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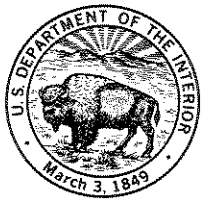
ESTIMATED MONTHLY PERCENTILE DISCHARGES AT UNGAGED SITES IN THE UPPER YELLOWSTONE RIVER BASIN IN MONTANA

By Charles Parrett and J. A. Hull

U.S. Geological Survey

Water-Resources Investigations Report 86-4009



Prepared in cooperation with the

MONTANA DEPARTMENT OF FISH, WILDLIFE AND PARKS

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UNITED STATES DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

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

Multiply inch-pound unit	By	To obtain SI unit
acre-foot per year	1,233	cubic meter per year
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
inch (in.)	25.40	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

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ABSTRACT

Once-monthly streamflow measurements were used to estimate selected percentile discharges on flow-duration curves of monthly mean discharge for 40 ungaged stream sites in the upper Yellowstone River basin in Montana. The estimation technique was a modification of the concurrent-discharge method previously described and used by H. C. Riggs to estimate annual mean discharge. The modified technique is based on the relationship of various mean seasonal discharges to the required discharges on the flow-duration curves. The mean seasonal discharges are estimated from the monthly streamflow measurements, and the percentile discharges are calculated from regression equations. The regression equations, developed from streamflow record at nine gaging stations, indicated a significant log-linear relationship between mean seasonal discharge and various percentile discharges.

The technique was tested at two discontinued streamflow-gaging stations; the differences between estimated monthly discharges and those determined from the discharge record ranged from -31 to +27 percent at one site and from -14 to +85 percent at the other. The estimates at one site were unbiased, and the estimates at the other site were consistently larger than the recorded values. Based on the test results, the probable average error of the technique was ±30 percent for the 21 sites measured during the first year of the program and ±50 percent for the 19 sites measured during the second year.

INTRODUCTION

In the early 1970's, Montana citizens became concerned about the possibility of massive water withdrawals for energy development within the Yellowstone River basin. That concern led to the Moratorium on Yellowstone River Appropriations, an act passed by the Montana Legislature in 1973. The moratorium prohibited large-scale industrial appropriations until 1977 (later extended to 1978) and, at the same time, allowed political subdivisions to reserve water for future use.

One of the water reservations subsequently granted under provisions of the moratorium was an in-stream reservation for fish and wildlife purposes to the Montana Department of Fish, Wildlife and Parks. On the Yellowstone River mainstem, the reservation was for about 5.5 million acre-feet per year near the point where the river leaves the State, and for lesser amounts at upstream points. For many smaller tributary streams, where little or no streamflow data were available, the reservation was for a specified monthly percentile discharge rather than a specific discharge or volume. Thus, for example, Yellowstone River tributaries upstream from Livingston, Mont., received a 20-percentile discharge reservation for October through April and a 50-percentile discharge reservation for May through September.

The monthly percentile discharges represent points on the flow-duration curve of mean monthly discharges. The flow-duration curve is a frequency curve that shows the percentage of time a particular mean monthly discharge is exceeded.

For the tributary streams where monthly percentile discharges were reserved, the Montana Department of Fish, Wildlife and Parks was required to develop a plan for quantifying the reserved percentile discharges within 5 years. The department subsequently developed a cooperative study with the U.S. Geological Survey to provide estimates of the required monthly percentile discharges at selected sites in the Yellowstone River basin upstream from Columbus, Mont.

The purposes of this report are to describe the technique used to estimate the monthly percentile discharges and to evaluate the reliability of the results. A 2-year project was established to make miscellaneous streamflow measurements at each of the selected sites on a monthly basis from November 1982 through September 1984. About one-half of the sites were measured during the first year of the project, and the rest were measured during the second year, so that 12 measurements were available at each site. The method used to estimate the percentile discharge was a variation of the concurrent-discharge technique used by Riggs (1969) to estimate monthly mean and annual mean discharges at ungaged sites. The reliability of the estimation technique was measured by comparing estimated monthly percentile discharges with those determined from discharge records for two discontinued streamflow-gaging stations.

DESCRIPTION OF THE STUDY AREA

Twenty-one sites in the Yellowstone River basin upstream from Livingston, Mont., were selected by the Montana Department of Fish, Wildlife and Parks for measurement during the first year of the investigation, and 19 sites between Livingston and Columbus, Mont., were selected for the second year. The basin study area and the location of the 40 measurement sites are shown in figure 1 and the measuring sites are described in table 11 (at the end of the report). Figure 1 also shows the location of 12 streamflow-gaging stations; records for 3 of the stations were used for correlation with the measurement sites and records for 9 of the stations were used in a regression analysis to develop estimating equations for the various monthly percentile discharges.

Twenty of the 21 sites measured the first year are on small streams with drainage areas ranging from 9.77 to 65.8 mi^2. One site (site 15) is located on a stream with a drainage area of 148 mi^2. All streams are perennial and drain mountainous areas where the topography is rugged and the mean annual precipitation ranges from about 20 to 40 in. (U.S. Soil Conservation Service, 1977). Four of the sites (sites 13, 19, 20, and 21) have upstream diversions for irrigation; thus, the estimates of monthly percentile discharge for these sites may not be as reliable as estimates made for unregulated sites.

Eighteen of the 19 sites measured during the second year of the program are also on small streams, with drainage areas ranging from 3.88 to 99.8 mi^2. One site (site 25) has a drainage area of 217 mi^2. The second-year measurement sites also are generally located in the mountains, although several sites are located in the foothills where the topography is not as rugged. Mean annual precipitation in the areas measured the second year ranges from about 16 to 40 in., and the climate and streamflow are generally more diverse than in the Yellowstone basin upstream from

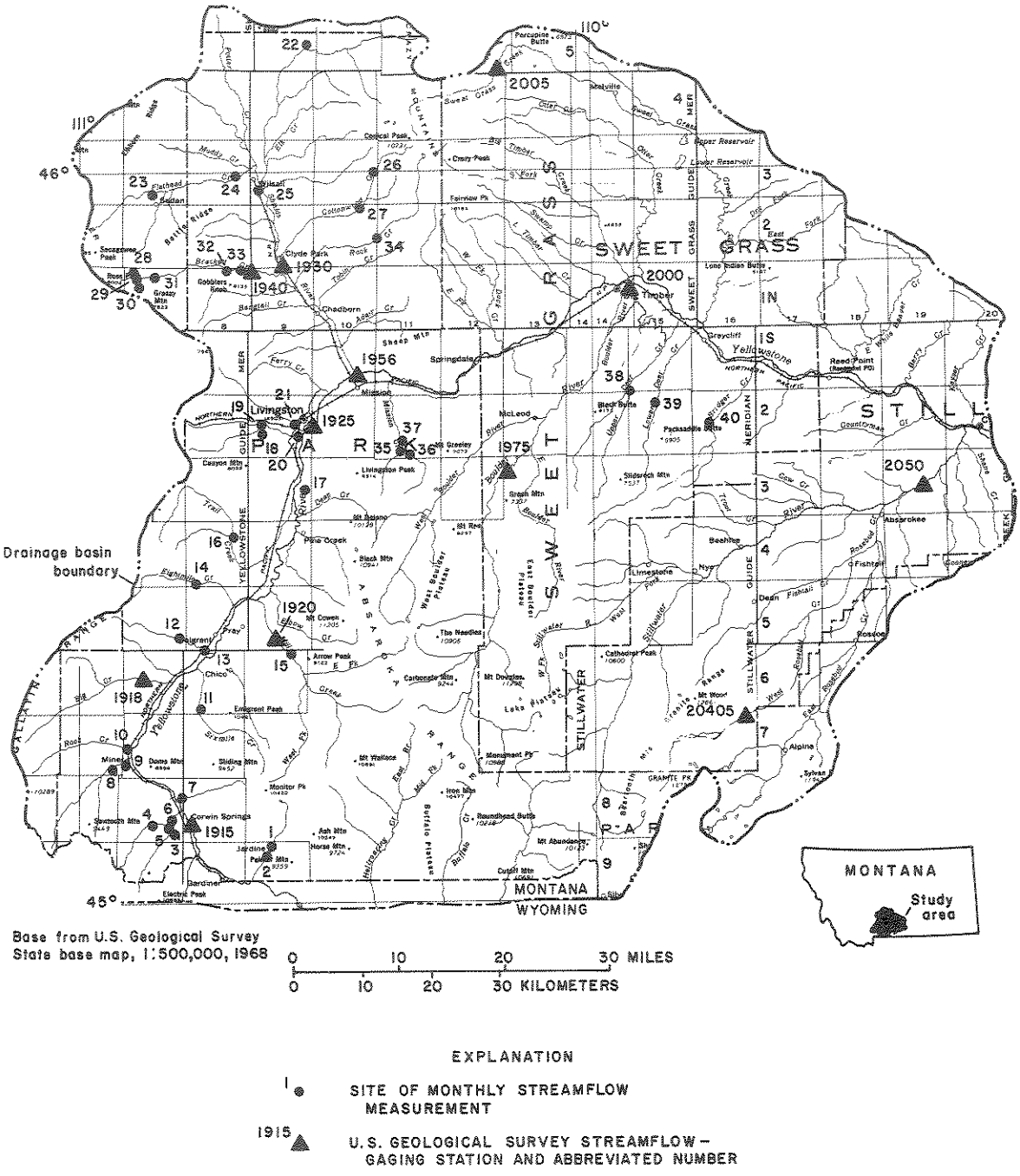


Figure 1.--Location of streamflow-measurement sites and streamflow-gaging stations.

Livingston. Seven of the sites measured the second year have significant upstream diversions for irrigation, and three of these sites are on the same stream (Flathead Creek). Other sites with significant irrigation diversions include Brackett Creek (site 33), Upper and Lower Deer Creeks (sites 38 and 39), and Bridger Creek (site 40).

