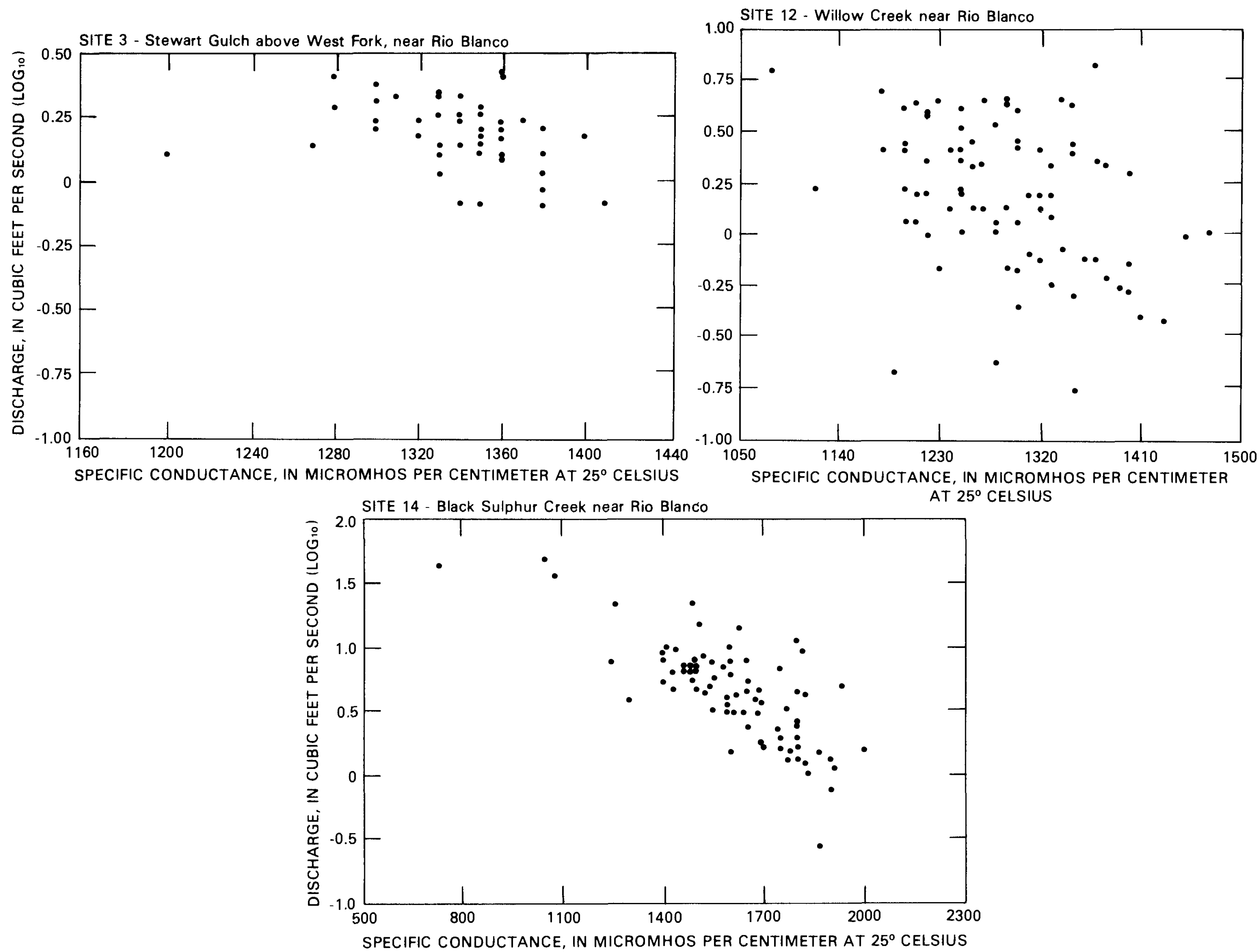


Figure 8.--Correlation of instantaneous discharge and specific conductance at sites on three perennial tributaries to Piceance Creek, water years 1977-81.

Variations in values of specific conductance for the intermittent streams in Piceance basin (table 5) were similar to those observed for Piceance Creek. Values generally were less than 500 micromhos in streams fed directly by snowmelt, but specific conductance increased to greater than 1000 micromhos during periods when springs, shallow ground-water systems, or oil-shale mine dewatering accounted for most of the streamflow.

pH

Continuous-monitor data and periodic field determinations (table 4) show that pH values in Piceance Creek and the perennial tributaries ranged from 7.1 to 8.9. A similar range of pH values existed for the intermittent streams (table 5). Values of pH were generally less than 8.0 during snowmelt runoff and greater than 8.2 during low flows and periods of photosynthetic activity (fig. 9). Downstream increases of 0.2 to 0.4 pH units were common in Piceance Creek.

Dissolved Oxygen

Dissolved-oxygen concentrations in Piceance Creek generally were greater than 5.0 mg/L at site 1, Piceance Creek below Rio Blanco, and 3.0 mg/L at site 13, Piceance Creek above Hunter Creek (table 4). Continuous-monitor data for site 1 that may be characteristic of a summer day in Piceance Creek are presented in figure 9. The data show the effects of the metabolic activities of algae and other aquatic plants and animals on stream chemistry: Supersaturation of dissolved oxygen from photosynthetic activity during the day, dissolved oxygen deficits from net respiration during the night. Corresponding changes in pH and small changes in specific conductance result from plant and animal uptake and release of carbon and other nutrients used for growth and maintenance of metabolic functions. The apparent decrease of 40 micromhos in specific conductance during the afternoon (fig. 9) may have resulted more from changes in water temperature rather than metabolic activities.

From data analysis, it can be generalized that daily changes of dissolved-oxygen concentrations exceeding 2.0 to 3.0 mg/L during summer months most likely were a function of photosynthetic activity. During the winter when stream temperatures were less than 5°C, concentrations of dissolved oxygen generally less than 10 mg/L represented an unsaturated condition. Spring discharges which had low concentrations of dissolved oxygen may have contributed to the minimal dissolved-oxygen values observed in Piceance Creek and the perennial tributaries Stewart and Willow Creeks (table 4) where they augment streamflow. Data for dissolved oxygen in the intermittent streams (table 5) was insufficient for analysis.

Suspended Sediment

Concentration ranges of suspended sediment in the perennial and intermittent streams in Piceance Creek basin are shown in tables 4 and 5. Suspended-sediment concentrations were extremely variable in the basin, and concentrations exceeding several tens of thousands milligrams per liter during runoff normally existed only for local reaches in a stream. Statistical relationships between the physical characteristics of Piceance basin and sediment characteristics are discussed in Kircher and Von Guerard (1982).

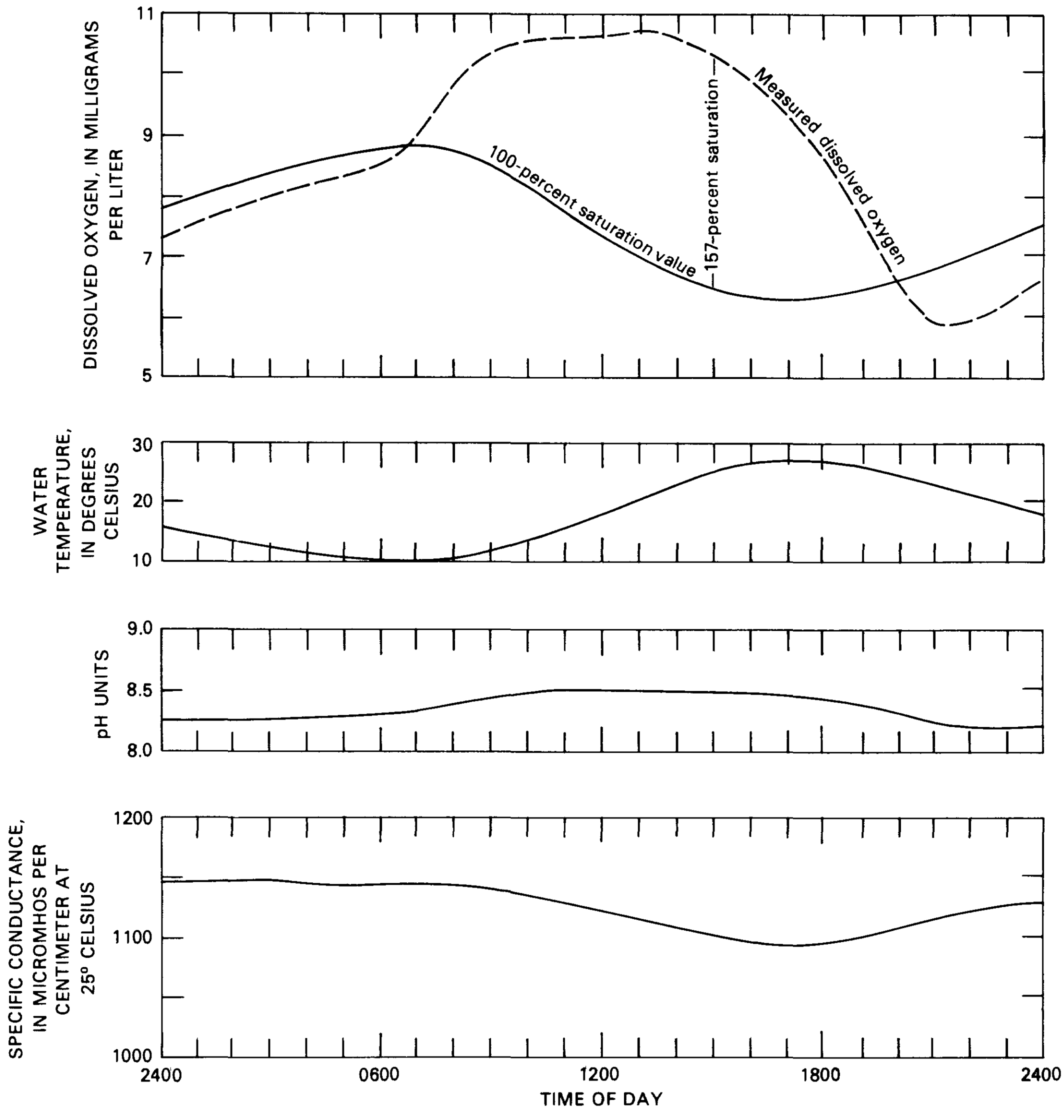


Figure 9.--Hourly water-quality monitor data for site 1, Piceance Creek below Rio Blanco, July 5, 1981.

Major Ions

Perennial streams.--Statistical data for concentrations of major ions in perennial streams in Piceance Creek basin are presented in table 6. In addition, these data were grouped according to hydrologic and seasonal classifications: Low flows during nonirrigation versus irrigation seasons, and high flows from snowmelt runoff versus summer storm runoff. Statistical summaries for these data groups for Piceance Creek are shown in figures 10 to 13; data for the perennial tributaries are shown in figures 14 to 16. If the data extremes were significantly extended by a single sample, then the second highest (or lowest) concentration is given for perspective.

Between site comparisons of water-quality type and relative contributions of cations and anions to dissolved solids are shown in figures 17 to 20. The data show annual mean concentrations after they have been converted to milliequivalents. This conversion was necessary to establish an equivalent basis for ion comparisons in determining water-quality type (Hem, 1970).

Within site variations in concentrations of the major ions at sites 1, 13, 15, and 18 on Piceance Creek can be summarized as follows:

1. Except for an occasional potassium value, concentrations of the major ions, (and related dissolved solids) generally were greatest during the low-flow irrigation season and least during the snowmelt runoff. Mean concentrations of major ions were significantly less during the high-flow years of 1979-80 than during the low-flow years of 1977-78 and 1981.
2. For a given discharge range at each site in Piceance Creek (figs. 10 to 13) concentrations of the major ions were greater during summer storms than during snowmelt runoff.
3. Concentrations of sodium and bicarbonate showed the greatest variation with changes in discharge and tended to decrease as discharge increased.
4. The concentration ratio of calcium/magnesium was greatest during snowmelt runoff and least during the low flows in the irrigation season. This ratio may be useful in determining the source of water flowing in Piceance Creek at any given time.
5. The concentration ratio of bicarbonate/sulfate and chloride concentrations at site 18 were significantly greater during low flows than during high flows.

The within-site variations of data for the perennial tributaries to Piceance Creek showed considerably less change in concentrations of the major ions with discharge than those observed in Piceance Creek. Least variation occurred in Stewart Gulch at site 3 where concentrations of the cations and anions generally remained constant throughout the 5-year study (fig. 14). Flow at this site is supplied almost entirely by springs. Similar chemical characteristics existed at site 12 at Willow Creek but ranges in concentrations were greater than in Stewart Gulch. Data for Willow Creek (fig. 15) show slightly lesser concentrations of magnesium, sodium, and sulfate during high flows than during low flows. The amount of flow in Willow Creek often was affected by irrigation practices.

Table 6.--*Statistical summary of concentrations of major ions in perennial streams in Piceance Creek basin, water years 1977-81*

[N=number of samples; $\bar{X}$=mean concentration of samples; S=standard deviation; $S_{\bar{x}}$ =standard error of the mean; Min=minimum concentration; Max=maximum concentration; ( )=value at second lowest or highest concentration. Shown for ranges that are exaggerated by a single extreme data value]

Cations, in milligrams per liter																								Dissolved solids, in milligrams per liter					
Calcium						Magnesium						Potassium						Sodium											
Mean				Range		Mean				Range		Mean				Range		Mean				Range		Mean				Range	
N	$\bar{X}$	S	$S_{\bar{x}}$	Min	Max	N	$\bar{X}$	S	$S_{\bar{x}}$	Min	Max	N	$\bar{X}$	S	$S_{\bar{x}}$	Min	Max	N	$\bar{X}$	S	$S_{\bar{x}}$	Min	Max	N	$\bar{X}$	S	$S_{\bar{x}}$	Min	Max
Site 1 Piceance Creek below Rio Blanco																													
55	68	9.9	1.33	22 (41)	83	55	46	6.5	0.88	27	57	57	3.3	2.2	0.29	2.1	19 (5.2)	55	123	21	2.9	63	170	55	701	87	12	442	891
Site 13 Piceance Creek above Hunter Creek																													
60	74	10	1.3	42	91	60	63	12	1.6	31	89	61	3.3	1.5	.19	2.1	13 (8.0)	60	153	33	4.3	76	230	57	886	138	18	473	1100
Site 15 Piceance Creek below Ryan Gulch																													
59	78	11	1.5	36	94	59	83	19	2.5	28 (40)	120	59	3.2	.85	.11	.3 (2.0)	5.5	59	191	56	7.3	78	370	59	1089	238	31	425 (588)	1720 (1610)
Site 18 Piceance Creek at White River																													
59	59	13	1.7	27	83	59	84	17	2.2	45	110	59	4.2	1.1	.15	2.2	6.9	59	446	261	34	130	1300	59	1665	652	85	720	3660
Site 3 Stewart Gulch above West Fork																													
52	89	5.1	.71	76	97	52	74	3.6	.49	67	80	53	1.5	.52	.07	1.0	4.8 (1.9)	52	124	6.7	.93	100	140	52	918	25	3.4	869	963
Site 12 Willow Creek near Rio Blanco																													
52	88	7.7	1.1	69	110	52	72	5.7	.79	55	82	53	1.9	.68	.09	.7	5.6 (3.2)	52	119	10	1.4	92 (110)	140	51	873	56	7.8	699 (767)	989
Site 14 Black Sulphur Creek near Rio Blanco																													
60	97	12	1.5	47 (75)	120	59	96	15	1.9	41	120	59	2.6	1.5	.20	1.5	13 (5.0)	59	153	28	3.7	62	200	55	1151	142	19	498 (645)	1380

Table 6.--*Statistical summary of concentrations of major ions in perennial streams in Piceance Creek basin, water years 1977-81*--Continued

Anions, in milligrams per liter																								Specific conductance, in micromhos					
Bicarbonate						Chloride						Fluoride						Sulfate											
Mean				Range		Mean				Range		Mean				Range		Mean				Range		Mean				Range	
N	$\bar{X}$	S	$S_{\bar{x}}$	Min	Max	N	$\bar{X}$	S	$S_{\bar{x}}$	Min	Max	N	$\bar{X}$	S	$S_{\bar{x}}$	Min	Max	N	$\bar{X}$	S	$S_{\bar{x}}$	Min	Max	N	X	S	$S_{\bar{x}}$	Min	Max
Site 1 Piceance Creek below Rio Blanco																													
55	505	75	10	290	640	55	15	5.5	0.74	7.7	49 (21)	55	0.95	0.26	0.03	0.3	1.7 (1.3)	55	175	25	3.3	120	230	92	1074	143	15	625	1400
Site 13 Piceance Creek above Hunter Creek																													
59	550	83	11	300	690	60	13	3.1	.40	8.6	27 (21)	60	1.1	.90	.12	.00 (.20)	4.8	61	286	56	7.1	130	380	95	1309	196	20	730	1640
Site 15 Piceance Creek below Ryan Gulch																													
58	618	120	16	260 (360)	960 (830)	59	16	5.3	.68	8.6	35	59	.85	.34	.04	.1	2.0	59	396	106	14	130	660	94	1613	337	35	703 (870)	2800 (2380)
Site 18 Piceance Creek at White River																													
59	[1]1108	527	69	[1]460	[1]2830	59	60	48	6.2	11	230	59	1.4	.70	.09	.2	3.5	59	446	113	15	200	740 (600)	93	2510	1010	105	1080	5500
Site 3 Stewart Gulch above West Fork																													
52	491	34	4.8	290 (460)	550	52	6.6	.94	.13	5.2	12 (7.7)	52	.28	.09	.01	.0	.5	52	360	19	2.6	330	440 (390)	53	1339	37	5.1	1200	1410
Site 12 Willow Creek near Rio Blanco																													
54	477	45	6.1	290 (380)	590	52	11	3.0	.42	.1 (9.5)	26 (18)	52	.41	.12	.02	.0	.7	52	332	32	4.5	240	420	87	1286	76	8.1	1050	1470
Site 14 Black Sulphur Creek near Rio Blanco																													
59	562	63	8.2	270 (410)	650	60	9.9	2.6	.33	5.6	23 (18)	60	.48	.11	.01	.0 (.2)	.7	60	473	92	12	170	610	96	1605	195	20	730 (1050)	2000

[1]Includes concentrations of carbonate (CO_3) that were converted to equivalents of bicarbonate (HCO_3).

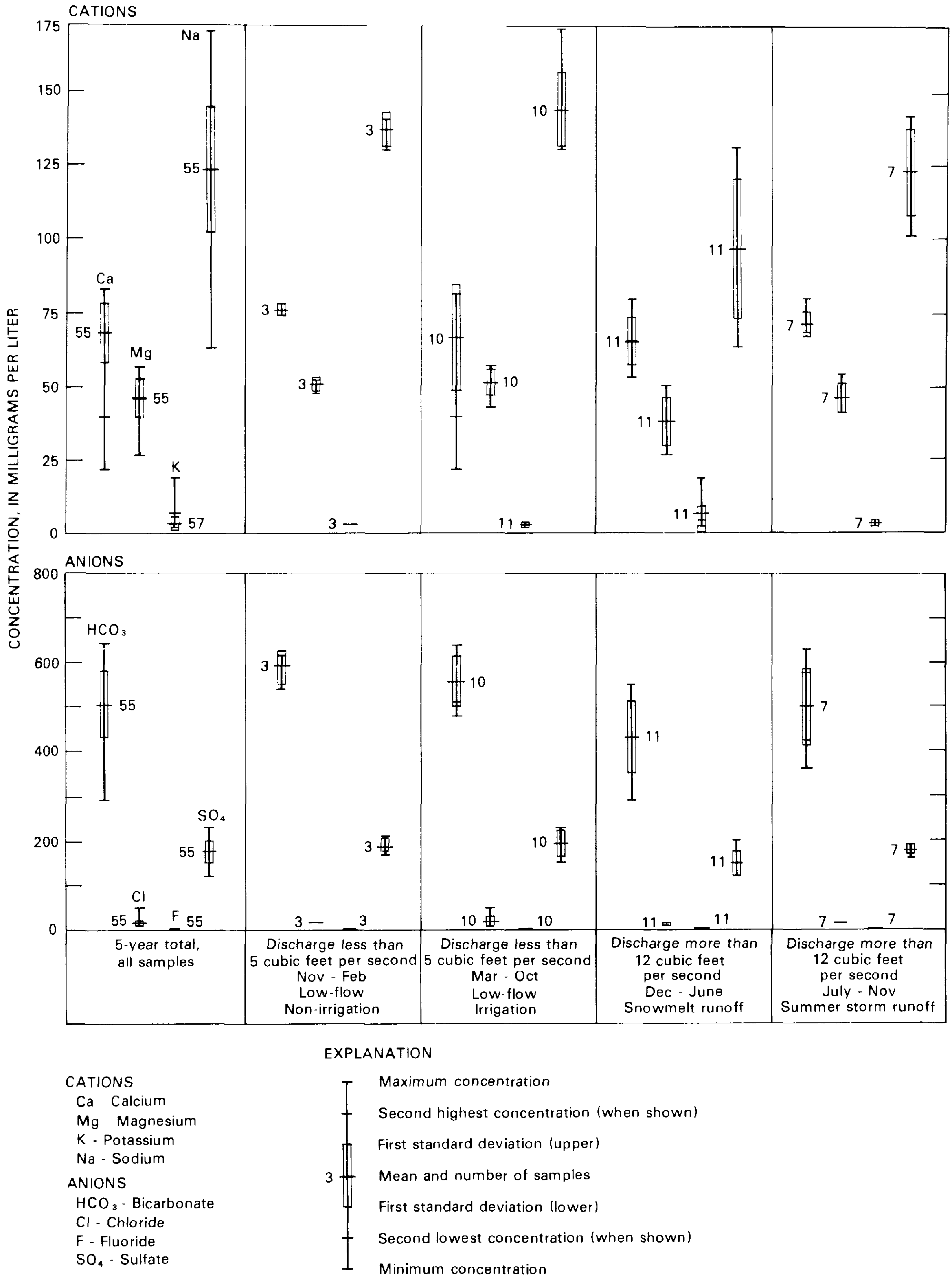


Figure 10.--Means, standard deviation, and extremes of concentrations of periodic samples for major ions for discharge and seasonal classifications, Piceance Creek below Rio Blanco (site 1), water years 1977-81.

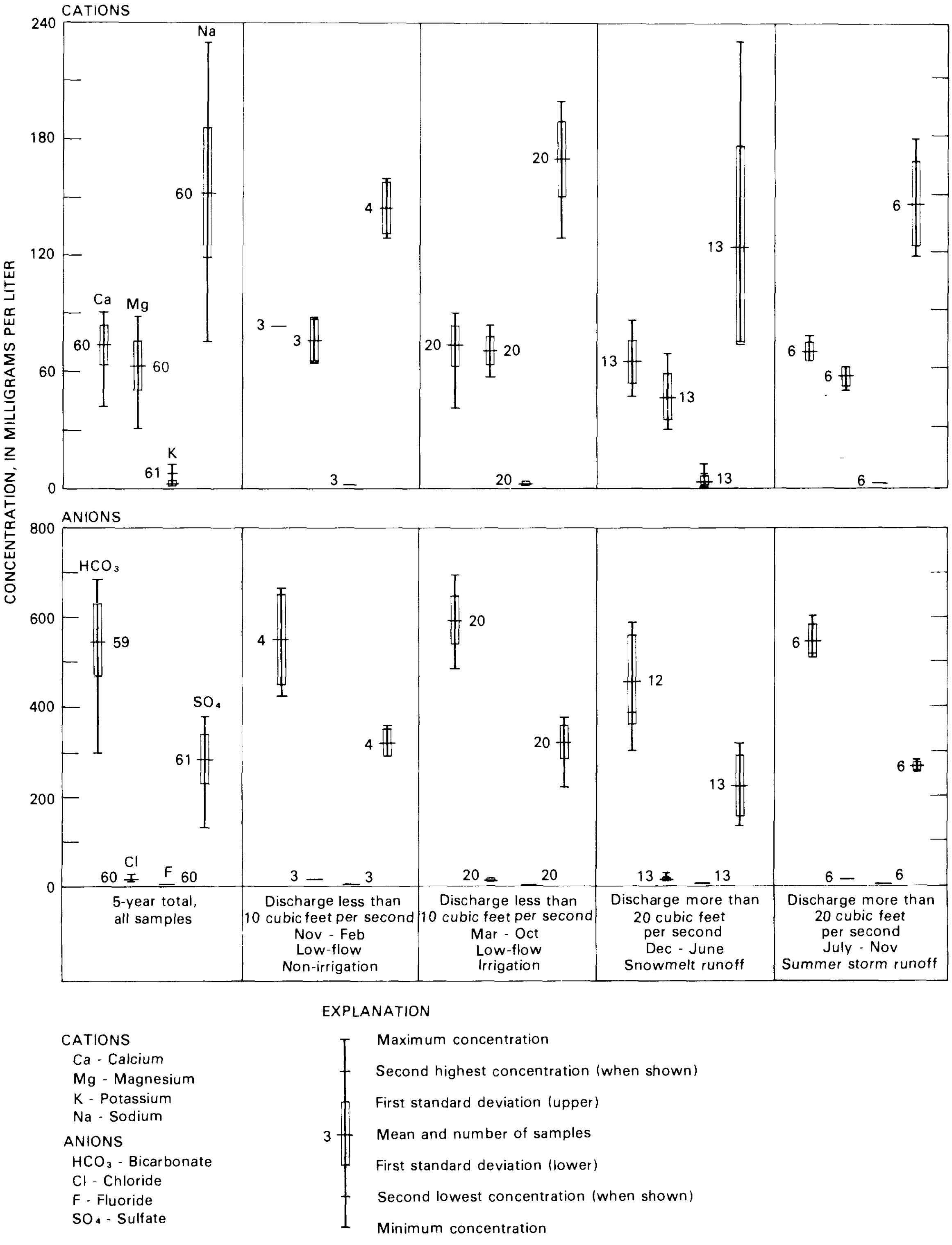


Figure 11.--Means, standard deviation, and extremes of concentrations of periodic samples for major ions for discharge and seasonal classifications, Piceance Creek above Hunter Creek near Rio Blanco (site 13), water years 1977-81.

