Sediment Transport and Water-Quality Characteristics and Loads, White River, Northwestern Colorado, Water Years 1975-88

by R.L. Tobin

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BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

Robert M. Hirsch, Acting Director

For additional information write to:

District Chief
U.S. Geological Survey
Box 25046, MS 415
Denver Federal Center
Denver, CO 80225

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
acre-foot (acre-ft)	1,233	cubic meter
acre-foot per square mile (acre-ft/mi^2)	476.1	cubic meter per square kilometer
cubic foot per second (ft^3/s)	0.028317	cubic meter per second
foot (ft)	0.3048	meter
inch (in.)	25.4	millimeter (mm)
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
ton	0.9072	metric ton (or megagram)
ton per acre-foot (ton/acre-ft)	0.0007357	megagram per cubic meter
ton per day (ton/d)	0.9072	metric ton (or megagram) per day
ton per square mile (ton/mi^2)	0.3503	ton per square kilometer

Temperature in degree Celsius (°C) can be converted to degree Fahrenheit (°F), by use of the following formula:

$$°F = 1.8°C + 32.$$

The following terms and abbreviations also are used in this report:

gram (g)
microgram per liter (µg/L)
microsiemens per centimeter at 25 degrees Celsius (µS/cm)
milligram per liter (mg/L)

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Abstract

Streamflow, sediment, and water-quality data for water years 1975-88 were compiled, analyzed, and compared for six streamflow-gaging stations and a secondary data site on the White River in northwestern Colorado. Data from two tributary streamflow-gaging stations and a discontinued streamflow-gaging station on the main stem were used to generate estimates of annual data for years of no data at two downstream sites. Annual loads of suspended sediment and dissolved solids were determined from regression estimates of daily loads. Onsite measurements of water quality were correlated with stream discharge, and concentrations of major ions, hardness, and dissolved solids were correlated with values of specific conductance. Concentration ranges of nutrients and trace constituents were determined.

Most stream discharge in the White River occurred during May and June from melted snowpack in the eastern part of the basin. The combined annual streamflow of the North Fork and South Fork accounted for about 78 percent of the total stream discharge in the White River. Annual stream discharge in the main stem ranged from about 200,000 acre-feet at most sites to about 1 million acre-feet at the most downstream site. Average annual stream discharge at the most downstream site was about 577,000 acre-feet.

Bedload in 24 of 25 measurements at 5 sites was 3.3 percent or less of the total sediment load; bedload was not considered substantial in the estimates of annual sediment loads. Annual suspended-sediment loads ranged from about 2,100 tons in the North Fork and South Fork to about 2 million tons at the most downstream site. Average annual suspended-sediment loads ranged from about 11,000 tons in the North Fork and South Fork to about 705,000 tons at the most downstream site. Vegetation cover and resistant strata probably decreased sediment transport from the basin upstream from the site downstream from Meeker.

The average size composition of suspended sediment in 27 samples collected for full-size analysis was 30 percent sand, 45 percent silt, and 25 percent clay. Sand percentage ranged from 2 to 64 percent in 174 samples collected for concentrations of suspended sediment. Annual capacity losses from sediment retention in a hypothetical 50,000 acre-foot reservoir constructed on the White River could range from less than 0.01 percent in the North Fork and South Fork to about 2.5 percent near the downstream sites. Estimates of volume displacement and percent capacity loss for a range of reservoir sizes were determined.

Maximum water temperatures in summer generally ranged from less than 20 degrees Celsius upstream from Meeker to 20 to 25 degrees Celsius downstream from Meeker. Specific conductance generally ranged from 200 to 400 microsiemens per centimeter in the North Fork and South Fork to 300 to 1,000 microsiemens per centimeter at the downstream sites. Values of specific conductance decreased as stream discharge increased.

Generally, values of pH at all sites ranged from 7.6 to 8.8, but the range generally decreased from 8.0 to 8.5 in high streamflow. The chemical buffering capacity in streamflow to resist possible changes in pH from biological activities was greatest at the downstream sites. Concentrations of dissolved oxygen were greater than 6.0 milligrams per liter at all sites. Biological activities during daytime probably caused values of dissolved oxygen to exceed 120-percent saturation.

Concentrations of dissolved solids generally ranged from about 100 milligrams per liter in the North Fork and South Fork to 630 milligrams per liter at the most downstream site. In low streamflow, composition of dissolved solids was mostly calcium, bicarbonate, and (or) sulfate upstream from the site downstream from Meeker, and mostly calcium, sodium, sulfate, and bicarbonate at the two most downstream sites. Calcium and bicarbonate were the principal constituents at all sites in the high streamflow during snowmelt runoff.

Annual loads of dissolved solids ranged from about 21,100 tons in the South Fork to about 480,000 tons at the most downstream site. Total solids transported in the White River were mostly as dissolved solids upstream from the site downstream from Meeker and mostly as suspended sediment at the two downstream sites.

Concentrations of ammonia as nitrogen in 46 of 51 samples at all sites were less than 0.05 milligram per

liter. Nitrite plus nitrate as nitrogen ranged from less than 0.1 milligram per liter at all sites to 0.53 milligram per liter at the most downstream site. Phosphorus concentrations in 45 of 51 samples at all sites were equal to or less than 0.03 milligram per liter. Periodic increases in concentrations of nutrients at the two downstream sites were attributed to intermittent runoff from agricultural lands.

Concentration ranges for 22 trace constituents in the White River were determined. Concentrations of 15 trace constituents commonly were detected, and concentrations of 11 constituents generally were greatest downstream from Meeker. Suspended sediment could be an important source or transportation medium for eight trace constituents.

The White River is an important and renewable source of good quality water in northwestern Colorado. Streamflow that originates as snowmelt in the North Fork and South Fork Basins dilutes and transports large concentrations of suspended sediment and dissolved solids that enter the White River in the central part of the basin. Some decrease in water quality occurs downstream from Meeker.

INTRODUCTION

The White River is a principal river in northwestern Colorado (fig. 1) and an important source of water in the Upper Colorado River Basin. Historically, water use and diversion within the White River Basin have been for agricultural and domestic needs. Constraints on water use generally were limited to years when basin runoff was small. However, during the national energy crisis in the 1970's and early 1980's, projected water needs in support of proposed oil-shale projects in the semiarid Piceance Basin caused an increase in filings for water diversions from the White River. The potential losses of water from the White River from additional diversions and the increases in water-use demands in the Lower Colorado River Basin prompted concerns that the White River would become an overallocated river and that water shortages would be common.

To meet projected local and downstream water needs, water managers reviewed and implemented plans to manage and store basin runoff. Kenney Reservoir, with a storage capacity of 13,800 acre-ft, was completed on the White River about 8 mi upstream from Rangely (fig. 1) in late 1984. Several proposals for additional main-stem impoundments presently (1988) are being studied. Decisions related to the optimal location of each impoundment and the final approval of each proposal will require an understanding of the hydrologic characteristics of the basin.

Although some hydrologic data essential for effective water management of the White River are available, comprehensive data collections and data analyses that describe and quantify sediment and water-quality characteristics with variations in stream discharge are incomplete. To address this need, the U.S. Geological Survey entered into a cooperative study in 1986 with the Yellow-Jacket Water Conservancy District to evaluate sediment and dissolved-solids transport and water-quality characteristics for the White River in northwestern Colorado. Water Users Association No. 1, Rio Blanco County, and the Colorado River Water Conservation District provided some additional support for the study.

Purpose and Scope

This report presents an evaluation of selected hydrologic data for the White River collected during water years 1975-88. Specifically, the report:

1. Quantifies annual sediment loads and defines sediment-size characteristics that occurred at selected streamflow-gaging stations (hereinafter referred to as sites) on the White River. The report relates changes in sediment characteristics in the White River with differences in basin hydrology and physiography and provides estimates of volume displacement and capacity loss in reservoirs from sediment retention.
2. Quantifies dissolved-solids loads and describes changes in water-quality characteristics that occurred at selected sites on the White River. Water-quality changes are correlated with variations in stream discharge and specific conductance, and differences in water quality are related to differences in basin physiography.

Approach

Water years 1975-88 (from October 1, 1974, to September 30, 1988) were selected for study because streamflow during the 14 years ranged from record highs to record lows, and the hydrologic conditions generally were representative of long-term hydrologic conditions for the basin. Periodic sediment and water-quality sampling also were begun in the mid-1970's at several sites on the White River and on the North Fork

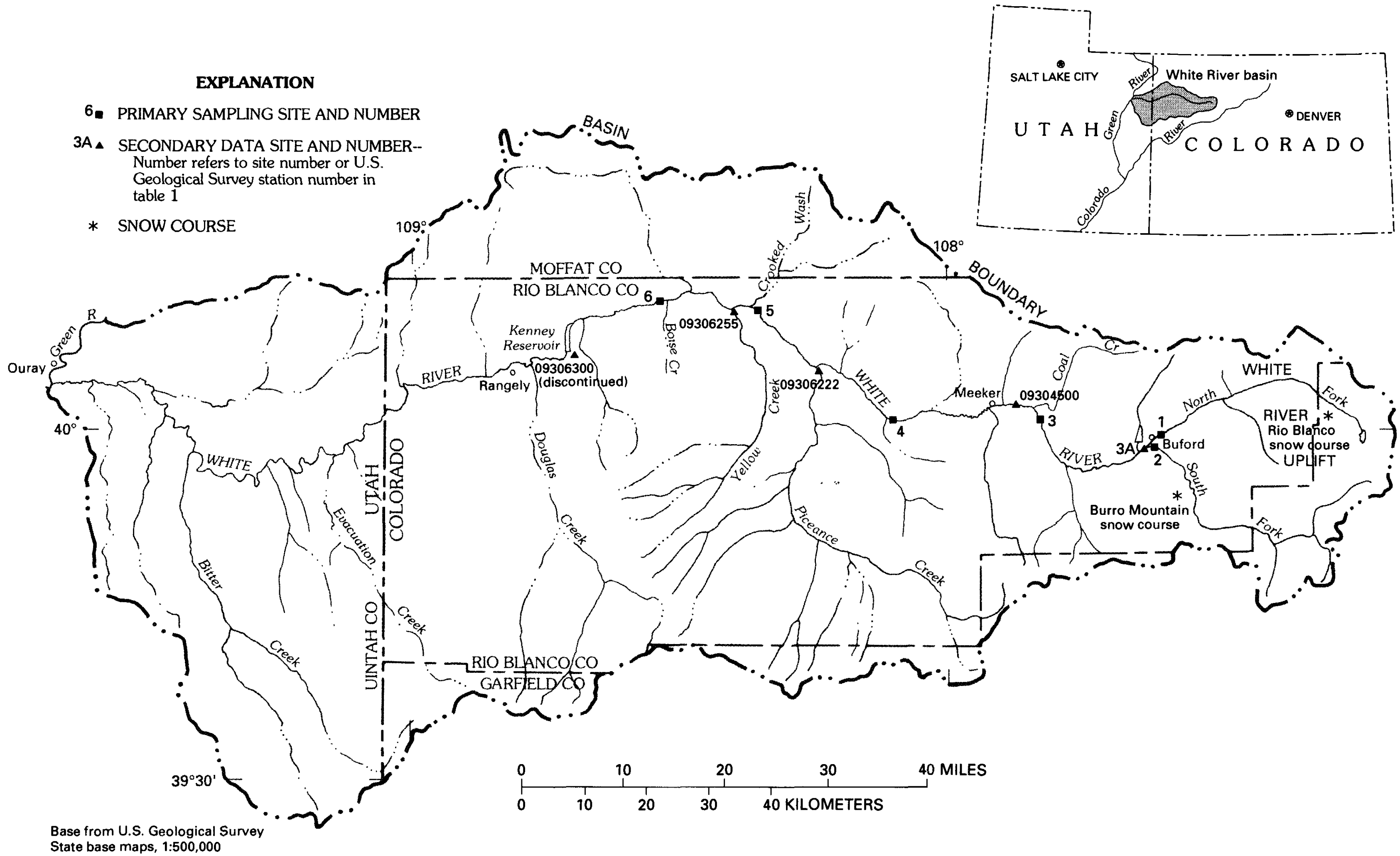

Figure 1. Location of the White River Basin and primary sampling and secondary data sites.

and South Fork of the White River (fig. 1), the principal headwater tributaries. Additional sediment and water-quality sampling was done for a range of streamflow during water years 1987-88.

Six streamflow-gaging stations were selected as primary sampling sites (fig. 1 and table 1) on the basis of location and availability of data. To facilitate data comparisons on the main stem of the White River, a secondary data site (site 3A) was established for data summaries at the confluence of the North Fork (site 1) and South Fork (site 2) (fig. 1 and table 1). All data for streamflow and suspended-sediment and dissolved-solids loads reported for site 3A were calculated as the combined daily or annual values of sites 1 and 2. In addition, hydrologic records were obtained at other streamflow-gaging stations (hereinafter referred to as secondary data sites or stations). Streamflow records [1910 to present (1988)] at station 09304500, about 2.5 mi east of Meeker, were used to compare streamflow during water years 1975-88 with long-term streamflow in the White River. Streamflow and water-quality records at stations 09306222 and 09306255 in Piceance Basin and at the discontinued station 09306300, about 5 mi east of Rangely (fig. 1 and table 1), also were used to verify or support data for sites 5 and 6.

Available hydrologic data for water years 1975-88 were retrieved from the U.S. Geological Survey WATSTORE (Hutchison, 1975) data base into minicomputers in Denver, Colo. The retrieved data were transferred to microcomputers where the data were compiled and analyzed by using data-base management and spreadsheet software. Most data used in this report also were published in the annual reports of the U.S. Geological Survey (1976-89).

Study objectives necessitated periodic collection of sediment and water-quality data at sites 1-6 during water years 1987-88 to enhance the data base. About 12 samples per year for suspended sediment and 4 samples per year for water-quality analyses were collected at each site to define sediment and water-quality characteristics for a range of streamflow. In addition, bedload was measured seven times at sites 1-4 during water years 1987-88 to supplement the bedload data base (water years 1984-88) for site 6. Depth-integrated techniques were used to collect suspended-sediment samples from equal stream-width increments, and a Helley-Smith sampler was used to collect bedload samples. Sediment-collection techniques and laboratory analyses used in this study are summarized in Guy (1969), Guy and Norman (1970), and Emmett (1980).

Water-quality measurements of temperature, specific conductance, pH, and dissolved oxygen were made onsite. Water samples were analyzed at the U.S. Geological Survey Central Laboratory in Denver, Colo., for major ions, nutrients, and trace constituents. All samples for laboratory analyses were collected, preserved, and analyzed in accordance with accepted procedures of the U.S. Geological Survey (Brown and others, 1970; Goerlitz and Brown, 1972; Fishman and Friedman, 1989).

Table 1. Site information

[mi^2, square miles; --, not available]

Site number from figure 1	U.S. Geological Survey station number	Name	Drainage area (mi^2)
		PRIMARY SAMPLING SITES	
1	09303000	North Fork White River at Buford	260
2	09304000	South Fork White River at Buford	177
3	09304200	White River above Coal Creek near Meeker	648
4	09304800	White River below Meeker	1,024
5	09306224	White River above Crooked Wash near White River City	1,821
6	09306290	White River below Boise Creek near Rangely	2,530
		SECONDARY DATA SITES	
3A	--	White River at confluence of North Fork and South Fork	437
--	09304500	White River near Meeker	755
--	09306222	Piceance Creek at White River	652
--	09306255	Yellow Creek near White River	262
--	09306300	White River above Rangely (discontinued)	2,773

Basin Characteristics

The White River Basin in northwestern Colorado includes most of Rio Blanco County and parts of Moffat and Garfield Counties (fig. 1). The principal structural elements that affect the direction and extent of streamflow in the basin (figs. 1 and 2) are as follows:

1. The White River uplift. A regional uplift that raised the eastern third of the basin to elevations ranging from 6,000 to 12,000 ft. Streams flow mostly north and west from the uplift.
2. The Grand Hogback monocline. The Grand Hogback is in the east-central part of the basin and is a north-south trending monoclinic ridge that developed during the White River uplift. The ridge is characterized by erosion-resistant strata that dip steeply to the west. Most surface runoff from the eastern third of the basin flows west via the White River through an erosional cut in the Grand Hogback 2 mi west of Meeker.
3. The Piceance structural basin. The Piceance Basin is the principal geologic structure in the west-central part of the White River Basin. Sedimentary strata in the basin are rich in oil shale and alkaline minerals. Stream courses are controlled by fracture patterns; most streams in the Piceance Basin flow north or northeast.
4. The Douglas Creek arch. The arch is a regional anticline near the western border of Colorado. The axis of the arch trends north-south, and surface runoff near the arch flows east and north into the White River or west into Utah.

In addition, smaller structures such as the Meeker dome, 3 mi east of Meeker, locally affect hydrologic patterns.

Surface geology in the White River Basin (fig. 2) is mostly sedimentary rocks ranging in age from the Paleozoic Era to the Cenozoic Era. Paleozoic and Mesozoic Era sedimentary rocks are most common in the eastern third of the basin; Mesozoic and Cenozoic Era sedimentary rocks dominate in the northern, central, and western parts of the basin. During the last half of the Cenozoic Era, extrusives of mostly basaltic composition intermittently covered exposed rocks along the crest of the White River uplift. These volcanics are still evident as resistant rock layers that cap older strata in the eastern parts of the basin. Other resistant rocks in this area are from the Paleozoic Era and the Triassic, Jurassic, and Cretaceous Periods. Cretaceous and Tertiary shales and siltstones are common in the central and western part of the basin and are less resistant to erosion than the rocks of the White River uplift.

The White River originates in the high mountain elevations of the White River uplift in eastern Rio Blanco and Garfield Counties. The White River flows from an alpine climate westward through transitional climates near Meeker into a semiarid climate in western Rio Blanco County. Tributary streams to the White River east of Meeker are mostly perennial or intermittent. Except for Piceance, Yellow, and Douglas Creeks, tributary streams west of Meeker are mostly ephemeral. About 14 mi west of Rangely, the White River enters Utah and subsequently is tributary to the Green River. The drainage area of the White River at the Colorado-Utah State line is 3,680 mi^2. Drainage areas for the White River at sites 1-6 are listed in table 1.

Natural vegetation cover in the basin at elevations generally greater than 7,000 ft primarily consists of conifer and aspen forests; pinon pines, junipers, mixed grasslands, and sagebrush predominate at elevations generally less than 7,000 ft. The conifer and aspen forests are common in the eastern parts of the basin and the high elevations along the rim of the Piceance Basin. Pinon pines, junipers, mixed grassland, and sagebrush are common in the central parts of the basin; sagebrush, sparse growths of grasses, pinon pines, and juniper are typical in the western parts of the basin. Irrigated and dry-farm crops of grains, mixed grasses, and alfalfa hay are grown in the central basin and along stream valleys throughout much of the White River Basin. Ranching and agriculture, recreation, and energy-resource mining are the primary land uses in the basin. A general discussion of the White River Basin is presented in Boyle and others (1984).

Surface-Water Hydrology

Average annual precipitation in the White River Basin ranges from 9 in. in the west to 22 in. in the eastern parts of the basin (National Climatic Data Center, 1982). The principal source of water in the White River originates from snowpack that accumulates in the mountainous areas in the eastern parts of the basin. Streamflow patterns for water years 1975-88 for site 4 (fig. 3) generally are representative of streamflow patterns for sites 1-6. Peak flows and most stream discharge occur during the months of May and June (fig. 3) when runoff from melting snowpack is at a maximum. Occasional intense thunderstorms may temporarily increase flow in the White River during

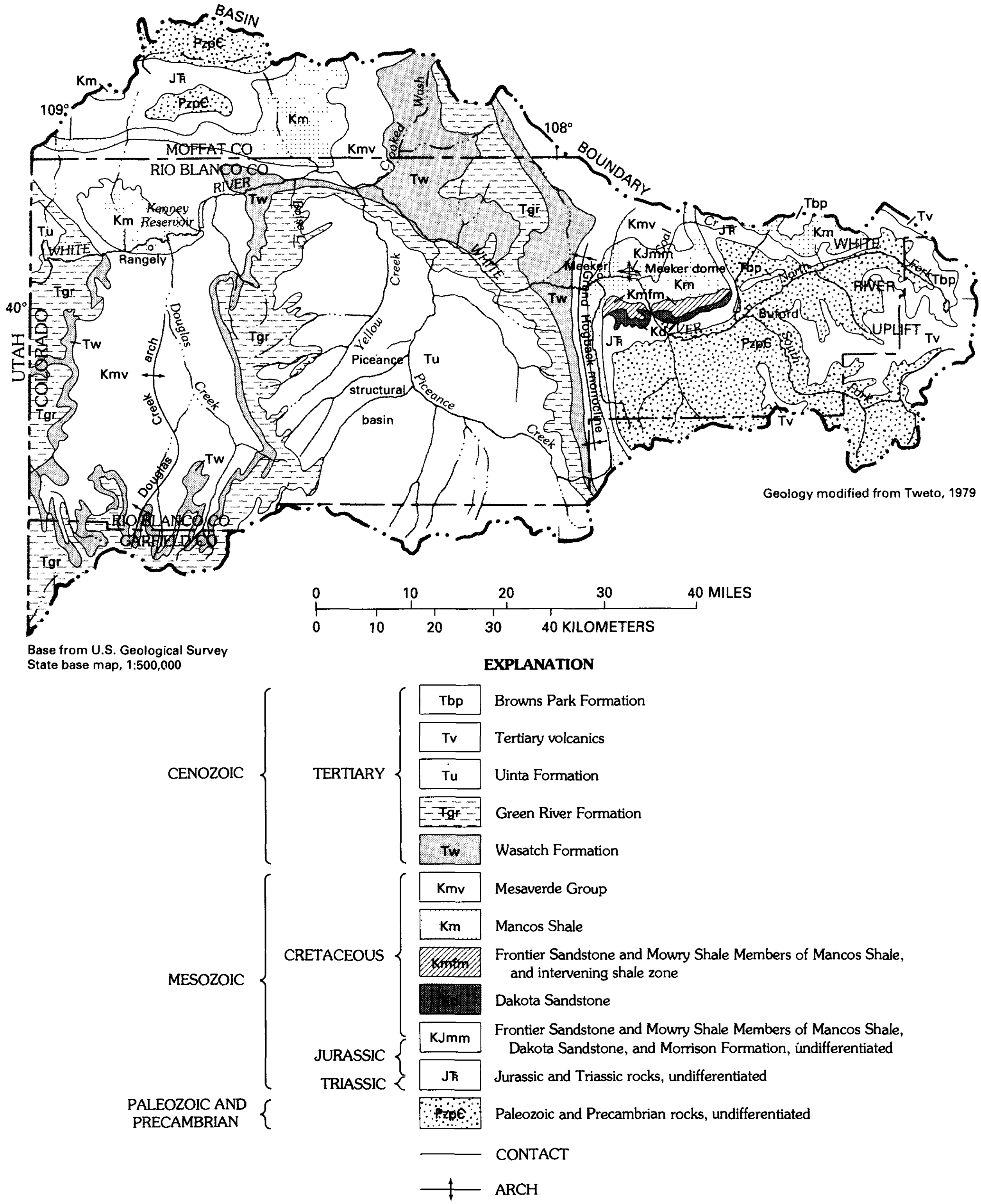

Figure 2. Generalized structure and bedrock geology (modified from Tweto, 1979).

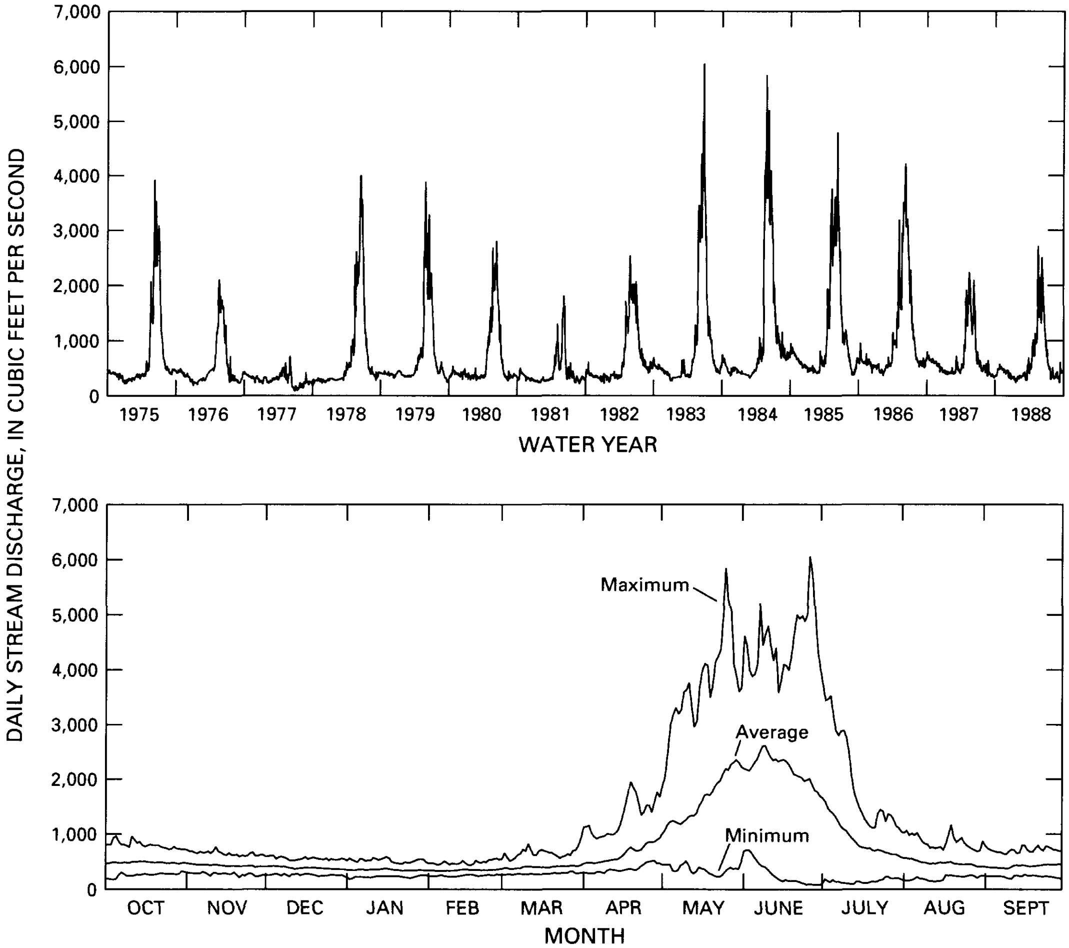

Figure 3. Daily stream discharge and maximum, average, and minimum daily stream discharge at site 4, water years 1975-88.

summer, but runoff contributions to the annual streamflow of the White River directly from rainfall generally are small.

Annual stream-discharge data in acre-feet for water years 1975-88 at sites 1-4 were available, but annual stream-discharge data for sites 5 and 6 in the lower White River were available only for water years 1983-88. To facilitate comparisons of annual data between all sites for 1975-88, estimates of annual stream discharge at sites 5 and 6 for water years 1975-82 were needed.

Because most tributary streams to the White River downstream from site 4 are ephemeral, it was assumed that during years of moderate and low runoff, the sum of the annual runoff (excluding small quantities of streamflow depletions for irrigation) measured at site 4 and station 09306222 would closely approximate the annual stream discharge at site 5. Similarly, the sum of the annual runoff at site 4 and stations 09306222 and 09306255 would reasonably approximate the annual stream discharge at site 6. Annual stream discharge at site 5 was calculated for water years 1975-82 as the sum of the annual discharge from site 4 and station 09306222. Values of calculated data for the study period (water years 1975-88) and measured annual discharge (water years 1983-88) at site 5 are correlated with annual stream discharge at site 4 in figure 4. A similar computation that also included annual stream discharge from station 09306255 was made for site 6 for water years 1975-82 (station 09306255 was discontinued for several years after water year 1982). The calculated annual stream discharge (water years 1975-82) and measured annual stream discharge (water years 1983-88) at site 6 are correlated with annual stream discharge at site 4 in figure 4. A regression was made between data sets of calculated and measured annual stream discharge at sites 5 and 6 and annual stream discharge at site 4. By using standard analysis of covariance techniques, no differences between regressions were measured between the calculated and measured values at each site at the 0.05 level of significance.

