SUSPENDED SEDIMENT IN SELECTED STREAMS OF SOUTHEASTERN MONTANA

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METRIC CONVERSION TABLE

The following factors may be used to convert inch-pound units published herein to the International System of units (SI).

Multiply inch-pound unit	By	To obtain metric unit
acre	0.4047	hectare
acre-foot (acre-ft)	1233	cubic meter
acre-foot per square mile per year [(acre-ft/mi^2)/yr]	476.1	cubic meter per square kilometer per year
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter (m)
foot per mile (ft/mi)	0.1894	meter per kilometer
inch	25.40	millimeter (mm)
mile (mi)	1.609	kilometer (km)
pound per cubic foot (lb/ft^3)	16.02	kilogram per cubic meter
square mile (mi^2)	2.590	square kilometer
ton (short)	907.2	kilogram
ton per day (ton/d)	0.0105	kilogram per second
ton per square mile per year [(ton/mi^2)/yr]	0.3503	tonne per square kilometer per year
ton per year (ton/yr)	907.2	kilogram per year

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) by the formula:

$$°C = 0.556\ (°F - 32)$$

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ABSTRACT

Suspended-sediment data collected from October 1974 through September 1979 at 44 stations in the Powder River structural basin of southeastern Montana were statistically summarized to define sediment relationships between stations and basins and to identify environmental factors that are important in determining sediment yield. Sediment-transport curves were developed for 30 of these stations. Mean-annual suspended-sediment discharges were determined at 15 stations using the flow-duration sediment-transport curve method. Sediment discharges compared within 20 percent at three stations where alternative calculation by daily sampling methods was possible. Mean sediment discharges ranged from 770 to 5,470,000 tons per year. Mean sediment yields ranged from 1.09 to 647 tons per square mile per year and were somewhat less than yields predicted by the Langbein-Schumm precipitation-sediment-yield relation. Low delivery ratios for small drainages indicate that streams may be aggrading. Geographic variations in sediment yield are attributed to precipitation and geology.

INTRODUCTION

Beneath the high plains of southeastern Montana lie large reserves of low-sulphur subbituminous coal. Within the Montana part of the Powder River structural basin an estimated 32 billion tons of coal can be strip mined (U.S. Department of the Interior, 1979). Production has increased from 1 million tons in 1969 to an estimated 40 million tons in 1980, and the trend for increasing reliance on this area to help meet the nation's need for domestic energy will likely continue. Increased coal production has caused concern for the environmental effects of large dislocations in land use due to surface mining and its associated development. Ringen, Shown, Hadley, and Hinkley (1979) in a study in north-central Wyoming conclude that sediment yield is a better indicator of the effects of disturbance on mined areas than chemical quality of water. Fluvial sediment patterns can be affected, and changes, especially increases, in sediment yields can lead to esthetic damage to streams, filling and scouring of stream channels, sediment deposition in reservoirs, and damage to aquatic ecosystems.

To define baseline conditions for water quality, including sediment, a network of data-collection stations was established in 1974 by the U.S. Geological Survey. Funding for the stations was provided by the U.S. Geological Survey and the U.S. Bureau of Land Management. The study area is bounded by Sarpy Creek and Rosebud Creek basins on the west, the Yellowstone River on the north, the Powder River basin on the east, and the Montana-Wyoming border on the south (fig. 1).

Purpose and scope

The purpose of this report is to summarize and evaluate fluvial-sediment data collected in the study area by the U.S. Geological Survey. The principal products

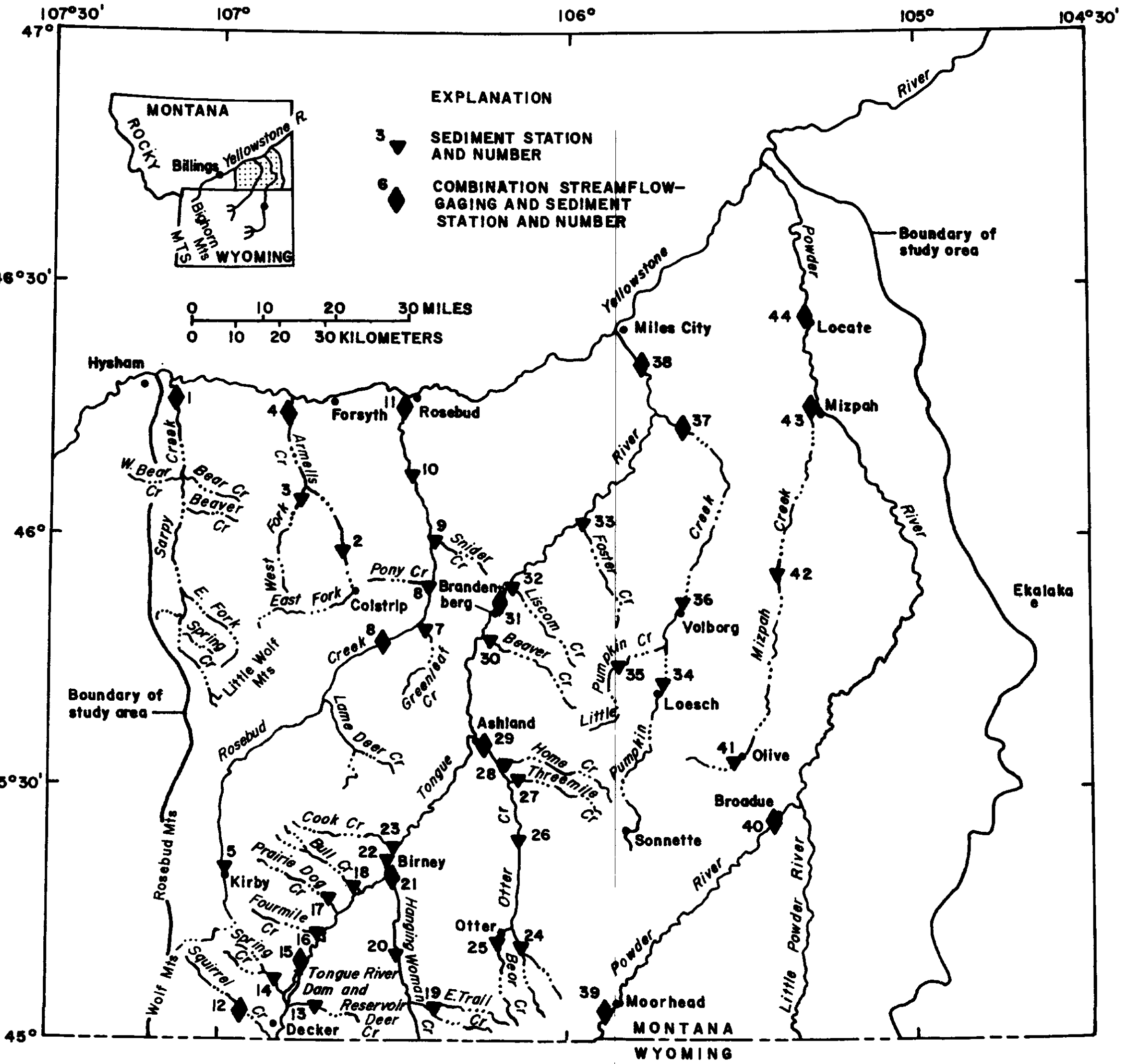

Figure 1.--Location of study area, sediment stations, and streamflow-gaging stations. The boundary of the study area approximates the boundary of the northern Powder River structural basin.

of this report are sediment concentration and load statistics, sediment-transport curves, calculated mean annual sediment yields at selected stations, and an areal sediment-yield map. A secondary purpose is to describe sediment relationships between stations and basins and to identify environmental factors that are important in determining sediment yield.

The data-collection network consists of 44 stations (table 1) on streams in the study area. The study extended from October 1974 through September 1979; that is, water years 1975-79. For most stations, this period approximates baseline pre-mining conditions, but it does not represent undisturbed natural conditions as other activities of man (primarily agricultural) have for some time affected the land. Because the study was short, it could not fully reflect the wide variability intrinsic to the hydrologic cycle, and the degree to which the data accurately characterize longer time periods was not established.

Description of data

The type and duration of records available differ among study stations. Suspended-sediment samples were collected daily at four stations, enabling direct calculation of suspended-sediment discharge. All stations were sampled monthly for 1 or more years, with streamflow being measured at the time of sampling; the result is a series of monthly data pairs consisting of instantaneous water discharge and instantaneous sediment concentration. Streams at a few of the monthly stations flowed only rarely. Fifteen of the monthly stations had continuous streamflow record, which enabled calculation of mean annual suspended-sediment discharges.

A statistical summary of the data is given in table 2. The data characterize conditions during monthly visits to the station, but not necessarily the full-time condition of the stream. When the number of samples for a stream is small, the statistics in table 2 may not reliably describe that stream; when the number of samples is large, the sample statistics may approach the true population statistics.

On large perennial streams, the number of samples generally is large and the range of conditions of that stream is well defined. The mean values for once-monthly measurements, however, are often overly large because sampling routines, although primarily assigned a regular time schedule, also have an event bias. That is, an attempt is made to measure large discharges. As a result, sample distribution is skewed towards large values. For example, the annual mean of once-monthly measurements was compared with the annual mean of once-daily measurements for the station Powder River at Locate (station 44). During water year 1975, which had larger than normal streamflows, the once-monthly mean for streamflow was 220 percent of the once-daily mean; and the once-monthly sediment concentration mean was 150 percent of the once-daily mean. In 1976, a more average streamflow year, the monthly means were 105 and 114 percent of the daily means.

For small intermittent and ephemeral streams, the number of samples commonly is small because the streams are often dry during the monthly visits. The resulting zero values were not used when calculating the once-monthly mean. Sampling of large streamflows is difficult on some streams because flow is of short duration. Therefore, both the mean and the range of once-monthly measurements given in table 2 may be misleading when the number of samples is small.

Water-quality data, including some analyses of the chemical characteristics of suspended sediment, though not discussed in this report, are available for all stations. These data and most of the sediment data described in this report have been published annually in water-resources data reports of the U.S. Geological Survey (see References cited). The water-quality data at stations in the study area have been summarized and evaluated in two Geological Survey reports (Knapton and McKinley, 1977; Knapton and Ferreira, 1980).

Methods of suspended-sediment sample collection, laboratory procedures, and daily sediment-record computation are documented in previous reports. The reader is referred to reports by Guy (1969, 1970) and Guy and Norman (1970) for descriptions of the methods.

PHYSICAL SETTING

The study area consists of upland prairie east of the foothills and mountain fronts of the northern Rocky Mountains. Moderately dense dendritic drainages have eroded into the broad rolling hills, forming broken badlands, rock-capped buttes, and alluvial valleys through which meandering intermittent streams flow. The area is in the Pine Parklands Subregion of the Rocky Mountain Foreland Environmental Region of Montana (Montana State Environmental Quality Council, 1972).

The climate is semiarid continental with cold winters, warm summers, and extreme variations in temperature and precipitation. At Colstrip, Mont. (fig. 1), annual rainfall has varied from 10.1 inches in 1952 to 24.74 inches in 1944, and temperatures have varied from -40° to 111°F. Average annual rainfall for the study area is 12 to 16 inches, based on the available record, with higher altitudes receiving the most moisture, and leeward low-altitude slopes the least. In the winter, frigid Canadian Arctic air masses move south for brief periods, causing blizzard winds and scattered snow. However, winter thaws are common and snow rarely accumulates to any large depth. Most of the annual precipitation occurs from April to June when frontal systems from the Pacific or Gulf Coast move over the area. Summer and fall thunderstorms cause intense short-duration rainfall on a localized scale. Cycles of drought over the long term have a large effect on the environment.

Soils are predominantly shallow (less than 25 inches deep), shaley to silty loams developed over shales or siltstones on moderate to steep slopes, and are mostly of the Elso-Midway-Thurlow Association (U.S. Department of Agriculture, 1971, 1978). Erodability depends mostly on slope and grain size. Loosely textured alluvial deposits, through which many of the streams flow, are easily erodable, especially by channel-cutting bank erosion. The growing season lasts from 100 days in the upland interior regions to 150 days in parts of the Yellowstone River valley. Land cover by native and introduced grasses varies locally depending on land use and grain size of underlying bedrock and soil.

The Tongue River Member of the Fort Union Formation of Paleocene age is the principal rock unit in the study area. It consists of variable and discontinuous layers of yellow to light-gray siltstone and sandstone with smaller amounts of red clinker (overburden baked by coal combustion) and coal deposits. To the north and east, however, the dark-gray shales of the Lebo Shale Member and Tullock Member of the Fort Union Formation predominate.

SUSPENDED-SEDIMENT CONCENTRATIONS

Streams transport particulate material that is eroded from the land surface; this sediment occurs in sizes from clay and silt (0.00024-0.062 mm) to sand (0.062-2.00 mm) to larger gravel and cobbles. Sediment is transported as: (1) suspended load, where sediment at any given time is in suspension as a colloid or is maintained in suspension by upward components of turbulent currents; or (2) bedload, where sediment is in almost continuous contact with the streambed as it moves by bouncing, skipping, and rolling. This report is concerned with the suspended mode of sediment transport.

Material ranging from very fine clay to sand-size particles generally comprises the suspended-sediment load. Concentrations of the finer particles are fairly uniform with stream depth, whereas the heavier coarse particles are more concentrated near the bottom. Because suspended-sediment samplers do not sample the bottom 3-5 inches of the water column, suspended-sediment discharge measurements may not include the correct proportion of the coarser particles. Colby (1957) estimated that this unmeasured suspended load per foot of stream width varies with mean stream velocity to the third power. More recently, Shen (1979) reported that the unmeasured load varies from 10 to 120 percent of the measured load.

Because of their weight, sand-size particles are not always in motion. Sands are commonly found in abundance in the streambed and their rate of movement is dependent on stream power, which is usually measured as water velocity, water discharge, stream slope, or some combination of these hydraulic variables. Colby (1956) determined that concentrations of suspended sands varied with mean stream velocity to the 2.5 power.

Turbulence in most streams is usually great enough to carry clay and silt-size particles in suspension at all times, and so the availability of such material becomes the determining factor with regard to concentration. Stream hydraulics is only one of the factors that relate to availability of fine material, and then only when the source of fines is in the stream channel itself. When the source is out of the channel, generally from sheet erosion of more or less distant slopes, climatic variables (such as duration, frequency and intensity of storms, length of time between storms, and location of storms relative to the drainage network) become important. The complexity of the factors affecting sediment transport often results in a wide scatter of points on graphs of stream discharge versus suspended-sediment concentration (fig. 2). Empirical methods for using these variables to predict sediment loads are discussed in a report by Guy (1964). Sharma and Dickinson (1980) investigated a more theoretical, systems modeling approach for sediment-load prediction.

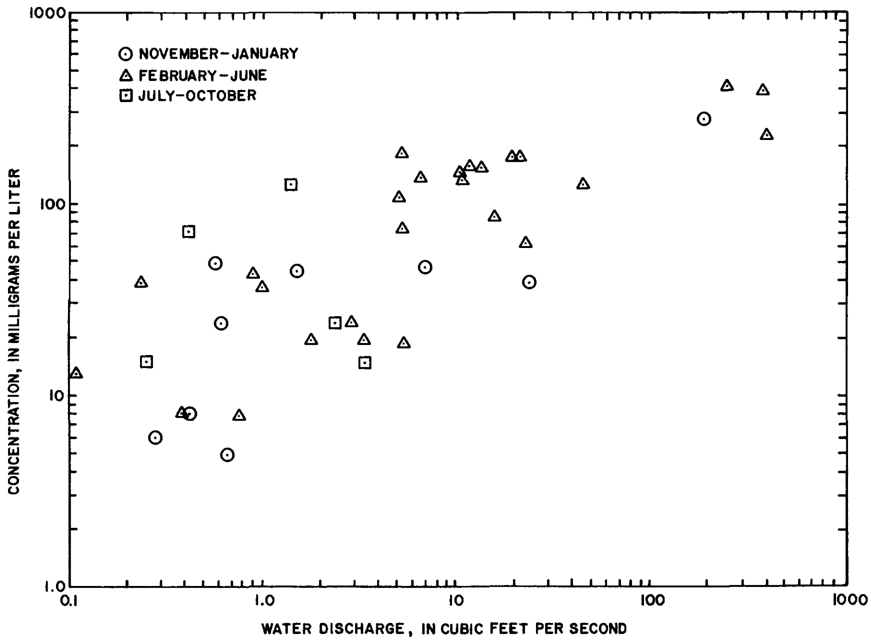

Figure 2.--Relationship of water discharge to suspended-sediment concentration for Sarpy Creek near Hysham (station 1), 1975-79.

When a sediment concentration peak is exactly in phase with a water-discharge peak (fig. 3A), both variables rise and fall together and a simple relation between them can be defined. Such a relation occurs when fine material is available in abundance in the streambed or nearby. However, if the sediment source is far removed, or if the sediment supply is limited, the sediment-concentration peak and water-discharge peak will not parallel each other. In large rivers, sediment peaks have been observed to lead or lag discharge peaks by several days (see Heidel, 1956). The property of hysteresis thus arises, as depicted by hysteresis loops (fig. 3B). In the loop shown, sediment concentration increases with increasing discharge (point 1 to point 2) to a maximum concentration at point 2, then the concentration begins to decrease with increasing discharge (point 2 to point 3). This decrease in concentration indicates that the source of sediment readily available for transport was limited. Hysteresis loops can be unique for each storm, so the relationship between the two variables becomes complex. This type of phenomenon is discussed further by Wood (1977). The Montana streams under study often function in this manner.

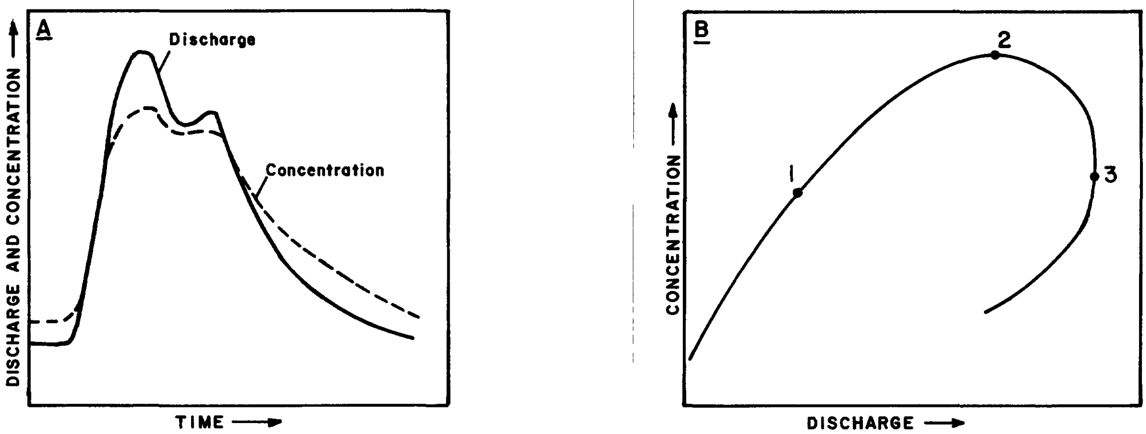

Figure 3.--Examples of relationship between water discharge and sediment concentration. A, in-phase variation. B, hysteresis loop.

Particle-size analyses of suspended sediment in the study area streams indicated that at least 85 percent of the material was silt and clay for almost all samples, irrespective of drainage-area size or magnitude of water discharge. When fine material is the principal part of the suspended-sediment load and availability of fines, not stream hydraulics, is the principal constraint on loads, as is true here, the loads are called "wash loads."

Suspended-sediment concentrations (table 2) for the study streams range from 2 mg/L (milligrams per liter) at Tongue River below Hanging Woman Creek, near Birney (station 22) and at Cook Creek near Birney (station 23) to 49,700 mg/L at Powder River at Moorhead (station 39). This large concentration was 98 percent fine material. Most streams in the study area have a sediment-concentration range of three orders of magnitude. The smallest mean of once-monthly concentrations is 18 mg/L at the Tongue River below the Tongue River Dam near Ashland (station 15). The largest mean of once-monthly concentrations is 6,900 mg/L for the Powder River at Broadus (station 40).

SEDIMENT-TRANSPORT CURVES

Sediment-transport curves are graphical descriptions of the relationship between water discharge and the sediment discharge[1] carried by that water.

$$Qss = 0.0027\ Q \cdot C \qquad (1)$$

where

Qss is instantaneous sediment discharge in tons per day,
Q is water discharge in cubic feet per second, and
C is concentration of suspended sediment in milligrams per liter.

