Evaluation of Water Quality, Suspended Sediment, and Stream Morphology with an Emphasis on Effects of Stormflow on Fountain and Monument Creek Basins, Colorado Springs and Vicinity, Colorado, 1981 through 2001

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Abstract

This report documents water quality and suspended sediment with an emphasis on evaluating the effects of stormflow on Fountain Creek Basin in the vicinity of Colorado Springs, Colorado. Water-quality data collected at 11 sites between 1981 and 2001 were used to evaluate the effects of stormflow on water quality. Suspended-sediment data collected at seven sites from 1998 through 2001 were used to evaluate effects of stormflow on suspended-sediment concentrations, discharges, and yields. Data were separated into three flow regimes: base flow, normal flow, and stormflow.

A comparison of stormwater-quality concentrations measured between 1981 and 2001 to Colorado acute instream standards indicated that, except for isolated occurrences, stormwater quality met acute instream standards. At several sites, 5-day biochemical oxygen demand, fecal coliform, and selected nutrient concentrations tended to be highest during stormflow and lowest during base flow. Dissimilar to the other nutrients, dissolved nitrite plus nitrate concentrations generally were highest during base flow and lowest during stormflow. Most dissolved trace-element concentrations associated with stormflow decreased or showed little change compared to base flow. However, median concentrations of total copper, iron, lead, nickel, manganese, and zinc for stormflow samples generally were much larger than nonstorm samples. The substantially larger concentrations of total copper, iron, lead, nickel, manganese, and zinc measured at site 5800 during stormflow as compared to other sites indicates a relatively large source of these metals in the reach between sites 5530 and 5800. Semivolatile organic compounds in samples collected during stormflow were detected relatively infrequently at the four sites monitored; however, analysis of pesticide data collected during stormflow showed a relatively frequent detection of pesticides at low levels. Nitrogen, phosphorus, and particulate trace-element loads substantially increased during stormflow.

Suspended-sediment concentrations, discharges, and yields associated with stormflow were significantly greater than during normal flow. Depending on the site and year, suspended-sediment concentrations associated with stormflow generally were 3 to10 times greater than concentrations measured during normal flow, and suspended-sediment discharges were usually more than 10 times greater during stormflow. The April through October cumulative suspended-sediment discharges and streamflows were largest in 1999 at all sites. Although large spatial variations in suspended-sediment yields occurred during normal flows, the suspended-sediment

yields associated with stormflow generally were more than 10 times greater than the suspended-sediment yields that occurred during normal flow. The smallest suspended-sediment yields generally were less than 1 ton per day per square mile during stormflow. The largest suspended-sediment yields occurred at sites located in the Cottonwood Creek Basin and were greater than 10 tons per day per square mile.

INTRODUCTION

Urbanization usually increases the impervious area of a watershed, which frequently increases storm runoff. Associated with storm runoff are properties and constituents that can degrade local stream-water quality and receiving water downstream. Increased storm runoff frequently increases erosion, transport, and deposition of sediment, which subsequently can affect channel morphology, aquatic habitat, and macroinvertebrates. Because of concerns about effects of urban runoff on water quality, the Water Quality Act of 1987 contains provisions that address storm-runoff discharges. The U.S. Environmental Protection Agency, under section 319 of the Water Quality Act of 1987, requires that States "assess the nature and extent of nonpoint sources of pollution."

In 1998, the U.S. Geological Survey, in cooperation with the Colorado Springs City Engineering and Colorado Springs Utilities, began a study of the Fountain Creek Basin (fig. 1) to document current conditions of water quality and suspended sediment, to evaluate changes in water quality and suspended sediment, and, to the extent possible, evaluate effects of stormflow on water quality and suspended sediment.

Purpose and Scope

This report documents water quality, suspended sediment, and changes in channel morphology for Fountain Creek Basin in the vicinity of Colorado Springs, Colo. More specifically, the report (1) provides a comparison of water-quality concentrations for base flow, normal flow, and stormflow; (2) summarizes detections of semivolatile organic compounds and pesticides associated with stormflow; (3) quantifies water-quality loads for stormflow and nonstormflow (base flow and normal flow); (4) compares water quality of stormflow for pre-1998 and post-1997 periods; (5) compares water-quality concentrations of stormflow to acute instream water-quality standards; (6) evaluates suspended-sediment concentrations, discharge, and yields for stormflow and normal flow; (7) describes the sediment-transport capacity of selected reaches of Fountain, Monument, and Cottonwood Creeks; and (8) describes changes in channel morphology of selected reaches of Fountain, Monument, and Cottonwood Creeks. For the purposes of this report, statistical trends or differences were determined by the reported significance level as determined by a statistical test. Statistical significance was defined as significant, or moderately significant with corresponding p-values of less than or equal to 0.05 and 0.1, respectively. A nonsignificant trend or difference was indicated when the p-value was greater than 0.1.

Water-quality data were collected at five sites on Fountain Creek, three sites on Monument Creek, and three sites in the Cottonwood Creek Basin with varying frequencies between 1981 and 2001 (table 1). Water-quality data prior to March 1998 were collected monthly; since March 1998, water-quality data have been collected bimonthly. Measurements of dissolved oxygen, pH, specific conductance, biochemical oxygen demand, fecal coliform, nitrogen, phosphorus, trace elements, semivolatile organic compounds, and pesticides were used to describe the water quality of Fountain Creek Basin in the vicinity of Colorado Springs, Colo.

Daily suspended-sediment data were collected at three sites on Fountain Creek, one site on Monument Creek, and three sites in the Cottonwood Creek Basin during April through October, 1998–2001 (table 1). These data were used to evaluate annual and spatial variations in suspended-sediment concentrations, discharge, and yields that occurred during stormflow and normal flow.

Data collected from sites on Fountain and Monument Creeks represent an integration of upstream water quality and suspended sediment for relatively large drainage areas. Between-site comparisons of water quality and suspended sediment characterize the changes that occur in the intervening drainage area(s). Data collected from sites in the Cottonwood Creek Basin characterize the water quality and suspended sediment of a relatively small basin (18.7 mi^2) that has undergone substantial

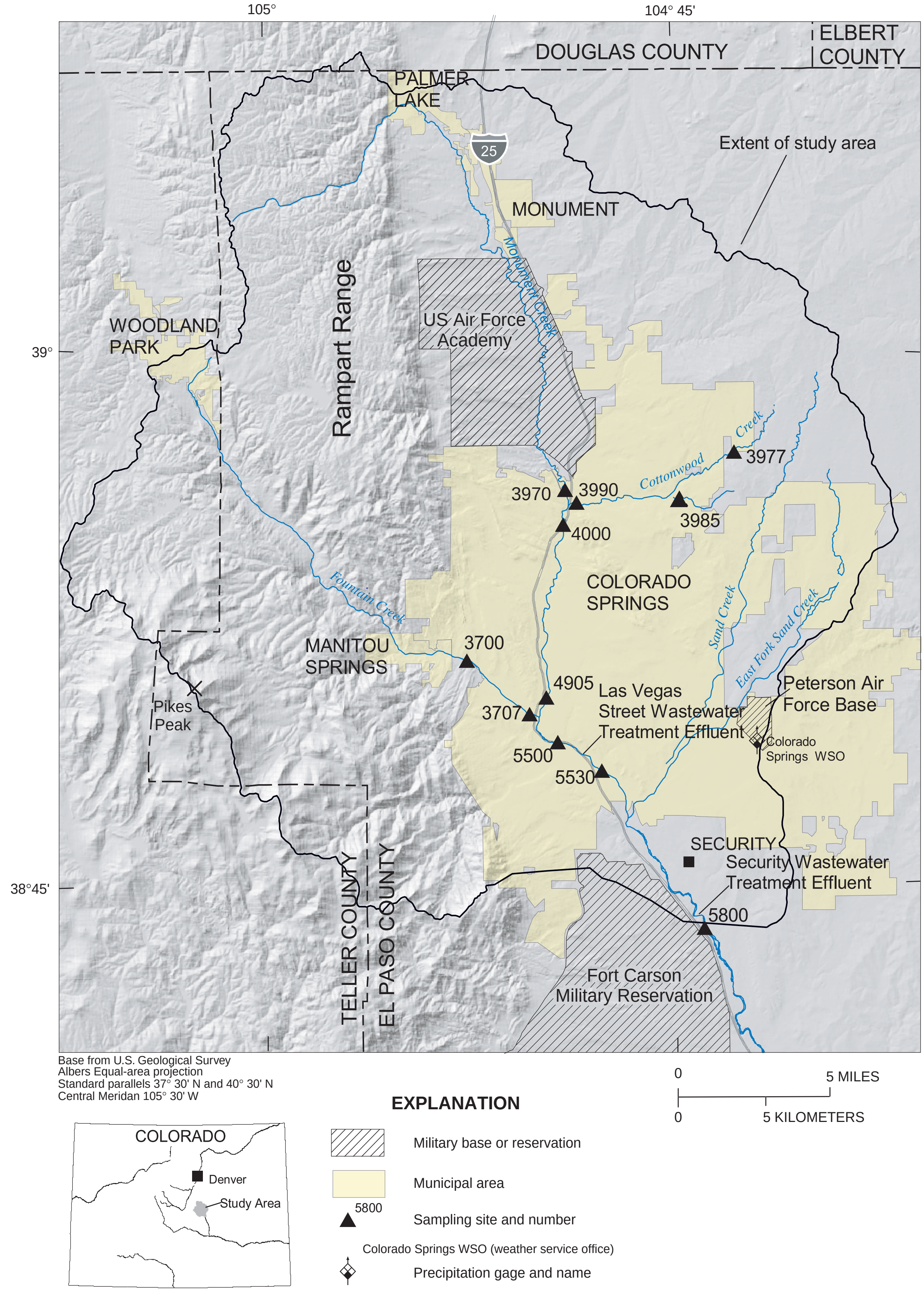


Figure 1. Location of study area and sampling sites for Fountain Creek Basin.

Table 1. Selected surface-water sites in Fountain Creek Basin, and water-quality constituents, suspended sediment, and biological properties measured or analyzed, 1981 through 2001

[FOCR, Fountain Creek; MOCR, Monument Creek; COCR, Cottonwood Creek; E. coli, escherichia coli; X, routine sampling; S, stormflow sampling and routine sampling; D, daily data; P, periodic measurements generally five times per year; --, not collected or analyzed]

Site number and name[1]	U.S. Geological Survey station number	Site type[2]	Period of data collection	5-day, Biochemical oxygen demand	Bacteria, fecal coliform and E. coli	Nutrients	Major ions and trace elements	Pesticides and organics	Suspended sediment	Cross-sectional measurements[3]
3700, FOCR at 33rd	07103700	Main stem, RW	1981–2001	S	S	S	S	S	D	P
3707, FOCR at 8th	07103707	Main stem, RW	1981, 1998–2001	X	X	X	X	--	--	--
3970, MOCR at Woodmen	07103970	Main stem, RW	1998–2001	S	S	S	S	S	D	P
3977, COCR at Cowpoke	07103977	Tributary to Monument Creek, MS4	1998–2001	X	X	X	--	--	D	P
3985, COCR Trib at Rangewood	07103985	Tributary to Monument Creek, MS4	1998–2001	--	X	X	--	--	D	P
3990, COCR at Mouth at Vincent	07103990	Tributary to Cottonwood Creek, MS4	1998–2001	X	X	X	--	--	D	P
4000, MOCR at Pikeview	07104000	Main stem, RW	1981–1999	X	X	X	X	--	--	--
4905, MOCR at Bijou	07104905	Main stem, RW	1981–2001	X	X	X	X	--	--	--
5500, FOCR at Nevada	07105500	Main stem, RW	1981–2001	S	S	S	S	S	D	P
5530, FOCR at Janitell	07105530	Main stem, RW	1981–2001	X	X	X	X	--	--	--
5800, FOCR at Security	07105800	Main stem, RW	1998–2001	S	S	S	S	S	D	P

1 Site name used in Colorado Springs Municipal Stormwater Permit.

2MS4 site is a municipal stormwater permit site, and an RW site is a receiving water or main-stem site.

3 Data collected by Colorado Springs City Engineering personnel.

development in the past decade and that in 1985 was characterized by von Guerard (1989a) as a basin producing high sediment yields.

Channel cross-sectional survey data collected by the City of Colorado Springs Engineering Unit multiple times a year from 1999 through 2001 for three reaches of Fountain Creek, one reach of Monument Creek, and three reaches of Cottonwood Creek were used to describe changes in channel morphology.

Description of Study Area

The study area has a drainage area of about 495 mi^2. Elevations in the study area range from about 5,460 ft at the southern end of the study area to 14,109 ft at the summit of Pikes Peak. There are two major physiographic landforms in the study area—the Front Range of the Southern Rocky Mountains and the Colorado Piedmont (Hansen and Crosby, 1982). The Front Range, which comprises about the western one-third of the study area, is underlain by granite. Soils in this area are well drained and occur on steep slopes (Larsen, 1981; von Guerard, 1989a). The Colorado Piedmont, which comprises the remaining eastern two-thirds of the area, abuts the base of the Rampart Range and is underlain by sandstone, shale, alluvial, and windlain deposits. Soils in this area generally are sandy and well drained with more gentle slopes (Larsen, 1981; von Guerard, 1989a). The soils and geology on the Colorado Piedmont are readily erodible, especially relative to the granitic rocks on the west side of the study area. More details of the soils and geology of the study area are contained in Larsen (1981) and von Guerard (1989a).

Fountain and Monument Creeks are the two main drainages within the study area and are located along the transition of the two distinctive physiographic landforms. Fountain Creek is a perennial stream that originates near the town of Woodland Park and flows southeastward through a deeply incised canyon to Manitou Springs (fig. 1). The stream channel upstream from Manitou Springs is meandering, has a pool-and-riffle regime, and has bed material that ranges from sand and gravel to cobbles and boulders. From Manitou Springs, Fountain Creek flows through alluvial terraces into a wide alluvial valley; the channel meanders less due to intermittent channelization, has a pool-riffle-and-run regime, and has bed material that is predominantly sand, gravel, and cobbles. Downstream from the confluence with Monument Creek, the channel becomes braided and the streambanks are intermittently lined with concrete. The bed material downstream from the confluence with Monument Creek is variable. Some stream reaches have predominantly cobble beds, some are scoured to bedrock, and others are a mixture of sand, gravel, and cobbles (von Guerard, 1989a).

Monument Creek, the main tributary to Fountain Creek, also is a perennial stream that originates in the Rampart Range and flows eastward toward Palmer Lake, then south to Colorado Springs. Upstream from the confluence with Cottonwood Creek, Monument Creek is meandering, has a pool-riffle-and-run regime, and has bed material consisting of sand, gravel, and cobbles. Downstream from the confluence with Cottonwood Creek, the channel becomes braided, sand and small gravel compose the streambed, and the streambanks are intermittently lined with concrete. The braided channel conditions occur intermittently throughout the remaining length of channel with few areas of pools and riffles.

Cottonwood Creek, a historically ephemeral stream, has become perennial with limited base flow as urbanization has occurred throughout the basin. Cottonwood Creek is deeply incised and primarily has a riffle-run regime; the streambed consists primarily of sand with some gravel.

The population of Colorado Springs and vicinity has increased from about 70,000 people in 1950 to about 310,000 in 1980 to about 510,000 in 2000. The rate of growth, about 8,000 people per year, was fairly constant between 1950 and 1990. Between 1990 and 2000, the rate of growth increased to about 11,000 people per year (Stogner, 2000).

Land Use

Land uses within the study area include urban, military reservations, agriculture, and undeveloped areas. Substantial changes in land use have occurred from increased population. Table 2 shows the total area for various land-use categories for 1998, 1999, and 2000. Estimates of the percentage of impervious and pervious material associated with each land use were applied to estimate the total impervious and pervious area upstream from each sampling site (table 2). Estimates of the percentage of impervious and pervious material associated with each land use

Table 2. Land uses and estimated total impervious and pervious areas for Fountain Creek Basin, 1998–2000 (land-use data provided by the City of Colorado Springs)

[mi^2, square miles; --, category not reported]

Site (see table 1)	Drainage area[1] (mi^2)	Commercial and Industrial (mi^2)	Residential (mi^2)	Streets and easements (mi^2)	Airports and military (mi^2)	Agriculture (mi^2)	Undeveloped (mi^2)	Estimated total impervious area (mi^2)	Estimated total pervious area (mi^2)	Cumulated drainage area[2] (mi^2)
1998										
3700	103	3.91	6.26	2.55	0.00	1.25	88.0	22.2	79.8	102
3970	181	4.72	28.8	7.15	28.9	22.7	87.8	45.8	134	180
3977	5.93	.06	2.08	--	0.00	0.94	3.03	1.69	4.42	6.11
3985	2.81	.17	0.58	--	.00	.96	1.07	0.73	2.05	2.78
3990	18.7	1.19	6.27	--	.00	2.44	8.98	5.85	13.0	18.9
5500	392	18.2	55.7	19.1	28.9	32.0	233	105	282	387
5800	495	31.6	82.9	36.8	34.9	59.0	257	154	348	502
1999										
3700	103	4.94	7.62	1.66	.00	1.24	87.1	22.9	79.7	103
3970	181	5.34	29.0	6.76	28.9	25.5	84.5	46.0	134	180
3977	5.93	.04	2.26	--	.00	2.95	0.95	1.75	4.45	6.20
3985	2.81	.17	.94	--	.00	.46	1.25	.87	1.95	2.82
3990	18.7	.91	7.97	--	.00	4.57	5.36	6.26	12.6	18.8
5500	392	20.1	57.5	17.7	28.9	34.5	228	106	281	387
5800	495	33.8	85.8	35.4	34.9	60.5	253	155	348	503
2000										
3700	103	7.10	5.53	1.79	.00	1.18	86.4	23.8	78.2	102
3970	181	5.71	30.2	7.44	28.9	22.9	85.3	45.0	135	180
3977	5.93	.56	2.40	--	.00	2.77	.46	2.18	4.01	6.19
3985	2.81	.71	.66	--	.00	.33	1.10	1.16	1.64	2.80
3990	18.7	1.88	7.55	--	.00	5.07	4.32	6.81	12.0	18.8
5500	392	23.4	57.7	26.0	28.9	30.6	220	114	273	387
5800	495	38.4	86.2	43.8	34.8	55.1	245	166	337	503

[1] Drainage area as reported by U.S. Geological Survey (Crowfoot and others, 2000).

[2] Drainage area computed from accumulating individual land uses provided by the City of Colorado Springs.

were applied using coefficients adapted from Arnold and Gibbons (1996) and the U.S. Environmental Protection Agency (1992). The following assumptions were made in estimating percentage of impervious material: 88 percent of commercial, 75 percent of industrial, 50 percent of residential, 90 percent of streets and easements, 15 percent of airports and military reservations, 15 percent of agricultural, and 15 percent of undeveloped land-use categories were assumed to be impervious. Land-use data for 1997–2000 were provided by the City of Colorado Springs. Additionally, a 1964 land-use map was scanned, georectified, and digitized to provide estimates of total impervious and pervious areas upstream from sites 3700, 3970, 5500, and 5800. Digital land-use data (U.S. Geological Survey, 2000) were used to estimate total impervious and pervious area upstream from these sites for 1992 (table 3). Between 1964 and 1992, the amount of estimated impervious area upstream from site 3700 (Fountain Creek near Manitou Springs) showed no appreciable change. By 1997, however, the amount of impervious area had increased by 38 percent to about 23 mi^2; impervious area increased by an estimated 5 percent between 1997 and 2000. In Monument Creek drainage upstream from Cottonwood Creek (site 3970), the amount of estimated impervious area increased by about 4 mi^2 between 1964 and 1992, which represented a 15-percent increase. Between 1992 and 1997, impervious area upstream from site 3970 was estimated to have an increased to about 45 mi^2 or by 44 percent; almost 90 percent of the estimated 45 mi^2 was reported to be outside the city of Colorado Springs. No appreciable change in impervious area occurred between 1997 and 2000. Overall, the amount of estimated impervious area within the 495-mi^2 study area upstream from site 5800, increased from about 85 mi^2 in 1964 to about 111 mi^2 in 1992 to about 153 mi^2 in 1997; and between 1998 and 2000, the amount of estimated impervious area increased by an estimated 8 percent within the 495-mi^2 study area.

Acknowledgments

The authors appreciate the efforts of many individuals who assisted in the collection of these data. Thanks to Bill Van Derveer and Tara Kelley, Colorado Springs Utilities, for their cooperation, help with planning, and support for the monitoring program. The authors thank the Colorado Springs City Engineering, Stormwater Drainage Team, for their cooperation and support, and for providing precipitation, land-use, and cross-sectional data. Finally, thanks to William D. Bemis, Erin E. Evans, and Wade J. Walker, U.S. Geological Survey, for their dedication and tireless efforts in collection of stormflow samples under harsh field conditions.

METHODS OF INVESTIGATION

Water-quality data were collected at five sites on Fountain Creek and three sites on Monument Creek for selected constituents and properties and at varying frequencies between 1981 and 2001 (table 1). In general, samples were collected monthly from 1981 though 1997 and bimonthly from 1998 through 2001. In addition, water-quality samples were collected periodically at three sites in the Cottonwood Creek Basin for selected constituents from 1998 through 2001. Water-quality data were collected and processed using standard U.S. Geological Survey techniques and procedures (U.S. Geological Survey, 1977; Sylvester and others, 1990; Horowitz and others, 1994; Wilde and others, 1998). Sampling equipment was cleaned using the part-per-billion protocols beginning about 1994. Field measurements for the study period include specific conductance, pH, dissolved oxygen, and water temperature obtained during most sampling events. Water samples collected between 1981 and 1997 were analyzed by the U.S. Geological Survey National Water-Quality Laboratory. Water samples collected between 1998 and 2001 were analyzed by the Colorado Springs Utilities Environmental Quality Laboratory with quality-control samples analyzed by the U.S. Geological Survey National Water-Quality Laboratory. Quality-control data collected since 1998 indicate that water-quality data analyzed by the Colorado Springs Utilities Environmental Quality Laboratory and used in this report provided results comparable to data analyzed by the U.S. Geological Survey National Water-Quality Laboratory. Samples for analysis of 5-day biochemical oxygen demand and fecal indicator bacteria were collected at most sites in the study area. Samples collected for biochemical oxygen demand were processed in the Pueblo Subdistrict Office laboratory until 1997, and samples collected beginning in April of 1998 were analyzed by the Colorado Springs

Table 3. Estimated impervious and pervious areas within and outside of Colorado Springs, Fountain Creek Basin, 1964, 1992, 1997–2000

[mi^2, square miles; --, insufficient data to report]

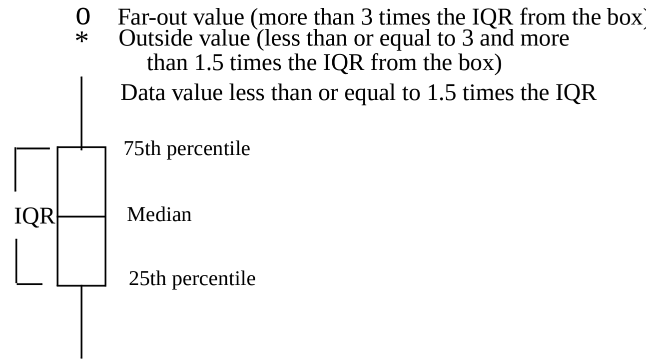
Site (see table 1)	Drainage area[1] (mi^2)	Estimated impervious area inside city (mi^2)	Estimated pervious area inside city (mi^2)	Estimated impervious area outside city (mi^2)	Estimated pervious area outside city (mi^2)	Estimated total impervious area upstream of site (mi^2)	Estimated total pervious area upstream of site (mi^2)
1964							
3700	103	--	--	--	--	16.6	85.5
3970	181	--	--	--	--	27.2	153
5500	392	--	--	--	--	62.7	321
5800	495	--	--	--	--	85.3	414
1992							
3700	103	--	--	--	--	16.5	85.6
3970	181	--	--	--	--	31.4	149
5500	392	--	--	--	--	74.1	312
5800	495	--	--	--	--	111	391
1997							
3700	103	0.87	2.56	21.8	77.2	22.7	79.8
3970	181	4.34	10.9	40.9	124	45.3	135
5500	392	24.5	43.3	79.4	240	104	283
5800	495	45.7	85.6	107	264	153	350
1998							
3700	103	.91	2.53	21.3	77.2	22.2	79.8
3970	181	4.55	10.7	41.2	123	45.8	134
5500	392	25.1	42.7	79.4	239	105	282
5800	495	47.0	84.3	107	264	154	348
1999							
3700	103	.89	2.55	22.0	77.2	22.9	79.7
3970	181	4.78	10.3	41.2	124	46.0	134
5500	392	25.7	42.0	79.9	239	106	281
5800	495	47.4	83.4	108	264	155	348
2000							
3700	103	.92	2.52	22.9	75.7	23.8	78.2
3970	181	4.85	10.2	40.2	125	45.0	135
5500	392	26.3	41.6	88.0	231	114	273
5800	495	48.6	82.3	117	255	166	337

[1] Drainage area as reported by U.S. Geological Survey (Crowfoot and others, 2000).

Utilities Environmental Quality Laboratory. Instantaneous discharge measurements were collected at all sites, as described in Rantz and others (1982).

Suspended-sediment samples generally were collected daily from April through October each year from 1998 through 2001 at seven sites (table 1). Suspended-sediment samples were collected as described by Edwards and Glysson (1988). Discrete point samples were collected using automatic samplers installed at selected streamflow gages and programmed to collect samples daily and during rises in stream stage. Suspended-sediment concentrations obtained from samples collected at a single point within the cross section were adjusted on the basis of relations developed from depth-integrated samples collected periodically using the equal-width-increment method (Koltun and others, 1994). For data collected between 1998 and 2000, daily suspended-sediment concentration and streamflow were subdivided using the SEDCALC program with the linear interpolation, uneven time interval option to compute the daily mean suspended-sediment concentration and discharge (Koltun and others, 1994). For data collected in 2001, the same procedure was done using the GCLASS program.

