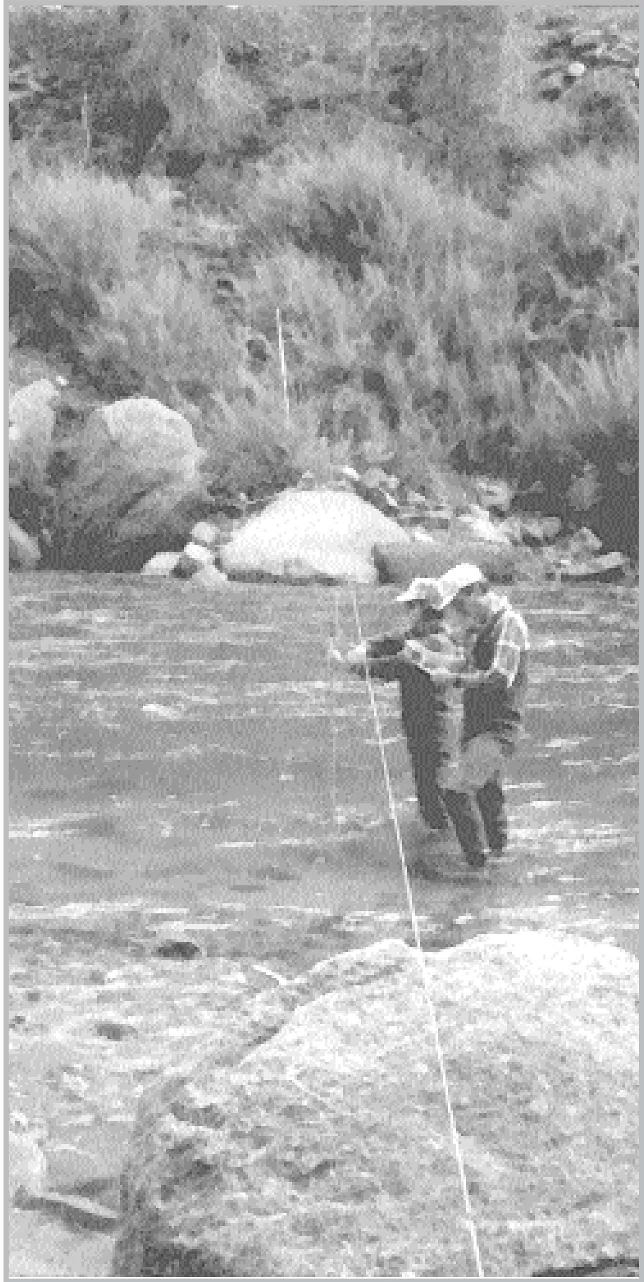
Arkansas River
Water Needs Assessment

Section 4. Hydrologic Analysis



By:

Steve Swanson, Bureau of Land Management

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July 2000

Preface

Each section of the *Arkansas River Water Needs Assessment* contains information that may be useful for a variety of purposes. However, each section is just a part of the overall *Arkansas River Water Needs Assessment* and the information contained therein should not be taken out of context or considered in isolation. Decisions regarding riverflows and reservoir levels should consider the findings of the assessment as a whole, while also recognizing that such decisions are limited by the necessity to supply water for domestic, agricultural, and other uses in the basin consistent with existing water rights held by water users. A summary of the entire assessment can be found in Section 1 of this report.

Acknowledgments

This assessment could not have been completed without an extensive amount of coordination and cooperation among the participating agencies. The following individuals participated in interagency workgroups throughout the assessment and are recognized for the significant amount of time and resources they invested in conducting various studies and documenting the findings in this report:

> Water Workgroup: Bill Carey (Bureau of Land Management), John Gierard (formerly Bureau of Reclamation, now Western Area Power Administration), Dan Muller (Bureau of Land Management), Roy Smith (Bureau of Land Management), Steve Swanson (Bureau of Land Management), and Steve Witte (Colorado Division of Water Resources).
>
> Biological Workgroup: Clay Bridges (Bureau of Land Management, retired), Mark Elkins (Colorado Division of Wildlife), Dave Gilbert (Bureau of Land Management), Doug Krieger (Colorado Division of Wildlife), Greg Policky (Colorado Division of Wildlife), and Rich Roline (Bureau of Reclamation).
>
> Recreation Workgroup: Mike French (Colorado Division of Parks and Outdoor Recreation), Steve Reese (Colorado Division of Parks and Outdoor Recreation, retired), Mike Sugaski (U.S. Forest Service), and Dave Taliaferro (Bureau of Land Management).
>
> Editorial and Graphics Workgroup: Linda Hill (Bureau of Land Management) and Jennifer Kapus (Bureau of Land Management).

The assessment team was guided throughout the process by a management advisory group, which was established through a formal memorandum of understanding. The members of this group are recognized for being responsive to the study team's needs and providing helpful advice, on numerous occasions, regarding controversial issues that arose during the study: Levi Deike (Bureau of Land Management), Dave Giger (Colorado Division of Parks and Outdoor Recreation), Alice Johns (Bureau of Reclamation), Dan McAuliffe (Colorado Department of Natural Resources), and Donnie Sparks (Bureau of Land Management).