Water discharge is considered to be the independent variable. Curves may be developed for various time intervals, seasons, storm types, and particle sizes. A thorough description of sediment-transport curves and their types and uses is available in a report by Colby (1956). For this report, instantaneous values from monthly sampling are used. An attempt was made to separate data by season, but no relationships were evident for the small number of data points available. Logarithmic transformation of the data was used to improve the relationship. Inspection of points indicated that a single slope, least-squares line was adequate for each station. An example of a computer-generated sediment-transport curve is shown in figure 4. The transport curves can be used to predict instantaneous sediment

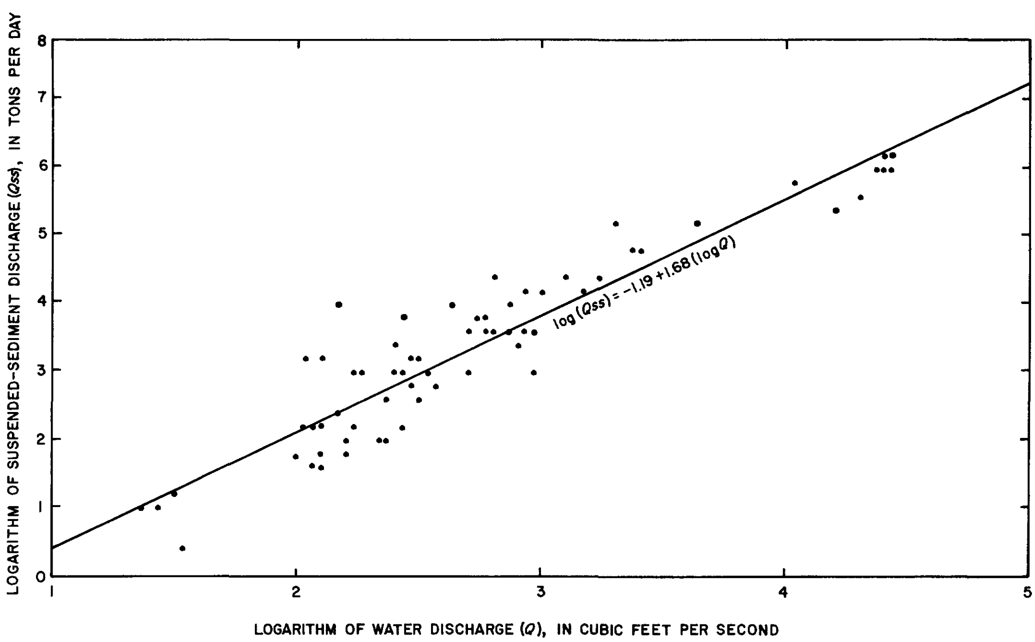

Figure 4.--Computer-generated sediment-transport curve for Powder River near Locate (station 44), 1975-79.

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[1]Sediment "discharge" and "load" are often used synonomously. However, strictly speaking, sediment discharge refers to the quantity of sediment that is transported past any cross section of a stream in a unit of time, whereas load is used when describing the material being transported.

discharge and daily sediment discharges. However, the predicted sediment discharge will be the mean sediment discharge for a given water discharge. The curves also can be used to compare different streams and basins.

The equations for the sediment-transport curves for the study stations are given in table 2. The regression slopes (table 2) show a wide range in values, from 1.10 for Bear Creek at Otter (station 25) to 2.33 for Tongue River at Miles City (station 38). Intercept values are all negative, ranging from -4.19 for Tongue River below Brandenberg Bridge near Ashland (station 31) to -0.12 for Mizpah Creek near Mizpah (station 43). Assuming that the sampled populations are statistically valid, then a greater slope would indicate a greater sediment-load carrying capacity, and, at a given discharge for two stations having identical slope, the sediment concentration is smaller at the station having the greater negative intercept.

ANNUAL VARIATIONS IN STREAMFLOW AND SEDIMENT

Streamflow record collection for several stations on the larger rivers began in 1929 (table 2). The smaller streams have been gaged for shorter periods, varying from 3 to 7 years.

The flow characteristics of these streams can be understood by examination of a typical hydrograph (fig. 5). In the fall (October-November) flows increase

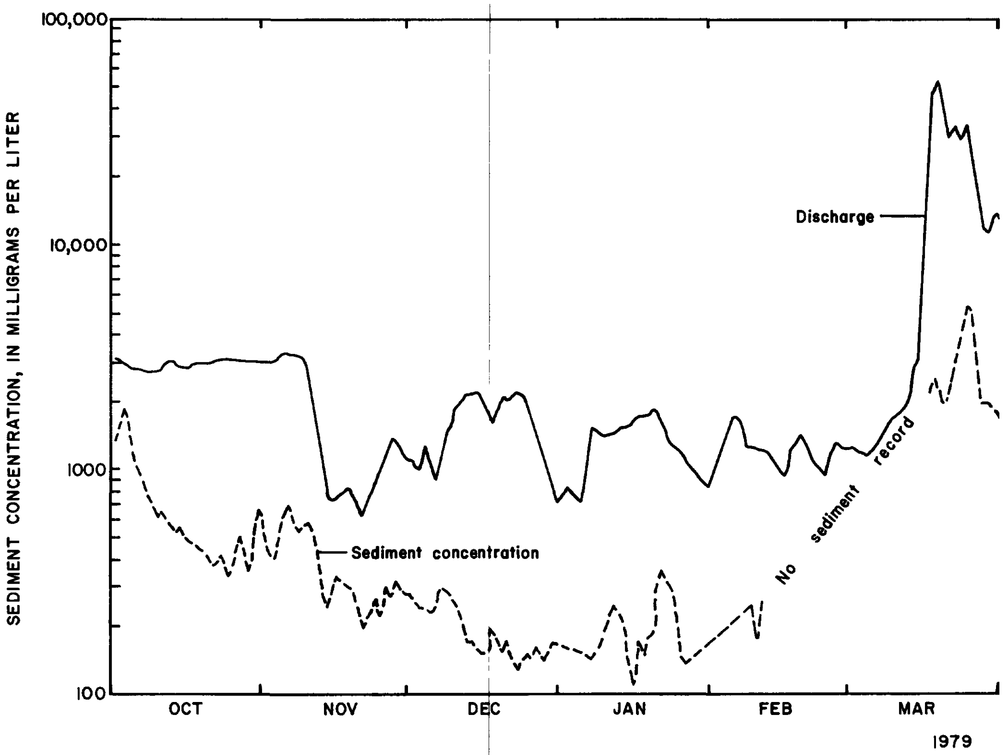
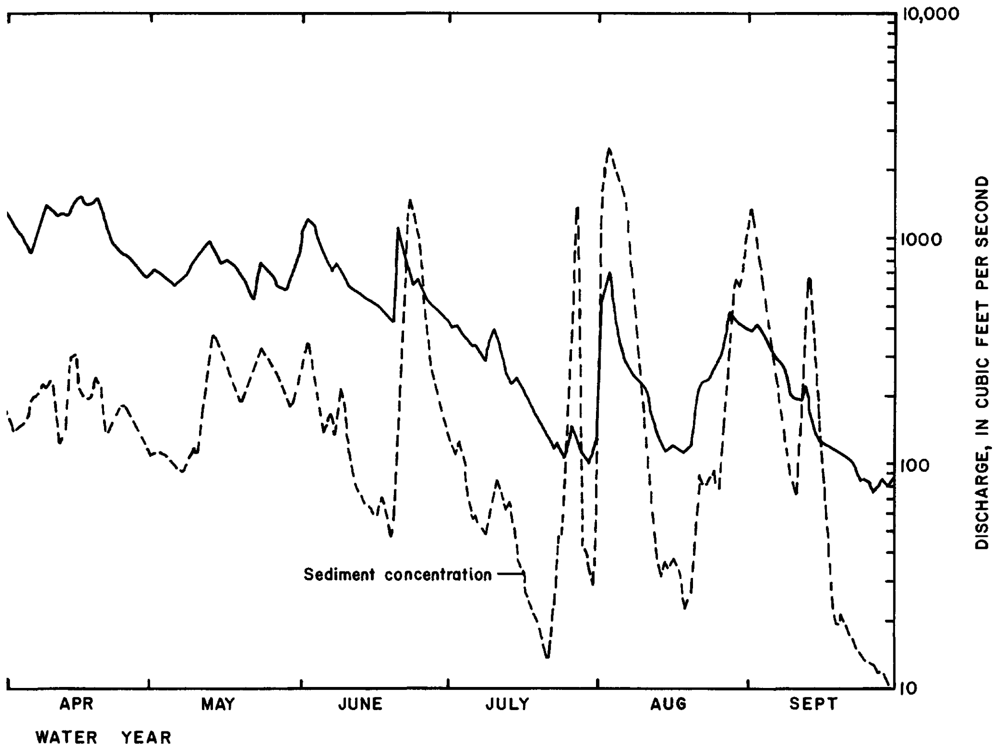


Figure 5.--Water discharge and suspended-sediment concentration for

slightly from the late summer lows as a result of decreasing temperature and smaller evapotranspiration rates. Occasional fall storms can cause a series of small peaks. Sediment concentrations decrease during this period except during storms. Freezing occurs in November or December with a concomitant decrease in flow as water is stored as ice. Steady low flows during the winter transport only small amounts of sediment. Thaws can occur in January and February, but generally occur in March. The maximum annual stream stage frequently occurs during ice jams. Sediment concentrations also increase during ice jams, as accumulated materials are mechanically eroded and suspended. As snow melts, more ground is exposed to runoff and soil material loosened by freeze-thaw action is readily available for transport. Several stages of snowmelt occur--the first at low plains altitudes and later ones at high altitudes, culminating in a large mountain snowmelt runoff in June. Superimposed on this snowmelt water is water from precipitation, which increases to its peak in May and June. Intense, relatively short-term periods of rainfall can produce runoff that transports the bulk of the sediment load for the entire year. Streamflow and sediment concentrations decrease toward late summer and early fall.

Flow-duration curves are cumulative-frequency curves that show the percentage of time that specified discharges are equaled or exceeded. The accuracy to which these curves describe stream behavior increases with the length of data base from which they are constructed. Flow-duration curves for Powder River near Locate (station 44) for the study (1975-79) and the period of record (1939-79) are shown in figure 6. Flows of 300 ft^3/s were exceeded 50 percent of the time during the study, whereas over the past 40 years flows of 220 ft^3/s were exceeded half the



Powder River near Locate (station 44), 1979 water year.

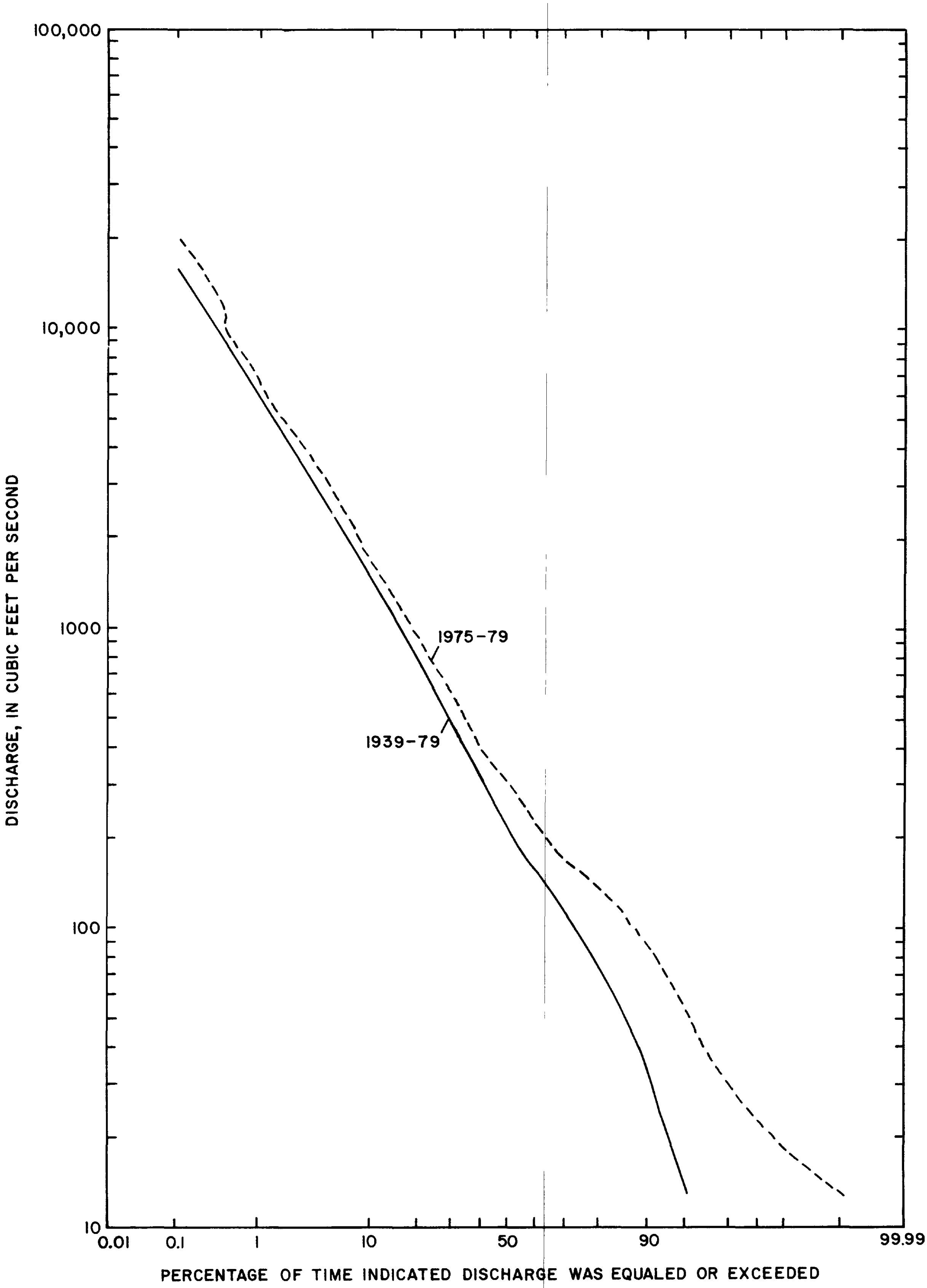


Figure 6.--Flow-duration curves for Powder River near Locate (station 44), 1939-79 and 1975-79.

time. A plot of total annual water discharge at two stations (fig. 7) shows the variability of streamflow in the study area, and also indicates that the study period was wetter than normal, with the mean annual discharge being about 125 percent of the long-term mean.

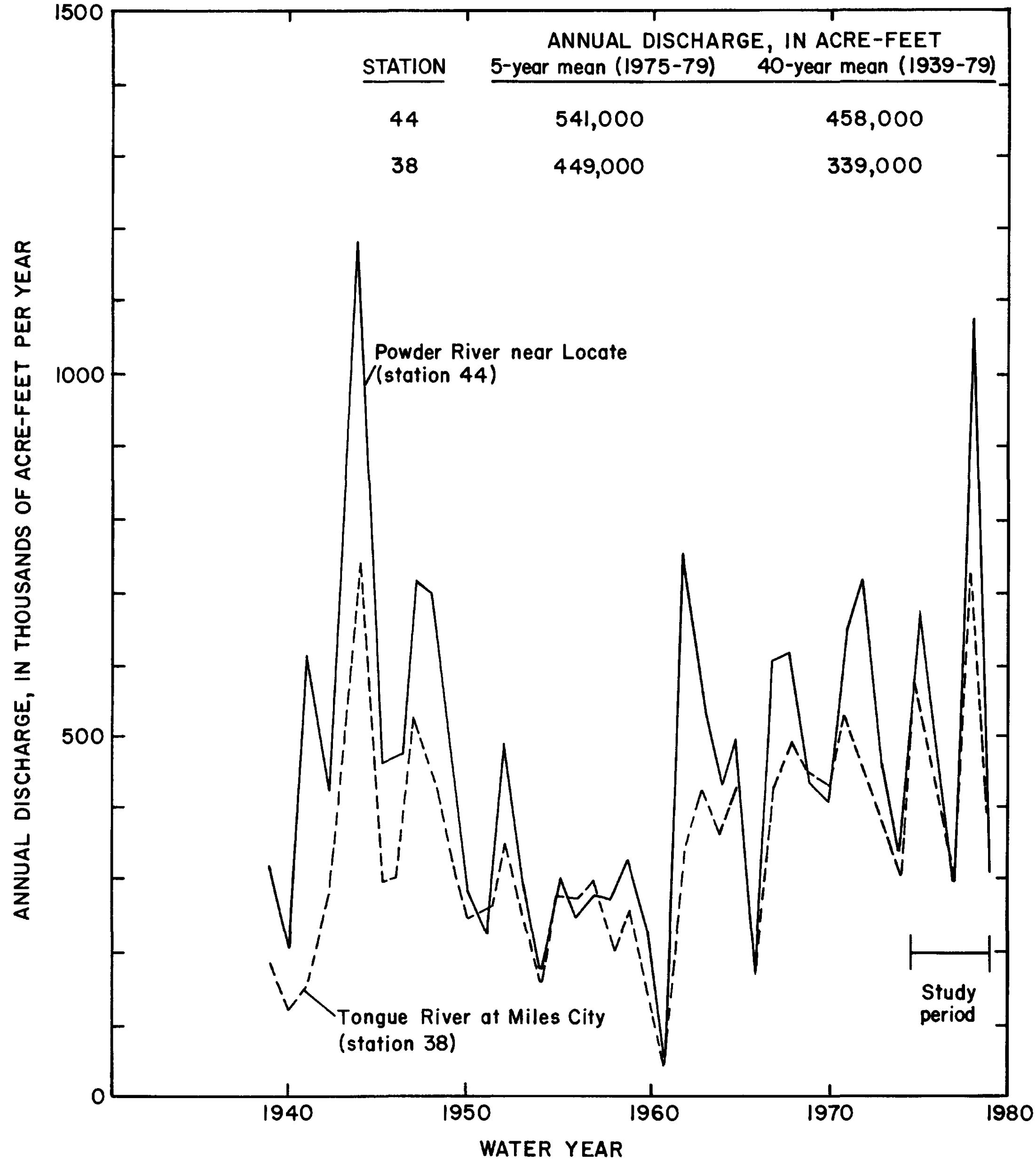


Figure 7.--Annual water discharge for Powder River near Locate and Tongue River at Miles City, water years 1939-79.

Sediment-transport curves can be combined with flow-duration data to compute sediment-discharge-duration values from which mean annual sediment discharges are calculated (Miller, 1951). A discussion of the accuracy of this method is given by Walling (1977). A sample computation is given in table 3. The steps are as follows: (A) Water discharges (column 2) for various percentages of time (column 1) are taken from flow-duration tables or curves. (B) Sediment discharges (column 3) for each water discharge are calculated using the sediment-transport curve. (C) Mean sediment discharges (column 5) for each time interval are calculated as the mean of the sediment discharges at the end points of each interval. (D) Each mean sediment discharge is multiplied by the time interval (expressed as a percentage of the total time) for which it occurs [(column 4 ÷ 100) x column 5 = column 6]. Intervals are chosen such that these products are as close to equal as possi-

Table 3.--*Sample computation of mean annual suspended-sediment discharge by flow-duration sediment-transport curve method*

column	1	2	3	4	5	6
parameter[1]	*t*	*Qe*	*Qss*	*Δt*	*Qssav*	*Qssd*
	0.0	390	280	--	--	--
	.200	310	206	0.200	243	0.486
	.400	290	188	.200	197	.394
	.600	280	180	.200	184	.368
	.800	230	138	.200	159	.318
	1.00	220	130	.200	134	.268
	1.20	200	115	.200	122	.244
	1.40	150	77.9	.200	96.2	.192
	1.70	134	67.0	.300	72.5	.218
	2.10	110	51.4	.400	59.2	.237
	2.50	95.0	42.3	.400	46.8	.187
	3.00	78.0	32.4	.500	37.4	.187
	3.50	67.0	26.5	.500	29.5	.148
	4.10	56.0	20.8	.600	23.6	.142
	5.90	41.0	13.7	1.80	17.3	.311
	7.60	30.0	9.02	1.70	11.4	.194
	10.2	22.0	5.96	2.60	7.49	.195
	13.6	16.0	3.89	3.40	4.92	.167
	19.3	8.20	1.59	5.70	2.74	.156
	38.1	3.20	.450	18.8	1.02	.192
	60.3	.600	.048	22.2	.249	.055
	100	.0001	.00	39.7	.024	.010
						4.669 x 365 = 1,704

[1] Abbreviations: *t*, percentage of time; *Qe*, water discharge equaled or exceeded (cubic feet per second); *Qss*, suspended-sediment discharge (tons per day); *Δt*, interval between succeeding percentages of time; *Qssav*, average suspended-sediment discharge for time interval (tons per day); *Qssd*, sediment discharge multiplied by time interval.

ble. (E) The products are totaled to give a mean suspended-sediment discharge in tons per day. (F) This total is then multiplied by 365 days to give the mean suspended-sediment discharge in tons per year.