DESCRIPTION OF ESTIMATION PROCEDURE

Riggs (1969) described how once-monthly discharge measurements can be used to estimate monthly mean discharge by assuming that the ratio of the measured discharge to the monthly mean discharge is the same as the ratio determined for a nearby gaged site (correlating site). The monthly mean discharges thus estimated for each month can be summed and averaged to provide an estimate of an annual mean discharge with generally good accuracy (±10 percent error). The long-term mean annual discharge can be estimated from a regional regression of the annual mean discharge for the measurement year versus the long-term mean annual discharge for several nearby gaged sites. If only one or two nearby gaged sites are available, the long-term mean annual discharge can be estimated from a regional average of the ratios of long-term mean annual discharge to annual mean discharge at the gages. The accuracy of the estimated long-term mean annual discharge is comparable to the accuracy of the estimated annual mean discharge (Riggs, 1969; Parrett and Hull, 1984).

The individual estimates of monthly mean discharge using the concurrent-discharge technique are generally not accurate. The authors found in a previous study (1984) that estimates of monthly mean discharge were commonly in error by as much as 40-50 percent even when the annual mean flow estimate was within 10 percent of the true value. The primary reason for the greater inaccuracy in estimating a monthly streamflow characteristic is that only one measurement is available for each month for making the estimate, whereas 12 measurements are available for making an estimate of an annual streamflow characteristic. In essence, averaging the individual monthly estimates significantly dampens the individual large errors that may be present in any 1 month. Ideally then, more than one measurement per month is needed to make estimates of monthly streamflow characteristics.

For this study, only one measurement per month was generally available, although two measurements were available for some sites during June (table 11). Therefore, the following several-step technique was devised for making the required monthly percentile discharge estimate from several measurements.

Estimating seasonal mean discharge

The concurrent-discharge technique of Riggs was used to estimate monthly mean discharge for the first year (November 1982 through October 1983) at each of the 21 selected sites upstream from Livingston and for the second year (1984 water year) for the remaining 19 sites (fig. 1). The nearby gaging station used as a correlating site the first year was Big Creek near Emigrant (station 06191800). Gaging stations used as correlating sites the second year were Big Creek near Emigrant and the Shields River near Livingston (station 06195600).

The estimated monthly mean discharges were then summed at each site for various flow seasons. In the study area upstream from Livingston, several different monthly groupings were tried. The grouping that showed the most consistent relationship between the monthly mean discharge and the seasonal mean discharge consisted of two seasons. Thus, a summer season (June through September) corresponds generally to the period of snowmelt runoff from the high-elevation mountains of the upper Yellowstone River basin. Likewise, the remaining months constitute a generally low-flow season for streams upstream from Livingston. Three sites downstream from Livingston (sites 26, 27, and 34) also were identified as having a two-season pattern of streamflow.

For the rest of the study area, three distinct seasons of streamflow were identified and used: A high-flow period from April through June, a 3-month period of generally low flow during the irrigation season from July through September, and a generally natural low-flow period from October through March. Where the three seasons were used, the two different low-flow seasons (July-September and October-March) were generally markedly different from each other. In general, the streams having significant upstream irrigation diversions had similar flows during the two low-flow seasons, whereas the streams without significant irrigation had significantly lower flows from October through March. The seasonal mean discharges determined for the measurement year at each site are given in tables 1 and 2.

Long-term mean seasonal discharges were determined by applying the average of the ratios of long-term mean seasonal discharge to measurement-year seasonal mean discharge at selected, concurrent gage sites. For the measurement year November 1982 through October 1983, the two gaged sites used to calculate the ratios were Big Creek near Emigrant, the correlating site, and Yellowstone River at Corwin Springs (station 06191500). Thus, for example, the long-term mean seasonal discharge for the high-flow season for Big Creek is 106 ft^3/s, and the ratio of the long-term mean seasonal discharge to the measurement year seasonal mean discharge is 1.03. Similarly, the ratio of the long-term mean seasonal discharge to the measurement year high-flow seasonal mean discharge for the Yellowstone River at Corwin Springs is 1.01, and the average of the two ratios is 1.02.

For the second measurement year (1984 water year), concurrent gaged sites used to calculate the ratios of long-term mean seasonal discharge to measurement-year seasonal mean discharge were Big Creek, Yellowstone River at Corwin Springs, Yellowstone River at Livingston (station 06192500), and Boulder River at Big Timber (station 06200000). The second correlating site, Shields River near Livingston, was not used to calculate the ratios because of its short (6-year) length of record. For the high-flow season (April-June), the average ratio calculated from the four gage sites was 1.04. Similarly for the irrigation season (July-September), the average ratio was 0.97, and for the low-flow season (October-March) it was 0.77. The same four concurrent gaged sites were used to calculate an average ratio of long-term mean seasonal discharge to measurement-year seasonal mean discharge for the two-season case (summer season June-September, and low-flow season October-May) so that long-term mean seasonal discharge could be determined for the Cottonwood Creek measurement sites (sites 26 and 27) and for the Rock Creek measurement site (site 34). In this case, the average ratio calculated for each season was 1.10. The seasonal mean discharges and long-term mean seasonal discharges thus estimated for each measurement site are given in tables 1 and 2.

To help further explain the reason for using mean seasonal discharges to estimate monthly percentile discharges, three graphs showing the relationships among mean monthly discharge, mean seasonal discharge, and a mid-monthly daily mean discharge or discharge measurement are shown in figure 2. The three graphs are for currently operating gaged sites on the Yellowstone River at Corwin Springs (station 06191500) and Big Creek near Emigrant (station 06191800), and for the discontinued gaged site on Brackett Creek near Clyde Park (station 06194000). As mentioned previously, Big Creek was used as a correlating site for all sites measured during the first year of the program. Brackett Creek was measured once-monthly during the 1984 water year and was used to test the results of the monthly percentile discharge estimating procedure. Data from all three sites were used to develop equations for estimating monthly percentile discharge. All discharges shown on the graphs for the three sites are dimensionless discharges that were derived by

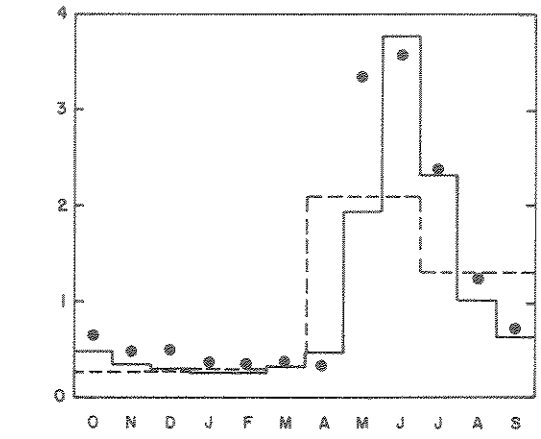
Table 1.--*Seasonal mean discharge at sites with two flow seasons*

Site No.	Stream name	Seasonal mean discharge, in cubic feet per second, for 1982-83 measurement year		Long-term mean seasonal discharge, in cubic feet per second	
		Summer season (June-Sept.)	Low-flow season (Oct.-May)	Summer season (June-Sept.)	Low-flow season (Oct.-May)
1	Bear Creek above North Fork Bear Creek	79.1	13.0	80.7	14.7
2	Bear Creek below North Fork Bear Creek	141	21.7	144	24.5
3	Mol Heron Creek	38.0	15.5	38.8	17.5
4	Cinnabar Creek above Cottonwood Creek	13.9	8.12	14.2	9.18
5	Cinnabar Creek at mouth	15.2	10.5	15.5	11.9
6	Mol Heron Creek below Cinnabar Creek	52.0	21.4	53.1	24.2
7	Cedar Creek at mouth	11.1	7.39	11.3	8.35
8	Tom Miner Creek above Canyon Creek	90.5	43.6	92.3	49.3
9	Tom Miner Creek at mouth	79.9	41.2	81.5	46.6
10	Rock Creek at mouth	45.3	10.3	46.2	11.6
11	Sixmile Creek	66.1	14.9	67.4	16.8
12	Fridley Creek above Miller Creek	28.1	13.9	28.7	15.7
13	Fridley Creek at mouth	11.5	4.16	11.7	4.70
14	Eightmile Creek	25.4	22.5	25.9	25.4
15	Mill Creek above diversions	313	68.5	319	77.4
16	Trail Creek	23.6	17.5	24.1	19.8
17	Suce Creek	13.4	2.34	13.7	2.64
18	Billman Creek above Miner Creek	8.23	12.1	8.39	13.7
19	Miner Creek	4.89	9.56	4.99	10.8
20	Billman Creek at mouth	10.7	20.9	10.9	23.6
21	Fleshman Creek at mouth	2.34	6.74	2.39	7.62
26	Cottonwood Creek above Slippery Creek	[1]53.4	[1]18.8	48.6	17.1
27	Cottonwood Creek below Little Cottonwood Creek	[1]43.9	[1]26.4	39.9	24.0
34	Rock Creek	[1]61.9	[1]19.8	56.3	18.0

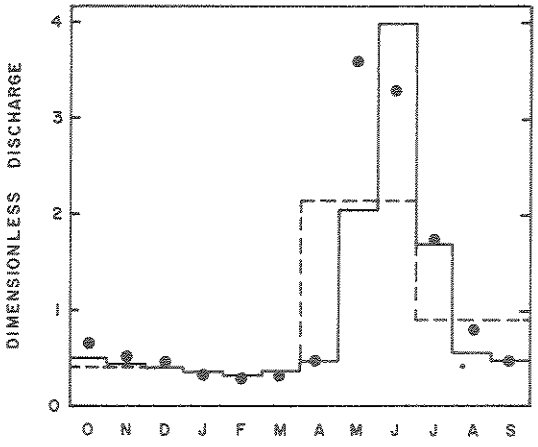
[1]Seasonal mean discharges determined from measurements in 1983-84.

