SUSPENDED SEDIMENT AND SEDIMENT-SOURCE AREAS
IN THE FOUNTAIN CREEK DRAINAGE BASIN
UPSTREAM FROM WIDEFIELD, SOUTHEASTERN COLORADO

By Paul von Guerard

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MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
Box 25046, Mail Stop 415
Federal Center
Denver, CO 80225-0046

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CONVERSION FACTORS

Inch-pound units used in this report may be converted to metric (International System) units by using the following conversion factors:

Multiply inch-pound units	*By*	*To obtain metric units*
acre	0.4047	hectare
acre-foot	0.001233	cubic hectometer
acre-foot per square mile	0.000476	cubic hectometer per square kilometer
cubic foot per second (ft^3/s)	0.028317	cubic meter per second
foot (ft)	0.3048	meter
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
pound per cubic foot (lb/ft^3)	16.03	kilogram per cubic meter
square mile (mi^2)	2.590	square kilometer
ton (short)	0.9072	megagram
ton per day (ton/d)	0.9072	megagram per day
ton per square mile (ton/mi^2)	0.3502	megagram per square kilometer
ton per square mile per day [$(ton/mi^2)/d$]	0.3502	megagram per square kilometer per day

Temperature can be converted from degree Fahrenheit (°F) to degree Celsius (°C) by using the following equation:

$$°C = 5/9\ (°F - 32).$$

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

milligram per liter (mg/L),
millimeter (mm).

Suspended-sediment concentrations are given only in milligrams per liter (mg/L) because these values are (within the range of values presented) numerically equal to concentrations expressed in parts per million.

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

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ABSTRACT

Suspended-sediment samples were collected from a network of 24 synoptic sampling sites to evaluate suspended-sediment yields and sediment-source areas in the Fountain Creek drainage basin upstream from Widefield, Colorado. Suspended-sediment yields ranged from 0.004 to 278 tons per square mile per day. The 24 sites represented urban and rural land use. The median suspended-sediment yield from urban drainage basins was 7.7 tons per square mile per day and the median suspended-sediment yield from rural drainage basins was 0.46 ton per square mile per day. Sediment-transport equations were derived for total suspended-sediment discharge and suspended-sand discharge at seven periodic-sampling sites. Annual suspended-sediment loads were computed for the 1985 water year using the streamflow-duration, sediment-transport equation method.

Urbanization in the downstream parts of the Monument Creek drainage basin, the main tributary to Fountain Creek, increased suspended-sediment loads and yields. The downstream 14 percent of the Monument Creek drainage basin contributed about 61 percent of the annual suspended-sediment load transported at the mouth of Monument Creek. About 73 percent of the annual suspended-sediment load for Fountain Creek at Colorado Springs was contributed by Monument Creek.

Abandoned mill tailings along Fountain Creek contributed little to total suspended-sediment load. Contributions of streambank erosion to basin sediment yields were not quantified. However, the measured rate of streambank erosion at a site on Fountain Creek has increased during a 37-year period.

INTRODUCTION

Erosion, transport, and deposition of sediment in a drainage basin can affect municipal and irrigation diversion structures, water quality, aquatic habitat, and recreational use of a stream. Fountain Creek (fig. 1) has been affected by higher erosion rates for more than a century. Chapman (1933) used Fountain Creek as an example of a stream that has been affected by higher erosion rates, which he believed began in the late 1870's as a result of agricultural development. Since 1950, agricultural development has been replaced by urban development. During these 30 years, the population of El Paso County has grown steadily (fig. 2). This growth has increased the demand for water in the area and has increased the potential for erosion and sedimentation in the drainage basin. Identifying sediment-source areas can be useful when planning residential, industrial, riparian, and agricultural land development.

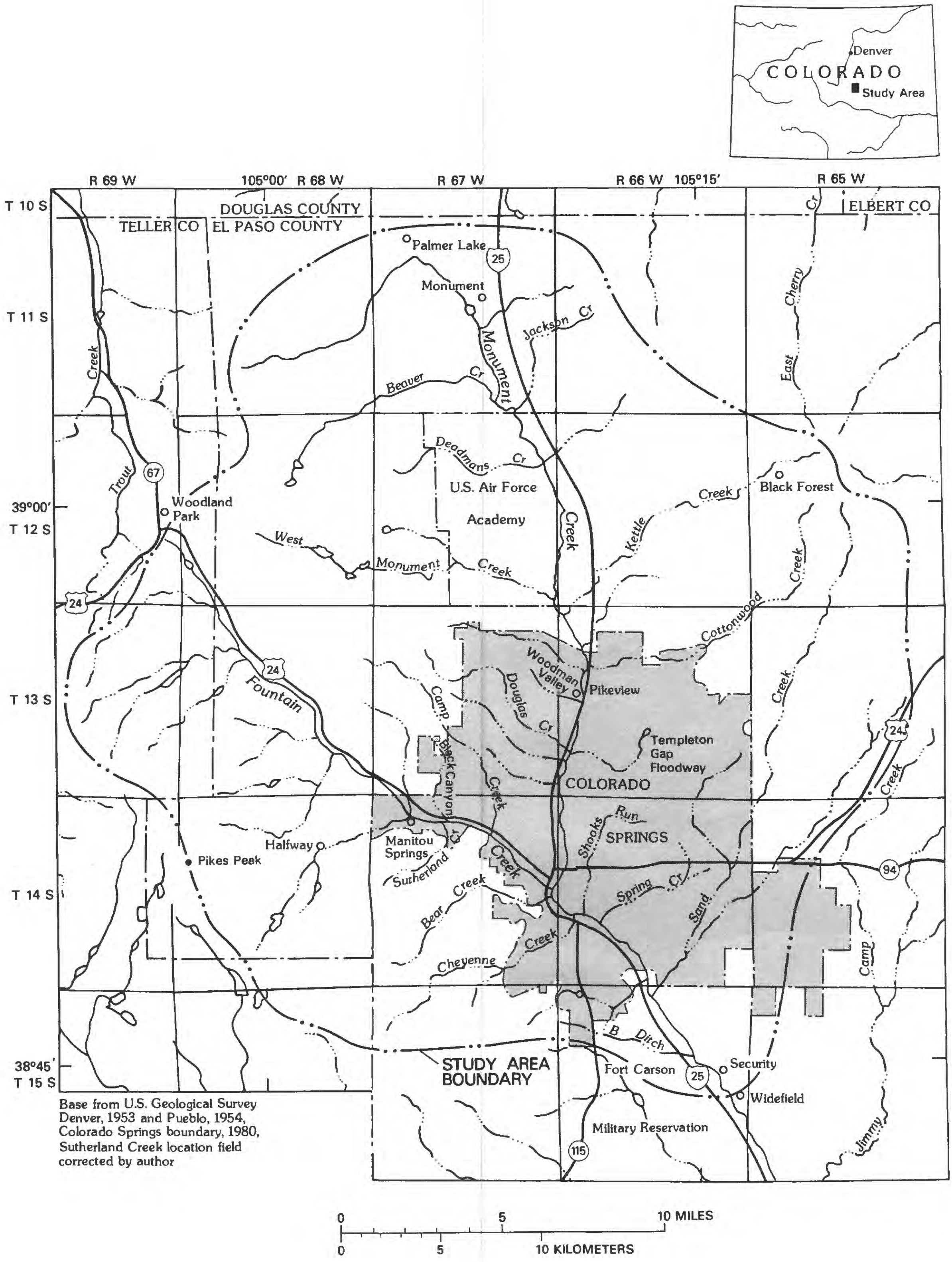


Figure 1.--Location of study area.

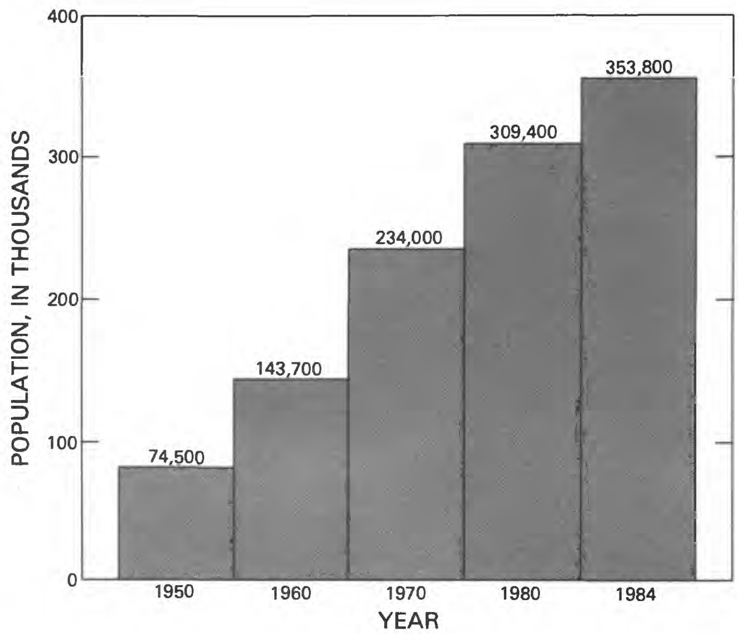


Figure 2.--Population growth in El Paso County during 1950-84 (Pikes Peak Area Council of Governments, 1985).

In 1985 the U.S. Geological Survey, in cooperation with the city of Colorado Springs, began a study to determine the suspended-sediment concentrations and yields and sediment-source areas in the Fountain Creek drainage basin upstream from Widefield. The study area, hereafter referred to as the basin, is in eastern Teller County and northwestern El Paso County upstream from Widefield. The basin includes 495 mi^2 of the Fountain Creek drainage, which also includes the city of Colorado Springs.

Purpose and Scope

The purpose of this report is to describe suspended-sediment concentrations, loads, yields, and suspended-sediment-source areas within the Fountain Creek drainage basin. A network of 24 synoptic sampling sites was established to determine the spatial variability of suspended-sediment yields in the basin. Data were collected at these sites twice--once during snowmelt runoff and once during rainfall runoff in the spring of 1985. In addition, suspended-sediment data collected periodically throughout the 1985 water year were available from seven other sites. These data were used to develop suspended-sediment-transport equations, which then were used to determine suspended-sediment loads in Fountain Creek and its main tributary, Monument Creek.

Acknowledgment

The author thanks Gene Y. Michael of the Colorado Springs Department of Utilities for collecting sediment data during a constrained work schedule. His invaluable information about runoff events, especially those that occurred during the synoptic sampling period, is appreciated.

DESCRIPTION OF STUDY AREA

The basin is located in and along the eastern slope of the Front Range section of the southern Rocky Mountains. Topographic variations have an important effect on the climatic conditions of the basin. Differences in climate, precipitation, surface geology, soils, physiography, and drainage affect the spatial variability of erosion rates that occur in the basin.

Climate and Precipitation

The basin can be divided into different climatic zones that are distinguished by vegetation types (table 1). Climatic conditions range from semiarid in the areas below 6,500 ft to alpine in areas above 11,500 ft. The air temperature in the basin may vary greatly due to differences in elevation. For example, in Colorado Springs on a sunny summer afternoon the temperature may be as high as 90 °F while the temperature on Pikes Peak, about 13 mi west and approximately 8,000 ft higher, may be only 40 °F. Mean air temperatures for January range from 29 °F in the semiarid zone to 22 °F in the subalpine and alpine zones. Mean temperatures during July range from 70 °F in lower elevations to 45 °F in the higher elevations (Hansen and others, 1978, p. 13, 25).

Precipitation in these climatic zones varies with elevation (table 1). Precipitation within the basin is distributed seasonally between rain and snow. As elevation increases, snowfall increases as a part of the total precipitation. Annual precipitation for 1948-85 at the Colorado Springs airport is shown in figure 3; annual precipitation for the period ranged from 8.6 to 25.4 in. The mean annual precipitation at this site is 15.7 in. Mean annual precipitation for the entire basin is 18.2 in. (Colorado Climate Center, 1984). Convective thunderstorms contribute most of the rainfall that occurs during May through September. Thunderstorms occur an average of 70 days each year (U.S. Geological Survey, 1970, p. 116).

Intense rainstorms of long duration are the primary mechanisms for erosion of the land surface in the basin. During periods of substantial moisture flow from the Gulf of Mexico, severe rainstorms can occur. Two of the most intense rainstorms ever measured in Colorado have occurred in the basin. The first storm occurred on May 30, 1935, when 18 in. of rain fell in the Black Forest area east of the U.S. Air Force Academy. The second storm occurred during June 14-17, 1965, when as much as 14 in. of rain fell, most of which fell in about 3 hours throughout the Monument and Fountain Creek drainage basins (Hansen and others, 1978, p. 44).

