MEAN ANNUAL STREAMFLOW OF SELECTED DRAINAGE BASINS IN THE COAL AREA OF SOUTHEASTERN MONTANA

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 81-61

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Helena, Montana
October 1981

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METRIC CONVERSION TABLE

The following factors may be used to convert the inch-pound units in this report to the International System (SI) of metric units.

Multiply inch-pound unit	By	To obtain SI unit
acre	4047	square meter
acre-foot	1233	cubic meter
cubic foot per second (ft^3/s)	28.32	liter per second
foot (ft)	0.3048	meter (m)
inch	25.4	millimeter
mile (mi)	1.609	kilometer (km)
square mile	2.590	square kilometer

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

Streamflow characteristics of drainage basins within the Fort Union coal region of southeastern Montana were estimated to provide premining data for evaluating the future effects of mining on the environment. Estimated annual mean streamflow at 22 data-collection stations for water years 1975-77 ranged from 0 to 887 cubic feet per second. These estimates are based on miscellaneous-streamflow records at each station and continuous-streamflow records from other stations in the study area. Estimated mean annual streamflow for a 10-year period (water years 1968-77) ranged from 0 to 572 cubic feet per second. These long-term estimates were based on data from stations near the study area having continuous-streamflow records. Estimated mean annual runoff in inches for selected drainage basins within the study area showed no discernible pattern. Many of the drainage basins had a mean annual runoff of less than 0.60 inch; the maximum observed mean annual runoff was 4.45 inches.

INTRODUCTION

The Fort Union coal region (fig. 1) in eastern Montana is underlain by vast amounts of coal having a small sulfur content. Most of the economically strippable coal in Montana is located in the Paleocene Fort Union Formation between the Yellowstone River and the Montana-Wyoming border (Struck, 1975).

Because of the increasing need for energy sources, areas of eastern Montana are being considered for strip mining and underground in-place gasification of coal (Melancon and others, 1979). These activities could disrupt the downgradient movement of ground water and possibly decrease the quantity of streamflow near mined areas. Strip mining could also alter the system of runoff channels, which would affect the irrigation of land near the mine site and downstream from the mine site (Northern Great Plains Resource Program, Water Work Group-Ground Water Subgroup, 1974; Struck, 1975).

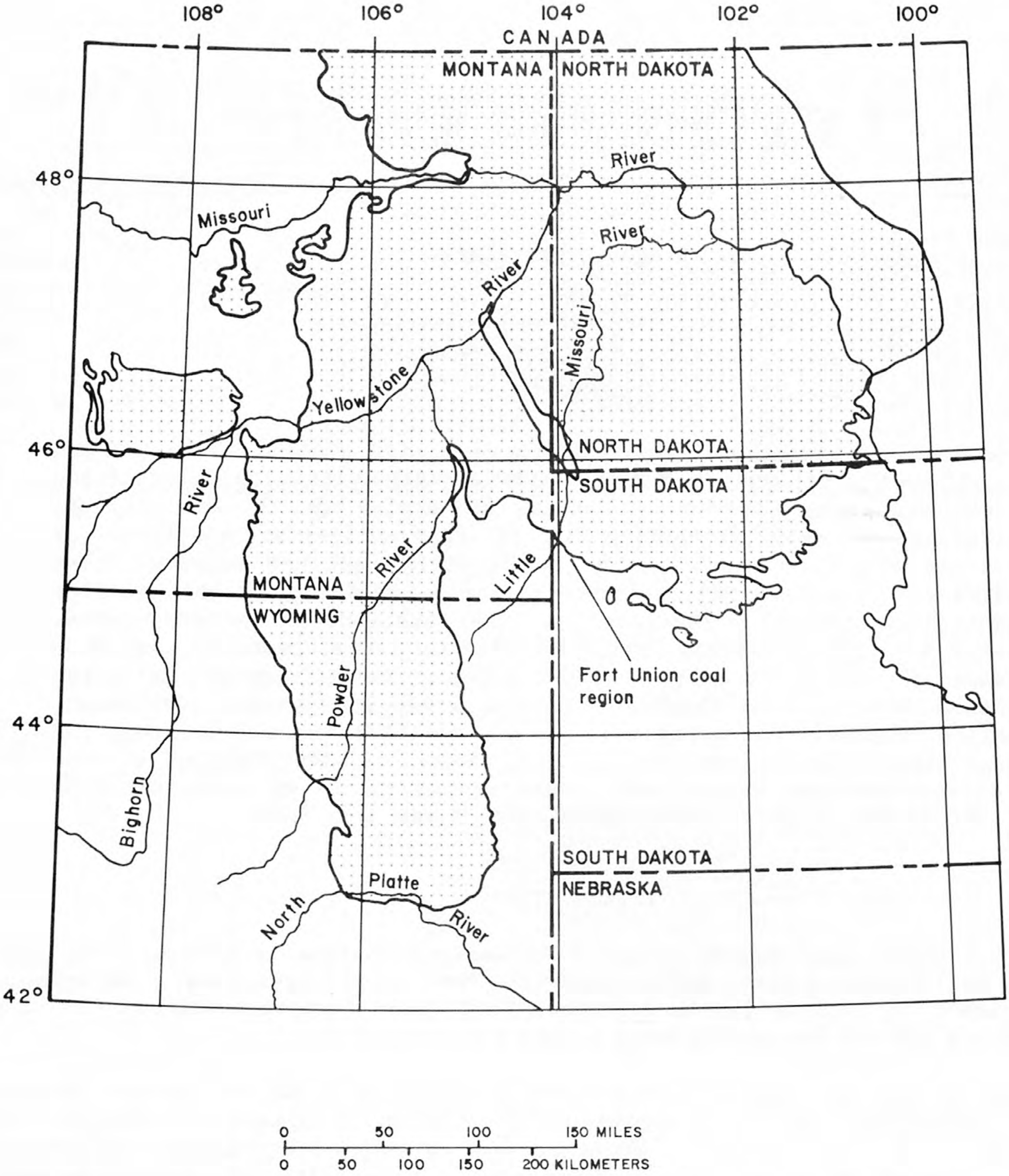

Figure 1.--Location of Fort Union coal region. The study area lies between the Yellowstone River and the Montana-Wyoming border, and between the Bighorn River and the Powder River. Modified from Northern Great Plains Resource Program, Water Work Group-Ground Water Subgroup (1974).