Table 2.--*Seasonal mean discharge at sites with three flow seasons*

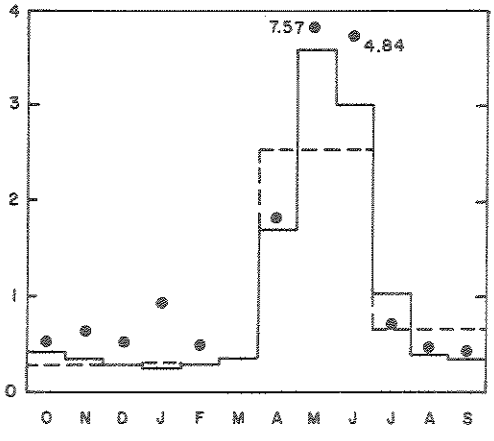
Site No.	Stream name	Seasonal mean discharge, in cubic feet per second, for 1983-84 measurement year			Long-term mean seasonal discharge, in cubic feet per second		
		High-flow season (Apr.-June)	Irrigation season (July-Sept.)	Low-flow season (Oct.-Mar.)	High-flow season (Apr.-June)	Irrigation season (July-Sept.)	Low-flow season (Oct.-Mar.)
22	Smith Creek	69.9	9.51	4.46	72.7	9.22	3.43
23	Flathead Creek above Cache Creek	33.9	9.38	7.17	35.3	9.10	5.52
24	Flathead Creek above Muddy Creek	94.6	23.7	22.8	98.4	23.0	17.6
25	Flathead Creek at mouth	104	17.5	32.1	108	17.0	24.7
28	North Fork Brackett Creek	31.1	7.94	3.56	32.3	7.70	2.74
29	Middle Fork Brackett Creek	26.8	3.36	2.19	27.9	3.26	1.69
30	South Fork Brackett Creek	20.4	4.10	1.66	21.2	3.98	1.28
31	Brackett Creek above Weasel Creek	82.1	15.6	7.11	85.4	15.1	5.47
32	Brackett Creek above Fox Creek	120	21.3	12.8	125	20.7	9.86
33	Brackett Creek near mouth (old gaged site)	125	19.5	15.5	130	18.9	11.9
35	Mission Creek above Little Mission Creek	47.9	26.4	8.19	49.8	25.6	6.31
36	Little Mission Creek	24.3	6.79	3.41	25.3	6.59	2.63
37	Mission Creek below Little Mission Creek	72.2	33.2	11.6	75.1	32.2	8.93
38	Upper Deer Creek	99.0	8.69	7.33	103	8.43	5.64
39	Lower Deer Creek	76.7	16.6	7.40	79.8	16.1	5.70
40	Bridger Creek	33.4	4.18	3.71	34.7	4.05	2.86



A. Yellowstone River at Corwin Springs (station 06191500) Drainage area = 2623 square miles



B. Big Creek near Emigrant (station 06191800) Drainage area = 60.9 square miles



C. Brackett Creek near Clyde Park (station 06194000) Drainage area = 57.9 square miles

EXPLANATION

——— LONG-TERM MEAN MONTHLY DISCHARGE

– – – – LONG-TERM MEAN SEASONAL DISCHARGE

● MID-MONTHLY DAILY MEAN DISCHARGE IN 1984 – – Measured discharge for Brackett Creek

Figure 2.--Bar graphs comparing dimensionless discharges for each month at selected gaged sites.

dividing each discharge value by the long-term mean annual discharge for each site. Each graph is thus directly comparable to the others even though the drainage areas and actual mean discharges are greatly different at each site.

Comparison of the bar graphs for the Yellowstone River and Big Creek indicates that the runoff patterns for the two streams are remarkably similar, even though there are large differences in size of drainage area. The mean monthly dimensionless discharges for July, August, and September and the corresponding irrigation-season mean seasonal dimensionless discharge for the Yellowstone River are slightly larger than those for Big Creek, indicating the greater lake storage in the Yellowstone River basin. The bar graph for Brackett Creek shows that runoff begins earlier in this stream basin than in Big Creek or the Yellowstone River, and that the mean monthly discharges during the high-flow season (April through June) are more consistent than in the other two basins. Because Brackett Creek is farther downstream than the other two sites, Brackett Creek is believed to be more generally representative of the ungaged measurement sites downstream from Livingston.

As indicated by all three bar graphs, the mid-monthly daily mean discharge is often significantly different from the mean monthly discharge, particularly during months of high flow. Of particular interest is the fact that the mid-monthly discharge is significantly larger than the mean monthly discharge for May at the Yellowstone River and Big Creek sites, but is significantly smaller than the mean monthly discharge for June at the same two sites. For these sites, it is thus apparent that using a seasonal average of three mid-monthly discharges for April, May, and June would result in better estimates of the mean monthly discharges for those 3 months than would using just the individual mid-monthly daily mean discharges.

For the Brackett Creek site, however, each of the three mid-monthly discharges is greater than the mean monthly discharge for April, May, and June. Using the average of the three mid-monthly discharges thus would not result in improved estimates for the mean monthly discharges overall, but the estimate for the month with the largest difference between mid-monthly and mean monthly discharge (June) would be improved.

Because of the often large differences in measured discharge from month to month at many of the ungaged measurement sites, averaging of monthly mean discharge estimates to produce seasonal mean discharge estimates is believed to result in overall improvement of the monthly percentile discharge estimates. As shown by the bar graph for Brackett Creek, however, the improvement of estimates due to averaging may be negligible at some sites.

Estimating monthly percentile discharges

The flow-duration curve of mean monthly discharges can be used to show monthly percentile discharges. For example, the 20-percentile discharge for April is the discharge exceeded, on the average, by the mean monthly discharge in April for 2 years of every 10. An example flow-duration curve for mean monthly discharge in April for Big Creek near Emigrant is shown in figure 3. In this instance, the 20-percentile discharge is 57.0 ft^3/s. On the average, the monthly mean discharge during April for Big Creek near Emigrant will be greater than 57.0 ft^3/s only 20-percent of the time (2 years of every 10).

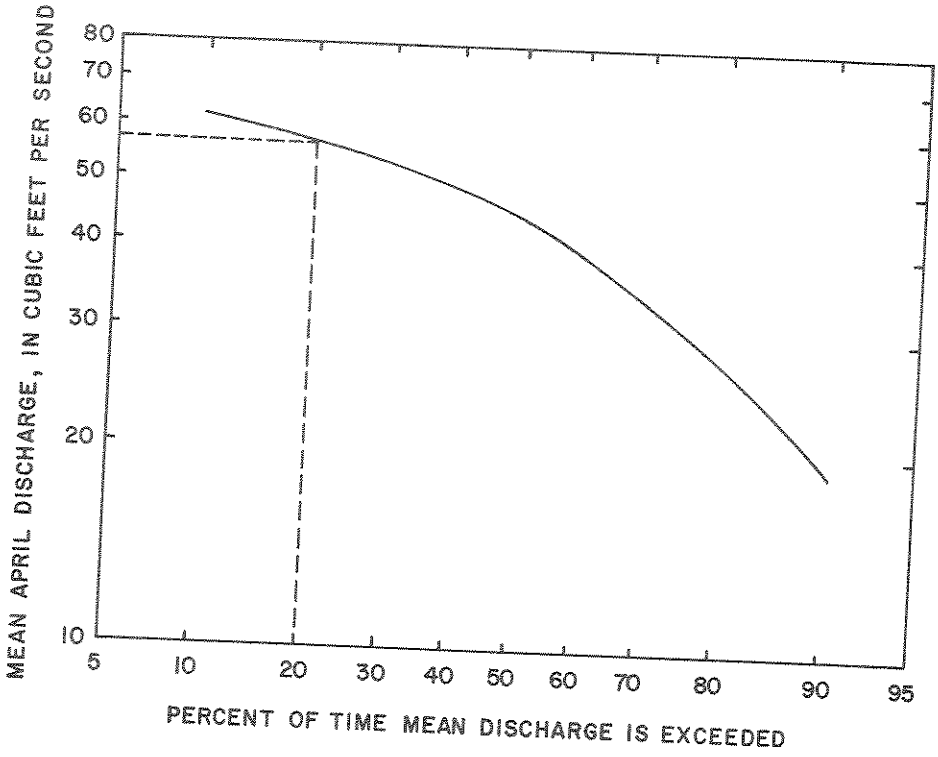


Figure 3.--Flow-duration curve of mean April discharge for Big Creek near Emigrant.

To obtain a relationship between the long-term mean seasonal discharges and the required long-term monthly percentile discharges, data from nine gaging stations were used, including one of the stations used as a correlating site for the determination of the seasonal mean discharges. Four of the stations used for the regression analyses were on streams with some upstream diversions for irrigation.

The streamflow-gaging-station data were used to develop regression equations relating the desired monthly percentile discharge to the appropriate long-term mean seasonal discharge. Because two different patterns of seasonal means were used (two seasons upstream from Livingston, three seasons for most sites downstream) and because the required monthly percentiles varied from site to site, more than 12 separate regression equations were required. The required monthly percentile and the number of seasons used to determine seasonal mean discharge (independent variable) for each month for each of the 40 measurement sites are given in table 3. Thus, 43 separate regression equations were needed to provide all the required monthly percentiles.

The regression equations developed for each month were of the following log-linear form:

$$\log Q_p = \log a + b \log Q_s \quad (1)$$

or

$$Q_p = a\, Q_s^{\,b} \quad (2)$$

where

Q_p is the monthly percentile discharge for a particular month,
a is the linear regression constant,
b is the regression coefficient, and
Q_s is the long-term mean seasonal discharge corresponding to the particular month.

For example, the regression equation developed for estimating the required percentile discharge for December for sites 1 through 21 was:

$$Q_{20} = 0.38\ Q_s^{1.09} \tag{3}$$

where

Q_s is the long-term mean seasonal discharge computed for October through May.

Likewise, the regression equation developed for estimating the required percentile discharge for May for sites 38 through 40 was:

$$Q_{90} = 1.20\ Q_s^{0.86} \tag{4}$$

where

Q_s is the long-term mean seasonal discharge computed for April through June.

Table 3.--*Determination of number of regression equations required*

Site Nos.	Percentiles required for specified months: October-April	Percentiles required for specified months: May-September	Number of seasons used to calculate seasonal means
1-21	20	50 [1]	2
26-27; 34	50	50 [1]	2
22-25; 28-33	50 [1]	50	3
35-37	50 [1]	90 [1]	3
38-40	90	90 [1]	3
Number of regressions required =	7 months x 4 = 28	5 months x 3 = 15	
Total number of regressions = 43			

[1] Percentiles and number of seasons are the same; one set of equations required.