During the assessment process, the services of several individuals were acquired through contracts and an interagency agreement. The timely deliverables, extraordinary assistance, and dedication to the assessment of these individuals under these formal arrangements were extremely appreciated. Kip Bossong (U.S. Geological Survey) compiled and analyzed a large amount of historic data, which significantly aided the streamflow analyses in this report. Bruce DiGennaro (formerly EDAW) provided a wealth of insight and strategy towards completing the recreation user surveys and assessment. Teresa Rice (formerly University of Colorado Natural Resource Law Center) completed an enormous amount of research on water uses and institutions. Both Bruce and Teresa wrote reports that are of such quality they could stand alone as exhaustive treatments of their respective assignments.

Certain individuals who were responsible for initiating preliminary discussions and studies leading to this assessment deserve special thanks for their vision and support. They include: Mac Berta (Bureau of Land Management, retired), Jim Fogg (Bureau of Land Management), Jack Garner (Bureau of Reclamation), Larry MacDonnell (formerly University of Colorado Natural Resource Law Center), Steve Norris (Colorado Division of Wildlife), Don Prichard (Bureau of Land Management), Donnie Sparks (Bureau of Land Management), Steve Vandas (U.S. Geological Survey), and Pete Zwaneveld (Bureau of Land Management).

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> Legal and Institutional Analysis Advisory Group: Carl Genova (Southeastern Colorado Water Conservancy District), Denzel Goodwin (Upper Arkansas River Water Conservation District), Alan Hamel (Pueblo Board of Water Works), Steven Kastner (Colorado Division of Water Resources), Phil Saletta (Colorado Springs Utilities), and Tom Simpson (Southeastern Colorado Water Conservancy District).

Biology, Hydrology, and Recreation Peer Reviewers: Mark Butler (U.S. Fish and Wildlife Service), Paul Flack (Colorado Division of Parks and Outdoor Recreation), Bill Hagdorn (Bureau of Land Management), Mike Lewis (U.S. Geological Survey), Rich Niemeyer (National Park Service), Scott Schuler (U.S. Forest Service), and Jay Thompson (Bureau of Land Management).

Advisor on Reservoir Operations: Tom Gibbens (Bureau of Reclamation, retired).

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Section 4. Hydrologic Analysis