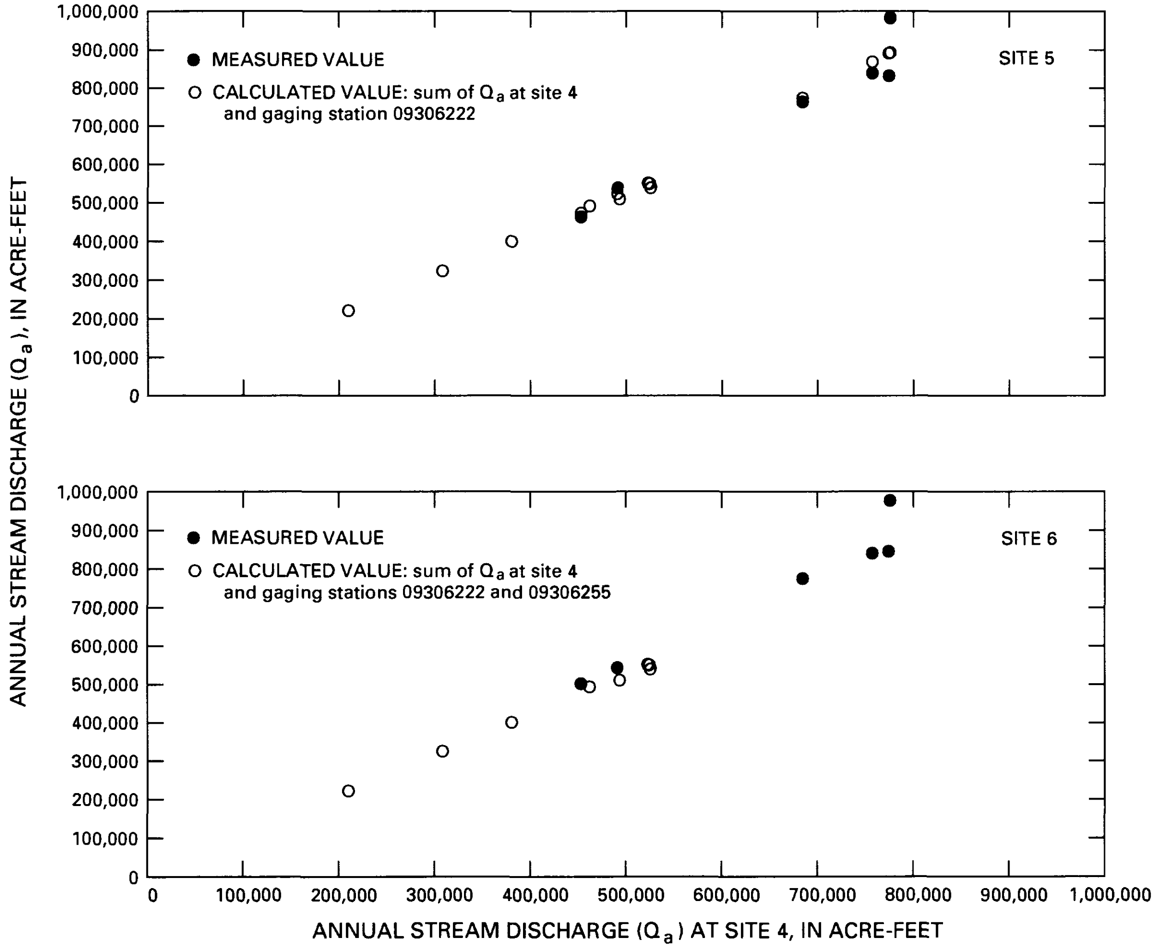

Figure 4. Correlation of calculated (water years 1975-88) and measured (water years 1983-88) annual stream discharge at site 5 and calculated (water years 1975-82) and measured (water years 1983-88) annual stream discharge at site 6 with measured annual stream discharge at site 4.

Statistical summaries for annual stream discharge at sites 1-6 and for the combined stream discharges of sites 1 and 2 (site 3A) are shown in figure 5; discharge data for sites 1-6 and stations 09306222, 09306255, and 09306300 are listed in table 2. The combined discharges (site 3A) of the North Fork (site 1) and South Fork (site 2) accounted for about 78 percent of the stream discharge of the White River upstream from site 6. The relation of annual stream-discharge contributions from subbasins (defined as the drainage area between sites) to annual stream discharge in the White River also are shown in figure 5. Stream-discharge losses that occurred between site 3A and site 3 were caused by streamflow diversions upstream from site 3 for irrigation of croplands in the Meeker area. Undetermined quantities of irrigation return flow contributed, in part, to the stream discharge measured at site 4.

Annual streamflow contributions to the White River from the semiarid tributary basins between sites 4 and 6 were small compared with the combined streamflows of the North Fork and South Fork Basins. An exception to the pattern occurred in 1984 when about 200,000 acre-ft of water entered the White River downstream from site 4 from Piceance Basin and other semiarid basins. The large runoff was a combination of low-elevation snowmelt and a regional spring rainstorm.

Annual stream discharge in most of the main stem of the White River ranged from about 200,000 acre-ft at sites 3A, 4, 5, and 6 during years of small runoff to almost 1 million acre-ft at sites 5 and 6 during years of large runoff. The average annual stream discharge at site 6 for water years 1975-88 was about 577,000 acre-ft. Record maximum and minimum daily stream discharges occurred in the White River during water years 1975-88. Based on streamflow records for 78 continuous years (1910-88) at station 09304500, daily discharge at this station near Meeker ranged from 78 ft^3/s in 1977 to 6,320 ft^3/s in 1984 (U.S. Geological Survey, 1987-89).

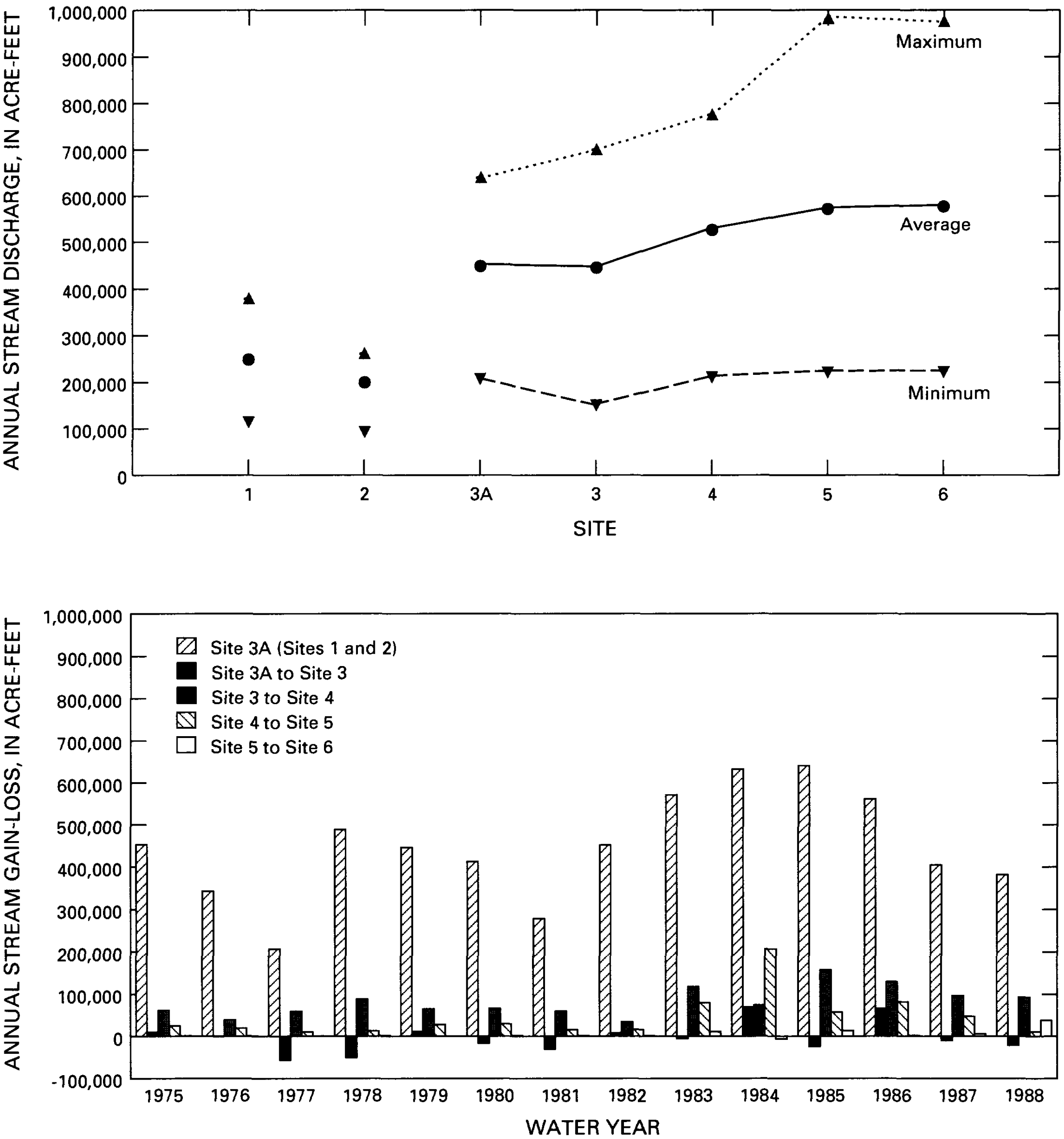

Figure 5. Average and range of annual stream discharge for the North Fork (site 1), the South Fork (site 2), and the main stem of the White River (sites 3A-6), water years 1975-88, and annual stream discharge gain-loss for segments of the White River between sites.

Flow-duration curves for station 09304500 and sites 1, 2, and 4 for water years 1975-88 are compared with the long-term (water years 1910-88) flow-duration curve for station 09304500 (fig. 6). A comparison of the short- and long-term flow-duration curves for station 09304500 indicates that high stream discharges in the White River during water years 1975-88 were slightly greater than the long-term average, and low stream discharges were slightly less than the long-term average. The convergence of the flow-duration curve for site 1 with the curves for station 09304500 and site 4 in low flows (less than 100 ft^3/s) indicates that stream discharge from the North Fork is the principal source of water in the White River during very dry periods. The decreases in daily streamflow that occur along the flow-duration curves at percentage of time values greater than 95 percent for station 09304500 and site 4 probably were caused by streamflow depletions resulting from irrigation diversions. Streamflow depletions from proposed reservoirs also would affect flow-duration values in the White River and are discussed in Kuhn and Ellis (1984).

Annual stream discharges from sites 1 and 2 for water years 1952-88 (Hutchison, 1975) were summed (site 3A), and a regression was made with period-of-record for water-content measurements of snowpack at

Table 2. Stream-discharge data for sites 1-6 and stations 09306222, 09306255, and 09306300, water years 1975-88

[ft^3/s, cubic feet per second; acre-ft, acre-feet; acre-ft/mi^2, acre-feet per square mile; --, no data; data calculations were done on unrounded data; all data rounded to standard significant figures]

Water year	SITE 1					SITE 2					SITE 3A				
	Daily discharge (ft^3/s)			Annual		Daily discharge (ft^3/s)			Annual		Daily discharge (ft^3/s)			Annual	
	Maximum	Minimum	Average	Discharge (acre-ft)	Yield (acre-ft/mi^2)	Maximum	Minimum	Average	Discharge (acre-ft)	Yield (acre-ft/mi^2)	Maximum	Minimum	Average	Discharge (acre-ft)	Yield (acre-ft/mi^2)
1975	1,430	131	343	248,300	955	1,920	83	283	204,700	1,160	--	--	626	[1]453,000	1,040
1976	768	110	245	177,600	683	1,650	88	227	164,700	931	--	--	472	[1]342,300	783
1977	394	96	157	113,400	436	585	70	129	93,200	526	--	--	285	[1]206,600	473
1978	1,470	108	348	251,700	968	2,620	76	327	236,700	1,340	--	--	675	[1]488,400	1,120
1979	1,460	150	331	239,500	921	2,200	78	285	206,600	1,170	--	--	616	[1]446,100	1,020
1980	1,220	141	309	224,600	864	1,940	73	258	187,600	1,060	--	--	568	[1]412,200	943
1981	912	124	218	158,000	608	1,120	47	166	120,500	681	--	--	385	[1]278,500	637
1982	1,050	130	342	247,700	953	1,240	76	282	204,000	1,150	--	--	624	[1]451,700	1,030
1983	2,190	133	439	317,700	1,220	2,970	90	350	253,600	1,430	--	--	789	[1]571,300	1,310
1984	3,000	155	523	379,800	1,460	2,270	108	347	252,200	1,420	--	--	871	[1]632,000	1,440
1985	2,360	193	522	378,200	1,460	2,420	120	363	262,500	1,480	--	--	885	[1]640,700	1,470
1986	1,340	180	417	301,600	1,160	2,100	117	359	259,900	1,470	--	--	776	[1]561,500	1,280
1987	990	170	304	220,300	847	1,270	120	255	184,300	1,040	--	--	559	[1]404,600	926
1988	1,390	110	296	214,600	825	1,590	80	229	166,600	941	--	--	525	[1]381,200	872
Maximum	3,000	193	523	379,800	1,460	2,970	120	363	262,500	1,480	--	--	885	640,700	1,470
Minimum	394	96	157	113,400	436	585	47	129	93,200	526	--	--	285	206,600	473
Average	1,430	138	342	248,100	954	1,850	88	276	199,800	1,130	--	--	618	447,900	1,020

Table 2. Stream-discharge data for sites 1-6 and stations 09306222, 09306255, and 09306300, water years 1975-88--Continued

Water year	SITE 3					SITE 4				
	Daily discharge (ft^3/s)			Annual		Daily discharge (ft^3/s)			Annual	
	Maximum	Minimum	Average	Discharge (acre-ft)	Yield (acre-ft/mi^2)	Maximum	Minimum	Average	Discharge (acre-ft)	Yield (acre-ft/mi^2)
1975	4,270	193	640	463,100	715	3,930	220	724	524,500	512
1976	2,500	107	471	341,600	527	2,110	180	524	380,500	372
1977	705	7	208	150,400	232	711	85	290	210,100	205
1978	3,530	54	604	437,600	675	4,010	175	726	525,800	513
1979	4,520	135	632	457,500	706	3,890	242	722	522,700	510
1980	3,020	151	545	395,800	611	2,810	266	637	462,100	451
1981	1,570	72	343	248,200	383	1,810	204	425	308,000	301
1982	2,740	202	635	459,900	710	2,550	212	682	493,600	482
1983	5,360	216	782	566,200	874	6,060	268	945	684,200	668
1984	5,260	250	966	701,400	1,080	5,850	310	1,070	775,800	758
1985	4,340	196	851	616,400	951	4,800	361	1,070	774,200	756
1986	4,030	305	867	627,500	968	4,220	355	1,050	757,000	739
1987	2,190	176	545	394,400	609	2,240	323	678	491,100	480
1988	2,540	164	496	360,000	556	2,720	230	624	453,000	442
Maximum	5,360	305	966	701,400	1,080	6,060	361	1,070	775,800	758
Minimum	705	7	208	150,400	232	711	85	290	210,100	205
Average	3,330	159	613	444,300	685	3,410	245	726	525,900	514

Table 2. Stream-discharge data for sites 1-6 and stations 09306222, 09306255, and 09306300, water years 1975-88--Continued

Water year	STATION 09306222			STATION 09306255			SITE 5				
	Daily discharge average (ft^3/s)	Annual		Daily discharge average (ft^3/s)	Annual		Daily discharge (ft^3/s)			Annual	
		Dis-charge (acre-ft)	Yield (acre-ft/mi^2)		Dis-charge (acre-ft)	Yield (acre-ft/mi^2)	Maxi-mum	Mini-mum	Aver-age	Dis-charge (acre-ft)	Yield (acre-ft/mi^2)
1975	34	24,570	39	1.58	1,140	4.4	--	--	758	[2]549,100	302
1976	27	19,570	31	1.46	1,060	4.0	--	--	551	[2]400,100	219
1977	15	10,540	17	1.28	925	3.5	--	--	305	[2]220,600	121
1978	18	12,710	20	2.26	1,640	6.3	--	--	744	[2]538,500	296
1979	39	27,920	44	1.42	1,030	3.9	--	--	761	[2]550,600	302
1980	41	29,860	47	2.85	2,070	7.9	--	--	678	[2]492,000	269
1981	22	15,820	25	1.92	1,390	5.3	--	--	447	[2]323,800	178
1982	22	15,960	25	2.25	1,630	6.2	--	--	704	[2]509,600	280
1983	90	65,170	103	--	--	--	5,600	300	1,060	764,400	420
1984	98	71,040	113	--	--	--	5,960	360	1,350	982,900	540
1985	110	79,280	126	--	--	--	4,150	380	1,150	831,800	457
1986	104	75,570	120	--	--	--	4,450	410	1,160	838,900	461
1987	50	36,330	58	--	--	--	2,520	352	743	538,200	296
1988	35	25,360	40	--	--	--	2,860	280	629	463,900	255
Maximum	110	79,280	126	2.85	2,070	7.9	5,960	410	1,350	982,900	540
Minimum	15	10,540	17	1.28	925	3.5	2,520	280	305	220,600	121
Average	50	36,400	58	1.88	1,360	5.2	4,260	347	789	571,700	314

Table 2. Stream-discharge data for sites 1-6 and stations 09306222, 09306255, and 09306300, water years 1975-88--Continued

Water year	SITE 6					STATION 09306300				
	Daily discharge (ft^3/s)			Annual		Daily discharge (ft^3/s)			Annual	
	Maximum	Minimum	Average	Discharge (acre-ft)	Yield (acre-ft/mi²)	Maximum	Minimum	Average	Discharge (acre-ft)	Yield (acre-ft/mi²)
1975	--	--	760	[3]550,200	217	4,100	290	758	549,100	198
1976	--	--	553	[3]401,100	159	2,030	274	571	414,600	150
1977	--	--	306	[3]221,600	88	687	62	312	226,000	82
1978	--	--	746	[3]540,200	214	3,740	237	718	520,100	188
1979	--	--	762	[3]551,600	218	3,440	267	754	545,700	197
1980	--	--	680	[3]494,000	195	2,780	196	686	497,000	179
1981	--	--	449	[3]325,200	129	1,810	178	449	325,300	117
1982	--	--	706	[3]511,200	202	--	--	--	--	--
1983	5,600	320	1,070	775,100	306	--	--	--	--	--
1984	6,170	390	1,340	976,700	386	--	--	--	--	--
1985	4,260	400	1,170	845,400	334	--	--	--	--	--
1986	3,980	430	1,160	841,200	332	--	--	--	--	--
1987	2,260	305	751	543,800	215	--	--	--	--	--
1988	2,740	218	692	502,100	198	--	--	--	--	--
Maximum	6,170	430	1,340	976,700	386	4,100	290	758	549,100	198
Minimum	2,260	218	306	221,600	88	687	62	312	226,000	82
Average	4,170	344	797	577,100	228	2,660	215	607	439,700	159

[1]Discharge data estimated as the sum of the annual discharges of sites 1 and 2.

[2]Discharge data estimated as the sum of the annual discharges of site 4 and station 09306222.

[3]Discharge data estimated as the sum of the annual discharges of site 4 and stations 09306222 and 09306255.

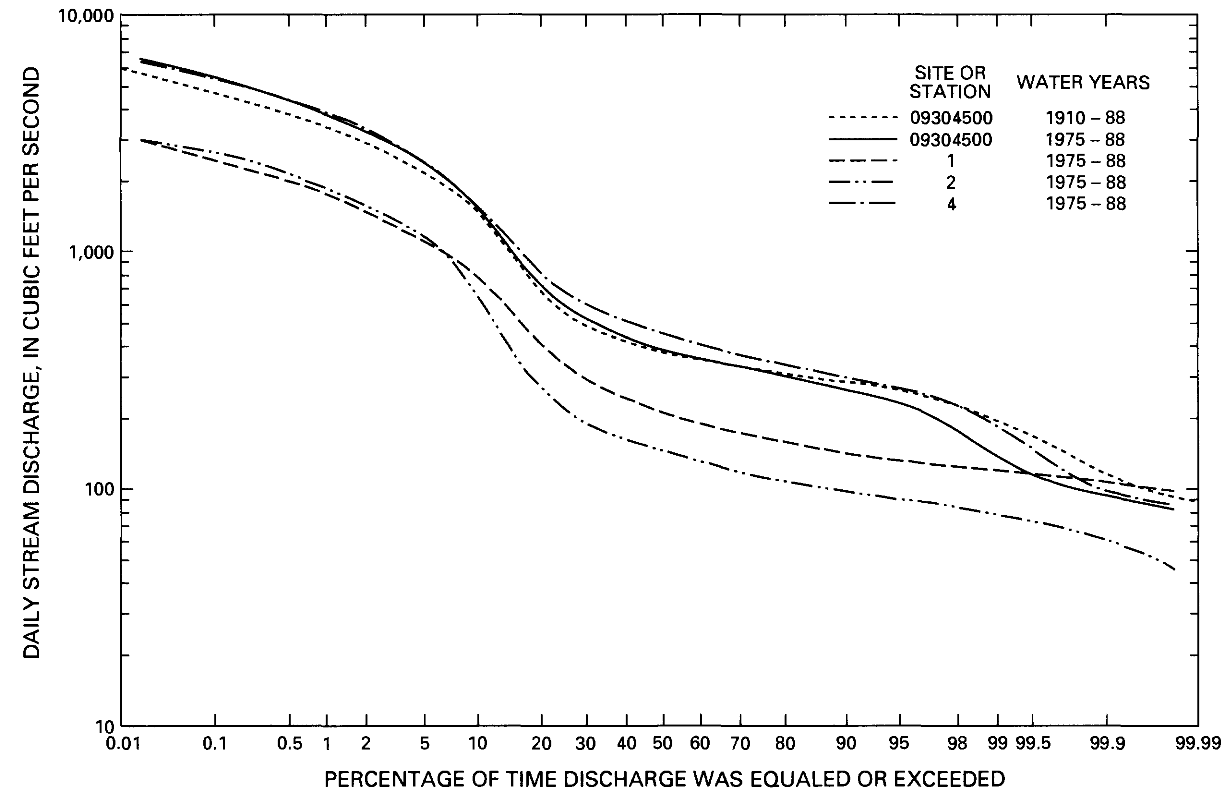

Figure 6. Flow-duration curves for selected sites on the White River.

the Burro Mountain and Rio Blanco snow courses (fig. 1). The snowpack measurements were made monthly during winter and spring by the U.S. Soil Conservation Service, Meeker, Colo. Analyses of 37 years of data for snowpacks measured in early April and early May indicated that snowpack depths generally were greater, and snowpack existed longer at the Burro Mountain site than at the Rio Blanco site. Snowpack data from the Burro Mountain snow course were used for estimating annual stream discharge. Data for site 3A and the Burro Mountain snow course are shown in figure 7. The coefficient of determination (r^2) shown in figure 7 is a widely used measure of linear correlation between two variables. Values of r^2 approach zero where variables have little or no linear correlation; values of r^2 approach 1.0 as linear correlation between variables improves. The r^2 value of 0.52 shown in figure 7 indicates a moderate correlation of streamflow to snowpack. The effect of variables such as seasonal winds and temperature, precipitation patterns, and soil moisture also can affect the runoff to the White River.

SEDIMENT TRANSPORT

Colby (1963) defines fluvial sediment as sediment that is transported by or suspended in water or that has been deposited by water. Sediment is transported in suspension (suspended-sediment load) and as particles along the streambed (bedload). The suspended-sediment load commonly consists of clay, silt, and sand that usually travel at the velocity of the stream. The sediment particles are held in suspension by the upward components of turbulent currents or by colloidal dispersion. Bedload consists of coarser sized sediment that comes from the bed and banks of the stream. Particles moving as bedload remain close to the streambed, usually within a few grain diameters for uniform sediment (Colby, 1963). The suspended-sediment load plus the bedload compose the total sediment load. Fluvial sediment generally is deposited in lakes or reservoirs, stream channels, or flood plains. Concepts of fluvial sediment are discussed in Colby (1963) and Guy (1970a).

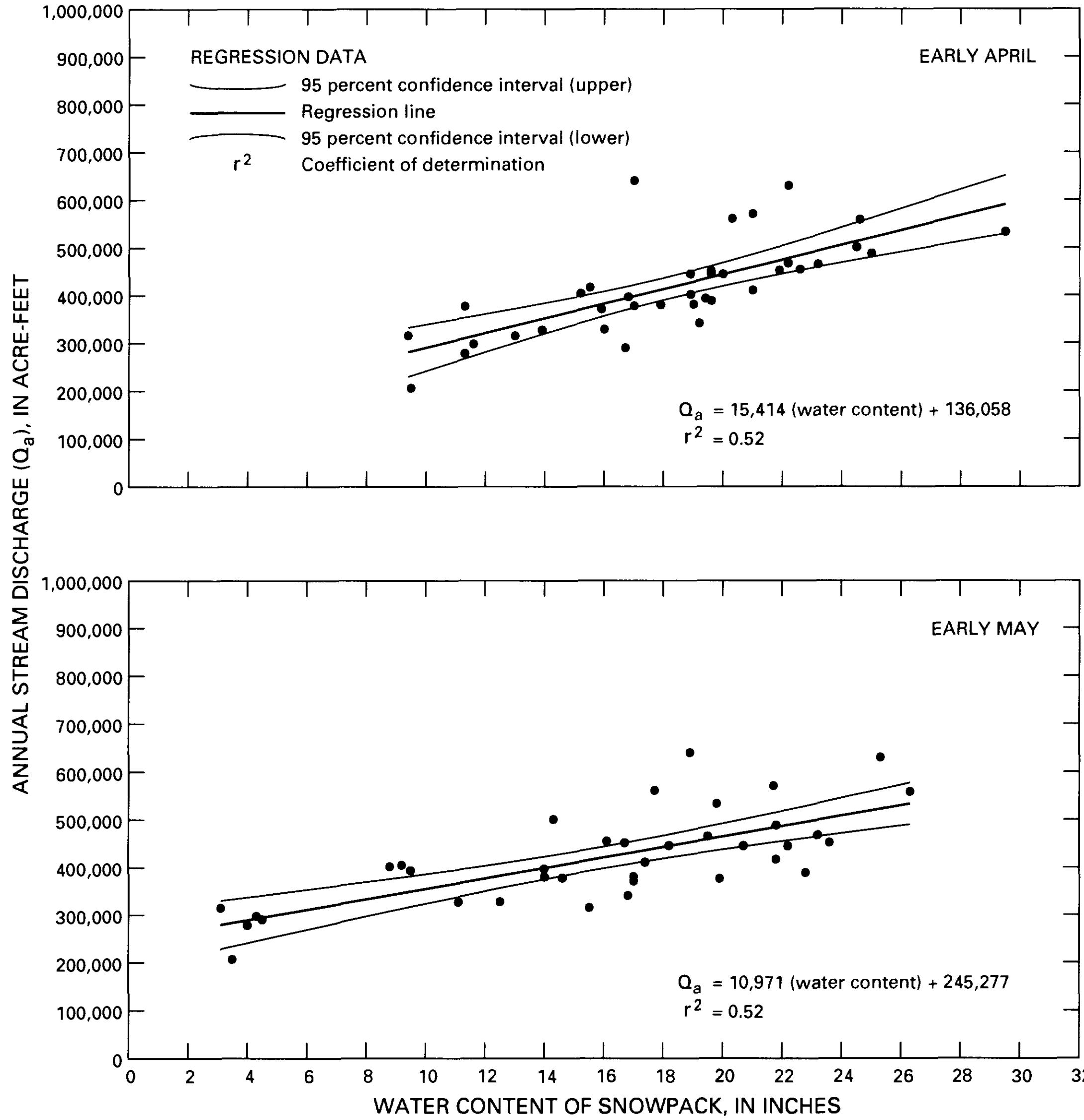

Figure 7. Relation of annual stream discharge (Q_a) in the White River at site 3A (Q_a at site 1 plus Q_a at site 2) to early April and early May measurements of snowpack at the Burrow Mountain snow course, water years 1952-88 (snowpack data from the U.S. Soil Conservation Service, written commun., 1988).

Loads

Annual loads of suspended sediment transported by the White River at sites 1-4 for water years 1975-88 and at sites 5 and 6 for water years 1983-88 were estimated from least-squares regressions that related instantaneous suspended-sediment load to stream discharge. Instantaneous suspended-sediment load (L_s), in tons per day, is a function of instantaneous stream discharge (Q), in cubic feet per second, sediment concentration (C), in milligrams per liter, and the conversion constant 0.0027. Instantaneous suspended-sediment load is calculated as follows:

$$L_s = (0.0027)QC. \quad (1)$$

One to three regressions were developed for each site. The regressions related log transformations of instantaneous suspended-sediment loads with log transformations of instantaneous stream discharge for water years 1975-88. The regression is expressed as:

$$\log L_s = a + b \log Q, \quad (2)$$

where (a) and (b) are regression coefficients.

The data were reviewed and grouped for three hydrologic events as follows: (1) Rising and peak streamflows during spring and summer from snowmelt

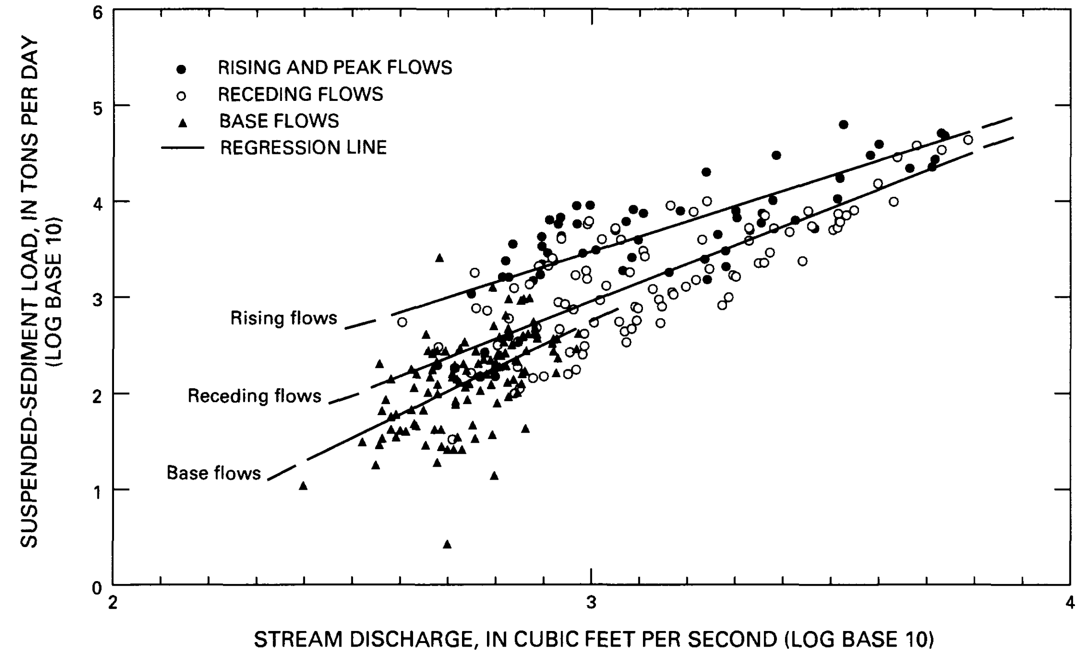

Figure 8. The relation of periodic measurements of suspended-sediment loads to stream discharge at site 6, water years 1983-88.

or storm runoff; (2) receding streamflows during spring and summer that follow peak runoff conditions; and (3) base or near constant streamflows during fall and winter. The regression-data groups for site 6 are shown in figure 8. Tests for differences at the 0.05 level of significance between data groups within each site were made by using standard analysis-of-covariance techniques. If tests indicated that data groups from the different hydrologic events at a given site were similar, the data were combined and a single regression was used for the combined hydrologic events.

