Quantity and Quality of Streamflow in the Southeastern Uinta Basin, Utah and Colorado

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By K. L. LINDSKOV AND BRIANT A. KIMBALL

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Quantity and Quality of Streamflow in the Southeastern Uinta Basin, Utah and Colorado

By K. L. Lindskov *and* Briant A. Kimball

Abstract

The southeastern Uinta Basin of Utah and Colorado includes an area of 3,000 square miles containing large oil-shale deposits. Future mining and retorting of the oil shale in northeastern Utah is expected to impact the area's water resources. In order to determine premining conditions, streamflow and water-quality data were collected during 1974-79. These data plus all other available information were used to define baseline conditions for streamflow and water-quality characteristics. The data and interpretations will provide a basis for evaluating impacts of future mining.

Areal and time variances in streamflow and water-quality characteristics were determined for the major rivers (Green and White) and the intra-area streams (streams that originate within the study area). The streamflow characteristics defined are average streamflow and low- and high-flow extremes. Graphs of frequency curves, duration curves, and draft-storage relations are presented for selected gaging stations. Areal variances in average and peak flows are illustrated. Water-quality characteristics are summarized according to the following categories: general water-quality characteristics, major dissolved constituents, trace elements, nutrients, pesticides, and sediment, biological, organic, and radiochemical characteristics. The means and ranges in values are discussed for the major rivers and the intra-area streams. The water-quality constituents are compared to water-quality criteria of the Environmental Protection Agency.

The major rivers flowing into the area convey an average of 5,900 cubic feet per second from a total drainage area of about 34,000 square miles. This is more than 100 times as much runoff as originates within the study area. The average flow for the major rivers is 0.17 cubic foot per second per square mile and does not vary significantly from one location to another within the study area. The flows of the intra-area streams vary from less than 0.001 to more than 0.10 cubic foot per second per square mile. Evapotranspiration losses can exceed inflow; thus average flows of some intra-area streams decrease in a downstream direction.

The quality of streamflow varies considerably between the major rivers and the intra-area streams. In the major rivers, the concentrations vary seasonally but do not vary significantly from one location to another. In the intra-area streams, concentrations vary both seasonally and from one location to another. The water quality in the major rivers generally is better than that in the intra-area streams. Dissolved-solids concentrations average 572 milligrams per liter for the Green River and 500 milligrams per liter for the White River, whereas mean concentrations for the intra-area streams range from 549 milligrams per liter in ephemeral streams to 5,320 milligrams per liter in Bitter Creek. Concentrations of major constituents generally do not exceed water-quality criteria of the Environmental Protection Agency except for hardness and sulfate. Several trace elements exceed water-quality criteria in intra-area streams. Dissolved-solids concentrations in base flow in short reaches of Bitter Creek can exceed 10,000 milligrams per liter.

INTRODUCTION

The dependence of the United States on imported petroleum supplies has focused attention on oil-shale deposits in the Upper Colorado Region (fig. 1). Large-scale mining and processing of the oil shale is expected to impact the area's water resources. Therefore, in 1974, the U.S. Geological Survey began a water-resources study of the southeastern Uinta Basin in Utah and Colorado (fig. 2), an area containing extensive, thick deposits of oil shale.

The results and interpretations given in this report are for the surface-water resources of the study area. The purpose of the surface-water study was to define the quantity and quality of streamflow prior to mining. This information could be used to identify some of the water-related problems that might be associated with the mining and processing of oil shale. Sediment characteristics are summarized by Seiler and Tooley (1982) and selected biological characteristics are reported by Naten and Fuller (1981); thus those aspects of water quality have not been fully treated in this report.

The data obtained during the study were used to define areal and time variances in streamflow and water-

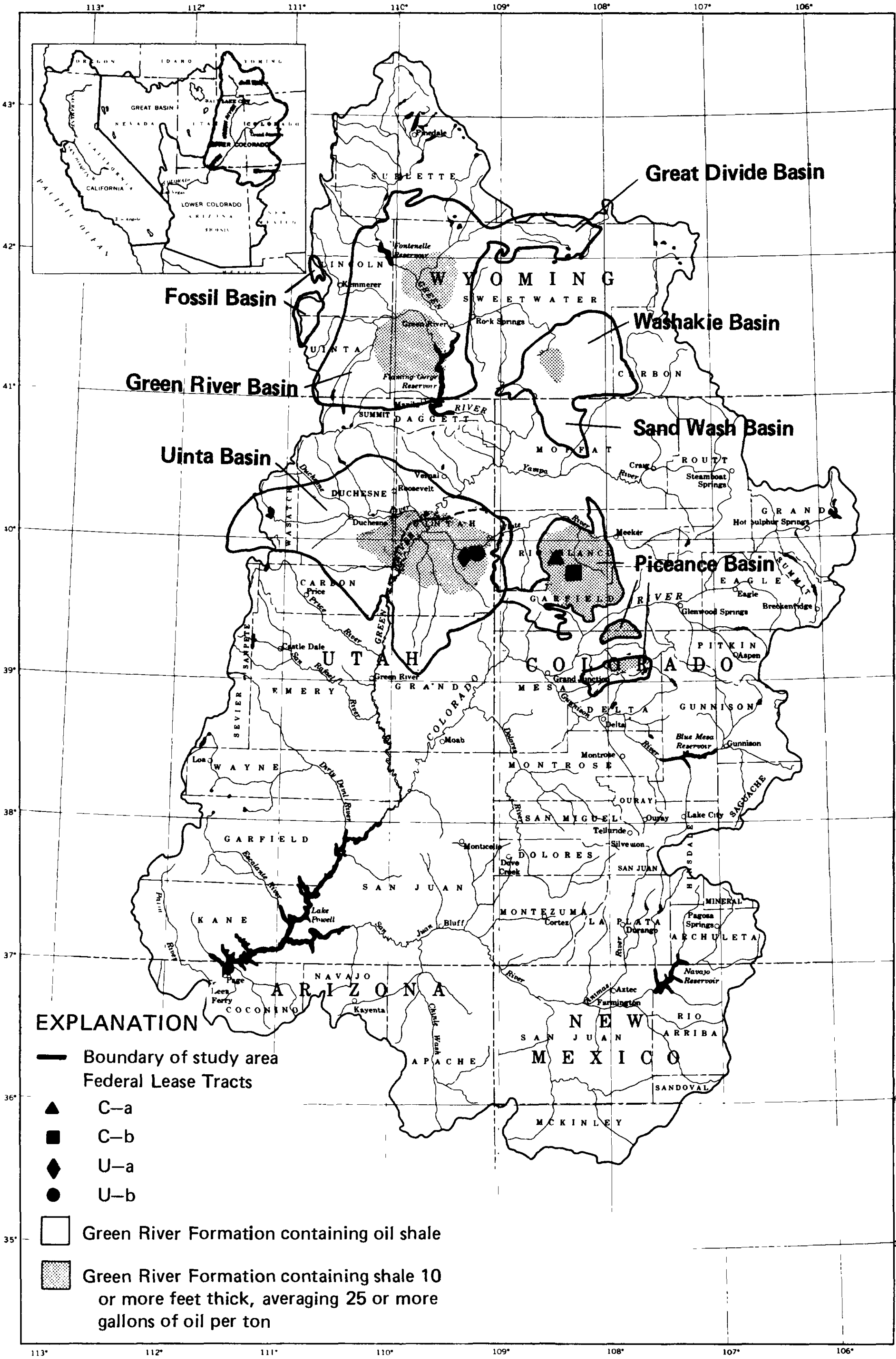


Figure 1. Location of study area within Upper Colorado Region. Structural boundaries of basins within the region from U.S. Department of the Interior (1979, p. 17).

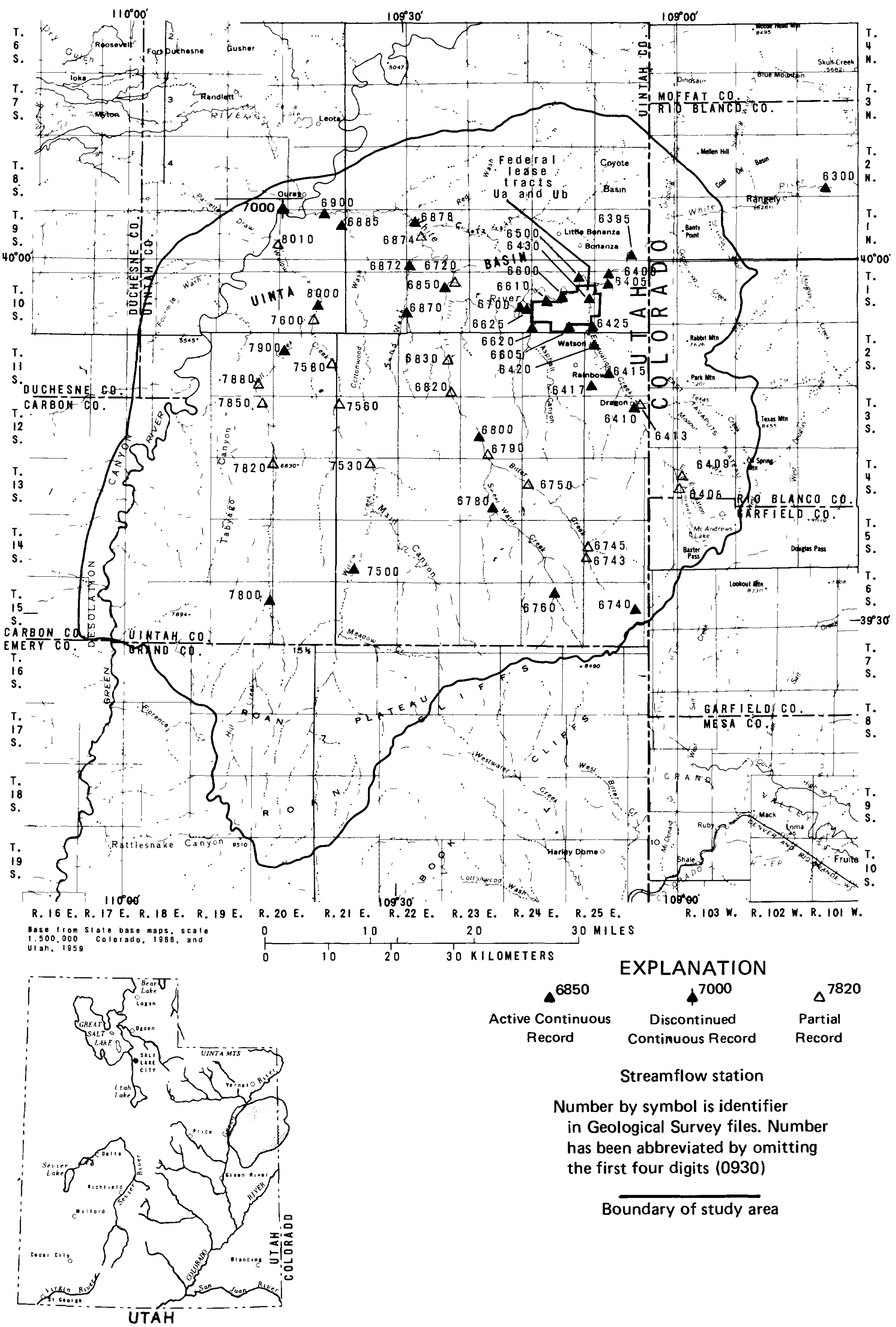


Figure 2. Location of streamflow-monitoring stations.

quality characteristics. These data and interpretations are useful for evaluating environmental-impact statements, assessing availability of water, and establishing baseline information necessary to determine the effects of mining and processing on the streamflow.

The southeastern Uinta Basin is sparsely populated, with less than 50 permanent residents; and the amount of information available to evaluate the area's surface-water resources was sparse until this investigation began. Although long-term records are available for the Green and White Rivers, little information existed for the intra-area streams (streams that originate within the study area). During 1974–79, therefore, records were obtained at 30 continuous-record stations and 19 partial-record stations (fig. 2). Flow and water-quality data were obtained at these sites for 1 to 6 years.

Other aspects of the water-resources study in the southeastern Uinta Basin are summarized in reports dealing with ground water, climate, channel migration, vegetation mapping, and geochemistry of spring water. A final report will summarize the results of the multidisciplinary hydrologic investigation and will discuss impacts that mining may have on the area's water resources. Most of the data collected during the study are reported by Conroy and Fields (1977) and Conroy (1979 and 1980).

DESCRIPTION OF STUDY AREA

Physiography and Drainage

The study area includes approximately 3,000 mi^2 in the southeastern Uinta Basin in Utah and Colorado. All the area drains to the Green River, which is a large tributary of the Colorado River. The White River flows west from Colorado across the northern part of the study area and enters the Green River near Ouray, Utah. The major drainageways in the study area are Evacuation and Bitter Creeks and Asphalt, Sand, and Coyote Washes—tributaries of the White River—and Hill and Willow Creeks—tributaries of the Green River (fig. 2). These drainages cut a broad plateau to form benchlike mesas and steep-walled canyons 500 to 1,000 ft deep and as much as 1 mi wide. The altitude of the land surface at its lowest point on the Green River is about 4,310 ft above sea level.[1] The land surface gently rises to the south and east, reaching about 9,500 ft above sea level in the Roan Cliffs at the headwaters of Willow Creek.

General Geology

The Uinta Basin contains a thick sequence of sedimentary rocks ranging from Precambrian to Tertiary age (Osmond, 1965). The rocks that are exposed in the southeastern Uinta Basin have been described by Cashion (1967), and only the exposed rocks will be discussed here. (See table 1.)

The Wasatch Formation of Tertiary age is exposed in the southern part of the study area in the Roan Cliffs along the deep canyons in the headwaters of the major drainages and in the western part of the study area in Desolation Canyon. The formation consists mostly of massive channel-filling sandstone and mudstone. The Wasatch is conformable and interfingers with the overlying Douglas Creek Member of the Green River Formation, also of Tertiary age. The Douglas Creek Member contains continuous sandstone, mudstone, and algal and oolitic limestone. The Douglas Creek Member is overlain by the Parachute Creek Member of the Green River Formation. The rich oil-shale deposits of the Green River Formation are contained in the Parachute Creek Member, which represents deposits in ancient Lake Uinta (Bradley, 1929, p. 88). The Parachute Creek Member consists mostly of marlstone, a limy mudstone high in magnesium; and marlstone with a high organic content is called oil shale.

The deposits of Lake Uinta are covered by river deposits of the Uinta Formation, also of Tertiary age. The sandstone, siltstone, and mudstone of the Uinta Formation are exposed over a large area near the White River.

Deposits of Quaternary alluvium have formed along each of the present drainages. In some of the larger drainages, the thickness is greater than 80 ft (W. F. Holmes and B. A. Kimball, U.S. Geological Survey, written commun., 1982). The Quaternary deposits, ranging in size from clay to platy boulders, consist of material derived from the surrounding Tertiary rocks.

Climate

The climate of the Uinta Basin at lower altitudes is semiarid, with hot, dry summers and occasional intense thunderstorms. Higher altitudes have a subhumid climate. Normal annual precipitation (Waltemeyer, 1982, pl. 1) ranges from less than 8 in. at lower altitudes to more than 20 in. in the headwaters of Willow Creek. Winters are cold, but snow usually accumulates only at altitudes above 6,000 ft, with subsequent spring runoff from snowmelt. At lower altitudes, in the northern part of the area, a single summer thunderstorm may often account for the entire yearly runoff of a small ephemeral stream.

Potential evapotranspiration in the study area is great. Using the Blaney-Criddle method, Cruff and

[1] 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. In this report, sea level is used in place of NGVD of 1929.

Thompson (1967, p. M15–M18) computed 51 in. for a location near Ouray. This value of 51 in. is more than six times the actual average annual precipitation for this location.

MONITORING NETWORK

Prior to this study, records of daily flow, including some water-quality sampling, were being collected at stations 09306500, White River near Watson, and 09306800, Bitter Creek near Bonanza (fig. 2). Some records were available for two discontinued stations on Willow Creek, 09307500 and 09308000, which were reactivated for this study. Eighteen years of record were also available for the discontinued station 09307000, Green River near Ouray. Price and Miller (1975, tables 6 and 7) used low-flow measurements along Willow Creek to determine channel losses and channel-geometry techniques to estimate average annual runoff from many of the ungaged streams.

For this study, streamflow quantity and quality were measured for 1 to 6 years at 30 gaging stations

Table 1. General lithologic character and water-bearing properties of exposed geologic units

<table>
<tr><th>Geologic age</th><th colspan="2">Geologic unit</th><th>Thickness (feet)</th><th>Lithologic character</th><th>General water-bearing properties</th></tr>
<tr><td>Quaternary</td><td colspan="2">Unconsolidated alluvial deposits</td><td>0– 150</td><td>Clay, silt, sand, and some gravel. Caliche always found near water table. Clay predominantly illite and lillite/smectite.</td><td>Generally yield less than 1,000 gallons per minute. Saturated in major drainages, with slow movement of water.</td></tr>
<tr><td rowspan="4">Tertiary</td><td colspan="2">Uinta Formation</td><td>0–5,000</td><td>Fluvial deposits of mostly thinly-bedded siltstone and fine-grained sandstone. Some beds of volcanic tuff. Cut in several places by gilsonite dikes.</td><td>Not water-bearing in many areas where deeply incised by streams. Commonly yields less than 5 gallons per minute to springs.</td></tr>
<tr><td rowspan="2">Green River Formation</td><td>Parachute Creek Member</td><td>500–1,200</td><td>Lacustrine deposits of thinly-bedded claystone, siltstone, fine-grained sandstone, limestone and some tuff. Contains prominent oil-shale deposits. Clay is illite and trioctahedral smectite. Local cavities of evaporite minerals, mainly nahcolite. Laterally continuous.</td><td>Overall permeability is slight. Springs generally yield less than 10 gallons per minute. Wells intersecting fractures yield as much as 5,000 gallons per minute. Contains bird's-nest aquifer locally.</td></tr>
<tr><td>Douglas Creek Member</td><td>200–1,300</td><td>Predominantly lacustrine deposits of claystone, siltstone, fine-grained sandstone, and limestone. Six tongues have been identified by Cashion (1967, p. 6–7). Clays mostly smectite. Channel-form sandstone common. Beds commonly are discontinuous.</td><td>Permeability varies. Springs in sandstones discharge as much as 50 gallons per minute. Water-bearing beds grouped as the Douglas Creek aquifer, which yields from 50 to 500 gallons per minute to wells.</td></tr>
<tr><td>Wasatch Formation</td><td>Renegade Tongue</td><td>0–1,000</td><td>Fluvial deposits of massive, irregularly-bedded sandstone and red and gray siltstone intertonguing with Douglas Creek Member of Green River Formation.</td><td>More permeable than Green River Formation. Springs yield as much as 200 gallons per minute. Constitutes part of the Douglas Creek aquifer.</td></tr>
</table>

(continuous records of flow and monthly to quarterly water-quality sampling) and at 19 partial-record stations (monthly measurements of flow and water-quality sampling). (See tables 2 and 3.) In addition, daily records of specific conductance and water temperature were obtained at 7 of the 30 continuous-record stations. Most were instrumented during the summer of 1974, and record collection began October 1, 1974. Others were instrumented during 1975–76.

A large number of the stations were on streams in the vicinity of Federal lease tracts Ua and Ub (fig. 2). Because mining plans for tracts Ua and Ub were delayed in 1976, many of the stations were discontinued. Thus, in 1976, the monitoring program changed to one with less emphasis in the vicinity of the tracts and more emphasis on defining time and areal variances of streamflow and water-quality for the entire area. Baseline monitoring was continued at 18 continuous-record stations.

Data obtained during October 1974 to September 1978 were published by Conroy and Fields (1977) and Conroy (1979 and 1980). Data obtained since September 1978 appear in annual releases by the U.S. Geological Survey entitled, "Water resources data for Utah." All daily values and miscellaneous monthly data are stored in the WATSTORE computer files of the Geological Survey. These data may be retrieved using the NAWDEX (National Water Data Exchange) system at local assistance centers throughout the United States (Edwards, 1977).

STREAMFLOW CHARACTERISTICS

Although more than 50 years of streamflow records are available for sites at key locations on the Green and White Rivers, little was known until this investigation about changes in the flow of these rivers within the Uinta Basin except at the key locations. Even less was known about the areal and time variances of flows for the intra-area streams which contribute to the Green and White Rivers. Because of large differences in runoff characteristics, the major rivers and the intra-area streams have been separated for discussion.

For both the major rivers and the intra-area streams, the time and areal variances are defined for annual and monthly runoff and low- and high-flow extremes. In addition, the storage requirements needed to satisfy selected draft rates are defined for the Green and White Rivers and Willow Creek.

Average Streamflow

Major Rivers

The Green and White Rivers convey water from a total of about 34,000 mi^2 into the study area. The total average flow of these rivers is about 5,900 ft^3/s (water years 1965–79), which is more than 100 times as much streamflow as originates within the study area itself.

The long-term average streamflow and the variance from year to year of the Green and White Rivers are defined by continuous records of flow. The 56 years of record for station 09306500, White River near Watson, are representative of flows in the White River in the study area. For the Green River, 18 years of record are available for the discontinued station 09307000, Green River near Ouray, which was located below the confluence with the White River. The quantity of flow measured at this site is representative of flows in the Green River downstream through Desolation Canyon prior to construction of Flaming Gorge Reservoir (dam completed in 1962, about 170 mi upstream from station 09307000).

Station 09307000 was discontinued in 1965, but flow at that station can be related to the flow at station 09315000, Green River at Green River, which is about 125 mi downstream from station 09307000 and has a contributing drainage area of about 41,000 mi^2. The annual flows at station 09315000 generally are equivalent to those at station 09307000 (fig. 3). The standard error of estimate for this relation is 2 percent, and the correlation coefficient is 0.997. The flow at station 09315000 is about 2 percent less than that for station 09307000 when flows are about 2,000 ft^3/s and 2 percent greater for values of about 10,000 ft^3/s. Losses along the 125-mile reach between the two stations apparently exceed inflow during dry years. Based on figure 3, the flows measured at station 09315000 for the period 1965–79 are considered equivalent to those of the Green River in the study area downstream from the confluence with the White River and represent conditions since Flaming Gorge Reservoir exceeded 70 percent of its usable capacity in 1965.

A similar comparison of flows in the White River throughout the study area can be made by comparing 5 years of concurrent flow at station 09306900, White River at mouth, near Ouray, to that at station 09306500, White River near Watson (fig. 4). The annual flows at the two stations generally are equivalent.

The flows in the Green and White Rivers, however, do vary considerably from year to year. The frequency curves in figures 5 and 6 define the probability of the annual mean flows being equal to or less than specified values during any year. A curve with a steeper slope defines more year-to-year variation in flow. For example, the frequency curve for the Green River (fig. 5) shows that in any year the probability of the annual mean flow being equal to or less than 3,300 ft^3/s is 2 percent. Also from figure 5, the probability that the annual mean flow will equal or exceed 7,300 ft^3/s in any year is 2 percent. As shown in figure 6, the values for the corresponding probabilities for the White River are 380 ft^3/s or less, and 1,200 ft^3/s or greater. Figures 7 and 8 show the year-to-year variances in annual mean flows for the Green River at Green River and the White River near Watson. For the Green River, the highest annual mean flow was 12,300 ft^3/s in 1907 and the lowest was 1,800 ft^3/s in 1934. For the White River, the highest value was 1,740 ft^3/s in 1929 and the lowest was 308 ft^3/s in 1977; however, there was no record prior to 1924.

To evaluate the potential of the Green and White Rivers for water supply, some knowledge of variations in flow for periods shorter than 1 year is needed. Annual runoff varies from year to year, but even greater variations occur over periods of months, weeks, and days; and for extended periods, flow may be much less than the annual mean value.

Figures 9 and 10 show mean, maximum, and minimum monthly flows for the White and Green Rivers. The lower flows tend to occur during midwinter when snow accumulates at the higher altitudes and again during late summer when evapotranspiration losses are great.

Even mean monthly flows do not entirely define the flow variances that must be accounted for, because these values represent the average flow for a particular month over a period of many years. Obviously, as shown in figures 9 and 10, any given month will be much drier some years than it is in other years. Variations in flows for periods shorter than a month are discussed in the section "Low Flows."

Intra-Area Streams

In contrast to those for the major rivers, the flows in the intra-area streams vary considerably throughout their courses and the amount of flow per unit area is highly variable. The data listed in table 2 for all stations with complete records for 1975–79 are considered representative of long-term means. In figure 11, the average precipitation for 1975–79 for eight long-term National Oceanic and Atmospheric Administration stations is shown to be representative of the 1941–70 normals for the same stations. Therefore, the average streamflows for 1975–79 were not adjusted to a long-term base period. Because of wide variations in average flow per square mile between ephemeral, intermittent, and perennial streams, attempts to relate data from records of less than 5 years to data from long-term stations generally were not successful.

The average annual flow measured for streams originating in the study area ranged from 0.12 to less than 0.001 $(ft^3/s)/mi^2$ (table 2). The larger value was calculated for the headwaters of Bitter Creek, where the normal annual precipitation is 17 inches. The stations with values less than 0.001 $(ft^3/s)/mi^2$ drain areas where normal annual precipitation generally is less than 10 in. (Waltemeyer, 1982, pl. 1).

Average annual runoff per square mile generally varies with altitude (fig. 12). Using the relation in figure 12, topographic maps, values for gaging stations listed in table 2, a photo of infrared imagery, and a map of annual precipitation (Waltemeyer, 1982, pl. 1), the variation in average annual runoff was mapped as shown in figure 13. By using figure 13 and planimetering areas of equal runoff, it was determined that the streams originating in the study area have the potential of contributing average annual flows of 47 ft^3/s to the White and Green Rivers. However, the actual contribution is only about 39 ft^3/s because about 8 ft^3/s is lost along the lower reaches of the intra-area streams. The information in figure 13 should be used with caution when estimating average annual flows in the lower reaches of Evacuation, Bitter, Hill, and Willow Creeks. Losses by evapotranspiration and infiltration can exceed inflow in the lower reaches of these streams, and average annual flows do, in fact, decrease at some locations in a downstream direction.

The variations in average annual flows along Evacuation, Bitter, Hill, and Willow Creeks are illustrated by the profiles in figures 14–17 which were constructed using data in table 2 and monthly flow measurements obtained at numerous partial-record stations during 1975–77. The measurements for the partial-record stations are given in Conroy and Fields (1977, table 6) and Conroy (1979, table 6). The drainage areas for the lower reaches of these streams generally contribute less than 0.005 $(ft^3/s)/mi^2$ and sometimes as little as 0.001 $(ft^3/s)/mi^2$ (fig. 13 and table 2), which may be less than channel losses. Therefore, average annual flows for each of these streams generally decrease along the lower 20 mi. Because Hill Creek enters Willow Creek at mile 14.9, the lower 20-mile reach of Willow Creek is an exception.

The greater loss rates for Bitter and Hill Creeks, compared to Evacuation and Willow Creeks, are due mostly to differences in evapotranspiration from the alluvium (W. F. Holmes and B. A. Kimball, U.S. Geological Survey, written commun., 1982). The wider flood plains and denser stands of phreatophytes along Bitter and Hill Creeks contribute to greater losses. Along some reaches, however, Hill Creek is above the water table and larger amounts of water are lost by seepage to the alluvium, which recharges the Douglas Creek aquifer.

In addition to the average flows of the intra-area streams varying throughout the course of any one stream and from one stream to another, annual mean flows vary considerably from year to year at the same site. For example, as shown in table 2, the annual flows during 1977 of many streams were about one-half of those observed during 1975. The frequency curve for station 09306800, Bitter Creek near Bonanza (fig. 18), shows that in any year the probability of the annual mean flow being equal to or less than 0.2 ft^3/s is 10 percent. The probability that the annual mean flow will equal or exceed 2.7 ft^3/s in any year is also 10 percent. As shown by the frequency curves in figures 19 and 20, the respective

Table 2. Selected streamflow characteristics

Station No.[1]	Station name	Period of record used (water years)	Drainage basin: Area (mi^2)	Drainage basin: Mean altitude (ft)	Annual flow for 1975	Annual flow for 1976
09306300[2]	White River above Rangely, Colorado	1973–79	2,770	.....	758	571
09306395	White River near Colorado-Utah State line	1977–79	3,680	.....	......	....
09306400	White River above Hells Hole Canyon, near Watson, Utah.	1975	3,700	.....	751	....
09306405	Hells Hole Canyon Creek at mouth, near Watson, Utah.	1975–79	24.5	.....	.11	.013
09306410	Evacuation Creek above Missouri Creek, near Dragon, Utah.	1975–79	100	6,870	1.07	1.41
09306415	Evacuation Creek below Park Canyon, near Watson, Utah.	1975	246	.....	1.24	....
09306417	Thimble Rock Canyon Creek near Watson, Utah.	1975	1.7	.....	0	......
09306420	Evacuation Creek at Watson, Utah	1975–76	259	.....	1.41	1.32
09306425	Evacuation Creek tributary near Watson, Utah	1975	12.4	.....	0	....
09306430	Evacuation Creek near Watson, Utah	1975–79	284	6,590	1.13	1.54
09306500	White River near Watson, Utah	1924–79	4,020	.....	772	546
09306600	White River above Southam Canyon, near Watson, Utah.	1975	4,030	.....	751	....
09306605	Southam Canyon Wash near Watson, Utah	1975–76	2.5	.....	.002	.0006
09306610	Southam Canyon Wash at mouth, near Watson, Utah.	1975–79	8.3	.....	.058	.007
09306620	Asphalt Wash below Center Fork, near Watson, Utah.	1975–76	94.4	.....	.015	.025
09306625	Asphalt Wash near mouth, near Watson, Utah	1975–79	97.5	.....	.025	.038
09306700	White River below Asphalt Wash, near Watson, Utah.	1975–79	4,130	.....	780	551
09306740	Bitter Creek above Dick Canyon, near Watson, Utah.	1975–78	11.7	8,220	2.12	2.23
09306760	Sweetwater Canyon Creek below South Canyon, near Watson, Utah.	1975–78	22.6	7,880	.59	.37
09306780	Sweetwater Canyon Creek near mouth, near Watson, Utah.	1975–78	124	7,370	.052	.13
09306800	Bitter Creek near Bonanza, Utah	1971–79	324	7,300	1.35	1.97
09306850	Bitter Creek at mouth, near Bonanza, Utah	1975–79	398	7,040	.95	1.10
09306870	Sand Wash near Ouray, Utah	1975–78	59.7	.....	.009	.010
09306872	Sand Wash near mouth, near Ouray, Utah	1977–78	71.1	.....	......	....
09306878	Coyote Wash near mouth, near Ouray, Utah	1977–79	228	.....	......	....
09306885	Cottonwood Wash at mouth, near Ouray, Utah	1977–78	70.6	.....	......	....
09306900	White River at mouth, near Ouray, Utah	1975–79	5,120	.....	787	572
09307500	Willow Creek above diversions, near Ouray, Utah.	1951–55, 1958–70, 1975–79	297	7,710	25.2	20.9
09307800	Hill Creek above Towave Reservoir, near Ouray, Utah.	1975–79	89.7	8,040	11.1	7.99
09307900	Hill Creek near mouth, near Ouray, Utah	1975–79	288	7,220	6.03	3.16
09308000	Willow Creek near Ouray, Utah	1948–55, 1975–79	897	7,140	24.2	20.7
09315000[2]	Green River at Green River, Utah	1895–99, 1905–79	44,850	.....	6,833	5,322

[1] See figure 2 for location of stations.
[2] Outside study area.

for continuous-record gaging stations

water year indicated (ft^3/s)			Average flow			Extreme flow for period of record used (ft^3/s)		Average number of days per year with no flow during period used
1977	1978	1979	1975–79 (ft^3/s)	Period of record (ft^3/s)	Period of record [(ft^3/s)/mi^2]	Maximum	Minimum	
312	718	754	623	651	0.24	4,260	62	0
323	731	765	.....	.....	.....	4,470	10	0
.....	.....	.....	.....	.....	.....	3,870	66	0
.069	.052	.075	.06	.06	.002	473	0	351
.71	.86	1.14	1.04	1.04	.010	835	.04	0
.....	.....	.....	.....	.....	.....	420	0	30
.....	.....	.....	.....	.....	.....	0	0	365
.....	.....	.....	.....	.....	.....	650	0	7
.....	.....	.....	.....	.....	.....	0	0	365
.68	.60	1.62	1.11	1.11	.004	1,980	0	<1
308	735	767	626	695	.17	8,160	11	0
.....	.....	.....	.....	.....	.....	.....	.....	0
.....	.....	.....	.....	.....	.....	4.4	0	362
.002	.001	.015	.02	.02	.002	392	0	358
.....	.....	.....	.....	.....	.....	135	0	358
.012	.003	.19	.05	.05	<.001	123	0	357
306	741	773	630	.....	.....	4,540	17	0
.65	.80	.....	.....	1.45	.12	11	0	<1
.40	.36	.....	.....	.43	.019	68	.02	0
.14	.033	.....	.....	.09	<.001	59	0	297
.90	.28	.45	.99	1.20	.004	1,660	0	86
.65	.58	.73	.80	.80	.002	117	.10	0
.008	.008	.....	.....	.01	<.001	27	0	359
.022	.11	.....	.....	.....	.....	137	0	355
.93	3.41	7.27	.....	3.87	.017	687	0	326
.060	.070	.....	.....	.06	<.001	286	0	358
311	740	810	644	.....	.....	4,260	1.6	0
15.0	16.5	31.0	21.7	20.1	.068	2,240	.30	0
4.20	5.09	14.3	8.54	8.54	.095	106	.07	0
1.05	.33	9.34	3.98	3.98	.014	201	0	208
9.96	10.7	32.9	19.7	24.2	.027	11,000	0	38
3,801	5,220	6,040	5,440	6,300	.14	68,100	255	0

Table 3. Summary of water-quality sampling of streams

[Number of samples collected for period of record shown]

Station No.[1]	Sediment characteristics	Major dissolved constituents	Trace elements	Nutrients	Biological characteristics	Pesticides	Radio-chemical charac-teristics	Other water-quality characteristics
				1900–50				
09315000[2]	....	564	298	417	...	...	...	770
				1951–70				
09306500	....	248	156	234	...	...	...	248
09315000[2]	339	676	236	337	...	26	...	1,018
				1971–79				
09306395	43	14	14	12	12	6	6	71
09306400	26	31	31	31	22	31	15	60
09306405	7	4	4	3	...	...	...	10
09306410	32	28	29	28	21	14	10	85
09306415	22	22	22	22	10	22	13	43
09306420	31	35	35	35	25	35	17	67
09306430	58	51	51	49	38	41	22	130
09306500	51	116	103	113	34	39	22	176
09306600	6	29	29	29	15	29	14	37
09306605	2	2	2	2	...	...	...	2
09306610	2	4	4	3	2	2	1	6
09306620	4	2	2	2	...	...	...	5
09306625	4	4	4	3	1	1	1	7
09306700	63	44	44	44	32	40	21	108
09306740	27	21	21	21	14	9	5	62
09306760	31	23	23	22	12	9	6	60
09306780	11	9	9	9	5	4	2	15
09306800	27	24	24	23	15	9	6	63
09306870	....	1	2	1	...	1	...	2
09306872	3	....	....	....	...	...	...	3
09306878	28	6	5	4	...	...	...	34
09306900	102	85	72	82	75	23	8	169
09307500	37	27	28	27	14	11	8	70
09307800	28	26	26	26	15	12	7	65
09307900	25	13	14	14	6	7	4	37
09308000	50	29	30	29	17	10	7	112
09315000[2]	110	131	72	110	72	29	35	209

[1] See figure 2 for location of stations.
[2] Outside study area.

values are 12 and 29 ft^3/s for station 09307500, Willow Creek above diversions, near Ouray, and 10 and 42 ft^3/s for station 09308000, Willow Creek near Ouray. The steeper slope for the curve in figure 18, compared to the curves in figures 19–20, indicates that annual flows for Bitter Creek are more variable than those for Willow Creek.

