REGIONALIZATION OF MEAN ANNUAL SUSPENDED-SEDIMENT LOADS IN STREAMS, CENTRAL, NORTHWESTERN, AND SOUTHWESTERN COLORADO

By John G. Elliott

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DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

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

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Box 25425
Denver, CO 80225-0425

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CONVERSION FACTORS

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

Multiply inch-pound unit	*By*	*To obtain metric unit*
acre-foot (acre-ft)	0.001233	cubic hectometer
cubic foot per second	0.028317	cubic meter per second
foot (ft)	0.3048	meter
mile	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
ton (short)	0.9072	metric ton
ton per day	0.9072	metric ton per day
ton per year	0.9072	metric ton per year

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 "Mean Sea Level."

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ABSTRACT

Regression analysis was used to develop models for estimating mean annual suspended-sediment loads for streams in Colorado. Mean annual suspended-sediment loads at 81 selected streamflow-gaging stations in the central, northwestern, and southwestern regions of Colorado were expressed as functions of geomorphic and hydrologic variables. A multiple-regression model that included mean basin elevation, mean annual streamflow, and drainage-basin area explained 78 percent of the variance in mean annual suspended-sediment load when all sites were analyzed together. The State was divided into four regions to decrease variance from spatial differences in geography and climate, and multiple-regression models were recomputed for three regions. The best multiple-regression models for the central, northwestern, and southwestern regions of Colorado included mean annual streamflow and mean basin elevation. A multiple-regression model was not developed for eastern Colorado because few sites in this region had adequate sediment-load records. Regionalization of mean annual suspended-sediment loads resulted in improved multiple-regression models for the central, northwestern, and southwestern regions of Colorado. The regional multiple-regression models can be used to estimate mean annual suspended-sediment loads for other streams in these regions when mean annual streamflow and mean basin elevation are known. Regional regression models based only on drainage area also were developed, and they can be used to estimate mean annual suspended-sediment load when annual streamflow is unknown.

INTRODUCTION

The production and transport of sediment is related to the geomorphic and hydrologic characteristics of a drainage basin. Suspended-sediment load affects the quality of water, the form and stability of channels, riparian habitats, and structures designed to impound or divert water. Effective management or development of water resources requires knowledge of geomorphic and hydrologic characteristics and long-term, mean annual suspended-sediment loads. In 1984, the U.S. Geological Survey began a cooperative study with the Colorado River Water Conservation District and the U.S. Bureau of Reclamation. The first phase of the study determined the annual suspended-sediment loads of selected streams in Colorado where sediment data were available (Elliott and DeFeyter, 1986). The second phase of the study, presented in this report, developed a method for estimating mean annual suspended-sediment loads for streams where no sediment or streamflow data were available.

Averaging annual sums of measured daily suspended-sediment discharge is the most accurate method of determining mean annual suspended-sediment load; however, measurement of daily suspended-sediment discharge is costly and is done at few sites in Colorado. Another method of estimating mean annual suspended-sediment load combines a long period of daily water-discharge measurements with a sediment-transport curve derived from periodic suspended-sediment-discharge measurements. This method was used to estimate mean annual suspended-sediment loads for Colorado streams that had suspended-sediment data (Elliott and DeFeyter, 1986).

The streamflow-gaging-station network in Colorado is extensive; however, many streams in the State are ungaged or have inadequate streamflow or suspended-sediment-discharge data necessary to estimate mean annual suspended-sediment loads with the previously mentioned methods. Regionalization is a method of estimating mean annual suspended-sediment loads for streams that have no sediment or streamflow data. Regionalization techniques, such as multiple regression, relate mean annual suspended-sediment loads from streams that have long-term records to geomorphic and hydrologic variables within a distinct geographic region. The resulting regional multiple-regression models are then used to estimate mean annual suspended-sediment loads of ungaged streams in the region.

Purpose and Scope

This report describes the results of an analysis of mean annual suspended-sediment loads from selected streams in Colorado. Regional multiple-regression models that related mean annual suspended-sediment loads to geomorphic and hydrologic variables were developed for drainage basins in three regions--central, northwestern, and southwestern. The analysis was based on the spatial variation of suspended-sediment loads due to regional differences in the geomorphic and hydrologic variables that affect sediment production and transport. The regional multiple-regression models can be used to estimate mean annual suspended-sediment loads of streams in these regions that have inadequate sediment or streamflow records.

Mean annual suspended-sediment loads from 81 selected streamflow-gaging stations in the central, northwestern, and southwestern regions of Colorado were expressed as functions of geomorphic and hydrologic variables in the multiple-regression analysis. Sediment-data sources and annual suspended-sediment loads for the U.S. Geological Survey streamflow-gaging stations used in this analysis are presented in a report by Elliott and DeFeyter (1986). Drainage-basin characteristics, such as mean basin elevation, mean basin-surface slope, basin length, and stream-channel length, were determined from U.S. Geological Survey topographic maps. Drainage-basin area, station elevation, mean annual streamflow, streamflow duration, and flood characteristics were obtained from the U.S. Geological Survey's National Water Data Storage and Retrieval System [(WATSTORE), U.S. Geological Survey, 1983]. Richter and others (1984) define many of the geomorphic and hydrologic variables used in this report. The geomorphic and hydrologic variables that explained a large quantity of variance in mean annual suspended-sediment loads were identified by stepwise multiple-regression analysis.

Acknowledgments

The author is grateful to K.L. DeFeyter, city of Denver, who spent many hours compiling geomorphic data used in the report. M.R. Karlinger and A.F. Choquette, U.S. Geological Survey, reviewed the manuscript and provided many helpful suggestions.

SEDIMENT DATA

The mean annual suspended-sediment load at a streamflow-gaging station was computed as the average of annual suspended-sediment loads. Annual suspended-sediment loads, in tons per year, were determined from measured or estimated daily suspended-sediment discharges, in tons per day. Most of the data were collected at U.S. Geological Survey streamflow-gaging stations. The methods used to compute annual suspended-sediment loads are discussed in detail by Elliott and DeFeyter (1986).

Sediment-Data-Collection Network

Sediment data have been collected from many streams in Colorado by several State and federal agencies. These data include suspended-sediment concentration and discharge, bedload discharge, and particle-size distribution. The U.S. Geological Survey has collected suspended-sediment data at 243 streamflow-gaging stations through water year 1984. At most of the streamflow-gaging stations, data were collected intermittently; however, at 73 of the streamflow-gaging stations, data were collected daily (Elliott and DeFeyter, 1986). Bedload data are not routinely collected by the U.S. Geological Survey and are not included in this analysis.

Suspended-Sediment Loads

The annual suspended-sediment load is the quantity of suspended sediment transported annually in a stream and may be determined as the yearly sum of daily suspended-sediment discharges. Daily suspended-sediment discharge either is determined from measured suspended-sediment concentration and daily water discharge (Porterfield, 1972), or is estimated by using a suspended-sediment transport curve and daily water discharge.

Elliott and DeFeyter (1986) estimated annual suspended-sediment loads for 133 streams in Colorado where suspended-sediment data were collected at streamflow-gaging stations. Annual suspended-sediment loads at 19 of these stations were determined entirely from the sums of daily suspended-sediment discharges calculated from measured suspended-sediment concentrations and daily water discharges. Annual suspended-sediment loads at the remaining stations were determined partly or entirely from the sums of daily suspended-sediment discharges estimated from suspended-sediment transport curves and daily water discharges.

The dependent variable in the multiple-regression analysis was mean annual suspended-sediment load. Mean annual suspended-sediment load at a station was computed as the average of several annual suspended-sediment loads. Ninety streamflow-gaging stations throughout the State were selected for the initial analysis of mean annual suspended-sediment loads (table 1). These stations are located on plate 1; site numbers, cross-referenced to station number, in table 1 and on plate 1 are the same as those used by Elliott and DeFeyter (1986). Streamflow at most stations included in the study was minimally affected by impoundments or diversions. Where impoundments and diversions substantially affected streamflow, mean annual suspended-sediment loads were determined for preregulation periods if the data were available; otherwise, the station was deleted from the analysis. Mean annual suspended-sediment loads were determined using a minimum of 5 years of annual suspended-sediment-load estimates.