Table 1.--*Vegetation type, elevation range, mean annual precipitation, and area of climatic zones in the Fountain Creek drainage basin upstream from Widefield*

Climatic zone[1]	Climax vegetation type[1]	Elevation range[1] (feet)	Mean annual precipitation, 1951-80 (inches)	Area (square miles)
Semiarid	Grasslands	<6,500	16.7	116
Foothills and lower montane	Pinon, juniper, and ponderosa pine	6,500-7,500	18.0	199
Upper montane	White fir, Douglas fir	7,500-9,000	18.2	81.3
Subalpine	Subalpine fir, Engelman spruce	9,000-11,500	20.0	86.7
Alpine	Tundra	>11,500	25.0	12.0

[1]Information provided by David Powell (U.S. Forest Service, oral commun., 1986).

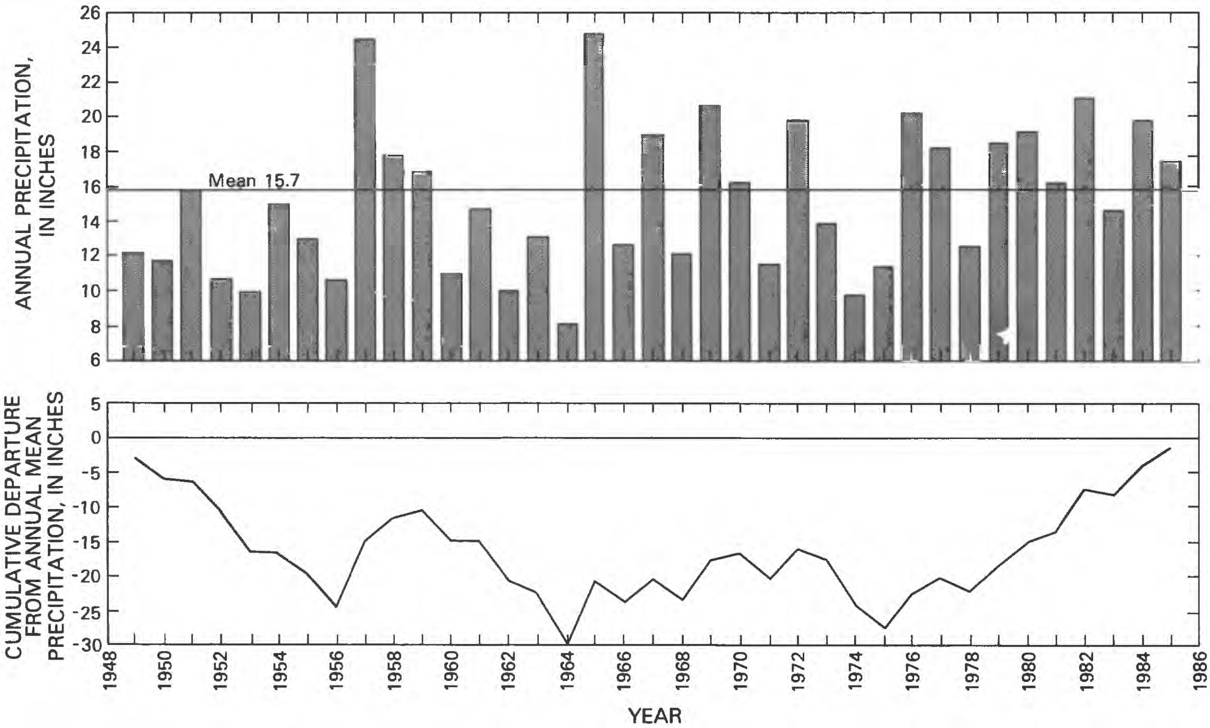


Figure 3.--Annual precipitation and cumulative departures from mean annual precipitation (1945-85) at Colorado Springs airport (modified from Livingston and others, 1976, p. 7).

Surface Geology and Soils

About one-third of the basin is underlain by Precambrian granite, and the remainder is underlain by sandstone and shale of Cretaceous age and alluvial and windlain deposits of Quaternary age (fig. 4). The Pikes Peak Granite is fine- to coarse-grained crystalline rock. The lower part of the Dawson Formation, Laramie Formation, and Foxhills Sandstone of Cretaceous age are comprised of fine- to coarse-grained sediments, which are weakly cemented. The Pierre Shale of Cretaceous age primarily is noncalcareous to very calcareous, silty claystone, or it is very clayey to sandy siltstone and shale. Alluvial deposits of Quaternary age are composed of variably sorted boulders, cobbles, gravel, sand, silt, and clay that become more sandy eastward. Windlain deposits of Quaternary age are loess, and sheets or dunes of fine to coarse sand (Hansen and Crosby, 1982, p. 12-15).

Soils in the basin tend to be sandy, moderately deep to deep, and well drained to excessively well drained. Areal distribution of soil types is similar to that of the surface geology (fig. 5), which affects the type of soils that develop. Except for the Pierre Shale, outcrops of bedrock in the basin weather to a sandy, granular type of regolith. The igneous and metamorphic rocks weather into varying quantities of coarse rock fragments in a sandy matrix. The Pierre Shale weathers to a clayey soil.

Physiography and Drainage

Elevations in the basin range from 5,640 ft at the outflow of the basin, upstream from Widefield, to 14,109 ft at the summit of Pikes Peak. There are two major landforms in the basin, the Front Range of the Rocky Mountains and the Colorado Piedmont (hereafter referred to as the Piedmont). A minor landform is the Hogback Ridge (fig. 6).

The Front Range is composed predominantly of Precambrian granite. A band of steeply tilted Paleozoic sedimentary rocks forms the Hogback Ridge, in the foothills near Manitou Springs and Colorado Springs. The Piedmont region is east of the Hogback Ridge. The sharp physiographic contrast between the Front Range and the Piedmont is a result of uplift and erosive resistance of Precambrian granite. Deep canyons along the eastern boundary of the Front Range widen upstream into the Front Range, land-surface slopes flatten, and narrow ridge tops expand into rolling uplands.

The Piedmont is underlain predominantly by the Dawson Formation and alluvial and windlain deposits. The Pierre Shale, Laramie Formation and Foxhills Sandstone, underlie the remainder of the Piedmont. The Piedmont can be subdivided into lowlands and uplands. Piedmont uplands include bench and valley topography in the area of the U.S. Air Force Academy and low rolling uplands covered by windlain sand and silts and remnants of ancient river gravels east of Fountain and Monument Creeks. Piedmont lowlands occur along the downstream reaches of Fountain, Monument, and Sand Creeks and include flood plains, terraces, and lowlands covered by alluvial and windlain deposits (Hansen and Crosby, 1982, p. 6-11).

Fountain Creek is a perennial stream that originates near Woodland Park in the Front Range. Fountain Creek flows southeastward through a deeply incised canyon to the western edge of the Piedmont near Manitou Springs. The stream channel upstream from Manitou Springs is meandering; the stream channel has a pool-and-riffle regime, and the bed material ranges from sand and gravel to cobbles and boulders. From Manitou Springs, Fountain Creek flows through a system of alluvial terraces into a wide alluvial valley. In this valley, the stream channel of Fountain Creek is meandering; the stream channel has a pool-and-riffle regime, and the bed material is predominantly sand, gravel, and cobbles. Downstream from the junction with Monument Creek, the channel of Fountain Creek becomes braided. The braided channels are intermittent and usually occur downstream from tributaries that are major sediment sources. The composition of the bed material in Fountain Creek downstream from the junction with Monument Creek is variable. Some stream reaches have cobble bottoms, some are scoured to bedrock, others have a mixture of sand, gravel, and cobbles, and some are braided channels that have large quantities of sand. Active streambank cutting is evident throughout the length of the channel.

Monument Creek, the main tributary to Fountain Creek, also is a perennial stream that originates in the Front Range. Monument Creek flows eastward to Palmer Lake and the Piedmont. From Palmer Lake, Monument Creek parallels the Front Range until the creek reaches Fountain Creek. Upstream from the junction of Cottonwood Creek, Monument Creek is meandering, pool and riffle, and bottom material consists of sand, gravel, and cobbles. Downstream from the junction of Cottonwood Creek, the channel becomes braided, and sand and small gravel comprise the bottom material. The braided channel conditions occur intermittently throughout the remaining length of the channel with areas of pools and riffles. Monument Creek is incised into the Dawson Formation and into various stream valley and windlain deposits in the Piedmont. The Monument Creek flood plain is narrow and intermittent, and active streambank cutting is evident along most of the course of the creek.

SUSPENDED-SEDIMENT CONCENTRATIONS AND YIELDS AND SEDIMENT-SOURCE AREAS DETERMINED FROM SYNOPTIC SAMPLING

Sediment discharge in a stream is the result of erosion and sediment-transport rates that occur throughout the drainage basin. Certain tributaries discharge large quantities of sediment to a stream and others discharge small quantities. Synoptic sampling of suspended-sediment discharge from several tributaries in a drainage basin can help identify areas that have large sediment yields and areas that have small sediment yields.

Synoptic-Sampling Network

To identify source areas of sediment, a synoptic-sampling network was established. The synoptic-sampling network consisted of 24 sites; 10 tributary to or on Fountain Creek, and 14 tributary to or on Monument Creek (fig. 7, table 2). Synoptic-sampling sites were selected that represent the hydrologic and land-use conditions of the basin.

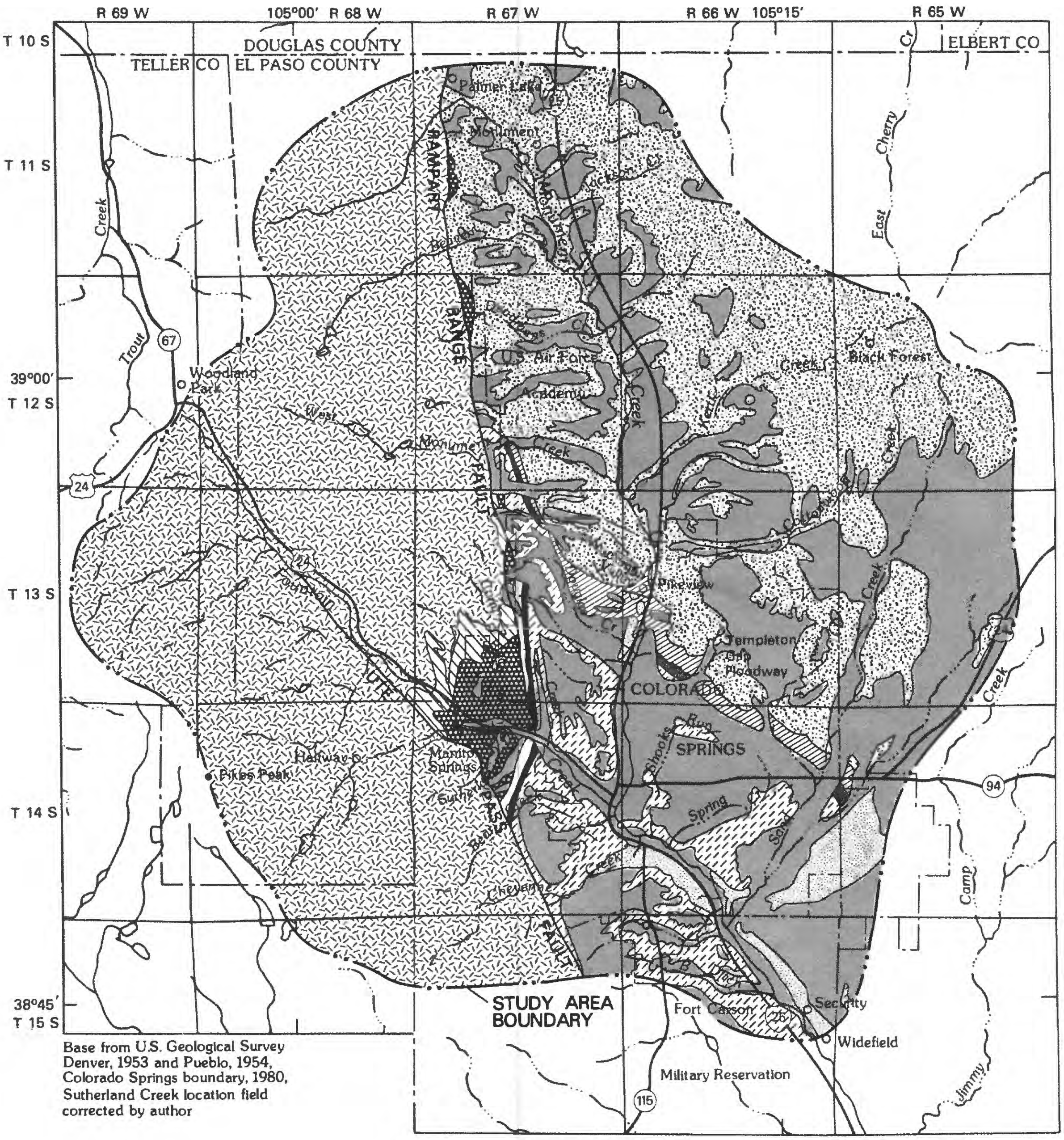


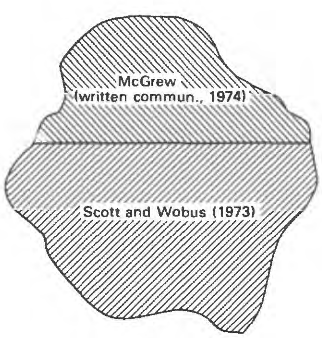
Figure 4.--Generalized geology (modified from Livingston and others, 1975, 1976).