Compared to the major rivers, the intra-area streams have even greater variations in flows for periods shorter than 1 year. Flows are not evenly distributed throughout each year and can be far less than the average values. Average, maximum, and minimum monthly mean flows are summarized in table 4 for the intra-area streams, and figures 21–23 show variances for three typical sites. Variations in monthly flows for station 09306625, Asphalt Wash near mouth, near Watson (fig. 21), are typical of those for ephemeral streams that receive most of their runoff from thunderstorms, although snowmelt contributes during some wet years. Variations in flows for station 09306800, Bitter Creek near Bonanza (fig. 22), represent those of the intermittent streams that have snowmelt runoff each year but are occasionally dry for the months July through February. For Willow Creek, the flows at station 09307500, Willow Creek above diver-

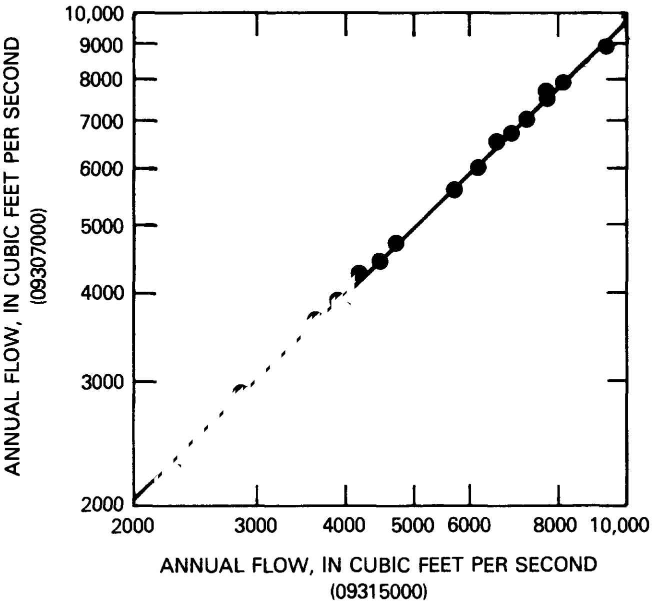


Figure 3. Relation of annual flow at station 09307000, Green River near Ouray, to that at station 09315000, Green River at Green River, water years 1948–55, 1957–66.

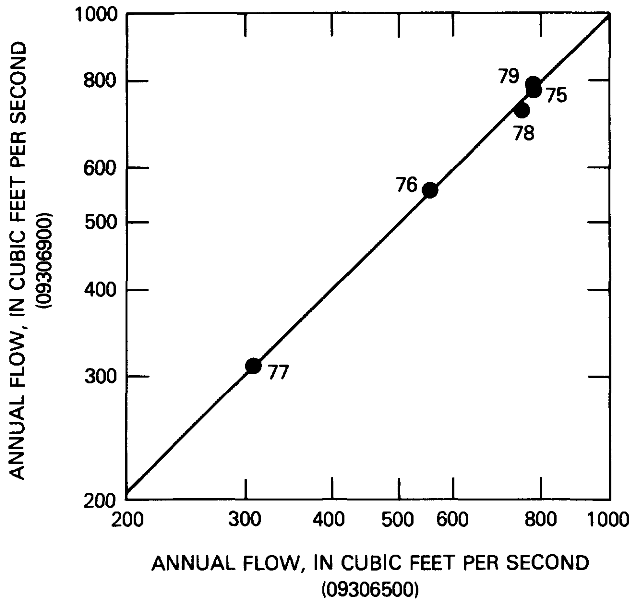


Figure 4. Relation of annual flow at station 09306900, White River at mouth, near Ouray, to that at station 09306500, White River near Watson, water years 1975–79.

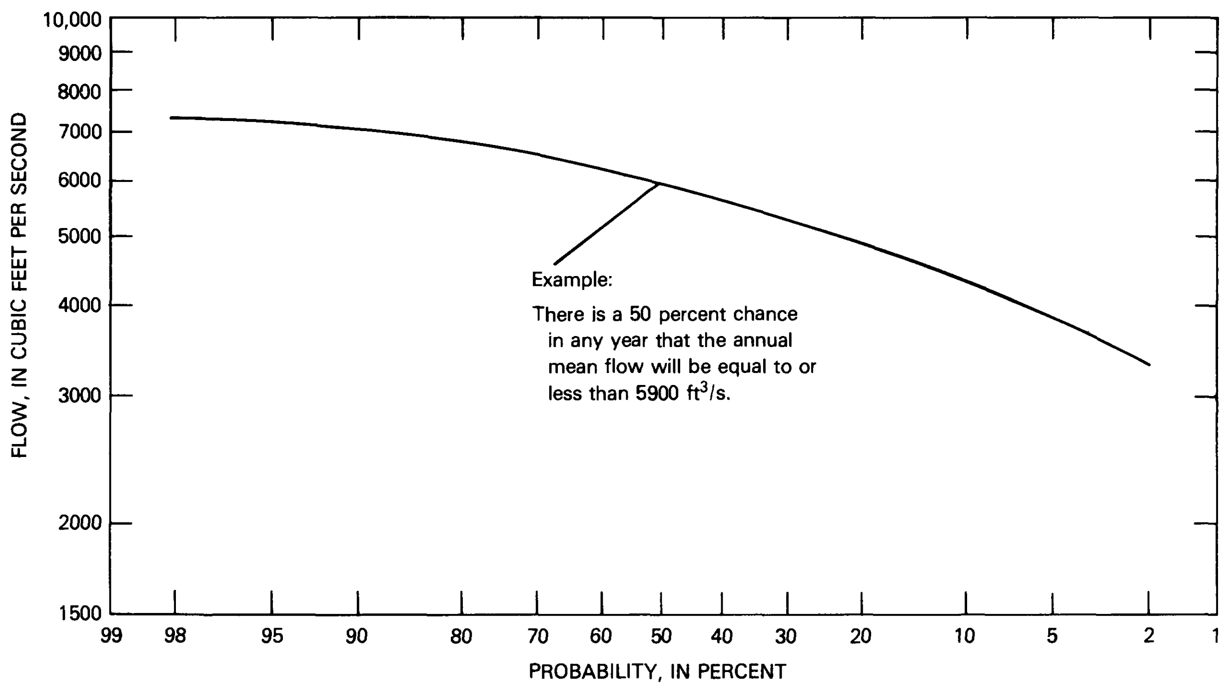


Figure 5. Frequency curve of annual mean flow at station 09315000, Green River at Green River, water years 1965–79.

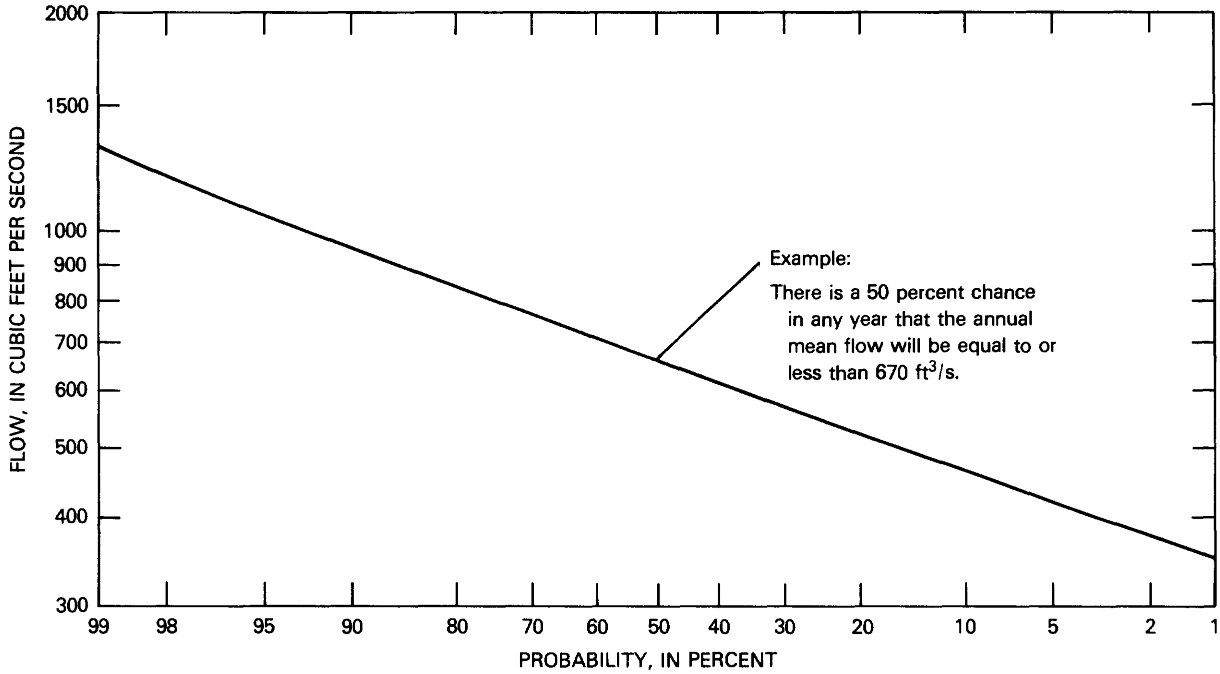


Figure 6. Frequency curve of annual mean flow at station 09306500, White River near Watson, water years 1924–79.

sions, near Ouray (fig. 23), show monthly variations typical of those for perennial streams.

Flows at station 09308000, Willow Creek near Ouray (fig. 24), show variations for the largest intra-area drainage. The drainage area at station 09308000 is 897 mi^2 (almost one-third of the entire project area), and it encompasses altitudes ranging from above 9,000 ft down to 4,860 ft at the station.

The average monthly mean flows (table 4) for most of the intra-area streams show similar patterns to those of the major rivers. The lower flows tend to occur during midwinter and late summer, whereas the average monthly mean flows generally are lowest during September–January. During most years, the monthly mean flows for the intermittent and ephemeral streams reach their maximums during March–May, which is about 1 to 3 months earlier than the annual maximum monthly mean flows of the major rivers. As shown in figure 21 and table 4, entire months with no flow are common for the ephemeral streams throughout the year.

Low Flows

Major Rivers

The variations in annual mean flows shown in figures 5–8 and monthly mean flows shown in figures 9–10 are useful for evaluating general variations in flows of the White and Green Rivers; but, for most management programs, flow characteristics that might prevail over other periods are more important. The most critical periods are those of prolonged low flow during droughts. Low-flow characteristics of the Green and White Rivers may be evaluated by the use of curves for flow duration, low-flow frequency, and draft storage.

Flow Duration

Duration curves of daily flows show the percentage of time that a specified daily-mean flow was equaled or exceeded. Two types of flow-duration curves are often used to evaluate the general distribution of flow in streams. One is the flow-duration curve, which is developed by arraying in ascending order all the daily flows at a station for the period of record, or for some representative period, and calculating the percentage of days when specific flows were equaled or exceeded. Thus, if a given flow was equaled or exceeded 95 percent of the days, flow was less than that value 5 percent of the days. The other is the daily-duration hydrograph, which is developed by arraying in ascending order all daily flows for a particular day of the year, calculating the percentage of days the flow on that date is equaled or exceeded, and repeating this for each of the 365 days in a year. For example, the hydrograph for 95 percent gives the daily-mean flows that are equaled or exceeded 95 percent of the time for each day of the year.

Figures 25–26 show flow-duration curves for stations 09306500, White River near Watson, and 09315000, Green River at Green River. The entire record (1924–79) was used for the White River; and the record since Flam-

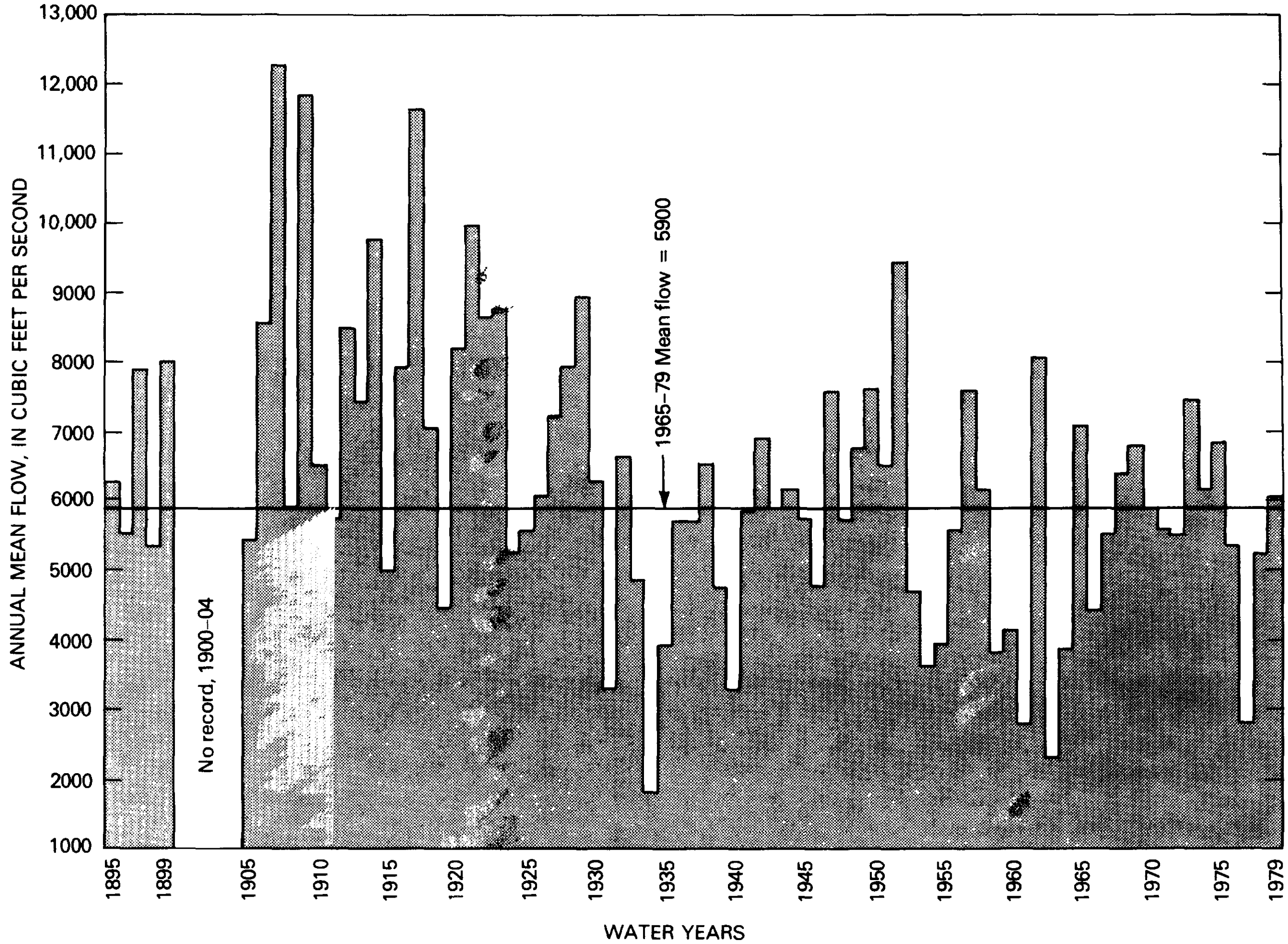


Figure 7. Annual mean flow for station 09315000, Green River at Green River.

ing Gorge Reservoir exceeded 70 percent of its usable capacity (1965–79) was used for the Green River. The flow-duration curves show, for example, that 10 percent of the time—an average of 36 days per year—daily flows have been equal to or less than 290 ft^3/s at station 09306500 and 2,600 ft^3/s at station 09315000. This does not suggest that the days were consecutive or even that daily flows less than 290 and 2,600 ft^3/s necessarily occurred in some years.

If it is assumed that the occurrences of flows for the period of record are representative of the distribution of future flows, the percentage of time that daily flows will be equaled or exceeded can be predicted using figures 25–26. As an example, assume that at a site on the White River a flow of 250 ft^3/s is required. Because the observed minimum flows have been less than the required flow, it is useful to know the probable number of days that there will be a shortage of water. Thus, figure 25 indicates that a flow of 250 ft^3/s will be available 95 percent of the time.

Unlike the flow-duration curves in figures 25–26, the daily-duration hydrographs in figures 27–28 identify the time of the year when flows will probably equal or exceed certain values. These hydrographs are useful for determining which time of the year shortages probably will occur. For the White River, for example, the daily mean flow for October 31 equaled or exceeded 300 ft^3/s 95 percent of the time and for 5 percent of the time the flow equaled or exceeded 700 ft^3/s. For the Green River, the daily mean flow for October 31 exceeded 1,200 ft^3/s 95 percent of the time and 4,700 ft^3/s 5 percent of the time.

Neither the flow-duration curve nor the daily-duration hydrograph show whether the days of insufficient flow will be consecutive; nor do they show, for extended periods, how frequently shortages will occur. It may be possible to operate for short periods on less than average requirements; or, if not, to suspend operation if the shortage does not occur too frequently. Therefore, one must know more about the low-flow characteristics

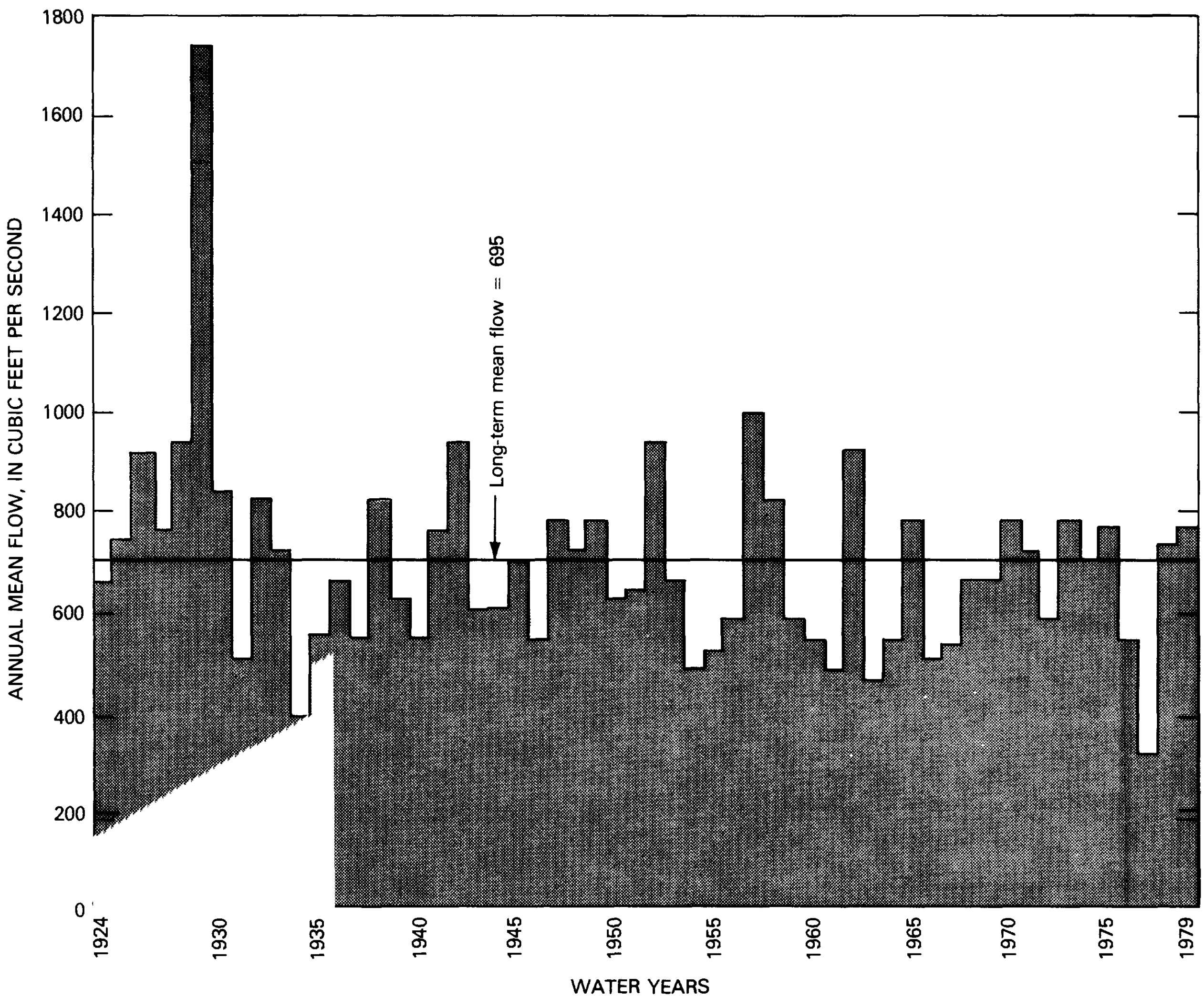


Figure 8. Annual mean flow for station 09306500, White River near Watson.

of the major rivers. How frequently will the flow be insufficient? How long will deficiencies last? How much storage will be required to satisfy demands? These questions may be answered by use of the low-flow frequency curves and storage-requirement (draft-storage) curves.

Low-Flow Frequency

The low-flow characteristics of the White and Green Rivers may be further defined by use of low-flow frequency curves (Riggs, 1968b, p. 9–14, 1972, p. 1–8), which show the probability of average flows being equal to or less than given values for a specified number of consecutive days. These low-flow frequency curves can be used to define how frequently, on the average, the flow will be insufficient and how long deficiencies will last. Figures 29–30 show low-flow characteristics of the White and Green Rivers presented as curves for 1, 7, 30, 60, 90, 120, and 183 consecutive days of average minimum flows.

Low-flow frequency curves are useful for predicting how often, on the average, minimum flows are expected to be less than selected values. The 1-day curve represents "run-of-the-river" flow. The 7-day curve represents flows available with a small amount of storage, such as provided by a dam in the main channel or off-site facilities. The curves for 30 days and longer represent the flow that would be provided by larger storage facilities. The supply from such storage would be the inflow for the indicated time period, less leakage and evaporation losses.

The probable number of days per year (5 percent of the time, or 18 days) that there will be shortage of water if 250 ft^3/s is required from the White River was previously determined from the flow-duration curve (fig. 25). From the low-flow frequency curves (fig. 29), one knows how

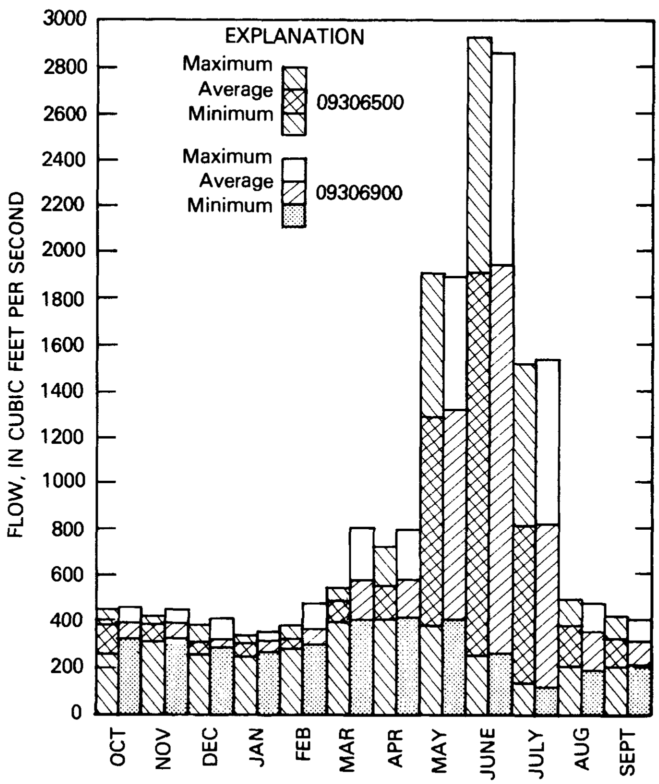


Figure 9. Average, maximum, and minimum monthly mean flows at stations 09306500 and 09306900 on the White River, water years 1975–79.

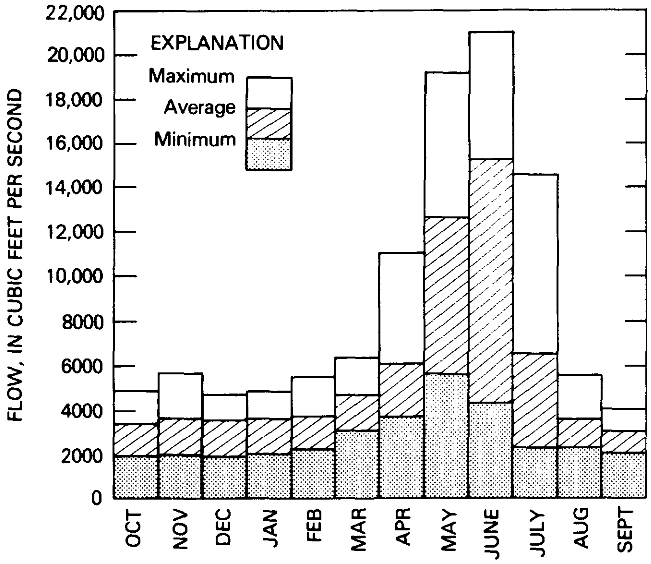


Figure 10. Average, maximum, and minimum monthly mean flows at station 09315000, Green River at Green River, water years 1965–79.

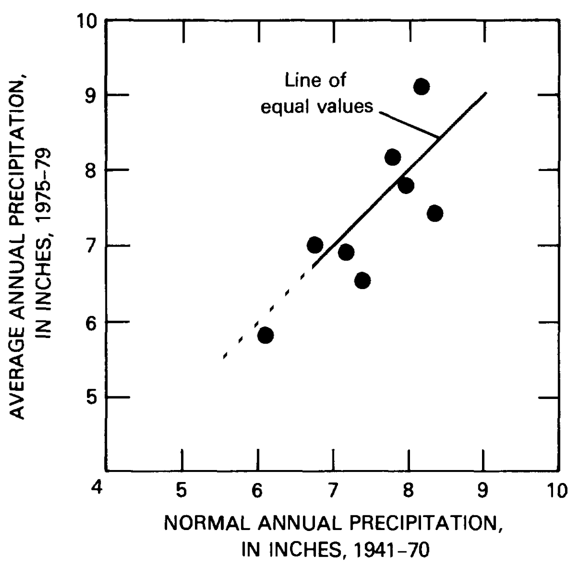


Figure 11. Relation of average annual precipitation measured during 1975–79 to normal annual precipitation published for 1941–70 for eight long-term National Oceanic and Atmospheric Administration stations near the study area.

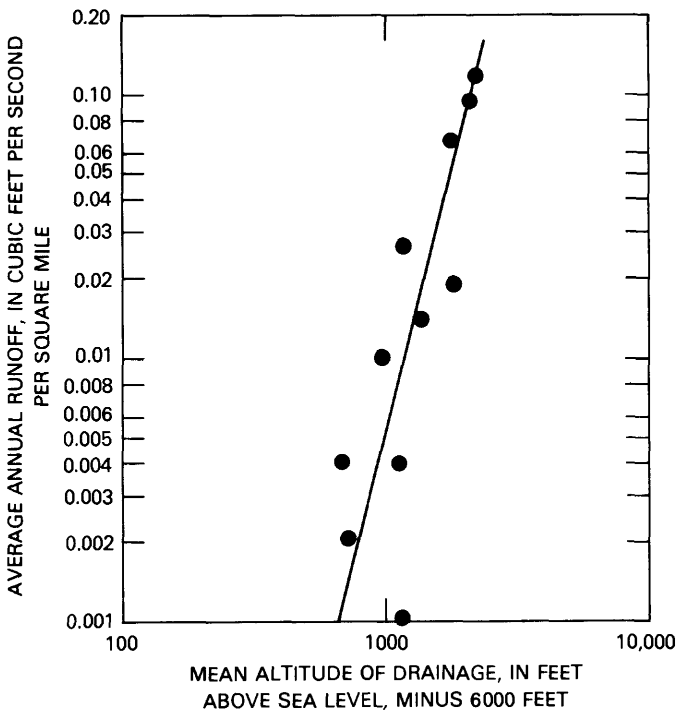
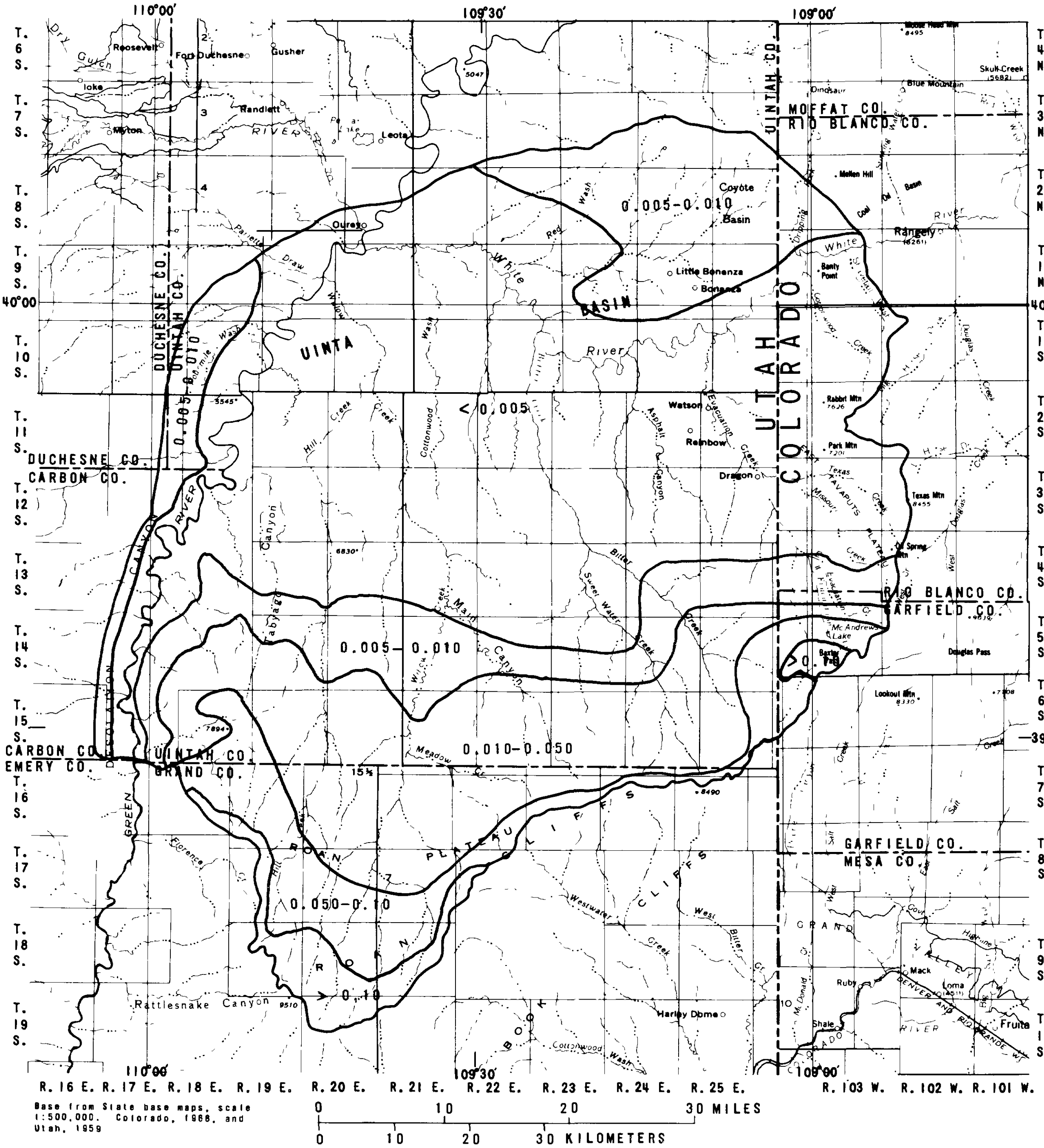


Figure 12. Relation of average annual runoff to mean altitude.



EXPLANATION

0.050–0.10 Range of average annual runoff, in cubic feet per second per square mile

——— Boundary of the study area

Figure 13. Variance in average annual runoff.

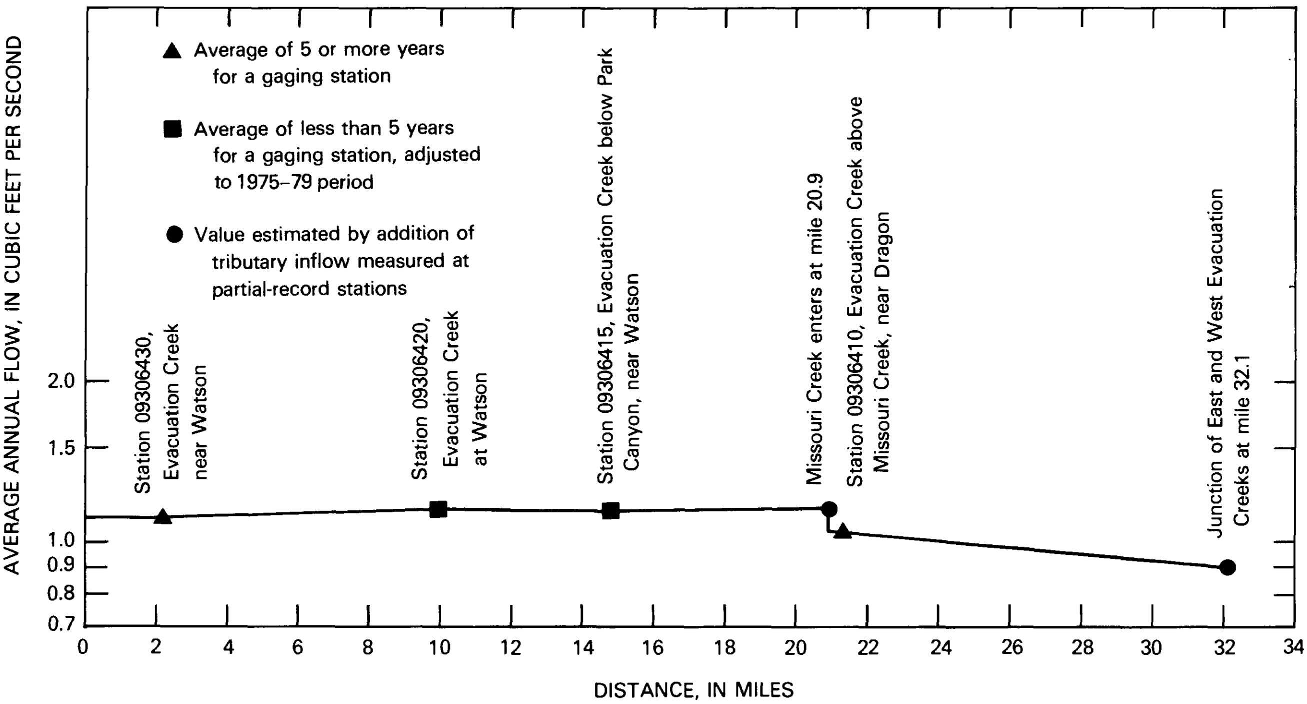


Figure 14. Relation of average annual flow in Evacuation Creek to distance upstream from mouth.

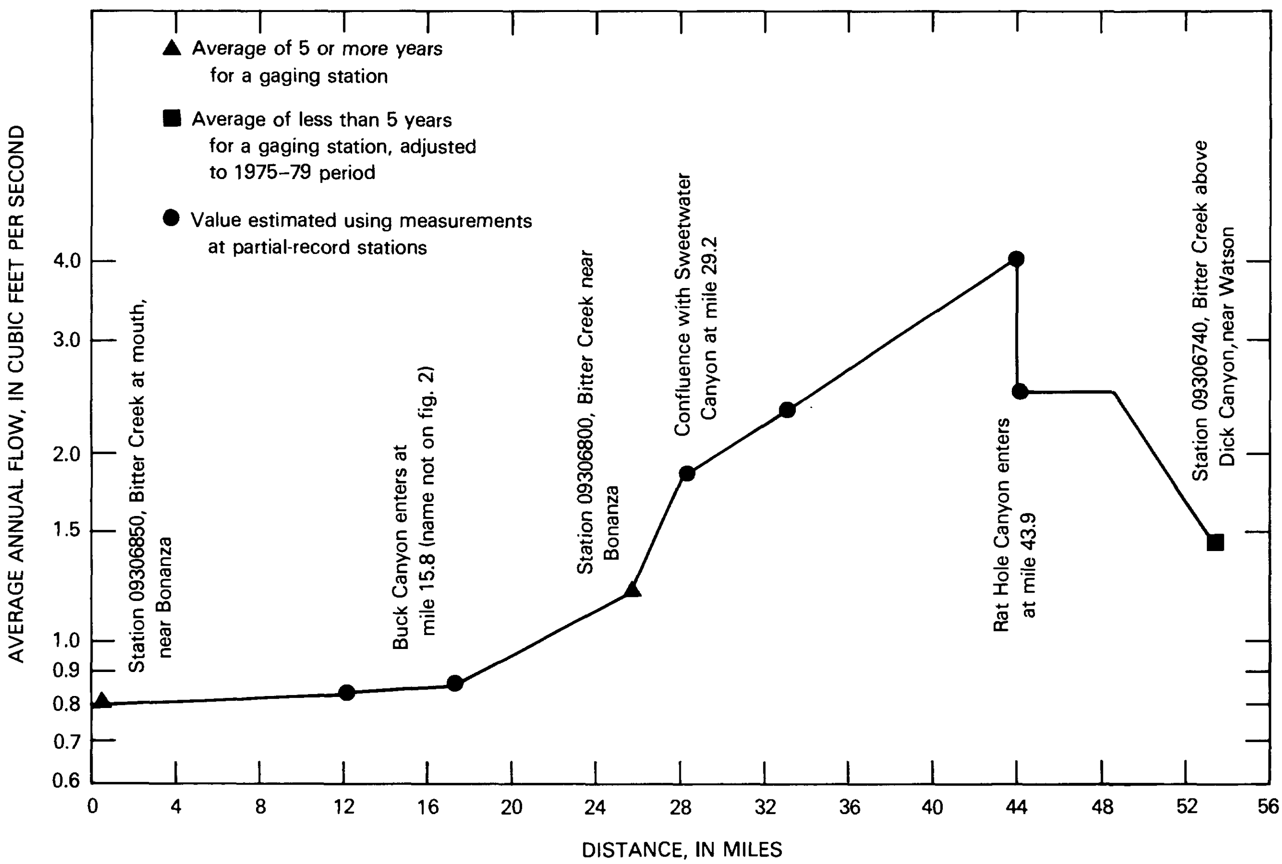


Figure 15. Relation of average annual flow in Bitter Creek to distance upstream from mouth.