Mean suspended-sediment discharges were calculated for 15 stations by the flow-duration sediment-transport curve method (table 4). The calculated discharges range from 770 ton/yr at Otter Creek near Ashland (station 29) to 5,470,000 ton/yr at Powder River at Broadus (station 40). Daily sediment data have been collected at four of the study sites, which enables a direct calculation of sediment discharge. The two methods of calculation are compared in table 5, showing agreement within 20 percent at three of the four sites. The method did not work well for Powder River at Moorhead (station 39), which resulted in overestimating the load by 125 percent. The overestimation was possible because a single extreme high flow occurred during the study, and it was not well defined by monthly sampling. The sediment-transport curve developed from monthly sampling data, therefore, was inaccurate in the high range of sediment load. Daily sediment samples were collected at the station during the flood, however, and a plot of these points shows that the sediment-transport curve flattens out considerably at the high end (see

Table 4.--*Calculated mean annual suspended-sediment discharges and yields*

Station name (station number)	Drainage area (square miles)	Mean sediment discharge (tons per year)	Mean yield (tons per square mile per year)	Mean yield (acre-feet per square mile per year)
Sarpy Creek near Hysham (1)	453	1,700	3.75	0.003
Armells Creek near Forsyth (4)	370	3,150	8.51	.007
Rosebud Creek near Colstrip (6)	799	22,000	27.5	.02
Rosebud Creek at mouth near Rosebud (11)	1,302	48,000	36.9	.03
Squirrel Creek near Decker (12)	33.6	1,190	35.4	.03
Tongue River at Tongue River Dam, near Decker (15)	1,770	10,300	5.82	.004
Hanging Woman Creek near Birney (21)	470	1,130	2.40	.002
Otter Creek near Ashland (29)	707	770	1.09	.001
Tongue River below Brandenberg Bridge, near Ashland (31)	4,062	194,000	47.8	.04
Pumpkin Creek near Miles City (37)	697	45,000	64.6	.05
Tongue River at Miles City (38)	5,379	634,000	118	.09
Powder River at Moorhead (39)[1]	8,088	5,230,000	647	.49
Powder River at Broadus (40)	8,748	5,470,000	625	.48
Mizpah Creek near Mizpah (43)	797	60,800	76	.06
Powder River near Locate (44)	13,189	4,240,000	321	.25

[1] Sediment discharge for this station is from daily records computation.

Table 5.--*Comparison of results for calculating sediment discharge in tons by daily record computation method and flow-duration sediment-transport curve method*

	Station 31	Station 39	Station 40	Station 44
Daily record computation method				
1975	268,000	5,760,000	6,950,000	8,690,000
1976	61,900	3,210,000	3,200,000	3,060,000
1977	65,600	3,550,000	3,990,000	3,480,000
1978	362,000	12,490,000	11,720,000	9,200,000
1979	77,900	1,130,000	1,050,000	1,040,000
Total	835,400	26,140,000	26,910,000	25,470,000
Mean	167,000	5,230,000	5,380,000	5,090,000
Flow-duration sediment-transport curve method				
Mean	194,000	11,800,000 [1](5,790,000)	5,470,000	4,240,000
Percent difference	+16	+125 [1](+11)	+2	-17

Station 31: Tongue River below Brandenberg Bridge, near Ashland
Station 39: Powder River at Moorhead (daily records are partial for water years 1978-79)
Station 40: Powder River at Broadus (daily records are partial for 1979 water year and estimated for 1975 water year)
Station 44: Powder River near Locate (daily records are partial for 1978 water year)
[1]Numbers in parentheses are results of calculations using a two-slope sediment transport curve.

fig. 19). The mean sediment discharge calculated for the station using this two-slope sediment-transport curve agreed within 11 percent of the daily record results. These results underscore the importance of critically reviewing the data before accepting the results of such calculations.

Mean sediment yields in weight and volume forms are also given in table 4. Yield, in tons per square mile per year, is calculated by dividing the sediment discharge at a station by the drainage area of the stream upstream from that station. The mean sediment yields ranged from 1.09 $(ton/mi^2)/yr$ at Otter Creek near Ashland (station 29) to 647 $(ton/mi^2)/yr$ at Powder River at Moorhead (station 39). To convert these yields to volume form, a specific weight of 60 lb/ft^3 was assumed for study area sediment, based on specific weights of sediment deposited in the Tongue River Reservoir (U.S. Bureau of Reclamation, 1949).

Initial specific weights for uncompacted sediment deposits are probably somewhat less, however (Welborn, 1967). Sediment yield in volume form ranged from 0.001 $(acre\text{-}ft/mi^2)/yr$ (station 29) to 0.49 $(acre\text{-}ft/mi^2)/yr$ (station 39).

INTERPRETATION OF SUSPENDED-SEDIMENT YIELDS

In this study sediment yield refers to the annual rate at which sediment is transported past a certain point in the drainage basin. Two factors are important to the interpretation of sediment yield. First, the yield is an "output" characteristic of the drainage area for which it is calculated. It does not imply that sediment yield is constant or uniform throughout the drainage. Second, sediment yield is not the same as erosion. Erosion occurs everywhere on the land surface, and can be quantified either by direct measurement or by theoretical calculations using such methods as the Universal Soil Loss Equation. Erosion rates vary even over short distances. Not all sediment that is eroded from the land surface immediately reaches the stream network; it may move only a short distance downslope, for instance, to where the slope of the land decreases. The relationship of sediment yield to erosion is determined by the sediment delivery ratio (or conveyance factor) for a given drainage area, which is the ratio of the sediment carried out of the basin (sediment yield) to the gross erosion within the basin.

A sediment-yield map (fig. 8) was constructed using the data from the 15 stations listed in table 4. The map is intended to show differences in sediment yield from basin to basin, but cannot be used to estimate erosion rates or exact sediment yields at stream points other than where the yield was measured. Drainages smaller than 2,000 mi^2 generally had the smallest yields--less than 70 $(ton/mi^2)/yr$ and commonly less than 10 $(ton/mi^2)/yr$. Very small drainages studied by the U.S. Department of the Interior (1977a, 1977b) had estimated sediment yields of 100-500 $(ton/mi^2)/yr$, but even these drainages were transporting less than 75 percent of the total estimated eroded material. This condition indicates that sediment is accumulating in the small- and medium-sized drainages. Stock dams and spreader dikes undoubtedly are partly responsible, but there also seems to be a trend towards stream aggradation. Streams throughout the western United States seem to have been aggrading since the 1950's (Dunne and Leopold, 1978, p. 691).

Yields on the upper Powder River average 636 $(ton/mi^2)/yr$, which is somewhat less than predicted by the general relation of Langbein and Schumm, (1958) between sediment yield and mean annual precipitation (see fig. 9). The smaller yields may be the result of the area receiving rainfall totals larger than average during the study. For instance, the 1974-79 mean rainfall for Ekalaka, Mont., was 17.15 inches whereas the 1931-60 mean was 13.22 inches. Increased precipitation can cause better vegetative cover and a decline in sediment yields (Langbein and Schumm, 1958, p. 1084). Tongue River sediment yields are small because the Tongue River Reservoir traps sediment.

The sediment-yield map (fig. 8) shows a trend of increasing sediment yield from west to east, and to a lesser degree from south to north. Precipitation decreases across the study area in a similar pattern toward a value which yields the largest sediment loads according to the Langbein-Schumm relation. Study area streams that transect the easily erodable shales of the Lebo Shale and Tullock Members of the Fort Union Formation also have large sediment yields.

Federal mining laws mandate that mine discharges contain less than 45 mg/L of suspended sediment. Because sampled mean sediment concentrations for virtually all study drainages exceeded this concentration, sediment contributed by properly designed mine-discharge networks probably will not grossly impact the sediment system. However, erosion and sediment yield from disturbed areas associated with mining but outside the established mine-drainage network could be significant, espe-

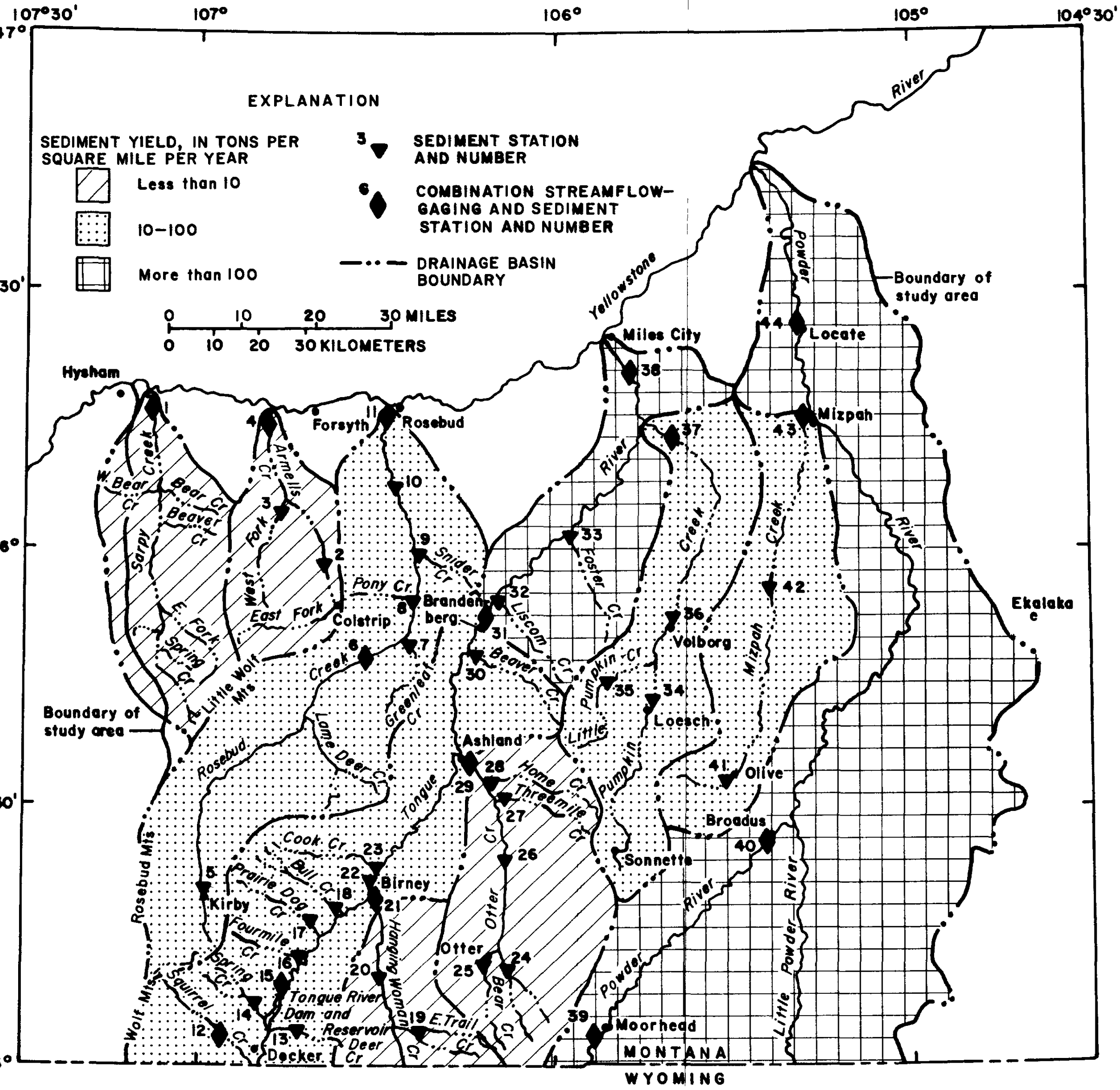


Figure 8.--Sediment-yield map.

cially during periods of large-scale runoff. Increased sediment loads could be a problem, especially on the Tongue River downstream from the dam where sediment supply is artificially small.

SEDIMENT IN THE STUDY AREA

In the sections that follow, suspended-sediment data for the study-area streams are grouped and described according to the major drainages. Locations of the stations are shown in figure 1 and described in table 1; descriptive statistics are presented in table 2. Sediment-transport curves for each station are presented in the basin descriptions.

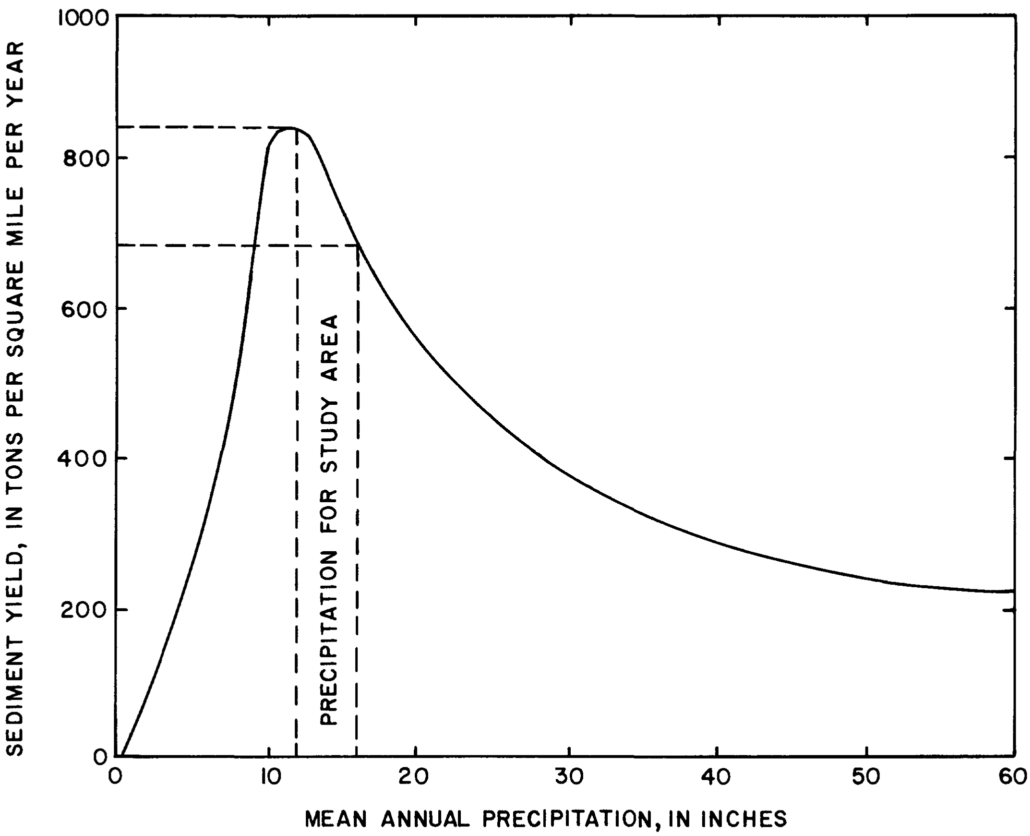


Figure 9.--General relationship of sediment yield to mean annual precipitation (modified from Langbein and Schumm, 1958).

Sarpy Creek basin

Sarpy Creek is an intermittent prairie stream flowing in a rather wide alluvial valley and, with a drainage area of 453 mi^2, is typical of the medium-size streams of the study area. Its headwaters arise in the high altitude pine-covered hills of the Little Wolf Mountains; however, within a short distance the stream declines in altitude to the flat and gently sloped main-stem valley, which is 30 miles long. Here the stream meanders through a series of pool-and-riffle complexes, sometimes barely maintaining any velocity. Cottonwood trees line the banks in an otherwise almost treeless landscape. Occasional springs and seeps contribute small amounts of water to the stream but do not prevent dry reaches from appearing during the long, hot summer.

Land use in the basin is predominantly agricultural. Large numbers of cattle graze on the natural and cultivated grasses and use the stream as a watering hole. About 970 acres of land are irrigated by water withdrawn from the stream. Coal extraction in the upstream reaches of the east and middle forks of Sarpy Creek began in 1974 at the Absaloka Mine operated by Westmoreland Resources, Inc. Approximately 4.5 million ton/yr of coal are currently produced from 1,300 acres; expansion to a 15 million-ton annual production rate is planned, which would involve as much as 15,000 acres.

Only one study site, Sarpy Creek near Hysham (station 1), is located in the basin. Continuous-streamflow records were collected at this station 11 stream miles upstream from the junction with the Yellowstone River.

The total runoff for Sarpy Creek during 1975-79 was 40,250 acre-ft, with flows varying significantly. No flow occurred for several periods, but a low base flow generally was maintained between rainfalls. Flows less than 10 ft^3/s occurred 80 percent of the time. Seven peaks were greater than 100 ft^3/s during the study period, most of which resulted from snowmelt runoff. The maximum discharge was 428 ft^3/s on March 4, 1975.

Forty sediment samples were collected during the study. Sediment concentrations ranged from 6 to 416 mg/L, with a mean of 96 mg/L. Concentrations varied widely with water discharge, reflecting the primary importance of sediment availability at the site. The suspended sediment was almost exclusively (92 percent) fine material of clay and silt size; curiously, the amounts of sand seemed to increase with a decrease in discharge. This writer attributes the anomaly to measurement error. Keeping bed material out of a sample is difficult when flows are less than 1 ft^3/s and depths are shallow.

The sediment-transport curve (fig. 10) was fairly well defined. The data indicate that the slope of the regression line changed with time. Stream discharges in 1975 carried less sediment than similar discharges later in the study. However, the paucity of data necessitated averaging these variations. The largest instantaneous suspended-sediment discharge was 410 ton/d. The calculated mean sediment discharge for Sarpy Creek is 1,700 ton/yr, with a sediment yield of 3.75 $(ton/mi^2)/yr$ -- one of the smallest in the study area.

Examination of the year-to-year variation in this sediment discharge is instructive, because the behavior of Sarpy Creek is typical of the medium- to small-sized streams in the study area. The 1975 water year began with normal low flows that continued until mid-January. Little sediment was transported during this period. Above-normal snowfall occurred from January through May. Snowmelt runoff occurred on January 19-22, February 25-March 8, March 19-22, April 15, and May 7-8. Streamflow was greater than normal throughout this period, and the high flows transported about 2,600 tons of sediment during the 19 days when streamflow exceeded 100 ft^3/s. The January peak was followed by cold temperatures, which caused the stream to be ice covered until the February runoff began. A sediment sample during the February runoff indicated an anomalously small sediment concentration. The small concentration was probably due to a limited availability of material because the ground was frozen and snow covered, the stream channels were frozen between events, and the earlier January thaw had depleted available sediment. After this series of peaks, streamflow decreased to normal base-flow levels for the rest of the year and little additional sediment was transported. Total runoff for the year was 14,570 acre-ft and the suspended-sediment discharge was about 3,500 tons.

For the 1976 water year precipitation was larger than average early in the year but produced no discharge peaks on Sarpy Creek. No snowmelt-runoff peaks occurred, and conditions became drier as the year continued. The maximum discharge for the year was 20 ft^3/s, and the total runoff was 1,580 acre-ft. A small amount (about 100 tons) of sediment was transported, and sediment brought to the channel by overland flow most likely began to accumulate there, as flows were too small to flush the channel.

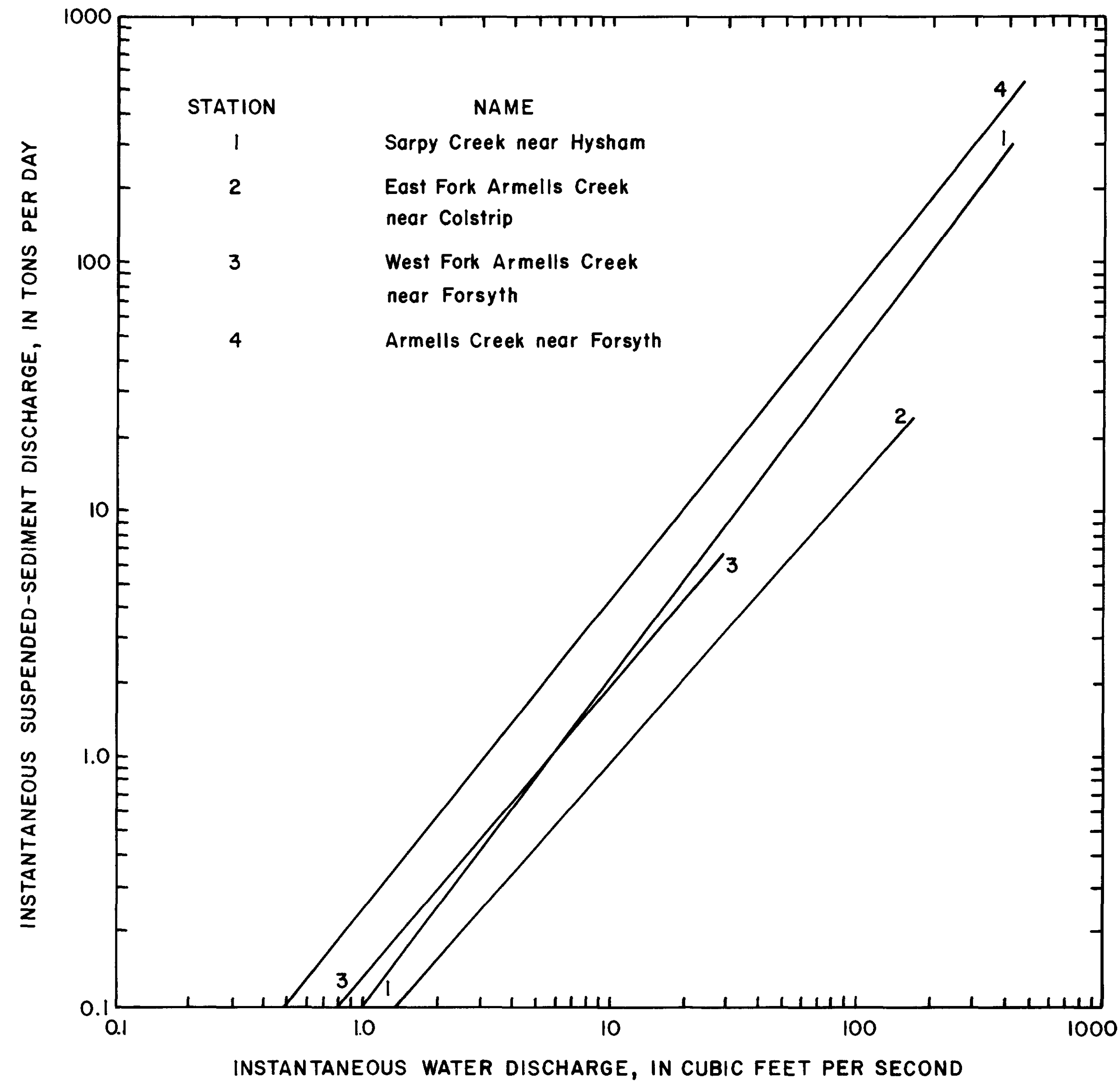


Figure 10.--Sediment-transport curves for Sarpy and Armells Creek drainage basins.