Attempts were made to use the most reliable data in this analysis. Many streamflow-gaging stations with suspended-sediment data were omitted from the analysis if: (1) There was significant streamflow regulation; (2) the period of record was too short (less than 5 years); (3) the relation between suspended-sediment discharge and water discharge had considerable variability, or (4) the data were of questionable accuracy. There are, however, some deficiencies in the data used in this analysis. Suspended-sediment transport curves used to estimate annual suspended-sediment loads were derived from data collected with both intermittent and daily frequencies. Suspended-sediment discharge versus water-discharge plots at different sites exhibited a wide range of variability (scatter). Suspended-sediment transport curves were derived from data collected during different time periods; hence sediment-record lengths and sample sizes are not equivalent, and most sediment records are not concurrent. Annual suspended-sediment loads at some sites were estimated for periods when no daily or intermittent sediment data were available. Finally, the effect of climatic variability on mean annual suspended-sediment loads was undetermined.

ANALYSIS OF MEAN ANNUAL SUSPENDED-SEDIMENT LOADS

Mean annual suspended-sediment loads from selected streams were analyzed in this study. Although attempts were made to use only reliable sediment data, the data set is not completely representative of all streams in Colorado. Many streamflow-gaging stations are not included in the analysis because they lacked adequate streamflow and sediment data, or because streamflow at these stations was regulated. The location of streamflow-gaging stations is not uniformly distributed throughout the State nor within all geographic regions of the State. The distribution of streamflow-gaging stations largely was determined by the historical need for streamflow and sediment data from specific streams and specific watersheds.

Multiple-regression analysis was used to relate mean annual suspended-sediment loads of streams in Colorado to geomorphic and hydrologic variables of the associated drainage basins. The resulting multiple-regression models can be used to estimate mean annual suspended-sediment loads at unregulated sites where no sediment data are available or at sites where no streamflow data are available. Accuracy of the resulting regional multiple-regression

Table 1.--*Mean annual streamflow and mean annual suspended-sediment load for selected streams*

[latitude and longitude in degrees, minutes, seconds]

Site number[1]	Station identification number	Station name	Latitude	Longitude	Mean annual streamflow (acre-feet)	Mean annual suspended-sediment load (tons)	Period for computation (water years)	Number of years for computation
6	06619400	Canadian River near Lindland	40°41'43"	106°03'56"	17,930	863	1979-83	5
8	06619450	Canadian River near Brownlee	40°28'29"	106°14'09"	30,290	3,970	1979-83	5
9	06620000	North Platte River near Northgate	40°56'10"	106°20'21"	311,100	22,100	1950-84	35
473	06712000	Cherry Creek near Franktown	39°21'21"	104°45'46"	12,000	39,000	1942-48	6
474	06712500	Cherry Creek near Melvin	39°36'18"	104°49'19"	18,000	260,000	1942-48	7
27	06719505	Clear Creek at Golden	39°45'11"	105°14'05"	142,000	16,000	1975-84	10
34	06724000	Saint Vrain Creek at Lyons	40°13'05"	105°15'34"	86,160	1,960	1950-84	35
37	06725450	Saint Vrain Creek below Longmont	40°09'29"	105°00'53"	84,770	51,500	1977-82	6
38	06733000	Big Thompson River at Estes Park	40°22'42"	105°30'48"	92,700	2,950	1948-84	37
39	06752000	Cache La Poudre River at mouth of canyon near Fort Collins	40°39'52"	105°13'26"	239,300	11,400	1950-84	35
41	06758000	Kiowa Creek at Elbert	39°12'35"	104°32'00"	644	32,100	1956-65	10
43	06758200	Kiowa Creek at Kiowa	39°20'14"	104°28'30"	2,750	61,900	1956-65	10
479	06759000	Bijou Creek near Wiggins	40°14'53"	104°02'08"	6,700	953,000	1951-55	5
45	06764000	South Platte River at Julesburg	40°58'46"	102°15'15"	434,100	638,000	1951-84	34
47	07083000	Halfmoon Creek near Malta	39°10'20"	106°23'19"	20,730	331	1948-84	37
61	07124200	Purgatoire River at Madrid	37°07'46"	104°38'20"	49,120	270,000	1973-84	12
66	07126300	Purgatoire River near Thatcher	37°21'30"	103°53'44"	27,460	365,000	1967-76	[2]10
70	08224110	San Luis Creek near Poncha Pass	38°24'22"	106°03'49"	732	204	1980-84	5
71	08224113	San Luis Creek above Villa Grove	38°24'04"	106°03'51"	747	197	1980-84	5
78	09049200	West Tenmile Creek at Copper Mountain	39°30'01"	106°09'56"	21,230	2,810	1974-79	6
82	09066050	Black Gore Creek near Vail	39°37'24"	106°16'47"	20,720	1,600	1974-79	6
83	09066250	Gore Creek at Vail	39°38'35"	106°20'44"	69,260	2,660	1974-79	6
85	09070000	Eagle River below Gypsum	39°38'58"	106°57'11"	416,200	81,200	1948-84	37

Table 1.--*Mean annual streamflow and mean annual suspended-sediment load for selected streams*--Continued

Site number[1]	Station identification number	Station name	Latitude	Longitude	Mean annual streamflow (acre-feet)	Mean annual suspended-sediment load (tons)	Period for computation (water years)	Number of years for computation
90	09085000	Roaring Fork River at Glenwood Springs	39°32'37"	107°19'44"	868,500	143,000	1960-84	25
488	09092000	Rifle Creek near Rifle	39°37'10"	107°45'45"	17,800	43,500	1940-57	12
91	09092830	Northwater Creek near Anvil Points	39°37'13"	108°00'44"	3,010	350	1975-81	7
92	09092850	East Middle Fork Parachute Creek near Rio Blanco	39°37'15"	108°01'46"	6,990	10,500	1977-83	7
93	09092970	East Fork Parachute Creek near Rulison	39°34'03"	108°01'14"	7,010	4,980	1978-83	6
94	09093000	Parachute Creek near Parachute	39°34'01"	108°06'37"	21,530	39,200	1965-84	15
95	09093500	Parachute Creek at Parachute	39°27'11"	108°03'33"	20,600	56,000	1949-82	14
97	09095000	Roan Creek near De Beque	39°27'12"	108°18'59"	26,920	74,400	1963-81	17
98	09095400	Dry Fork near De Beque	39°22'08"	108°15'41"	3,460	16,700	1975-82	8
491	09128500	Smith Fork near Crawford	38°43'40"	107°30'22"	39,500	12,000	1914-57	44
100	09129800	Clear Fork near Ragged Mountain	39°08'36"	107°25'50"	26,660	6,880	1966-73	8
103	09132500	North Fork Gunnison River near Somerset	38°55'45"	107°26'53"	341,500	69,500	1962-84	23
493	09143500	Surface Creek at Cedaredge	38°54'06"	107°55'14"	19,600	3,000	1918-57	40
107	09149500	Uncompahgre River at Delta	38°44'31"	108°04'49"	207,700	294,000	1950-84	35
494	09166500	Dolores River at Dolores	37°28'16"	108°30'15"	356,000	119,100	1914-57	44
132	09175500	San Miguel River at Naturita	38°13'04"	108°33'57"	197,900	27,700	1950-81	32
139	09239500	Yampa River at Steamboat Springs	40°29'01	106°49'54"	339,000	11,000	1905-77	70
140	09241000	Elk River at Clark	40°43'03"	106°54'55"	243,000	5,200	1911-77	59
142	09242500	Elk River near Trull	40°30'53"	106°57'12"	430,000	7,600	1905-27	20
144	09243700	Middle Creek near Oak Creek	40°23'08"	106°59'33"	3,210	3,180	1976-84	8
145	09243800	Foidel Creek near Oak Creek	40°20'45"	107°05'04"	572	227	1976-83	7
146	09243900	Foidel Creek at mouth near Oak Creek	40°23'25"	106°59'39"	1,960	1,760	1976-84	8
148	09244300	Grassy Creek near Mount Harris	40°26'49"	107°08'42"	1,010	2,380	1959-66	8

Table 1.--*Mean annual streamflow and mean annual suspended-sediment load for selected streams*--Continued