The regressions used to estimate instantaneous suspended-sediment load (L_s) were assumed applicable for computing daily suspended-sediment load (L_{sd}) from daily stream discharge (Q_d) for the three hydrologic events (Porterfield, 1972). Because bias may be introduced when antilogs are taken of log-transformed data for regression analysis, a bias correction factor (C_b), as presented by Ferguson (1986) and discussed by Elliott and DeFeyter (1986), was applied to each regression. The bias correction factor for conversion from common logarithms to the general antilogarithm form is a function of the regression variance (s^2) and is expressed as:

$$C_b = e^{(2.65s^2)}, \qquad (3)$$

where e = 2.71828 and is the base for natural logarithms.

The general antilogarithm form of the regression (eq. 2) combined with the bias correction factor (eq. 3) is:

$$L_s = 10^a Q^b C_b. \qquad (4)$$

By using the assumption that

$$L_s \cong L_{sd}, \qquad (5)$$

one to three regressions were developed for each site to compute daily suspended-sediment loads for the White River. Regression coefficients used to compute daily suspended-sediment loads (L_{sd}) from daily stream discharge (Q_d) at sites 1-4 for water years 1975-88 and sites 5 and 6 for water years 1983-88 are listed in table 3. The annual suspended-sediment loads (L_{sa}) in the White River were measured as the total of daily suspended-sediment loads (L_{sd}) for each water year where L_{sd} values were determined using the regression equations in table 3.

Instantaneous bedload was measured a total of 7 times at sites 1-4 during snowmelt runoff in June 1988, and instantaneous bedload was measured 18 times at site 6 during 1984-86. The bedload samples were collected simultaneously with samples for suspended sediment at identical locations in the stream. Instantaneous bedload (L_b), in tons per day, is a function of sampled bedload weight (W_b), in grams; width of the stream (D_w), in feet; the conversion constant 0.0952;

Table 3. Regression information used to determine suspended-sediment loads in the White River at sites 1-4, water years 1975-88, sites 5 and 6, water years 1983-88, and station 09306300, water years 1975-81

[L_{sd}, daily suspended-sediment load in tons per day; Q_d, daily discharge in cubic feet per second. Hydrologic events are: (1) Rising and peak streamflows during spring and summer from snowmelt or storm runoff; (2) receding streamflows during spring and summer that follow peak runoff conditions; (3) base or near constant streamflows during fall and winter]

Site	Hydrologic event	Number of samples	Logarithm form (base 10) $\log L_{sd} = a + b \log Q_d$					Antilogarithm form $L_{sd} = 10^a Q_d^b C_b$
			Coefficients (a)	Coefficients (b)	Standard error (SE)	Variance (s^2)	Bias correction factor (C_b)	
1	1	14	-2.67	1.62	0.192	0.037	1.103	$L_{sd} = 10^{-2.67}Q_d^{1.62}1.103$
1	2,3	47	-3.04	1.65	0.267	0.071	1.207	$L_{sd} = 10^{-3.04}Q_d^{1.65}1.207$
2	1	12	-1.96	1.40	0.199	0.040	1.112	$L_{sd} = 10^{-1.96}Q_d^{1.40}1.112$
2	2,3	45	-3.17	1.68	0.378	0.143	1.461	$L_{sd} = 10^{-3.17}Q_d^{1.68}1.461$
3	1,2,3	59	-4.67	2.24	0.345	0.119	1.371	$L_{sd} = 10^{-4.67}Q_d^{2.24}1.371$
4	1	37	-1.11	1.27	0.313	0.098	1.297	$L_{sd} = 10^{-1.11}Q_d^{1.27}1.297$
4	2,3	103	-2.75	1.67	0.294	0.086	1.256	$L_{sd} = 10^{-2.75}Q_d^{1.67}1.256$
5	1	11	0.81	0.89	0.305	0.093	1.279	$L_{sd} = 10^{0.81}Q_d^{0.89}1.279$
5	2,3	21	-3.26	1.93	0.349	0.122	1.382	$L_{sd} = 10^{-3.26}Q_d^{1.93}1.382$
6	1	60	-0.98	1.47	0.352	0.124	1.389	$L_{sd} = 10^{-0.98}Q_d^{1.47}1.389$
6	2	97	-2.66	1.87	0.407	0.166	1.553	$L_{sd} = 10^{-2.66}Q_d^{1.87}1.553$
6	3	121	-4.55	2.44	0.393	0.154	1.504	$L_{sd} = 10^{-4.55}Q_d^{2.44}1.504$
09306300	1	52	0.01	1.13	0.445	0.198	1.690	$L_{sd} = 10^{0.01}Q_d^{1.13}1.690$
09306300	2	45	-1.36	1.45	0.349	0.122	1.381	$L_{sd} = 10^{-1.36}Q_d^{1.45}1.381$
09306300	3	130	-1.28	1.29	0.342	0.117	1.363	$L_{sd} = 10^{-1.28}Q_d^{1.29}1.363$

horizontal width of the sampler intake (S_w), in feet; number of verticals (N); and the time of sampling per vertical (T), in seconds. Instantaneous bedload is calculated as:

$$L_b = \frac{W_b D_w 0.0952}{S_w NT}. \quad (6)$$

Instantaneous bedload was compared with instantaneous suspended-sediment load (table 4) to determine if bedload was a substantial component of sediment transport in the White River. For a stream-discharge range of 371 to 1,580 ft^3/s, bedload in six of the seven measurements at sites 1-4 was 3.3 percent or less of the total sediment load. The bedload of 13.1 tons/d measured at site 3 on June 3, 1988, was 8.3 percent of the total sediment load. Although the quantity of bedload measured at site 3 was not large compared with the downstream bedload at site 6, the percentage bedload of the total sediment load at site 3 seems unusually large; the measurement may represent conditions of local, short-term, bedload movement. Stream discharge in the data set for site 6 (table 4) ranged from 599 to 6,090 ft^3/s. Bedload at site 6 was 1.3 percent or less of the total sediment load for all 18 measurements. Because the measured bedload in the White River generally was a small component of the total sediment load in comparison with the suspended-sediment load, it was not included in the estimates of annual sediment loads or annual capacity losses in reservoirs at sites 1-6.

Because values of daily stream discharge were unavailable at sites 5 and 6 for water years 1975-82, regressions and data comparisons were used to develop

Table 4. Bedload data for sites 1-4 and site 6, White River, water years 1984-88

[ft^3/s, cubic feet per second; mg/L, milligrams per liter; <, value less than value shown]

Date	Site	Dis-charge (ft^3/s)	Stream width (feet)	Bedload				Suspended sediment		Total sediment	
				Number of sections	Time per section (seconds)	Weight of sample (grams)	Bedload (tons/day)	Concen-tration (mg/L)	Load (tons/day)	Load (tons/day)	Percent bedload (percent)
06/27/88	1	533	50	21	60	15	0.2	11	16	16	1.3
06/02/88	2	697	65	40	60	100	1.0	20	38	39	2.6
06/27/88	2	371	65	20	60	5	0.1	4	4	4	2.5
06/03/88	3	1,450	89	40	60	931	13.1	37	145	158	8.3
06/27/88	3	600	89	20	60	13	0.4	7	11	12	3.3
06/03/88	4	1,580	90	41	60	666	9.3	82	350	359	2.6
06/28/88	4	917	90	20	60	15	0.4	29	72	72	0.6
05/01/84	6	957	132	46	60	891	16.2	1,100	2,840	2,860	0.6
05/17/84	6	4,760	115	42	60	816	14.2	2,940	37,800	37,800	<0.1
06/01/84	6	5,210	110	42	60	1,432	23.8	1,930	27,100	27,100	<0.1
06/06/84	6	5,140	110	42	60	1,455	24.2	1,620	22,500	22,500	0.1
06/08/84	6	6,090	110	42	60	3,004	49.9	2,610	42,900	43,000	0.1
06/14/84	6	3,960	110	42	60	1,926	32.0	1,420	15,200	15,200	0.2
06/29/84	6	3,300	110	42	60	1,608	26.7	679	6,050	6,080	0.4
07/13/84	6	1,760	105	40	60	1,023	17.0	410	1,950	1,970	0.9
11/30/84	6	599	135	20	60	66	2.8	152	246	249	1.1
04/23/85	6	1,890	100	20	60	907	28.8	1,980	10,100	10,100	0.3
05/29/85	6	3,760	110	40	60	2,910	50.8	1,090	11,100	11,200	0.5
06/13/85	6	3,500	110	40	60	1,298	22.6	861	8,140	8,160	0.3
04/23/86	6	1,250	103	40	60	838	13.7	1,170	3,940	3,950	0.3
05/08/86	6	2,400	109	40	60	1,629	28.2	796	5,170	5,200	0.5
06/02/86	6	3,260	108	20	60	2,062	70.6	599	5,270	5,340	1.3
06/05/86	6	3,280	109	20	60	1,735	60.0	705	6,240	6,300	1.0
06/11/86	6	3,280	108	20	60	425	14.6	835	7,380	7,390	0.2
06/11/86	6	2,290	108	20	60	490	16.8	364	2,250	2,270	0.7

estimates of annual suspended-sediment loads at sites 5 and 6 for water years 1975-82. Two regressions were determined from correlations of measured annual suspended-sediment loads at sites 5 and 6 with measured annual suspended-sediment loads at site 4 for water years 1983-88. A second pair of regressions was determined from correlations of measured annual suspended-sediment loads at sites 5 and 6 (water years 1983-88) with annual stream discharge at sites 5 and 6 (water years 1983-88). Differences between regression values and measured values generally were less than 20 percent for the first pair of regressions and generally were less than 10 percent for the second pair of regressions.

Regression estimates of annual suspended-sediment loads at site 6 were increased by 130,000 tons during water year 1978. The adjustment is based on a daily value of 132,000 tons measured at station 09306300 above Rangely on September 8, 1978. The large daily suspended-sediment load at station 09306300 occurred 1 day after an intense storm in the Yellow Creek Basin. The storm caused about 290,000 tons of sediment to discharge to the White River between sites 5 and 6 (U.S. Geological Survey, 1978-86).

Regression values from regression pairs of annual suspended-sediment loads at sites 5 and 6 for water years 1975-82 were compared with the measured annual suspended-sediment loads at site 4 and station 09306300 (table 5). Best estimates of annual suspended-sediment loads at site 5 for water years 1975-82 and at site 6 for water years 1975, 1978-79, and 1982 were obtained from the second pair of regressions (suspended-sediment loads and annual stream discharge). Regression estimates of annual suspended-sediment loads at site 6 for water years 1976-77 and 1980-81 did not compare well with measured values at site 4 and station 09306300. The regression values were for years when annual stream discharges were less than 500,000 acre-ft and generally less than the stream-discharge range used in the regressions. Thus, for water years 1976-77 and 1980-81, the annual suspended-sediment loads at site 6 were obtained by averaging the annual suspended-sediment loads determined for site 5 and the measured annual suspended-sediment loads at station 09306300. Correlation of estimated and measured values of annual suspended-sediment loads for sites 5 and 6 and measured values of annual suspended-sediment loads at site 4 and station 09306300 with annual stream discharge are shown in figure 9.

Maximum and minimum daily suspended-sediment loads and annual suspended-sediment loads for the White River for water years 1975-88 are listed in table 5; statistical summaries of annual suspended-sediment loads for sites 1-6 and for the combined loads of sites 1 and 2 (site 3A) are shown in figure 10. Annual suspended-sediment loads in the White River ranged from slightly more than 2,100 tons at sites 1 and 2 to about 2 million tons at site 6. Average annual suspended-sediment loads were least in the North Fork (site 1, about 11,500 tons) and South Forks (site 2, about 11,100 tons) and greatest at site 6 (about 705,000 tons). A comparison of annual loads of suspended sediment in the main stem of the White River indicates that sediment loads increased gradually between sites 3A and 4 and increased greatly downstream from site 4. The increases in sediment loads downstream from site 4 probably resulted from the intermittent inputs of fluvial sediment from semiarid basins and from the seasonal inputs of fluvial sediment from the perennial streams, Piceance and Yellow Creeks.

Comparison of bar graphs of annual suspended-sediment loads (fig. 10) for the river segments (river subbasins) indicates that the subbasin between sites 4 and 5 generally was the principal source of fluvial sediment during years of moderate to low streamflow. Irrigation diversions that transported unmeasured quantities of suspended sediment from the White River upstream from site 3 probably caused an underestimation of suspended-sediment loads between sites 3 and 3A. During years of high stream discharge (water years 1983-86), precipitation in the low-elevation basins was extensive, and greater quantities of sediment entered the White River between sites 5 and 6 than between sites 4 and 5. Although shales and siltstones are the most common rocks in the river subbasins between sites 3 and 6, the natural and agricultural vegetation cover is more extensive in the river subbasin between sites 3 and 4 than in the subbasins between sites 4 and 6. The vegetation cover in the subbasin between sites 3 and 4 probably decreased sediment erosion and transport compared with the downstream subbasins. In the high-elevation basins upstream from site 3, natural vegetation cover is even more extensive, and exposed rocks mostly are indurated sandstones and siltstones, which substantially decreased sediment erosion and transport.

Table 5. Suspended-sediment loads measured using the regressions in table 3 or estimated from regressions of annual suspended-sediment load and annual stream discharge for sites 1-6 and station 09306300, White River, water years 1975-88

[tons/acre-ft, tons per acre-foot; tons/mi^2, tons per square mile; --, no data; *, estimated; data calculations on unrounded data, all data rounded to standard significant figures]

Water year	SITE 1						SITE 2					
	Daily load (tons)			Annual			Daily load (tons)			Annual		
					Yield						Yield	
	Maximum	Minimum	Average	Load (tons)	(tons/acre-ft)	(tons/mi^2)	Maximum	Minimum	Average	Load (tons)	(tons/acre-ft)	(tons/mi^2)
1975	305	3	32	11,800	0.05	45	492	2	31	11,200	0.05	63
1976	111	3	16	5,730	0.03	22	398	2	21	7,590	0.05	43
1977	38	2	6	2,120	0.02	8	93	1	6	2,110	0.02	12
1978	319	3	36	13,200	0.05	51	761	1	50	18,100	0.08	102
1979	315	4	29	10,700	0.04	41	595	2	35	12,700	0.06	72
1980	236	4	24	8,800	0.04	34	499	1	30	10,800	0.06	61
1981	147	3	12	4,550	0.03	18	231	1	12	4,510	0.04	25
1982	185	3	25	9,150	0.04	35	266	1	29	10,600	0.05	60
1983	608	4	48	17,400	0.05	67	907	2	48	17,600	0.07	99
1984	1,010	5	63	23,100	0.06	89	622	3	39	14,300	0.06	81
1985	685	7	64	23,400	0.06	90	680	3	41	14,900	0.06	84
1986	274	6	36	13,200	0.04	51	558	3	42	15,500	0.06	88
1987	168	5	21	7,490	0.03	29	275	3	21	7,690	0.04	43
1988	291	3	28	10,200	0.05	39	377	2	21	7,550	0.05	43
Maximum	1,010	7	64	23,400	0.06	90	907	3	50	18,100	0.08	102
Minimum	38	2	6	2,120	0.02	8	93	1	6	2,110	0.02	12
Average	335	4	31	11,500	0.04	44	482	2	30	11,100	0.05	63

Table 5. Suspended-sediment loads measured using the regressions in table 3 or estimated from regressions of annual suspended-sediment load and annual stream discharge for sites 1-6 and station 09306300, White River, water years 1975-88--Continued

Water year	SITE 3A (SITE 1 plus SITE 2)						SITE 3					
	Daily load (tons)			Annual			Daily load (tons)			Annual		
					Yield						Yield	
	Maximum	Minimum	Average	Load (tons)	(tons/ acre-ft)	(tons/ mi²)	Maximum	Minimum	Average	Load (tons)	(tons/ acre-ft)	(tons/ mi²)
1975	--	--	63	23,000	0.05	53	3,910	4	168	61,400	0.13	95
1976	--	--	36	13,300	0.04	30	1,180	1	73	26,800	0.08	41
1977	--	--	12	4,230	0.02	10	69	0	7	2,600	0.02	4
1978	--	--	86	31,300	0.06	72	2,550	0	178	64,800	0.15	100
1979	--	--	64	23,400	0.05	54	4,440	2	191	69,600	0.15	107
1980	--	--	54	19,600	0.05	45	1,800	2	119	43,700	0.11	67
1981	--	--	25	9,060	0.03	21	420	0	27	9,820	0.04	15
1982	--	--	54	19,800	0.04	45	1,450	4	139	50,900	0.11	79
1983	--	--	96	35,000	0.06	80	6,500	5	312	114,000	0.20	176
1984	--	--	102	37,400	0.06	86	6,230	7	440	161,000	0.23	248
1985	--	--	105	38,300	0.06	88	4,050	4	274	100,000	0.16	154
1986	--	--	79	28,700	0.05	66	3,430	11	261	95,200	0.15	147
1987	--	--	42	15,200	0.04	35	880	3	69	25,100	0.06	39
1988	--	--	48	17,800	0.05	41	1,220	3	77	28,200	0.08	44
Maximum	--	--	105	38,300	0.06	88	6,500	11	440	161,000	0.23	248
Minimum	--	--	12	4,230	0.02	10	69	0	7	2,600	0.02	4
Average	--	--	62	22,600	0.05	52	2,720	3	167	60,900	0.12	94

Table 5. Suspended-sediment loads measured using the regressions in table 3 or estimated from regressions of annual suspended-sediment load and annual stream discharge for sites 1-6 and station 09306300, White River, water years 1975-88--Continued

Water year	SITE 4						SITE 5					
	Daily load (tons)			Annual			Daily load (tons)			Annual		
	Maximum	Minimum	Average	Load (tons)	Yield (tons/acre-ft)	Yield (tons/mi^2)	Maximum	Minimum	Average	Load (tons)	Yield (tons/acre-ft)	Yield (tons/mi^2)
1975	3,610	18	290	106,000	0.20	104	--	--	--	*386,000	*0.70	*212
1976	1,640	13	146	53,300	0.14	52	--	--	--	*235,000	*0.59	*129
1977	414	4	46	16,900	0.08	17	--	--	--	*53,000	*0.24	*29
1978	3,710	12	307	112,000	0.21	109	--	--	--	*375,000	*0.70	*206
1979	3,570	21	293	107,000	0.20	104	--	--	--	*387,000	*0.70	*213
1980	2,360	25	231	84,400	0.18	82	--	--	--	*328,000	*0.67	*180
1981	1,350	16	116	42,400	0.14	41	--	--	--	*157,000	*0.48	*86
1982	2,090	17	229	83,500	0.17	82	--	--	--	*346,000	*0.68	*190
1983	6,260	25	458	167,000	0.24	163	18,400	45	1,750	638,000	0.83	350
1984	5,980	32	503	184,000	0.24	180	19,400	64	2,340	853,000	0.87	468
1985	4,660	41	504	184,000	0.24	180	14,100	71	1,770	647,000	0.78	355
1986	3,960	40	452	165,000	0.22	161	15,000	82	1,760	644,000	0.77	354
1987	1,770	34	216	78,700	0.16	77	9,010	61	989	361,000	0.67	198
1988	2,270	19	204	74,800	0.17	73	10,100	39	863	315,000	0.68	173
Maximum	6,260	41	504	184,000	0.24	180	19,400	82	2,340	853,000	0.87	468
Minimum	414	4	46	16,900	0.08	17	9,010	39	863	*53,000	*0.24	*29
Average	3,120	23	285	104,000	0.19	102	14,300	60	1,580	*409,000	*0.67	*225

Table 5. Suspended-sediment loads measured using the regressions in table 3 or estimated from regressions of annual suspended-sediment load and annual stream discharge for sites 1-6 and station 09306300, White River, water years 1975-88--Continued

Water year	SITE 6						STATION 0906300					
	Daily load (tons)			Annual			Daily load (tons)			Annual		
	Maximum	Minimum	Average	Load (tons)	Yield (tons/ acre-ft)	Yield (tons/ mi^2)	Maximum	Minimum	Average	Load (tons)	Yield (tons/ acre-ft)	Yield (tons/ mi^2)
1975	--	--	--	*530,000	*0.96	*209	21,300	105	1,670	610,000	1.11	220
1976	--	--	--	*303,000	*0.76	*120	9,610	98	1,000	367,000	0.89	132
1977	--	--	--	*93,000	*0.42	*37	2,820	14	289	105,000	0.46	38
1978	--	--	--	*631,000	*1.17	*249	132,000	81	2,040	747,000	1.44	269
1979	--	--	--	*535,000	*0.97	*211	17,400	94	1,720	628,000	1.15	226
1980	--	--	--	*432,000	*0.87	*171	13,700	63	1,440	525,000	1.06	189
1981	--	--	--	*219,000	*0.67	*87	8,440	56	710	259,000	0.80	93
1982	--	--	--	*415,000	*0.81	*164	--	--	--	--	--	--
1983	47,900	54	3,610	1,320,000	1.70	522	--	--	--	--	--	--
1984	55,200	88	5,330	1,950,000	2.00	771	--	--	--	--	--	--
1985	32,000	94	3,660	1,340,000	1.59	530	--	--	--	--	--	--
1986	29,000	112	3,210	1,170,000	1.39	462	--	--	--	--	--	--
1987	12,600	48	1,280	467,000	0.86	185	--	--	--	--	--	--
1988	16,700	21	1,260	462,000	0.92	183	--	--	--	--	--	--
Maximum	55,200	112	5,330	1,950,000	2.00	771	132,000	105	2,040	747,000	1.44	269
Minimum	12,600	21	1,260	*93,000	*0.42	*37	2,820	14	289	105,000	0.46	38
Average	32,200	70	3,060	*705,000	*1.08	279	29,300	73	1,270	463,000	0.99	167

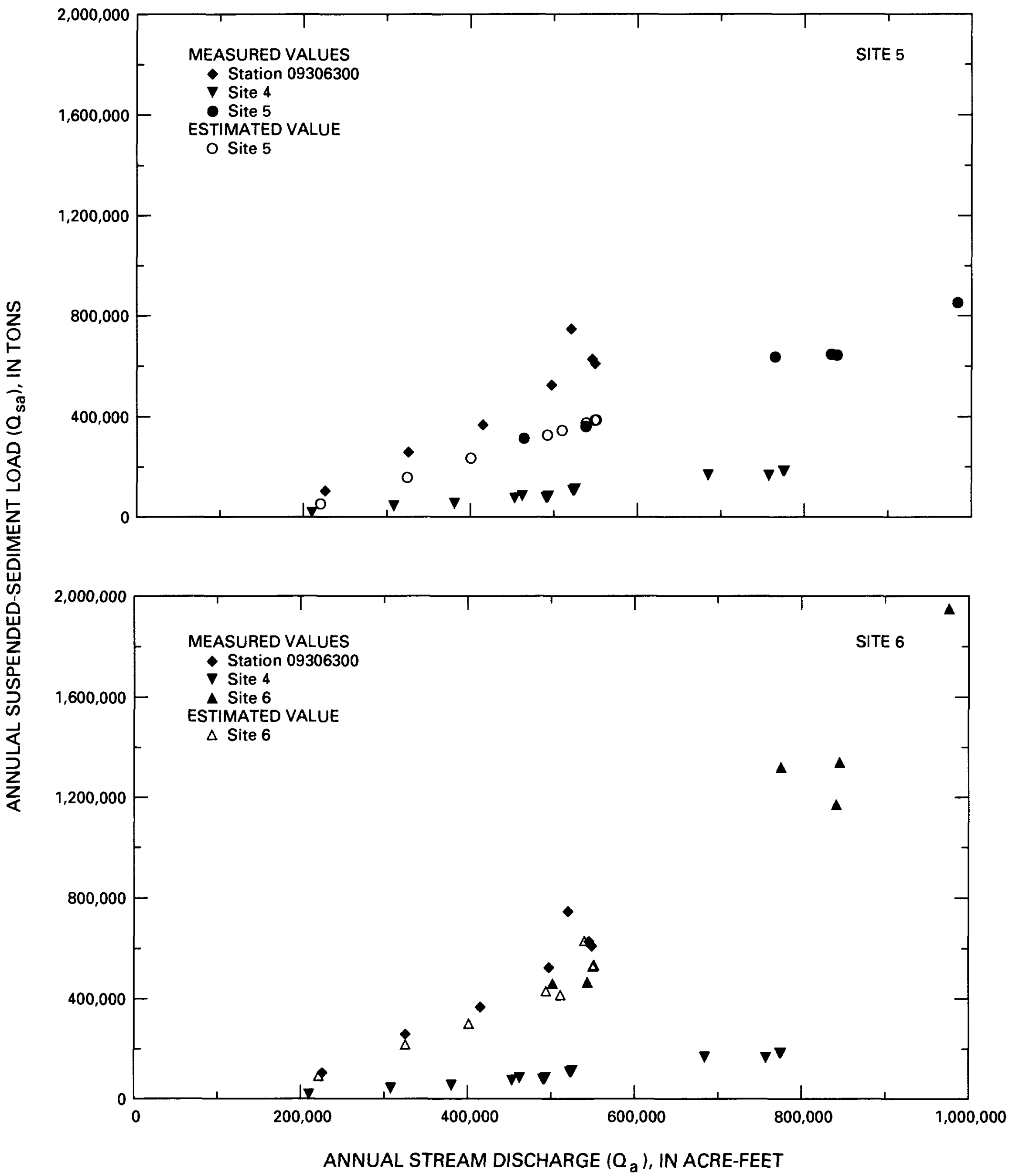

Figure 9. Correlation of estimated (water years 1975-82) and measured (water years 1983-88) annual suspended-sediment loads at sites 5 and 6 and measured annual suspended-sediment loads at site 4 (water years 1975-88) and station 09306300 (water years 1975-81) with annual stream discharge.

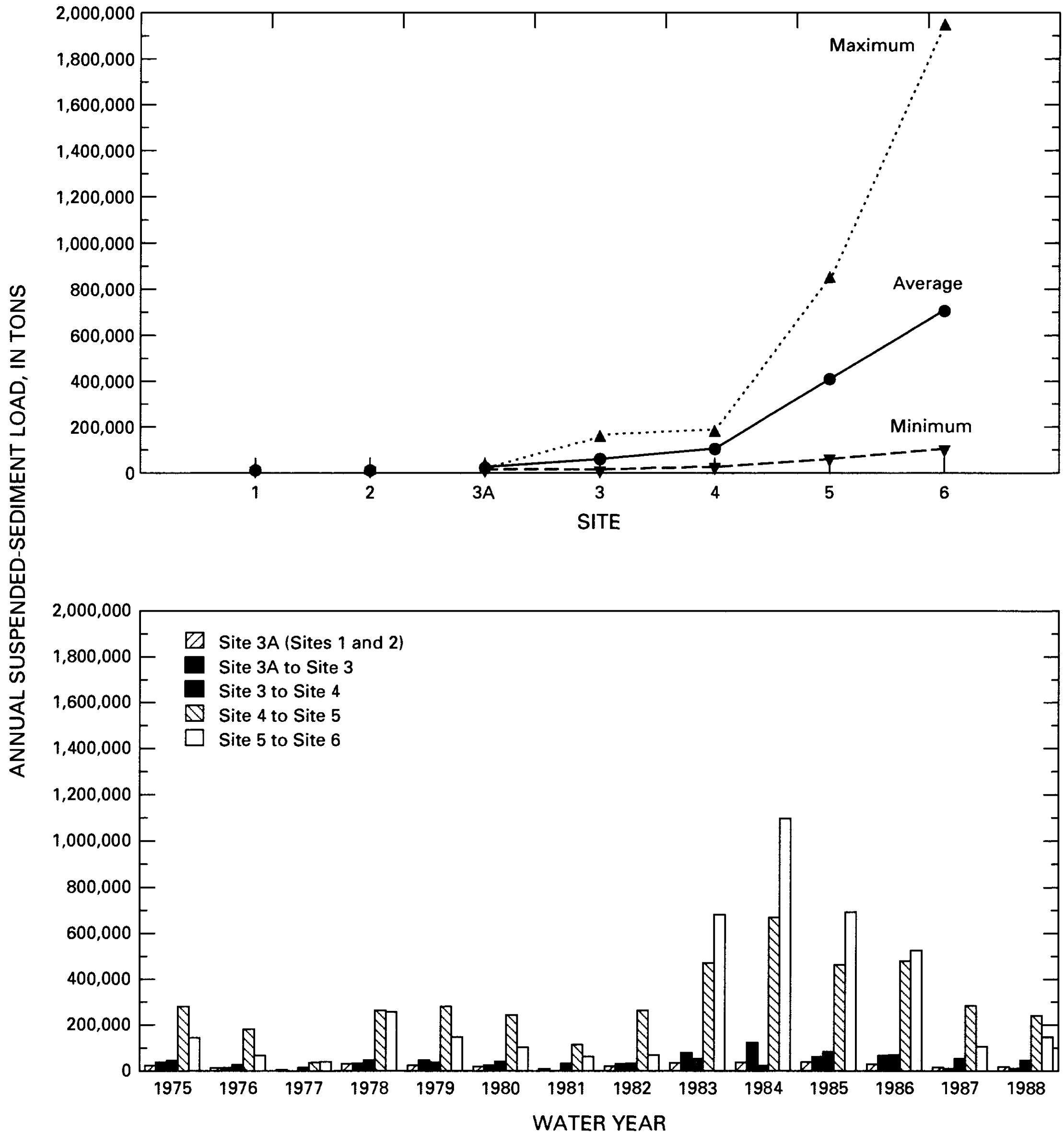

Figure 10. Average and range of annual suspended-sediment loads for the North Fork (site 1), the South Fork (site 2), and the main stem of the White River (sites 3A-6), water years 1975-88, and annual suspended-sediment loads for segments of the White River between sites.