The 1977 water year was a drought year, with no flow in Sarpy Creek for much of the year. A period of snowmelt runoff produced a maximum discharge of 76 ft^3/s. Total runoff was 1,870 acre-ft, and a small amount (100 tons) of sediment was transported as sediment continued to accumulate.

The following water year continued dry, even though snowpack was greater than normal. In March 1978, a thaw caused flooding throughout southeastern Montana. Sarpy Creek peaked at 309 ft^3/s and sediment concentrations were large as accumulated sediment was released. In May 1978, continued thawing combined with large rainfall amounts caused record floods in southeastern Montana. Sarpy Creek, with a discharge of 372 ft^3/s, peaked more quickly and less violently than other streams, but large amounts of sediment were transported. Streamflow slowly decreased to base flow, until a second rainfall peak occurred in mid-September. In all, flow exceeded 100 ft^3/s for 13 days, with 1,600 tons of sediment transported. Annual totals were 10,450 acre-ft of runoff and about 2,500 tons of sediment.

In 1979, a long, cold winter caused low-altitude snowpack to accumulate to greater than normal levels. When the thaw began in March, Sarpy Creek experienced a long snowmelt runoff that peaked at 419 ft^3/s on March 16 and continued at moderate levels through early June. Flow exceeded 100 ft^3/s for 14 days, and transported 1,700 tons of sediment. The totals for the year were 11,780 acre-ft of runoff and about 3,000 tons of sediment.

Armells Creek basin

Armells Creek is an intermittent prairie stream adjacent and similar to Sarpy Creek. The East and West Forks, which have headwaters in the Little Wolf Mountains, have formed low-gradient alluvial valleys. About two-thirds of the length of the 370-mi^2 Armells Creek basin is drained by the East and West Forks. The streams flow through a succession of pools separated by riffles. Dense aquatic growth is common, especially along the East Fork.

Ranching is the predominate land use. Cattle graze and drink along the length of the stream. Stock ponds are common and flood irrigation is practiced during periods of high flow. Coal mining began at Colstrip, Mont., in the East Fork Armells Creek drainage in 1924 to fuel the steam engines of the Northern Pacific Railroad. The company continued to mine until 1958. In 1968 the mines were reopened by Western Energy Company, which operated three mines in the area with a production of 10 million tons in 1978. A fourth mine is run by Peabody Coal Company, and several new mines are planned for the area. The coal seams at some locations straddle East Fork Armells Creek and extraction is made to within 100 feet of the creek.

Three sediment stations are operated in Armells Creek basin. They are located on East Fork Armells Creek about 7 miles north of Colstrip (station 2), on West Fork Armells Creek near its confluence with the East Fork (station 3), and near the mouth of Armells Creek near Forsyth (station 4), about 2 miles upstream from the Yellowstone River.

The total runoff for Armells Creek for water years 1975-79 was 36,201 acre-ft, 10 percent less than that of Sarpy Creek. The smaller amount of runoff from a larger drainage area may be attributable to the lower average altitude of the headwater areas, which receive less precipitation. Armells Creek generally maintains a low base flow between widely scattered periods of rain and snowmelt runoff that is flashy and lasts only a few days. The maximum discharge was 960 ft^3/s and flows of 10 ft^3/s were exceeded 15 percent of the time.

Sediment concentrations for East Fork Armells Creek were small, ranging from 4 to 180 mg/L, with a mean of 42 mg/L. Even after moderate rains, streamflow remained small, as did sediment concentrations. The valley is flat and wide near the station; sluggish velocities in an often ill-defined channel create almost-marshlike conditions where runoff and sediment easily can be dissipated. Although mined areas upstream have experienced problems with sheet and gully erosion, the sediment does not appear to be reaching station 2. The West Fork of Armells Creek (station 3) exhibits more typical concentration patterns, but was not sampled for discharges exceeding 28 ft^3/s. At the low range of sampling, it functions similar to Sarpy Creek.

Sediment concentration in Armells Creek near Forsyth (station 4) ranged from 13 to 1,860 mg/L, with a mean of 180 mg/L. Relatively large concentrations at low discharges indicate that sediment is available at these times, and probably is being stored in pools. Relative depletion of sediment occurs sometimes in winter, as during 1975 when successive periods of snowmelt runoff appeared to remove fines and leave only sand and gravel in the streambed.

Sediment-transport curves for stations 2-4 are shown in figure 10. The slopes are similar, but the intercepts vary, which probably illustrates differences in availability of sediment; thus, East Fork Armells Creek (station 2) carries the least sediment at a given discharge.

The calculated mean sediment discharge for Armells Creek is 3,150 ton/yr. It is almost twice that of Sarpy Creek despite similar drainage areas and runoff amounts. Two factors combine to cause this condition. First, Armells Creek had larger water-discharge peaks with respectively larger sediment transport capability. Second, Armells Creek transports more sediment at a given discharge than Sarpy Creek, reflecting greater availability of material.

Rosebud Creek basin

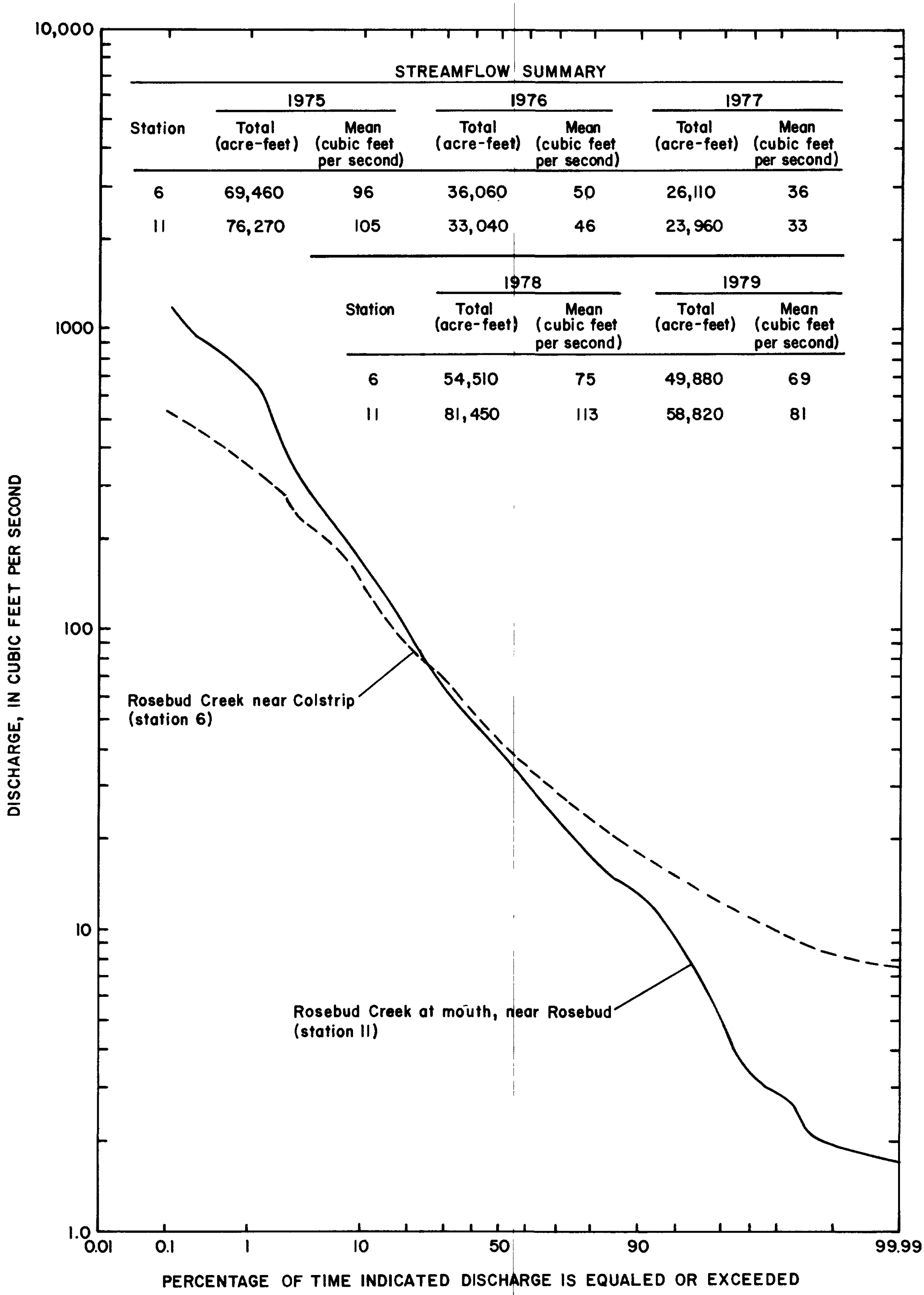
The Rosebud Creek drainage is long and narrow and consists of a one-half-mile-wide alluvial valley bounded on both sides by benches that lead into steep slopes fronting the high land divides. Headwaters in the Rosebud Mountains are at almost 5,000 feet; the mouth of Rosebud Creek is at 2,500 feet. Stream slopes are about 6 ft/mi except upstream from Kirby, Mont., where the slope is about 10 ft/mi.

The valley floor of the 1,302 mi^2 drainage supports a good hay crop with some irrigation. The benches have a sparse vegetative cover and are used primarily for stock grazing. The uplands are of the ponderosa pine, savannah-type environment.

Stations 5 to 11 are located in the basin. Five of these are on the main stem and have good data representation, although not all stream sites were sampled concurrently. Greenleaf Creek near Colstrip (station 7) and Snider Creek near Brandenberg (station 9) are small tributaries that rarely flow and each were sampled only twice.

Rosebud Creek flows perennially, although it may be intermittent during periods of drought. Historical sources indicate that earlier than the 1950's the stream became dry during late summer, even in the upstream reaches (Montana State Engineer's Office, 1948). Rosebud Creek has experienced streamflow variations during the study similar to those described for Sarpy Creek, with water years 1975, 1978, and 1979 being wet, and water years 1976 and 1977 being dry. Runoff totals and flow-duration curves for the two continuous-recording streamflow stations in the basin (stations 6 and 11) are shown in figure 11. The curves show that mean streamflows are about the same along the creek and water is lost during periods of low streamflow. The water loss is most likely due to irrigation and evaporation, although some water may seep into the ground. At rates greater than 70 ft^3/s, streamflow gains in a downstream direction and the peaks at the mouth of Rosebud Creek are twice as large as those at Colstrip.

Rosebud Creek at Kirby (station 5) is located in the upstream drainage, at stream mile 184. The channel at this station is U-shaped and lined with brush and



Station	1975 Total (acre-feet)	1975 Mean (cubic feet per second)	1976 Total (acre-feet)	1976 Mean (cubic feet per second)	1977 Total (acre-feet)	1977 Mean (cubic feet per second)
6	69,460	96	36,060	50	26,110	36
11	76,270	105	33,040	46	23,960	33

Station	1978 Total (acre-feet)	1978 Mean (cubic feet per second)	1979 Total (acre-feet)	1979 Mean (cubic feet per second)
6	54,510	75	49,880	69
11	81,450	113	58,820	81

Figure 11.--Flow-duration curves and streamflow statistics for Rosebud Creek near Colstrip and Rosebud Creek at mouth, near Rosebud, 1975-79.

grasses. The bottom varies from sand and gravel in riffle sections to silt and clay in the ponded sections. Sediment concentrations ranged from 12 to 624 mg/L, with a mean of 190 mg/L. This station was sampled only at times of high streamflow during water years 1978 and 1979 and had the smallest mean sediment concentration on Rosebud Creek for the period. During periods of high streamflow, 90 percent or more of the suspended sediment was finer than sand size.

Rosebud Creek near Colstrip (station 6) at stream mile 86 is the next station downstream. The channel at that station is also U-shaped, and entrenched about 10 feet. Grasses and trees line the channel and woody debris clogs the channel in places, much of it left by the floods of 1978. Beaver dams impede streamflow and constantly modify streamflow patterns. The bottom consists of sand, gravel, and cobbles in riffle sections and silt and clay in ponded sections. Sediment concentrations were larger than at Kirby, with a range of 19 to 1,040 mg/L and a mean of 220 mg/L. Concentrations and sediment discharges varied widely at this station. Hysteresis loops that demonstrate this variation are illustrated in figure 12. Streamflows during spring breakups in 1975, 1978, and 1979 were all large and remained so for several months. Sediment was readily available at the start of these events, and transport curves follow the same steep slope. As the runoff continued, sediment became depleted and sediment loads decreased, following a less steep transport curve on the recession of the runoff. The 1977 spring breakup was limited, and no hysteresis loop was formed because sediment supply remained available. Short-lived winter thaws in 1975 and 1976 carried smaller sediment loads because the ground was frozen.

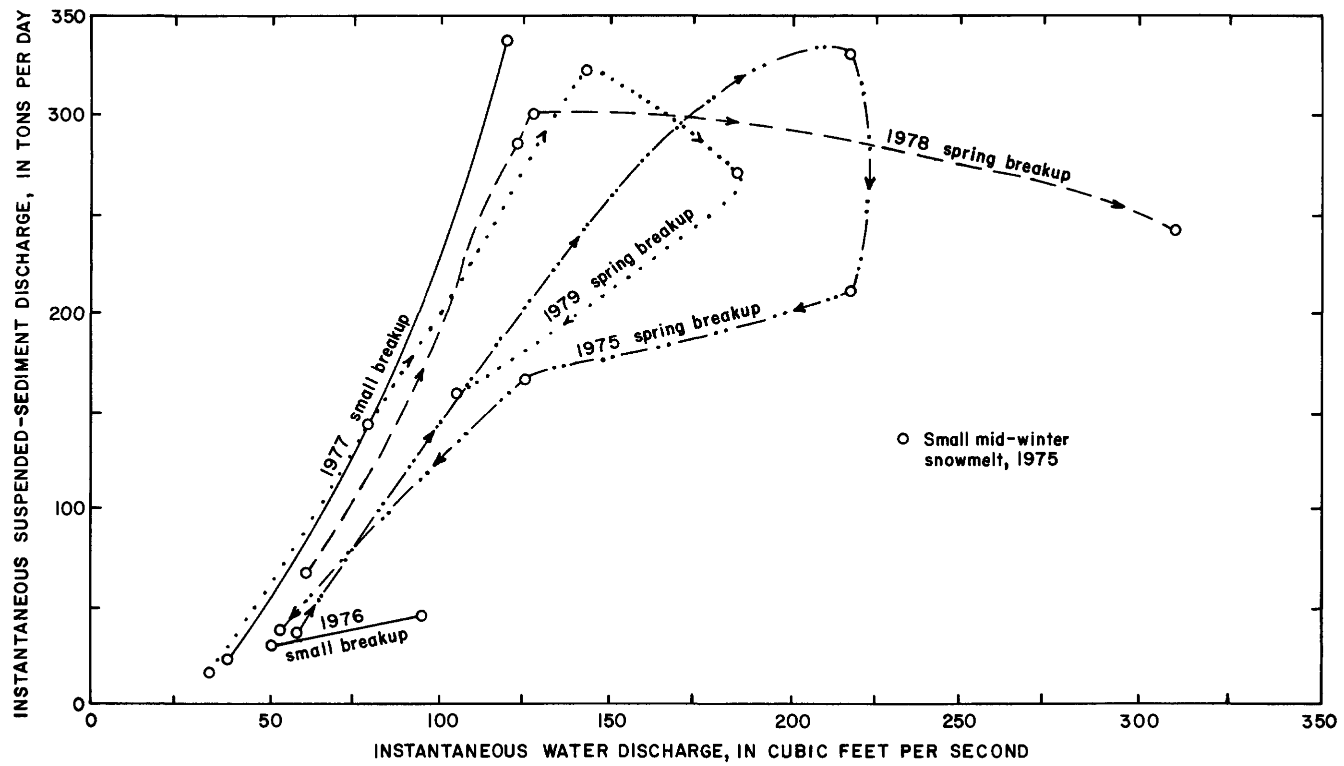


Figure 12.--Relationship of water discharge to suspended-sediment discharge for Rosebud Creek near Colstrip (station 6).

Rosebud Creek above Pony Creek, near Colstrip (station 8) is at stream mile 56. The channel is similar to that at the upstream station, although perhaps less entrenched. Sediment concentrations for the sampled period (water years 1975-77) ranged from 12 to 822 mg/L with a mean of 180 mg/L, which is almost identical to the mean (179 mg/L) at station 6 for this period.

Rosebud Creek near Rosebud (station 10) is at stream mile 22.0. The channel is U-shaped here also. Velocities are slow and the bottom consists of deep, soft mud. Beaver dams may be responsible for the muddy section at the station. Reaches upstream and downstream from this station are swift-flowing with a sand and gravel bottom. Sediment concentrations ranged from 18 to 946 mg/L, with a mean of 350 mg/L. The concentrations varied considerably for small water discharges, probably as a result of the muddy nature of the streambed.

Rosebud Creek at mouth, near Rosebud (station 11) is located 0.8 mile from the junction with the Yellowstone. The channel is broadly U-shaped and slightly entrenched with a gravel and cobble bottom. Velocities are generally large. Vegetation is sparse. Sediment concentrations ranged from 35 to 7,240 mg/L, with a mean of 540 mg/L--largest for the drainage. Sediment is generally transported through this reach without deposition. However, during large-scale rainstorms of small intensity, buildup of fine material in the gravelly bed has been observed. The water discharge is apparently insufficient to flush the channel of the large amounts of sediment provided. In this instance they remain in the channel until a large runoff supplies transporting power.

Sediment-transport curves for the stations in the Rosebud Creek drainage (fig. 13) are similar. They converge at about 200 ft^3/s. Sediment concentrations also tend to equalize at higher streamflows. This indicates that at higher levels of streamflow all new material that enters the channel continues movement until either material or water discharge decreases.

The frequency of water discharges greater than 100 ft^3/s, during which the bulk of sediment movement occurs, is greater at the mouth than at the stations near Colstrip. In fact, the mean sediment discharge at the mouth (48,000 ton/yr) is twice that near Colstrip (22,000 ton/yr). Sediment yields, however, are similar for the two stations, being 27.5 $(ton/mi^2)/yr$ at the mouth and 36.9 $(ton/mi^2)/yr$ near Colstrip.

Tongue River basin

Stations 12 to 38 are located within the 5,379-mi^2 Tongue River basin. Four of these stations are on the main stem Tongue River; 12 are on the principal tributaries of Hanging Woman, Otter, and Pumpkin Creeks; and the rest are on smaller, mostly intermittent creeks. The headwaters of the upper Tongue River drainage (1,477 mi^2) are in the Bighorn Mountains of Wyoming and are not discussed in this report. Upon entering Montana, the Tongue River flows past one of the most active coal-mining areas in the region and then into the Tongue River Reservoir (capacity of 68,000 acre-ft) formed by the Tongue River Dam. About 25 million tons of coal are extracted annually from four mines in the basin. Several additional mines are planned. Downstream from the dam a 10-mile-long steep walled canyon contains the river before opening into the wide alluvial valley that is typical of the study area. Vegetation is of two types: (1) Grassland-sagebrush ecosystem at lower altitudes and (2) ponderosa pine along ridges and uplands.

