AN ASSESSMENT OF LOW FLOWS IN STREAMS IN NORTHEASTERN WYOMING

By G.W. Armentrout, Jr. and James F. Wilson, Jr.

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CONVERSION FACTORS AND VERTICAL DATUM

The following factors may be used to convert the inch-pound units used in this report to metric units:

Multiply	By	To obtain
cubic foot per second	0.02832	cubic meter per second
foot	0.3048	meter
inch	2.540	centimeter
mile	1.609	kilometer
square mile	2.590	square kilometer

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level of 1929."

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ABSTRACT

This report is a brief summary and assessment of low flows in the following basins in northeastern Wyoming: Little Bighorn, Tongue, Powder, Little Missouri, Belle Fourche, Cheyenne, and Niobrara Rivers, and about 200 river miles of the North Platte River and its tributaries. Only existing data from streamflow stations and miscellaneous-observation sites during the period, 1930-80, were used. Data for a few stations in Montana and South Dakota were used in the analysis. Data were available for 56 perennial streams, 38 intermittent streams, and 34 ephemeral streams.

The distribution of minimum observed flows of record at all stations and sites and the 7-day 10-year low flows at mountain stations and main-stem plains stations are shown on a map. Seven-day low flows were determined by fitting the log Pearson Type III distribution to the data; results are tabulated only for stations with at least 10 years of record that included at least one major drought. Stations installed since about 1960 are considered not to have included a major drought. Most streams that originate in the foothills and plains have no flow during part of every year, and are typical of much of the study area. For stations on these streams, the frequency of the annual maximum number of consecutive days of no flow was determined, as an indicator of the likelihood of extended periods of no flow or drought.

For estimates at ungaged sites on streams in the Bighorn Mountains only, a simple regression of 7-day 10-year low flow on drainage area has a standard error of 64 percent, based on 19 stations with drainage areas of 2 to 200 square miles. The 7-day 10-year low flow in main-stem streams can be interpolated from graphs of 7-day 10-year low flow versus distance along the main channel.

Additional studies of low flow are needed. The data base, particularly synoptic baseflow information, needs considerable expansion. Also, the use of storage-analysis procedures should be considered as a means of assessing the availability of water in streams that otherwise are fully appropriated or that are ephemeral.

INTRODUCTION

As the development of coal and other energy minerals has increased in northeastern Wyoming there has been a corresponding increase in the demand for water. Ground water is the principal source for domestic, stock, municipal, and industrial use; surface water is the principal source for irrigation, the largest use of water. Streams in the mountains that border the study area (fig. 1) and a few large streams that flow across the area either are perennial or flow for extended periods during most years. Water in those streams generally is fully appropriated. Most plains streams in the central part of the area flow only in response to precipitation; these ephemeral streams are dry most of the time. Because the availability of surface water is so limited, planners and others concerned with water use need additional information for assessing long-term supplies.

One means of assessing the potential supplies of limited surface-water resources is a low-flow analysis--a statistical evaluation of minimum streamflows observed at gaging stations and miscellaneous-observation sites. Such an analysis provides information about existing flows that are an integral part of the hydrologic system, support the present ecologic system, and support and are affected by the humans who use the water. The study of minimum flows in streams of northeastern Wyoming was done during 1982. This report describes the results of the study, which was part of the U.S. Geological Survey's Coal-Hydrology Program.

Purpose and Scope

The purpose of this report is to summarize and assess selected low-flow characteristics of streams in northeastern Wyoming (fig. 1 and plate 1), as a basis for more detailed low-flow studies in the future. Low-flow characteristics are indicators of the amount of water available under present conditions--that is, without considering the use of artificial storage. The study was not intended to be an in-depth treatment of low flows in the area. Possible future studies are discussed at the end of this report.

Only existing data from Geological Survey streamflow stations and miscellaneous streamflow-observation sites through water year 1980 were used in the analysis. A few stations in Montana and South Dakota were used, to extend the analysis across the State lines. The period of record was used as a criterion to select the stations used in the analysis. In general, standard low-flow frequency-analysis techniques were used to analyze records for stations on mountain streams and main stems of plains streams fed by mountain tributaries. Standard techniques, however, cannot be applied to records of flows in ephemeral streams that are typical of much of the study area. For those streams, which are dry most of the time, the number of consecutive days of no flow was analyzed.

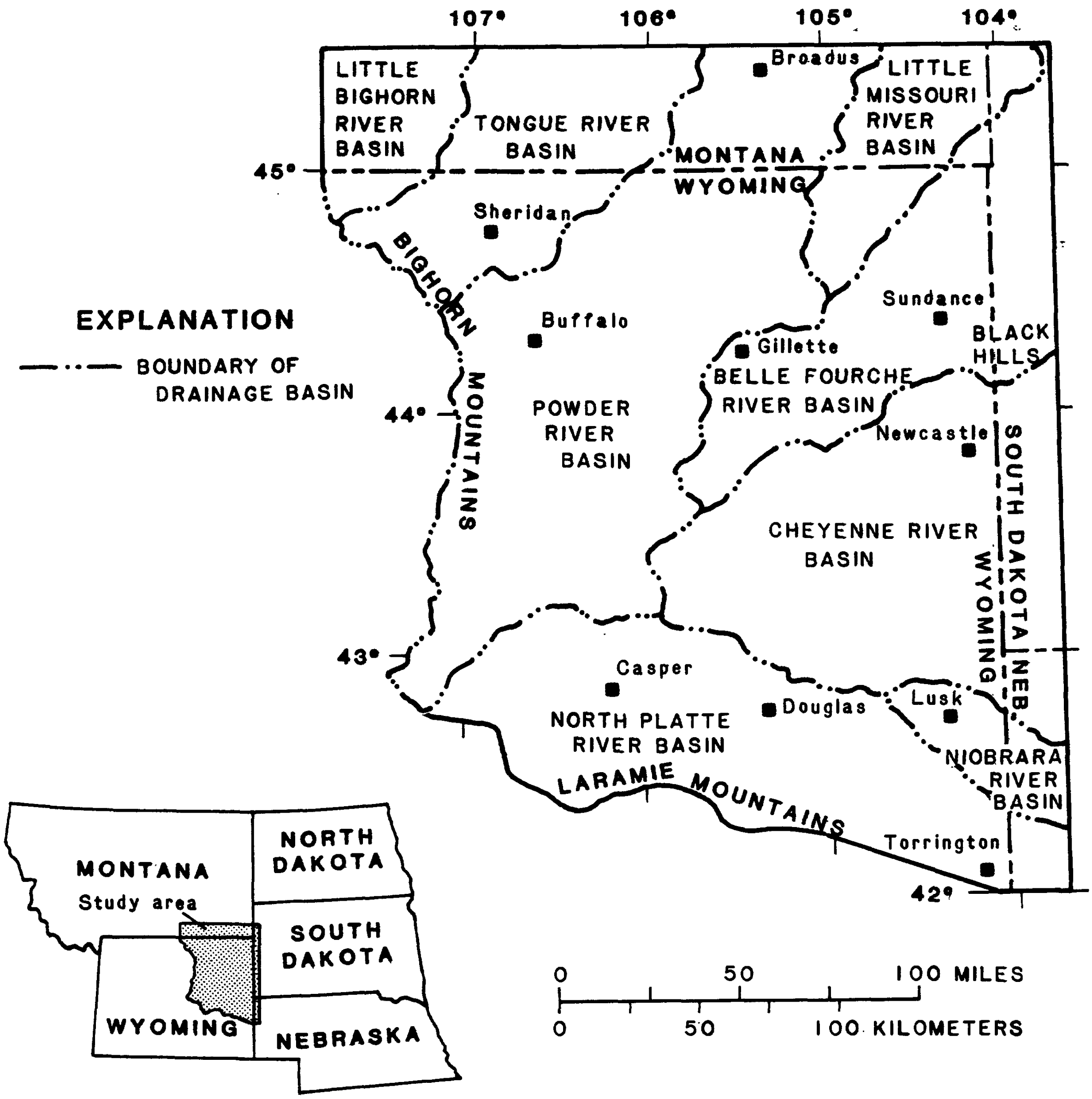

Figure 1.--Location of the study area and principal river basins. (Eight streamflow stations in adjacent States were used in the study.)

Use of Low-Flow Information

Low-flow information is useful for: (1) Planning and design of water supplies, (2) analysis of environmental and economic consequences of human activities, (3) modeling water-quality processes in streams, and (4) determination of optimum and maintenance flows for instream uses (Riggs, 1980, p. 728). According to Chiang and Johnson (1976, p. 227), "If the low flow capacity of a stream is not adequate to satisfy all the demands for its water, including the environmental and recreational needs for in-stream uses, the matter of priorities becomes a paramount and difficult issue." Riggs (1980, p. 717) describes the degradation in water quality as streamflow decreases in a given reach, and states: "The natural or existing low-flow characteristics of a stream, or both, should be considered in establishing a specified flow to be maintained for one or more purposes."