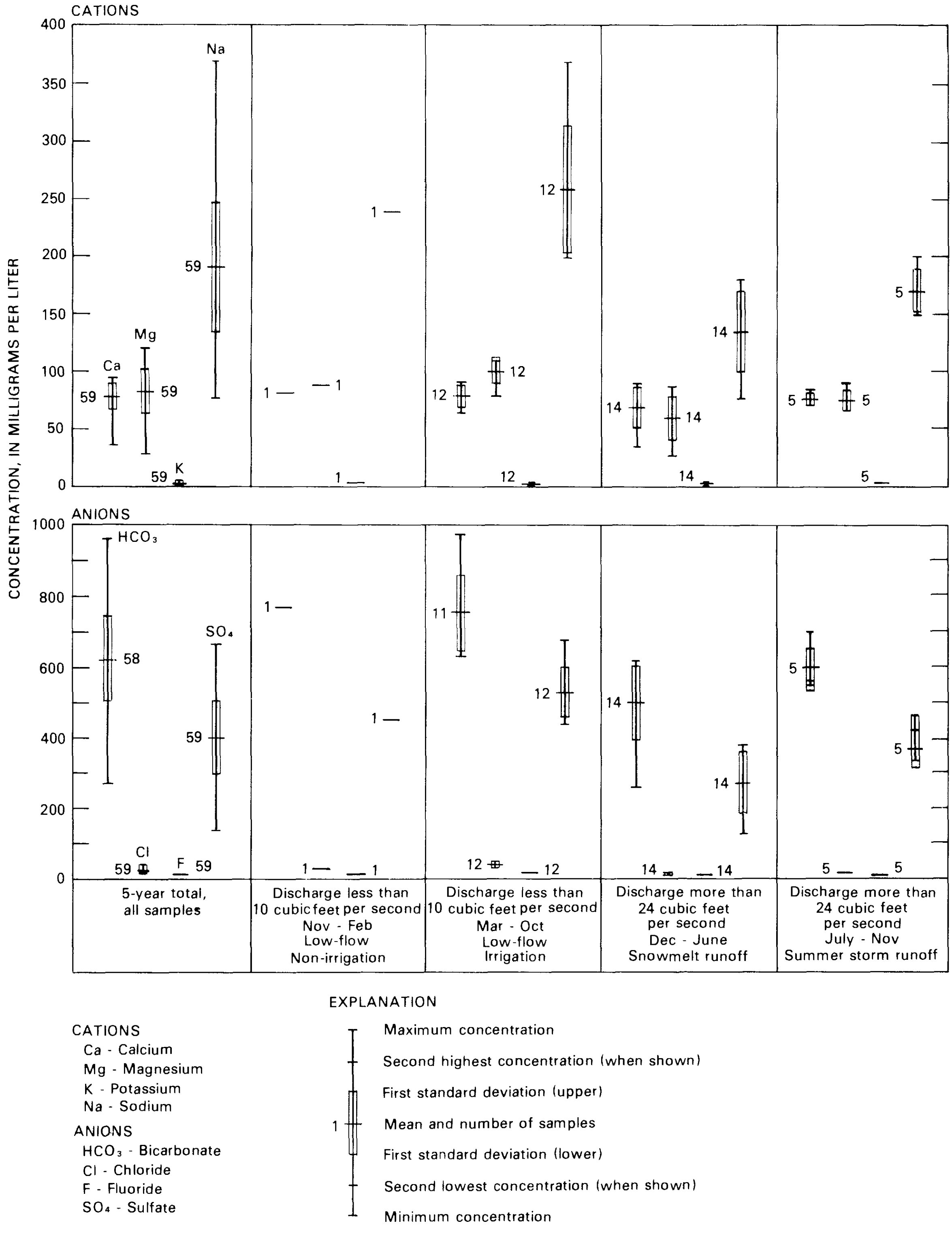


Figure 12.--Means, standard deviation, and extremes of concentrations of periodic samples for major ions for discharge and seasonal classifications, Piceance Creek below Ryan Gulch, near Rio Blanco (site 15), water years 1977-81.

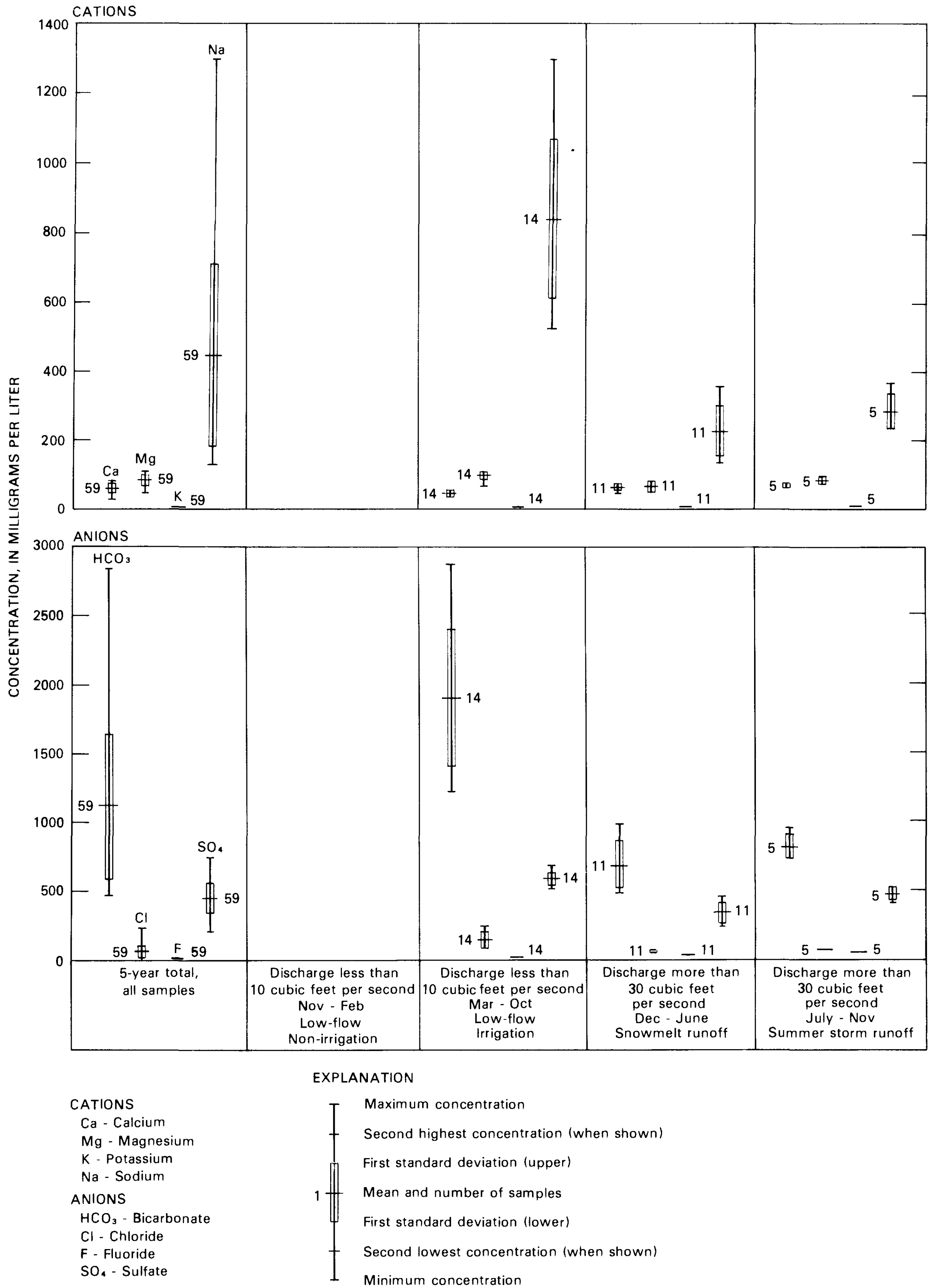


Figure 13.--Means, standard deviation, and extremes of concentrations of periodic samples for major ions for discharge and seasonal classifications, Piceance Creek at White River (site 18), water years 1977-81.

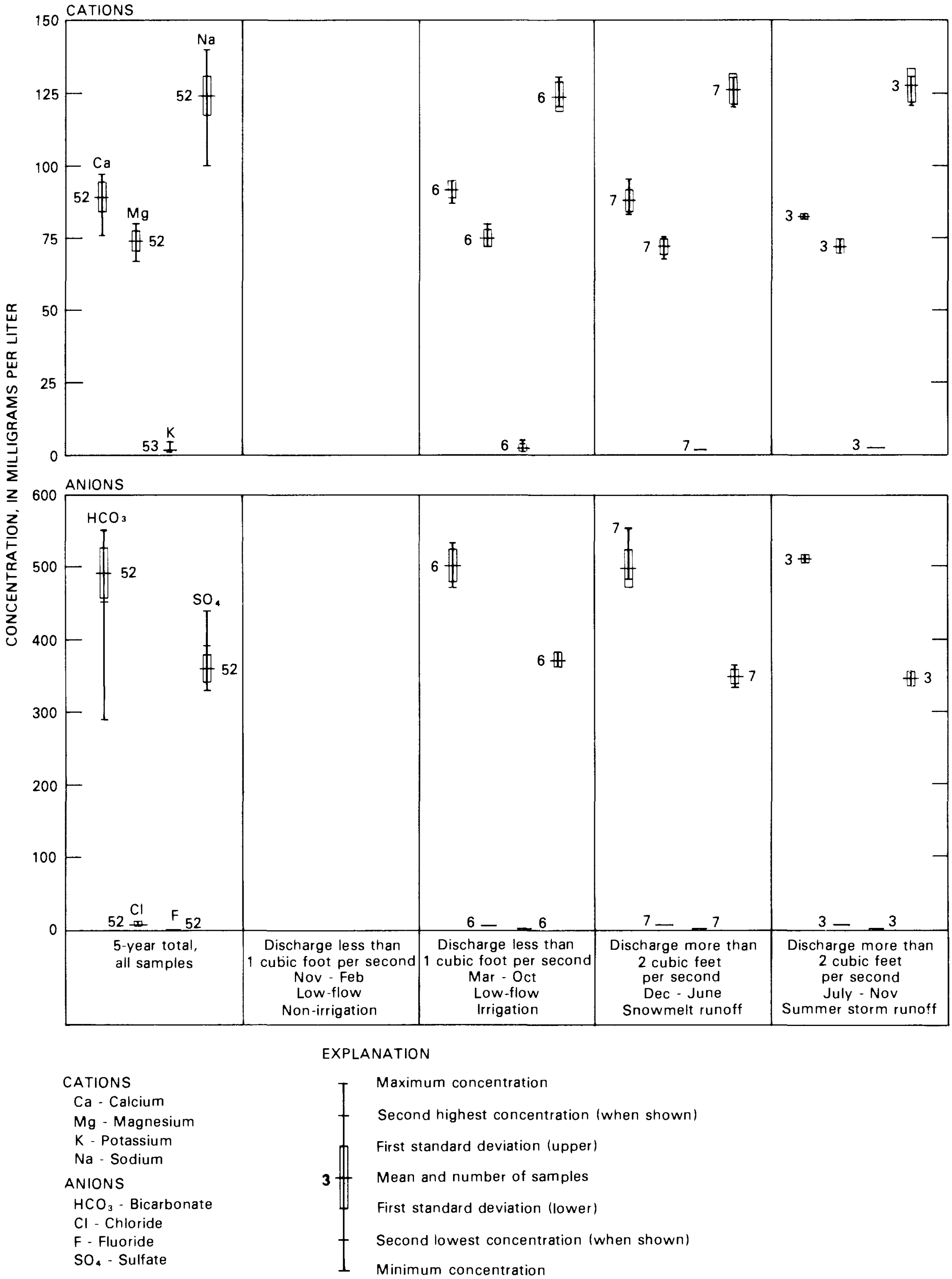


Figure 14.--Means, standard deviation, and extremes of concentrations of periodic samples for major ions for discharge and seasonal classifications, Stewart Gulch above West Fork, near Rio Blanco (site 3), water years 1977-81.

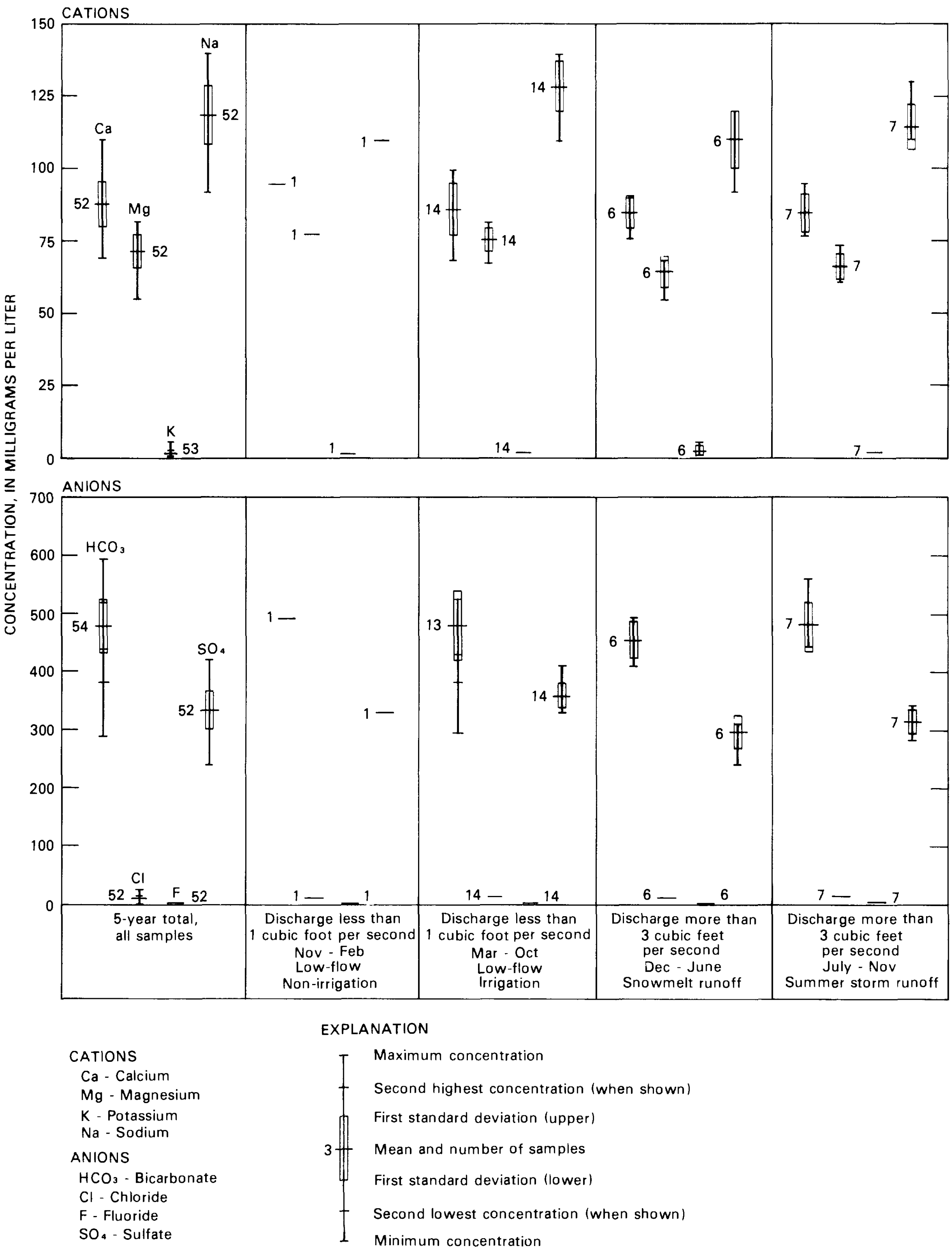


Figure 15.--Means, standard deviation, and extremes of concentrations of periodic samples for major ions for discharge and seasonal classifications, Willow Creek near Rio Blanco (site 12), water years 1977-81.

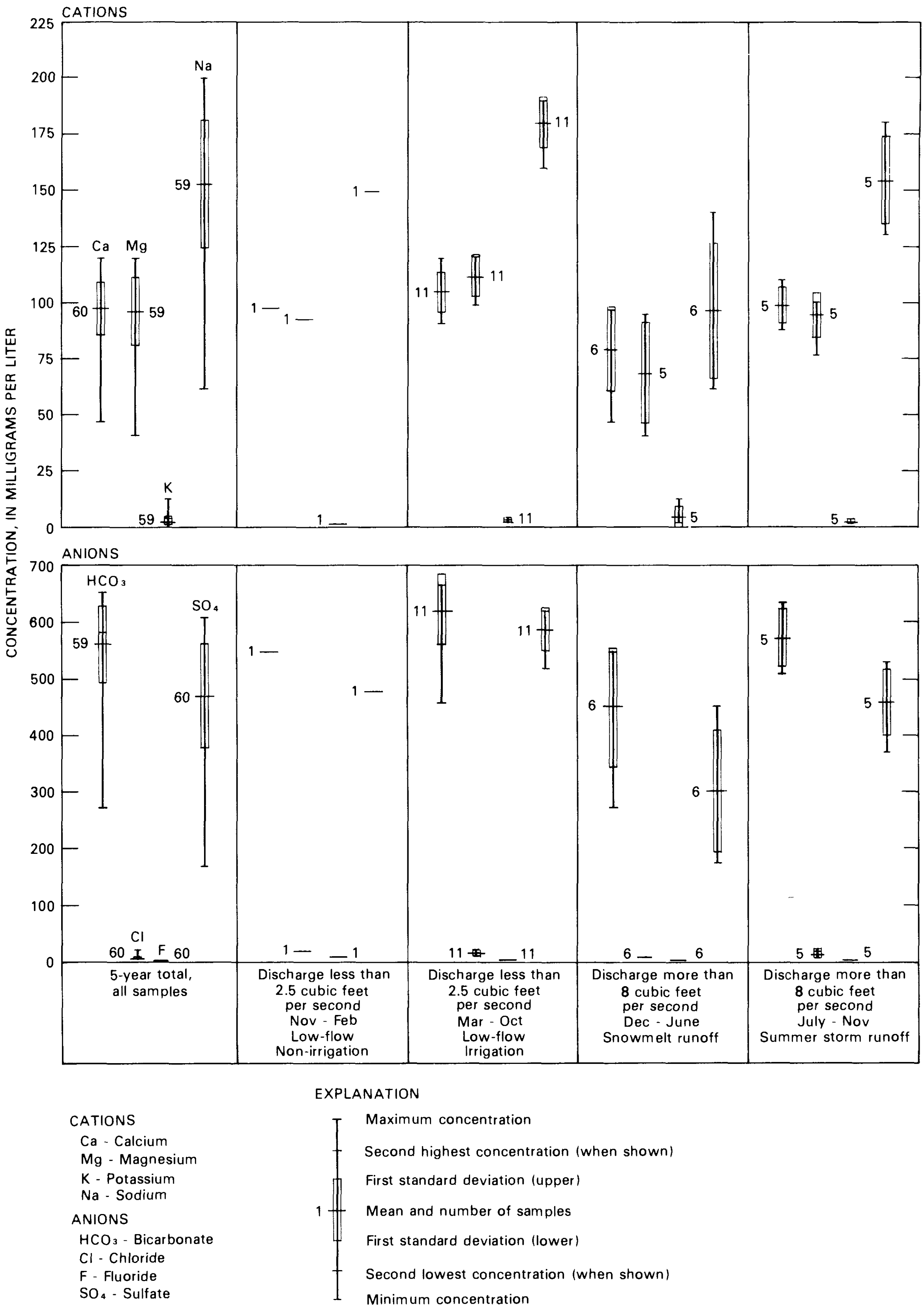


Figure 16.--Means, standard deviation, and extremes of concentrations of periodic samples for major ions for discharge and seasonal classifications, Black Sulphur Creek near Rio Blanco (site 14), water years 1977-81.

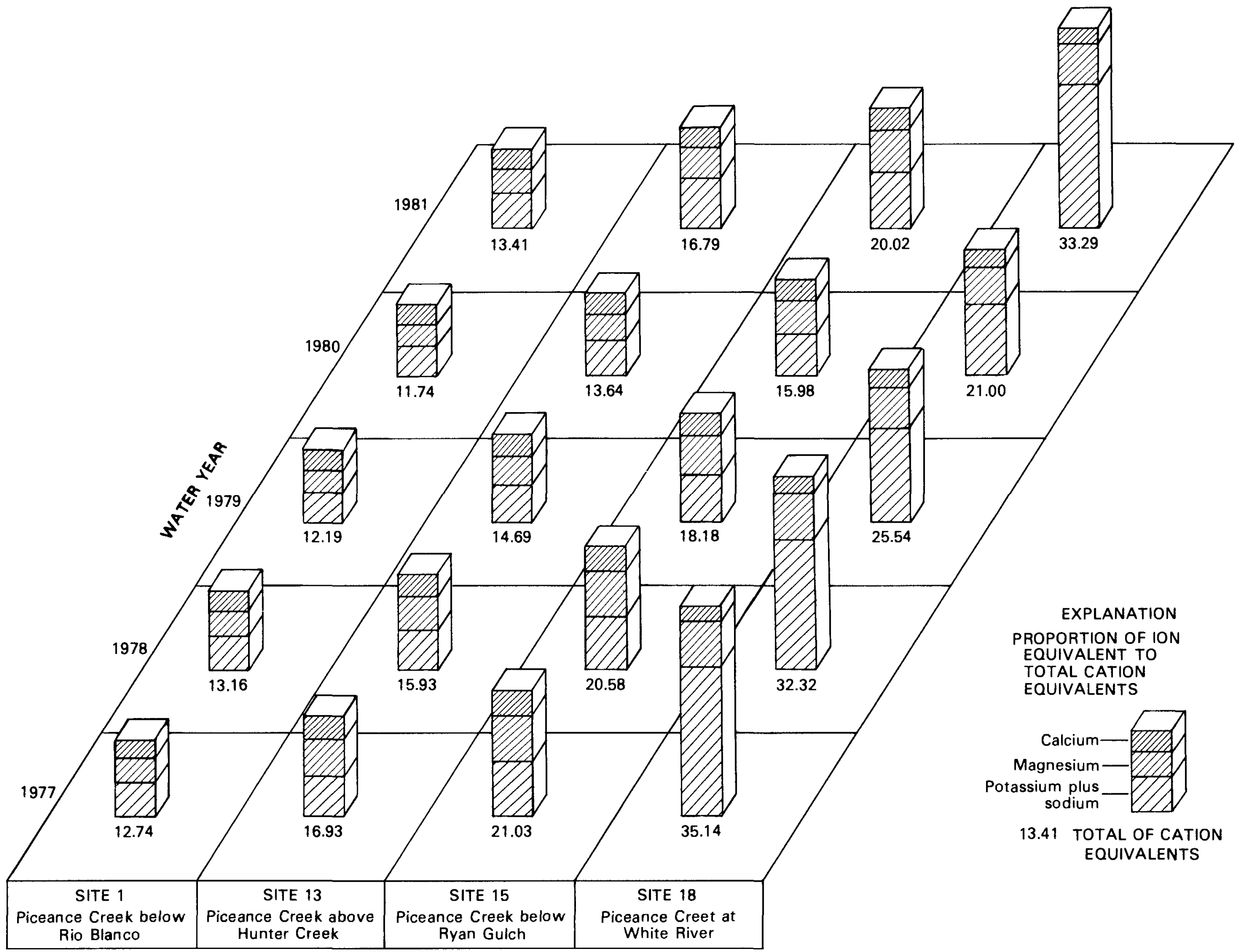


Figure 17.--Relative proportion of ion equivalents to total cation equivalents calculated from annual mean concentrations of calcium, magnesium, potassium, and sodium at four sites on Piceance Creek, water years 1977-81.