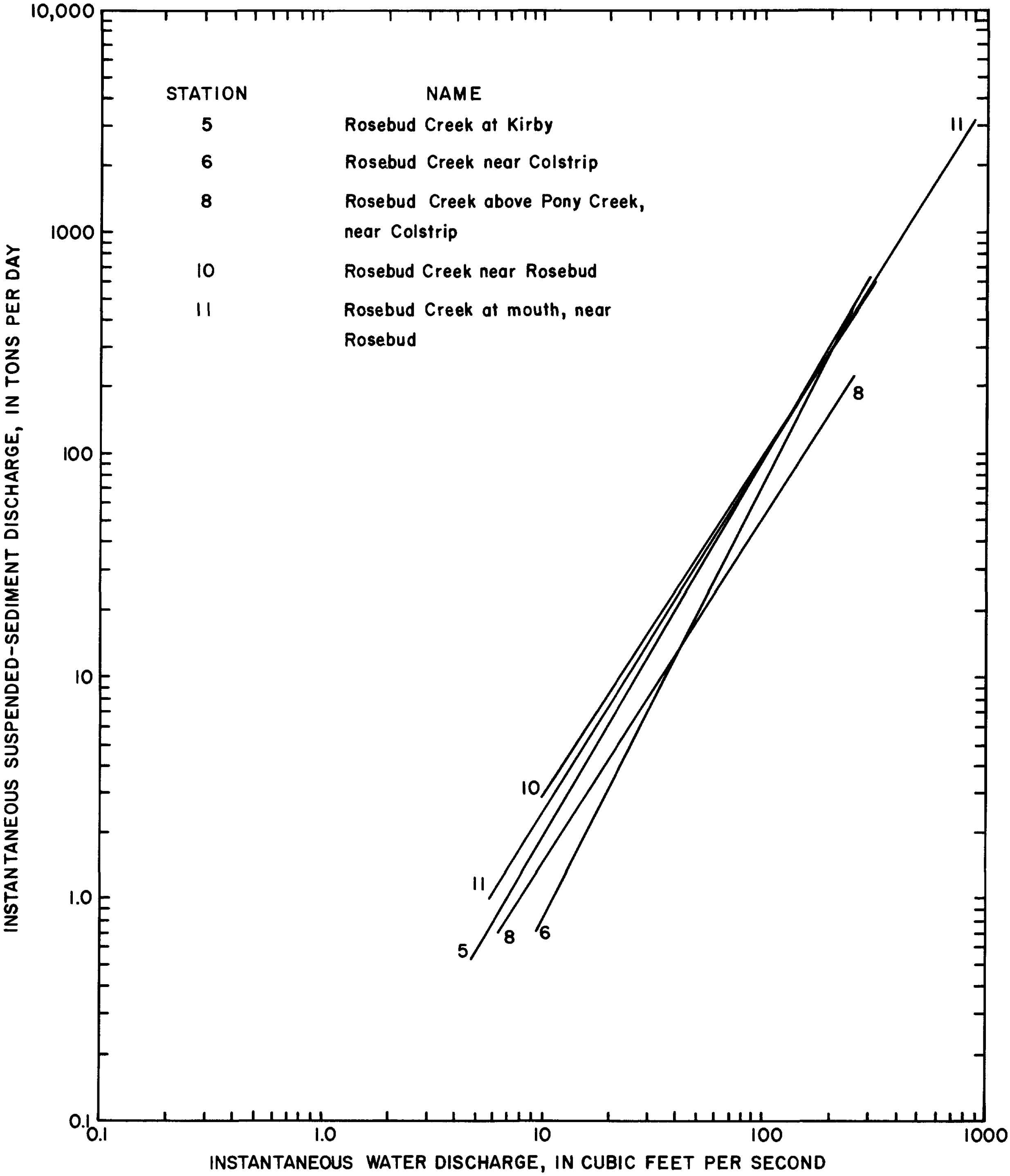


Figure 13.--Sediment-transport curves for Rosebud Creek drainage basin.

National forest covers about 438,000 acres between the Tongue and Powder Rivers. Land use in the basin is primarily agricultural, combining stock grazing with some irrigated crops. More than 2,000 small stock-watering reservoirs are in the drainage and about 26,000 acres are irrigated, principally by water from the reservoir.

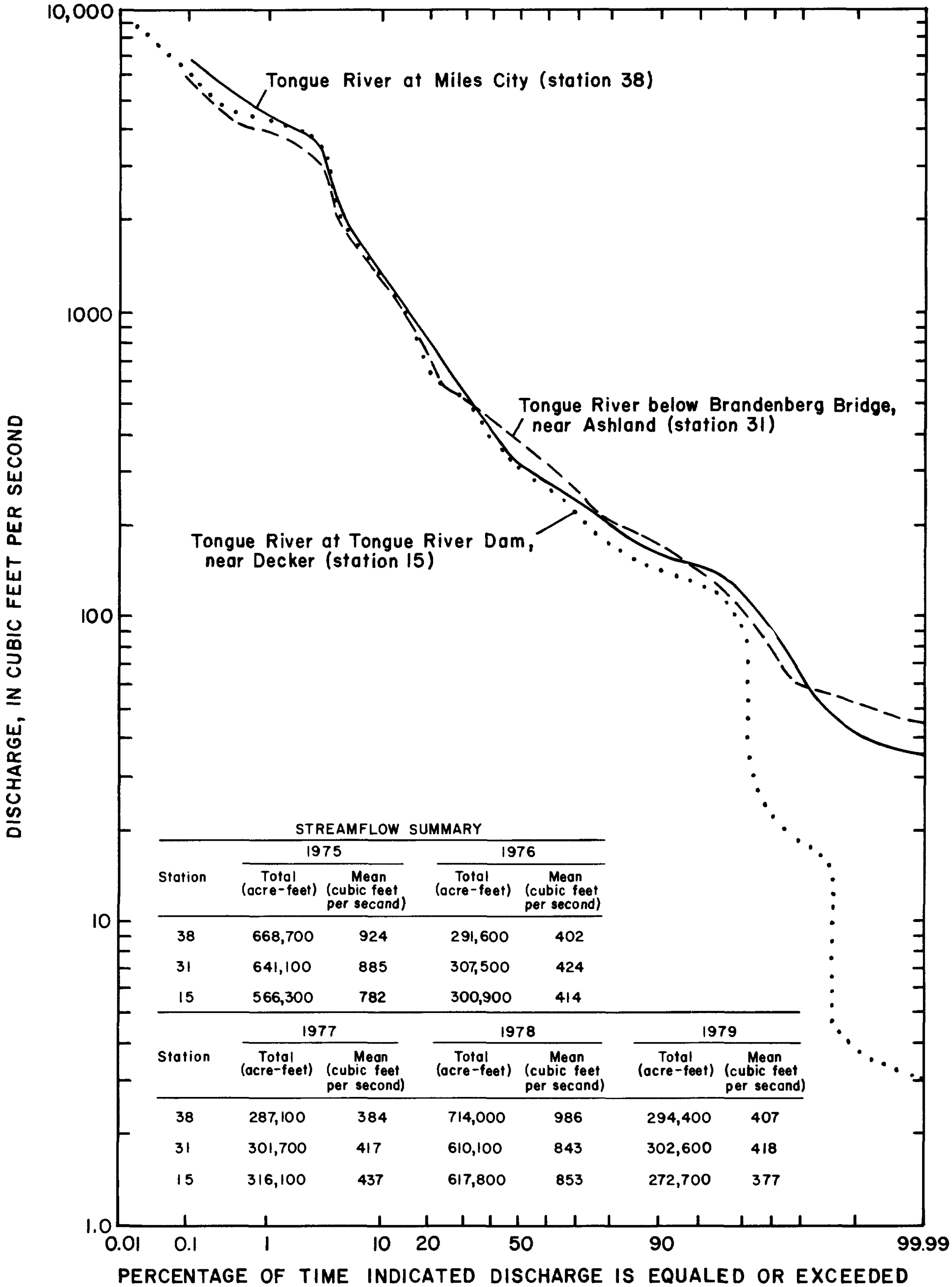
Tongue River

The main-stem stations are located downstream from the dam (station 15), downstream from Hanging Woman Creek (station 22), downstream from Brandenberg Bridge (station 31), and at the mouth near Miles City (station 38). Three of these stations (15, 31, and 38) had continuous-streamflow records, and two (31 and 38) had daily sediment samples collected for several years in addition to the monthly sediment sampling.

Comparison of flow-duration curves and streamflow statistics for the study (fig. 14) shows that streamflows were virtually identical along the length of the river. However, a comparison of monthly discharges showed downstream increases during spring breakup and decreases during warm and irrigation seasons. The annual streamflow patterns for the study period have been similar to those described for smaller streams, such as Sarpy Creek, except that two distinct spring runoffs occur--one during low-altitude (about 4,000 feet) snowmelt and a second in early summer when high-mountain snowmelt occurs. Streamflows on the Tongue River are regulated at the Tongue River Dam, and generally maintained in the range of 150 to 250 ft^3/s except during spring and summer.

The Tongue River at Tongue River Dam, near Decker station (number 15) is located 0.5 mile downstream from the dam at stream mile 188. The river is just entering the canyon at this point and the flood plain is only about 1,500 feet wide. The channel is wide and rectangular with a rocky bed. Periphytic algae are abundant during the warm months. Sediment concentrations were small at this site, with a mean of 18 mg/L and a narrow range of 4 to 59 mg/L. In fact, sediment concentrations were almost constant with little correlation to water discharge. This condition reflects the sediment trapping efficiency of the Tongue River Dam. A study of sediment accumulation in the reservoir (U.S. Department of the Interior, 1979) indicated that the mean sediment concentration in the Tongue River would be about 750 mg/L without the reservoir. This concentration, however, seems somewhat large based on monthly suspended-sediment concentrations measured upstream from the reservoir during water years 1980-81. Being vastly underloaded, the river uses its hydraulic power to erode its bed, causing the channel to be armored through the canyon. Observations (Koch, 1977) indicate that some degradation is probably occurring. Sand concentrations in suspended sediment are larger in the middle reach of the Tongue River than elsewhere in the study area.

The next downstream station is Tongue River below Hanging Woman Creek, near Birney (station 22) at stream mile 150. The valley is wider (1 mile) at this station and sediment is more available. The channel is rectangular and meandering, and bed material is principally sand, gravel, and cobbles. Mean sediment concentration is 60 mg/L, with a range of 2 to 812 mg/L. The largest sediment loads are carried during periods of rainfall when material is available from sheet erosion of the valley downstream from the canyon. The second largest sediment discharge of 1,100 ton/d was carried at a relatively small water discharge (502 ft^3/s) and large sediment concentration (812 mg/L) after a period of intense rains. The largest sediment discharge of 2,020 ton/d was carried at a large water discharge (4,150 ft^3/s) and small sediment concentration (180 mg/L), when steady light rains contributed material to a snowmelt runoff already in progress.



STREAMFLOW SUMMARY

Station	1975 Total (acre-feet)	1975 Mean (cubic feet per second)	1976 Total (acre-feet)	1976 Mean (cubic feet per second)
38	668,700	924	291,600	402
31	641,100	885	307,500	424
15	566,300	782	300,900	414

Station	1977 Total (acre-feet)	1977 Mean (cubic feet per second)	1978 Total (acre-feet)	1978 Mean (cubic feet per second)	1979 Total (acre-feet)	1979 Mean (cubic feet per second)
38	287,100	384	714,000	986	294,400	407
31	301,700	417	610,100	843	302,600	418
15	316,100	437	617,800	853	272,700	377

Figure 14.--Flow-duration curves and streamflow statistics for main-stem Tongue River stations, 1975-79.

The two downstream main-stem stations, Tongue River below Brandenberg Bridge, near Ashland (station 31, mile 78) and Tongue River at Miles City (station 38, mile 8) are located in the same wide alluvial valley environment. Data from these stations continue the pattern of increasing sediment concentration toward the mouth. The mean concentration was 240 mg/L and the range 8 to 1,440 mg/L near Brandenberg Bridge; the mean concentration was 620 mg/L and the range 5 to 5,090 mg/L at Miles City. Daily sediment samples were collected at both stations. Comparison of daily sediment records indicates that the stations have similar characteristics. Although daily variation was somewhat greater at the downstream station, both stations showed sharp sediment peaks during rains, and much longer periods of large sediment discharge during periods of spring snowmelt. Peaks generally coincided in time. Sediment depletion caused hysteresis on two time scales: (1) On a daily basis after precipitation-runoff peaks, and (2) on a weekly or monthly basis during spring snowmelt.

Sediment-discharge and concentration-duration statistics were derived from the daily sediment records (table 6). These statistics indicate how often various limits can be expected to be exceeded. For instance, sediment concentrations below Brandenberg Bridge (station 31) have equaled or exceeded 340 mg/L for 10 percent of the time, and concentrations at Miles City (station 38) have equaled or exceeded 750 mg/L for 10 percent of the time.

Sediment-transport curves (fig. 15) for the main-stem stations are generally well-defined. In a downstream direction, the increasing availability of sediment is reflected in the transport curves, at first by increasingly steeper slopes and then by increasingly larger (less negative) intercepts. Although transport-curve slopes for the Tongue River approach values similar to those for the Powder River (where sediment supply is much more abundant), the intercept values remain much more negative for the Tongue River; this condition gives some indication of the relative lack of available sediment in the Tongue River compared to the Powder River.

Mean sediment discharges were calculated to be 10,300 ton/yr near the dam, 194,000 ton/yr near Brandenberg Bridge, and 634,000 ton/yr at Miles City. These correspond to sediment yields of 5.82 (ton/mi^2)/yr near the dam, 47.8 (ton/mi^2)/yr near Brandenberg Bridge, and 118 (ton/mi^2)/yr at Miles City. The most effective range of water discharge for transporting sediment load was calculated for the Tongue River at Miles City. The results indicate that the 3,200 to 4,700 ft^3/s range in water discharge transported about 46 percent of the annual sediment discharge during the 12 days per year that this range of streamflow occurred on the average during the study.

Hanging Woman Creek

The 470 mi^2 Hanging Woman Creek basin covers an area from the northern slopes of Squaw Butte in north-central Wyoming through upland prairie and parts of the Custer National Forest to the confluence with the Tongue River near Birney, Mont. Cattle ranching is the principal land use. Three stations are located within the drainage. East Trail Creek near Otter (station 19) is located on one of the large tributaries and is within the Hanging Woman Creek coal field, which was studied in detail by the U.S. Bureau of Land Management (U.S. Department of the Interior, 1977b). Station 20, Hanging Woman Creek below Horse Creek near Birney, is 25 miles from the mouth at the midpoint of the drainage in Montana. Hanging Woman Creek near Birney (station 21) is a continuous-recording streamflow station 3 miles from the mouth.

Table 6.--*Duration statistics for daily sediment stations*

Station[1]	Variable and period of record[2] P =	Value equaled or exceeded "P" percent of the time 10	25	50	75	90	95
Station 31	*Q* (1975-79)	1,300	570	360	230	170	140
	C (1975-78)	340	120	42	18	9.3	5.3
	Qss (1975-79)	1,100	170	40	12	5.1	3.1
Station 38	*Q* (1975-79)	1,300	640	320	220	160	140
	C (1978-79)	750	200	83	37	22	18
	Qss (1978-79)	3,200	320	85	22	11	7.8
Station 39	*Q* (1975-79)	1,400	500	270	150	95	65
	C (1975-77)	9,500	3,900	920	190	110	76
	Qss (1975-77)	29,000	4,900	610	90	31	10
Station 40	*Q* (1976-79)	1,100	520	280	150	95	56
	C (1976-78)	11,000	4,900	1,700	350	210	150
	Qss (1976-78)	36,000	7,900	1,200	160	69	28
Station 44	*Q* (1975-79)	1,700	740	300	150	93	57
	C (1975-77)	9,800	4,600	1,100	200	120	60
	Qss (1975-79)	26,000	6,000	610	85	36	14

[1]Station 31 is Tongue River below Brandenberg Bridge, near Ashland,
38 is Tongue River at Miles City,
39 is Powder River at Moorhead,
40 is Powder River at Broadus, and
44 is Powder River near Locate

[2]*Q* is water discharge, in cubic feet per second;
C is sediment concentration, in milligrams per liter; and
Qss is sediment discharge, in tons per day

The creek is perennial at the mouth, although 90 percent of the time discharges are less than 10 ft^3/s and 50 percent of the time discharges are less than 2 ft^3/s. Peaks are larger and shorter-lived than those of similar-sized streams in the study area. During the 1978 water year, both Otter and Hanging Woman Creeks had a mean discharge of about 11 ft^3/s, but the maximum discharge for that year was 338 ft^3/s for Otter Creek and 1,730 ft^3/s for Hanging Woman Creek (see table 7). Also, the slope of the flow-duration curve for Hanging Woman Creek is steeper than that for Otter Creek in the high-flow range.

Mean sediment concentrations for 1978-79 were 85 mg/L at station 20 and 99 mg/L at station 21, indicating a slight downstream increase. East Trail Creek, sampled less and at a smaller range of streamflows, had a mean concentration of 31 mg/L. East Trail Creek and Hanging Woman Creek near Birney were both sampled on

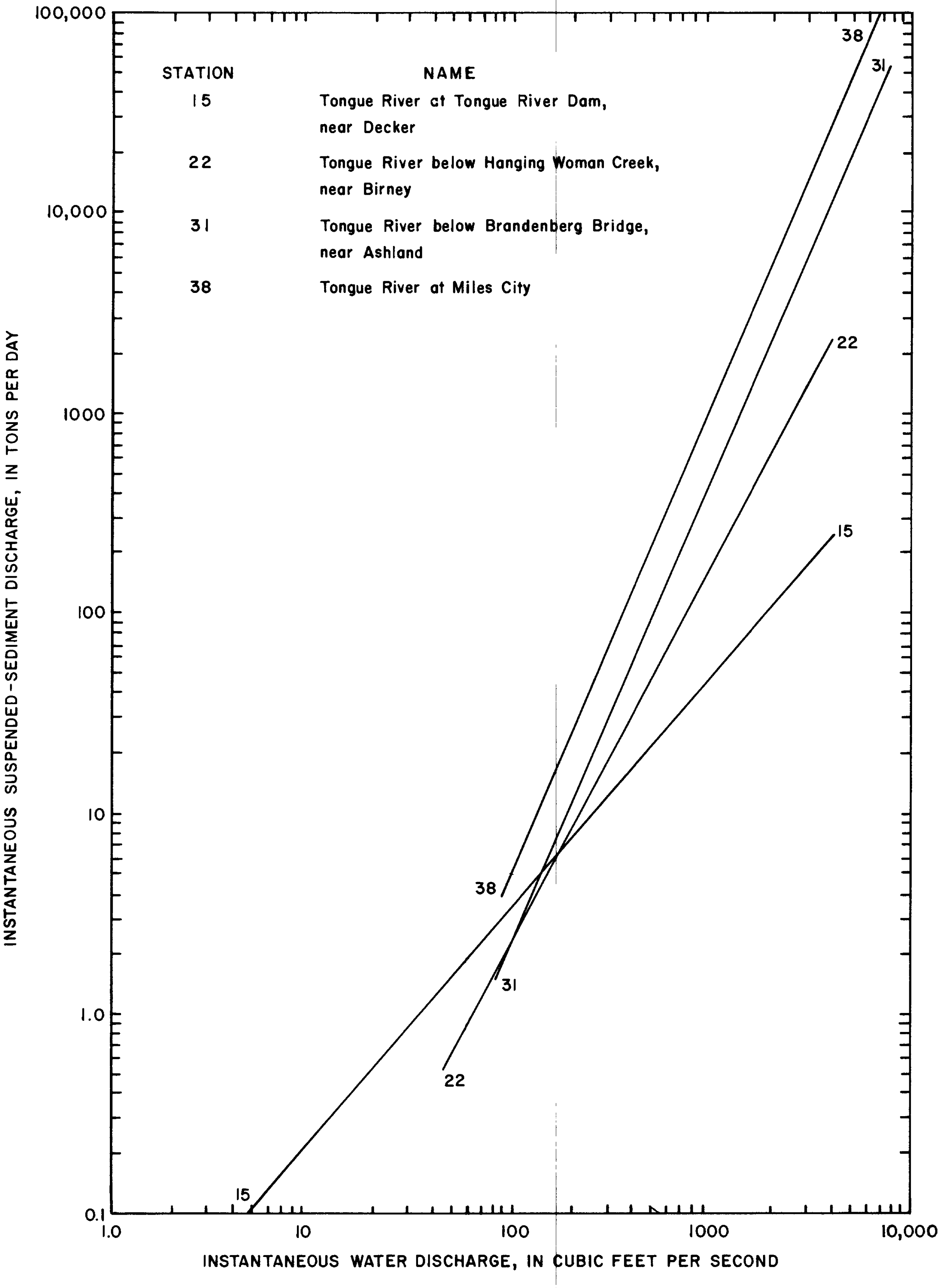


Figure 15.--Sediment-transport curves for main-stem Tongue River stations.

Table 7.--*Streamflow statistics for selected streams*

Water year	Discharge[1]	Sarpy Creek (station 1)	Squirrel Creek (station 12)	Hanging Woman Creek (station 21)	Otter Creek (station 29)	Pumpkin Creek (station 37)	Mizpah Creek (station 43)
1975	Maximum	390	--	844	308	1,880	1,780
	Mean	20.1	--	13.6	19.0	33.6	33.3
	Total	14,570	--	9,820	13,720	24,330	24,010
1976	Maximum	14	12	25	19	260	226
	Mean	2.17	2.99	3.42	5.04	15.3	9.38
	Total	1,580	2,170	2,480	3,660	11,120	6,810
1977	Maximum	52	55	78	16	103	63
	Mean	2.59	4.45	2.31	3.29	2.93	2.56
	Total	1,870	3,220	1,670	2,380	2,120	1,850
1978	Maximum	340	323	1,730	338	1,980	1,670
	Mean	14.4	8.70	11.3	11.0	49.5	46.3
	Total	10,450	6,300	8,140	7,930	35,850	33,530
1979	Maximum	385	58	42	110	850	471
	Mean	16.3	6.25	2.83	9.44	26.8	28.3
	Total	11,780	4,520	2,050	6,830	19,390	20,500

[1]Maximum discharge, in cubic feet per second
Mean discharge, in cubic feet per second
Total discharge, in acre-feet per year

May 19, 1978, 1 day after record flood peaks. Sediment concentrations and discharges, although undoubtedly less than during the previous days, were maximum values observed at these stations for the period of record. East Trail Creek, with a drainage area of 31 mi^2, had a water discharge of 36 ft^3/s and a sediment discharge of 44 ton/d. Hanging Woman had a discharge of 359 ft^3/s and a sediment discharge of 549 ton/d. Therefore, East Trail Creek, with 10 percent of the total drainage area, supplied 10 percent of the water and slightly less than 10 percent of the sediment load. Slopes of sediment-transport curves for the three sites (fig. 16) are remarkably similar. Lack of transporting water generally limits sediment movement in the East Trail Creek drainage, although data for this drainage indicate that sediment availability decreases in winter and after long periods of large sediment discharge.