Because only nine gaged sites were used in the regression analyses, the regression lines were graphically fitted to the nine data points rather than using a mathematical, least-squares fitting procedure. The graphical fitting allowed some subjective weighting of the data points when one or two gaged sites were thought to be more hydrologically similar to the measurement sites where the percentile discharge estimates were required. For example, when fitting regression lines for the estimation of percentile discharges for sites measured the first year, more weight was usually given to the Big Creek gaged site (station 06191800) because it is more like measurement sites 1 through 21 than any of the other gaged sites. Likewise, when fitting regression lines for the estimation of percentile discharges for sites measured the second year, more weight was usually given to the Big Creek or Shields River (station 06193000) gaged site.

Regression constants, regression coefficients, and coefficients of determination (r^2) were computed for each of the 43 graphical regressions (tables 4-6). The regression constants range from 0.17 to 4.49, with the largest values for any given percentile occurring in May or June. The regression coefficients range from 0.86 to 1.14, indicating that the relationship between the various percentile discharges and the mean seasonal discharges is almost linear (coefficient = 1.00) for all 43 equations. The coefficients of determination range from 0.927 to 0.999, indicating that the regression lines fit the data points with only a small degree of scatter in all instances.

For purposes of illustration, three of the graphical regressions are shown in figure 4. The regression line relating the 50-percentile discharge for April to the mean seasonal discharge for April through June (three-season pattern) is shown in figure 4A. This regression had the smallest coefficient of determination and consequently the greatest scatter about the regression line. As indicated by figure 4A, the regression line closely fits the nine data points regardless of the

Table 4.--*Regression constants*

Month	Three-season pattern for indicated percentile required		Two-season pattern for indicated percentile required	
	50	90	50	20
January	0.76	0.48	0.22	0.28
February	.76	.48	.22	.25
March	1.00	.51	.23	.32
April	.60	.17	.99	1.59
May	1.65	1.20	4.49	--
June	.57	1.26	2.87	--
July	1.35	.85	.60	--
August	.51	.22	.17	--
September	.53	.25	.21	--
October	1.20	.61	.38	.52
November	.98	.86	.35	.52
December	.85	.58	.26	.38

Table 5.--*Regression coefficients*

Month	Three-season pattern for indicated percentile required		Two-season pattern for indicated percentile required	
	50	90	50	20
January	1.00	1.07	1.13	1.12
February	1.00	1.07	1.13	1.14
March	.97	1.04	1.13	1.10
April	.86	.94	.96	.94
May	.92	.86	.94	--
June	1.14	1.00	.95	--
July	1.04	1.00	1.09	--
August	1.04	1.09	1.13	--
September	.98	1.00	1.05	--
October	1.01	1.12	1.13	1.11
November	1.03	1.00	1.11	1.08
December	1.02	1.05	.99	1.09

Table 6.--*Coefficients of determination* (r^2)

Month	Three-season pattern for indicated percentile required		Two-season pattern for indicated percentile required	
	50	90	50	20
January	0.999	0.995	0.989	0.991
February	.998	.996	.991	.991
March	.994	.994	.988	.986
April	.927	.952	.965	.956
May	.995	.987	.990	--
June	.992	.982	.998	--
July	.999	.996	.997	--
August	.999	.998	.994	--
September	.995	.996	.989	--
October	.999	.996	.988	.990
November	.998	.998	.989	.993
December	.999	.997	.989	.994

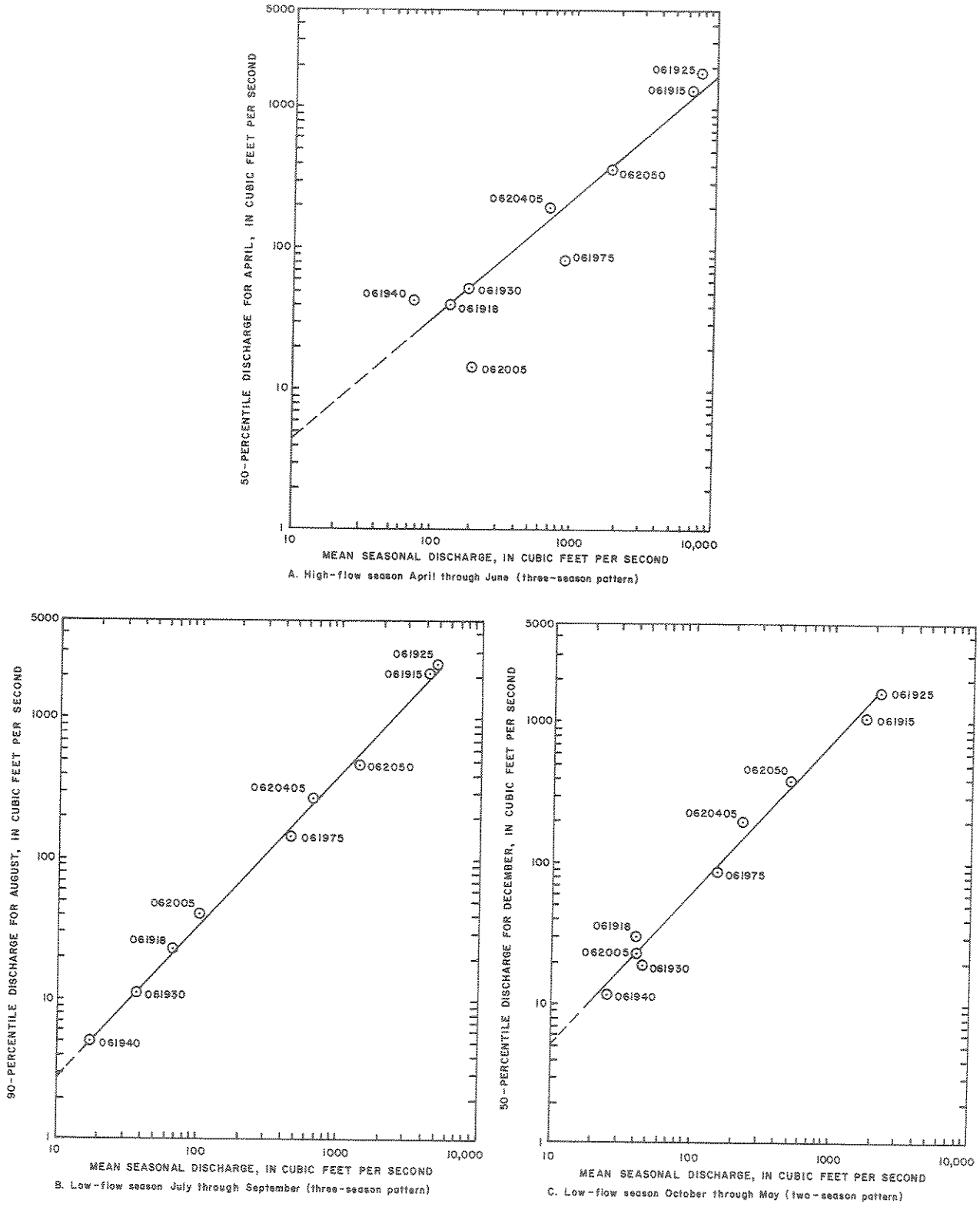


Figure 4.--Regression equations relating monthly percentile discharge to mean seasonal discharge at nine gaged sites.

relatively small coefficient of determination. The regression line relating the 90-percentile discharge for August to the mean seasonal discharge for July through September (three-season pattern) is shown in figure 4B. This regression illustrates the scatter about the regression line for a month when irrigation is most significant. The regression line relating the 50-percentile discharge for December to the mean seasonal discharge for October through May is shown in figure 4C. This graph illustrates the scatter about the regression line for a typical low-flow month where a two-season mean discharge was used. As before, the fit to the nine data points is generally very good.

Extending streamflow records to a common base period

The monthly percentile discharges for the nine gaged sites used in the regression analyses were obtained from flow-duration curves of mean monthly discharge for each month. The number of points used to develop each flow-duration curve is equal to the number of years of record at the site. In general, the more data points (years of record) used to draw the flow-duration curve, the more reliable the curve. Also, a flow-duration curve based on a short record may reflect short-term hydrologic conditions that are not representative of long-term, future conditions. Accordingly, a procedure for extending short-term streamflow records to a longer, common base period was used.

The method chosen to extend streamflow records was a statistical regression procedure developed by the U.S. Army Corps of Engineers (1971). The regression procedure (HEC-4) uses monthly flow data from several streamflow gages in an area to estimate missing monthly flow values for each gage and for each year of record. The method also preserves the variance of the unadjusted short-term record by adding a random component to the estimated values. Starting with the first year of data, missing monthly streamflows are estimated at all stations for each month in sequence. Thus, when a missing flow is being estimated, there is always a valid value for all stations already examined that month and for all remaining stations in either the current or the preceding month. The equation for estimating missing flows has the following general form:

$$Q_{i,j} = B_1 Q_{i,1} + \ldots + B_{j-1} Q_{i,j-1} + B_j Q_{i-1,j} + B_{j+1} Q_{i,j+1} + \ldots + B_n Q_{i,n} + \sqrt{1-R^2}_{i,j} \; (Z_{i,j}), \tag{5}$$

where

$Q_{i,j}$ is the monthly flow logarithm, expressed as a standard normal deviate, for month i and station j,

B_j is the beta coefficient for station j computed from a correlation matrix of flows at all n stations,

$R_{i,j}$ is the multiple correlation coefficient for month i and station j, and

$Z_{i,j}$ is a random number generated from a standard normal population.

If any station being used to estimate a missing monthly flow is also missing a flow value for that month (i), then the flow for the preceding month ($i-1$) is used in the right side of equation 5. If, for example, the monthly flow at station 1 and month i were missing, the first term on the right side of equation 5 would be $B_1 Q_{i-1,1}$.

For this study, the HEC-4 procedure was used to develop a common base period for nine gaged sites used in the regression analyses. The earliest year that any two of the nine gages had record was 1934. Consequently, 1934 was the first year of the common base period, and the HEC-4 procedure was used to extend all short-term gage record through 1982. The monthly percentile discharges at each site were thus taken from flow-duration curves developed from the common 1934-82 base period.

