Paul Jordan says method not so good in this report

RELATION OF SEDIMENT YIELD TO CLIMATIC AND PHYSICAL CHARACTERISTICS IN THE MISSOURI RIVER BASIN

U. S. GEOLOGICAL SURVEY

Water – Resources Investigations 79 – 49

RELATION OF SEDIMENT YIELD TO CLIMATIC AND PHYSICAL CHARACTERISTICS IN THE MISSOURI RIVER BASIN

By P. R. Jordan

U.S. GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS 79-49

March 1979

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, SECRETARY

GEOLOGICAL SURVEY

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Open-File Report

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

Factors for converting inch-pound units, used in this report, to metric units and the respective abbreviations are given below to three significant figures.

Inch-pound units	Multiply by	Metric units
Cubic foot per second (ft^3/s)	0.0283	Cubic meter per second (m^3/s)
Foot (ft)	0.305	Meter (m)
Inch (in)	25.4	Millimeter (mm)
Mile (mi)	1.61	Kilometer (km)
Square mile (mi^2)	2.59	Square kilometer (km^2)
Ton (short)	907	Kilogram (kg)
Tons per year (tons/yr)	0.907	Megagrams per year (mg/yr)
Tons per square mile per year [($tons/mi^2$)/yr]	0.350	Megagrams per square kilometer per year [(mg/km^2)/yr]
Pounds per acre per year [(lb/acre)/yr]	0.112	Megagrams per square kilometer per year [(mg/km^2)/yr]

ABSTRACT

Data from 64 stream-sediment stations and reservoirs in the plains area and from 15 stream-sediment stations in the mountainous area were analyzed to determine the relation of sediment yield to basin characteristics. Data from each sediment station and reservoir represented at least 7 years of sediment discharge in the plains area or 4 years of sediment discharge in the mountainous area. Results of the analysis show the approximate relations of sediment yield to basin characteristics in the plains area, but data for the mountainous area are insufficient to show any significant relation.

In the plains area the sediment yield was most closely related to contributing drainage area, mean streamflow, average thickness of loess, and average land slope. A regression equation, using these characteristics, estimates sediment yields with a standard error of +142 percent and -59 percent. The relation of sediment yield to size of drainage area was consistent with the relation found earlier for the upper Mississippi River basin.

INTRODUCTION

Previous methods of estimating sediment yields at unsampled sites in the Missouri River basin occupy two extremes of complexity: (1) soil-loss equations for estimating sheet and rill erosion from individual fields and other very small areas used with delivery ratios for movement of the sediment to a stream location and (2) geographical contouring of data from stream sampling and reservoir surveys, with applicability of results limited by the degree of similarity of stream basins in a given geographic area. The first method requires data that only can be obtained by detailed surveys, including data on individual field slopes, slope lengths, seasonal cropping patterns, and conservation practices. The method gives good results in estimating sheet and rill erosion from fields, but the difficulty of accurately estimating gully and streambank erosion and delivery ratios severely hampers its application to the estimation of sediment yields. The second method fails to account for many of the differences between stream basins and may give biased estimates in areas where sediment-yield data are scarce. The study reported here was undertaken to provide an estimation method using easily measurable characteristics of each individual drainage basin of streams draining 2 mi^2 to 5,000 mi^2.

SELECTION OF SEDIMENT-DISCHARGE DATA FOR ANALYSIS

The search for appropriate sediment-discharge data for this study covered the annual water-resources data reports of the U.S. Geological Survey, other published sources (Committee on Sedimentation, 1972, 1973; Harris, 1962; Hembree and others, 1964; Holland, 1971, Jordan and others, 1964; Kister and Mundorff, 1963; Osterkamp, 1977; Task Force on Sedimentation, 1969), and unpublished summaries of data provided by the U.S. Army Corps of Engineers.

For the purposes of this study, each record of sediment discharge to be used must cover a long enough period of approximately constant land use to reasonably represent an average of the variations in precipitation and runoff. A statistical analysis of the year-to-year variation of sediment discharges at numerous stations in the plains area in and near the Missouri River basin showed that the coefficients of variation (ratio of the standard deviation to the mean) of annual sediment discharges averaged 0.75. After examining the lengths of record available and the relation of standard error of the mean to length of record for a coefficient of variation of 0.75, it was concluded that a minimum record length of 7 years would provide an acceptable combination of accuracy with an adequate number of stations in the plains area.

The 7-year standard for the plains area was applied to data obtained from reservoir resurveys as well as to data from stream-sediment stations having daily or near-daily samples. In addition, reservoir survey data were used only where the specific weight of the deposited sediment had been determined. Trap efficiencies of 75 to 95 percent were estimated, based on particle size of sediment and size of reservoir in relation to inflow.

Although data for the mountainous area are not adequate to determine an average coefficient of variation of annual sediment discharges, evidence suggests that streamflows and sediment discharges are less variable from year to year in the mountains than in the plains. Thus, it was decided, somewhat arbitrarily, to use a minimum record length of 4 years in the mountainous area.

All sediment-discharge data used in this study were chosen to represent either natural, undisturbed conditions or normal agricultural activity. Thus, data were excluded if they were significantly affected by diversions, return flows, strip mining, urbanization, or similar activities. Data at most sites were excluded if they were significantly affected by impoundments. At a few sites downstream from major impoundments, the impoundments were assumed to trap all their sediment inflow, and all the sediment discharge at the site in question was assumed to be derived from the intervening drainage area downstream from the impoundment. Values of other variables used in the analysis then were determined for the same intervening area.

Exclusion of sediment-discharge data affected by diversions and return flows severely limited the number of sites in the mountainous area that had usable data from daily sediment records or reservoir resurveys. Data on average sediment discharges were developed from intermittent samples by determining the relation of "instantaneous" (sampling time of a few minutes) sediment discharge to the concurrent streamflow rate. The relation then was applied to a streamflow-duration curve. This sediment-transport curve method is described by Colby (1956) and Jordan and others (1964, p. 60-63). After developing the data from intermittent sampling, only 15 sites in the mountainous area could be used in this study.