Low-flow information can be used to assess the possibility of drought, or insufficient flow for the intended uses of the water. Sen (1980, p. 99) stressed the importance of considering the possibility of drought conditions during the projected life of a water-resources system. For northeastern Wyoming, the assessment of existing low flows and the possibility of drought can be useful in determining: (1) The need for supplies for supplemental watering of stock, (2) the frequency of flushing of ephemeral streams for dilution and disposal of wastes, and (3) the consequences of not building structures, such as stream-bypass canals and detention ponds, for new or expanded mines, mills, and energy plants. In this report the potential for drought is indicated by the frequency of periods of no flow in ephemeral plains streams.

Previous Investigations

Basic references on the subject of low-flow investigations include: An evaluation of various definitions of baseflow recession (Singh, 1969), a discussion of the probability distribution of low flow (Matalas, 1963), a description of standard methods of low-flow analysis used by the Geological Survey (Riggs, 1972), and a summary of approaches most used by government agencies, consulting firms, universities, and utility companies (Riggs, 1980).

Although there is little difficulty in computing low-flow characteristics for individual streamflow stations, estimating low flows at ungaged sites is quite another matter. The technique most often used (called regionalization) is some variation of mathematical regression. The results commonly are less than satisfactory, mainly because of the difficulty in determining the independent variables that affect low flows and in defining those variables quantitatively. Consequently, regionalization of low flows in various parts of the United States and in other countries is characterized by a wide variety of approaches. Selected references on the subject include: Furness (1960), Furness and Busby (1967), Singh and Stall (1974), Skelton (1974), Chang and Boyer (1977), Huntzinger (1978), Institute of Hydrology (1979), Lara (1979), and Bingham (1982). In general, the farther east the study area, the more accurate were the results. Some interesting studies that did not include regionalization were those by Speer and others (1964, 1965) and by Chiang and Johnson (1976).

The only previous comprehensive analysis of low-flow information for Wyoming streams was done by Wahl (1970). Wahl's study was a part of a nationwide assessment of streamflow data on a state-by-state basis. The study included regressions of low-flow characteristics on basin characteristics. Even for mountain streams, the accuracy of the regression equations for low flows failed by a substantial margin to meet arbitrary accuracy goals based on streamflow variability. This finding was common in similar reports for other States. Wahl concluded that additional data were needed and that alternative methods for regionalizing low-flow data also were needed.

Since 1970 the streamflow data base for northeastern Wyoming has been increased substantially, particularly for small, ephemeral streams. In response to energy-resource development many new stations were established on small streams. Also, during 1977-78 a set of base-flow measurements was made at more than 100 miscellaneous sites in northeastern Wyoming (Druse and others, 1981).

Studies of the frequency, duration, and other characteristics of droughts may be useful to those considering the results of low-flow analyses. Selected references on that subject are: Huff and Changenon (1964), Whipple (1966), and Sen (1980). A detailed report of the drought of 1976-77 in the central and western United States was prepared by Matthai (1979).

DESCRIPTION OF THE AREA

The study area, which includes all of northeastern Wyoming (fig. 1 and plate 1), extends from the Laramie Mountains northward into Montana, and from the Bighorn Mountains eastward into South Dakota. Low-flow data for selected stations near the Wyoming border in Montana and South Dakota were used in the study. The area in Wyoming includes all of the following basins: Little Bighorn, Tongue, Powder, Little Missouri, Belle Fourche, Cheyenne, and Niobrara Rivers, and about 200 river miles of the North Platte River and its tributaries (about 7 percent of its total drainage area) between Alcova and Guernsey Reservoirs.

For purposes of hydrologic analysis, the study area was subdivided into two geographic types--mountains and plains. Mountain areas were defined as those higher than about 7,500 feet above sea level in the Laramie Mountains and southern Bighorn Mountains; higher than 5,000 feet in the northern Bighorn Mountains; and higher than 5,000 to 5,500 feet in the Black Hills. The remainder of the area, including the lower foothills adjacent to the mountains, was classified as plains.

Average annual precipitation is 15 to 25 inches in the Bighorn Mountains, 15 to 24 inches in the Black Hills, and 12 to 14 inches in the Laramie Mountains. Most of the study area consists of plains, where the average annual precipitation is 12 to 14 inches. In some parts of the area as little as 7 inches of annual precipitation has been recorded.

There are many reports that describe the hydrology of the area. Hodson and others (1973) describe the water resources (especially ground water) of northeastern Wyoming. Lowry, Wilson, and others (1986) describe the hydrology of the Powder River basin in relation to development of the area's large deposits of coal; the report includes a bibliography of more than 350 references. Methods for estimating average annual discharge and flood-flow characteristics at ungaged sites are given in a report by Lowham (1976); a report on revised methods is planned for publication in 1987. Evapotranspiration, an important factor affecting low flows, was estimated at several sites in the Powder River basin by Lenfest (1986).

LOW-FLOW CHARACTERISTICS AT STATIONS

Data Available

Streamflow records at Geological Survey gaging stations and observations at miscellaneous sites were used in the analysis. There are two types of gaging stations: continuous-record stations, at which the discharge is monitored with a recorder, and partial-record stations, at which only the annual maximum discharge generally is determined. A few high-flow partial-record stations (no longer in operation) were equipped with hydrograph recorders that were operated during May-September each year. Annual minimum flows were determined at recording stations, and when observed, no flow was noted at partial-record and nonrecording stations and miscellaneous sites.

Prior to about 1972 most continuous-record stations in the area were located on streams flowing from the mountains and on the few large rivers that are fed by mountain streams and flow across the plains. Between 1972 and 1980 many new stations were installed in the central part of the area, particularly on small plains streams, as part of the Geological Survey and U.S. Bureau of Land Management coal-hydrology programs. Although the new stations have added substantially to the data base available for low-flow analysis, their short length of record limits the usefulness of the data for detailed analysis.

The stations and sites used in the analysis are listed in downstream order in table 1; the locations are shown in plate 1 (in pocket). Although the permanent 8-digit station numbers used by the Geological Survey are listed in table 1, a sequential identification number (1-128) is used throughout this report to identify stations and sites.

Data were available for three types of streams: (1) Perennial streams, which flow continuously; (2) intermittent streams, which flow only at certain times of the year when the stream receives water from springs or some surface source such as melting snow; and (3) ephemeral streams, which flow only in direct response to precipitation, and whose channel is at all times above the water table. The hydrographs of daily discharge for an ephemeral stream and a perennial stream (fig. 2) illustrate why the analysis of low flows differs for these two types of streams. The distribution of stations and sites by stream type is summarized as follows:

Station/site type	Number of stations/sites			
	Stream type			
	Perennial	Intermittent	Ephemeral	Total
Continuous record	54	30	12	96
Partial record	2	7	17	26
Miscellaneous site	—	—	6	6
Totals	56	37	35	128

Data for low-flow studies should include a period of time that includes at least one drought or very dry period. Low-flow characteristics from frequency curves are most reliable when the record is long and homogeneous; a record of 15-20 years may not contain a representative sample of low flows (Riggs, 1980, p. 724). Also, long-term records for streams in the Rocky Mountain area indicate that streamflow prior to 1930 was significantly larger than that since 1930 (the reason for the change is not known). Therefore, except for observations of no flow and (or) minimum flow of record, records for many of the stations and sites listed in table 1 were not analyzed further.

An attempt was made to correlate short-term records for a few stations on the north flank of the Laramie Mountains with long-term records at nearby stations. The correlation failed, probably because the short-term records began during the early 1970's; the subsequent period generally was one of high flows, while the period of record at long-term stations includes at least one major drought. As explained by Riggs (1972, p. 6-9), low flows may be from a streamflow population different from that of the rest of the record at a station.

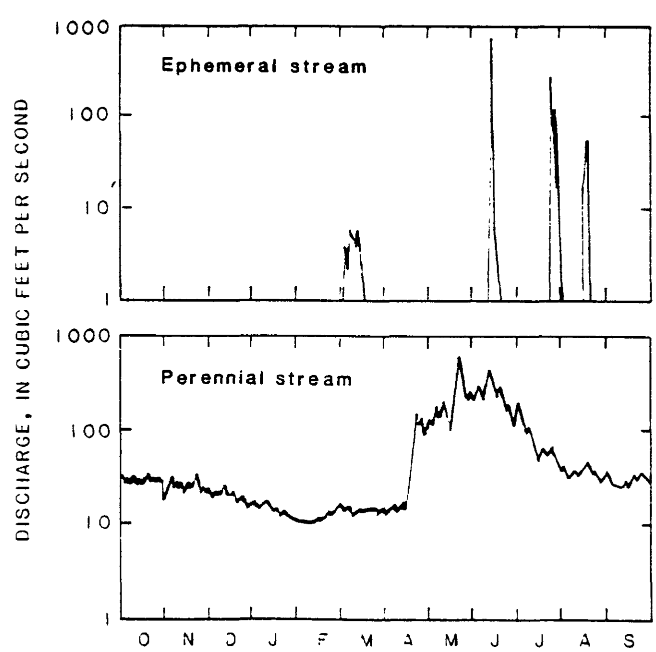

Figure 2.--Typical hydrographs of daily discharge for an ephemeral stream and a perennial stream in northeastern Wyoming (1979 water year). From Lowry, Wilson, and others (1986, p. 43).