Site number[1]	Station identification number	Station name	Latitude	Longitude	Mean annual streamflow (acre-feet)	Mean annual suspended-sediment load (tons)	Period for computation (water years)	Number of years for computation
149	09244410	Yampa River below diversion near Hayden	40°29'18"	107°09'33"	788,300	105,000	1966-84	19
153	09244470	Stokes Gulch near Hayden	40°28'06"	107°14'47"	1,200	761	1977-81	5
154	09245000	Elkhead Creek near Elkhead	40°40'11"	107°17'04"	38,400	11,000	1954-77	24
155	09245500	North Fork Elkhead Creek near Elkhead	40°40'50"	107°17'12"	12,300	1,300	1959-73	15
160	09249200	South Fork of Williams Fork near Pagoda	40°12'44"	107°26'32"	31,700	22,000	1966-77	12
161	09249750	Williams Fork at mouth near Hamilton	40°26'14"	107°38'50"	157,000	160,000	1905-27	20
165	09250510	Taylor Creek at mouth near Axial	40°18'48"	107°47'57"	355	1,200	1976-84	9
166	09250600	Wilson Creek near Axial	40°18'56"	107°47'50"	1,590	19,100	1975-80	6
167	09250610	Jubb Creek near Axial	40°18'45"	107°49'18"	78	18	1976-81	6
169	09251000	Yampa River near Maybell	40°30'10"	108°01'45"	1,107,000	516,000	1950-84	35
170	09253000	Little Snake River near Slater	40°59'58"	107°08'34"	164,000	19,000	1943-77	32
171	09255000	Slater Fork near Slater	40°58'57"	107°22'56"	53,600	12,000	1932-77	46
173	09260000	Little Snake River near Lily	40°32'50"	108°25'25"	418,700	1,270,000	1950-84	35
174	09260050	Yampa River at Deerlodge Park	40°27'02"	108°31'20"	1,500,000	1,940,000	1941-83	43
178	09303000	North Fork White River at Buford	39°59'15"	107°36'50"	230,600	16,800	1952-84	33
181	09304000	South Fork White River at Buford	39°58'28"	107°37'29"	185,900	31,900	1952-84	33
182	09304200	White River above Coal Creek near Meeker	40°00'18"	107°49'29"	412,200	52,600	1962-84	23
184	09304800	White River below Meeker	40°00'48"	108°05'33"	469,500	111,000	1962-84	23
185	09306007	Piceance Creek below Rio Blanco	39°49'34"	108°10'57"	14,200	49,400	1975-84	10
187	09306022	Stewart Gulch above West Fork near Rio Blanco	39°49'09"	108°11'08"	1,130	156	1975-82	8
196	09306052	Scandard Gulch at mouth near Rio Blanco	39°48'51"	108°14'35"	8	58	1975-84	8
197	09306058	Willow Creek near Rio Blanco	39°50'14"	108°14'37"	1,420	500	1975-82	8

Table 1.--*Mean annual streamflow and mean annual suspended-sediment load for selected streams*--Continued

Site number[1]	Station identification number	Station name	Latitude	Longitude	Mean annual streamflow (acre-feet)	Mean annual suspended-sediment load (tons)	Period for computation (water years)	Number of years for computation
198	09306061	Piceance Creek above Hunter Creek near Rio Blanco	39°51'02"	108°15'31"	18,980	61,800	1975-84	10
199	09306175	Black Sulphur Creek near Rio Blanco	39°52'16"	108°17'18"	4,660	3,780	1976-81	6
200	09306200	Piceance Creek below Ryan Gulch near Rio Blanco	39°55'16"	108°17'49"	25,360	43,400	1973-84	11
203	09306222	Piceance Creek at White River	40°05'16"	108°14'35"	30,800	76,000	1975-84	9
206	09306235	Corral Gulch below Water Gulch near Rangely	39°54'22"	108°31'56"	193	449	1975-82	6
209	09306241	Box Elder Gulch Tributary near Rangely	39°54'50"	108°29'05"	4	10	1975-82	8
210	09306242	Corral Gulch near Rangely	39°55'13"	108°28'20"	1,850	26,100	1975-84	10
215	09306255	Yellow Creek near White River	40°10'07"	108°24'02"	1,360	39,900	1975-82	8
217	09306300	White River above Rangely	40°06'26"	108°42'44"	458,600	402,000	1973-81	9
[3]218	09306395	White River near Colorado-Utah State line, Utah	40°00'50"	109°04'48"	568,000	1,550,000	1977-84	8
219	09341200	Wolf Creek near Pagosa Springs	37°26'47"	106°53'00"	22,530	897	1969-75	7
220	09343000	Rio Blanco near Pagosa Springs	37°12'46"	106°47'38"	58,920	33,700	1952-71	20
225	09344300	Navajo River above Chromo	37°01'55"	106°43'56"	84,040	13,600	1957-70	14
229	09346000	Navajo River at Edith	37°00'10"	106°54'25"	52,790	41,400	1972-84	13
232	09347200	Middle Fork Piedra River near Pagosa Springs	37°29'12"	107°09'46"	31,660	1,030	1970-75	6
233	09349800	Piedra River near Arboles	37°05'18"	107°23'50"	277,500	209,000	1963-84	22
234	09352900	Vallecito Creek near Bayfield	37°28'39"	107°32'35"	104,300	832	1963-84	22
236	09357500	Animas River at Howardsville	37°49'59"	107°35'56"	69,420	4,420	1950-82	33
237	09358900	Mineral Creek above Silverton	37°51'04"	107°43'31"	15,870	667	1969-75	7
[3]238	09363500	Animas River near Cedar Hill, New Mexico	37°02'17"	107°52'25"	674,300	272,000	1964-84	20
239	09366500	La Plata River at Colorado-New Mexico State line	36°59'59"	108°11'17"	23,950	42,500	1950-84	35
242	09372000	McElmo Creek near Colorado-Utah State line	37°19'27"	109°00'54"	33,980	221,000	1952-84	33

[1]Site numbers assigned in a previous report (Elliott and DeFeyter, 1986).

[2]Mean annual streamflow and mean annual suspended-sediment load computed for period prior to reservoir completion.

[3]Streamflow-gaging stations in adjacent States, but most of drainage basin in Colorado.

models is affected by: (1) The likelihood of identifying the independent variables that have the greatest effect on mean annual suspended-sediment loads; (2) the accuracy of estimates of mean annual suspended-sediment loads, and the accuracy of measurement of independent variables; and (3) the adequacy of the selected multiple-regression models to account for the factors that control sediment production and sediment transport.

Geomorphic and Hydrologic Variables

Several geomorphic and hydrologic variables that may affect sediment production and transport were identified. These variables were quantified from U.S. Geological Survey topographic maps or retrieved from WATSTORE; many of these variables are defined and summarized by Richter and others (1984). Geomorphic variables included drainage-basin area, site elevation, mean basin elevation, mean basin-surface slope, basin relief, basin length, basin width, lemniscate index, basin aspect, channel gradient, and valley gradient. The lemniscate index is a quantification of roundness or elongation of drainage-basin shape, and expresses a relation between maximum basin length and maximum basin width. The lemniscate index is defined as the square of basin length times π (pi) divided by four times the drainage area (Chorley and others, 1957). Hydrologic variables included mean annual streamflow, flow-duration characteristics, and floodflow characteristics. Precipitation characteristics, vegetation type, and land-use practices affect sediment production and transport but were not included because adequate data were not available for all drainage basins in the study area.

Most of the geomorphic and hydrologic variables used in this report had log normal frequency distributions. Logarithmic transformations (natural logarithm, base e) were done for mean annual suspended-sediment loads and all independent variables prior to the initial analysis. Several independent variables correlated significantly with other independent variables, and were deleted from the subsequent analysis. Eight of the original geomorphic and hydrologic variables were selected for multiple-regression analysis; these were drainage-basin area, site elevation, mean basin elevation, mean basin-surface slope, lemniscate index, mean annual streamflow, water discharge equaled or exceeded 10 percent of the time, and 10-year flood. These geomorphic and hydrologic variables are listed in table 2.

Stepwise Multiple-Regression Analysis

The multiple-regression models presented in this report were derived with a least-squares linear regression of logarithmic-transformed data. Troutman and Williams (1987) assessed several types of curve-fitting techniques and indicated that ordinary least-squares regression is an appropriate technique when prediction of the dependent variable is the objective, and when the assumption of linearity can be met.