Purpose and scope

The purpose of this report is to estimate streamflow characteristics of drainages within the coal area prior to significant mine development so that future effects of mining on the quantity of surface water can be evaluated. Premining data describing the streamflow in selected drainages would also provide a basis for the development of land-use plans and environmental-impact statements.

During water years 1975-77, the U.S. Geological Survey, in cooperation with the U.S. Bureau of Land Management and the U.S. Environmental Protection Agency, operated a network of 36 data-collection stations in southeastern Montana (fig. 2). Water samples were collected at these stations to provide a description of water

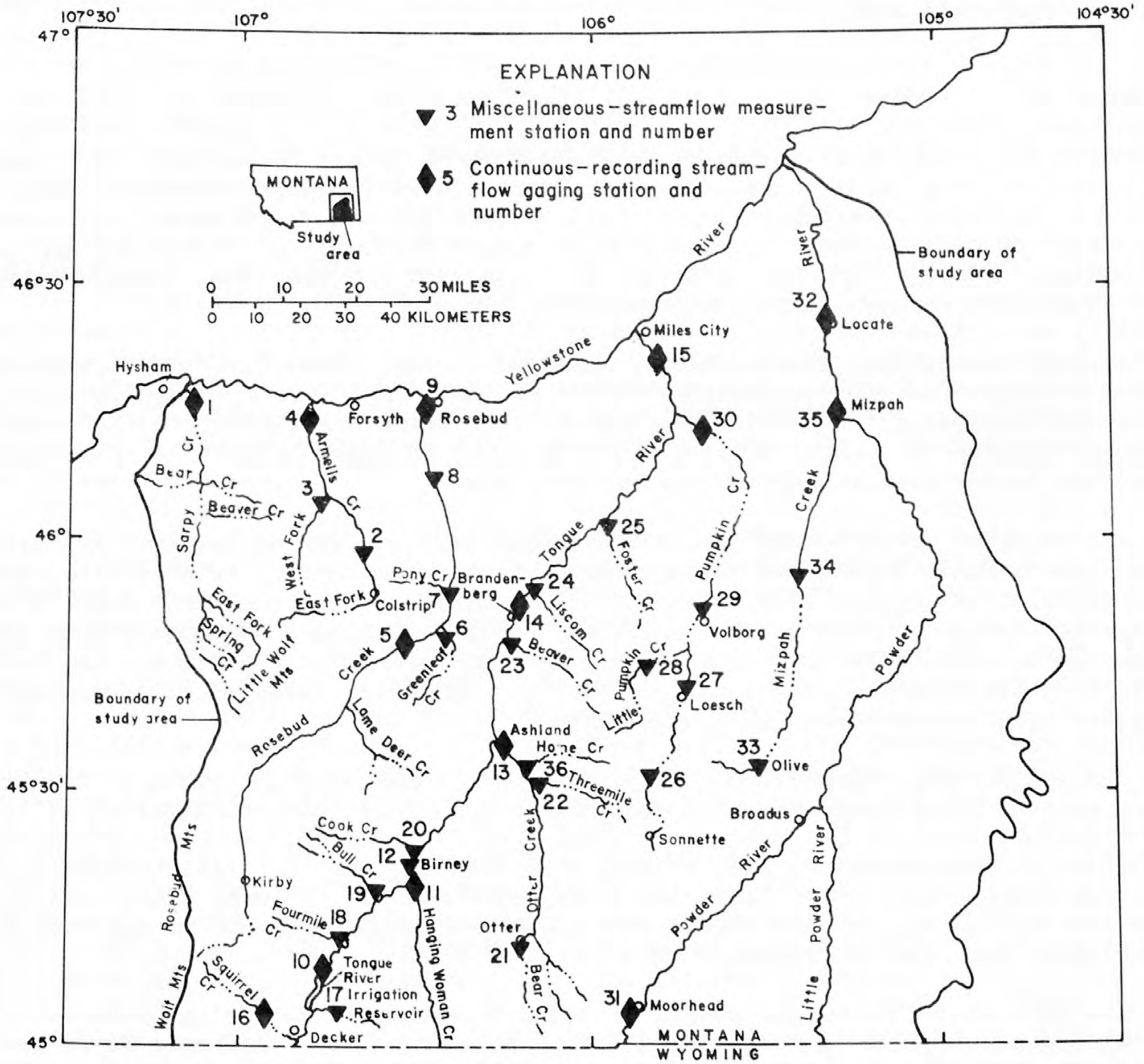

Figure 2.--Location of streamflow stations in the study area.

quality in selected drainage basins in the Fort Union coal area of southeastern Montana (Knapton and McKinley, 1977). Of the network stations, 14 were continuous-recording streamflow gaging stations (herein called continuous stations). Miscellaneous monthly or near-monthly streamflow measurements were made at the remaining 22 stations (herein called miscellaneous stations). Descriptions of the network stations are given in table 1 at the end of this report.

Streamflow data from the station network were used to estimate annual mean streamflow for stations in the coal area where only miscellaneous-streamflow measurements were made. This report presents estimates of the annual mean streamflow at the miscellaneous stations for water years 1975-77 and estimates of 10-year mean annual streamflow for all network stations for water years 1968-77. From these estimates, a map was constructed showing mean annual runoff in selected drainage basins of the study area.

Study area

The study area is in southeastern Montana between the Yellowstone River and the Montana-Wyoming border (fig. 2). The climate is characterized by warm summers (mean monthly July temperature of 74°F) and cold winters (mean monthly January temperature of 19°F). Annual precipitation ranges from 12 to 16 inches, with a snowfall of 35 to 50 inches. From 70 to 75 percent of the total precipitation falls from April through September as rainfall (Struck, 1975).

Rosebud Creek, the Tongue River, and the Powder River are the principal streams tributary to the Yellowstone River in the study area that are perennial throughout their length. Sarpy Creek and Armells Creek are intermittent in their upstream reaches and perennial near their mouths. Snowmelt runoff in the study area often occurs between mid-January and late March.