Water-quality and suspended-sediment data presented in this report are frequently summarized using boxplots. Boxplots graphically display the constituent variability and provide an easy method for comparing spatial, temporal, and flow-related data. Boxplots are useful because the variability between data sets, unusual values, and selected summary statistics are easily observed. Boxplots contain the following information. The horizontal line within the box represents the median value (50 percent of the data are greater than this value and 50 percent of the data are less than this value). The lower horizontal line of the box is the 25th percentile or lower quartile (25 percent of the data are less than this value). The upper horizontal line of the box is the 75th percentile or upper quartile (75 percent of the data are less than this value). The interquartile range (IQR) contains the values between the 25th and 75th percentiles and is the difference between the 25th and 75th percentiles. The bottom of the vertical line on the boxplot is the smallest value within 1.5 times the IQR of the box. The top of the vertical line on the boxplot is the largest value within 1.5 times the IQR of the box. Outside values are greater than 1.5 times the IQR from the box and far-out values are greater than 3 times the IQR from the box. An example of a boxplot is shown below:



PRECIPITATION, STREAMFLOW, AND STORMFLOW

Annual precipitation generally decreases with distance from the headwaters of the watershed and as elevation decreases. The mean annual precipitation varies considerably from year to year. At the Colorado Springs Weather Service Office (WSO) at Peterson Air Force Base (fig. 1), annual precipitation for 1949–2001 ranged from 8.6 to 26.8 inches (fig. 2). Annual precipitation increased significantly between 1949 and 2001 ($p<0.05$). The mean annual precipitation increased from 14.9 inches from 1949 through 1980 to 18.5 inches from 1981 through 2001. A Kendall trend analysis revealed no significant trend for the period 1981 through 2001 at the Colorado Springs WSO suggesting that, although annual precipitation since 1981 generally was above the long-term average of 16.4 inches and varied considerably, there has not been an overall trend in annual precipitation. Between 1998 and 2001, when most of the data used in this report were collected, the annual precipitation ranged from 15.7 inches in 2001 to 26.8 inches in 1999, which was the maximum annual precipitation for the 52-year period of record.

Convective thunderstorms contribute most of the rainfall during May through September. Stogner (2000) indicated that about 57 percent of the daily precipitation that occurs is less than 0.1 inch, about 22 percent is between 0.11 and 0.25 inch, about 12 percent is between 0.26 and 0.5 inch, about 4 percent is between 0.51 and 0.75 inch, about 2 percent is between 0.76 and 1 inch, and about 3 percent is greater than 1 inch. These data indicate that daily precipitation

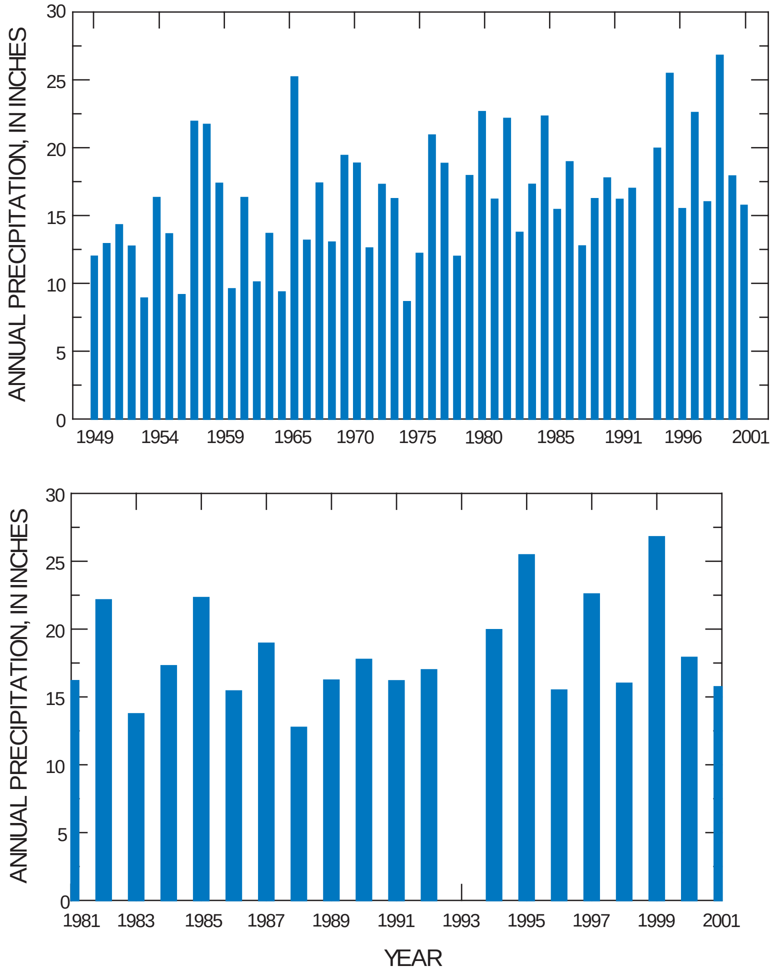


Figure 2. Annual precipitation at the Colorado Springs Weather Service Office, 1949–2001 and 1981–2001.

greater than 0.25 inch occurs an average of 77 days each year; daily precipitation greater than 0.5 inch occurs an average of 33 days each year; and daily precipitation greater than 1 inch occurs an average of 11 days each year.

Streamflow in the Fountain Creek Basin varies seasonally and, for the purposes of this report, was grouped into three flow regimes: base flow, normal flow, and stormflow. The base-flow period occurs from November to April. During base flow, streamflow is fairly uniform and, upstream from site 5500, is primarily sustained by ground-water discharge. Downstream from site 5500, base flow is composed predominantly of wastewater-treatment plant effluent. Normal flow generally begins in mid-April with the onset of snowmelt and extends into October. Streamflow during normal flow is highly variable. Changes in streamflow during the summer are primarily caused by convective thunderstorms. Stogner (2000) evaluated trends in streamflow regimes from 1977 through 1999. Significant increases in high-streamflow and low-streamflow regimes were detected at most locations on Fountain and Monument Creeks in the study area.

As part of this study, the number of stormflow events and stormflow from April through October for each year were estimated from 1981 through 2001 using a program to separate the base-flow component from the daily mean streamflow (Wahl and Wahl, 1995). The program implements a deterministic procedure to estimate the base-flow component of the daily hydrograph by combining a local minimums approach with a recession slope test. Based on inspection of streamflow hydrographs, a decision was made that daily mean streamflow greater than 2 times the computed daily base flow was indicative of stormflow for all sites except 3977 and 3985. For these two sites, a decision was made that daily mean streamflow greater than 3 times the computed daily base flow was indicative of stormflow. Therefore, for sites 3700, 3970, 3990, 4000, 5500, 5530, and 5800, the daily stormflow was computed as follows:

Daily stormflow = daily mean streamflow –
(2 × daily base flow), in cubic feet per second.

For sites 3977 and 3985, the daily stormflow was computed as follows:

Daily stormflow = daily mean streamflow –
(3 × daily base flow), in cubic feet per second.

Annual stormflow was computed by summing the computed daily stormflow that occurred between April through October each year. The annual average stormflow was computed by dividing the annual stormflow by the number of stormflow events that occurred from April through October each year. A Kendall trend analysis of annual stormflow, annual number of stormflow events, and annual average stormflow for sites 3700, 5500, and 5800 indicated no significant trends from 1981 through 2001. The Kendall trend analysis for site 4000 indicated a significant upward trend ($p<0.005$) in annual stormflow, a moderately significant trend ($p< 0.07$) in annual number of stormflow event, but no significant trend ($p=0.38$) in annual average stormflow from 1981 through 2001.

Summary statistics for annual stormflow, annual number of storm-runoff events, and annual average stormflow for sites 3700, 4000, 5500, and 5800 from 1981 through 1987, 1998 through 2001, and for the years 1998, 2000, and 2001 are shown in table 4. These data indicate that stormflow usually occurs between about 25 and 50 days each year, depending on location. The data also indicate that the annual average stormflow at all sites was larger for the 4-year period from 1998–2001 than for the 17-year period from 1981–1997. However, if 1999 is excluded from the 1998–2001 period, there was a marked decrease in annual average stormflow. Figure 3 shows the relation between annual precipitation and the annual average stormflow. Regression models were developed to evaluate the relation between annual precipitation and annual average stormflow for sites 3700, 4000, 5500, and 5800. Annual precipitation was significantly correlated ($p< 0.05$) with annual average stormflow at all sites, and annual precipitation explained between 40 and 65 percent of the observed variation in annual average stormflow.

An analysis of the 1998–2001 streamflow data, which corresponds to the period when suspended-sediment data were collected, indicated that, for sites 3700 and 3970, stormflow for 1998, 2000, and 2001 was less than 5 percent of the total streamflow measured between April and October; in 1999, stormflow at sites 3700 and 3970 accounted for 18 and 23 percent, respectively, of the total streamflow measured between April and October. For the three sites in Cottonwood Creek Basin (sites 3977, 3985, and 3990), stormflow for 1998, 2000, and 2001 ranged from 9 to 52 percent of the total streamflow between April and October; in 1999, stormflow at these sites ranged from 38 to 50 percent of the total streamflow between April and October. For sites 5500 and 5800 located on Fountain Creek near the southern end of the study area and drainage basin, stormflow for 1998, 2000, and 2001 ranged from 3 to 34 percent of the total streamflow measured between April and October; in 1999, stormflow at these sites was about 30 percent of the total streamflow measured between April and October. The large storm that occurred in the study area in late April to early May 1999, which resulted in widespread flooding throughout the basin, had a large effect on the total volume of stormflow for 1999. This one storm, which at most sites continued for 6 consecutive days from April 29 to May 4, 1999, accounted for about 75 percent of the annual stormflow in 1999 for all the sites on Fountain and Monument Creeks (sites 3700, 3970, 5500, and 5800), and between about 40 to 60 percent of the annual stormflow in 1999 for the sites in Cottonwood Creek Basin (sites 3977, 3985, and 3990).

Table 4. Summary statistics for annual stormflow, annual number of stormflow events, and annual average stormflow in Fountain Creek Basin, 1981 through 2001

Statistic	Annual stormflow (cubic feet per second)			Annual number of stormflow events			Annual average stormflow (cubic feet per second)		
	1981–97	1998–2001	1998, 2000, 2001	1981–97	1998–2001	1998, 2000, 2001	1981–97	1998–2001	1998, 2000, 2001
Site 3700, Fountain Creek near Manitou Springs									
Minimum	26	10	10	9	1	1	13	26	26
Maximum	2,945	2,764	70	62	27	8	181	189	57
Median	143	46	22	23	7	6	32	45	33
Mean	420	717	34	24	10	5	49	76	39
Standard deviation	699	1,365	32	13	11	4	42	76	16
Site 4000, Monument Creek at Pikeview									
Minimum	327	781	781	7	30	30	39	46	46
Maximum	3,728	21,600	21,600	64	115	115	212	326	109
Median	1,114	5,643	2,500	36	41	35	64	86	64
Mean	1,276	8,418	8,295	36	57	60	93	136	73
Standard deviation	999	9,440	11,560	16	39	48	58	129	32
Site 5500, Fountain Creek at Colorado Springs									
Minimum	314	1,122	1,122	12	18	18	69	108	108
Maximum	13,340	22,070	4,667	73	45	45	434	880	180
Median	3,192	2,959	1,251	52	33	27	141	170	160
Mean	3,793	7,277	2,347	48	32	30	189	332	149
Standard deviation	2,853	9,997	2,010	16	12	14	121	367	37
Site 5800, Fountain Creek at Security									
Minimum	1,376	1,736	1,736	18	14	14	158	325	325
Maximum	17,465	32,340	5,605	58	38	26	939	1,319	413
Median	4,115	4,256	2,908	33	26	26	310	390	367
Mean	5,018	10,650	3,416	32	26	22	376	606	368
Standard deviation	3,731	14,550	1,984	10	10	7	231	477	44

WATER QUALITY

Previous studies done by Edelmann (1990), Ruddy (1993), and Bossong (2001) characterized water quality, evaluated spatial and temporal trends in water quality, and compared water-quality constituents to the State of Colorado’s instream water-quality standards for Fountain and Monument Creeks. Bossong (2001) did not detect significant trends in most water-quality constituents from 1987 through 1997; however, at several sites in the study area, downward trends were detected for 5-day biochemical oxygen demand (BOD_5), fecal coliform, total copper, dissolved iron, total lead, and dissolved and total manganese, nickel, and zinc. Bossong (2001) indicated upward trends at a few sites for specific conductance, chloride, and orthophosphorus.

As part of this study, a comparison of constituent concentrations for two periods, from 1981 through 1997 (pre-1998) and from 1998 through 2001 (post-1997) for base-flow, normal-flow, and stormflow conditions indicated, for most constituents, no overall trend. However, BOD_5 concentrations in data collected from post-1997 were noticeably smaller at most sites than for the pre-1998 period; also, ammonia nitrogen, at site 5530, which is downstream from the

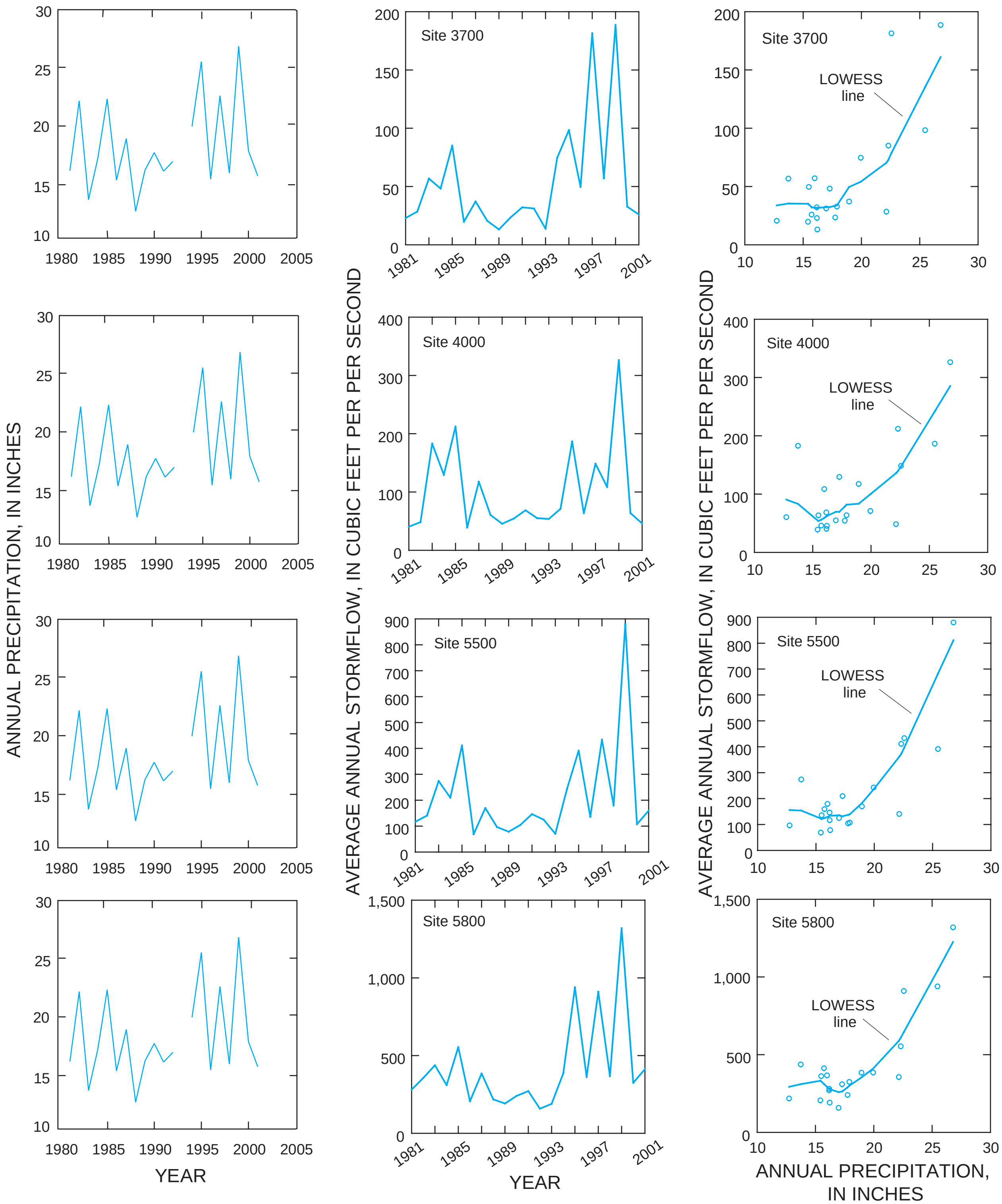


Figure 3. Relation of annual precipitation at Colorado Springs Weather Service Office and average annual stormflow for Monument and Fountain Creeks, 1981 through 2001.

Las Vegas Street Wastewater Treatment effluent outfall, was smaller in the post-1997 data. Because there were no overall trends between these two periods for the majority of constituents, a decision was made to use data collected from 1981 through 2001 to compare water-quality concentrations and loads from samples collected during base flow and normal flow to water quality during stormflow. Additionally, this report compares water quality associated with stormflow samples collected from the pre-1998 period to water quality associated with stormflow samples collected from the post-1997 period and relates water-quality concentrations during stormflow to acute instream water-quality standards.

Some constituent concentrations were reported below the laboratory analytical reporting limit (ARL). These data are considered censored. Helsel and Hirsch (1992) describe several methods to estimate summary statistics when data include censored values. The approach used in this report was to calculate summary statistics and to compare censored water-quality data to instream water-quality standards using the ARL as the estimated concentration. This methodology produced a conservative (worst case) estimate of the constituent concentration. In most cases, the frequency of censored values did not affect the summary statistics. However, where summary statistics shown in the tables were affected by censored values, the statistic is reported as less than the ARL. Boxplots were plotted using the ARL as the estimated concentration, again providing the worst-case estimate of the constituent concentration; the ARL was overlaid on the affected figures to show values above the ARL.

Comparison of Water Quality between Base Flow, Normal Flow, and Stormflow

Water quality commonly varies with different flow regimes. As stated previously, streamflow in the Fountain Creek Basin varies seasonally and water-quality data were separated into three flow regimes: base flow, normal flow, and stormflow. Water-quality samples collected between November and April that were unaffected by stormflow were identified as base-flow samples. Water-quality samples collected during the remainder of the year that were unaffected by stormflow were identified as normal-flow samples. Samples that were collected when the streamflow was affected by stormflow were identified as stormflow samples. Water-quality data associated with base flow, normal flow, and stormflow were compared to identify variations in water quality that have occurred among the different flow regimes.

Water-quality data determined to have been associated with stormflow were identified by visual inspection of hydrograph, precipitation data, concentration and sediment data, and by using a base-flow-separation program (Wahl and Wahl, 1995). The number of stormflow samples analyzed varied among sites (table 5).

Onsite Measurements

Dissolved oxygen, pH, and specific conductance were measured onsite concurrently with sample collection. Variations in dissolved oxygen, pH, and specific conductance with respect to base flow, normal flow, and stormflow are shown in figure 4. Dissolved-oxygen concentrations were consistently larger during base-flow conditions because the colder water temperatures that occur during the winter months allow more oxygen to stay in solution. Dissolved-oxygen concentrations generally were greater than 6 mg/L and were similar for normal flow and stormflow at all sites. Values of pH generally ranged from about 7.5 to 8.3 and were similar for all three flow regimes. However, sites 3970, 4000, and 4905, which are located on Monument Creek, tended to have larger pH values during the normal flow. Specific conductance, which is an indicator of dissolved solids, decreased as flow increased. The largest specific-conductance values occurred during base flow and, as a result of dilution, were smaller during stormflow.

Spatially, specific conductance generally doubled during base flow and normal flow between Fountain Creek sites 3700 and 3707, upstream from the confluence with Monument Creek, which indicates a source of relatively large dissolved solids. Site 3985, a tributary to Cottonwood Creek, generally had specific-conductance values greater than 1,100 μS/cm during base flow and normal flow, which generally were 50 percent larger than values measured at other sites. Specific conductance steadily increased in Monument Creek downstream from the confluence with Cottonwood Creek and increased during all flow regimes between sites 5500 and 5530.

Table 5. Number of nonstorm and stormflow samples collected in Fountain Creek Basin, 1981 through 2001

[BOD_5, 5-day biochemical oxygen demand]

Site number (see table 1)	Dissolved oxygen, pH, specific conductance, BOD_5, bacteria		Nitrogen and phosphorus		Trace elements	
	Number of nonstorm samples	Number of storm samples	Number of nonstorm samples	Number of storm samples	Number of nonstorm samples	Number of storm samples
3700	442	21	237	14	230	14
3707	34	4	34	4	34	4
3970	129	14	32	14	34	9
3977	16	1	16	1	0	0
3985	57	3	16	1	0	0
3990	219	4	19	1	0	0
4000	408	14	217	13	208	13
4905	220	11	221	11	220	11
5500	247	36	246	36	236	36
5530	234	30	234	30	177	25
5800	39	11	41	11	30	11

Biochemical Oxygen Demand and Fecal Coliform Bacteria

BOD_5 concentrations tended to be slightly larger at Fountain Creek sites 3700 and 3707, upstream from the Monument Creek confluence, during stormflow than during base flow and normal flow (fig. 5). At site 3970, Monument Creek upstream from Cottonwood Creek, BOD_5 concentrations were significantly larger during stormflow than during base flow and normal flow; the median storm-sample BOD_5 concentration at site 3970 was 6.2 mg/L, while the nonstorm median concentration was 1.0 mg/L (table 6). BOD_5 concentrations also tended to be larger at sites 4905, 5500, and 5800 during stormflow than during nonstormflow. Generally BOD_5 concentrations at sites upstream from site 5500 were similar during base flow and normal flow. Between sites 5500 and 5530, BOD_5 increased significantly downstream from the Las Vegas Street Wastewater Treatment effluent; the largest concentrations occurred during base flow. The median BOD_5 increased from about 1 mg/L at site 5500 to 13 mg/L at site 5530 during nonstormflow (table 6). During stormflow, the median concentration increased from 3 mg/L at site 5500 to 10.5 mg/L at site 5530.

Fecal coliform bacteria concentrations were highly variable, generally ranging by more than a factor of 10 at each site and flow regime (fig. 5). Fecal coliform concentrations tended to be largest during stormflow and smallest during base flow. At most Fountain and Monument Creek sites, the median fecal coliform concentrations during stormflow were greater than 1,000 col/100 mL, whereas the median fecal coliform concentrations at most sites during base flow generally were less than 100 col/100 mL. At sites 3970, Monument Creek upstream from Cottonwood Creek, and site 5800, Fountain Creek at Security, which is downstream from Sand Creek, the median fecal coliform concentrations during storm events were 10,400 and 7,000 col/100 mL, respectively (table 6).

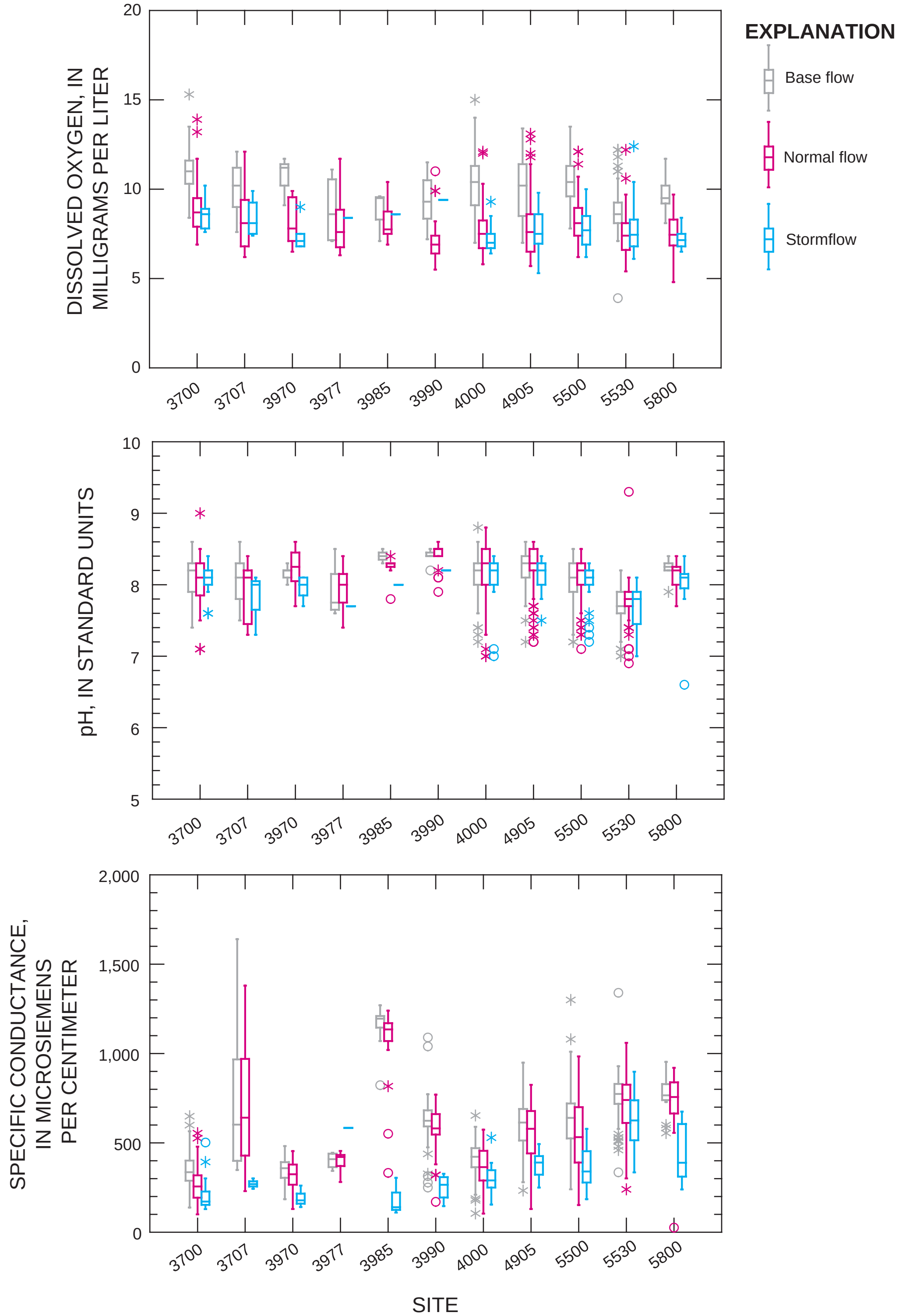


Figure 4. Variations in dissolved-oxygen concentrations, pH, and specific conductance for base flow, normal flow and stormflow in Fountain Creek Basin, 1981 through 2001.