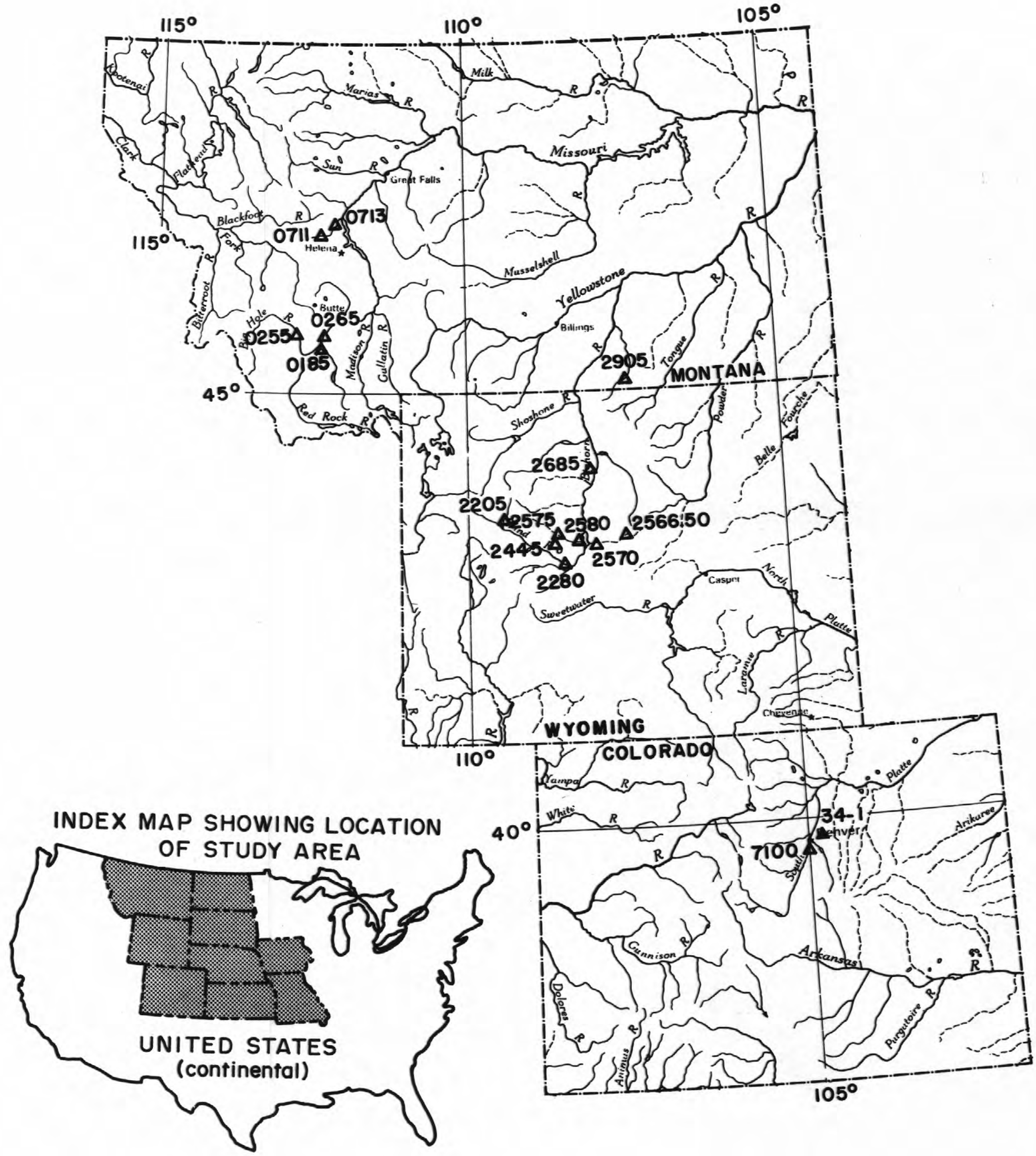
Sediment-discharge records of streams do not include sediment transported on and near the bed of the stream. For most streams the amount not included is a small percentage of the total and has been disregarded in this study. For streams where the amount was known to be significant, an approximate adjustment factor was applied. Sediment surveys of reservoirs include the sediment transported to the reservoir along the streambed, so no adjustment was needed.

Data sites meeting the requirements of this study for both the plains and mountainous areas are shown on figure 1.

Many sites and their data had unique features that did not fit the most common pattern. Extrapolations of many sediment-discharge records were obtained, as noted, from the MRB study (Missouri River Basin Comprehensive Framework Study, Task Force on Sedimentation, 1969). These features and the handling of the data at these sites are explained in the following paragraphs, in downstream order.

05454500 Iowa River at Iowa City, Iowa. Daily sediment-discharge records were available for 1944-70. Reservoir construction began a few miles upstream in late 1956 and probably had an effect on the sediment discharge. Therefore, the sediment-discharge records used were limited to 1944-56.

05455000 Ralston Creek at Iowa City, Iowa. Drainage area was rural until about 1962 when housing construction started. Sediment-discharge records for 1953-61 were used.


115°
110°
105°
115°
45°
40°
110°
105°
MONTANA
WYOMING
COLORADO
Kootenai
Clark
Flathead
Blackfoot
Bitterroot
Big Hole
Marias
Milk
Sun
Missouri
Great Falls
Helena
Butte
Musselshell
Yellowstone
Billings
Madison
Gallatin
Red Rock
Shoshone
Bighorn
Tongue
Powder
Belle Fourche
Sweetwater
North Platte
Casper
Laramie
Cheyenne
Yampa
White
Platte
Arikaree
Denver
Gunnison
Arkansas
Dolores
Purgatoire
0711
0713
0265
0255
0185
2905
2685
2205
2575
2580
2566.50
2445
2570
2280
34-1
7100
INDEX MAP SHOWING LOCATION OF STUDY AREA
UNITED STATES
(continental)