The boundary of the study area approximates the boundary of the northern part of the Powder River structural basin, which is characterized by relatively recent stream erosion of gently dipping strata of sandstone, siltstone, and shale with intermixed coal beds (Knapton and McKinley, 1977). Geologic formations that are transected by streams and that might affect gain or loss in streamflow are the Hell Creek Formation of Late Cretaceous age, the Fort Union Formation of Paleocene age, and alluvium of Pleistocene and Holocene age.

The Hell Creek Formation is predominantly yellowish-gray to tan, fine-to medium-grained silty sandstone containing thin coal beds (Lewis and Roberts, 1977). Only the lower part of the Hell Creek Formation is important as a water-bearing unit (Knapton and McKinley, 1977; Lewis and Roberts, 1977). Because the Hell Creek Formation crops out only in the downstream reaches of Sarpy Creek, Armells Creek, Rosebud Creek, and the middle reach of the Powder River, it is not a major contributor to streamflow in the study area.

The Fort Union Formation comprises three members, in ascending order: the Tullock Member, Lebo Shale Member, and Tongue River Member. The Tongue River Member is composed of massive sandstone, coal, and clinker beds, and is the major aquifer in most of the study area (Lewis and Roberts, 1977). Streams in the study area derive most of their base flow from water discharged from the Tongue River Member (Lee and others, 1981; Lee, 1980).

The alluvium is composed of mixed gravel, sand, silt, and clay. Generally, water from the alluvium sustains or prolongs flow in most stream channels during periods of low flow. At times of high flow, water is lost from the channel to the alluvium.

METHODS OF ESTIMATING

Annual mean streamflow for a given water year

Annual mean streamflow at miscellaneous stations was estimated from streamflow records at continuous stations using a modification of a method described by Riggs (1969). A continuous station generally has a hydrologic setting similar to that of the miscellaneous station for which annual mean streamflow is estimated.

The method of estimation is based on two assumptions. First, the daily mean streamflow at a miscellaneous station for any given day is assumed to be equal to streamflow measured at any time during the day. Second, the ratio of concurrent daily mean streamflows of two streams near the middle of a month equals the ratio of their means for that month.

Streamflow at the miscellaneous stations was infrequently measured near the middle of each month. The measurements often deviated from the 15th of each month by more than 5 days -- the limit indicated by Riggs (1969) for satisfying the second assumption. Therefore, the method described by Riggs was modified so that the sampling interval in this study equaled the interval between sampling dates rather than between the first and last day of each month. For each interval the ratio of mean streamflows from continuous and miscellaneous stations was estimated graphically from ratios of concurrent daily mean streamflows at the beginning and at the end of each interval.

The method of estimating annual mean streamflow for the miscellaneous stations is illustrated with Cook Creek (miscellaneous station) and Hanging Woman Creek (continuous station). Concurrent daily mean streamflows for both streams (table 2) are plotted in figure 3, and connecting lines drawn between each successive data point. The first and last data points are also connected to obtain an estimate of mean streamflow for the period before and after the first and last streamflow measurements of the water year. A 45-degree relation line is drawn through the midpoint of each connecting line. The mean discharge from the continuous station for the interval between measurements is projected to the 45-degree line to obtain the estimated mean discharge for that period at the miscellaneous station.

For example, as shown by the dashed line in figure 3, the mean streamflow of 0.62 ft^3/s recorded for Hanging Woman Creek for the interval between August 4 and September 1 corresponds to an estimated mean streamflow of 0.35 ft^3/s for Cook Creek. The annual mean streamflow (table 2) is calculated by weighting each interval mean streamflow by the number of days the interval contains.

Mean annual streamflow for a 10-year period

Records from 19 continuous-recording streamflow stations near the study area were used to estimate mean annual streamflow for a 10-year period. For these sites the mean annual streamflows for water years 1968-77 were regressed on the mean annual

Table 2.--*Data used to estimate annual mean streamflow of Cook Creek near Birney*

Streamflow, in cubic feet per second			Interval mean streamflow, in cubic feet per second		
Date	Cook Creek (measured)	Hanging Woman Creek (measured)	Interval	Hanging Woman Creek (recorded)	Cook Creek (estimated)
10/08/75	0.49	2.5			
			10/08/75-11/10/75	3.21	0.75
11/11/75	.76	2.8			
			11/11/75-12/02/75	3.05	1.00
12/03/75	1.3	3.2			
			12/03/75-01/07/76	2.91	1.95
1/08/76	1.6	1.5			
			01/08/76-02/03/76	4.19	2.08
2/04/76	.90	4.0			
			02/04/76-03/02/76	10.39	1.90
3/03/76	1.2	8.0			
			03/03/76-04/06/76	5.30	1.08
4/07/76	1.2	4.4			
			04/07/76-05/04/76	4.50	1.15
5/05/76	1.4	5.8			
			05/05/76-06/08/76	2.12	.92
6/09/76	2.0	2.7			
			06/09/76-07/07/76	3.38	1.66
7/08/76	.53	1.6			
			07/08/76-08/03/76	1.16	.58
8/04/76	.62	.80			
			08/04/76-08/31/76	.62	.35
9/01/76	.25	.60			
			09/01/76-10/07/75	.89	.25
Annual mean streamflow, 1976 water year (computed from interval mean streamflow)				3.42	1.13

streamflows for water years 1975-77. The resulting regression equation was then used with the test stations to predict mean annual streamflow for water years 1968-77.