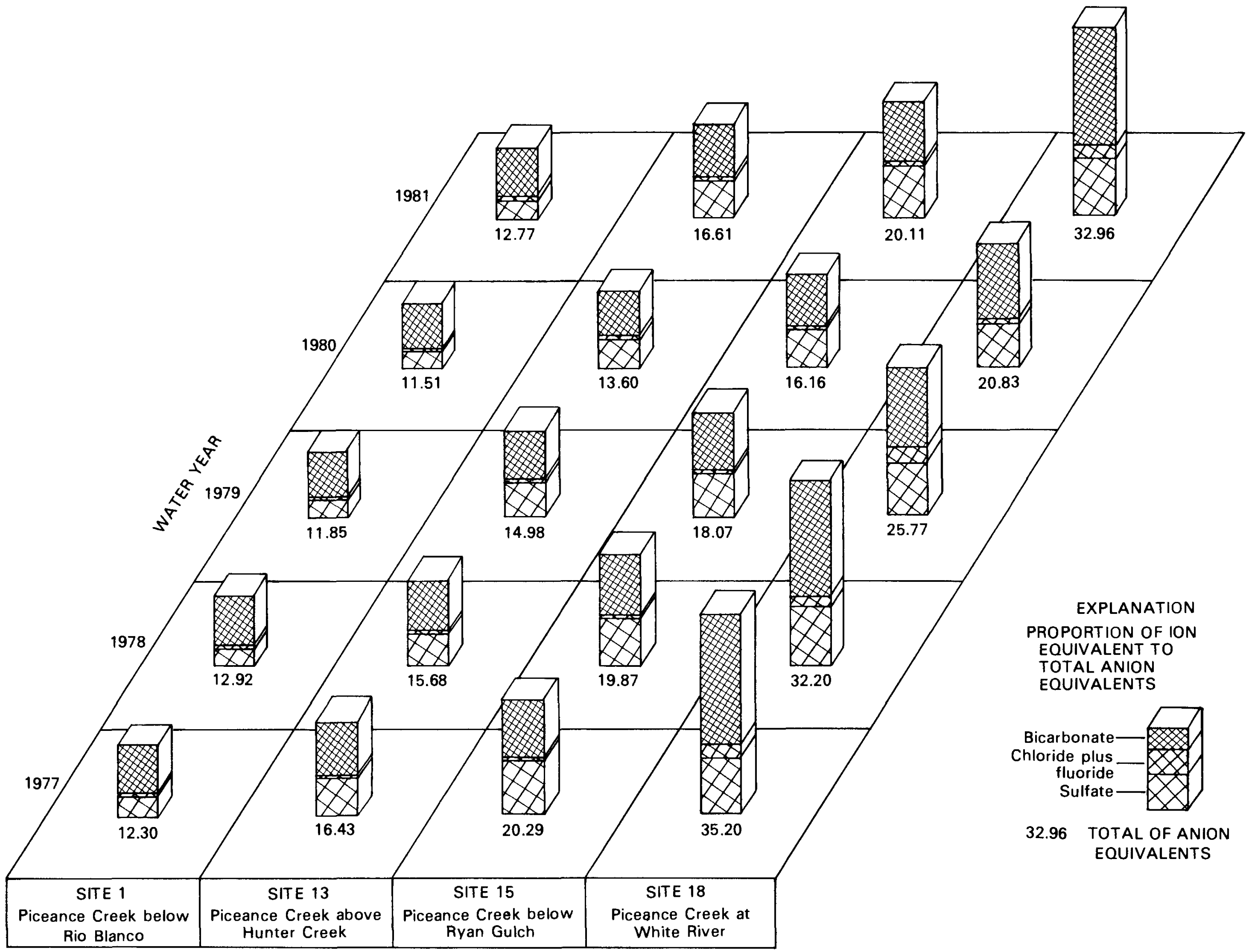


Figure 18.--Relative proportion of ion equivalents to total anion equivalents calculated from annual mean concentrations of bicarbonate, chloride, fluoride, and sulfate at four sites on Piceance Creek, water years 1977-81.

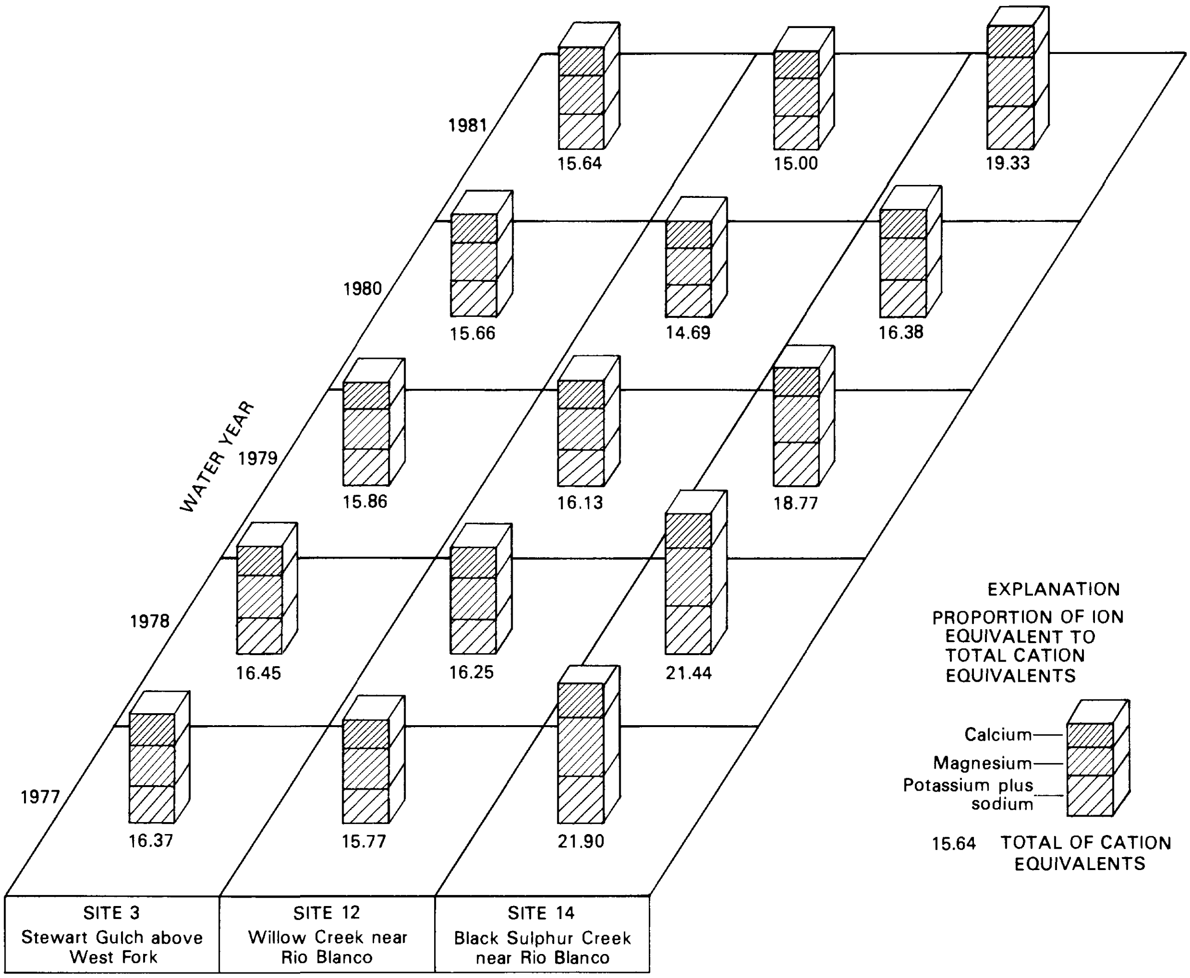


Figure 19.--Relative proportion of ion equivalents to total cation equivalents calculated from annual mean concentrations of calcium, magnesium, potassium, and sodium for perennial tributaries, Piceance Creek basin, water years 1977-81.

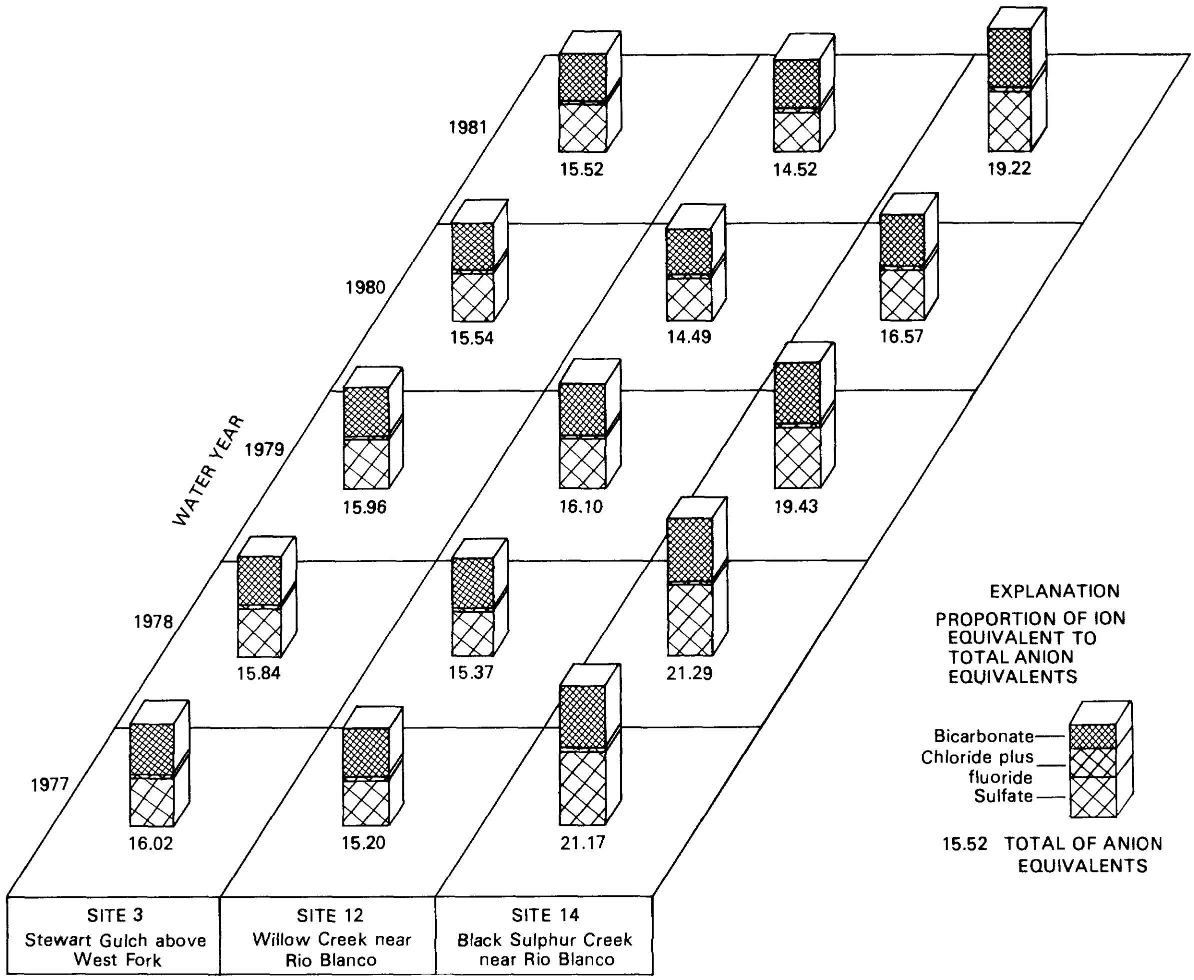


Figure 20.--Relative proportion of ion equivalents to total anion equivalents calculated from annual mean concentrations of bicarbonate, chloride, fluoride, and sulfate for perennial tributaries, Piceance Creek basin, water years 1977-81.

Concentrations of sodium, bicarbonate, and sulfate (fig. 16) varied more in Black Sulphur Creek at site 14 than in the other two perennial tributaries. These variations were similar to those observed in Piceance Creek. Concentrations of the major ions were least during the snowmelt runoff season and greatest during low flows (fig. 16). A shift toward a magnesium and sulfate water-quality type occurred during low-flow periods when local springs accounted for most of the flow in Black Sulphur Creek.

A between site comparison of data (figs. 10 to 20) for the perennial streams in Piceance Creek basin indicate that:

1. The water quality in the upper reaches of Piceance Creek above the Ryan Gulch (site 15) was generally a sodium magnesium bicarbonate type. The 5-year means for dissolved solids (table 6) show that dissolved solids within this reach increased from 700 mg/L at the upper site below Rio Blanco (site 1) downstream to 1,090 mg/L at site 15 below Ryan Gulch.
2. Water-quality type changed to a sodium bicarbonate type downstream below site 15 (figs. 17 and 18). Concentrations of chloride and dissolved solids (table 6) increased more than 50 percent from Ryan Gulch (site 15) to the mouth of White River site 18. These changes were particularly evident during the low-flow periods. The mean concentration for dissolved solids at site 18 during the low-flow water year of 1977 was 1,880 mg/L: the mean for dissolved solids was 1,200 mg/L during the 1980 water year, considered to be a wet year. These changes in water quality resulted from ground-water inputs to the stream, mostly along bedrock fractures in the vicinity of Alkali Flat, that are associated with the Green River Formation (Weeks and others, 1974). The sodium, bicarbonate, and chloride concentrations were greatly diluted during runoff periods, although water quality continued to remain a sodium bicarbonate type.
3. Concentration ranges of dissolved solids were similar in Stewart Gulch and Willow Creek (table 6): Dissolved solids ranged from 869 to 963 mg/L in Stewart Gulch at site 3 and from 699 to 989 mg/L in Willow Creek at site 12. Magnesium, sodium, bicarbonate, and to a slightly lesser extent, calcium and sulfate, characterized the water quality in Stewart Gulch and Willow Creek (figs. 19 and 20). The dissolved solids averaged several hundred milligrams per liter greater in Black Sulphur Creek at site 14 than in Stewart Gulch and Willow Creek and sulfate frequently was the dominant anion in Black Sulphur Creek.
4. The concentration ratio of calcium/magnesium (figs. 10 to 13) decreased in Piceance Creek from site 1 downstream to the mouth at White River. The ratio calcium/magnesium, however, tended to increase at all stations during runoff events. Relative increases in this ratio coincided with overland runoff. Conversely, relative increases of magnesium versus calcium occurred during periods when springs and irrigation returns provided most of the streamflow in Piceance Creek basin.
5. Sulfate concentrations increased downstream in Piceance Creek. These increases were due to inflow from perennial tributaries that had greater sulfate concentrations than Piceance Creek (table 6).

6. Although not shown graphically, mean fluoride concentrations for periodic samples prior to the 1981 water year generally were 1.0 mg/L at the upstream site below Rio Blanco (site 1), decreased to 0.7 to 0.8 mg/L at the Hunter Creek and Ryan Gulch sites (sites 13 and 15), and then increased several tenths of a milligram per liter downstream at the White River site (site 18). Concentration means for periodic samples for fluoride during the 1981 water year in Piceance Creek were 1.0 mg/L at site 1, 2.3 mg/L at site 13, and 1.2 mg/L at site 15. Corresponding increases in concentrations of sodium and bicarbonate also occurred in Piceance Creek below site 1 during this time. These increases in Piceance Creek were related to the periodic flows in Piceance Creek Tributary (site 9) which had high concentrations of flouride, sodium, and bicarbonate. Streamflow in Piceance Creek Tributary during the 1981 water year originated principally from the dewatering of oil-shale mines at Tract C-b.

Intermittent streams.--Water-quality type and concentration ranges of dissolved solids for intermittent flows compared with data means for perennial flows in Piceance Creek basin are shown in figure 21. Two samples, one from Sorghum Gulch (site 7) and one from Horsedraw Gulch (site 17), each having dissolved solids in excess of 1,000 mg/L, probably were associated with mine-dewatering activities.

Data for Piceance Creek Tributary at site 9 show a change in water quality to a sodium bicarbonate type and increases in dissolved solids from water years 1979-81. These changes resulted from changes in the water quality of waters produced and treated from the mining of oil shale from progressively deeper zones within the aquifers underlying Tract C-b. The water quality of these discharges correlate with the water-quality characteristics of the aquifer systems in Piceance basin described in Welder and Saulnier, (1978) and Robson and Saulnier (1981).

Of the remaining 15 samples plotted for the intermittent sites (fig. 21), calcium accounted for more than 50 percent of the total cation milliequivalents in 9 samples, and bicarbonate was the dominant anion in all samples. Concentrations of dissolved solids were less than 300 mg/L in 70 percent of the samples and less than 600 mg/L in all samples. A change in water-quality type to magnesium, sodium, and sulfate generally coincided with increases in concentrations of dissolved solids. The differences in water-quality types of the intermittent flows when compared to the perennial flows may be attributed to the characteristics of the leached basin soils and chemical equilibrium controls in water. The basin soils probably have greater residual concentrations of the less soluble calcium and magnesium carbonates than residual concentrations from the more soluble sodium related minerals. With time, the more soluble minerals would have been removed from the soils by surface flows or percolation to the aquifers.

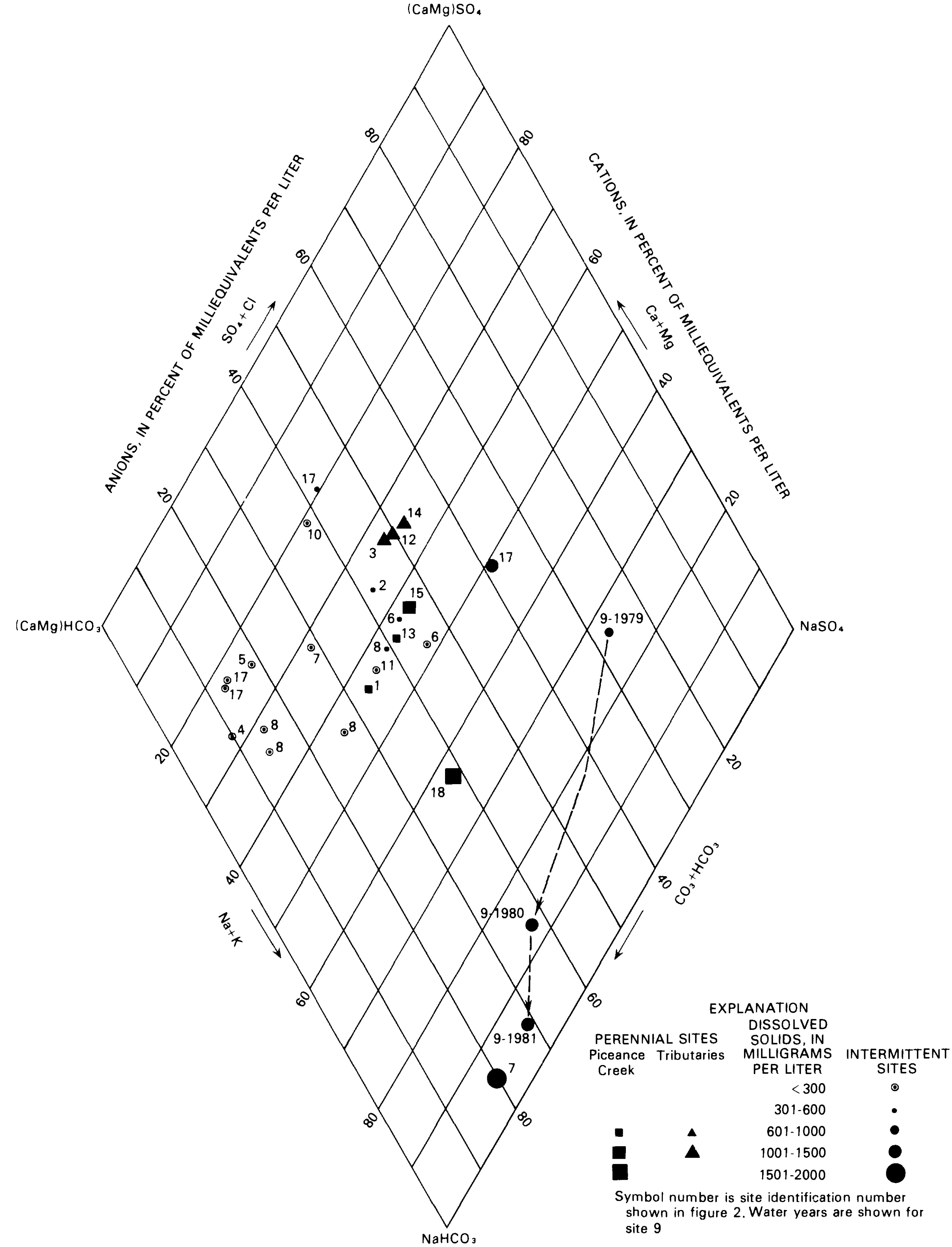


Figure 21.--Water-quality types and concentration ranges of dissolved solids for perennial and intermittent streams in Piceance Creek basin. Data for the perennial sites are based on a 5-year mean for water years 1977-81. Except for site 9, data for the intermittent sites are for individual analyses of samples taken during runoff events. Data for site 9 are for a single analysis in water year 1979, means of 15 samples for water year 1980, and means of 11 samples for water year 1981.

Regressions.--Concentrations of most of the major ions in streams in Piceance Creek basin were inversely correlated with discharge and directly correlated with specific conductance. The variability in concentrations of most of these constituents with respect to discharge, however, was sufficiently great to preclude the use of meaningful regressions. Least squares regressions of dissolved solids versus specific conductance for the perennial streams and for a data composite for the intermittent streams are given in table 7. The regressions for the perennial streams provide an estimate of dissolved solids calculated from specific-conductance measurements for the data range shown in table 6. Estimates of dissolved solids generally become more reliable as values of the correlation coefficient approach one. The poor correlation coefficient, r=0.50, for site 3 resulted because the ranges of dissolved solids and specific conductance at this site were small (table 6),

Table 7.--*Estimates of dissolved solids from values of specific conductance for perennial and intermittent streams in Piceance Creek basin, Water years 1977-81*

Site number and name	Least squares regression: Dissolved solids (DS), in milligrams per liter, estimated from specific conductance (SC), in micromhos per centimeter		
	Number of samples	Equation	Correlation coefficient (r)
PERENNIAL STREAMS			
1 Piceance Creek below Rio Blanco	55	DS=0.64SC+4	0.97
13 Piceance Creek above Hunter Creek	58	DS=0.68SC-17	.97
15 Piceance Creek below Ryan Gulch	58	DS=0.75SC-97	.98
18 Piceance Creek at White River	59	DS=0.68SC+9	.99
3 Stewart Gulch above West Fork	52	DS=0.39SC+400	.50
12 Willow Creek near Rio Blanco	51	DS=0.77SC-126	.90
14 Black Sulphur Creek near Rio Blanco	55	DS=0.78SC-123	.98
INTERMITTENT STREAMS			
Composite of sites 2, 4, 5, 6, 7, 8, 10, 11, and 17	14	DS=0.65SC-3	.99

and data points tended to cluster about the data means. The regression for the intermittent streams was calculated from a data composite of nine sites for a specific-conductance range of 108 to 910 micromhos and a dissolved-solids range of 68 to 597 mg/L.

Estimates of dissolved solids also may be made directly from measurements of specific conductance (Hem, 1970) by the following equation:

$$DS = SC \times A$$

where DS=dissolved solids, in milligrams per liter;
SC=specific conductance, in micromhos; and
(A)=the mean ratio of DS/SC computed from the data base for a specific site.

The mean value of (A) and first standard deviation were computed from greater than 50 samples at each site for the perennial flows and are shown below.