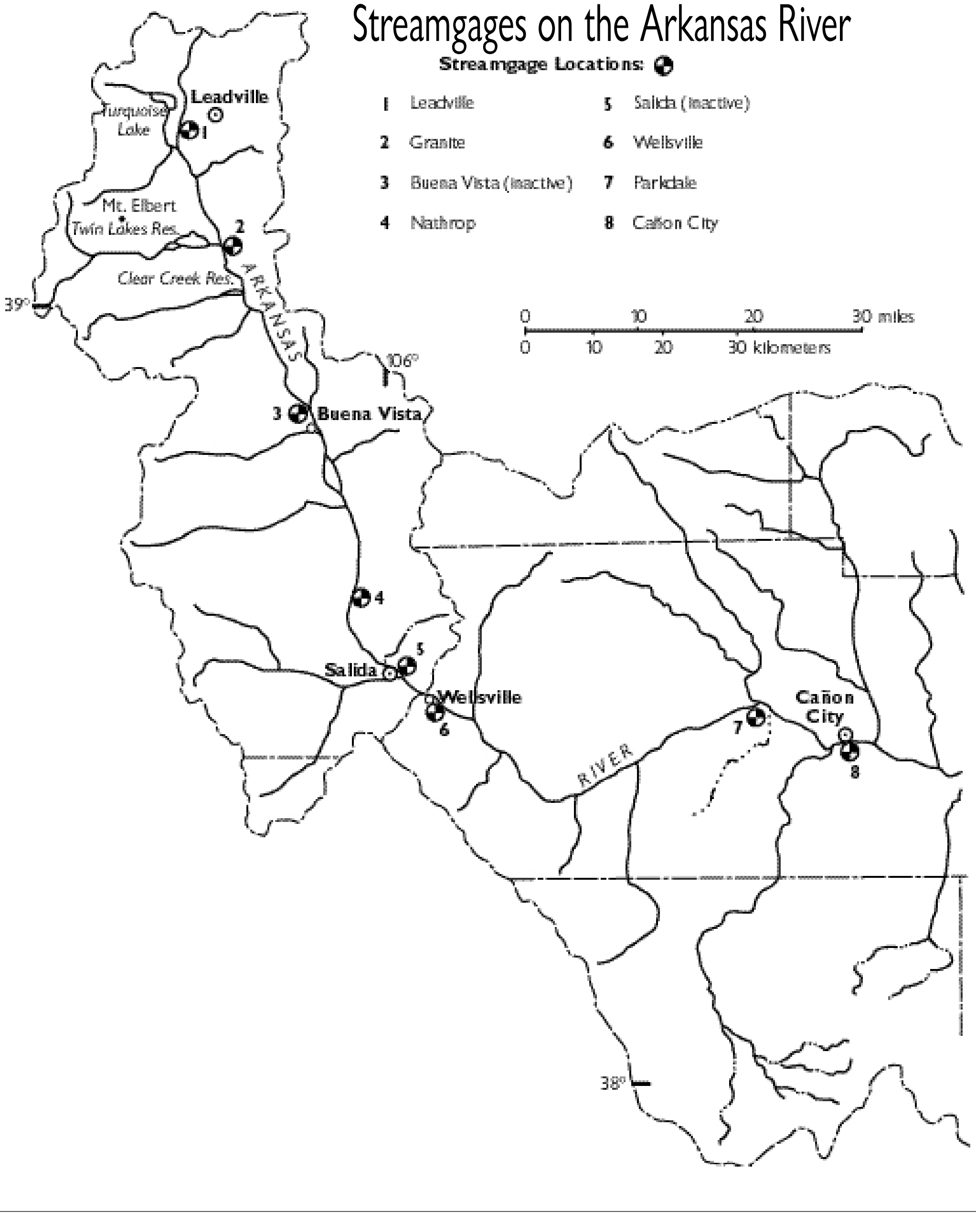
Historical Streamflow

Approximately 745,000 people both within and outside of the watershed depend on the Arkansas River and its tributaries for water supplies. This demand results in one of the most intensively managed river systems in the United States. A multitude of water rights, five major reservoirs, and extensive transbasin diversions complicate the management of the system.

The purpose of this section is to analyze historical and current flows. Fortunately, there are streamgages, two inactive and six active (Figure 4-1), maintained by the United States Geological

FIGURE 4-1

Streamgages on the Arkansas River



Survey (USGS) or the Colorado Department of Water Resources that supply up to 105 years of record. In addition, there are comprehensive reservoir operations records and accurate transbasin diversion data, all of which provide a reasonably complete picture of historical streamflows.

The analysis of streamflow was broken into several distinct time periods for several reasons. The Cañon City stream gage, located at the lower end of the study area, provided the longest period of record (1889-1995) available for analysis. This long period of record, along with the gage location, framed the overall time period analyzed. The development of various management systems in the watershed also dictated the selection of significant time periods. For streamflow study purposes, the watershed was evaluated solely as a high altitude, snowmelt-driven system, which requires analysis of specific annual (monthly) time periods as well as long-term historical periods.

The first designated time period is from 1889-1910. The starting year, 1889, is the earliest flow record available for the Upper Arkansas Basin and is compiled from the Cañon City gage. Based on the flow record, this period was chosen to best represent a natural, undisturbed, unregulated system. However, there were some minor alterations to streamflow, which will be discussed in the next section.

The period from 1911-1960 represents the second time period. This period was chosen because of its relatively stable institutional situation regarding water management. Although there are some variations (e.g., transbasin diversions, reservoir management, additional storage), these changes did not dictate extensive alterations in how the overall system was operated.

Not included in the analysis was the period from 1961-1981. This is a period of significant changes in the institutional status of the system. Major transbasin water projects such as the Fryingpan-Arkansas and the Homestake Projects were coming on line during this period, making streamflow analysis difficult.

The final time period analyzed is from 1982-1995. This period was selected due to the completion of the projects occurring from 1961-1981 and the full implementation of the associated institutional changes. Also, although the system was extensively managed during this timeframe, the flow records, reservoir operations records, and transbasin diversion volumes are readily available and accurate. This period will also require a further subdivision due to some unusual controls placed on the system after 1990.

1889-1910 Period

As previously indicated, the period from 1889-1910 is the best available representation of a natural hydrograph with some limitations. There were minor off-channel diversions and transbasin imports occurring during this time, but they resulted in minimal changes in flow. The most significant modifications occur from 1901-1910 when three upper basin reservoirs, Clear Creek, Twin Lakes, and Sugarloaf, were constructed with a combined storage capacity of approximately 85,000 acre feet. Therefore, the best representation of unaltered flow in the system is prior to 1900. Also limiting the analysis of this time period is the Cañon City gage data. Much of the winter daily flow data from 1889-1910 is recorded as average monthly data, which limits the use of medians, flow frequency analysis, and flow duration analysis.