Natural runoff in inches

Agriculture is a significant land use in the study area. Water used to irrigate valley and bench land is obtained primarily through withdrawal of surface water, either by diversion or pumpage (Melancon and others, 1979). Water loss

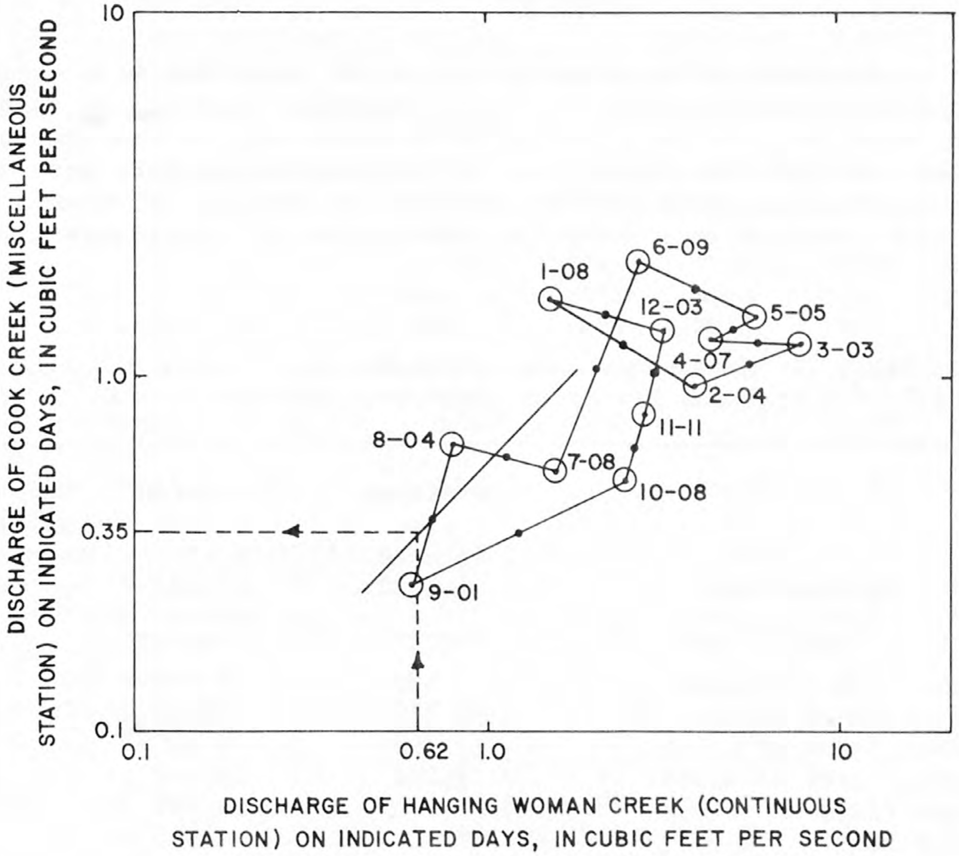

Figure 3.--Procedure for estimating annual mean streamflow using concurrent streamflow for Cook Creek and Hanging Woman Creek during the 1976 water year. Procedure is described in the text. Each point is identified by the month and day of measurement.

from irrigation was estimated from the irrigated acreage in the contributing drainage area for each station (Montana State Engineer's Office, 1947, 1948a, 1948b, 1951, 1961). Water loss in the study area is based on an estimated average cropland of 20 percent grain and 80 percent alfalfa. An average consumptive water use of 14.9 inches was calculated from a weighted average of 29.0 inches for alfalfa and 18.5 inches for grain minus an average 12 inches of rainfall during the growing season.

At each station the estimated mean annual streamflow in cubic feet per second was converted to mean annual runoff in acre-feet minus runoff from any streamflow stations upstream. The irrigation water loss in acre-feet was added to this mean annual runoff and the sum of these values was converted to depth in inches for each contributing drainage basin. The resulting value, mean annual runoff, represents the amount of natural runoff reported as a depth in inches for a particular drainage area. Values of mean annual runoff will allow comparisons to be made among drainage basins having different amounts of irrigated acreage.

Mean annual streamflows for stations in the study area that have continuous-streamflow records are listed in table 3. Where possible, stations on tributaries of larger streams were used for the calculation of annual mean streamflow for small tributary stations, because the streamflows and drainage areas were more similar. However, where miscellaneous stations were located on the main stem of a stream, main-stem continuous stations were used for calculation of annual mean streamflow estimates.

Table 3.--*Mean annual streamflow for water years 1968-77 for stations having continuous-streamflow records*

Station number (fig. 2)	Station name	Drainage area (square miles)	Irrigated acres, estimated	Mean annual streamflow (cubic feet per second)
1	Sarpy Creek nr Hysham	450	970	12.0*
4	Armells Creek nr Forsyth	370	200	10.4*
5	Rosebud Creek nr Colstrip	799	800	73.1*
9	Rosebud Creek at mouth	1,302	2,000	73.7*
10	Tongue River at Tongue River Dam	1,770	64,800	552
11	Hanging Woman Creek nr Birney	470	1,240	9.55*
13	Otter Creek at Ashland	707	4,200	13.1*
14	Tongue River bl Brandenberg Bridge	4,062	73,000	564*
15	Tongue River at Miles City	5,379	90,000	586
16	Squirrel Creek nr Decker	33.6	690	9.82*
30	Pumpkin Creek nr Miles City	697	3,600	23.4*
31	Powder River at Moorhead	8,088	66,300	508
32	Powder River nr Locate	13,194	74,500	677
35	Mizpah Creek nr Mizpah	797	6,800	20.6*

* Estimates based on less than 10 years of record.

The estimated annual mean streamflows at the miscellaneous stations for water years 1975, 1976, and 1977 are given in table 4. Estimates of zero and low flows are generally based on seven or fewer streamflow measurements within the respective water year. Missing streamflow values in table 4 indicate that no measurements were made in that year. The accuracy of the estimated annual mean streamflows is dependent mainly on the similarity of the hydrologic regimes between each miscellaneous station and continuous station. The more similar the hydrologic regimes are for the two streams, the closer their concurrent streamflows will plot to a 45-degree relation line (fig. 3).