Table 1.--Streamflow stations and sites included in assessment of low flows

[ID no: Station or site identification number used in this report;
Record type: Con, continuous; PR, partial record; Misc, miscellaneous;
Stream type: Per, perennial; Int, intermittent; Eph, ephemeral]

ID no.	Permanent station number	Station name	Post-1929 period of record	Record type	Stream type	Drainage area (square miles)
		Little Bighorn River Basin				
1	06289000	Little Bighorn River at State line near Wyola, Mont.	1940-80	Con	Per	193
		Tongue River Basin				
2	06297000	South Tongue River near Dayton	1946-71	Con	Per	85.0
3	06298000	Tongue River near Dayton	1941-80	Con	Per	204
4	06298500	Little Tongue River near Dayton	1952,1953, 1956-74	Con	Per	25.1
5	06299500	Wolf Creek at Wolf	1946-71	Con	Per	37.8
6	06300500	East Fork Big Goose Creek near Big Horn	1954-73	Con	Per	20.1
7	06301500	West Fork Big Goose Creek near Big Horn	1954-71	Con	Per	24.4
8	06302000	Big Goose Creek near Sheridan	1931-71	Con	Per	120
9	06303500	Little Goose Creek in canyon near Big Horn	1942-71	Con	Per	51.6
10	06305500	Goose Creek below Sheridan	1942-80	Con	Per	392
11	06306100	Squirrel Creek near Decker, Mont.	1976-80	Con	Int	33.6
12	06306300	Tongue River at State line near Decker, Mont.	1960-80	Con	Per	1,477
1/	06306500	Tongue River near Decker, Mont.	1930-38	Con	Per	1,585
		Powder River Basin				
13	06309200	Middle Fork Powder River near Barnum	1962-80	Con	Per	45.2
14	06309280	Buffalo Creek below North Fork Buffalo Creek near Arminto	1975-79	Con	Eph	18.6
15	06309500	Middle Fork Powder River above Kaycee	1950-70	Con	Per	450
16	06310000	Red Fork Powder River near Barnum	1930,1931, 1951-53	Con	Per	142
17	06311000	North Fork Powder River near Hazelton	1947-80	Con	Per	24.5
18	06311400	North Fork Powder River below Pass Creek near Mayoworth	1974-80	Con	Per	100
1/	06311500	North Fork Powder River near Mayoworth	1941-73	Con	Per	106

Table 1.--Streamflow stations and sites included in assessment of low flows--Continued

ID no.	Permanent station number	Station name	Post-1929 period of record	Record type	Stream type	Drainage area (square miles)
		Powder River Basin--Continued				
19	06312000	North Fork Powder River near Kaycee	1931	Con	Per	244
20	06312500	Powder River near Kaycee	1939,1941-71, 1979,1980	Con	Per	980
21	06312700	South Fork Powder River near Powder River	1961-80	PR	Int	262
22	06312795	Sanchez Creek above reservoir near Arminto	1970-80	PR	Eph	5.53
23	06312910	Dead Horse Creek tributary near Midwest	1965-72	PR	Eph	1.53
24	06313000	South Fork Powder River near Kaycee	1939,1951-69, 1979,1980	Con	Int	1,150
25	06313020	Bobcat Creek near Edgerton	1965-80	PR	Int	8.29
26	06313050	East Teapot Creek near Edgerton	1965-73	PR	Eph	5.44
27	--	Salt Creek at Midwest	(pre-1930)	Misc	Eph	--
28	06313100	Coal Draw near Midwest	1961-80	PR	Int	11.4
29	06313180	Dugout Creek tributary near Midwest	1974-80	Con	Eph	.8
30	06313400	Salt Creek near Sussex	1977-80	Con	Per	765
31	06313450	North Spring Draw near Sussex	1980	PR	Eph	5.21
32	06313500	Powder River at Sussex	1939,1951-57, 1978-80	Con	Per	3,090
33	06313700	Dead Horse Creek near Buffalo	1958-71,1971-80	Con	Int	151
34	06314000	North Fork Crazy Woman Creek near Buffalo	1943-49, 1974-80	Con	Per	44.9
35	06314500	North Fork Crazy Woman Creek below Spring Draw near Buffalo	1949-71	Con	Per	51.7
36	06315000	North Fork Crazy Woman Creek near Greub	1951-68	Con	Per	174
37	06315500	Middle Fork Crazy Woman Creek near Greub	1943-71	Con	Per	82.7
38	06316000	Crazy Woman Creek near Buffalo	1931-32	Con	Per	464
39	06316400	Crazy Woman Creek at upper station near Arvada	1964-70,1977-80	Con	Per	945
1/	06316500	Crazy Woman Creek near Arvada	1940-43,1951-64	Con	Per	956
40	06316480	Headgate Draw at upper station near Buffalo	1965-73	PR	Eph	3.32
41	06317000	Powder River at Arvada	1931-33,1935-80	Con	Per	6,050
42	06317050	Rucker Draw near Spotted Horse	1961-80	PR	Eph	3.98
43	06317500	North Fork Clear Creek near Buffalo	1950-68	Con	Per	29.0
44	06318500	Clear Creek near Buffalo	1939-80	Con	Per	120
45	06319500	South Fork Rock Creek near Buffalo	1942-48,1951-53	Con	Per	43.8

Table 1.--Streamflow stations and sites included in assessment of low flows--Continued

ID no.	Permanent station number	Station name	Post-1929 period of record	Record type	Stream type	Drainage area (square miles)
		Powder River Basin--Continued				
46	06320000	Rock Creek near Buffalo	1944,1946-71	Con	Per	60.0
47	06321500	North Piney Creek near Story	1952-80	Con	Per	36.8
48	06323000	Piney Creek at Kearney	1941-80	Con	Per	118
49	06323500	Piney Creek at Ucross	1951-80	Con	Per	267
50	06324000	Clear Creek near Arvada	1940-80	Con	Per	1,110
51	06324500	Powder River at Moorhead, Mont.	1930-72,1975-80	Con	Per	8,088
52	06324890	Little Powder River below Corral Creek near Weston	1978-80	Con	Int	204
53	06324925	Little Powder River near Weston	1978-80	Con	Int	540
54	06324970	Little Powder River above Dry Creek near Weston	1973-80	Con	Int	1,235
55	06324995	Badger Creek at Biddle, Mont.	1972-80	PR	Eph	6.06
56	06325000	Little Powder River at Biddle, Mont.	1939-42	Con	Int	1,540
57	06325500	Little Powder River near Broadus, Mont.	1948-53,1958-61, 1963-72	Con	Int	1,974
		Little Missouri River Basin				
58	06334000	Little Missouri River near Alzada, Mont.	1930-32,1936-69	Con	Int	904
		Cheyenne River Basin				
59	06363700	Porcupine Creek near Turnercrest	1959-76	PR	Eph	31.5
60	06365300	Dry Fork Cheyenne River near Bill	1978-80	Con	Int	128
61	06365900	Cheyenne River near Dull Center	1977-80	Con	Int	1,527
62	06375600	Little Thunder Creek near Hampshire	1978-80	Con	Eph	234
63	06376300	Black Thunder Creek near Hampshire	1973-80	Con	Eph	535
64	06378300	Lodgepole Creek near Hampshire	1978-80	Con	Eph	354
65	06379600	Box Creek near Bill	1956-58,1961-80	PR	Eph	112
66	06382200	Pritchard Draw near Lance Creek	1964-80	PR	Eph	5.1
67	06386000	Lance Creek near Riverview	1949-54,1957-80	Con	Eph	2,070
68	06386500	Cheyenne River near Riverview	1949-73	Con	Eph	5,270
69	06387500	Turner Creek near Osage	1959-80	PR	Eph	47.8
70	06388800	Blacktail Creek tributary near Newcastle	1960-80	PR	Eph	.25
71	06392900	Beaver Creek at Mallo Camp near Four Corners	1975-80	Con	Per	10.3
72	06392950	Stockade Beaver Creek near Newcastle	1975-80	Con	Per	107
73	06394000	Beaver Creek near Newcastle	1945-80	Con	Per	1,320
74	06395000	Cheyenne River at Edgemont, S.D.	1930-32,1947-80	Con	Int	7,143

Table 1.--Streamflow stations and sites included in assessment of low flows--Continued