Table 2.--*Mean annual suspended-sediment loads, geomorphic, and hydrologic variables for selected streams*

[Region: C, central; E, eastern; N, northwestern; S, southwestern; --, insufficient data]

Site number	Station identification number	Mean annual suspended-sediment load (tons)	Drainage-basin area (square miles)	Site elevation (feet)	Mean basin elevation (feet)	Mean basin-surface slope (feet per foot)	Lemniscate index (unitless)	Mean annual streamflow (acre-feet)	Water discharge equaled or exceeded 10 percent of time (cubic feet per second)	10-year flood (cubic feet per second)	Region
6	06619400	863	44.0	8,150	9,300	0.276	1.45	17,930	64.1	367.0	C
8	06619450	3,970	158	7,930	8,900	.163	2.09	30,290	119	530	C
9	06620000	22,100	1,431	7,810	8,900	.122	.839	311,100	1,250	5,300	C
473	06712000	39,000	169	6,170	--	--	--	12,000	16.7	4,090	E
474	06712500	260,000	360	5,608	--	--	--	18,000	22.0	11,800	E
27	06719505	16,000	400	5,695	10,100	.499	2.72	142,000	575	2,030	C
34	06724000	1,960	212	5,292	8,900	.315	1.79	86,160	394	2,510	C
37	06725450	51,500	424	4,850	7,300	.216	2.02	84,770	203	3,280	E
38	06733000	2,950	137	7,493	10,200	.391	1.27	92,700	400	1,580	C
39	06752000	11,400	1,056	5,220	8,420	.198	.955	239,300	1,230	5,860	C
41	06758000	32,100	28.6	6,740	7,120	.064	5.08	644	.10	--	E
43	06758200	61,900	111	6,350	--	--	--	2,750	5.20	11,500	E
479	06759000	953,000	1,314	4,490	--	--	--	6,700	.09	35,300	E
45	06764000	638,000	23,140	3,447	--	--	--	434,100	1,100	--	E
47	07083000	331	23.6	9,830	11,800	.517	1.20	20,730	88.0	408	C
61	07124200	270,000	550	6,262	7,900	--	1.31	49,120	182	11,000	E
66	07126300	365,000	1,791	4,790	6,940	.116	2.47	27,460	96.0	23,500	E
70	08224110	204	6.57	8,780	9,600	.267	2.26	732	1.80	29.2	C
71	08224113	197	11.2	8,710	9,600	.269	1.39	747	1.80	48.2	C
78	09049200	2,810	21.0	9,835	11,200	.305	1.00	21,230	99.6	672	C
82	09066050	1,600	19.6	8,570	10,200	.360	2.23	20,720	93.7	420	C
83	09066250	2,660	55.0	8,250	9,830	.433	1.79	69,260	345	1,480	C
85	09070000	81,200	944	6,275	9,500	.320	1.48	416,200	1,610	5,990	N
90	09085000	143,000	1,451	5,721	9,800	.386	1.45	868,500	3,510	13,900	N
488	09092000	43,500	137	5,809	8,200	.284	1.17	17,800	44	788	N
91	09092830	350	12.6	7,420	8,600	.319	1.95	3,010	6.40	292	N
92	09092850	10,500	22.1	7,400	8,500	.329	1.32	6,990	17.2	451	N
93	09092970	4,980	20.4	6,880	8,600	.301	1.94	7,010	25.5	501	N
94	09093000	39,200	141	5,770	8,100	.369	.602	21,530	61.4	938	N
95	09093500	56,000	198	5,100	7,500	.375	1.15	20,600	60.0	1,270	N
97	09095000	74,400	321	5,380	7,500	.456	1.27	26,920	65.0	1,500	N
98	09095400	16,700	109	5,085	7,500	.367	2.52	3,460	12.5	808	N
491	09128500	12,000	43.7	7,091	9,200	.408	.856	39,500	120	847	C
100	09129800	6,880	38.5	7,450	9,530	.333	1.32	26,660	119	870	C
103	09132500	69,500	526	6,039	8,900	.291	.755	341,500	1,510	6,040	C
493	09143500	3,000	39.5	6,220	9,300	.155	3.21	19,600	74.0	594	N
107	09149500	294,000	1,129	4,926	8,100	.178	2.52	207,700	596	2,870	N
494	09166500	119,100	504	6,919	9,800	.312	2.04	356,000	1,410	6,260	S
132	09175500	27,700	1,069	5,393	9,000	.235	1.77	197,900	936	5,670	S
139	09239500	11,000	604	6,695	8,800	.205	1.76	339,000	1,560	5,200	C
140	09241000	5,200	206	7,268	9,000	.247	1.04	243,000	1,190	3,680	C
142	09242500	7,600	415	6,590	8,400	.240	1.61	430,000	2,010	5,200	C
144	09243700	3,180	23.5	6,720	7,700	.257	5.65	3,210	11.0	216	C
145	09243800	227	8.61	6,880	7,400	.192	1.77	572	1.50	137	C
146	09243900	1,760	17.5	6,730	7,200	.160	3.48	1,960	5.50	88.3	C

Table 2.--*Mean annual suspended-sediment loads, geomorphic, and hydrologic variables for selected streams*--Continued

Site number	Station identification number	Mean annual suspended-sediment load (tons)	Drainage-basin area (square miles)	Site elevation (feet)	Mean basin elevation (feet)	Mean basin-surface slope (feet per foot)	Lemniscate index (unitless)	Mean annual streamflow (acre-feet)	Water discharge equaled or exceeded 10 percent of time (cubic feet per second)	10-year flood (cubic feet per second)	Region
148	09244300	2,380	26.0	6,580	--	--	--	1,010	1.30	336	C
149	09244410	105,000	1,430	6,380	8,600	0.210	0.620	788,300	3,650	11,100	N
153	09244470	761	13.6	6,375	6,800	.133	5.43	1,200	.36	--	N
154	09245000	11,000	64.2	6,845	8,400	.189	1.70	38,400	185	1,780	C
155	09245500	1,300	21.0	7,005	8,600	.210	1.73	12,300	58.0	829	C
160	09249200	22,000	46.7	7,235	9,200	.235	1.08	31,700	153	846	N
161	09249750	160,000	419	6,170	--	--	--	157,000	1.50	--	N
165	09250510	1,200	7.22	6,300	7,200	--	5.80	355	.30	31.0	N
166	09250600	19,100	27.4	6,300	7,530	.341	3.79	1,590	4.40	75.7	N
167	09250610	18	7.53	6,400	7,200	--	5.11	78	.20	11.2	N
169	09251000	516,000	3,410	5,900	8,000	.181	.751	1,107,000	5,380	14,800	N
170	09253000	19,000	285	6,831	8,600	.227	1.03	164,000	887	3,540	N
171	09255000	12,000	161	6,600	8,400	.181	2.01	53,600	257	1,440	N
173	09260000	1,270,000	3,730	5,685	7,100	.091	1.50	418,700	2,020	9,210	N
174	09260050	1,940,000	7,660	5,600	7,280	.125	1.09	1,500,000	11,400	--	N
178	09303000	16,800	260	7,010	9,530	.237	1.50	230,600	733	2,220	C
181	09304000	31,900	177	6,970	9,800	.259	2.53	185,900	637	2,610	C
182	09304200	52,600	648	6,400	9,140	.230	1.40	412,200	1,440	4,790	N
184	09304800	111,000	1,024	5,928	8,450	.200	1.78	469,500	1,470	5,140	N
185	09306007	49,400	177	6,366	7,630	.283	1.45	14,200	26	483	N
187	09306022	156	44.0	6,430	7,620	.235	2.20	1,130	2.50	26.0	N
196	09306052	58	7.97	6,434	7,100	.136	6.00	8	.01	16.4	N
197	09306058	500	48.4	6,273	7,420	.272	3.70	1,420	4.40	54.5	N
198	09306061	61,800	309	6,214	7,550	.263	1.29	18,980	34.8	490	N
199	09306175	3,780	103	6,130	7,350	.209	2.50	4,660	12.9	196	N
200	09306200	43,400	506	6,070	7,420	.243	.979	25,360	45.4	322	N
203	09306222	76,000	652	5,730	7,270	.240	1.17	30,800	50.1	507	N
206	09306235	449	8.61	6,980	7,520	.253	1.93	193	.70	237	N
209	09306241	10	2.39	6,655	7,100	.159	23.7	4	.01	27.6	N
210	09306242	26,100	31.6	6,570	7,200	.236	1.54	1,850	3.80	716	N
215	09306255	39,900	262	5,535	6,880	.197	2.63	1,360	2.8	1,800	N
217	09306300	402,000	2,773	5,270	7,410	.184	1.93	458,600	1,500	4,230	N
218	09306395	1,550,000	3,680	5,030	6,870	.162	2.22	568,000	3,670	6,390	N
219	09341200	897	14.0	7,900	10,700	.421	1.93	22,530	94.7	692	S
220	09343000	33,700	58.0	7,950	10,000	.428	1.46	58,920	250	1,450	S
225	09344300	13,600	96.4	7,700	10,000	.341	2.01	84,040	327	1,170	S
229	09346000	41,400	172	7,033	9,200	.277	2.17	52,790	362	1,660	S
232	09347200	1,030	32.2	8,210	10,500	.526	1.94	31,660	118	1,410	S
233	09349800	209,000	629	6,148	8,300	.290	1.62	277,500	1,110	5,680	S
234	09352900	832	72.1	7,906	11,400	.537	2.75	104,300	423	2,290	S
236	09357500	4,420	55.9	9,617	11,900	.516	1.09	69,420	316	1,460	S
237	09358900	667	11.0	9,980	11,800	.504	1.02	15,870	66.6	481	S
238	09363500	272,000	1,090	5,960	9,300	.306	2.61	674,300	2,440	9,780	S
239	09366500	42,500	331	5,975	7,700	.168	2.35	23,950	87.4	2,340	S
242	09372000	221,000	346	4,890	6,300	.128	2.53	33,980	93.0	1,900	S