Mainstream sites - Piceance Creek

	1	13	15	18
DS/SC ratio (A)------	0.65+.02	0.67+.03	0.68+.03	0.68+.03

Tributary sites

	3	12	14
DS/SC ratio (A)------	0.68+.02	0.68+.02	0.71+.02

The slight increase in (A) downstream and somewhat greater value of (A) compared to the two upstream sites (1 and 13) on Piceance Creek probably were related to the greater concentrations of sulfate (Hem, 1970) in the tributaries discharging to Piceance Creek.

Nutrients

Mean concentrations and one standard deviation for the concentrations of dissolved-nitrogen species and total phosphorus in Piceance Creek basin are shown in figure 22. Because the data base for the intermittent streams was small, and the hydrology was similar at all sites the data at these sites were composited and considered to be reasonably representative of the intermittent, short-term flows in the basin.

Analyses of the data (U.S. Geological Survey, 1978-82) show that nutrient concentrations at the sites of all perennial stations varied considerably during the study period. Highest concentrations, which exceeded several milligrams per liter for dissolved nitrogen and total phosphorus, frequently occurred during runoff events. Minimum concentrations were common during low flows.

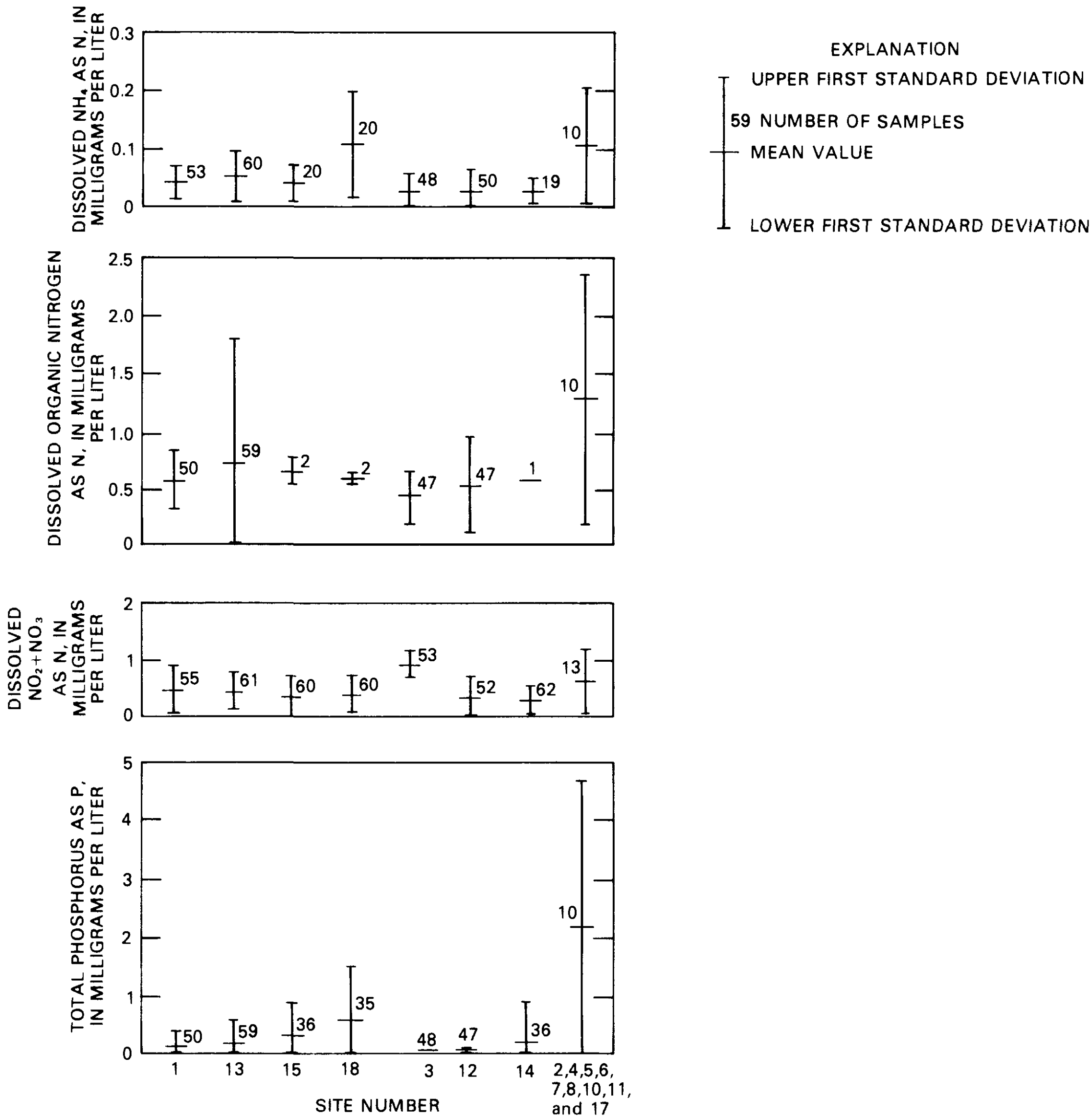


Figure 22.--Concentration means and first standard deviations of the nutrients, nitrogen and phosphorus, for perennial streams and a data composite of intermittent streams in Piceance Creek basin, water years 1977-81.

A between site comparison of the data shown in figure 22 shows that ammonia concentrations at the mouth of Piceance Creek (site 18) were twice those detected in the upper reaches above Ryan Gulch at site 15. The greater mean concentration of organic nitrogen at site 13, Piceance Creek above Hunter Creek, compared to the other sites on perennial streams may have resulted from mine dewatering or agricultural activities in that area. The mean concentration of nitrite plus nitrate as nitrogen of 0.91 mg/L in Stewart Gulch at site 3 was twice the amount detected in the other perennial streams. Because streamflow at this site was mainly from local springs, the high nitrite plus nitrate concentrations may represent a water-quality characteristic of the local water table or bedrock aquifer in that area. Concentrations of total phosphorus increased downstream in Piceance Creek.

Composite data for the intermittent streams show that the concentrations of nitrogen and phosphorus were greater and had a greater range than in the perennial streams. Because streamflow at the intermittent sites normally occurred only during runoff events, the high concentrations of nutrients in these flows, and in the high flows of the perennial streams, indicate that a large percentage of the nutrient loading to surface flows originated from the land surface and soil zones.

Trace Constituents

Concentration ranges of dissolved trace constituents in perennial and intermittent streams in Piceance Creek basin are shown in figure 23. Where one sample in a data set extended the maximum range beyond what appeared to be general background range, the second highest concentration is shown for perspective. Because the data are for dissolved constituents, the concentration ranges shown may not represent what was actually present in the stream in a total water-sediment mixture. As an example, in addition to dissolved concentrations, total recoverable concentrations for many of the trace constituents listed in figure 23 were determined at several sites in the Piceance Creek basin during the 1979-81 water years. A comparison of total recoverable concentrations versus dissolved concentrations showed that total concentrations were several magnitudes greater than dissolved concentrations for the constituents, aluminum, chromium, cobalt, copper, iron, led, manganese, nickel, and zinc. Generally, the differences were greatest during runoff events when suspended-sediment concentrations in the stream were high.

A review of data for perennial and intermittent flows (fig. 23) indicate the following:

1. Dissolved concentrations of barium, lead, manganese, and mercury generally were greatest upstream and tended to decrease downstream. These decreases in concentrations could have resulted from streamflow dilution, chemical complexing and precipitation with ions such as sulfate or carbonate, or absorption by stream sediments or basin soils during the irrigation season.

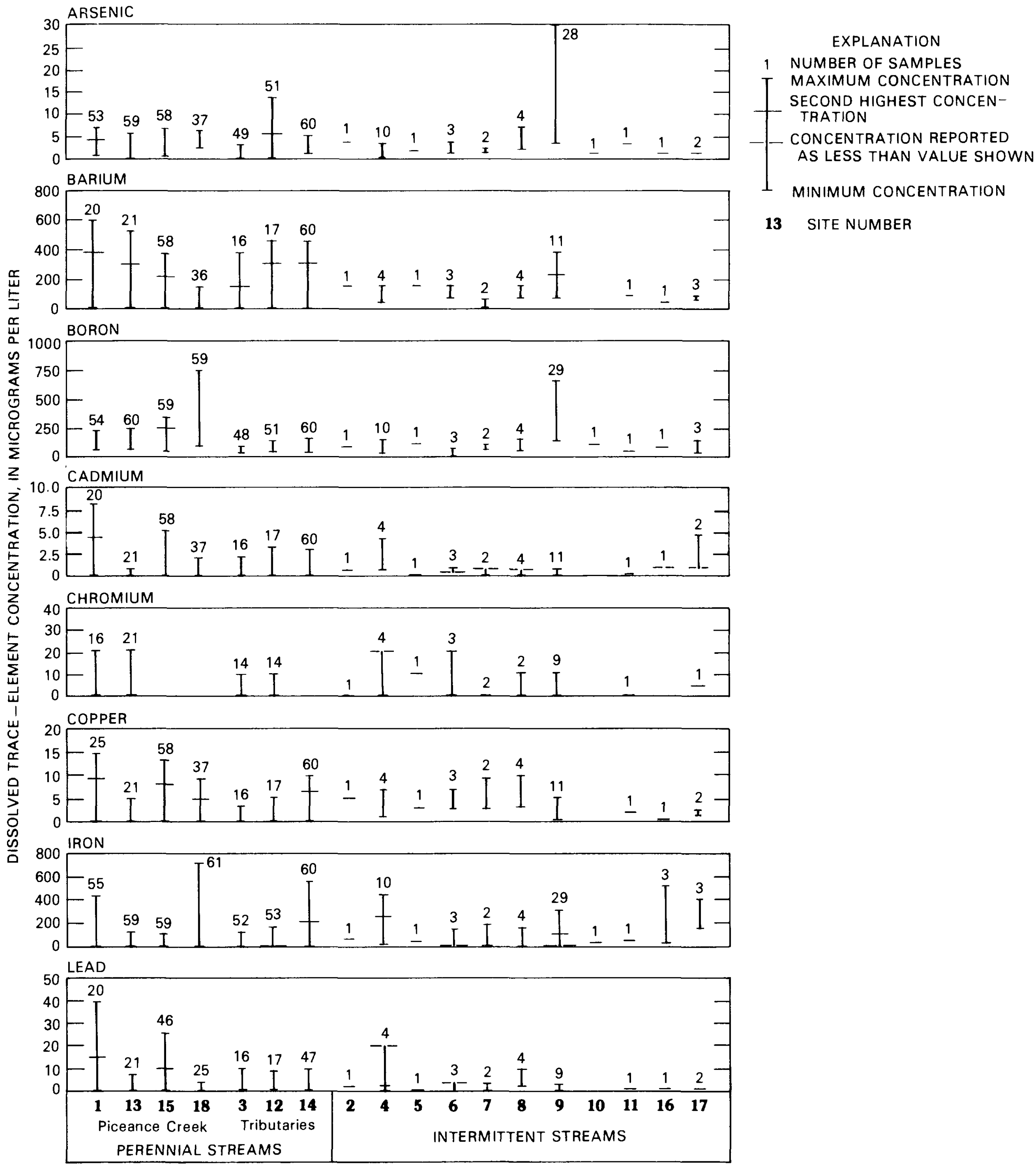


Figure 23.--Minimum-maximum concentration range for dissolved trace constituents in perennial and intermittent streams, Piceance Creek basin, water years 1976-81.

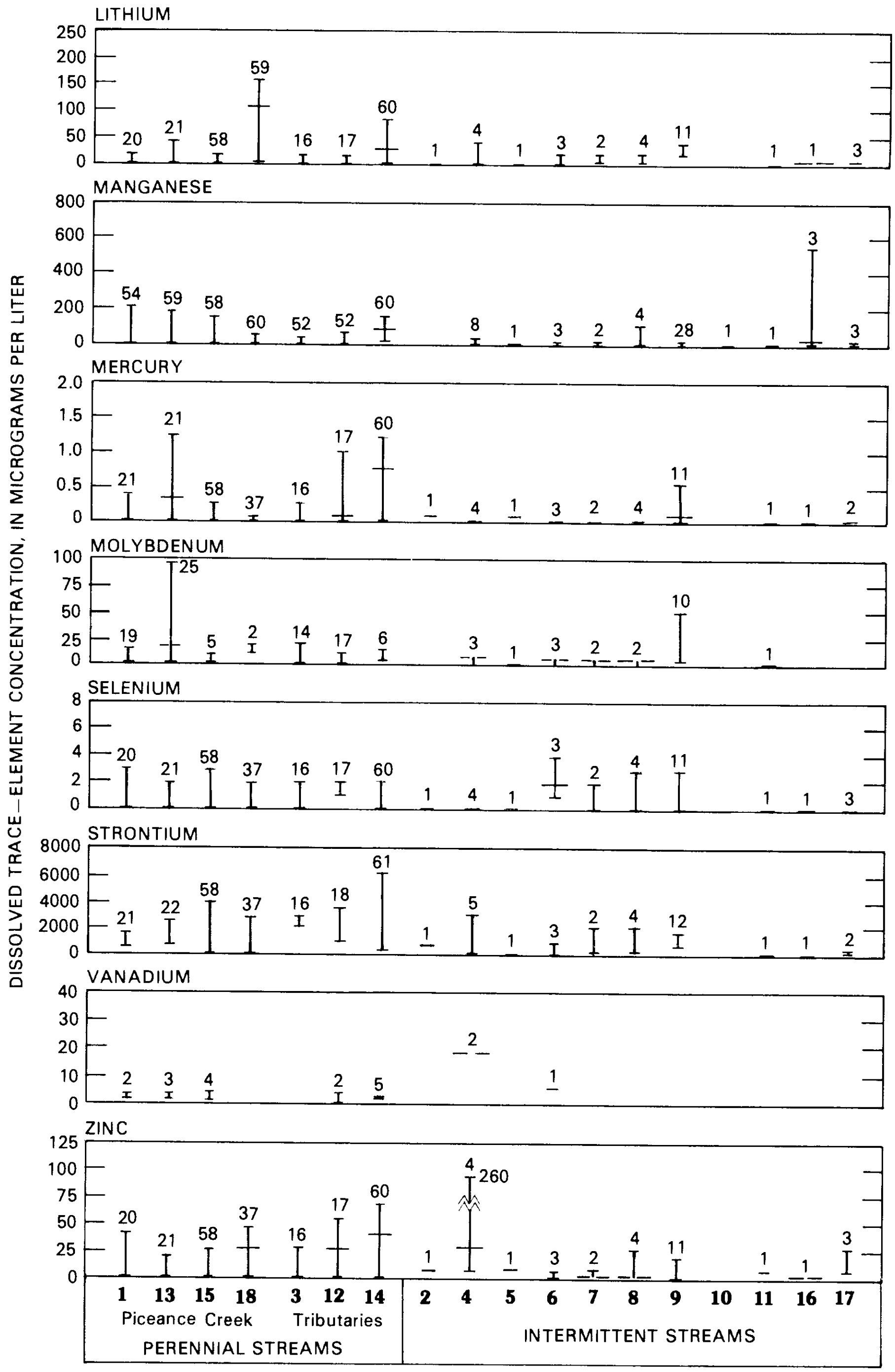


Figure 23.--Minimum-maximum concentration range for dissolved trace constituents in perennial and intermittent streams, Piceance Creek basin, water years 1976-81--Continued.

2. Strontium tended to increase in a downstream direction. Apparently, this increase was due to tributary inflows, particularly from Black Sulphur Creek (site 14) which had greater concentrations of strontium than in Piceance Creek.
3. The minimum concentrations of arsenic, and concentrations of boron, iron, lithium, and possibly molybdenum increased downstream from site 15, Piceance Creek below Ryan Gulch. These increases correlated well with the increases in sodium and bicarbonate in this reach of Piceance Creek. The changes in water quality were attributed to ground-water augmentation to the stream, particularly in the area of Alkali Flat (fig 2).
4. The constituents chromium, copper, selenium, vanadium and, except as noted above, arsenic, boron, iron, lead, lithium, and molybdenum apparently were uniformly dispersed in the perennial and intermittent streams.
5. Except for lead, molybdenum, and selenium, concentrations of trace constituents in the perennial tributaries were greater in Willow and Black Sulphur Creeks (sites 12 and 14) than in Stewart Gulch at site 3. Strontium concentrations were greatest in Black Sulphur Creek, which also had high concentrations of sulfate. The two constituents may have originated from a common mineral assemblage or chemical equilibrium controls that were different at this site than other sites in the basin. Trace amounts of the minerals celestite ($SrSO_3$) occur locally in the Green River Formation (Milton, 1977).
6. Mercury commonly was detected in Black Sulphur Creek, site 14, at concentrations in excess of 0.1 ug/L.
7. Concentration ranges for barium, manganese, mercury, and zinc were generally less in the intermittent streams than in the perennial flows.
8. Ranges of trace constituents in discharges from the oil-shale mine at Tract C-b are represented by data for Piceance Creek Tributary at site 9. Concentrations of arsenic, boron, molybdenum, and lithium at site 9 were greater than those detected in the upstream reaches of Piceance Creek. The high concentrations of arsenic, boron, molybdenum, and lithium are characteristic of ground waters from the Green River Formation in Piceance basin (Weeks and others, 1974). Mercury was detected in only one of 11 samples from Piceance Creek Tributary.

Radioactive Substances

Data ranges for radioactive substances in the Piceance Creek basin are presented in tables 8 and 9. Maximum activities recorded for radioactive substances in streams are summarized in figure 24. Except at site 3, Stewart Gulch above West Fork, a review of water-quality and suspended-sediment data (U.S. Geological Survey 1977-82) indicated that relatively high radioactive counts commonly occured when concentrations of suspended matter were high in stream water. This was especially evident in the data for the intermittent streams. Streamflow in these channels occured only during times of snowmelt or thunderstorm activity. During these periods, unconsolidated soils were carried by runoff to the streams where they contributed to high concentrations of suspended sediment, and possibly, increases in radioactive counts in streams.

Table 8.--*Minimum-maximum data range for radioactive substances in perennial streams in Piceance Creek basin, water years 1976-81*

[Gross Alpha as picocuries per liter (pCi/L) as Uranium-natural and micrograms per liter (μg/L) as Uranium-natural; Gross Beta as picocuries per liter (pCi/L) as Cesium-137 and as Strontium-90/Yttrium-90; N, number of samples; range, minimum and maximum values; <, value less than value shown]

Water year	Gross Alpha								Gross Beta								Radium 226, dissolved (pCi/L)		Uranium, natural, dissolved (μg/L as Uranium)	
	pCi/L as Uranium-natural				μg/L as Uranium-natural				pCi/L as Cesium-137				pCi/L as Strontium/Yttrium-90							
	dissolved		suspended		dissolved		suspended		dissolved		suspended		dissolved		suspended					
	N	range	N	range	N	range	N	range	N	range	N	range	N	range	N	range	N	range	N	range
									Site 1 Piceance Creek below Rio Blanco											
1976	-	---------	-	--------	4	<8.1-18	4	<0.4-3.4	4	3.5-6.3	4	0.5-3.7	4	2.8-5.0	4	0.5-2.9	2	0.05-0.08	--	-------
1977	-	---------	-	--------	1	<10	1	<.4	1	5.5	1	<.4	1	4.9	1	<.4	--	---------	--	-------
1978	-	---------	-	--------	4	<6.6-17	4	<.4-140	4	<2.7-6.1	4	<.4-94	4	<2.5-5.5	4	<.4-83	4	.09-.16	3	2.2-3.7
1979	-	---------	-	--------	5	<7.8-<13	5	<.4-150	5	3.6-<4.9	5	<.4-83	5	3.3-<4.6	5	<.4-73	5	.05-.11	5	2.4-3.2
1980	4	<4.9-16	4	<.3-39	4	<7.2-23	4	<.4-57	4	<4.9-8.2	4	<.4-64	4	<4.8-<8.2	4	<.4-60	4	.07-.10	4	2.4-3.0
1981	3	6.0-13	3	.3-.4	3	<8.8-<19	3	<.4-.6	3	<5.2-<8.5	3	<.4-1.0	3	<5.0-<8.2	3	<.4-.9	3	.07-.11	3	2.5-3.1
Total	7	<4.9-16	7	<.3-39	21	<6.6-23	21	<.4-150	21	<2.7-<8.5	21	<.4-94	21	<2.5-<8.2	21	<.4-83	18	.05-.16	15	2.2-3.7
									Site 13 Piceance Creek above Hunter Creek											
1976	-	---------	-	--------	4	9.3-35	4	<.4-13	4	3.9-8.1	4	1.0-7.2	4	3.1-6.6	4	.9-5.8	1	.05	--	-------
1977	-	---------	-	--------	1	<15	1	5.2	1	14	1	3.5	1	11	1	2.8	1	.13	1	3.1
1978	-	---------	-	--------	4	<7.6-23	4	<.4-200	4	<2.4-24	4	<.4-120	4	<2.1-21	4	<.4-110	4	.06-.11	4	2.4-5.0
1979	-	---------	-	--------	5	5.9-<16	5	<.4-150	5	3.4-6.3	5	<.4-84	5	3.1-6.0	5	<.4-76	5	.07-.11	5	2.4-4.2
1980	4	<4.3-<8.8	4	1.6-50	4	<6.3-<13	4	2.4-73	4	5.4-<7.5	4	1.2-66	4	5.1-<7.2	4	1.2-61	4	.07-.10	4	2.6-3.2
1981	3	<9.5-16	3	.3-2.4	3	<14-<24	3	<.4-3.6	3	<6.2-<11	3	<.4-3.1	3	<6.0-<10	3	<.4-3.0	3	.09-.11	3	3.7-4.2
Total	7	<4.3-16	7	.3-50	21	5.9-35	21	<.4-200	21	<2.4-24	21	<.4-120	21	<2.1-21	21	<.4-110	18	.05-.13	17	2.4-5.0
									Site 3 Stewart Gulch above West Fork											
1976	-	---------	-	--------	4	<7.9-13	4	<.4-4.3	4	3.1-560	4	<.4-3.4	4	2.5-450	4	<.4-2.8	2	.03-.06	--	-------
1977	-	---------	-	--------	--	--------	--	--------	--	---------	--	--------	--	---------	--	--------	--	---------	--	-------
1978	-	---------	-	--------	4	<8.0-<11	4	<.4-4.7	4	<2.2-<5.0	4	<.4-3.3	4	<1.9-<4.6	4	<.4-3.0	4	.06-.71	3	2.1-2.6
1979	-	---------	-	--------	4	<13-<15	4	<.4-4.9	4	<4.3-<5.5	4	<.4-2.7	4	<4.0-<5.3	4	<.4-2.4	4	.06-.09	4	2.8-3.2
1980	3	<7.5-<9.5	3	<.3-1.0	3	<11-<14	3	<.4-1.5	3	<5.8-<7.3	3	<.4-1.3	3	<5.6-<7.0	3	<.4-1.3	3	.09-.10	3	2.6-3.2
1981	3	<9.5-16	3	.3-.8	3	<14-<23	3	<.4-1.2	3	<6.5-<10	3	<.4-1.4	3	<6.3-<9.6	3	<.4-1.3	3	.07-.10	3	2.4-3.1
Total	6	<7.5-16	6	<.3-1.0	18	<7.9-<23	18	<.4-4.9	18	<2.2-560	18	<.4-3.4	18	<1.9-450	18	<.4-3.0	16	.03-.71	13	2.1-3.2
									Site 12 Willow Creek near Rio Blanco											
1976	-	---------	-	--------	4	<8.3-23	4	4.8-24	4	4.7-38	4	3.4-9.5	4	3.8-31	4	2.8-7.6	1	.05	--	-------
1977	-	---------	-	--------	--	--------	--	--------	--	---------	--	--------	--	---------	--	--------	--	---------	--	-------
1978	-	---------	-	--------	4	<9.4-<9.9	4	<.4-6.6	4	<2.4-3.1	4	<.4-4.7	4	<2.1-2.7	4	<.4-4.0	4	.04-.13	3	1.7-2.5
1979	-	---------	-	--------	4	<8.5-<17	4	<.4-2.4	4	<2.6-12	4	<.4-2.0	4	<2.3-11	4	<.4-1.8	4	.04-.06	4	2.3-2.8
1980	3	<6.3-<8.2	3	<.3-<2.0	3	<9.2-<12	3	<.4-<3.0	3	<5.8-<7.2	3	<.4-<3.0	3	<5.7-<6.9	3	<.4-<3.3	3	.06-.07	3	2.1-2.6
1981	3	10-18	3	.3-2.5	3	15-<26	3	<.4-3.7	3	<8.5-10	3	<.4-3.2	3	<8.3-9.7	3	<.4-3.1	3	.07-.09	3	2.3-2.6
Total	6	<6.3-18	6	<.3-2.5	18	<8.3-<26	18	<.4-24	18	<2.4-38	18	<.4-9.5	18	<2.1-31	18	<.4-7.6	15	.04-.13	13	1.7-2.8
									Site 14--Black Sulphur Creek near Rio Blanco											
1979	-	---------	-	--------	1	19	1	7.2	1	6.4	1	4.4	1	5.9	1	3.8	1	.08	1	3.7
Total	-	---------	-	--------	1	19	1	7.2	1	6.4	1	4.4	1	5.9	1	3.8	1	.08	1	3.7