ID no.	Permanent station number	Station name	Post-1929 period of record	Record type	Stream type	Drainage area (square miles)
		Belle Fourche River Basin				
75	06409000	Castle Creek above Deerfield Reservoir near Hill City, S.D.	1949-80	Con	Per	83
76	06425720	Belle Fourche River below Rattlesnake Creek near Piney	1976-80	Con	Int	495
77	06425780	Belle Fourche River above Dry Creek near Piney	1976-80	Con	Int	594
78	06425900	Caballo Creek at mouth near Piney	1978-80	Con	Eph	260
79	06425950	Raven Creek near Moorcroft	1978-80	Con	Eph	76
80	06426000	Belle Fourche River near Moorcroft	1930-32	Con	Int	1,380
81	06426400	Donkey Creek near Moorcroft	1978-80	Con	Int	246
82	06426500	Belle Fourche River below Moorcroft	1944-70,1976-80	Con	Int	1,670
83	--	Wind Creek near Moorcroft	1975	Misc	Eph	--
84	--	Mule Creek near Moorcroft	1975	Misc	Eph	--
85	06428000	Belle Fourche River at Hulett	1930-32,1939-51	Con	Per	2,800
86	06428100	Belle Fourche tributary no. 2 near Hulett	1962-80	PR	Per	10.2
87	06428500	Belle Fourche River at Wyoming-South Dakota State line	1947-80	Con	Int	3,280
88	06429300	Ogden Creek near Sundance	1962-80	PR	Int	8.42
89	06429500	Cold Springs Creek at Buckhorn	1975-80	Con	Per	19.0
90	06430500	Redwater Creek at Wyoming-South Dakota State line	1930-31,1955-80	Con	Per	471
		Niobrara River Basin				
91	06454000	Niobrara River at Wyoming-Nebraska State line	1956-80	Con	Per	450
		North Platte River Basin				
92	06641400	Bear Springs Creek near Alcova	1960-80	PR	Eph	9.48
93	06642000	North Platte River at Alcova	1961-80	Con	Per	10,812
94	06643000	Bates Creek near Alcova	1936-54,1957-61	Con	Int	393
95	06643300	Coal Creek near Goose Egg	1960-80	PR	Int	5.39
96	06644000	Poison Spider Creek near Goose Egg	1951-56	Con	Per	301
97	06644120	Middle Fork Casper Creek near Casper	1968-75	PR	Int	--
98	06644500	Casper Creek at Casper	1947-56	Con	Int	668
99	06644840	McKenzie Draw tributary near Casper	1965-80	PR	Per	2.02
100	06646300	Little Deer Creek below East Cart Creek near Glenrock	1975-76	Con	Int	7.48

Table 1.--Streamflow stations and sites included in assessment of low flows--Continued

ID no.	Permanent station number	Station name	Post-1929 period of record	Record type	Stream type	Drainage area (square miles)
		North Platte River Basin--Continued				
101	06646500	Deer Creek at Glenrock	1930-33,1936-60	Con	Int	212
1/	06646600	Deer Creek below Miller Wasteway near Glenrock	1962-80	Con	Int	213
102	06646700	East Fork Dry Creek tributary near Glenrock	1961-80	Con	Eph	2.60
103	06646780	Sand Creek near Glenrock	1978-80	Con	Eph	79.9
104	06646800	North Platte River near Glenrock	1961-80	Con	Per	13,538
105	06647500	Box Elder Creek at Boxelder	1947-51,1962-67, 1972-80	Con	Per	63.0
106	06647900	Little Box Elder Creek at Little Box Cave near Careyhurst	1975-80	Con	Eph	8.47
107	06648000	Box Elder Creek near Careyhurst	1930-32,1936-69	Con	Int	202
108	06648720	Frank Draw tributary near Orpha	1965-73	PR	Eph	.79
109	06648780	Sage Creek tributary near Orpha	1965-80	PR	Eph	1.38
110	06649000	La Prele Creek near Douglas	1930-71	Con	Per	135
111	06649500	La Prele Creek near Orpha	1933,1936-70	Con	Int	177
112	06649900	North Platte River tributary near Douglas	1961-80	PR	Eph	8.53
113	06650500	Wagonhound Creek near La Bonte	1940-69	Con	Int	112
114	06651500	La Bonte Creek near La Bonte	1930-32,1936-69	Con	Int	287
115	06651800	Sand Creek near Orin	1955,1961-80	PR	Int	27.8
116	06652000	North Platte River at Orin	1961-80	Con	Per	14,888
117	06652400	Watson Draw near Lost Springs	1960-80	PR	Eph	6.95
118	--	Elkhorn Creek near Glendo	1975	Misc	Eph	--
119	--	Cottonwood Creek near Glendo	1975	Misc	Eph	--
120	--	Whiskey Gulch near Glendo	1975	Misc	Eph	--
121	06652800	North Platte River below Glendo Reservoir	1958-80	Con	Per	15,548
122	06653000	Horseshoe Creek near Esterbrook	1947-51	Con	Int	45.5
123	06653300	Horseshoe Creek near Cassa	1962-68	Con	Int	180
124	06653500	Horseshoe Creek near Glendo	1936-70	Con	Int	211
125	06654550	Cottonwood Creek near Binford	1974	Con	Int	61.0
126	06655000	Cottonwood Creek at Wendover	1930-32,1936-42, 1947-55,1974	Con	Per	196
127	06656000	North Platte River below Guernsey Reservoir	1930-80	Con	Per	16,237
128	06671000	Rawhide Creek near Lingle	1930-71	Con	Per	522

1/ Low-flow records for these stations are considered equivalent and were combined as one station for frequency analysis.

Minimum Observed Flows

The minimum flow of record is an important low-flow characteristic (Riggs, 1980, p. 722). The minimum instantaneous discharge during the period of record at each streamflow station and observed no flow at each miscellaneous-observation site are shown on plate 1. The minimum flow is zero at almost all stations and sites except those in the mountain areas, a few in the foothills adjacent to the mountains, and those on main stems of principal streams on the plains. A notable exception is Salt Creek near Sussex (ID no. 30), where the minimum observed flow is 5 cubic feet per second, even though the station is far from the mountains. Salt Creek has perennial base flow because of water discharged to the stream from a nearby oil field. Prior to about the 1930's Salt Creek was an ephemeral plains stream (Bille, 1978). Because the record for Salt Creek is considered to be artificial, it was not used in the statistical analysis of low flows.

Flow-Duration Curves

Flow-duration curves are cumulative frequency curves that show the percent of time during which specified discharges were equalled or exceeded at a streamflow station during a given period of record. They provide "a convenient means for studying the flow characteristics of a stream and for comparing one basin with another" (Searcy, 1959, p. 1-2). Riggs (1972, p. 15) states: "The lower end of the duration curve is an expression of the low-flow characteristics of a stream, but it provides less information than a low-flow frequency curve, because the duration curve applies to the period of record rather than to a year."

Although flow-duration curves are not the principal analytical technique used in this study, they are useful to illustrate the substantial differences in flow types in streams of northeastern Wyoming. Examples showing the differences are shown in figure 3. The curve for the mountain stream (which is perennial) is flat on the lower end, indicating the existence of substantial storage of surface or ground water in the basin for sustaining the flow. In contrast, the lower ends of the two curves for the plains stream (which is perennial, but goes dry during some years) are very steep, indicating negligible storage and no flow about 4 percent of the time during the period, 1962-80. The curves for the plains stream also demonstrate the differences in low-flow characteristics when the period of record does not contain a representative sample of low flows. Low flows during the selected shorter period (1962-82), which does not include a drought, are considerably larger than low flows during the complete period of record (1931-33, 1935-80).

Curves for other streams in the area are similar to the examples in figure 3. Tables of flow-duration data for most stations on perennial or intermittent streams may be requested from the Cheyenne, Wyo. office of the Geological Survey. Generally, flow-duration data for ephemeral streams have little use because of the extended periods of no flow in such streams.