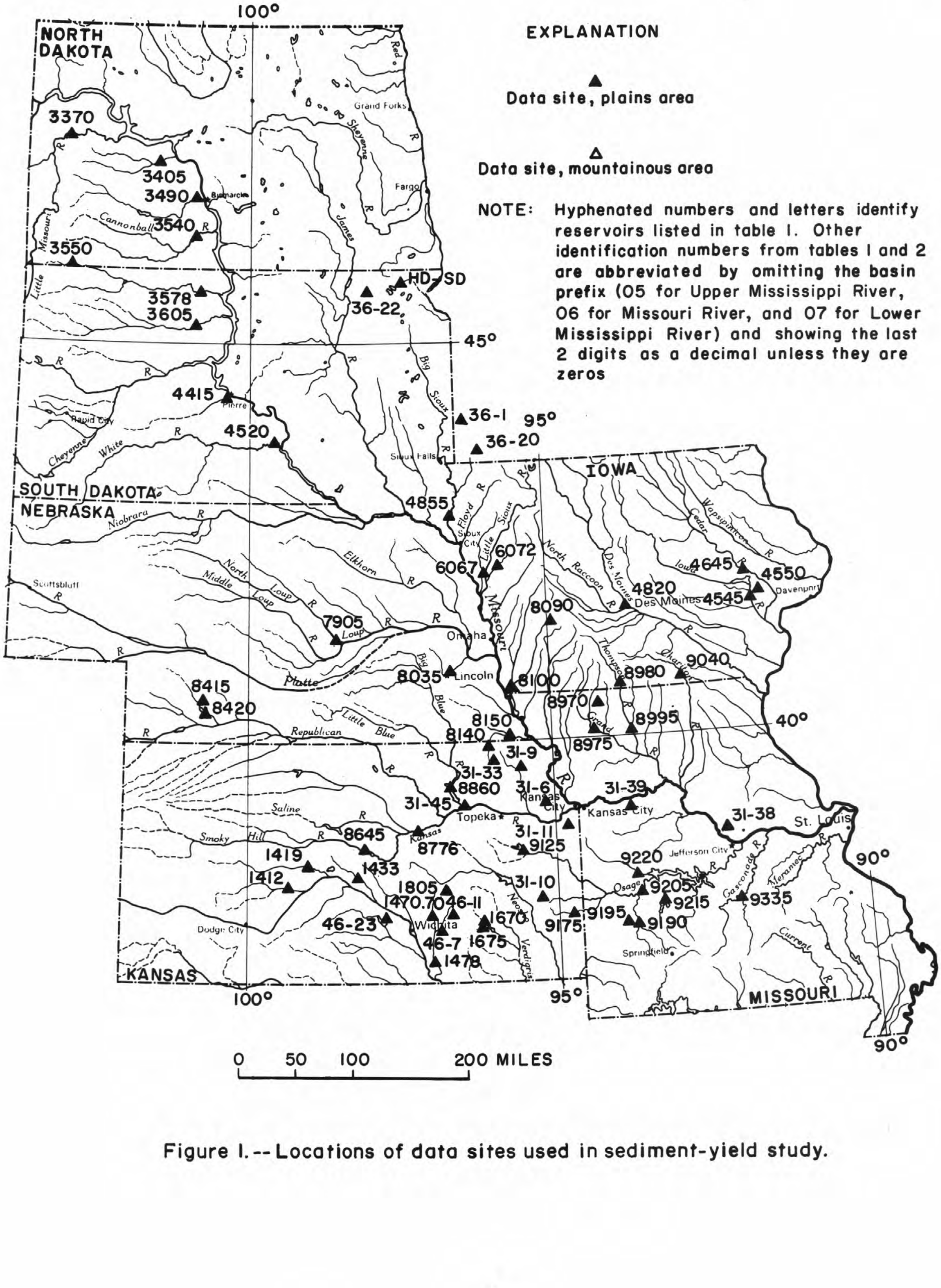


Figure 1.--Locations of data sites used in sediment-yield study.

05482000 Des Moines River at Des Moines, Iowa. Records for the Saylorville station were used 1962-73.

06220500 East Fork Wind River near DuBois, Wyoming. Average sediment discharge for 1950-57 was calculated by sediment-transport curve method using sediment data collected in 1951-53 and streamflow data for 1950-57.

06290500 Little Bighorn River below Pass Creek near Wyola, Montana. Average sediment discharge for 1939-73 was calculated by sediment-transport curve method using sediment data collected in 1970-73 and streamflow data for 1939-73.

06349000 Heart River at Mandan, North Dakota. Sediment-discharge records for 1951-71 represented sediment yield from intervening drainage area between Heart Butte Dam and Mandan. Records available for 1949-50 were omitted to avoid effects of dam construction and first year after completion.

06355000 North Fork Grand River near Haley, North Dakota. Sediment-discharge data for 1962-66 were from near-daily records, and data for 1947-60 were calculated by the sediment-transport curve method based on intermittent sampling in 1951-52.

06357800 Grand River at Little Eagle, South Dakota. Records for the Wakpala station were used 1948-51 and 1958-62. Sediment-discharge records represent sediment yield from intervening drainage area between Shadehill Reservoir and the Little Eagle and Wakpala stations.

06360500 Moreau River near Whitehorse, South Dakota. Records for the Promise station were used 1948-51 and 1958.

06607200 Maple River at Mapleton, Iowa. Average sediment discharge was based on daily records for 1940-51 with extrapolation through 1963 as given in the MRB study. The basin now contains numerous detention structures, but most were not in existence during the period of sediment sampling, 1940-51.

06790500 North Loup River near St. Paul, Nebraska. Sediment-discharge records were available for only 6 years, but the data were used because of the unusually low variability. The published sediment discharges were increased by 25 percent to account for sediment transported on and near the streambed. It was assumed that the records represented sediment discharge from only the area contributing directly to surface runoff, and the mean streamflow was from the intervening area between the Taylor and St. Paul gaging stations.

06803500 Salt Creek at Lincoln, Nebraska. Sediment-discharge records used represented conditions prior to construction of reservoirs in the basin.

06809000 Davids Creek near Hamlin, Iowa. Four detention structures in a small part of the basin had slight effect on sediment discharge at the station.

06810000 Nishnabotna River above Hamburg, Iowa. Average sediment discharge was based on daily records for 1940-51 with extrapolation to 1952-63 as given in the MRB study.

06814000 Turkey Creek near Seneca, Kansas. Average sediment discharge was based on daily records for 1950-54 with extrapolation for 1948-49 and 1955-63 as given in the MRB study.

06815000 Big Nemaha River at Falls City, Nebraska. Average sediment discharge was based on daily records for 1950-67 with extrapolation for 1948-49 as given in the MRB study.

06841500 Mitchell Creek above Harry Strunk Lake, Nebraska. Average sediment discharge was based on daily records for 1952-57 and monthly relation of sediment discharge to streamflow for 1958-72.

06864500 Smoky Hill River at Ellsworth, Kansas. Sediment-discharge records represented yield from intervening drainage area between Cedar Bluff Reservoir and Ellsworth.

06877600 Smoky Hill River at Enterprise, Kansas. Sediment-discharge records represented yield from intervening drainage area between five reservoirs and Enterprise.

06897000 East Fork Big Creek near Bethany, Missouri. Average sediment discharge was based on daily records for 1949-59 with extrapolation for 1948 and 1960-63 as given in the MRB study.

06897500 Grand River near Gallatin, Missouri. Average sediment discharge was based on daily records for 1948-51 with extrapolation for 1952-63 as given in the MRB study.

06898000 Thompson River at Davis City, Iowa. Average sediment discharge was based on daily records for 1950-54 with extrapolation for 1948-49 and 1955-63 as given in the MRB study.

06899500 Thompson River at Trenton, Missouri. Average sediment discharge was based on daily records for 1943-51 with extrapolation through 1963 as given in the MRB study.

06904000 Chariton River near Centerville, Iowa. Average sediment discharge was based on daily records for 1950-54 with extrapolation for 1948-49 and 1955-63 as given in the MRB study.