EXPLANATION

QUATERNARY	*Holocene*	STREAM VALLEY AND WINDLAIN DEPOSITS
	Pleistocene	BROADWAY ALLUVIUM
TERTIARY	*Paleocene*	DAWSON ARKOSE
CRETACEOUS	*Upper Cretaceous*	LARAMIE FORMATION
		FOX HILLS SANDSTONE
		PIERRE SHALE, NIOBRARA FORMATION, CARLILE SHALE, GREENHORN LIMESTONE, AND GRANEROS SHALE, UNDIVIDED
	Lower Cretaceous	DAKOTA SANDSTONE AND PURGATOIRE FORMATION
PERMIAN, TRIASSIC AND JURASSIC	*Upper Jurassic*	MORRISON FORMATION, RALSTON CREEK FORMATION, LYKINS FORMATION, AND LYONS SANDSTONE, UNDIVIDED
PENNSYLVANIAN AND PERMIAN		FOUNTAIN FORMATION
CAMBRIAN AND ORDOVICIAN		ORDOVICIAN, AND CAMBRIAN ROCKS, UNDIVIDED
PRECAMBRIAN		PRECAMBRIAN ROCKS

CONTACT

FAULT



SOURCES OF GEOLOGIC DATA

Figure 4.--Generalized geology (modified from Livingston and others, 1975, 1976)--Continued.

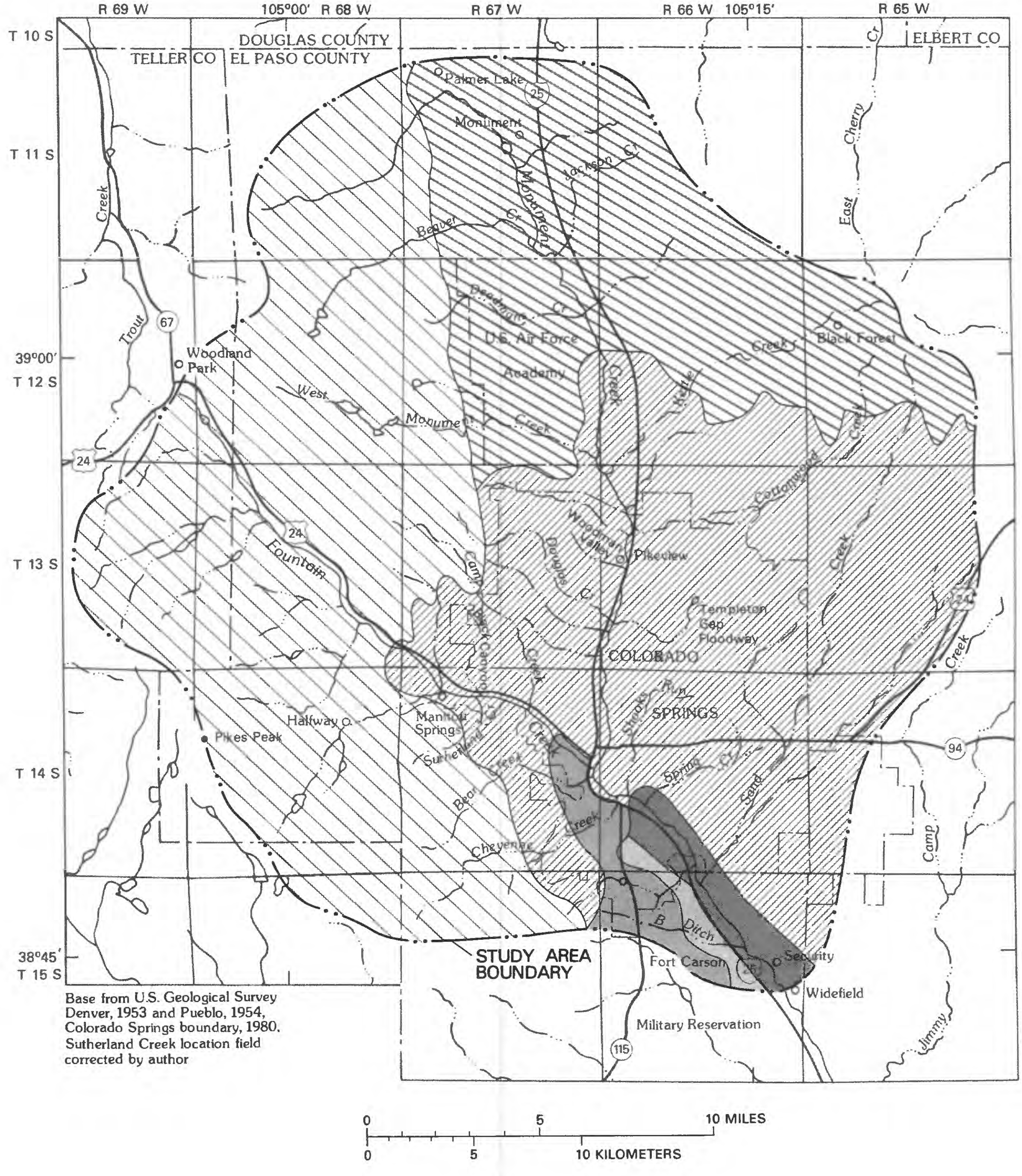


Figure 5.--Generalized soils (modified from Larsen, 1981).

EXPLANATION

SOILS ON COLD, SUBHUMID TO SEMIARID MOUNTAINS AND FOOTHILLS

COLDCREEK-ROCK OUTCROP-KUTLER-- Rock outcrop and deep and moderately deep, strongly sloping to extremely steep, well drained and somewhat excessively drained soils that formed in material weathered from acid igneous rock

KETTLE-PRING-PEYTON-- Deep, nearly level to steep, well drained soils that formed in material weathered from arkosic sedimentary rock

TRUCKTON-BLAKELAND-BRESSER-- Deep, nearly level to moderately steep, sandy soils that formed in material weathered from arkosic sedimentary rock

SOILS ON MILD, SEMIARID TO ARID PLAINS

SCHAMBER-RAZOR-- Deep and moderately deep, gently rolling to steep, well drained soils that formed in material weathered from gravelly alluvium and in residuum derived from shale

RAZOR-MIDWAY-- Moderately deep and shallow, gently sloping to moderately steep, well drained soils that formed in material derived from calcareous shale

MANZANOLA-LIMON-- Deep, nearly level to gently sloping, well drained soils that formed in calcareous alluvium

Figure 5.--Generalized soils (modified from Larsen, 1981)--Continued.

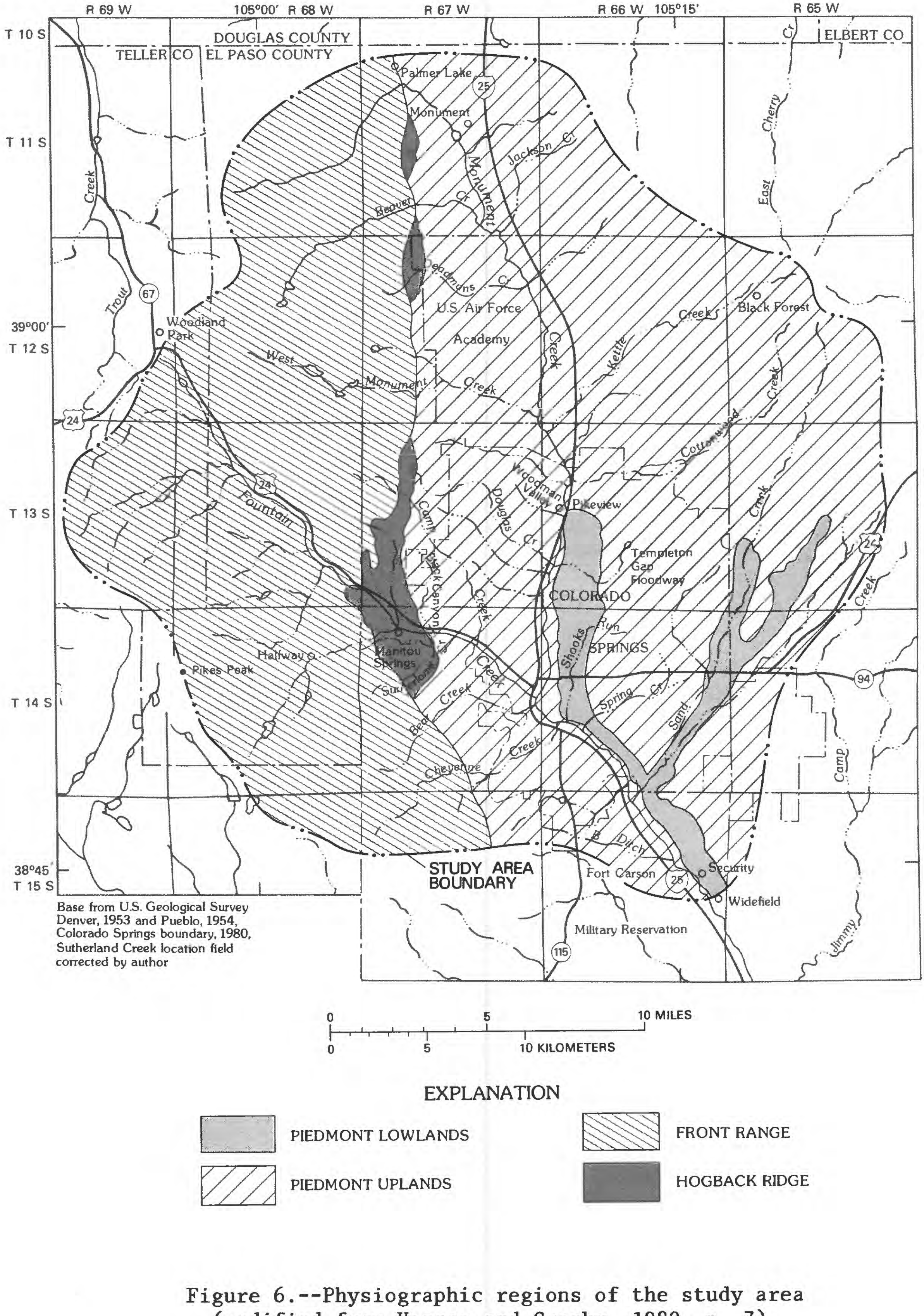
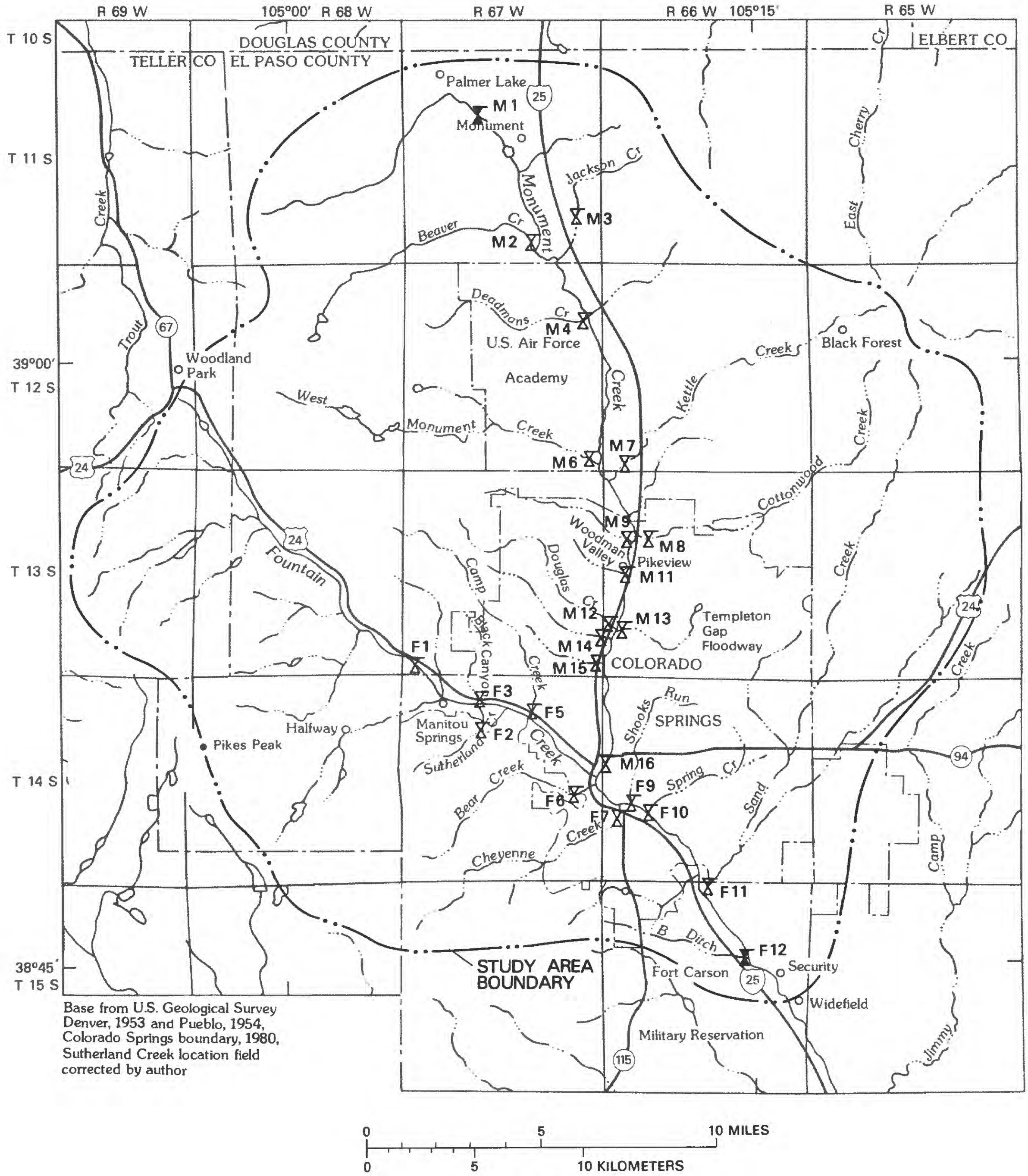