With these limitations taken into consideration, Figure 4-2 illustrates the mean daily flows by month at Cañon City for the period 1889-1910. Figure 4-3 provides a view of the storage effects after 1901. Flows through the winter are slightly lower after 1901. Mean winter (November-April) flows prior to 1901 are approximately 420 cfs and after 1901 are 350 cfs, indicating some upper basin winter storage effects. Starting in May and continuing through June, spring runoff flows drop significantly after 1901 due to the upper basin storage. This stored water is released in late July

FIGURE 4-2

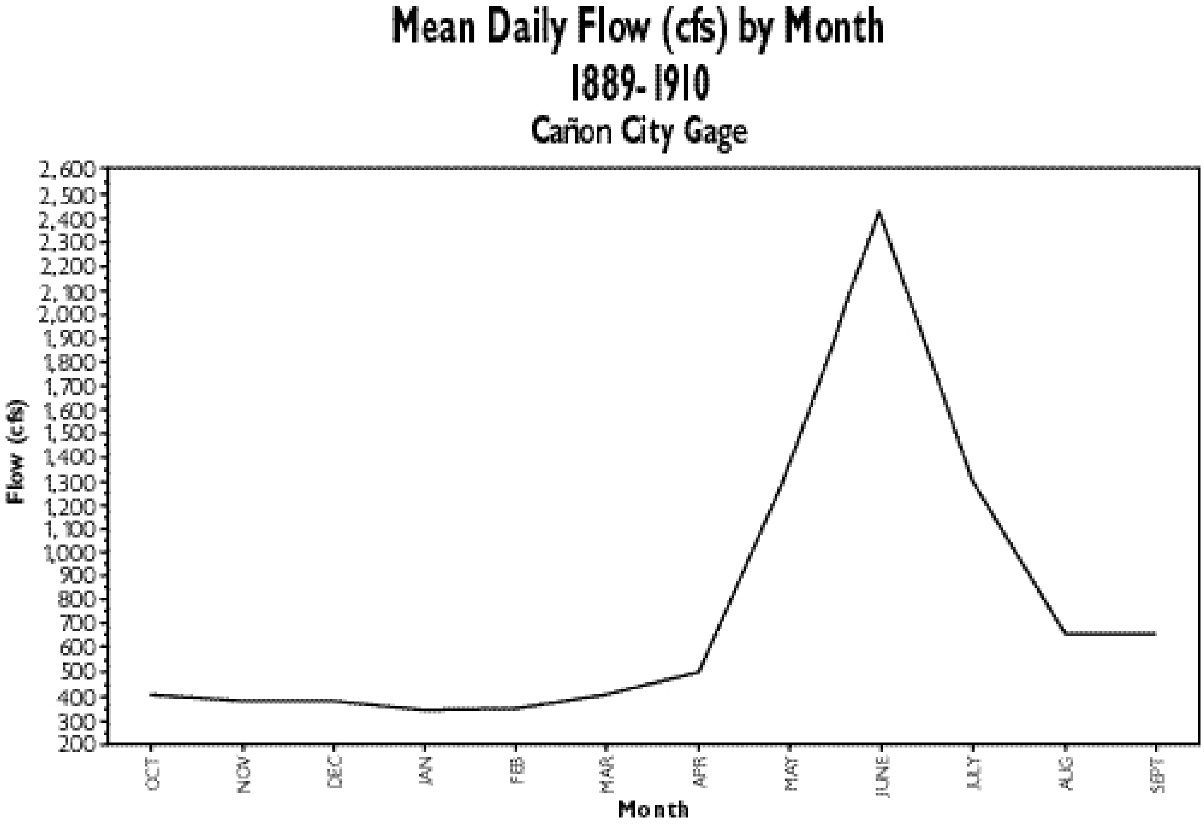
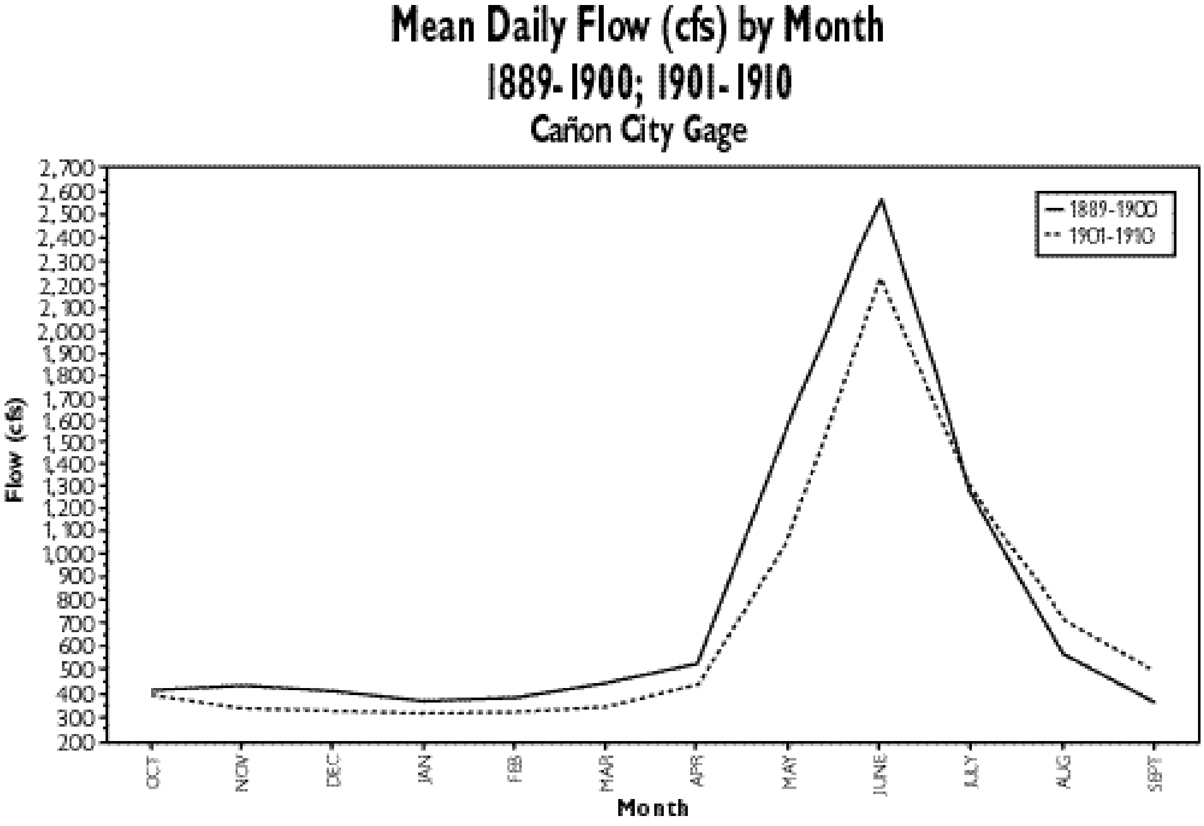