Sediment source yields for the East Trail Creek drainage have been estimated to be 0.20 to 0.33 $(acre\text{-}ft/mi^2)/yr$, and sediment discharges are estimated at 0.02 to 0.07 $(acre\text{-}ft/mi^2)/yr$ based on stock-pond siltation (U.S. Department of the Interior, 1977b). These estimates result in a delivery ratio of 0.1 to 0.2; that is, 10 to 20 percent of the material eroded from the land surface is actually

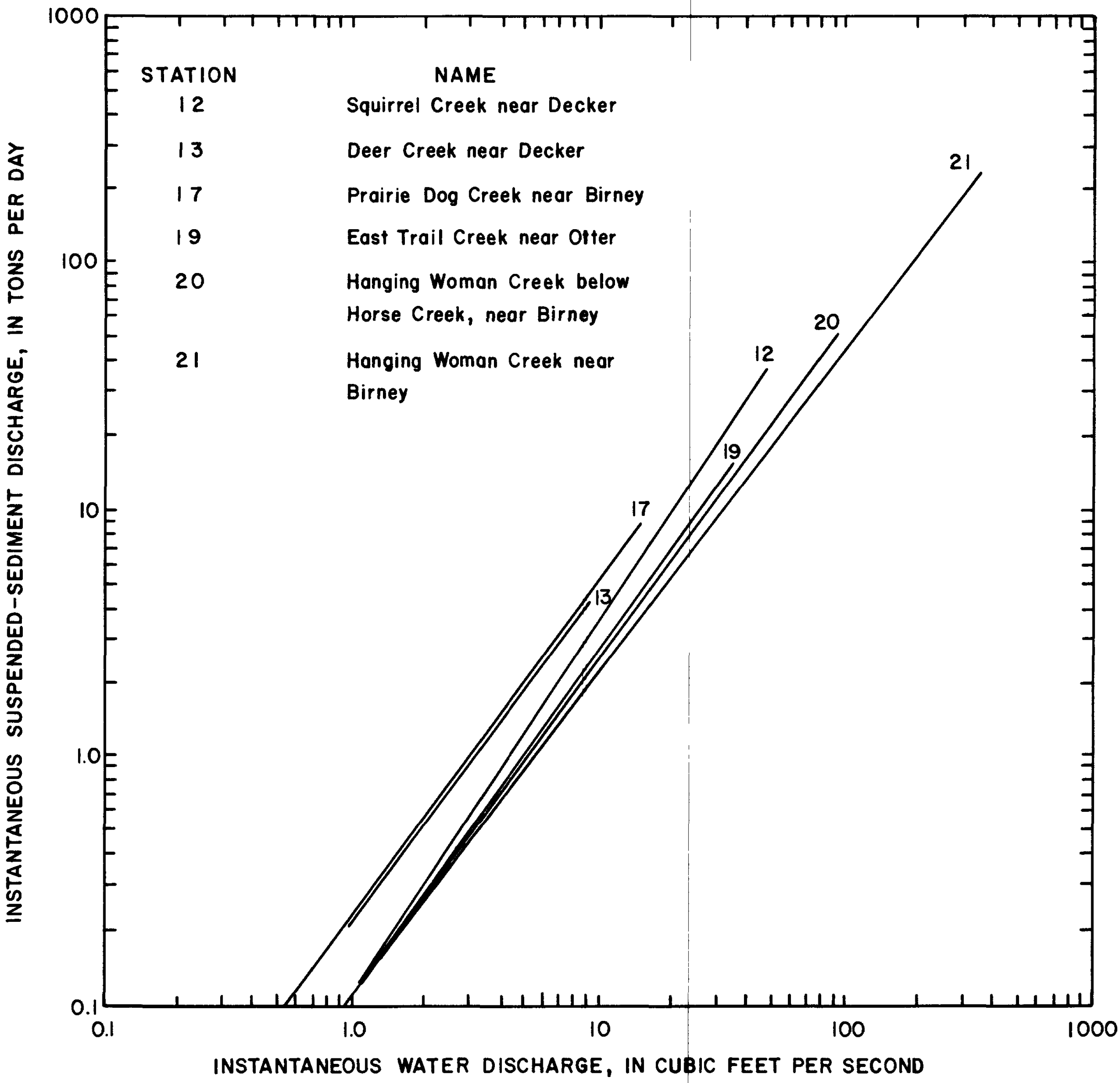


Figure 16.--Sediment-transport curves for Tongue River tributaries, upstream stations.

transported out of the basin. The mean sediment discharge for Hanging Woman Creek calculated by the flow-duration sediment-transport curve method is 1,130 ton/yr, which, converted to a volume yield, is 0.002 (acre-ft/mi^2)/yr. The calculated load may be underestimated because of the rapid fluctuations in streamflow.

Otter Creek

Otter Creek, draining an area of 707 mi^2, is the largest tributary of the Tongue River. The drainage covers an area from near the Montana-Wyoming border to Ashland, Mont. About 60 percent of the drainage area is national forest land. Precipitation in the basin is greater than in other parts of the study area, and vegetation is somewhat more dense. Coal underlies much of the basin; one producing mine is near Ashland. Ranching is the principal land use. There are numerous stock ponds, and about 4,200 acres are irrigated, mostly by water spreading.

Three sediment stations are located on Otter Creek. They are, in downstream order: Otter Creek near Otter (station 24), Otter Creek below Fifteenmile Creek near Otter (station 26), and Otter Creek at Ashland (station 29), which was also a continuous-streamflow station.

Annual mean discharges ranged from 3.3 to 19 ft^3/s for Otter Creek at Ashland, with a maximum discharge of 425 ft^3/s. The fluctuations in flow are somewhat less than in streams like Hanging Woman Creek. Runoff from the basin is among the smallest in the study area.

Mean sediment concentrations were small and increased in a downstream direction from 52 to 57 to 120 mg/L (1978-79) for the three stations. Otter Creek near Otter maintained only a low streamflow even during major peaks elsewhere, and sediment concentrations varied mostly with rainfall. Sediment availability often seems small, and varies from year to year. During the 1979 spring runoff, sediment concentrations at the downstream two main-stem stations were small until an intense storm in June provided additional material. The maximum instantaneous sediment discharge was 420 ton/d at the mouth station during the May 1978 floods.

Three stations are located on small tributaries to Otter Creek. Bear Creek at Otter (station 25), with a drainage area of 90 mi^2, is the principal headwater tributary to Otter Creek. Threemile Creek near Ashland (station 27) and Home Creek near Ashland (station 28) occupy similar-sized adjacent drainages near the mouth of Otter Creek.

Threemile Creek was sampled twice during the study. On January 20, 1974, the ground was frozen and a discharge of 1.8 ft^3/s transported a sediment discharge of 0.12 ton/d. On March 19, 1975, the ground was partly frozen and a discharge of 22 ft^3/s transported a sediment discharge of 13 ton/d. Data were insufficient to develop a sediment-transport curve.

Home Creek was sampled 25 times during water years 1977-79. Streamflow was less than 1 ft^3/s for all samples except on May 19, 1978, when a water discharge of 23 ft^3/s transported a sediment discharge of 22 ton/d. Low-flow sediment concentrations ranged from 6 to 134 mg/L. The concentrations correlated poorly with water discharge.

Bear Creek was sampled five times during water years 1975-76. Sediment concentrations were less than 100 mg/L for the sampled discharge range of 0.01 to 53 ft^3/s. The small concentrations were probably the result of upstream impoundments trapping sediment. In addition, most samples were collected when the ground was at least partly frozen.

Sediment-transport curves for the Otter Creek basin stations are shown in figure 17. They are similar, except that the curve for Otter Creek below Fifteenmile Creek (station 26) had a steeper slope. The basin seems to have fairly homogenous sediment characteristics. Several of these characteristics are described in Bureau of Land Management reports (U.S. Department of the Interior, 1975, 1977a) for the Threemile Creek-Home Creek study area, namely: (1) Sediment source yields are in the range of 0.04 to 0.47 $(acre\text{-}ft/mi^2)/yr$, (2) channels are grass-covered with

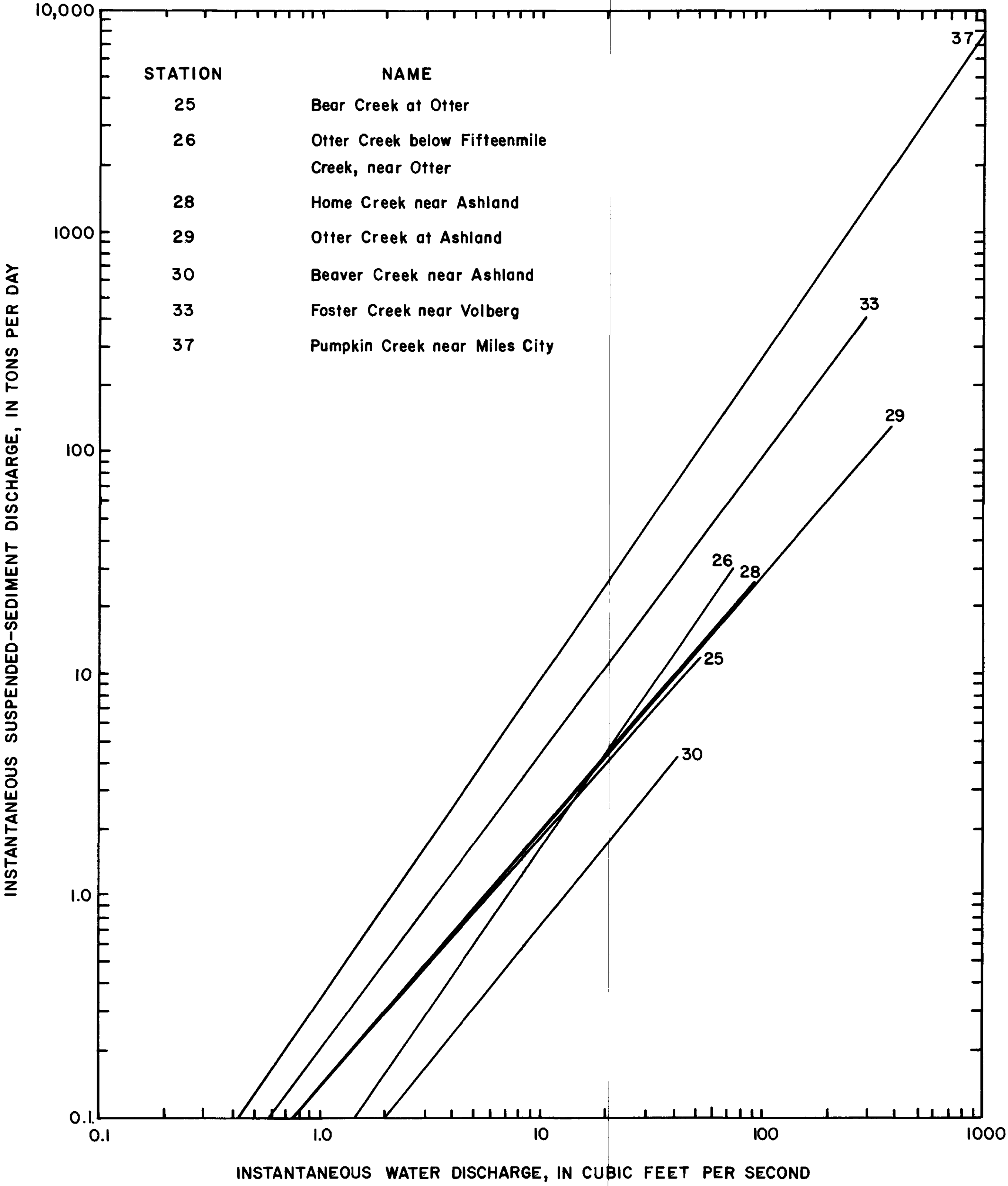


Figure 17.--Sediment-transport curves for Tongue River tributaries, downstream stations.

few headcuts, (3) channel erosion is not an important source for sediment, and (4) delivery ratios are small.

The calculated mean sediment discharge for Otter Creek at Ashland is 770 ton/yr, with a sediment yield of 1.09 (ton/mi^2)/yr, the smallest in the study area. Little runoff and a lack of available material for transport apparently account for the small yields. Although sheet erosion takes place in the basin, much of the sediment load does not reach the larger streams. Sediment is deposited on bottomland terraces and some of the entrenched stream channels appear to be aggrading.

Pumpkin Creek

Pumpkin Creek originates in the low hills near Sonnette, Mont., and meanders northward for 150 stream miles to its junction with the Tongue River 15 miles from Miles City. Though intermittent, it is the second largest tributary to the Tongue River, draining a 700-mi^2 area that consists mostly of broad, rolling, and dissected prairie. Drainage divides are generally low and trees are scarce. Cattle range through the grassy valleys and benchlands, and the creek is often dammed for stock ponds and hay irrigation.

Five sampling stations were established in the basin. One station, Pumpkin Creek near Sonnette, was dry during all visits; two others, Pumpkin Creek near Volborg (station 36) and Little Pumpkin Creek near Volborg (station 35), which were sampled only during the dry water years of 1976-77, produced no sampled flows greater than 5 ft^3/s. Pumpkin Creek near Loesch (station 34), at stream mile 95 and just downstream from a stock pond, showed more consistent flow than at the stations near Volborg. Pumpkin Creek near Miles City (station 37), located 7 stream miles from the mouth, is also a streamflow-gaging station.

Pumpkin Creek flows only during spring snowmelt and after intense rains. Because of numerous channel impoundments, natural-streamflow conditions no longer exist. At Pumpkin Creek near Miles City no-flow conditions occur about 50 percent of the time, although beyond this percentage the flow-duration curve rises steeply; 10 percent of the time flow exceeded 46 ft^3/s. Annual mean discharges ranged from 2.93 ft^3/s in 1977 to 49.5 ft^3/s in 1978. The maximum mean daily discharge was 1,980 ft^3/s on May 19, 1978.

Sediment concentrations at the upstream sites generally were erratic, but average for the study area, although large concentrations were occasionally sampled at low streamflows at Pumpkin Creek near Loesch (606 mg/L at 0.01 ft^3/s). The maximum sediment discharge at this station was 54 ton/d during the flood of May 1978, which was the only high streamflow sampled at any of the upstream stations. Pumpkin Creek near Miles City had a mean sediment concentration of 1,600 mg/L. The largest concentration was 23,000 mg/L at a flow of 83 ft^3/s after rainfall totaling 1.5 inches during September 12-13, 1979.

Because of the scarcity of data, a sediment-transport curve could be developed only for Pumpkin Creek near Miles City (fig. 17). The curve has a fairly steep slope and a very large intercept value, reflecting a relative abundance of sediment supply. Examination of the data indicates that two transport curves (fig. 18) might be better for this station. Several rainfall-caused sediment peaks all lie along a steep transport curve, whereas the longer spring breakup periods seem to

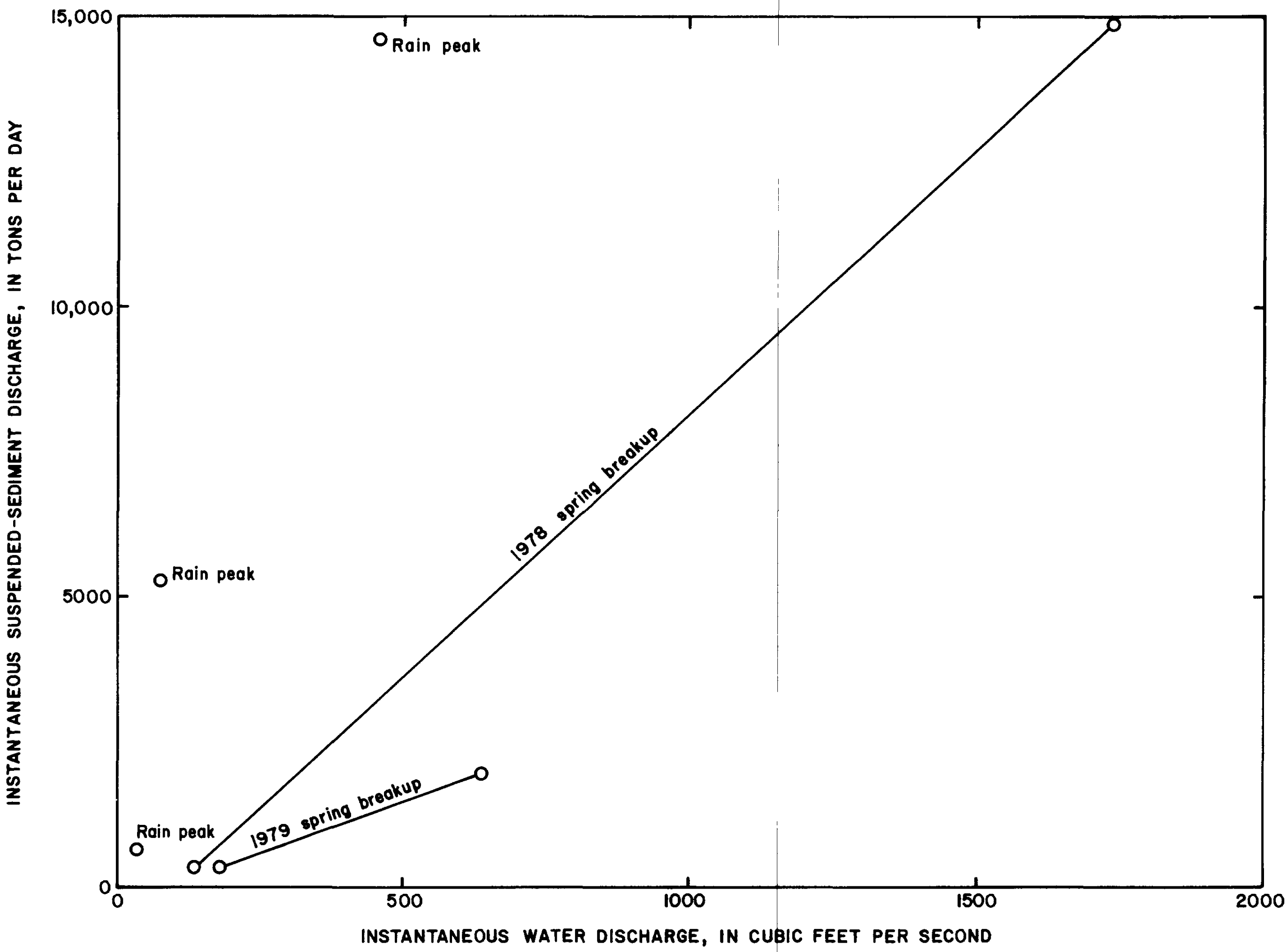


Figure 18.--Relationship of water discharge to suspended-sediment discharge for Pumpkin Creek near Miles City (station 37).

follow less-steep curves. One curve was used, however, because there was not enough data to develop two well-defined curves.

A mean suspended-sediment discharge of 45,000 ton/yr was calculated for Pumpkin Creek near Miles City. Therefore, Pumpkin Creek, with 13 percent of the drainage area and 4 percent of the streamflow, contributed 7.1 percent of the sediment discharge for the Tongue River basin.

Small tributaries

Ten stations were located on small tributaries of the Tongue River. Data pertaining to these stations are summarized in the paragraphs that follow.

Squirrel Creek is the largest of these small tributaries and was sampled at the streamflow-gaging station (Squirrel Creek near Decker, station 12) 7 miles upstream from its mouth. The drainage area of 34 mi^2 is located west of Decker, Mont., upstream from coal mines and the Tongue River Reservoir. The stream is perennial because a small spring upstream from the station maintains base flow of about 1 ft^3/s. Total runoff for water years 1976-79 was 16,210 acre-ft, with a peak flow of 323 ft^3/s on May 19, 1978. Another rainfall peak of 16 ft^3/s occurred in July 1977. Other than these, the principal flow has been broad March-to-June spring-snowmelt runoff with peaks of about 50 ft^3/s. Sediment concentrations ranged from 5 to 970 mg/L, with a mean of 110 mg/L. Contrary to conditions at other stations, the largest concentration occurred during spring breakup. Rains caused smaller sediment peaks. The sediment-transport curve for this station is shown in figure 16. A mean sediment discharge of 1,190 ton/yr was calculated for this station. This value corresponds to a sediment yield of 0.03 (acre-ft/mi^2)/yr, which agrees well with Bureau of Land Management (U.S. Department of the Interior, 1977b) estimates of yields for small drainage areas in the vicinity.

Deer Creek near Decker (station 13) is located at the midpoint of a small drainage about 8 miles northeast of Decker. Low streamflows were sampled nine times in 2 years, with a mean sediment concentration of 110 mg/L. The largest sediment discharge of 7.7 ton/d occurred during the March 1975 spring breakup.