06912500 Hundred and Ten Mile Creek near Quenemo, Kansas. Average sediment discharge was based on daily records for 1949-54 with extrapolation for 1948 and 1955-63 as given in the MRB study. Data represented conditions prior to construction of reservoir at site.

06917500 Marmaton River near Fort Scott, Kansas. Average sediment discharge was based on daily records for 1950-54 with extrapolation for 1948-49 and 1955-63 as given in the MRB study.

06919000 Sac River near Stockton, Missouri. Average sediment discharge was based on daily records for 1950-54 with extrapolation for 1948-49 and 1955-63 as given in the MRB study.

06919500 Cedar Creek near Pleasant View, Missouri. Average sediment discharge was based on daily records for 1950-53 with extrapolation for 1949 and 1954-63 as given in the MRB study.

06920500 Osage River at Osceola, Missouri. Average sediment discharge was based on daily records for 1943-51 with extrapolation through 1963 as given in the MRB study.

06921500 Pomme de Terre River at Hermitage, Missouri. Average sediment discharge was based on daily records for 1943-51 with extrapolation through 1961 as given in the MRB study.

06922000 South Grand River near Brownington, Missouri. Average sediment discharge was based on daily records for 1943-51 with extrapolation through 1963 as given in the MRB study.

06933500 Gasconade River at Jerome, Missouri. Average sediment discharge was based on daily records for 1943-51 with extrapolation through 1963 as given in the MRB study.

DRAINAGE-BASIN CHARACTERISTICS

Selection of drainage-basin characteristics for use in this study was governed by several considerations including ease of determination for large basins and significance of the characteristic as indicated by previous studies (Agricultural Research Service, 1975; Anderson, 1954; Flaxman, 1972; Hindall, 1975; Osterkamp, 1977; Pacific Southwest Inter-Agency Committee, 1968; Schumm and Hadley, 1961; Scott and others, 1968; Wischmeier and Smith, 1965). Practical use of a method of estimating sediment yield demands that each basin characteristic used can be determined for fairly large basins without extensive field work or low-level aerial photography. For many basins, detailed topographic mapping has not been completed for part of the drainage area, so sampling methods were applied to the drainage area covered by detailed maps, and it was assumed that the remaining drainage area did not differ significantly in its characteristics. Careful consideration was given to the characteristics found to be significant in earlier studies. In this study as many of the same characteristics as practical were used; however, some similar characteristics were determined that were more practical for the sizes of basins. Some characteristics indicated to be significant by earlier studies were not used because they could not be determined for all of the basins from available information.

The following paragraphs describe the climatic and physical characteristics used in this study. Capitalized abbreviations in parentheses are the symbols used in subsequent tables and equations.

Climatic Characteristics

Mean annual precipitation (PREC), in inches, was determined from National Oceanic and Atmospheric Administration (formerly the U.S. Weather Bureau) series, "Climates of the States."

Rainfall erosion index (REI), was determined from the report by Wischmeier and Smith (1965, fig. 1) for the plains region only, with slight extrapolation for a few locations in Montana, Wyoming, and Colorado.

Physical Characteristics

Contributing drainage area (AREA), in square miles, is the drainage area that contributed surface runoff and sediment to the site. For a site downstream from a major reservoir, the reservoir was assumed to trap nearly all of the sediment inflow, and the contributing drainage area was the intervening area between the reservoir and the site.

Mean streamflow (FLOW), in cubic feet per second, is the mean for the period of record of sediment discharge, if available. For most stream-sediment stations, the streamflow was recorded by a gaging station at the same site. For most of the lakes and ponds having sediment surveys, the mean streamflow was estimated from regional relationships. For a site downstream from a major reservoir, the mean streamflow was the recorded or estimated flow from the intervening area between the reservoir and the site.

Average thickness of loess (LSTH), in feet, was approximated from a map showing loess deposits of the United States (Geological Society of America, 1952).

Loess cover 2 feet (LSPCT), in percentage, is the amount of the basin area that is covered by at least 2 feet of loess, approximated from the same map used for average thickness of loess.

Average land slope (LANDSL), in feet per foot, was determined in only the plains area from topographic maps at a random sample of points in the basin. At each point on a map the slope was determined for a line approximately normal to the nearest contour lines and spanning the interval from the contour line above to the contour line below the point. The sample size was adjusted according to the variability of slopes in the basin to give a standard error no larger than 15 percent of the average slope.

Average overland distance (OVDIST), in feet, is an index of the average length of overland flow in the basin. It was determined in only the plains area from the same random sample of points used for average land slope by measuring the straight line distance to the nearest stream channel shown on the topographic map. The result is an index, rather than a true length of overland flow, because many small stream channels are not shown on the topographic maps, and the distance was measured on a straight-line rather than an actual-flow path.

Cropland (CROP), in percent, is the percentage of the basin area used for row crops (determined in only the plains area). It did not include hay or grass. The percentages for most basins were estimated from ERTS images or from State land-use maps based on ERTS images for Kansas, Nebraska, and South Dakota. For a few small basins, the percentages were obtained by the author's observations.

The cropland data available may not represent accurately the percentage of each basin that had row crops during the period of sediment record. The cropland data available for each basin generally represented conditions in only a single year, which may not have been during the period of sediment record. Some land-use maps did not separate row crops from other kinds of crops, such as hay. Remotely sensed images from a satellite are difficult to interpret in terms of row crops, particularly where small fields of row crops are interspersed with other types of land use. For the few basins that had more than one source of cropland data, differences were as large as 30 percentage points. Cropland data in this report do not reflect differences in farming practices, such as terracing, which probably have large influence on sediment yields.

Average basin elevation (ELEV), in feet above National Geodetic Vertical Datum of 1929, was approximated from topographic maps for the mountainous area only.

The data used in this study are listed in table 1 for the plains area and table 2 for the mountainous area.