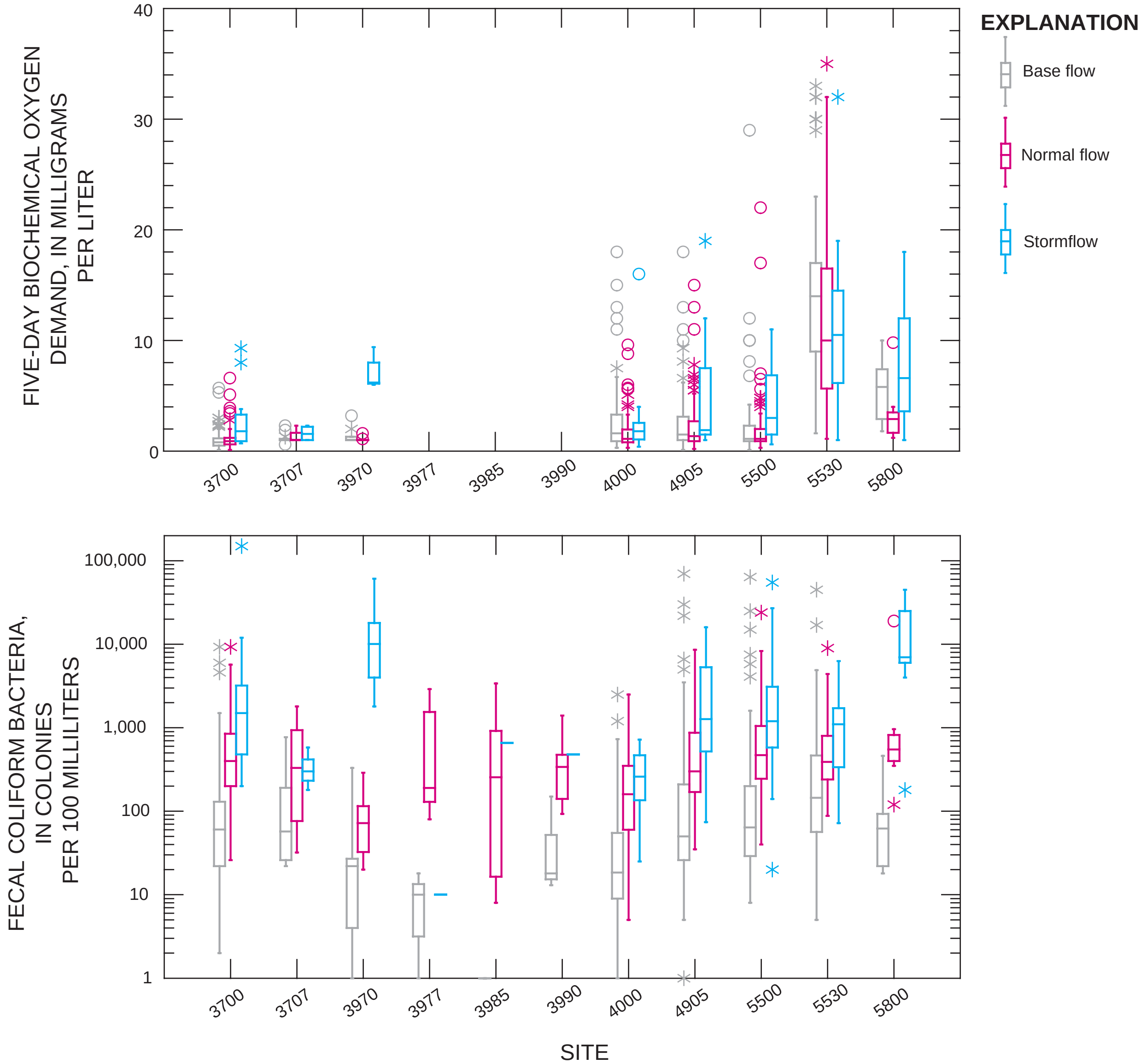


Figure 5. Variations in 5-day biochemical oxygen demand (BOD) and fecal coliform for base flow, normal flow, and stormflow in the Fountain Creek Basin, 1981 through 2001.

Nitrogen and Phosphorus

Nutrient data analyzed for this report include dissolved ammonia, dissolved nitrite plus nitrate, total phosphorus, and dissolved orthophosphorus. Dissolved ammonia, total phosphorus, and dissolved orthophosphorus concentrations in Fountain Creek upstream from the Monument Creek confluence tended to have larger concentrations during stormflow and the smaller concentrations during base flow (fig. 6) and nonstormflow (table 7). Dissolved ammonia and dissolved orthophosphorus concentrations in Monument Creek upstream from Cottonwood (site 3970) tended to be larger during stormflow and smaller during base flow. However, total phosphorus

Table 6. Summary statistics for onsite measurements, biochemical oxygen demand (BOD), and fecal coliform for nonstorm and stormflow samples for sites in Fountain Creek Basin, 1981 through 2001

[n/a, not applicable; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; mL, milliliters; <, less than; >, greater than; E, estimated]

Statistic	Fountain Creek upstream from Monument Creek				Monument Creek					
	Site 3700		Site 3707		Site 3970		Site 4000		Site 4905	
	Nonstorm	Storm	Nonstorm	Storm	Nonstorm	Storm	Nonstorm	Storm	Nonstorm	Storm
Specific conductance (µS/cm)										
Minimum	100	129	230	243	130	141	104	155	130	250
Maximum	649	502	1,640	301	482	261	653	529	949	493
Median	300	172	623	269	336	178	400	290	588	390
No. of samples	407	20	28	3	114	15	387	13	200	11
pH (standard units)										
Minimum	7.1	7.6	7.3	7.3	7.7	7.7	7.0	7.0	7.2	7.5
Maximum	9.0	8.4	8.6	8.1	8.6	8.1	8.8	8.4	8.6	8.4
Median	8.2	8.1	8.1	8.0	8.2	8.0	8.2	8.2	8.3	8.2
No. of samples	214	14	30	4	21	7	199	13	202	9
Dissolved oxygen (mg/L)										
Minimum	6.9	7.6	6.2	7.4	6.5	6.8	5.8	6.4	5.7	5.3
Maximum	15.3	10.2	12.1	9.9	11.7	9.0	15.0	9.3	13.4	9.8
Median	9.9	8.6	9.3	8.1	9.6	7.1	8.7	7.0	8.4	7.5
No. of samples	220	13	29	4	20	6	200	13	203	11
5-Day biochemical oxygen demand (BOD) (mg/L)										
Minimum	.1	.7	.6	<1.0	1.0	6.0	.3	.4	.1	<1.0
Maximum	6.6	9.3	2.3	2.3	3.2	9.4	E 18.0	15.0	E 18.0	E 19.0
Median	.9	1.8	1.0	<1.6	1.0	6.2	1.4	1.8	1.4	1.9
No. of samples	203	13	29	4	22	7	189	11	200	9
Fecal coliform bacteria (colonies per 100 mL)										
Minimum	E 2	200	E 22	180	1	1,800	<1	E 25	<1	E 74
Maximum	9,300	E 150,000	E 1,800	580	330	61,000	E 2,500	E 720	E 70,000	E 16,000
Median	140	1,500	78	300	33	10,400	55	260	180	1,500
No. of samples	177	13	19	3	20	6	151	8	164	8

Table 6. Summary statistics for onsite measurements, biochemical oxygen demand (BOD), and fecal coliform for nonstorm and stormflow samples for sites in Fountain Creek Basin, 1981 through 2001—Continued

[n/a, not applicable; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; mL, milliliters; <, less than; >, greater than; E, estimated]

Statistic	Monument Creek Reach -- Cottonwood Creek Sites						Fountain Creek downstream from Monument Creek					
	Site 3977		Site 3985		Site 3990		Site 5500		Site 5530		Site 5800	
	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm
Specific conductance (µS/cm)												
Minimum	281	583	332	110	314	146	152	185	240	335	560	239
Maximum	455	n/a	1,270	304	1,090	327	1,300	578	1,340	898	950	675
Median	421	n/a	1,160	140	605	266	595	340	766	626	780	376
No. of samples	15	1	54	3	215	4	205	33	195	28	28	12
pH (standard units)												
Minimum	7.4	7.7	7.8	8.0	7.9	8.2	7.1	7.2	6.9	7.0	7.7	6.6
Maximum	8.5	n/a	8.5	n/a	8.6	n/a	8.5	8.3	9.3	8.1	8.4	E 8.4
Median	8.0	n/a	8.3	n/a	8.4	n/a	8.2	8.1	7.8	7.8	8.2	8.1
No. of samples	15	1	54	1	24	1	210	35	202	28	27	12
Dissolved oxygen (mg/L)												
Minimum	6.3	8.4	6.9	8.6	5.5	9.4	6.2	6.2	3.9	6.1	4.8	6.6
Maximum	11.7	n/a	10.4	n/a	11.5	n/a	13.5	10.0	12.2	12.4	11.7	8.4
Median	7.6	n/a	7.9	n/a	7.3	n/a	9.6	7.7	8.2	7.4	9.1	7.2
No. of samples	15	1	15	1	24	1	270	34	202	30	27	10
5-Day biochemical oxygen demand (BOD) (mg/L)												
Minimum							E .1	.6	<1.0	<1.0	1.2	<1.0
Maximum	No data						29.0	11.0	35.0	32.0	10.0	18.0
Median							1.1	3.0	13.0	10.5	3.0	8.2
No. of samples	0	0	0	0	0	0	188	35	187	28	25	11
Fecal coliform bacteria (colonies per 100 mL)												
Minimum	<1	E 10	<1	660	E 13	480	E 8	E 20	E 5	E 72	E 18	E 180
Maximum	E 2,900	n/a	E 3,400	n/a	E 1,400	n/a	E 64,000	55,000	E 45,000	E 6,300	E 19,000	45,000
Median	160	n/a	250	n/a	200	n/a	200	1,200	290	1,100	240	7,000
No. of samples	14	1	13	1	14	1	157	28	153	24	18	10

concentrations at site 3970 were larger during base flow and smaller during stormflow. Data for the sites in the Cottonwood Creek Basin (sites 3977, 3985, and 3990) during stormflow are scarce, but the limited data suggest that dissolved ammonia, total phosphorus, and dissolved orthophosphorus concentrations may be substantially larger during stormflow. Downstream from Cottonwood Creek, dissolved ammonia concentrations in Monument Creek (sites 4000 and 4905) were relatively constant, total phosphorus concentrations tended to be larger in stormflow samples than base-flow or normal-flow samples, and dissolved orthophosphorus concentrations tended to be smaller in normal-flow and stormflow samples, with the largest concentrations occurring during base flow. Between sites 5500 and 5530, dissolved ammonia, total phosphorus, and dissolved orthophosphorus concentrations generally increased significantly downstream from the Las Vegas Street Wastewater Treatment effluent outfall. Median dissolved ammonia concentrations increased from less than 0.05 mg/L at site 5500 during each flow regime to about 5 mg/L at site 5530 during base flow, to about 1.5 mg/L at site 5530 during normal flow, and to about 1.3 mg/L at

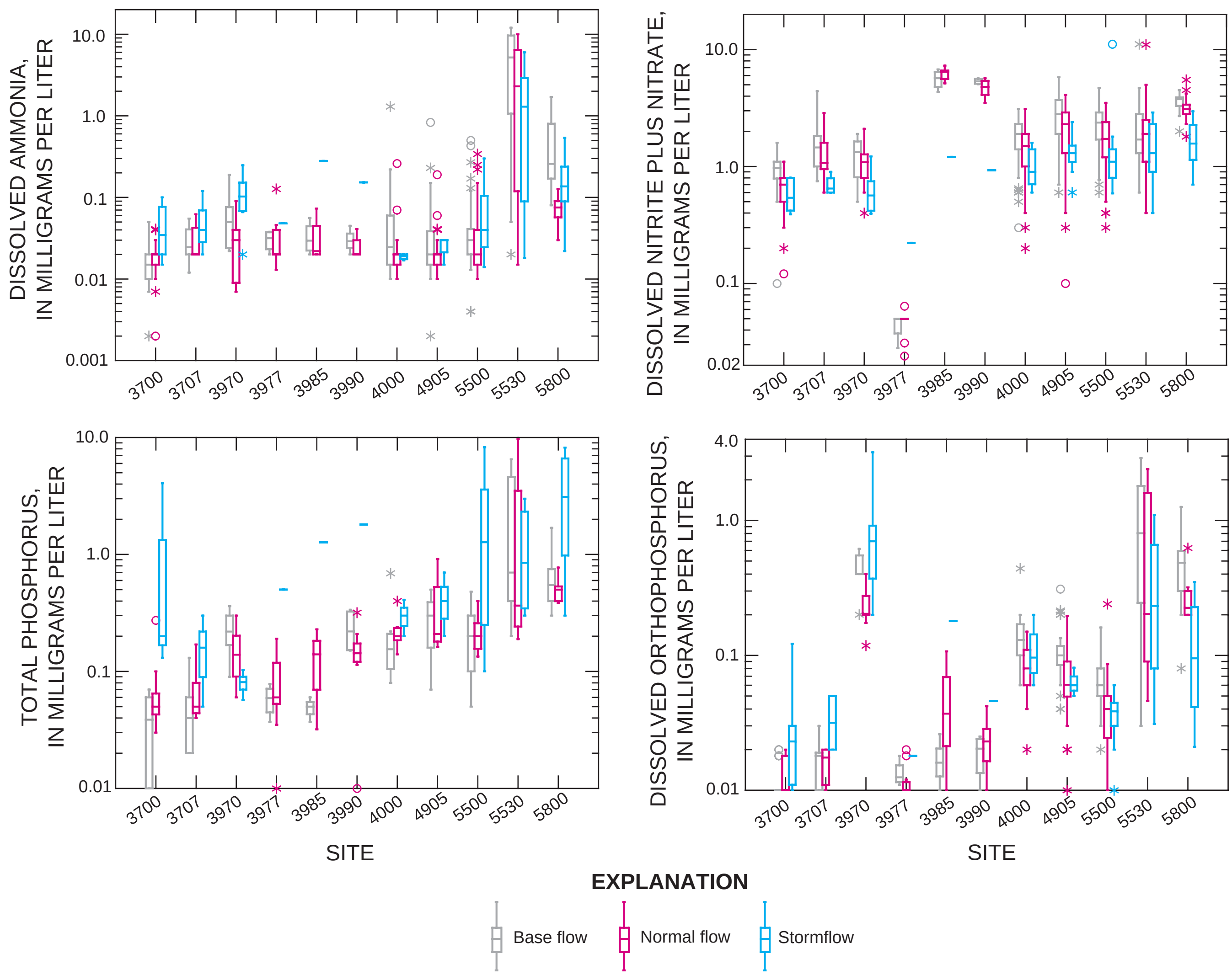


Figure 6. Variations in nitrogen and phosphorus concentrations for base flow, normal flow, and stormflow in Fountain Creek Basin, 1981 through 2001.

Table 7. Summary statistics for nutrient concentrations for nonstorm and stormflow samples for sites in Fountain Creek Basin, 1981 through 2001

[Units are in milligrams per liter; n/a, not applicable; E, estimated value; <, less than]

Statistic	Fountain Creek upstream from Monument Creek				Monument Creek					
	Site 3700		Site 3707		Site 3970		Site 4000		Site 4905	
	Nonstorm	Storm	Nonstorm	Storm	Nonstorm	Storm	Nonstorm	Storm	Nonstorm	Storm
Dissolved ammonia										
Minimum	<0.002	0.015	<0.010	0.02	<0.007	<0.020	<0.010	0.017	<0.002	0.015
Maximum	.050	.100	.062	.120	.189	.247	1.30	.020	.830	.030
Median	<.02	.035	<.020	.040	.030	.102	.020	<.020	.020	.030
No. of samples	69	10	16	3	18	9	59	4	70	3
Dissolved nitrite plus nitrate										
Minimum	.10	.39	.60	.60	.40	.40	.20	.60	.10	.60
Maximum	1.60	.80	4.40	.90	2.10	1.22	3.10	1.60	5.80	2.40
Median	.80	.54	1.38	.65	1.17	.60	1.80	.90	2.60	1.30
No. of samples	221	14	30	4	23	9	205	13	210	11
Total phosphorus										
Minimum	<.01	.13	.02	.05	.06	.06	.08	.20	.07	.20
Maximum	.27	4.06	.17	.30	.36	.10	.69	.41	.92	.70
Median	.05	.20	.05	.16	.18	.08	.20	.30	.21	.40
No. of samples	81	7	27	3	18	9	15	3	27	3
Dissolved orthophosphorus										
Minimum	<.010	<.010	<.010	.020	.118	.200	.020	.060	<.010	.050
Maximum	.020	.122	.030	.050	.616	3.20	.440	.200	.310	.081
Median	<.018	.023	<.018	.035	.245	.701	.105	.096	.090	.060
No. of samples	17	9	16	2	18	9	58	4	71	3

Table 7. Summary statistics for nutrient concentrations for nonstorm and stormflow samples for sites in Fountain Creek Basin, 1981 through 2001—Continued

[Units are in milligrams per liter; n/a, not applicable; E, estimated value; <, less than]

Statistic	Monument Creek -- Cottonwood Creek Sites						Fountain Creek downstream from Monument Creek					
	Site 3977		Site 3985		Site 3990		Site 5500		Site 5530		Site 5800	
	Nonstorm	Storm	Nonstorm	Storm	Nonstorm	Storm	Nonstorm	Storm	Nonstorm	Storm	Nonstorm	Storm
Dissolved ammonia												
Minimum	0.013	0.048	<0.020	0.280	<0.020	0.153	0.004	0.014	<0.015	0.018	<0.020	0.022
Maximum	.127	.n/a	.073	n/a	.045	n/a	.500	.300	12.00	6.00	1.70	.539
Median	<.020	n/a	.025	n/a	<.020	n/a	.020	.040	3.70	1.30	.127	.134
No. of samples	15	1	15	1	16	1	84	23	63	17	23	11
Dissolved nitrite plus nitrate												
Minimum	E .02	.22	4.34	1.21	3.50	.93	.30	.59	.40	.40	1.80	.70
Maximum	.06	n/a	7.28	n/a	5.67	n/a	4.70	11.10	11.10	2.90	5.50	2.96
Median	<.05	n/a	6.16	n/a	5.00	n/a	2.10	1.10	1.80	1.30	3.38	1.44
No. of samples	15	1	15	1	16	1	209	36	204	30	29	12
Total phosphorus												
Minimum	<.01	.50	E .03	1.27	<.01	1.80	.05	.10	.19	.30	.30	.30
Maximum	.19	n/a	.23	n/a	.34	n/a	.48	8.24	9.70	3.00	1.69	8.19
Median	.06	n/a	.075	n/a	.15	n/a	.20	1.47	.49	1.10	.50	4.17
No. of samples	15	1	15	1	16	1	29	14	32	4	21	11
Dissolved orthophosphorus												
Minimum	<.01	.018	<.010	.180	.010	.046	<.010	.010	.030	.031	.080	.021
Maximum	E .011	n/a	.107	n/a	.042	n/a	.240	.060	2.90	1.10	1.26	.349
Median	<.01	n/a	.030	n/a	.023	n/a	.050	.038	.535	.235	.300	.095
No. of samples	15	1	15	1	16	1	70	20	74	10	21	11

site 5530 during stormflow. Median total phosphorus concentration increased significantly during base flow and normal flow between sites 5500 and 5530 but decreased slightly during stormflow. Median dissolved orthophosphorus increased significantly between sites 5500 and 5530 during each flow regime.

Unlike the other nutrients, dissolved nitrite plus nitrate concentrations generally were largest during base flow and smallest during stormflow at most sites in the study area. Concentrations for all flow regimes generally were less than 2 mg/L. However, at sites 3985 and 3990 in Cottonwood Creek Basin, dissolved nitrite plus nitrate concentrations during base flow and normal flow generally were greater than 5.0 mg/L and probably resulted from fertilizer applied to lawns and gardens being leached to ground water and subsequently discharged to the stream. The larger nitrite plus nitrate concentrations and smaller dissolved nitrogen ammonia concentrations at site 5800 probably resulted from biological processes that convert ammonia to nitrite and nitrate, which decreases the concentration of ammonia and increases the concentration of nitrite plus nitrate.

Trace Elements

Trace elements analyzed for this report included both dissolved and total arsenic, boron, cadmium, chromium, copper, iron, manganese, lead, mercury, nickel, silver, zinc, and total cyanide. Water samples were not analyzed for trace elements at sites in Cottonwood Creek Basin (sites 3977, 3985, and 3990). Concentrations of many trace elements, such as dissolved and total cadmium, chromium, silver, and mercury, total cyanide, and dissolved arsenic and lead, were predominantly below the laboratory ARL for samples collected during base flow and normal flow. Therefore, this discussion is limited to total arsenic, dissolved and total boron, dissolved and total copper, dissolved and total iron, dissolved and total manganese, total lead, total nickel, and dissolved and total zinc.

Most dissolved trace-element concentrations associated with stormflow decreased or showed little change compared to base flow (figs. 7 and 8). Median concentrations of total copper, iron, lead, nickel, manganese, and zinc for stormflow samples generally were much larger than nonstorm samples (figs. 7 and 8, table 8); concentrations of total boron for stormflow samples generally were smaller than concentrations for base flow and normal flow. Median total copper concentrations in stormflow samples indicated little difference from nonstorm samples in Fountain Creek upstream from Monument Creek (sites 3700 and 3707), and median total copper concentrations were about 1.5 to 6 times larger at most of the other sites in Monument Creek and Fountain Creek. At site 5800, downstream from Sand Creek, total copper concentrations from stormflow samples were several times greater than storm sample concentrations at most other sites. Concentrations of total iron generally were much larger in stormflow samples than nonstorm samples; median total iron concentrations from stormflow samples at sites 3700 and 3707 were 3 to 8 times greater than nonstorm samples in the Fountain Creek reach upstream from Monument Creek and between 1.5 to 12 times greater than nonstorm samples in the Monument Creek reach (sites 3970, 4000 and 4905). At site 5800, the median nonstorm total iron concentration was 2,060 mg/L, and the median stormflow concentration was 58,450 mg/L, about 28 times greater than the nonstorm median concentration. Median dissolved manganese and zinc concentrations generally were similar or smaller in stormflow samples than nonstorm samples throughout the basin; the median storm concentrations of dissolved manganese and zinc at site 5800 were about 2 to 3 times smaller than the median nonstorm concentration. Median total manganese concentrations were larger for stormflow samples than nonstorm samples at most sites and much larger at site 5800. Total manganese concentrations for stormflow samples at site 5800 were several times greater than those at other sites. Median storm-sample concentrations of total lead and zinc concentrations generally were considerably larger than median concentrations for nonstormflow. Total arsenic, copper, iron, lead, manganese, nickel, and zinc concentrations tended to be larger during stormflow, while the dissolved phase of these metals remained low during stormflow, which indicates that these metals are transported in the particulate phase and are adsorbed to sediments during stormflow. Additionally, the substantially larger concentrations of total arsenic, copper, iron, lead, nickel, manganese, and zinc measured at site 5800 during stormflow, as compared to other sites, indicate a relatively large source of these metals in the reach between site 5530 and 5800.

Concentrations of most dissolved and total trace elements associated with base flow and normal flow

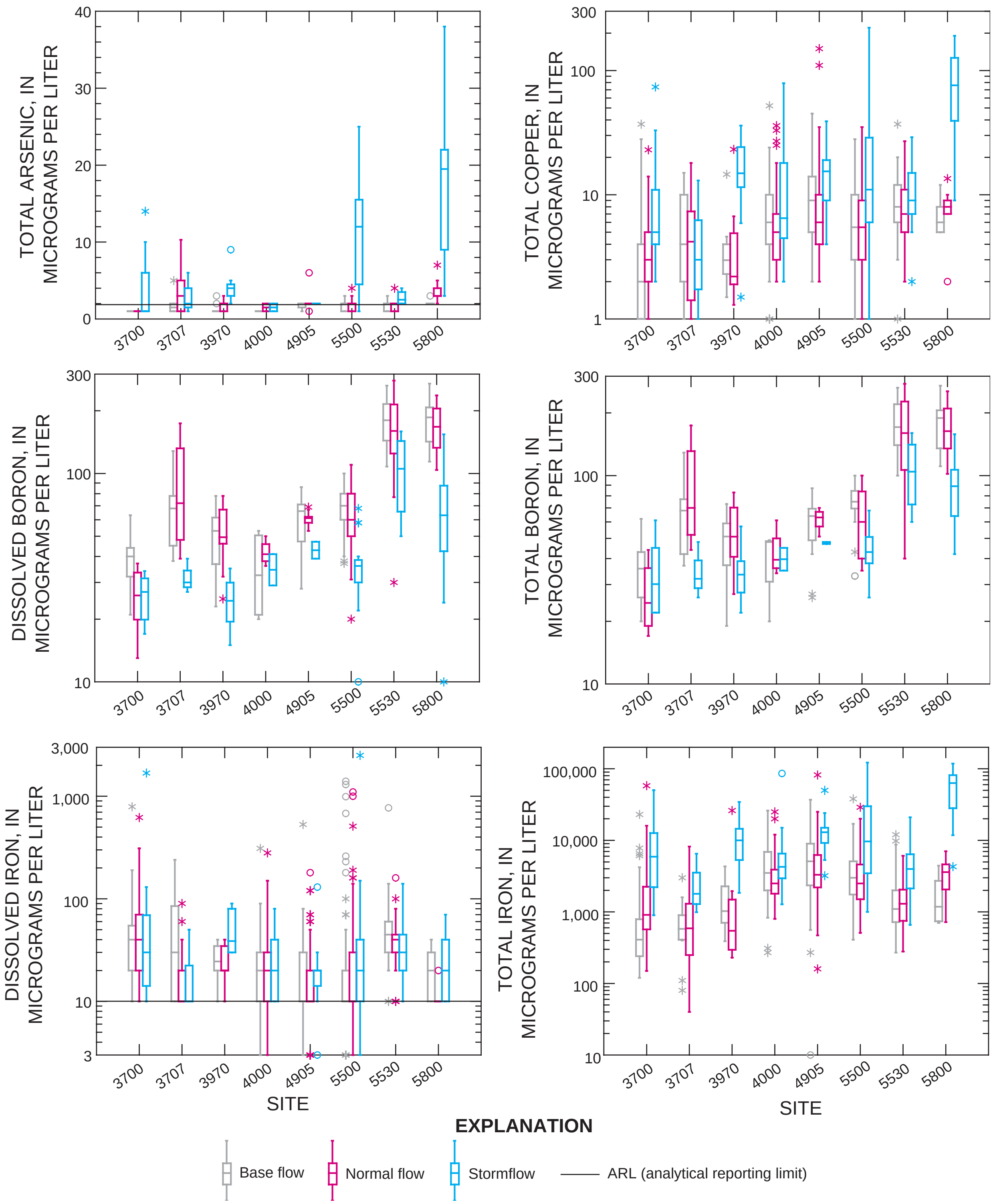


Figure 7. Variations in arsenic, boron, copper, and iron concentrations for base flow, normal flow, and stormflow in Fountain Creek Basin, 1981 through 2001.