Spring Creek near Decker (station 14) drains an area that will be disrupted during development of the newly opened Spring Creek Mine; about 33,000 feet of the stream channel will be relocated during the first 9 years of mine operation. The creek was sampled only twice during 1978-79--once during the March 1978 spring breakup and in May 1978 before the floods of that year. The March sample had a sediment concentration of 1,220 mg/L at a flow of 18 ft^3/s. The May sample had a concentration of 92 mg/L at a flow of 1.0 ft^3/s.

Fourmile Creek near Birney (station 16) was observed flowing only twice in 2 years. The mean sediment concentration was 70 mg/L at a mean discharge of 0.77 ft^3/s.

Prairie Dog Creek near Birney (station 17) is within a drainage being studied in detail by the Bureau of Land Management (see Cary and Johnson, 1981). Sediment and erosion data will be available when this study is completed. Monthly mean sediment concentration was 140 mg/L. The largest concentration of 1,420 mg/L occurred on the rising side of a flood at a relatively small discharge of 15 ft^3/s.

Bull Creek near Birney (station 18) was sampled twice during winter thaws in 1975. Sediment concentrations were small (mean of 39 mg/L) owing to frozen ground.

Beaver Creek near Ashland (station 30) was sampled three times during winter thaws in 1975. Discharges as large as 42 ft^3/s produced a maximum observed sediment concentration of 73 mg/L, again reflecting the lack of available material during winter. The mean concentration for nine samples was 29 mg/L.

Liscom Creek near Ashland (station 32), adjacent to Beaver Creek, also was sampled during winter thaws in 1975. Sediment concentrations were much larger than concentrations in Beaver Creek. However, a discharge of 18 ft^3/s on Liscom Creek produced a small sediment concentration of 223 mg/L. The reason for this dissimilar behavior is not known.

Foster Creek near Volborg (station 33) was sampled 14 times during 1975-77. Sediment concentration ranged from 4 to 4,260 mg/L, with a mean of 420 mg/L. This is the largest mean of all small drainages in the study area. It is most likely indicative of a relative abundance of material. The peak concentration of 4,260 mg/L occurred in June 1976 at a discharge of 4.4 ft^3/s after intense rains. Less sediment was available during winter-thaw peaks. A March 1975 peak of 300 ft^3/s transported 130 mg/L of sediment. The sediment-transport curve for this station is shown in figure 17. Its high intercept again indicates good availability of material.

Powder River basin

The Powder River drains an area of 13,500 mi^2, flowing from high altitudes on the eastern slopes of the Bighorn Mountains in northern Wyoming, crossing the Montana-Wyoming border near Moorhead, and continuing north about 150 miles to its junction with the Yellowstone River north of Locate, Mont. More than half the basin is in Wyoming and is not discussed here. The river meanders through a wide valley, but is not deeply entrenched. There is active channel and gully erosion, as well as sheet erosion on the sparsely covered, soft, shaley benches along the valley. The stream gradient averages 5.5 ft/mi in Montana. The west side of the drainage is high with rugged relief, whereas the east side is characterized by low to moderate relief with gently sloping divides. Precipitation also varies from west to east. The high altitude western areas receive as much as 20 inches of rain, but leeward slopes on the east receive only about 10 inches. The average for the basin is about 12 inches.

Land use has both promoted and retarded sediment movement. The valley has seen intense cattle and sheep grazing, which reached its peak between 1880 and 1920, with a resulting deterioration of vegetative cover and increased sediment movement. Conversely, dams for stock ponds and spreader dikes for flood irrigation have slowed movement of water and sediment.

Three study stations were located on the main stem of the Powder River in Montana: Moorhead (station 39), Broadus (station 40), and Locate (station 44). All three had continuous streamflow and daily sediment records, although the periods of record are not all concurrent.

The three remaining network stations in the Powder River basin were located on Mizpah Creek, the principal tributary to the Powder River in Montana. Only the station near the mouth--Mizpah Creek at Mizpah (station 43), which also had continuous streamflow record--was sampled during a meaningful range of flows.

Powder River

The environmental setting at all three stations is similar. The valley narrows somewhat in an upstream direction, and at Moorhead adjacent bluffs form a mile-wide canyon. The river bed consists of constantly shifting sands. A size analysis showed 96 percent sand and larger grains in the bed at Arvada, Wyo., which is about 35 miles southwest of Moorhead.

The Powder River is perennial in Montana, but intermittent in some reaches in Wyoming. Fall and winter discharges are about 100 ft^3/s. Superimposed on these flows are periods of large spring snowmelt at low altitudes in March and April, and the broader mountain-snowmelt runoff in May through July. The water that passes

Moorhead is generally derived from the Bighorn Mountains, where annual runoff can be as much as 25 inches. Little additional water is supplied between Moorhead and Broadus, because the drainage area increases by only 8 percent. The drainage area increases by 50 percent between Broadus and Locate. This increase consists entirely of low-altitude prairie and badlands. The increase in flow between Broadus and Locate varied from 10 to 40 percent during the study, depending on low-altitude snow and rainfall patterns. The total runoff at Locate for water years 1975-79 was 2,700,000 acre-ft with a maximum flow of 30,000 ft^3/s.

Sediment concentration generally increased in a downstream direction, although there are many exceptions depending on the source of the sediment load. The ranking of mean annual concentrations among the stations varied from year to year. Sediment peaks generally coincided with water-discharge peaks within about a day. The greatest exception was during the May 1978 flood breakup when the sediment peak preceded the water peak by 1 week at all three sites. The maximum sediment concentration of 49,700 mg/L occurred at Moorhead in June 1975.

Sediment-transport curves for the three sites (fig. 19) are similar. The hysteresis loop that occurred at Powder River near Locate across the flood peak of May 22, 1978, is also shown in figure 19. Some evidence exists that for these sites spring runoff and midwinter thaws do not follow differently sloped transport curves, as was observed for other stations in the study area. Instead, either all points are on the same curve or the transport curves are translated from year to year, keeping the same slope but varying in intercept. Duration statistics for water discharge, sediment concentration, and sediment discharges are given in table 6.

Sediment discharges for the three stations were determined through daily sampling and by the flow-duration sediment-transport-curve method. Sediment discharges are very similar along the river for the low-flow years of 1976, 1977, and 1979. In 1975 the sediment discharges increased downstream primarily due to higher and longer duration flows at the downstream stations. There were 22 percent fewer days exceeding 1,000 ft^3/s at Moorhead than at Locate. In 1978, sediment discharges decreased downstream, again attributable to water discharge as the peaks became smaller in a downstream direction. Mean sediment discharge for each of the three stations for the study was between 5.1 and 5.4 million ton/yr, which may indicate that over the long term the river is near equilibrium for sediment throughout its length in Montana.

The suspended load measured on the Powder River is principally wash load. On the average, 82 percent of the load was finer than sand at both Moorhead and Locate. However, sand movement in the unsampled zone and along the bed may contribute a significant load. Estimates for the Powder River at Arvada, Wyo., indicate that bedload is 2 percent of the total load. Whether this percentage is representative of the entire Powder River at all ranges of discharge can be determined only by more intensive sampling.

Mizpah Creek

Mizpah Creek rises in the uplands west of Broadus and flows northward for 80 miles to its junction with the Powder River near Mizpah, Mont. The upstream half of the 800-mi^2 drainage consists of a broad grass- and sage-covered land having little relief. The downstream half, beginning near the sampling station at Volborg

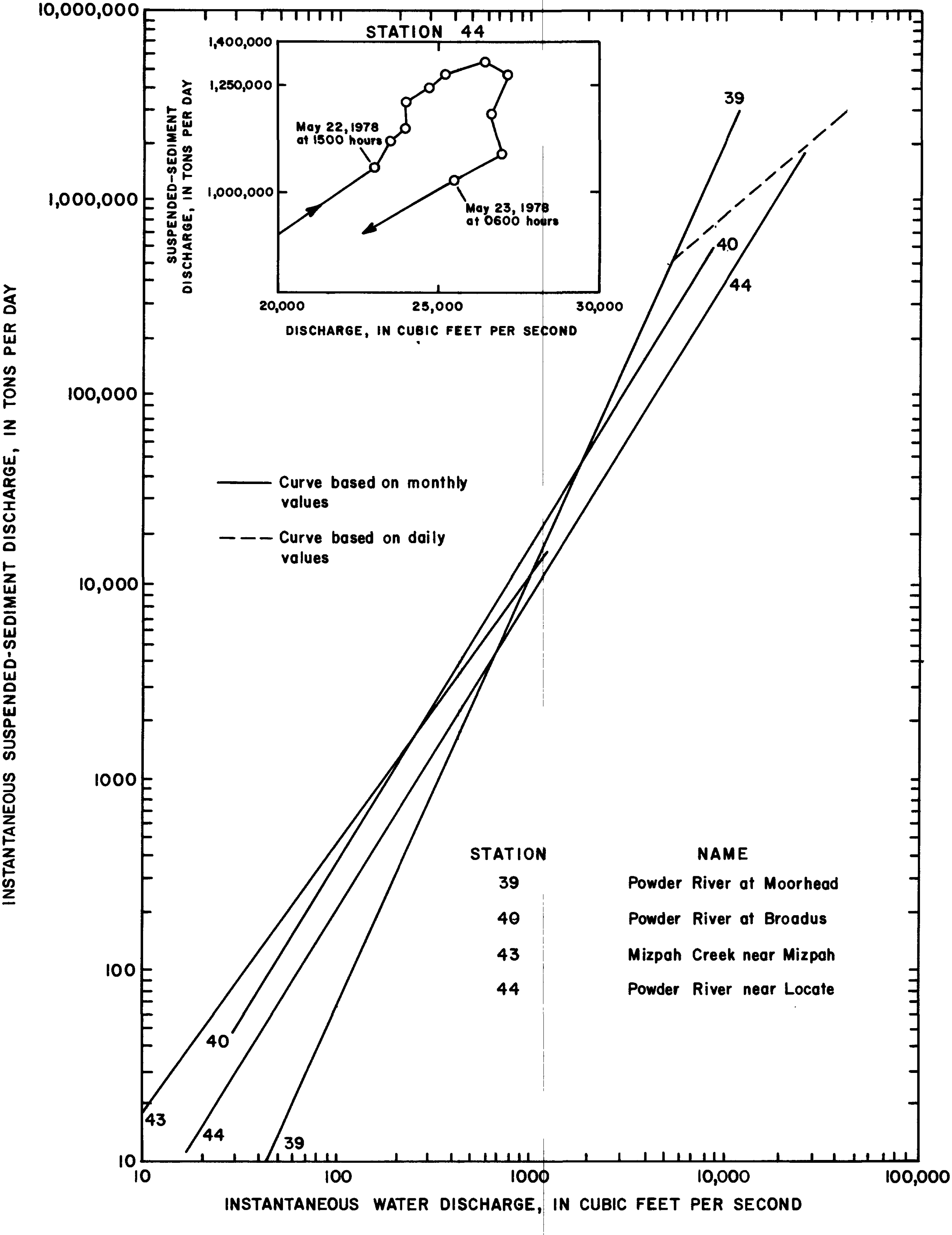


Figure 19.--Sediment-transport curves for Powder River drainage area.

(station 42) where the creek crosses the geologic contact between the Tongue River and Tullock Members of the Fort Union Formation, contains a much narrower valley with steeper adjacent hill slopes. Vegetation also becomes more sparse toward the mouth of Mizpah Creek. Intermittent streamflows are often contained or dissipated by stock-pond dams and water-spreader dikes.

Upstream stations at Olive (station 41) and Volborg (station 42) were sampled 26 and 17 times and never exceeded a water discharge of 8.9 ft^3/s. Sediment concentrations were small. The samples contained larger percentages of sand-size particles than elsewhere in the study area, probably as a result of sample-collection errors.

Streamflows at the mouth station, Mizpah Creek near Mizpah (station 43), were intermittent, exhibiting characteristics similar to Pumpkin Creek. No-flow periods are interrupted by sudden rainfall peaks, short midwinter thaws, and the longer spring snowmelt which takes place between March and June. The maximum sampled discharge of 1,270 ft^3/s occurred during the spring snowmelt of 1978 and transported the largest sediment discharge. Because rainstorm peaks occur so suddenly, many were gone before they could be sampled.

Sediment concentrations near Mizpah were largest during rainstorms, such as on July 6, 1977, when 0.5 inch of rain resulted in a concentration of 15,800 mg/L at a discharge of only 0.58 ft^3/s. The peak instantaneous concentration of 18,400 mg/L also occurred after a rainstorm. Suspended-sediment particle sizes were consistently small, with an average 96 percent less than sandsize. Calculated mean sediment discharge was 60,800 ton/yr with a sediment yield of 76 $(ton/mi^2)/yr$.

SUMMARY

Sampled suspended-sediment concentrations from 44 stations in the study area ranged from 2 to 49,700 mg/L, and indicated wide variability. Generally, more than 85 percent of the suspended sediment is smaller than sandsize. Factors, primarily climatic, that control the availability of this fine material are the limiting constraints on sediment discharges. Sediment-transport curves were developed for 30 stream stations.

Most sediment movement occurs during occasional periods of large-scale runoff, and has unique characteristics for each event. Sediment movement in the smaller drainages such as Sarpy, Armells, Otter, and Hanging Woman Creeks is substantially affected by the storage and flushing balance induced by the pool-and-riffle nature of their channels and the extreme variability of streamflow. Rosebud Creek performs much like these smaller creeks, with a readily apparent storage-and-flushing balance, but with a larger frequency of discharges capable of flushing the system. Sediment discharge in the Tongue River is very small downstream from the dam but increases in a downstream direction. The Powder River is in equilibrium, with an abundant sediment supply.

Calculated mean suspended-sediment loads for 15 study area stations ranged from 770 to 5,470,000 ton/yr. Mean annual yields, ranging from 1.09 to 646 $(ton/mi^2)/yr$, were somewhat less than yields predicted by the well-known Langbein-Schumm relation. Smaller yields may be due to greater-than-normal rainfall during the study, or to an overall trend toward stream aggradation. Geographic variation in sediment yield is attributed mainly to rainfall patterns and geologic differences.

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Table 1.--*Station descriptions*

[Number to left of station name is the same as shown on fig. 1; number to right is Geological Survey station number. Station descriptions are in downstream order.]

Station 1 SARPY CREEK NEAR HYSHAM, MT (06294940)

LOCATION.--Lat 46°14'12", long 107°08'03", in SE1/4 SE1/4 sec. 30, T. 6 N., R. 37 E., Treasure County, 100 ft (30 m) upstream from bridge on FAS Route 415, 0.8 mi (1.3 km) upstream from Hysham Canal, and 5.5 mi (8.8 km) southeast of Hysham.

Station 2 EAST FORK ARMELLS CREEK NEAR COLSTRIP, MT (06294980)

LOCATION.--Lat 45°58'42", long 106°38'38", in SE1/4 SW1/4 SW1/4 sec. 28, T. 3 N., R. 41 E., Rosebud County, on private road bridge, 0.9 mi (1.4 km) downstream from Corral Creek, and 6.7 mi (10.8 km) north of Colstrip.

Station 3 WEST FORK ARMELLS CREEK NEAR FORSYTH, MT (06294991)

LOCATION.--Lat 46°05'10", long 106°46'09", in SW1/4 SW1/4 NW1/4 sec. 21, T. 4 N., R. 40 E., Rosebud County, 0.7 mi (1.1 km) upstream from mouth, and 13.5 mi (21.7 km) southwest of Forsyth.

Station 4 ARMELLS CREEK NEAR FORSYTH, MT (06294995)

LOCATION.--Lat 46°14'59", long 106°48'22", in SE1/4 NW1/4 NE1/4 sec. 26, T. 6 N., R. 39 E., Rosebud County, 300 ft (90 m) upstream from bridge on Interstate Highway I-94, 2 mi (3 km) upstream from mouth, and 6 mi (10 km) southwest of Forsyth.

Station 5 ROSEBUD CREEK AT KIRBY, MT (06295110)

LOCATION.--Lat 45°19'59", long 106°59'10", in SW1/4 SE1/4 NW1/4 sec. 8, T. 6 S., R. 39 E., Bighorn County, at private bridge at Kirby, 50 ft (15 m) downstream from Cache Creek.

Station 6 ROSEBUD CREEK NEAR COLSTRIP, MT (06295250)

LOCATION.--Lat 45°46'03", long 106°34'10", in SE1/4 SW1/4 NE1/4 sec. 8, T. 1 S., R. 42 E., Rosebud County, 10 ft (3 m) downstream from bridge on FAS Route 315, 1.5 mi (2.4 km) downstream from Lee Coulee, and 8.4 mi (13.5 km) southeast of Colstrip.

Station 7 GREENLEAF CREEK NEAR COLSTRIP, MT (06295350)

LOCATION.--Lat 45°48'57", long 106°25'08", in NW1/4 NW1/4 NW1/4 sec. 29, T. 1 N., R. 43 E., Rosebud County, on county road, 0.8 mi (1.3 km) upstream from mouth, and 11.0 mi (17.7 km) southeast of Colstrip.

Table 1.--*Station descriptions*--Continued

Station 8 ROSEBUD CREEK ABOVE PONY CREEK, NEAR COLSTRIP, MT (06295400)

LOCATION.--Lat 45°53'33", long 106°24'03", in NE1/4 SE1/4 SE1/4 sec. 29, T. 2 N., R. 43 E., Rosebud County, on private road bridge, 0.3 mi (0.5 km) upstream from Pony Creek and 11.6 mi (18.7 km) northeast of Colstrip.

Station 9 SNIDER CREEK NEAR BRANDENBERG, MT (06295420)

LOCATION.--Lat 45°55'39", long 106°23'02", in S1/2 NE1/4 sec. 16, T. 2 N., R. 43 E., Rosebud County, at county road crossing, 0.3 mi (0.5 km) upstream from mouth, and 7.8 mi (12.6 km) northwest of Brandenberg.

Station 10 ROSEBUD CREEK NEAR ROSEBUD, MT (06295500)

LOCATION.--Lat 46°06'46", long 106°27'08", in SW1/4 NE1/4 SW1/4 sec. 12, T. 4 N., R. 42 E., Rosebud County, on private road bridge, 1.0 mi (1.6 km) downstream from Cottonwood Creek, and 12 mi (19 km) south of Rosebud.

Station 11 ROSEBUD CREEK AT MOUTH, NEAR ROSEBUD, MT (06296003)

LOCATION.--Lat 46°15'53", long 106°28'30", in SW1/4 NW1/4 NE1/4 sec. 21, T. 6 N., R. 42 E., Rosebud County, 0.4 mi (0.6 km) upstream from bridge on Interstate Highway I-94, 0.8 mi (1.3 km) upstream from mouth, and 1.6 mi (2.6 km) southwest of Rosebud.

Station 12 SQUIRREL CREEK NEAR DECKER, MT (06306100)

LOCATION.--Lat 45°03'05", long 106°55'36", in NW1/4 NW1/4 sec. 14, T. 9 S., R. 39 E., Big Horn County, 0.4 mi (0.6 km) upstream from Powers Cormack ditch, 0.5 mi (0.8 km) northwest of C X Ranch, 4 mi (6 km) northwest of Decker, and 7 mi (11 km) upstream from mouth.

Station 13 DEER CREEK NEAR DECKER, MT (06306800)

LOCATION.--Lat 45°03'19", long 106°42'09", in NW1/4 SW1/4 SW1/4 sec. 10, T. 9 S., R. 41 E., Big Horn County, at county road bridge, 6.1 mi (9.8 km) upstream from mouth, and 8.5 mi (13.7 km) northeast of Decker.

Station 14 SPRING CREEK NEAR DECKER, MT (06306900)

LOCATION.--Lat 45°05'09", long 106°50'12", in SW1/4 NW1/4 SE1/4 sec. 33, T. 8 S., R. 40 E., Bighorn County, on county road bridge, 0.2 mi (0.3 km) downstream from South Fork, 1.2 mi (1.9 km) upstream from Tongue River Reservoir, and 5.3 mi (8.5 km) northwest of Decker.

Station 15 TONGUE RIVER AT TONGUE RIVER DAM, NEAR DECKER, MT (06307500)

LOCATION.--Lat 45°08'29", long 106°46'15", SW1/4 SE1/4 SE1/4 sec. 12, T. 8 S., R. 40 E., Big Horn County, 0.5 mi (0.8 km) downstream from Tongue River Dam, 4 mi (6 km) upstream from Post Creek, 8 mi (13 km) northeast of Decker, 16 mi (26 km) southeast of Kirby, and at mile 162.3 (261.1 km).

Table 1.--*Station descriptions*--Continued

Station 16 FOURMILE CREEK NEAR BIRNEY, MT (06307510)

LOCATION.--Lat 45°12'28", long 106°42'52", in NE1/4 NW1/4 NE1/4 sec. 28, T. 7 S., R. 41 E., Rosebud County, on dirt road, 0.9 mi (1.4 km) upstream from mouth, and 12.5 mi (20.1 km) southwest of Birney.

Station 17 PRAIRIE DOG CREEK NEAR BIRNEY, MT (06307528)

LOCATION.--Lat 45°17'28", long 106°40'56", in SE1/4 NW1/4 NW1/4 sec. 26, T. 6 S., R. 41 E., Rosebud County, about 3.3 mi (5.2 km) upstream from mouth, and 7 mi (11.0 km) southwest of Birney.