Figure 6.--Physiographic regions of the study area (modified from Hansen and Crosby, 1982, p. 7).



EXPLANATION

F6 SYNOPTIC SUSPENDED-SEDIMENT AND WATER-DISCHARGE MEASUEMENT SITE AND NUMBER

M1 SYNOPTIC SUSPENDED-SEDIMENT MEASUREMENT SITE THAT IS ALSO A CONTINUOUS STREAMFLOW-GAGING STATION AND NUMBER

Figure 7.--Locations of synoptic-sampling sites.

Table 2.--*Location identification, drainage-basin area, and land-use designation for synoptic-sampling sites in the Fountain Creek drainage basin upstream from Widefield*

[R, rural; U, urban]

Site number in figure 7	Synoptic-sampling-site name	Latitude	Longitude	Drainage-basin area (square miles)	Land use
F1	Fountain Creek upstream from Manitou Springs	38°52'01"	104°55'24"	73.2	R
F2	Sutherland Creek	38°51'30"	104°53'46"	5.2	R
F3	Black Canyon	38°51'33"	104°53'49"	2.2	R
F5	Camp Creek	38°51'18"	104°52'10"	9.1	U
F6	Bear Creek	38°49'21"	104°50'25"	10.5	U
F7	Cheyenne Creek	38°48'51"	104°49'20"	25.7	U
F9	Shooks Run	38°49'05"	104°49'00"	8.7	U
F10	Spring Creek	38°48'33"	104°47'40"	8.3	U
F11	Sand Creek	38°47'15"	104°46'32"	51.4	U
F12	B Ditch Drain near Security[1]	38°45'09"	104°45'41"	7.9	U
M1	Monument Creek at Palmer Lake[2]	39°06'07"	104°53'27"	25.9	R
M2	Beaver Creek	39°03'16"	104°52'07"	22.8	R
M3	Jackson Creek	39°02'54"	104°50'51"	4.4	R
M4	Deadmans Creek	39°00'59"	104°50'28"	5.1	R
M6	West Monument Creek	38°57'36"	104°50'15"	23.1	R
M7	Kettle Creek	38°57'08"	104°49'28"	17.3	R
M8	Cottonwood Creek	38°55'42"	104°48'36"	17.9	U
M9	Woodman Valley Creek	38°55'43"	104°49'21"	3.3	U
M11	Unnamed	38°54'28"	104°49'23"	1.3	U
M12	Douglas Creek	38°53'34"	104°49'50"	6.1	U
M13	Templeton Gap Floodway	38°53'20"	104°49'02"	8.7	U
M14	Unnamed	38°53'00"	104°50'05"	3.7	U
M15	Unnamed	38°51'22"	104°50'06"	2.1	U
M16	Monument Creek at Bijou Street at Colorado Springs[3]	38°50'18"	104°49'41"	236.0	U

[1]U.S. Geological Survey streamflow-gaging station and periodic water-quality sampling site 07105780.

[2]U.S. Geological Survey streamflow-gaging station and periodic water-quality and sediment-sampling site 07103747.

[3]U.S. Geological Survey periodic water-quality and sediment-sampling site 07104905.

Suspended-sediment samples and water-discharge data were collected during two hydrologic events. Samples were collected on April 1-2, 1985, during a snowmelt-runoff period. An early spring blizzard covered the entire basin with about 14 in. of snow, which had a water equivalent of about 1.2 in. Snowmelt conditions were uniform throughout most of the basin, except in higher elevations where snowmelt was limited because of colder temperatures. A second set of samples were collected on May 21, 1985, during a rainfall-runoff period. Rainfall runoff occurred throughout the entire basin; however, rainfall runoff was sustained for only a few hours, which precluded sampling at all 24 sites.

Instantaneous water-discharge measurements were obtained at all sites except for those sites that have continuous streamflow records. Water-discharge measurements were obtained using techniques described in Rantz and others (1982). Suspended-sediment samples were collected using a DH-48 depth-integrating sampler and the equal-width-increment (equal-transit rate) method described by Guy and Norman (1970). All samples were analyzed for suspended-sediment concentration. Samples also were analyzed for the percentage of sediment finer than silt and clay (less than 0.062 mm). Suspended sediment concentrations can be characterized by determining the percentage of sand, silt, and clay. Once in suspension, silt- and clay-sized particles remain in suspension whereas sand- and larger-sized particles are suspended by the upward components of turbulent-stream currents. Instantaneous suspended-sediment discharge was computed for each site using the following formula (Porterfield, 1972):

$$Qs = Qw \times C \times K \tag{1}$$

where Qs = suspended-sediment discharge, in tons per day;
Qw = water discharge, in cubic feet per second;
C = suspended-sediment concentration, in milligrams per liter; and
K = unit-conversion constant (0.0027).

Instantaneous suspended-sediment yields were computed for each synoptic-sampling site by dividing the instantaneous suspended-sediment discharge (Qs) by the drainage-basin area (square miles) upstream from the site. Suspended-sediment yield is that part of the total erosion that leaves the drainage basin.

Synoptic-Sampling Results

Water-discharge and suspended-sediment data collected during the snowmelt-runoff period (April 1-2, 1985) are listed in table 3. Mean suspended-sediment concentration for the 24 sites was 2,750 mg/L, and the median concentration was 1,330 mg/L.

A suspended-sediment-yield map (fig. 8) was prepared for data collected during the snowmelt-runoff period. The map (fig. 8) is only a qualitative representation of instantaneous suspended-sediment yields in the basin. The map is based on one sample per drainage basin and does not represent annual suspended-sediment yields or the total suspended-sediment yield for the given runoff event. However, the map does illustrate the general spatial variability of suspended-sediment yields within the basin. Sixteen of the 24 sites, representing about 60 percent of the drainage-basin area, had suspended-sediment yields that ranged from 0.004 to 5.1 (tons/mi^2)/d. Mean suspended-sediment yield for 24 sites was 5.3 (tons/mi^2)/d, and the median yield was 2.4 (tons/mi^2)/d.

Table 3.--*Suspended-sediment data for synoptic-sampling sites collected during the snowmelt-runoff period, April 1-2, 1985*

[ft^3/s, cubic feet per second; mg/L, milligrams per liter; tons/d, tons per day; mm, millimeters; (tons/mi^2)/d, tons per square mile per day; --, no data]

Site number in figure 7	Date	Instantaneous water discharge (ft^3/s)	Suspended sediment				
			Concentration (mg/L)	Discharge (tons/d)	Percent finer than 0.062 mm	Sand discharge (tons/d)	Instantaneous yield [(tons/mi^2)/d]
F1	4-1	11.6	342	10.7	34.2	7.0	0.15
F2	4-1	2.1	190	1.1	77.5	.24	.21
F3	4-1	.53	7,810	11.2	81.6	2.1	5.1
F5	4-1	1.3	439	1.5	97.4	.04	.17
F6	4-1	4.8	1,880	24.4	--	--	2.3
F7	4-1	7.4	199	4.0	89.9	.40	.16
F9	4-1	19.2	477	24.7	78.9	5.2	2.8
F10	4-1	11.6	443	13.9	57.1	6.0	1.7
F11	4-1	8.5	5,360	123	39.6	74.3	2.4
F12	4-1	13.8	3,160	118	89.0	13.0	14.9
M1	4-2	10.5	328	9.3	57.5	3.9	0.36
M2	4-2	6.4	82	1.4	91.4	.12	.06
M3	4-2	2.1	115	.65	42.8	.37	.15
M4	4-2	2.8	636	4.8	79.8	.97	.94
M6	4-1	2.2	13	.08	100	.00	.004
M7	4-1	6.0	5,320	86.0	68.6	27.0	5.0
M8	4-1	24.1	5,690	370	79.7	75.0	20.7
M9	4-1	2.9	786	6.2	86.6	.83	1.9
M11	4-2	.71	13,800	26.4	99.1	.24	20.3
M12	4-2	7.2	1,980	38.5	84.4	6.0	6.3
M13	4-1	12.4	2,890	96.7	85.1	14.4	11.1
M14	4-2	5.2	3,020	42.4	93.5	2.8	11.5
M15	4-1	1.6	5,620	24.3	85.3	3.6	11.6
M16	4-1	127	5,330	1,830	69.4	560	7.7

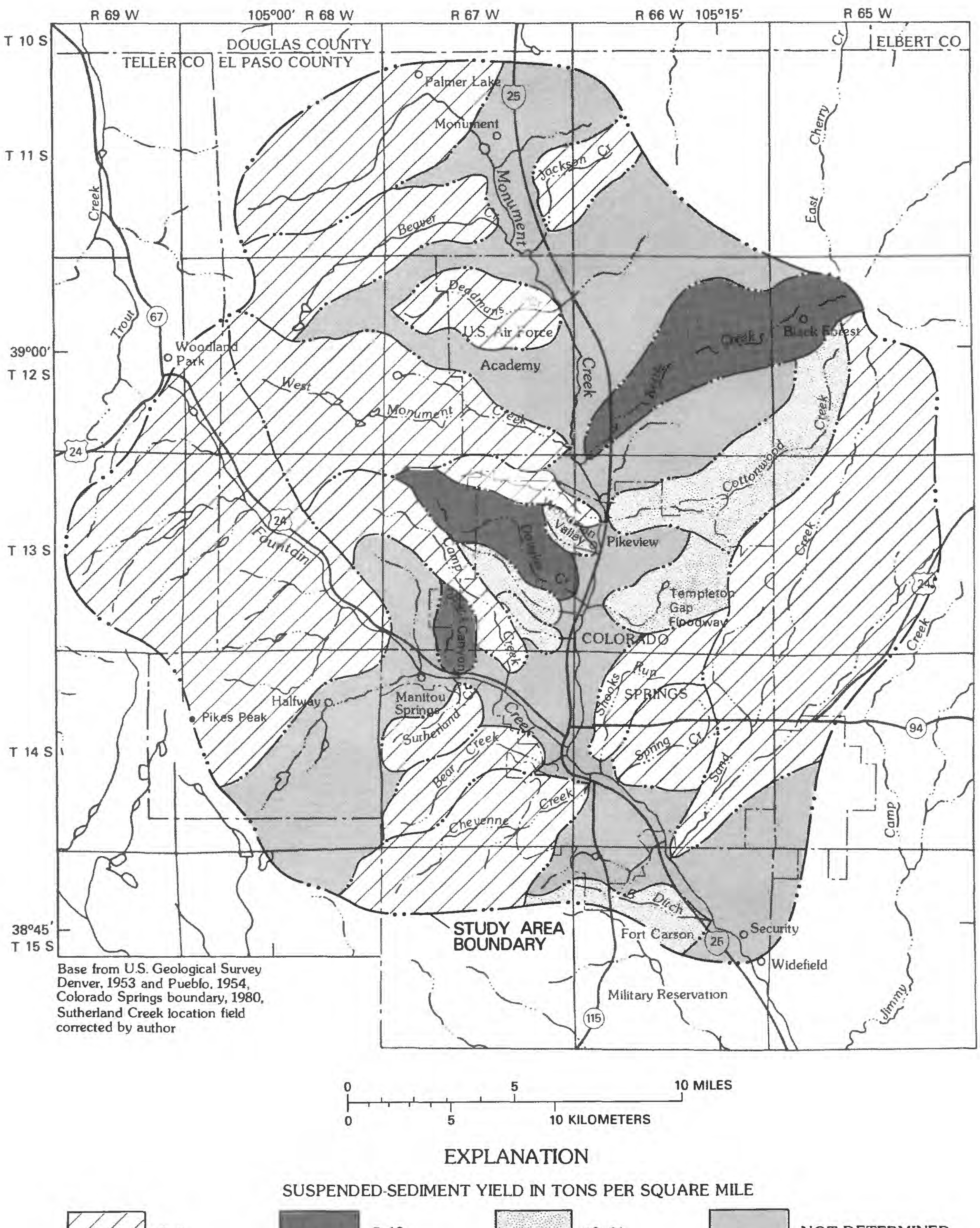


Figure 8.--Suspended-sediment yields determined from data collected during the snowmelt-runoff period, April 1-2, 1985.