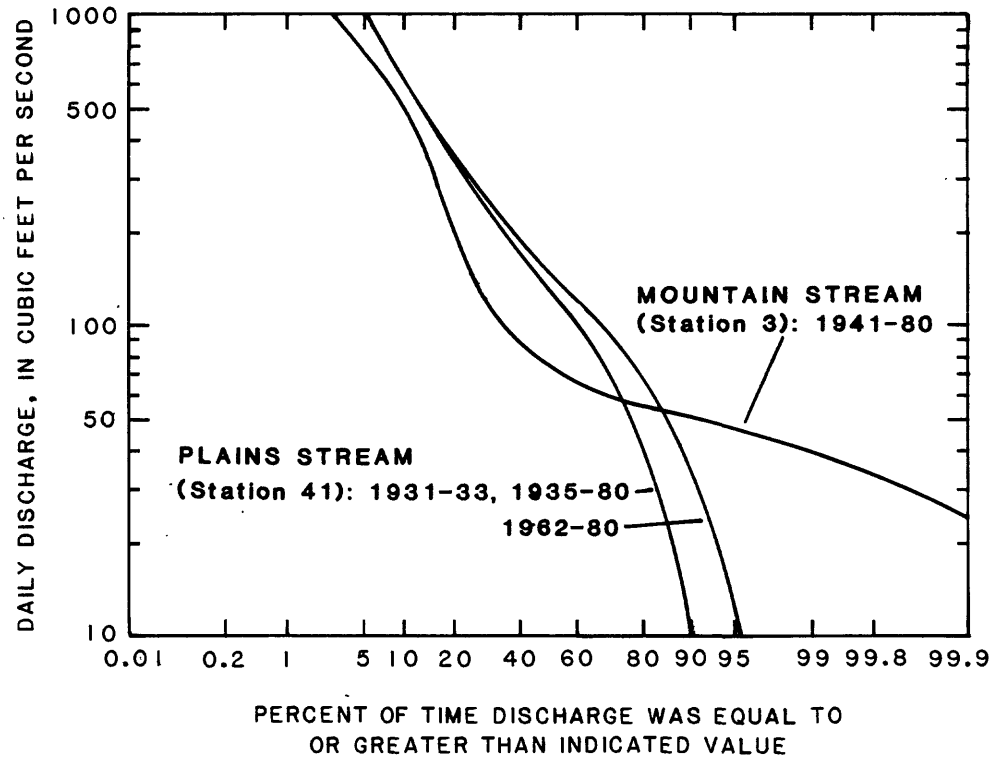

Figure 3.--Flow-duration curves for a mountain stream and a plains stream in northeastern Wyoming. (Station names are given in table 1.)

Frequency Analysis

The principal analytical procedure used in this study was the statistical analysis of the magnitude and frequency of low flows at streamflow stations. This "standard" procedure is described by Riggs (1972). Time and resources available for this study did not permit evaluation of other techniques described by Riggs (1972), such as analysis of base-flow recession curves. Although the results of frequency analysis have limitations, they are considered to be adequate as general indicators of low-flow characteristics of streams. Frequency analysis was applied to records for perennial and selected intermittent streams--mainly mountain and main-stem plains streams. Because ephemeral streams in the plains are dry most of the time, the frequency of periods of no flow was determined for ephemeral streams.

Seven-Day Low Flows

Minimum seven-day average flows for selected recurrence intervals were calculated from streamflow records at stations on perennial mountain streams and on some perennial and intermittent plains streams. The calculations were made for stations on 42 perennial streams and 13 intermittent streams, at which records had been collected for at least 10 years and included a drought. Most stations installed after 1960 were excluded because the records do not include the droughts of the 1930's or 1950's.

Calculations of 7-day low flow were made for some stations where the flow is affected by human activities. Some larger streams, such as Clear Creek, the upstream reaches of the Powder River, and the North Platte River, convey flows that originate in the mountains through or far onto the plains. Flow in some mountain streams is used and reused as it is conveyed to the plains; consequently, low flows in the plains reaches of these streams consist mainly of the seepage water and return flows. Generally, this water use has been consistent enough that the low-flow data can be analyzed statistically in the same manner as data for undisturbed streams.

Low-flow characteristics of regulated streams apply only so long as the pattern of regulation is unchanged (Riggs, 1980, p. 729). The North Platte River is completely regulated; its flows are determined by release rules that generally are implemented based on variation in inflow. Because the pattern of regulation has been more or less the same throughout the period of record used in the analysis, low-flow characteristics were determined for stations on the North Platte. Low-flow characteristics were not determined for stations downstream from small dams on streams in the mountains.

For selected stations the frequency of minimum average-annual discharge for 7 consecutive days was calculated, based on the climatic year (April-March). The results are listed in table 2. The 7-day low flow commonly is used as the principal low-flow indicator; frequency values for other periods, such as 1, 3, 14, 30, and 60 consecutive days, were calculated but are not included in this report. This information is available from the Geological Survey office in Cheyenne, Wyo.

Table 2.—Frequency distribution of minimum average 7-day flows at selected streamflow stations with sufficient records to include a drought, in northeastern Wyoming and adjacent parts of Montana and South Dakota.

[ID no.: Station identification number used in this report (see table 1); data in table: discharge, in cubic feet per second]

ID no.	Probability that annual minimum discharge will not exceed the indicated value (percent): 5	10	20	50	80	90	99
	Recurrence interval (years): 20	10	5	2	1.25	1.11	1.01
1	36	39	43	50	58	62	72
2	7.3	7.9	8.6	10	12	13	17
3	39	40	42	45	49	51	57
4	.93	1.0	1.2	1.5	1.8	2.0	2.5
5	2.7	3.0	3.3	3.9	4.4	4.6	5.0
7	1.1	1.3	1.5	2.1	2.8	3.2	4.5
8	2.9	3.7	4.7	7.1	10	12	16
9	5.2	5.5	5.9	6.9	8.0	8.6	10
10	8.4	11	16	27	43	53	79
12	6.4	13	27	70	130	160	210
15	16	18	20	25	30	34	43
17	.79	.92	1.1	1.5	1.9	2.2	2.7
18	9.2	10	12	15	17	18	20
20	.09	.15	.29	1.0	3.6	6.8	32
24	.23	.52	1.1	3.1	4.8	5.2	5.5
32	4.8	5.1	5.6	8.0	15	23	89
35	1.2	1.3	1.6	2.3	3.2	3.8	5.6
36	0	0	.45	1.5	3.0	3.8	5.6
37	2.4	2.8	3.5	5.0	6.8	7.8	10
39	0	0	0	0	5.5	14	47
41	0	0	0	0	23	35	90
43	1.4	1.7	2.2	3.2	4.2	4.7	5.5
44	.20	.36	.71	2.4	6.9	12	33
46	.96	1.3	1.9	3.1	4.4	4.9	5.7
47	3.6	3.9	4.3	5.1	6.0	6.5	7.9
48	4.4	5.0	6.0	8.4	12	14	22
49	1.4	2.5	4.6	11	19	23	30
50	.10	.14	.24	.52	.81	.90	.99
51	0	.38	2.6	16	45	63	99
57	0	0	.03	.55	1.8	2.5	3.9
58	0	0	0	0	.02	.11	.39
73	0	0	0	.21	1.0	1.8	6.2
75	3.2	3.8	4.6	6.2	7.6	8.3	9.6
82	0	0	0	0	0	.05	3.1
85	0	0	0	.85	2.6	4.3	12
87	0	0	0	3.5	12	14	16
90	4.2	5.0	6.3	9.9	16	22	43
91	.77	.95	1.2	1.7	2.3	2.6	3.3
93	180	227	294	448	624	718	928
94	0	0	0	.05	.14	.20	.47
98	0	0	0	.16	.30	.40	.76
101	0	0	0	.06	.38	.84	4.4

Table 2.--Frequency distribution of minimum average 7-day flows at selected streamflow stations with sufficient records to include a drought--Continued

ID	Probability that annual minimum discharge will not exceed the indicated value (percent)						
	5	10	20	50	80	90	99
	Recurrence interval (years)						
no.	20	10	5	2	1.25	1.11	1.01
104	355	405	466	574	658	690	736
105	0	0	0	.09	.28	.47	1.5
107	.08	.13	.20	.36	.59	.76	1.2
110	0	.01	.31	1.6	3.0	3.5	3.9
111	0	0	0	.09	.67	1.7	22
113	0	0	0	.08	.21	.31	.79
114	0	0	0	1.8	3.5	3.9	4.1
116	403	451	509	619	718	764	850
121	.93	1.1	1.3	2.0	3.3	4.4	9.9
124	.01	.24	.83	2.3	3.4	3.7	3.8
126	.70	.88	1.1	1.8	2.5	3.0	4.1
127	.78	1.8	4.8	29	155	358	2,310
128	.35	.90	2.0	5.7	12	16	25

The probabilities that the 7-day low flow during any given year will be less than specified values are given in table 2. For example, at station 10 there is a probability of 0.10 (10 percent chance) that the minimum average 7-day flow in any year will be less than 11 cubic feet per second, and a probability of 0.90 (90 percent chance) that the flow will be less than 53 cubic feet per second. Low flows with recurrence intervals greater than 20 years (probabilities less than 5 percent) are not listed in table 2.

Calculated values of frequency distributions typically are uneven, particularly if the period of record is relatively short. For each station the log Pearson Type III frequency distribution was fitted to the data using the mean, standard deviation, and skew coefficient calculated from the data. The data in table 2 are log Pearson Type III results. Typical log Pearson Type III frequency curves for 1, 3, 7, 14, 30, and 60-day low flows are shown in figure 4. Like the flow-duration curves (fig. 3), the curves in figure 4 illustrate the difference between streams that always flow and streams that occasionally go dry.