A total of five samples for size analyses were collected during a stream-discharge range from 1,840 to 2,470 ft^3/s at sites 3, 4, and 5 during water years 1987-88. Size analyses of suspended sediment were determined for 22 samples collected during a stream-discharge range from 599 to 6,090 ft^3/s at site 6 during water years 1984-88. The sand, silt, and clay compositions are listed below:

Site	Number of samples	Average percentage		
		Sand	Silt	Clay
3	1	27	48	25
4	2	26	44	30
5	2	37	41	22
6	22	30	46	24
Total: 3-6	Total: 27	Average: 30	45	25

In addition, a total of 174 suspended-sediment samples collected for sediment concentrations at sites 1-6 were analyzed for sand percentages (greater than 0.062 mm). The percentage variation of sand among samples was great and ranged from 2 to 64 percent. Data correlations of size composition with stream discharge and suspended-sediment concentrations were poor, and definable patterns of suspended-sediment size with subbasin geology were inconclusive.

Retention in Reservoirs

Retention of fluvial-sediment loads will occur in reservoirs that are constructed on the main stem of the White River. The efficiency of sediment retention is a function of reservoir capacity, inflow volume, mean velocity of flow through the reservoir, and size composition of the sediment load (Churchill, 1948; Brune, 1953). Generally, reservoir retention of sediment will increase as the ratio of the reservoir capacity to inflow volume increases or the percent composition of silt and clay in the sediment load decreases, or both. Based on sediment data collected at site 6 during water years 1985-87, sediment retention in Kenney Reservoir, about 8 mi downstream from site 6, was estimated at 91 to 98 percent (Tobin and Hollowed, 1990). Proposed reservoirs constructed on the White River that have capacities larger than Kenney Reservoir (13,800 acre-ft) could have sediment-retention values that exceed 98 percent.

Assuming 98-percent sediment retention and an average sediment size composition of 30 percent sand, 45 percent silt, and 25 percent clay, original and 20-year compacted volumes of sediment deposits for two ranges of sediment loads (fig. 11) were calculated from methods of Strand and Pemberton (1982). In order to assess the sensitivity of sediment loads on capacity loss in reservoirs, annual capacity losses in a hypothetical 50,000 acre-ft reservoir on the White River were determined for a range of annual sediment loads (table 6). Annual capacity losses calculated using average annual suspended-sediment loads at sites 1 through 6 (table 5) for a range of hypothetical reservoir sizes constructed on the White River at or near each site are shown in figure 12. If values of maximum and minimum annual suspended-sediment loads (table 5) are used, then the annual capacity losses in a 50,000 acre-ft reservoir could range from less than 0.01 percent near sites 1 and 2 to about 2.5 percent near site 6. Because the variability in annual sediment loads at each site (fig. 10 and table 5) is substantial, the curves in figure 12 are general estimates only.

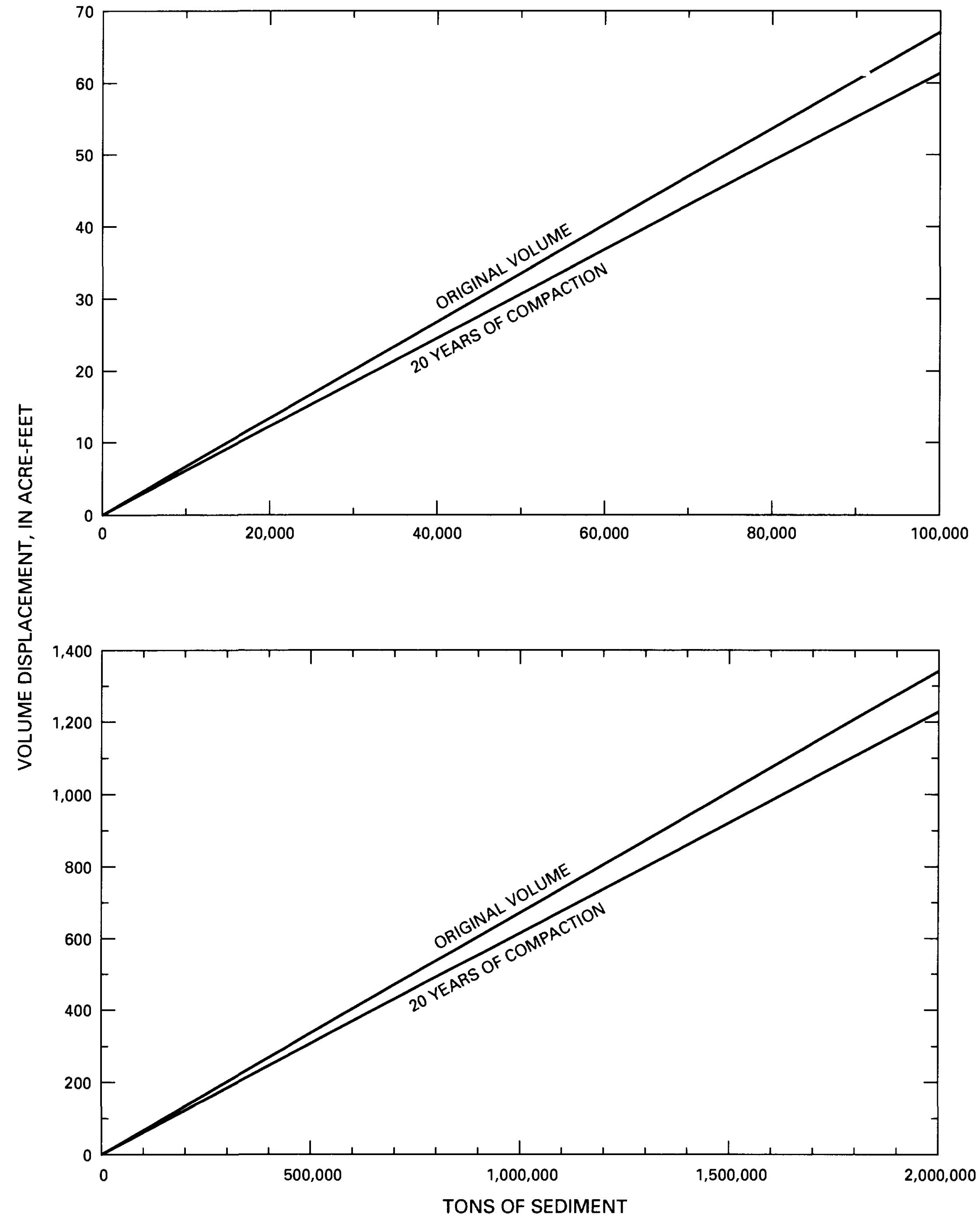

Figure 11. Volume displacement from retained fluvial sediment in reservoirs. Calculations are based on 98-percent sediment retention and an average size of composition of 30 percent sand, 45 percent silt, and 25 percent clay (from methods of Strand and Pemberton, 1982).

Table 6. Estimated volume displacement by fluvial sediment in a 50,000 acre-foot reservoir constructed on the White River

[Data are relative to initial reservoir capacity]

Annual sediment load (tons)	At 91-percent sediment retention				At 98-percent sediment retention			
	Initial volume displace-ment (acre-feet)	Initial capacity loss (percent)	Volume after 20 years (acre-feet)	Capacity loss after 20-years compaction (percent)	Initial volume displace-ment (acre-feet)	Initial capacity loss (percent)	Volume after 20 years (acre-feet)	Capacity loss after 20-years compaction (percent)
10,000	6	0.01	6	0.01	7	0.01	6	0.01
20,000	12	0.02	11	0.02	13	0.03	12	0.02
30,000	19	0.04	17	0.03	20	0.04	18	0.04
40,000	25	0.05	23	0.05	27	0.05	25	0.05
50,000	31	0.06	29	0.06	34	0.07	31	0.06
60,000	37	0.07	34	0.07	40	0.08	37	0.07
70,000	44	0.09	40	0.08	47	0.09	43	0.09
80,000	50	0.10	46	0.09	54	0.11	49	0.10
90,000	56	0.11	51	0.10	60	0.12	55	0.11
100,000	62	0.12	57	0.11	67	0.13	61	0.12
200,000	125	0.25	114	0.23	134	0.27	123	0.25
300,000	187	0.37	171	0.34	201	0.40	184	0.37
400,000	249	0.50	228	0.46	268	0.54	246	0.49
500,000	311	0.62	285	0.57	335	0.67	307	0.61
600,000	374	0.75	342	0.68	402	0.80	369	0.74
700,000	436	0.87	399	0.80	469	0.94	430	0.86
800,000	498	1.00	456	0.91	536	1.07	491	0.98
900,000	560	1.12	513	1.03	604	1.21	553	1.11
1,000,000	623	1.25	570	1.14	671	1.34	614	1.23
1,100,000	685	1.37	628	1.26	738	1.48	676	1.35
1,200,000	747	1.49	685	1.37	805	1.61	737	1.47
1,300,000	809	1.62	742	1.48	872	1.74	799	1.60
1,400,000	872	1.74	799	1.60	939	1.88	860	1.72
1,500,000	934	1.87	856	1.71	1,006	2.01	922	1.84
1,600,000	996	1.99	913	1.83	1,073	2.15	983	1.97
1,700,000	1,059	2.12	970	1.94	1,140	2.28	1,044	2.09
1,800,000	1,121	2.24	1,027	2.05	1,207	2.41	1,106	2.21
1,900,000	1,183	2.37	1,084	2.17	1,274	2.55	1,167	2.33
2,000,000	1,245	2.49	1,141	2.28	1,341	2.68	1,229	2.46

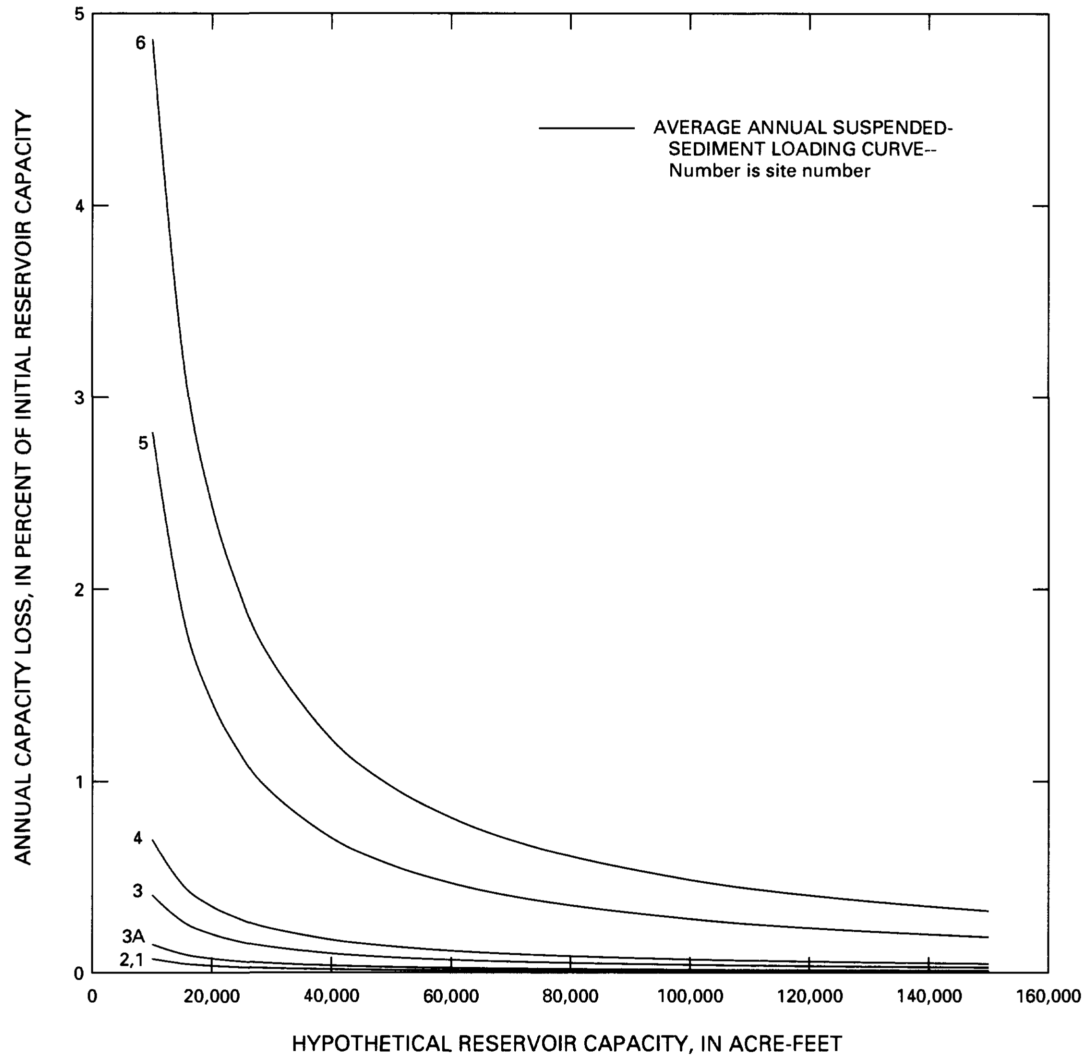

Figure 12. Estimates of annual loss of initial reservoir capacity for possible reservoirs constructed on the White River at or near sites 1-6. (Calculations based on average annual suspended-sediment loads and 98-percent sediment retention, and an average sediment-size composition of 30 percent sand, 45 percent silt, and 25 percent clay.)

WATER-QUALITY CHARACTERISTICS AND LOADS

Constituents dissolved in natural streams can vary greatly in concentration, depending on the source and nature of the constituent, volume of water (dilution factor), water temperature, concentrations of dissolved gases, adsorption capacities of fluvial sediment, and metabolic activities (Hem, 1985). Water-quality characteristics such as water temperature, pH, and dissolved oxygen often vary daily, depending on the physical and biological environments. Measurements of water temperature, specific conductance, pH, and dissolved oxygen commonly are made onsite. Conversely, concentrations of the major ions (used in this report to calculate dissolved solids), nutrients, and trace constituents tend to vary with geography, season, and hydrology. Determinations for these values commonly are done in a laboratory.

Onsite Measurements

Water temperature, specific conductance, pH, and dissolved oxygen were measured periodically during daytime at sites 1-4 during water years 1975-88 and at sites 5 and 6 during water years 1983-88. Data for each site were plotted against time, temperature, streamflow, and other constituents. Values or concentrations were analyzed for possible correlations or for trends within and among sites. A discussion of the significant correlations or trends for the four onsite measurements follows.

Water Temperature

Correlations of water temperature and stream discharge at sites 1-6 are shown in figure 13. Maximum temperatures occurred in summer during small

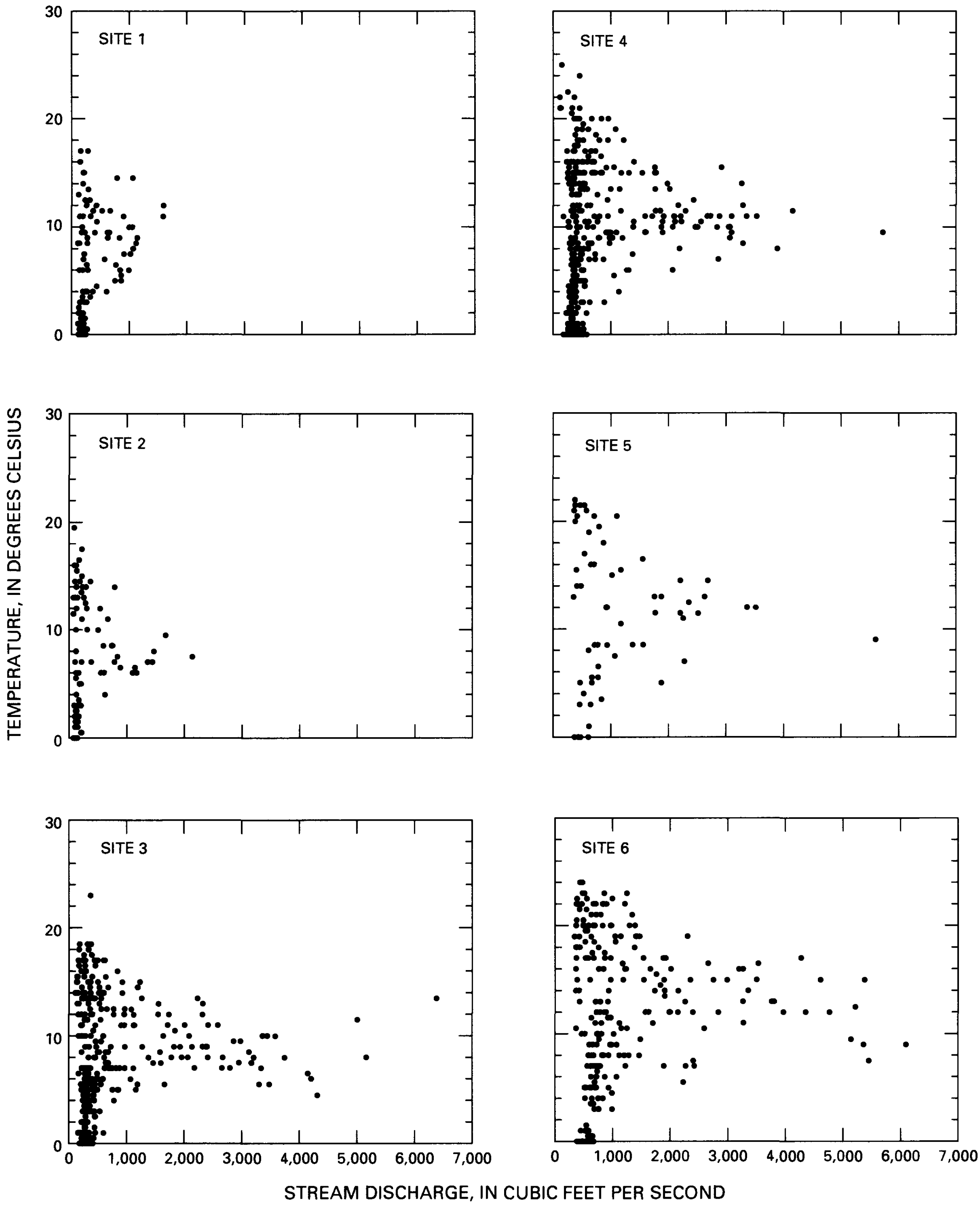

Figure 13. Correlation of periodic measurements of water temperature and stream discharge at sites 1-6, water years 1975-88.

streamflow periods and generally ranged from 20 to 25°C at sites 4-6. Maximum temperatures mostly were less than 20°C at sites 1-3. Minimum temperatures of 0°C were measured at all sites during winter.

In spring, when stream discharge from snowmelt in the White River generally exceeded 1,000 to 2,000 ft^3/s, stream temperature ranged from 5 to 18°C at sites 3-6. Analysis of available daily temperature records at site 4 (water years 1978-83) indicates that daily changes in temperature of 3 to 8°C were typical during summer.

Specific Conductance

Periodic measurements of specific conductance and the relation of specific conductance to stream discharge at sites 1-6 are shown in figure 14. The mathematical expressions for estimating specific conductance from stream discharge (fig. 14) are antilogs of the regressions that related log-transformed values of specific conductance with log-transformed values of stream discharge. The expressions include a bias correction factor (C_b) derived from methods used in equations 3 and 4. The large scatter of specific-conductance values for sites 5 and 6 (fig. 14) probably was caused by the seasonal or intermittent inflow of water that had large values of specific conductance. The water entered the White River as irrigation return flow or as early spring runoff from the low-elevation basins, or both.

Because specific-conductance values are small in snowmelt, specific conductance decreased at all sites as streamflow increased during the spring runoff. Values and ranges of specific conductance were least (generally from 200 to 400 µS/cm) at sites 1 and 2 and increased (generally from 300 to 1,000 µS/cm) downstream to site 6. Large values of specific conductance (from 750 to 1,100 µS/cm) were measured at site 4 during periods of low streamflow prior to water year 1983 (fig. 15). The large values were attributed to the inflow of ground water that had large values of specific conductance that discharged to the White River from seeps and springs. The seeps and springs most likely were associated with improperly completed gas and oil exploratory wells (CH2M Hill Central, 1982). The wells were drilled into a geologic and topographic structure known as the Meeker dome, 3 mi east of Meeker (fig. 2). The wells were recompleted and plugged during 1980-81 (water years 1980-82) through efforts sponsored by the U.S. Bureau of Reclamation. Measurements of specific conductance at site 4 were less than 750 µS/cm during water years 1983-88 (fig. 15).

pH

Values of pH at sites 1-6 are plotted against stream discharge in figure 16. Although pH values in the White River ranged from 7.4 (site 4) to 9.1 (site 3), most values of pH ranged from 7.6 to 8.8. In the high streamflow of spring runoff, pH values at sites 1 and 2 generally ranged from 8.0 to 8.3, and pH in the main stem of the White River (sites 3-6) mostly ranged from 8.0 to 8.5. Except for the single unexplained pH value of 9.1 at site 3 (fig. 16), the pH range generally was greatest at all sites during low streamflow.

Correlation of pH with dissolved oxygen for sites 1-6 indicates that pH exceeded 8.5 at sites 1-4 only when the percent saturation of dissolved oxygen equaled or exceeded 100 percent. A similar correlation was not evident at sites 5 and 6. Also, the ranges of pH values at sites 5 and 6 generally were smaller than the ranges of pH values at sites 1-4. During low streamflow, when values of specific conductance were greater at sites downstream than sites upstream, the chemical buffering capacity in the river to resist biologically induced changes in pH generally was greater in the White River downstream from site 4 than in the upper White River at sites 1-4.

Dissolved Oxygen

The saturated concentration of dissolved oxygen in streams is directly related to the partial pressure of atmospheric oxygen and inversely related to water temperature. Concentrations that deviate from the 100-percent saturation values in natural water primarily are caused by metabolic processes. Oxygen is produced from the photosynthesis of algae and plants, and oxygen is consumed by respiration and during the decomposition of organic matter. Correlation of dissolved oxygen and temperature, and the 90-, 100-, and 120-percent saturation curves for sites 1-6 are shown in figure 17. Concentrations greater than the 100-percent saturation curve indicate a super-saturated condition; concentrations less than the curve indicate an unsaturated condition. A comparison of data at sites 1-6 (fig. 17) indicates the following:

1. All concentrations of dissolved oxygen measured at sites 1-6 were greater than 6.0 mg/L. Concentrations were greatest during winter; a maximum concentration of 14.2 mg/L was measured at site 4 when the water temperature was 0°C.

2. Photosynthetic activities, as measured by the relative frequency and extent of dissolved-oxygen concentrations greater than the 100-

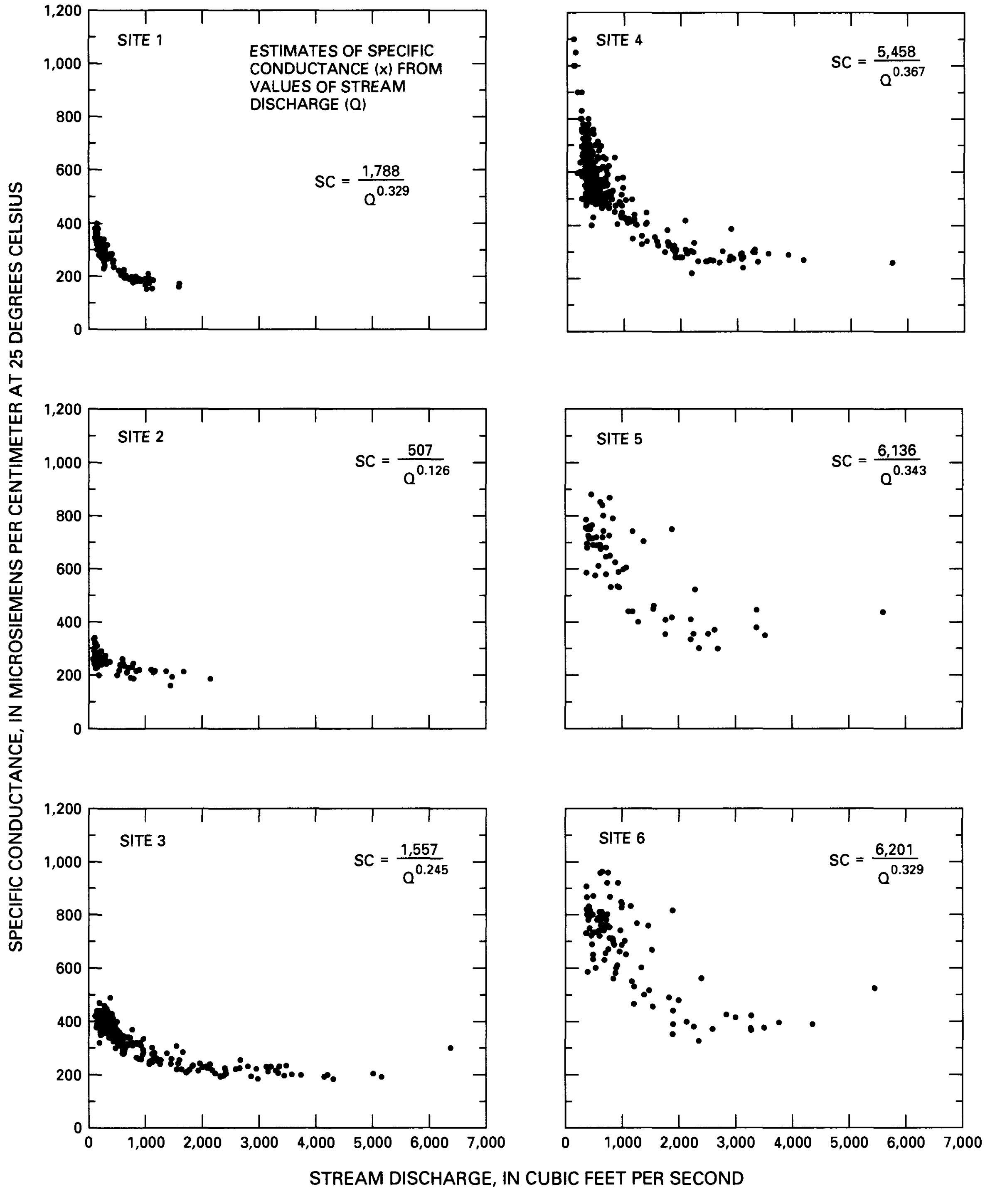

Figure 14. Relation of specific conductance to stream discharge at sites 1-6, water years 1975-88.

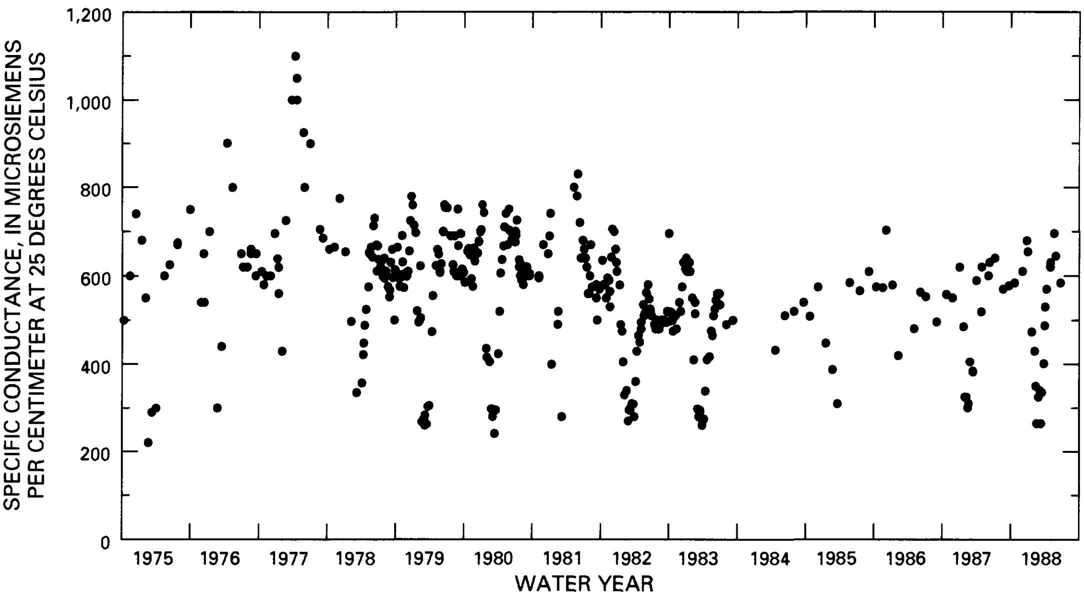

Figure 15. Periodic measurements of specific conductance at site 4, water years 1975-88.

percent saturation curve, were least at site 1 and greatest at sites 4-6.

3. Conditions of oxygen supersaturation tended to be greatest during low streamflows of summer and winter. A maximum supersaturation of dissolved oxygen (149 percent) was measured in the White River at site 4 on September 10, 1984. Concentrations of dissolved oxygen equal to or greater than 120-percent saturation were measured at all sites. The occurrences of supersaturated conditions in cold water (temperatures less than 5°C) indicate that algae or aquatic plants probably were active in the White River in winter.