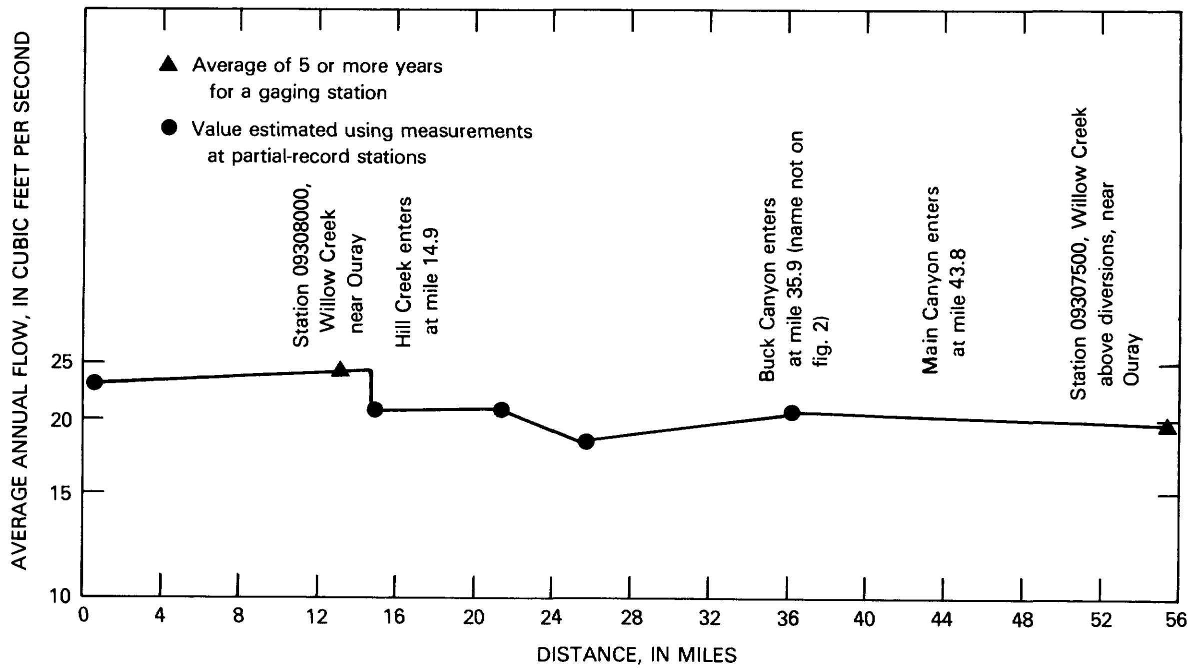


Figure 16. Relation of average annual flow in Willow Creek to distance upstream from mouth.

often on the average the deficiency will occur and how long the shortage can be expected to last. The annual minimum 1-day flow will be less than 250 ft^3/s at intervals averaging between 1 and 2 years; the annual minimum 7-day flow will be less than 250 ft^3/s, or insufficient at intervals averaging about 2 years; the annual minimum 30-day flow will be insufficient about every 3 years; and the annual minimum 90-day flow will be insufficient about every 10 years.

Storage Requirements

With information on intensity, duration, and frequency of droughts, it is possible to investigate the option of storing water during periods of excess flow to alleviate the effects of insufficient flow. The flows of the White and Green Rivers are variable and are less than their average annual flows about 75 percent of the time (figs. 25 and 26 and table 2). If the demand for water from these rivers is a constant amount, the withdrawal would be limited by the minimum flows unless storage is provided. If surface water were the only option considered for water supply, then it would become necessary to consider storing water for use during periods of insufficient flow.

Storage can be replenished each year if the average draft rate is less than the minimum annual mean flow. Variations of inflow within each year then determine the required seasonal storage. The average or mean annual flows are 695 ft^3/s (1924–79) for the White River and 5,900 ft^3/s (1965–79) for the Green River. These values occur at approximately the 25-percent duration points, and these rivers generally will support demands of about 45 percent of the average annual flow without carryover storage. For greater draft rates, the volume of water used cannot be replaced within some years and carryover, or over-year storage, is required.

Draft-storage curves show the volumes of storage required to maintain specific draft rates while allowing for the probability of failure. Using the records of streamflow at station 09306500, White River near Watson, and station 09315000, Green River at Green River, draft-storage curves were prepared by the procedures outlined by Riggs and Hardison (1973, p. 1–20). (See figures 31 and 32.) The computations resulted in combining seasonal with over-year storage to give storages required to meet only water-supply withdrawals, with no allowances for reservoir evaporation and other losses or instream uses. The actual design of a storage reservoir should take into account the reservoir site, silt accumulation, evaporation, possible leakage, unusable storage below water-supply outlets, and requirements for minimum releases for instream uses.

As an example of the use of the draft-storage curves in figures 31 and 32, assume that the total water requirement at a site on the White River is 250 ft^3/s. Figure 25 indicates that the White River will be unable to meet the requirement 5 percent of the time. Figure 29 shows that daily flow will be insufficient to satisfy the draft of 250 ft^3/s at intervals between 1 and 2 years. If the user cannot afford to be without water for a day every 1–2 years on the average, 7 days every 2 years, 30 days every 3 years, or 90 days every 10 years, a reservoir must be built with

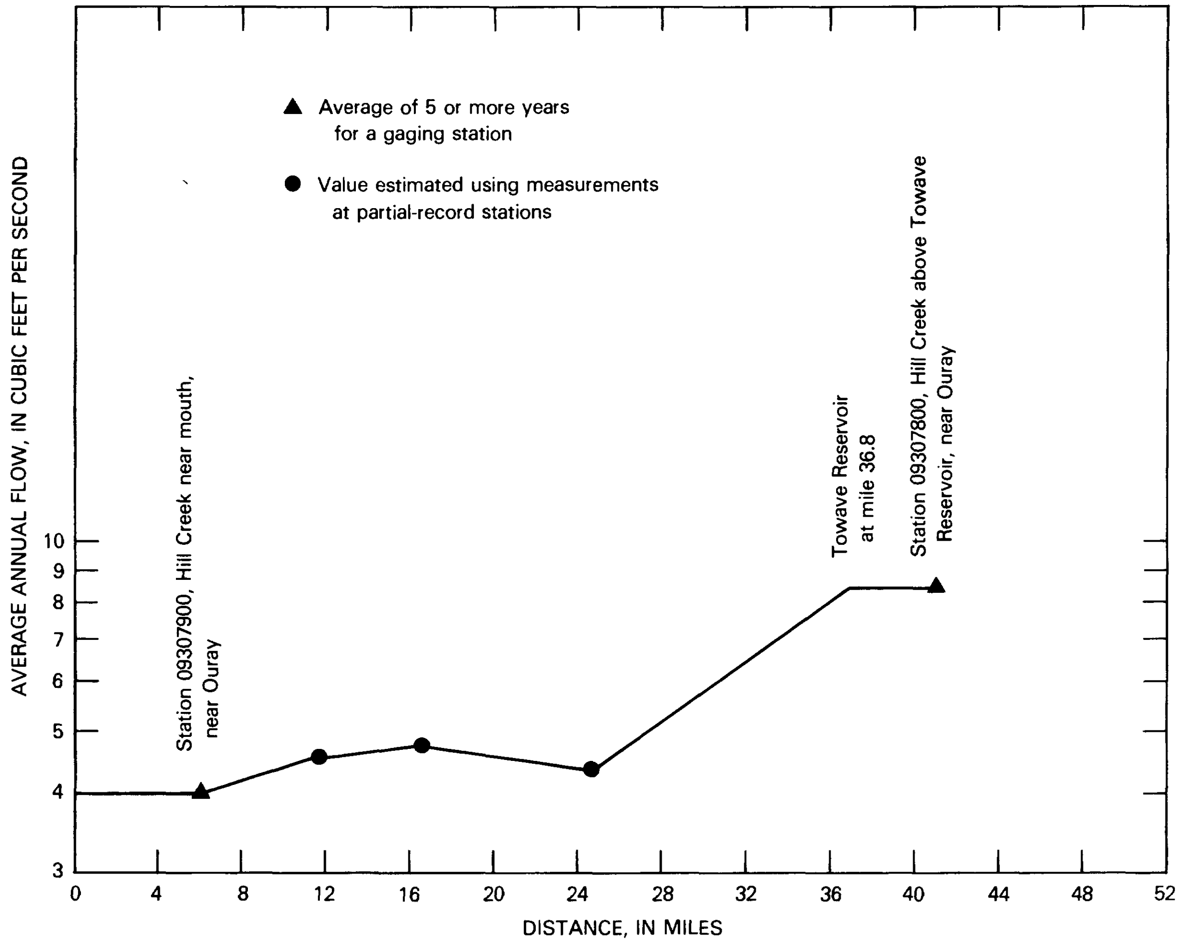


Figure 17. Relation of average annual flow in Hill Creek to distance upstream from mouth.

enough storage to maintain the draft of 250 ft^3/s during dry periods. Figure 31 shows that to meet the sustained demand of 250 ft^3/s (36 percent of 695 ft^3/s), a storage capacity of 5,040 acre-ft (0.01 x 504,000 acre-ft) would be required. This value represents a 5-percent chance of deficiency, or insufficient capacity to sustain the demand on the average of once in 20 years. This chance of deficiency does not imply that failure will occur once in each 20 years; but for a long period of operation, failure will occur on the average of once in 20 years. For example, during 100 years of operation, failure would be expected to occur five times; thus the chance of failure in any one year is 5 percent.

If a smaller chance of failure were desired for a site on the White River, the recurrence-interval curve for 50 years (2-percent chance of deficiency in any given year) in figure 31 can be used in determining the storage required. It would require 25,200 acre-ft of storage to reduce the chance of failure in any given year to 2 percent. Because of the short period of record since regulation began at Flaming Gorge Reservoir, a curve for the 50-year recurrence interval is not shown in figure 32.

Intra-Area Streams

If all the streamflow from the intra-area streams were captured, only 34,000 acre-ft would be available in an average year. This is less than 1 percent of the average flow of the Green River. More than half of all the runoff from the intra-area streams is measured at station 09308000, Willow Creek near Ouray, where sufficient records are available for defining low-flow characteristics. In addition to the records at station 09308000, 23 years of record are available for station 09307500, Willow Creek above diversions, near Ouray, which measures perennial flow of the headwaters of Willow Creek.

Many of the intra-area streams outside of the Willow Creek drainage flow for less than 30 days during most

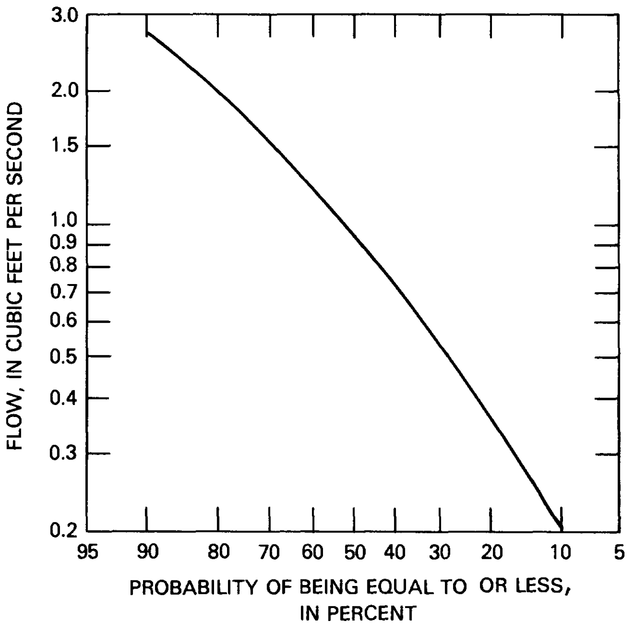


Figure 18. Frequency curve of annual mean flow at station 09306800, Bitter Creek near Bonanza, water years 1971–79.

years, and the volumes of runoff are small; thus these streams have little potential for water supply. Therefore, except for Willow Creek, only the general distribution of flow for the intra-area streams is evaluated in this report.

Flow Duration

Figure 33 shows flow-duration curves for stations 09307500, Willow Creek above diversions, near Ouray, and 09308000, Willow Creek near Ouray. The entire period of record (table 4) was used for each station. As shown in figure 33, the flow at station 09307500 is less variable than that at station 09308000. The shape of the duration curve for station 09307500 generally is flatter and more representative of base flow in perennial streams that originate at altitudes above 8,500 ft and have mean basin altitudes greater than 7,500 ft. The steeper slope of the duration curve for station 09308000 represents the intermittent flow resulting from diversions and channel losses as the flow travels through areas where annual runoff is less than 0.005 ($ft^3/s)/mi^2$ (fig. 13) and where evapotranspiration is considerable.

Figures 34 and 35, which are daily-duration hydrographs for stations 09307500 and 09308000, identify the

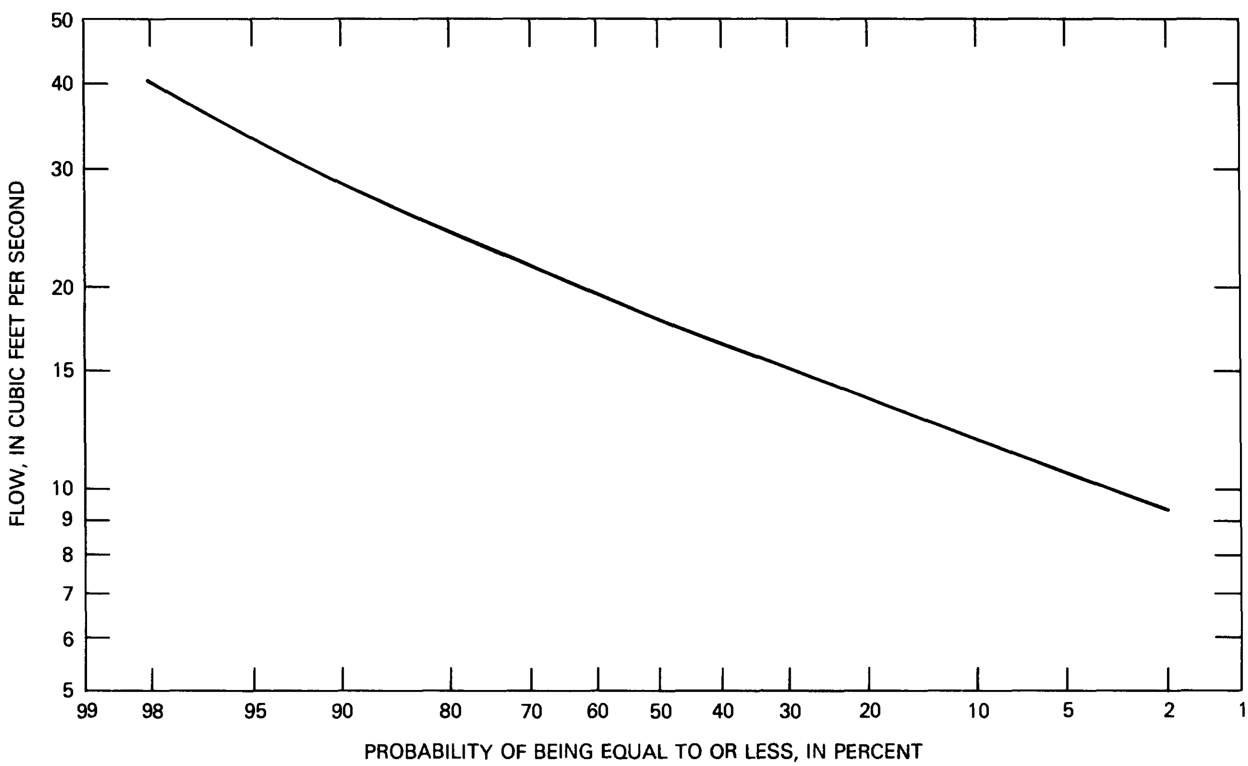


Figure 19. Frequency curve of annual mean flow at station 09307500, Willow Creek above diversions, near Ouray, water years 1951–55, 1958–70, 1975–79.

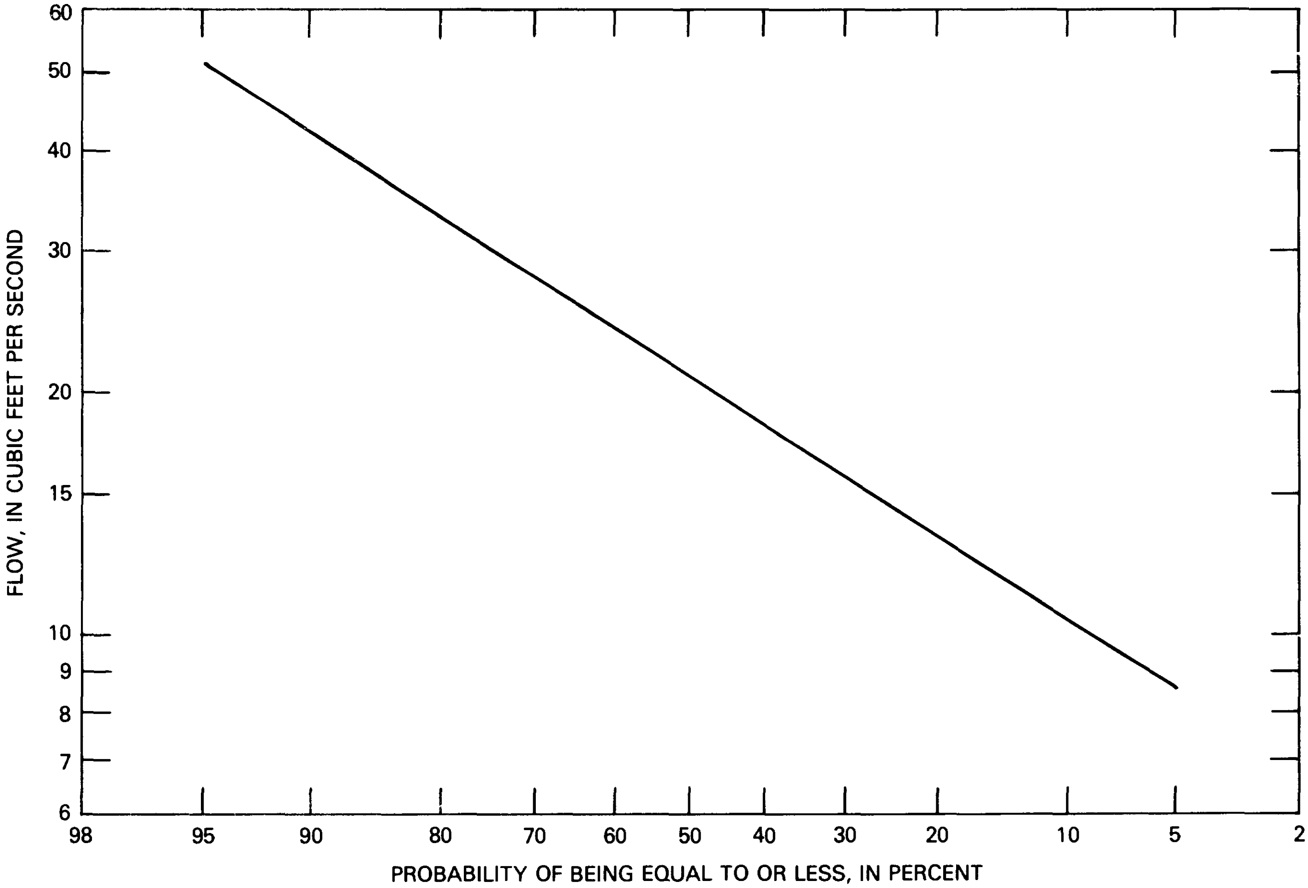


Figure 20. Frequency curve of annual mean flow at station 09308000, Willow Creek near Ouray, water years 1948–55, 1975–79.

percent chance flows for each calendar day will equal or exceed certain values. For Willow Creek, the distribution of flows throughout the year is similar to those for the major rivers. The higher flows resulting from snowmelt runoff generally occur from March to June, with minimum flows during winter and summer.

Figure 36 shows the range of duration curves at all 14 stations with 4 or more years of record on the intra-area streams, including Willow Creek. The lower boundary represents minimum flow per square mile, and the upper boundary represents maximum flow. The spread between the two boundaries is due to differences in flow characteristics among the streams. Those that plot near the lower boundary are ephemeral and drain areas at lower altitudes where annual precipitation generally is less than 10 in. Those that plot near the upper boundary drain areas at higher altitudes where annual precipitation generally exceeds 15 in.

Low-Flow Frequency

Only the two Willow Creek stations have enough record (more than 10 years) for frequency analysis (figs. 37 and 38). Most of the intra-area streams do not flow for 30 or more days during most years; thus the low flow for 30 consecutive days or less at most sites is zero. Exceptions are sites such as station 09306850, Bitter Creek at mouth, near Bonanza, where a spring discharges near the gaging station. The streamflow disappears within a few miles of the springs.

The perennial flow for small streams originating at altitudes above 8,500 ft should have flow per square mile similar to that at station 09307500 (fig. 37), Willow Creek above diversions, near Ouray. At most sites, the 7-day, 10-year low flow (minimum average flow for 7 consecutive days with a recurrence interval of 10 years) is zero. Even at sites where the 7-day, 10-year low flow is not zero, values are small.

Storage Requirements

With the exception of Willow Creek, the intra-area streams have little potential for water supply. Draft-storage relations for the two Willow Creek gaging stations are shown in figures 39–40 for 2, 5, and 10 percent chances of deficiency. The average annual flows in Wil-

Table 4. Average annual flow and average, maximum, and minimum monthly mean flow for continuous-record gaging stations on intra-area streams

Station No.	Period of record (water years)	Average-annual flow (ft^3/s)		Monthly mean flow (ft^3/s)											
				Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
09306405	1975–79	0.06	Average	0.07	0.05	0	0	0.06	0.06	0.10	0.02	0.01	0.17	0.03	0.22
			Maximum	.35	.26	0	0	.25	.17	.50	.07	.03	.79	.11	.76
			Minimum	0	0	0	0	0	0	0	0	0	0	0	0
09306410	1975–79	1.04	Average	.51	.63	.38	.36	1.89	1.34	1.32	2.63	1.02	.91	.98	.51
			Maximum	1.12	1.30	.45	.41	7.83	2.71	1.92	4.78	2.12	1.41	2.70	.98
			Minimum	.26	.28	.26	.29	.30	.42	.48	.48	.36	.37	.25	.18
09306415	1975	......	Average	.20	.20	.20	.20	.10	2.31	2.25	6.12	1.24	.83	.17	.91
			Maximum	......	......	......	......	......	......	......	......	......	......	......	......
			Minimum	......	......	......	......	......	......	......	......	......	......	......	......
09306417	1975	......	Average	0	0	0	0	0	0	0	0	0	0	0	0
			Maximum	......	......	......	......	......	......	......	......	......	......	......	......
			Minumum	......	......	......	......	......	......	......	......	......	......	......	......
09306420	1975–76	......	Average	.02	.04	.11	.08	3.36	2.33	2.28	4.50	.79	.93	.84	1.16
			Maximum	.05	.06	.15	.10	6.46	2.68	2.45	5.25	1.48	1.21	1.61	1.96
			Minimum	.01	.03	.06	.07	.25	1.98	2.12	3.76	.10	.65	.07	.37
09306425	1975	......	Average	0	0	0	0	0	0	0	0	0	0	0	0
			Maximum	......	......	......	......	......	......	......	......	......	......	......	......
			Minimum	......	......	......	......	......	......	......	......	......	......	......	......
09306430	1975–79	1.11	Average	.28	.24	.04	.03	2.08	1.97	1.75	2.91	.60	1.27	1.19	1.00
			Maximum	1.13	1.01	.05	.04	10.1	5.25	5.23	5.92	1.30	4.03	2.43	2.04
			Minimum	.04	.02	.02	.02	.02	.04	.02	.02	.02	.14	.20	.04
09306605	1975–76	......	Average	0	0	0	0	.01	0	0	0	0	0	0	0
			Maximum	0	0	.01	0	.03	0	0	0	0	0	0	0
			Minumum	0	0	0	0	0	0	0	0	0	0	0	0
09306610	1975–76	......	Average	.04	.12	0	0	.17	.03	.02	0	.03	0	0	0
			Maximum	.08	.23	0	0	.31	.06	.03	0	.06	0	0	0
			Minimum	0	0	0	0	.02	0	0	0	0	0	0	0
09306620	1975–76	......	Average	0	0	0	0	.18	0	0	0	0	.03	0	.03
			Maximum	0	0	0	0	.25	0	0	0	0	.06	.01	.06
			Minimum	0	0	0	0	.11	0	0	0	0	0	0	0
09306625	1975–79	.05	Average	.01	0	0	0	.05	.34	.09	0	.03	.03	.04	.04
			Maximum	.03	0	0	0	.24	1.70	.42	0	.15	.16	.12	.09
			Minimum	0	0	0	0	0	0	0	0	0	0	0	0

09306740	1975–78	1.45	Average	.94	.79	.81	.59	.53	.80	1.56	3.50	3.59	1.81	1.36	1.08
			Maximum	1.44	1.02	1.27	1.05	1.02	1.33	1.89	6.24	6.82	3.17	2.43	1.91
			Minumum	.42	.46	.41	.34	.10	.37	1.10	.83	.50	.48	.50	.32
09306760	1975–78	.43	Average	.38	.40	.44	.39	.38	.62	.71	.43	.37	.34	.37	.33
			Maximum	.45	.44	.63	.45	.45	1.26	1.58	.60	.40	.39	.45	.39
			Minimum	.34	.35	.30	.30	.30	.40	.41	.34	.34	.31	.31	.30
09306780	1975–78	.09	Average	0	0	0	.01	.32	.39	.22	.01	0	.14	0	0
			Maximum	0	0	.01	.03	.81	.57	.37	.03	.01	.54	0	.01
			Minimum	0	0	0	0	.02	.18	.08	0	0	0	0	0
09306800	1971–79	1.20	Average	.46	.74	.69	.72	1.01	1.94	2.71	2.31	1.76	1.50	.48	.10
			Maximum	1.72	2.26	2.08	2.69	2.98	5.19	4.96	4.92	5.54	6.59	1.97	.51
			Minimum	0	0	0	0	0	.19	.44	.39	.12	0	0	0
09306850	1975–79	.80	Average	.57	.58	.55	.59	.96	1.11	1.00	1.27	1.27	.60	.62	.51
			Maximum	.65	.65	.66	.75	2.29	2.48	1.42	2.88	2.51	.82	.94	.59
			Minumum	.46	.42	.49	.51	.56	.61	.60	.60	.47	.42	.30	.42
09306870	1975–78	.01	Average	.01	0	0	0	.03	.04	0	0	0	.02	.02	.01
			Maximum	.02	0	0	0	.05	.10	0	0	0	.04	.08	.02
			Minimum	0	0	0	0	0	0	0	0	0	0	0	0
09306872	1977–78	......	Average	0	0	0	0	0	.64	.01	.01	.07	.02	.05	0
			Maximum	0	0	0	0	0	1.29	.02	.02	.14	.03	.10	0
			Minimum	0	0	0	0	0	0	0	0	0	0	0	0
09306878	1977–79	3.87	Average	1.16	1.37	0	0	.03	35.6	3.28	.17	.02	2.63	1.16	.35
			Maximum	2.07	3.84	0	0	.09	74.9	7.48	.47	.07	7.66	2.02	.67
			Minimum	0	0	0	0	0	.13	.35	0	0	0	.31	0
09306885	1977–78	.06	Average	0	0	0	0	0	.41	0	0	0	.34	.01	0
			Maximum	0	0	0	0	0	.82	0	0	0	.68	.03	0
			Minumum	0	0	0	0	0	0	0	0	0	0	0	0
09307500	1951–55, 1958–70, 1975–79	20.1	Average	13.3	13.4	11.7	11.6	14.4	25.8	41.6	46.2	24.1	14.5	12.6	11.0
			Maximum	20.5	19.2	17.3	16.7	29.5	59.9	132	139	74	31.6	20.9	19.2
			Minimum	7.31	7.51	7.45	5.48	8.0	12.8	20.8	13.7	4.8	1.31	1.68	3.53
09307800	1975–79	8.54	Average	5.02	5.53	5.32	5.24	4.7	6.66	10.1	21.4	19.5	9.10	5.17	4.45
			Maximum	8.38	7.21	8.32	7.71	5.28	8.92	12	51.2	44	17.8	11.1	7.58
			Minimum	3.16	4.0	4.0	3.51	3.87	3.25	7.39	6.14	3.7	1.4	.97	1.11
09307900	1975–79	3.98	Average	.25	.33	.06	.11	1.27	5.85	6.47	14.2	14.0	3.32	1.77	.04
			Maximum	1.17	1.57	.28	.48	2.46	12.5	9.90	42.3	41.4	7.82	3.81	.12
			Minimum	0	0	0	0	0	.14	2.12	.07	0	0	0	0
09308000	1948–55, 1975–79	24.2	Average	14.1	17.8	14.4	13.5	16.7	34.1	54.2	60.8	30.5	16.2	10.4	7.56
			Maximum	37.5	39.2	27.7	20.0	25.6	50.7	120	222	94.9	59.9	49.8	28.9
			Minumum	.09	6.55	3.58	4.35	7.41	16.9	10.3	2.62	.44	.01	0	0

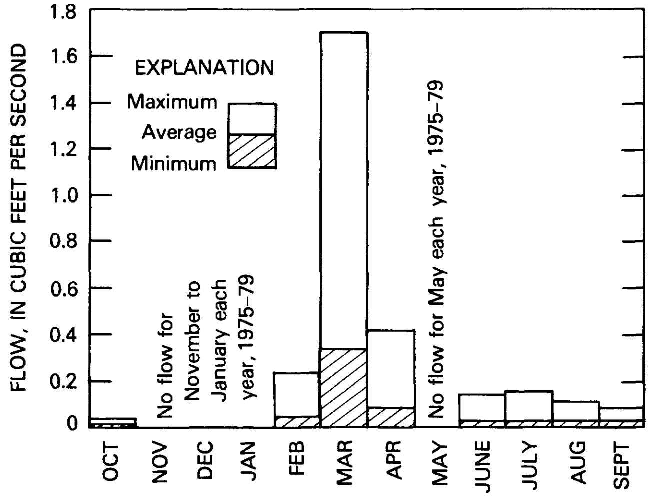


Figure 21. Average, maximum, and minimum monthly mean flows at station 09306625, Asphalt Wash near mouth, near Watson, water years 1975–79.

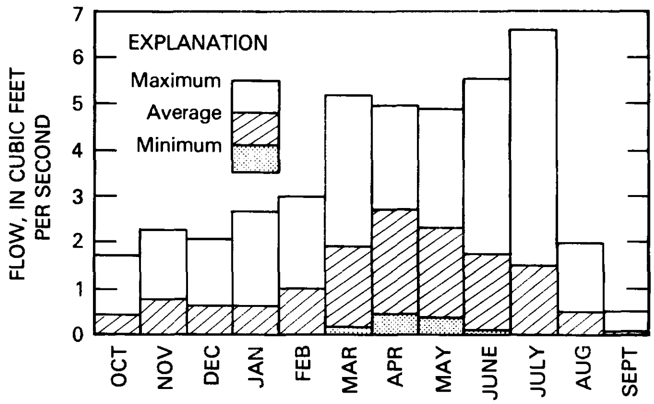


Figure 22. Average, maximum, and minimum monthly mean flows at station 09306800, Bitter Creek near Bonanza, water years 1971–79.

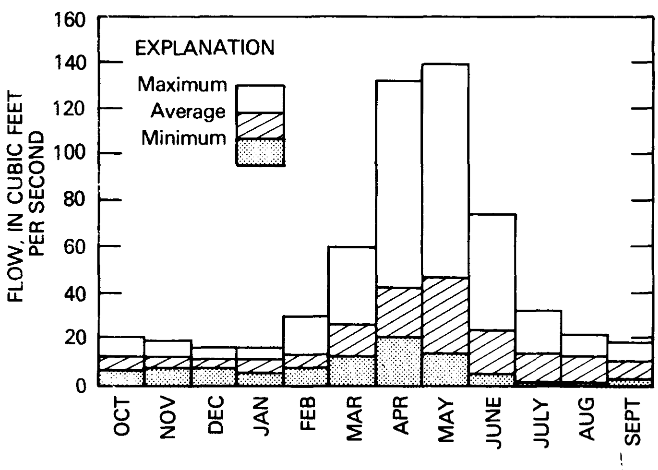


Figure 23. Average, maximum, and minimum monthly mean flows at station 09307500, Willow Creek above diversions, near Ouray, water years 1951–55, 1958–70, 1975–79.

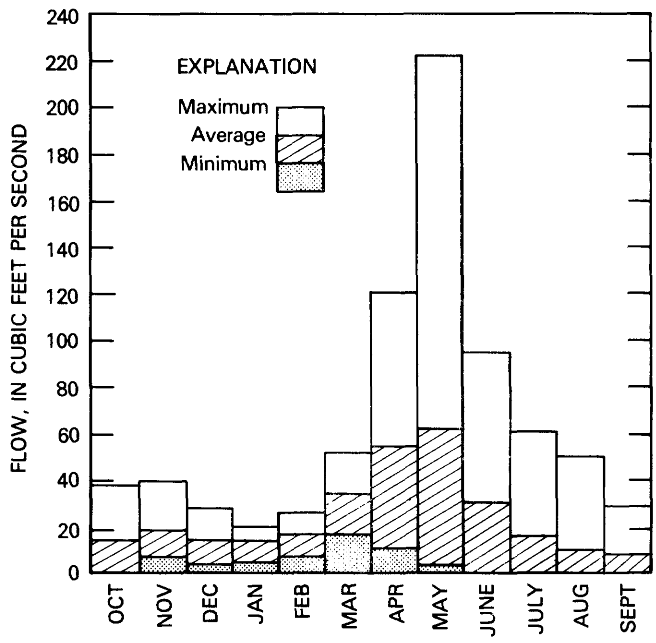


Figure 24. Average, maximum, and minimum monthly mean flows at station 09308000, Willow Creek near Ouray, water years 1948–55, 1975–79.

low Creek occur at approximately 30-percent duration points (fig. 33), and the stream generally will support demands of about 40 percent of the average annual flow without over-year storage.

High Flows

Major Rivers

Peak-Flow Frequencies

Figures 41 and 42 show flood-frequency curves for the White and Green Rivers. The curves are based on observed records (annual maximums or peak flows), which were fitted to log-Pearson Type III frequency relations according to the recommendation of the U.S. Water Resources Council (1981).

Each frequency curve shows the average interval, in years, between floods that equal or exceed a given peak flow. This does not mean that floods occur with any regularity; the recurrence intervals are average values only. It would be possible to have two floods of 50-year recurrence interval in successive years or even in the same year. Figure 41 shows that a peak flow of 8,000 ft^3/s has a recurrence interval of about 50 years, thus indicating that about two flood peaks of at least 8,000 ft^3/s should occur

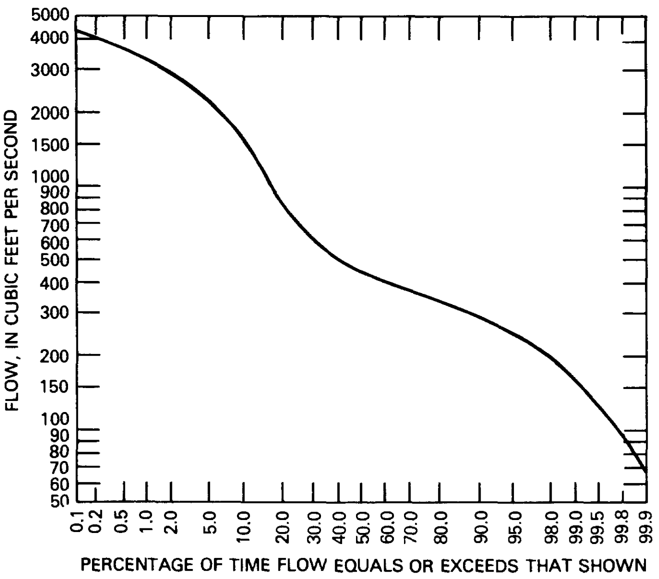


Figure 25. Duration of daily mean flow at station 09306500, White River near Watson, water years 1924–79.