The multiple-regression models estimate the mean response of the dependent variable (mean annual suspended-sediment load) given known values of the independent variables. The form of the multiple-regression models is a linear function of logarithmic-transformed variables:

$$\log Y = \log \beta_0 + \beta_1 \log X_1 + \beta_2 \log X_2 + \ldots + \beta_p \log X_p. \qquad (1)$$

Taking the antilogs, the form of the multiple-regression models becomes multiplicative:

$$Y = \beta_0 X_1^{\beta_1} X_2^{\beta_2} \ldots X_p^{\beta_p}, \qquad (2)$$

where Y = mean annual suspended-sediment load,
β = regression coefficients,
X = geomorphic or hydrologic variables, and
p = number of independent variables in the model.

A transformation bias is created when the logarithm of the estimated mean response (log of mean annual suspended-sediment load) is detransformed (equation 2). This transformation bias usually results in underestimation of the detransformed mean response (mean annual suspended-sediment load). 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:

$$C_b = e^{0.5 \text{ MSE}} , \qquad (3)$$

where C_b = transformation bias correction factor,

e = base of the natural logarithm, and

MSE = mean squared error of the regression model (Miller, 1984).

An exploratory analysis of data was made to determine which geomorphic and hydrologic variables should be included as independent variables in the multiple-regression models. An iterative statistical procedure, stepwise multiple regression, was used to identify individual or groups of independent variables that accounted for a large proportion of variance in mean annual suspended-sediment load. In this iterative procedure, eight independent variables were selectively added to and removed from the multiple-regression model until the maximum coefficient of multiple determination (R^2) was attained for the model with one independent variable, for the model with two independent variables, for the model with three independent variables, and so forth. To ensure that all variables included in the multiple-regression model were significant, independent variables added to the model in the stepwise procedure were restricted to those whose F statistic was significant at the 0.95 level.

The R^2 is defined as the ratio of the regression sum of squares to the total sum of squares, and measures the proportionate decrease of total variation in the dependent variable associated with the set of independent variables in the multiple-regression model (Neter and others, 1985, p. 241). Adding more independent variables to the multiple-regression model will increase R^2, but a large R^2 does not necessarily indicate that the fitted multiple-regression model is the most appropriate model of the sediment production and transport system.

The adjusted coefficient of multiple determination (R_a^2) accounts for the effects of the number of independent variables in the multiple-regression model and of the sample size on degrees of freedom. The R_a^2 facilitates comparison of multiple-regression models that are developed from different numbers of independent variables and from different sample sizes; therefore, this statistic is presented with the multiple-regression models in this report.

The mean squared error (MSE) also is presented with the multiple-regression models. The MSE is an unbiased estimator of the variance of the multiple-regression model and is used to derive the bias correction factor (equation 3). The unit of MSE is the natural logarithm of mean annual suspended-sediment load (log of tons).

Multiple-regression models initially were derived with data from all sites in the area. The model that accounted for the largest proportion of variance in mean annual suspended-sediment load included, in order of decreasing significance, the independent variables: mean basin elevation, in feet divided by 5,000; mean annual streamflow, in acre-feet; and drainage-basin area, in square miles. Mean basin elevation was determined as the average elevation of 25 or more points in the drainage basin. The sampled points were located using a grid placed over a topographic map of the drainage basin. For this model, the R_a^2 was 0.78, and the MSE was 1.432. Mean basin elevation was not determined for 7 of the original 90 sites; therefore, the multiple-regression model was developed from a sample of 83 sites. All independent variables in this multiple-regression model were significant at the 95-percent level; no other independent variables added to this three-variable model accounted for a significant proportion of variance in mean annual suspended-sediment load.

Regionalization of Mean Annual Suspended-Sediment Loads

Colorado has diverse geography and climate that affects regional variability of streamflow characteristics (Kircher and others, 1985). Regional differences in geography, climate, and hydrology also may affect mean annual suspended-sediment loads. Regionalization of mean annual suspended-sediment loads involves analysis of data from within a geographically unique region. Regionalization of mean annual suspended-sediment loads from sites that have similar geographic, climatic, and hydrologic characteristics can decrease the prediction error of the resulting multiple-regression model. Most of the sites initially included in this report were grouped into three regions: (1) Central, (2) northwestern, and (3) southwestern. A multiple-regression model relating mean annual suspended-sediment load to geomorphic and hydrologic variables was developed for each of these three regions. A fourth region, eastern, that included the piedmont and plains of eastern Colorado initially was examined; however, no multiple-regression model was developed for the eastern region because only nine sites were located in that region.

A regression residual is the difference between the mean annual suspended-sediment load measured in a stream and the mean annual suspended-sediment load predicted by the multiple-regression model. Residuals from each regional multiple-regression model were plotted against the predicted mean annual suspended-sediment loads and analyzed. Sites having residuals that plotted as outliers in one region were reevaluated, and some were reassigned to neighboring regions. New multiple-regression models were developed and residuals were reanalyzed to confirm the assignment of region. Regions to which sites finally were assigned are indicated in table 2, and boundaries of the regions are delineated on plate 1.

The central region includes the central Rocky Mountains near the Continental Divide. Based on the sample of streamflow-gaging stations included in this report, drainage-basin areas range from 6.60 to 1,431 mi^2. Most site elevations in the central region are above 6,000 ft, and the mean of mean basin elevations is 9,208 ft. Mean annual streamflow ranges from 572 to 430,000 acre-ft. Streamflow peaks in this region are primarily runoff from snowmelt (Elliott and others, 1982). The central region includes headwater tributaries of the Arkansas, Colorado, North Platte, South Platte, White, and Yampa Rivers.

The northwestern region includes the mountains and plateaus of an area that generally is west of the Continental Divide and north of the Uncompahgre Plateau. These geographic features are orographic barriers to air masses moving from the northwest or southwest and affect precipitation distribution. Drainage-basin areas in this region range from 2.39 to 7,660 mi^2. Site elevations range from 4,926 to 7,420 ft, and the mean of mean basin elevations is 7,873 ft. Mean annual streamflow ranges from 4.0 to 1,500,000 acre-ft. The northwestern region includes low-elevation reaches and tributaries of the Yampa, White, and Colorado Rivers; high-elevation watersheds of the Roan Plateau; and other low-elevation watersheds.

The southwestern region is located generally west of the Continental Divide and south of the Uncompahgre Plateau and includes the southwestern part of the San Juan Mountains. Drainage-basin areas range from 11.0 to 1,091 mi^2. Site elevations in this region range from 4,890 to 9,980 ft, and the mean of mean basin elevations is 9,707 ft. Mean annual streamflow ranges from 15,870 to 674,300 acre-ft. The southwestern region includes tributaries of the Dolores and San Juan Rivers.

Multiple-regression models were developed for the central, northwestern, and southwestern regions using the stepwise multiple-regression analysis described in the previous section. The best regional multiple-regression models for these three regions included, in order of decreasing significance, mean annual streamflow (Q_a), and mean basin elevation (E_b) (table 3). Note that E_b is actually mean basin elevation divided by 5,000, a scaling factor. No other independent variables accounted for a significant (0.95 level) proportion of variance in mean annual suspended-sediment load (L_{ss}) when included in the multiple-regression models with mean annual streamflow and mean basin elevation. The central, northwestern, and southwestern regions contained a total of 81 sites. Mean basin elevations were not determined for 2 of these sites; therefore, the regression models that included E_b were based on a total sample of 79 sites.