4. Net oxygen depletions, as measured by concentrations of dissolved oxygen less than the 100-percent saturation curve (fig. 17), were least at sites 1-3 and greatest at sites 4 and 6. Most concentrations of dissolved oxygen in the White River were greater than 90-percent saturation. Concentrations of dissolved oxygen less than 90-percent saturation shown for site 4 (fig. 17) were measured prior to 1981. From 1981-88, all values of dissolved oxygen measured at site 4 were greater than 91-percent saturation. Because the occurrence and extent of oxygen depletions in the White River generally were small, biological or chemical oxygen-consumption activities, or both, probably were small.

The maximum and minimum values in this report for water temperature, pH, and dissolved oxygen need to be considered as range estimates. Because extreme conditions may be more important to the health of aquatic organisms than average conditions, diel monitoring to determine daily ranges of water temperature, specific conductance, pH, and dissolved oxygen during medium- and low-flow periods at several sites in the White River is necessary.

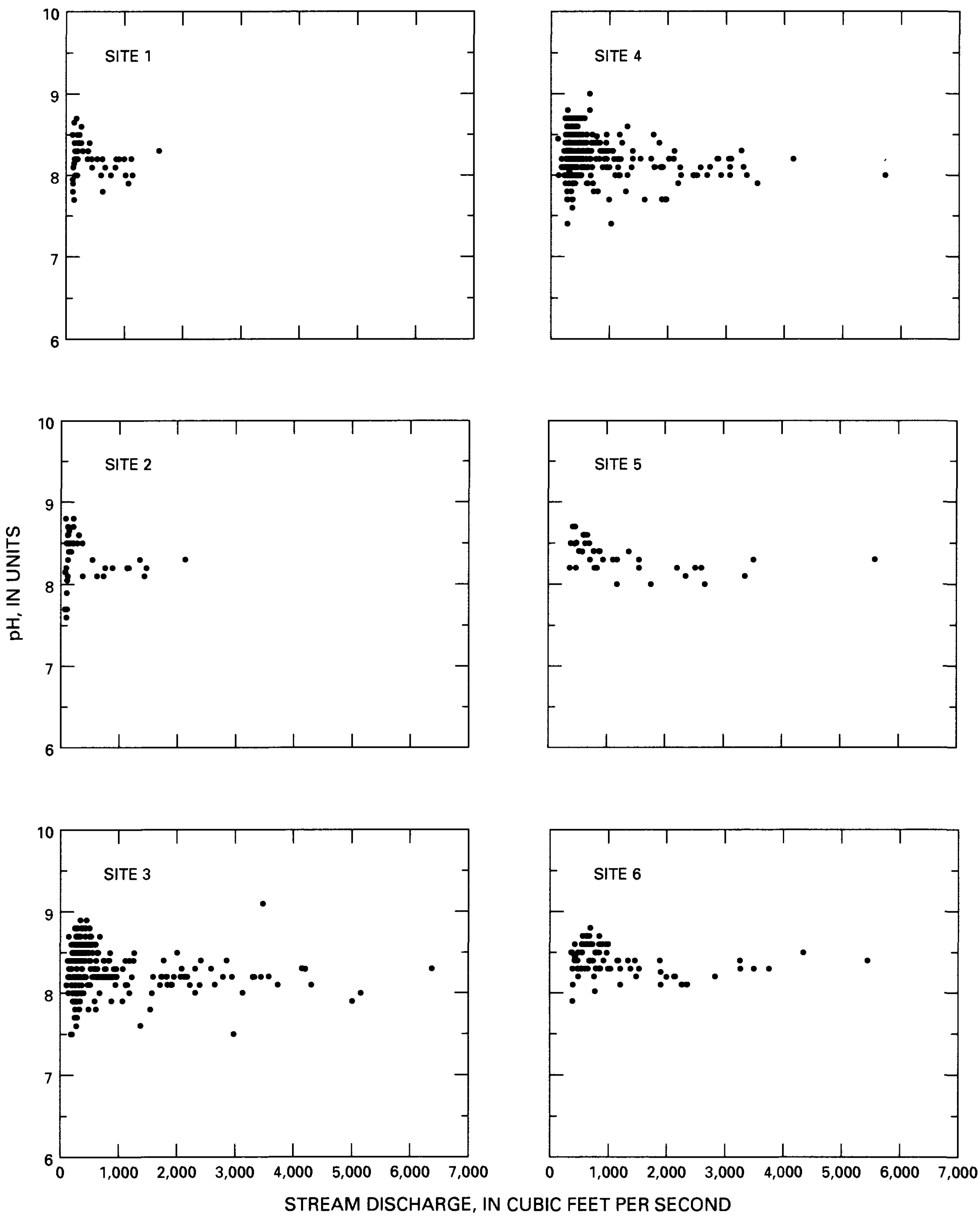

Figure 16. Correlation of periodic measurements of pH and stream discharge at sites 1-6, water years 1975-88.

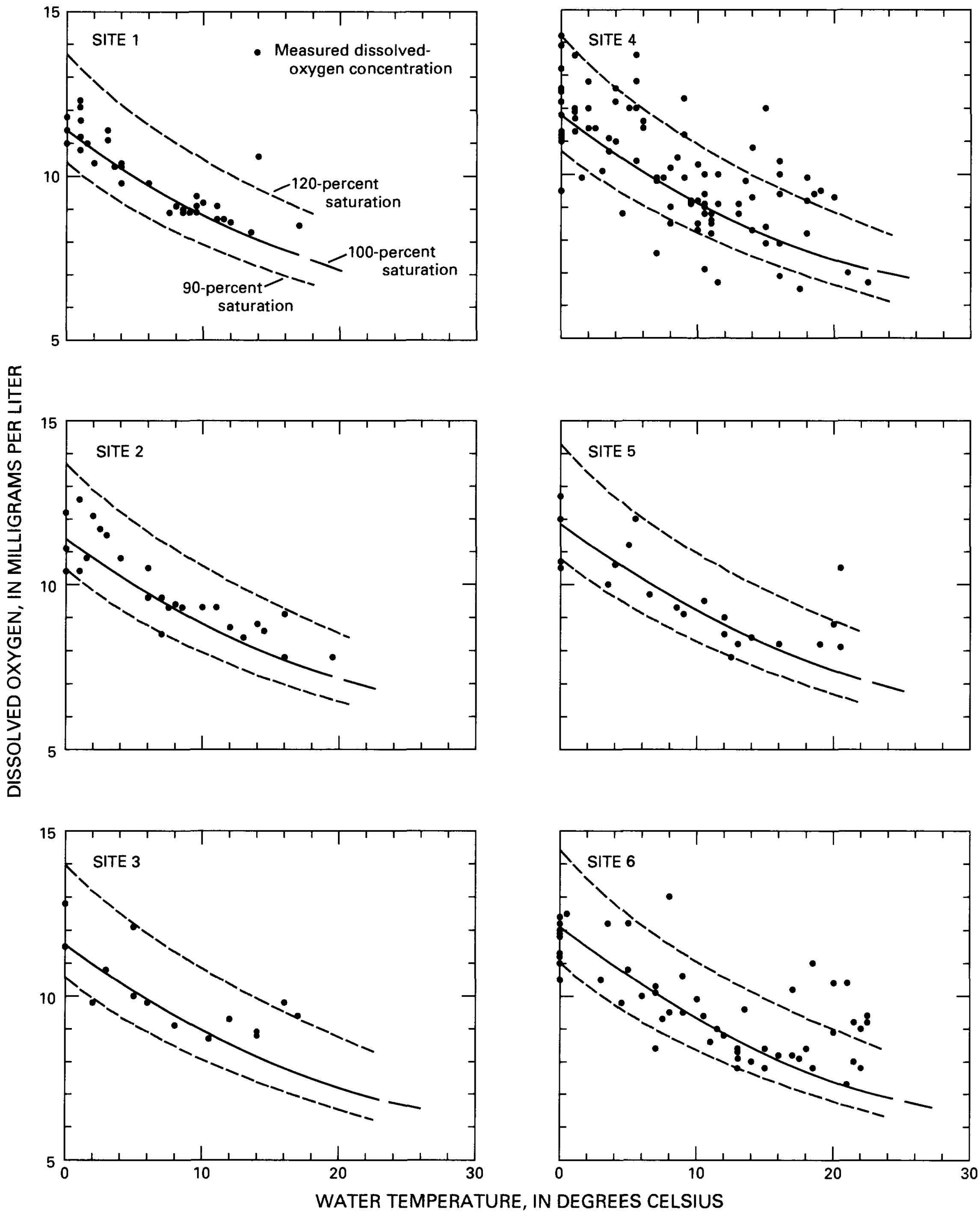

Figure 17. Correlation of periodic measurements of dissolved oxygen and water temperature at sites 1-6, water years 1975-88.

Major Ions and Dissolved-Solids Loads

Major ions that account for most of the dissolved solids in natural waters are listed below:

Cations (positive charge)	Anions (negative charge)
Calcium (Ca)	Alkalinity ($CaCO_3$)
Magnesium (Mg)	Bicarbonate (HCO_3)
Potassium (K)	Carbonate (CO_3)
Sodium (Na)	Chloride (Cl)
	Fluoride (F)
	Sulfate (SO_4)

Although noncarbonates can contribute to alkalinity, alkalinity in natural water can be attributed almost entirely to bicarbonate and carbonate without serious error (Hem, 1985). Concentrations of total alkalinity commonly are reported as calcium carbonate ($CaCO_3$), in milligrams per liter. In natural waters that have pH values less than 9, bicarbonate is the principal component of alkalinity. Thus, when alkalinity is significant in the geochemical classification of water (table 7), the bicarbonate component commonly is used for nomenclature purposes.

Concentrations of the major ions and values of stream discharge for sites 1-6 are shown in figures 18-20. Because concentrations of potassium were less than 4.5 mg/L and concentrations of fluoride were less than 0.4 mg/L at all sites during water years 1975-88, potassium and fluoride were considered minor constituents and were not included in figures 18-20. In addition, concentrations of major ions, hardness, and dissolved solids were regressed with values of specific conductance. Specific conductance generally is a good indicator of the total ion activity because charged ions in water make the solution conductive. Regression information for sites 1-6 are presented in table 8.

Concentrations of selected major ions at site 4 were graphed chronologically for water years 1975-88 (fig. 21). Data analyses indicated that a substantial decrease in the concentration ranges of sodium, chloride, and, possibly, sulfate occurred after April 1982. Correlation of these constituents to specific conductance also changed after April 1982 (fig. 22). Decreases or changes in the above-mentioned constituents during the same period were not evident upstream at site 3. The decreases in sodium, chloride, and sulfate at site 4 probably are related to well recompletions that decreased or eliminated saline ground water that entered the White River in the vicinity of the Meeker dome. Because water chemistry changed at site 4 in 1982, data presentations and analyses (fig. 19 and table 8) used to determine relations and ranges of the major ions at site 4 were limited to data collected after April 1982.

Table 7. Chemical criteria used to classify water types and hardness

[Water types, modified from Piper, Garrett, 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 percentages of 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 percentages of anions are used.	Soft	Less than 60
		Moderately hard	61-120
		Hard	121-180
		Very hard	More than 180

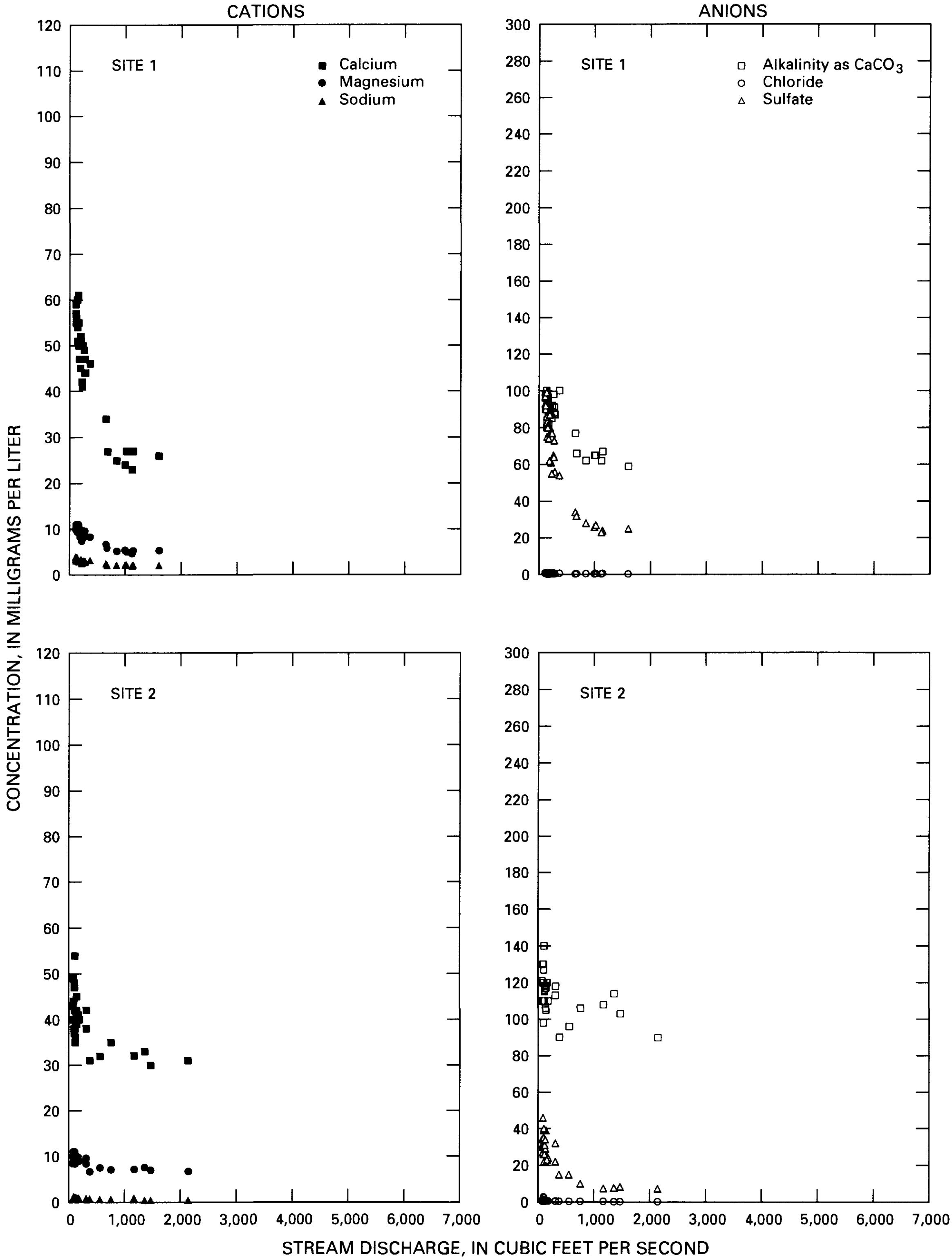

Figure 18. Correlation of periodic measurements of selected major ions with stream discharge at sites 1 and 2, water years 1975-88.

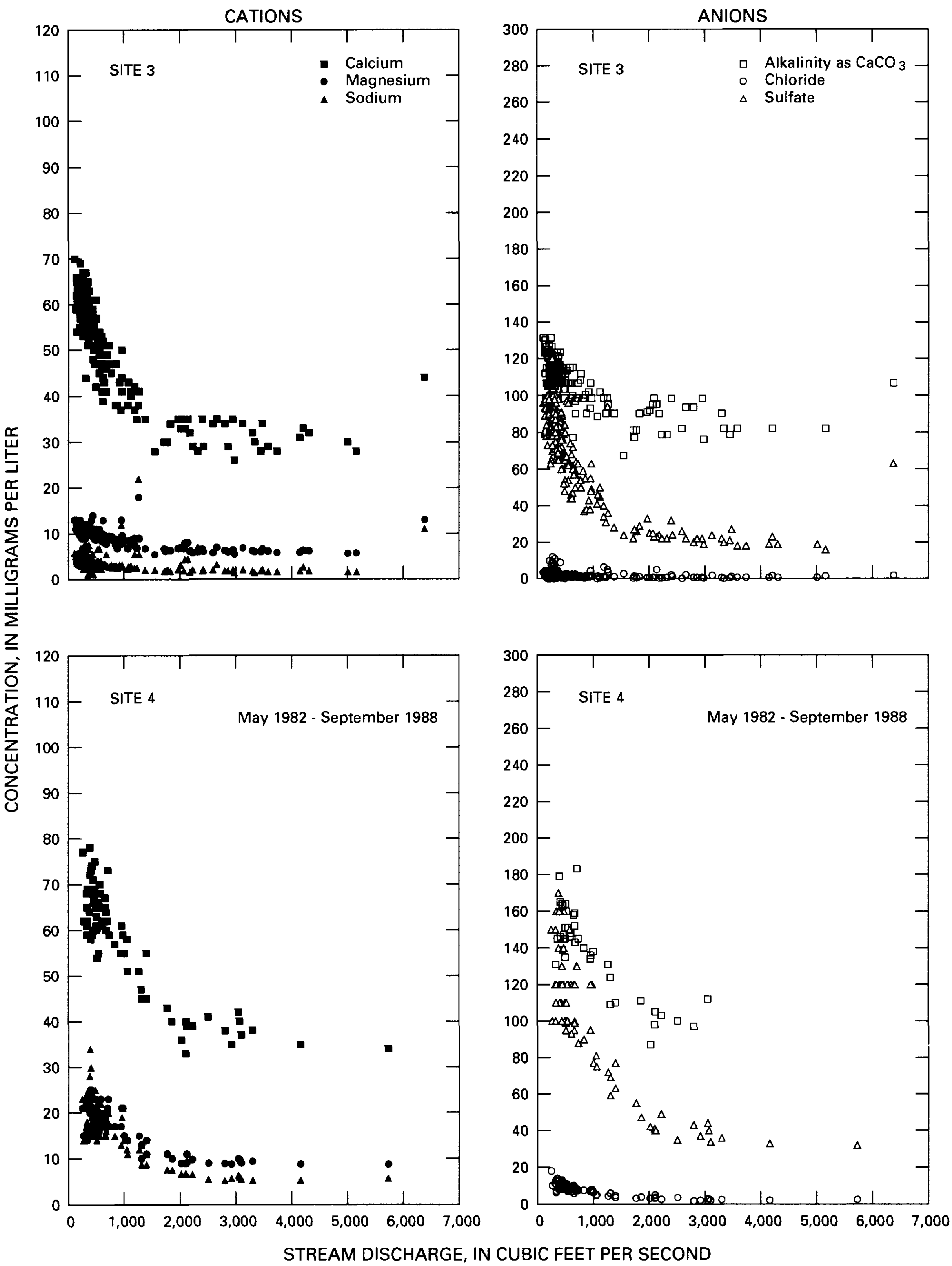

Figure 19. Correlation of periodic measurements of selected major ions with stream discharge at site 3, water years 1975-88, and at site 4 from May 1982 to September 1988 (period subsequent to well completions at the Meeker dome).

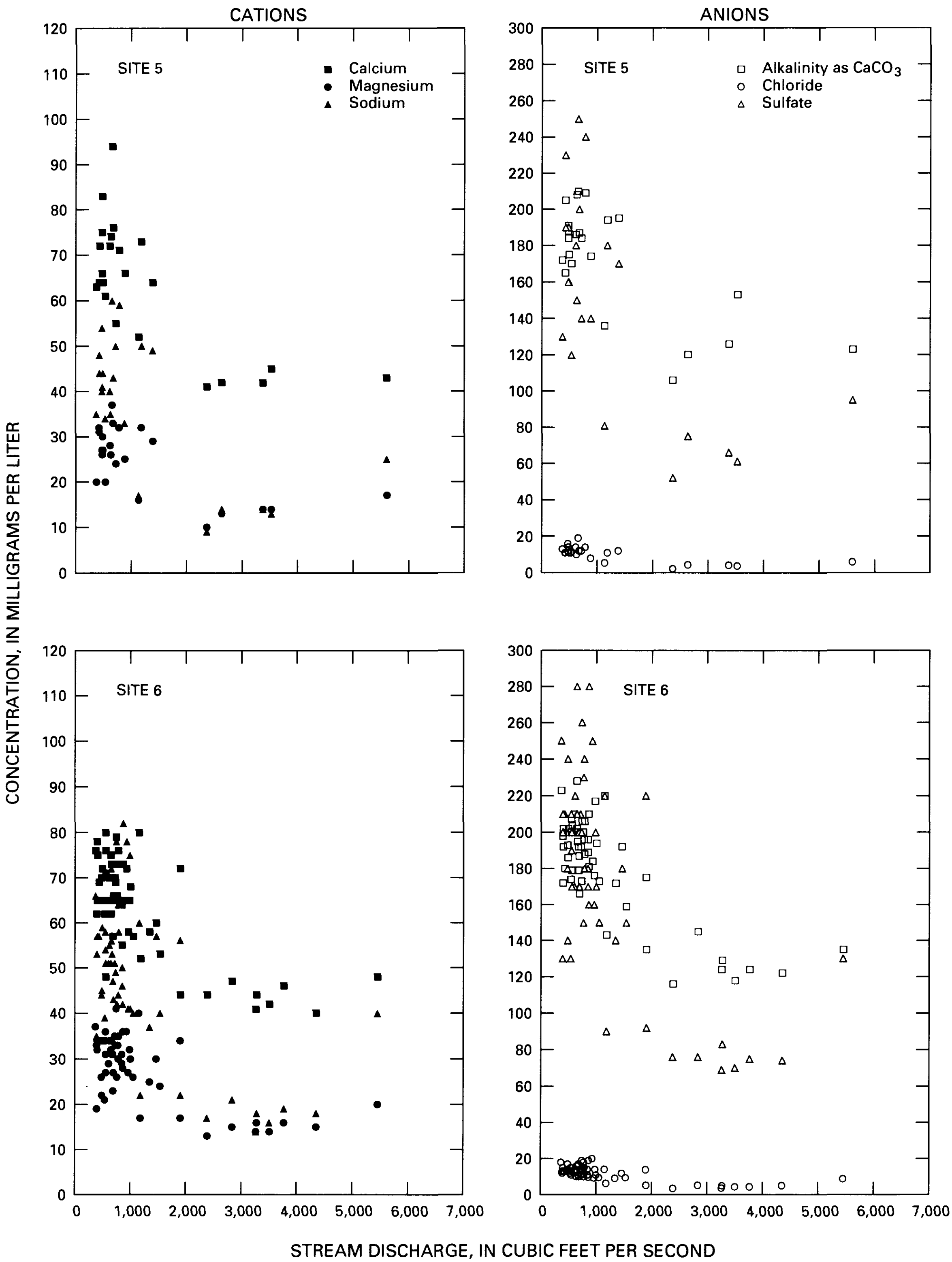

Figure 20. Correlation of periodic measurements of selected major ions with stream discharge at sites 5 and 6, water years 1983-88.

Table 8. Regression information for estimating concentrations of major ions from measurements of specific conductance at sites 1-6, White River, water years 1975-88

[Regression significance increases as the coefficient of determination (r^2) approaches 1.0; mg/L, milligrams per liter; y, constituent concentration, in milligrams per liter]

Constituent name and symbol (y)	Sample		Regression data, where y = a + b (specific conductance)			
	Number	Range (mg/L)	Coefficients (a)	Coefficients (b)	Standard error (SE)	Coefficient of determination (r^2)
SITE 1 (WATER YEARS 1977-88)						
Calcium (Ca)	36	23-61	0.95	0.152	3.71	0.90
Magnesium (Mg)	36	4.7-11	1.11	0.026	0.61	0.90
Potassium (K)	36	0.7-1.4	0.60	0.001	0.13	0.38
Sodium (Na)	36	2.0-4.0	1.10	0.006	0.26	0.76
Alkalinity ($CaCO_3$)	36	59-100	43.32	0.142	6.86	0.69
Chloride (Cl)	36	0.1-0.9	0.15	0.001	0.18	0.21
Fluoride (F)	36	0.1-0.4	0.16	0.000	0.06	0.03
Sulfate (SO_4)	36	23-100	-30.36	0.335	9.15	0.88
Hardness ($CaCO_3$)	36	77-200	6.56	0.487	12.42	0.89
Dissolved solids	36	105-257	12.17	0.625	15.63	0.89
SITE 2 (WATER YEARS 1977-88)						
Calcium (Ca)	31	30-54	6.75	0.125	2.64	0.80
Magnesium (Mg)	31	6.7-11	2.09	0.026	0.71	0.71
Potassium (K)	31	0.5-1.3	0.21	0.002	0.16	0.31
Sodium (Na)	31	1.0-4.5	-0.27	0.009	0.60	0.30
Alkalinity ($CaCO_3$)	31	90-140	54.42	0.223	6.60	0.66
Chloride (Cl)	31	0.3-2.9	-0.43	0.005	0.56	0.11
Fluoride (F)	31	0.1-0.3	0.19	0.000	0.04	0.06
Sulfate (SO_4)	31	7.3-46	-30.28	0.215	5.55	0.72
Hardness ($CaCO_3$)	31	100-180	28.73	0.409	9.07	0.78
Dissolved solids	31	110-209	13.25	0.564	11.18	0.81

Table 8. Regression information for estimating concentrations of major ions from measurements of specific conductance at sites 1-6, White River, water years 1975-88--Continued

Constituent name and symbol (y)	Sample		Regression data, where y = a + b (specific conductance)			
	Number	Range (mg/L)	Coefficients (a)	Coefficients (b)	Standard error (SE)	Coefficient of determination (r^2)
SITE 3 (WATER YEARS 1975-88)						
Calcium (Ca)	297	26-70	-1.05	0.154	2.78	0.93
Magnesium (Mg)	297	5.4-18	1.88	0.023	1.05	0.67
Potassium (K)	297	0.4-4.3	0.90	0.001	0.48	0.01
Sodium (Na)	297	1.1-22	1.40	0.007	2.03	0.05
Alkalinity ($CaCO_3$)	246	67-131	59.28	0.135	7.44	0.57
Chloride (Cl)	297	0.0-12	-0.33	0.006	1.57	0.06
Fluoride (F)	12	0.1-0.3	0.16	0.000	0.07	0.00
Sulfate (SO_4)	297	16-120	-47.70	0.343	8.77	0.86
Hardness ($CaCO_3$)	297	88-230	4.13	0.486	9.81	0.91
Dissolved solids	11	130-281	-9.51	0.665	6.36	0.99
SITE 4 (WATER YEARS 1982-88)						
Calcium (Ca)	85	33-78	10.11	0.101	3.36	0.92
Magnesium (Mg)	85	8.8-25	-2.00	0.039	1.39	0.91
Potassium (K)	85	0.0-3.9	0.96	0.001	0.67	0.03
Sodium (Na)	85	5.2-34	-8.92	0.052	2.26	0.87
Alkalinity ($CaCO_3$)	40	87-183	48.20	0.194	9.86	0.84
Chloride (Cl)	85	1.8-18	-4.62	0.026	1.59	0.77
Fluoride (F)	19	0.1-0.3	0.10	0.000	0.06	0.18
Sulfate (SO_4)	85	32-170	-55.33	0.328	7.63	0.96
Hardness ($CaCO_3$)	85	120-300	17.03	0.413	11.47	0.94
Dissolved solids	20	169-416	-6.80	0.653	7.86	0.99

Table 8. Regression information for estimating concentrations of major ions from measurements of specific conductance at sites 1-6, White River, water years 1975-88--Continued

Constituent name and symbol (y)	Sample		Regression data, where y = a + b (specific conductance)			
	Number	Range (mg/L)	Coefficients (a)	Coefficients (b)	Standard error (SE)	Coefficient of determination (r^2)
			SITE 5 (WATER YEARS 1983-88)			
Calcium (Ca)	23	41-94	15.25	0.077	6.41	0.80
Magnesium (Mg)	23	10-37	-3.09	0.044	2.03	0.93
Potassium (K)	23	1.0-2.3	1.05	0.001	0.27	0.23
Sodium (Na)	23	9-60	-18.10	0.088	4.44	0.92
Alkalinity ($CaCO_3$)	23	106-210	64.98	0.172	12.35	0.85
Chloride (Cl)	23	2.2-19	-4.52	0.024	1.80	0.83
Fluoride (F)	23	0.1-0.4	0.08	0.000	0.07	0.27
Sulfate (SO_4)	23	52-250	-61.22	0.339	15.86	0.93
Hardness ($CaCO_3$)	23	140-390	24.50	0.378	20.17	0.91
Dissolved solids	23	193-605	-18.23	0.679	17.51	0.98
			SITE 6 (WATER YEARS 1983-88)			
Calcium (Ca)	54	40-80	22.10	0.059	6.34	0.69
Magnesium (Mg)	54	13-41	-2.59	0.044	2.60	0.88
Potassium (K)	54	1.0-3.7	0.49	0.002	0.50	0.27
Sodium (Na)	54	14-82	-23.24	0.101	4.80	0.92
Alkalinity ($CaCO_3$)	54	116-228	66.05	0.165	12.47	0.82
Chloride (Cl)	54	3.3-20	-4.61	0.024	1.92	0.80
Fluoride (F)	54	0.1-0.3	0.06	0.000	0.05	0.46
Sulfate (SO_4)	54	69-280	-65.41	0.345	12.16	0.95
Hardness ($CaCO_3$)	54	160-370	43.22	0.331	21.40	0.86
Dissolved solids	54	229-632	-22.09	0.680	19.10	0.97

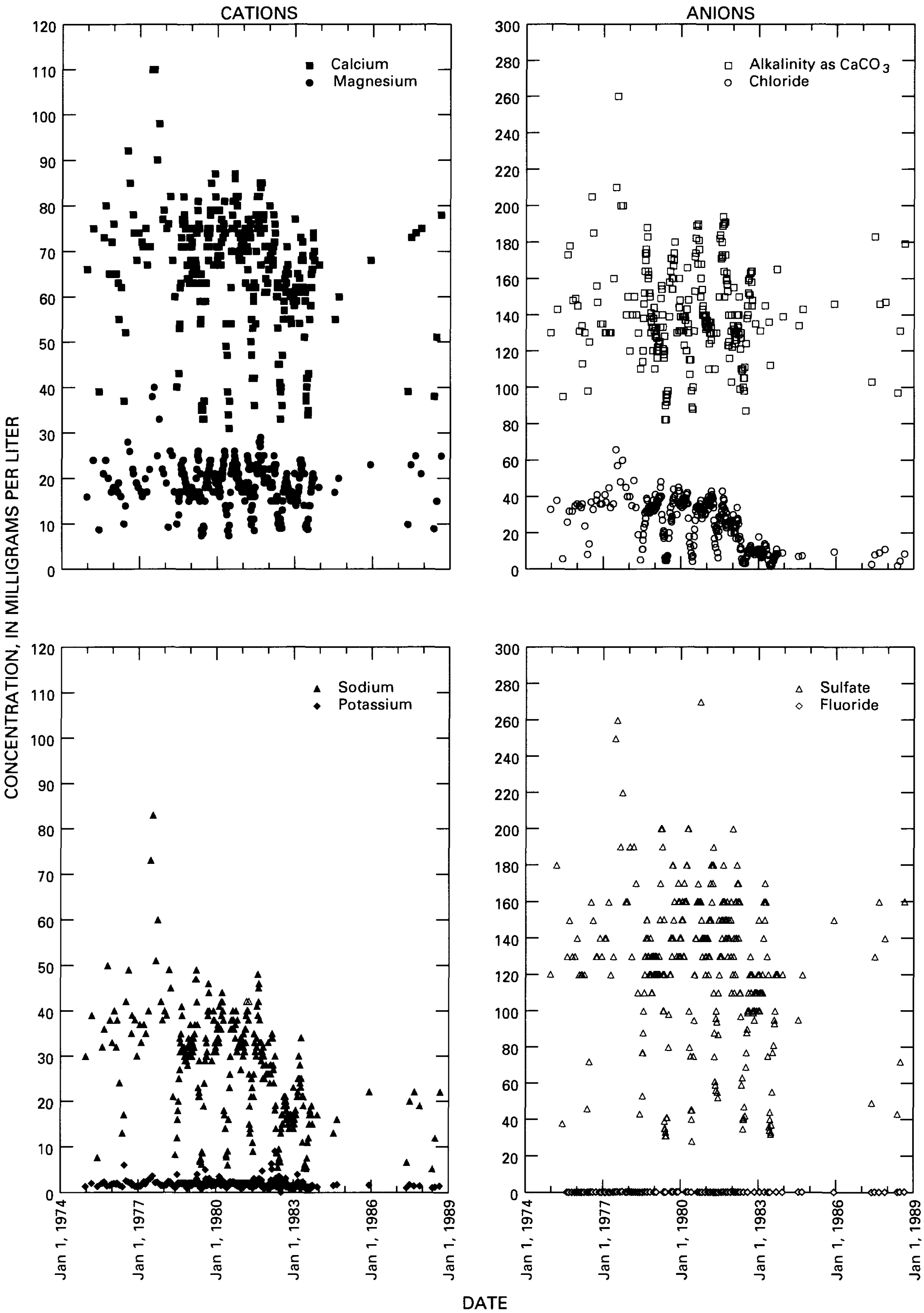

Figure 21. Periodic measurements of major ions at site 4, water years 1975-88.