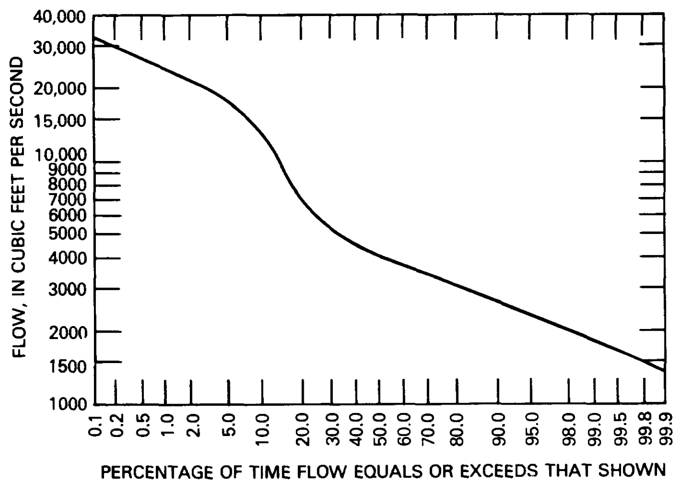


Figure 26. Duration of daily mean flow at station 09315000, Green River at Green River, water years 1965–79.

in 100 years. The probability of the peak flow equaling or exceeding 8,000 ft^3/s in any year is 2 percent.

The entire record (1904–05, 1923–79) for station 09306500, White River near Watson, was used for computing the frequency curve shown in figure 41, which is representative of the entire reach of the White River in the study area (fig. 4). Although the peak flow during the summer months may be significantly larger or smaller from one location to another, the annual peak flows are not significantly different. Of the 59 observed maximums for station 09306500, 34 resulted from snowmelt runoff and 25 from thunderstorm runoff. The annual maximum flows commonly occur from March to October.

For the Green River, only the records from 1965–79 for station 09315000, Green River at Green River, were used for computing the frequency curve shown in figure 42. This curve is representative of peak flows in the Green River since Flaming Gorge Reservoir exceeded 70 percent of its usable capacity, from the confluence of the Green River where the White River enters and downstream through Desolation Canyon (fig. 3). The Green River is regulated by Flaming Gorge Reservoir; thus figure 42 only represents what will happen in the future if operating procedures of the reservoir are not changed or regulation remains similar.

Annual Flood Volumes

Figures 43–44 show average rates of flow that are equaled or exceeded for durations of 1, 3, 7, and 15 consecutive days for the indicated recurrence intervals for the White and Green Rivers. The curves in figures 43–44 were computed by fitting log-Pearson Type III frequency relations to observed annual maximum average flows for the given number of days. As with the peak flow, the entire record for station 09306500, White River near Watson, was used, whereas only the records since 1965 were used for station 09315000, Green River at Green River. These floodflow frequency curves are useful for routing flow through reservoirs and for design of spillways.

Intra-Area Streams

Peak-Flow Frequencies

Only the two Willow Creek stations have enough record (more than 10 years) for defining frequency curves. Figure 45, which shows a composite frequency curve for stations 09307500 and 09308000, gives peak flow per square mile for the indicated recurrence intervals in years. Figure 45 is representative of all locations on the main stem of Willow Creek with drainage areas exceeding 100 mi^2.

All the remaining gaging stations on the intra-area streams have less than 10 years of record for annual maximums; thus frequency curves are not given for these stations. However, the mean annual peak flows were computed (log-Pearson Type III) for all stations with 4 or more years of record, and the results are summarized in table 5. Data are also included for station 09307200, Pariette Draw near Ouray, which is about 3 mi northwest of the study area (fig. 46). Efforts to relate mean annual peak flows with basin characteristics (Riggs, 1973, p. 1–15) were not successful when the entire study area was used, but good results were obtained by dividing the area into three subareas with similar flood characteristics as outlined in figure 46. Figures 47–49 show the relation of

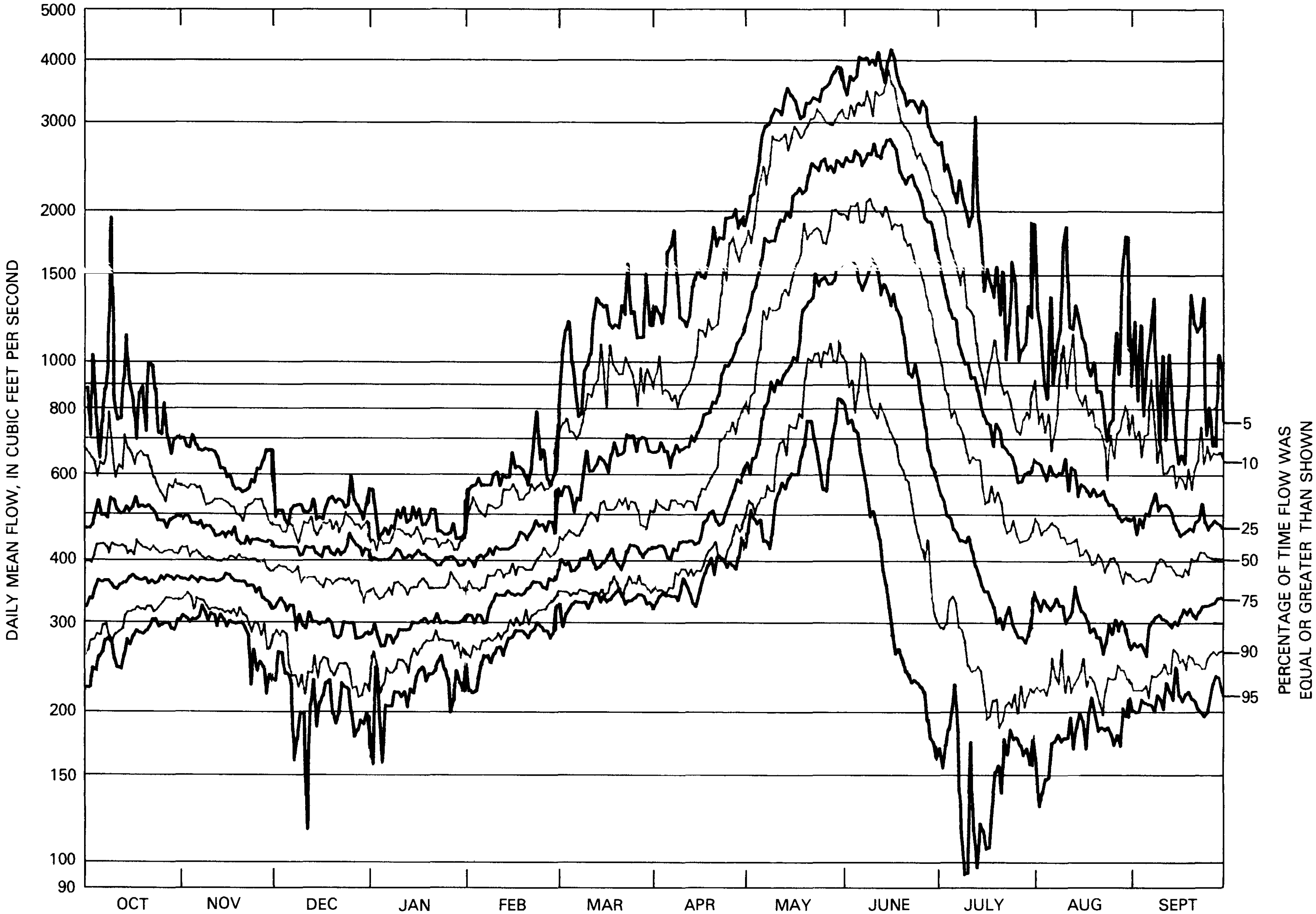


Figure 27. Daily-duration hydrographs for indicated percentage of time flow at station 09306500, White River near Watson, was equal to or greater than that shown, water years 1924–79.

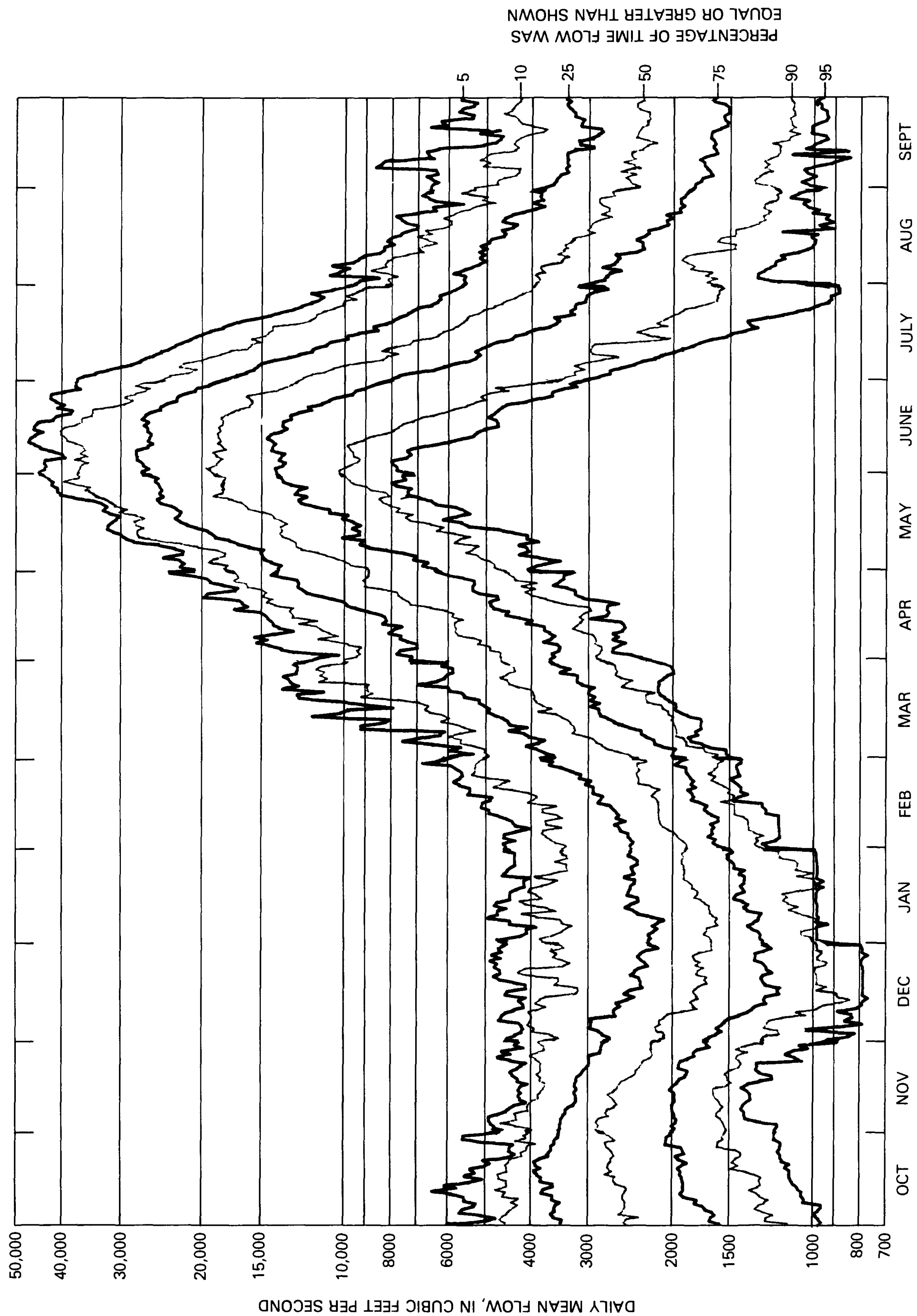


Figure 28. Daily-duration hydrographs for indicated percentage of time flow at station 09315000, Green River at Green River, was equal to or greater than that shown, water years 1965–79.

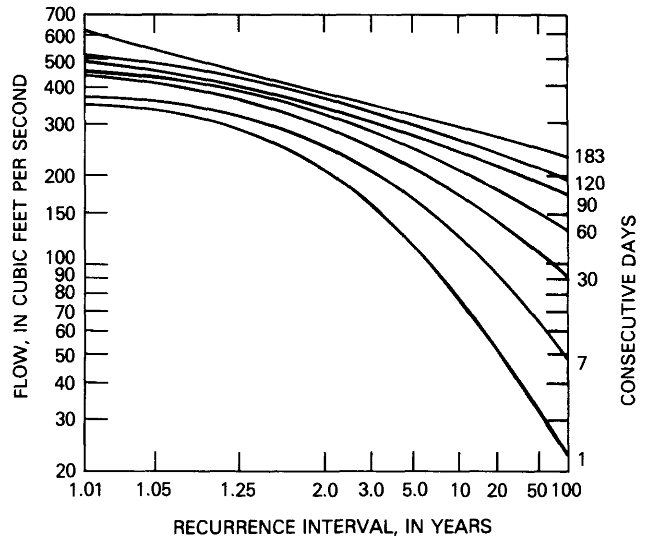


Figure 29. Magnitude and frequency of annual low flows at station 09306500, White River near Watson, years ending March 31, 1924–79.

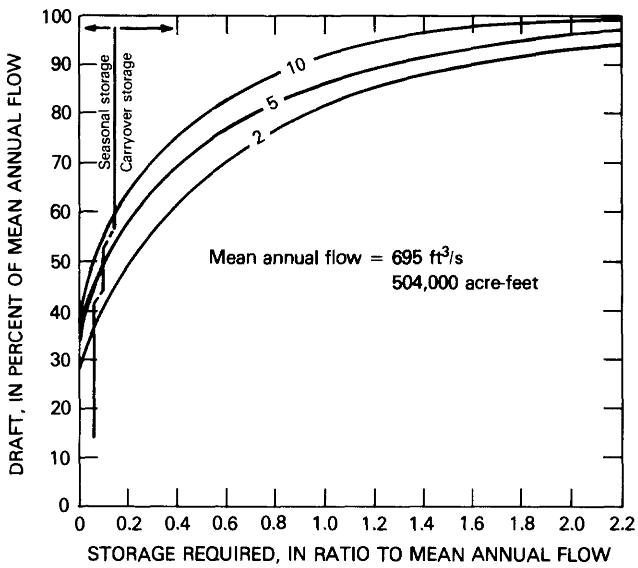


Figure 31. Draft-storage relations for indicated percentage chance of deficiency at station 09306500, White River near Watson, years ending March 31, 1924–79.

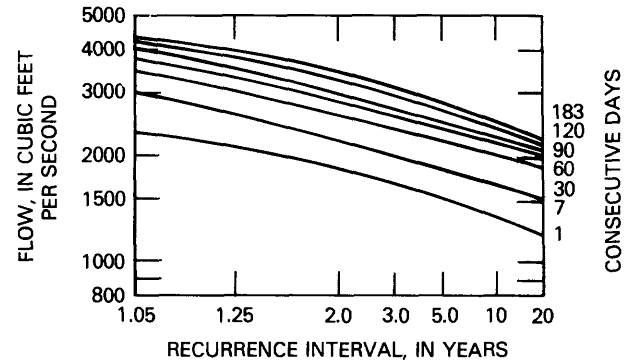


Figure 30. Magnitude and frequency of annual low flows at station 09315000, Green River at Green River, years ending March 31, 1965–79.

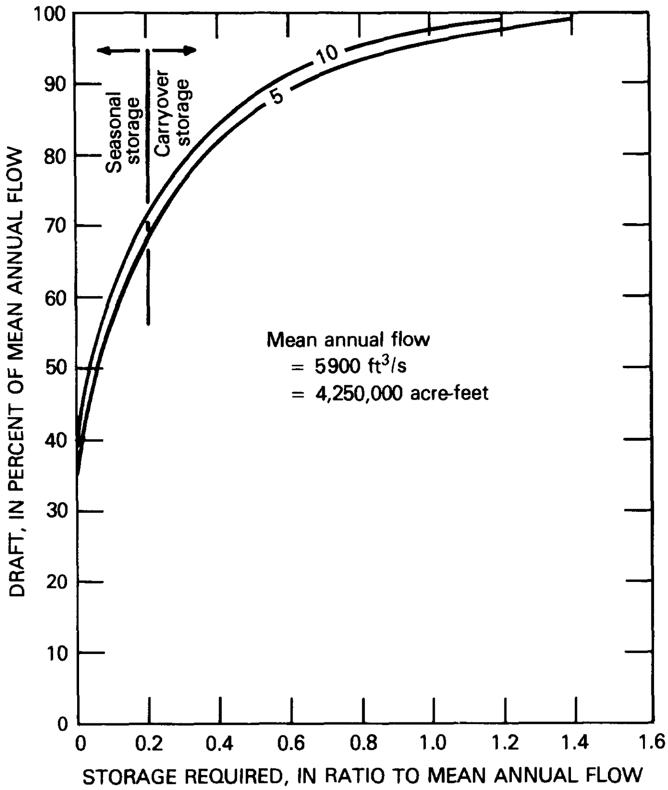


Figure 32. Draft-storage relations for indicated percentage chance of deficiency at station 09315000, Green River at Green River, years ending March 31, 1965–79.

mean annual peak flow to drainage area for the three subareas. Station 09306625 drains areas in both subareas A and C; thus the value for this station does not appear in figure 47 or 49.

For streams with drainage areas of the same size, flood peaks are largest in subarea A and smallest in subarea C. For streams which drain about 100 mi^2, the mean annual peak flows are 280 ft^3/s for subarea A, 55 ft^3/s for subarea B, and 12 ft^3/s for subarea C. These large differences in mean annual floods are attributed to differences in vegetative cover, soils, and snowmelt versus thunderstorm floods in the subareas. The soils in subarea A contain more clay and those in subarea C are more sandy. Snowmelt peaks are common in subarea B.

The relations shown in figures 47–49 can be used to estimate the mean annual peak flow at any ungaged site in the study area. Only the drainage area of the site on the stream is needed to use the estimating equations. The equations were derived by fitting least-squared regressions to the logarithms of each set of data for the three

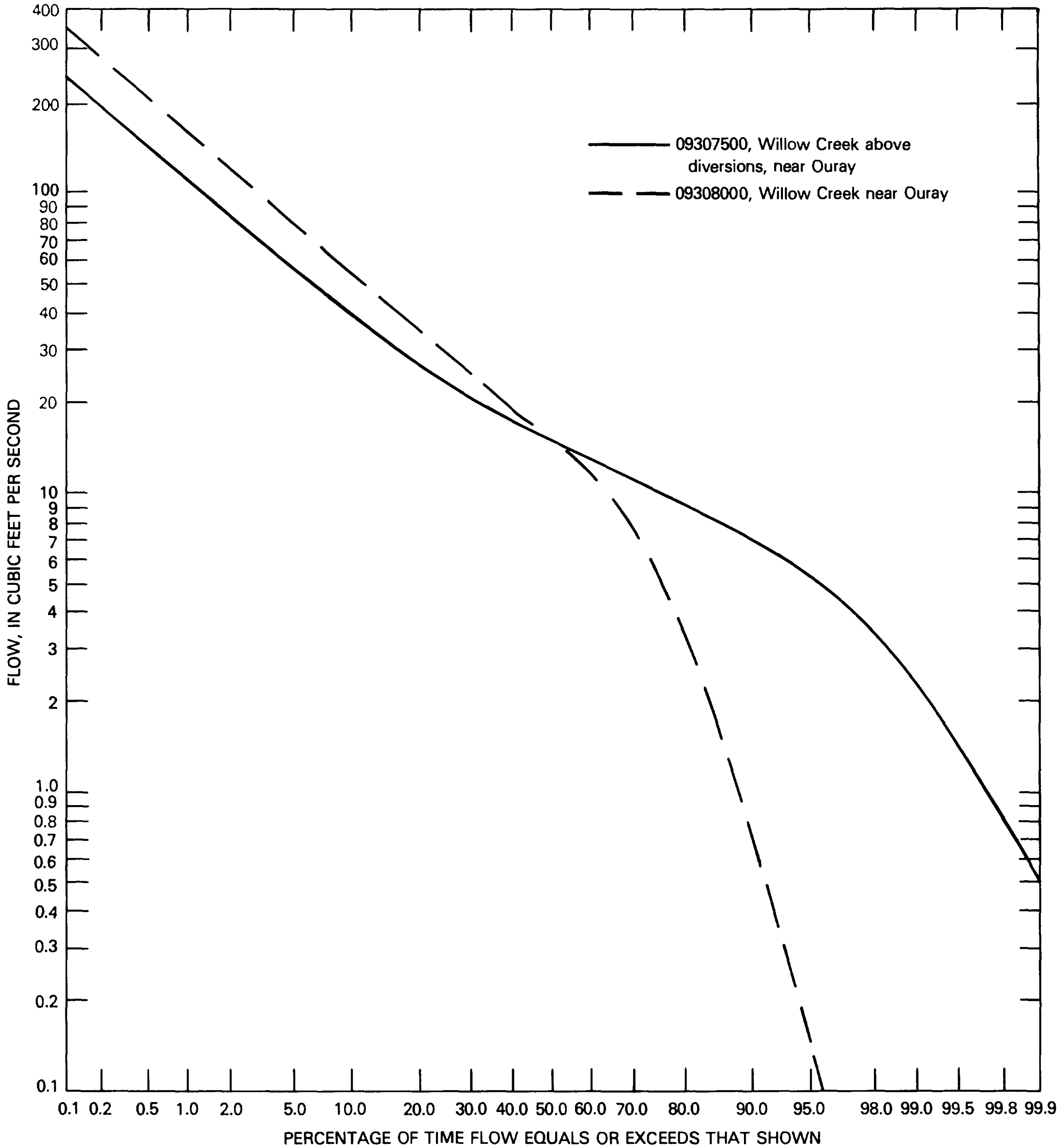


Figure 33. Duration of daily mean flow for two Willow Creek stations.

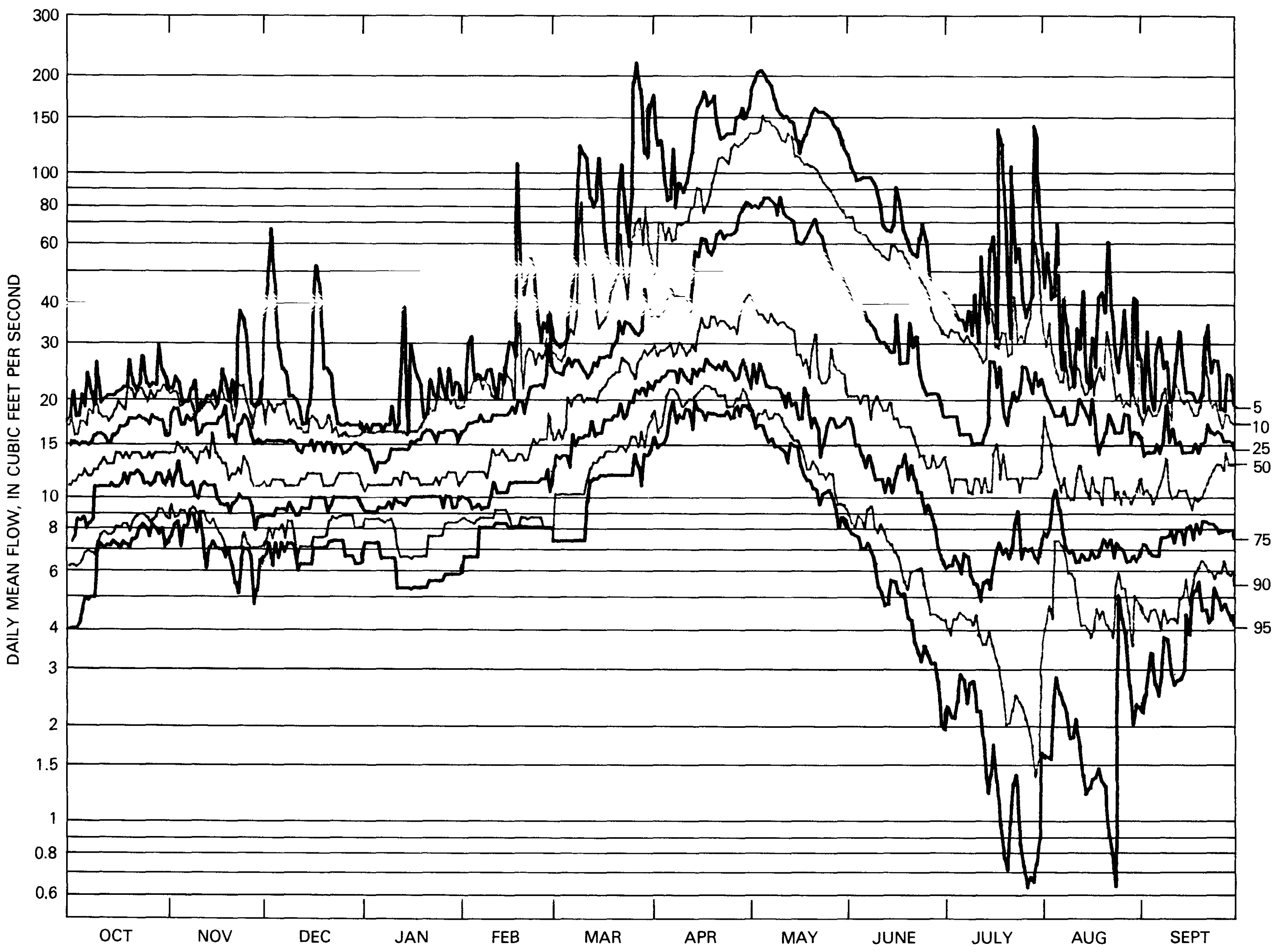


Figure 34. Daily-duration hydrographs for indicated percentage of time flow at station 09307500, Willow Creek above diversions, near Ouray, was equal to or greater than that shown, water years 1951–55, 1958–70, 1975–79.

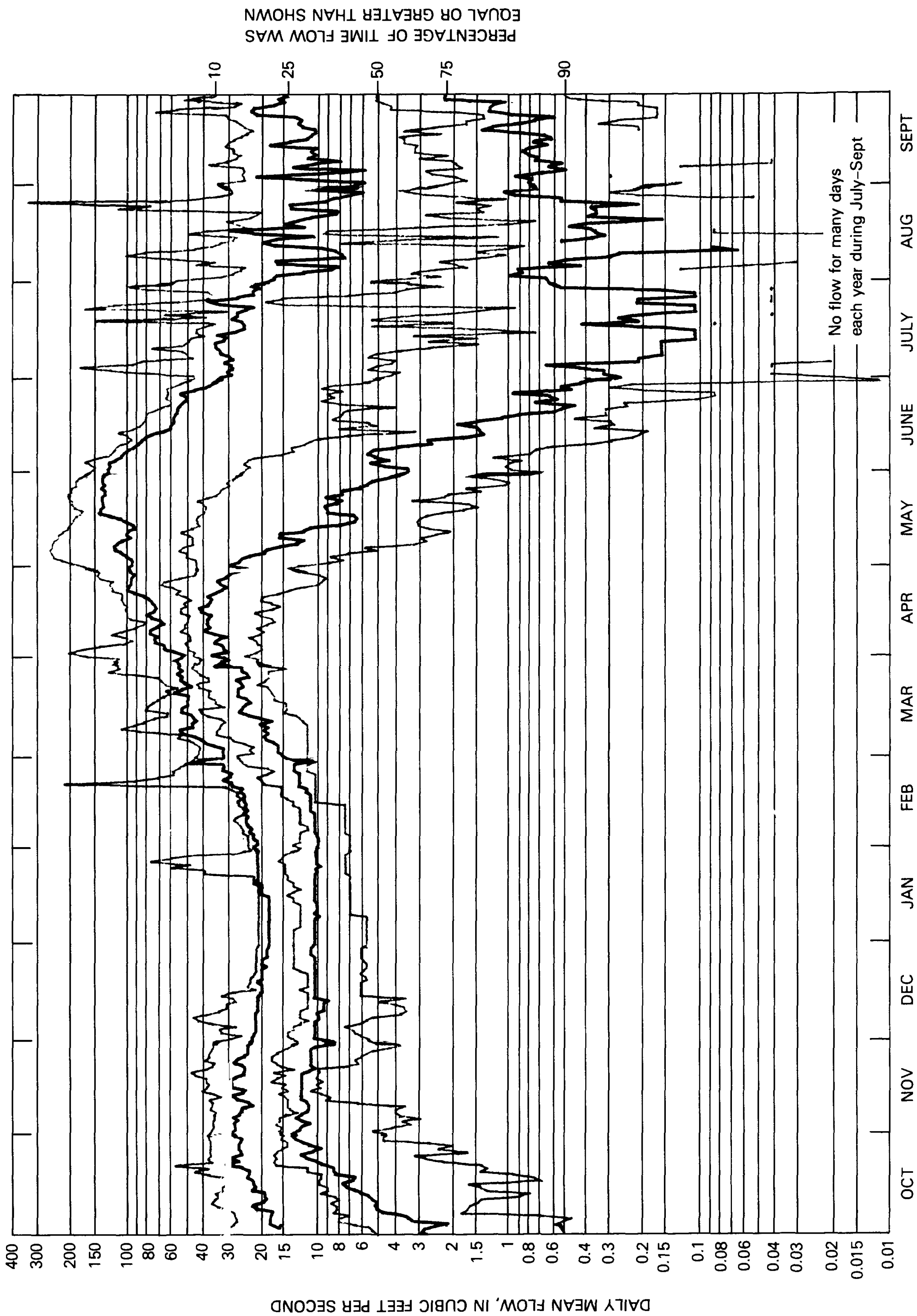


Figure 35. Daily-duration hydrographs for indicated percentage of time flow at station 09308000, Willow Creek near Ouray, was equal to or greater than that shown, water years 1948–55, 1975–79.

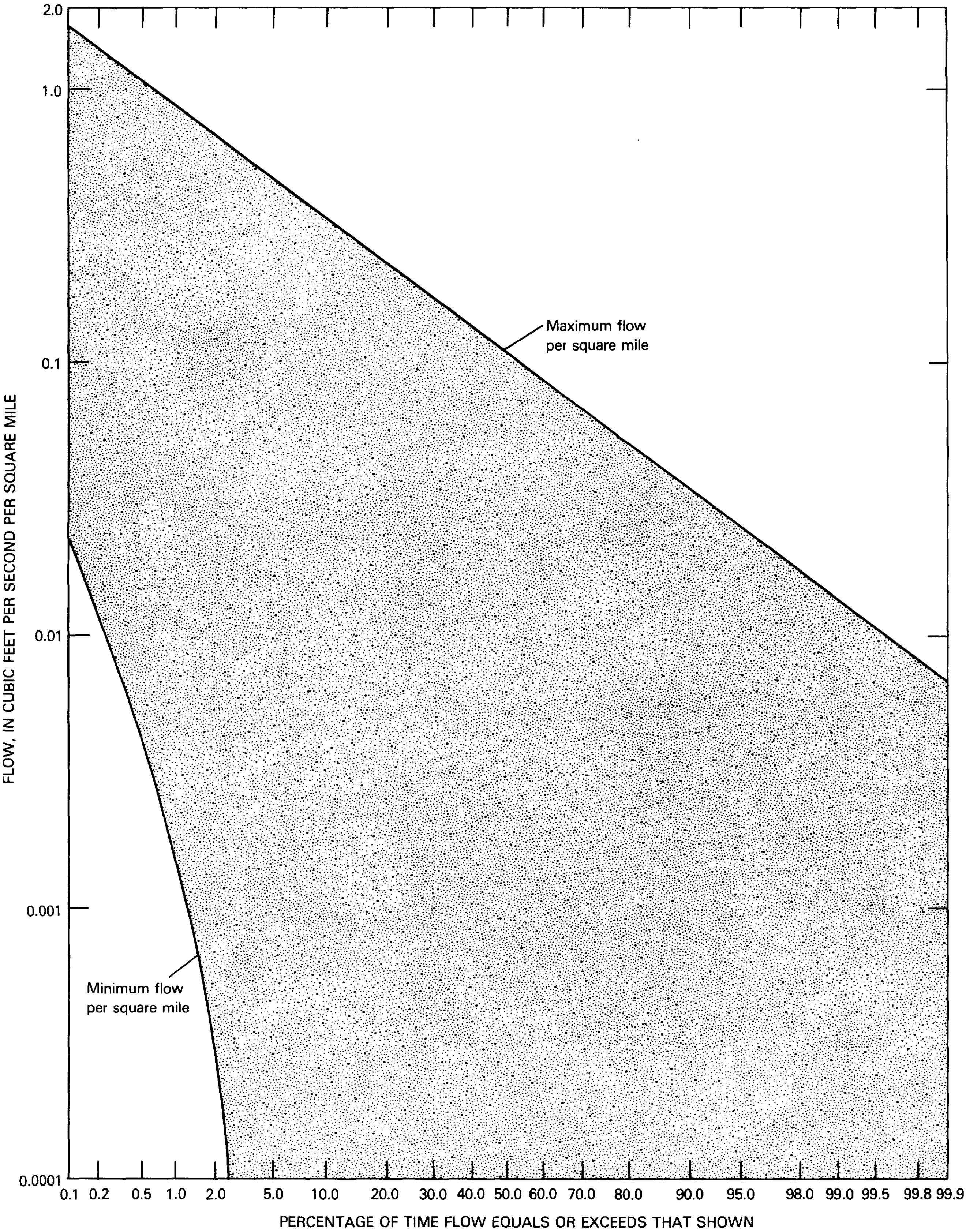


Figure 36. Range of duration of daily flows of the intra-area streams.

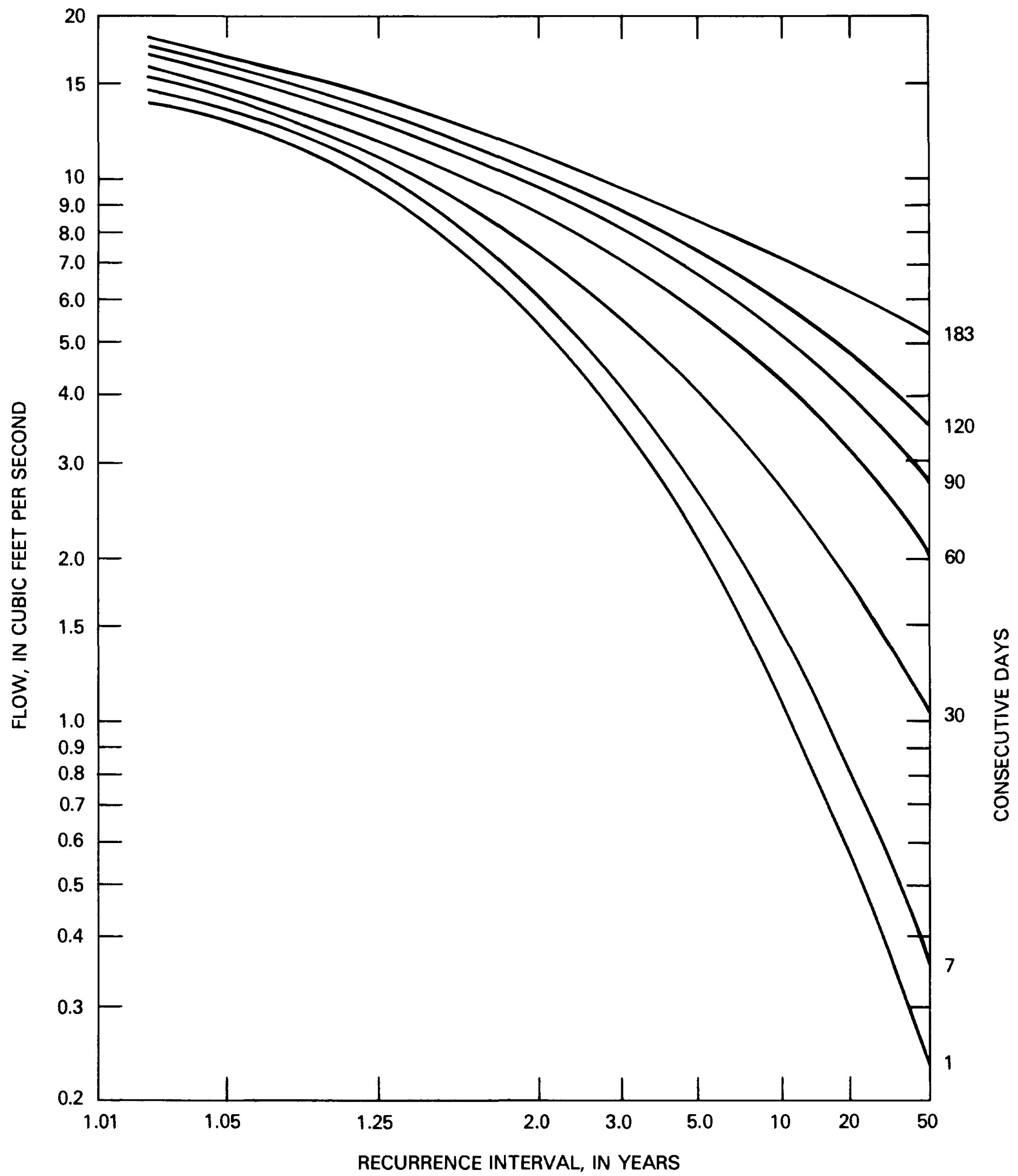


Figure 37. Magnitude and frequency of annual low flows at station 09307500, Willow Creek above diversions, near Ouray, years ending March 31, 1951–55, 1958–70, 1975–79.

subareas. Because the exponent of the drainage area was near unity, mathematical fits were made assuming the following:

$$Q_2 = C \times DA$$

where

Q_2 = the mean annual peak flow, in cubic feet per second;

C = a constant;

and

DA = the drainage area, in square miles.