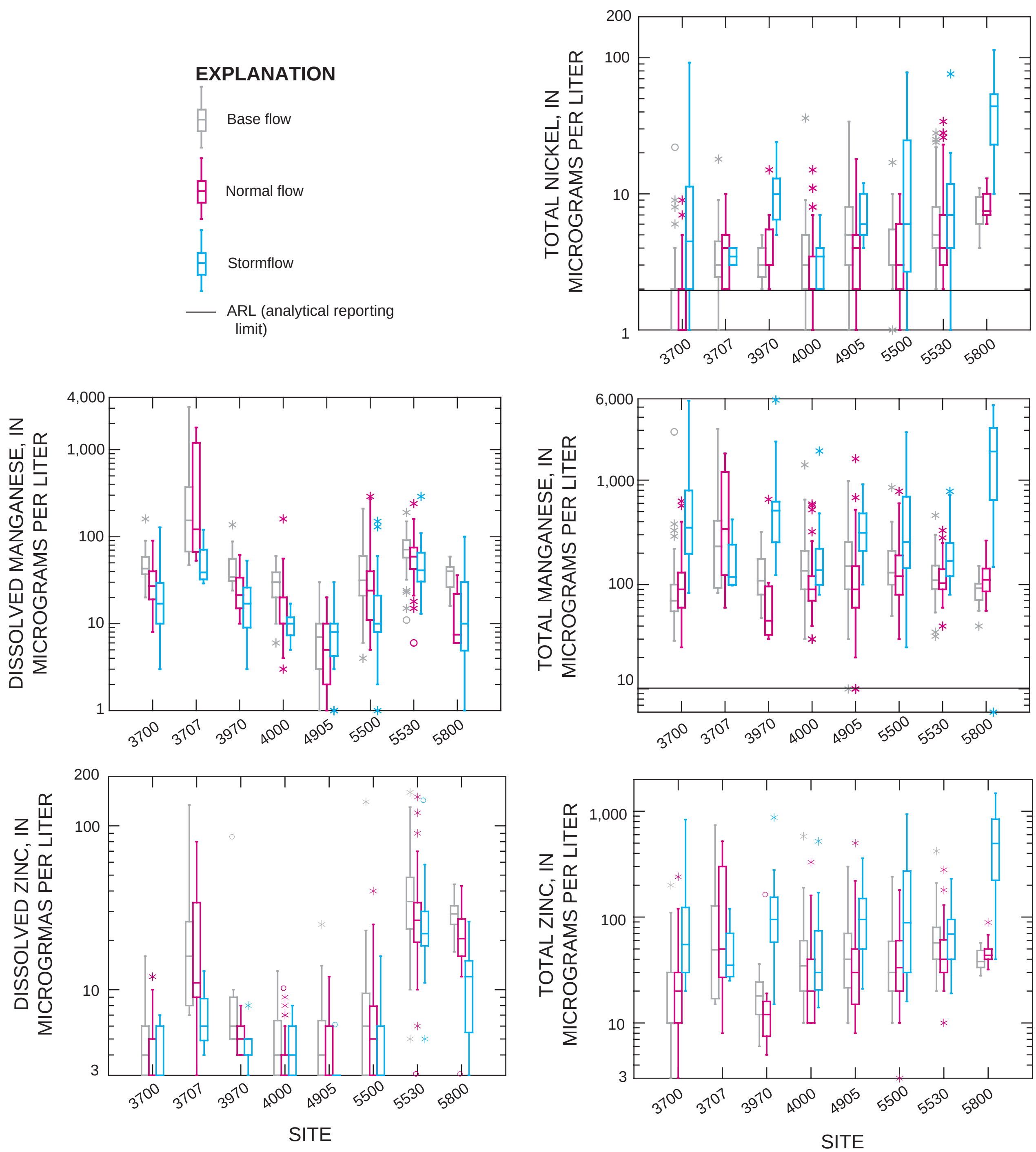


Figure 8. Variations in nickel, manganese, and zinc concentrations for base flow, normal flow, and stormflow in Fountain Creek Basin, 1981 through 2001.

Table 8. Summary statistics for trace-element concentrations for nonstorm and stormflow samples for sites in Fountain Creek Basin, 1981 through 2001

[Units are in micrograms per liter; n/a, not applicable; <, less than]

Statistic	Fountain Creek upstream from Monument Creek				Monument Creek						Fountain Creek downstream from Monument Creek					
	Site 3700		Site 3707		Site 3970		Site 4000		Site 4905		Site 5500		Site 5530		Site 5800	
	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm
Total arsenic																
Minimum	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	2.0	<1.0	1.0	<1.0	2.0	<1.0	3.0
Maximum	1.0	14	10.3	6.0	3.0	9.0	2.0	2.0	6.0	2.0	4.0	25	4.0	4.0	7.0	94
Median	<1.0	1.0	2.0	2.0	1.0	4.0	1.0	<1.0	2.0	2.0	2.0	12	2.0	2.5	2.0	20
No. of samples	23	7	19	3	23	9	10	2	20	2	32	15	33	4	21	11
Dissolved boron																
Minimum	13	17	38	27	23	15	20	29	28	39	20	<10	30	50	100	<10
Maximum	63	34	174	39	78	35	53	41	86	47	110	68	279	159	270	170
Median	32	27	69	30	51	24	41	35	62	43	70	36	160	110	180	63
No. of samples	23	8	19	3	23	9	10	2	20	2	38	15	38	4	21	11
Total boron																
Minimum	17	22	37	26	19	22	20	35	26	47	33	26	40	60	100	42
Maximum	62	61	174	48	83	57	61	45	87	48	100	68	276	159	270	169
Median	32	31	70	32	51	34	41	40	64	48	70	43	170	110	180	92
No. of samples	22	8	19	3	23	9	9	2	20	2	32	15	33	4	21	11
Dissolved copper																
Minimum	<0.6	1.0	<0.6	<0.6	<0.6	0.8	0.9	1.0	<0.6	1.0	<0.6	1.0	<1.0	<1.0	2.0	1.0
Maximum	10	3.0	1.8	2.2	3.7	2.8	5.0	2.0	6.8	3.0	10	4.0	11	11	6.0	4.0
Median	<1.0	1.0	1.0	1.0	1.4	1.1	1.0	1.0	1.0	1.5	1.0	1.4	4.0	3.0	3.0	2.0
No. of samples	115	10	18	3	20	9	89	12	109	4	109	22	121	19	19	10
Total copper																
Minimum	<.6	2.0	<.6	<.6	1.3	1.5	<1.0	2.0	2.0	4.0	<1.0	<1.0	<1.0	2.0	2.0	9.0
Maximum	37	74	18	13	23	36	52	79	150	39	35	221	37	29	12	190
Median	3.0	5.0	4.0	3.0	2.5	15	5.0	6.5	8.0	16	5.5	11	8.0	9.0	7.0	71
No. of samples	212	15	27	4	20	9	195	11	206	11	194	36	136	23	19	11
Dissolved iron																
Minimum	<10	<10	<10	<10	<10	<10	3.0	<10	<3.0	<3.0	<3.0	<3.0	<10	<10	<10	<10
Maximum	790	1,680	240	50	40	90	310	80	530	130	1,400	2,500	770	140	40	70
Median	40	30	20	<10	20	40	20	20	10	20	10	20	40	30	<10	20
No. of samples	199	15	28	4	22	9	174	11	182	11	180	34	137	20	19	10

Table 8. Summary statistics for trace-element concentrations for nonstorm and stormflow samples for sites in Fountain Creek Basin, 1981 through 2001—Continued

[Units are in micrograms per liter; n/a, not applicable; <, less than]

Statistic	Fountain Creek upstream from Monument Creek				Monument Creek						Fountain Creek downstream from Monument Creek					
	Site 3700		Site 3707		Site 3970		Site 4000		Site 4905		Site 5500		Site 5530		Site 5800	
	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm
Total iron																
Minimum	120	900	40	990	230	1,850	270	1,280	10	3,210	410	1,000	270	660	700	4,290
Maximum	58,000	50,200	8,200	6,500	26,100	34,400	26,000	86,000	82,000	50,000	38,000	122,000	12,000	21,000	5,480	118,000
Median	720	5,900	580	1,800	820	9,980	2,850	4,280	3,900	13,000	2,800	9,650	1,160	4,020	2,060	58,450
No. of samples	212	15	27	4	20	9	196	12	207	10	193	36	134	24	18	9
Dissolved manganese																
Minimum	8.0	3.0	47	29	10	3.0	3.3	5.0	<1.0	<1.0	4.0	1.0	6.0	13	6.0	1.0
Maximum	160	128	3,100	120	137	53	160	17	30	30	290	150	240	290	59	100
Median	39	17	140	39	31	17	20	10	7.0	8.0	30	10	67	41	26	8.0
No. of samples	214	15	29	4	23	9	186	12	198	11	193	34	139	19	21	11
Total manganese																
Minimum	25	83	60	98	30	123	30	80	<10	100	30	25	32	80	40	6.0
Maximum	2,900	5,760	3,100	420	654	5,850	1,400	1,900	1,600	910	850	2,870	460	780	260	5,220
Median	80	350	296	120	89	510	100	140	120	320	130	260	110	170	96	1,860
No. of samples	215	15	30	4	23	9	196	12	210	10	195	34	122	18	21	11
Total lead																
Minimum	1.0	3.0	<1.0	3.0	<1.0	3.0	<1.0	2.0	<1.0	5.0	<1.0	3.0	<1.0	3.0	<1.0	9.0
Maximum	53	300	17	55	51	97	120	140	91	55	72	277	46	38	12	538
Median	3.0	17	2.5	18	4.0	30	5.0	9.0	6.0	17	5.0	23	4.0	12	3.0	170
No. of samples	204	15	30	4	23	9	195	12	209	10	195	36	125	34	21	11
Dissolved zinc																
Minimum	2.0	3.0	<3.0	4.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	5.0	<3.0	<3.0
Maximum	16	7.0	134	13	84	8.0	13	8.0	25	6.0	140	16	160	140	44	26
Median	<3.0	3.0	16	6.0	6.0	5.0	3.0	<3.0	4.0	3.0	5.0	3.0	31	22	26	14
No. of samples	116	10	19	3	23	9	100	5	111	5	111	23	124	20	21	11
Total zinc																
Minimum	<3.0	20	8.0	25	5.0	15	10	14	8.0	21	<3.0	16	10	19	28	40
Maximum	240	830	740	120	158	872	580	520	500	360	240	940	420	230	68	1,480
Median	20	55	50	36	14	95	30	<30	30	95	30	88	50	69	42	460
No. of samples	214	15	29	3	23	9	196	12	210	10	195	36	137	24	21	11

were relatively small in Fountain Creek upstream from Monument Creek. However, concentrations of dissolved and total boron, manganese, and zinc increased significantly between sites 3700 and 3707 during base flow and normal flow, which indicates a constant source of trace elements in this reach, possibly from Gold Hills Mesa, a former tailings hill for a gold refinery located just upstream from the confluence with Monument Creek. Some trace elements increased downstream from the Las Vegas Street Wastewater Treatment effluent outfall during base flow and normal flow and subsequently decreased downstream from site 5530. Median dissolved and total boron concentrations more than doubled between sites 5500 and 5530 during all three flow regimes. Median dissolved manganese and median dissolved and total zinc concentrations increased significantly during base flow and normal flow then subsequently decreased downstream from site 5530.

SEMIVOLATILE ORGANIC COMPOUNDS AND PESTICIDES ASSOCIATED WITH STORMFLOW

Semivolatile organic compounds are a large group of compounds of concern in the environment. These compounds are abundant in the environment, may be toxic and(or) carcinogenic to organisms, and could represent a long-term source of contamination. Semivolatile organic compounds originate from natural and anthropogenic (manmade) sources and can be found in automobile engine exhaust, asphalt used in road construction, crude oil, coal, coal tar pitch, creosote, and roofing tar, or the compounds can form during the incomplete burning of coal, oil, gas, wood, garbage, or other organic substances (Moore and Ramamoorthy, 1984). Semivolatile organic compounds are present throughout the environment in the air, water, and soil and can occur in the air, attached to dust particles, or as solids in soil or sediment.

Pesticides are used to control many different types of weeds, insects, and other pests in a wide variety of agricultural and urban settings. Concerns have steadily grown about the potential adverse effects of pesticides on the environment and human health through contamination of the hydrologic system. Water is one of the primary means by which pesticides are transported from their application areas to other parts of the environment. Through physical processes such as erosion, surface runoff, and ground-water recharge, trace amounts of pesticides used on lawns, gardens, road rights-of-way, and crops can eventually become part of the ground-water system and streams. Although many modern pesticides are designed to degrade rapidly, increasing amounts of impervious areas may increase the amount of pesticides and semivolatile organic compounds that reach Fountain and Monument Creeks, especially during storms.

Water samples were collected for analysis of 16 semivolatile organic compounds and 47 pesticides at four sites during stormflow. No samples were collected during base flow or normal flow. Semivolatile organic compound and pesticide data were collected from sites 3700, 3970, 5500, and 5800 from 1998 through 2001. Most concentrations of semivolatile organic compounds were below the ARL; however, many samples had quantities of these compounds detected, but because these detections were less than the ARL, the data are considered estimated. In addition, estimated values of several compounds were determined, which indicates that values were less than the ARL, but an estimate was made of the concentration. Only 8 of the 16 semivolatile compounds analyzed were detected (table 9). No compounds were detected at site 3700; about 20 to 30 percent of the samples had detectable concentrations of semivolatile organic compounds during stormflow at sites 5500 and 5800, respectively. Fluoranthene and pyrene were detected in one out of nine samples at site 3970. Detections of chrysene and phenanthrene occurred in 2 out of 10 samples, and fluoranthene and pyrene were detected in 3 samples at site 5500, while detections of benz[a] anthracene, benzo[b] fluoranthene, benzo[a] pyrene, and benzo[k] fluoranthene occurred in 1 out of 10 samples at site 5500. Detections of fluoranthene occurred in 2 out of 10 samples at site 5800, and a detection of pyrene occurred in 1 sample. There were no quantifiable detections at site 3700. Additionally, there were numerous reported estimated values (table 9). Detections of low-level concentrations of these semivolatile organic compounds presumably were washed from the land surface, streets, and storm drains during storms.

Table 9. Detections of semivolatile organic compounds in stormflow samples for selected sites in Fountain Creek Basin, 1998 through 2001

[n, number of samples]

Constituent name	Site 3700 n=7			Site 3970 n=9			Site 5500 n=10			Site 5800 n=10		
	Number of detections	Number of less-than values	Number of estimated values	Number of detections	Number of less-than values	Number of estimated values	Number of detections	Number of less-than values	Number of estimated values	Number of detections	Number of less-than values	Number of estimated values
Acenaphthylene	0	7	0	0	9	0	0	10	0	0	10	0
Acenaphthene	0	7	0	0	9	0	0	10	0	0	10	0
Anthracene	0	7	0	0	9	0	0	10	0	0	10	0
Benz[a]anthracene	0	7	0	0	9	0	1	7	2	0	8	2
Benzo[b]fluoranthene	0	7	0	0	8	1	1	6	3	0	7	3
Benzo[a]pyrene	0	7	0	0	8	1	1	6	3	0	7	3
Benzo[ghi]perylene	0	7	0	0	8	1	0	8	2	0	8	2
Benzo[k]fluoranthene	0	7	0	0	9	0	1	8	1	0	8	2
Chrysene	0	7	0	0	8	1	2	6	2	0	7	3
1,2,5,6-Dibenzanthracene	0	7	0	0	9	0	0	10	0	0	10	0
Fluoranthene	0	7	0	1	6	2	3	6	1	2	7	1
Fluorene	0	7	0	0	9	0	0	10	0	0	10	0
Indeno[1,2,3-cd]pyrene	0	7	0	0	8	1	0	7	3	0	8	2
Naphthalene	0	6	1	0	7	2	0	5	5	0	5	5
Phenanthrene	0	7	0	0	8	1	2	7	1	0	7	3
Pyrene	0	7	0	1	6	2	3	6	1	1	7	2

Of the 47 pesticides analyzed, atrazine, diazinon, malathion, metolachlor, prometon, and trifluralin were detected at all four sites. Permethrin, simazine, tebuthiuron, terbacil, terbufos, thiobencarb, triallate, Alpha-BHC and p,p'-DDE were detected in about 30 percent of the samples at site 5500 and once at site 5800 (table 10).

Diazinon and malathion are commonly used organophosphorus insecticides. The nitrogen-containing herbicides prometon and simazine indicate urban and agricultural sources. Many pesticides break down rapidly in the environment and do not pose a serious threat to humans; however, the U.S. Environmental Protection Agency has identified atrazine as a possible carcinogen. The relatively frequent detection of pesticides at low levels indicates pesticides have been routinely transported to streams, probably as overland runoff during storms, and merits continued monitoring. Water-quality standards have not been set for many pesticides, and existing standards do not consider the cumulative effects of several pesticides in the water at the same time.

Loads for Stormflow and Nonstormflow

Instantaneous loads for storm and nonstormflows were computed for nutrients and trace elements to estimate the quantity of these constituents transported in Fountain and Monument Creeks (tables 11 and 12). “Load” represents the mass of a constituent transported past a river cross section during a specific time interval and is calculated by multiplying the instantaneous streamflow by the constituent concentration times a conversion factor to obtain an estimated load, in pounds per day. Loads vary considerably as a result of changes in streamflow, constituent concentrations, or both. Large constituent loads occur in response to snowmelt and from storms. Median streamflow associated with stormflow were generally between 2 to 5 times greater than nonstormflow for Fountain Creek upstream from Monument Creek, 3 to 5 times greater for Monument Creek, and 1.5 to 4 times greater for Fountain Creek downstream from Monument Creek (table 6).

Table 10. Detections of pesticides in stormflow samples for selected sites in Fountain Creek Basin, 1998 through 2001

Constituent name	Site 3700 n=8			Site 3970 n=10			Site 5500 n=10			Site 5800 n=10		
	Number of detections	Number of less-than values	Number of estimated values	Number of detections	Number of less-than values	Number of estimated values	Number of detections	Number of less-than values	Number of estimated values	Number of detections	Number of less-than values	Number of estimated values
Acetochlor	0	8	0	0	10	0	0	10	0	0	10	0
Alachlor	0	8	0	0	10	0	0	10	0	0	10	0
Atrazine	3	5	0	5	4	1	7	1	2	6	2	2
Benfluralin	0	8	0	0	10	0	0	10	0	0	10	0
Butylate	0	8	0	0	10	0	0	10	0	0	10	0
Carbaryl	0	1	7	0	0	10	0	1	9	0	1	9
Carbofuran	0	8	0	0	10	0	0	10	0	0	10	0
Chlorpyrifos	0	8	0	1	9	0	0	10	0	0	10	0
Cyanazine	0	8	0	0	10	0	1	9	0	0	10	0
Dacthal	0	7	1	0	5	5	1	3	6	0	3	7
Deethylatrazine	0	7	1	0	10	0	0	10	0	0	10	0
Diazinon	7	1	0	10	0	0	10	0	0	10	0	0
Dieldrin	0	8	0	0	10	0	0	10	0	0	10	0
2,6-Diethylaniline	0	8	0	0	10	0	0	10	0	0	10	0
Disulfoton	0	8	0	0	10	0	0	10	0	0	10	0
EPTC	0	8	0	0	10	0	0	10	0	0	10	0
Ethalfluralin	0	8	0	0	10	0	0	10	0	0	10	0
Ethoprop	0	8	0	0	10	0	0	10	0	0	10	0
Fonofos	0	8	0	0	10	0	0	10	0	0	10	0
Lindane	0	8	0	0	10	0	0	10	0	0	10	0
Linuron	0	8	0	0	10	0	0	10	0	0	10	0
Malathion	3	4	1	7	2	1	8	0	2	7	1	2
Methyl-Azinphos	0	8	0	0	10	0	0	10	0	0	10	0
Methyl-Parathion	0	8	0	0	10	0	0	10	0	0	10	0
Metolachlor	1	7	0	2	8	0	2	8	0	1	9	0
Metribuzin	0	8	0	0	10	0	0	10	0	0	10	0
Molinate	0	8	0	0	10	0	0	10	0	0	10	0
Napropamide	0	8	0	0	10	0	0	10	0	0	10	0
Parathion	0	8	0	0	10	0	0	10	0	0	10	0
Pebulate	0	8	0	0	10	0	0	10	0	0	10	0
Pendimethalin	0	8	0	1	9	0	1	9	0	1	9	0
Permethrin	0	8	0	0	10	0	3	7	0	1	9	0
Phorate	0	8	0	0	10	0	0	10	0	0	10	0
Prometon	0	3	5	3	2	5	7	0	3	6	1	3
Propachlor	0	8	0	0	10	0	0	10	0	0	10	0
Propanil	0	8	0	0	10	0	0	10	0	0	10	0
Propargite	0	8	0	0	10	0	0	10	0	0	10	0
Pronamide	0	8	0	0	10	0	0	10	0	0	10	0
Simazine	0	8	0	0	10	0	3	7	0	1	9	0
Tebuthiuron	0	8	0	0	9	1	3	7	0	1	9	0
Terbacil	0	8	0	0	10	0	3	7	0	1	9	0
Terbufos	0	8	0	0	10	0	3	7	0	1	9	0
Thiobencarb	0	8	0	0	10	0	3	7	0	1	9	0
Triallate	0	8	0	0	10	0	3	7	0	1	9	0
Trifluralin	1	7	0	5	3	2	4	2	4	5	3	2
Alpha-BHC	0	8	0	0	10	0	3	7	0	1	9	0
p,p'-DDE	0	8	0	0	10	0	3	7	0	1	9	0

Table 11. Summary statistics for nutrient loads for nonstorm and stormflow samples for sites in Fountain Creek Basin, 1981 through 2001

[Units are in pounds per day; n/a, not applicable; <, less than]

Statistic	Fountain Creek upstream from Monument Creek				Monument Creek					
	Site 3700		Site 3707		Site 3970		Site 4000		Site 4905	
	Nonstorm	Storm	Nonstorm	Storm	Nonstorm	Storm	Nonstorm	Storm	Nonstorm	Storm
Dissolved ammonia										
Minimum	<0.4	2.8	<0.1	8.2	<0.5	<10.2	<0.3	3.2	<0.7	5.4
Maximum	28	70	5.8	22	58.4	393	467	11	313	24
Median	<1.4	13	<1.6	9.5	4.0	56	2.6	8.7	2.4	18
No. of samples	81	11	19	3	20	7	59	4	70	3
Dissolved nitrite plus nitrate										
Minimum	6.5	32	7.8	123	52	270	41	136	21	250
Maximum	449	724	280	332	350	3,150	790	1,550	1,800	1,270
Median	52	99	53	160	150	347	202	259	337	510
No. of samples	233	15	34	3	25	7	203	13	211	9
Total phosphorus										
Minimum	<.5	18	.2	24	4.2	34	5.0	49	4.2	120
Maximum	37	3,070	22	55	73	275	132	168	202	560
Median	<3.2	303	1.5	39	18	56	21	111	40	340
No. of samples	37	7	30	2	20	7	15	3	28	2
Dissolved orthophosphorus										
Minimum	<.1	<1.4	<.1	9.2	7.1	103	1.4	32	<.8	29
Maximum	13	92	5.6	9.5	620	12,580	126	55	115	48
Median	<.8	8.2	<.7	9.3	34	600	13	38	11	30
No. of samples	80	10	18	2	20	7	58	4	71	3

Table 11. Summary statistics for nutrient loads for nonstorm and stormflow samples for sites in Fountain Creek Basin, 1981 through 2001—Continued

[Units are in pounds per day; n/a, not applicable; <, less than]

Statistic	Monument Creek – Cottonwood Creek sites						Fountain Creek downstream from Monument Creek					
	Site 3977		Site 3985		Site 3990		Site 5500		Site 5530		Site 5800	
	Nonstorm	Storm	Nonstorm	Storm	Nonstorm	Storm	Nonstorm	Storm	Nonstorm	Storm	Nonstorm	Storm
Dissolved ammonia												
Minimum	<0.1	0.1	<0.1	5.7	<0.4	37	1.1	4.2	<15	19	<36	130
Maximum	.3	n/a	.6	n/a	3.6	n/a	508	750	6,760	3,630	1,140	1,810
Median	<.1	n/a	.1	n/a	<1.0	n/a	4.8	38	2,200	1,380	98	546
No. of samples	15	1	15	1	15	1	80	22	81	11	23	11
Dissolved nitrite plus nitrate												
Minimum	E .1	.6	10	25	98	226	110	177	181	168	1,470	2,010
Maximum	.7	n/a	56	n/a	494	n/a	5,690	13,100	4,120	4,450	4,220	10,360
Median	<.1	n/a	23	n/a	173	n/a	426	761	905	1,210	2,190	4,830
No. of samples	15	1	15	1	18	1	200	35	199	29	25	12
Total phosphorus												
Minimum	<.1	1.2	E .1	26	<.2	436	4.3	67	79	375	117	754
Maximum	2.2	n/a	1.5	n/a	26	n/a	292	131,590	3,560	1,390	1,400	65,000
Median	.1	n/a	.4	n/a	6.8	n/a	48	2,860	380	607	367	14,640
No. of samples	15	1	15	1	15	1	29	13	32	3	21	11
Dissolved orthophosphorus												
Minimum	<.1	<.1	<.1	3.7	.2	11	<1.2	2.8	14	50	31	208
Maximum	.2	n/a	.4	n/a	2.8	n/a	212	351	1,440	849	1,050	408
Median	<.1	.1	.1	n/a	.8	n/a	11	57	304	276	25	299
No. of samples	15	1	15	1	15	1	70	20	73	10	21	11