From the range of recurrence intervals for the 7-day low flow listed in table 2, the 7-day 10-year low flow ($7Q_{10}$) was selected for further regional analysis. The $7Q_{10}$ commonly is cited as a standard to which laws and regulations apply (Riggs, 1980, p. 721). It also is used to design water-supply projects (Chang and Boyer, 1977, p. 997) and to facilitate water management (Chiang and Johnson, 1976). The 7-day low flow will be less than the $7Q_{10}$ at intervals averaging 10 years in length; the probability is 0.10 (10 percent chance) that the 7-day low flow in any one year will be less than the $7Q_{10}$. The areal distribution of the $7Q_{10}$ in mountain and main-stem plains streams is shown on plate 1.

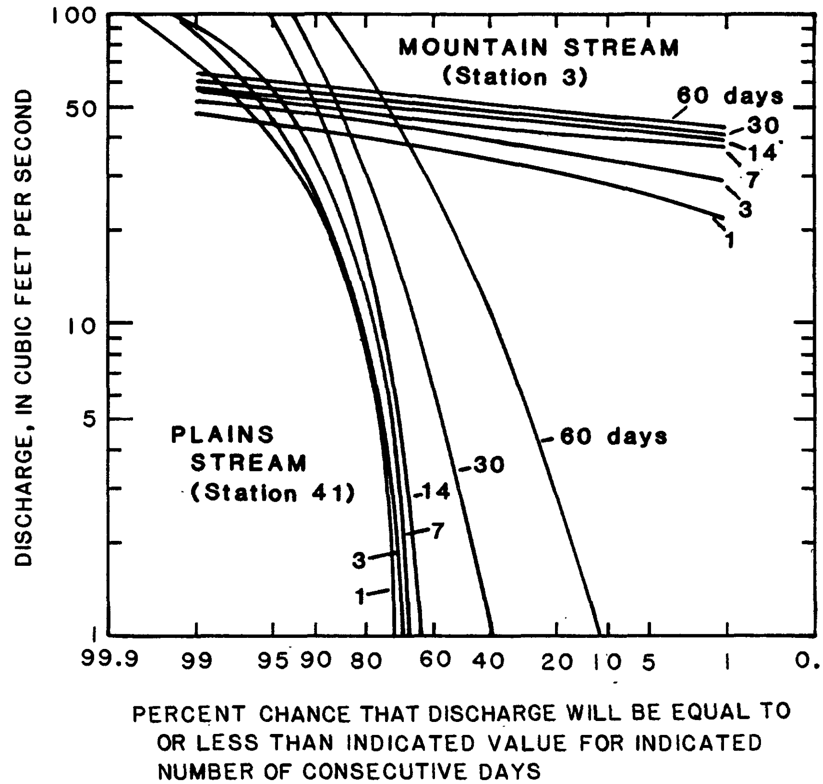

Figure 4.--Low-flow frequency curves for a mountain stream and a plains stream in northeastern Wyoming. (Station names are given in table 1.)

No-Flow Periods

Most streams that originate in the foothills and plains, including the semiarid north slope of the Laramie Mountains, have no flow during part of every year. In fact, many of these streams are ephemeral. Therefore, standard methods of frequency analysis could not be used. Instead, records for stations on plains and foothills streams were analyzed for the frequency of the annual maximum number of consecutive days of no flow. Frequency analysis of no-flow days provides an indication of the likelihood of the occurrence of extended periods of no flow or drought.

Due to the lack of information for plains streams, short-term records were used for the determination of the frequency of no-flow periods. The only plains-stream records available prior to about 1972 were on the large streams. Generally, the records do not include the droughts of the 1930's or 1950's, and were used only if they contained periods of no flow.

Frequency data for periods of no flow in plains and foothill streams are listed in table 3. Frequencies were not computed for 5 stations that had less than 10 years of record. Data for some of the stations used in the analysis of 7-day low flows also were used in the analysis of no-flow days. The table includes the maximum observed number of consecutive days of no flow during the period of record for all stations and the 7-day 10-year low flow for stations with 10 or more years of record, regardless of whether the period of record includes a major drought. Smoothed curves for five stations are shown in figure 5. All five stations have long periods of record that include a major drought.

LOW-FLOW CHARACTERISTICS AT UNGAGED SITES

Although the scope of this study was limited mainly to the general summary of low-flow characteristics described in the preceding sections, the possibility of applying regression techniques to the data was investigated. This was done because of the potential usefulness of equations for predicting low-flow characteristics at ungaged sites. Geologic factors, which have an important effect on low flows but are difficult to quantify as independent variables, were not investigated. Simple regression for $7Q_{10}$ at mountain stations and interpolative graphs for selected main-stem streams are reported here.

Most of the streams in the study area are ephemeral; however, equations for predicting periods of no-flow days or other charateristics at sites on plains streams could not be developed. Although the maximum number of no-flow days was found to be correlated with average annual discharge, average annual discharge itself would have to be estimated from regression equations, such as those of Lowham (1976). Therefore, no-flow periods for ephemeral plains streams can be estimated only by areal interpolation of the data shown on plate 1 or listed in table 3 .

Table 3.—Seven-day 10-year low flows and frequency of no flow for selected periods of consecutive days, at selected stations on plains and foothills streams in northeastern Wyoming and adjacent parts of Montana and South Dakota

[ID no.: Station identification number used in this report (see table 1); $7Q_{10}$: 7-day 10-year low flow, in cubic feet per second; max: maximum annual number of consecutive days of no flow recorded at station; <, less than; >, greater than]

ID no.	$7Q_{10}$	Probability of no flow in any one year (percent) — Period of consecutive days: 1	3	7	14	30	60	90	120	183	365	Max
16	(1)											12
20	0.15	3	<1									1
24	.52	14	9	9	9	5	5	<1				79
29	(1)											344
33	0					>99	88	88	63	25	<1	294
36	0	17	17	11	<1							11
39	0	61	61	57	48	43	30	4	<1			139
41	0	71	69	65	52	21	4	<1				91
44	.36	2	<1									3
50	.14	10	8	5	2	<1						26
51	.38	15	15	7	7	<1						26
54	(1)											21
57	0	37	32	16	16	5	<1					88
58	0	83	83	77	60	43	34	23	20	11	<1	286
63	(1)											265
67	0	96	96	96	93	86	57	46	32	2	<1	330
68	0			>99	96	96	84	76	68	40	<1	338
73	0	37	31	26	23	20	6	3	<1			174
74	0	70	64	61	39	21	9	6	6	<1		239
76	(1)											235
77	(1)											152
82	0	90	90	87	87	77	63	43	30	20	<1	309
85	0	21	21	21	14	14	7	<1				72
87	0	36	36	36	33	27	18	6	6	<1		224
94	0	59	55	50	41	23	5	<1				109
98	0	22	22	22	11	<1						114
101	0	41	39	35	26	11	4	<1				75
105	0	47	41	35	6	<1						28
107	.13	14	6	3	<1							21
110	.01	13	12	10	2	<1						45
111	0	53	39	39	36	19	11	11	3	<1		138
113	0	48	48	38	31	21	17	17	14	7	<1	309
114	0	26	26	23	20	14	9	<1				85
124	.24	8	8	6	3	3	<1					9
126	.88	5	<1									2
128	.90	5	5	2	<1							9

[1] Not calculated.