The resulting equations are

Subarea A: $Q_2 = 2.8 \times DA$

B: $Q_2 = 0.55 \times DA$

C: $Q_2 = 0.12 \times DA$

Having provided a way to estimate the mean annual peak flow at ungaged sites, the next step is to provide a method for estimating the peak flows that are exceeded less frequently than the mean annual peak flows. This was done by plotting a curve to show the ratio of the less frequent peak flows to the mean annual peak

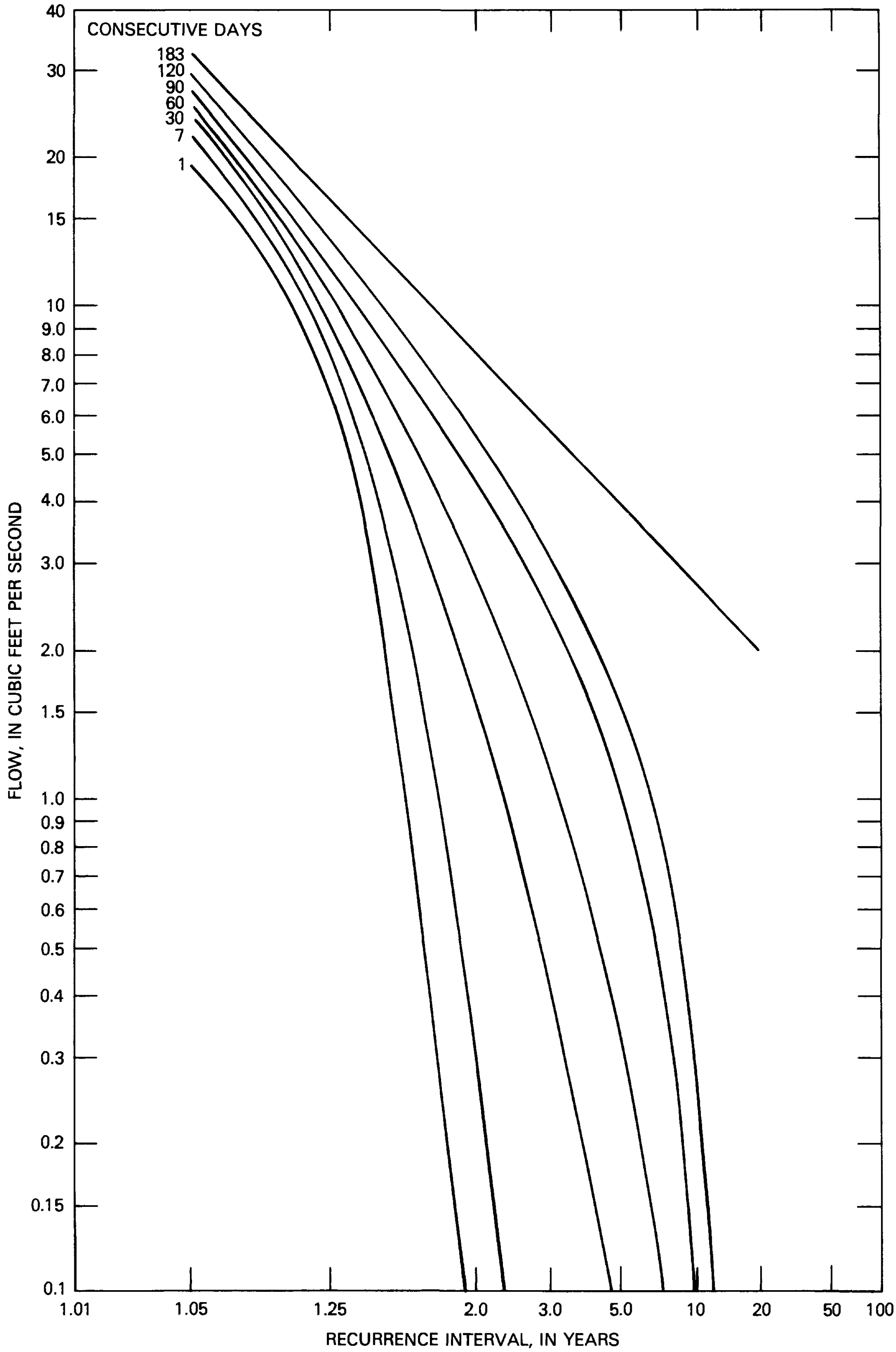


Figure 38. Magnitude and frequency of annual low flows at station 09308000, Willow Creek near Ouray, years ending March 31, 1948–55, 1975–79.

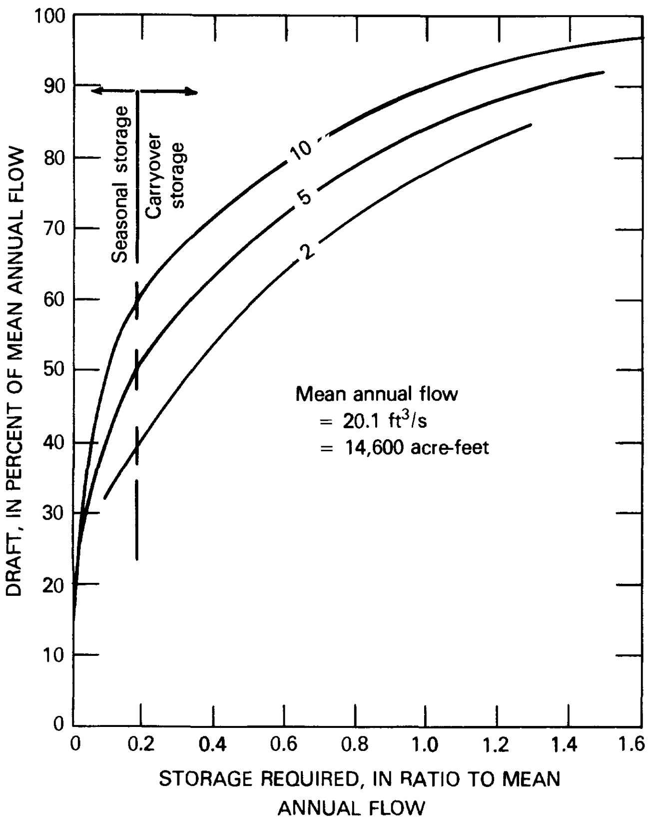


Figure 39. Draft-storage relations for indicated percentage chance of deficiency at station 09307500, Willow Creek above diversions, near Ouray, years ending March 31, 1951-55, 1958-70, 1975-79.

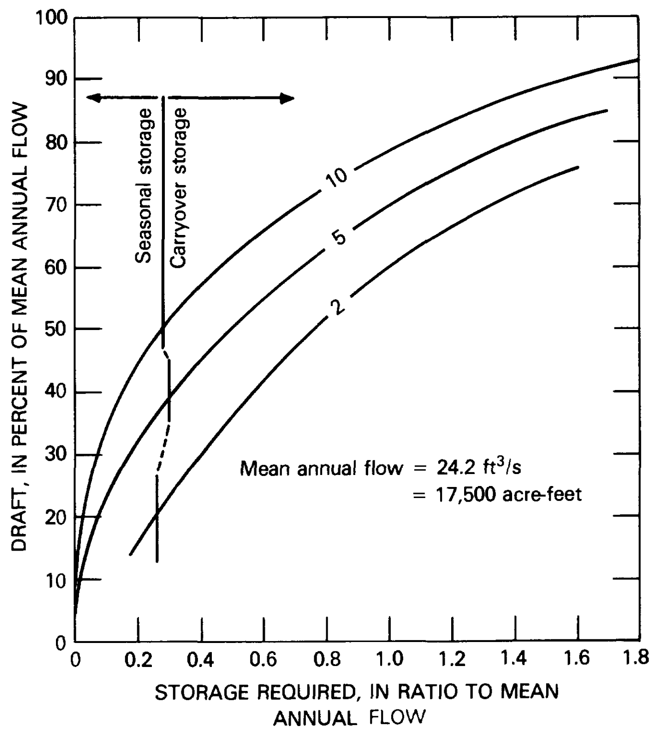


Figure 40. Draft-storage relations for indicated percentage chance of deficiency at station 09308000, Willow Creek near Ouray, years ending March 31, 1948-55, 1975-79.

flow (fig. 50). The ratios were developed as averages for the two Willow Creek stations with sufficient length of record to compute peak flow with recurrence intervals longer than 2 years. For the 100-year flood, figure 50 gives a ratio of 15, compared to about 5.5 from extending the information given in Patterson and Somers (1966, p. 4). The ratios shown in figure 50 are more representative of the study area; those of Patterson and Somers (1966) are more representative of larger streams, with drainage areas generally exceeding 500 mi^2. The ratios shown in figure 50 correspond more closely to actual ratios for streams in surrounding areas which have a record long enough for frequency analysis and which drain less than 500 mi^2.

Fields (1975, p. 11) also provides a method for estimating peak flows with 25- and 50-year recurrence intervals. The method by Fields, however, does require that a selected channel width be measured in the field. Butler and Cruff (1971, p. 28-32) show equations which relate peak flow to basin and climatic characteristics.

Annual Flood Volumes

Figure 51 shows average rates of flow that are equaled or exceeded for durations of 1, 3, 7, and 15 consecutive days for the indicated recurrence intervals for Willow Creek. The curves were computed as averages of log-Pearson Type III frequency relations for the observed records at stations 09307500 and 09308000. Figure 51 is representative of all locations on the main stem of Willow Creek with drainage areas exceeding 100 mi^2.

For other sites on intra-area streams, flood hydrographs can be estimated by using a technique developed by Eychaner (1976, p. 1-18) which provides a method for computing synthetic hydrographs for basins of 5 to 300 mi^2 with peak flows from 1 to 7,000 ft^3/s. Although the study by Eychaner did not include the Uinta Basin, his analysis was for streams in the Colorado River basin that have similar flow characteristics; and his technique is considered applicable to the southeastern Uinta Basin.

WATER-QUALITY CHARACTERISTICS

The chemical quality of streamflow depends on the origin of the water, the rate of evapotranspiration, the soils and rocks that are encountered enroute to the stream, the rocks underlying the streambed, the length of contact with those soils and rocks, and the individual reaction rates between water and the minerals of the soils and rocks. These factors combine to produce temporal and areal variation in the water quality.

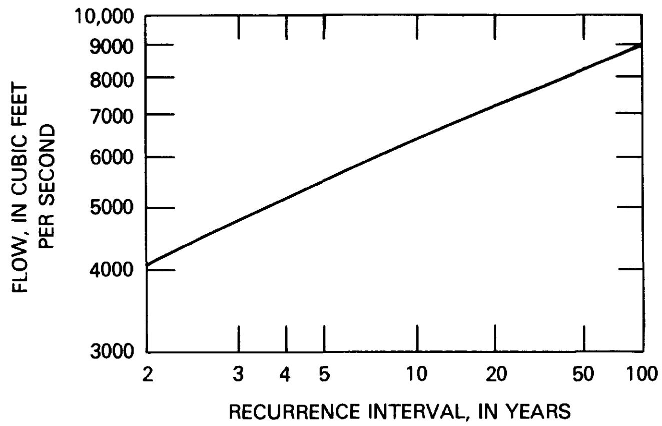


Figure 41. Peak-flow frequencies representative of the White River in the study area.

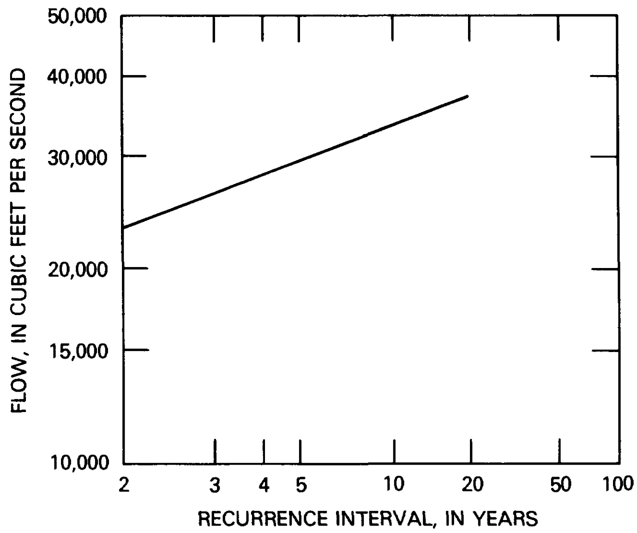


Figure 42. Peak-flow frequencies representative of the Green River from its confluence with the White River downstream through Desolation Canyon.

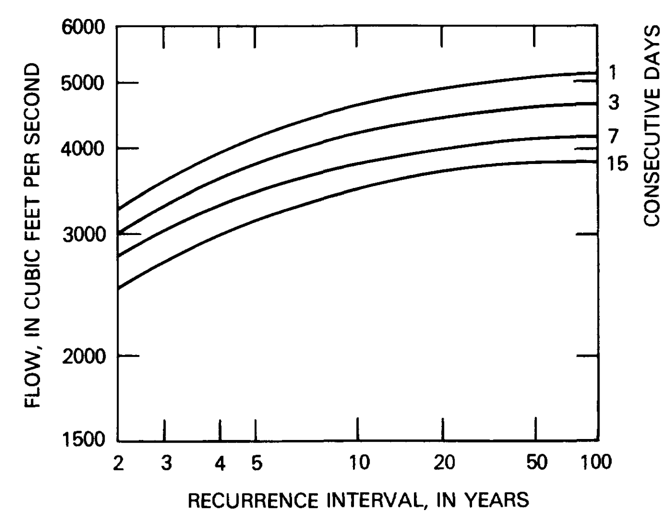


Figure 43. Magnitude and frequency of annual high flows of the White River.

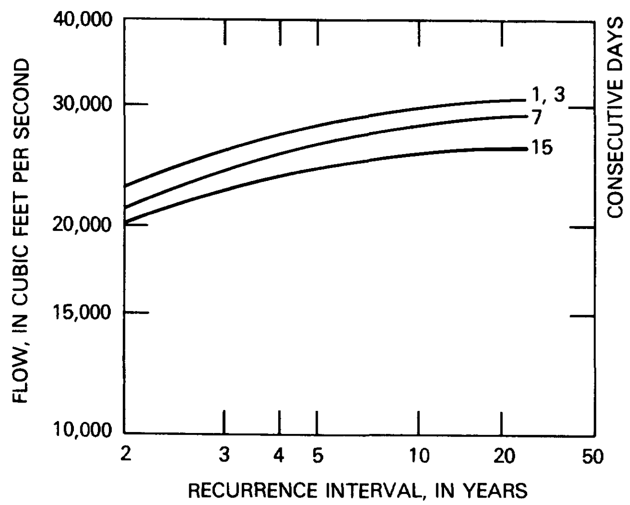


Figure 44. Magnitude and frequency of annual high flows for the Green River from confluence with the White River downstream through Desolation Canyon.

The quality of streamflow in the southeastern Uinta Basin varies considerably between the major rivers and the intra-area streams. In the major rivers, the concentrations of most constituents vary seasonally but do not vary significantly during a given season from one location to another. In the intra-area streams, concentrations vary both seasonally and from one location to another within a given drainage. The sampling sites are shown in figure 2.

Water-Quality Criteria

Water-quality criteria for various uses of water are given by the U.S. Environmental Protection Agency (1976) and are listed in table 6. Throughout the following discussion of water-quality characteristics, the instances are noted where certain characteristics exceed the water-quality criteria cited in table 6.

Flow and General Water-Quality Characteristics

Three of the general characteristics of streamflow listed in table 7—flow, specific conductance, and temperature—were obtained continuously at seven or eight monitoring sites. Generally, this was done only during April–November. The other characteristics listed in table 7 were obtained periodically when monthly flow measurements were made or water-quality samples were obtained.

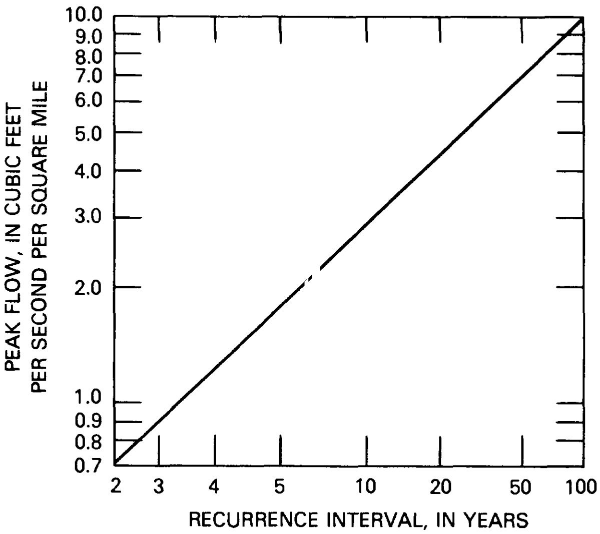


Figure 45. Peak-flow frequencies representative of two sites on Willow Creek.

Flow Variability in Relation to Water Quality

Flow has been discussed fully under streamflow characteristics and will be discussed here only as it relates to water quality. The source of flow has a strong effect on the water quality of streamflow. In the major rivers, the main sources of water are outside the study area, and the Green River is relatively uniform in water quality because of the regulation and mixing of upstream sources by Flaming Gorge Reservoir. Water quality in the White River is more variable because of the different sources of tributary inflow, which contribute water of differing chemical composition.

In terms of sources of streamflow, the White River basin can be divided into an upper and a lower subbasin (fig. 52). The "upper basin" consists of the mountainous uplands, which contribute most of the flow to the White River. For example, the mean flow at station 09304800, White River below Meeker, Colo., is 620 ft^3/s (water years 1962–79), which represents 95 percent of the mean flow of the White River at station 09306500 in the study area. The White River above Rangely, Colo., station 09306300, has a mean flow of 651 ft^3/s (water years 1973–79), which is 99 percent of the flow at station 09306500.

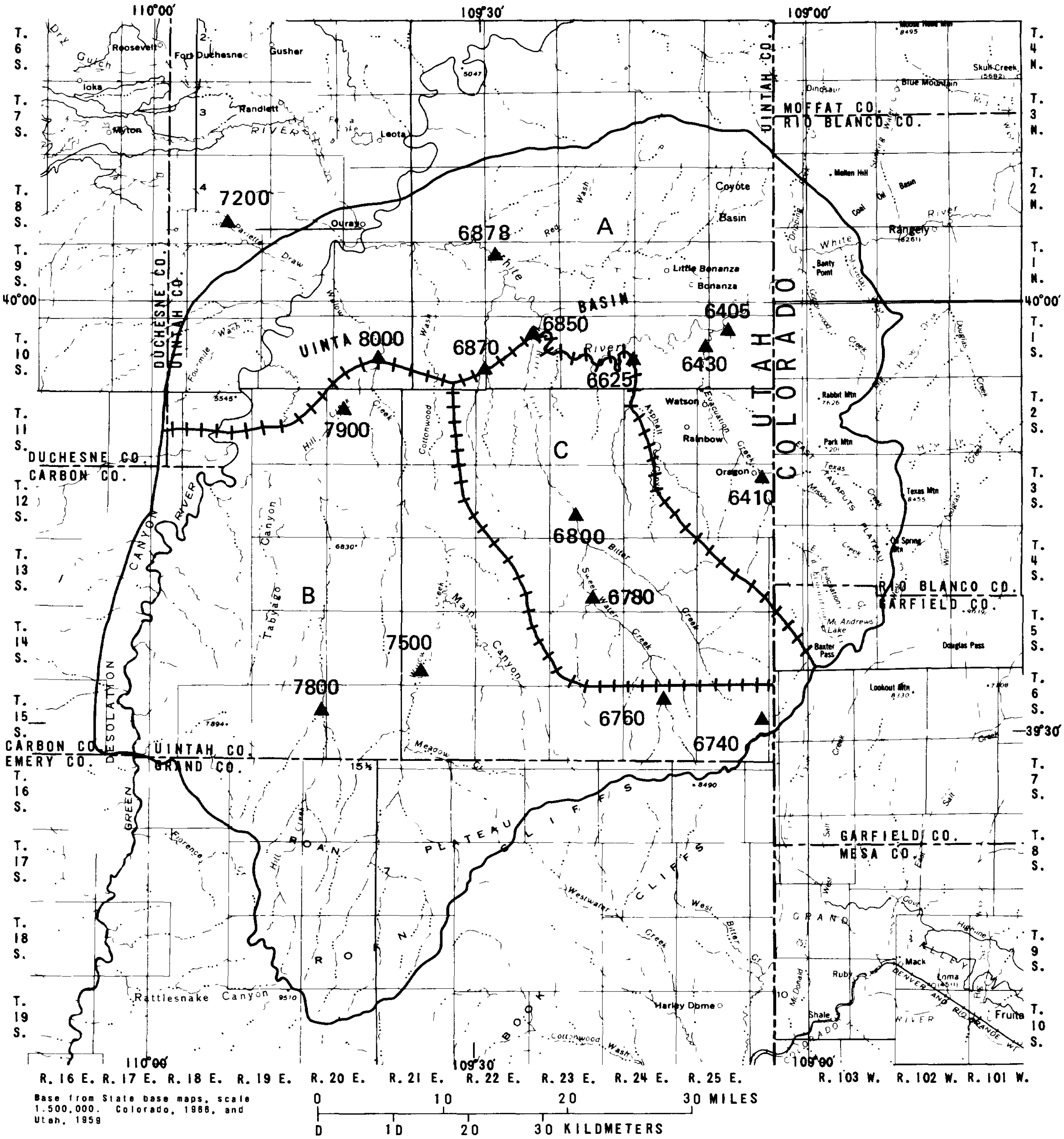
The "lower basin" consists of semiarid lowlands, which contribute little to the flow of the White River. During seasons of low flow, however, their contribution is proportionately greater; and the water quality reflects this contribution. As the White River flows through the lowlands, the flow remains essentially constant; but the water quality deteriorates due to inflow from the intra-area streams. Thus the major variations in water quality in the White River are due to mixing of water from the upper and lower basins and the subsequent effects of evapotranspiration.

In the intra-area streams, the high flow is sporadic and variable, and the base flow (ground-water discharge) affects the water quality more than it does in the major rivers. Base flow in Willow Creek generally is less than 10

Table 5. Peak-flow characteristics for continuous-record gaging stations

Station No.	Subarea in figure 46	Period of record used (water years)	Drainage area (mi^2)	Mean annual peak flow (ft^3/s)
09306405	A	1975–79	24.5	132
09306410	A	1975–79	100	281
09306430	A	1975–79	284	694
09306625	A, C	1975–79	97.5	55
09306740	B	1975–78	11.7	7.6
09306760	B	1975–78	22.6	16
09306780	C	1975–78	124	15
09306800	C	1971–79	324	58
09306850	C	1975–79	398	40
09306870	C	1975–78	59.7	7
09306878	A	1977–80	228	524
09307200[1]	A	1976–79	153	274
09307500	B	1951–55, 1958–70, 1975–79	297	248
09307800	B	1975–79	89.7	39
09307900	B	1975–79	288	74
09308000	B	1948–55, 1960–61, 1963–68, 1975–79	897	549

[1] Outside study area. (See fig. 46.)



EXPLANATION

▲ 6740 Gaging station. Number has been abbreviated by omitting the first four digits (0930)

—— Boundary of the study area

C ┼┼┼┼┼ Letter designating and boundary of areas with similar peak flow per square mile

Figure 46. Hydrologic areas with similar flood characteristics.

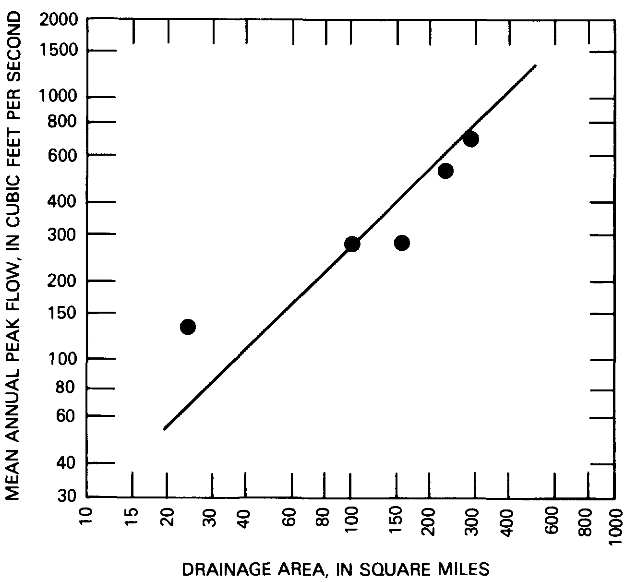


Figure 47. Relation of mean annual peak flow to drainage area for streams in area A (fig. 46).

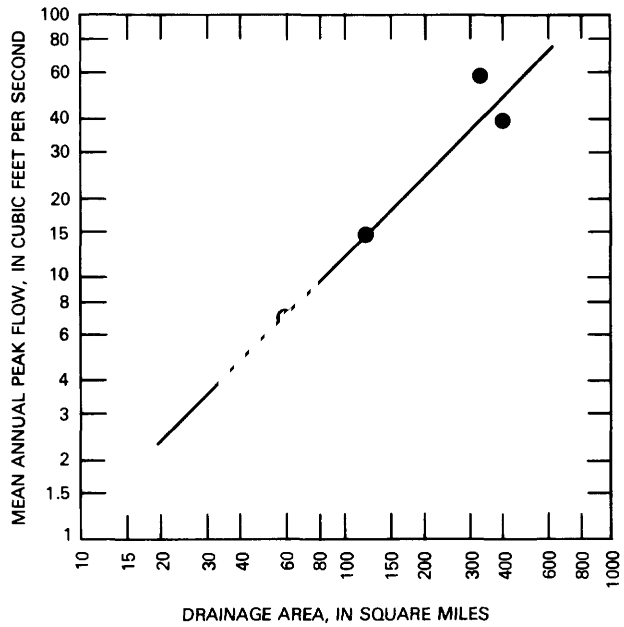


Figure 49. Relation of mean annual peak flow to drainage area for streams in area C (fig. 46).

ft³/s, and in Bitter and Evacuation Creeks, it is less than 1 ft³/s. The water-quality samples were grouped into high-flow and base-flow samples by these general, arbitrary breakoff points. These divisions allowed a good characterization of the water quality of the base flow in each of the drainages (with perennial flow), but the characterization for high flow is not as good because fewer samples were obtained. However, the generalizations that are made about high flow should be valid despite the somewhat sparse sampling of the intra-area streams.

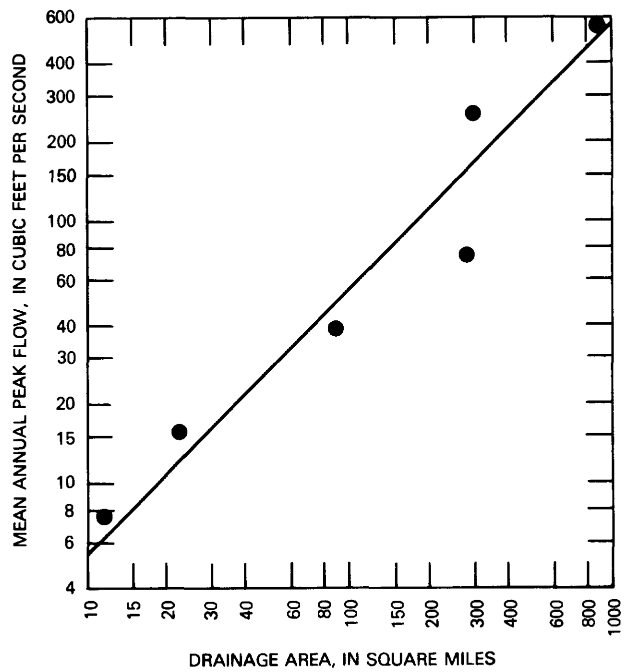


Figure 48. Relation of mean annual peak flow to drainage area for streams in area B (fig. 46).

Specific Conductance

Specific conductance was measured continuously at 8 stations and periodically at all 21 stations listed in table 7. Conductance has a close relation to the dissolved-solids concentration; thus it can be used as an easily measured indication of the dissolved-solids concentration of natural waters. Although the response of conductance to different electrolytes (the charged solutes) varies (Davis and DeWeist, 1966, p. 83–86), the overall correlation to dissolved-solids concentrations is useful for water-quality monitoring.

The continuous records of specific conductance were poor because of problems with equipment. The probes were often buried in sediment as the river and streambeds changed, particularly during times of high flow. Thus the variation in dissolved-solids concentrations according to changes in flow was not always determined. Despite the problems with continuous records, however, the large number of periodic measurements do allow for interpretations of variations in conductance.

Relations of dissolved solids (sum of constituents) to conductance were developed from the water-quality data for the major rivers and the perennial and intermittent intra-area streams (table 8). The relations for the individual stations on the White River are similar enough so that all the data were combined into a single relation in table 8. The correlation is high ($r = 0.977$); and in general, the dissolved-solids concentration is about 65 percent of the measured specific conductance.

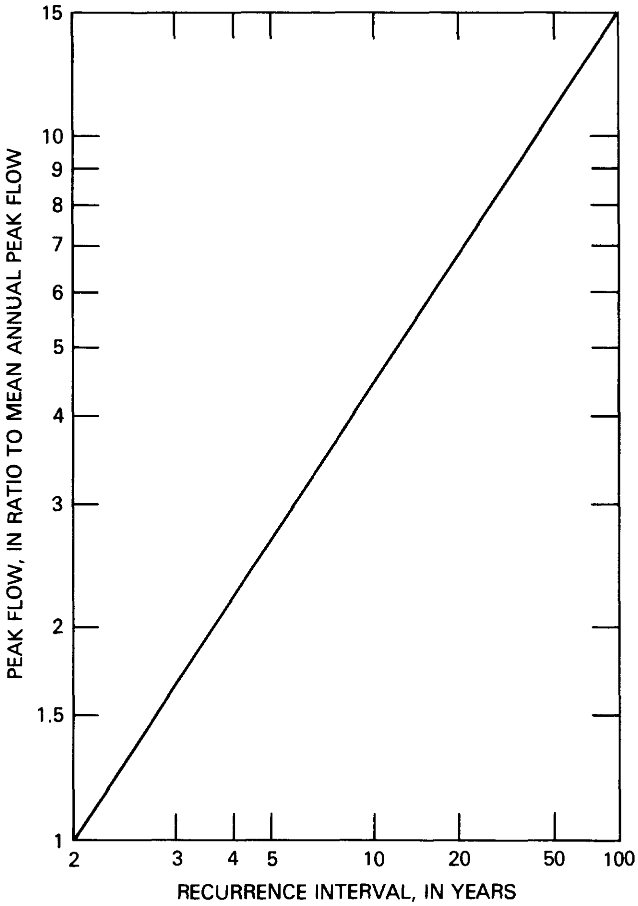


Figure 50. Composite peak-flow frequency curve for intra-area streams.

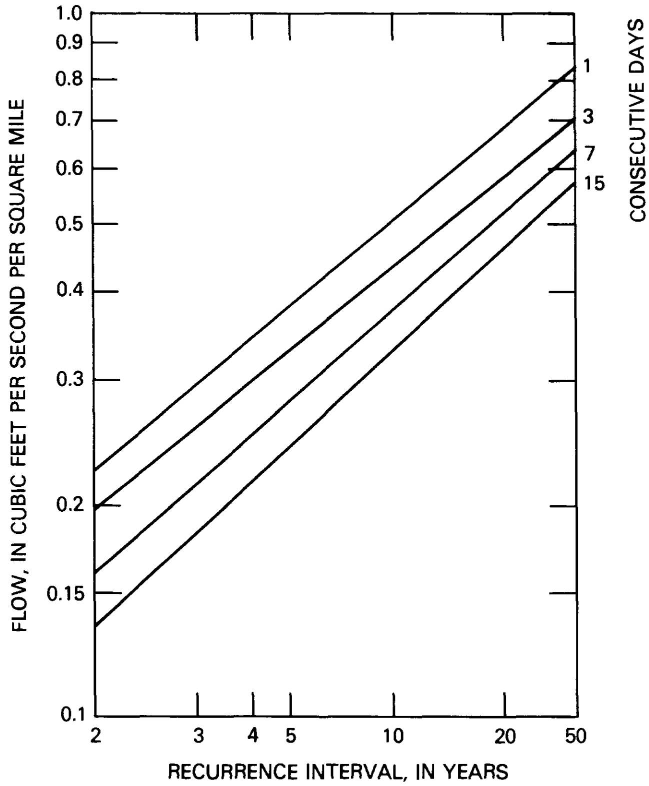


Figure 51. Magnitude and frequency of annual high flows representative of sites on Willow Creek.

The equations developed for the intra-area streams vary from station to station in a particular drainage. The relations are similar to the major rivers for stations that are in the upper reaches of the intra-area streams, but the relations differ for stations that are near the mouths of the drainages. In general, there is little variation in conductance at these lower stations. The equations in table 8 are for the combined stations in each drainage. Equations were not developed for the ephemeral streams because of insufficient data.

Conductance generally varies inversely with changes in streamflow in the major rivers. Figure 53 summarizes the variation in specific conductance for the White River and its relation to flow. This same seasonal variation is present in the Green River.

Specific conductance increases in a downstream direction in each of the intra-area streams (where there is perennial flow) except Evacuation Creek. The reasons for these changes are detailed in the section "Major Dissolved Constituents."

Hydrogen-Ion Concentration (pH)

Since the concentration of hydrogen ions (pH) in natural waters generally is low, in the range of 10^{-6} to 10^{-9} moles per liter, the concentrations are reported as the negative logarithm of the hydrogen-ion activity.[2] This value is called the pH. Since pH is a log value, the mean value given in table 7 for streams in the study area is actually a geometric mean for hydrogen-ion concentrations.

No continuous records of pH were obtained at any of the monitoring sites, but instantaneous measurements were made when water-quality samples were taken. The pH of water in the major rivers shows little variation. There is not significant correlation to flow or to the concentration of any of the major constituents. However, there is some direct correlation to the concentration of dissolved solids. Drever (1982) has shown how the pH is tied to the charge balance of the solutes. When there is a change of solute concentrations, and the change in anions is not as large as the change in cations, the pH changes to maintain the charge balance.

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[2] For activity-concentration relations, see Garrels and Christ (1965, ch. 2).

The nearly constant pH observed in streams in the study area is in part due to the buffering effect of the carbonate systems. Stumm and Morgan (1981, ch. 4) have described carbonate buffering in detail. In addition to carbonate buffering, the pH can be partly buffered by other water-rock interactions, such as ion exchange between stream sediments and the water. Mineral dissolution reactions, which also can affect the pH buffer, tend to increase pH above what would be expected for a pure carbonate buffer. The mean partial pressure of carbon dioxide (pCO_2) calculated from pH and the alkalinity by WATEQ2 (Ball, Jenne, and Nordstrom, 1979) is $10^{-2.9}$ atmospheres. This is greater than $10^{-3.5}$ atmospheres, which is the value for water in equilibrium with the carbon dioxide of the atmosphere (Garrels and Christ, 1965, p. 85–86). However, surface water is commonly supersaturated with carbon dioxide (Holland, 1978, p. 107).

The ranges of pH for perennial flow in the intra-area streams are similar to those of the major rivers (table 7). Willow and Evacuation Creeks have ranges of about 2.2 units, with means of 8.1, whereas Bitter Creek has a range of 1.3 units and a mean of 8.0. None of the intra-area perennial streams shows seasonal patterns of pH, nor does pH vary significantly from year to year, another indication of a well-buffered system. The mean pH does, however, increase in each of the intra-area streams in a downstream direction primarily because of an increase in the dissolved-solids concentration. The mean pH of 7.9 for the ephemeral streams is slightly lower than that for the intra-area perennial streams.