Table 1.--Basin characteristics and sediment yields at selected sediment stations

Station identification number	Station name	Total drainage area (mi^2)	Contr. drainage area (mi^2)	Mean annual precip. (in)	Mean stream-flow (ft^3/s)
05454500	Iowa R. at Iowa City, IA	3,271	3,271	32.0	1,540
05455000	Ralston Cr. at Iowa City, IA	3.01	3.01	32.1	1.31
05464500	Cedar R. at Cedar Rapids, IA	6,640	6,510	31.3	3,640
05482000	Des Moines R. at Des Moines, IA	6,000	6,000	28.7	1,900
06337000	Little Missouri R. nr Watford City, ND	8,310	8,310	14.2	505
06340500	Knife R. at Hazen, ND	2,240	2,240	15.8	163
06349000	Heart R. at Mandan, ND	3,310	1,600	15.9	109
06354000	Cannonball R. at Breien, ND	4,100	4,100	15.6	247
06355000	N. Fk. Grand R. nr Haley, ND	509	509	14.0	32.8
06357800	Grand R. at Little Eagle, SD	5,370	2,250	14.4	116
06360500	Moreau R. nr Whitehorse, SD	4,880	4,880	14.1	243
06441500	Bad R. nr Fort Pierre, SD	3,107	3,107	16.3	180
06452000	White R. nr Oacoma, SD	10,200	10,200	17.0	592
06485500	Big Sioux R. at Akron, IA	9,030	7,060	23.7	1,140
06606700	Little Sioux R. nr Kennebec, IA	2,738	2,738	27.6	783
06607200	Maple R. at Mapleton, IA	669	669	27.3	233
06790500	N. Loup R. nr St. Paul, NE	4,460	1,270	23	512
06803500	Salt Cr. at Lincoln, NE	684	684	28.0	208
06809000	Davids Cr. nr Hamlin, IA	26.0	26.0	31.0	9.87
06810000	Nishnabotna R. ab Hamburg, IA	2,806	2,800	30.6	1,080
— 06814000	Turkey Cr. nr Seneca, KS Nemaha	276	276	30.9	160
06815000	Big Nemaha R. at Falls City, NE	1,340	1,340	31.7	658
06841500	Mitchell Cr. ab Harry Strunk Lake, NE	52	52	21.5	2.44
06842000	Harry Strunk Lake, nr Cambridge, NE	880	640	21.2	84
06864500	Smoky Hill R. at Ellsworth, KS	7,580	2,050	22.5	273
06877600	Smoky Hill R. at Enterprise, KS	19,260	6,969	24	926
06886000	Big Blue R. at Randolph, KS	9,100	9,100	26.0	2,240
06897000	East Fork Big Cr. nr Bethany, MO	95	95	34.0	46.9
06897500	Grand R. nr Gallatin, MO	2,250	2,250	34.0	1,060
06898000	Thompson R. at Davis City, IA	701	701	31.7	391
06899500	Thompson R. at Trenton, MO	1,670	1,670	34.0	1,010

and reservoirs in the plains area.

Rainfall erosion index	Avg. thickness of loess (ft)	Loess cover 2 ft (percent)	Avg. land slope (ft/ft)	Avg. overland dist. (ft)	Cropland (pct)	Period of sed. record used	Source of sed. data (1)	Avg. annual sed. disch. (tons)	Avg. annual sed. yield (tons/mi^2)
165	11	60	0.054	740	80	1944-56	A	1,160,000	355
175	28	100	.071	620	85	1953-61	A	5,620	1,870
170	2.4	90	.035	700	70	1944-54	A	887,000	136
155	.1	1	.025	1,230	85	1955-73	A	947,000	158
40	0	0	.24	720	20	1949-71	B	6,920,000	833
50	0	0	.068	790	70	1949-68	B	156,000	69.6
60	0	0	.072	860	70	1951-71	B	336,000	210
60	0	0	.037	880	80	1949-51,1959-71	B	493,000	120
50	0	0	.081	1,490	40	1951-52,1962-66	C,B	27,000	53.0
60	0	0	.067	1,060	30	1948-51,1958-71	B	629,000	280
60	0	0	.086	510	20	1948-51,1958, 1960-71	B	2,400,000	492
65	0	0	.083	690	30	1948-71	B	3,870,000	1,250
65	.5	20	.17	680	40	1940-71	B	12,800,000	1,250
125	16	100	.053	1,020	95	1941-51	B	1,120,000	159
155	8.3	80	.020	1,090	85	1940-63	D	2,270,000	829
160	26	100	.066	740	85	1940-51	D	1,790,000	2,680
125	50	90	.12	700	35	1947-52	A	1,800,000	1,420
155	5	80	.082	760	50	1950-59	E	1,860,000	2,720
170	24	100	.085	820	85	1953-68	A	33,800	1,300
175	30	100	.074	630	85	1940-51	D	11,700,000	4,180
185	2	50	.076	645	60	1950-54	D	670,000	2,430
170	6	60	.058	758	50	1950-67	D	4,980,000	3,720
110	30	100	.11	870	60	1952-57	A	55,000	1,060
110	30	100	.11	770	50	1949-62	F	350,000	547
150	4	50	.027	630	70	1951-67	G	881,000	430
155	4	70	.039	700	55	1958-72	A	2,660,000	382
160	12	70	.059	750	60	1949-59	G	8,140,000	894
190	6.0	50	.093	1,120	80	1949-59	D	84,000	884
200	6	50	.067	790	75	1948-51	D	4,700,000	2,090
185	11.9	50	.13	920	85	1950-54	D	1,000,000	1,430
200	4	50	.11	710	80	1943-51	D	6,200,000	3,710

Table 1.--Basin characteristics and sediment yields at selected sediment stations

Station identification number	Station name	Total drainage area (mi^2)	Contr. drainage area (mi^2)	Mean annual precip. (in)	Mean stream-flow (ft^3/s)
06904000	Chariton R. nr Centerville, IA	708	708	33.5	252
06912500	Hundred and Ten Mile Cr nr Quenemo, KS	321	321	34.7	152
06917500	Marmaton R. nr Ft. Scott, KS	411	411	39.4	290
06919000	Sac R. nr Stockton, MO	1,160	1,160	40.0	853
06919500	Cedar Cr. nr Pleasant View, MO	420	420	40.0	272
06920500	Osage R. at Osceola, MO	8,220	8,220	38.0	3,940
06921500	Pomme de Terre R. at Hermitage, MO	655	655	42.0	511
06922000	S. Grand R. nr Brownington, MO	1,660	1,660	38.0	1,200
06933500	Gasconade R. at Jerome, MO	2,840	2,840	42.0	2,600
07141200	Pawnee R. nr Larned, KS	2,148	2,010	19.8	67.9
07141900	Walnut Cr. at Albert, KS	1,410	1,306	22.0	39.1
07143300	Cow Cr. nr Lyons, KS	728	499	23.5	67.8
07147070	Whitewater R. at Towanda, KS	426	426	34	198
07147800	Walnut R. at Winfield, KS	1,872	1,872	31.7	931
07167000	Fall R. nr Eureka, KS	307	307	33.0	179
07167500	Otter Cr. at Climax, KS	129	129	33.0	68.6
07180500	Cedar Cr. nr Cedar Point, KS	110	110	31.2	52.5
SCS 31-6	Leavenworth County St. Lake, KS	3.83	3.56	35	1.8
SCS 31-10	Moran Lake nr Moran, KS	5.35	5.28	38	3.5
SCS 31-11	Lake Olathe nr Olathe, KS	6.20	6.11	35.5	3.6
SCS 31-45	Lake Elbo nr Manhattan, KS	3.20	3.14	31.1	.86
SCS 34-1	Castlewood Res. nr Denver, CO	167.2	166.9	14	19
SCS 36-1	Split Rock Res. nr Ihlen, MN	41.3	41.1	24	7.3
SCS 36-20	Lake Okabena nr Worthington, MN	17.40	16.27	26.8	12.6
SCS 36-22	Richmond Lake nr Aberdeen, SD	82	73.5	18	7.1
SCS 46-7	Sante Fe Res. nr Augusta, KS	37.93	37.55	31	19
SCS 46-11	Lake El Dorado nr El Dorado, KS	35.1	34.3	32	18
SCS 46-23	Nichlaus Pond nr Haven, KS	2.29	2.27	29	.48
SCS HD-SD	Hickman Dam nr Britton, SD	10.37	8.2	19	.18

and reservoirs in the plains area--continued.