Data collection during the rainfall-runoff period (May 21, 1985) included 7 Fountain Creek and 10 Monument Creek tributaries (table 4). A suspended-sediment-yield map was prepared for this sampling period (fig. 9). The limitations of figure 8 also apply to figure 9. The mean suspended-sediment yield (at the 17 sites) was 38.0 $(tons/mi^2)/d$ and the median yield was 5.1 $(tons/mi^2)/d$.

Differences in Suspended-Sediment Concentrations and Yields Based on Land Use

Generally, suspended-sediment concentrations and yields from drainage basins in urbanized or developing areas are greater than those from drainage basins located in rural areas (Detwyler, 1971, p. 212). Tributary drainage basins included in the synoptic-sampling network were classified as having either rural or urban land use (table 2). Land use in the basin is in transition and has limited development throughout. Drainage basins where urban activity was the predominant land use were classified as urban; all other drainage basins were classified as rural.

Table 4.--*Suspended-sediment data for synoptic-sampling sites collected during the rainfall-runoff period, May 21, 1985*

[ft^3/s, cubic feet per second; mg/L, milligrams per liter; tons/d, tons per day; mm, millimeters; $(tons/mi^2)/d$, tons per square mile per day]

Site number in figure 7	Instantaneous water discharge (ft^3/s)	Suspended sediment				
		Concentration (mg/L)	Discharge (tons/d)	Percent finer than 0.062 mm	Sand discharge (tons/d)	Instantaneous yield [$(tons/mi^2)/d$]
F1	44.9	775	93.9	52.3	44.8	1.3
F2	9.2	672	16.7	78.6	3.6	3.2
F3	9.0	25,200	612	82.8	105	278
F5	21.6	130	7.6	87.2	1.0	.83
F6	15.8	5,530	236	75.6	57.6	22.5
F9	50.3	1,140	155	64.1	56.0	17.8
F11	266	15,100	10,800	72.6	2,960	210
M1	42.5	94	10.8	47.5	5.7	.42
M2	34.6	124	11.6	80.9	2.2	.51
M3	6.2	98	1.6	35.2	1.0	.37
M4	9.7	321	8.4	42.7	4.8	1.6
M6	16.5	89	4.0	54.0	1.8	.17
M7	26.4	6,380	455	67.7	147	26.3
M8	33.0	10,000	891	83.2	150	49.8
M9	3.4	2,050	18.8	87.6	2.4	5.7
M12	9.6	1,200	31.1	88.0	3.7	5.1
M16	329	6,100	5,420	63.6	1,970	23.0

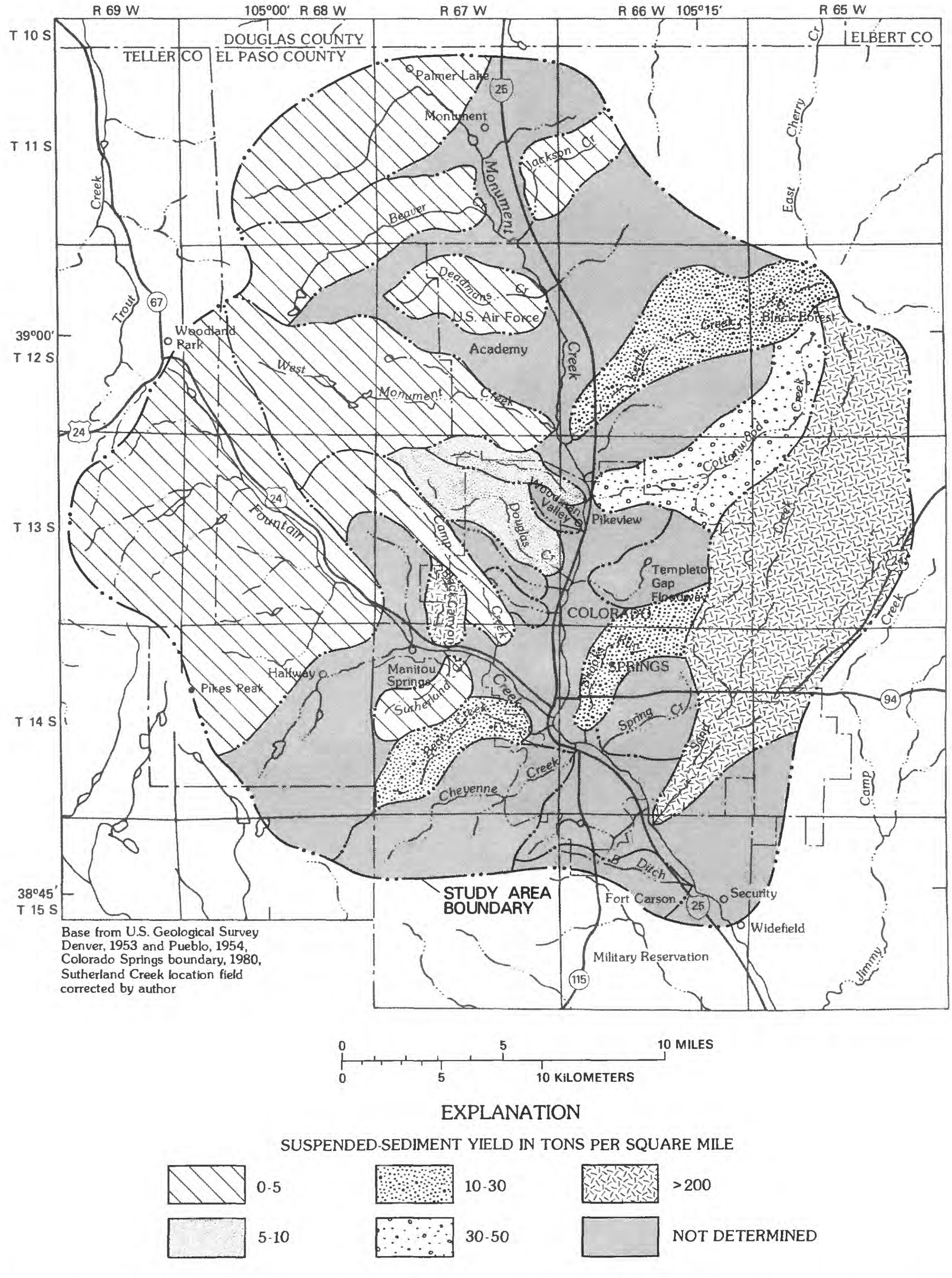


Figure 9.--Suspended-sediment yields determined from data collected during the rainfall-runoff period, May 21, 1985.

During the snowmelt-runoff period, the smallest measured suspended-sediment concentration was 13 mg/L at West Monument Creek (site M6; fig. 7, table 3), a drainage basin that is forested and mostly undeveloped. The largest measured suspended-sediment concentration was 13,800 mg/L at site M11, which is unnamed and located in a drainage basin that is undergoing urbanization. The smallest measured suspended-sediment yield was 0.004 (ton/mi^2)/d at West Monument Creek (site M6). Urban drainage basins had the largest measured suspended-sediment yields, as indicated by Cottonwood Creek (site M8) that had a yield of 20.7 (tons/mi^2)/d and by site M11 that had a yield of 20.3 (tons/mi^2)/d.

During the rainfall-runoff period, the smallest measured suspended-sediment concentration was 89 mg/L at West Monument Creek (site M6; table 4). The largest measured suspended-sediment concentration was 25,200 mg/L at Black Canyon (site F3), which is predominantly formed in the highly erodible Fountain Formation and is mostly rural. The smallest measured suspended-sediment yield was 0.17 (ton/mi^2)/d at site M6. The largest measured suspended-sediment yield was 278 (tons/mi^2)/d at site F3.

Suspended-sediment yields were categorized by land use and compared with drainage-basin area using ordinary least-squares regression (SAS Institute, 1985). Correlation between suspended-sediment yield and drainage-basin area was not significant at the 0.05 significance level. Hydrologic data usually do not have a normal distribution. They often are skewed and serially correlated. Therefore, when doing statistical analyses, the data commonly are transformed to follow a normal distribution, or nonparametric statistical techniques are used that are less sensitive to the skewed distribution. Suspended-sediment yields from different land-use classifications were compared by using the nonparametric Wilcoxon rank-sum test (SAS Institute, 1985). The mean suspended-sediment yield for urban drainage basins from both sampling periods was 19.6 (tons/mi^2)/d, and the median yield was 7.7 (tons/mi^2)/d; whereas, the mean suspended-sediment yield for rural drainage basins was 18.0 (tons/mi^2)/d, and the median yield was 0.46 (ton/mi^2)/d. There was a significant difference between urban and rural mean suspended-sediment yields at the 0.05 significance level.

Differences in Suspended-Sediment Concentrations Between Snowmelt Runoff and Rainfall Runoff

Suspended-sediment samples collected during the rainfall-runoff period had a larger mean concentration than those collected during the snowmelt-runoff period. Sites where data had been collected during both runoff periods were compared by season. The mean suspended-sediment concentration for urban and rural land uses during the snowmelt-runoff period was 2,750 mg/L; whereas, the mean concentration for both land uses during the rainfall-runoff period was 4,410 mg/L. Increased detachment of soil particles because of rain splash, the greater length of time rainfall runoff is in contact with the land surface, and faster rates of surface runoff are responsible for the increase in suspended-sediment concentration determined during the rainfall-runoff period.

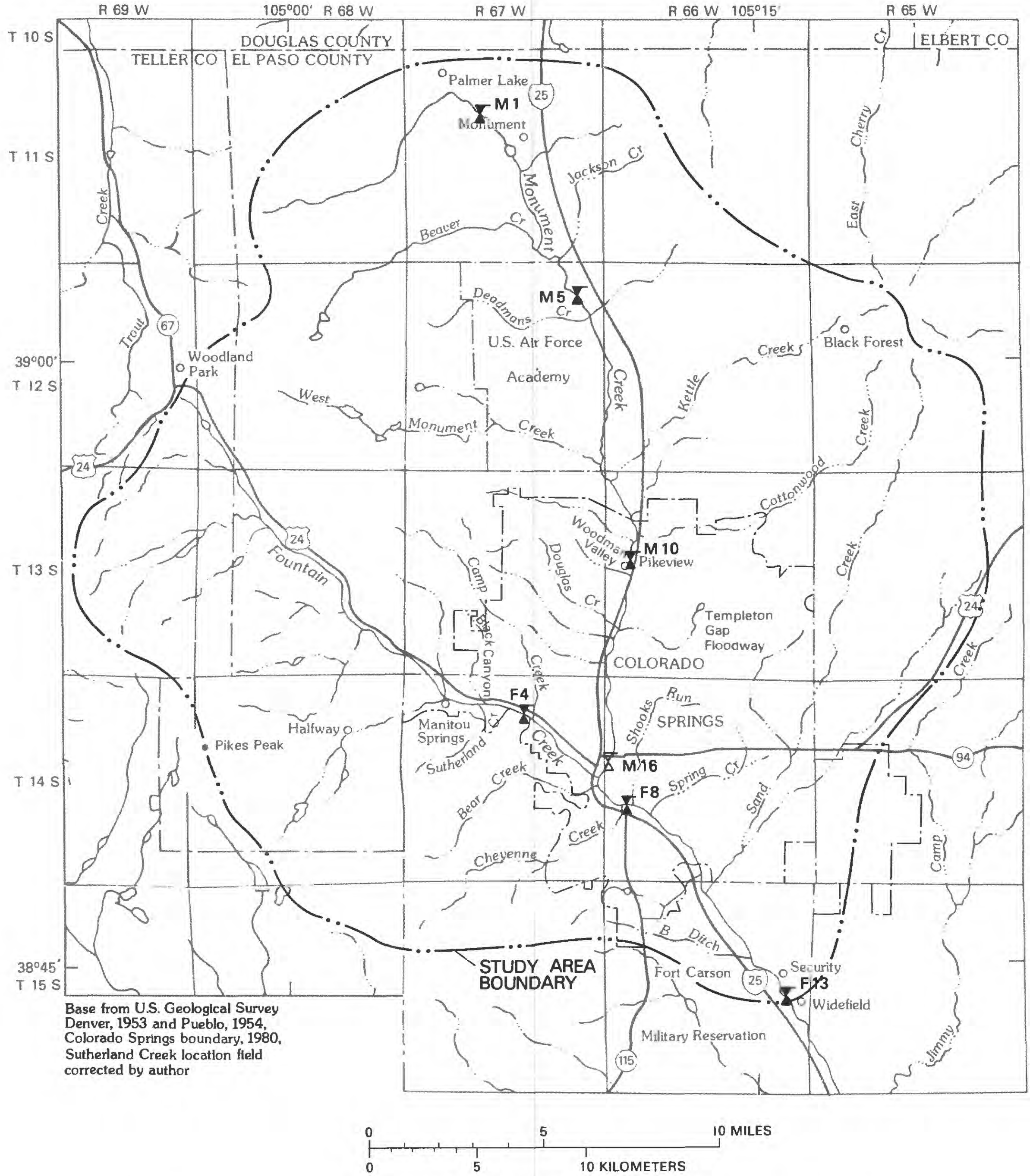
SUSPENDED-SEDIMENT LOADS AND YIELDS FROM SEDIMENT-SOURCE AREAS DETERMINED FROM PERIODIC SAMPLING