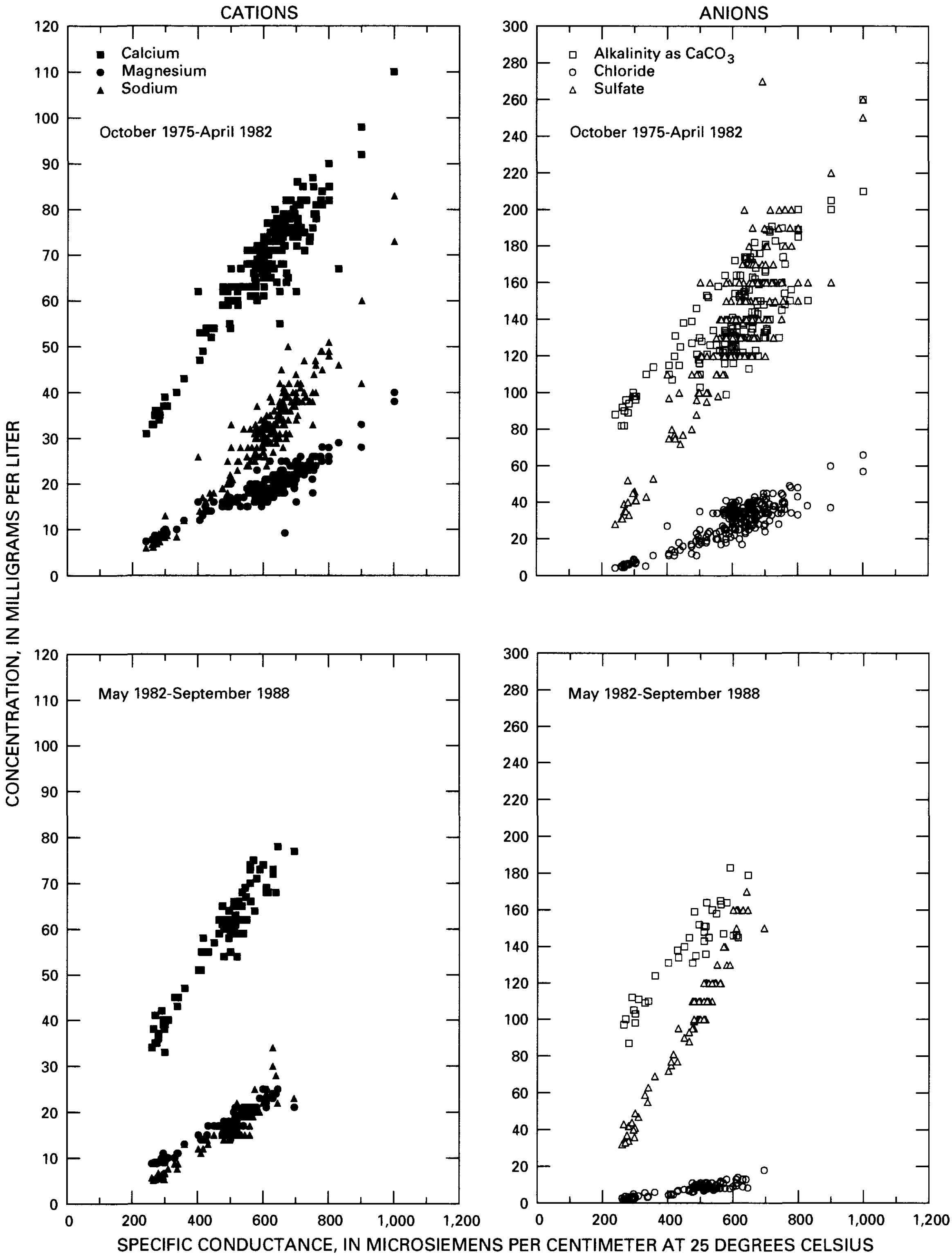

Figure 22. Correlation of periodic measurements of selected major ions with specific conductance at site 4, water years 1975-88.

Analyses of the data shown in figures 14, 18-22, and table 8 indicate the following:

1. For all streamflow ranges, concentrations of the major ions increased downstream from sites 1 and 2 to site 6. Concentrations of major ions at sites 1-6 were greatest in low streamflow and least in high streamflow. Dissolved solids ranged in concentration from about 100 to 250 mg/L at sites 1 and 2 to about 230 to 630 mg/L at site 6. The increases in dissolved-solids concentrations (and related increases in specific conductance) in low streamflow indicated that base flows in the White River probably were maintained from ground water or alluvial storage, or both, and from irrigation return flow that had large concentrations of dissolved solids. During spring runoff, the large concentrations of dissolved solids in base flows were diluted by snowmelt that contained small concentrations of dissolved solids.

2. The composition of dissolved solids at site 1 was mostly calcium, bicarbonate, and sulfate. The composition of dissolved solids at site 2 was mostly calcium and bicarbonate. Sulfate concentrations were greater at site 1 than at site 2 probably because sulfate-rich minerals, such as gypsum or anhydrite, were more common in surface and near-surface sedimentary deposits in the North Fork Basin.

3. In low streamflow, the composition of dissolved solids in the main stem of the White River changed from mostly calcium, bicarbonate, and (or) sulfate in the upstream reaches (upstream from site 4) to mostly calcium, sodium, sulfate, and bicarbonate in the downstream reaches (sites 5 and 6). During snowmelt runoff when streamflow in the White River was greater than 1,000 ft^3/s, calcium and bicarbonate generally were the principal constituents at all sites. Water hardness ranged from moderately hard in the high streamflow upstream from site 4 to very hard in medium and low streamflow at site 1 and sites 3-6. The increases of sodium and sulfate that occurred downstream in low streamflow probably were caused from irrigation return flow and from ground water that had been in contact with the extensive silt and shale deposits of the central and downstream areas of the White River Basin.

4. Sodium (Na) concentrations were compared with calcium (Ca) and magnesium (Mg) concentrations using the sodium-absorption ratio (SAR) of the water (U.S. Salinity Laboratory Staff, 1954). The SAR is used with values of specific conductance to assess the hazard of sodium in replacing calcium and magnesium in soil structures when the water is used for irrigation. The ratio is expressed as:

$$SAR = \frac{(Na^+)}{\sqrt{\frac{(Ca^{++}) + (Mg^{++})}{2}}}, \qquad (7)$$

where ion concentrations (in parentheses) are expressed in milliequivalents per liter. For the range of values of specific conductance for the White River, values of SAR generally less than 6 indicate a low sodium hazard. All values of SAR at sites 1-6 were less than 2.1.

Annual loads of dissolved solids at sites 1-6 were measured by using regression methods and assumptions similar to the procedures described in the "Loads" section of this report, except that instantaneous dissolved-solids loads were regressed with daily stream discharge. Instantaneous dissolved-solids load (L_{ds}, in tons per day) is a function of instantaneous stream discharge (Q), in cubic feet per second, dissolved-solids concentration (C_{ds}), in milligrams per liter, and the conversion constant 0.0027. Dissolved-solids load is calculated as follows:

$$L_{ds} = (0.0027) Q C_{ds} . \qquad (8)$$

Data analyses indicated that a single regression for each site was applicable for all hydrologic events (table 9). Two regressions were used at site 4 to define the slight differences in water quality for the periods before and after early 1982. Daily loads of dissolved solids (L_{dsd}) were computed by using the regression information (table 9) and summed by water year to obtain annual dissolved-solids loads (L_{dsa}) for sites 1-4 for water years 1975-88 and sites 5 and 6 for water years 1983-88.

Estimates of annual dissolved-solids loads at sites 5 and 6 for water years 1975-82 were derived by using two pairs of least-squares regressions. The first pair of regressions related measured annual dissolved-solids loads at sites 5 and 6 (water years 1983-88) with measured annual dissolved-solids loads at site 4. The second regression pair was obtained by relating

Table 9. Regression information used to determine dissolved-solids loads at sites 1-6, White River, water years 1975-88

[Ldsd, daily dissolved-solids load in tons per day; Qd, daily discharge in cubic feet per second]

Site	Number of samples	Logarithm form (base 10) $\log L_{dsd} = a + b \log Q_d$ — Coefficients (a)	(b)	Standard error (SE)	Variance (s^2)	Bias correction factor (C_b)	Antilogarithm form $L_{dsd} = 10^a Q_d^b C_b$
1	36	0.537	0.656	0.031	0.001	1.0025	$L_{dsd} = 10^{0.537} Q_d^{0.656} 1.0025$
2	31	-0.036	0.855	0.038	0.001	1.0038	$L_{dsd} = 10^{-0.036} Q_d^{0.855} 1.0038$
3	12	0.516	0.722	0.032	0.001	1.0028	$L_{dsd} = 10^{0.516} Q_d^{0.722} 1.0028$
[1]4	72	1.132	0.573	0.056	0.003	1.0085	$L_{dsd} = 10^{1.132} Q_d^{0.573} 1.0085$
[2]4	20	0.971	0.630	0.051	0.003	1.0070	$L_{dsd} = 10^{0.971} Q_d^{0.630} 1.0070$
[3]5	23	0.934	0.691	0.091	0.008	1.0220	$L_{dsd} = 10^{0.934} Q_d^{0.691} 1.0220$
[3]6	54	0.988	0.690	0.080	0.006	1.0172	$L_{dsd} = 10^{0.988} Q_d^{0.690} 1.0172$

[1]October 1975 to April 1982.
[2]May 1982 to September 1988.
[3]Water years 1983-88.

measured annual dissolved-solids loads with annual stream discharge at sites 5 and 6 for water years 1983-88. Differences between regression values and measured values were less than 7 percent for the first pair of regressions and less than 3 percent for the second pair of regressions. The best estimated values of annual dissolved-solids loads at sites 5 and 6 for water years 1975-82 were obtained by using the regression estimates from the second regression pair. Estimated values of annual dissolved-solids loads (water years 1975-82) and measured values of annual dissolved-solids loads (water years 1983-88) for sites 5 and 6 and measured dissolved-solids loads for site 4 (water years 1975-88) are correlated with annual stream discharge in figure 23.

Selected data for daily and annual dissolved-solids loads for the White River are listed in table 10. Statistical summaries of annual dissolved-solids loads for sites 1-6, the combined loads of sites 1 and 2 (site 3A), and contributions to annual dissolved-solids loads from river segments (river subbasins) of the White River are shown in figure 24. Annual dissolved-solids loads ranged from about 21,100 tons at site 2 to about 480,000 tons at site 6. The average annual dissolved-solids loads were least in the North Fork (site 1, about 54,000 tons) and South Fork (site 2, about 38,700 tons) and greatest at site 6 (estimated at about 348,000 tons). A comparison of annual loads of dissolved solids in the main stem of the White River (fig. 24) indicates that the average annual dissolved-solids loads increased downstream by about 250,000 tons between sites 3A and 6. Except for water years of very low stream discharge (1977) or years of high stream discharge (1983-86), annual contributions of dissolved-solids loads from each subbasin in the White River Basin varied little.

Comparisons of bar graphs of annual dissolved-solids loads (fig. 24) contributed from the river segments (river subbasins) indicate that the North and South Fork Basins and the river subbasins between sites 3 and 5 were the principal sources of dissolved solids in the White River. Although concentrations of dissolved solids in the North Fork (site 1) and South Fork (site 2) were small [generally from 100 to 250 mg/L (Hutchison, 1975)], annual dissolved-solids loads were substantial because most of the water in the White River originates upstream from sites 1 and 2. Irrigation diversions from the White River upstream from site 3 probably caused an underestimation of dissolved-solids loads between sites 3 and 3A and a negative load in water year 1977 (fig. 24). Water from irrigation return flow, ground water, and the chemical action of surface runoff on poorly consolidated shales and siltstones probably accounted for most of the additional increase in dissolved-solids loads from the subbasins between sites 3 and 5.

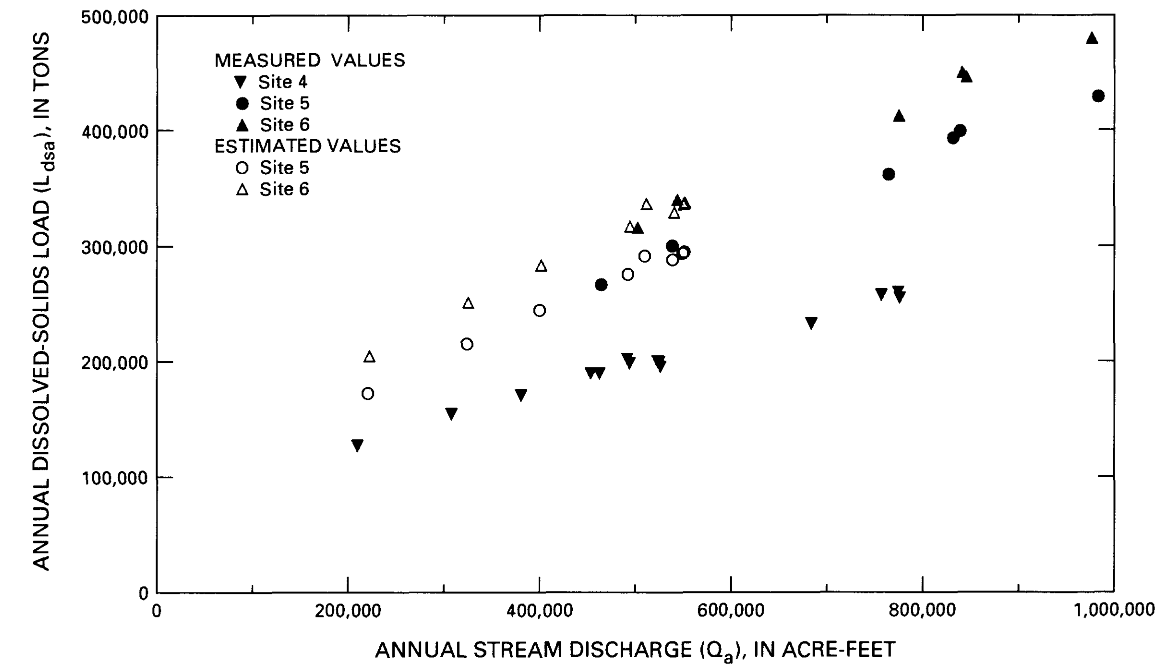

Figure 23. Correlation of estimated (water years 1975-82) and measured (water years 1983-88) annual dissolved-solids loads at site 5 and 6 and measured annual dissolved-solids loads at site 4 (water years 1975-88) with annual stream discharge.

A comparison of the annual suspended-sediment loads (table 5) and annual dissolved-solids loads (table 10) indicate that total solids (suspended sediment plus dissolved solids) transported in the White River were mostly as dissolved solids upstream from site 4 and mostly as suspended sediment downstream from site 4. Annual total-solids loads at sites 1-6 ranged from about 23,200 tons at site 2 (water year 1977) to about 2.4 million tons at site 6 (water year 1984). The estimated average annual total-solids load at site 6 for water years 1975-88 was about 1.1 million tons.

Nutrients

A total of 51 water samples were collected periodically at sites 1-6 during water years 1987-88 and were analyzed for dissolved concentrations of nitrogen and phosphorus. The samples were collected in downstream order to define changes in nutrient concentrations as water moved downstream. Dissolved concentrations of ammonia as nitrogen (hereinafter referred to as ammonia), nitrite plus nitrate as nitrogen (hereinafter referred to as nitrite plus nitrate), organic nitrogen, and phosphorus for water years 1987-88 at sites 1-6 are shown as grouped data for each site in figures 25 and 26. Analyses of data for water years 1987-88 and a review of other nutrient data collected periodically during water years 1975-86 indicate that changes in nutrient concentrations correlated poorly with changes in stream discharge.

Concentrations of ammonia in the White River (fig. 25) ranged from less than 0.01 to 0.11 mg/L, and concentrations were less than or equal to 0.05 mg/L in 46 of 51 samples. Concentrations of nitrite plus nitrate in the White River ranged from less than 0.1 mg/L at all sites to 0.53 mg/L at site 6. Concentrations were least at site 1 (all values less than 0.1 mg/L) and generally were small at sites 2-4 (all values were less than 0.18 mg/L). Concentrations of nitrite plus nitrate generally increased downstream and exceeded 0.20 mg/L in 12 of 22 samples at sites 5 and 6.

Table 10. Dissolved-solids loads measured using the regressions in table 9 or estimated from regressions of annual dissolved-solids loads and annual stream discharge for sites 1-6, White River, water years 1975-88

[tons/acre-ft, tons per acre-feet; tons/mi^2, tons per square mile; --, no data; *, estimated; data calculations are on unrounded data; all data rounded to standard significant figures]

Water year	SITE 1						SITE 2					
	Daily load (tons)			Annual			Daily load (tons)			Annual		
	Maximum	Minimum	Average	Load (tons)	Yield (tons/acre-ft)	Yield (tons/mi^2)	Maximum	Minimum	Average	Load (tons)	Yield (tons/acre-ft)	Yield (tons/mi^2)
1975	405	85	148	54,200	0.22	208	593	40	108	39,400	0.19	223
1976	270	75	122	44,800	0.25	172	521	43	90	33,100	0.20	187
1977	174	69	94	34,200	0.30	132	215	35	58	21,100	0.23	119
1978	413	75	146	53,200	0.21	205	773	38	119	43,300	0.18	245
1979	411	92	145	53,100	0.22	204	666	38	107	39,200	0.19	221
1980	365	89	140	51,400	0.23	198	598	36	99	36,400	0.19	206
1981	302	82	114	41,700	0.26	160	374	25	70	25,700	0.21	145
1982	331	84	150	54,900	0.22	211	408	38	109	39,800	0.20	225
1983	536	85	170	62,200	0.20	239	861	43	128	46,900	0.18	265
1984	659	94	191	69,800	0.18	268	684	51	129	47,300	0.19	267
1985	563	109	195	71,100	0.19	273	722	55	136	49,500	0.19	280
1986	389	104	172	62,900	0.21	242	640	54	134	48,900	0.19	276
1987	319	100	142	51,900	0.24	200	416	55	102	37,200	0.20	210
1988	398	75	136	49,900	0.23	192	504	39	91	33,400	0.20	189
Maximum	659	109	195	71,100	0.30	273	861	55	136	49,500	0.23	280
Minimum	174	69	94	34,200	0.18	132	215	25	58	21,100	0.18	119
Average	395	87	148	54,000	0.23	208	570	42	106	38,700	0.20	218

Table 10. Dissolved-solids loads measured using the regressions in table 9 or estimated from regressions of annual dissolved-solids loads and annual stream discharge for sites 1-6, White River, water years 1975-88--Continued

Water year	SITE 3A (SITE 1 plus SITE 2)						SITE 3					
	Daily load (tons)			Annual			Daily load (tons)			Annual		
	Maximum	Minimum	Average	Load (tons)	Yield (tons/ acre-ft)	Yield (tons/ mi^2)	Maximum	Minimum	Average	Load (tons)	Yield (tons/ acre-ft)	Yield (tons/ mi^2)
1975	--	--	256	93,600	0.21	214	1,380	147	323	118,000	0.25	182
1976	--	--	213	77,900	0.23	178	938	96	263	96,100	0.28	148
1977	--	--	152	55,300	0.27	127	376	13	148	54,100	0.36	83
1978	--	--	264	96,500	0.20	221	1,200	59	301	110,000	0.25	170
1979	--	--	253	92,300	0.21	211	1,440	114	315	115,000	0.25	177
1980	--	--	240	87,800	0.21	201	1,080	124	287	105,000	0.27	162
1981	--	--	185	67,400	0.24	154	670	72	215	78,300	0.32	121
1982	--	--	259	94,700	0.21	217	1,000	152	323	118,000	0.26	182
1983	--	--	299	109,000	0.19	250	1,630	160	367	134,000	0.24	207
1984	--	--	320	117,000	0.19	268	1,610	178	429	157,000	0.22	242
1985	--	--	330	121,000	0.19	276	1,400	149	400	146,000	0.24	225
1986	--	--	306	112,000	0.20	256	1,320	205	408	149,000	0.24	230
1987	--	--	244	89,100	0.22	204	852	138	301	110,000	0.28	170
1988	--	--	228	83,300	0.22	191	949	131	273	100,000	0.28	154
Maximum	--	--	330	121,000	0.27	276	1,630	205	429	157,000	0.36	242
Minimum	--	--	152	55,300	0.19	127	376	13	148	54,100	0.22	83
Average	--	--	254	92,600	0.21	212	1,132	124	311	114,000	0.27	175

Table 10. Dissolved-solids loads measured using the regressions in table 9 or estimated from regressions of annual dissolved-solids loads and annual stream discharge for sites 1-6, White River, water years 1975-88--Continued

Water year	SITE 4						SITE 5					
	Daily load (tons)			Annual			Daily load (tons)			Annual		
					Yield						Yield	
	Maximum	Minimum	Average	Load (tons)	(tons/acre-ft)	(tons/mi^2)	Maximum	Minimum	Average	Load (tons)	(tons/acre-ft)	(tons/mi^2)
1975	1,570	301	545	199,000	0.38	194	--	--	--	*299,000	*0.54	*164
1976	1,100	268	467	171,000	0.45	167	--	--	--	*252,000	*0.63	*138
1977	590	174	348	127,000	0.60	124	--	--	--	*196,000	*0.89	*108
1978	1,590	264	534	195,000	0.37	190	--	--	--	*296,000	*0.55	*163
1979	1,560	317	548	200,000	0.38	195	--	--	--	*300,000	*0.54	*165
1980	1,290	335	516	189,000	0.41	185	--	--	--	*281,000	*0.57	*154
1981	1,010	288	422	154,000	0.50	150	--	--	--	*228,000	*0.70	*125
1982	1,220	294	542	198,000	0.40	193	--	--	--	*287,000	*0.56	*158
1983	2,280	319	638	233,000	0.34	228	3,420	452	992	362,000	0.47	199
1984	2,230	350	697	255,000	0.33	249	3,570	513	1,174	429,000	0.44	236
1985	1,960	385	712	260,000	0.34	254	2,780	532	1,077	393,000	0.47	216
1986	1,810	381	707	258,000	0.34	252	2,910	561	1,093	399,000	0.48	219
1987	1,220	359	553	202,000	0.41	197	1,970	505	823	300,000	0.56	165
1988	1,370	290	516	189,000	0.42	185	2,150	431	730	267,000	0.58	147
Maximum	2,280	385	712	260,000	0.60	254	3,570	561	1,174	429,000	*0.89	236
Minimum	590	174	348	127,000	0.33	124	1,970	431	730	*196,000	0.44	*108
Average	1,490	309	553	202,000	0.41	197	2,800	499	982	*306,000	*0.57	*168

Table 10. Dissolved-solids loads measured using the regressions in table 9 or estimated from regressions of annual dissolved-solids loads and annual stream discharge for sites 1-6, White River, water years 1975-88--Continued

Water year	SITE 6					
	Daily load (tons)			Annual		
				Load (tons)	Yield	
	Maximum	Minimum	Average		(tons/ acre-ft)	(tons/ mi^2)
1975	--	--	--	*338,000	*0.61	*134
1976	--	--	--	*286,000	*0.71	*113
1977	--	--	--	*223,000	*1.01	*88
1978	--	--	--	*335,000	*0.62	*132
1979	--	--	--	*339,000	*0.61	*134
1980	--	--	--	*319,000	*0.65	*126
1981	--	--	--	*260,000	*0.80	*103
1982	--	--	--	*325,000	*0.64	*128
1983	3,820	530	1,130	412,000	0.53	163
1984	4,080	607	1,310	480,000	0.49	190
1985	3,160	618	1,220	446,000	0.53	176
1986	3,020	649	1,230	450,000	0.53	178
1987	2,040	512	930	340,000	0.63	134
1988	2,330	406	863	316,000	0.63	125
Maximum	4,080	649	1,310	480,000	*1.01	190
Minimum	2,040	406	863	*223,000	0.49	*88
Average	3,080	554	1,120	*348,000	*0.64	*137

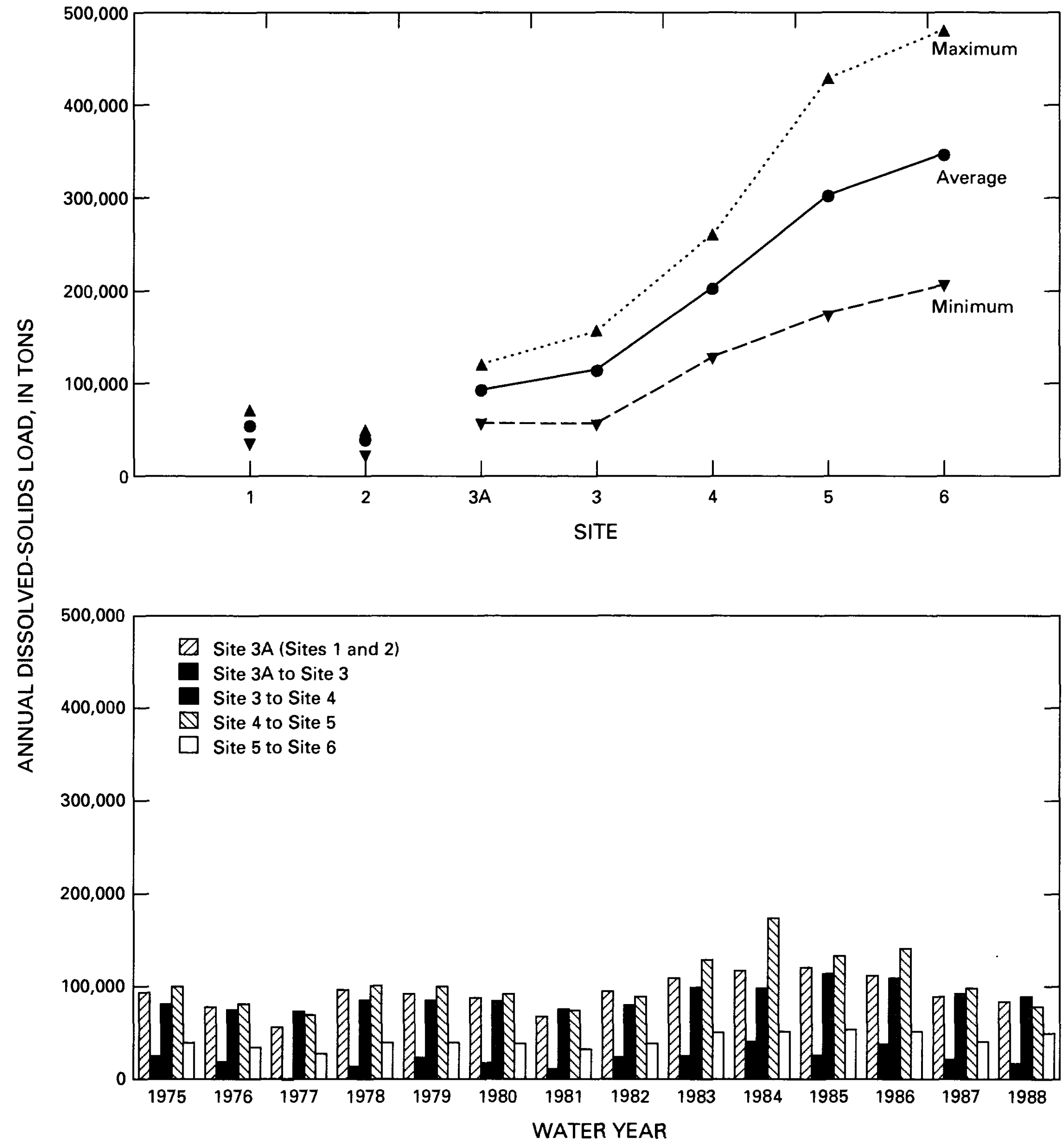

Figure 24. Average and range of annual dissolved-solids loads for the North Fork (site 1), the South Fork (site 2), and the main stem of the White River (sites 3A-6), water years 1975-88, and annual dissolved-solids loads for segments of the White River between sites.