Table 12. Summary statistics for trace-element loads for nonstorm and stormflow samples for sites in Fountain Creek Basin, 1981 through 2001

[Units are in pounds per day; n/a, not applicable; <, less than]

Statistic	Fountain Creek upstream from Monument Creek				Monument Creek						Fountain Creek downstream from Monument Creek					
	Site 3700		Site 3707		Site 3970		Site 4000		Site 4905		Site 5500		Site 5530		Site 5800	
	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm
Total arsenic																
Minimum	<0.02	<0.14	<0.02	<0.37	<0.1	<0.58	<0.1	<0.11	<0.1	1.2	<0.1	0.52	<0.31	1.9	<0.78	7
Maximum	.47	9.7	.32	1.2	.37	35	.66	.16	1.24	1.6	8.5	290	11	6.8	4.3	700
Median	<.09	.65	.11	.47	.12	2.9	<.31	n/a	.34	n/a	.46	27	1.2	4.1	1.8	100
No. of samples	23	7	19	3	19	9	8	2	20	2	32	15	33	4	20	12
Dissolved boron																
Minimum	1.3	3.3	1.1	6.2	3.4	7.2	4.0	6.6	4.3	28	10	<19	59	110	82	<63
Maximum	6.6	26	12	13	18	98	24	16	21	31	85	280	270	170	220	470
Median	2.8	8.0	4.0	7.2	6.6	13	6.7	11	10	30	17	54	120	140	120	240
No. of samples	23	7	19	3	26	6	8	2	20	2	35	15	36	4	20	12
Total boron																
Minimum	1.2	3.6	1.2	6.6	3.8	7.2	4.9	7.3	4.3	29	10	20	53	130	80	140
Maximum	8.0	42	12	12	19	130	22	19	21	38	170	420	250	178	220	740
Median	2.8	9.0	4.0	8.8	6.7	25	6.3	13	10	33	17	73	120	140	130	320
No. of samples	22	7	19	3	26	6	7	2	20	4	32	15	33	4	20	12
Dissolved copper																
Minimum	<.01	.1	<.02	<.2	<.01	.5	.02	.2	<.03	.4	<.04	.3	<.5	<1.5	1.2	2.8
Maximum	.9	2.3	.3	.5	.8	3.5	1.8	.6	1.6	1.1	5.9	29	9.2	7.0	5.0	39
Median	<.07	.3	.09	.4	.2	1.1	.1	.5	.2	.6	.3	1.6	1.9	2.3	2.4	6.4
No. of samples	115	9	18	3	23	6	96	5	109	8	104	22	119	19	18	11
Total copper																
Minimum	<.01	.2	<.02	<.5	.1	4.2	<.05	.3	.07	2.4	<.09	<.3	<.9	2.6	2.3	13
Maximum	5.7	56	1.6	1.8	13	140	35	170	100	47	39	3,480	27	21	13	1,240
Median	.2	1.7	.1	.6	.4	16	.6	2.3	1.0	7.1	1.0	6.6	4.1	6.6	4.7	310
No. of samples	212	14	27	3	23	6	194	12	208	9	194	35	138	21	18	12
Dissolved iron																
Minimum	<.3	<1.4	<.1	<1.8	<.6	<21	.2	<1.2	<.2	<1.1	<.2	<1.4	<4.6	<11	<4.7	<9.9
Maximum	110	1,270	6.5	7.0	71	90	150	130	91	65	680	1,810	540	140	25	440
Median	2.5	5.1	1.0	<3.4	2.4	32	1.9	5.6	1.6	8.0	2.9	10	19	18	<9.6	75

Table 12. Summary statistics for trace-element loads for nonstorm and stormflow samples for sites in Fountain Creek Basin, 1981 through 2001—Continued

[Units are in pounds per day; n/a, not applicable; <, less than]

Statistic	Fountain Creek upstream from Monument Creek				Monument Creek						Fountain Creek downstream from Monument Creek					
	Site 3700		Site 3707		Site 3970		Site 4000		Site 4905		Site 5500		Site 5530		Site 5800	
	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm	Non-storm	Storm
No. of samples	199	14	28	4	25	6	172	11	184	9	177	32	137	18	18	11
Total iron																
Minimum	2.6	73	0.4	310	14	1,920	15	210	1.1	1,920	31	260	79	400	280	7,000
Maximum	7,820	16,490	390	910	8,830	135,290	25,570	190,230	31,960	59,880	47,250	1,948,000	32,910	20,540	7,770	819,610
Median	45	930	22	430	130	9,800	350	1,380	530	5,570	570	5,340	590	3,140	1,560	211,350
No. of samples	212	14	27	4	23	6	200	12	209	8	193	35	140	22	17	10
Dissolved manganese																
Minimum	.4	.6	.5	7.4	.6	2.5	.2	1.0	<.1	<.2	.9	1.1	3.9	19	4.3	1.4
Maximum	16	97	62	17	39	21	59	22	16	36	55	94	190	81	44	970
Median	2.2	3.2	8.3	11	4.3	10	2.6	2.7	.8	2.9	6.2	8.3	35	35	20	40
No. of samples	204	14	29	4	26	6	186	12	200	9	189	33	139	17	20	12
Total manganese																
Minimum	.5	10	2.2	21	1.8	92	1.5	13	<.3	59	3.5	13	17	46	20	38
Maximum	590	4,350	72	59	450	9,200	730	4,200	870	1,090	1,270	13,700	1,350	800	260	39,230
Median	5.3	67	12	36	12	420	14	54	16	130	25	150	60	150	72	8,740
No. of samples	215	14	30	4	26	6	196	12	212	8	195	33	124	16	20	12
Total lead																
Minimum	.01	.2	<.01	1.3	<.06	5.1	<.05	.3	<.05	3.0	<.09	1.3	<.5	1.7	<.4	23
Maximum	11	220	3.7	11	27	380	37	310	43	52	72	4,420	65	55	12	4,030
Median	.2	2.4	.1	2.7	.2	26	.5	2.5	.8	8.1	1.0	11	2.2	7.0	2.2	680
No. of samples	214	14	30	4	26	6	195	12	211	8	195	35	137	22	20	12
Dissolved zinc																
Minimum	.04	.3	<.04	.8	<.2	<1.8	<.06	<1.3	<.1	<1.1	<.2	<.8	<1.8	8.0	<1.9	<18
Maximum	2.8	3.5	3.8	2.8	9.5	12	5.4	2.2	23	2.4	14	48	79	89	44	250
Median	<.3	1.0	.9	2.4	.7	2.2	.5	<1.4	.5	1.5	1.1	4.2	16	15	16	36
No. of samples	116	9	19	3	26	6	100	5	111	5	106	23	122	20	20	12
Total zinc																
Minimum	<.06	2.5	.3	6.2	.4	21	.5	2.3	.3	12	<.4	5.1	5.8	17	14	88
Maximum	41	630	24	17	84	1,090	180	1,150	230	430	290	15,010	160	180	73	11,100
Median	1.1	12	2.4	9.7	2.0	94	3.2	9.8	4.4	35	6.4	51	28	49	28	2,150
No. of samples	214	14	29	4	26	6	196	12	212	8	195	35	139	22	20	12

Nitrogen and Phosphorus

Instantaneous nutrient loads varied considerably from site to site, and median stormflow loads were often considerably larger than nonstorm loads (table 11). Variations in dissolved nitrite plus nitrate and total phosphorus loads with respect to base flow, normal flow, and stormflow are shown in figure 9. In Fountain Creek upstream from Monument Creek, median dissolved ammonia load at site 3700 ranged from less than 1.4 pounds per day during nonstormflow to 13 pounds per day during stormflow. Median dissolved ammonia loads at site 3707 ranged from less than 1.6 pounds per day during nonstormflow to 9.5 pounds per day during stormflow. The median dissolved nitrite plus nitrate loads in this reach were about 52 pounds per day for nonstorm samples;

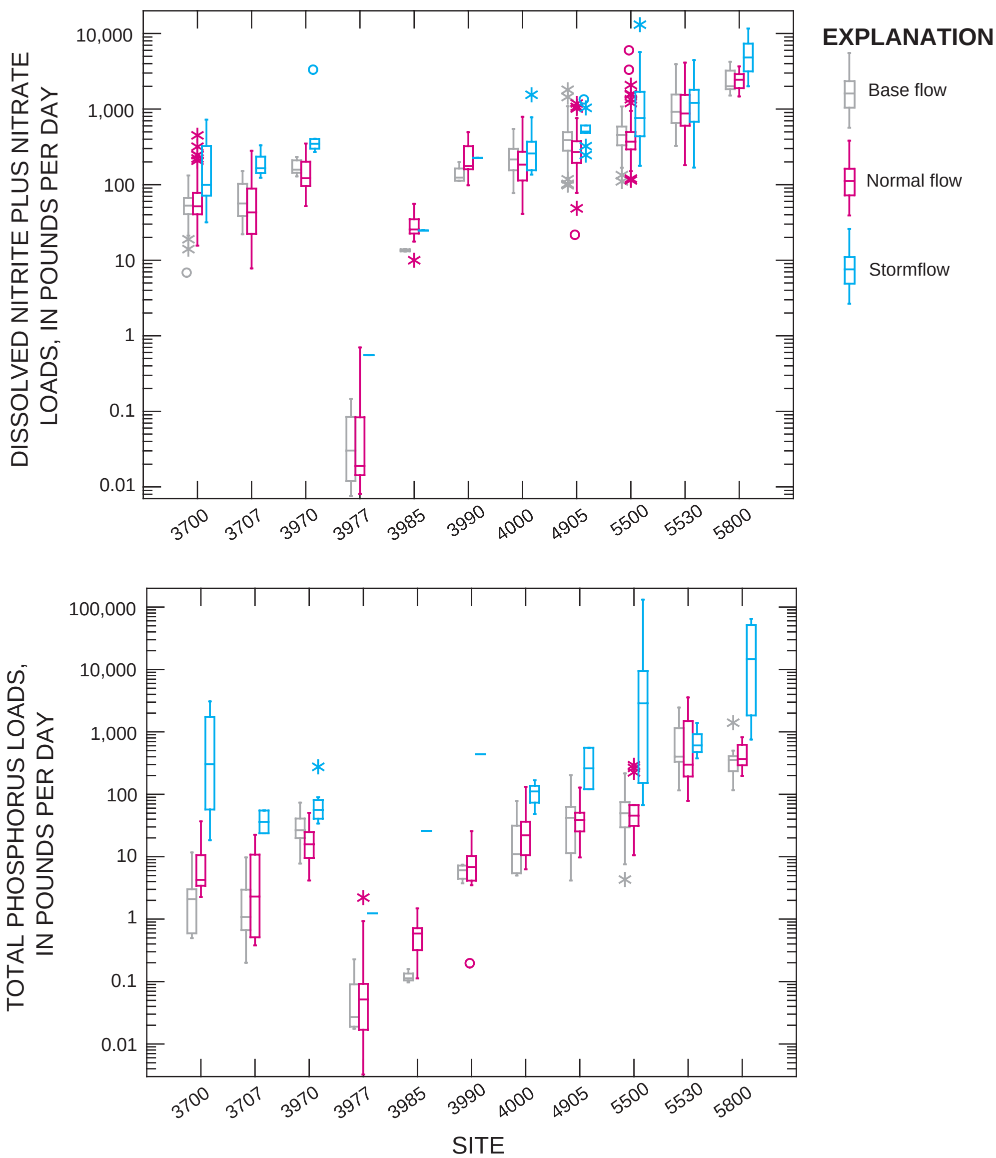


Figure 9. Variations in dissolved nitrite plus nitrate and total phosphorus loads for base flow, normal flow, and stormflow in Fountain Creek Basin, 1981 through 2001.

median stormflow loads were 99 pounds per day at site 3700 and 160 pounds per day at site 3707, about 2 to 3 times greater than nonstorm loads (fig. 9). The median nonstorm load for total phosphorus was less than 3 pounds per day, and the median stormflow load was 300 pounds per day at site 3700 and 39 pounds per day at site 3707. Median dissolved orthophosphorus loads ranged from less than 1 pound per day for nonstormflows to 8.2 pounds per day at site 3700, to 9.3 pounds per day at site 3707 during stormflow.

The median dissolved ammonia load at site 3970 was 4.0 pounds per day for nonstormflow and 56 pounds per day for stormflow. Stormflow loads of dissolved nitrite plus nitrate and total phosphorus were about 2 to 3 times greater than nonstorm loads and about 18 times greater for dissolved orthophosphorus loads at site 3970. Nutrient loads from Cottonwood Creek generally were small, with the exception of nitrite plus nitrate at sites 3985 and 3990 (fig. 9). The median nonstorm dissolved nitrite plus nitrate load at site 3990 was 173 pounds per day. The dissolved nitrite plus nitrate load from the single storm sample collected was 226 pounds per day. Median dissolved ammonia loads at site 4905 was 2.4 pounds per day for nonstormflow, and stormflow loads were 7.5 times greater than nonstorm loads. Median dissolved nitrite plus nitrate load at site 4905 was 337 pounds per day for nonstorm loads; stormflow loads were 1.5 times greater than nonstorm loads.

Nutrient loads in Fountain Creek downstream from Monument Creek were considerably larger than loads in Fountain Creek upstream from Monument Creek (fig. 9, table 11). The median dissolved ammonia and dissolved nitrite plus nitrate loads were 4.8 and 426 pounds per day, respectively, for nonstormflow at site 5500; median stormflow loads were about 8 and 1.8 times greater than nonstorm loads, respectively. The median total phosphorus and dissolved orthophosphorus loads were 48 and 11 pounds per day for nonstormflow at site 5500; median stormflow loads were 2,860 and 57 pounds per day.

The median nonstorm ammonia load at site 5530 was 2,200 pounds per day for nonstorm samples, and the median stormflow load was 1,380 pounds per day. Median nonstorm load for dissolved ammonia at site 5800 was 98 pounds per day for nonstorm samples; stormflow loads were about 5 times larger than nonstorm loads. The median nonstorm nitrite plus nitrate loads were 905 pounds per day at site 5530 and 2,190 pounds per day at site 5800, and stormflow loads were 1,210 and 4,830 pounds per day, respectively. Total phosphorus loads increased by about 1.6 times at site 5530 during stormflow (607 pounds per day) and increased by almost 40 times at site 5800, from 367 to 14,640 pounds per day.

Trace Elements

Instantaneous loads were calculated for dissolved and total boron, copper, iron, manganese, and zinc, and total arsenic and lead (table 12). Trace-element loads for nonstormflow generally were relatively small for Fountain Creek sites 3700 and 3707 upstream from Monument Creek (figs. 10, 11, and table 12). Median nonstorm loads generally were less than 5 pounds per day for dissolved trace elements; median stormflow loads for these constituents generally were about 2 to 4 times greater than nonstorm loads, which corresponds to proportional changes in streamflow. Median nonstorm loads of total arsenic, copper, and lead were less than 1 pound per day, and stormflow loads were 4 to 27 times greater than nonstorm loads. Nonstorm loads of total boron and zinc were less than 5 pounds per day, and total manganese loads were less than 13 pounds per day; stormflow loads for these constituents were about 2 to 13 times larger than nonstorm loads. Total iron loads during stormflow were about 20 times larger than nonstorm loads in this reach.

Median nonstorm loads at Monument Creek sites 3970, 4000, and 4905 were less than 5 pounds per day for dissolved copper, iron, manganese, and zinc, and less than 11 pounds per day for dissolved boron. Stormflow loads for these constituents generally were 2 to 6 times larger than nonstorm loads; stormflow load for dissolved iron at site 3970 was 13 times greater than the nonstorm load. Nonstorm loads of total copper and zinc were less than 5 pounds per day. At site 3970, the median total copper stormflow load was 40 times greater than nonstorm load, and the median total zinc stormflow load was 47 times greater than the median nonstorm load. The median total iron loads in Monument Creek ranged from 130 to 530 pounds per day for nonstormflow and 1,380 to 9,800 pounds per day for stormflow.

Most trace-element loads in Fountain Creek downstream from Monument Creek were much larger

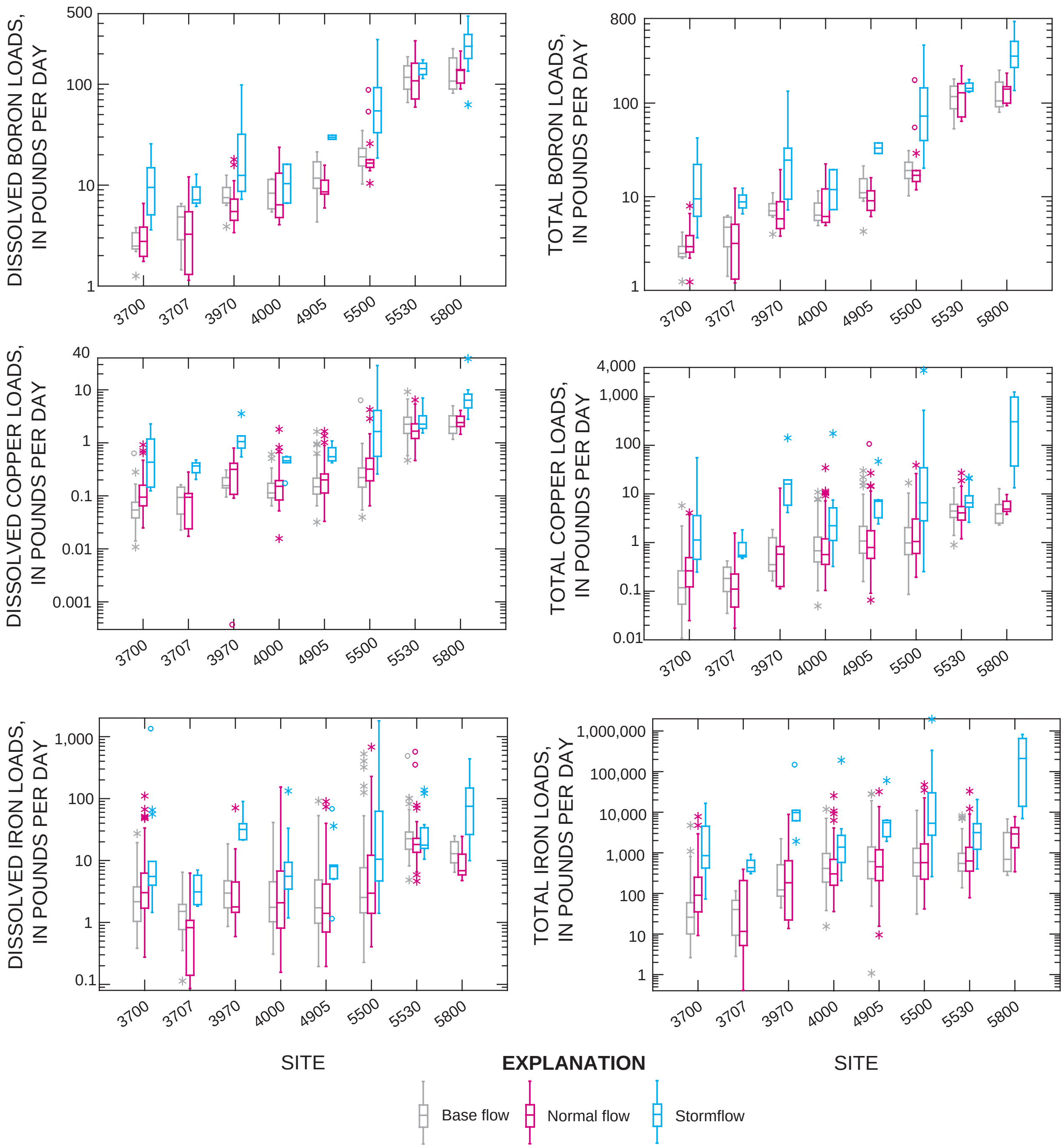


Figure 10. Variations in boron, copper, and iron loads for base flow, normal flow, and stormflow in Fountain Creek Basin, 1981 through 2001.

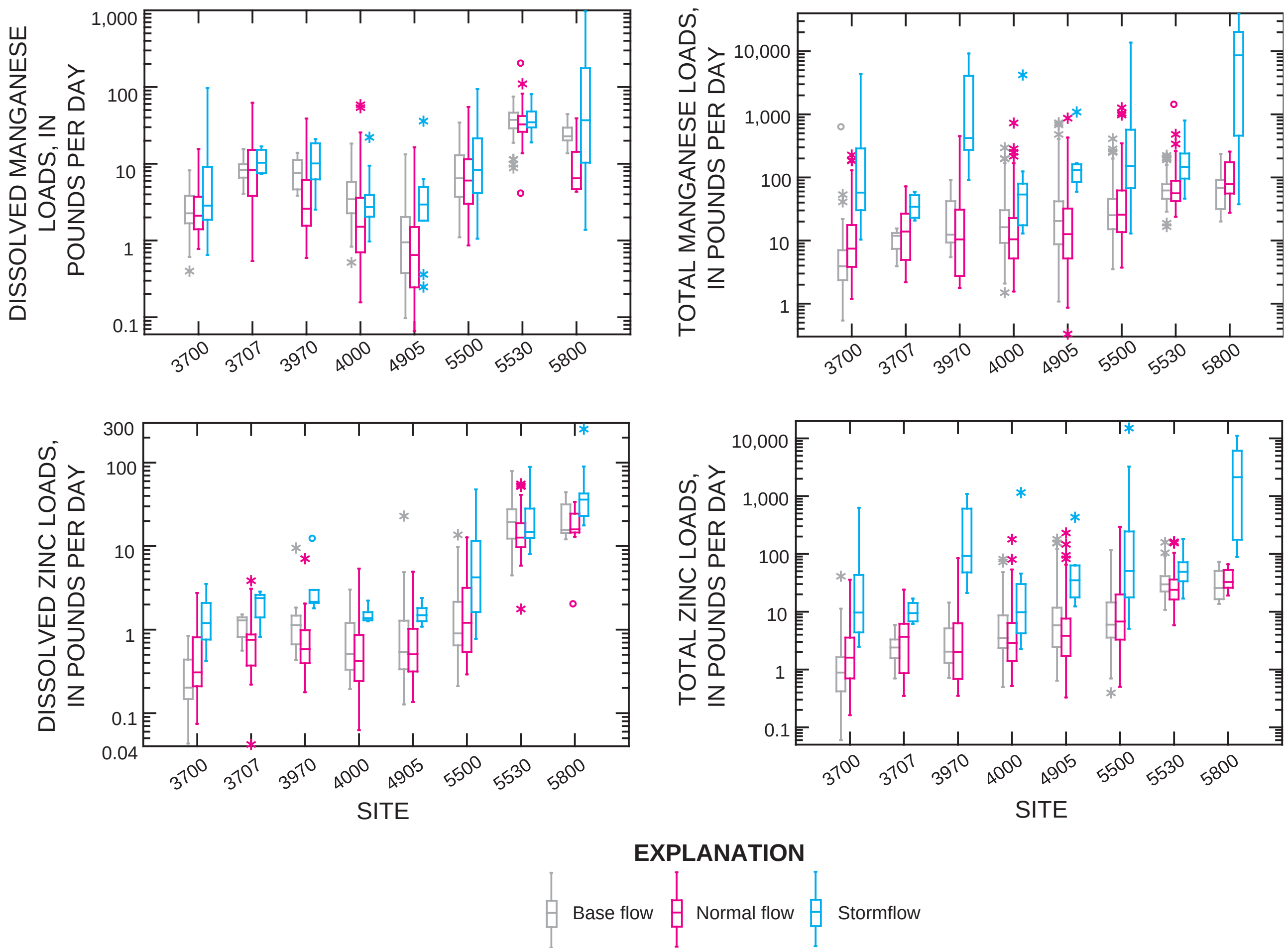


Figure 11. Variations in manganese and zinc loads for base flow, normal flow, and stormflow in Fountain Creek Basin, 1981 through 2001.

than Fountain Creek upstream from Monument Creek and in Monument Creek (table 12 and figs. 10, 11). Median nonstorm loads at site 5500 generally were less than 7 pounds per day for dissolved copper, iron, manganese, and zinc, and less than 18 pounds per day for dissolved boron. Stormflow loads for most these constituents were 2 to 4 times larger than nonstorm loads. Nonstorm total iron and manganese loads were relatively large at site 5500; the median total iron load was 570 pounds per day; and the median total manganese load was 25 pounds per day. Most median nonstorm loads at site 5530 were substantially larger than those at site 5500, but differences in storm and nonstorm loads at site 5530 generally were less pronounced and ranged from about 1 to 5 times greater (table 12). Nonstorm loads at site 5800 were similar to site 5530 with the exception of total iron. The median nonstorm total iron load at site 5800 was 1,560 pounds per day, and the stormflow load was 211,350 pounds per day compared to 590 pounds per day and 3,140 pounds per day at site 5530. Stormflow loads at site 5800 also were much larger than nonstorm loads for total arsenic, total copper, dissolved and total iron, total manganese, total lead, and total zinc. Stormflow loads for total copper, manganese, lead, and zinc were about 65 to 300 times greater than nonstorm loads.