RELIABILITY OF ESTIMATION PROCEDURE

Regardless of the generally good fit to the data points, estimates of monthly percentile discharge were required for sites with smaller discharges than any of the gaged sites. Thus, the regression equations had to be used to make estimates outside the range of data used to derive the equations, and the results may be questionable. Accordingly, two measurement sites where some streamflow record was available were used to make an independent evaluation of the predictive reliability of the regression equations.

The 43 regression equations developed from the gaging-station data were used to estimate the various monthly percentile discharges required at the 40 selected sites (tables 7 and 8). One of the first-year measurement sites (Mill Creek, site 15) was located about 2 miles upstream from a discontinued streamflow-gaging station (Mill Creek near Pray, site 06192000). Although no significant tributaries occur between the gage and the measurement site, several large ditches divert irrigation water during the irrigation season. Streamflow at the two sites thus is not equivalent during the irrigation season but is considered to be equivalent during the rest of the year. The monthly percentile discharges estimated at the measurement site, therefore, can be compared to the monthly percentile discharges determined from the record for the non-irrigation season. As indicated in table 9, the differences between the estimated percentile discharges and those determined from the record range from -31 percent to +27 percent, with the average monthly difference being +3 percent. The estimated discharges were larger than those from the record for 5 months, and the discharges from the record were larger than those estimated for 4 months. No strong bias in the estimation technique thus is indicated for the Mill Creek site.

Although using one gaged site as a test site is not a rigorous test of the accuracy of the estimation technique, the Mill Creek gaged site is believed to be hydrologically similar to the other 20 sites measured the first year. Also, the expected error of the estimated monthly percentile discharges for those 20 sites probably is comparable to the differences found for Mill Creek (about $\pm$30 percent).

One of the sites measured during the second year of the program (site 33) is also the site of a discontinued streamflow-gaging station (Brackett Creek near Clyde Park, 06194000). For this site, the estimated monthly percentile discharges could be compared to percentile discharges from the record for all 12 months (table 10). The differences between estimated values and values from the record ranged from -14 percent to +85 percent, with the average monthly difference being +28 percent. The estimation procedure consistently overestimated monthly percentile discharges for Brackett Creek for 10 of the 12 months, evidently because the measured flows during the 1984 water year were substantially larger than mean flows based on the record. Because other gaged sites used for correlation purposes did not indicate such a large difference between 1984 streamflow and record-based mean flows, the bias toward large estimates on Brackett Creek would not necessarily apply to

Table 7.--*Estimates of monthly percentile discharge at 1982-83 measurement sites*

Site No.	Stream	Percentile discharge for month indicated, in cubic feet per second											
		20 percent				50 percent					20 percent		
		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1	Bear Creek above North Fork Bear Creek	5.68	5.35	6.15	19.9	56.2	186	71.9	24.3	21.1	10.3	9.48	7.11
2	Bear Creek below North Fork Bear Creek	10.1	9.58	10.8	32.2	90.8	322	135	46.7	38.8	18.1	16.5	12.4
3	Mol Heron Creek	6.91	6.53	7.46	23.4	66.2	92.7	32.4	10.6	9.78	12.5	11.4	8.60
4	Cinnabar Creek above Cottonwood Creek	3.35	3.13	3.67	12.8	36.1	35.7	10.8	3.41	3.41	6.09	5.70	4.26
5	Cinnabar Creek at mouth	4.29	4.21	4.88	16.3	46.1	38.8	11.9	3.76	3.73	8.13	7.54	5.65
6	Mol Heron Creek below Cinnabar Creek	9.93	9.45	10.6	31.8	89.7	125	45.6	15.1	13.6	17.9	16.2	12.3
7	Cedar Creek at mouth	3.02	2.81	3.30	11.7	33.0	28.7	8.43	2.63	2.68	5.48	5.15	3.84
8	Tom Miner Creek above Canyon Creek	22.0	21.3	23.3	62.0	175	211	83.2	28.3	24.3	39.4	35.0	26.6
9	Tom Miner Creek at mouth	20.7	19.9	21.9	58.8	166	188	72.7	24.6	21.3	37.0	33.0	25.0
10	Rock Creek at mouth	4.36	4.09	4.74	15.9	45.0	109	39.1	12.9	11.8	7.90	7.34	5.50
11	Sixmile Creek	6.60	6.23	7.13	22.6	63.7	157	59.1	19.8	17.5	11.9	10.9	8.23
12	Fridley Creek above Miller Creek	6.12	5.77	6.62	21.2	59.8	69.6	23.3	7.55	7.13	11.1	10.2	7.64
13	Fridley Creek at mouth	1.58	1.46	1.76	6.81	19.2	29.7	8.76	2.74	2.78	2.90	2.77	2.05
14	Eightmile Creek	10.5	9.99	11.2	33.3	93.9	63.2	20.8	6.72	6.40	18.9	17.1	12.9
15	Mill Creek above diversions	36.5	35.6	38.3	94.8	268	688	323	115	89.7	64.9	57.0	43.5
16	Trail Creek	7.93	7.52	8.54	26.3	74.3	59.0	19.3	6.20	5.93	14.3	13.1	9.84
17	Suce Creek	.83	.76	.93	3.96	11.2	34.5	10.4	3.27	3.28	1.53	1.48	1.09
18	Billman Creek above Miner Creek	5.25	4.94	5.70	18.6	52.6	21.6	6.10	1.88	1.96	9.50	8.78	6.59
19	Miner Creek	4.02	3.77	4.38	14.9	42.0	13.2	3.46	1.05	1.14	7.30	6.79	5.08
20	Billman Creek at mouth	9.66	9.18	10.4	31.0	87.7	27.8	8.11	2.53	2.58	17.4	15.8	11.9
21	Fleshman Creek at mouth	2.72	2.53	2.99	10.7	30.3	6.57	1.55	.46	.52	4.95	4.66	3.48

Table 8.--*Estimates of monthly percentile discharge at 1983-84 measurement sites*

Site No.	Stream	Percentile discharge[1] for month indicated, in cubic feet per second											
		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
22	Smith Creek	2.61	2.61	3.31	23.9	85.1	75.5	13.6	5.14	4.67	4.17	3.49	2.99
23	Flathead Creek above Cache Creek	4.20	4.20	5.24	12.9	43.8	33.1	13.4	5.07	4.61	6.74	5.69	4.86
24	Flathead Creek above Muddy Creek	13.4	13.4	16.1	31.1	112	107	35.2	13.3	11.4	21.7	18.8	15.8
25	Flathead Creek at mouth	18.8	18.8	22.4	33.6	123	119	25.7	9.71	8.51	30.6	26.7	22.4
26	Cottonwood Creek above Slippery Creek	5.44	5.44	5.69	15.1	74.8	105	41.4	13.7	12.4	9.40	8.18	6.43
27	Cottonwood Creek below Little Cottonwood Creek	7.98	7.98	8.34	20.9	79.8	105	33.3	11.0	10.1	13.8	11.9	9.43
28	North Fork Brackett Creek	2.08	2.08	2.66	11.9	40.4	29.9	11.3	4.26	3.92	3.32	2.77	2.38
29	Middle Fork Brackett Creek	1.28	1.28	1.66	10.5	35.3	25.3	4.61	1.74	1.69	2.04	1.68	1.45
30	South Fork Brackett Creek	.97	.97	1.27	8.29	27.4	18.5	5.68	2.15	2.05	1.54	1.26	1.09
31	Brackett Creek above Weasel Creek	4.16	4.16	5.20	27.5	98.7	90.7	22.7	8.58	7.58	6.68	5.64	4.81
32	Brackett Creek above Fox Creek	7.49	7.49	9.21	38.1	140	140	31.5	11.9	10.3	12.1	10.3	8.77
33	Brackett Creek near mouth (old gaged site)	9.04	9.04	11.0	39.5	145	146	28.7	10.8	9.45	14.6	12.6	10.6
34	Rock Creek below Little Rock Creek	5.77	5.77	6.03	15.9	68.0	132	48.6	16.2	14.5	9.96	8.66	6.81
35	Mission Creek above Little Mission Creek	4.80	4.80	5.97	17.3	[2]78.6	[2]62.7	[2]21.8	[2]7.54	[2]6.40	7.71	6.54	5.56
36	Little Mission Creek	2.00	2.00	2.55	9.66	[2]38.1	[2]31.9	[2]5.60	[2]1.72	[2]1.65	3.19	2.65	2.28
37	Mission Creek below Little Mission Creek	6.79	6.79	8.36	24.6	[2]122	[2]94.6	[2]27.4	[2]9.68	[2]8.05	11.0	9.35	7.93
38	Upper Deer Creek	[2]3.06	[2]3.06	[2]3.08	[2]13.3	[2]64.6	[2]130	[2]7.17	[2]2.25	[2]2.11	[2]4.23	[2]4.85	[2]3.57
39	Lower Deer Creek	[2]3.09	[2]3.09	[2]3.12	[2]10.4	[2]51.9	[2]101	[2]13.7	[2]4.55	[2]4.03	[2]4.28	[2]4.90	[2]3.61
40	Bridger Creek	[2]1.48	[2]1.48	[2]1.52	[2]4.77	[2]25.3	[2]43.7	[2]3.44	[2]1.01	[2]1.01	[2]1.98	[2]2.46	[2]1.75

[1] 50 percent for all sites, except as indicated.
[2] 90 percent.

Table 9.--*Differences between monthly percentile discharges determined from gage record and regression equations for Mill Creek (site 15)*

Month	Percentile discharge for month indicated, in cubic feet per second: Estimated from regression equations	Percentile discharge for month indicated, in cubic feet per second: Determined from discharge record	Percent difference[1] from discharge record
January	36.5	33.0	+11
February	35.6	34.0	+5
March	38.3	33.0	+16
April	94.8	80.0	+19
May	268	388	-31
June	688	757	-9
July	323	--	--
August	115	--	--
September	89.7	--	--
October	64.9	51.0	+27
November	57.0	58.0	-2
December	43.5	47.0	-8

[1]Average percent difference = +3

Table 10.--*Differences between monthly percentile discharges determined from gage record and regression equations for Brackett Creek (site 33)*

Month	Percentile discharge for month indicated, in cubic feet per second: Estimated from regression equations	Percentile discharge for month indicated, in cubic feet per second: Determined from discharge record	Percent difference[1] from discharge record
January	9.04	7.00	+29
February	9.04	7.00	+29
March	11.0	9.00	+22
April	39.5	42.0	-6
May	145	93.0	+56
June	146	79.0	+85
July	28.7	27.0	+6
August	10.8	10.0	+8
September	9.45	11.0	-14
October	14.6	11.0	+33
November	12.6	9.00	+40
December	10.6	7.00	+51

[1]Average percent difference = +28

the other 18 sites measured in 1984. Thus, the mean of the largest absolute differences between estimated and record-based percentile discharges for Brackett Creek (±50) probably are comparable to the expected errors of the estimation procedure for the sites measured during 1984. The sites measured during the second year of the program were not as similar as the first-year measurement sites, and the probable error of the estimated monthly percentile discharges is greater for the second-year sites.