Concentrations of organic nitrogen in the White River ranged from less than 0.16 mg/L at site 5 to 1.50 mg/L at site 6. Except for the small concentration range at site 2 (less than 0.20 to 0.50 mg/L), the general similarities of the data ranges for each site indicate that the sources of organic nitrogen in the basin were widespread.

Concentrations of phosphorus in the White River were equal to or less than 0.03 mg/L in 45 of 51 samples and less than 0.08 mg/L in 50 of 51 samples. A single concentration of 0.62 mg/L was measured at site 6 on June 23, 1987. The phosphorus concentration in a water sample collected the same day at site 5 was 0.05 mg/L. The large phosphorus concentration measured at site 6 probably was from a temporary, localized input that contained large concentrations of phosphorus. The phosphorus entered the White River upstream from site 6 and, perhaps, downstream from site 5. Although phosphorus concentrations in the White River generally were 0.03 mg/L or less, concentrations occasionally exceeded 0.03 mg/L downstream from site 4.

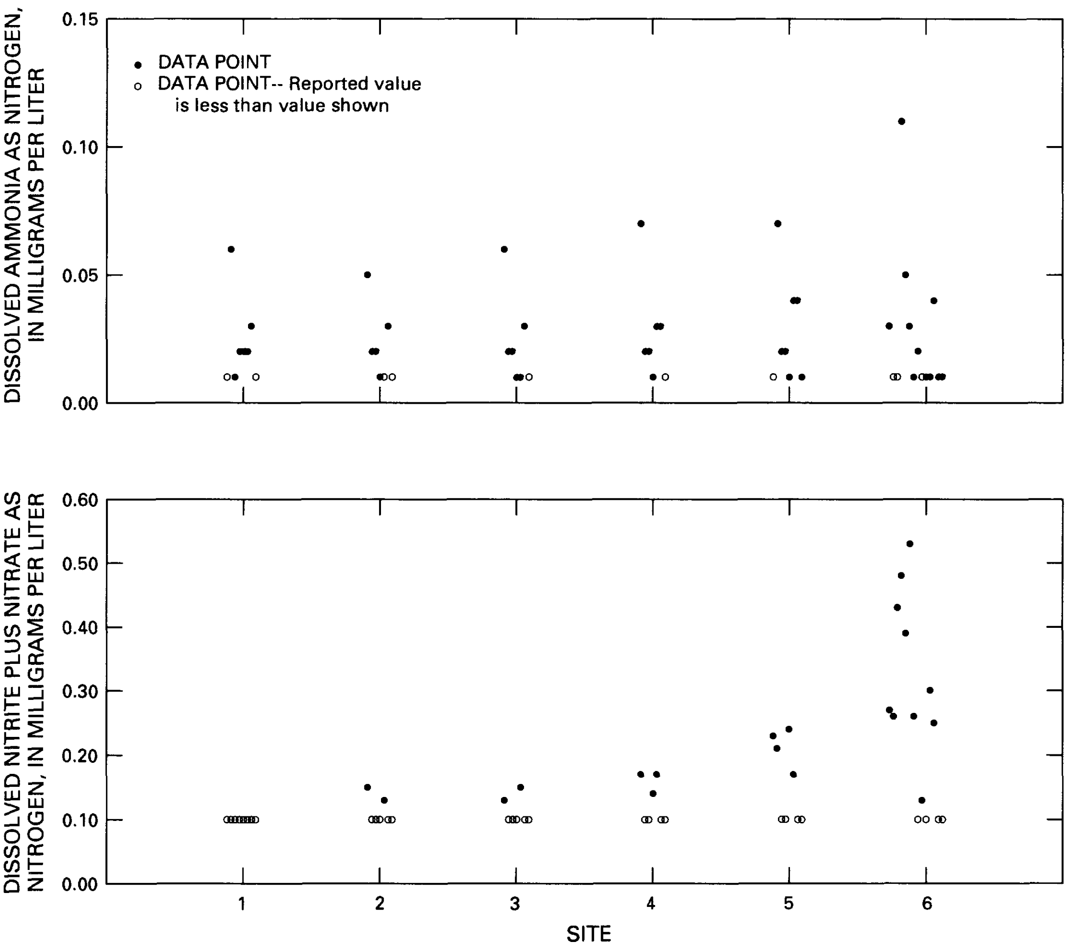

Figure 25. Concentrations of dissolved ammonia as nitrogen and nitrite plus nitrate as nitrogen for sites 1-6, water years 1987-88.

Concentrations of nitrogen and phosphorus generally were greater at sites 5 and 6 than at sites 1-4. The increases in nutrients downstream from site 4 probably were related to nutrient transport in intermittent runoff from agricultural land. Changes in nutrient concentrations also could result from the decomposition of organic matter in the river. Five samples containing concentrations of ammonia greater than 0.05 mg/L also contained concentrations of organic nitrogen that ranged from 0.54 to 1.0 mg/L. The samples were collected during the spring of 1987 and may have contained organic matter in various stages of decomposition. The combined concentrations of dissolved nitrogen (ammonia and nitrite plus nitrate) at site 6 and concentrations of dissolved phosphorus at all sites often exceeded the concentration levels of 0.3 mg/L as nitrogen and 0.01 mg/L as phosphorus that are considered sufficient to produce nuisance algae growths (Sawyer, 1947).

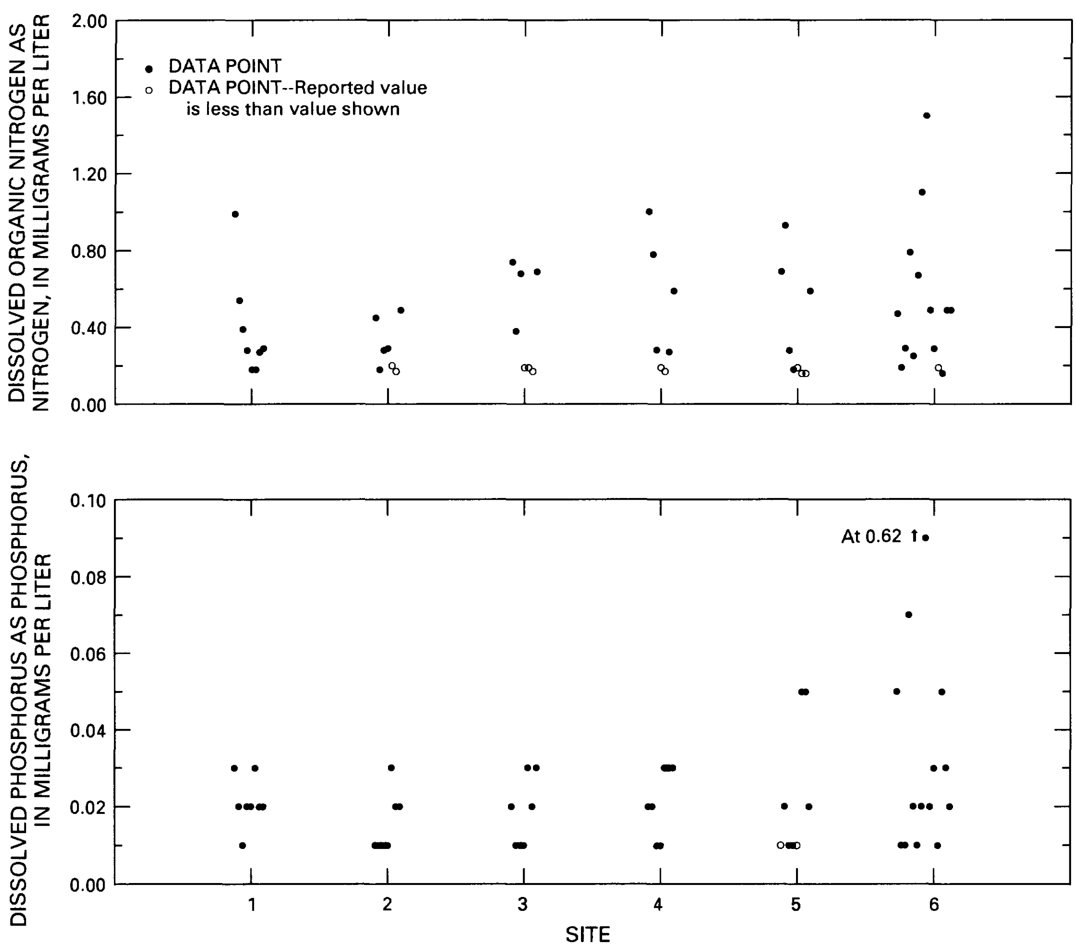

Figure 26. Concentrations of dissolved organic nitrogen and phosphorus for sites 1-6, water years 1987-88.

Trace Constituents

Data for dissolved and total or total recoverable concentrations of 27 trace constituents analyzed from water samples collected intermittently at sites 1-6 were compiled for water years 1975-88. Data were unavailable for concentrations of bromide, hexavalent chromium, iodide, and thallium; and concentrations of total cyanide in 29 water samples from sites 1-6 were less than 0.01 mg/L. No additional analyses of the above five constituents were done. Data also were unavailable for total recoverable boron and vanadium.

Ranges for the remaining 22 trace constituents are listed in table 11. Data from filtered water samples were grouped by site, and concentration distributions are shown as dissolved concentrations in figure 27. Total or total recoverable concentrations (hereinafter referred to as total), determined from unfiltered water samples, were grouped by site, and concentration distributions are shown in figure 28. Although the data were sparse at some sites and many concentrations were reported as less than values, the concentrations of trace constituents in the White River are summarized as follows:

1. Dissolved and total concentrations of 15 trace constituents (aluminum, arsenic, barium, boron, copper, iron, lead, lithium, manganese, molybdenum, nickel, selenium, strontium, vanadium, and zinc) commonly were detected in the White River. All concentrations of arsenic and selenium were equal to or less than 5 µg/L, and the concentration range for dissolved manganese (5-70 µg/L) at site 4 was unexplainably large when compared with manganese concentrations (generally less than 20 µg/L) at sites 1-3, 5, and 6.

Table 11. Concentration ranges of trace constituents for sites 1-6, White River, water years 1975-88

[Total, analytically determined as total or total recoverable; µg/L, micrograms per liter; Number, number of samples; Maximum, maximum measured value given preference to maximum values reported as less than values; <, value less than value shown; --, no data]

Constituent and (symbol)	Statistic	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6	
		Dissolved (µg/L)	Total (µg/L)	Dissolved (µg/L)	Total (µg/L)	Dissolved (µg/L)	Total (µg/L)	Dissolved (µg/L)	Total (µg/L)	Dissolved (µg/L)	Total (µg/L)	Dissolved (µg/L)	Total (µg/L)
Aluminum	Number	4	6	4	5	1	5	15	22	3	5	7	9
(Al)	Maximum	50	1,300	40	1,800	10	1,900	50	4,800	20	7,200	110	49,000
	Minimum	<10	40	<10	60	10	50	0	40	<10	190	<10	230
Antimony	Number	3	5	3	4	--	4	--	4	3	5	7	--
(Sb)	Maximum	2	<1	<1	1	--	<1	--	6	1	<1	5	--
	Minimum	<1	<1	<1	<1	--	<1	--	<1	<1	<1	<1	--
Arsenic	Number	11	6	9	5	1	5	35	22	5	5	10	9
(As)	Maximum	3	1	1	<1	1	3	2	2	1	2	1	3
	Minimum	0	<1	<1	0	1	<1	<1	<1	<1	<1	<1	1
Barium	Number	5	5	3	4	--	4	17	21	5	5	10	9
(Ba)	Maximum	32	<100	22	100	--	100	300	800	51	100	100	200
	Minimum	19	<100	15	<100	--	<100	20	0	33	<100	30	<100
Beryllium	Number	4	6	4	5	1	5	15	21	3	5	7	9
(Be)	Maximum	<1	<10	<1	<10	<1	<10	<10	10	<0.5	<10	<10	<10
	Minimum	<0.5	0	<0.5	0	<1	0	<1	0	<0.5	<10	<0.5	<10
Boron	Number	9	--	4	--	1	--	82	--	12	--	53	--
(B)	Maximum	10	--	<10	--	0	--	250	--	60	--	80	--
	Minimum	<10	--	0	--	0	--	0	--	20	--	20	--
Cadmium	Number	6	6	4	5	1	5	18	22	5	5	10	9
(Cd)	Maximum	<1	<1	7	<1	<1	<1	1	1	2	<1	<1	3
	Minimum	<1	0	<1	0	<1	0	0	0	<1	<1	<1	<1

Table 11. Concentration ranges of trace constituents for sites 1-6, White River, water years 1975-88 --Continued

Constituent and (symbol)	Statistic	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6	
		Dissolved (µg/L)	Total (µg/L)	Dissolved (µg/L)	Total (µg/L)	Dissolved (µg/L)	Total (µg/L)	Dissolved (µg/L)	Total (µg/L)	Dissolved (µg/L)	Total (µg/L)	Dissolved (µg/L)	Total (µg/L)
Chromium	Number	6	6	4	5	1	5	18	22	5	5	10	9
(Cr)	Maximum	<10	10	<1	10	0	6	20	24	1	9	10	60
	Minimum	0	<1	0	1	0	0	0	0	<1	<1	<1	2
Cobalt	Number	3	5	3	4	--	4	14	21	3	5	7	9
(Co)	Maximum	1	3	2	2	--	3	<4	7	1	6	5	20
	Minimum	<1	<1	<1	<1	--	<1	0	0	<1	<1	<1	<1
Copper	Number	6	6	4	5	1	5	18	22	5	5	10	9
(Cu)	Maximum	6	13	6	10	3	3	5	12	5	8	11	94
	Minimum	1	<1	<1	<1	3	1	0	1	1	1	2	2
Iron	Number	12	6	10	5	5	5	75	12	5	5	51	--
(Fe)	Maximum	80	1,500	60	1,700	380	1,900	270	5,300	32	8,100	120	--
	Minimum	<10	60	<10	60	<10	40	6	70	10	190	<3	--
Lead	Number	11	6	9	5	1	5	18	22	5	5	10	9
(Pb)	Maximum	7	5	11	3	2	5	5	18	3	6	4	43
	Minimum	<1	<5	0	3	2	<5	0	1	<1	<5	<1	3
Lithium	Number	4	6	4	5	1	5	15	22	3	5	4	9
(Li)	Maximum	6	<10	6	<10	8	10	22	30	16	20	17	70
	Minimum	<4	0	<4	0	8	<10	3	0	6	10	8	10
Manganese	Number	12	6	11	5	5	5	35	22	5	5	10	9
(Mn)	Maximum	20	40	20	60	6	60	70	170	19	260	12	1,200
	Minimum	<1	<10	<1	<10	6	<10	5	20	4	<10	6	30

Table 11. Concentration ranges of trace constituents for sites 1-6, White River, water years 1975-88 --Continued

Constituent and (symbol)	Statistic	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6	
		Dissolved (µg/L)	Total (µg/L)	Dissolved (µg/L)	Total (µg/L)	Dissolved (µg/L)	Total (µg/L)	Dissolved (µg/L)	Total (µg/L)	Dissolved (µg/L)	Total (µg/L)	Dissolved (µg/L)	Total (µg/L)
Mercury	Number	11	6	9	5	1	5	18	22	5	5	10	9
(Hg)	Maximum	<0.5	0.2	0.1	<0.1	0	0.1	0.9	1.6	0.1	<0.1	0.1	0.5
	Minimum	0	0	0	0	0	<0.1	0	0	<0.1	<0.1	<0.1	<0.1
Molyb-	Number	6	6	4	5	1	5	18	22	5	5	10	9
denum	Maximum	2	3	<10	4	<10	4	2	4	2	8	5	18
(Mo)	Minimum	<1	1	<1	1	<10	1	<1	0	<1	2	<1	<1
Nickel	Number	6	6	4	5	1	5	18	22	5	5	10	9
(Ni)	Maximum	3	5	2	6	0	5	6	13	7	13	5	89
	Minimum	<1	0	0	0	0	0	0	0	<1	<1	<1	<1
Selenium	Number	11	6	9	5	1	5	31	22	5	5	10	9
(Se)	Maximum	<1	1	<1	2	0	1	3	3	3	3	5	3
	Minimum	0	0	0	0	0	0	<1	<1	1	<1	1	<1
Silver	Number	5	5	3	4	--	4	7	4	5	5	10	--
(Ag)	Maximum	<1	4	<1	<1	--	50	<2	1	<1	1	1	--
	Minimum	<1	<1	<1	<1	--	<1	0	<1	<1	<1	<1	--
Strontium	Number	8	5	3	4	--	4	40	11	12	5	26	--
(Sr)	Maximum	550	500	250	270	--	600	1,200	790	900	990	1,100	--
	Minimum	220	250	79	70	--	240	260	250	330	420	330	--
Vanadium	Number	1	--	1	--	1	--	15	--	--	--	--	--
(V)	Maximum	3	--	2	--	2	--	1	--	--	--	--	--
	Minimum	3	--	2	--	2	--	0	--	--	--	--	--
Zinc	Number	6	6	4	5	1	5	18	22	5	5	10	9
(Zn)	Maximum	14	10	10	20	4	20	20	40	8	40	34	270
	Minimum	<3	<10	<3	<10	4	<10	0	3	5	<10	<3	<10

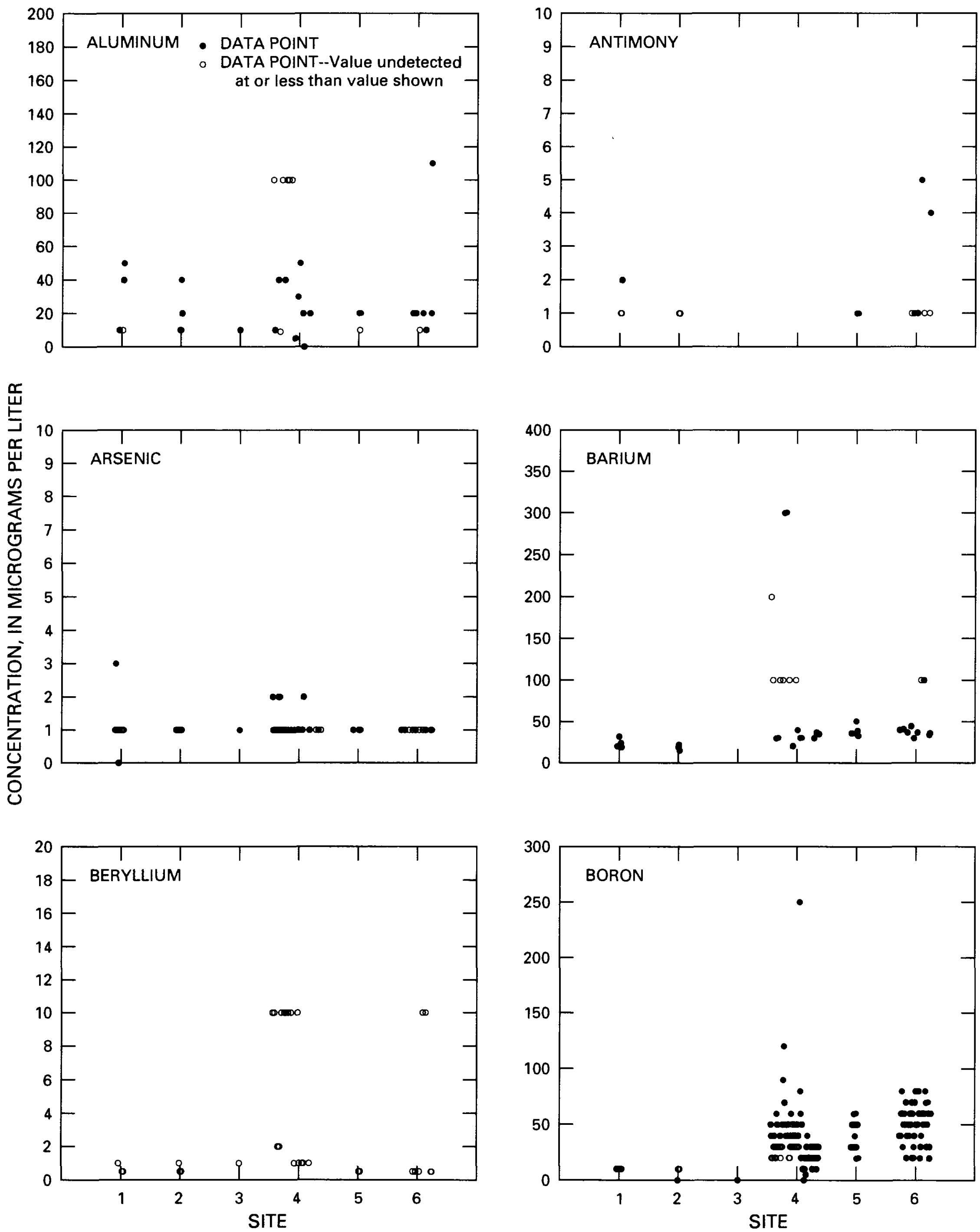

Figure 27. Concentrations of dissolved trace constituents for sites 1-6, water years 1975-88.

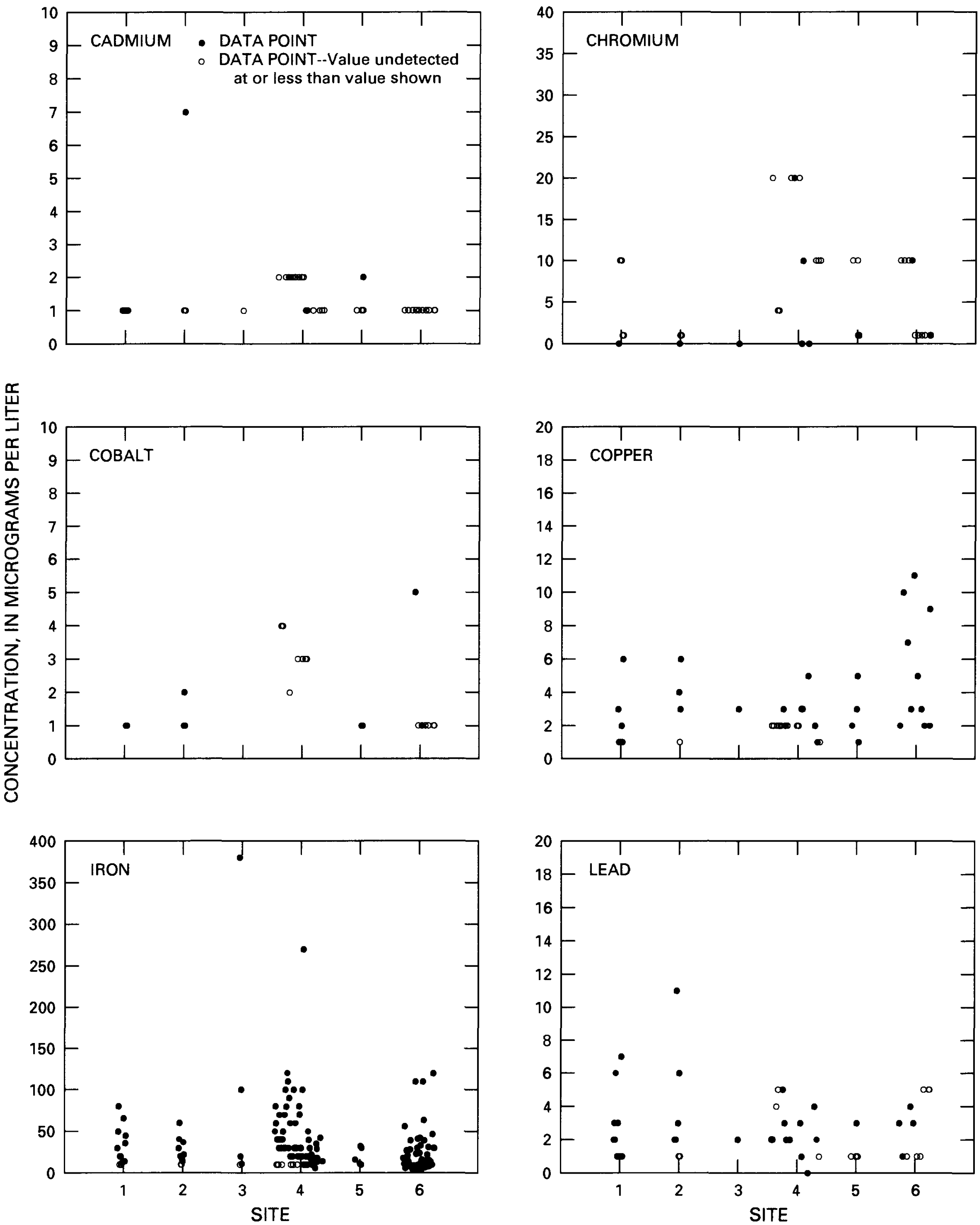

Figure 27. Concentrations of dissolved trace constituents for sites 1-6, water years 1975-88.--Continued

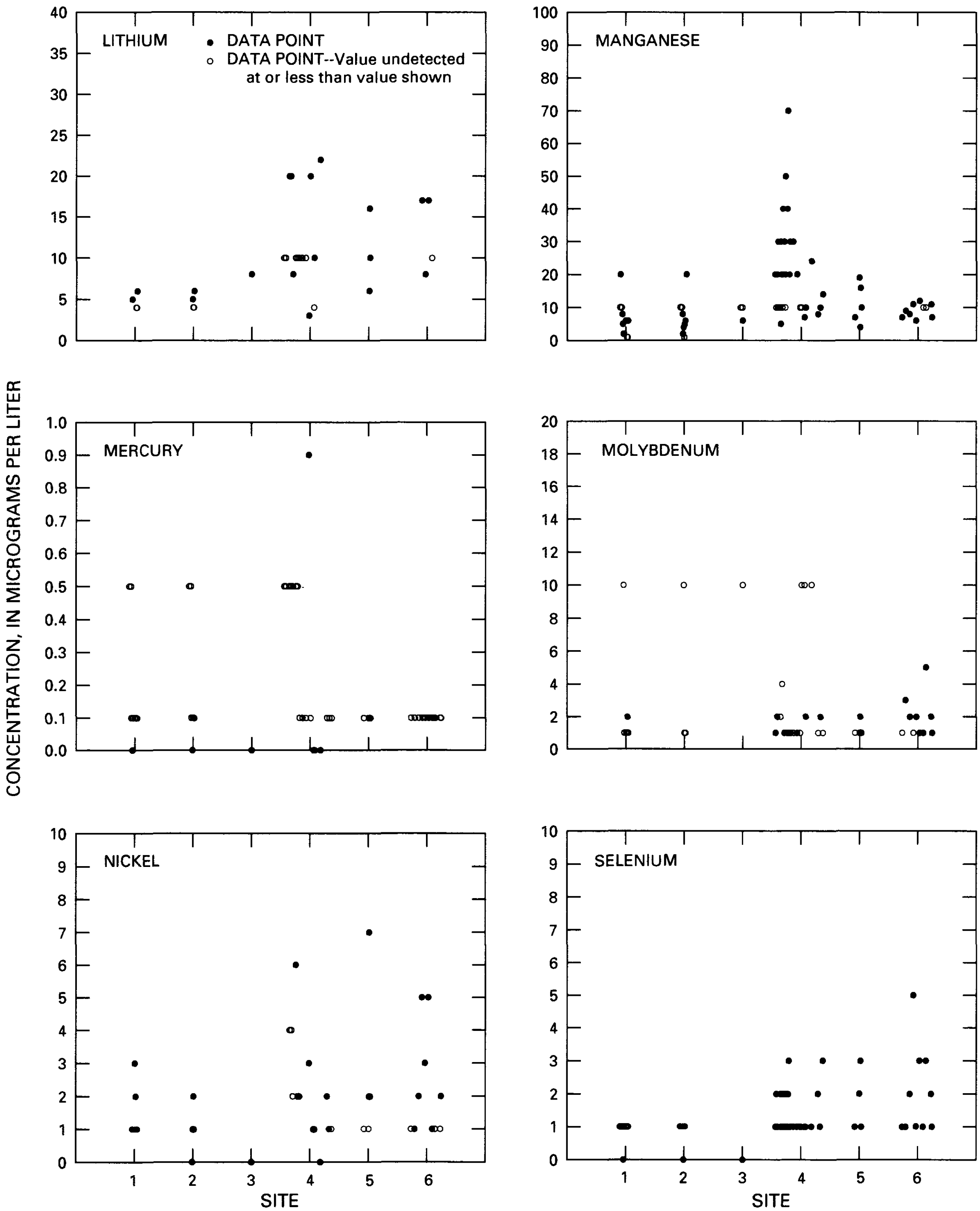

Figure 27. Concentrations of dissolved trace constituents for sites 1-6, water years 1975-88.--Continued