Analyses of data from synoptic suspended-sediment sampling helped to semiquantitatively determine sediment-source areas for tributaries throughout the basin during certain runoff conditions. The following is a discussion of sediment-source areas as determined from data for the periodic suspended-sediment-sampling network (fig. 10, table 5). These data represent the net effect of instream and tributary suspended-sediment yields upstream from specific sampling sites on Fountain and Monument Creeks.

Table 5.--*Characteristics of periodic suspended-sediment-sampling sites*

Site number in figure 10	U.S. Geological Survey station number	Approximate distance from headwaters (miles)	Drainage-basin area (square miles)	Station name
F4	07103700	12	103	Fountain Creek near Colorado Springs.
M1	07103747	10	25.9	Monument Creek at Palmer Lake.
M5	07103780	20	81.9	Monument Creek above North Gate Boulevard at U.S. Air Force Academy.
M10	07104000	28	204	Monument Creek at Pikeview.
M16	07104905	35	236	Monument Creek at Bijou Street at Colorado Springs.
F8	07105500	17	392	Fountain Creek at Colorado Springs.
F13	07105800	26	495	Fountain Creek at Security.

Annual suspended-sediment load may be computed using the streamflow-duration sediment-transport-equation method described by Miller (1951). This method can be applied where the streamflow record is adequate to determine the frequency of water discharge (streamflow duration) and where sufficient data are available to determine the relation between water discharge and suspended-sediment discharge (sediment-transport equation). Annual suspended-sediment load is computed by combining the relation between water discharge and suspended-sediment discharge, as defined by the suspended-sediment-transport equation, with the mean frequency of water-discharge intervals determined from



EXPLANATION

M 16 PERIODIC-SEDIMENT AND WATER-DISCHARGE MEASUEMENT SITE AND NUMBER

F8 PERIODIC-SEDIMENT MEASUREMENT SITE THAT IS ALSO A CONTINUOUS STREAMFLOW GAGING STATION AND NUMBER

Figure 10.--Location of periodic suspended-sediment-sampling sites.

the streamflow-duration curve (Elliott and others, 1984, p. 18-19). Annual suspended-sediment yields were calculated for each periodic sampling site by dividing the annual suspended-sediment load in tons by the drainage-basin area in square miles.

Periodic-Sampling Network

Periodic suspended-sediment data were collected at seven sites in the basin during the 1985 water year (fig. 10, table 5). Suspended-sediment and water-discharge relations were developed using an ordinary least-squares regression procedure (SAS Institute, 1985). Annual suspended-sediment load and annual suspended-sand loads were computed for each periodic-sampling site using the sediment-transport equations listed in table 6.

Table 6.--*Suspended-sediment-transport equations derived from suspended-sediment discharge measured for Fountain and Monument Creeks during the 1985 water year*

[n, sample size; C_b, bias correction factor; R^2, coefficient of determination; SE, standard error of estimate in percent; Qs, suspended-sediment discharge, in tons per day; Qsa, suspended-sand discharge, in tons per day; Q, water discharge, in cubic feet per second]

Site number in figure 10	U.S. Geological Survey station number	Regression equation	n	C_b	R^2	SE
F4	07103700	$Qs = 0.008Q^{2.19}$	38	2.16	0.59	157
		$Qsa = .004Q^{2.10}$	37	1.56	.69	125
M1	07103747	$Qs = .070Q^{1.6}$	13	1.25	.80	128
		$Qsa = .063Q^{1.48}$	13	1.71	.75	115
M5	07103780	$Qs = .008Q^{2.10}$	31	1.24	.92	96
		$Qsa = .0055Q^{2.07}$	30	1.19	.93	89
M10	07104000	$Qs = .14Q^{1.70}$	34	1.32	.77	119
		$Qsa = .07Q^{1.64}$	32	1.49	.77	120
F16	07104905	$Qs = .07Q^{1.96}$	35	1.32	.75	105
		$Qsa = .009Q^{2.19}$	33	1.41	.83	114
F8	07105500	$Qs = .0098Q^{2.11}$	47	1.47	.83	118
		$Qsa = .0009Q^{2.39}$	47	1.36	.85	124
F13	07105800	$Qs = .0055Q^{2.10}$	37	1.57	.70	125
		$Qsa = .0017Q^{2.20}$	36	1.83	.62	141

The regression equation estimates the mean response of the dependent variable (suspended-sediment load) given known values of the independent variable. The form of the regression equation is a linear function of the logarithmic-transformed variable:

$$\log Y = \log B_0 + B_1 \log X \qquad (2)$$

Taking the antilogs, the form of the regression equation becomes:

$$Y = B_0 X^{B_1} \quad (3)$$

where Y = suspended-sediment load,
B = regression coefficients,
X = hydrologic variable.

A transformation bias is produced when the logarithms of the estimated mean response (log of suspended-sediment load) is detransformed (eq. 3). This tranformation bias usually results in underestimation of the detransformed mean response (suspended-sediment load). For estimates of the detransformed mean response, transformation bias is multiplicative and increases exponentially with variance. It is possible, however, to eliminate the major part of this transformation bias by multiplying the estimated mean annual suspended-sediment load by a correction factor (Miller, 1984):

$$C_b = e^{0.5 MSE} \quad (4)$$

where C_b = transformation bias correction factor;
e = bias of the natural logarithm; and,
MSE = mean squared error of the regression equation.

Continuous streamflow records are available from six of the periodic-sampling sites; however, the continuous streamflow record available at Monument Creek at the U.S. Air Force Academy (site M5) (fig. 10, table 5) was only from April 19 through September 30, 1985. Daily mean streamflow was estimated for the remainder of the water year by comparing the partial record at the U.S. Air Force Academy (site M5) with the corresponding record for Monument Creek at Palmer Lake (site M1). These data were compared using ordinary least-squares regression (SAS Institute, 1985). Because of the similiarity in streamflow record between the two sites, the missing record for the 1985 water year at the U.S. Air Force Academy (site M5) was estimated using the following equation:

$$Q_{M5} = 6.02 + (2.06\ Q_{M1}) \quad (5)$$

where Q_{M5} = daily mean water streamflow at Monument Creek above Northgate Boulevard at the U.S. Air Force Academy, in cubic feet per second;
Q_{M1} = daily mean water streamflow at Monument Creek at Palmer Lake, in cubic feet per second.

For this equation the coefficient of determination (R^2) is 0.95 and the standard error is 26.6 percent.

The daily mean water discharge at Monument Creek at Bijou Street at Colorado Springs (site M16) was estimated from daily streamflow records from nearby sites (fig. 10). The daily mean water discharge at Fountain Creek near Colorado Springs (site F4) and Monument Creek at Pikeview (site M10) were subtracted from the daily mean water discharge at Fountain Creek at Colorado Springs (site F8) to obtain the daily mean water discharge from the area between sites F4 and M10 and site F8. By dividing this discharge by the drainage upstream from site F8 minus the drainage areas upstream from sites F4 and M10, a daily mean water yield for the drainage area between site F8 and sites F4 and M10 was calculated. This water yield was multiplied by the drainage area between site M10 and site M16 to get a daily mean water discharge for the drainage area between the two sites. This daily mean discharge plus the daily mean water discharge at site M10 is an estimate of the daily mean water discharge at site M16. Thus, the equations for obtaining the daily mean water discharge at site M16 are:

$$Q_{M16} = Q_{M10} + [(Q_{F8} - Q_{M10} - Q_{F4})/(A_{F8} - A_{M10} - A_{F4})](A_{M16} - A_{M10}) \quad (6)$$

$$Q_{M16} = Q_{M10} + [(Q_{F8} - Q_{M10} - Q_{F4})/85]\ 32 \quad (7)$$

$$Q_{M16} = Q_{M10} + 0.38(Q_{F8} - Q_{M10} - Q_{F4}) \quad (8)$$

where Q_{M16} = daily mean water discharge for Monument Creek at Bijou Street at Colorado Springs (site M16), in cubic feet per second;

Q_{M10} = daily mean water discharge at Monument Creek at Pikeview (site M10), in cubic feet per second;

Q_{F8} = daily mean water discharge at Fountain Creek at Colorado Springs (site F8), in cubic feet per second;

Q_{F4} = daily mean water discharge for Fountain Creek near Colorado Springs (site F4), in cubic feet per second;

A_{F8} = drainage area upstream from site F8 in square miles;

A_{M10} = drainage area upstream from site M10, in square miles;

A_{F4} = drainage area upstream from site F4, in square miles;

A_{M16} = drainage area upstream from site M16, in square miles;

85 = drainage area upstream from site F8; minus the drainage areas upstream from sites F4 and M10, in square miles; and

32 = difference in drainage areas between site M10 and site M16, in square miles.

Periodic-Sampling Results

Hydrologic and suspended-sediment characteristics for the 1985 water year were computed for seven sites in the basin. Characteristics included annual runoff, annual suspended-sediment load, annual suspended-sand load, and annual suspended-sediment yield.

Annual suspended-sediment load in lower Fountain Creek is affected greatly by its main tributary, Monument Creek. During the 1985 water year, annual suspended-sediment load for Fountain Creek near Colorado Springs (site F4; fig. 10, table 5), was 28,300 tons (fig. 11, table 7), or about 7 percent of the 408,000 tons of suspended-sediment load transported at Fountain Creek at Colorado Springs (site F8). The junction of Monument Creek is located 1.3 mi upstream from the sample site Fountain Creek at Colorado Springs (site F8). The suspended-sediment load transported at Monument Creek at Bijou Street (site M16) about 0.75 mi upstream from the junction of Fountain Creek and Monument Creek was 73 percent of the suspended-sediment load at Fountain Creek at Colorado Springs (site F8).

Although suspended-sediment load in Fountain Creek increased at site F8, which is located about 1.3 mi downstream from the junction with Monument Creek, suspended-sediment load decreased further downstream, at Fountain Creek at Security (site F13) (fig. 10, table 5). Suspended-sediment load for the 1985 water year at Fountain Creek at Security (site F13), was 333,000 tons (fig. 11, table 7) or about 18 percent less than the suspended-sediment load at Fountain Creek at Colorado Springs (site F8), which is located about 10 mi upstream. Stream channel and flood-plain storage of sediment in 1985 may explain the apparent decrease in annual suspended-sediment loads between sites F8 and F13. Although suspended-sand load at Fountain Creek at Colorado Springs (site F8) was 158,000 tons or about 38 percent of the total suspended-sediment load transported for the 1985 water year at this site, the suspended-sand load was 216,000 tons or about 64 percent of the total suspended-sediment load at Fountain Creek at Security (site F13). The increase in suspended-sand load as a percentage of the total suspended-sediment load at Fountain Creek at Security (site F13) may result from the contributions from Sand Creek, an ephemeral tributary that enters Fountain Creek about 5.3 mi upstream. Suspended-sediment data for Sand Creek are limited; however, data collected during the synoptic sampling indicate that Sand Creek (site F11) may be a major source of suspended sand in the basin (tables 3, 4). Between sites F8 and F13, it seems that part of the suspended-sediment load is deposited upstream from the junction of Sand Creek, but additional sand is contributed by Sand Creek that increases the sand load at Fountain Creek at Security (site F13).