Table 9.--*Minimum-maximum data range for radioactive substances in intermittent streams in Piceance Creek basin, water years 1976-81*

[Gross Alpha as picocuries per liter (pCi/L) as Uranium-natural and micrograms per liter (μg/L) as Uranium-natural; Gross Beta as picocuries per liter (pCi/L) as Cesium-137 and as Strontium-90/Yttrium-90; N, number of samples; range, minimum and maximum values; <, value less than value shown]

Water year	Gross Alpha								Gross Beta								Radium 226, dissolved (pCi/L)		Uranium, natural, dissolved (μg/L as Uranium)	
	pCi/L as Uranium-natural				μg/L as Uranium-natural				pCi/L as Cesium-137				pCi/L as Strontium/Yttrium-90							
	dissolved		suspended		dissolved		suspended		dissolved		suspended		dissolved		suspended					
	N	range	N	range	N	range	N	range	N	range	N	range	N	range	N	range	N	range	N	range
									Site 4 West Fork Stewart Gulch near Rio Blanco											
1976	--	--------	--	-------	2	<12-33	2	<0.4-2.1	2	3.2-<3.4	2	0.6-2.4	2	2.7-<2.9	2	0.6-2.0	1	<0.1	1	2.3
1980	1	<1.8	1	58	1	<2.6	1	85	1	11	1	45	1	11	1	46	1	.05	1	.05
Total	1	<1.8	1	58	3	<2.6-33	3	<.4-85	3	3.2-11	3	.6-45	3	2.7-11	3	.6-46	2	.05-<.1	2	.05-2.3
									Site 5 West Fork Stewart Gulch at mouth											
1980	1	<1.7	1	<29	1	<2.5	1	<42	1	9.6	1	52	1	9.7	1	53	1	.10	1	.18
Total	1	<1.7	1	<29	1	<2.5	1	<42	1	9.6	1	52	1	9.7	1	53	1	.10	1	.18
									Site 6 Sorghum Gulch near Rio Blanco											
1976	--	--------	--	-------	2	<3.0-6.1	2	5.5-1100	2	5.2-7.4	2	7.9-520	2	4.1-6.1	2	6.3-440	1	.15	-	-------
1980	1	7.5	1	3.1	1	11	1	4.6	1	7.2	1	4.3	1	7.4	1	4.2	1	.12	1	5.6
Total	1	7.5	1	3.1	3	<3.0-11	3	4.6-1100	3	5.2-7.4	3	4.3-520	3	4.1-7.4	3	4.2-440	2	.12-.15	1	5.6
									Site 7 Sorghum Gulch at mouth											
1977	--	--------	--	-------	1	5.8	1	97	1	13	1	64	1	11	1	51	-	-------	-	-------
1980	1	<20	1	120	1	<30	1	180	1	<13	1	120	1	<12	1	110	1	.09	1	1.4
Total	1	<20	1	120	2	5.8-<30	2	97-180	2	<13-13	2	64-120	2	11-<12	2	51-110	1	.09	1	1.4
									Site 8 Cottonwood Gulch near Rio Blanco											
1977	--	--------	--	-------	1	4.4	1	830	1	12	1	280	1	10	1	250	-	-------	-	-------
1980	1	6.3	1	.4	1	9.2	1	.6	1	<4.4	1	<.4	1	<4.5	1	<.4	1	.07	1	5.4
Total	1	6.3	1	.4	2	4.4-9.2	2	.6-830	2	<4.4-12	2	<.4-280	2	<4.5-10	2	<.4-250	1	.07	1	5.4
									Site 9 Piceance Creek Tributary near Rio Blanco											
1979	--	--------	--	-------	1	<15	1	580	1	14	1	370	1	13	1	350	1	.16	1	1.6
1980	4	<1.9-<16	4	5.4-43	4	<2.8-<23	4	7.9-63	4	2.3-<12	4	6.0-60	4	2.3-<12	4	5.7-62	4	.06-.09	4	1.0-4.2
1981	3	14-23	3	.3-3.6	3	<21-<34	3	<.4-5.3	3	<11-<16	3	<.4-4.4	3	<10-<15	3	<.4-4.2	3	.11-.14	3	1.5-2.3
Total	7	<1.9-23	7	.3-43	8	<2.8-<34	8	<.4-580	8	2.3-<16	8	<.4-370	8	2.3-<15	8	<.4-350	8	.06-.16	8	1.0-4.2
									Site 11 Scandard Gulch at mouth											
1980	1	2.5	1	39	1	3.7	1	57	1	8.5	1	50	1	8.4	1	50	1	.08	1	1.3
Total	1	2.5	1	39	1	3.7	1	57	1	8.5	1	50	1	8.4	1	50	1	.08	1	1.3
									Piceance Creek basin											
Total	13	<1.7-23	13	.3-120	20	<2.5-33	20	<.4-1100	20	2.3-<16	20	<.4-520	20	2.3-<15	20	<.4-440	16	.05-.16	15	.05-.5.6

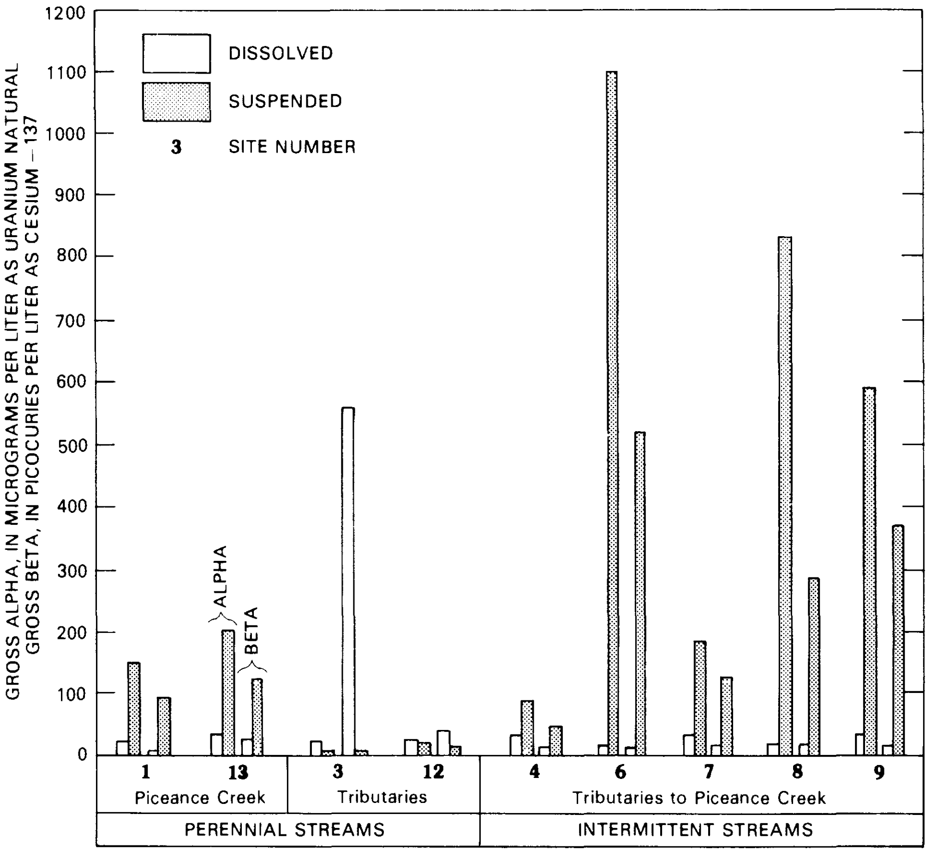


Figure 24.--Maximum recorded activity for radioactive substances in perennial and intermittent streams in Piceance Creek basin, water years 1976-81. Data are for sites having two or more samples.

A count of 560 pCi/L dissolved gross beta as Cs-137 occurred in Stewart Gulch at site 3 in the 1976 water year: dissolved gross alpha counts for the same sample were less than 11 pCi/L. The high gross beta count appeared to be an unnatural condition. The high count occurred only once in a total of 18 samples collected during water years 1976-81. The next greatest value for gross beta during this 6-year period was less than 10 pCi/L, and three other samples taken during the 1976 water year were all less than 4.6 pCi/L. The radionuclides responsible for this anomaly and the other widespread radioactive emissions were not determined.

Insecticides and Herbicides

During October 1975 to September 1980, a total of 10 unfiltered water samples and 13 bed material samples were collected in Piceance Creek at the 2 upstream sites, 1 and 13, and 2 tributaries, Stewart Gulch (site 3) and Willow Creek (site 12). All samples were analyzed for the following insecticides and herbicides:

Insecticides		Herbicides
(Organochlorine)	(Organophosphorus)	(Chlorophenoxy Acid)
Aldrin	Diazinon	2,4-D
Chlordane	Ethion	2,4,5-T
DDD	Malathion	Silvex
DDE	Methyl parathion	
DDT	Methyl trithion	
Dieldrin	Parathion	
Endrin	Trithion	
Heptachlor		
Heptachlor epoxide		
Lindane		
Toxaphene		

Herbicides were not detected at any of the sites. One or more of the insecticides DDD, DDE, DDT, and dieldrin were detected at the 0.1 to 1.5 µg/kg level in all bed material samples taken from the mainstream sites 1 and 13.

A concentration of 0.1 µg/kg of DDE was reported in one of four bed material samples taken from Stewart Gulch at site 3. Similar concentrations of DDE and a diazinon concentration of 0.9 µg/kg were determined in bed material samples taken from Willow Creek at site 12. The presence of these insecticides probably relates to past or present agricultural or insect-control activities in that part of the basin.

Yellow Creek Basin

Temperature

Summer temperatures (table 10) in excess of 30°C were common in Yellow Creek at site 26; the maximum recorded temperature at this site was 35°C, and the maximum daily range was 25.5°C. The greatest daily range in temperature (28°C) occurred in upper Corral Gulch at site 20. Discharges from the oil-shale mine at Tract C-a combined with the potential insulation effects of an incised channel below the lease tract probably accounted for the small temperature range in Corral Gulch at site 24. Because the intermittent streams flow mostly in spring, temperature ranges (table 11) were less than the temperature ranges of the perennial streams.

Specific Conductance

Measurements of instantaneous specific conductance and discharge are shown in figure 25. Poor correlations are shown between specific conductance and discharge at sites 20 and 24 in Corral Gulch. Streamflows at both sites were maintained mostly by local springs. Additional streamflow also was supplied to Corral Gulch upstream from site 24 from oil-shale mine dewatering at Tract C-a beginning during the 1978 water year. Generally, specific conductance values less than 900 micromhos at the Corral Gulch sites can be attributed to overland runoff from thunderstorms or snowmelt. The anomalously high value of 6,490 micromhos (table 10) for Corral Gulch at site 20 in the 1981 water year is believed to be associated with the discharges from oil- and gas-drilling activities.

The specific conductance-discharge correlation for Yellow Creek near its mouth at site 26 was better defined than at the Corral Gulch sites, 20 and 24, in the headwater areas of Yellow Creek basin. The water quality of medium and low flows in Yellow Creek at site 26 represented a mixture from many springs in the basin. The greater values of specific conductance at site 26 when compared with sites in Corral Gulch were related to streamflow augmentation from high conductance ground-water sources in the downstream reaches of Yellow Creek.

A range of specific conductance values for the intermittent sites is shown in table 11. Values generally were least during snowmelt runoff but increased to over 1,000 micromhos when streamflow was mostly from local springs.

pH

Monitor data for pH and dissolved oxygen were not available for streams in Yellow Creek basin. Data ranges for periodic field determinations of pH for the perennial and intermittent streams are shown in tables 10 and 11. Values of pH generally were inversely related to flow and were lowest during snowmelt runoff when streamflow was high. Stream pH was highest in Yellow Creek at site 26 where pH values normally ranged between 8.4 and 8.9 and were 0.4 to 0.7 units higher than the pH values in Corral Gulch at sites 20 and 24. The high pH in Yellow Creek is related to the geochemical controls of high alkalinity ground water that enters the stream channel in the lower reaches of Yellow Creek.

Table 10.--*Summary of continuous-monitor data and field determinations for selected water-*

[°C=degrees Celsius; micromhos=micromhos per centimeter at 25°C; mg/L=milligrams

Site number and name	Water-quality characteristics	1977 water year			1978 water year		
		minimum	maximum	maximum daily range	minimum	maximum	maximum daily range
20 Corral Gulch below Water Gulch.	Temperature (°C)----------	0.0	24.5	19.0	0.5	31.0	22.0
	Specific conductance (micromhos)-------------	ND	1,410	ND	120	1,280	ND
	pH (units)----------------	ND	ND	ND	(7.3)	(8.2)	ND
	Dissolved oxygen (mg/L)----	ND	ND	ND	(7.3)	(8.6)	ND
	Suspended-sediment concentration (mg/L)----------	ND	1,000	ND	ND	6,530	ND
24 Corral Gulch near Rangely.	Temperature (°C)----------	0.0	21.5	18.0	0.0	25.0	19.0
	Specific conductance (micromhos)-------------	455	2,410	ND	751	1,680	ND
	pH (units)----------------	(7.9)	(8.5)	ND	(7.2)	(8.2)	ND
	Dissolved oxygen (mg/L)----	(9.2)	(12.8)	ND	(6.6)	(12.8)	ND
	Suspended-sediment concentration (mg/L)----------	5	88,000	ND	4	(52,000)	ND
26 Yellow Creek near White River.	Temperature (°C)----------	0.0	33.5	23.0	0.0	35.0	22.5
	Specific conductance (micromhos)-------------	610	5,150	ND	1,890	5,790	ND
	pH (units)----------------	(8.4)	(8.9)	ND	(7.6)	(9.0)	ND
	Dissolved oxygen (mg/L)----	(6.5)	(9.3)	ND	(7.4)	(12.6)	ND
	Suspended-sediment concentration (mg/L)----------	3	15,000	ND	(326)	(52,100)	ND

Dissolved Oxygen

Field determinations of dissolved oxygen (tables 10 and 11) indicate that concentrations of dissolved oxygen in streams within Yellow Creek basin varied with stream temperature and the activities of the aquatic biota. Dissolved oxygen concentrations frequently exceeded 10.0 mg/L during winter and early spring when stream temperatures were less than 5.0°C and the saturation capacities of streams for dissolved oxygen were high. Summertime concentrations of dissolved oxygen were less than 10 mg/L except when supersaturation conditions occurred from photosynthetic activities.

quality characteristics for perennial streams in Yellow Creek basins, water years 1977-81

per liter; ND=not determined; ( )=data from field determinations only]

1979 water year			1980 water year			1981 water year				5-year
minimum	maximum	maximum daily range	minimum	maximum	maximum daily range	minimum	maximum	maximum daily range	5-year range	maximum daily range
0.0	27.5	22.5	0.0	26.0	23.0	0.0	33.5	28.0	0.0-33.5	28.0
635	1,880	ND	580	1,260	ND	590	6,490	ND	120-6,490	ND
(7.8)	(8.4)	ND	(7.9)	(8.4)	ND	(7.8)	(8.1)	ND	(7.3-8.4)	ND
(7.5)	(12.6)	ND	(8.1)	(10.6)	ND	(7.3)	(12.0)	ND	(7.3-12.6)	ND
16	(8,660)	ND	5	5,120	ND	ND	17,800	ND	5-17,800	ND
2.5	29.0	14.5	.5	21.5	14.0	5.0	20.5	10.5	.0-29.0	19.0
678	2,050	ND	271	2,100	ND	390	1,890	ND	271-2,410	ND
(7.5)	(8.2)	ND	(7.5)	(8.4)	ND	(7.5)	(7.9)	ND	(7.2-8.5)	ND
(5.6)	(9.8)	ND	(5.6)	(11.2)	ND	(4.4)	(7.5)	ND	(4.4-12.8)	ND
8	14,000	ND	5	(14,800)	ND	2	21,800	ND	2-88,000	ND
0.0	32.5	21.5	0.0	31.5	25.5	0.0	33.5	22.5	.0-35.0	25.5
457	(5,200)	ND	517	4,440	ND	1,000	3,840	ND	457-5,790	ND
(8.0)	(8.9)	ND	(8.3)	(8.8)	ND	(8.4)	(8.9)	ND	(7.6-9.0)	ND
(6.3)	(14.2)	ND	(10.1)	(13.6)	ND	(4.4)	(13.2)	ND	(4.4-14.2)	ND
ND	8,460	ND	3	13,200	ND	8	7,130	ND	3-(52,100)	ND

Suspended Sediment

The suspended-sediment concentrations for the Yellow Creek basin (tables 10 and 11) seem to be similar to those in Piceance Creek basin (tables 4 and 5). An extremely large sediment yield of 290,000 tons per day was estimated for Yellow Creek at site 26 for a single thunderstorm in the 1978 water year (U.S. Geological Survey, 1979). These sediments were derived from the lower third of the drainage basin of Yellow Creek (Vernon W. Norman, U.S. Geological Survey, oral commun., 1979). A maximum suspended-sediment concentration of 113,000 mg/L in Yellow Creek basin was recorded in Box Elder Tributary at site 23 during a September thunderstorm in 1981. A review of other unpublished data, however, would suggest that instantaneous concentrations of suspended-sediment considerably greater than 100,000 mg/L during runoff events are not unusual in the Yellow Creek basin (Caroline Hollowed, U.S. Geological Survey, oral commun., 1984). The variability of the sediment data tend to demonstrate the great intensity of local sediment movement that can occur in a semiarid basin.

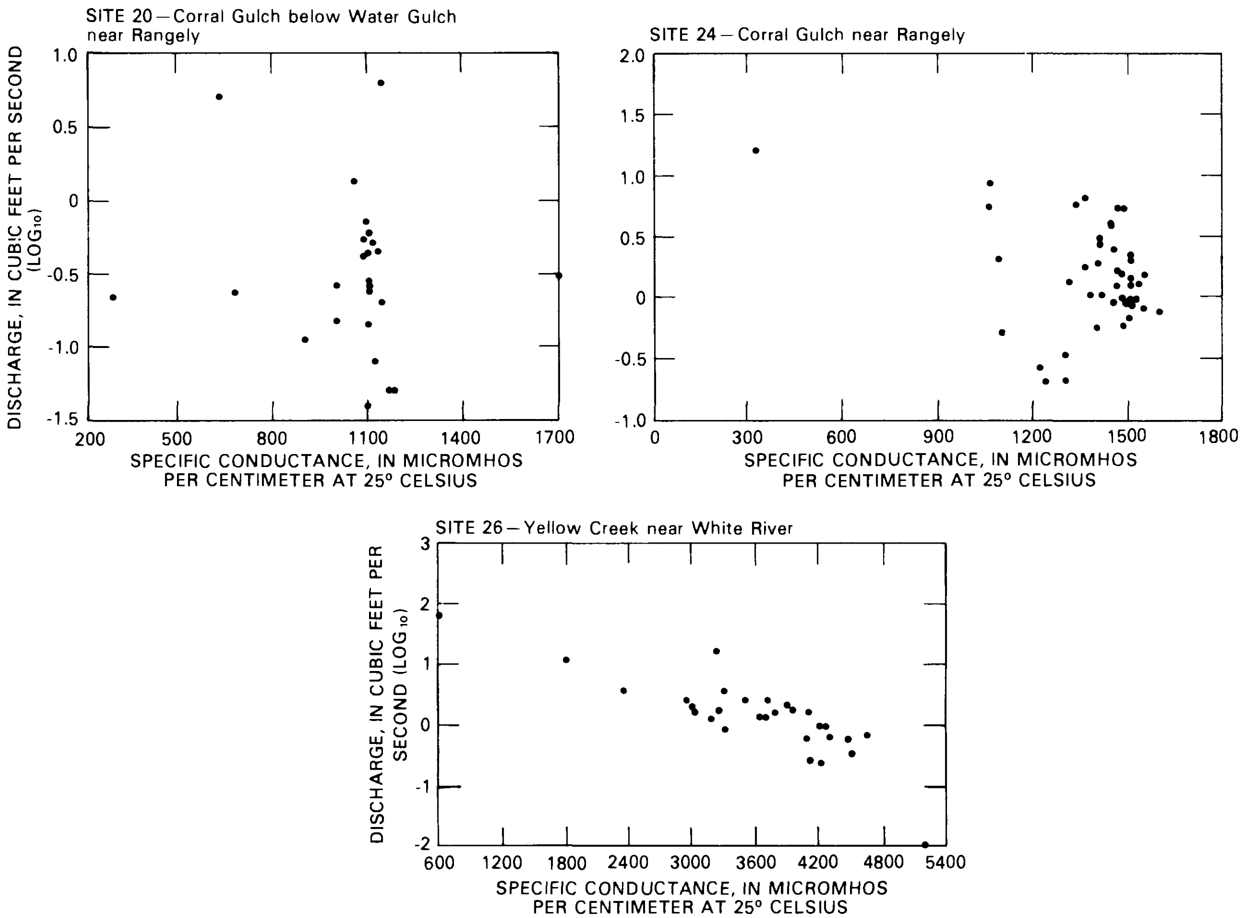


Figure 25.--Correlation of instantaneous discharge and specific conductance at three sites on perennial streams in Yellow Creek basin, water years 1977-81.

Table 11.--*Summary of continuous-monitor data and field determinations for selected water-quality characteristics for intermittent streams in Yellow Creek basin, water years 1977-81*

[°C=degrees Celsius; micromhos=micromhos per centimeter at 25°C; mg/L=milligrams per liter; ND=not determined]

Water-quality characteristics	5-year range for all available data, water years 1977-81				
	Site 19	Site 21	Site 22	Site 23	Site 25
Temperature (°C)--	9.0-13.5	3.0-22.0	0.0-32.0	0.5	6.0-8.5
Specific conductance (micromhos)	202-602	243-1,030	117-980	120-1,500	453-2,130
pH (units)--------	ND	7.8-8.3	6.9-8.7	8.0	8.2-8.6
Dissolved oxygen (mg/L)----------	ND	ND	6.4-11.9	11.6	8.5-12.7
Suspended-sediment concentration (mg/L).	6,680-8,360	0-18,500	0-33,100	0-113,000	0-53,000

Major Ions

Perennial streams.--Statistical data for concentrations of major ions in perennial streams in Yellow Creek basin are presented in table 12. These data also were grouped according to the hydrologic and seasonal classifications: low flows during the nonirrigation versus irrigation seasons and high flows from snowmelt runoff versus summer storm runoff. The terms non-irrigation versus irrigation, however, do not apply to the Corral Gulch sites, because little or no irrigation activity occurred in this area during the study period. In addition, because discharge at Corral Gulch, site 24, was greatly affected by oil-shale mine dewatering that began in early 1978 (fig. 6), the discharge classifications snowmelt and summer storm runoff would be misleading and were deleted. Statistical summaries for these data groups are shown in figures 26 to 28. If the data extremes were extended significantly by a single sample, the second highest (or lowest) concentration is given for perspective.

Between site comparisons of water-quality type and relative contributions of the cations and anions to dissolved solids are displayed in figures 29 and 30. The data show annual mean concentrations after they have been converted to milliequivalents. This conversion was necessary to establish an equivalent basis for ion comparisons in determining water-quality type (Hem, 1970).