Rainfall erosion index	Avg. thickness of loess (ft)	Loess cover 2 ft (percent)	Avg. land slope (ft/ft)	Avg. overland dist. (ft)	Crop-land (pct)	Period of sed. record used	Source of sed. data (1)	Avg. annual sed. disch. (tons)	Avg. annual sed. yield (tons/mi^2)
185	6	50	.084	820	85	1950-54	D	360,000	508
220	1	20	.034	730	55	1949-54	D	340,000	1,060
240	2	30	.040	850	65	1950-54	D	188,000	457
240	1	20	.061	1,170	60	1950-54	D	165,000	142
240	1	20	0.034	800	60	1950-53	D	92,300	220
235	1.5	30	.048	580	70	1943-51	D	3,100,000	377
235	1	20	.071	810	85	1943-51	D	191,000	292
225	3	50	.043	820	80	1943-51	D	820,000	494
230	1	20	.12	150	25	1943-51	D	390,000	137
130	3	50	.026	910	55	1958-73	H	155,000	77.1
130	3	50	.031	800	60	1964-72	H	88,000	67.4
160	3.0	50	.017	620	65	1960-72	H	79,700	160
220	1.5	20	.026	630	50	1962-73	H	600,000	1,410
225	1	20	.031	590	35	1962-71	A	830,000	443
235	.5	20	.081	640	15	1954-73	H	110,000	358
235	.5	40	.056	560	25	1953-73	H	40,100	311
220	.5	20	.034	570	20	1940-73	H	53,400	485
210	4	50	.10	1,080	17	1931-47	F	13,000	3,650
240	4	33	.027	660	40	1913-39	F	3,000	568
215	12	100	.023	950	35	1932-49	F	19,000	3,110
185	3	30	.085	710	8	1949-65	F	3,300	1,050
50	4	65	.057	640	5	1890-1933	F	31,000	186
120	4	50	.026	980	85	1938-49	F	23,000	560
135	3	50	.027	1,370	77	1897-1963	F	11,000	676
80	0	0	.024	3,010	18	1937-69	F	35,000	476
225	1	30	.019	610	35	1928-37	F	24,000	639
225	1	30	.019	710	10	1928-37	F	23,000	671
180	0	0	.047	660	84	1932-67	F	840	370
85	1	30	.018	1,750	90	1939-58	F	1,400	171

Table 1.--Basin characteristics and sediment yields at selected sediment stations

Station identification number	Station name	Total drainage area (mi²)	Contr. drainage area (mi²)	Mean annual precip. (in)	Mean stream-flow (ft³/s)
ARS 31-9	Mission Lake nr Horton, KS Brown	8.15	7.76	32.4	3.5
ARS 31-33	Sabetha Lake nr Sabetha, KS Nemaha	9.17	8.99	31	3.3
ARS 31-38	Ashland Res. nr Ashland, MO	3.78	3.75	38.4	2.7
ARS 31-39	Higginsville Old City Lake nr Higginsville, MO	2.73	2.63	37	1.6

(1) Sources of sediment data:

A. U.S. Geological Survey, annual data reports
B. U.S. Army Corps of Engineers, Omaha District, unpublished summary
C. Hembree and others, 1964
D. Task Force on Sedimentation, 1969
E. Kister and Mundorff, 1963, p. 21
F. Committee on Sedimentation, 1972
G. U.S. Army Corps of Engineers, Missouri River Division
H. Osterkamp, 1977.

and reservoirs in the plains area--continued.

Rainfall erosion index	Avg. thickness of loess (ft)	Loess cover 2 ft (percent)	Avg. land slope (ft/ft)	Avg. overland dist. (ft)	Cropland (pct)	Period of sed. record used	Source of sed. data (1)	Avg. annual sed. disch. (tons)	Avg. annual sed. yield (tons/mi^2)
187	6	67	.051	870	70	1924-67	F	25,000	3,220
187	3	67	.055	580	52	1936-60	F	44,000	4,890
217	8	65	.034	700	25	1937-68	F	5,500	1,470
215	5.5	67	.062	1,680	35	1924-64	F	7,300	2,770

Table 2.--Basin characteristics and sediment yields at selected sediment stations in the mountainous area.

Station identification number	Station name	Total drainage area (mi^2)	Contr. drainage area (mi^2)	Mean annual precip. (in)	Mean streamflow (ft^3/s)	Avg. thickness of loess (ft)	Loess cover 2 ft (percent)	Avg. basin elev. (ft)	Period of sed. record used	Source of sed. data (1)	Avg. annual sed. disch. (tons)	Avg. annual sed. yield (tons/mi^2)
06018500	Beaverhead R. at Twin Bridges, MT	3,619	3,619	12	397	0	0	6,770	1962-69	A	26,700	7.4
06025500	Big Hole R. nr Melrose, MT	2,476	2,476	12	1,220	0	0	7,140	1957, 1960-64	A	26,900	10.9
06026500	Jefferson R. nr Twin Bridges, MT	7,632	7,632	12	1,810	0	0	6,580	1957-59, 1962, 1965-69	A	99,200	13.0
06071100	Little Prickly Pear Cr. at Sieben Ranch nr Wolf Cr., MT	270	270	12	67.0	0	0	5,090	1962-67	A	6,550	24.3
06071300	Little Prickly Pear Cr. at Wolf Cr., MT	381	381	14	112	0	0	5,200	1962-67	A	21,400	56.2
06220500	E. Fk. Wind R. nr Dubois, WY	439	439	14	322	0	0	8,420	1951-53	A	346,000	788
06228000	Wind R. nr Riverton, WY	2,309	2,309	9	774	0	0	7,860	1949-56	A	458,000	198
06244500	Fivemile Cr. nr Pavillion, WY	118	118	11	1.68	0	0	6,520	1953-58, 1964-68	A	6,690	56.7
06256650	Badwater Cr. at Lysite, WY	415	415	10	18.6	0	0	6,530	1965-70	A	344,000	829
06257000	Badwater Cr. nr Bonneville, WY	808	808	9	22.8	0	0	6,200	1948-60, 1964-69	A	517,000	640
06257500	Muddy Cr. nr Pavillion, WY	267	267	11	5.00	0	0	6,860	1948-58, 1960-63, 1966-68	A	117,000	438
06258000	Muddy Cr. nr Shoshoni, WY	332	332	9	18.4	0	0	7,090	1948-68	A	245,000	738
06268500	Fifteen Mile Cr. nr Worland, WY	518	518	10	10.7	0	0	7,100	1950-69	A	659,000	1,270
06290500	Little Bighorn R. bl Pass Cr. nr Wyola, MT	428	428	18	276	0	0	5,250	1970-73	A	64,000	150
06710000	S. Platte R. at Littleton, CO	3,069	3,069	15	341	0	0	8,290	1942-48	B	388,000	126