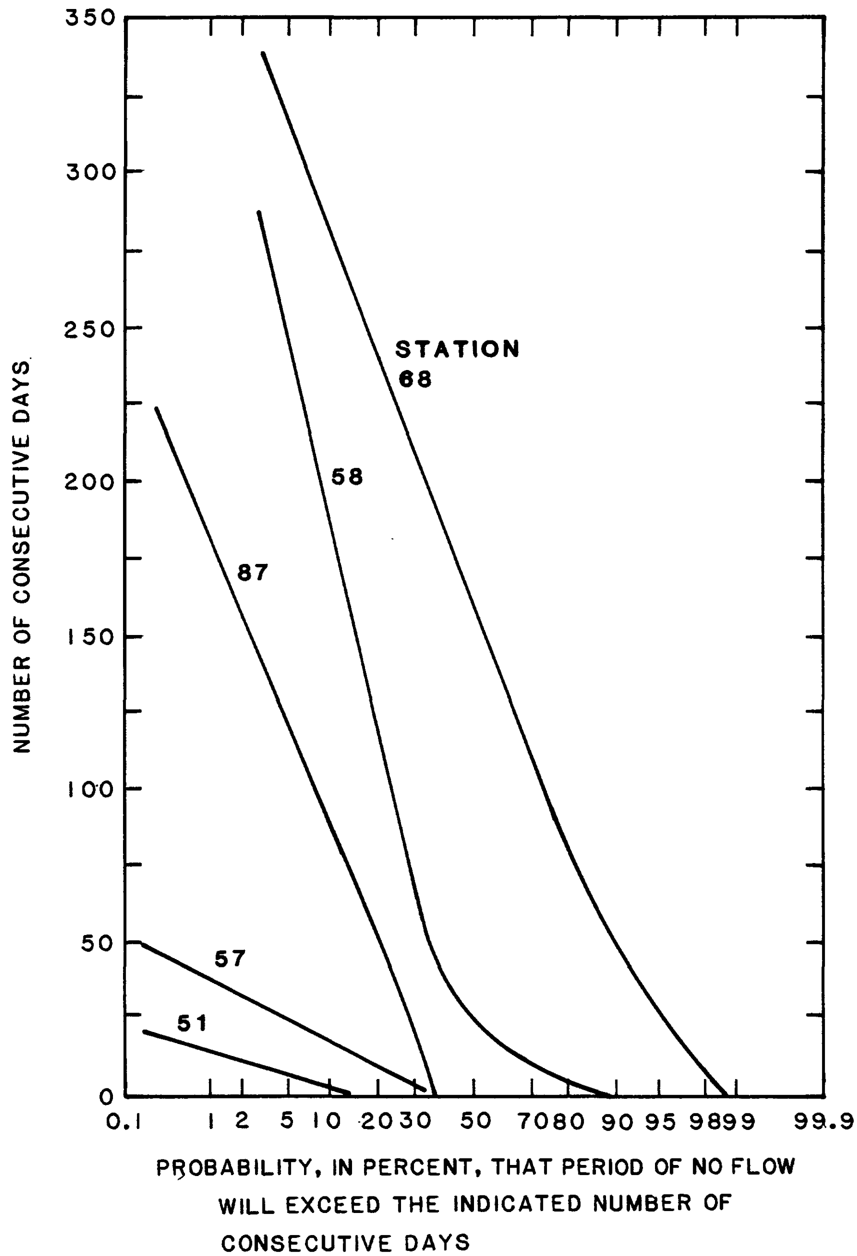

Figure 5.--Frequency curves for maximum number of consecutive days of no flow at five stations on plains streams in northeastern Wyoming and adjacent parts of Montana. (Station names are given in table 1.)

Mountain Streams

The $7Q_{10}$ for streams in the Bighorn Mountains (see plate 1) was correlated with drainage area. The regression equation is shown graphically in figure 6. It was determined using 19 stations; the correlation coefficient is 0.71 and the standard error is 64 percent. The equation may be used to estimate $7Q_{10}$ at ungaged sites in the Bighorns only, but the applicable area is only a small part of the study area.

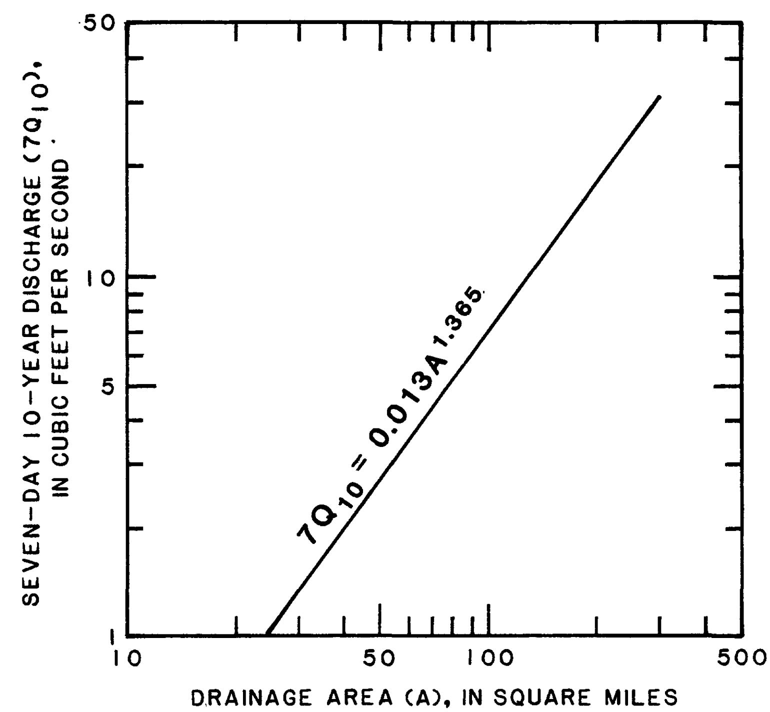

Figure 6.--Relation of 7-day 10-year low flow to drainage area, for streams in the Bighorn Mountains and Black Hills in Wyoming.

Selected Main-Stem Streams

A technique commonly used for estimating low-flow characteristics at ungaged sites on main-stem streams, especially regulated streams, is interpolation of a graph of the selected characteristic versus distance along the channel. Such a graph was prepared for the $7Q_{10}$ in the main stem of the Powder River and one of its principal tributaries, Clear Creek (fig. 7). Flows in the main stems of streams on the plains normally are depleted by evapotranspiration; in the case of the Powder River, withdrawals for irrigation also are a major reason for the downstream decrease in low flows.

The $7Q_{10}$ also was plotted against channel distance for the North Platte River (fig. 8). The reach of this stream within the study area is totally regulated. A considerable amount of water is stored temporarily in the alluvium during the high flows of the snowmelt and irrigation seasons, contributing to subsequent low flows. The low flows downstream from Glendo and Guernsey dams are from seepage after the dams are closed. The graphs in figures 7 and 8 can be interpolated by using the channel distance to the site of interest, as measured on a large-scale map.

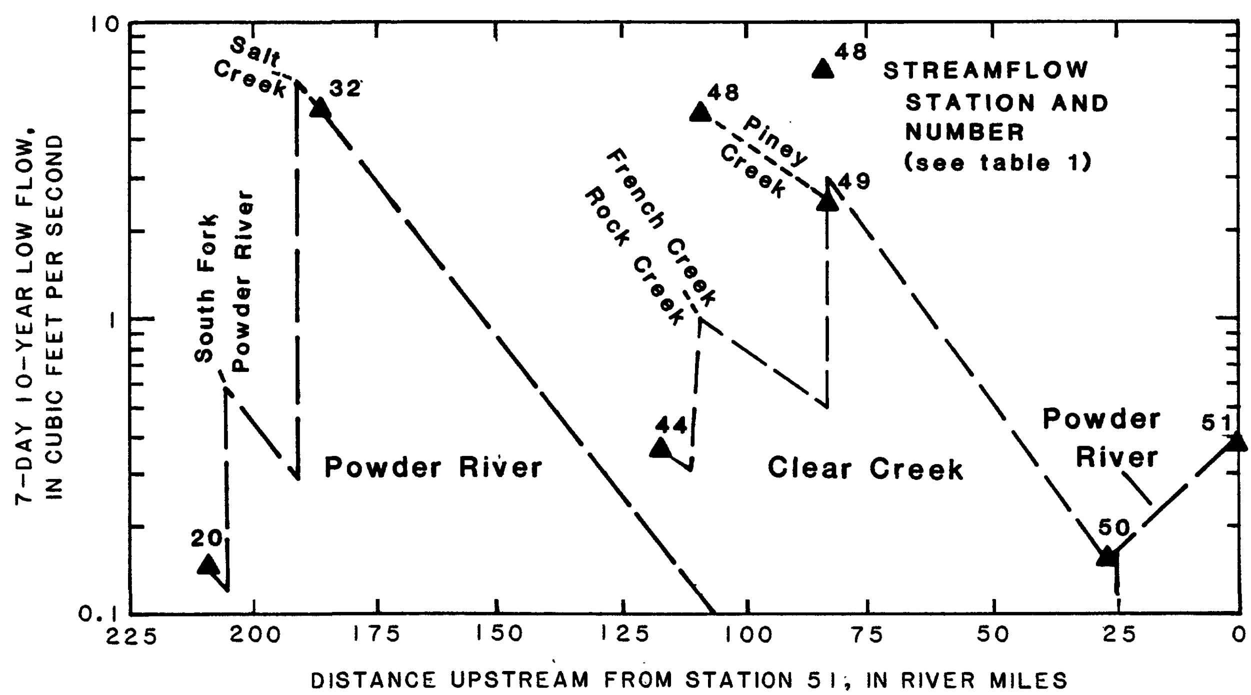

Figure 7.--Relation of 7-day 10-year low flow to distance along channels of the Powder River upstream from Moorhead, Montana, and Clear Creek upstream from its mouth at the Powder River. (Station 41 at river mile 50 not shown. Flow is less than 0.1 cubic foot per second.)