The plots of streamflow at continuous stations versus streamflow at nearby upstream miscellaneous stations are generally good when both stations are on the same

Table 4.--*Estimated annual mean streamflow for water years 1975, 1976, and 1977 and mean annual streamflow for water years 1968-77 for stations having miscellaneous-streamflow records*

Station number (fig. 2)	Station name	Drainage area (square miles)	Irrigated acres, estimated	Streamflow, in cubic feet per second: Annual mean 1975	Annual mean 1976	Annual mean 1977	Mean annual 1968-77
2	E. Fork Armells Cr nr Colstrip	155	0	3.25	2.95	0.95	3.87
3	W. Fork Armells Cr nr Forsyth	148	0	3.89	.27	.11	2.42
6	Greenleaf Cr nr Colstrip	30.5	50	.28	0	--	.21
7	Rosebud Cr ab Pony Cr	1,153	0	90.4	45.4	20.5	63.7
8	Rosebud Cr nr Rosebud	1,215	241	88.3	49.9	33.6	69.5
12	Tongue River bl Hanging Woman Cr	2,533	67,000	887	436	430	572
17	Deer Cr nr Decker	38.3	0	1.41	.01	.01	.91
18	Fourmile Cr nr Birney	22.3	0	.08	0	--	.07
19	Bull Cr nr Birney	45.8	63	.53	--	--	.70
20	Cook Cr nr Birney	62.6	80	4.54	1.13	1.31	3.80
21	Bear Cr at Otter	90.4	528	.30	0	--	.23
22	Threemile Cr nr Ashland	51.5	77	.84	0	--	.59
23	Beaver Cr nr Ashland	92.3	0	4.19	.17	--	2.73
24	Liscom Cr nr Ashland	47.6	156	.90	0	--	.63
25	Foster Cr nr Volborg	116	240	18.1	1.18	.15	9.63
26	Pumpkin Cr nr Sonnette	70.7	456	--	0	0	0
27	Pumpkin Cr nr Loesch	172.7	1,192	--	.62	1.14	2.97
28	Little Pumpkin Cr nr Volborg	101	321	--	.08	.25	.76
29	Pumpkin Cr nr Volborg	386	2,037	--	1.83	.89	4.26
33	Mizpah Cr at Olive	129	3,700	--	.61	.17	1.51
34	Mizpah Cr nr Volborg	510	5,120	--	2.99	.82	5.65
36	Home Cr nr Ashland	58.7	278	--	--	.52	4.22

main stem, such as for the main-stem stations on Armells Creek, Rosebud Creek, Pumpkin Creek, and Mizpah Creek. Most of the time, the hydrologic regimes at these continuous stations are a direct reflection of the hydrologic regimes of the upstream miscellaneous stations.

The most suitable continuous stations for pairing with miscellaneous stations on the smaller drainage basins tributary to Rosebud Creek, Tongue River, and Pumpkin Creek were chosen through trial and error. The pair plotting closest to a 45-degree relation line was chosen for the streamflow estimate. The resulting paired stations did not show similar relationships between concurrent streamflows. The hydrologic regimes could be different because the most suitable continuous stations were located too far from the miscellaneous stations and had larger drainage areas. Flow in the larger drainage basins is generally perennial, whereas flow in the smaller drainage basins occurs infrequently. Estimation of mean annual streamflow using the method of Riggs (1969) will not work well when a perennial stream is related to an intermittent or ephemeral stream.

Tongue River at Tongue River Dam, Tongue River at Miles City, Powder River at Moorhead, and Powder River near Locate (stations 10, 15, 31, and 32) are the only continuous stations listed in table 3 that have 10 years of continuous streamflow records during water years 1968-77. These stations have drainage areas and streamflows much larger than most of the miscellaneous stations, and data from the Tongue and Powder River stations generally were not used to calculate annual mean streamflows at miscellaneous stations. Therefore, additional stations having continuous-streamflow records for at least 10 years were selected from outside but near the study area to show the relationship between mean annual streamflow for water years 1975-77 and 1968-77 (table 5). Drainage areas and streamflows at selected stations

Table 5.--*Mean annual streamflow for stations outside the study area and stations having continuous-streamflow records during water years 1968-77*

Station	Name	Drainage area (square miles)	Mean annual streamflow, in cubic feet per second	
			1975-77	1968-77
06131000	Big Dry Creek nr Van Norman, MT	2,554	24.8	43.4
06177500	Redwater River at Circle, MT	547	2.83	6.48
06216000	Pryor Creek at Pryor, MT	117	53.0	42.5
06288200	Beauvais Cr nr St. Xavier, MT	100	27.6	23.6
06306250	Prairie Dog Creek nr Acme, WY	358	39.3	43.2
06308500	Tongue River at Miles City, MT[1]	5,379	570	586
06324000	Clear Creek nr Arvada, WY	1,100	196	195
06342500	Powder River at Moorhead, MT[1]	8,088	503	508
06326500	Powder River nr Locate, MT[1]	13,194	596	677
06334500	Little Missouri River at Camp Crook, SD	1,970	113	141
06335000	Little Beaver Creek nr Marmarth, ND	587	28.5	51.3
06335500	Little Missouri River at Marmarth, ND	4,640	321	369
06350000	Cannonball River at Regent, ND	580	42.6	63.3
06351680	White Butte Fork Cedar Creek nr Scranton, ND	42.9	3.12	4.83
06355500	North Fork Grand River nr White Butte, SD	1,190	25.7	46.4
06356000	South Fork Grand River at Buffalo, SD	148	9.82	8.96
06356500	South Fork Grand River nr Cash, SD	1,350	45.0	53.3
06359500	Moreau River nr Faith, SD	2,660	111	111
06430500	Redwater Creek at WY-SD State line	1,219	44.7	46.1

[1] Continuous station

outside the study area are more similar to drainage areas and streamflows of the miscellaneous stations than those of continuous stations having 10 years of record inside the study area. The annual mean streamflow for Tongue River at Tongue River Dam was not used to develop the regression because the flow is controlled by releases from the Tongue River Reservoir.