Comparison of Water Quality of Stormflow between Pre-1998 and Post-1997 Periods

This section discusses changes in stormwater quality that occurred between two periods—1981–97 (pre-1998) and 1998–2001 (post-1997). Most sites did not have a sufficient amount of stormflow samples to statistically evaluate differences between the two periods; only sites 3700 and 5500 had enough data for this purpose. Both sites represent relatively large drainage areas. Site 3700 has a drainage area of about 103 mi^2 and represents an integration of water quality from the headwaters of Fountain Creek to Fountain Creek downstream from Manitou Springs (site 3700). Site 5500 has a drainage area of about 392 mi^2 and represents an integration of water-quality characteristics and flow from upper Fountain Creek and Monument Creek.

A Wilcoxon-Mann-Whitney rank-sum statistical test was performed on the data to determine if concentrations between the two periods were significantly different. This test is a nonparametric t-test on the ranks of two sample sets. Significant differences were indicated when the significance level or p-value was less than 0.05, and moderately significant differences were indicated when the p-value was less than 0.1.

Onsite Measurements, Biochemical Oxygen Demand and Fecal Coliform Bacteria

The Wilcoxon-Mann-Whitney rank-sum analysis was done for streamflow, dissolved oxygen, pH, specific conductance, BOD_5, and fecal coliform (table 13). BOD_5 concentrations at site 3700, Fountain Creek near Manitou Springs, were significantly different; evaluation of the data for the two periods indicated that BOD_5 significantly increased in the stormflow samples between the pre-1998 and post-1997 periods. Streamflow, dissolved oxygen, specific conductance, and fecal coliform were not statistically different at site 3700 between the two periods.

Statistical analysis indicated that streamflows associated with stormwater samples were significantly larger at site 5500 between the two periods. A Spearman rank-correlation analysis between streamflow and water-quality constituents did not indicate a significant relation. Therefore, statistical differences in water-quality constituents that were detected between the two periods were not attributed to differences in streamflow that occurred. Statistically significant differences between the two periods at site 5500 also were detected for specific conductance, BOD_5, and fecal coliform bacteria. Similar to site 3700, evaluation of the data for the two periods indicated that BOD_5 and fecal coliform bacteria significantly increased in the stormflow samples between the pre-1998 and post-1997 periods and specific conductance decreased between the two periods. No significant differences were detected for dissolved oxygen and pH. Changes between the two periods may have resulted from changes in land use and an increase in the amount of impervious areas, which results in an increased amount of stormwater runoff into Fountain and Monument Creeks.

Table 13. Results of Wilcoxon-Mann-Whitney rank-sum test for differences between stormflows for pre-1998 and post-1997 measurements of streamflow, dissolved oxygen, pH, specific conductance, biochemical oxygen demand, and fecal coliform for sites 3700 and 5500

[Shaded p-values indicate statistically significant differences between the pre-1998 and post-1997 periods]

Site	Streamflow	Dissolved oxygen	pH	Specific conductance	Biochemical oxygen demand	Fecal coliform
3700	0.1391	0.5661	0.2433	0.8501	0.0258	0.4744
5500	.0009	.8995	.8769	.0773	.0183	.0166

Nitrogen and Phosphorus

Significant differences between pre-1998 and post-1997 periods were detected for dissolved orthophosphorus only at sites 3700 and 5500 (table 14). At both sites, dissolved orthophosphorus concentrations significantly increased in the post-1997 data. No significant differences were detected for dissolved ammonia, nitrite plus nitrate, or total phosphorus.

Trace Elements

Statistically significant differences and p-values for selected trace elements for the two periods for sites 3700 and 5500 are shown in table 15. Total arsenic data were not available for the period before 1997 and, therefore, are not included in the table. No significant differences were detected in dissolved and total copper, iron, manganese, and zinc for stormflow between the two periods at site 3700. Total lead concentrations were indicated to be moderately significantly different between the two periods at site 3700. Differences between the two periods at site 5500 were statistically significant for total copper, iron, lead, manganese, zinc, and dissolved manganese. At site 5500, total copper, iron, lead, and manganese concentrations increased in stormflow samples collected in the post-1997 period compared to stormflow samples collected in the pre-1998 period. Dissolved manganese concentrations decreased in the post-1997 period.

Comparison of Water Quality of Stormflow to Instream Standards

The Colorado Department of Public Health and Environment has established instream standards for streams according to designated uses, water quality, and the stream characteristics of each segment in the basin. Standards for many constituents are fixed values; standards for other constituents, specifically for some trace elements, are calculated values, which use mean hardness in determining the standard. The mean hardness used in this report was calculated using all data regardless of flow regime. Standards have not been established for all trace elements, and most of the standards are applied to dissolved constituents. In this report, water-quality concentrations from stormflow samples were compared to the acute standards for three stream reaches in the study area. The Colorado Department of Public Health (2001a, 2001b) defined

Table 14. Results of Wilcoxon-Mann-Whitney rank-sum test for differences between stormflow for pre-1998 and post-1997 periods for nitrogen and phosphorus for sites 3700 and 5500.

[Shaded p-values indicate statistically significant differences between the pre-1998 and post-1997 periods; n/a, no data available prior to 1998]

Site	Dissolved ammonia	Dissolved nitrite plus nitrate	Total phosphorus	Dissolved ortho-phosphorus
3700	0.1702	0.5201	n/a	0.0364
5500	.7044	.7452	.3516	.0549

Table 15. Results of Wilcoxon-Mann-Whitney rank-sum test for differences between stormflow for pre-1998 and post-1997 periods for trace elements for sites 3700 and 5500

[Shaded p-values indicate statistically significant differences between the pre-1998 and post-1997 periods]

Site	Dissolved copper	Total copper	Dissolved iron	Total iron	Total lead	Dissolved manganese	Total manganese	Dissolved zinc	Total zinc
3700	1.000	0.2470	0.9420	0.3829	0.0956	1.000	0.1282	1.000	0.3045
5500	.5129	.0027	.9845	.005	.0251	.0141	.0459	.7804	.0129

acute standard as the level not to be exceeded by a concentration in a single sample or by an average calculated from all samples collected during a 1-day period.

Although there is not an acute standard for fecal coliform bacteria, it is worth noting that instantaneous fecal coliform bacteria concentrations measured during stormflow frequently exceeded the standard for fecal coliform that is based on a monthly geometric mean. At site 3700, Fountain Creek upstream from Monument Creek, 11 of 13 stormflow samples were greater than 200 col/100 mL, and 2 of 3 stormflow samples collected at site 3707 had concentratons greater than 200 col/100 mL. In Monument Creek, six of eight stormflow samples collected at site 3970 had concentrations greater than 200 col/100 mL; at site 4000, six of eight stormflow samples had concentrations greater than 200 col/100 mL; and at site 4905, seven of eight stormflow samples had concentrations greater than 200 col/100 mL. In Fountain Creek downstream from Monument Creek, eight of twenty-eight stormflow samples at site 5500 had concentrations greater than 2,000 col/100 mL; at site 5530, six of twenty-four stormflow samples had concentrations greater than 2,000 col/100 mL; and at site 5800, eight of nine stormflow samples had concentrations greater than 2,000 col/100 mL.

Ammonia and Nitrate Nitrogen

Acute water-quality standards have been established for un-ionized ammonia and dissolved nitrate. The standard for dissolved nitrate is a 1-day standard of 10 mg/L. Concentrations of dissolved ammonia were converted to un-ionized ammonia, and the computed un-ionized ammonia concentrations were compared to the acute standard. The standard for un-ionized ammonia is a calculated value that uses ammonia concentrations, water temperature, and pH. The acute un-ionized ammonia standard was not exceeded at any site in the study area. Concentrations of dissolved nitrite plus nitrate were used to determine exceedances of the instream standard for nitrate because nitrite concentrations typically are extremely small; therefore, essentially the nitrite plus nitrate concentration is in the form of nitrate. The dissolved nitrate standard of 10 mg/L was exceeded in one stormflow sample collected at site 5500 during the pre-1998 period.

Trace Elements

Acute water-quality standards have been established for total arsenic, chromium, cyanide, and dissolved cadmium, copper, lead, nickel, silver, and zinc. The acute standard for total arsenic (50 μg/L) was exceeded in one stormflow sample collected at site 5800. The acute standard for total chromium (50 μg/L) was exceeded in one stormflow sample at site 5800. Acute standards for dissolved cadmium, copper, lead, nickel, silver, and zinc are based on calculated values using mean hardness. These standards were not exceeded in any of the stormflow samples collected at any site. Occasionally, the calculated standard for dissolved silver was less than the ARL. In cases where the concentration was less than the reporting limit, it was assumed that the standard was not exceeded.

Semivolatile Organic Compounds and Pesticides

Semivolatile organic compound and pesticide data were collected from sites 3700, 3970, 5500, and 5800 during stormflow from 1998 through 2001. These compounds were compared to acute standards established for several semivolatile organic compounds and pesticides. However, acute water-quality standards have not been established for all organic constituents. Acute standards have been set for acenapthylene, fluoranthene, and napthalene. The standard for acenapthylene is 1,700 μg/L; the standard for fluroanthene is 3,980 μg/L; and the standard for naphthalene is 2,300 μg/L. Sample concentrations of these three semivolatile organic compounds were well below the standards, therefore, there were no exceedances in stormflow samples collected at the three sites. There are no acute instream standards for the remaining semivolatile organic compounds sampled. Of the 47 pesticides analyzed in stormwater samples, only parathion has an acute water-quality standard (0.065 μg/L) and it was not exceeded in any storm sample.

SUSPENDED-SEDIMENT CONCENTRATIONS, DISCHARGES, AND YIELDS

Between 1998 and 2001, daily suspended-sediment concentrations and discharge were collected at seven sites (table 1): site 3970 on Monument Creek, sites 3977, 3985, and 3990 in the Cottonwood Creek

Basin, and sites 3700, 5500, and 5800 on Fountain Creek. Samples generally were collected from April 1 through October 31 during 1998–2001. This period generally encompasses the months that generally have appreciable stormflow. Data for all seven sites are published in Crowfoot and others (1999, 2000, 2001). Suspended-sediment discharge is the mass of suspended sediment transported over time and, in this report, is expressed in tons per day. Suspended-sediment discharge in a stream is the result of erosion and sediment-transport rates that occur throughout the basin. Certain tributaries discharge large quantities of sediment to a stream and others discharge small quantities. Additionally, in-channel processes erode streambanks, mobilize (scour) streambed sediments, and deposit (fill) streambed sediments. Von Guerard (1989a) indicated that the areas producing the largest suspended-sediment yields tended to be in streams on the readily erodible Colorado Piedmont. Daily suspended-sediment yield was computed by dividing the daily suspended-sediment discharge by the drainage area and, in this report, is expressed in tons per day per square mile.

The base-flow separation program described earlier was used to identify daily suspended-sediment data as being associated either as normal flow—streamflows unaffected by stormflow—or as stormflow. These data were used to characterize suspended-sediment concentrations, discharges, and yields for normal and stormflow conditions, which were then used to evaluate annual variations in suspended-sediment concentrations, discharges, and yields for normal and stormflow conditions; spatial variations in suspended-sediment concentrations; spatial variations in suspended-sediment discharges; and spatial variations in suspended-sediment yields.

Annual Variations in Suspended-Sediment Concentrations, Discharges, and Yields

Variations that occurred annually from April through October of 1998–2001 in suspended-sediment concentrations, discharges, and yields for normal flow and stormflow for the Fountain and Monument Creek sites (3700, 3970, 5500, and 5800) are shown in figure 12, and the three sites in the Cottonwood Creek Basin (sites 3977, 3985, 3990) are shown in figure 13. Each year suspended-sediment concentrations, discharges, and yields associated with stormflow were significantly ($p<0.001$) greater than those during normal flow. Depending on the site and year, suspended-sediment concentrations associated with stormflow generally were 3–10 times greater than concentrations measured during normal flow. Suspended-sediment discharges and yields during stormflow usually were more than 10 times greater than during normal flow.

Tukey’s Studentized range test (SAS, 1985) was done to determine whether statistical differences in suspended-sediment concentrations and discharges occurred annually between 1998, 1999, 2000, and 2001 and to evaluate any annual patterns in the differences. The analysis indicated no significant annual differences in suspended-sediment concentrations associated with stormflow at most sites; moderately significant annual differences were detected at sites 3700 and 3977. Significant annual differences were detected in concentrations associated with normal flow at all sites except sites 3985 and 3990. Suspended-sediment concentrations measured during normal flow at the Fountain and Monument Creek sites in 1998 and 1999 tended to be larger than concentrations measured in 2000 and 2001 (figs. 12 and 13).

Analysis of suspended-sediment discharges indicated significant annual differences during stormflow for sites 3700, 3970, 5500, and 3977; moderately significant annual differences were detected at site 5800. Analysis of suspended-sediment discharges during normal flow indicated significant annual differences at all sites. At most sites indicating significant annual differences, suspended-sediment discharge during stormflow and normal flow tended to be largest in 1999.

During the 4-year period (1998–2001), total annual suspended-sediment discharge during stormflow for the Fountain and Monument Creek sites generally occurred less than 20 percent of the days between April and October but transported about 4.5 times more sediment, on average, than was transported during normal flow. For the three sites located in Cottonwood Creek drainage, about 10 times more sediment, on average, were transported annually during stormflow than during normal flow. Additionally, on average, about 10 times more tons/ft^3/s were transported annually during stormflow than during normal flow in Fountain and Monument Creeks, and for the Cottonwood Creek Basin.

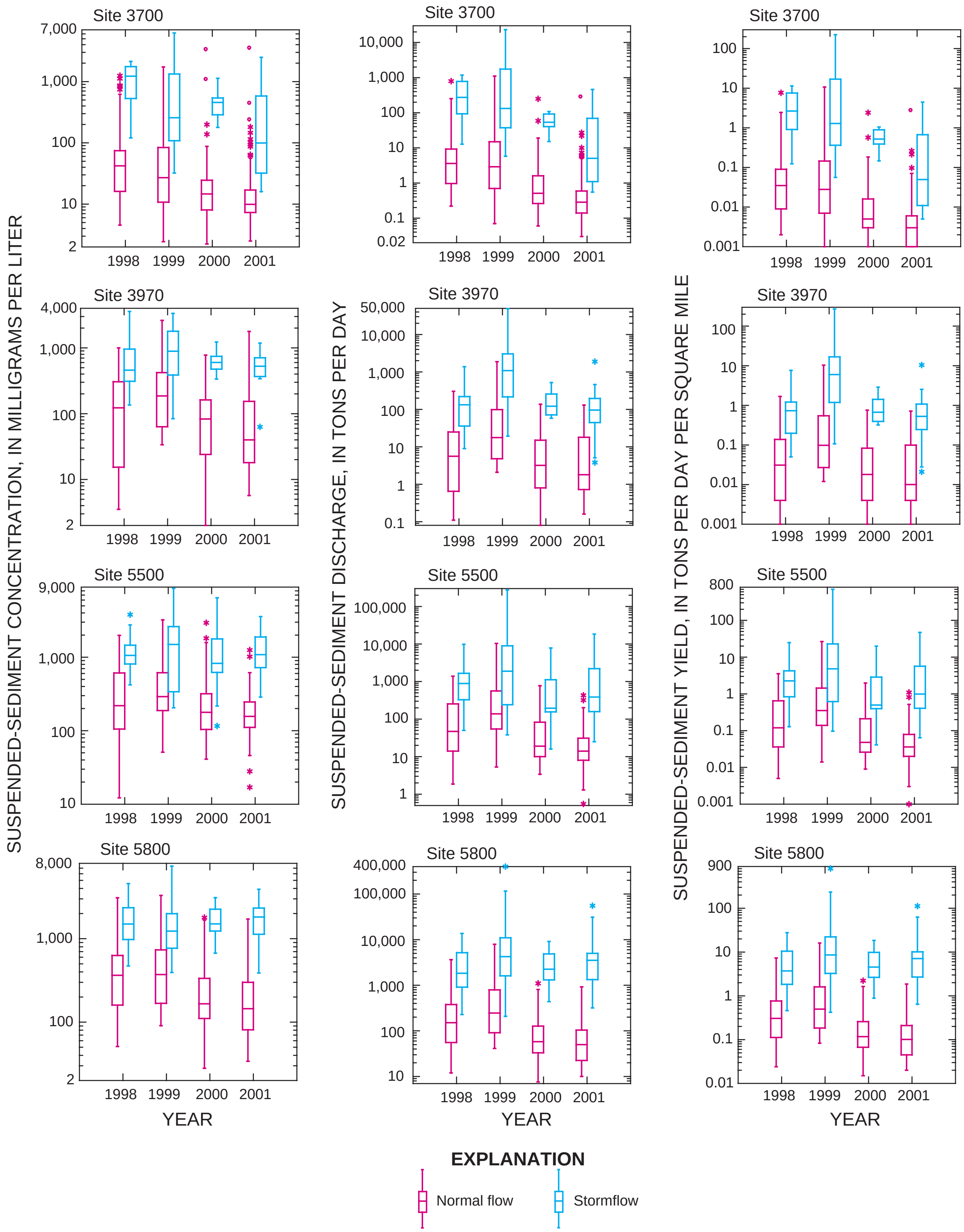


Figure 12. Annual variations in suspended-sediment concentration, discharge, and yield for stormflow and normal flow in Fountain Creek Basin, 1998 through 2001.

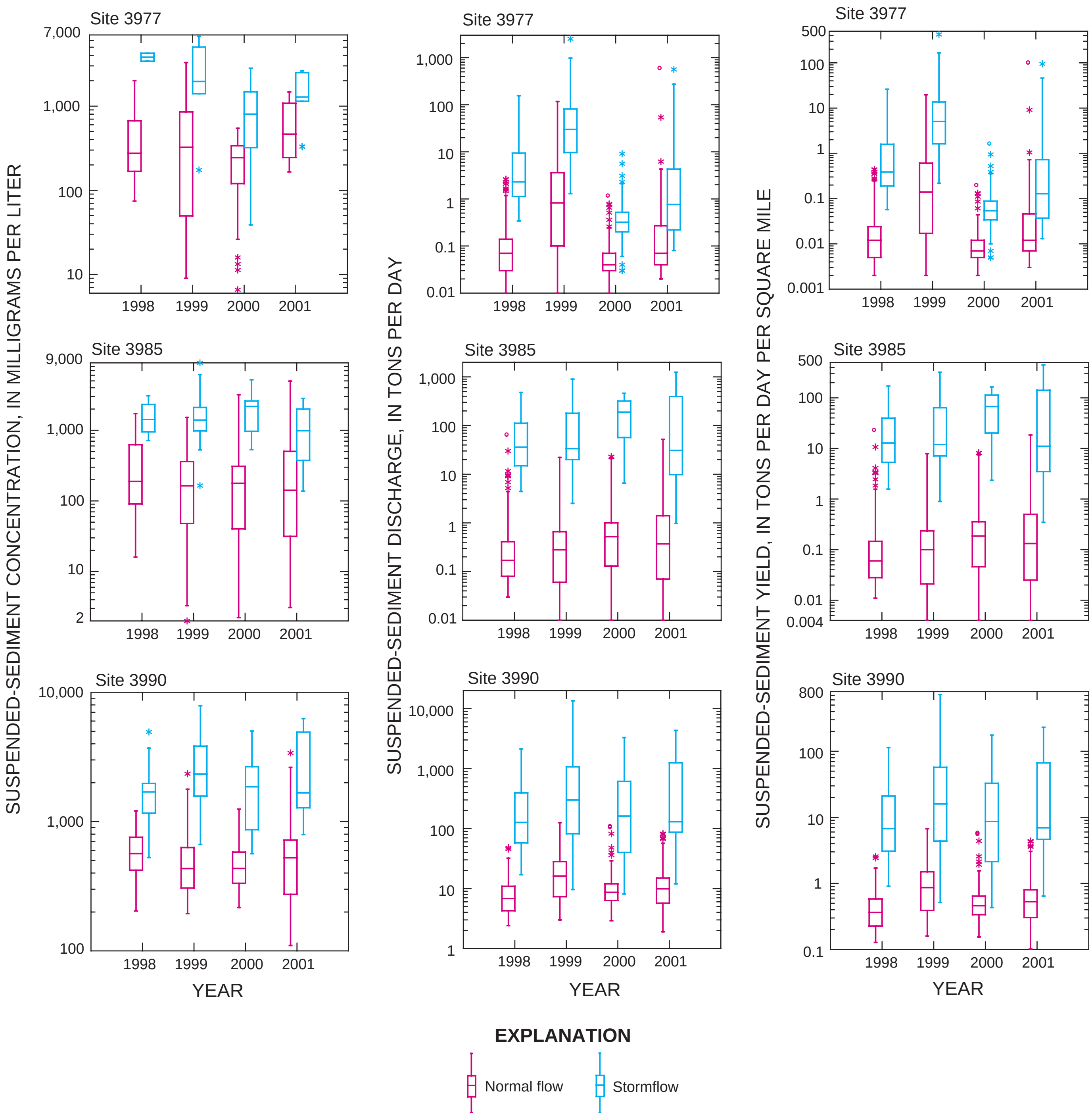


Figure 13. Annual variations in suspended-sediment concentration, discharge, and yield for stormflow and normal flow in Cottonwood Creek Basin, 1998 through 2001.

Spatial Variations in Suspended-Sediment Concentrations

Spatial variations in suspended-sediment concentrations in Fountain Creek Basin are shown in figure 14. Tukey's Studentized range test of suspended-sediment concentrations associated with normal flow indicated that several sites had significantly ($p<0.05$) different concentrations. Sites ranked from smallest to largest suspended-sediment concentrations during normal flow were 3700, 3970, 3985, 5500, 5800, 3977, and 3990. During normal flow, site 3700 (Fountain Creek near Manitou Springs) had the smallest suspended-sediment concentrations, site 3990 (Cottonwood Creek at Mouth) had the largest suspended-sediment concentrations, and sites 3977 (Cottonwood Creek at Cowpoke located near the creek's headwaters), 5500, and 5800 did not have significantly different concentrations. Site 3700, where the smallest suspended-sediment concentrations tended to occur, drains predominantly granitic rocks and soils formed from weathered igneous rocks (Larsen, 1981; von Guerard, 1989a). Suspended-sediment concentrations during normal flow at site 3700 were usually less than 20 mg/L and generally ranged (25th to 75th percentile) from about 10 to 50 mg/L. Site 3970, located on Monument Creek upstream from Cottonwood Creek, had the next smallest suspended-sediment concentrations; during normal flow, concentrations usually were less than about 90 mg/L and generally ranged from about 30 to 250 mg/L. Suspended-sediment concentrations at the remaining sites in the Cottonwood Creek Basin and Fountain Creek downstream from the confluence with Monument Creek generally ranged from about 100 mg/L to 500 mg/L during normal flow.

Tukey's Studentized range test of suspended-sediment concentrations measured during stormflow indicated that a few sites had significantly ($p<0.05$) different concentrations. Sites ranked from smallest to largest suspended-sediment concentrations during stormflow were 3700, 3970, 5500, 3977, 3985, 5800, and 3990. Tukey's test indicated significant differences in suspended-sediment concentrations measured during stormflow between sites 3700 and 3970 and no significant differences in concentrations between sites 5500, 3977, 3985, and 5800. Concentrations at sites 3700 and 3970 were significantly different than all other sites. At site 3700, suspended-sediment concentrations during stormflow generally were between about 90 and about 1,300 mg/L. Site 3970, during stormflow, had concentrations generally between about 300 and about 1,100 mg/L. Suspended-sediment concentrations at the three sites in the Cottonwood Creek Basin and two sites on Fountain Creek downstream from the confluence with Monument Creek (sites 5500 and 5800) generally ranged between 500 mg/L and 3,000 mg/L during stormflow.

Spatial Variations in Suspended-Sediment Discharges

Spatial variations in suspended-sediment discharges are shown in figure 14. Tukey's Studentized range test of suspended-sediment discharges measured during normal flow indicated that several sites had significantly ($p<0.05$) different sediment discharges. Sites ranked from smallest to largest suspended-sediment discharges during normal flow were 3977, 3985, 3700, 3970, 3990, 5500 and 5800, which generally increased in a downstream direction as streamflow increased. All sites were significantly different from one another. Expressed mathematically, the significant differences between sites for suspended-sediment discharges for normal flow are as follows:

$$\textit{site } 3977 < \textit{site } 3985 < \textit{site } 3700 < \textit{site } 3970 < \textit{site } 3990 < \textit{site } 5500 < \textit{site } 5800.$$

During normal flow, site 3977, a site with the second smallest drainage area and streamflow had the smallest suspended-sediment discharges with sediment discharges usually less than 0.10 tons/d. Site 5800, which has the largest drainage area and largest streamflows, had the largest suspended-sediment discharges during normal flow (usually greater than about 90 tons/d) and generally ranged from about 40 to 260 tons/d. Site 5500 (Fountain Creek located 1.3 mi downstream from the confluence with Monument Creek) had suspended-sediment discharges that generally ranged from 12 to 140 tons/d during normal flow.

Tukey's Studentized range test of suspended-sediment discharges measured during stormflow indicated that sites ranked from smallest to largest were 3977, 3985, 3700, 3970, 3990, 5500 and 5800—rankings that were the same as normal flow. Sites 3977 and 3985 were significantly different from one another.