It is important to note that the estimates of monthly percentile discharges furnished to the Montana Department of Fish, Wildlife and Parks for the two gaged sites (Mill Creek and Brackett Creek) were based on actual gage data (non-irrigation months only for Mill Creek). In addition, the estimates for the other sites on Brackett Creek were adjusted to reflect the difference between the estimates from the regression equations and the values from the record determined for the gaged site.

To apply the estimation technique described in this report to a different study area, different seasonal mean discharges would probably need to be computed. The season would need to be selected so that the monthly mean discharges for each month comprising the seasons are approximately equal. At the same time, the number of seasons would be limited so that each seasonal mean discharge is based on an average of at least three monthly mean discharge estimates. Having at least three values to average tends to dampen any large individual errors that could be present in any single monthly mean discharge estimate.

CONCLUSIONS

Monthly percentage discharges were estimated for ungaged sites based on once-monthly streamflow measurements. The technique used is a modification of the concurrent-discharge technique previously used to estimate annual mean discharge. Several steps were required to use the modified technique.

Based on the results of an application to two discontinued streamflow-gaging stations, the modified technique provides reasonably accurate estimates of monthly percentile discharge at the selected sites. For the 21 sites measured during the first year of the project, the probable average error for any month is within the range of differences found at the Mill Creek test site (±30 percent). For the sites measured during the second year, the expected average error of the monthly estimates is within the range of differences found at the Brackett Creek test site but without the bias toward overestimation. The mean of the largest absolute differences between estimated and record-based monthly percentile discharges for Brackett Creek (±50 percent) probably is close to the average error of the monthly estimates made for the sites measured the second year.

The expected errors of monthly percentile discharge estimated for this study are significantly larger than the errors reported by Riggs (1969) and Parrett and Hull (1984) for estimating mean annual discharge. This result is to be expected, however, because an estimate of mean annual discharge is based on an average of 12 separate measurements. An estimate of a monthly streamflow characteristic made using the concurrent-discharge technique is based on only one measurement for that month. Thus, using the concurrent-discharge technique to estimate monthly discharges would provide substantially more accurate estimates only if more measurements per month were made or, better yet, if the measurements were continued for several years.

The accuracy of the concurrent-discharge technique for estimating either mean annual discharge or monthly percentile discharge also is largely dependent upon having a suitable correlating gaged site. If the correlating gaged site has streamflow characteristics different from those of the ungaged measurement site, the resulting monthly mean discharge estimate will be in error. The seasonal mean discharge or the annual mean discharge subsequently calculated from the individual monthly estimates thus could be subject to a substantial cumulative error. The errors of estimation described above for this study include the errors due to imperfect correlation but, because each study area and its correlating sites are unique, the errors of estimation likely would be different for different study areas.

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Table 11.--*Site descriptions and streamflow measurements*

[ft, foot; ft^3/s, cubic foot per second; mi, mile]

Site No.	Stream name	Location	Date	Discharge (ft^3/s)
1	Bear Creek above North Fork Bear Creek	Lat 45°04'25", long 110°37'50", in SW¼SE¼SW¼ sec. 4, T. 9 S., R. 9 E., Park County, 200 ft upstream from North Fork Bear Creek in Jardine.	11-15-82	10.8
			12-13-82	6.66
			01-18-83	3.47
			02-15-83	6.08
			03-16-83	6.17
			04-14-83	5.60
			05-18-83	16.4
			06-01-83	139
			06-14-83	144
			07-14-83	129
			08-15-83	25.9
			09-16-83	13.9
			10-13-83	23.4
2	Bear Creek below North Fork Bear Creek	Lat 45°04'25", long 110°37'50", in SW¼NW¼NW¼ sec. 9, T. 9 S., R. 9 E., Park County, at bridge over Bear Creek in Jardine.	11-15-82	21.3
			12-13-82	14.6
			01-18-83	8.93
			02-15-83	10.4
			03-16-83	10.0
			04-14-83	7.78
			05-18-83	25.3
			06-01-83	240
			06-14-83	[1]240
			07-14-83	184
			08-15-83	40.2
			09-16-83	23.7
			10-13-83	36.9
3	Mol Heron Creek	Lat 45°06'34", long 110°49'09", in SW¼SW¼NW¼ sec. 25, T. 8 S., R. 7 E., Park County, at culvert just upstream from Cinnabar Creek, 1.5 mi upstream from mouth, and 1.5 mi west of Corwin Springs.	11-15-82	17.6
			12-13-82	16.5
			01-18-83	10.1
			02-15-83	10.4
			03-15-83	9.19
			04-13-83	11.9
			05-17-83	10.8
			06-01-83	55.2
			06-14-83	71.2
			07-13-83	52.0
			08-15-83	19.2
			09-15-83	13.4
			10-13-83	17.1

Table 11.--*Site descriptions and streamflow measurements*--Continued

Site No.	Stream name	Location	Date	Discharge (ft^3/s)
4	Cinnabar Creek above Cottonwood Creek	Lat 45°06'39", long 110°51'33", in NW¼SE¼NW¼ sec. 27, T. 8 S., R. 7 E., Park County, 0.5 mi upstream from Cottonwood Creek, 2 mi upstream from the mouth, and 3.6 mi west of Corwin Springs.	11-15-82	8.48
			12-13-82	6.70
			01-18-83	5.27
			02-15-83	4.71
			03-15-83	5.71
			04-13-83	4.99
			05-17-83	7.33
			06-01-83	29.6
			06-14-83	25.0
			07-13-83	10.3
			08-15-83	10.1
			09-15-83	7.35
			10-13-83	9.08
5	Cinnabar Creek at mouth	Lat 45°06'34", long 110°49'10", in SW¼SW¼NW¼ sec. 25, T. 8 S., R. 7 E., Park County, at culvert at mouth, 1.5 mi west of Corwin Springs.	11-15-82	12.5
			12-14-82	7.92
			01-18-83	7.01
			02-15-83	6.39
			03-15-83	7.64
			04-13-83	8.00
			05-17-83	9.34
			06-01-83	28.6
			06-14-83	25.7
			07-13-83	12.4
			08-15-83	12.5
			09-15-83	8.25
			10-13-83	8.15
6	Mol Heron Creek below Cinnabar Creek	Lat 45°07'23", long 110°48'49", in SW¼SE¼NW¼ sec. 24, T. 8 S., R. 7 E., Park County, at bridge on county road, 0.6 mi upstream from mouth, and 1.5 mi northwest of Corwin Springs.	11-15-82	30.1
			12-13-82	24.4
			01-18-83	17.1
			02-15-83	16.8
			03-15-83	16.8
			04-13-83	19.9
			05-17-83	20.1
			06-01-83	83.8
			06-14-83	96.9
			07-13-83	64.4
			08-15-83	31.7
			09-15-83	21.7
			10-13-83	25.3

Table 11.--*Site descriptions and streamflow measurements*--Continued

Site No.	Stream name	Location	Date	Discharge (ft^3/s)
7	Cedar Creek at mouth	Lat 45°08'35" long 110°48'45", in SE¼NE¼NW¼ sec. 13, T. 8 S., R. 7 E., Park County, at culverts on U.S. Highway 89, 2.5 mi northwest of Corwin Springs.	11-16-82	7.71
			12-14-82	6.87
			01-18-83	5.74
			02-15-83	6.40
			03-15-83	5.14
			04-13-83	6.34
			05-17-83	4.37
			06-01-83	17.7
			06-14-83	26.3
			07-14-83	21.3
			08-15-83	1.16
			09-15-83	.89
			10-13-83	8.09
8	Tom Miner Creek above Canyon Creek	Lat 45°11'22", long 110°56'03", in NW¼NW¼NW¼ sec. 36, T. 7 S., R. 6 E., Park County, 300 ft upstream from Canyon Creek, 1.8 mi upstream from mouth, 9 mi northwest of Corwin Springs.	11-16-82	[2]53.0
			12-14-82	28.9
			01-19-83	23.5
			02-15-83	21.2
			03-15-83	29.1
			04-13-83	27.1
			05-17-83	49.1
			06-01-83	168
			06-15-83	164
			07-13-83	97.2
			08-15-83	52.6
			09-15-83	30.7
			10-13-83	35.0
9	Tom Miner Creek at mouth	Lat 45°11'57", long 110°54'28", in SE¼SW¼NE¼ sec. 30, T. 7 S., R. 7 E., Park County, at bridge near mouth on county road, 0.5 mi south of bridge over Yellowstone River, and 8.5 mi northwest of Corwin Springs.	11-16-82	52.9
			12-14-82	35.0
			01-19-83	23.2
			02-15-83	21.1
			03-15-83	29.4
			04-13-83	23.9
			05-17-83	43.6
			06-01-83	165
			06-15-83	166
			07-13-83	83.8
			08-15-83	33.0
			09-15-83	21.1
			10-13-83	27.9