Table 3.--*Regional multiple-regression models for mean annual suspended-sediment loads using geomorphic and hydrologic variables*

[C_b, bias correction factor; R_a^2, coefficient of multiple determination of the log-transformed model adjusted for degrees of freedom; MSE, mean squared error of the log-transformed model, in log of tons; n, number of sites; L_{ss}, mean annual suspended-sediment load, in tons; Q_a, mean annual streamflow, in acre-feet; E_b, mean basin elevation divided by 5,000, in feet]

Region	Detransformed model	C_b	R_a^2	MSE	n
Central-----------	$L_{ss} = 23.1\ Q_a^{0.68}\ E_b^{-3.40}$	1.45	0.70	0.744	26
Northwestern------	$L_{ss} = 82.7\ Q_a^{0.98}\ E_b^{-9.39}$	1.98	0.85	1.37	39
Southwestern------	$L_{ss} = 39.6\ Q_a^{1.06}\ E_b^{-9.09}$	1.54	0.82	0.868	14

The multiple-regression models presented in this report express a statistical relation between several variables in the sediment-production and sediment-transport system. Although these multiple-regression models do not necessarily express the functional relation between variables (Draper and Smith, 1981, p. 413) these models can provide some insight into important controls on the production and transport of sediment in three Colorado regions. Mean annual streamflow is included in all three regional multiple-regression models in table 3, and the positive regression coefficient indicates an increase in L_{ss} with increasing Q_a. Because suspended-sediment load is determined by streamflow and suspended-sediment concentration, it is reasonable to expect a strong positive relation between L_{ss} and Q_a.

Mean basin elevation also is included in all three regional multiple-regression models and has a negative coefficient indicating an increase in L_{ss} with decreasing E_b. In the initial analysis of variables, E_b and mean annual precipitation were positively correlated (r = 0.62), but precipitation was not included in the multiple-regression analysis because only 40 sites had precipitation data. Other factors that affect sediment production and sediment transport also may have some correlation with E_b; therefore, E_b may be a surrogate for some unquantified variables not included in the multiple-regression models. Mean annual suspended-sediment load may increase with decreasing E_b because of some factors that vary with elevation in Colorado. These factors include precipitation type (snow versus rain) and the nature of runoff, geology, vegetation, and land use.

Drainage-basin area is not included in the regional multiple-regression models in table 3. Unlike the multiple-regression model developed for all sites, drainage-basin area did not account for a significant (0.95 level) proportion of the variance in mean annual suspended-sediment loads when included in the regional multiple-regression models with mean annual streamflow and mean basin elevation.

The three regional multiple-regression models in table 3 can provide reasonable estimates of mean annual suspended-sediment loads for other sites in those three regions that lack adequate sediment data. On the basis of larger values of R_a^2 and smaller values of MSE, regional multiple-regression analysis resulted in multiple-regression models that explained a larger proportion of variance in mean annual suspended-sediment load than did the multiple-regresion model derived for all sites in the study area. The multiple-regression model for the central region had a slightly smaller R_a^2 (0.70) than did the multiple-regression model for all sites (0.78), but the multiple-regression model for the central region also had a much smaller MSE (0.744) than did the multiple-regression model for all sites (1.432). Multiple-regression models for the northwestern region and the southwestern region had larger values of R_a^2 and smaller values of MSE than did the multiple-regression model for all sites.

The independent variables in the regional multiple-regression models in table 3 do not account for all of the variance in mean annual suspended-sediment loads. This is due to the natural variation (probability distribution) of the dependent variable (mean annual suspended-sediment load) given the set of independent variables, inappropriateness of the multiple-regression model, and measurement errors. A regression residual is the difference between the observed and the predicted or expected value of the dependent variable. If the multiple-regression model is appropriate, the residuals should reflect the properties assumed for the model error; that is, error mean zero and error variance constant (Neter and others, 1985, p. 110). Standardized residuals (the residual divided by the standard deviation of the residual) from the multiple-regression models in table 3 are plotted against the expected value by region in figure 1.

The standardized residuals from the central region and the southwestern region are centered about zero, and, for most of the range of expected values, there generally is a constant variance about zero. The standardized-residual plots indicate that the multiple-regression models in table 3 are appropriate for the central and southwestern regions. The standardized residuals from the northwestern region are centered about zero, but they do not have a constant variance about zero. Variance of the residuals is small for the high range of expected values and is larger for the middle range of expected values. The middle range of expected values corresponds to smaller drainage basins in the northwestern region. The effect of variation in climate, lithology, and vegetation on mean annual suspended-sediment loads in the northwestern region probably is greater in small drainage basins than in large drainage basins. Even though the standardized residuals from the northwestern region do not display constant variance, the multiple-regression model in table 3 may be the best available for estimation of mean annual suspended-sediment loads in the northwestern region.

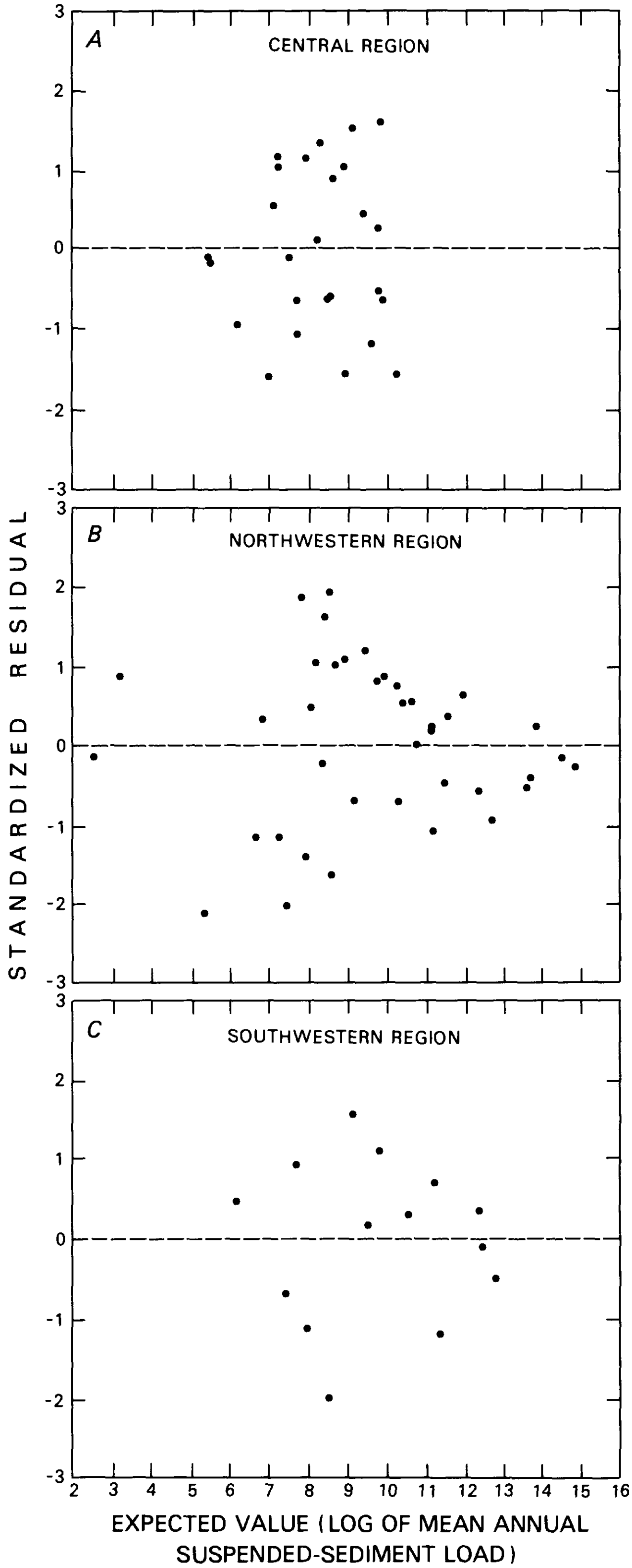

Figure 1.--Standardized residuals from regional multiple-regression models developed for: (*A*) central region, (*B*) northwestern region, and (*C*) southwestern region, using geomorphic and hydrologic variables.