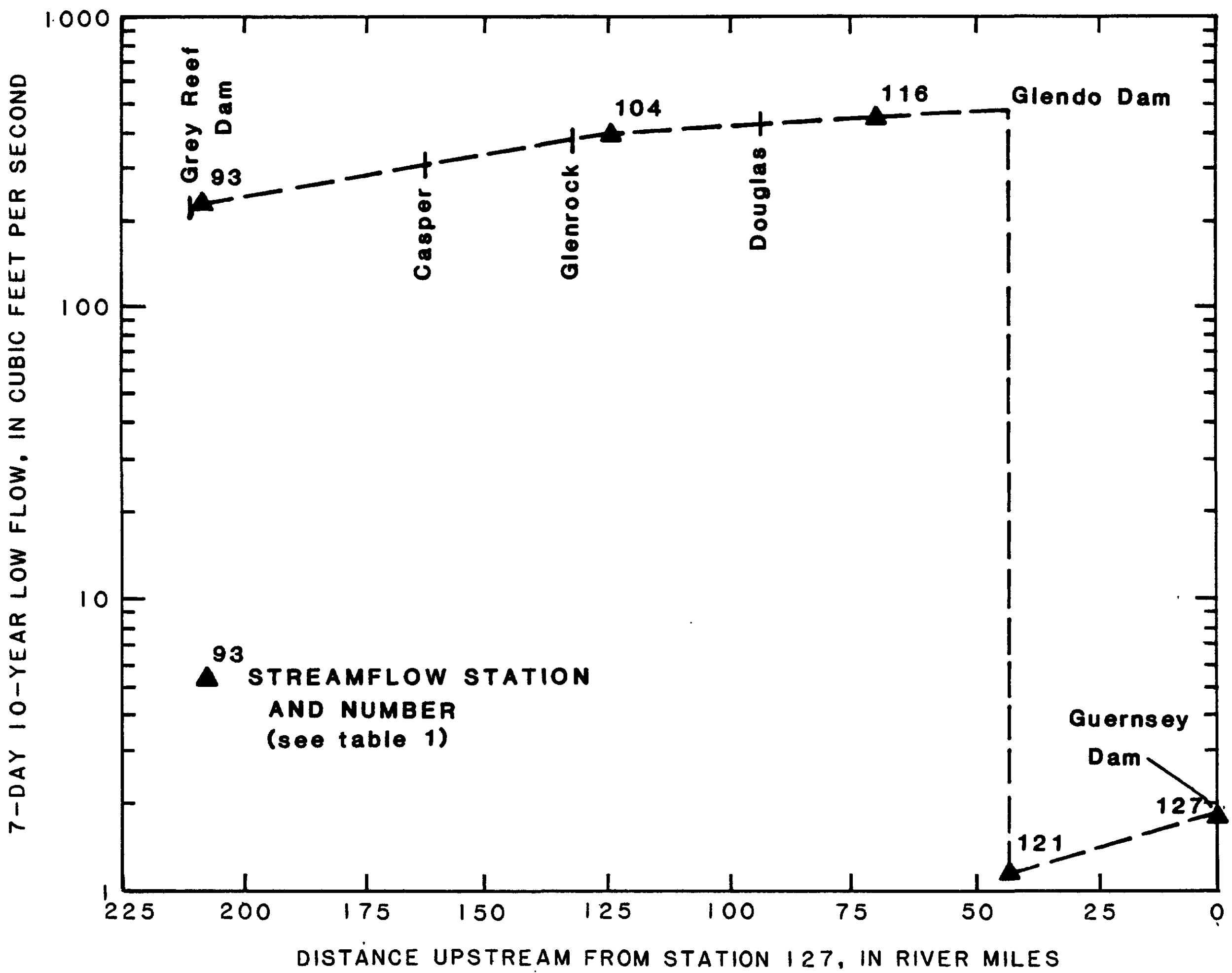

Figure 8.--Relation of 7-day 10-year low flow to distance along channel, North Platte River between Grey Reef Dam and Guernsey Dam, Wyoming.

DISCUSSION

Accuracy of Results

The accuracy of the results described in this report generally cannot be assessed quantitatively. However, the user of the information should be aware of the general accuracy and limitations of the data and techniques used. The following discussion is separated into three sequential categories: (1) Data used, (2) frequency distributions used, and (3) estimating techniques for ungaged sites.

Data errors include streamflow-measurement errors and time-sampling errors. Streamflow measurements and computation of streamflow records were made following well-established procedures of the Geological Survey. Errors in measurements and records computation tend to balance out and are considered to be negligible in comparison with errors in statistical analyses of the data. Of course, the on-site observation of no flow by a hydrographer is without error. Time-sampling errors, on the other hand, may be substantial. As shown by the flow-duration curves (fig. 3), low-flow characteristics not only depend on the length of record, they also are influenced greatly by the inclusion or exclusion of a major drought. Only those stations in operation for 10 or more years between 1930 and about 1960 are considered to have recorded a significant drought. Low-flow characteristics for stations installed since about 1960 (there have been many in northeastern Wyoming) are likely to be much larger than characteristics determined for a period of equal length prior to about 1960. Furthermore, records prior to 1930 were not used because they may be from a different population of streamflow than those since 1930, due to unexplained causes.

The accuracy of frequency distributions is dependent on the time-sampling errors described above and on the curve-fitting method used. Regarding assessment of time-sampling errors, in its guidelines on discussing the results of low-flow investigations, the Water Resources Division, U.S. Geological Survey (written commun., 1979) states: "The general relation for estimating the reliability of a point on a frequency curve, in terms of length of record and variability, assumes that the data are completely random. This assumption is not fully acceptable for low flows; * * * Thus, the purely statistical estimate of the reliability of a frequency curve is weak." Such an estimate of reliability was not attempted in this study. Also, the extremes of a frequency curve (probabilities of 5 percent or less, or 90 percent or greater, table 2) may be less reliable than the rest of the curve because of extrapolation, or because the smallest flows may be affected by human activities. For some stations, the log Pearson Type III distribution produces higher or lower estimates of low flows than a simple graphical fit of the data; however, the fit of that distribution to the data between probabilities 5 and 90 percent was very good for most of the stations listed in table 2.

The use of a regression equation to estimate the $7Q_{10}$ at ungaged sites in northeastern Wyoming is limited to perennial streams in the Bighorn Mountains. Although the equation (fig. 6) has a reasonably small standard error, 64 percent, it should be used with caution. Also, it should be used only for sites having drainage areas of 2 to 200 square miles, which is the range of the data used. Likewise, the necessarily straight-line interpolation of the graphs for main stems (figs. 7 and 8) should be done with caution. As discussed in the next section, a multiple-regression equation using additional independent variables would improve the accuracy of the estimated characteristics.

Future Investigations

The results of this investigation indicate a need for future investigations. There are two possible approaches to follow in future investigations: (1) Improvement of the low-flow data base and the information needed to explain quantitatively the causes of variations in low flows; and (2) assessment of the availability of what appear to be marginal quantities of water for human use. Given the predominance of ephemeral streams on the plains of northeastern Wyoming, the improvement of the low-flow information base is attractive from a scientific viewpoint; however, assessing the availabilty of water for storage of meager natural flows may be more important from an economics viewpoint. The two approaches are not mutually exclusive; both require records from streamflow stations and an understanding of the hydrology of small streams in semiarid regions. Hence, both approaches should be considered.

A comprehensive data-collection plan is needed to improve the data base. Such a plan could be manpower-intensive, a definite disincentive. More stations, especially on small plains streams, are needed. Long-term records are essential for sampling low flows over time, but are not necessarily essential for obtaining a large spatial increase in information. The use of low-flow partial-records stations (only high-flow stations have been used in Wyoming to date) would be an inexpensive way to increase the data base substantially. The most important part of the data-collection plan would be obtaining baseflow measurements at as many sites on as many streams as possible, for correlation with long-term baseflow at continuous-record stations. Some baseflow measurements should be planned as seepage runs that will provide information about gains from or losses to ground water. Water-quality measurements (temperature and specific conductance) should be obtained along with the discharge measurements, for possible indications of the geology or of the effect of human activity. The details of comprehensive low-flow data collection are described by Riggs (1972, p. 15-16).

Synoptic baseflow information, as described above, probably would provide a sound basis for estimating low-flow characteristics at ungaged sites, with or without using regression. However, the regression approach, in spite of its limitations for estimating low flows, would be enhanced by the expanded data base and by using multiple regression instead of the two-variable regression used in this report. Standard errors would be improved substantially by using several carefully researched independent variables--basin and meteorological characteristics and, if possible, a characteristic based on geology.

A potentially more accurate method (Stedinger and Thomas, 1985) uses baseflow measurements at an ungaged site to establish a regression relationship with low flows at a nearby streamflow station. The mean and standard deviation of annual low flows at the ungaged site are estimated from the regression and used to determine low-flow frequency information at the ungaged site. This method, as well as the one described in the preceding paragraph, apply only to perennial and intermittent streams.

Potential long-term supplies of water can be estimated by applying a mathematical technique called storage analysis. Storage analysis provides the probability that a hypothetical reservoir will be unable to provide a specified downstream water supply. The procedures for storage analysis of perennial streams (mainly the mountain streams in northeastern Wyoming) are described by Riggs and Hardison (1973). This might be done for streams that otherwise are fully appropriated. Glover (1984) developed a model for applying storage analysis to ephemeral streams that are typical of the plains areas. Streamflow-station records are required for both procedures. The use of these procedures should be considered for future investigations.

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