Water Temperature

Water temperatures were obtained during 1975–79 at all stations—continuously at 8 and instantaneously at all during periodic visits for water-quality sampling or flow measurement. The variation in water temperature is seasonal, and it closely follows changes in air temperature for all sites where continuous records were collected. For the major rivers, changes in the water temperature follow changes in air temperature by 1 or 2 days. An analysis of the harmonic variations in water temperature for the White River at station 09306500 and for the Green River at station 09315000 (Steele, Gilroy, and Hawkinson, 1974, p. 56) confirms that changes in water temperature closely follow changes in air temperature.

Water temperature for the Green River at station 09315000 ranges from 0° to 30°C and averages 12.6°C. On the White River, at station 09306500, the mean water temperature is 10.4°C, and the range is 0° to 33°C.

Each station shows a seasonal variance in water temperature that is directly related to the seasonal variance in air temperature. For example, the correlation coefficient between air and water temperature at station 09306500 is 0.914. The variation in monthly mean temperature for station 09306500 is shown in figure 54. Although monthly mean temperatures may be higher during the late summer months at other White River sites, the general pattern of water temperature shown in figure 54 is the same for each of the other continuous-record stations.

Year-to-year variations in water temperatures are due to variations in annual air temperature. The annual mean water temperature at station 09306500 during water years 1975–79 varied from a low of 8.0°C in 1979 to a high of 9.4°C in 1977. By comparison, the annual mean air temperature at Bonanza (National Oceanic and Atmospheric Administration station) during water years 1975–79 ranged from 7.7°C in 1979 to 10.5°C in 1977.

The intra-area streams show about the same range in temperature as do the major rivers, and the mean monthly temperatures are usually within 1 or 2 degrees of mean monthly temperatures for the major rivers. However, the response on the intra-area streams to changes in air temperatures is more immediate.

Dissolved Oxygen

Dissolved oxygen determines the capacity of a stream to assimilate certain waste materials and also the suitability of a stream to support aquatic life. The dissolved-oxygen concentrations in the study area generally are near saturation and are sufficient for aquatic life. The observed dissolved-oxygen concentrations from monthly sampling at station 09315000, Green at Green River, during 1952–79 ranged from 4.0 to 14 mg/L, and the mean concentration was 9.6 mg/L. The concentrations show a strong seasonal variance, with the highest values observed during January and February and the lowest values during July and August. The solubility of oxygen increases with decreasing temperature; thus part of the seasonal variation is the result of the increased capacity of the stream to retain dissolved oxygen at lower temperatures.

The concentrations and variations of dissolved oxygen at station 09306500 in the White River are similar to those in the Green River (table 7). The range is smaller than that in the Green River, and the mean is slightly lower.

The mean dissolved-oxygen concentration varies from one intra-area stream to another. The highest measured concentrations are in Bitter Creek (all stations), with a mean of 10 mg/L and a range of 6.0 to 15.7 mg/L. The mean concentration for Willow Creek (including Hill Creek) is 9.2 mg/L, and for Evacuation Creek it is 8.0 mg/L. The range of dissolved oxygen in Evacuation Creek is 3.8 to 11.3 mg/L, whereas in Willow Creek the range is from 5.9 to 12.2 mg/L.

Table 6. Water-quality criteria (U.S. Environmental Protection Agency, 1976)

[The value given is maximum, unless otherwise noted; dot leaders, indicate no criteria given by U.S. Environmental Protection Agency, 1976]

Constituent	Use		
	Domestic[1] water supply	Aquatic life[2]	Irrigation
Physiochemical parameters			
pH (standard units)	5.0–9.0	6.5–9.0	.....
Dissolved oxygen (mg/L)	.....	[3]5	.....
Hardness[4] (as $CaCO_3$)	.....	.....	.....
Major inorganic constituents (mg/L)			
Chloride	250	.....	.....
Sulfate	250	.....	.....
Nitrate (as N)	10	.....	.....
Dissolved solids	[5]500	.....	.....
Trace elements (µg/L)			
Arsenic	50	.....	100
Barium	1,000	.....	.....
Beryllium	.....	1,100	500
Boron	.....	.....	750
Cadmium	10	12	.....
Chromium	50	100	.....
Copper	1,000	.....	.....
Iron	300	1,000	.....
Lead	50	.....	.....
Manganese	50	100	.....
Mercury	2	.05	.....
Selenium	10	.....	.....
Silver	50	.....	.....
Zinc	5,000	.....	.....
Organic constituents (µg/L)			
Pesticides			
Aldrin/dieldrin	.....	0.003	.....
Chlordane	.....	.01	.....
DDT	.....	.001	.....
Demeton	.....	.1	.....
Endosulfan	.....	.003	.....
Endrin	0.2	.004	.....
Heptachlor	.....	.001	.....
Lindane	4	.01	.....
Malathion	.....	.1	.....
Mirex	.....	.001	.....
Parathion	.....	.04	.....
Toxaphene	5	.005	.....
Herbicides			
2, 4-D	100	.....	.....
2, 4, 5-TP	10	.....	.....

Table 6. Water-quality criteria (U.S. Environmental Protection Agency, 1976)—Continued

Constituent	Use		
	Domestic[1] water supply	Aquatic life[2]	Irrigation
Organic constituents (µg/L)—Continued			
Other			
Polychlorinated Biphenyls (PCBs)	.....	0.001	.....
Phenol	1	.....	.....

[1] Includes uncontaminated ground water and ground and surface requiring disinfection or treatment.
[2] Trace-element criteria applies to water having a total hardness from 0 to 100 mg/L as $CaCO_3$; values for water of greater hardness may be equal or greater than that shown. Total trace-element concentrations are given.
[3] Indicates a minimum criteria.
[4] Hardness is classified as follows:

Concentration (mg/L as $CaCO_3$)	*Description*
0 to 75	soft
75 to 150	moderately hard
150 to 300	hard
More than 300	very hard

[5] Secondary maximum contaminant level (U.S. Environmental Protection Agency, 1977).

Alkalinity

Alkalinity is due to many chemical species in natural water (Wigley, 1977, pp. 12–15), but is due mostly to bicarbonate in the waters of the southeastern Uinta Basin. Alkalinity was determined by titration with sulfuric acid. Most determinations were made in the laboratory, but several determinations were made in the field.

The mean alkalinity of the Green River at station 09315000 is 173 mg/L as $CaCO_3$; and the mean alkalinity of the White River is 180 mg/L at station 09306500. The range is greater in the Green River, although there is little variation from season to season. Minimum values for the monthly mean alkalinity are observed in May and June during snowmelt runoff in the White River (140 mg/L as $CaCO_3$ for high flow from the upper basin at station 09306500). Minimum values also occur during snowmelt runoff in the Green River. The maximum values occur during the late summer when evapotranspiration is great. The mean for base flow at station 09306500 is 190 mg/L as $CaCO_3$. The mean for base flow at station 09315000 is 177 mg/L.

Alkalinity in the intra-area streams is generally higher than in the major rivers. Bitter Creek has the highest mean alkalinity for the intra-area streams (table 7), followed by Evacuation Creek and then by Willow Creek. The ranges of alkalinity in these streams also are greater than in the major rivers.

Ephemeral streams show a larger range in alkalinity than do the major rivers but a smaller range than the intermittent and perennial intra-area streams (table 7). Since the streamflow in the ephemeral streams is from thunderstorm or snowmelt runoff, the alkalinity is low, with a mean of 183 mg/L as $CaCO_3$.

Hardness

Hardness is due to divalent ions, primarily calcium and magnesium, in natural waters, and noncarbonate hardness is the total hardness, less the alkalinity (Hem, 1970, p. 224). In the major rivers, Willow Creek, and some of the ephemeral streams, carbonate hardness (that portion of hardness equivalent to the alkalinity) is greater than noncarbonate hardness (table 7). In Bitter Creek (stations 09306740–09306850) and Evacuation Creek (stations 09306410–09306430), the noncarbonate hardness is generally greater than the carbonate hardness (alkalinity in table 7).

Although the mean hardness for the major rivers is less than that for the intra-area perennial streams, it still exceeds the criteria for soft water (table 6). There is seasonal variation of hardness because of the seasonal variation of calcium and magnesium. Hardness decreases as flow in the major rivers increases, and the lowest values were observed in May and June during snowmelt runoff from the upper basin.

Table 7. Summary of general water-quality characteristics of streamflow

[Flow: Values at time of sampling are summarized to indicate range in flow sampled. Table 2 summarizes flow values for the continuous records. pH: Geometric mean for pH values.]

Station No.	Period of record used (water years)		Flow (cubic feet per second)	Specific conductance (micromhos per centimeter at 25°)	pH (standard units)	Water temperature (degrees Celsius)	Dissolved oxygen (milligrams per liter)	Alkalinity	Hardness	Hardness noncarbonate	Oil and grease (milligrams per liter
								(milligrams per liter as $CaCO_3$)			
09306395	1977–79	Mean	870	760	8.0	12.6	8.5	171	269	96.8	...
		Maximum	3,700	1,570	8.8	31.0	13.3	260	450	180	...
		Minimum	40.0	228	6.4	0	6.2	110	150	41	...
		Number of observations	70	([1])	20	([1])	15	14	14	14	0
09306405	1975–79	Mean	21.5	1,530	....	13.4	....	196	712	530	...
		Maximum	88.0	2,670	8.3	22.5	....	410	1,400	130	...
		Minimum	1.7	710	8.3	1.0	....	93	290	....	...
		Number of observations	9	4	1	8	0	4	4	4	0
09306410	1975–79	Mean	.89	4,080	8.1	10.5	8.2	418	858	440	.5
		Maximum	11.6	4,900	8.6	34.0	11.2	445	960	550	1.0
		Minimum	.13	1,500	7.4	0	6.2	320	550	230	0
		Number of observations	83	63	43	([1])	45	28	28	28	2
09306415	1975	Mean	3.0	3,930	8.2	11.4	8.0	375	1,020	635	2.2
		Maximum	46.0	5,600	9.2	31.5	11.0	469	1,300	880	14.0
		Minimum	.01	2,250	7.1	0	3.8	230	590	360	0
		Number of observations	42	22	18	39	14	22	22	22	21
09306420	1975–76	Mean	3.3	4,600	8.0	9.7	7.1	403	1,140	739	3.4
		Maximum	46.0	6,170	8.8	34.0	10.3	527	1,600	1,100	52
		Minimum	.01	454	7.4	0	3.8	126	180	48	0
		Number of observations	67	40	31	64	24	35	35	35	30
09306430	1975–79	Mean	8.1	4,100	7.9	14.3	7.8	371	1,030	655	10.1
		Maximum	456	7,320	9.0	33.5	11.3	450	1,200	920	250
		Minimum	.01	559	7.3	0	4.8	98	250	130	0
		Number of observations	129	([1])	63	([1])	46	51	51	51	29
09306500	1950–79	Mean	634	730	7.8	10.4	8.9	180	283	98.8	1.5
		Maximum	3,980	4,450	9.0	33.0	15.0	299	1,410	806	6.0
		Minimum	42	250	....	0	6.4	107	110	....	0
		Number of observations	426	([1])	343	([1])	56	194	365	353	30
09306610	1975–79	Mean	1.5	789	8.0	5.6	....	164	147	13.5	...
		Maximum	4.7	1,480	8.1	17.0	11.5	189	220	31	0
		Minimum	.2	330	7.9	0	11.5	119	84	....	0
		Number of observations	6	4	3	6	1	4	4	4	1
09306625	1975–79	Mean	5.5	1,090	7.7	9.3	....	139	144	50	...
		Maximum	8.7	1,920	8.0	11.5	12.0	189	230	130	0
		Minimum	.10	418	7.4	0	12.0	39	68	....	0
		Number of observations	7	3	2	6	1	4	4	4	1
09306740	1975–78	Mean	1.5	704	8.2	8.9	8.7	209	306	96.3	...
		Maximum	9.0	1,100	8.6	23.5	11.2	249	380	150	...
		Minimum	.03	320	7.6	0	6.6	103	140	33	...
		Number of observations	62	39	24	62	28	21	21	21	0
09306760	1975–78	Mean	.38	1,330	8.1	11.3	8.5	245	666	420	...
		Maximum	.63	1,500	8.5	23.0	9.8	297	760	480	...
		Minimum	.28	975	7.2	2.0	7.5	180	620	380	...
		Number of observations	60	40	25	59	28	23	23	23	0

Table 7. Summary of general water-quality characteristics of streamflow—Continued

Station No.	Period of record used (water years)		Flow (cubic feet per second)	Specific conductance (micromhos per centimeter at 25°)	pH (standard units)	Water temperature (degrees Celsius)	Dissolved oxygen (milligrams per liter)	Alkalinity (milligrams per liter as $CaCO_3$)	Hardness (milligrams per liter as $CaCO_3$)	Hardness noncarbonate (milligrams per liter as $CaCO_3$)	Oil and grease (milligrams per liter)
09306780	1975–78	Mean	0.76	2,300	8.2	9.2	9.0	288	1,170	878	...
		Maximum	2.4	5,250	8.5	24.5	11.3	462	2,900	2,400	...
		Minimum	.04	1,800	8.0	0	6.7	178	860	600	...
		Number of observations	14	10	9	15	8	9	9	9	0
09306800	1971–79	Mean	1.4	6,660	7.8	10.7	9.8	467	3,080	2,610	...
		Maximum	5.9	9,500	8.4	30.0	12.7	595	3,800	3,200	...
		Minimum	<.01	4,000	7.4	0	6.0	376	2,000	1,600	...
		Number of observations	61	(1)	32	61	26	24	24	24	0
09306850	1975–79	Mean	.99	13,400	8.0	16.0	11.2	595	2,910	2,300	...
		Maximum	7.9	19,000	8.3	31.5	15.7	691	3,500	3,200	...
		Minimum	.30	2,150	7.4	1.0	7.5	120	750	460	...
		Number of observations	75	(1)	38	(1)	39	28	27	27	0
09306878	1977–79	Mean	55.6	496	7.4	18.1	....	234	19.8	....	...
		Maximum	610	1,020	8.4	26.5	10.1	410	37	....	...
		Minimum	.04	350	6.5	7.5	10.1	160	10	....	...
		Number of observations	33	7	2	14	1	6	6	....	0
09306900	1975–79	Mean	586	816	8.2	12.0	8.7	198	276	78.1	...
		Maximum	3,970	1,900	8.8	32.0	12.2	345	400	150	...
		Minimum	13.0	330	7.4	0	2.2	110	110	....	...
		Number of observations	159	(1)	90	(1)	87	85	84	83	0
09307500	1951–55,	Mean	23.9	729	8.1	9.2	9.1	271	330	58.9	...
	1958–70,	Maximum	167	920	8.5	25.0	12.2	313	370	100	...
	1975–79	Minimum	4.4	535	7.4	0	6.8	205	260	32	...
		Number of observations	68	39	32	69	33	27	27	27	0
09307800	1975–79	Mean	9.1	606	8.0	7.7	9.1	259	288	28.9	...
		Maximum	83	800	8.6	24.0	11.6	337	370	49	...
		Minimum	.50	410	6.8	0	6.9	209	250	4	...
		Number of observations	64	42	37	64	37	24	24	24	0
09307900	1975–79	Mean	7.7	1,140	8.2	8.4	9.5	342	432	92.6	...
		Maximum	64.0	2,020	8.5	25.5	11.2	431	580	160	...
		Minimum	.01	825	7.8	0	7.0	283	350	28	...
		Number of observations	37	16	15	34	16	13	13	13	0
09308000	1948–55,	Mean	62.8	2,020	8.2	10.3	9.3	402	510	109	...
	1975–79	Maximum	825	10,200	9.0	34.0	11.8	660	920	240	...
		Minimum	.05	840	7.4	0	5.9	233	310	40	...
		Number of observations	111	(1)	37	(1)	38	29	29	29	0
09315000	1952–79	Mean	6,270	833	7.9	12.6	9.6	173	306	133	...
		Maximum	27,800	3,250	8.7	30.0	14.0	344	1,880	1,620	...
		Minimum	2,090	255	7.0	0	4.0	16	120	....	...
		Number of observations	351	(1)	347	(1)	85	952	1,168	1,106	0

[1] Both continuous records and field observations were used.

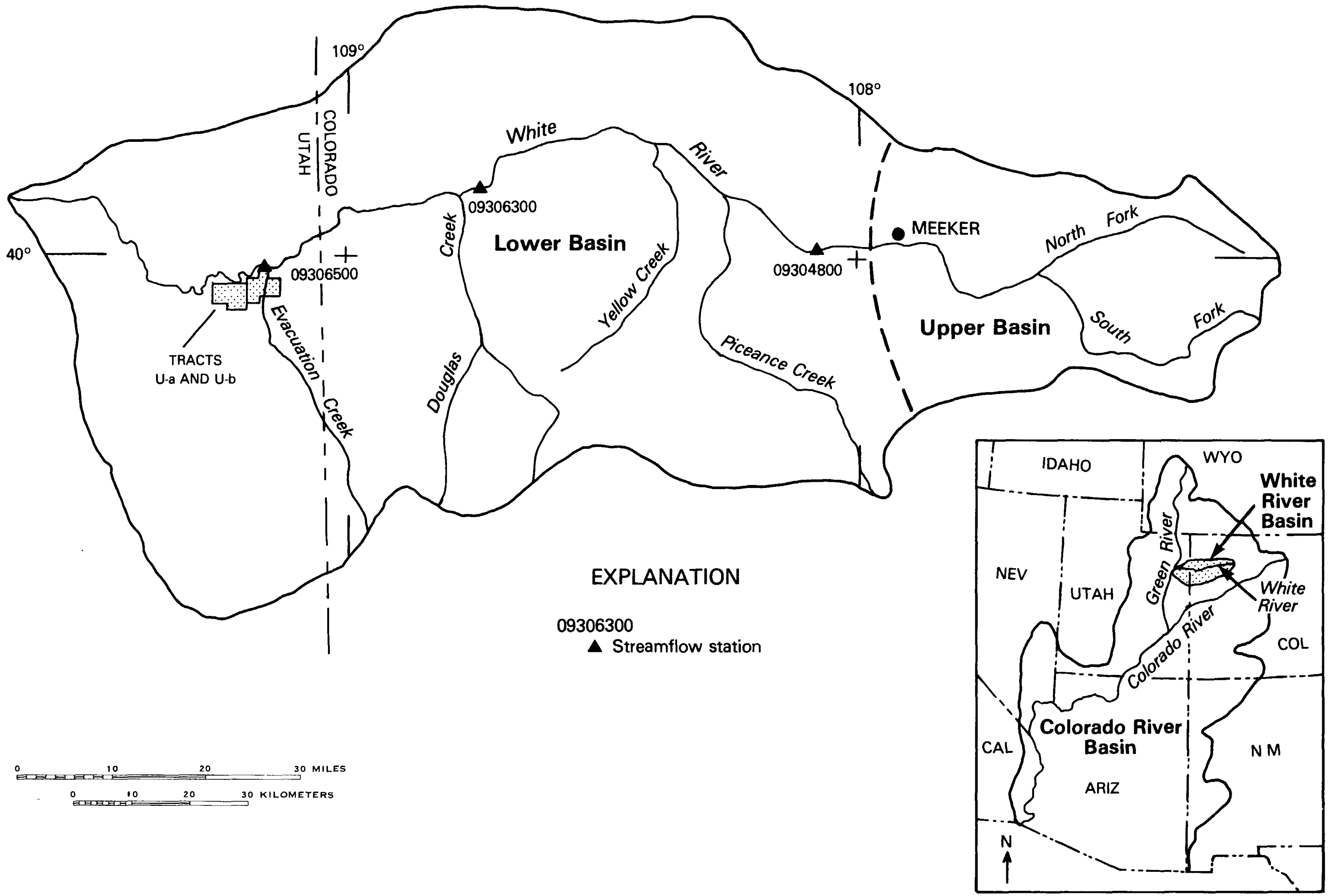

Figure 52. Upper and lower subbasins in the White River basin (modified from VTN Colorado, Inc., 1977, fig. II-2).

Table 8. Summary of regressions of dissolved-solids concentration to specific conductance

[The equation is of the form $y = ax^b$

where

y = calculated dissolved-solids concentration (milligrams per liter);

a, b = coefficients from the regressions;

x = specific conductance (micromhos per centimeter)]

Drainage	Period of record	a	b	Correlation coefficient (r)
Green River[1]	1967–79	0.402	1.075	0.990
White River	1975–79	.544	1.025	.977
Evacuation Creek	1975–79	.381	1.088	.976
Bitter Creek	1975–79	.279	1.132	.996
Willow Creek (including Hill Creek)	1975–79	.317	1.110	.986

[1] Station 09315000, Green River at Green River, Utah.

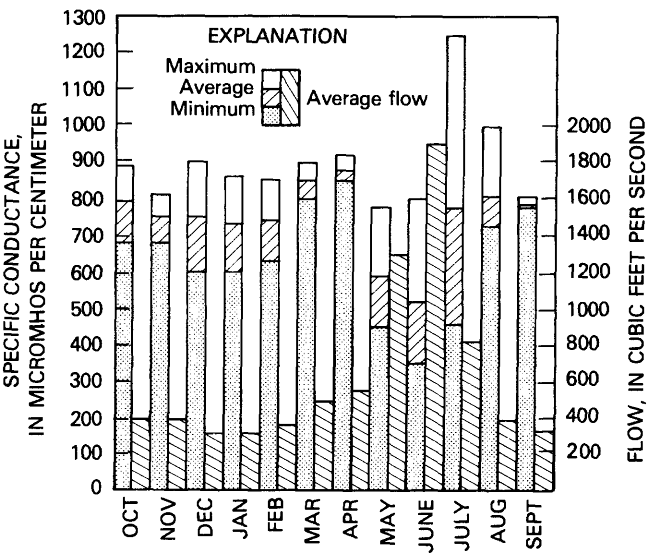

Figure 53. Average, maximum, and minimum monthly mean specific conductance and average monthly flow at station 09306500, White River near Watson, water years 1975–79.

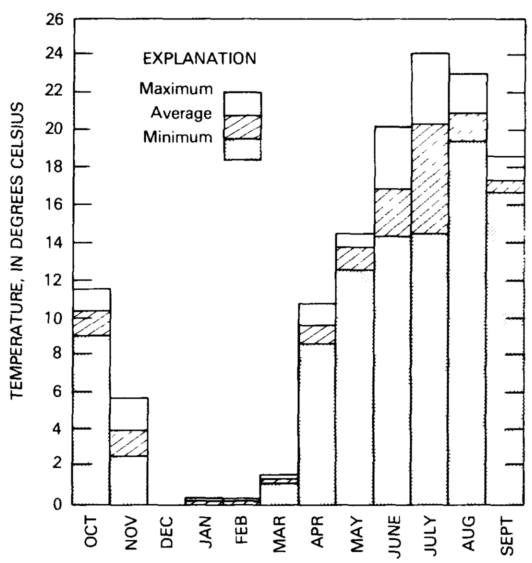

Figure 54. Average, maximum, and minimum monthly mean water temperatures at station 09306500, White River near Watson, water years 1950–79.

Intra-area streams contain very hard water during periods of base flow, and even during periods of high flow the water is moderately hard or hard (table 6). Since flow in the ephemeral streams comes from thunderstorms and snowmelt, the water is softer than it is in the perennial streams. Even so, the water in the ephemeral streams ranges from soft to very hard.

Oil and Grease

Determinations of oil and grease were made only for water samples from the White River, Evacuation Creek, Southam Canyon Wash, and Asphalt Wash. The concentration of oil and grease at station 09306500 on the White River ranges from 0 to 6 mg/L. Concentrations are highest during the winter and lowest during the late summer, perhaps due to the volatilization of the oil and grease at higher temperatures. No oil and grease was observed at Asphalt Wash or Southam Canyon Wash, although only one sample was obtained from each. At station 09306430 on Evacuation Creek, however, analysis of 29 samples showed a range of concentrations from 0 to 250 mg/L. The mean concentration for the stations in Evacuation Creek increases downstream from 0.5 mg/L at station 09306410 to 10.1 mg/L at station 09306430. The large increase in oil and grease could result from the crossing of the outcrop of the Mahogany Zone by the stream channel between these two stations.

Sediment Characteristics

Several aspects of suspended sediment and erosion have been studied for the White River and intra-area streams by Seiler and Tooley (1982), and table 9 is a brief summary of sediment data for those streams and the Green River. The table illustrates both the large range of suspended-sediment concentrations and also the variability of particle-size distributions. During periods of snowmelt runoff, the silt- and clay-size particles are less abundant than during thunderstorm runoff.

The concentration of suspended sediment measured for six stations on the White River ranged from 3 to 51,700 mg/L. The sediment concentration generally increases with flow. The particle-size distribution also shows a large range of values. The clay-size particles (less than 0.004 mm) generally were 84 percent or less of the suspended-sediment load, and the silt plus clay-size particles (all particles less than 0.062 mm) were 100 percent or less.

The intra-area streams show a large range of sediment concentration, from 6 to 31,800 mg/L in Bitter Creek, 2 to 183,000 mg/L in Evacuation Creek, and 739 to 277,000 mg/L in the ephemeral streams. The lowest concentrations are from base flow in short reaches of Evacuation and Bitter Creeks, and the highest observed concentration occurred during thunderstorm runoff in Hells Hole Canyon.

The concentration of suspended sediment, and particularly the clay-size relation, will be discussed in the section "Trace elements." The percentage of clay-size material in the suspended sediment in Bitter Creek generally is less than 70 percent, in Evacuation Creek is less than 38 percent, and in the ephemeral streams is less than 98 percent.

The sediment concentration measured for Willow Creek ranged from 13 to 112,000 mg/L. The high concentrations are due to thunderstorm runoff. The clay-size material generally is less than 80 percent, and it is greatest during thunderstorm runoff, when clay-size material is eroded from the streambanks and added by overland flow.

Major Dissolved Constituents

The major dissolved constituents (calcium, magnesium, sodium, potassium, bicarbonate, carbonate, sulfate, chloride, fluoride, and silica) along with dissolved solids are summarized for the major rivers and intra-area streams in table 10. The major constituents show a considerable amount of variation between the major rivers, the perennial intra-area streams, and the ephemeral streams. The dissolved solids, which are an indicator of the general character of the major constituents, are discussed below with regard to time and areal variances.

Major Rivers

The dissolved solids show little variation from station to station during a given season in the major rivers, but there is variation from season to season. The large range of dissolved-solids concentrations at station 09315000 in the Green River, from 215 to 3,160 mg/L, is due to seasonal variance, as shown in figure 55. In contrast to figures 53 and 54, figure 55 (fig. 56 also) represents maxima and minima of periodic sampling rather than actual recorded maximum and minimum monthly mean values. The largest ranges in the monthly values are in July and August when thunderstorm runoff flushes soluble minerals from the ephemeral drainages and evapotranspiration concentrates the dissolved solids in solution. The monthly average concentration of dissolved solids increases slightly with early spring runoff, but it then decreases as the snowmelt runoff begins from the mountains of the upper basin. After this period of high flow, the concentration again increases as flow decreases (see fig. 10). There is no significant year-to-year variance in the annual mean concentration of dissolved solids for the Green River.

The mean dissolved-solids concentration for the Green River during the period 1928–64 is 587 mg/L, whereas the mean for the period 1965–79 is 572 mg/L. The small decrease could be due to regulation of flow by Flaming Gorge Reservoir. Bolke and Waddell (1975, p. 17) have shown that initially the dissolved-solids concentration increased downstream from the reservoir, mostly from the leaching of gypsum from soils of the newly inundated lands. After this initial leaching effect, the downstream dissolved-solids concentration gradually began decreasing. The variance of dissolved-solids concentration during a given water year has been reduced because the reservoir mixes high flow and base flow before the water is released downstream (Bolke and Waddell, 1975, fig. 5).

During base flow on the Green River, the dissolved solids are predominately sulfate, calcium, and sodium; and the dissolved-solids concentration averages about 627 mg/L. During high flow, bicarbonate is the dominant anion. Calcium increases relative to sodium during high flow, and the dissolved-solids concentration averages about 385 mg/L.

The temporal variations of dissolved-solids concentrations in the White River are similar to those of the Green River, but the extremes are more pronounced without the regulation by a reservoir. There is little variation from station to station during a given season.

The overall mean of dissolved-solids concentration at station 09306500 on the White River is 500 mg/L, and the range is from 203 to 1,400 mg/L. Figure 56 illustrates the seasonal variance in dissolved-solids concentrations at station 09306500. From October through February the pattern is constant, with an average near 500 mg/L,

Table 9. Summary of sediment characteristics of streamflow, water years 1975–79

[Flow, in cubic feet per second; sediment concentration, in milligrams per liter; sediment discharge, in tons per day; and particle-size diameter, in millimeters]

	All samples					Samples with particle-size determinations												
	Station	Date	Flow	Sediment concen-tration	Sediment discharge	Station	Date	Flow	Sediment concen-tration	Sediment discharge	Particle size, percent finer than indicated diameter							
											0.002	0.004	0.016	0.031	0.062	0.125	0.250	0.500
GREEN RIVER (station 09315000)																		
Lowest concentration sampled . .	09315000	11-15-76	3,640	36	354	09315000	10-20-76	3,670	68	674	56	64	75	...	95	97	100	100
Highest concentration sampled . .	09315000	7-21-77	2,550	19,500	134,000	09315000	7-22-77	2,740	10,800	79,900	39	59	96	...	100	100	100	100
Lowest flow sampled.	09315000	12-12-77	1,760	138	656	09315000	10-20-77	1,800	268	1,300	62	70	91	...	96	100	100	100
Highest flow sampled.	09315000	5-24-79	22,000	3,640	216,000	09315000	5-24-77	22,000	3,640	216,000	24	30	51	...	81	93	99	100
WHITE RIVER (stations 09306395, 09306400, 09306500, 09306600, 093067000, 09306900)																		
Lowest concentration sampled . .	09306900	2- 3-79	340	3	2.8	09306500	12- 3-74	236	78	50	28	36	...	...	88	93	99	100
Highest concentration sampled . .	09306900	7- 6-77	219	51,700	30,600	09306395	8-25-77	642	23,200	40,200	33	47	78	96	99	100	100	100
Lowest flow sampled.	09306900	7-15-77	16.3	241	11	09306395	7- 7-77	166	12,900	5,780	62	84	99	99	100	100	100	100
Highest flow sampled.	09306500	6- 9-75	3,980	8,320	89,400	09306500	6- 9-75	3,980	8,320	89,400	31	40	61	...	77	91	98	100
WILLOW CREEK (stations 09307500, 09307800, 09307900, 09308000)																		
Lowest concentration sampled . .	09307800	10-21-75	8.7	13	0.31	09307800	1-20-75	5.9	116	1.9	45	58	...	...	98	99	99	100
Highest concentration sampled . .	09308000	7-20-77	385	112,000	116,000	09308000	7-20-79	16	27,700	1,200	40	66	98	...	100	100	100	100
Lowest flow sampled.	09307900	11-21-75	.03	180	.01	09307900	7-20-77	3.5	23,400	221	50	80	98	...	100	100	100	100
Highest flow sampled.	09308000	7-20-77	385	112,000	116,000	09308000	5-29-79	224	26,000	15,700	22	30	57	...	86	95	99	100
BITTER CREEK (stations 09306740, 09306760, 09306780, 09306800, 09306850)																		
Lowest concentration sampled . .	09306850	9-14-77	0.49	6	0.01	09306740	11-18-74	1.1	59	0.18	43	62	...	...	94	98	100	100
Highest concentration sampled . .	09306760	3-19-75	.43	31,800	37	09306760	3-19-75	.43	31,800	37	17	29	52	...	77	88	97	99
Lowest flow sampled.	09306740	2- 1-77	.03	23	<.01	09306780	4-21-75	.29	3,980	3.1	47	70	98	...	100	100	100	100
Highest flow sampled.	09306740	5-18-76	9.0	298	7.2	09306740	5-30-75	9.0	132	3.2	26	30	...	...	72	84	95	100
EVACUATION CREEK (stations 09306410, 09306415, 09306420, 09306430)																		
Lowest concentration sampled . .	09306410	7-13-78	0.3	2	<0.01	09306420	11-14-74	0.01	49	<0.01	27	30	...	...	91	99	100	100
Highest concentration sampled . .	09306420	7- 8-76	14	183,000	6,920	09306430	7- 5-77	456	178,000	219,000	27	38	60	78	84	95	100	100
Lowest flow sampled.	09306420	10- 9-75	.01	16	<.01	09306420	11-14-74	.01	49	<.01	27	30	...	...	91	99	100	100
Highest flow sampled.	09306430	7- 5-77	456	178,000	219,000	09306430	7- 5-77	456	178,000	219,000	27	38	60	78	84	95	100	100
EPHEMERAL STREAMS (stations 09306405, 09306605, 09306610, 09306620, 09306625, 09306870, 09306872, 09306878, 09306885)																		
Lowest concentration sampled . .	09306605	2-12-76	0.01	739	0.02	09306885	3- 9-78	3.1	2,630	22	76	81	86	...	95	99	100	100
Highest concentration sampled . .	09306405	9-10-75	40	277,000	29,900	09306405	7-16-75	16.0	151,000	6,520	38	51	77	...	94	98	99	100
Lowest flow sampled.	09306605	2-13-76	.01	2,020	.05	09306878	3-11-77	.04	5,250	.57	96	98	100	100	100	100	100	100
Highest flow sampled.	09306878	3-22-79	610	30,900	50,900	09306878	3-23-79	56.0	11,900	1,800	57	66	74	...	92	97	100	100

Table 10. Summary of major dissolved constituents of streamflow

[Period of record is water years 1975–79, unless otherwise indicated.]

	Milligrams per liter, except number of observations													
	Calcium dissolved (Ca)	Magnesium, dissolved (Mag)	Sodium dissolved (Na)	Potassium, dissolved (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate dissolved (SO_4)	Chloride, dissolved (Cl)	Fluoride, dissolved (F)	Silica, dissolved (SiO_2)	Dissolved solids, residue at 180°C	Dissolved solids, sum of constituents	Dissolved solids, tons per day	Dissolved solids, tons per acre-foot
GREEN RIVER AT GREEN RIVER (station 09315000)[1]														
Mean	71.1	30.5	76.3	3.1	205	0.81	257	27.3	0.38	8.0	595	572	8,400	0.80
Maximum	507	150	135	7.0	382	20	2,000	70	1.1	53	3,440	3,160	36,700	4.3
Minimum	31	11	23	1.0	107	0	62	7.1	.1	1.8	212	215	2,780	.3
Number of observations	327	325	258	163	321	316	335	326	149	286	283	215	323	325
WHITE RIVER NEAR WATSON (station 09306500)[2]														
Mean	72.1	25.1	83.3	2.7	226	0.40	189	61.2	0.34	15.3	574	500	875	0.77
Maximum	283	170	566	12	736	25	2,160	420	1.0	32	2,380	1,400	9,160	3.2
Minimum	26	9.7	14	1.0	94	0	40	7.5	.1	6.6	209	203	106	.3
Number of observations	366	366	544	314	622	448	636	633	150	354	606	195	677	677
WILLOW CREEK (stations 09307500, 09307800, 09307900, 09308000)														
Mean	70.9	51.5	111	2.8	386	1.7	282	13.2	0.42	15.1	696	742	31.2	1.0
Maximum	91	180	890	8.5	789	32	2,000	84	1.3	19	2,290	3,650	286	5.0
Minimum	52	24	15	1.1	250	0	54	1.8	.1	3.8	307	309	.1	.4
Number of observations	93	93	93	93	90	78	93	93	93	93	80	93	91	93
BITTER CREEK (stations 09306740, 09306760, 09306780, 09306800, 09306850)														
Mean	206	305	1,070	6.8	458	.....	3,480	76.7	0.58	13.4	5,780	5,320	13.8	7.8
Maximum	490	750	4,000	19	842	.....	10,000	510	3.3	33	15,900	15,500	80	22
Minimum	31	14	15	.9	125	.....	63	1.0	.1	1.6	195	196	.2	.3
Number of observations	105	104	105	105	98	.....	105	105	105	105	87	104	102	105
EVACUATION CREEK (stations 09306410, 09306415, 09306420, 09306430)														
Mean	152	154	690	7.0	473	0.52	2,010	41.0	0.81	10.3	3,560	3,310	16.6	4.7
Maximum	240	250	1,100	12	642	42	3,300	100	2.3	17.0	5,620	5,310	1,090	7.6
Minimum	49	14	29	1.4	120	0	83	3.4	.2	5.5	281	283	.02	.4
Number of observations	136	136	136	136	132	120	136	136	136	135	124	135	134	136
EPHEMERAL STREAMS (stations 09306405, 09306605, 09306610, 09306620, 09306625, 09306870, 09306872, 09306878, 09306885)														
Mean	60.0	8.9	107	4.6	190	.....	239	10.8	0.43	10.5	924	549	19.9	0.75
Maximum	470	57	360	18	500	.....	1,600	34	.9	22	2,520	2,410	265	3.4
Minimum	2.7	.5	13	1.6	47	.....	7.5	1.5	.1	4.4	351	85	0	.1
Number of observations	24	24	24	24	21	.....	24	24	23	24	8	24	22	24

[1] Period of record, water years 1965–79.
[2] Period of record, water years 1950–79.