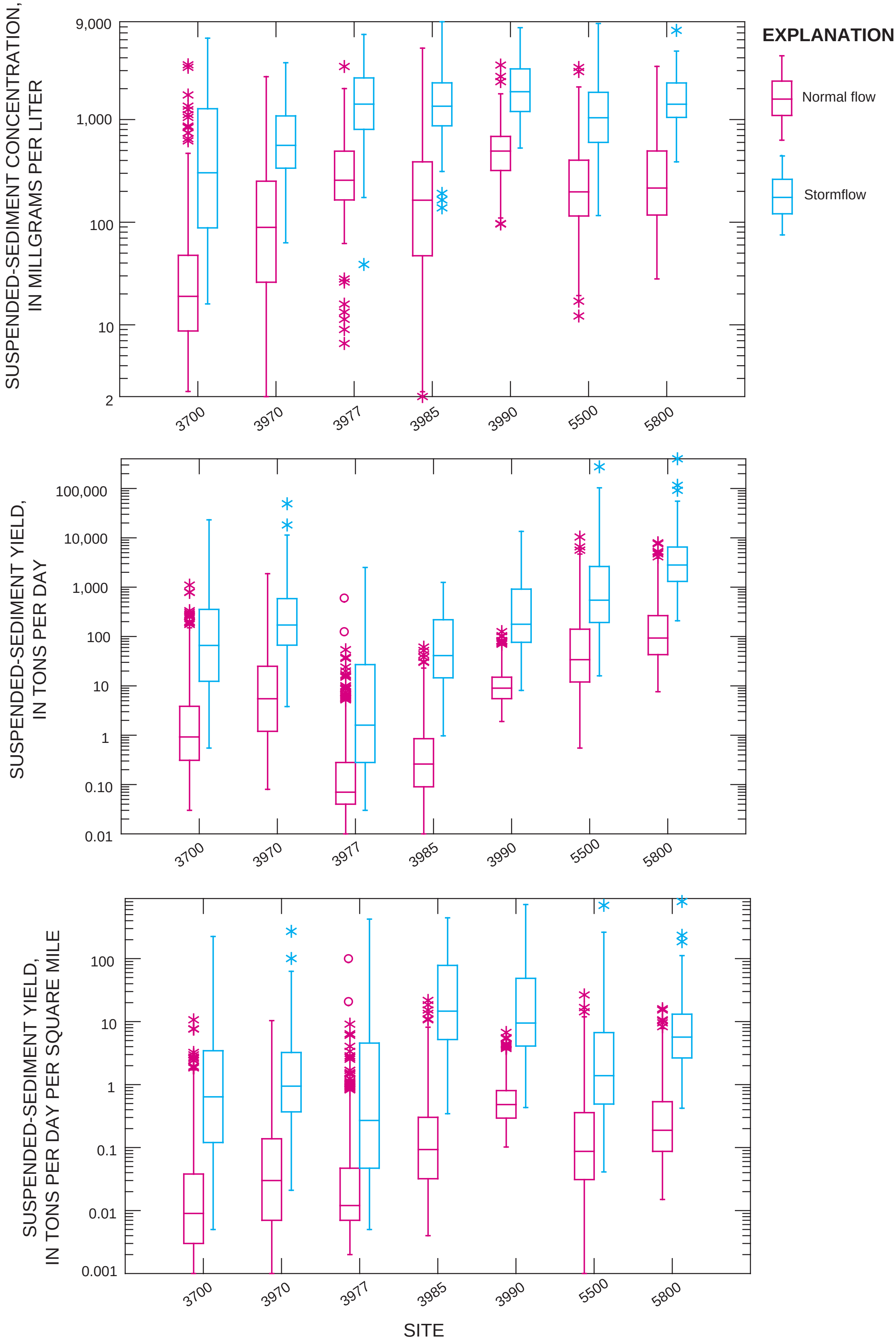


Figure 14. Spatial variations in suspended-sediment concentrations, discharge, and yield for stormflow and normal flow in Fountain Creek Basin, 1998 through 2001.

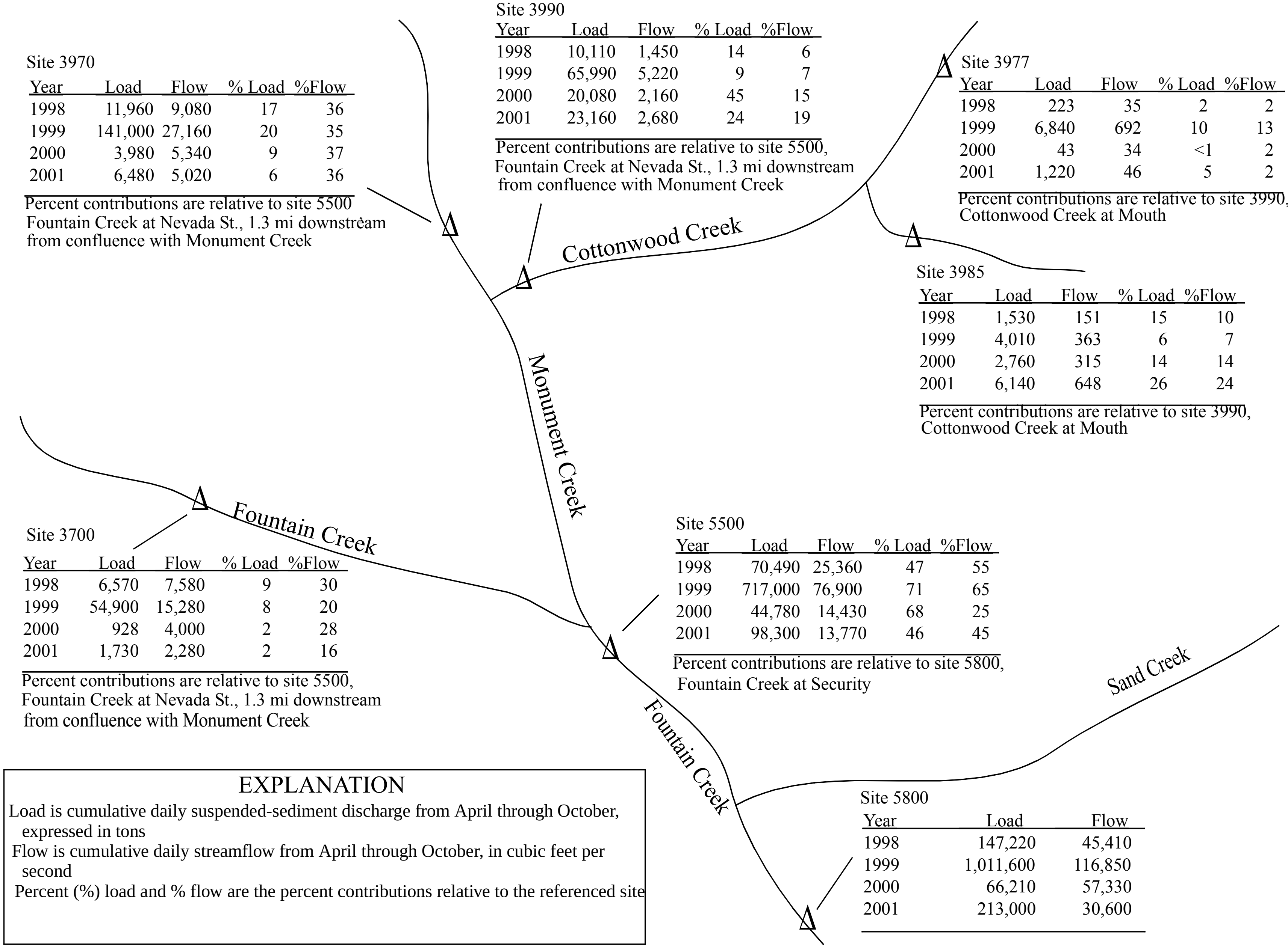
Sites 3985 and 3700 were not significantly different from one another but were significantly different from other sites. Sites 3970 and 3990 were not significantly different from one another but were significantly different from other sites. Sites 5500 and 5800 were significantly different from one another and all other sites. Expressed mathematically, the significant differences between sites for suspended-sediment discharge for stormflow are as follows:

site 3977 < site 3985 = site 3700 < site 3970 = site 3990 < site 5500 < site 5800.

During stormflow, site 3977 generally had the smallest suspended-sediment discharges with sediment discharges that generally ranged from about 0.30 to 27 tons/d. Site 3985, a site with the smallest drainage area, had the next smallest sediment discharges, with sediment discharges that generally ranged from 14 to about 220 tons/d. Although site 3985 has a drainage area of 2.81 mi^2, almost 50 percent less drainage area than site 3977, the median suspended-sediment discharge was 25 times greater than the median sediment discharge at site 3977. This difference may be the result of a larger number of thunderstorms that occurred in this small basin, or from the relatively large percentage of urban development that may have affected stormflow in this small basin, or a combination of the two. The cause could not be determined because precipitation data was insufficient. Site 5800 had the largest suspended-sediment discharges that generally ranged from about 1,300 to 6,500 tons/d during stormflow. Suspended-sediment discharges at site 5500, located a few miles upstream from site 5800 and about 1.3 mi downstream from the confluence with Monument Creek, generally ranged from about 190 to 2,600 tons/d during stormflow. Although there are only a few stream miles between sites 5500 and 5800, the intervening drainage area is 103 mi^2. The significant differences in suspended-sediment discharges between sites 5500 and 5800 result from runoff that occurs within this 103-mi^2 drainage area. One of the likely dominant source areas is the Sand Creek Basin. Von Guerard (1989a) indicated that Sand Creek was a significant source area for sediment. Stogner (2000) reported that the annual per-square-mile increase in high streamflow regimes for this reach was about 5 times greater than other stream reaches studied. The reach from 5500 to 5800 showed the greatest annual change in total streamflow during high flows, which indicates that, on average, the intervening drainage area contributed more total flow and more flow per square mile than any of the other drainage areas studied.

Variations in total cumulative daily suspended-sediment discharges and the percentage contributions of sediment discharge and streamflow relative to the downstream site from 1998 through 2001 are shown in figure 15. The April through October cumulative suspended-sediment discharges and streamflows were largest in 1999 at all sites. The large storm that continued for 6 consecutive days between April 29 and May 4, 1999, had a significant effect on the cumulative suspended-sediment discharge for 1999. The total suspended-sediment discharge associated with this one storm composed between 63 and 71 percent of the annual suspended-sediment discharge in 1999 for all the sites located on Fountain and Monument Creeks (sites 3700, 3970, 5500, and 5800) and between 36 to 58 percent of the annual suspended-sediment discharge in 1999 for the sites in the Cottonwood Creek Basin (sites 3977, 3985, and 3990).

The data shown in figure 15 indicate that for the Cottonwood Creek Basin, 69 percent or more of the cumulative streamflow and cumulative sediment discharge reported at site 3990, Cottonwood Creek at the mouth, occurred in the intervening 10-mi^2 drainage area downstream from sites 3977 and 3985. A comparison of the relative streamflow and sediment-discharge contributions at sites 3700, 3970, and 3990 to streamflow and sediment discharges reported at site 5500, which is located on Fountain Creek about 1.3 mi downstream from the confluence with Monument Creek (fig. 15), indicates that (1) site 3700, Fountain Creek near Manitou Springs, contributed less than 30 percent of the streamflow and less than 10 percent of sediment discharge reported at site 5500; (2) site 3970, Monument Creek upstream from Cottonwood Creek, contributed about 35 percent of the streamflow and 20 percent or less of sediment discharge reported at site 5500; and (3) site 3990 contributed less than 20 percent of the streamflow and less than 25 percent of sediment discharge reported at site 5500 during 1998, 1999, and 2001. However, in 2000, though contributing just 15 percent of the streamflow, site 3990 contributed 45 percent of the sediment discharge reported at site 5500. The intervening 89-mi^2 drainage area between sites 3700, 3970, 3990, and site 5500 is about 23 percent of the total



Site 3970

Year	Load	Flow	% Load	%Flow
1998	11,960	9,080	17	36
1999	141,000	27,160	20	35
2000	3,980	5,340	9	37
2001	6,480	5,020	6	36

Percent contributions are relative to site 5500 Fountain Creek at Nevada St., 1.3 mi downstream from confluence with Monument Creek

Site 3990

Year	Load	Flow	% Load	%Flow
1998	10,110	1,450	14	6
1999	65,990	5,220	9	7
2000	20,080	2,160	45	15
2001	23,160	2,680	24	19

Percent contributions are relative to site 5500, Fountain Creek at Nevada St., 1.3 mi downstream from confluence with Monument Creek

Site 3977

Year	Load	Flow	% Load	%Flow
1998	223	35	2	2
1999	6,840	692	10	13
2000	43	34	<1	2
2001	1,220	46	5	2

Percent contributions are relative to site 3990, Cottonwood Creek at Mouth

Site 3985

Year	Load	Flow	% Load	%Flow
1998	1,530	151	15	10
1999	4,010	363	6	7
2000	2,760	315	14	14
2001	6,140	648	26	24

Percent contributions are relative to site 3990, Cottonwood Creek at Mouth

Site 3700

Year	Load	Flow	% Load	%Flow
1998	6,570	7,580	9	30
1999	54,900	15,280	8	20
2000	928	4,000	2	28
2001	1,730	2,280	2	16

Percent contributions are relative to site 5500, Fountain Creek at Nevada St., 1.3 mi downstream from confluence with Monument Creek

Site 5500

Year	Load	Flow	% Load	%Flow
1998	70,490	25,360	47	55
1999	717,000	76,900	71	65
2000	44,780	14,430	68	25
2001	98,300	13,770	46	45

Percent contributions are relative to site 5800, Fountain Creek at Security

Site 5800

Year	Load	Flow
1998	147,220	45,410
1999	1,011,600	116,850
2000	66,210	57,330
2001	213,000	30,600

EXPLANATION

Load is cumulative daily suspended-sediment discharge from April through October, expressed in tons

Flow is cumulative daily streamflow from April through October, in cubic feet per second

Percent (%) load and % flow are the percent contributions relative to the referenced site

Figure 15. Cumulative daily suspended-sediment discharge and streamflow, percent load, and streamflow contributions from April through October in Fountain Creek Basin, 1998 through 2001.

392-mi^2 drainage area upstream from site 5500. This intervening drainage area contributed between 20 and 40 percent of the streamflow and between 44 and 68 percent of the sediment discharge transported each year from April through October. The intervening drainage area between site 5500 and 5800 is about 103 mi^2. Between 35 and 75 percent of the streamflow and between 29 and 54 percent of the sediment discharge transported each year from April through October was contributed from the intervening 103-mi^2 drainage area.

Spatial Variations in Suspended-Sediment Yields

Spatial variations in suspended-sediment yields are shown in figure 14. Suspended-sediment yields normalize suspended-sediment discharges by dividing the sediment discharges by the drainage area. Suspended-sediment yields provide a means for identifying source-contribution areas. Tukey’s Studentized range test of suspended-sediment yields measured during normal flow indicated sites ranked from smallest to largest yields were 3700, 3977, 3970, 3985, 5500, 5800, and 3990. All sites were significantly different from one another, except for sites 3985 and 5500. Expressed mathematically, the significant differences between sites for suspended-sediment yields for normal flow are as follows:

site 3700 < site 3977 < site 3970 < site 3985 = site 5500 < site 5800 < site 3990.

During normal flow, site 3700, a site with a drainage area of 103 mi^2, had similar yields as site 3977, a site with a drainage area of 5.93 mi^2. These sites had the smallest suspended-sediment yields during normal flow, with yields usually less than 0.15 ton/d/mi^2. Site 3990 (Cottonwood Creek at Mouth), a site with a drainage area of about 18.7 mi^2, had the largest suspended-sediment yields during normal flow; yields generally ranged from about 0.3 to 0.8 ton/d/mi^2. Although large spatial variations in suspended-sediment yields occurred during normal flows, the suspended-sediment yields that were associated with stormflow generally were more than 10 times greater than the suspended-sediment yields that occurred during normal flow.

Tukey’s Studentized range test of suspended-sediment yields associated with stormflow indicated sites ranked from smallest to largest yields were 3977, 3700, 3970, 5500, 5800, 3990, and 3985. Tukey’s test indicated numerous statistical groupings with respect to suspended-sediment yields associated with stormflow. Sites 3977 and 3700 were not significantly different from one another; sites 3700 and 3970 were not significantly different from one another; sites 3970 and 5500 were not significantly different from one another; sites 5800 and 3990 were not significantly different from one another; and sites 3990 and 3985 were not significantly different from one another. Conversely, site 3977 was significantly different from sites 3970, 5500, 5800, 3990, and 3985; sites 3700, 3970, and 5500 were significantly different from sites 5800, 3990, and 3985; and site 5800 was significantly different from site 3985. Sites 3977, 3700, and 3970 had the smallest suspended-sediment yields. These sites usually had suspended-sediment yields less than 1 ton/d/mi^2 during stormflow. The two sites with the largest suspended-sediment yields, 3990 and 3985, are in the Cottonwood Creek Basin, a drainage basin having highly erodible sedimentary rocks and soils. The suspended-sediment yields at these sites were usually greater than 10 tons/d/mi^2, and generally ranged from more than 4 to less than 80 tons/d/mi^2.

Possible relations between suspended-sediment yield and percent impervious area and annual precipitation were evaluated using Spearman rank-correlation analysis (SAS, 1985). Cumulative suspended-sediment yield and median suspended-sediment yield for 1998–2000 at each site were correlated with estimated percent impervious area upstream from each site and annual precipitation at the Colorado Springs WSO. The cumulative annual suspended-sediment yield was not was significantly correlated with percent impervious area or annual precipitation. The annual median suspended-sediment yield was moderately significantly correlated with percent impervious area ($p<0.10$) but was not significantly correlated with annual precipitation. Because the data were not normally distributed, the data were logarithmically transformed, and the logarithmically transformed annual median suspended-sediment yield was regressed with logarithmically transformed percent impervious area. This regression model did not indicate a significant relation between annual median suspended-sediment yield and percent impervious area.

STREAM MORPHOLOGY

Stream channels naturally change over time in response to streamflow characteristics and sediment delivery from the surrounding watershed (Leopold and others, 1964; Schumm, 1977; Karlinger and others, 1983). Change in streamflow characteristics and(or) sediment delivery from the surrounding watershed will in turn initiate a series of responses as the channel adjusts to those changes.

Sediment-Transport Capacity

The ability of streamflow to transport sediment (transport capacity) can be described by using the Shields dimensionless shear-stress relation for estimating the particle size of bed material at the threshold of movement (von Guerard, 1989b). Maximum particle sizes of bed material transportable at various streamflows were estimated by using the following equation (von Guerard, 1989b; Elliott and others, 1984):

$$d_c = \left(\frac{\overline{DS}}{\left(\left(\frac{\gamma_s}{\gamma_w} \right) - 1 \right) - \tau_c} \right) (304.8) \tag{1}$$

where

d_c = particle size of bed material, in millimeters, at threshold of movement;

D = mean channel depth, in feet

S = water-surface slope

γ_s/γ_w = ratio of specific weights of sediment and water (2.65);

τ_c = dimensionless critical shear stress—the critical shear stress necessary for movement of bed material; and

304.8 = a unit conversion constant, in millimeters per feet.

Values of τ_c of 0.045 and 0.060 were used as the upper and lower limits for the transport of coarse materials in Fountain Creek (von Guerard, 1989b).

Streamflow and channel morphology data collected during streamflow measurements at sites on Cottonwood, Monument, and Fountain Creeks were used to evaluate the capacity of streamflows to transport coarse sand and gravel of 1- to 32-mm size fractions, the predominant size fraction in Monument, Cottonwood, and Fountain Creeks. Analyses indicate that minimum measured streamflows at all sites generally have the capacity to transport coarse to very coarse sands of 1 to 2 mm. Analyses also indicate that the transport of bed material of the coarse gravel of 16- to 32-mm-size fractions is possible as streamflows approach and exceed 20 ft^3/s to 30 ft^3/s at sites in the Cottonwood Creek Basin, 20 ft^3/s to 150 ft^3/s at site 3970 in Monument Creek, and 20 ft^3/s to 1,000 ft^3/s at sites 3700, 5500, and 5800 in Fountain Creek.

Descriptive Assessment of Changes in Channel Morphology

Substantial changes in channel morphology are most often associated with infrequent or catastrophic floods that may cause rapid changes in channel shape and(or) location and capture the attention of area residents. However, more common streamflow conditions associated with bankfull streamflow, while less catastrophic, are considered to be the dominant force in development and maintenance of channel morphology (Leopold and others, 1964; Rosgen, 1996). Changes in channel morphology for one reach of Monument Creek near site 3970, three reaches of Fountain Creek near sites 3700, 5500, and 5800, and three reaches of Cottonwood Creek near sites 3977, 3985, and 3990 are described using periodic cross-section surveys made by Colorado Springs City Engineering personnel from 1999 through 2001 (Frank Helme, Colorado Springs City Engineering, unpub. data, 2002). Cross-section surveys documented channel downcutting, channel aggradation or infilling, and(or) bank scour that has occurred between 1999 and 2001.

Monument Creek

Bed material of Monument Creek at site 3970 is primarily sand and gravel. Surveys of cross sections along this reach since the 1999 flood have documented episodes of channel degradation and aggradation. Channel geometry as defined by the most recent series of cross-section surveys, November 2001, indicates that streambanks are generally stable and little lateral movement of streambanks has occurred. Episodes of aggradation and degradation appear to be limited to the streambed (fig. 16). Between April 1999 and November 2001, the upper and middle sections of the surveyed reach have tended to degrade as thalwegs have decreased from about 1 to 3 ft (fig. 17). The farthest downstream section of the reach has tended to aggrade since the 1999 flood. As of the November 2001 survey, the thalweg has aggraded approximately 1 ft at the downstream section of the reach.

Cottonwood Creek

Bed material in the Cottonwood Creek channel varies from primarily sand and gravel in its upper reaches (site 3977) to bedrock at its confluence with Monument Creek (site 3990). Changes in channel morphology in the upper reach of Cottonwood Creek have included episodes of channel degradation and aggradation that generally were limited to the streambed (fig. 18). Channel degradation reached its maximum during the spring of 2000 with a net decrease in thalweg of about 2 ft in all cross sections along the reach. Since the spring of 2000, cross-section surveys indicate that the upper reach has undergone episodes of aggradation followed by periods of degradation where previously deposited materials were reworked and transported out of the cross sections. Streambed elevations decreased about 1 ft between 1999 and 2001. Changes in channel morphology in the central and lower reaches of Cottonwood Creek generally were small (fig. 19) due to the increasingly common incidence of bedrock outcroppings. Historically, however, changes in channel morphology in regions of bedrock outcropings

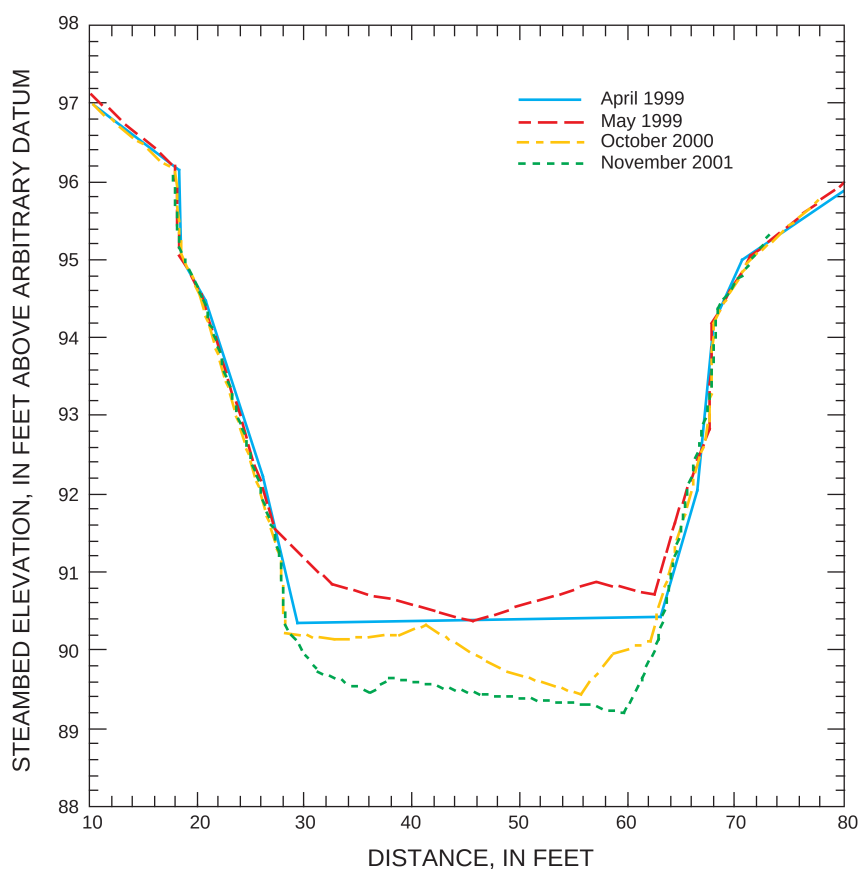


Figure 16. Selected stream-channel cross-section surveys for site 3970 on Monument Creek, April 1999 through November 2001 (Colorado Springs City Engineering, unpub. data, 2001).

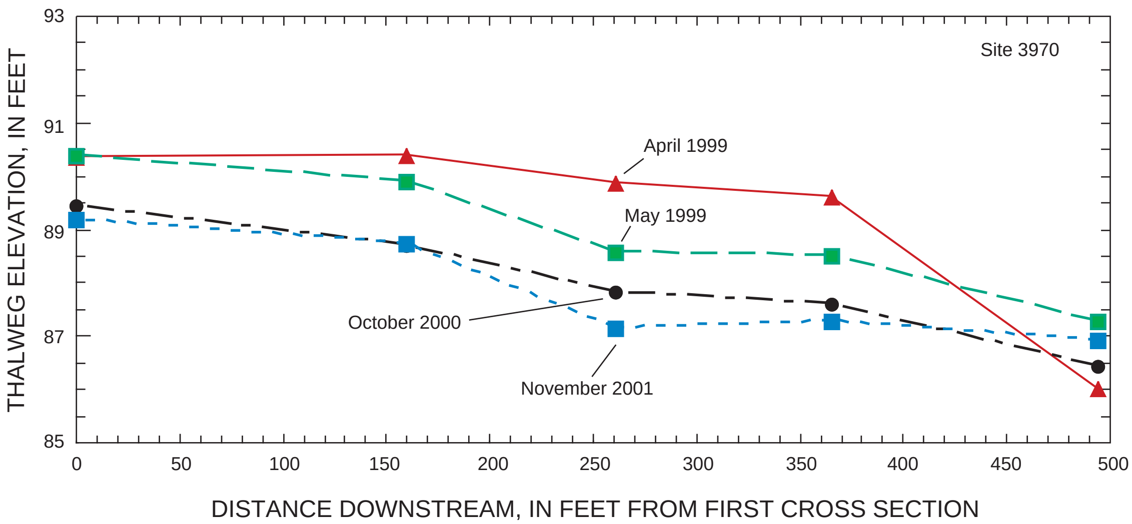


Figure 17. Variations in thalweg elevations at site 3970 in Monument Creek, April 1999 through November 2001 (Colorado Springs City Engineering, unpub. data, 2001).