(1) Sources of sediment data:

A. U.S. Geological Survey, annual data reports
B. U.S. Army Corps of Engineers, Missouri River Division.

ANALYSIS AND RESULTS

The standard least-squares multiple-regression technique was used in the analysis. The technique, which is described in numerous statistics texts, has been applied widely in hydrology, including studies of sediment yield (Anderson, 1954; Flaxman, 1972; Hindall, 1975; Scott and others, 1968). In order to achieve a nearly linear relationship between sediment discharge (abbreviated QSED in subsequent tables) or sediment yield (abbreviated SEDYLD) and basin characteristics, the numbers were converted to their logarithmic equivalents. The resulting linear regression model is of the form:

$$\log Y = \log a + b_1 \log X_1 + b_2 \log X_2 + \ldots + b_k \log X_k ,$$

which is equivalent to

$$Y = a X_1^{b_1} X_2^{b_2} \ldots X_k^{b_k} ,$$

in which

Y is the regression estimate;
a is a constant determined by the statistical analysis;
$X_1, X_2, \ldots X_k$ are drainage-basin characteristics;
$b_1, b_2, \ldots b_k$ are exponents determined by the statistical analysis.

Regressions were computed for the plains and mountainous areas separately and then for the combined areas. However, all the basin characteristics were not available for all the basins in both areas (for example, REI is not available for the mountainous basins). In the plains area the average basin elevations were roughly estimated to the nearest 1,000 feet and are not shown on table 1.

Some of the statistical properties of the variables are shown in tables 3-5. The correlation matrices show that one pair of basin characteristics (REI and PREC in the plains area) are so closely related that one could be used as effectively as the other in a regression. Tables 4 and 5 show correlation coefficients between the logarithms of the variables; for most variables, the correlations of the logarithms are higher than the correlations of the unaltered variables.

Table 3.--Means and standard deviations of variables.

Symbol	Variable	Plains area Mean	Plains area Standard deviation	Mountainous area Mean	Mountainous area Standard deviation
PREC	Mean annual precipitation (in)	28.3	7.99	11.9	2.53
REI	Rainfall erosion index	163	60.9	--	--
AREA	Contributing drainage area (mi^2)	1,826	2,572	1,539	2,046
FLOW	Mean streamflow (ft^3/s)	489	806	360	527
LSTH	Average thickness of loess (ft)	6.37	9.79	0	0
LSPCT	Loess cover, 2 feet or more (percent)	45.1	32.1	0	0
LANDSL	Average land slope (ft/ft)	.0619	.0390	--	--
OVDIST	Average overland distance (ft)	844	388	--	--
CROP	Cropland (percent)	54.9	25.4	--	--
ELEV	Average basin elevation (ft)	1,300	525	6,730	1,020
QSED	Average sediment discharge (tons/yr)	1,388,000	2,643,000	220,400	214,900
SEDYLD	Average sediment yield [($tons/mi^2$)/yr]	1,084	1,180	356	401

Table 4.--Correlation matrix for logarithms of variables in plains area.

	PREC	REI	AREA	FLOW	LSTH[1/]	LSPCT[2/]	LANDSL	OVDIST	CROP	QSED	SEDYLD
SEDYLD	0.355	0.327	-0.347	-0.184	0.483	0.410	0.273	-0.030	0.001	0.116	1.000
QSED	-.154	-.163	.891	.886	.059	-.026	.347	-.247	.217	1.000	
CROP	.207	.167	.204	.235	.275	.172	-.087	.180	1.000		
OVDIST	-.190	-.229	-.220	-.310	-.043	-.156	-.173	1.000			
LANDSL	-.150	-.265	.203	.193	.130	-.086	1.000				
LSPCT[2/]	.562	.607	-.211	.024	.835	1.000					
LSTH[1/]	.331	.348	-.165	-.047	1.000						
FLOW	.045	.024	.921	1.000							
AREA	-.308	-.303	1.000								
REI	.963	1.000									
PREC	1.000										

[1/] Logarithm of (LSTH + 0.5)

[2/] Logarithm of (LSPCT + 1.0)

Table 5.--Correlation matrix for logarithms of variables in mountainous area.

	PREC	AREA	FLOW	ELEV[1/]	QSED	SEDYLD
SEDYLD	-0.338	-0.480	-0.526	0.278	0.744	1.000
QSED	-.325	.229	.031	.592	1.000	
ELEV[1/]	-.308	.373	.114	1.000		
FLOW	.412	.806	1.000			
AREA	.065	1.000				
PREC	1.000					

[1/] Logarithm of (ELEV minus 4000).

For each set of data (plains, mountains, and combined areas), regressions were first computed using all available drainage-basin characteristics as the independent variables and average yearly sediment discharge (QSED), in tons per year, as the dependent variable. These regressions showed that the most significant variables were contributing drainage area, average streamflow, average thickness of loess, average land-surface slope, and average elevation. Regressions using only one of each pair of closely related variables showed that loess area, average annual precipitation, and REI are also significant (80-percent level or better). Flood-frequency data were not available for all stations in either area and are not given in this report. For plains-area stations where the data were available, the flood flow having a 50-percent chance of exceedance had a close correlation with the average streamflow and was significant when used in a regression instead of using the average streamflow.

Regressions also were computed using sediment yield (SEDYLD, equal to QSED divided by AREA), in tons per square mile per year, as the dependent variable. Results of regressions with the most significant combinations of independent variables are given in table 6. The results are shown stepwise with the single most significant independent variable first, proceeding to the combination for which the addition of another variable would give no significant improvement.