Table 12.--*Statistical summary of concentrations of major ions in perennial streams in Yellow Creek basin, water years 1977-81*

[N=number of samples; $\overline{X}$=mean concentration of samples; S=standard deviation; $S_{\overline{x}}$=standard error of the mean; Min=minimum concentration; Max=maximum concentration; ( )=value at second lowest or highest concentration. Shown for ranges that are exaggerated by a single extreme data value]

Cations, in milligrams per liter																								Dissolved solids, in milligrams per liter					
Calcium						Magnesium						Potassium						Sodium											
Mean				Range		Mean				Range		Mean				Range		Mean				Range		Mean				Range	
N	$\overline{X}$	S	$S_{\overline{x}}$	Min	Max	N	$\overline{X}$	S	$S_{\overline{x}}$	Min	Max	N	$\overline{X}$	S	$S_{\overline{x}}$	Min	Max	N	$\overline{X}$	S	$S_{\overline{x}}$	Min	Max	N	$\overline{X}$	S	$S_{\overline{x}}$	Min	Max
Site 20 Corral Gulch below Water Gulch																													
25	80	17	3.4	32 (50)	100	26	54	13	2.6	15 (31)	68	26	3.7	11	2.1	0.8	56 (4.6)	26	80	21	4.1	22 (51)	150 (99)	17	662	156	38	202 (405)	770
Site 24 Corral Gulch near Rangely																													
48	74	17	2.5	19 (40)	97	48	70	10	1.5	14 (55)	83	49	1.6	.72	.10	.5	4.4	48	152	33	4.8	30 (79)	200	40	939	148	23	200 (680)	1080
Site 26 Yellow Creek near White River																													
30	31	16	2.9	12	100 (47)	30	93	31	5.6	11 (27)	140	30	4.7	1.3	.24	2.1	8.6	30	765	211	39	130 (370)	1200	21	2284	545	119	489 (1540)	2850

Table 12.--*Statistical summary of concentrations of major ions in perennial streams in Yellow Creek basin, water years 1977-81*--Continued

Anions, in milligrams per liter																								Specific conductance, in micromhos					
Bicarbonate						Chloride						Fluoride						Sulfate											
Mean				Range		Mean				Range		Mean				Range		Mean				Range		Mean				Range	
N	$\bar{X}$	S	$S_{\bar{x}}$	Min	Max	N	$\bar{X}$	S	$S_{\bar{x}}$	Min	Max	N	$\bar{X}$	S	$S_{\bar{x}}$	Min	Max	N	$\bar{X}$	S	$S_{\bar{x}}$	Min	Max	N	X	S	$S_{\bar{x}}$	Min	Max
Site 20 Corral Gulch below Water Gulch																													
17	345	97	24	110	440	26	13	28	5.5	3.8	150 (21)	26	0.34	0.36	0.07	0.1	2.1 (.4)	26	264	55	11	52 (160)	310	26	1049	239	47	287 (630)	1700 (1180)
Site 24 Corral Gulch near Rangely																													
41	529	77	12	130 (423)	600	49	11	3.7	.52	4.0	30 (18)	49	.65	.32	.05	.0	1.4	48	346	64	9.2	52 (220)	440	49	1393	203	29	321 (1060)	1600
Site 26 Yellow Creek near White River																													
20	[1]1608	449	100	[1]280 (1050)	[1]2230	30	139	51	9.4	16 (63)	260	30	2.2	.53	.10	.6 (1.4)	2.9	29	489	145	27	110	640	30	3608	898	164	620 (2350)	5200

[1]Includes concentrations of carbonate (CO_3) that were converted to equivalents of bicarbonate (HCO_3).

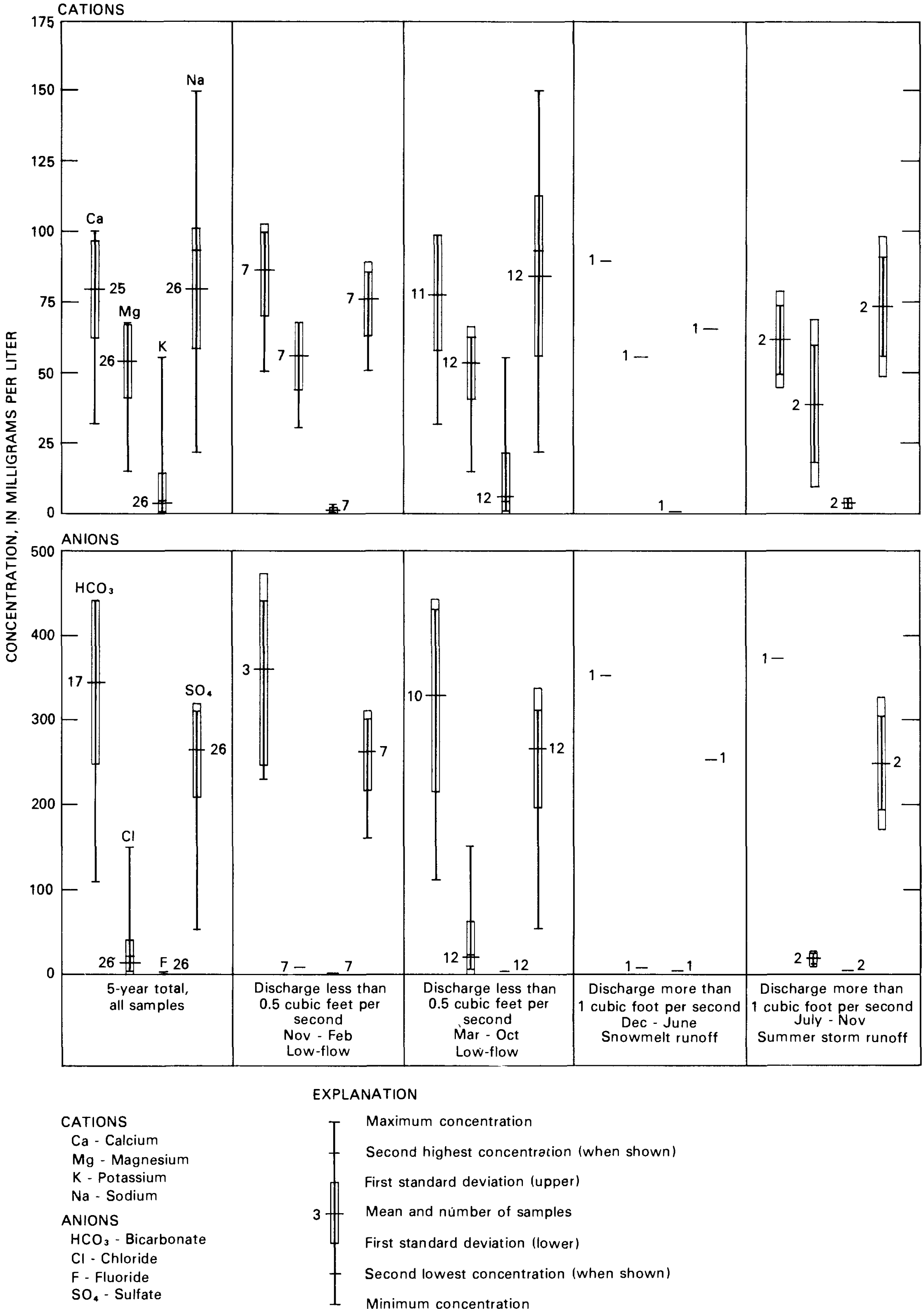


Figure 26.--Means, standard deviation, and extremes of concentrations of periodic samples for major ions for discharge and seasonal classifications, Corral Gulch below Water Gulch near Rangely (site 20), water years 1977-81.

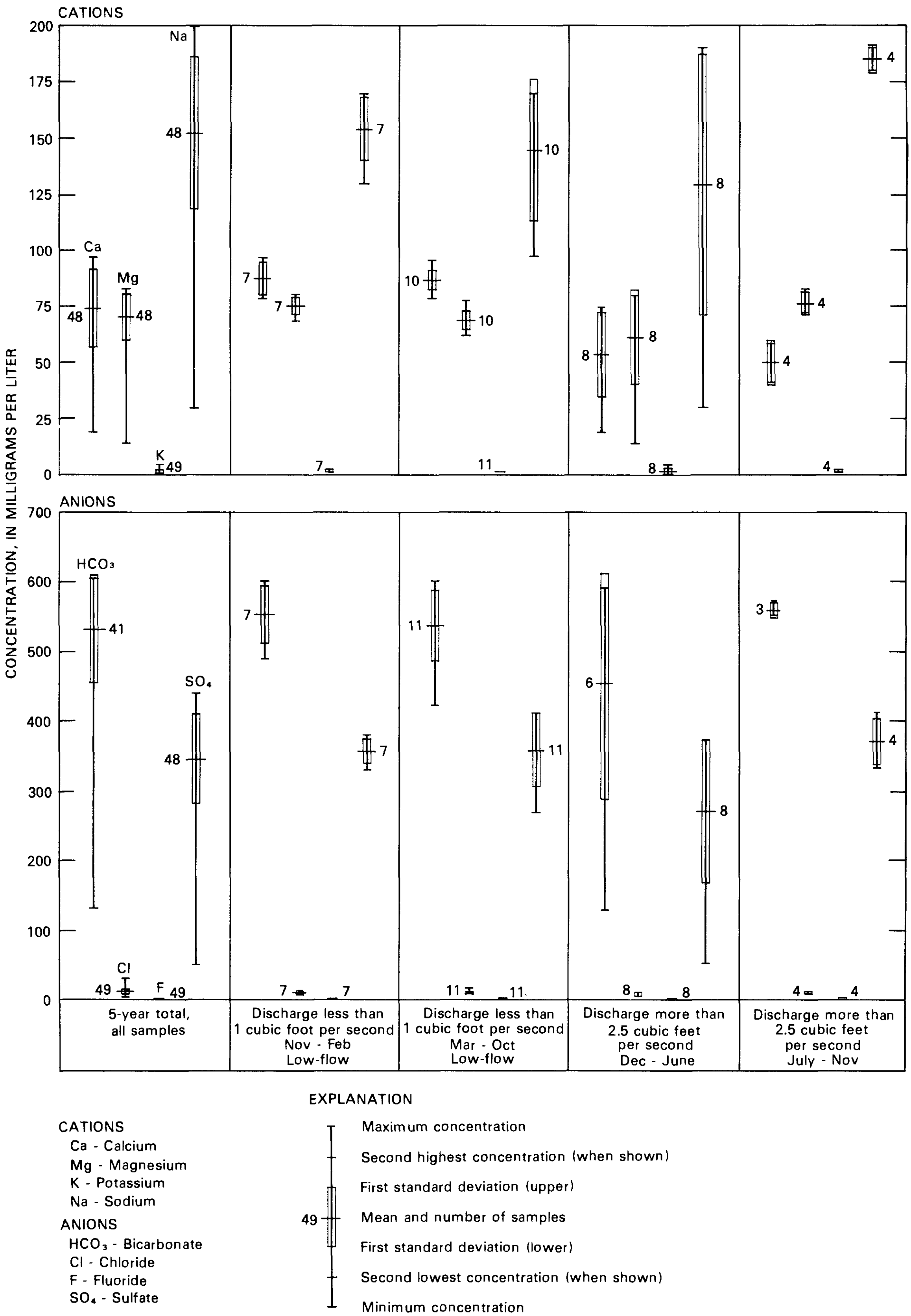


Figure 27.--Means, standard deviation, and extremes of concentrations of periodic samples for major ions for discharge and seasonal classifications, Corral Gulch near Rangely (site 24), water years 1977-81.

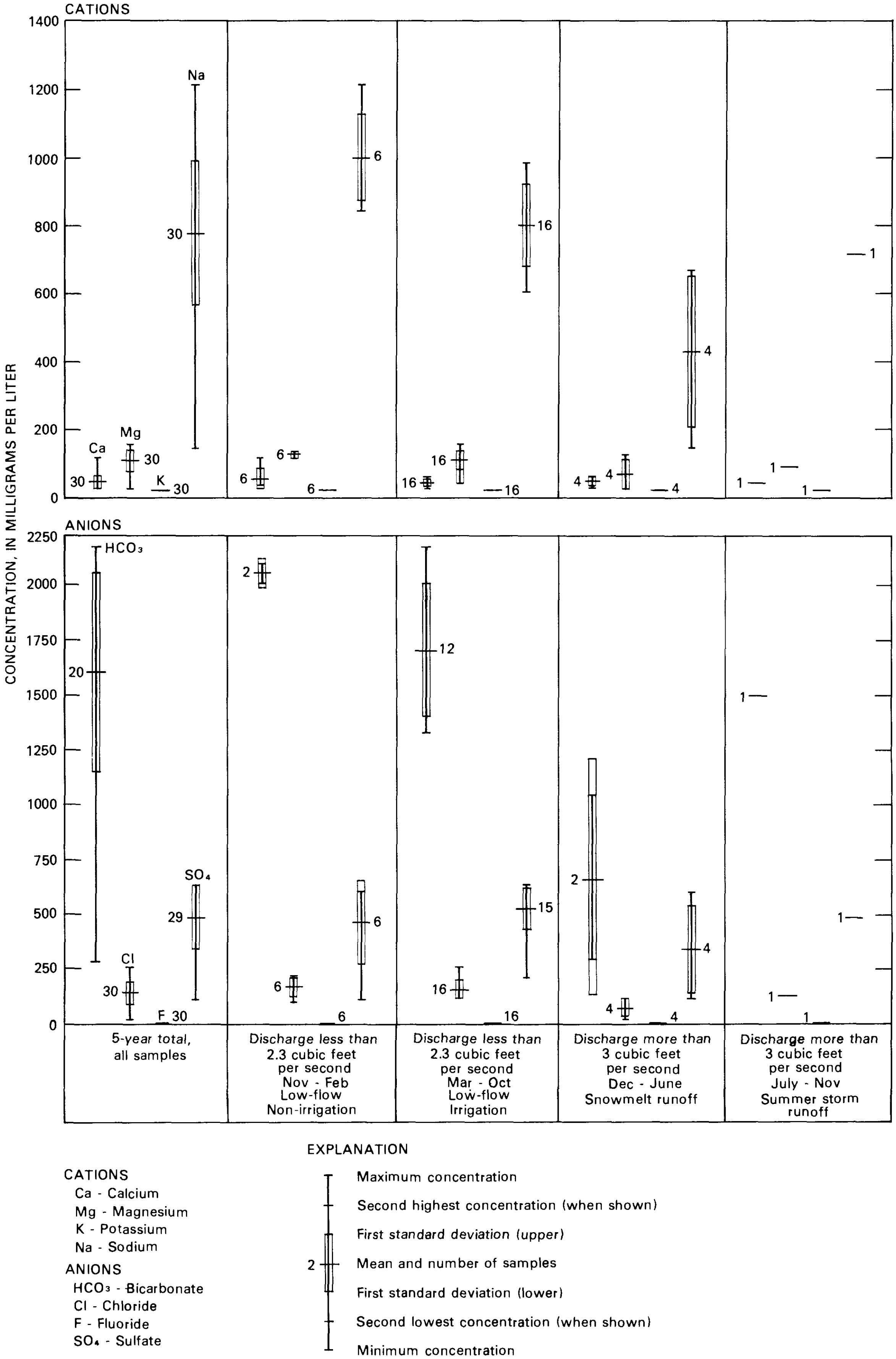


Figure 28.--Means, standard deviation, and extremes of concentrations of periodic samples for major ions for discharge and seasonal classifications, Yellow Creek near White River (site 26), water years 1977-81.

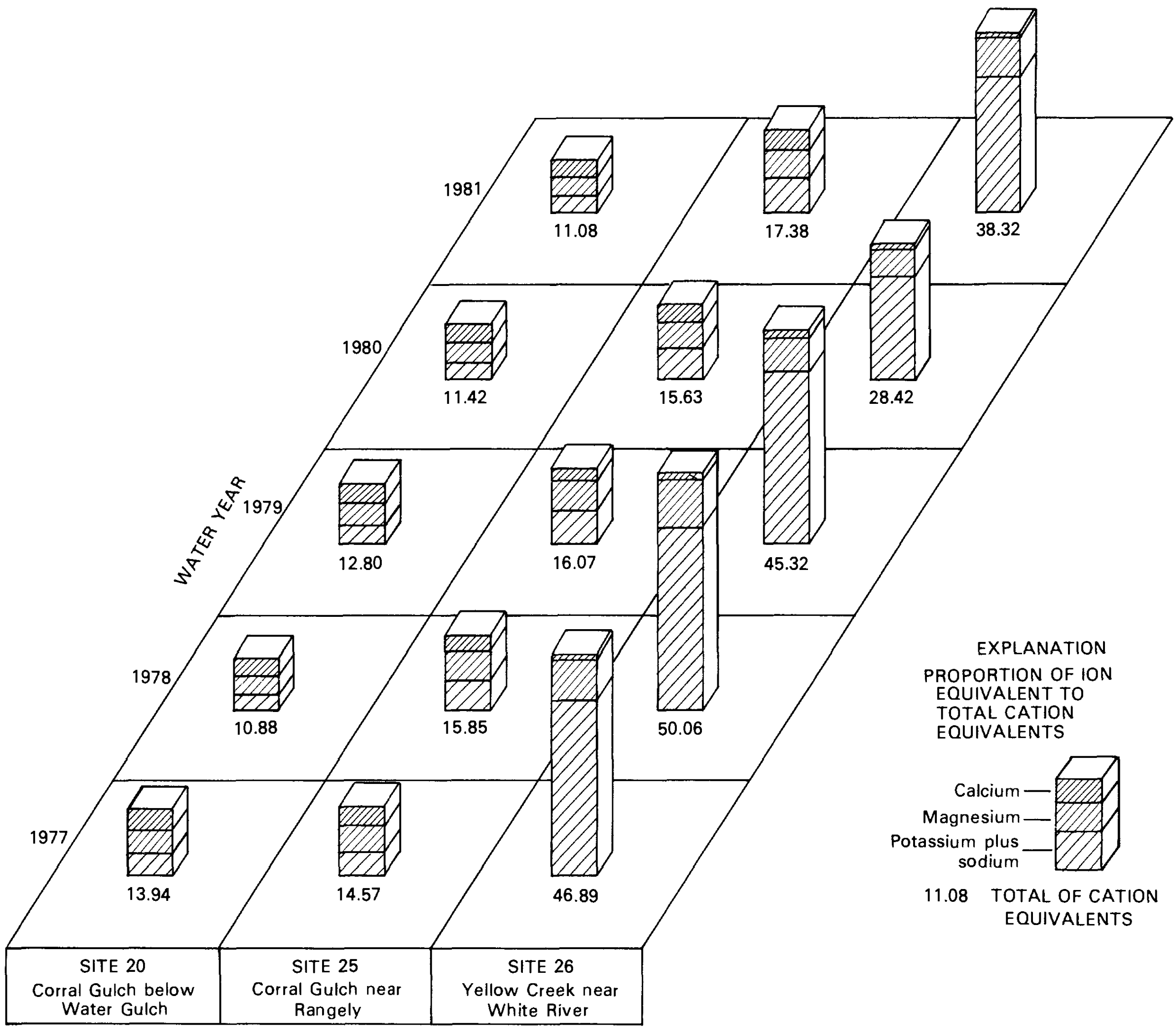


Figure 29.--Relative proportion of ion equivalents to total cation equivalents calculated from annual mean concentrations of calcium, magnesium, potassium, and sodium for perennial streams in Yellow Creek basin, water years 1977-81.

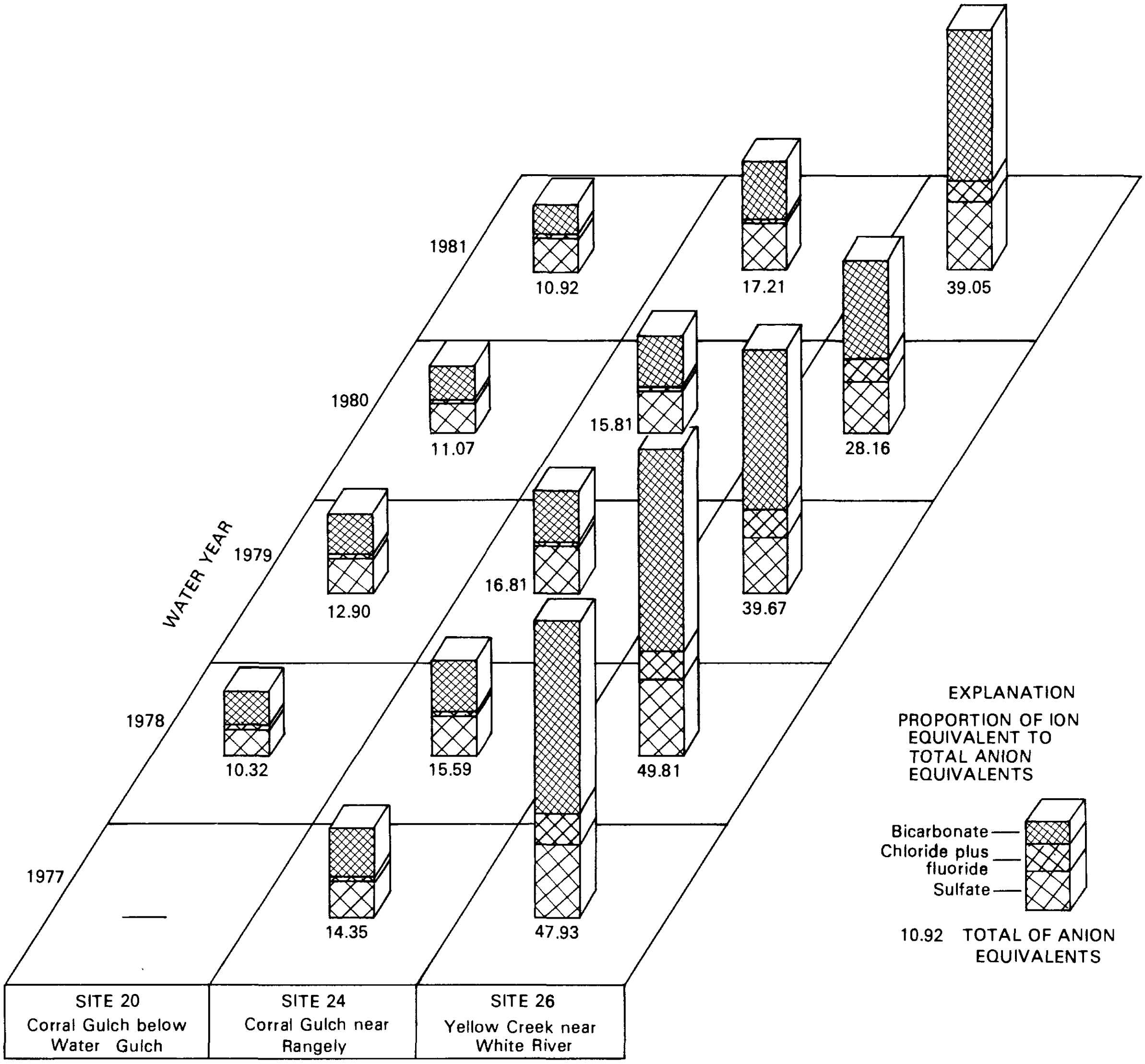


Figure 30.--Relative proportion of ion equivalents to total anion equivalents calculated from annual mean concentrations of bicarbonate, chloride, fluoride, and sulfate for perennial streams in Yellow Creek basin, water years 1977-81.

The within site variations in concentrations of the cations and anions (figs. 26 to 28) at the three perennial streamflow sites 20, 24, and 26 in Yellow Creek basin are summarized:

1. Data for sites 20 and 24 are difficult to assess because of an incomplete data base and periodic discharges (fig. 6) of energy development related activities in the area. The data for Corral Gulch at site 20 show little change in mean concentrations for the cations and anions for the flow-season classifications. Minimum concentrations coincided with runoff events. The maximum values of 56 mg/L for potassium, and 150 mg/L for sodium and chloride (fig. 26) at this site are believed to be due to oil and gas exploration activities. Variations in relative concentrations of the major ions at Corral Gulch at site 24 were functions mainly of runoff events and discharges from mine-dewatering activities. Annual mean concentrations of sulfate increased 30 to 80 mg/L during the 1978-81 water years as compared with similar data in the 1977 water year (U.S. Geological Survey, 1977-82). Minimum concentrations of the major ions occurred during runoff events.
2. Stable water-quality conditions, a small concentration ratio (less than 0.5) for calcium/magnesium, sodium concentrations greater than 500 mg/L, and chloride concentrations in excess of 100 mg/L were characteristic of the flow in Yellow Creek at site 26 prior to September 1978 and after late spring of 1980 (fig. 31). The intervening period from September 1978 to late spring 1980 was characterized by large changes in concentrations of both cations and anions, a fluctuating concentration ratio for calcium/magnesium, and a significant reduction in flow followed by several runoff events. Initially, the variations in the data were caused by a storm event in September 1978 when great quantities of sediment were transported and deposited near the mouth of Yellow Creek. The following winter and spring, water quality in Yellow Creek at site 26 probably reflected the effects from channel restabilization and mineral solution complicated by a deep winter freeze. The decrease in concentrations of general ions in February 1980 (fig. 31) were from samples taken during a runoff event.
3. Mean concentrations of major ions in Yellow Creek at site 26 (figs. 28 to 30) were significantly less during the high flow year of 1980 than during low flow years.