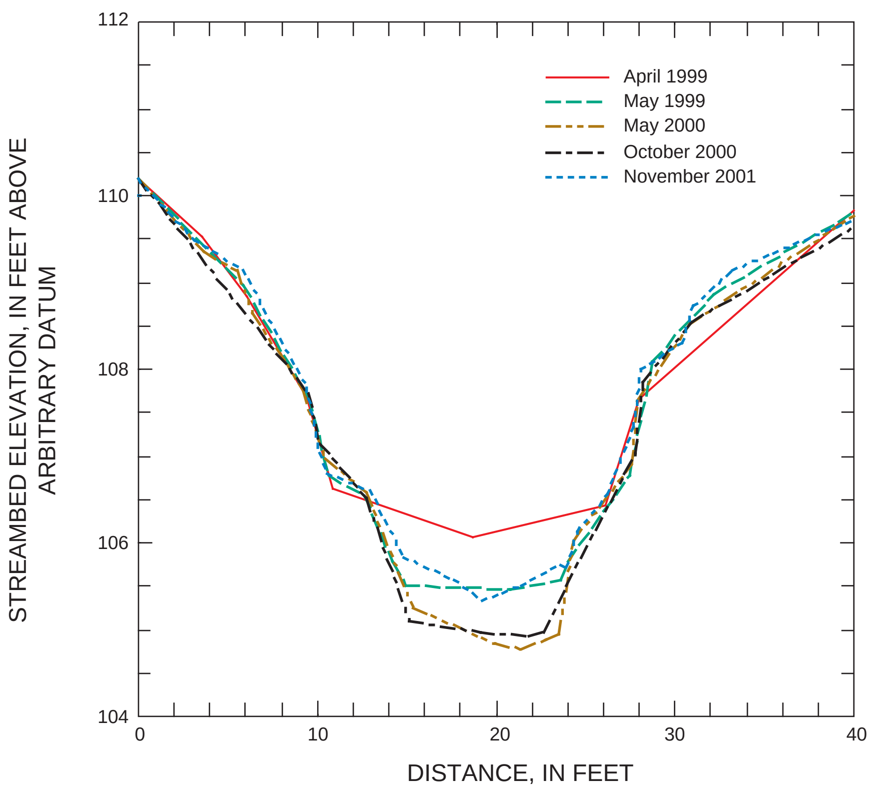


Figure 18. Selected stream-channel cross-section surveys for site 3977 on Cottonwood Creek, April 1999 through November 2001 (Colorado Springs City Engineering, unpub. data, 2001).

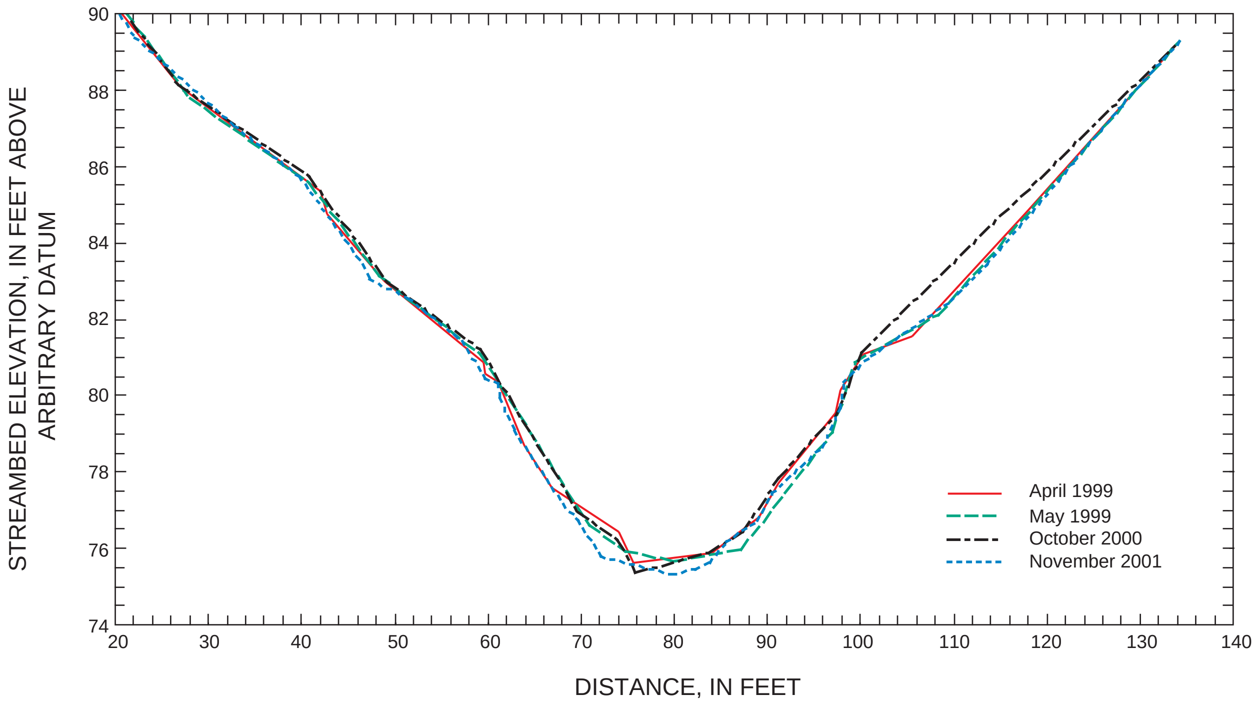


Figure 19. Selected stream-channel cross-section surveys for site 3990 on Cottonwood Creek, April 1999 through November 2001 (Colorado Springs City Engineering, unpub. data, 2001).

have also been substantial. Streamflow can slowly erode bedrock along fractures, at times developing subsurface channels capable of conveying most if not all streamflow during periods of low streamflow. Over time and during selected periods of high streamflow, the undermined shale is subsequently removed in small to large sheets in relative short periods of time (Jim Bruce, U.S. Geological Survey, oral commun., 2001). Erosional episodes of this nature, however, were not apparent during cross-section surveys as of November 2001.

Fountain Creek

Bed and bank material of Fountain Creek at sites 3700, 5500, and 5800 is primarily sand and gravel. Surveys of cross sections at these sites since the 1999 flood have documented episodes of channel degradation and aggradation. Between April 1999 and November 2001, the surveyed reach at site 3700 has tended to aggrade as thalwegs have increased 0.5 to 1.5 ft at three of the five cross sections (fig. 20). Surveyed reaches at sites 5500 and 5800 have tended to degrade since the 1999 flood. Between April 1999 and November 2001 survey, the thalweg has degraded approximately 2 to 3 ft at sections of the surveyed reach at site 5500 and 0.5 to 3 ft at sections of the surveyed reach at site 5800. However, at site 5500, the thalweg has tended to aggrade from October 2000 to November 2001, with the farthest downstream two sections aggrading by 0.5 to 1.5 ft.

Channel cross-section geometry as defined by the most recent series of cross-section surveys, November 2001, indicates that streambanks at sites in Fountain Creek are more prone to erosion than sites in Monument Creek, and lateral movement of streambanks has occurred (figs. 21 and 22). The most striking lateral changes occurred at site 5500 (fig. 22). Before April 1999, channel width at one cross section in the study reach was about 70 ft. After the 1999 flood, the width of this cross section increased about 30 ft. As of the November 2001 survey date, the width at this cross section has increased by about an additional 50 ft. Channel widths at other cross sections in this reach, as well as reaches at sites 3700 and 5800 in Fountain Creek, also increased, but not at as great a magnitude.

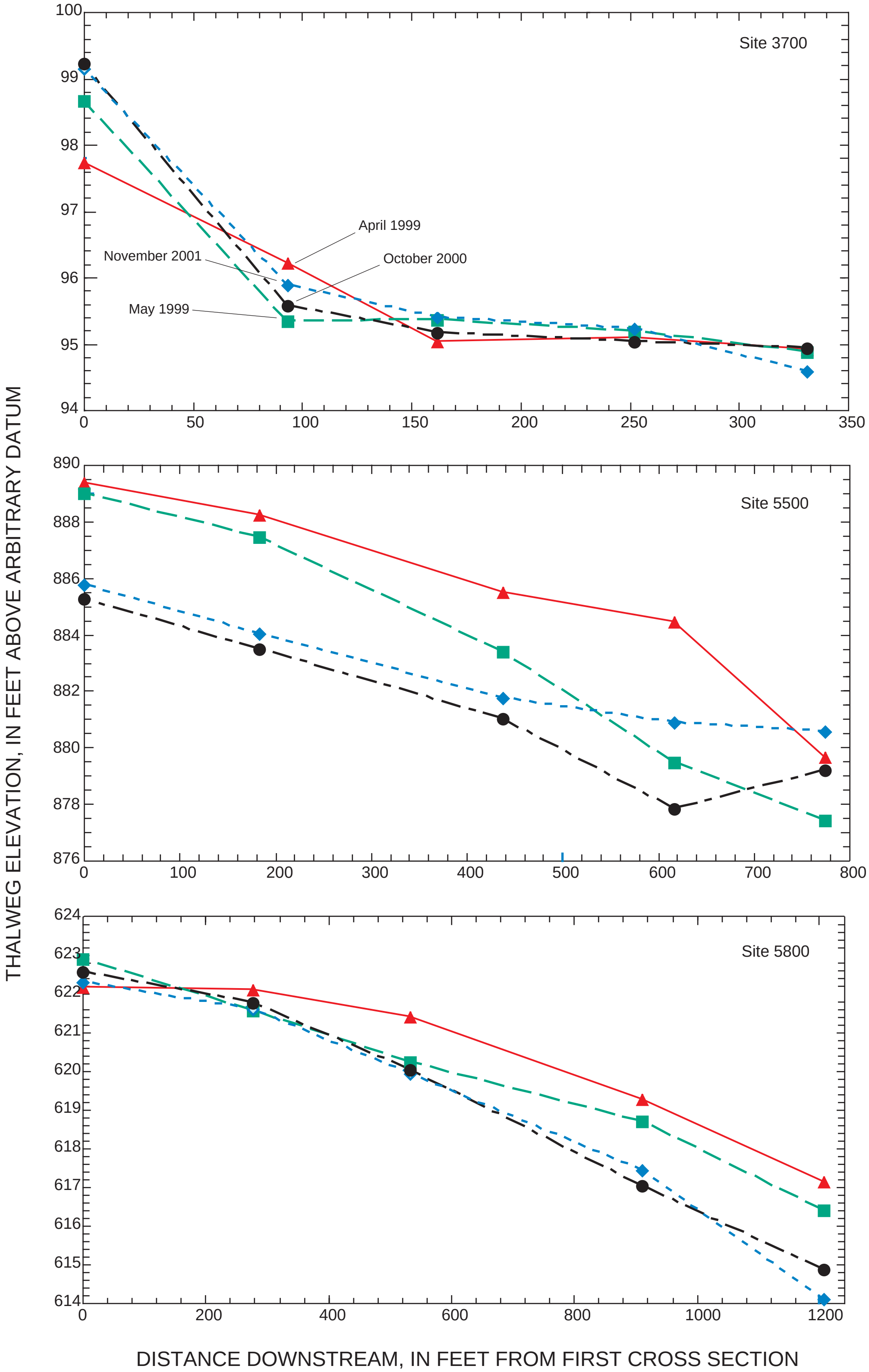


Figure 20. Variations in thalweg elevations at sites in Fountain Creek, April 1999 through November 2001 (Colorado Springs City Engineering, unpub. data, 2001).

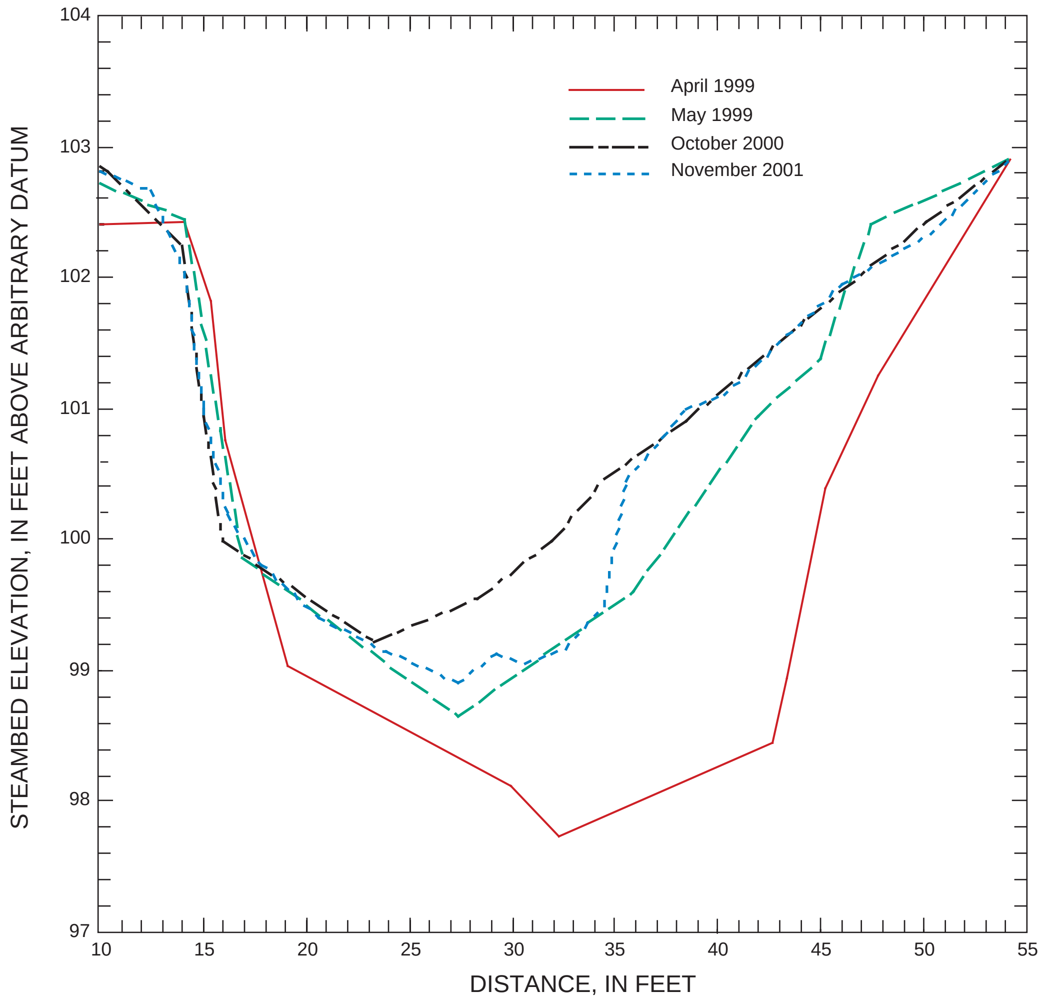


Figure 21. Selected stream-channel cross-section surveys for site 3700, April 1999 through November 2001 (Colorado Springs City Engineering, unpub. data, 2001).

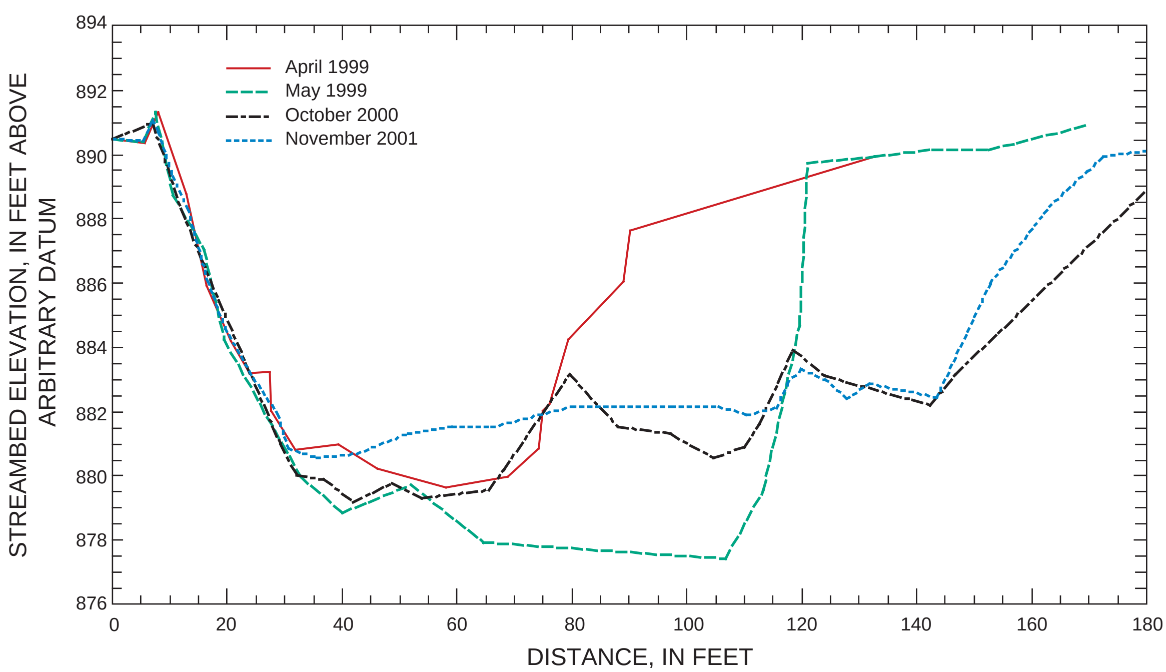


Figure 22. Selected stream-channel cross-section surveys for site 5500, April 1999 through November 2001 (Colorado Springs City Engineering, unpub. data, 2001).

SUMMARY

This report documents water quality and suspended sediment with an emphasis on evaluating the effects of stormflow on Fountain Creek Basin in the vicinity of Colorado Springs, Colo., from 1981 through 2001. From 1949 through 2001 annual precipitation in the basin ranged from 8.6 to 26.8 inches, and from 1981 through 2001, annual precipitation in the basin ranged from 12.7 to 26.8 inches. The maximum annual precipitation for the 52-year period of record occurred in 1999. A trend analysis revealed no significant trend for the period 1981–2001 even though annual precipitation since 1981 generally has been above the long-term average of 16.4 inches.

A trend analysis of annual stormflow, annual number of storm-runoff events, and annual average stormflow for sites 3700, 5500, and 5800 indicated no significant trends from 1981 through 2001. A trend analysis for site 4000 indicated a significant upward trend in annual stormflow, a moderately significant trend in annual number of storm-runoff events, but no significant trend in annual average stormflow from 1981 through 2001.

Water quality frequently differed among the different flow regimes. Specific conductance, which is an indicator of dissolved solids, was highest during base flow and lowest during stormflow because of dilution. Spatially, specific conductance generally doubled between sites 3700 and 3707, indicating a source of relatively high dissolved solids is present in the intervening reach. A tributary to Cottonwood Creek (site 3985) generally had specific-conductance values 50 percent larger than the values measured at other sites. At site 3970, Monument Creek upstream from Cottonwood Creek, 5-day biochemical oxygen demand concentrations were significantly higher during stormflow than during base flow and normal flow. Fecal coliform bacteria concentrations were highly variable, generally different by more than a factor of 10 at each site and flow regime; concentrations tended to be largest during stormflow and smallest during base flow. Dissolved ammonia, total phosphorus, and dissolved orthophosphorus concentrations in Fountain Creek upstream from the Monument Creek confluence tended to have the highest concentrations during stormflow and the lowest concentrations during base flow. Dissolved ammonia and dissolved orthophosphorus concentrations in Monument Creek upstream from Cottonwood tended to have the highest concentrations during stormflow and the lowest concentrations during base flow. Downstream from Cottonwood Creek, dissolved ammonia concentrations in Monument Creek were relatively constant, total phosphorus concentrations tended to increase during each flow regime, and dissolved orthophosphorus concentrations tended to decrease during each flow regime, with the highest concentrations occurring during base flow. Between sites 5500 and 5530, dissolved ammonia, total phosphorus, and dissolved orthophosphorus concentrations generally increased significantly downstream from the Las Vegas Street Wastewater Treatment effluent outfall. Most dissolved trace-element concentrations associated with stormflow decreased or showed little change compared to base flow. However, median concentrations of total copper, iron, lead, nickel, manganese, and zinc in stormflow samples generally were much larger than nonstorm samples. The substantially larger concentrations of these metals at site 5800 during stormflow, as compared to other sites, indicates a relatively large source of these metals in the reach between sites 5530 and 5800.

Most semivolatile organic compounds were below the analytical detection limit, and only 8 of 16 semivolatile compounds analyzed were detected. No compounds were detected at site 3700; about 20 and 30 percent of the samples had detectable concentrations of semivolatile organic compounds during stormflow at sites 5500 and 5800, respectively. In addition, there were numerous reported estimated values. Analysis of the pesticide data showed a relatively frequent detection of pesticides at low levels, indicating pesticides have been routinely transported to streams, probably as overland runoff during storms.

Nitrogen, phosphorus, and particulate trace-element loads substantially increase during stormflow. Trace-element loads in Fountain Creek downstream from Monument Creek were much larger than those in Fountain Creek upstream from Monument Creek and in Monument Creek.

At Fountain Creek near Manitou Springs (site 3700), 5-day biochemical oxygen demand and dissolved orthophosphorus concentrations were significantly higher in the stormflow samples for the post-1997 period than for the pre-1998 period. Total lead was the only trace element that indicated a statistical difference in trace-element concentrations at site 3700 for the two periods. At Fountain Creek 1.3 mi downstream from Monument Creek (site 5500), statistically significant increases between the two periods were detected for 5-day biochemical oxygen demand, fecal coliform bacteria, and dissolved orthophosphorus concentrations. Additionally, total copper, iron, lead, manganese, and zinc concentrations significantly increased in stormflow samples collected in the post-1997 period compared to stormflow samples collected in the pre-1998 period. Dissolved manganese concentrations significantly decreased in the post-1997 period. A comparison of stormflow concentrations measured between 1981 and 2001 to acute instream standards indicated that, except for isolated occurrences, stormflow concentrations did not exceed acute instream standards.

Depending on the site and year, suspended-sediment concentrations associated with stormflow generally were 3 to10 times greater than concentrations measured during normal flow, and suspended-sediment discharges and yields during stormflow usually were more than 10 times greater than those during normal flow. Total annual suspended-sediment discharge during stormflow for the Fountain and Monument Creek sites generally occurred less than 20 percent of the days between April and October but transported about 4.5 times more tons of sediment, on average, than was transported during normal flow. For the three sites located in the Cottonwood Creek drainage, about 10 times more tons of sediment, on average, were transported annually during stormflow than during normal flow. Additionally, on average, about 10 times more tons per cubic foot per second was transported annually during stormflow than during normal flow in Fountain and Monument Creeks and for the sites in Cottonwood Creek Basin.

Suspended-sediment concentrations associated with normal flow indicated that several sites had significantly different concentrations. The largest suspended-sediment concentrations during normal flow generally were less than 500 mg/L. Suspended-sediment concentrations measured during stormflow indicated that a few sites had significantly different concentrations. The highest suspended-sediment concentrations during stormflow tended to occur at the three sites in the Cottonwood Creek Basin and the two sites on Fountain Creek downstream from the confluence with Monument Creek; concentrations generally ranged between 500 and 3,000 mg/L.

Suspended-sediment discharge during normal flow generally increased in a downstream direction as streamflow increased. Suspended-sediment discharge during normal flow generally ranged from less than 0.10 ton/d (site 3977) to greater than 90 tons/d at site 5800. Site 5800 had the largest suspended-sediment discharges, generally ranging from about 1,300 to 6,500 tons/d during stormflow. Suspended-sediment discharges at site 5500 generally ranged from about 190 to almost 2,600 tons/d during stormflow.

The April through October cumulative suspended-sediment discharges and streamflows were largest in 1999 at all sites. The data indicate that for the Cottonwood Creek Basin, 69 percent or more of the cumulative streamflow and cumulative sediment discharge reported at site 3990, Cottonwood Creek at the mouth, occurred in the intervening 10-mi^2 drainage area downstream from sites 3977 and 3985. The intervening 89-mi^2 drainage area between sites 3700, 3970, 3990, and site 5500 is about 23 percent of the drainage area upstream from site 5500. This intervening drainage area contributed between 20 and 40 percent of the streamflow and between 44 and 68 percent of the sediment discharge transported each year from April through October. Between 35 and 75 percent of the streamflow and between 29 and 54 percent of the sediment discharge transported each year from April through October were contributed from the intervening 103-mi^2 drainage area between sites 5500 and 5800.

Suspended-sediment yields provide a means for identifying source contribution areas. During normal flow, site 3700, a site with a drainage area of 103 mi^2, had similar yields to site 3977, a site with a drainage area of 5.93 mi^2. These sites had the smallest suspended-sediment yields during normal flow, with yields generally less than 0.15 ton/d/mi^2. Site 3990, a site with a drainage area of about 18.7 mi^2, had the largest suspended-sediment yields during normal flow; yields generally ranged from about 0.3 to 0.8 ton/d/mi^2. Although large spatial variations in suspended-sediment yields occurred during normal flow, the suspended-sediment yields that were associated with stormflow generally were more than 10 times greater than the suspended-sediment yields that occurred during normal flow. Suspended-sediment yields associated with stormflow indicated sites ranked from smallest to largest yields were 3977, 3700, 3970, 5500, 5800, 3990, and 3985. Sites 3977, 3700, and 3970 had the smallest suspended-sediment yields with yields generally less than 1 ton/d/mi^2 during stormflow. The two sites with the largest suspended-sediment yields, 3990 and 3985, located in the Cottonwood Creek Basin, had yields that generally were greater than 10 tons/d/mi^2.

Analysis of the sediment transport capacity for Fountain, Monument, and Cottonwood Creeks indicated that minimum streamflows at all sites generally have the capacity to transport coarse to very coarse sands. Channel cross-section geometry indicates that streambanks at sites in Fountain Creek are more prone to erosion and lateral movement than streambanks at sites on Monument Creek. Episodes of channel degradation and aggradation have occurred at most sites surveyed between 1999 and 2001, and changes in streambed elevation generally ranged from about 0.5 to 3 ft.

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