FIGURE 4-3



through September when natural runoff flows begin to diminish. From 1889-1901, the mean daily flow for the period from August 1-August 15 is approximately 650 cfs. From 1901-1910, the mean daily flow for the same period is approximately 770 cfs, which is indicative of upper basin storage releases for late season irrigation requirements. This augmented flow continues through August and September, finally diminishing in early October. There were some transbasin diversions in place prior to 1910, but the volume of water transferred is small compared to the reservoir storage effects.

The overall net effects of the period from 1889-1910 are a slight reduction in winter flows (October-April) accompanied by a large reduction in spring runoff flows (May-June) and a subsequent increase in late summer and early fall (August-September) flows. These effects are predominantly the result of upper basin storage put into service after 1900.

1911-1960 Period

The period defined from 1911-1960 is characterized by relatively stable water management within the basin. There is a continuing trend of increasing import water, mostly in the Twin Lakes system, but there are no significant new projects completed in the upper basin. By 1961, transbasin imports had reached almost 50,000 acre-feet/year, most of which supplemented low natural flows occurring after peak runoff in June. Figure 4-4 provides the mean monthly hydrograph for the period 1911 1960. Figure 4-5 provides a comparison between the 1901-1910 period and the 1911-1960 period. The figure indicates similar fall, winter, and spring flows, with obvious increases in July and August from 1911-1960. This additional flow represents the additional transbasin diversions brought into the watershed to augment mid- to late summer natural flows. For example, the mean daily flow for August 1-August 15 for this time period is approximately 1,000 cfs. This is an increase of 230 cfs from the 1901-1910 period and is almost completely attributable to transbasin imported water.

1982-1995 Period

The 1982-1995 period marks an era of significant institutional changes in the watershed. Two large transbasin diversion projects were completed between 1961 and 1981, one of which created significant changes in streamflow. The Fryingpan-Arkansas Project involved the construction of three new reservoirs, a trans-Continental Divide tunnel, and the expansion of two of the existing reservoirs to transport unappropriated west slope water into the Arkansas River Basin. This project created tremendous flexibility in the process of storage and water movement in the Upper Arkansas Basin and has significant impacts on flows (a comprehensive discussion of upper basin imports and diversions is included in the Institutional and Legal Analysis section). The Homestake Project moved water from the Eagle River watershed, approximately 160 miles west of Colorado Springs, into Homestake Reservoir and then through the Continental Divide via the Homestake Tunnel into Arkansas River Basin reservoirs. However, after 1986, most of the Homestake water did not reach the main stem but was diverted directly out of the basin, thus having little impact on streamflow. In addition to new water projects coming online, there are several other factors that complicate the evaluation of this time period. The wettest period on record is from 1982-1987, 1989-1992 is extremely dry, and 1995 is the wettest single year on record. After 1989, an informal plan to artificially augment late summer flows to support the commercial rafting industry was implemented, and in 1995, annual flow recommendations to protect and enhance the fisheries were presented. These modifications after 1989 dictate subdividing this period into 1982-1989 and 1990-1995. A comparison of historical records was also completed using the current time periods, 1982-1989 and 1990-1995, with the period 1911-1960. The time period from 1911-1960 was chosen for comparative purposes because it provides the longest history of relatively stable management of the system. This 50 years of data better represent a long-term base condition of streamflow than the short-term “natural” record prior to 1900.