Suspended-sediment load was computed at four sites on Monument Creek (fig. 12, table 7). Monument Creek at Palmer Lake (site M1), which drains about 11 percent of the Monument Creek drainage basin, contributed 3,620 tons or only about 1.2 percent of the annual suspended-sediment load transported at Monument Creek at Bijou Street (site M16). The suspended-sediment load for 1985 at Monument Creek at the U.S. Air Force Academy (site M5), which drains about 35 percent of the Monument Creek drainage basin, was 17,900 tons or only about 6.0 percent of the annual suspended-sediment load transported at site M16. Monument Creek at Pikeview (site M10) drains about 86 percent of the Monument Creek basin and contributed 117,000 tons, or only about 39 percent of the suspended-sediment load transported at site M16.

Differences in Suspended-Sediment Loads and Yields Based on Land Use

Suspended-sediment loads in Fountain Creek increased about 1,340 percent between Fountain Creek near Colorado Springs (site F4) and Fountain Creek at Colorado Springs (site F8). These large increases in suspended-sediment load can be attributed to changes in land use between the two sites, primarily the affects of urbanization on Monument Creek.

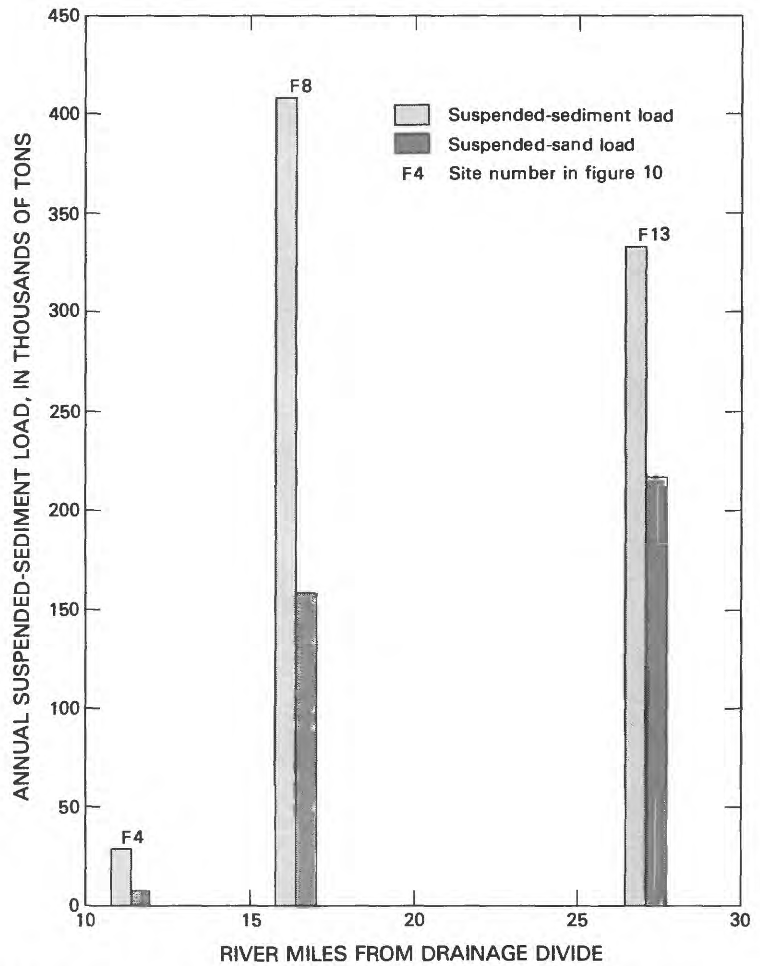


Figure 11.--Suspended-sediment loads at periodic-sampling sites along Fountain Creek for the 1985 water year.

Table 7.--*Suspended-sediment-load data for 1985 water year at periodic suspended-sediment-sampling sites on Fountain and Monument Creeks*

[acre-ft, acre-feet; tons/mi^2, tons per square mile]

Site number in figure 10	U.S. Geological Survey station number	Annual water discharge (acre-ft)	Suspended sediment		
			Annual load (tons)	Annual sand load (tons)	Annual yield (tons/mi^2)
F4	07103700	25,200	28,300	6,680	275
M1	07103747	8,470	3,620	2,270	140
M5	07103780	21,300	17,900	6,330	219
M10	07104000	48,400	117,000	50,700	574
M16	07104905	60,700	297,000	135,000	1,260
F8	07105500	101,000	408,000	158,000	1,040
F13	07105800	145,000	333,000	216,000	673

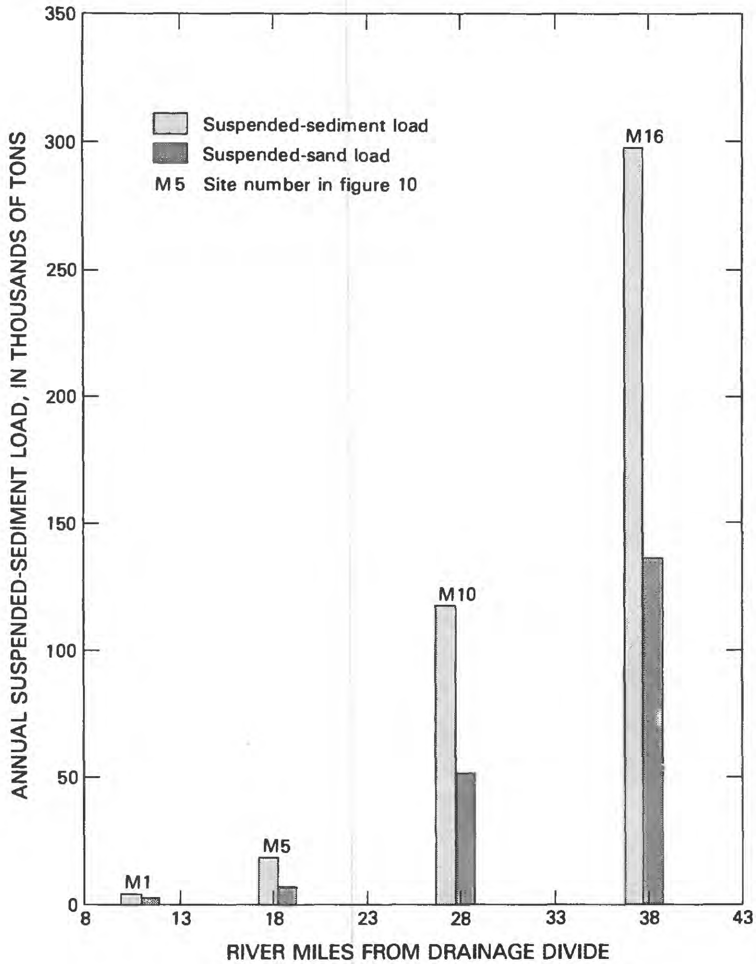


Figure 12.--Suspended-sediment loads at periodic-sampling sites along Monument Creek for the 1985 water year.

The drainage basin upstream from Monument Creek at the U.S. Air Force Academy (site M5) is mostly undeveloped. Suspended-sediment loads increased 550 percent between site M5 and Monument Creek at Pikeview (site M10). Greater suspended-sediment loads at Monument Creek at Pikeview (site M10) than at the U.S. Air Force Academy (site M5) in part can be attributed to sediment loading from streams that have drainage basins underlain by the easily eroded Dawson Formation and Quaternary windlain deposits. However, Cottonwood Creek (site M8), a drainage basin that is undergoing urbanization, joins Monument Creek about 0.10 mi upstream from site M10. During the periods of synoptic sampling, some of the largest suspended-sediment loads were measured at site M8 (figs. 8, 9; tables 3, 4).

Between Monument Creek at Pikeview (site M10) and Monument Creek at Bijou Street at Colorado Springs (site M16) near the mouth of Monument Creek, suspended-sediment loads increased 153 percent (fig. 12, table 7). During the 1985 water year, about 61 percent of the annual suspended-sediment load at the mouth of Monument Creek was derived from the downstream 14 percent of the Monument Creek drainage basin between sites M10 and M16, an area that is mostly urbanized.

Increases in annual suspended-sediment loads in the downstream parts of the Monument Creek drainage basin can be attributed to certain fluvial and land-use conditions. The channel of Monument Creek is incised about 10 to 40 ft into the valley floor, which inhibits flood-plain development and subsequent storage of sediment. Urbanization in the downstream parts of the Monument Creek drainage basin increases the frequency and magnitude of storm runoff. Increases in unit runoff cause adjustments to the dimensions of the stream channel to accommodate the higher flows (Detwyler, 1971, p. 212). Lateral erosion of the streambank and degradation of the channel have resulted. Areas of exposed soils due to continuing urban development have provided new sediment sources and increased the suspended-sediment load in downstream parts of Monument Creek.

Suspended-sediment yields usually decrease with an increase in drainage-basin area because the opportunity for deposition of sediments increases within the drainage basin. However, the increase in suspended-sediment loads resulting from urbanization has resulted in an increase in suspended-sediment yields at all sites with the exception of Fountain Creek at Security (site F13), where suspended-sediment yields decreased 54 percent compared to suspended-sediment yields at Fountain Creek at Colorado Springs (site F8). The decrease of suspended-sediment yields at site F13 is due to decreased suspended-sediment loads resulting from deposition of sediment in the flood plain and stream channel between site F8 and site F13.

ESTIMATED SEDIMENT YIELDS FROM MILL TAILINGS AND OCCURRENCE OF STREAMBANK EROSION

The discovery of gold in Cripple Creek in 1890 began a cycle of mining and gold milling in the Colorado Springs area. The Golden Cycle Gold Mill[1] operated from 1906 to 1948 on the western side of Colorado Springs. During milling operations, about 14.5 million tons of tailings accumulated and covered about 160 acres, forming the area known as Gold Hills Mesa. The mill tailings are located adjacent to Fountain Creek just upstream from its confluence with Monument Creek (fig. 13). Gold Hills Mesa had been a major source of windblown sediments in the vicinity of Colorado Springs until reclamation efforts were initiated in 1949. The addition of 357,000 tons of topsoil and the introduction of a variety of forage plants helped to stabilize the tailings (Colorado Springs Gazette Telegraph, September 2, 1951). Today, vegetation covers much of the area; however, parts of the northern side of the mesa are completely devoid of vegetation. This part, about 84 acres of Gold Hills Mesa, is severely eroded and drains directly to Fountain Creek.

Mean annual sediment yields were estimated for Gold Hills Mesa using the technique developed by the Pacific Southwest Inter-Agency Committee (PSIAC) (1968). The PSIAC technique uses nine factors that affect sediment yields. These factors are: (1) Surface geology, (2) soils, (3) climate, (4) runoff, (5) topography, (6) ground cover, (7) land use, (8) upland erosion, and (9) channel erosion and sediment transport. Each factor has a numerical

[1]The use of industry or firm names in this report is for location purposes only and does not impute responsibility for any present or potential effects on the natural resources.