Table 11.--*Site descriptions and streamflow measurements*--Continued

Site No.	Stream name	Location	Date	Discharge (ft^3/s)
10	Rock Creek at mouth	Lat 45°12'39", long 110°54'11", in NE¼NW¼SE¼ sec. 19, T. 7 S., R. 7 E., Park County, at bridge at mouth on county road, 0.4 mi north of bridge over Yellowstone River, and 9 mi northwest of Corwin Springs.	11-16-82	10.4
			12-14-82	7.77
			01-19-83	6.91
			02-16-83	4.61
			03-15-83	6.21
			04-13-83	6.64
			05-17-83	12.6
			06-01-83	123
			06-14-83	110
			07-13-83	50.9
			08-15-83	10.1
			09-15-83	4.77
			10-13-83	6.52
11	Sixmile Creek	Lat 45°16'15", long 110°46'31", in SW¼SE¼NW¼ sec. 32, T. 6 S., R. 8 E., Park County, at bridge on county road, 3.5 mi upstream from mouth, and 7 mi south of Emigrant.	11-16-82	12.5
			12-15-82	6.06
			01-19-83	9.33
			02-16-83	8.19
			03-15-83	9.52
			04-13-83	9.88
			05-17-83	16.1
			06-01-83	103
			06-14-83	138
			07-12-83	96.8
			08-15-83	28.0
			09-15-83	17.8
			10-14-83	22.1
12	Fridley Creek above Miller Creek	Lat 45°21'38", long 110°47'58", in NE¼SW¼NE¼ sec. 36, T. 5 S., R. 7 E., Park County, just upstream from Miller Creek, 2 1/2 mi upstream from mouth, and 3 1/4 mi west of Emigrant.	11-16-82	15.4
			12-15-82	7.63
			01-19-83	7.47
			02-16-83	6.91
			03-15-83	12.2
			04-13-83	9.11
			05-17-83	15.5
			06-01-83	56.2
			06-14-83	60.8
			07-13-83	29.2
			08-16-83	10.2
			09-15-83	9.09
			10-13-83	10.8

Table 11.--*Site descriptions and streamflow measurements*--Continued

Site No.	Stream name	Location	Date	Discharge (ft^3/s)
13	Fridley Creek at mouth	Lat 45°20'43", long 110°45'23", in SE¼SW¼NW¼ sec. 4, T. 6 S., R. 8 E., Park County, at culvert on U.S. Highway 89, 2 mi southwest of Emigrant.	11-16-82	3.71
			12-15-82	3.60
			01-19-83	3.80
			02-16-83	2.83
			03-15-83	4.88
			04-13-83	2.83
			05-17-83	2.88
			06-01-83	13.7
			06-14-83	22.6
			07-13-83	19.2
			08-16-83	3.82
			09-15-83	3.98
			10-13-83	3.62
14	Eightmile Creek near Emigrant	Lat 45°26'15", long 110°46'05", in NW¼NE¼NW¼ sec. 5, T. 5 S., R. 8 E., Park County, above small reservoirs, 1.6 mi downstream from Big Draw, and 5 1/2 mi northwest of Pray.	11-16-82	20.6
			12-15-82	8.06
			01-20-83	18.8
			02-16-83	16.8
			03-14-83	20.4
			04-12-83	17.4
			05-16-83	[3]21.5
			05-31-83	[3]38.0
			06-13-83	[3]40.0
			07-13-83	23.7
			08-16-83	20.5
			09-14-83	19.7
			10-14-83	20.7
15	Mill Creek above diversions	Lat 45°20'11", long 110°35'19", in SE¼SE¼SW¼ sec. 2, T. 6 S., R. 9 E., Park County, at U.S. Forest Service boundary, 2 mi downstream from the East Fork, 6 mi upstream from old U.S. Highway 89, and 5 1/2 mi southeast of Pray.	11-17-82	77.8
			12-15-82	23.1
			01-20-83	25.8
			02-14-83	36.3
			03-14-83	48.0
			04-12-83	38.0
			05-16-83	80.9
			05-31-83	567
			06-15-83	583
			07-12-83	538
			08-15-83	111
			09-14-83	64.1
			10-12-83	89.9

Table 11.--*Site descriptions and streamflow measurements*--Continued

Site No.	Stream name	Location	Date	Discharge (ft^3/s)
16	Trail Creek	Lat 45°29'58", long 110°42'03", in NW¼SW¼SE¼ sec. 11, T. 4 S., R. 8 E., Park County, at culvert on county road, just above Pine Creek, 13 mi southwest of Livingston.	11-16-82	11.7
			12-15-82	4.61
			01-20-83	6.33
			02-16-83	12.8
			03-14-83	16.8
			04-12-83	11.8
			05-16-83	27.0
			05-31-83	62.4
			06-13-83	50.1
			07-12-83	23.0
			08-16-83	10.6
			09-14-83	8.28
			10-12-83	7.37
17	Suce Creek	Lat 45°34'01", long 110°33'30", in SW¼NW¼NE¼ sec. 24, T. 3 S., R. 9 E., Park County, at bridge on old U.S. Highway 89, 1 mi upstream from mouth, and 6 1/2 mi south of Livingston.	11-17-82	1.78
			12-16-82	.84
			01-17-83	1.04
			02-14-83	.97
			03-14-83	2.79
			04-12-83	1.97
			05-16-83	3.03
			05-31-83	37.2
			06-13-83	39.2
			07-12-83	8.41
			08-16-83	5.30
			09-14-83	3.41
			10-12-83	1.56
18	Billman Creek	Lat 45°39'30", long 110°39'04", in NW¼SW¼SW¼ sec. 17, T. 2 S., R. 9 E., Park County, at concrete bridge, 0.1 mi upstream from Miner Creek, 0.15 mi south of frontage road, and 4 1/2 mi west of Livingston.	11-17-82	3.29
			12-16-82	3.62
			01-17-83	3.60
			02-14-83	3.65
			03-14-83	8.51
			04-12-83	8.87
			05-16-83	24.8
			05-31-83	24.1
			06-13-83	13.6
			07-12-83	8.47
			08-16-83	4.05
			09-14-83	2.89
			10-12-83	2.40

Table 11.--*Site descriptions and streamflow measurements*--Continued

Site No.	Stream name	Location	Date	Discharge (ft^3/s)
19	Miner Creek	Lat 45°39'16", long 110°39'05" in NW¼NW¼NW¼ sec. 20, T. 2 S., R. 9 E., Park County, 0.4 mi south of old U.S. Highway 10, and 4 1/2 mi west of Livingston.	11-17-82	[2] 2.16
			12-16-82	3.41
			01-17-83	2.52
			02-14-83	2.01
			03-14-83	8.99
			04-12-83	4.84
			05-16-83	20.6
			05-31-83	15.6
			06-13-83	8.97
			07-12-83	4.44
			08-16-83	1.99
			09-14-83	1.66
			10-12-83	1.85
20	Billman Creek at mouth	Lat 45°38'27", long 110°34'25", in NW¼NE¼NE¼ sec. 26, T. 2 S., R. 9 E., Park County at bridge on U.S. Highway 89, just south of Interstate 90, in Livingston.	11-17-82	6.48
			12-16-82	2.44
			01-17-83	4.69
			02-14-83	5.35
			03-14-83	18.0
			04-12-83	13.8
			05-16-83	44.6
			05-31-83	39.1
			06-13-83	17.8
			07-12-83	12.1
			08-16-83	2.48
			09-14-83	1.80
			10-12-83	4.19
21	Fleshman Creek at mouth	Lat 45°39'49", long 110°34'54", in NE¼NE¼NW¼ sec. 23, T. 2 S., R. 9 E., Park County, at culvert on old U.S. Highway 10, 0.8 mi west of junction with old Highway 89, 1.2 mi west of post office in Livingston.	11-15-82	3.93
			12-16-82	3.48
			01-17-83	2.44
			02-14-83	2.27
			03-14-83	3.72
			04-12-83	4.17
			05-16-83	13.0
			05-31-83	6.77
			06-13-83	2.44
			07-12-83	3.31
			08-16-83	1.10
			09-14-83	.85
			10-12-83	1.35

Table 11.--*Site descriptions and streamflow measurements*--Continued

Site No.	Stream name	Location	Date	Discharge (ft^3/s)
22	Smith Creek	Lat 46°10'34", long 110°32'13", in NW¼NE¼SE¼ sec. 24, T. 5 N., R. 9 E., Park County, at private bridge 0.1 mi above Meadow Creek, and 14 mi northeast of Wilsall.	10-12-83	5.23
			11-16-83	8.23
			12-13-83	3.66
			01-10-84	4.86
			02-14-84	3.61
			03-13-84	2.78
			04-16-84	19.7
			05-14-84	160
			06-12-84	59.8
			07-16-84	10.3
			08-14-84	7.96
			09-12-84	5.10
23	Flathead Creek above Cache Creek	Lat 45°58'37", long 110°50'12", in NW¼SE¼SE¼ sec. 27, T. 3 N., R. 7 E., Park County, at bridge on county road, 1.3 mi north of old town of Sedan, and 8 1/2 mi west of Wilsall.	10-12-83	6.54
			11-16-83	7.62
			12-13-83	7.10
			01-10-84	11.8
			02-14-84	7.60
			03-13-84	5.86
			04-16-84	23.6
			05-14-84	55.8
			06-12-84	26.2
			07-16-84	11.7
			08-14-84	5.84
			09-12-84	5.16
24	Flathead Creek above Muddy Creek	Lat 45°59'31", long 110°42'26", in NW¼SW¼SW¼ sec. 23, T. 3 N., R. 8 E., Park County, at old bridge crossing, 0.1 mi south of Flathead Road, and 2.3 mi west of Wilsall.	10-12-83	23.2
			11-16-83	36.0
			12-13-83	18.2
			01-10-84	29.2
			02-14-84	20.6
			03-13-84	18.5
			04-16-84	66.0
			05-14-84	148
			06-12-84	80.0
			07-16-84	26.1
			08-14-84	8.88
			09-12-84	23.8