FIGURE 4-4

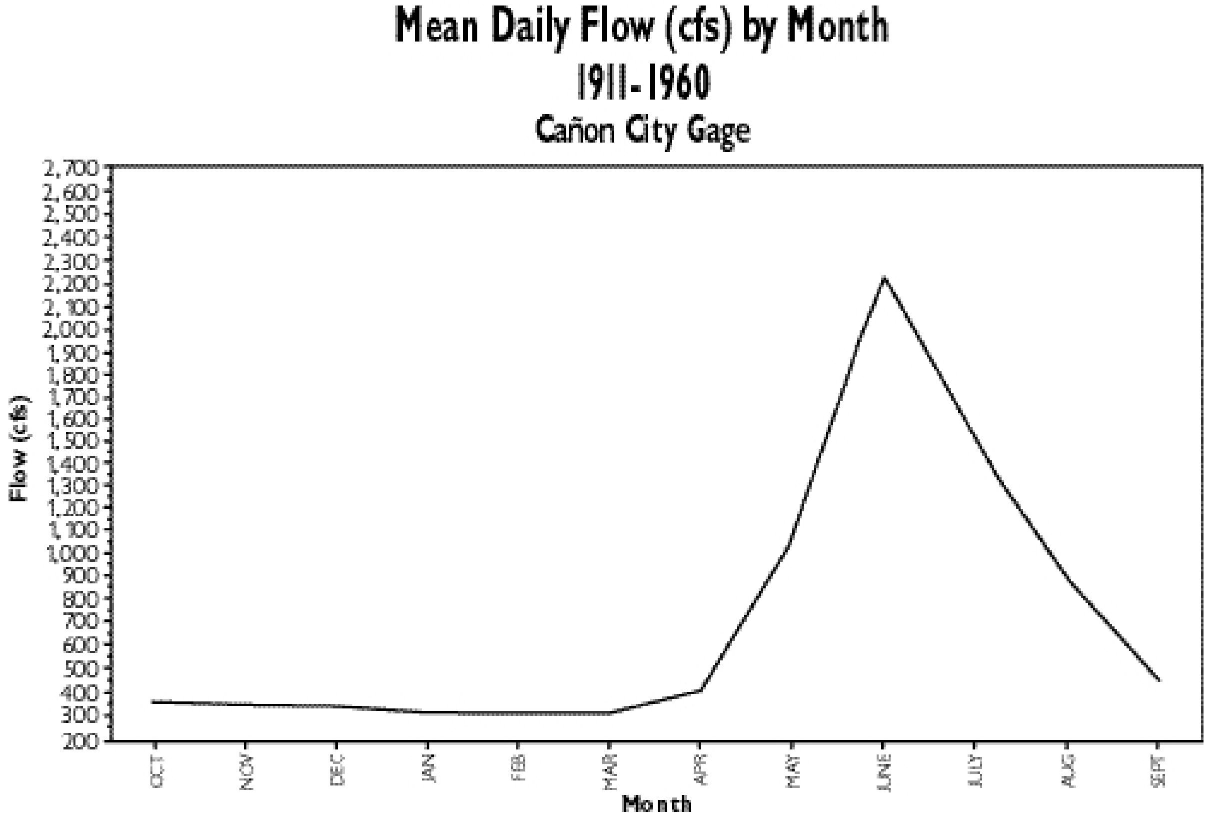
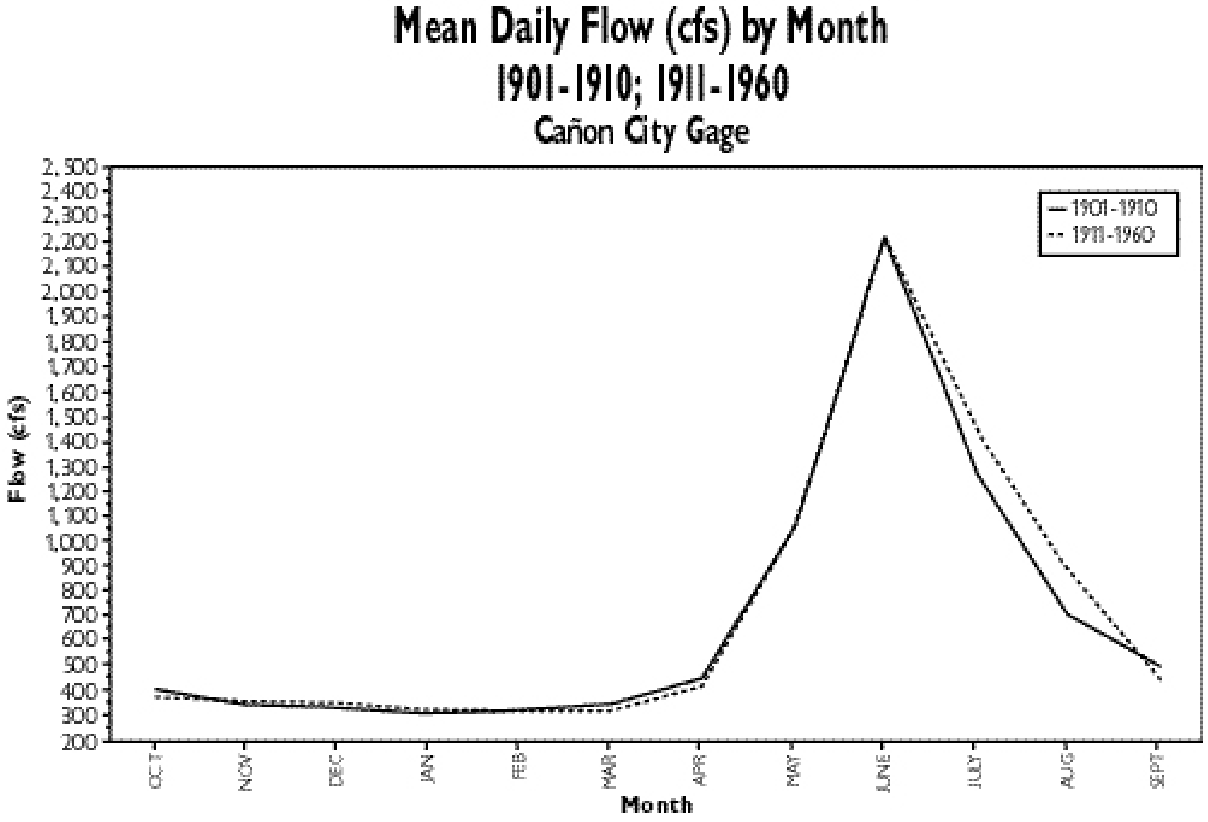