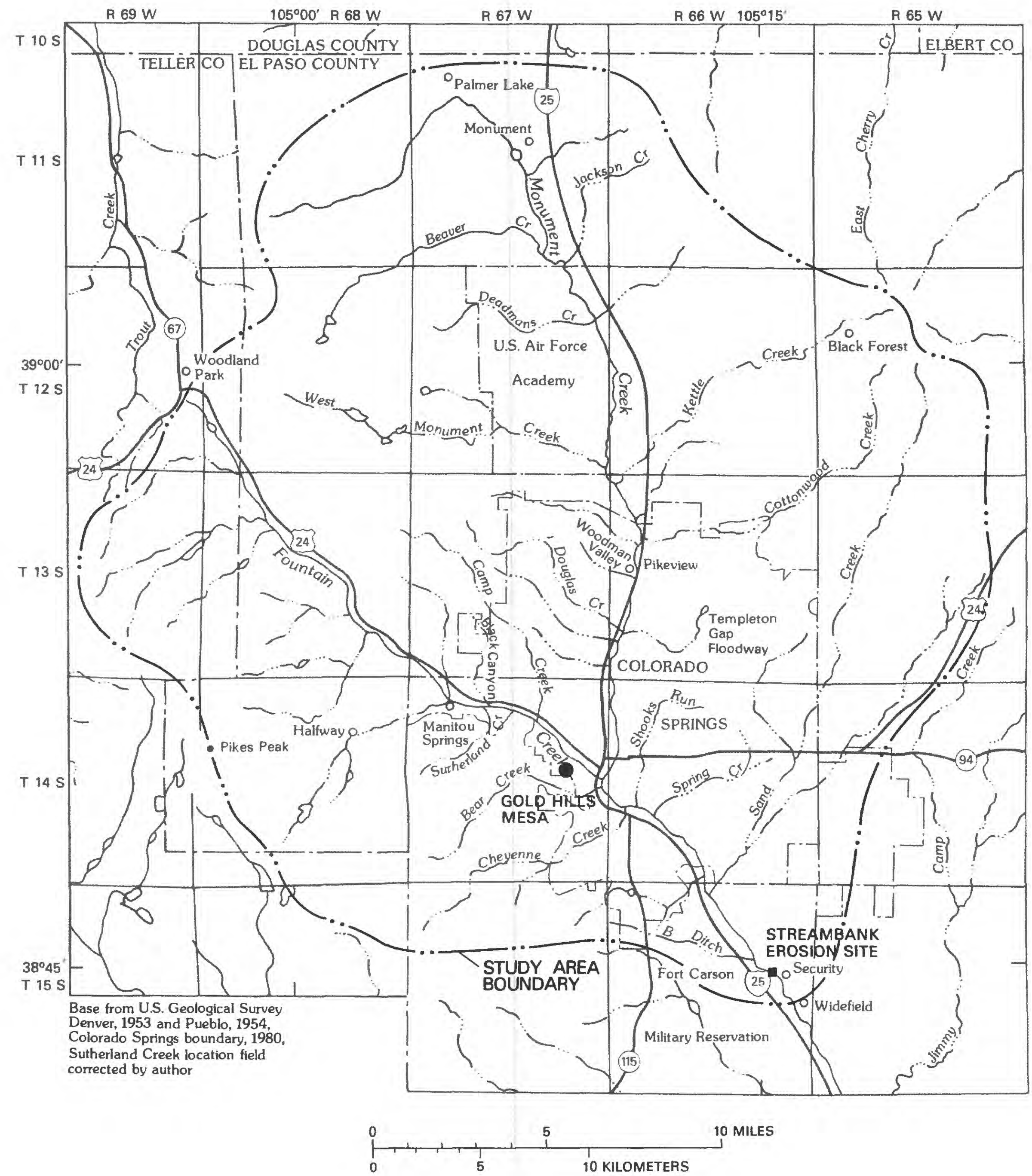


Figure 13.--Location of Gold Hills Mesa and streambank-erosion site.

rating (table 8). The sum of these numerical ratings then is compared with the rating in table 9 that corresponds to a range of mean annual sediment yields, in acre-feet per square mile. Estimated sediment yields, in acre-feet per square mile, were converted to tons per square mile assuming an average bulk density of 84 lb/ft^3 (Schaller and Sutton, 1978, p. 671-672).

Estimated mean annual sediment yields for the northern side of Gold Hills Mesa averaged 1,790 $tons/mi^2$ (table 10). Estimated mean annual sediment yields from the remainder of the area averaged 420 $tons/mi^2$. Gold Hills Mesa contributed about 290 tons or only about 0.07 percent of the annual suspended-sediment load for the 1985 water year at Fountain Creek at Colorado Springs (site F8).

Streambank erosion may contribute large quantites of material to the annual sediment load of a stream. Sedimentation studies in the Eel River basin in California indicated that streambank erosion during floods produced between 60 and 65 percent of the sediment yield in the basin (Brown and Ritter, 1971, p. 59). Studies in Iowa indicated that streambank erosion contributed 14 million tons, or 45 percent, of the suspended sediment transported from the State (Odgaard, 1984, p. 61-62). Along parts of Fountain and Monument Creeks, streambank erosion is evident; however, the scope of this report does not include the quantification of the contribution of streambank erosion to the sediment yield of the basin. The following is a semiquantitative discussion of streambank erosion as a sediment source.

Aerial photographs of a meander bend located 1.05 mi upstream from Fountain Creek at the Security gage (site F13) (fig. 13) are available for 1947, 1960, 1966, 1976, and 1984. Aerial photographs for 1976 and 1984 were taken in the early spring. All photographs used were enlarged to a scale of 1:4,800. The right bank of the meander bend was mapped, and its location was compared with the location mapped from the succeeding photograph for each of these years.

Streambank erosion averaged 8.8 ft annually for the 37-year period, but this value was not converted to tons. A breakdown of stream bank-erosion rates for the period between photographs is presented in table 11. The smallest annual average quantity of streambank erosion was 4.9 ft during the period 1947-60 and the largest annual average quantity was 14.6 ft during 1976-83. Streambank erosion for 1961-66 averaged 11.2 ft per year, which was a 128-percent increase compared to the rate for 1947-60. Record flooding occurred in the basin during the 1965 water year. Five times during June and July 1965, flood discharges exceeded 9,500 ft^3/s and the peak streamflow of record, 25,000 ft^3/s, occurred on July 24 (Snipes and others, 1974). Stream discharges of this magnitude have a profound effect on stream-channel morphology. Streambank-erosion rates were computed for 1947-66 and 1967-83 to average the effect of the extreme events in 1965 and to compare erosion rates from periods of approximately equal length. The average annual rate of streambank erosion for 1967-83 was 11.2 ft or 65 percent greater than the annual rate of 6.8 ft for 1947-66. A combination of factors may explain increases in streambank erosion measured at this site--stream-channel equilibrium may have been disturbed by the 1965 floods, the above-average precipitation during 1966-83 (fig. 3), and the resulting increase in frequency and magnitude of flood peaks due to urbanization in the basin.

Table 8.--*Factors for estimating mean annual sediment yield using the Pacific Southwest Inter-Agency Committee method*

[Data from Pacific Southwest Inter-Agency Committee, 1968; the numbers in parentheses indicate values to be assigned appropriate characteristics. The small letters a, b, c, refer to independent characteristics to which full value may be assigned]

Sediment-yield levels[1]	Surface geology	Soils	Climate	Runoff	Topography	Ground cover	Land use	Upland erosion	Channel erosion and sediment transport
	(10)	(10)	(10)	(10)	(20)	(10)	(10)	(25)	(25)
High	a. Marine shales and related mudstones and siltstones.	a. Fine textured; easily dispersed; saline-alkaline; high shrink-swell characteristics. b. Single-grain silts and fine sands.	a. Storms of several days duration with short periods of intense rainfall. b. Frequent, intense, convective storms. c. Freeze-thaw occurrence.	a. High peak flows per unit area. b. Large volume of flow per unit area.	a. Steep upland slopes (in excess of 30 percent), high relief; little or no flood-plain development.	Ground cover does not exceed 20 percent. a. Vegetation sparse; little or no litter. b. No rock in surface soil.	a. More than 50 percent cultivated. b. Almost all of area intensively grazed. c. All of area recently burned.	a. More than 50 percent of the area characterized by rill and gully or landslide erosion.	a. Eroding banks continuously or at frequent intervals with large depths and long flow duration. b. Active headcuts and degradation in tributary channels.
	(5)	(5)	(5)	(5)	(10)	(0)	(0)	(10)	(10)
Moderate	a. Rocks of medium hardness. b. Moderately weathered. c. Moderately fractured.	a. Medium textured soil. b. Occasional rock fragments. c. Caliche layers.	a. Storms of moderate duration and intensity. b. Infrequent convective storms.	a. Moderate peak flows. b. Moderate volume of flow per unit area.	a. Moderate upland slopes (less than 20 percent). b. Moderate fan or flood-plain development.	Cover not exceeding 40 percent. a. Noticeable litter. b. If trees present, understory not well developed.	a. Less than 25 percent cultivated. b. Fifty percent or less recently logged. c. Less than 50 percent intensively grazed. d. Ordinary road and other construction.	a. About 25 percent of the area characterized by rill and gully or landslide erosion. b. Wind erosion with deposition in stream channels.	a. Moderate flow depths, medium flow duration, with occasionally eroding banks or bed.
	(0)	(0)	(0)	(0)	(0)	(-10)	(-10)	(0)	(0)
Low	a. Massive, hard formations.	a. High percentage of rock fragments. b. Aggregated clays. c. High in organic matter.	a. Humid climate with rainfall of low intensity. b. Precipitation in form of snow. c. Arid climate; low intensity storms. d. Arid climate; rare convective storms.	a. Low peak flows per unit area. b. Low volume of runoff per unit area. c. Rare runoff events.	a. Gentle upland slopes (less than 5 percent). b. Extensive alluvial plains.	a. Area completely protected by vegetation; rock fragments litter; little opportunity for rainfall to reach erodible material.	a. No cultivation. b. No recent logging. c. Low intensity grazing.	a. No apparent signs of erosion.	a. Wide shallow channels with flat gradients; short flow duration. b. Channels in massive rock; large boulders or well vegetated. c. Artificially controlled channels.

[1]If experience so indicates, interpolation between the three sediment-yield levels may be made.

Table 9.--*Pacific Southwest Inter-Agency Committee estimates of sediment yields for ratings determined from table 8.*

[Data from Pacific Southwest Inter-Agency Committee, 1968]

Rating	Mean annual sediment yield (acre-feet per square mile)
0-25	0.2
25-50	0.2-0.5
50-75	0.5-1.0
75-100	1.0-3.0
100	3.0

CONCLUSIONS

During 1985, suspended-sediment data were collected in the Fountain Creek basin in southeastern Colorado from a network of 24 synoptic-sampling sites during a snowmelt-runoff period and 17 synoptic-sampling sites during a rainfall-runoff period. Suspended-sediment concentrations ranged from 13 to 13,800 mg/L during the snowmelt-runoff period and from 89 to 25,200 mg/L during the rainfall-runoff period. The mean suspended-sediment concentration for urban and rural land uses during the snowmelt-runoff period was 2,750 mg/L; whereas, the mean concentration for both land uses during the rainfall-runoff period was 4,410 mg/L. Maps showing suspended-sediment yield were made for each period. Suspended-sediment yields were not uniform throughout the basin. During the snowmelt-runoff period, measured suspended-sediment yields in the basin ranged from 0.004 to 20.7 (tons/mi^2)/d and during the rainfall-runoff period, measured suspended-sediment yields measured ranged from 0.17 to 278 (tons/mi^2)/d. Suspended-sediment yields from urban drainage basins were larger than yields from rural drainage basins. The median suspended-sediment yield from urban drainage basins was 7.7 tons/mi^2, and the median suspended-sediment yield from rural drainage basins was 0.46 ton/mi^2. Increased unit runoff and increased areas of exposed soils are most likely the reasons that urban drainage basins have the larger suspended-sediment yields.

Annual suspended-sediment loads were computed for the 1985 water year at seven periodic suspended-sediment sampling sites and ranged from 3,620 tons at Monument Creek at Palmer Lake (site M1) to 408,000 tons at Fountain Creek at Colorado Springs (site F8). Annual suspended-sediment yields ranged from 140 tons/mi^2 at site M1 to 1,260 tons/mi^2 at Monument Creek at Bijou Street (site M16). Monument Creek contributed about 73 percent of the 408,000 tons of suspended-sediment transported at Fountain Creek at Colorado Springs (site F8). Suspended-sediment load downstream at Fountain Creek at Security (site F13) was 333,000 tons or about 18 percent less than at site F8; however, suspended-sand load as a percentage of the total suspended-sediment

Table 10.--*Values used for estimating mean annual sediment yields at Gold Hills Mesa using the Pacific Southwest Inter-Agency method*

Location of estimate	Surface geology	Soils	Climate	Runoff	Topography	Ground cover	Land use	Upland erosion	Channel erosion and sediment transport	Rating total	Estimated mean annual sediment yield per square mile	
											acre-feet	tons
North side from the top of Gold Hills Mesa to Fountain Creek[1]	5	3	5	5	15	6	0	20	15	74	0.98	[3]1,790
Top of Gold Hills Mesa and areas to the south[2]	5	3	5	1	4	1	2	6	1	28	.23	[3]420

[1]Approximate area is 86 acres.
[2]Approximate area is 74 acres.
[3]Assumed bulk density of 84 pounds per cubic foot used to convert sediment yields in acre-feet per square mile to tons per square mile.

Table 11.--*Compilation of streambank-erosion rates at a site along Fountain Creek 1.05 miles upstream from Fountain Creek at Security (site F13)*

Period	Number of years between photographs	Total streambank erosion (feet)	Average streambank erosion rate (feet per year)
1947-60	14	68	4.9
1961-66	6	67	11.2
1967-75	9	74	8.2
1976-83	8	117	14.6

load increased from 38 percent at site F8 to 64 percent at site F13. Annual suspended-sediment transport at Monument Creek at Bijou Street (site M16) was 297,000 tons, with 61 percent of the suspended-sediment load transport originating from the downstream 14 percent of the Monument Creek drainage basin.

Annual mean sediment yield from Gold Hills Mesa is an estimated 290 tons, but is only about 0.07 percent of the 1985 annual suspended-sediment load at Fountain Creek at Colorado Springs (site F8). Contributions of streambank erosion to basin suspended-sediment yields were not calculated; however, streambank erosion increased during the past 37 years at a site on Fountain Creek that is located 1.05 miles upstream from Security.

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