Station 18 BULL CREEK NEAR BIRNEY, MT (06307530)

LOCATION.--Lat 45°17'17", long 106°35'55", in NE1/4 SW1/4 NW1/4 sec. 28, T. 6 S., R. 42 E., Rosebud County, 0.4 mi (0.6 km) upstream from mouth, and 4.8 mi (7.7 km) southwest of Birney.

Station 19 EAST TRAIL CREEK NEAR OTTER, MT (06307560)

LOCATION.--Lat 45°04'25", long 106°24'11", in NW1/4 SE1/4 NE1/4 sec. 12, T. 9 S., R. 43 E., Bighorn County, 1.1 mi (1.8 km) upstream from mouth, and 14 mi (23 km) southwest of Otter.

Station 20 HANGING WOMAN CREEK BELOW HORSE CREEK, NEAR BIRNEY, MT (06307570)

LOCATION.--Lat 45°04'09", long 106°24'35", in SE1/4 SE1/4 NW1/4 sec. 12, T. 9 S., R. 43 E., Bighorn County, 0.8 mi (1.3 km) downstream from flume No. 2, 1.1 mi (1.8 km) upstream from mouth, and 14 mi (23 km) southwest of Otter.

Station 21 HANGING WOMAN CREEK NEAR BIRNEY, MT (06307600)

LOCATION.--Lat 45°17'57", long 106°30'28", in N1/2 NW1/4 SE1/4 sec. 19, T. 6 S., R. 43 E., Rosebud County, 0.5 mi (0.8 km) downstream from bridge on Birney-Otter Road, 1.6 mi (2.6 km) downstream from East Fork, 1.6 mi (2.6 km) south of Birney, and 3.3 mi (5.3 km) upstream from mouth.

Station 22 TONGUE RIVER BELOW HANGING WOMAN CREEK, NEAR BIRNEY, MT (06307610)

LOCATION.--Lat 45°20'19", long 106°31'28", in SW1/4 SE1/4 SE1/4 sec. 1, T. 6 S., R. 42 E., Rosebud County, at bridge on county road, 1.2 mi (1.9 km) northwest of Birney, 2.5 mi (4.0 km) downstream from Hanging Woman Creek, and at mile 148.8 (239.4 km).

Station 23 COOK CREEK NEAR BIRNEY, MT (06307615)

LOCATION.--Lat 45°22'39", long 106°29'45", in SW1/4 NE1/4 NW1/4 sec. 25, T. 5 S., R. 42 E., Rosebud County, on dirt road 0.1 mi (0.2 km) upstream from mouth, and 3.8 mi (6.1 km) north of Birney.

Table 1.--*Station descriptions*--Continued

Station 24 OTTER CREEK NEAR OTTER, MT (06307665)

LOCATION.--Lat 45°08'15", long 106°07'22", in NE1/4 NE1/4 SE1/4 sec. 18, T. 8 S., R. 46 E., Powder River County, 0.2 mi (0.3 km) downstream from Pasture Creek, 5.5 mi (8.8 km) upstream from Bradshaw Creek, and 6.2 mi (10.0 km) southeast of Otter.

Station 25 BEAR CREEK AT OTTER, MT (06307670)

LOCATION.--Lat 45°12'20", long 106°12'15", in NW1/4 NE1/4 sec. 27, T. 7 S., R. 45 E., Powder River County, 500 ft (150 m) west of Otter Post Office, and 2.6 mi (4.2 km) upstream from mouth.

Station 26 OTTER CREEK BELOW FIFTEENMILE CREEK, NEAR OTTER, MT (06307717)

LOCATION.--Lat 45°23'29", long 106°08'37", in N1/2 sec. 23, T. 5 S., R. 45 E., Powder River County, on county road bridge, 1.0 mi (1.6 km) downstream from Fifteenmile Creek, and 13.1 mi (21.1 km) northeast of Otter.

Station 27 THREEMILE CREEK NEAR ASHLAND, MT (06307730)

LOCATION.--Lat 45°30'46", long 106°09'25", in NW1/4 SE1/4 SE1/4 sec. 3, T. 4 S., R. 45 E., Rosebud County, on dirt road, 1.5 mi (2.4 km) upstream from mouth, and 7.6 mi (12.2 km) southeast of Ashland.

Station 28 HOME CREEK NEAR ASHLAND, MT (06307735)

LOCATION.--Lat 45°32'35", long 106°11'39", in SE1/4 NE1/4 SE1/4 sec. 29, T. 3 S., R. 45 E., Powder River County, 150 ft (45.7 m) west of Otter Creek road culvert, 1.0 mi (1.6 km) upstream from mouth, about 2.0 mi (3.2 km) south of Highway 212, and 5.1 mi (8.2 km) southeast of Ashland.

Station 29 OTTER CREEK AT ASHLAND, MT (06307740)

LOCATION.--Lat 45°35'18", long 106°15'17", in NE1/4 NE1/4 SE1/4 sec. 11, T. 3 S., R. 44 E., Rosebud County, 200 ft (60 m) downstream from bridge on U.S. Highway 212, 2.5 mi (4.0 km) upstream from mouth, and 0.3 mi (0.5 km) southeast of Ashland.

Station 30 BEAVER CREEK NEAR ASHLAND, MT (06307810)

LOCATION.--45°47'52", long 106°14'17", in NW1/4 SE1/4 NE1/4 sec. 34, T. 1 N., R. 44 E., Rosebud County, at county road bridge, 0.8 mi (1.3 km) upstream from mouth, and 14.7 mi (23.7 km) north of Ashland.

Station 31 TONGUE RIVER BELOW BRANDENBERG BRIDGE, NEAR ASHLAND, MT (06307830)

LOCATION.--Lat 45°52'18", long 106°11'7", in NE1/4 SW1/4 NW1/4 sec. 6, T. 1 N., R. 45 E., Custer County, 3.1 mi (5.0 km) downstream from Goodale Creek, 6.5 mi (10.5 km) downstream from Brandenberg Bridge, and 21 mi (34 km) north of Ashland.

Table 1.--*Stations descriptions*--Continued

Station 32 LISCOM CREEK NEAR ASHLAND, MT (06307840)

LOCATION.--Lat 45°54'09", long 106°09'51", in SE1/4 NW1/4 NW1/4 sec. 27, T. 2 N., R. 45 E., Custer County, at county road bridge, 0.8 mi (1.3 km) upstream from mouth, and 21 mi (34 km) northeast of Ashland.

Station 33 FOSTER CREEK NEAR VOLBORG, MT (06307890)

LOCATION.--Lat 46°01'53", long 105°57'07", in NE1/4 SE1/4 NW1/4 sec. 12, T. 3 N., R. 46 E., Custer County, 0.6 mi (1.0 km) upstream from mouth, and 18.5 mi (29.8 km) northwest of Volborg.

Station 34 PUMPKIN CREEK NEAR LOESCH, MT (06308160)

LOCATION.--Lat 45°42'40", long 105°43'40", in NW1/4 sec. 31, T. 1 S., R. 49 E., Powder River County, at bridge on county road, 0.9 mi (1.4 km) northeast of Loesch, and 5.5 mi (14.5 km) upstream from Little Pumpkin Creek.

Station 35 LITTLE PUMPKIN CREEK NEAR VOLBORG, MT (06308170)

LOCATION.--Lat 45°46'00", long 105°46'42", in NE1/4 SE1/4 NE1/4 sec. 10, T. 1 S., R. 48 E., Powder River County, at county bridge 1.1 mi (1.8 km) upstream from Horkan Creek, 6.9 mi (11.1 km) southwest of Volborg, and 7.7 mi (12.4 km) upstream from mouth.

Station 36 PUMPKIN CREEK NEAR VOLBORG, MT (06308190)

LOCATION.--Lat 45°51'50", long 105°40'10", in W1/2 sec. 5, T. 1 N., R. 49 E., Custer County, at bridge on U.S. Highway 212, 1.5 mi (2.4 km) upstream from Basin Creek, and 1.6 mi (2.6 km) northeast of Volborg.

Station 37 PUMPKIN CREEK NEAR MILES CITY, MT (06308400)

LOCATION.--Lat 46°13'42", long 105°41'24", in SE1/4 NW1/4 SW1/4 sec. 35, T. 6 N., R. 48 E., Custer County, 30 ft (9 m) upstream from bridge on U.S. Highway 312, 7.5 mi (12.1 km) upstream from mouth, and 16 mi (26 km) southeast of Miles City.

Station 38 TONGUE RIVER AT MILES CITY, MT (06308500)

LOCATION.--Lat 46°21'30", long 105°48'24", in SE1/4 sec. 23, T. 7 N., R. 47 E., Custer County, 4 mi (6 km) south of Miles City, and 8 mi (13 km) upstream from mouth.

Station 39 POWDER RIVER AT MOORHEAD, MT (06324500)

LOCATION.--Lat 45°04'04", long 105°52'10", in NW1/4 SE1/4 NW1/4 sec. 8, T. 9 S., R. 48 E., Powder River County, at bridge on county road, 1.1 mi (1.8 km) upstream from discontinued post office at Moorhead, 1.2 mi (1.9 km) upstream from present streamflow gage, and 4.0 mi (6.4 km) north of Wyoming-Montana State line.

Station 40 POWDER RIVER AT BROADUS, MT (06324710)

LOCATION (REVISED).--Lat 45°25'37", long 105°24'05", in NE1/4 SE1/4 sec. 3, T. 5 S., R. 51 E., Powder River County, on right bank 100 ft (30.5 m) upstream from bridge on U.S. Highway 212, 0.4 mi (0.6 km) downstream from Doyle Creek, 1 mi (2 km) south of Broadus, and 7 mi (11 km) upstream from Little Powder River.

Station 41 MIZPAH CREEK AT OLIVE, MT (06326050)

LOCATION.--Lat 45°32'30", long 105°31'40", in SW1/4 sec. 26, T. 3 S., R. 50 E., Powder River County, at bridge on U.S. Highway 212 at Olive, approximately 1.0 mi (1.6 km) downstream from YT Creek.

Station 42 MIZPAH CREEK NEAR VOLBORG, MT (06326200)

LOCATION.--Lat 45°56'00", long 105°23'40", in SW1/4 sec. 9, T. 2 N., R. 51 E., Custer County, at bridge on county road, approximately 2.0 mi (3.2 km) downstream from Spring Creek, and 15.1 mi (24.3 km) northeast of Volborg.

Station 43 MIZPAH CREEK NEAR MIZPAH, MT (06326300)

LOCATION.--Lat 46°15'39", long 105°17'34", in NW1/4 NE1/4 SW1/4 sec. 24, T. 6 N., R. 51 E., Custer County, 10 ft (3 m) upstream from county bridge, 1.0 mi (1.6 km) upstream from mouth, and 1.6 mi (2.6 km) northwest of Mizpah.

Station 44 POWDER RIVER NEAR LOCATE, MT (06326500)

LOCATION.--Lat 46°26'56", long 105°18'44", in NW1/4 SW1/4 sec. 14, T. 8 N., R. 51 E., Custer County, 1.5 mi (2.4 km) downstream from bridge on U.S. Highway 12 at present site of Locate (5 mi, 8 km, west of former site of Locate), 1.5 mi (2.4 km) upstream from Locate Creek, and 25 mi (40 km) east of Miles City.

Table 2.--*Sampling period, descriptive statistics, and regression summaries for stations*

Station no.	Station name (abbreviated)	Sampling period[1] (water years) 1973–1979	Variable[2]	Sample size[3]	Minimum	Maximum	Mean	Standard deviation	Regression[4] Log *Qss* = *I* + *S* (log *Q*): *I*	*S*
1	Sarpy Creek near Hysham.		*Q*	43	0.00	411	35	95		
			C	40	6	416	96	99	-1.02	1.34
			Qss	40	.00	410	29	88		
2	East Fork Armells Creek near Colstrip.		*Q*	41	.01	169	8.0	27		
			C	41	4	180	42	37	-1.15	1.13
			Qss	41	.00	31	1.3	4.9		
3	West Fork Armells Creek near Forsyth.		*Q*	21	.00	28	2.6	6.9		
			C	18	7	261	74	79	-.89	1.18
			Qss	18	.00	20	1.7	5.1		
4	Armells Creek near Forsyth.		*Q*	53	.01	462	30	95		
			C	51	13	1,860	180	300	-.61	1.26
			Qss	51	.00	2,000	69	300		
5	Rosebud Creek at Kirby.		*Q*	21	4.8	231	38	53		
			C	18	12	624	190	190	-1.43	1.68
			Qss	18	.29	380	43	95		
6	Rosebud Creek near Colstrip.		*Q*	54	9.6	310	65	64		
			C	53	19	1,040	220	260	-2.06	1.95
			Qss	53	1.3	340	65	100		
7	Greenleaf Creek near Colstrip.		*Q*	2	4.9	15	9.9	--		
			C	2	78	86	82	--		
			Qss	2	1.0	3.5	2.3	--		
8	Rosebud Creek above Pony Creek, near Colstrip.		*Q*	37	6.4	258	55	56		
			C	36	12	822	180	200	-1.41	1.55
			Qss	36	.99	230	38	60		
9	Snider Creek near Brandenberg.		*Q*	2	10	52	31	--		
			C	2	128	147	140	--		
			Qss	2	3.5	21	12	--		
10	Rosebud Creek near Rosebud.		*Q*	32	10	312	66	66		
			C	32	18	946	350	270	-1.08	1.54
			Qss	32	3.3	590	82	120		
11	Rosebud Creek at mouth near Rosebud.		*Q*	59	5.8	916	93	160		
			C	55	35	7,240	540	1,100	-1.25	1.64
			Qss	55	1.5	18,000	560	2,600		
12	Squirrel Creek near Decker.		*Q*	42	.26	50	6.3	10		
			C	42	5	970	110	160	-.97	1.49
			Qss	42	.01	76	4.8	14		
13	Deer Creek near Decker.		*Q*	10	.06	9.1	2.6	3.7		
			C	9	13	410	110	120	-.68	1.35
			Qss	9	.00	7.7	1.3	2.5		
14	Spring Creek near Decker.		*Q*	2	1.0	18	9.5	--		
			C	2	92	1,220	660	--		
			Qss	2	.25	59	30	--		
15	Tongue River at Tongue River Dam, near Decker.	To 5/39	*Q*	45	3.1	4,140	490	690		
			C	42	4	59	18	12	-1.79	1.16
			Qss	42	.13	390	32	65		
16	Fourmile Creek near Birney.		*Q*	2	.71	.84	.77	--		
			C	2	39	102	70	--		
			Qss	2	.08	.23	.15	--		

Table 2.--*Sampling period, descriptive statistics, and regression summaries for stations*--Continued

Station no.	Station name (abbreviated)	Sampling period[1] (water years) 1973 1974 1975 1976 1977 1978 1979	Variable[2]	Sample size[3]	Minimum	Maximum	Mean	Standard deviation	Regression[4] Log $Qss = I + S (\log Q)$ I	S
17	Prairie Dog Creek near Birney.		Q	11	.04	15	2.9	4.3		
			C	19	6	1,420	140	320	-.67	1.36
			Qss	11	.01	58	5.6	17		
18	Bull Creek near Birney.		Q	2	2.0	14	8.0	--		
			C	2	28	50	39	--		
			Qss	2	.15	1.9	1.0	--		
19	East Trail Creek near Otter.		Q	12	.10	36	4.7	10		
			C	9	3	454	91	140	-.98	1.39
			Qss	9	.00	44	5.3	15		
20	Hanging Woman Creek below Horse Creek, near Birney.		Q	18	.06	94	7.9	23		
			C	16	5	609	85	150	-1.02	1.38
			Qss	16	.00	150	10	39		
21	Hanging Woman Creek near Birney.		Q	57	.56	359	17	53		
			C	56	9	566	89	110	-.96	1.30
			Qss	56	.03	550	14	75		
22	Tongue River below Hanging Woman Creek near Birney.		Q	60	46	4,150	570	760		
			C	53	2	812	60	120	-3.36	1.86
			Qss	53	1.0	2,000	170	390		
23	Cook Creek near Birney.		Q	34	.10	43	2.7	7.7		
			C	34	2	3,470	140	590		
			Qss	34	.01	400	12	69		
24	Otter Creek near Otter.		Q	18	.01	1.6	.44	.51		
			C	18	6	201	52	50		
			Qss	18	.00	.17	.04	.05		
25	Bear Creek at Otter.		Q	5	.01	53	15	22		
			C	5	27	92	61	25	-.84	1.10
			Qss	5	.00	7.3	2.5	3.1		
26	Otter Creek below Fifteenmile Creek, near Otter.		Q	18	.50	76	10	18		
			C	18	5	132	57	43	-1.25	1.44
			Qss	18	.00	24	2.5	5.6		
27	Threemile Creek near Ashland.		Q	2	1.8	22	12	--		
			C	2	24	212	120	--		
			Qss	2	.12	13	6.4	--		
28	Home Creek near Ashland.		Q	25	.01	23	1.0	4.6		
			C	25	6	356	57	73	-.87	1.16
			Qss	25	.00	22	.89	4.4		
29	Otter Creek at Ashland.		Q	55	.06	390	25	71		
			C	54	10	536	87	92	-.87	1.14
			Qss	54	.01	420	20	77		
30	Beaver Creek near Ashland.		Q	9	.58	42	13	18		
			C	9	6	73	29	23	-1.36	1.21
			Qss	9	.01	5.7	1.4	2.4		
31	Tongue River below Brandenberg Bridge, near Ashland.		Q	63	83	8,260	930	1,500		
			C	36	8	1,440	240	360	-4.19	2.28
			Qss	36	5.3	25,000	2,100	5,600		
32	Liscom Creek near Ashland.		Q	3	.30	18	9.5	9.0		
			C	3	60	223	120	93	--	--
			Qss	3	.05	11	4.2	5.9		

Table 2.--*Sampling period, descriptive statistics, and regression summaries for stations*--Continued

Station no.	Station name (abbreviated)	Sampling period[1] (water years) 1973–1979	Variable[2]	Sample size[3]	Minimum	Maximum	Mean	Standard deviation	Regression[4] Log *Qss* = *I* + *S* (log *Q*) *I*	*S*
33	Foster Creek near Volborg.		*Q*	14	.01	300	29	79		
			C	14	4	4,260	420	1,100	-.69	1.32
			Qss	14	.00	110	15	30		
34	Pumpkin Creek near Loesch.		*Q*	28	.01	146	5.9	27		
			C	28	4	606	110	120		
			Qss	28	.00	54	2.0	10		
35	Little Pumpkin Creek near Volborg.		*Q*	6	.01	1.1	.37	.40		
			C	6	4	91	34	33		
			Qss	6	.00	.05	.02	.02		
36	Pumpkin Creek near Volborg.		*Q*	9	.02	4.6	1.8	1.6		
			C	9	9	177	49	54		
			Qss	9	.01	.6	.17	.25		
37	Pumpkin Creek near Miles City.		*Q*	33	.01	1,730	110	320		
			C	31	21	23,400	1,600	4,600	-.47	1.44
			Qss	31	.00	15,000	1,300	3,800		
38	Tongue River at Miles City.	To 4/38	*Q*	66	90	7,700	960	1,600		
		*To 10/46	*C*	51	5	5,090	620	1,100	-3.98	2.33
			Qss	51	2.7	96,000	5,700	17,000		
39	Powder River at Moorhead.	*To 5/29	*Q*	78	20	12,100	910	1,900		
		*To 10/51	*C*	34	139	49,700	5,600	10,000	-2.61	2.22
			Qss	34	28	1,300,000	60,000	230,000		
40	Powder River at Broadus.		*Q*	31	40	8,910	1,300	2,000		
			C	29	233	27,300	6,900	8,400	-1.09	1.73
			Qss	29	25	54,000	49,000	120,000		
41	Mizpah Creek at Olive.		*Q*	28	.01	4.0	.50	.80		
			C	26	6	733	130	190		
			Qss	26	.00	.38	.08	.10		
42	Mizpah Creek near Volborg.		*Q*	19	.01	8.9	.96	2.2		
			C	17	12	385	82	87		
			Qss	17	.00	1.7	.15	.40		
43	Mizpah Creek near Mizpah.		*Q*	33	.04	1,270	60	230		
			C	30	23	18,400	2,700	5,000	-.12	1.38
			Qss	30	.01	14,000	640	2,600		
44	Powder River near Locate.	*To 10/38	*Q*	80	24	27,200	5,400	9,500		
		*To 3/38	*C*	78	31	34,500	6,500	7,600	-1.19	1.68
			Qss	78	2.8	1,300,000	240,000	450,000		

[1] Sampling period: asterisk indicates omissions in the record. Date, where shown, indicates extent of historical record

To 5/39 — Period of continuous water-discharge records

(open box) — Period of monthly sediment and water discharge records

[2] *Q* Water discharge, in cubic feet per second;
C Sediment concentration, in milligrams per liter; and
Qss Sediment discharge, in tons per day.

[3] Zero-flow values not counted as samples and not used in calculations

[4] *I*, regression intercept;
S, regresion slope. Regressions omitted where data insufficient