FIGURE 4-5



Comparison of Seasonal Flows for Each Time Period

Comparison of these time periods is best illustrated by a further annual breakdown to winter flows (October-April), spring or runoff flows (May-July), and late summer flows (August-September).

Figure 4-6 and Table 4-1 provide a comparison of annual mean monthly hydrographs and mean monthly flows, respectively, for the periods 1911-1960, 1982-1989, and 1990-1995.

FIGURE 4-6

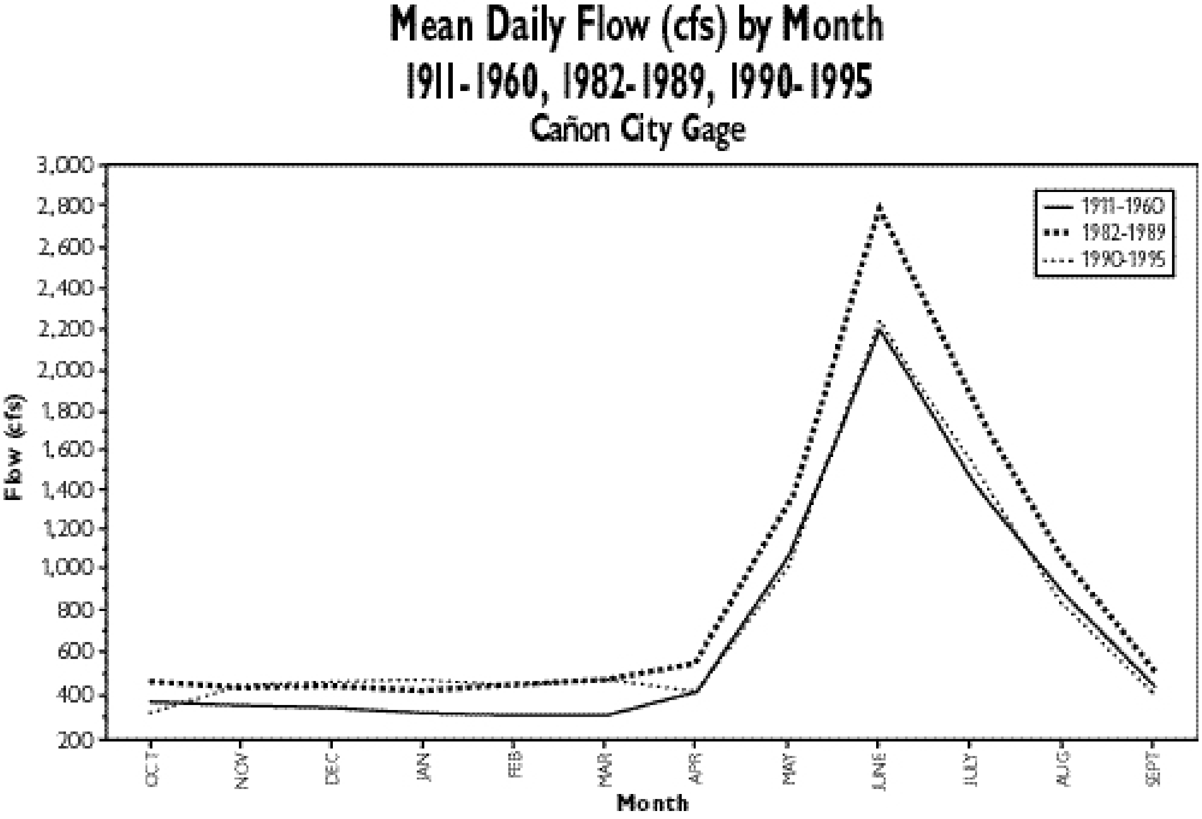


TABLE 4-1

Annual Mean Monthly Flow (cfs)