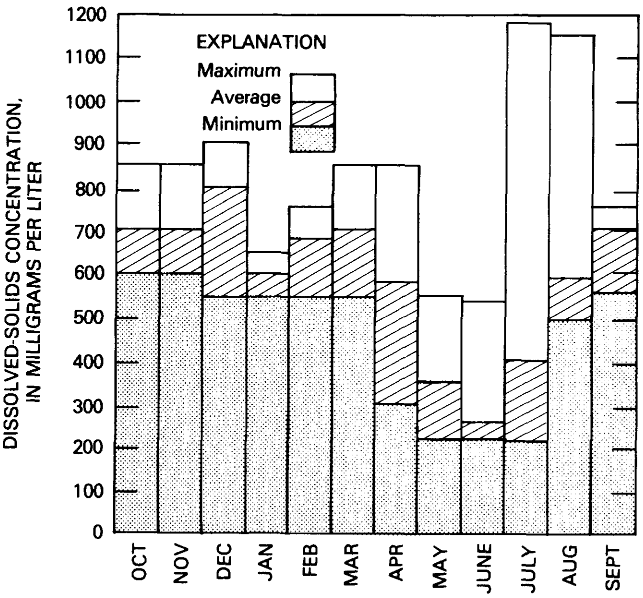

Figure 55. Average, maximum, and minimum dissolved-solids concentration at station 09315000, Green River at Green River, water years 1965–79.

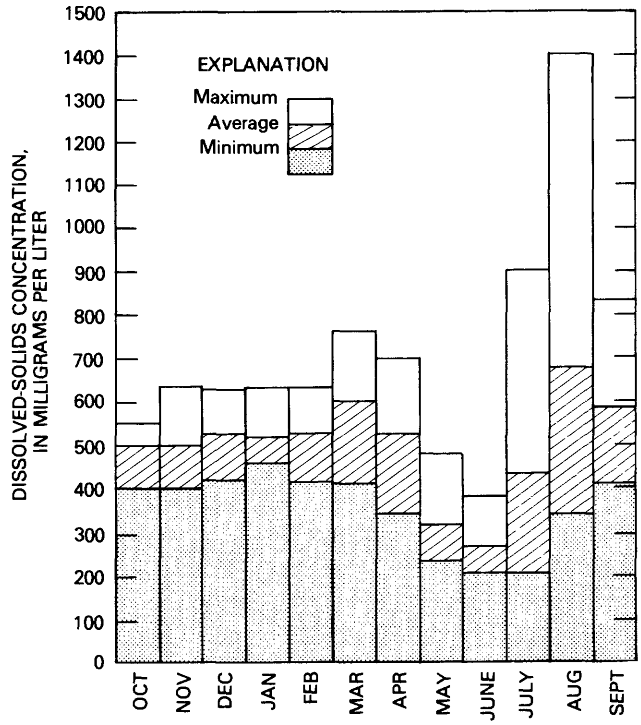

Figure 56. Average, maximum, and minimum dissolved-solids concentration at station 09306500, White River near Watson, water years 1950–79.

representing the base flow from the upper White River basin. In March, the average increases to about 600 mg/L due to snowmelt runoff from lower altitudes along the intra-area streams. When snowmelt runoff from the upper basin begins in May and continues in June, the average dissolved-solids concentration decreases to about 300 mg/L, the lowest for the year. During July, after the period of high flow, the average dissolved-solids concentration increases again. During August and September, the average dissolved-solids concentration increases still more, but the effects of evapotranspiration and thunderstorm runoff cause a wide range in the observed values. The reasons for the variations were studied in detail for the White River.

The plot in figure 57 of dissolved-solids concentration versus streamflow for the White River represents values from all the gaging stations on the White River during water years 1975–79. The samples fall into four groups, and the relation of dissolved-solids concentration to streamflow and the chemical character of the water varies from group to group. The groups represent different sources of streamflow, as is designated in figure 57.

The mean concentrations of major solutes in the four groups in figure 57 are given in table 11. The chemical characteristics vary between high and base flow in both the upper and lower White River basins. The dominant solutes in the samples representing base flow from the lower basin are sodium and sulfate, which also are the most common solutes in ground water from the bird's-nest aquifer described by Homes and Kimball (U.S. Geological Survey, written commun., 1982). Base flow from the upper basin also is of the sodium sulfate type, but it is fresher than the base flow of the lower basin. Ground water from the lower basin is mostly discharged from the Green River Formation (W. F. Holmes and B. A. Kimball, U.S. Geological Survey, written commun., 1982), whereas ground water from the upper basin is discharged from older rocks, which in general contain less-soluble minerals than does the Green River Formation (Hintze, 1980, for Utah; and U.S. Geological Survey, 1935, for Colorado).

High flow from the upper basin originates as snowmelt in the high mountains of Colorado; it has a low dissolved-solids concentration and greatly dilutes the base flow from the lower basin. The dominant solutes are calcium, sodium, sulfate, and bicarbonate (alkalinity as $CaCO_3$). Among the various sources of water in the White River, this water is of the best quality (fig. 57).

When high flow enters the White River from the lower basin, it is due to low-altitude snowmelt or thunderstorms. In both cases, but particularly with thunderstorms, the dissolved-solids concentration of the flow is greater than that of high flow from the upper basin. This results from the dissolution of soluble efflorescent crusts that accumulate along the drainages in the lower basin. A sample of these crusts from station 09306410 in Evacuation Creek was examined by X-ray diffraction. The salts included burkeite ($Na_2CO_3{\cdot}2Na_2SO_4$), thenardite (Na_2SO_4), trona ($NaHCO_3{\cdot}Na_2CO_3{\cdot}2H_2O$), mirabilite ($Na_2SO_4{\cdot}10H_2O$), calcite ($CaCO_3$), and dolomite ($CaCO_3{\cdot}MgCO_3$). Halite (NaCl) was also detected. These

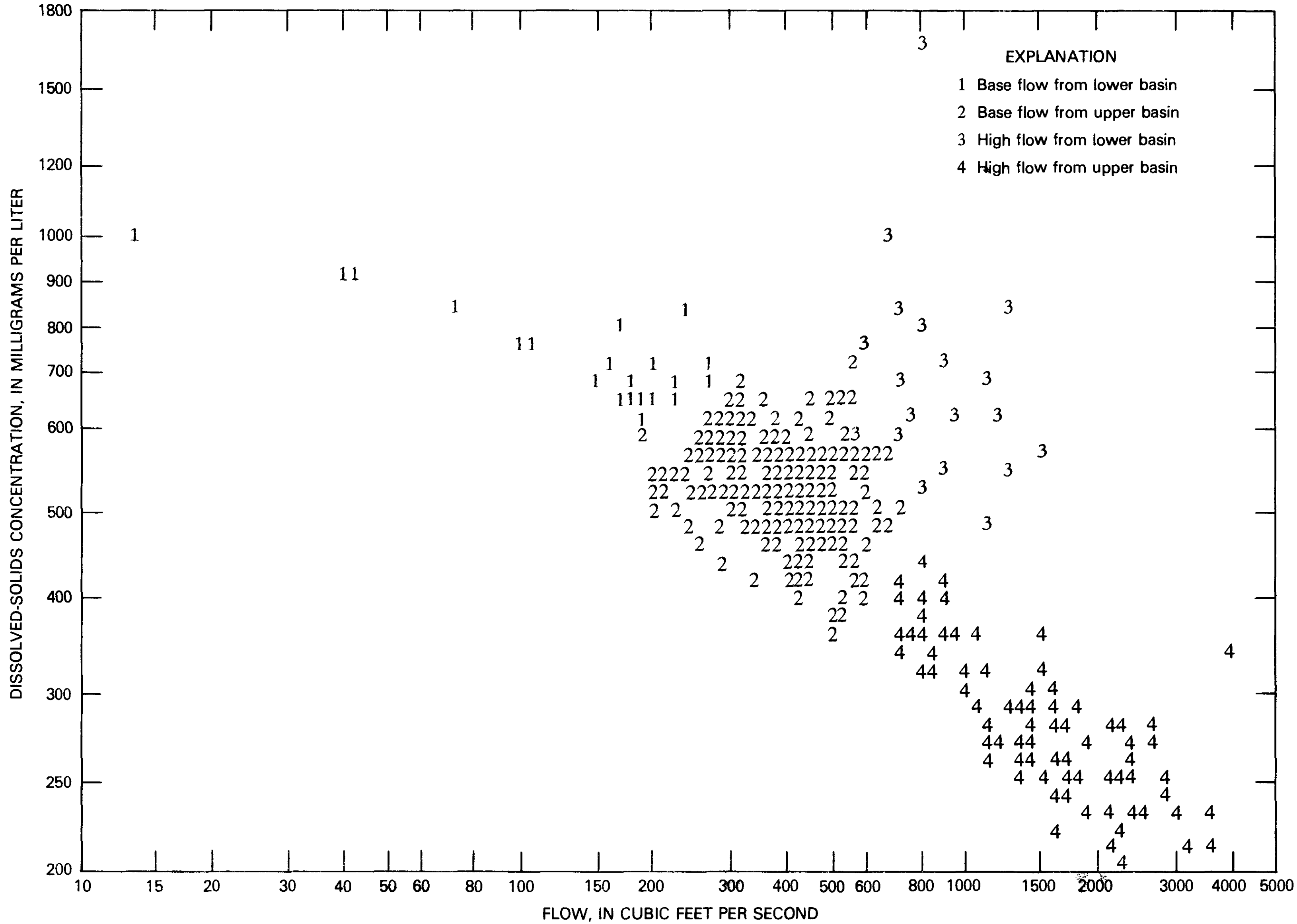

Figure 57. Relation of dissolved-solids concentration to flow in the White River, water years 1975–79.

Table 11. Summary of major dissolved constituents, general water-quality characteristics, and mineral equilibria for various sources in the White River

	Lower basin		Upper basin	
	Base flow	High flow	Base flow	High flow
Mean flow (ft^3/s)	150	750	400	2,000
Mean values for major dissolved constituents and general water-quality characteristics (milligrams per liter except specific conductance and pH)				
Calcium	81	87	70	49
Magnesium	37	30	26	15
Sodium	121	116	71	31
Potassium	3.7	4.5	2.2	1.8
Alkalinity as $CaCO_3$	217	198	188	135
Sulfate	270	256	180	83
Chloride	78	80	43	19
Fluoride	.4	.5	.4	.3
Silica	14	13	13	14
Specific conductance (micromhos per centimeter at 25°C)	1,290	1,360	896	517
pH (standard units)[1]	8.0	7.8	8.1	7.8
Mineral equilibria				
Calcite, SI[2]	0.657	0.316	0.528	0.093
Dolomite, SI	1.200	.249	.696	.157
Quartz, SI	.457	.592	.598	.522

[1] pH values are in logarithmic units thus this mean is a geometric mean.

[2] Saturation index, which is the logarithm of the ratio of the ion-activity product of a given mineral to the equilibrium constant for that mineral, adjusted for the temperature of the sample.

evaporite salts are quickly dissolved and enter streams with overland flow. This process of cyclic wetting and drying in the laboratory is described by Drever and Smith (1978).

To determine the effect of the dissolution of the efflorescent crusts on the water quality, one might subtract the concentrations in high flow from the upper basin (column 4 in table 11), which represent dilute flow, from the concentrations in high flow from the lower basin (column 2 in table 11). This results in the following concentrations:

Calcium	38	mg/L
Magnesium	15	mg/L
Sodium	85	mg/L
Potassium	2.7	mg/L
Chloride	61	mg/L
Sulfate	173	mg/L
Alkalinity	63	mg/L
Silica	-1	mg/L

The effect of the sodium sulfate salts is evident from this exercise. However, all the solutes except silica are significantly increased in solution. This points out the potential increase in dissolved-solids concentration in the White River from thunderstorms in the lower basin.

The concentration of calcium shows little relation to flow (correlation coefficient, r is < 0.1) in base flow from the lower basin. Instead, it remains constant at flows less than 250 ft^3/s, with a slight decrease at base flows of less than 50 ft^3/s. This results from the control on calcium concentration by calcite. Kimball (1981b) found that calcite was one of the most abundant stream sediments in the White River. Thus, during low flow, calcium is consumed by the reaction

$$Ca^{2+} + 2HCO_3^- = CaCO_3(s) + CO_2 + H_2O \quad (1)$$

The state of saturation can be expressed as a saturation index (table 11), which is the logarithm of the ratio of the ion activity product of a given mineral to the equilibrium constant for that mineral, adjusted for the temperature of the sample. For example, the saturation index (SI) for calcite ($CaCO_3$) would be

$$SI_{calcite} = \log \left[\frac{{}^{a}Ca^{+2} \cdot {}^{a}CO_3^{-2}}{K_{T,\ calcite}} \right] \quad (2)$$

Any saturation index that is less than zero represents undersaturation with a given mineral, and a saturation index greater than zero represents supersaturation. Activities and saturation indices were calculated using WATEQ2 (Ball and others, 1979), a chemical-equilibrium model.

Although base flow from the lower basin has the greatest degree of supersaturation for calcite (SI=0.657), high flow from the lower basin and base flow from the upper basin also are supersaturated. Only when the major solutes are diluted by snowmelt runoff from the upper basin is there any undersaturation. Concentrations of calcium exceed 90 mg/L only during high flow from the lower basin when calcium is added to the streamflow by the dissolution of efflorescent crusts.

Magnesium concentrations are relatively large during base flow and high flow from the lower basin. Magnesium is an important component in ground water from the bird's-nest aquifer, and it is also contributed by dissolution of the efflorescent crusts. The mean concentration of magnesium in base flow from the upper basin (26 mg/L) is simply diluted by high flow from the upper basin (to a mean of 15 mg/L). Magnesium is not affected by carbonate equilibria in the same way as calcium. It only appears that magnesium is limited in solution at base flow of generally less than 50 ft^3/s. Although dolomite is a major phase in the stream sediments (Kimball, 1981b), the kinetics of dolomite precipitation are too slow for precipitation to affect the magnesium concentration (Berner, 1971, p. 148–149). Magnesium is associated with the fine-grained clays in the suspended sediment of the White River (Kimball, 1981b). Perhaps uptake of magnesium could exert some control on magnesium concentrations when the magnesium concentration is sufficiently high (about 50 mg/L).

Sodium has the greatest range of concentration among the cations in the White River (from 14 to 566 mg/L). High concentrations of sodium were observed in both high and base flows from the lower basin (means of 116 and 121 mg/L). During base flow, from the lower basin, sodium varies inversely with flow (r = -0.7). When flow becomes very low, there does not appear to be any control on the concentration of sodium, unlike calcium and magnesium. It continues to increase and approaches the concentration of sodium in the bird's-nest aquifer (740 mg/L) (W. F. Holmes and B. A. Kimball, U.S. Geological Survey, written commun., 1982). High flow from the lower basin causes the dissolution of efflorescent crusts, which generally are sodium salts, thus leading to possible high concentrations of sodium in the river. During base flow from the upper basin, the sodium concentrations are fairly constant at about 71 mg/L. This base flow concentration is diluted by high flow from the upper basin to a mean of 31 mg/L.

The behavior of potassium in the White River is unlike that of any of the other solutes. The range of potassium is from 1.0 to 12 mg/L (table 10), suggesting that there is some specific control on potassium concentrations. The abundant illite in the stream sediments (Kimball, 1981b) and in the rocks of the Green River Formation could provide such a control. The conversion of smectite minerals to illite in the Texas Gulf Coast involves the uptake of potassium (Boles and Franks, 1979, p. 63). Even though this is a diagenetic reaction, the presence of smectite and illite in the sediments may cause the uptake of potassium.

Potassium concentrations are highest during high flow from the lower basin. Kennedy and Malcolm (1978, p. 145–149) have suggested that high concentrations of potassium could be a contribution from organic matter. This may be true in the southeastern Uinta Basin; however, the amount of available organic matter there is much smaller than in the area in California studied by Kennedy and Malcolm. The increase in concentration is more likely from dissolution of the efflorescent crusts, which generally contain potassium along with sodium.

The concentration of chloride generally is highest in the lower basin, either as base or high flow. The mean concentration in base and high flow from the lower basin is near 80 mg/L. However, the range of chloride concentrations is much greater for high flow from the lower basin because of dissolution of the efflorescent crusts along the intra-area streams.

During base flow from the lower basin, the chloride concentrations are nearly constant. There is no mineralogic control on the chloride concentration, but there is a control from ground-water input. The chloride concentrations in base flow from the lower basin reflects the concentration in the ground-water inflow, which has a mean of 101 mg/L (W. F. Holmes and B. A. Kimball, U.S. Geological Survey, written commun., 1982).

The mean chloride concentration in base flow from the upper basin is 43 mg/L. When this base flow is the main component of flow in the White River, the chloride concentration remains close to this average value. During high flow from the upper basin, the base-flow concentration is diluted to a mean of 19 mg/L.

The variations in sulfate concentrations in the White River are similar to those discussed for sodium. The highest concentrations are from dissolution of efflorescent crusts by high flow in the lower basin, and the lowest concentrations are during high flow from the upper basin. There does not appear to be any mineralogic control on the concentration of sulfate during base flow. Instead, sulfate varies inversely with flow (r = -0.905). Sulfate is concentrated (mean of 1,300 mg/L) in ground water in the bird's-nest aquifer, and discharge from the aquifer is the source of the high concentrations at base flow in the White River. In addition, sulfate is concentrated by evapotranspiration.

Concentrations of bicarbonate (actually alkalinity, due mostly to bicarbonate) do not show a good relation to flow in any of the different groups of streamflow. Instead, the concentrations vary widely from each source. The major control on bicarbonate concentration is the control by calcite equilibrium, as given in equation 1 (p. 53). The highest concentrations were observed in high and base flow from the lower basin. The mean concentration during base flow from the lower basin (217 mg/L) is the largest for any of the sources. The efflorescent crusts contain sodium bicarbonate salts; thus they should contribute to bicarbonate concentrations.

During base flow from the lower basin, bicarbonate does not show the same limiting control by calcite that is seen with calcium. Eugster and Jones (1979, fig. 2) have pointed out that during the course of evaporative concentration, when a solution reaches saturation with respect to calcite, three different chemical evolution paths can occur. If the milliequivalents of calcium are greater than the milliequivalents of bicarbonate, then the solution will become depleted in bicarbonate and enriched calcium. If the bicarbonate milliequivalents are greater than calcium milliequivalents, then calcium will be depleted and bicarbonate will be enriched. Only if the milliequivalents of each solute are exactly equal at calcite equilibrium will they remain in equal concentrations. In the waters of the White River, taking the concentrations of high flow from the upper basin as the dilute starting water, the mean bicarbonate is 2.70 meq/L, and the mean calcium is 2.45 meq/L. Thus, when this water is concentrated, one would expect that calcium would be depleted by calcite precipitation and bicarbonate would be enriched. This apparently is the case for the White River.

The concentration of silica remains nearly constant in the White River, no matter where the flow originates, at a mean of about 14 mg/L. This is well below the concentration of silica (about 20 mg/L) that is discharged by deep circulating springs to the intra-area streams (Kimball, 1981a, table 3). Table 11 shows that the water is consistently supersaturated with respect to quartz. Saturation indexes calculated by WATEQ2 (Ball and others, 1979) for chalcedony and cristobalite are close to zero. However, these minerals are not common in the stream sediments (Kimball, 1981b). The waters are undersaturated with respect to amorphous silica.

Siever and Woodford (1973) have demonstrated the sorption of silica from solutions containing various clay minerals. They found that there generally is a "crossover point" which represents an equilibrium between sorption and desorption by a particular clay. The crossover point indicates a total sorption capacity. It is possible that the various clay minerals in the stream sediments of the White River have this same effect on silica concentrations in the White River. This sorption effect does vary with pH and changes in ionic strength (Siever and Woodford, 1973, fig. 5); thus the effect differs in the intra-area streams.

Intra-Area Streams

The patterns of major constituents in the intra-area streams not only differ greatly from that of the major rivers, but they also differ greatly from one stream to another. The concentrations of major constituents in the intra-area streams generally are much greater than in the major rivers. The input of these streams to the White River deteriorates the water quality, but it is a natural process. The mean dissolved-solids concentrations are 742 mg/L for Willow Creek (including Hill Creek), 5,320 mg/L for Bitter Creek, and 3,310 mg/L for Evacuation Creek. The variations in major solutes and controls on the solutes are discussed below.

The water quality in the headwaters of Willow and Hill Creeks is good, with mean dissolved-solids concentrations of 478 mg/L for station 09307500, and 365 mg/L for station 09307800. Both streams are perennial in these upper reaches. Downstream from each of the upper stations (fig. 2), the water quality deteriorates significantly (fig. 58). At station 09308000 below the confluence of Willow and Hill Creeks, the mean dissolved-solids concentration is 1,300 mg/L. The water quality varies at this station between high and base flows. During high flow, generally in May and June, the mean dissolved-solids concentration is 950 mg/L, and during base flow the mean concentration is 1,870 mg/L. The large range of dissolved-solids concentrations at station 09308000 (592–3,650 mg/L) indicates the large variability in water quality.

At station 09308000, sodium and sulfate increase in about the same amounts by about 11 meq/L from high flow to base flow. Magnesium, chloride, and bicarbonate also increase, but only about one-third as much. Calcium, by contrast, is less concentrated in the base flow.

The solutes that increase from high flow to base flow are the major components of ground water that seep into the drainage downstream. They are also the solutes that are most affected by evapotranspiration, which is large along the courses of Willow and Hill Creeks. The calcium decrease is due to the precipitation of calcite (see eq. 1). The decrease in silica, though not large, might be attributed to increased sorption of silica on the stream sediments. The mean pH also increases in the base flow in response to the charge balance during evaporative concentration of the solutes (Drever, 1982, ch. 9).

Only the water in the upper reaches of Willow and Hill Creeks is of suitable quality for domestic supply. Downstream, the dissolved-solids concentration is rarely below the limit of 500 mg/L established by the Environmental Protection Agency for drinking water (table 6). However, the water in these creeks is used for irrigation of some crops, generally alfalfa, a salt-tolerant crop.

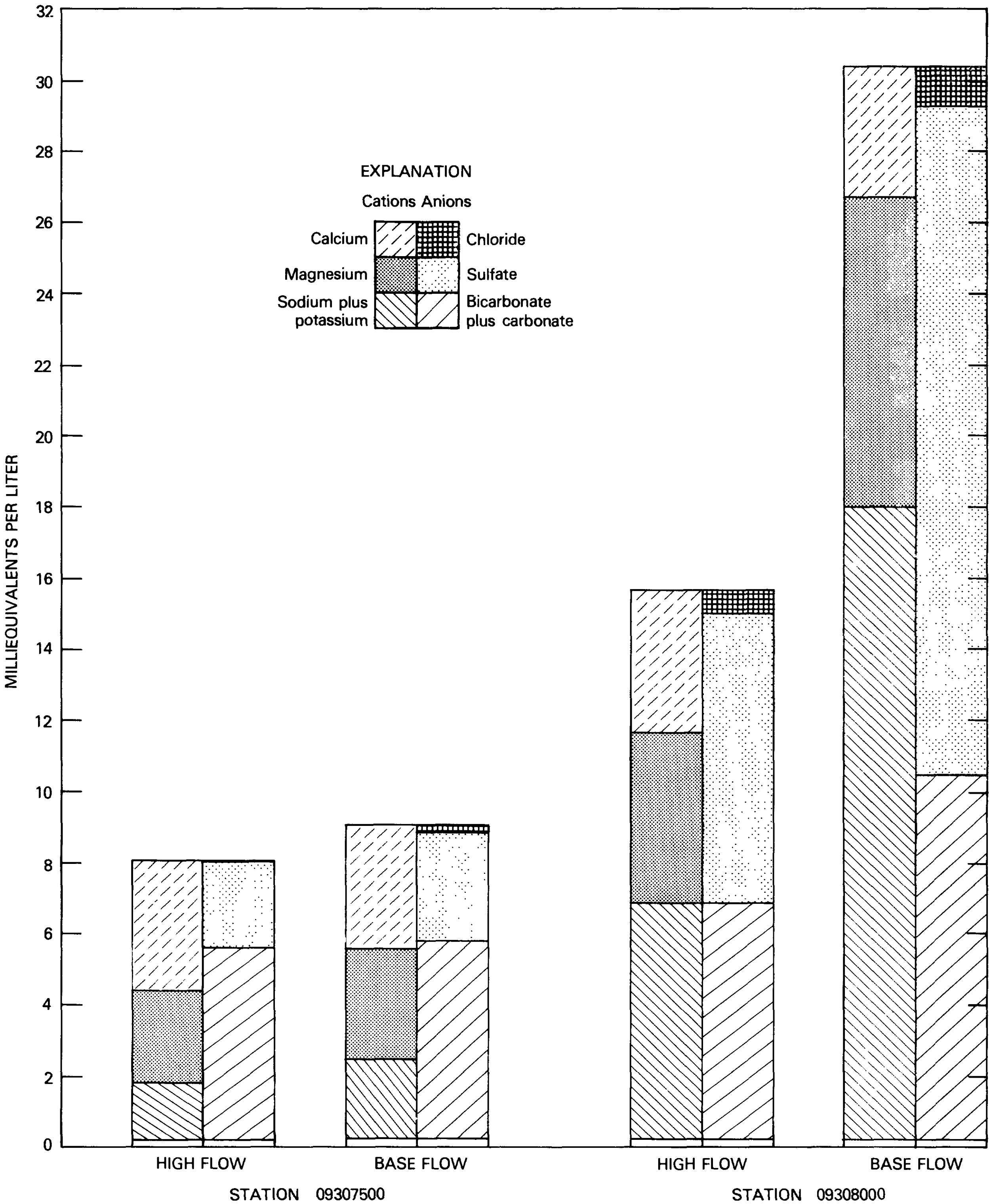

Figure 58. Variance in water quality during base flow and high flow in Willow Creek.

The variation of major constituents in Bitter Creek resembles that in Willow Creek; however, there is an even larger change from the upper reaches to the lower reaches (fig. 59). The mean dissolved-solids concentration at station 09306740 in the upper reaches of Bitter Creek is 412 mg/L, whereas at station 09306850 at the mouth of Bitter Creek the mean dissolved-solids concentration is 13,100 mg/L.

The dissolved-solids concentration shows an inverse relation to flow with little variation at the upper station on Bitter Creek, but at lower stations there is more variation during periods of high flow. The minimum concentration at station 09306850 during high flow (5.6 ft^3/s was the largest flow measured during water-quality sampling) was 2,900 mg/L.

The effects of evaporative concentration are more pronounced in Bitter Creek than in any of the other intra-area streams. The changes that occur in the chemical character of the streamflow closely resemble the changes that occur in the chemical quality of the ground water in the Bitter Creek alluvium (W. F. Holmes and B. A. Kimball, U.S. Geological Survey, written commun., 1982). Only the water in the upper reaches of Bitter Creek is suitable for irrigation, and the water is used for irrigation at several ranches in the upper reaches before it is concentrated by evapotranspiration.

In general, the changes are similar to those that have been mentioned for Willow Creek. Sodium and sulfate increase considerably, while magnesium and chloride increase somewhat less (fig. 59). Calcium is removed from the water by the precipitation of calcite. This precipitation removes bicarbonate from the water, but since bicarbonate milliequivalents are greater than calcium milliequivalents in the dilute waters upstream, calcium is affected more than bicarbonate. Potassium increases slightly, but as in the other streams, it is controlled by sorption and concentrations remain low. Silica decreases downstream probably due to sorption on clays.

The concentrations of major constituents do not vary in Evacuation Creek as they do in Bitter and Willow Creeks. The mean concentration of dissolved solids is nearly the same at each of the gaging stations on Evacua-

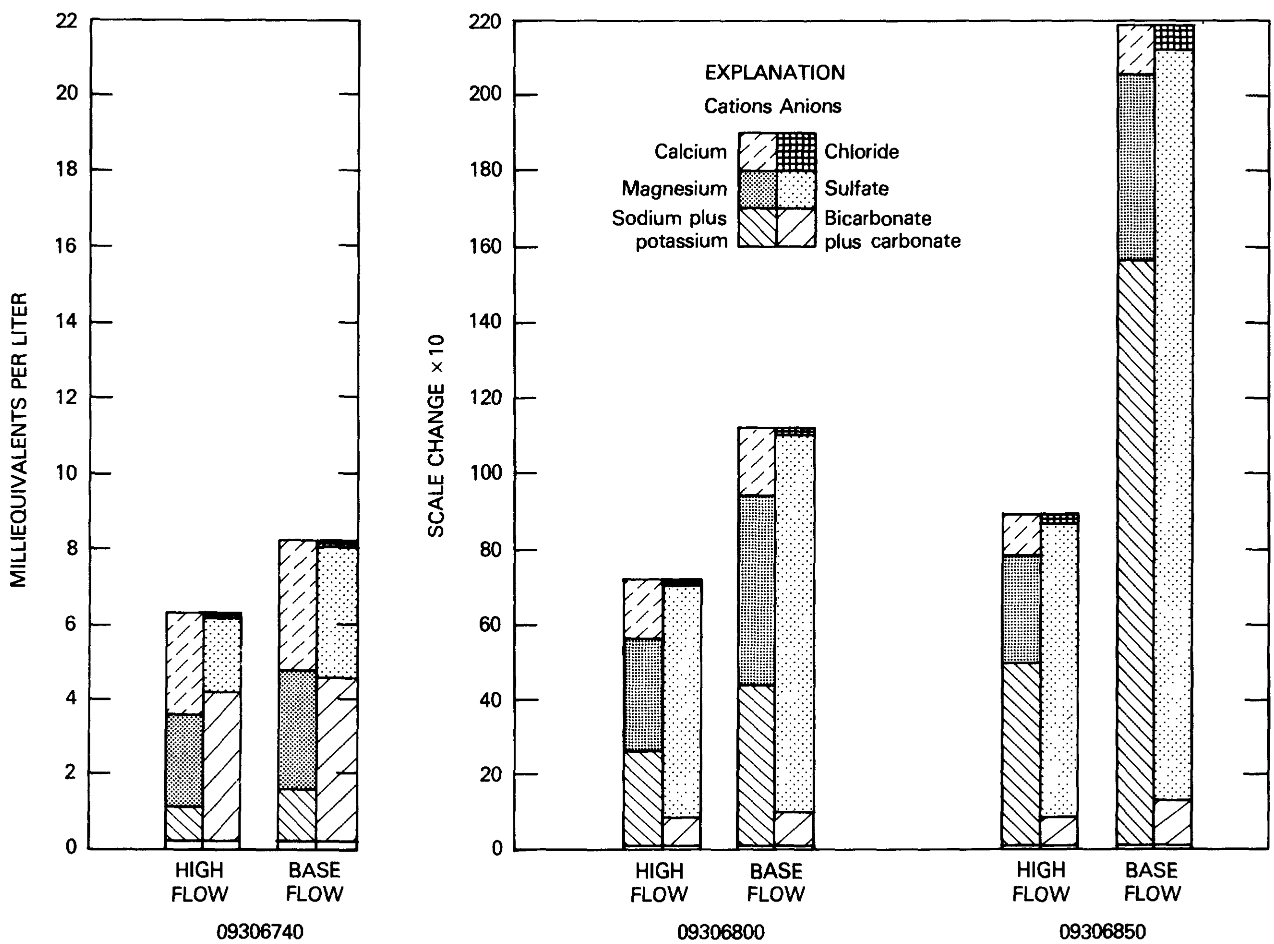

Figure 59. Variance in water quality during base flow and high flow in Bitter Creek.

tion Creek (fig. 60). At station 09306410, which is below what might be considered the upper reaches of Evacuation Creek, the mean concentration of dissolved solids is 2,840 mg/L, whereas the mean concentration at station 09306430 near the mouth of Evacuation Creek is 3,290 mg/L. Mean concentrations at the stations in between are in the same range. During periods of high flow (above 5 ft^3/s), dissolved-solids concentrations may decrease below 1,000 mg/L, but there were few observations in that range. The concentrations of dissolved solids at all stations are consistently above the Environmental Protection Agency criteria for domestic use (table 6). Hardness and sulfate consistently exceed Environmental Protection Agency criteria.

The water quality is affected by evaporative concentration between stations 09306410 and 09306420, but there is also a hydraulic connection between Evacuation Creek and the bird's-nest aquifer. W. F. Holmes and B. A. Kimball (U.S. Geological Survey, written commun., 1982) show recharge from the stream to the bird's-nest aquifer in the upstream area of Evacuation Creek, near station 09306420, and discharge from the aquifer to the stream in the lower reaches. This may account for the relatively uniform water quality that was observed in Evacuation Creek. Although the chemical character of the water in the bird's-nest aquifer does change somewhat as the water moves downdip (W. F. Holmes and B. A. Kimball, U.S. Geological Survey, written commun., 1982), the water is not subject to evaporative concentration while in the aquifer. By contrast, concentration due to evapotranspiration of water from the alluvial aquifers can be intense.

The average dissolved-solids concentration in the ephemeral streams is 549 mg/L, with a range from 85 to 2,410 mg/L (table 10). The chemical character of the dissolved solids varies considerably. During base flow in Asphalt Wash, at station 09306625, the predominant dissolved solids are sodium and bicarbonate; however, overall concentrations are only about 300 mg/L. During high flow from thunderstorm runoff, the dissolved-solids concentration is 628 mg/L, and sodium and sulfate predominate. Other ephemeral streams show a similar pattern of increased dissolved-solids concentration with high flow from thunderstorm runoff.

Unlike the dissolved-solids concentrations in the major rivers and the perennial intra-area streams, the concentrations in the ephemeral streams show a small positive correlation with discharge ($r = 0.489$) rather than a negative correlation. During intense thunderstorm runoff the input of dissolved-solids loads from the ephemeral streams to the White River could be as much as 3.4 tons per acre-ft. By contrast, the maximum observed dissolved-solids load for the White River is 3.2 tons per acre-ft.

Trace Elements

Table 12 is a summary of concentrations of dissolved trace elements for the major rivers and the intra-area streams in the southeastern Uinta Basin. Concentrations of trace elements generally are in the micrograms-per-liter range, and they do not contribute significantly to the dissolved-solids sum. Thus there is no way to get a general overview of the total trace-element concentration; instead each trace element must be considered individually. In general, the concentrations of dissolved trace elements are less than the criteria listed in table 6.

The concentrations of the various trace elements are similar in the Green and White Rivers. For the most part, concentrations of dissolved trace elements are constant both from station to station and from season to season. Barium shows a consistent increase in concentration downstream in the White River. Other increases or decreases in concentration for a given trace element are not consistent. Only boron and strontium show temporal variance. Boron decreases from a mean concentration of about 150 μg/L during base flow to about 50 μg/L during high flow at station 09306500. Strontium shows the same pattern, decreasing from about 950 μg/L at base flow to about 400 μg/L during high flow.

Trace-element concentrations in the intra-area streams are greater than in the major rivers. There is not much temporal variance, but there is areal variance, with a general increase in a downstream direction.

In Willow Creek, the variations are mostly from station to station with only slight seasonal variations for most constituents. The maximum observed concentrations exceed the criteria listed in table 6 for arsenic, boron, iron, manganese, and mercury. The water-quality criteria are exceeded more often at the downstream stations, where the trace elements have become concentrated by evapotranspiration along with the major elements.

Both temporal and areal variation in the concentrations of several trace elements are evident in Bitter Creek. The trace elements that show the greatest changes are aluminum, boron, lithium, manganese, mercury, strontium, and zinc. Several of these decrease during high flow, and boron decreases the most.

The trace elements in the Bitter Creek drainage that have maximum observed concentrations exceeding the criteria listed in table 6 are boron, manganese, mercury, and selenium. Boron exceeds the criteria for several months of the year in minimum as well as maximum and monthly mean concentrations.