The regression developed from stations having 10 years of record is shown in figure 4. It was used to estimate mean annual streamflow for 1968-77 at miscella-

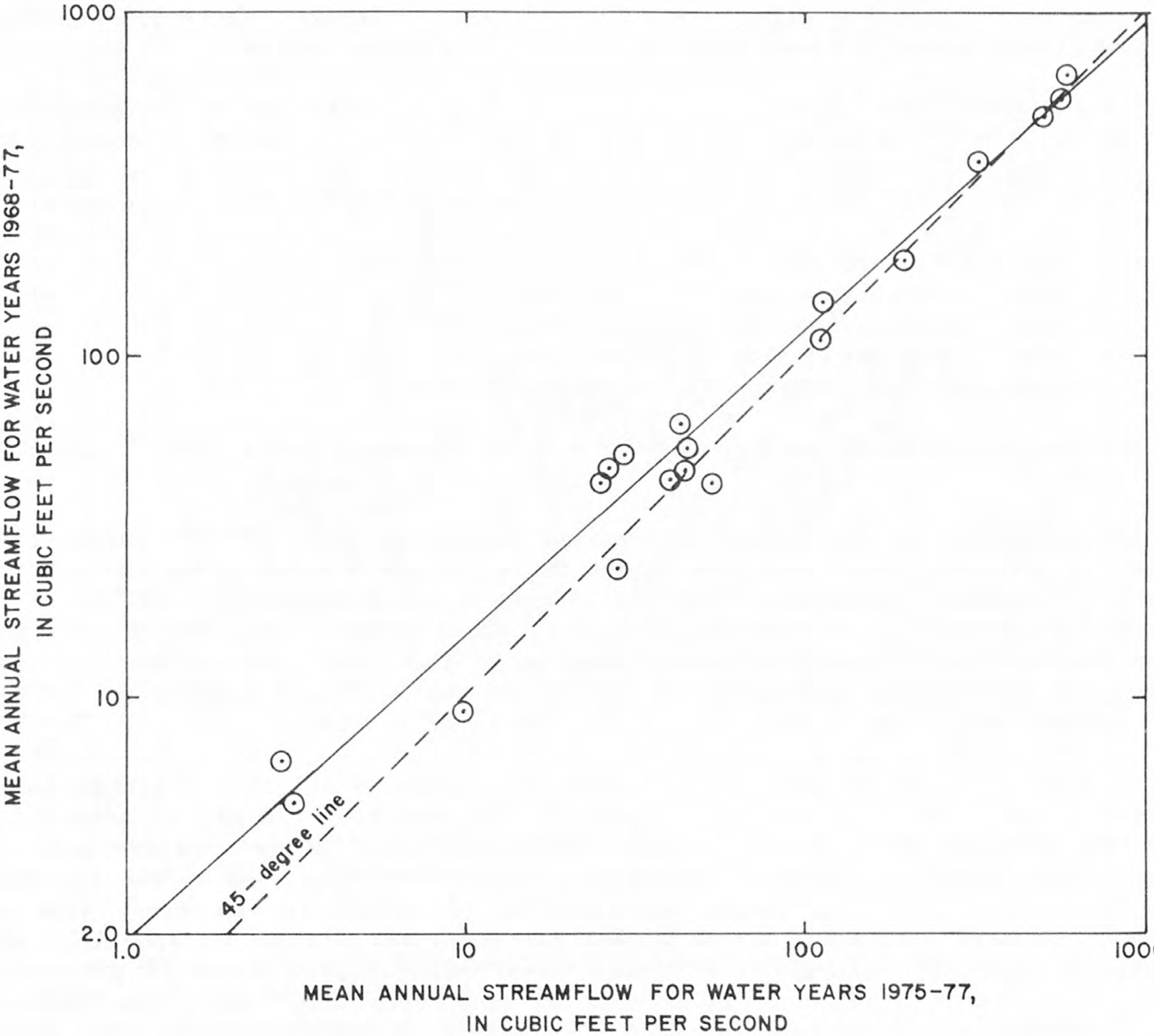

Figure 4.--Relationship of mean annual streamflow for water years 1975-77 to mean annual streamflow for water years 1968-77 at stations outside the study area and continuous stations having records for water years 1968-77.

neous stations and continuous stations having less than 10 years of record. This regression is described by the equation:

$$\log Y = 0.246 + 0.908 \log X \tag{1}$$

where Y is mean annual streamflow for water years 1968-77 and
X is mean annual streamflow for water years 1975-77.

This regression analysis has a correlation coefficient (r) equal to 0.985, a level of significance (p) of less than 0.0001, and an average standard error (SE) equal to 26 percent. At miscellaneous stations where only one or two annual mean streamflow estimates existed for water years 1975-77, the following regression equations were formulated, relating these water years to the 10-year period:

$\log Y = 0.094 + 0.900 \log F_1$ $\quad r = 0.977,\ p < 0.0001,\ SE = 32$ percent
$\log Y = 0.121 + 0.932 \log F_2$ $\quad r = 0.988,\ p < 0.0001,\ SE = 23$ percent
$\log Y = 0.825 + 0.705 \log L_1$ $\quad r = 0.930,\ p < 0.0001,\ SE = 57$ percent
$\log Y = 0.519 + 0.829 \log L_2$ $\quad r = 0.963,\ p < 0.0001,\ SE = 41$ percent

where Y is mean annual streamflow for water years 1968-77,
F_1 is annual mean streamflow for water year 1975,
F_2 is mean annual streamflow for water years 1975-76,
L_1 is annual mean streamflow for water year 1977, and
L_2 is mean annual streamflow for water years 1976-77.

The resulting estimates of mean annual streamflow for water years 1968-77 are given in table 4.

The regression of mean annual streamflow for water years 1975-77 versus 1968-77 (fig. 4) gives a greater than one-to-one ratio for small streamflows and approximately a one-to-one relationship for the largest streamflows. The position of the line could be the result of less variability in annual mean streamflows of the large streams compared to the small streams. Because of the lesser variability for large streams, the mean annual streamflow of the last 3 years is more similar to the mean annual streamflow of the 10-year period for the large streams.

The general range of mean annual runoff in inches in selected drainage basins for water years 1968-77 is shown in figure 5. In preparing the map of mean annual runoff, an estimate of irrigated acreage for each contributing drainage area was used to adjust runoff to natural conditions, thereby removing some of the variability between stations. Originally, distribution of runoff in the study area was thought to be more uniform if water losses for different irrigation practices were considered. However, natural mean annual runoff exhibits no definite pattern on the map, even between adjacent watersheds of equal drainage area. The range of values indicated for each drainage basin in figure 5 represents the mean annual runoff for each drainage as a whole. Smaller drainages within the delineated drainage basin may have mean annual runoff values greater than or less than the indicated range.