It often is desirable to estimate mean annual suspended-sediment loads for streams that are ungaged. Mean annual suspended-sediment loads can be estimated with models that include only geomorphic variables. When hydrologic variables were omitted from the data set, multiple-regression analysis for the central, northwestern, and southwestern regions, indicated that drainage area was the only variable that accounted for a significant (0.95 level) proportion of variance in mean annual suspended-sediment load. Regional multiple-regression models for estimating mean annual suspended-sediment load for streams without streamflow data are presented in table 4. Standardized residuals from the multiple-regression models in table 4 are plotted by region in figure 2.

Table 4.--*Regional multiple-regression models for mean annual suspended-sediment loads using only geomorphic variables*

[C_b, bias correction factor; R_a^2, coefficient of multiple determination of the log-transformed model, adjusted for degrees of freedom; MSE, mean squared error of the log-transformed model, in log of tons; n, number of sites; L_{ss}, mean annual suspended-sediment load, in tons; A_d, drainage-basin area, in square miles]

Region	Detransformed model	C_b	R_a^2	MSE	n
Central-----------	$L_{ss} = 109\ A_d^{0.80}$	1.60	0.61	0.945	27
Northwestern------	$L_{ss} = 21.6\ A_d^{1.31}$	2.34	0.81	1.70	40
Southwestern------	$L_{ss} = 31.0\ A_d^{1.27}$	1.96	0.73	1.35	14

The regional multiple-regression models in table 3 can be used to estimate mean annual suspended-sediment load with reasonable accuracy when mean annual streamflow and mean basin elevation are known. The regional multiple-regression models in table 4 can be used to estimate mean annual suspended-sediment load when only drainage-basin area is known. The models in tables 3 and 4 provide estimates of the mean value of the dependent variable (mean annual suspended-sediment load). True values of mean annual suspended-sediment load probably will be different from the estimated values. All estimates of mean annual suspended-sediment load will be subject to logarithmic-detransformation bias unless multiplied by the bias-correction factors in tables 3 and 4. These regional multiple-regression models are appropriate only for the specified geographic regions and for the range of independent variables for which they were developed. Descriptive statistics for geomorphic and hydrologic variables used in the regional multiple-regression models are presented in table 5. The range and distribution of geomorphic and hydrologic variables for each region are illustrated by the box plots in figure 3.

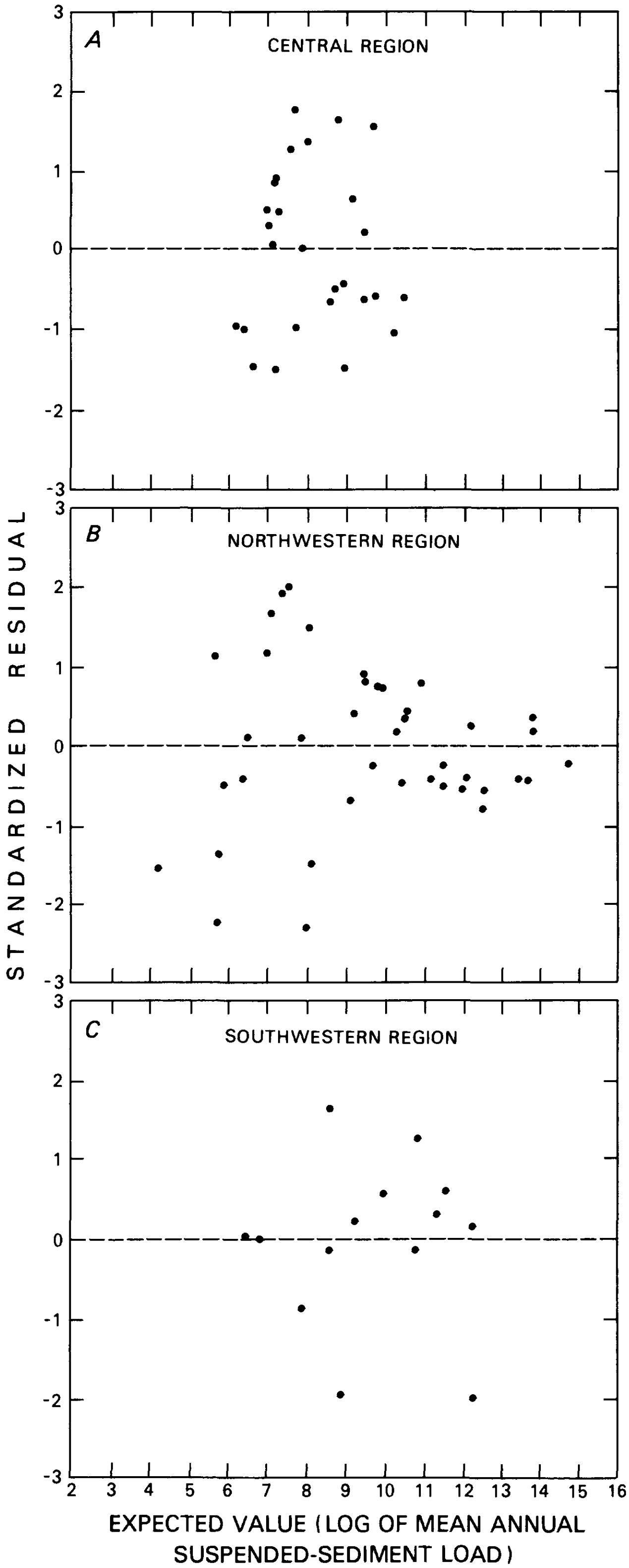

Figure 2.--Standardized residuals from regional multiple-regression models developed for: (*A*) central region, (*B*) northwestern region, and (*C*) southwestern region, using only geomorphic variables.

Table 5.--*Descriptive statistics for geomorphic and hydrologic variables used in regional multiple-regression models*

[n, number of sites; P25, 25th percentile; P75, 75th percentile; SD, standard deviation; CV, coefficient of variation (SD divided by mean times 100); drainage-basin area, in square miles; mean basin elevation, in feet; mean annual streamflow, in acre-feet]

Variable	n	Mean	Median	Minimum	Maximum	P25	P75	SD	CV
CENTRAL REGION									
Drainage-basin area	27	223	55	6.60	1,431	21	260	343	154
Mean basin elevation	26	9,208	9,100	7,200	11,800	8,550	9,812	1,044	11
Mean annual streamflow	27	109,100	38,400	572	430,000	12,300	230,600	130,600	120
NORTHWESTERN REGION									
Drainage-basin area	40	800	169	2.39	7,660	28	871	1,511	189
Mean basin elevation	39	7,870	7,550	6,800	9,800	7,250	8,500	795	10
Mean annual streamflow	40	196,300	20,100	4	1,500,000	1,655	361,100	346,600	177
SOUTHWESTERN REGION									
Drainage-basin area	14	320	134	11.0	1,091	50	535	357	112
Mean basin elevation	14	9,707	9,900	6,300	11,900	8,825	10,875	1,578	16
Mean annual streamflow	14	143,100	64,170	15,870	674,300	29,730	217,800	184,700	129