The concentration of trace elements in Evacuation Creek also is greater than in the major rivers. The concentrations of trace elements show little seasonal variation. Boron, bromide, gallium, iron, lithium, manganese, nickel, and strontium all show an apparent increase in

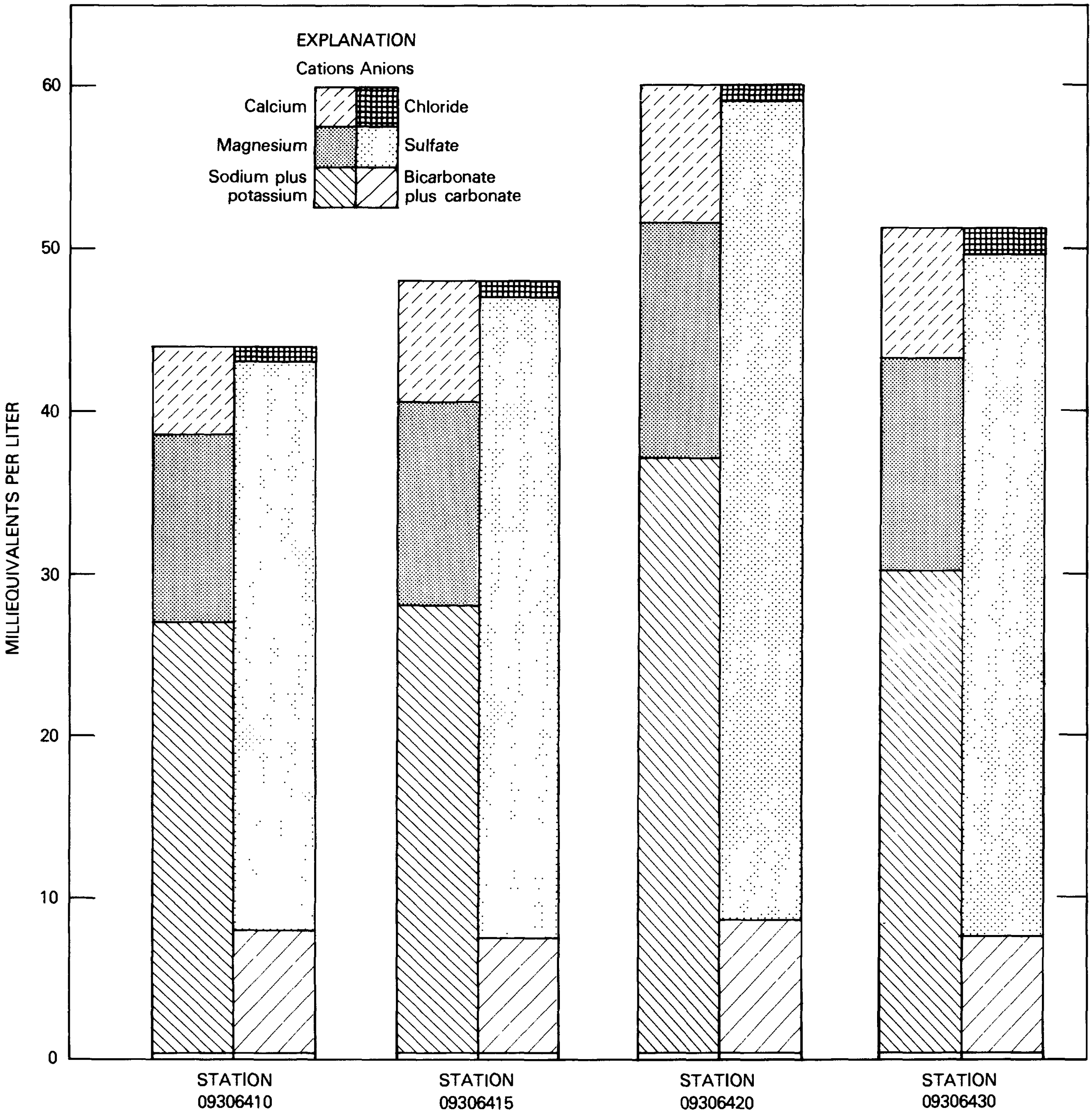

Figure 60. Variance in mean water quality in Evacuation Creek.

concentration in a downstream direction. Most concentrations increase between stations 09306410 and 09306420, with only slight changes downstream from station 09306420. This is because much of the streamflow in the lower reach of Evacuation Creek is base flow from the bird's-nest aquifer.

In Evacuation Creek, boron, iron, manganese, mercury, and selenium all have maximum concentrations that exceed the criteria listed in table 6.

The sampling program for trace elements in the ephemeral streams was not as extensive as for the major rivers and other intra-area streams because it was difficult to obtain sufficient samples during floods. Of the observations summarized in table 12, the criteria listed in table 6 were exceeded only by the maximum concentrations of iron and manganese.

At station 09315000 on the Green River and station 09306900 on the White River, concentrations of both

Table 12. Summary of concentrations

[Period of record is water years 1975–79,

Micrograms per liter, except

	Aluminum (Al)	Arsenic (As)	Barium (Ba)	Beryllium (Be)	Bismuth (Bi)	Boron (B)	Bromide (Br)	Cadmium (Cd)	Chromium (Cr)	Cobalt (Co)	Copper (Cu)	Cyanide (Cn)	Gallium (Ga)	Germanium (Ge)
GREEN RIVER AT GREEN														
Mean	....	2	<100	....	....	131	340	....	....	....	....	....	....	....
Maximum	....	5	400	....	....	250	430	4	<20	<3	19	....	....	....
Minimum	....	<1	80	....	....	<20	230	(2)	(2)	(2)	<2	....	....	....
Number of observations	....	24	8	....	....	99	27	24	24	24	24	....	....	....
WHITE RIVER NEAR														
Mean	20	1	<100	<10	....	154	100	....	....	....	....	0.5	....	....
Maximum	120	4	500	10	<17	17,000	300	<2	<20	<11	8	10	<6	<20
Minimum	10	<1	52	<2	<2	<20	0	(2)	(2)	(2)	(2)	0	0	<2
Number of observations	33	28	24	10	9	242	36	24	24	19	25	22	9	9
WILLOW CREEK (stations 09307500,														
Mean	26	10	<100	....	....	620	170	....	....	....	23	....	....	....
Maximum	330	58	300	<10	<12	5,100	700	3	<20	<12	670	....	<5	<12
Minimum	10	1	60	<1	0	<20	0	(2)	(2)	(2)	(2)	....	<2	<3
Number of observations	86	76	27	8	7	92	20	32	32	7	75	....	7	7
BITTER CREEK (stations 09305740,														
Mean	60	4	<100	....	....	3,300	510	....	....	....	<20	....	....	....
Maximum	1,600	19	400	<18	<85	16.000	2,400	<2	25	<40	210	....	<40	<85
Minimum	5	<1	27	<3	0	<20	0	(2)	(2)	<2	(2)	....	0	<2
Number of observations	87	76	27	5	5	105	22	28	28	5	75	....	5	5
EVACUATION CREEK (stations														
Mean	21	2	<100	<10	....	1,100	280	....	....	....	15	1	....	....
Maximum	130	6	400	10	<100	2,700	600	<2	30	<75	600	20	<40	<170
Minimum	5	<1	20	<4	<6	<20	100	(2)	(2)	(2)	(2)	0	<3	<7
Number of observations	95	87	65	23	17	103	97	67	67	54	80	61	17	17
EPHEMERAL STREAMS (stations 09306405, 09306605, 09306610,														
Mean	140	9	....	....	....	200	70	....	....	....	21	....	....	....
Maximum	870	37	200	20	<10	440	100	7	2	<10	45	10	<5	<20
Minimum	40	1	<100	10	<8	50	0	(2)	(2)	<10	3	0	<3	<20
Number of observations	10	7	4	2	2	24	3	4	4	2	7	2	2	2

[1] Period of record, water years 1965–79.
[2] Not detected.
[3] Period of record, water years 1950–79.

of dissolved trace elements for streamflow

unless otherwise indicated.]

number of observations

Iron (Fe)	Lead (Pb)	Lithium (Li)	Manga-nese (Mn)	Mercury (Hg)	Molyb-denum (Mo)	Nickel (Ni)	Sele-nium (Se)	Silver (Ag)	Stron-tium (Sr)	Tin (Sn)	Tita-nium (Ti)	Vana-dium (V)	Zinc (Zn)	Zirco-nium (Zr)
RIVER (station 09315000)[1]														
42	....	....	<10	....	....	....	2	....	....	....	....	....	<20	....
190	70	....	20	<0.5	....	....	5	([2])	....	....	....	....	120	....
<10	<1	....	<10	<.5	....	....	<1	([2])	....	....	....	....	([2])	....
26	24	....	26	24	....	....	24	8	....	....	....	....	24	....
WATSON (station 09306500)[3]														
42	....	12	<10	....	2	3	1	....	830	....	....	2	<20	....
270	5	30	30	<0.5	4	12	3	<2	1,200	<17	<10	4	110	<30
<10	<1	<10	<10	<.1	<1	([2])	<1	([2])	60	<2	<2	0	([2])	<3
37	24	28	37	24	24	19	23	10	26	9	9	24	24	9
09307800, 09307900, 09308000)														
43	....	22	26	<0.1	17	....	1	....	960	....	....	6	<20	....
650	34	70	170	1.7	58	<12	5	<2	1,900	<12	<8	18	870	17
<10	<1	<10	<10	<.1	1	<2	<1	([2])	460	<3	<2	1.4	([2])	5
91	32	87	46	75	28	8	76	7	87	7	7	28	76	7
09306760, 09306780, 09306800, 09306850)														
36	....	100	60	<0.5	27	....	2	....	3,700	....	....	3	63	....
90	19	280	170	7	130	....	10	<9	9,000	<85	<40	4	1,400	<130
<10	<1	<10	<10	<.1	<1	<2	<1	([2])	370	<2	<1	0	([2])	<3
103	27	94	55	75	27	5	76	5	94	5	5	27	75	5
09306410, 09306415, 09306420, 09306430)														
44	....	82	83	....	31	5	2	....	3,400	....	....	1	<20	....
470	5	300	410	<0.5	70	18	20	<8	4,300	<100	<80	7	110	<170
<10	<1	<10	<10	<.1	<1	([2])	<1	([2])	1,200	<6	<3	0	([2])	<10
102	67	86	89	79	65	54	79	23	63	17	17	65	79	17
09306620, 09306625, 09306870, 09306872, 09306878, 09306885)														
253	....	25	50	....	18	....	1	....	1,270	....	....	11	73	....
2,000	23	60	520	<0.5	30	([2])	2	<2	3,500	<10	<7	14	130	<20
<10	<1	<10	<10	<.1	6	([2])	<1	([2])	340	<8	<5	8	20	<10
23	4	6	20	6	6	2	7	3	9	2	2	3	7	2

suspended recoverable and dissolved trace elements were determined (table 13). As reported in table 13, a suspended recoverable concentration is due to a particular analytical procedure (see Skougstad and others, 1979, p. 4) and might represent the amount of a trace element that is "available." Of the trace elements studied, only copper, molybdenum, and selenium, show dissolved concentrations greater than suspended concentrations. The suspended concentrations often have maximum and mean values that exceed the criteria listed in table 6. It is unclear whether these suspended recoverable trace elements are bound to the suspended-sediment particles by adsorption or by organic and metallic coatings, or whether they are part of the sediment particle structure itself. If they are bound to the particles by adsorption or on coatings, they could eventually be dissolved during mixing with dilute water or upon entering a reducing environment. The transport of these trace elements by stream sediment is discussed further by Kimball (1981b).

Nutrients

The major nutrients (nitrogen and phosphorus) are summarized in table 14. Phosphorus remains relatively constant throughout the year, and it appears to be unaffected by changes in flow or temperature. Nitrogen, on the other hand, varies during the year. The highest concentrations for nitrogen are in the winter, when temperature is low and biological activity is slight. Concentrations may be affected by high flow in June and July, but the decrease of nitrogen during these and subsequent months is more likely due to increased biological activity. The major nutrients in the Green and White Rivers and intra-area streams vary in much the same way; however, the nutrient levels are higher in the intra-area streams. The concentrations of nitrogen and phosphorus are less than the criteria listed in table 6 at all sampling sites.

Biological Characteristics

Naten and Fuller (1981) discussed some of the biological characteristics of the streamflow of the southeastern Uinta Basin. The reader is referred to their report for a discussion.

Organic Characteristics

Stuber and Leenheer (1978) made a detailed study of dissolved organic-carbon compounds derived from oil-shale wastes. Through a process of fractionation with macroreticular resins, Leenheer and Huffman (1979) have divided the dissolved compounds of organic carbon into hydrophilic and hydrophobic acids, bases, and neutrals. Although the procedure does not provide for identification of particular organic compounds, these groupings allow for important generalizations about the dissolved-organic carbon in the streamflow.

Table 15 shows the mean and standard deviation for the various organic-carbon fractions taken from 10 samples of streamflow collected in the southeastern Uinta Basin and the dissolved organic-carbon fractionation of two oil-shale retort waters. Unlike the retort waters, which show greater complexity, the streamflow is mostly composed of hydrophobic and hydrophilic acids. The hydrophobic acids are mainly humic and fulvic acids, whereas the hydrophilic acids are mainly hydroxy, such as formic, acetic, propionic, and butyric, all naturally occurring compounds.

In contrast, the retort waters contain much larger portions of neutrals and bases in both the hydrophilic and hydrophobic groups. The hydrophobic neutrals are oils and other hydrocarbons. Hydrophobic bases and the aromatic amines are among other compounds that can be toxic. The hydrophilic neutrals are basically sugars, and the bases are proteins and amino acids.

The contrasting character of the natural water and the retort waters indicates that the hydrophobic-base fraction might be used to monitor effects of oil-shale development on the natural waters (Stuber and Leenheer, 1978, p. 12). However, Stuber and Leenheer suggest that improvements in the methods and interpretations are necessary before any large-scale monitoring should be initiated.

Pesticides

Of the pesticides shown in table 6, the great majority were never detected; and only phenols were consistently found in streamflow in the southeastern Uinta Basin. The mean concentration of phenols in both the major rivers and the intra-area streams was near 3.7 μg/L which exceeds the criteria listed in table 6. The maximum observed concentration was 25 μg/L in Evacuation Creek. Although such extreme values are uncommon, concentrations generally do exceed the water-quality criteria for all streams. DDT and 2,4,5-T were each present once in samples of the bottom material of the White River.

Radiochemical Characteristics

Gross-alpha and gross-beta radiation were the main radiochemical characteristics investigated, and they are summarized in table 16. In general, gross-alpha radiation is due to uranium and thorium and the daughter products

Table 13. Summary of dissolved and suspended concentrations of trace elements

[Micrograms per liter, except number of observations.]

	Aluminum, dissolved (Al)	Aluminum, suspended recoverable (Al)	Arsenic, dissolved (As)	Arsenic, suspended total (As)	Barium, dissolved (Ba)	Barium, suspended recoverable (Ba)	Beryllium, dissolved (Be)	Beryllium, suspended recoverable (Be)	Cadmium, dissolved (Cd)	Cadmium, suspended recoverable (Cd)	Chromium, dissolved (Cr)	Chromium, suspended recoverable (Cr)	Cobalt, dissolved (Co)	Cobalt, suspended recoverable (Co)	Copper, dissolved (Cu)	Copper, suspended recoverable (Co)	Iron, dissolved (Fe)	Iron, suspended recoverable (Fe)
GREEN RIVER AT GREEN RIVER (station 09315000)[1]																		
Mean	...	......	2	3	<100	<100	....	....	....	....	....	12	....	....	.....	45	42	5,100
Maximum	...	......	5	14	400	200	....	....	4	49	<20	91	3	250	19	470	190	19,000
Minimum	...	......	<1	<1	80	<100	....	....	([2])	([2])	([2])	([2])	([2])	([2])	<2	([2])	<10	830
Number of observations	...	......	24	18	8	8	....	....	24	23	24	23	24	22	24	23	26	5
WHITE RIVER AT MOUTH, NEAR OURAY (station 09306900)[3]																		
Mean	...	26,000	2	14	<100	300	....	....	....	....	....	40	....	....	50	45	20	23,000
Maximum	50	220,000	5	110	400	2,500	10	10	2	9	<20	350	<4	250	1,000	330	120	40,000
Minimum	10	30	<1	<1	70	<100	<1	<10	([2])	([2])	([2])	([2])	([2])	2	([2])	([2])	<10	2,300
Number of observations	39	9	34	9	22	12	15	12	22	13	22	13	16	12	34	13	70	4

	Lead, dissolved (Pb)	Lead, suspended recoverable (Pb)	Lithium, dissolved (Li)	Lithium, suspended recoverable (Li)	Manganese, dissolved (Mn)	Manganese, suspended recoverable (Mn)	Mercury, dissolved (Hg)	Mercury, suspended recoverable (Hg)	Molybdenum, dissolved (Mo)	Molybdenum, suspended recoverable (Mo)	Nickel, dissolved (Ni)	Nickel, suspended recoverable (Ni)	Selenium, dissolved (Se)	Selenium, suspended total (Se)	Silver, dissolved (Ag)	Silver, suspended recoverable (Ag)	Zinc, dissolved (Zn)	Zinc, suspended recoverable (Zn)
GREEN RIVER AT GREEN RIVER (station 09315000)[1]																		
Mean	...	<100	....	....	<10	510	....	<0.5	...	...	...	...	2	....	<2	....	<20	75
Maximum	70	500	....	....	20	7,600	<0.5	9	...	...	...	...	5	1	<20	([2])	120	1,200
Minimum	<1	<1	....	....	<10	<10	<.5	<.5	...	...	...	...	<1	<1	([2])	([2])	([2])	([2])
Number of observations	24	22	....	....	26	24	24	22	...	...	...	...	24	23	8	8	24	24
WHITE RIVER AT MOUTH, NEAR OURAY (station 09306900)[3]																		
Mean	...	<100	12	40	<10	800	....	<0.5	2	<1	2	60	1	<1	....	....	23	<10
Maximum	23	300	30	230	20	6,800	<0.5	2	5	5	7	300	4	3	([2])	<2	180	200
Minimum	([2])	([2])	5	<10	2	<10	<.1	<.1	<1	<1	([2])	<2	<1	<1	([2])	([2])	([2])	([2])
Number of observations	22	13	39	11	30	13	34	13	21	11	15	12	34	13	2	4	34	13

[1] Period of record, water years 1965–79.
[2] Not detected.
[3] Period of record, water years 1950–79.

Table 14. Summary of nutrient concentrations of streamflow

[Period of record is water years 1975–79, unless otherwise indicated.]

Milligrams per liter, except number of observations

	Nitrogen, nitrate, dissolved (N)	Nitrogen, nitrate, total (N)	Nitrogen, nitrite, dissolved (N)	Nitrogen, nitrite, total (N)	Nitrogen, nitrite + nitrate, dissolved (N)	Nitrogen, nitrite + nitrate, total (N)	Nitrogen, ammonia, dissolved (N)	Nitrogen, ammonia total (N)	Nitrogen, dissolved organic (N)	Nitrogen, total organic (N)	Nitrogen, ammonia + organic, dissolved (N)	Nitrogen, ammonia + organic, total (N)	Nitrogen, ammonia + organic, suspended total (N)	Nitrogen, dissolved (N)	Nitrogen, total (N)	Phosphorus, dissolved (P)	Phosphorus, total (P)	Phosphate, total (PO_4)	Phosphate, ortho, dissolved (PO_4)	Phosphorus, ortho, dissolved (P)	Phosphorus, ortho, total (P)
GREEN RIVER AT GREEN RIVER (station 09315000)[1]																					
Mean	0.5	...	0	...	0.5	0.4	...	0.05	...	1.1	0.4	1.4	0.7	...	1.8	0.03	0.5	0.3	0.04	0.02	...
Maximum	.8	0.6	<.01	0.01	2.7	.8	<0.01	.3	...	3.7	.9	30	3.4	0.5	31	.07	9.1	4.3	.4	.1	...
Minimum	.2	.4	<.01	.01	<.1	<.1	<.01	<.01	...	.3	<.1	.2	.07	.2	.4	<.01	<.01	<.01	<.01	<.01	...
Number of observations	9	2	2	2	47	67	2	22	...	16	22	61	16	2	61	22	66	36	56	39	...
WHITE RIVER (stations 09306395, 09306400, 09306500, 09306600, 09306700, 09306900)																					
Mean	0.1	0.1	0.01	0.02	0.2	0.2	0.04	0.05	...	1.3	0.3	0.9	1.8	...	1.5	0.03	0.3	0.7	0.05	0.02	0.06
Maximum	1.1	.4	.04	.08	4.3	.8	.3	.6	0.4	8.5	.4	9.1	5.3	5.5	0.4	.8	4.0	.07	<.01	.5	.2
Minimum	<.01	<.01	<.01	<.01	<.1	<.1	<.01	<.01	.4	.01	<.1	...	<.01	.4	.1	<.01	<.01	.03	...	<.01	<.01
Number of observations	177	12	180	12	210	55	180	52	1	54	6	234	6	2	55	7	232	6	203	203	41
WILLOW CREEK (stations 09307500, 09307800, 09307900, 09308000)																					
Mean	0.2	...	0.01	...	0.2	...	0.03	...	...	...	...	1.3	...	...	...	0.2	0.5	8.2	0.1	0.04	...
Maximum	1.4	...	.3	...	1.5	...	.4	...	0.2	...	0.3	12	...	0.3	...	1.1	7.3	22	.4	.1	...
Minimum	<.01	...	<.01	...	<.1	...	<.01	...	.3	...	.3	<.1	...	.3	...	.02	<.01	.5	<.01	<.01	...
Number of observations	86	...	86	...	91	...	88	...	1	...	1	90	...	1	...	5	90	4	91	91	...
BITTER CREEK (stations 09306740, 09306760, 09306780, 09306800, 09306850)																					
Mean	1.6	...	0.03	...	1.7	...	0.07	...	...	...	...	1.4	...	...	...	...	0.2	...	0.1	0.03	...
Maximum	7.0	...	.1	...	8.3	...	.5	...	...	...	...	15	...	...	...	...	5.4	...	.5	.2	...
Minimum	.01	...	<.01	...	<.1	...	<.01	...	...	...	...	<.1	...	...	...	...	<.01	...	<.01	<.01	...
Number of observations	93	...	93	...	103	...	94	...	...	...	...	94	...	...	...	...	94	...	102	102	...
EVACUATION CREEK (stations 09306410, 09306415, 09306420, 09306430)																					
Mean	1.1	...	0.02	...	1.1	...	0.03	...	...	...	...	1.7	...	...	...	0.02	0.6	...	0.04	0.02	...
Maximum	8.8	...	.1	...	8.8	...	.1	...	...	...	...	30	...	...	...	.03	33	6.1	.2	.06	...
Minimum	<.01	...	<.01	...	<.1	...	<.01	...	...	...	...	<.1	...	...	...	.01	<.01	.03	<.01	<.01	...
Number of observations	123	...	125	...	132	...	127	...	...	...	...	128	...	...	...	3	129	2	132	131	...

Table 14. Summary of nutrient concentrations of streamflow—Continued

	Nitrogen, nitrate, dissolved (N)	Nitrogen, nitrate, total (N)	Nitrogen, nitrite, dissolved (N)	Nitrogen, nitrite, total (N)	Nitrogen, nitrite + nitrate, dissolved (N)	Nitrogen, nitrite + nitrate, total (N)	Nitrogen, ammonia, dissolved (N)	Nitrogen, ammonia total (N)	Nitrogen, dissolved organic (N)	Nitrogen, total organic (N)	Nitrogen, ammonia + organic, dissolved (N)	Nitrogen, ammonia + organic, total (N)	Nitrogen, ammonia + organic, suspended total (N)	Nitrogen, dissolved (N)	Nitrogen, total (N)	Phosphorus, dissolved (P)	Phosphorus, total (P)	Phosphate, total (PO_4)	Phosphate, ortho, dissolved (PO_4)	Phosphorus, ortho, dissolved (P)	Phosphorus, ortho, total (P)
	Milligrams per liter, except number of observations																				
EMPHERAL STREAMS (stations 09306405, 09306605, 09306610, 09306620, 09306625. 09306870, 09306872, 09306878, 09306885)																					
Mean	2.0	...	0.09	...	1.6	...	0.04	...	...	...	...	13	...	...	...	...	10	...	0.2	0.1	...
Maximum	3.4	...	.2	...	3.6	...	.09	...	...	...	...	37	...	...	...	0.1	40	...	.6	.2	...
Minimum	.8	...	.02	...	<.1	...	<.01	...	...	...	...	1.2	...	...	...	.1	.03	...	<.01	<.01	...
Number of observations	5	...	5	...	19	...	6	...	...	...	...	6	...	...	...	1	6	...	19	19	...

[1] Period of record, water years 1965–79.

Table 15. Summary of the fractionation of dissolved organic compounds

[Percentages from 10 streamflow samples taken within the study area and of two retort waters. From Stuber and Leenheer (1978, tables 2 and 3.]

Fraction		Mean	Standard deviation
Streamflow samples[1]			
Hydrophobic	acid	36	5
	neutral	7	5
	base	.3	1
Hydrophilic	acid	40	16
	neutral	14	11
	base	7	9
Total hydrophobic		45	7
Total hydrophilic		55	7
150-ton retort water Dissolved organic carbon = 5,000 mg/L			
Hydrophobic	acid	28	
	neutral	28	
	base	9	
Hydrophilic	acid	17	
	neutral	10	
	base	8	
Total hydrophobic		65	
Total hydrophilic		35	
Omega-9 in situ retort water Dissolved organic carbon = 1,000 mg/L			
Hydrophobic	acid	19	
	neutral	17	
	base	13	
Hydrophilic	acid	29	
	neutral	10	
	base	12	
Total hydrophobic		49	
Total hydrophilic		51	

[1] Percentage of mean dissolved organic carbon = 7.3.

of their decay, mostly radium and radon. Gross-beta radiation is due to cesium-137 and strontium-90 for many natural waters. In addition to gross-alpha and beta radiation, determinations were made for radium-226, cesium-137, and uranium, but these are not reported in table 16.

Concentrations of dissolved alpha and beta radiation are similar in the White and Green Rivers. The concentrations of dissolved alpha are generally less than 15 μg/L for the White and Green Rivers. The mean gross-beta concentrations are about 5 picocuries per liter as strontium/yttrium-90. The suspended alpha and beta concentrations for the major rivers are greater than dissolved concentrations. This can be attributed to the sediment sources for the two rivers.

Dissolved gross beta as strontium/yttrium-90 shows seasonal variation. It increases with dissolved solids and is inversely related to flow, so it has maximum values during the periods of base flow and evapotranspiration and minimum values during the snowmelt runoff in May and June. The other radiochemical constituents show little seasonal variation, but some of the suspended constituents were not sampled sufficiently to provide an assessment of seasonal variation.

The concentrations of gross alpha and gross beta in Willow Creek are not very different from those in the major rivers. The mean gross-alpha concentration is about 12 μg/L as U-natural, and the mean gross-beta concentration is 4.9 picocuries per liter as strontium/yttrium-90. Suspended gross-alpha and beta concentra-

Table 16. Summary of radiochemical concentrations of streamflow

[Period of record is water years 1975–79, unless otherwise indicated.]

	Micrograms per liter as U-natural		Picocuries per liter as strontium/yttrium-90	
	Gross alpha, dissolved	Gross alpha, suspended	Gross beta, dissolved	Gross beta, suspended
GREEN RIVER AT GREEN RIVER (station 09315000)[1]				
Mean	11.3	54.1	5.6	24.9
Maximum	26.0	800	11.0	330
Minimum	3.6	1.2	2.4	
Number of observations	39	39	39	39
WHITE RIVER (stations 09306395, 09306400, 09306500, 09306600, 09306700, 09306900)				
Mean	9.0	19.3	3.9	10.3
Maximum	35.0	140	25	99
Minimum	3.7	.4	1.1	.6
Number of observations	86	23	86	23
WILLOW CREEK (stations 09307500, 09307800, 09308000)				
Mean	12.2	37.1	4.9	21.4
Maximum	41.0	200	12.0	110
Minimum	2.2	.4	1.4	.4
Number of observations	27	24	27	24
BITTER CREEK (stations 09306740, 09306760, 09306780, 09306800, 09306850)				
Mean	63.8	7.4	23.0	4.9
Maximum	190	65.0	220	38.0
Minimum	3.3	.4	1.4	.4
Number of observations	25	22	25	22
EVACUATION CREEK (stations 09306410, 09306415, 09306420, 09306430)				
Mean	55.7	20.7	24.8	8.1
Maximum	280	220	230	76.0
Minimum	10	<.1	6.4	.4
Number of observations	62	11	62	11
EPHEMERAL STREAMS (stations 09306405, 09306605, 09306610, 09306620, 09306625, 09306870, 09306872, 09306878, 09306885)				
Mean	.....	.....	.....	.....
Maximum	10	.....	21.0	.....
Minimum	3.6	.....	6.6	.....
Number of observations	2	.....	.....	.....

[1] Period of record, water years 1965–78.

tions show a large seasonal variation. During spring runoff, when suspended-sediment concentrations are high, the mean suspended gross-alpha concentrations generally exceed 50 $\mu g/L$ as U-natural, whereas during base flow it is less than 10 $\mu g/L$ as U-natural.

In Willow Creek, there is a significant increase in both dissolved and suspended gross-alpha and beta concentrations in a downstream direction. Upstream at station 09307500 the dissolved gross-alpha concentrations are less than 10 $\mu g/L$ as U-natural, and at station 09308000 the concentrations generally exceed 10 $\mu g/L$ as U-natural. A similar increase occurs for gross beta and for suspended gross alpha and beta. This increase could be due to evapotranspiration or from the added radiochemical constituents from the black shales of the Green River Formation.

Radiochemical concentrations in Bitter Creek range from 3.3 to 190 $\mu g/L$ as U-natural, whereas gross beta ranges from 1.4 to 220 picocuries per liter as strontium/yttrium-90. The variation in concentration downstream is large. The mean gross-beta concentration at station 09306740 is 2 picocuries per liter as strontium/yttrium-90, and the mean concentration increases downstream to about 50 picocuries per liter as strontium/yttrium-90 at station 09306850. Gross-alpha radiation also shows a large increase from a mean of less than 5 $\mu g/L$ as U-natural to about 100 $\mu g/L$ as U-natural between the same two stations.

Sampling was insufficient to determine any seasonal variation that might be present in these concentrations. However, both dissolved alpha and beta radiation show a moderate negative correlation with flow. This indicates that concentrations would decrease during high flow. On the other hand, concentrations of suspended alpha and beta radiation increase with flow because of their relation to suspended-sediment concentrations.

The highest observed concentrations for the radiochemical constituents are in the Evacuation Creek drainage. The range of dissolved gross beta as strontium/yttrium-90 is from 6.4 to 230 picocuries per liter. Gross alpha, dissolved, ranges from 10 to 280 $\mu g/L$.

NEED FOR FUTURE MONITORING

Benson and Carter (1973) classified streamflow data according to whether it is needed for current use, for planning and design, to define long-term trends, or to determine effect on the stream environment. Each of these needs are discussed below.

Data for Current Use

This classification represents the need for information on the actual flow at any moment, day, week, month, or year. As oil-shale development progresses, many of these stations will be required to determine effects of mining on streamflow. The existing (1982) stations 09306395 and 09306900 (fig. 2), on the White River for the most part, meet the current-use requirements for that river. For the Green River and the intra-area streams, the present network is not designed for current-use purposes. The number and location of current-use stations will be determined by State and Federal regulatory agencies, and the burden of operation of these stations probably will be the responsibility of the oil-shale companies.

Data for Planning and Design

Stations needed for planning and design are those established to provide a base or sample of streamflow information that can be transferred to ungaged sites so that useful estimates for any point on any stream can be made. The following existing (1982) stations on the intra-area streams provide data for planning and design purposes: stations 09306405, 09306410, 09306430, 09306625, 09306800, 09306850, 09306872, 09306878, 09306885, 09307500, and 09308000. (See fig. 2 and table 2.) If these stations are all continued until each has 10 complete years of record, adequate length of record would be available for defining mean flows. If one-half are continued until they have 25 years of record, an adequate base would be available to estimate high-flow extremes with a frequency of 100 years.

Data to Define Long-Term Trends

Long-term streamflow quality and quantity are needed to evaluate any existing natural trends and cycles; serve as a base or index for extending short-term records; and evaluate trends resulting from changes in the flow regime of streams as they become increasingly regulated over a period of time. Long-term stations are best located on streams that drain basins which have undergone no significant manmade changes and which are expected to remain in a comparable condition in the future. The existing (1982) stations 09306410, Evacuation Creek above Missouri Creek, near Dragon, and 09307500, Willow Creek above diversions, near Ouray (fig. 2), are suitable as long-term stations.

Data to Determine Effect on the Stream Environment

Environmental data include a wide variety of water-related information other than quantity and quality of flow. Examples of such data are stream-channel characteristics, including widths, depths, slopes, and hydraulic roughness; basin characteristics, including area, land-surface slope, soils, forest cover, percent impervious area, land use, and mean annual precipitation; and time-of-travel and dispersion characteristics of solutes in streams.

Much information on the stream environment is summarized in the following reports: Peterson (U.S. Geological Survey, written commun., 1977), Jurado and Fields (1978), Butler and England (1979), Holmes (1979), Naten and Fuller (1981), Seiler and Tooley (1982), and Waltemeyer (1982). In addition, results of two time-of-travel studies on the White River are summarized in the files of the Geological Survey. Thus no additional data of this type are being obtained (1982).

SUMMARY

All streamflow data available for a 3,000-square-mile area of the southeastern Uinta Basin were used to define time and areal variances in quantity and quality of flows in the major rivers and intra-area streams. For both quantity and quality of flow, individual characteristics are summarized according to expected maximums, minimums, and averages.

About 5,900 ft^3/s flows into the study area from the major rivers, which drain an area of about 34,000 mi^2. This is more than 100 times the total flow contributed by the intra-area streams which originate within the study area. Flow from the intra-area streams varies from less than 0.001 to more than 0.10 $(ft^3/s)/mi^2$. This compares to an average flow of 0.17 $(ft^3/s)/mi^2$ for the major rivers which receive almost all their flow from outside the study area. In areas where the flow is less than 0.001 $(ft^3/s)/mi^2$ evapotranspiration losses along stream channels can exceed inflow, causing average flow to decrease in a downstream direction. Peak flows, however, are often greater in the areas where average flows are small. Thunderstorms often cause peak flows in excess of 2 $(ft^3/s)/mi^2$. At higher altitudes, annual peak flows generally come from snowmelt.

The quality of streamflow varies considerably between the major rivers and the intra-area streams. In the major rivers, the concentrations vary seasonally but do not vary significantly from one location to another. In the intra-area streams, concentrations vary both seasonally and from one location to another. The water quality in the major rivers generally is better than that in the intra-area streams. Dissolved-solids concentrations average 572 mg/L for the Green River and 500 mg/L for the White River, whereas mean concentrations for the intra-area streams range from 549 mg/L for the ephemeral streams to 5,320 mg/L for Bitter Creek. Concentrations of solutes generally do not exceed water-quality criteria of the Environmental Protection Agency. Major exceptions are hardness and sulfate. Several trace-element concentrations exceed the water-quality criteria in intra-area streams. Dissolved-solids concentrations in base flow in short reaches of Bitter Creek can exceed 10,000 mg/L.

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CONVERSION FACTORS

For use of those readers who may prefer to use metric units rather than inch-pounds units, the conversion factors for the terms used in this report are listed below:

Multiply	inch-pound unit	By	To obtain	metric unit
Acre		0.4047	Square hectometer	(hm^2)
		0.004047	Square kilometer	(km^2)
Acre-foot	(acre-ft)	0.001233	Cubic hectometer	(hm^3)
		1,233	Cubic meter	(m^3)
Cubic foot per second	(ft^3/s)	0.02832	Cubic meter per second	(m^3/s)
Cubic foot per second per square mile	[(ft^3/s)/mi^2]	0.01093	Cubic meter per second per square kilometer	[(m^3/s)/km^2]
Foot	(ft)	0.3048	Meter	(m)
Gallon per minute	(gal/min)	0.00006309	Cubic meter per second	(m^3/s)
		0.06309	Liter per second	(L/s)
Inch	(in.)	25.40	Millimeter	(mm)
Micromho per centimeter at 25° Celsius (umhos/cm at 25° C		1.000	Microsiemens per centimeter at 25° Celsius (uS/cm at 25°C)	
Mile	(mi)	1.609	Kilometer	(km)
Square mile	(mi^2)	2.590	Square kilometer	(km^2)
Ton		0.9072	Metric ton	t
Tons per day		0.9072	Metric tons per day	t/d
Tons per acre-foot		735.8	Metric tons per cubic hectometer	t/hm^3

Chemical concentration and water temperature are given only in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (μg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is about the same as for concentrations in parts per million.

Chemical concentration in terms of ionic interacting values is given in milliequivalents per liter (meq/L). Meq/L is numerically equal to equivalents per million.

Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation: °F=1.8(°C)+32.

Some radiochemical values are reported in picocuries per liter (pCi/L).