The variability in runoff is exemplified by the small tributaries of the Tongue River. As an example, Home Creek and Threemile Creek have similar drainage areas, are at similar elevations, are adjacent to each other, and are on the same facing slope of Otter Creek drainage. Yet Home Creek yields about four times the mean

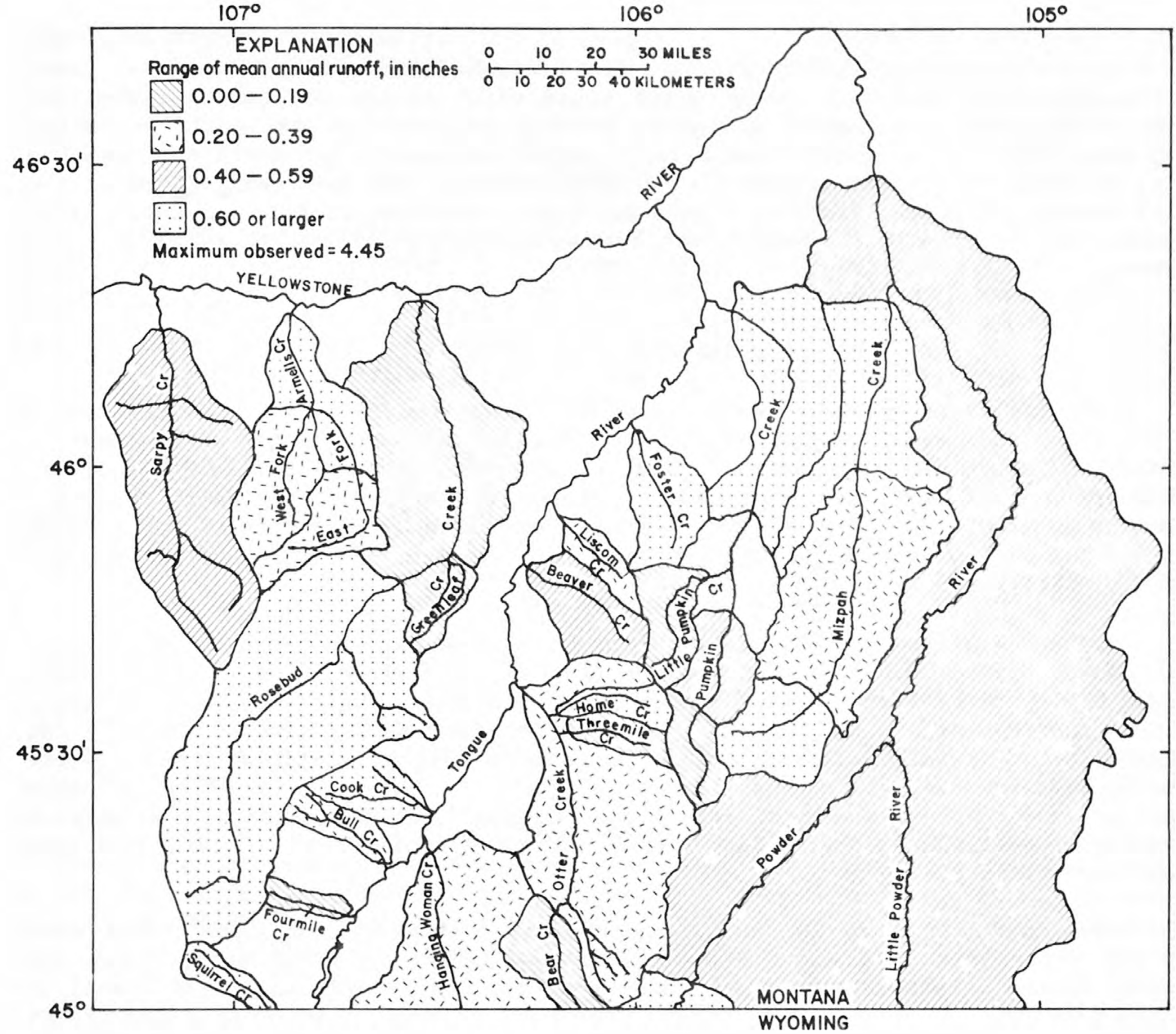

Figure 5.--Estimated natural mean annual runoff in selected drainage basins for water years 1968-77.

annual runoff of Threemile Creek. Squirrel Creek (table 3) and Cook Creek (table 4), which have drainage areas similar to Home Creek but are on the east-facing slopes of the Tongue River drainage, have mean annual runoff larger than does Home Creek. The same variability in mean annual runoff could prevail not only for similar tributaries to the Powder River, but also for tributaries too small to be shown on the map.

Variability of mean annual runoff in the study area could be the result of many factors. Perhaps most importantly, the nonuniformity of weather conditions throughout the study area could cause extreme local differences in runoff in different drainage basins. Small intermittent and ephemeral streams may flow only as a result of localized rainstorms. Streams with large drainage areas tend to reflect an average of localized rainstorms from all the smaller contributing drainage areas. Because many of the miscellaneous stations had drainage areas much smaller than those of the continuous stations, large error could exist in the streamflow estimates. Water losses from unaccounted irrigated acreage or inaccuracies in the estimated crop distribution also could have a large effect on runoff for small drainage basins, as could the common practice of ponding water in the upstream reaches of the small drainage basins. Finally, losses and gains could result from the interchange of water where streams intersect shallow aquifers in the contributing drainage basins.

ACCURACY OF ESTIMATES

Riggs (1969) reports that annual mean streamflow can be estimated within about 10 percent of its actual value on perennial streams affected by the same storms as streams having continuous stations. Estimated annual mean streamflows for Squirrel Creek and Sarpy Creek were compared to recorded annual mean streamflows to determine the accuracy of estimates in the study area. Hanging Woman Creek was used as the continuous station for Squirrel Creek, and Armells Creek was used as the continuous station for Sarpy Creek.

Percentage errors in estimating annual mean streamflows of Squirrel Creek were -11 for water year 1976 and +29 for water year 1977. Squirrel Creek is a perennial stream having large streamflows in relation to its small drainage area (see tables 3 and 4 for comparison of drainage areas and streamflows). However, because the Squirrel Creek drainage area is similar in size to several stations having miscellaneous measurements, ±10 percent is considered to be a conservative minimum limit of error for estimates of annual mean streamflow. Estimated streamflows at miscellaneous stations located on the same main-stem streams as continuous stations could have smaller errors.