Although surface flows in many of the stream channels in Yellow Creek basin are not continuous (perennial flows exist only in local areas), between site comparisons of the data (figs. 26 to 30 and table 12) in the Yellow Creek basin are as follows:

1. Water quality was a mixed magnesium calcium bicarbonate type in upper Corral Gulch at site 20. A magnesium sodium bicarbonate water-quality type is shown at Corral Gulch, site 24, during the 1977 water year prior to oil-shale mine dewatering. A shift to a sodium magnesium type for cations and an increase in concentrations of sulfate and dissolved solids occurred during the C-a mine-dewatering period starting in 1978. Mean concentrations of dissolved solids increased several hundred mg/L from site 20 to site 24.

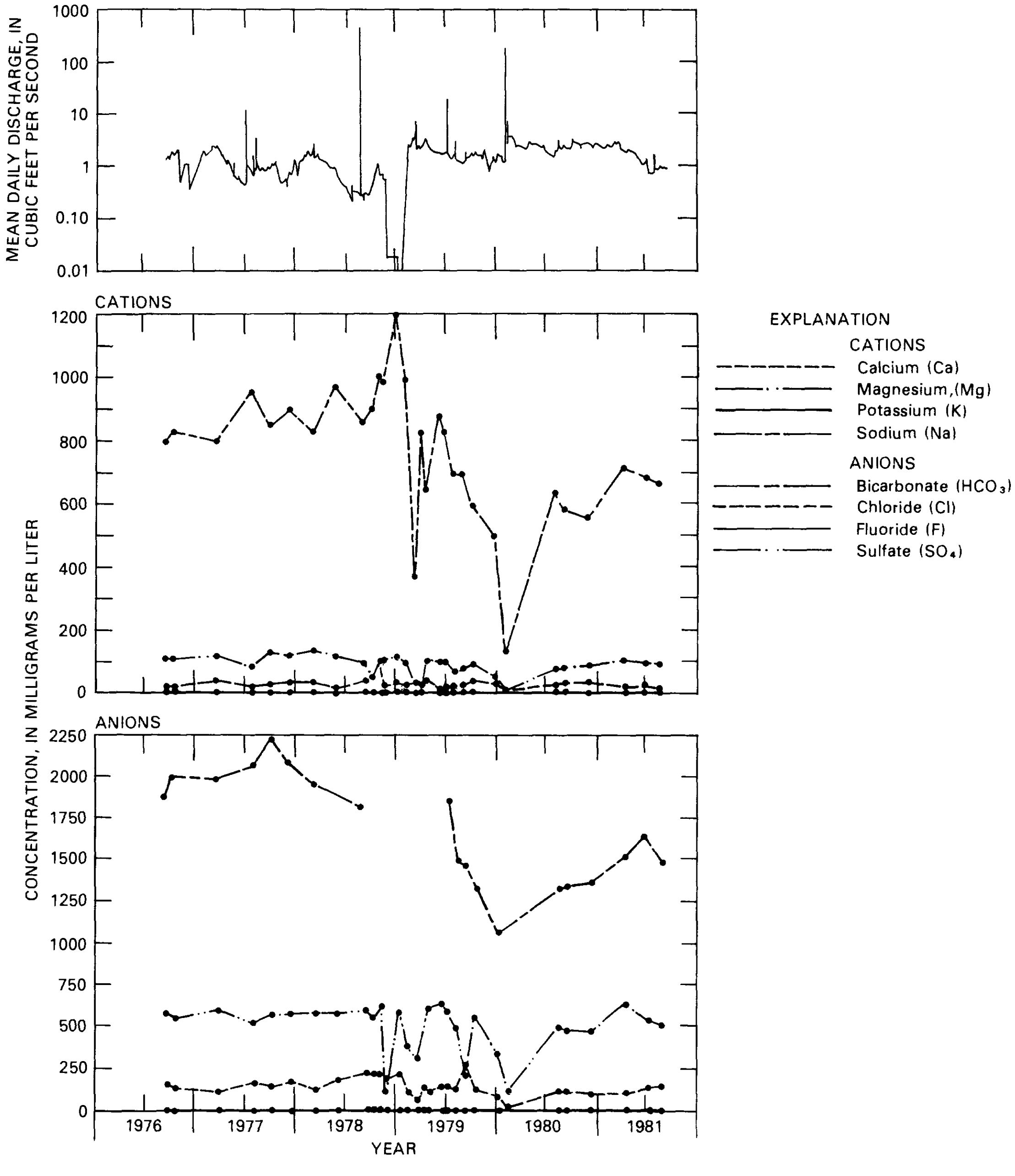


Figure 31.--Relative comparisons of concentrations of cations and anions and mean daily discharge for Yellow Creek near White River (site 26), water years 1977-81.

2. Water quality was different at the mouth of Yellow Creek at site 26 than in Corral Gulch (figs. 29 and 30). Water-quality type at site 26 was characterized by the ions sodium and bicarbonate, mean chloride concentrations were greater (in the 100- to 200-mg/L range), and mean dissolved-solids concentrations generally were two to four times greater than those measured for Corral Gulch. Water-quality characteristics at the mouth of Yellow Creek are believed to be greatly affected by high conductance ground water from the Green River Formation. Ground water discharges through springs and fractures to the stream channel upstream from site 26 (Saulnier, 1978).

Intermittent streams.--Water-quality type and concentration ranges of dissolved solids for intermittent flows compared with data means for perennial flows in Yellow Creek basin are shown in figure 32. Calcium and bicarbonate were the characteristic ions in water samples containing less than 300 mg/L dissolved solids: magnesium and sulfate concentrations were characteristic of samples that exceeded 300 mg/L.

Water-quality types varied more in Stake Springs Draw at site 19 and Dry Fork at site 21 than in Box Elder Gulch at site 22 and Corral Gulch at site 25 (fig. 32 and U.S. Geological Survey, 1978-82). A mixed calcium magnesium bicarbonate type was common at site 22, and a magnesium sodium sulfate bicarbonate type dominated the water chemistry at the mouth of Corral Gulch at site 25. Concentrations of dissolved solids were greatest at Corral Gulch, site 25, where they ranged from 894 to 1,300 mg/L.

In comparison with other intermittent streams, the greater concentrations of dissolved solids and the more consistent chemical type observed for the flows in Box Elder Gulch (site 22) and Corral Gulch (site 25) were related to the hydrology at those sites. Flows at the Box Elder and Corral Gulch sites were sustained for extended periods by base flow and local springs. Streamflow at the Stake Springs, Dry Fork, and Box Elder Tributary sites occurred for short periods, principally from overland runoff. The chemical samples of the latter three sites tend to represent ions that were available in the basin soils as compared with the water chemistry of water table and bedrock aquifer discharges measured in Box Elder Gulch and Corral Gulch.

Regressions.--Concentrations of most of the major ions in streams in Yellow Creek basin were inversely correlated with discharge and directly correlated with specific conductance. The variability in concentrations of these constituents with respect to discharge, however, was sufficiently great to preclude the use of meaningful regressions. Least squares regressions of dissolved solids versus specific conductance for the perennial streams and for data composites for the intermittent streams are given in table 13. The regressions for the perennial streams provide an estimate of dissolved solids calculated from specific conductance measurements for the data range shown in table 12. The regressions for the intermittent streams were calculated for specific conductance ranges of 130 to 602 micromhos for sites 19, 21, and 23, 145 to 900 micromhos for site 22, and 1,310 to 1,850 micromhos for site 25.

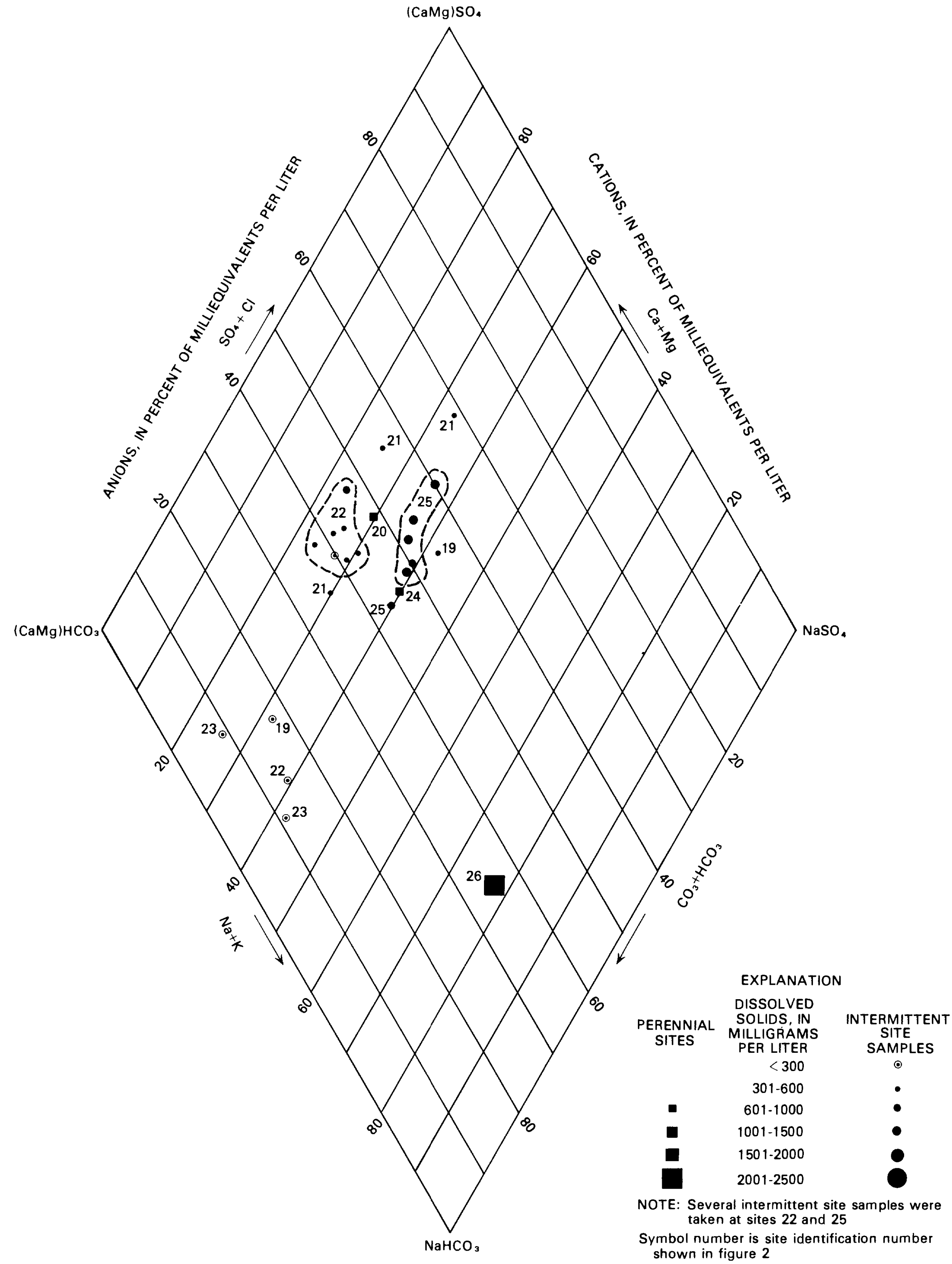


Figure 32.--Water-quality types and concentration ranges of dissolved solids for perennial and intermittent streams, Yellow Creek basin. Data for the perennial sites are based on a 5-year mean for water years 1977-81. Data for the intermittent sites are for individual analyses of samples taken during runoff events.

Table 13.--*Estimates of dissolved solids from values of specific conductance for perennial streams in Yellow Creek basin, water years 1977-81*

Site number and name	Least squares regression: Dissolved solids (DS), in milligrams per liter, estimated from specific conductance (SC), in micromhos per centimeter		
	Number of samples	Equation	Correlation coefficient (r)
20 Corral Gulch below Water Gulch--------------	17	DS=0.66SC+2	0.98
24 Corral Gulch near Rangely--	40	DS=0.68SC-10	.98
26 Yellow Creek near Rangely--	20	DS=0.67SC-3	.99

Estimates of dissolved solids also may be made directly from measurements of specific conductance (Hem, 1970) from the following equation:

DS=SC X A

where DS=dissolved solids, in milligrams per liter;
SC=specific conductance, in micromhos; and
(A)=the mean ratio of DS/SC computed from the data base for a specific site. The mean value of (A) and the first standard deviation were computed from 17 samples at site 20, 40 samples at site 24, and 20 samples at site 26 from the perennial streams and are shown below.

	Streamflow sites		
	20	24	26
DS/SC ratio(A)	0.67+.03	0.68+.02	0.67+.02

Nutrients

Means and standard deviation for concentrations of nitrogen and phosphorus in Yellow Creek basin are shown in figure 33. Data for the intermittent sites were grouped according to flow duration characteristics: flows at sites 19, 21, and 23 were short term and flashy, streamflow at sites 22 and 25 were sustained for longer periods from near-surface ground-water sources and springs.

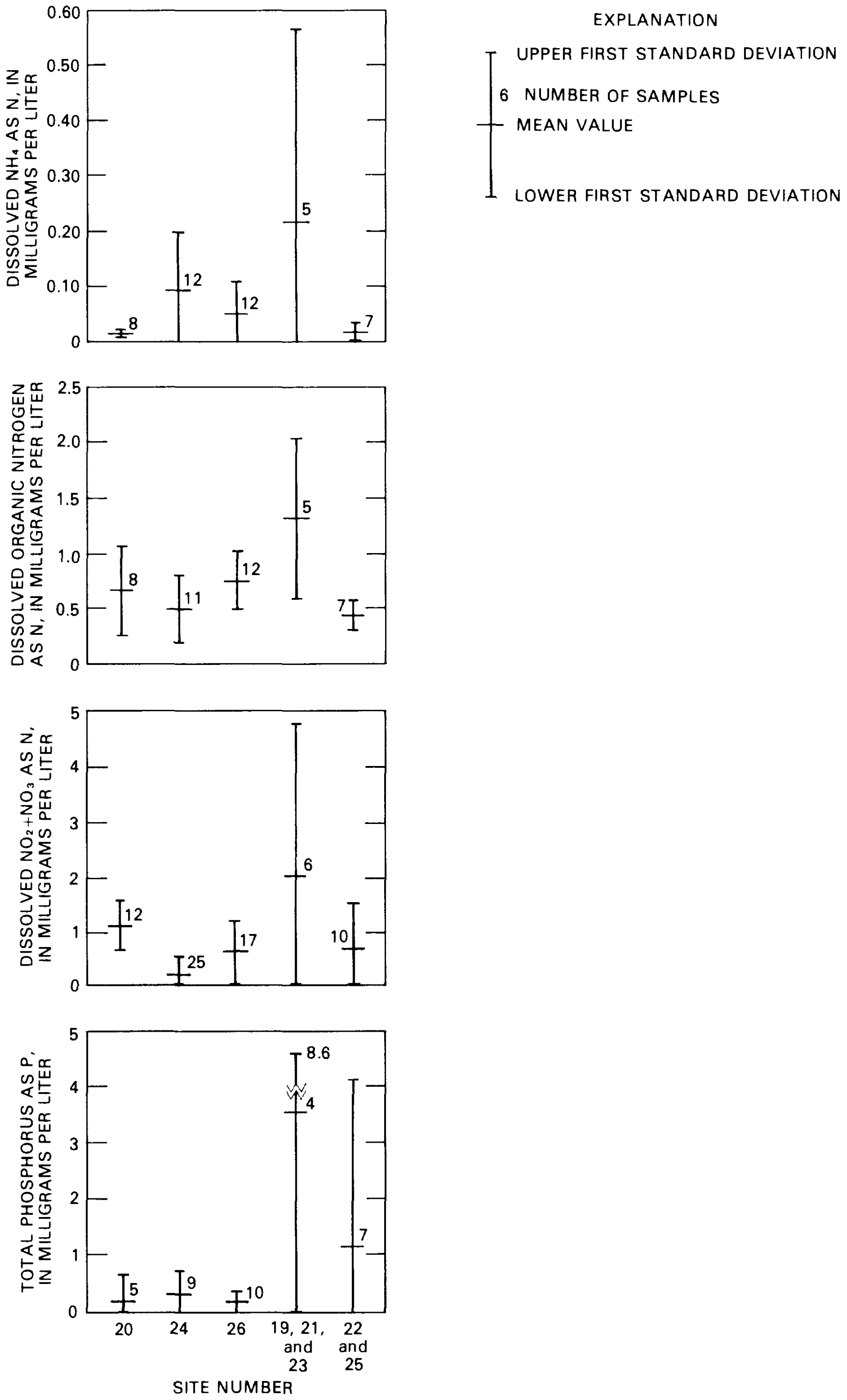


Figure 33.--Concentration means and first standard deviations of the nutrients, nitrogen and phosphorus, for perennial streams and data composites of intermittent streams, in Yellow Creek basin, water years 1977-81.

Attempts to relate nutrient concentrations at the perennial stations with discharge were inconclusive. In general, maximum concentrations of nutrients occurred during other than low flow conditions.

The greater and more consistent concentrations of nitrite plus nitrate in Corral Gulch at site 20 than at the two other perennial flows in Yellow Creek basin probably were related to local spring sources that had high concentrations of nitrate nitrogen. The concentration and range of nutrients in short-duration flows at sites 19, 21, and 23 were large when compared with perennial and intermittent flows sustained by ground water and springs. This indicates that major nutrient transport in the streams of Yellow Creek basin occurred during periods of overland runoff when soil leaching and sediment-transportation activities were at a maximum.

Trace Constituents

Concentration ranges of dissolved trace constituents in perennial and intermittent streams in Yellow Creek basin are shown in figure 34. Where one sample in a data set extended the maximum range beyond what appeared to be general background range, the second highest concentration is shown for perspective. Data for Corral Gulch near Rangely, site 24, are for combined natural flows and flows that originated from mine-dewatering activities at Tract C-a.

Except for boron, lithium, and strontium, the data show that most trace constituents in streams appeared to be uniformly distributed through the Yellow Creek basin. The high concentration ranges for boron and lithium in Yellow Creek near White River, site 26, were likely due to water seepage from ground-water aquifers into the stream channel upstream from this site (Saulnier, 1978).

The high strontium concentrations measured in Corral Gulch near Rangely, site 24, (fig 34) probably were related to the quality of water from mine discharges to that stream channel. Although not shown in the data tables in this report, dissolved strontium concentrations for seven samples taken during the 1976 water year ranged from 1,600 to 2,000 ug/L; during the 1978-79 water years, when the dewatering of oil-shale mines occurred, strontium ranged from 1,900 to 7,000 μg/L. As discussed earlier, mean concentrations of sulfate also increased during this period. The two constituents may have a common mineral assemblage or chemical equilibrium control at this site. Relative to the other intermittent streams, the apparent high concentrations of arsenic and selenium at Box Elder Gulch, site 22, may reflect the bias of a small data base or may represent effects from ground-water sources.

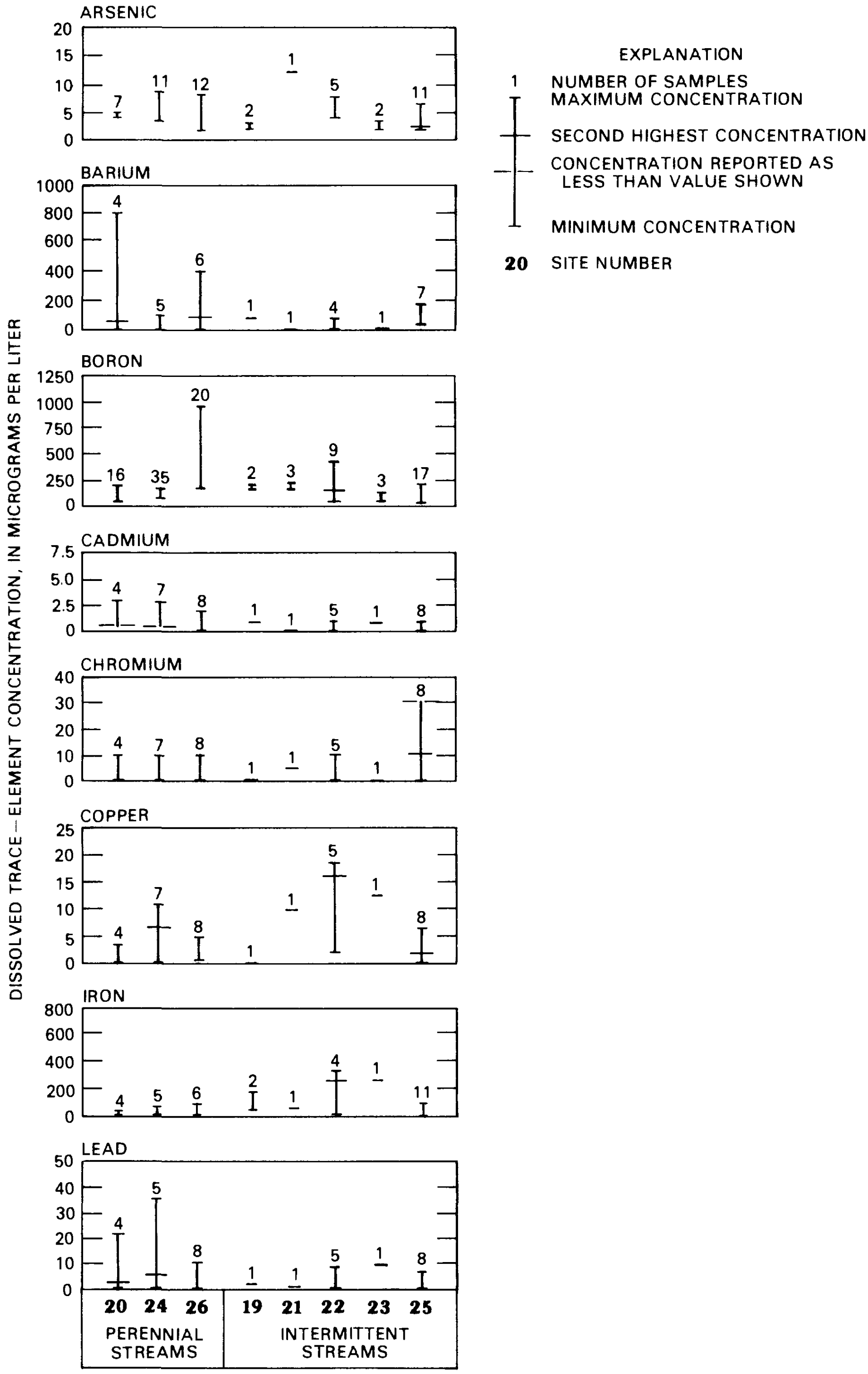


Figure 34.--Minimum-maximum concentration range for dissolved trace constituents in perennial and intermittent streams, Yellow Creek basin, water years 1976-81.

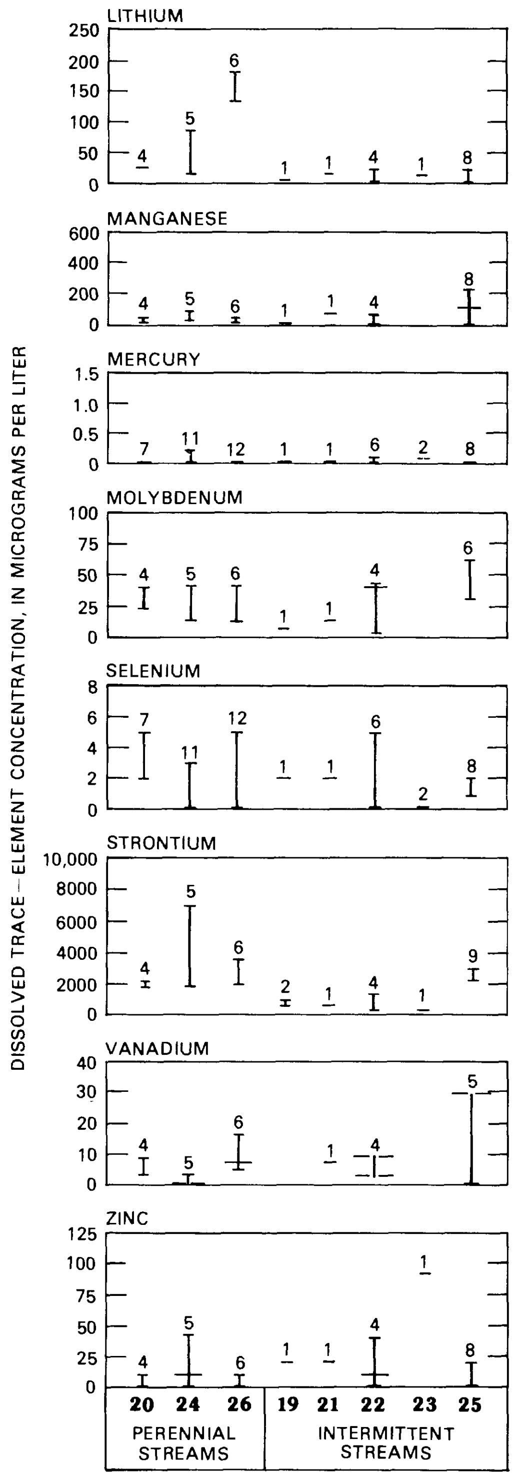


Figure 34.--Minimum-maximum concentration range for dissolved trace constituents in perennial and intermittent streams, Yellow Creek basin, water years 1976-81--Continued.