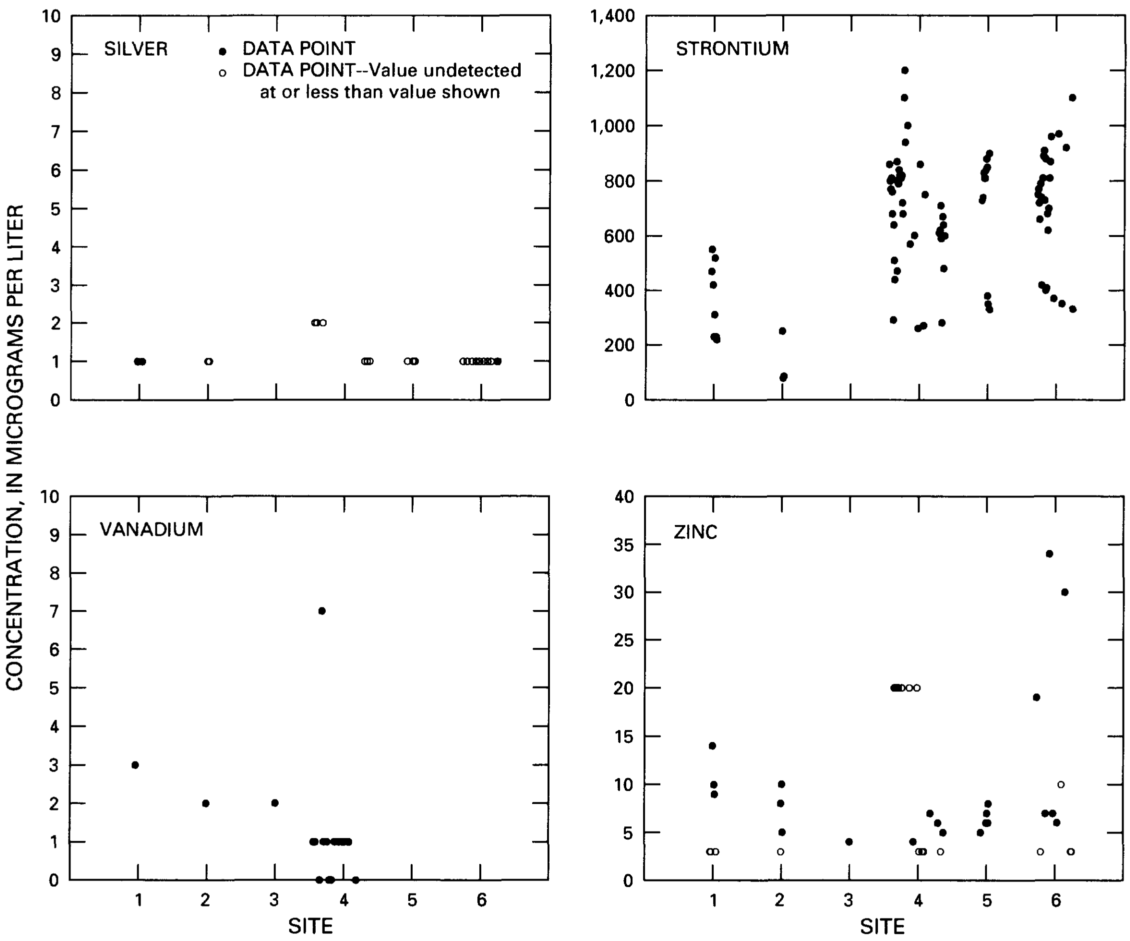

Figure 27. Concentrations of dissolved trace constituents for sites 1-6, water years 1975-88.--Continued

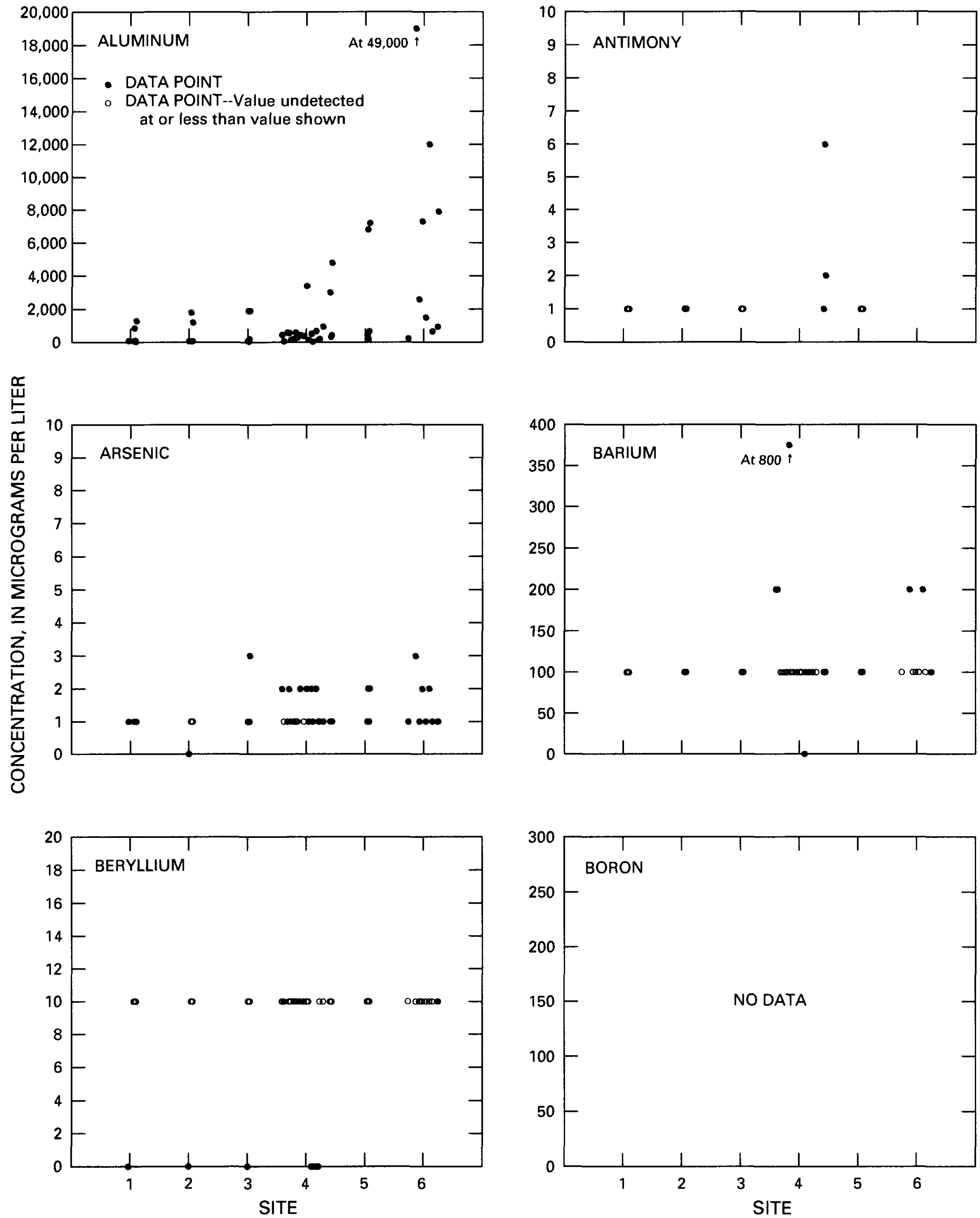

Figure 28. Concentrations of total or total recoverable trace constituents for sites 1-6, water years 1975-88.

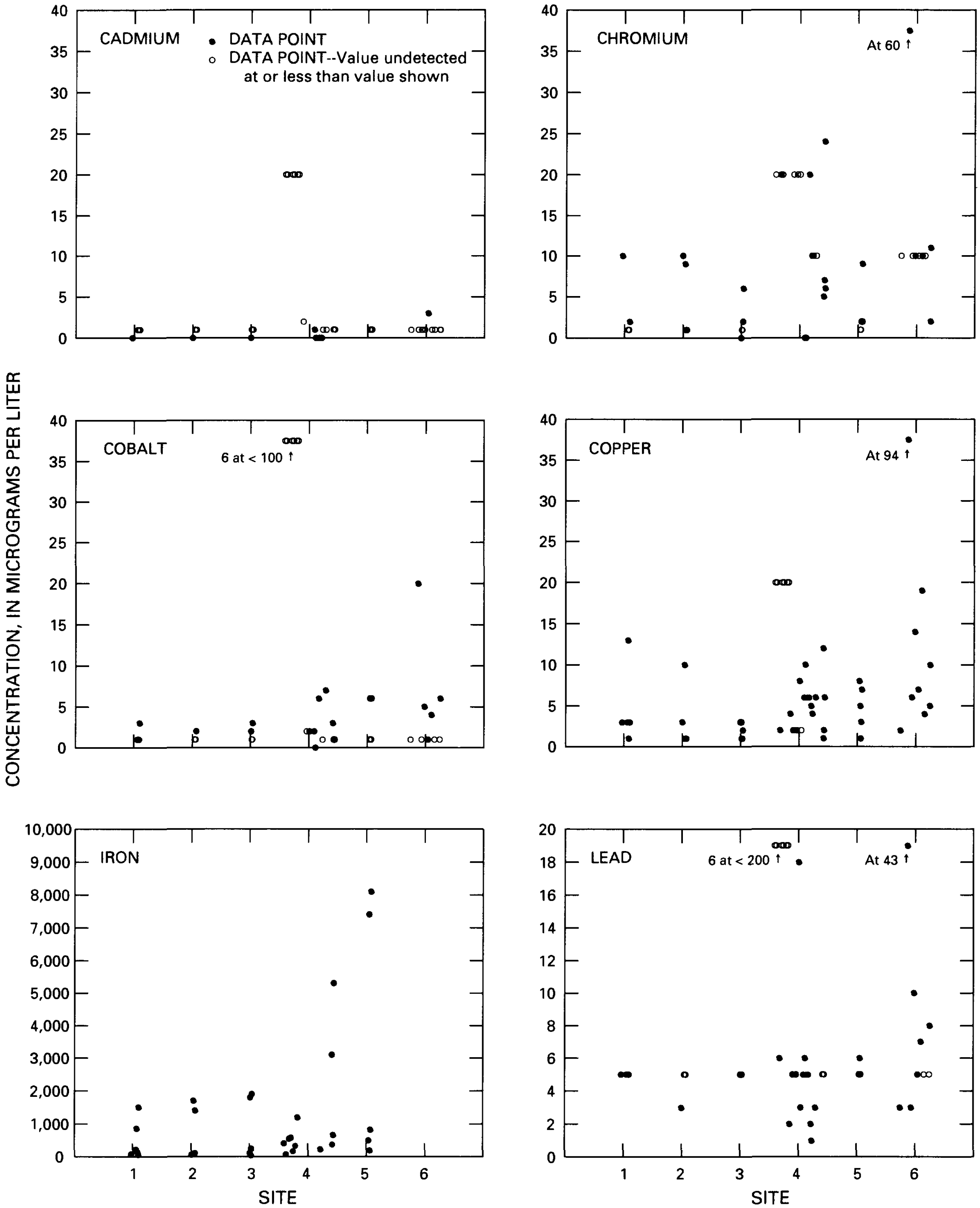

Figure 28. Concentrations of total or total recoverable trace constituents for sites 1-6, water years 1975-88.--Continued

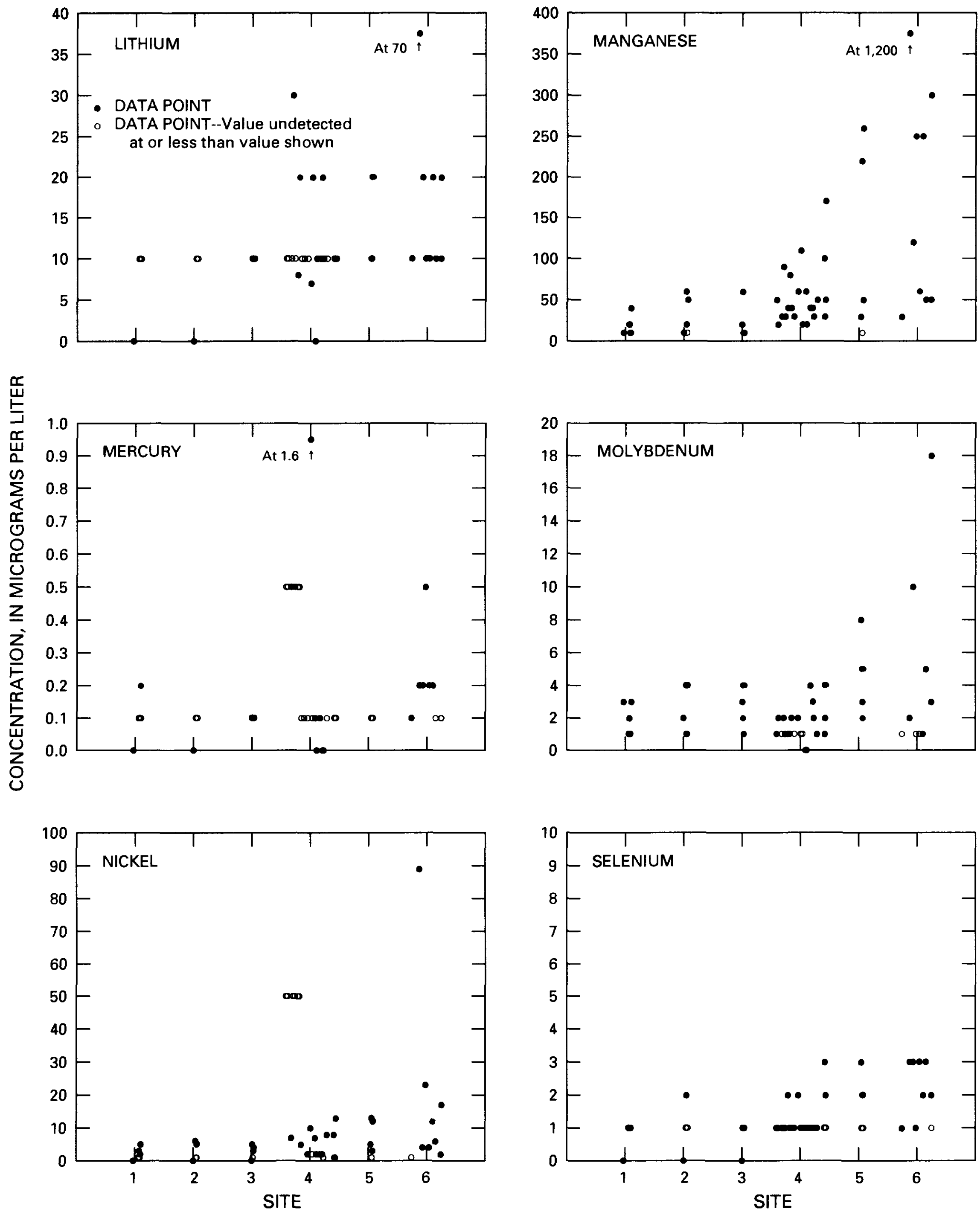

Figure 28. Concentrations of total or total recoverable trace constituents for sites 1-6, water years 1975-88.--Continued

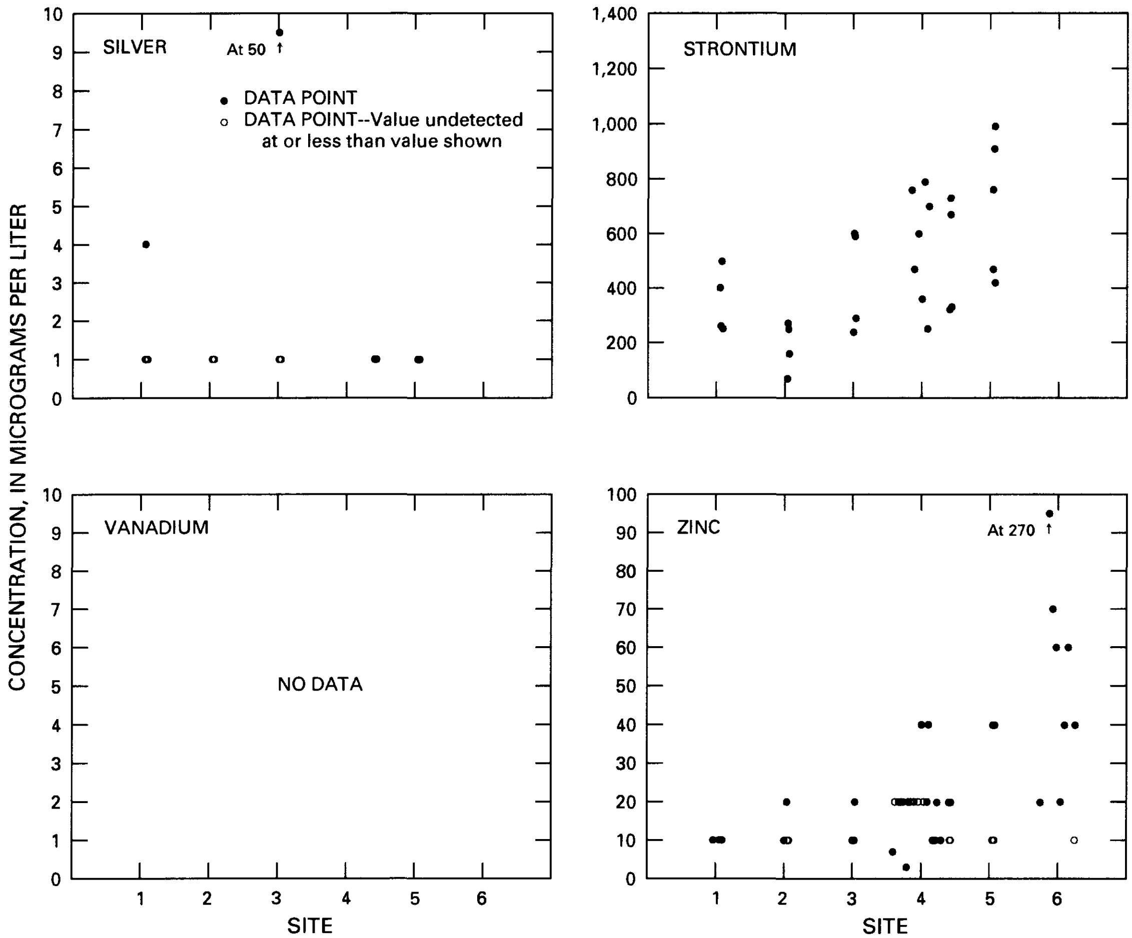

Figure 28. Concentrations of total or total recoverable trace constituents for sites 1-6, water years 1975-88.--Continued

2. Except for a small number of samples containing concentrations greater than analytical detection limits, most values of antimony, beryllium, cadmium, mercury, and silver, and dissolved concentrations of chromium and cobalt were near or less than detection limits. Total concentrations of chromium and cobalt commonly were greater than detection limits.

3. Concentrations of total aluminum, chromium, cobalt, copper, iron, manganese, molybdenum, nickel, and zinc generally were about 2 to greater than 10 times the dissolved concentrations.

4. Generally, concentration ranges of dissolved or total aluminum, boron, cobalt, copper, iron, lithium, manganese, molybdenum, nickel, strontium, and zinc were greatest downstream from site 3.

Comparison of data distributions indicate that sources of aluminum, arsenic, boron, barium, cobalt, copper, iron, lead, lithium, manganese, molybdenum, nickel, selenium, strontium, zinc, and perhaps chromium probably are widespread in the White River Basin. Concentrations of strontium were least in the South Fork (site 2); also sulfate concentrations were least at site 2 (figs. 18-20). Thus, the South Fork Basin probably contains fewer sources of strontium and sulfate minerals such as celestite than does the North Fork Basin. The generally small concentrations (less than 11 µg/L as total) of antimony, arsenic, beryllium, cadmium, cobalt, mercury, molybdenum, silver, selenium, and vanadium in the White River indicate that quantities of these trace constituents probably were scarce or limited.

Total concentrations for aluminum, cobalt, copper, iron, manganese, molybdenum, nickel, and zinc also were greater than dissolved concentrations downstream from site 3. Sediment loads increased downstream from site 3 (fig. 10). Suspended sediment could be an important source or transportation medium for these eight constituents. Conversely, the increases downstream from site 3 and the general range similarity for concentrations of dissolved and total lithium and strontium indicate that these constituents, and perhaps the soluble salts of boron, were transported to the White River mostly as dissolved ions.

SUMMARY

In 1986, the U.S. Geological Survey entered into a cooperative study with the Yellow-Jacket Water Conservancy District, Water Users Association No. 1, Rio Blanco County, and the Colorado River Water Conservation District to compile, review, and analyze sediment and water-quality data for the White River in northwestern Colorado. Streamflow, sediment, and water-quality data for water years 1975-88 were compiled and analyzed for six streamflow-gaging stations (sites) on the White River. Data comparisons for the main stem White River were improved by combining data from the North Fork (site 1) and South Fork (site 2) at a secondary data site (site 3A) immediately downstream from the confluence of the North Fork and South Fork. Annual data for the two most downstream sites (sites 5 and 6) for water years 1975-82, a period of no data, were generated from correlations and combinations of existing hydrologic data from sites 5 and 6 with data from site 4, two tributary gaging stations (09306222 and 09306255), and a discontinued gaging station (09306300) downstream from site 6.

Most annual streamflow in the White River occurred during May and June from melted snowpack in the eastern part of the basin. The combined stream discharges of the North Fork (site 1) and South Fork (site 2) accounted for about 78 percent of the total stream discharge of the White River at site 6. Annual stream discharge for much of the main stem White River ranged from about 200,000 acre-ft during low streamflow years to almost 1 million acre-ft at sites 5 and 6 during high streamflow years. The average annual stream discharge at site 6 for water years 1975-88 was about 577,000 acre-ft. The combined annual stream discharges (site 3A) measured at sites 1 and 2 were correlated with measurements of snowpack.

Daily loads of suspended sediment in the White River were estimated from least-squares regressions that related instantaneous suspended-sediment loads to daily stream discharge. Data were grouped for three hydrologic events, and from one to three regressions were developed for each site. Annual suspended-sediment loads were measured as the sum of the estimated daily suspended-sediment loads for each water year.

Instantaneous bedload measurements at sites 1-4 and site 6 were compared with instantaneous suspended-sediment loads to determine if bedload was a substantial component of total sediment transport. Bedloads in 6 of 7 measurements at sites 1-4 were 3.3 percent or less of the total sediment load, and the 18 measurements of bedload at site 6 were 1.3 percent or less of the total sediment load. Bedload was considered as small compared to suspended-sediment loads

and bedload was not included in estimates of annual sediment loads in the White River.

Annual suspended-sediment loads in the White River ranged from about 2,100 tons at sites 1 and 2 to about 2 million tons at site 6. Average annual suspended-sediment loads were least in the North Fork and South Fork at sites 1 and 2 (11,500 and 11,100 tons) and greatest at site 6 (about 705,000 tons). Annual suspended-sediment loads greatly increased downstream from site 4. The increases in sediment loads were from the accumulative inputs of sediment eroded from poorly consolidated strata in the semiarid tributary basins between sites 4 and 6. Extensive vegetation cover or resistant strata or both in the tributary basins upstream from site 4 substantially decreased sediment erosion and transport.

The average size composition of suspended sediment in 27 samples collected for size analysis at sites 3-6 was 30 percent sand, 45 percent silt, and 25 percent clay. Sand percentages in 174 samples collected for sediment concentrations, however, ranged from 2 to 64 percent. Data correlations of size composition with stream discharge and sediment concentration were poor.

Sediment retention in proposed reservoirs larger than 13,800 acre-ft on the White River could exceed 98 percent. Annual capacity loss in a hypothetical 50,000 acre-ft reservoir could range from less than 0.01 percent near sites 1 and 2 to about 2.5 percent near site 6. Annual capacity losses for a range of hypothetical reservoir sizes constructed on the White River at or near sites 1-6 were estimated.

Water temperature, specific conductance, pH, and dissolved oxygen were measured periodically at sites 1-6. Maximum water temperatures in summer generally ranged from less than 20°C at sites 1-3 to 20 to 25°C at sites 4-6. Daily changes in temperature from 3 to 8°C at site 4 were typical during summer.

Specific conductance in the White River decreased as stream discharge from snowmelt increased. Values of specific conductance and ranges of specific conductance were least, generally from 200 to 400 μS/cm at sites 1 and 2, and increased gradually to 300 to 1,000 μS/cm downstream to site 6. Large values of specific conductance (750 to 1,100 μS/cm) were measured at site 4 in low streamflow prior to water year 1983. After recompletion in 1980-81 of improperly completed exploratory wells 3 mi east of Meeker, specific-conductance values at site 4 were less than 750 μS/cm.

Although extreme values of pH in the White River ranged from 7.4 (site 4) to 9.1 (site 3), most values of pH ranged from 7.6 to 8.8. The range in pH generally decreased to values that ranged from 8.0 to 8.5 in high streamflow. Correlation of pH with dissolved oxygen indicates that pH exceeded 8.5 at sites 1-4 only when the percent saturation of dissolved oxygen equaled or exceeded 100 percent. The chemical buffering capacity in the river to resist biologically induced changes in pH in low streamflow probably was greatest in the White River downstream from site 4.

All concentrations of dissolved oxygen measured at sites 1-6 were greater than 6.0 mg/L; a maximum concentration of 14.2 mg/L was measured at site 4 when the water temperature was 0°C. Photosynthetic activity of algae and aquatic plants produced concentrations of dissolved oxygen that exceeded 120 percent in the low streamflows at all sites. Most concentrations of dissolved oxygen in the White River were greater than 90-percent saturation. Thus, net daytime biological or chemical oxygen-consumption activities or both in the White River probably were small.

Concentrations of dissolved solids ranged from about 100 to 250 mg/L at sites 1 and 2 to about 230 to 630 mg/L downstream at site 6. Concentrations of dissolved solids (and major ions) were greatest in low streamflow and least in high streamflow. In low streamflow, composition of dissolved solids was mostly calcium, bicarbonate, and (or) sulfate upstream from site 4 and mostly calcium, sodium, sulfate, and bicarbonate downstream from site 4. In snowmelt runoff, when streamflow in the White River was greater than 1,000 ft^3/s, calcium and bicarbonate generally were the principal constituents at all sites. Concentrations of the major ions, hardness, and dissolved solids were regressed on values of specific conductance.

Annual loads of dissolved solids in the White River were computed from least-squares regressions that related instantaneous dissolved-solids loads to daily stream discharge for sites 1-6. Annual dissolved-solids loads ranged from 21,100 tons at site 2 to an estimated 480,000 tons at site 6. Average annual dissolved-solids loads were least at site 2 (38,700 tons) and greatest at site 6 (about 348,000 tons). Data comparisons indicated that total solids transported in the White River primarily were dissolved solids upstream from site 4 and suspended sediment downstream from site 4. Annual total solids in the White River ranged from about 23,200 tons at site 2 to about 2.4 million tons at site 6.

A total of 51 water samples for analyses of dissolved nutrients were collected periodically at sites 1-6 during water years 1987-88. Although concentrations of ammonia as nitrogen ranged from less than 0.01 to 0.11 mg/L, ammonia concentrations were equal to or less than 0.05 mg/L in 46 of the 51 samples. Concentrations of nitrite plus nitrate as nitrogen ranged from less than 0.1 mg/L at all sites to 0.53 mg/L at site 6. Concentrations of organic nitrogen ranged from less than 0.16 to 1.50 mg/L. Phosphorus was measured once at a concentration of 0.62 mg/L at site 6, but most concentrations of phosphorus (45 of 51 samples) were equal to or less than 0.03 mg/L. Large nutrient concentrations in intermittent runoff from agricultural lands probably caused concentrations of nitrogen and phosphorus to increase downstream from site 4.

Concentration ranges and distribution patterns for 22 trace constituents in the White River were determined. In addition, concentrations of total cyanide in 29 water samples were less than 0.01 mg/L. Concentrations of 15 trace constituents commonly were detected in the White River, and concentrations of 11 trace constituents generally were greatest downstream from site 3. Total or total recoverable concentrations generally were greater than dissolved concentrations for eight constituents downstream from site 3. Sediment loads increased downstream from site 3; thus, suspended sediment could be an important source or transportation medium for trace constituents in the White River.

The White River is an important and renewable resource of good quality water in northwestern Colorado. Annually, large quantities of snowmelt, mostly from high elevations, enter the main stem of the White River from the North and South Fork Basins. Snowmelt contains small quantities of suspended sediment and dissolved solids. Thus, the high streamflow that originates from the North Fork and South Fork during spring and early summer dilutes and transports the large concentrations of suspended sediment and dissolved solids that enter the White River from the central parts of the basin. Large quantities of fluvial sediment from semiarid tributary basins, large concentrations of dissolved solids from ground-water sources, and concentrations of nitrogen and phosphorus in irrigation return flow contribute to some decrease in water quality in the White River downstream from site 4.

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