DISCUSSION OF RESULTS

Accuracy of predicting sediment discharge or sediment yield, as indicated by the standard error of estimate, falls far short of the accuracy that can be attained for many other hydrologic variables, such as mean streamflow and flood-frequency discharges. For the plains area, the standard error of estimate of +142 percent and -59 percent means that where the regression equation shows a sediment yield (SEDYLD) of 1,000 (tons/mi^2)/yr for a particular basin, there is a 32-percent chance that the actual sediment yield exceeds 2,420 (142 percent higher) or is less than 410 (59 percent lower). The even larger standard errors for the mountainous area mean that, although the regressions shown are statistically significant, the estimates produced are little better than simply using the mean of the 15 QSED or SEDYLD values for the estimates.

It should be noted that the regression equations for QSED and SEDYLD in the plains area are equivalent beyond the first step, since SEDYLD is equal to QSED divided by AREA. Both forms are provided for convenience in directly calculating predicted values of whichever dependent variable is of most interest to the user. Note that SEDYLD has an inverse relation to AREA; the exponents of -0.125 and -0.156 for AREA are consistent with findings from other studies and provide independent confirmation by a different method of analysis. An exponent of -0.20 has been in widespread use by the Soil Conservation Service (Holeman, 1975). This study for the Missouri River basin most closely confirms the relation for the adjoining upper Mississippi River basin, where an exponent of -0.12 was found to apply (Interagency Task Force on Sedimentation, 1970, p. G-27, G-30, fig. G-14).

Table 6.--Constants and exponents for regression equations.

(Equation of the form $Y = a X_1^{b_1} X_2^{b_2} \ldots.$)

Dependent variable Y	Constant a	Exponent b for indicated basin characteristic: AREA	FLOW	LSTH +0.5	LANDSL	ELEV minus 4,000	Standard error of estimate: log units	Percent (+)	Percent (-)
P L A I N S A R E A									
QSED	1,510	0.842	--	--	--	--	0.473	197	66
	789	.875	--	0.399	--	--	.424	165	62
	5,240	.844	--	.354	0.563	--	.402	152	69
	7,780	.561	0.309	.288	.579	--	.384	142	59
SEDYLD	363	--	--	.440	--	--	.442	177	64
	789	-.125	--	.399	--	--	.424	165	62
	5,240	-.156	--	.354	.563	--	.402	152	60
	7,780	-.439	.309	.288	.579	--	.384	142	59
M O U N T A I N O U S A R E A									
QSED	0.00582	--	--	--	--	2.126	0.574	279	74
SEDYLD	13,400	-0.699	--	--	--	--	.693	393	80
	.00592	-.987	--	--	--	2.112	.598	296	75
P L A I N S A N D M O U N T A I N O U S A R E A S									
QSED	1,660	0.783	--	--	--	--	0.579	279	74
	784	.841	--	0.499	--	--	.505	220	69
	16,100	.863	--	.378	--	-0.411[1/]	.497	212	68

[1/] Exponent for ELEV rather than (ELEV minus 4,000).

The lack of statistical significance of the percentage cropland (CROP) may be due partly to the inaccuracy of data on percentage cropland and partly to the wide variation in erosion rates and sediment yields for different crops and different conservation practices. The large variation in sediment yields for rangeland in varying conditions also may influence the results. An illustration of the variations can be seen in the results of small-area studies near Chickasha, Oklahoma, reported by Rhoades, Welch, and Coleman (1975), where sediment yields from seven cropland watersheds ranged from 448 to 2,652 (lb/acre)/yr, and yields from four rangeland watersheds ranged from 54 to 11,900 (lb/acre)/yr. In the study presented here, it was impractical to differentiate between different kinds of row crops, conservation practices, and between rangeland and pasture.

Limits of Definition

When a regression equation is developed from a set of data, a "residual" is the amount by which the observed value of the dependent variable differs from the value calculated by the regression equation. Study of residuals is an important part of the use of statistical-regression technique. In the current investigation, the residuals at each step of the stepwise regressions were plotted against each independent variable. This plotting revealed that there were no significant nonlinearities within the ranges of the data used, and that the accuracy of prediction appears to be slightly better for small basins than for large basins; the reason for this effect is not known.

The residuals showed no distinct geographic trend when plotted on a map of the region. However, the equations produced the largest overestimate of sediment yield in a basin that has consistently low relief, thick loess, and is nearly all cropland. The equations produced the largest underestimates of sediment yields in the basins containing significant areas of "badlands." The "badland" areas are characterized by sparse vegetation, thick, easily eroded clay, and steep slopes. The reason that the regressions did not indicate more significance for the average land slope may be that only 2 or 3 of the 64 plains basins contain "badlands" and have steep slopes. Whatever the reason, the regression equations should not be used for basins containing significant areas of "badlands." Preliminary computations indicate that the regression estimates are improved by treating thick clay in the same way as the loess. Data are too sparse, however, to permit a recommendation.

These extremes of poor estimates indicate that the equations are not appropriate for unusual combinations of geomorphic or land-use characteristics. In addition, extensive theoretical and empirical study has shown conclusively that a regression equation should not be applied to data outside the range of the data used in the development of the equation. This caution applies to variables not appearing in the equation, as well as those that do, because the limited range of a variable in the data used may be the reason that it does not appear in the equation. To aid in avoiding the misapplication of the equations, the ranges of variables in the data used are given in table 7. The data have been rounded inward to encourage conservative application of the equations.

Table 7.--Extremes of data on basin characteristics for application of regression equations.

Characteristic	Plains area		Mountainous area	
	Minimum	Maximum	Minimum	Maximum
AREA (mi^2)	2.3	10,000	120	7,600
PREC (in)	14	42	9	18
REI	40	240	---	---
FLOW (ft^3/s)	.2	3,900	1.7	1,800
LSTH (ft)	0	50	0	0
LSPCT (percent)	0	100	0	0
LANDSL (ft/ft)	.02	.2	---	---
OVDIST (ft)	150	3,000	---	---
CROP (percent)	5	95	---	---
ELEV (ft)	---	---	5,100	8,400

CONCLUSIONS

This study of the relationships between sediment yield and drainage-basin characteristics has found useful relations only in the plains area. The mountainous area appears to lack adequate data to show similar relationships.

The most significant characteristics among those studied in the plains area were contributing drainage area, mean streamflow, average thickness of loess, and average land slope. A regression equation using these four characteristics estimates sediment yields with a standard error of +142 and -59 percent.

Sediment yields (per unit of drainage area) varied with the -0.125 or -0.156 power of the size of drainage area. This result is consistent with the relation found by a different method of analysis in the Upper Mississippi River basin.

The relations found in this study are poorly applicable to basins that contain significant areas of "badlands," have low relief and thick loess, or have other extremes of characteristics. The regression equation should be used only for basins whose characteristics fall within the ranges of data shown in this report.

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WRI 79-49