Table 11.--*Site descriptions and streamflow measurements*--Continued

Site No.	Stream name	Location	Date	Discharge (ft^3/s)
25	Flathead Creek at mouth	Lat 45°59'18", long 110°39'11", in NW¼NW¼NE¼ sec. 30, T. 3 N., R. 9 E., Park County, at bridge on county road, 0.2 mi east of U.S. Highway 89, at Wilsall.	11-16-83	40.0
			12-13-83	22.8
			01-10-84	50.6
			02-14-84	29.2
			03-13-84	48.1
			04-16-84	84.4
			05-15-84	181
			06-12-84	56.4
			07-16-84	34.9
			08-14-84	1.65
			09-12-84	2.89
			10-15-84	19.5
26	Cottonwood Creek above Slippery Creek	Lat 45°59'17", long 110°25'43", in SW¼SE¼SW¼ sec. 24, T. 3 N., R. 10 E., Park County, 0.5 mi upstream from Slippery Creek, 1.3 mi upstream from U.S. Forest Service boundary, and 11 mi northeast of Clyde Park.	10-12-83	19.5
			11-16-83	13.9
			12-13-83	[2] 9.20
			01-10-84	[2] 9.06
			02-14-84	[2] 8.32
			03-13-84	[2] 8.32
			04-16-84	[2]15.7
			05-14-84	72.0
			06-12-84	97.0
			07-16-84	63.7
			08-14-84	20.6
			09-12-84	12.7
27	Cottonwood Creek below Little Cottonwood Creek	Lat 45°57'01", long 110°27'10", in NE¼NW¼SW¼ sec. 2, T. 2 N., R. 10 E., Park County, at bridge on county road, 8 1/2 mi northeast of Clyde Park.	10-12-83	17.3
			11-16-83	18.1
			12-13-83	15.9
			01-10-84	12.2
			02-14-84	10.7
			03-13-84	9.62
			04-16-84	20.1
			05-14-84	125
			06-12-84	71.6
			07-16-84	42.2
			08-14-84	23.5
			09-12-84	23.5

Table 11.--*Site descriptions and streamflow measurements*--Continued

Site No.	Stream name	Location	Date	Discharge (ft^3/s)
28	North Fork Brackett Creek	Lat 45°51'41", long 110°53'07", in NW¼SE¼SW¼ sec. 5, T. 1 N., R. 7 E., Park County, 0.1 mi upstream from the confluence with the Middle Fork, and 14 mi west of Clyde Park.	10-13-83	3.82
			11-18-83	5.03
			12-14-83	3.22
			01-11-84	4.47
			02-15-84	2.76
			03-13-84	2.42
			04-16-84	15.9
			05-15-84	72.3
			06-13-84	33.8
			07-17-84	9.98
			08-15-84	4.57
			09-13-84	3.00
29	Middle Fork Brackett Creek	Lat 45°51'36", long 110°53'13", in SE¼SW¼SW¼ sec. 5, T. 1 N., R. 7 E., Park County, at culvert on campground road, 0.1 mi upstream from confluence with North Fork, 14 mi West of Clyde Park.	10-13-83	2.31
			11-18-83	3.55
			12-14-83	2.14
			01-11-84	2.89
			02-15-84	1.12
			03-13-84	1.57
			04-16-84	16.7
			05-15-84	51.7
			06-13-84	32.0
			07-17-84	4.18
			08-15-84	1.88
			09-13-84	1.37
30	South Fork Brackett Creek	Lat 45°51'28", long 110°52'51", in NW¼NW¼NE¼ sec. 8, T. 1 N., R. 7 E., Park County, at bridge on county road just upstream from the confluence with Brackett Creek, and 13 1/2 mi west of Clyde Park.	10-13-83	1.72
			11-18-83	2.34
			12-14-83	1.83
			01-10-84	2.59
			02-14-84	1.12
			03-13-84	1.00
			04-16-84	14.8
			05-15-84	34.0
			06-12-84	23.9
			07-17-84	5.14
			08-15-84	2.21
			09-12-84	1.68

Table 11.--*Site descriptions and streamflow measurements*--Continued

Site No.	Stream name	Location	Date	Discharge (ft^3/s)
31	Brackett Creek above Weasel Creek	Lat 45°51'42", long 110°50'17", in NW¼SW¼SE¼ sec. 3, T. 1 N., R. 7 E., Park County, at U.S. Forest Service bridge upstream from Weasel Creek, 11 1/2 mi west of Clyde Park.	10-13-83	7.53
			11-18-83	10.6
			12-13-83	7.19
			01-11-84	9.95
			02-14-84	5.00
			03-13-84	4.99
			04-16-84	47.4
			05-15-84	158
			06-13-84	89.7
			07-17-84	19.6
			08-15-84	8.21
			09-12-84	6.56
32	Brackett Creek above Fox Creek	Lat 45°52'24", long 110°43'27", in NW¼NW¼NW¼ sec. 3, T. 1 N., R. 8 E., Park County, at bridge to Ward Ranch, just upstream from Fox Creek, 6 mi west of Clyde Park.	10-12-83	12.8
			11-18-83	12.2
			12-13-83	12.5
			01-10-84	25.9
			02-14-84	10.9
			03-13-84	9.51
			04-16-84	44.1
			05-14-84	223
			06-12-84	127
			07-17-84	23.4
			08-14-84	13.3
			09-12-84	11.8
33	Brackett Creek near Clyde Park (discontinued gaged site 06194000)	Lat 45°52'00", long 110°40'10", in SW¼SE¼NE¼, sec. 1, T. 1 N., R. 8 E., Park County, near right bank on upstream side of private bridge, 3 1/2 mi southwest of Clyde Park, and 4 mi upstream from mouth.	10-12-83	15.1
			11-18-83	17.5
			12-13-83	16.0
			01-10-84	26.9
			02-14-84	14.0
			03-13-84	11.0
			04-16-84	51.5
			05-14-84	216
			06-12-84	138
			07-16-84	21.8
			08-14-84	13.7
			09-12-84	12.3

Table 11.--*Site descriptions and streamflow measurements*--Continued

Site No.	Stream name	Location	Date	Discharge (ft^3/s)
34	Rock Creek below Little Rock Creek	Lat 45°54'12", long 110°25'57", in NW¼SW¼SW¼ sec. 24, T. 2 N., R. 10 E., Park County at bridge on county road 0.75 mi downstream from Little Rock Creek, and 8 1/2 mi east of Clyde Park.	10-12-83	20.0
			11-16-83	18.0
			12-13-83	13.8
			01-11-84	10.0
			02-14-84	9.20
			03-13-84	8.55
			04-16-84	22.3
			05-14-84	63.2
			06-12-84	69.0
			07-16-84	68.6
			08-14-84	48.6
			09-12-84	31.9
35	Mission Creek above Little Mission Creek	Lat 45°37'22", long 110°22'33", in NE¼NE¼NW¼, sec. 33, T. 2 S., R. 11 E., Park County, at culvert on county road upstream from Little Mission Creek, 8 1/2 mi southeast of Livingston.	10-14-83	9.19
			11-17-83	11.9
			12-15-83	6.59
			01-12-84	8.14
			02-16-84	5.94
			03-14-84	5.50
			04-18-84	18.8
			05-16-84	162
			06-13-84	58.3
			07-17-84	34.2
			08-15-84	12.3
			09-13-84	11.6
36	Little Mission Creek	Lat 45°37'16", long 110°22'30", in SE¼NE¼NW¼ sec. 33, T. 2 S., R. 11 E., Park County, at bridge on county road, 8 1/2 mi southeast of Livingston.	10-14-83	3.01
			11-17-83	3.21
			12-15-83	2.17
			01-12-84	4.39
			02-16-84	2.50
			03-14-84	3.98
			04-18-84	16.0
			05-16-84	95.2
			06-13-84	19.4
			07-17-84	8.05
			08-15-84	3.89
			09-13-84	3.33

Table 11.--*Site descriptions and streamflow measurements*--Continued

Site No.	Stream name	Location	Date	Discharge (ft^3/s)
37	Mission Creek below Little Mission Creek near Livingston	Lat 45°37'24", long 110°22'34", in NE¼NE¼NW¼ sec. 33, T. 2 S., R. 11 E., Park County, downstream from Little Mission Creek, 8 1/2 mi southeast of Livingston.	10-14-83	[4] 12.2
			11-17-83	[4] 15.1
			12-15-83	[4] 8.76
			01-12-84	[4] 12.5
			02-14-84	[4] 8.44
			03-14-84	[4] 9.48
			04-18-84	[4] 34.8
			05-16-84	[4] 257
			06-13-84	[4] 77.7
			07-17-84	[4] 42.2
			08-15-84	[4] 16.2
			09-13-84	[4] 14.9
38	Upper Deer Creek	Lat 45°42'08", long 109°55'59", in SW¼NE¼SE¼ sec. 36, T. 1 S., R. 14 E., Sweet Grass County, at private crossing on creek, 0.2 mi downstream from the west fork, and 8 1/2 mi southwest of Greycliff.	10-13-83	7.52
			11-17-83	7.82
			12-14-83	[2] 4.98
			01-11-84	[2]11.4
			02-15-84	5.59
			03-14-84	7.09
			04-17-84	36.7
			05-15-84	344
			06-13-84	61.2
			07-17-84	10.3
			08-15-84	4.90
			09-13-84	4.29
39	Lower Deer Creek	Lat 45°41'59", long 109°52'49", in SW¼SW¼SE¼ sec. 4, T. 2 S., R. 15 E., Sweet Grass County, at private bridge crossing just upstream from Log Cabin Creek, 7 mi southwest of Greycliff.	10-13-83	7.29
			11-17-83	7.12
			12-14-83	5.81
			01-11-84	12.0
			02-15-84	5.88
			03-14-84	7.80
			04-17-84	19.9
			05-15-84	238
			06-13-84	70.7
			07-17-84	20.3
			08-15-84	9.10
			09-13-84	7.54

Table 11.--*Site descriptions and streamflow measurements*--Continued

Site No.	Stream name	Location	Date	Discharge (ft^3/s)
40	Bridger Creek	Lat 45°39'08", long 109°46'22", in NE¼NW¼NE¼ sec. 20, T. 2 S., R. 16 E., Sweet Grass County, at county road below the Forks, 8 mi south of Greycliff.	10-13-83	2.88
			11-17-83	2.52
			12-14-83	2.20
			01-11-84	4.71
			02-15-84	5.65
			03-14-84	4.19
			04-17-84	10.9
			05-15-84	122
			06-13-84	18.6
			07-17-84	4.69
			08-15-84	2.70
			09-13-84	2.08

[1] Discharge determined from rating table.
[2] Estimated.
[3] Partly estimated.
[4] Discharge obtained by adding discharge at sites 35 and 36.