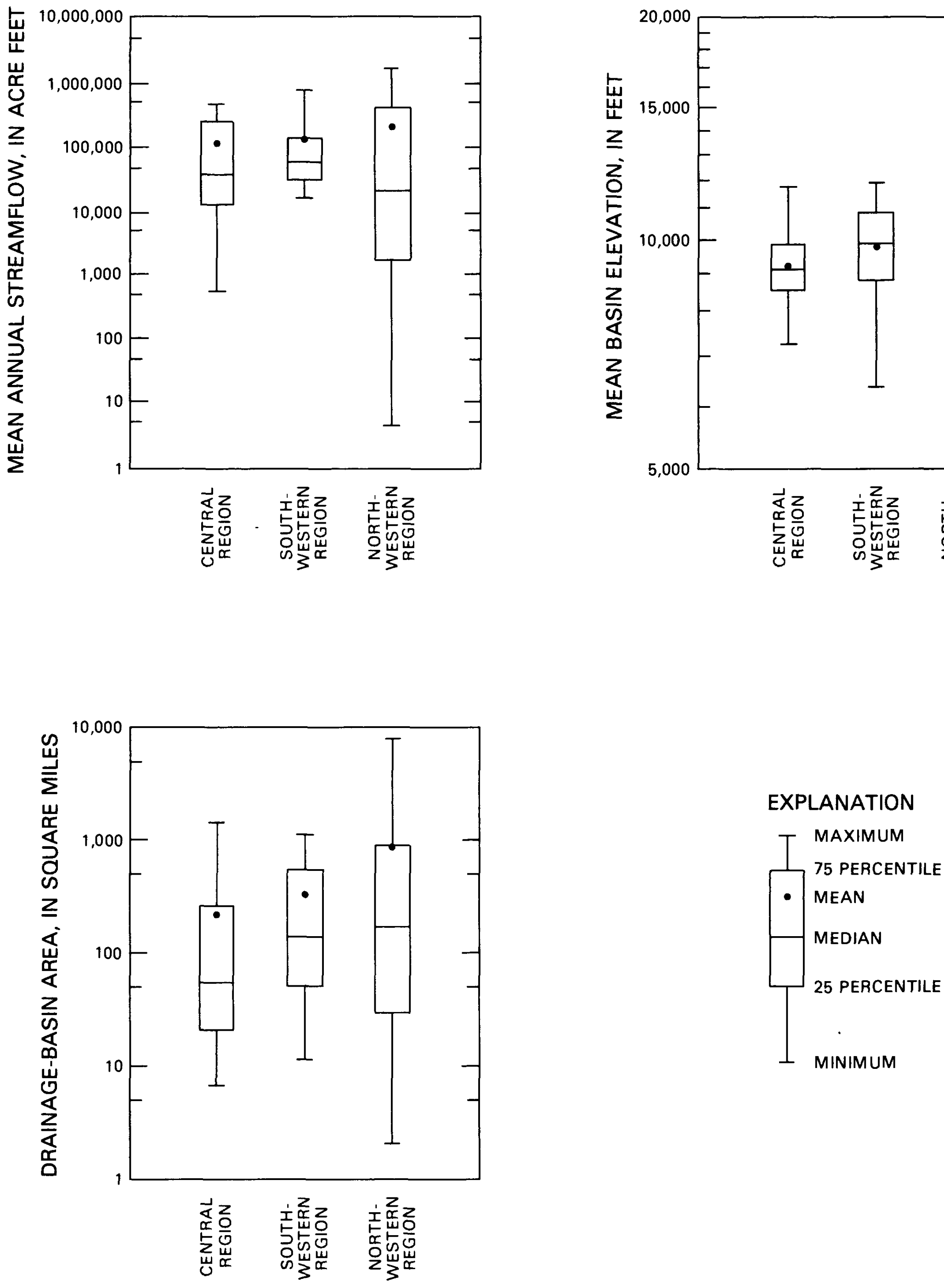

Figure 3.--Range and distribution of geomorphic and hydrologic variables used in regional multiple-regression models.

SUMMARY AND CONCLUSIONS

Streamflow and sediment-discharge data have been collected at numerous streamflow-gaging stations in Colorado; however, many stations have inadequate records to determine mean annual suspended-sediment loads. Mean annual suspended-sediment loads can be estimated for many streams that have inadequate streamflow or suspended-sediment-load data by use of regional multiple-regression models. Regional multiple-regression models were developed with data from 81 streamflow-gaging stations in Colorado. These stations had 5 or more years of streamflow and sediment record and were minimally affected by streamflow regulation.

Mean annual suspended-sediment loads of streams were related to geomorphic and hydrologic variables using stepwise multiple regression. Several geomorphic and hydrologic variables thought to affect mean annual suspended-sediment loads initially were included as independent variables in the analysis. Geomorphic and hydrologic variables that were significantly correlated with other independent variables or that were insignificant (0.95 level) in the initial stepwise multiple-regression models were excluded from the subsequent analysis. Independent variables selected for analysis were drainage basin area, site elevation, mean basin elevation, mean basin-surface slope, lemniscate index, mean annual streamflow, water discharge equaled or exceeded 10 percent of the time, and peak flow with a 10-year recurrence interval.

A multiple-regression model that included the independent variables: mean basin elevation, mean annual streamflow, and drainage-basin area, accounted for 78 percent of the variance in mean annual suspended-sediment loads when all sites in the study area were included in the model. The mean squared error (MSE) was 1.432.

Streamflow characteristics are affected by regional differences in Colorado's geography and climate, and these regional differences also might affect the variation of mean annual suspended-sediment loads. Regionalization involves analysis of mean annual suspended-sediment loads from a geographically unique area and this procedure usually decreases the error of the multiple-regression model. The study area was subdivided into three regions that had sufficient data for analysis (central, northwestern, and southwestern), and multiple-regression models relating mean annual suspended-sediment load to geomorphic and hydrologic variables were developed for each region. The multiple-regression models that had the largest adjusted coefficient of multiple determination (R_a^2) and the smallest MSE for the central, northwestern, and southwestern regions contained the variables mean annual streamflow and mean basin elevation. No other geomorphic or hydrologic variables were significant at the 0.95 level when included with mean annual streamflow and mean basin elevation in the multiple-regression models.

Regionalization of mean annual suspended-sediment loads resulted in improved multiple-regression models based on larger values of R_a^2 and smaller values of MSE. The multiple-regression model for the central region indicated a modest improvement when compared to the multiple-regression model for all sites; this model had a slightly smaller R_a^2 but a much smaller MSE. Multiple-regression models for the northwestern and southwestern regions indicated improvements in the values of R_a^2 and MSE when compared with the multiple-regression model for all sites. Drainage-basin area was not significant at the 0.95 level when included in the three regional multiple-regression models with mean annual streamflow and mean basin elevation.

The multiple-regression models in table 3 can be used to estimate mean annual suspended-sediment loads for sites in the central, northwestern, and southwestern regions of Colorado if mean annual streamflow and mean basin elevation are known. When no streamflow data are available for a site in one of these regions, the multiple-regression models in table 4 can be used to estimate mean annual suspended-sediment load if drainage-basin area is known. Regional multiple-regression models using only drainage-basin area are adequate predictive models, but they do not explain as much variance in mean annual suspended-sediment loads as do the equations that contain mean annual streamflow and mean basin elevation.

REFERENCES CITED

Chorley, R.J., Malm, D.E.G., and Pogorzelski, H.A., 1957, A new standard for estimating drainage basin shape: American Journal of Science, v. 255, no. 2, p. 138-141.

Draper, N.R., and Smith, Harry, 1981, Applied regression analysis (2d ed.): New York, John Wiley and Sons, 709 p.

Elliott, J.G., and DeFeyter, K.L., 1986, Sediment-data sources and estimated annual suspended-sediment loads of rivers and streams in Colorado: U.S. Geological Survey Water-Resources Investigations Report 86-4344, 148 p.

Elliott, J.G., Jarrett, R.D., and Ebling, J.L., 1982, Annual snowmelt and rainfall peak-flow data on selected foothills region streams, South Platte River, Arkansas River, and Colorado River basins, Colorado: U.S. Geological Survey Open-File Report 82-426, 86 p.

Kircher, J.E., Choquette, A.F., and Richter, B.D., 1985, Estimation of natural streamflow characteristics in western Colorado: U.S. Geological Survey Water-Resources Investigations Report 85-4086, 28 p.

Miller, D.M., 1984, Reducing transformation bias in curve fitting: The American Statistician, v. 38, no. 2, p. 124-126.

Neter, John, Wasserman, William, and Kutner, M.H., 1985, Applied linear statistical models--Regression, analysis of variance, and experimental designs, 2d ed.: Homewood, Illinois, Irwin, 1,127 p.

Porterfield, George, 1972, Computation of fluvial-sediment discharge (reprint 1977): U.S. Geological Survey Techniques of Water-Resources Investigations, bk. 3, chap. C3, 66 p.

Richter, B.D., Kircher, J.E., Remmers, M.A., and Forst, B.A., 1984, Summary of basin and streamflow characteristics for selected basins in western Colorado and adjacent States: U.S. Geological Survey Open-File Report 84-137, 266 p.

Troutman, B.M., and Williams, G.P., 1987, Fitting straight lines in the earth sciences, *in* Size, W.B., ed., Use and abuse of statistical methods in the earth sciences: New York, Oxford University Press, p. 107-128.

U.S. Geological Survey, 1983, Unit-values, daily-values, and water-quality data, in WATSTORE (National Water Storage and Retrieval System): Reston, Va., available from WATSTORE Program Office, computer tape.

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