Percentage errors in estimating annual mean streamflows of Sarpy Creek were +29 for water year 1976 and -46 for water year 1977. Flow of Sarpy Creek and several of the streams having miscellaneous-streamflow records is intermittent, in contrast to the perennial flow of the control streams. Comparing intermittent streams to perennial streams could introduce errors in streamflow estimates because of their different flow regimes. Therefore, in this study area ±50 percent is considered to be a conservative maximum limit of error for estimates of mean annual streamflow. This error would be increased if the two streams did not exhibit similar flow regimes.

Annual mean streamflow can be estimated by methods that relate flow characteristics to measurable drainage basin and climatic characteristics or channel geometry. A current study of the Geological Survey is relating annual mean streamflow to channel width and channel depth at stations in this area. Based on this work, the degree of uncertainty in estimates using the method of Riggs for annual mean streamflow could be evaluated further. Actual errors could be calculated if continuous-recording streamflow records were collected at some of the miscellaneous stations.

Estimates of mean annual runoff possibly could be improved by using infrared photography to obtain better estimates of the amount of ponded water and irrigated acreage in each of the drainage basins. However, large variability between drainage basins may still be present, because of non-uniform weather conditions and the effects of ground water-surface water interchange. The present range of error must be considered when evaluating the effects of mining on the quantity of surface water.

SUMMARY

Streamflow characteristics of drainage basins within the Fort Union coal region of southeastern Montana were estimated to provide premining data for evaluating the effects of mining on the environment. Estimated values for annual mean streamflow at 22 stations utilizing miscellaneous-streamflow measurements made during water years 1975-77 ranged from 0 to 887 ft^3/s. At these stations, estimated mean annual streamflow for a 10-year period (water years 1968-77) ranged from 0 to 572 ft^3/s.

Streamflows were estimated using data from 14 continuous-recording streamflow stations in the study area and several stations near the study area that have flow regimes similar to the stations with miscellaneous-streamflow measurements. Mean annual streamflow for water years 1968-77 at the continuous stations ranged from 9.55 to 677 ft^3/s in the study area and from 4.83 to 369 ft^3/s near the study area.

Estimated mean annual runoff in inches for selected drainage basins within the study area showed no discernible pattern even though estimated losses resulting from irrigation were added to the estimates. Many of the drainage basins had a mean annual runoff of less than 0.60 inch; the maximum observed mean annual runoff was 4.45 inches.

The method described by Riggs (1969) for estimating annual streamflow has been reported to be accurate to within about 10 percent for perennial streams affected by the same storms as the continuous station. Conservative estimates of the accuracy of the method for this study area are considered to range from 10 to 50 percent.

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Table 1.--*Station descriptions*

[Number to left of station name is the same as shown on fig. 2; number to right is formal Geological Survey number]

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, on left bank 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, on right bank 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 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, on left bank 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 6 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.

Station 7 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 8 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 9 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, on left bank 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 10 TONGUE RIVER AT TONGUE RIVER DAM, NEAR DECKER, MT (06307500)

LOCATION.--Lat 45°08'29", long 106°46'15", in NE1/4 sec. 13, T. 8 S., R. 40 E., Big Horn County, on left bank 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).

Station 11 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, on right bank 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 12 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 13 OTTER CREEK AT ASHLAND, MT (06307740)

LOCATION.--Lat 45°33'18", long 106°15'17", in NE1/4 NE1/4 SE1/4 sec. 11, T. 3 S., R. 44 E., Rosebud County, on left bank 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 14 TONGUE RIVER BELOW BRANDENBERG BRIDGE, NEAR ASHLAND, MT (06307830)

LOCATION.--Lat 45°52'18", long 106°11'17", in NE1/4 SW1/4 NW1/4 sec. 6, T. 1 N., R. 45 E., Custer County, on left bank 3.1 mi (5.0 km) downstream from Goodale Creek, 6.5 mi (10.5 km) downstream from Brandenberg Bridge, and 21 mi (33.8 km) north of Ashland.

Station 15 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, on right bank 4 mi (6.4 km) south of Miles City, and 8 mi (12.9 km) upstream from mouth.

Station 16 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, at gaging station 0.4 mi (0.6 km) upstream from Powers Cormack ditch, 0.5 mi (0.8 km) northwest of CX Ranch, 4 mi (6.4 km) northwest of Decker, and 7 mi (11 km) upstream from mouth.

Station 17 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 18 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 19 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 20 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.

Station 21 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 22 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 23 BEAVER CREEK NEAR ASHLAND, MT (06307810)

LOCATION.--Lat 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 24 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 25 FOSTER CREEK NEAR VOLBORG, MT (06307890)

LOCATION.--Lat 46°01'53", long 105°57'07", 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 26 PUMPKIN CREEK NEAR SONNETTE, MT (06308080)

LOCATION.--Lat 45°32'20", long 105°49'03", in NE1/4 SE1/4 SE1/4 sec. 29, T. 3 S., R. 48 E., Powder River County, at bridge on U.S. Highway 212, 5.9 mi (9.5 km) upstream from Winter Gulch, and 9.1 mi (14.6 km) north of Sonnette.

Station 27 PUMPKIN CREEK NEAR LOESCH, MT (06308160)

LOCATION.--Lat 45°42'40", long 105°43'50", 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 9 mi (14.5 km) upstream from Little Pumpkin Creek.

Station 28 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 Harkan Creek, 6.9 mi (11.1 km) southwest of Volborg, and 7.7 mi (12.4 km) upstream from mouth.

Station 29 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 30 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, on right bank 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 31 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 gage, and 4.0 mi (6.4 km) north of Wyoming-Montana State line.

Station 32 POWDER RIVER NEAR LOCATE, MT (06365000)

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

Station 33 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 mi (1.6 km) downstream from YT Creek.

Station 34 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 mi (3.2 km) downstream from Spring Creek, and 15.1 mi (24.3 km) northeast of Volborg.

Station 35 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, on left bank 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 36 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, approximately 2.0 mi (3.2 km) south of Highway 212, and 5.1 mi (8.2 km) southeast of Ashland.