Radioactive Substances

Data ranges for radioactive substances in perennial and intermittent streams in Yellow Creek basin are presented in table 14 and maximum recorded activities are summarized in figure 35. The source radionuclides for these activities in streams apparently were associated with the suspended material in the streams because relatively high values commonly occurred during periods when concentrations of suspended-sediment were high. The specific radionuclides of the radioactive substances were not identified.

Insecticides and Herbicides

A total of 24 unfiltered water samples and six bed-material samples were analyzed for insecticides and herbicides from Corral Gulch below Water Gulch at site 20, Corral Gulch near Rangely at site 24, and Yellow Creek near White River at site 26 during October 1975 to September 1980 (water years 1976-80). In addition, a total of six unfiltered water samples and three bed-material samples were collected from the intermittent sites, Box Elder Gulch near Rangely, site 22, and Corral Gulch at 84 Ranch, site 25. All samples were analyzed for the following:

Insecticides		Herbicides
(Organochlorine)	(Organophosphorus)	(Chlorophenoxy Acid)
Aldrin	Diazinon	2,4-D
Chlordane	Ethion	2,4,5-T
DDD	Malathion	Silvex
DDE	Methyl parathion	
DDT	Methyl trithion	
Dieldrin	Parathion	
Endrin	Trithion	
Heptachlor		
Heptachlor epoxide		
Lindane		
Toxaphene		

Herbicides were not detected at any site. The insecticides DDE and chlordane were detected only once in the 1976 water year at low concentration ranges of 0.1 to 0.2 μg/kg in bed materials from the Corral Gulch sites 20, 24, and 25. The presence of these insecticides at the Corral Gulch sites most likely were residuals from past agricultural or insect control activities.

Table 14.--*Minimum-maximum data range for radioactive substances in perennial and intermittent streams in Yellow Creek basin, water years 1976-81*

[Gross Alpha as picocuries per liter (pCi/L) as Uranium-natural and micrograms per liter (μg/L) as Uranium-natural; Gross Beta as picocuries per liter (pCi/L) as Cesium-137 and as Strontium-90/Yttrium-90; N, number of samples; range, minimum and maximum values; <, value less than value shown]

Water year	Gross Alpha: pCi/L as Uranium-natural, dissolved N	range	pCi/L as Uranium-natural, suspended N	range	μg/L as Uranium-natural, dissolved N	range	μg/L as Uranium-natural, suspended N	range	Gross Beta: pCi/L as Cesium-137, dissolved N	range	pCi/L as Cesium-137, suspended N	range	pCi/L as Strontium/Yttrium-90, dissolved N	range	pCi/L as Strontium/Yttrium-90, suspended N	range	Radium 226, dissolved (pCi/L) N	range	Uranium, natural, dissolved (μg/L as Uranium) N	range
PERENNIAL STREAMS																				
Site 20 Corral Gulch below Water Gulch																				
1976	-	---------	-	--------	3	<9.4-<14	3	<0.4-3.2	3	3.5-6.4	3	<0.4-2.4	3	2.8-5.2	3	<0.4-1.9	2	0.08-.11	1	4.2
1977	-	---------	-	--------	--	---------	--	--------	--	---------	--	--------	--	---------	--	--------	--	--------	-	-------
1978	-	---------	-	--------	2	<8.2-12	2	.8-110	2	<3.0-3.9	2	1.1-65	2	<2.8-3.4	2	1.1-60	2	.07-.10	2	5.1-5.9
1979	-	---------	-	--------	1	<.14	1	.8	1	<5.0	1	.8	1	<4.4	1	.8	1	.10	1	6.3
1980	2	5.4-<5.8	2	2.0-6.7	2	8.0-<8.5	2	2.9-99	2	<45-<4.7	2	.6-64	2	<4.2-<4.7	2	.6-62	2	.09-.10	2	5.7-6.4
1981	-	---------	-	--------	--	---------	--	--------	--	---------	--	--------	--	---------	--	--------	--	--------	-	-------
Total	2	5.4-<5.8	2	2.0-6.7	8	8.0-<14	8	<.4-110	8	<3.0-6.4	8	<.4-65	8	<2.8-5.2	8	<.4-62	7	.07-.11	6	4.2-6.4
Site 24 Corral Gulch near Rangely																				
1976	-	---------	-	--------	4	<7.4-<13	4	<.4	4	2.4-5.6	4	<.4-1.4	4	2.0-4.5	4	<.4-1.2	3	.05-.10	-	-------
1977	-	---------	-	--------	--	---------	--	--------	--	---------	--	--------	--	---------	--	--------	--	--------	-	-------
1978	-	---------	-	--------	3	<8.2-<26	3	<.4-290	3	4.5-16	3	.6-190	3	4.0-15	3	.5-170	3	.07-.21	2	3.1-5.0
1979	-	---------	-	--------	2	<15-<16	2	1.0-42	2	<5.7-<5.9	2	.7-17	2	<5.4-<5.8	2	.7-14	2	.07-.13	2	.53-3.3
1980	2	<8.2-88	2	26-61	2	<12-130	2	38-90	2	<6.1-24	2	28-75	2	<5.7-23	2	27-72	2	.10	1	9.8
1981	-	---------	-	--------	--	---------	--	--------	--	---------	--	--------	--	---------	--	--------	--	--------	-	-------
Total	2	<8.2-88	2	26-61	11	<7.4-130	11	<.4-290	11	2.4-24	11	<.4-190	11	2.0-23	11	<.4-170	10	.05-21	5	.53-9.8
Site 26 Yellow Creek near White River																				
1976	-	---------	-	--------	4	<24-68	4	.8-96	4	<7.7-45	4	1.1-46	4	<6.2-36	4	.9-39	1	.12	-	-------
1977	-	---------	-	--------	--	---------	--	--------	--	---------	--	--------	--	---------	--	--------	--	--------	-	-------
1978	-	---------	-	--------	3	<8.6-<41	3	<.6-29	3	<4.1-11	3	.7-16	3	<3.8-9.2	3	.6-15	3	.10-.18	2	3.6-5.1
1979	-	---------	-	--------	2	<31-<51	2	3.6-14	2	<13-<20	2	2.1-5.2	2	<13-<18	2	1.9-4.3	2	.11-.92	2	5.4-5.5
1980	2	6.1-<16	2	.3-100	2	9.0-<23	2	.5-150	2	6.9-<13	2	.8-60	2	7.1-<12	2	.7-61	2	.10-.11	2	3.1-5.1
1981	-	--------	-	--------	--	---------	--	--------	--	---------	--	--------	---	---------	--	--------	--	--------	-	-------
Total	2	6.1-<16	2	.3-100	11	<8.6-68	11	.5-150	11	<4.1-45	11	.7-60	11	<3.8-36	11	.6-61	8	.10-.92	6	3.1-5.5

Table 14.--*Minimum-maximum data range for radioactive substances in perennial and intermittent streams in Piceance Creek basin, water years 1976-81*--Continued

Water year	Gross Alpha								Gross Beta								Radium 226, dissolved (pCi/L)		Uranium, natural, dissolved (µg/L as Uranium)	
	pCi/L as Uranium-natural				µg/L as Uranium-natural				pCi/L as Cesium-137				pCi/L as Strontium/Yttrium-90							
	dissolved		suspended		dissolved		suspended		dissolved		suspended		dissolved		suspended					
	N	range	N	range	N	range	N	range	N	range	N	range	N	range	N	range	N	range	N	range
INTERMITTENT STREAMS																				
Site 19 Stake Springs Draw near Rangely																				
1977	-	----	-	--	1	13	1	110	1	23	1	26	1	18	1	22	1	0.11	1	2.2
Total	-	----	-	--	1	13	1	110	1	23	1	26	1	18	1	22	1	.11	1	2.2
Site 22 Box Elder Gulch near Rangely																				
1976	-	----	-	--	2	2.3-11	2	<.4-3.4	2	5.8-16	2	<.4-.8	2	4.8-13	2	<.4-.7	-	-------	-	-------
1978	-	----	-	--	1	<6.0	1	17	1	3.7	1	14	1	3.3	1	13	1	.16	1	7.1
1979	-	----	-	--	1	<12	1	110	1	<4.5	1	57	1	<4.1	1	49	1	.10	1	4.2
1980	1	<4.3	1	52	1	<6.3	1	76	1	<4.1	1	65	1	<4.1	1	64	1	.12	1	4.4
Total	1	<4.3	1	52	5	2.3-11	5	<.4-110	5	3.7-16	5	<.4-65	5	3.3-13	5	<.4-64	3	.10-.16	3	4.2-7.1
Site 25 Corral Gulch at 84 Ranch																				
1976	-	----	-	--	4	<12-22	4	<.4-.6	4	6.1-18	4	<.4-1.4	4	5.3-14	4	<.4-1.2	3	.02-.06	-	-------
1977	-	----	-	--	1	<14	1	<.4	1	8.7	1	<.4	1	7.1	1	<.4	1	.11	1	5.6
[1]1979	-	----	-	--	1	<14	1	<.4	1	6.1	1	<.4	1	5.6	1	<.4	1	.07	1	6.3
Total	-	----	-	--	6	<12-22	6	<.4-.6	6	6.1-18	6	<.4-1.4	6	5.3-14	6	<.4-1.2	5	.02-.06	2	5.6-6.3
Yellow Creek basin																				
Total	1	<4.3	1	52	12	2.3-22	12	<.4-110	12	3.7-23	12	<.4-65	12	3.3-18	12	<.4-64	9	.02-.16	6	2.2-7.1

[1]Unpublished data.

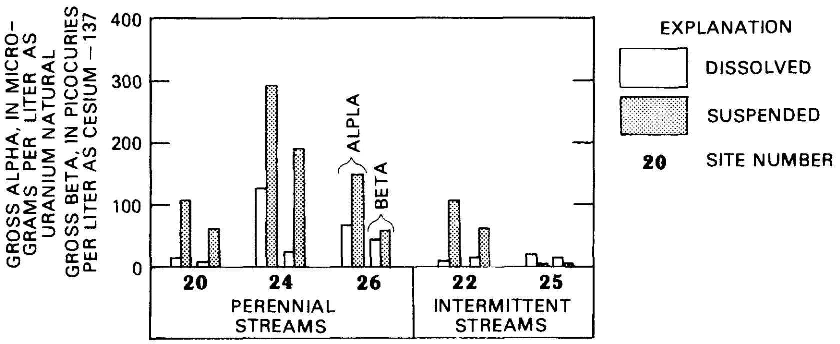


Figure 35.--Maximum recorded activity for radioactive substances in perennial and intermittent streams, Yellow Creek basin, water years 1976-81. Data are for sites having two or more samples.

SUMMARY AND CONCLUSIONS

Water-quality data from continuous-recording monitors, periodic field determinations, and laboratory analyses of samples collected periodically for major ions, nutrients, trace constituents, radioactive substances, and insecticides and herbicides are summarized for the Piceance Creek and Yellow Creek basins for water years 1977-81. Data for the 1976 water year were included when they effectively supplemented the data base.

Summer temperatures in the perennial flows near the upstream reaches of Piceance Creek and in Yellow Creek basin were warm and frequently exceeded 25°C. Warmest stream temperatures exceeded 30°C in the lower reaches of Piceance Creek and Yellow Creeks at sites 18 and 26. Perennial stream temperatures during summer were coolest along the middle reaches of Piceance Creek where cooler waters from springs and spring-fed tributaries discharge to Piceance Creek. Maximum ranges in daily temperature were 20.0°C in Piceance Creek at site 18, 25.5°C in Yellow Creek at site 26, and a maximum for Piceance Creek and Yellow Creek basins of 28°C in upper Corral Gulch at site 20.

Generally, specific conductance was inversely correlated with discharge in Piceance Creek and Yellow Creek basins. The correlations were best defined at the mouths of Piceance and Yellow Creeks. Specific conductance in perennial flows ranged from 200 to 10,000 micromhos in Piceance Creek basin and from 120 to 6,490 micromhos in Yellow Creek basin. Specific conductance in intermittent streams ranged from 100 to 2,570 micromhos in Piceance Creek basin and from 117 to 2,130 micromhos in Yellow Creek basin. Values were least during snowmelt runoff and greatest when ground-water recharge or discharge from energy development activities accounted for most of the streamflow.

Values of pH in the perennial and intermittent streams of Piceance Creek and Yellow Creek basins ranged from 6.9 to 9.0. pH generally was least during periods of snowmelt runoff and greatest in low flows that were augmented principally from ground-water sources. Values of pH increased downstream and were 0.4 to 0.7 units higher at the mouths of Piceance and Yellow Creeks at sites 18 and 26 when compared with upstream sites. Minimum concentrations of dissolved oxygen in streams were greater than 3.0 mg/L in Piceance and Yellow Creeks. Maximum concentrations of dissolved oxygen, that ranged from 12 to 16 mg/L, and increases of several tenths of a unit of pH occurred during periods of active photosynthesis.

The greatest variations in stream chemistry at streamflow sites were related to flow. Concentrations of dissolved solids were least and large percentages of calcium and bicarbonate occurred during the high flows of snowmelt runoff. Concentrations of dissolved solids were greatest, and the ions, sodium, magnesium, bicarbonate, and sulfate tended to dominate stream chemistry during base flows when spring discharges and irrigation-return flows accounted for most of the flow in streams. Chemical concentrations and water-quality types varied less in the perennial streams in which springs were the major source of streamflow throughout most of the year.

Water quality changed from a sodium magnesium bicarbonate type in the upper reaches of Piceance Creek to a high percentage sodium bicarbonate type downstream from Alkali Flat near the mouth of Piceance Creek. Concentrations of chloride and fluoride also increased in the lower reach. The 5-year mean for dissolved solids ranged from 700 mg/L in the upper reaches of Piceance Creek at site 1 to 1,670 mg/L at the mouth of Piceance Creek at site 18. These changes were attributed to ground-water seepage from bedrock aquifers to Piceance Creek in the area of Alkali Flat. A similar pattern existed in Yellow Creek basin where dissolved-solids concentrations were considerably less in the Corral Gulch sites 20, 24, and 25 than in Yellow Creek near White River at site 26. The 5-year mean for concentrations of dissolved solids at site 26 was 2,280 mg/L. Calcium and bicarbonate dominated the major ions, and dissolved-solids concentrations generally were less than 600 mg/L in the flashy intermittent flows of Piceance Creek and Yellow Creek basins.

Regressions of dissolved solids versus specific conductance are provided for given ranges of specific conductance. In addition, estimates of dissolved solids from measurements of specific conductance may be made using the mean dissolved solids/specific conductance ratio (DS/SC). Except for the 0.71 ratio in Black Sulphur Creek at site 14, the ratios in perennial streams ranged from 0.64 to 0.68 in Piceance Creek basin and 0.67 to 0.68 in Yellow Creek basin. Relative increases in concentrations of sulfate may have contributed to the greater DS/SC ratios.

Data show that maximum nutrient loading to the streams in Piceance Creek and Yellow Creek basins occurred during storm and snowmelt runoff. During runoff, concentrations of dissolved nitrogen and total phosphorus frequently exceeded several milligrams per liter in the perennial and intermittent streams. The comparatively high mean nitrite plus nitrate concentrations of about 1 mg/L in the spring-fed streams, Stewart Gulch above West Fork (site 3), and Corral Gulch below Water Gulch (site 20) indicate that this species of nitrogen may be a characteristic of water table or local bedrock aquifer systems.

Ranges of the dissolved concentrations of 16 trace constituents are presented. Concentrations of barium, lead, manganese, and mercury in Piceance Creek were greatest in the upstream reach but, because of geochemical factors, decreased downstream. Arsenic, boron, iron, lithium, and possibly molybdenum concentrations were greatest in Piceance Creek near the mouth at site 18; these increases were from ground water that augmented the flow in Piceance Creek downstream from Piceance Creek below Ryan Gulch at site 15.

Boron and lithium concentrations were greatest in Yellow Creek basin near the mouth of Yellow Creek at site 26. The high concentration ranges for boron (200 to 960 μg/L) and lithium (130 to 170 μg/L) at this site were similar to those observed at the mouth of Piceance Creek (site 18) and resulted from ground-water discharge to Yellow Creek upstream of site 26.

Concentrations of trace constituents in Yellow Creek basin when compared with similar data from Piceance Creek basin show that concentration ranges generally were similar for arsenic, boron, cadmium, chronium, copper, and lead. Concentrations of barium, iron, manganese, mercury, and zinc were less in the perennial streams of Yellow Creek basin than in Piceance Creek basin; lithium, molybdenum, selenium, and strontium concentrations were greater. Strontium concentrations tended to be higher (greater than 4,000 ug/L) in samples having high concentrations (greater than 350 mg/L) of sulfate; the two constituents may have a common mineral assemblage. Mercury was frequently detected in excess of 0.1 μg/L in Black Sulphur Creek at site 14.

High counts from radioactive substances were detected in association with high concentrations of suspended matter at many of the sampling sites in Piceance and Yellow Creek basins. Activity counts were greater in Piceance Creek basin than in Yellow Creek basin, but uranium concentrations generally were 1 to 2 μg/L greater in Yellow Creek basin. The specific radionuclides responsible for the radioactive activities were not identified.

One or more of the insecticides DDD, DDE, DDT, dieldrin, and diazinon were detected at concentrations as great as 1.5 μg/kg in many of the samples of bed material in Piceance Creek or its perennial tributaries. Concentrations of DDE and chlordane also were detected between 0.1 and 0.2 μg/kg in the bed material at the Corral Gulch sites 20, 24, and 25. These insecticides probably were residuals from agricultural or insect control activities. Herbicides were not detected at any sites in Piceance Creek or Yellow Creek basins.

Discharges to Piceance Creek and Corral Gulch resulting from activities of energy-resource development occurred during the study. Apparent impacts from these discharges on the chemistry of streams in Piceance Basin included increases in concentrations of the major ions, sodium, bicarbonate, fluoride, and to a lesser degree sulfate, and an increase in concentrations of the trace constituents, arsenic, boron, lithium, and strontium.

SELECTED REFERENCES

Coffin, D.L., Welder, F.A., and Glanzman, R.K., 1971, Geohydrology of the Piceance Creek structural basin between the White and Colorado Rivers, northwestern Colorado: U.S. Geological Survey Hydrologic Investigations Atlas HA-370.

Colorado Department of Health, 1978, Water Quality Standards for Colorado: Denver, Water Quality Control Division, 47 p.

Covay, K.J., Stranathan, H.E., and Tobin, R.L., 1984, Selected biological characteristics of streams in the Piceance Creek basin, northwestern Colorado, water years 1977-81: U.S. Geological Survey Water-Resources Investigations 84-4138, (in press).

Dean, W.E., Ringrose, C.D., and Klusman, R.W., 1979, Geochemical variation in soils in the Piceance Creek basin, western Colorado: U.S. Geological Survey Bulletin 1479.

Donnell, J.R., 1961, Tertiary geology and oil-shale resources of the Piceance Creek basin between the Colorado and White Rivers, northwestern Colorado: U.S. Geological Survey Bulletin 1082-L, p. 835-891.

Durfor, C.N., and Becker, Edith, 1964, Public water supplies of the 100 largest cities in the United States, 1962: U.S. Geological Water-Supply Paper 1812, 364 p.

Forstner, Ulrich, and Wittmann, G.T.W., 1979, Metal pollution in the aquatic environment: New York, Springer-Verlag, 486 p.

Frickel, D.G., Shown, L.M., and Patton, P.C., 1975, An evaluation of hillslope and channel erosion related to oil-shale development in the Piceance basin, northwestern Colorado: Colorado Water Resources Circular 30, 37 p.

Goerlitz, D.F. and Brown, Eugene, 1972, Methods for analysis of organic substances in water: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter A3, 626 p.

Greeson, P.E., Ehlke, T.A., Irwin, G.A., Lium, B.W., and Slack, K.V., 1977, Methods for collection and analysis of aquatic biological and microbiological samples: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter A4, 332 p.

Hem, J.D., 1970, Study and interpretation of the chemical characteristics of natural water (2d ed.): U.S. Geological Survey Water-Supply Paper 1473, 363 p.

Kircher, J.E., and Von Guerard, Paul, 1982, Evaluation of sediment yields and sediment data collection network in the Piceance basin, northwestern Colorado: U.S. Geological Survey Water-Resources Investigations 82-4046, 25 p.

Milton, Charles, 1977, Mineralogy of the Green River Formation: The Mineralogical Record, v. 8, no. 5, September-October 1977, p. 368-378.

Piper, A.M., Garrett, A.A., and others, 1953, Native and contaminated ground waters in the Long Beach-Santa Ana area, California: U.S. Geological Survey Water-Supply Paper 1136, 320 p.

Robson, S.G., and Saulnier, G.J., Jr., 1981, Hydrogeochemistry and simulated solute transport, Piceance basin, northwestern Colorado: U.S. Geological Survey Professional Paper 1196, 65 p.

SAS Institute, 1979, SAS Users Guide: SAS Institute, Inc., 494 p.

Saulnier, G.J., Jr., 1978, Genesis of the saline waters of the Green River Formation, Piceance basin, northwestern Colorado: Reno, Nevada University, unpublished Ph.D. dissertation, 120 p.

Searcy, J.K., 1959, Flow-duration curves: U.S. Geological Survey Water-Supply Paper 1542-A, Manual of hydrology: Part 2. Low-flow techniques, 33 p.
Skougstad, M.W., Fishman, M.J., Friedman, L.C., Erdmann, D.E., and Duncan, S.S., eds., 1979, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter A2, 626 p.
Stumm, Werner, and Morgan, J.J., 1970, Aquatic Chemistry, New York, John Wiley and Sons, Inc., 583 p.
Taylor, O. James, 1982, Three-dimensional mathematical model for simulating the hydrologic system in the Piceance basin, Colorado: U.S. Geological Survey Water-Resources Investigations 82-637, 35 p.
Thatcher, L.L., Janzer, V.J., and Edwards, K.W., 1977, Methods for determination of radioactive substances in water and fluvial sediment: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter A5, 95 p.
Thornbury, W.E., 1965, Regional Geomorphology of the United States, New York, John Wiley and Sons, Inc., 609 p.
U.S. Geological Survey, 1975, Water resources data for Colorado, Water Year 1974, Pt.1--Streamflow, Pt.2--Quality of water: Available from U.S. Department of Commerce, National Technical Information Service, Springfield, Va., as PB 287-726 and PB 287-727.
_____1976, 1977, Water resources data for Colorado, Water years, 1975 and 1977, Pt. 2--Colorado River basin: Available from U.S. Department of Commerce, National Technical Information Service, Springfield, Va., as PB 275-623 and PB 278-700.
_____1978-1982, Water resources data for Colorado, Water years, 1977-1981, v.3, Dolores River basin, Green River basin, San Juan basin: Available from U.S. Department of Commerce, National Technical Information Service, Springfield, Va., as PB 80-119969, PB 80-217979, PB 82-202405, and PB 83-124446.
Weeks, J.B., Leavesley, G.H., Welder, F.A., and Saulnier, G.J., Jr., 1974, Simulated effects of oil-shale development on the hydrology of Piceance basin, Colorado: U.S. Geological Survey Professional Paper 908, 84 p.
Welder, F.A., and Saulnier, G.J., Jr., 1978, Geohydrologic data from twenty-four test holes drilled in the Piceance basin, Rio Blanco County, Colorado, 1975-76: U.S. Geological Survey Open-File Report 78-734, 132 p.
Yen, T.F., and Chilingarian, G.V., eds, 1976, Oil Shale, Amsterdam, Elsevier Scientific Publishing Company, 292 p.

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