Cañon City Gage

Month	1911-1960	1982-1989	1990-1995
October	370	464	320
November	361	464	433
December	352	444	463
January	327	424	475
February	318	456	451
March	318	479	483
April	417	550	408
May	1,062	1,330	1,001
June	2,218	2,802	2,256
July	1,464	1,862	1,546
August	885	1,055	823
September	447	520	418

Table 4-2 provides the mean annual flow (acre-feet) for each timeframe. The high annual flow from 1982-1989 is reflective of the wettest time period on record, 1982-1987. Although more water appears to pass annually during the 1990-1995 period than the 1911-1960 period, the flow is heavily weighted by 1995, the wettest year on record. The exclusion of 1995 adjusts the mean annual flow down to 470,000 acre-feet, which more accurately reflects this unusually dry period.

TABLE 4-2

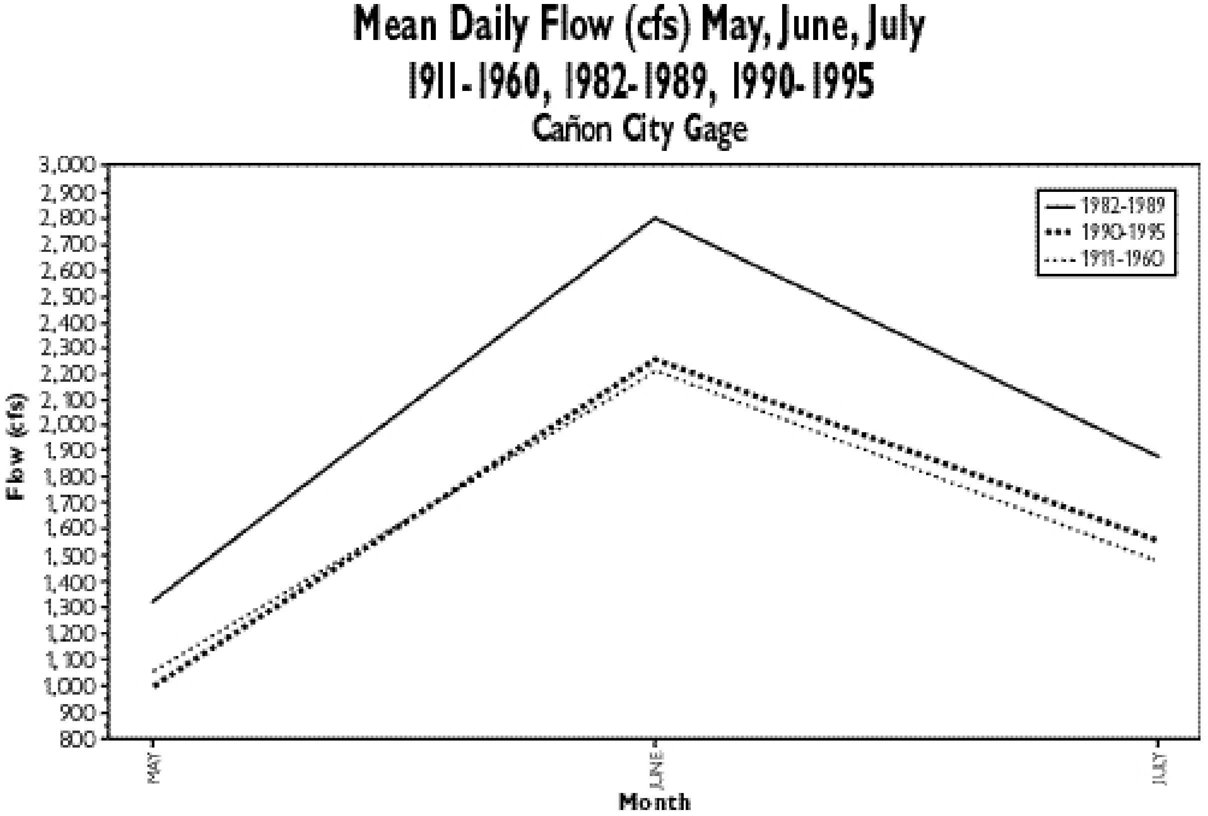
Mean Annual Flow (acre-feet)

1911-1960	1982-1989	1990-1995
516,000	655,000	550,000

For each of the time periods, approximately 53 percent of the annual flow is passed during the 3 month snowmelt runoff (May-July). Figure 4-7 illustrates a comparison of mean daily monthly flows for the runoff period (May-July). Although the values are obviously higher from 1982-1989, this reflects an unusually wet time period. Overall, the difference in flows will only reflect differences in snowpack and summer temperatures and not significant changes in institutional controls.

Winter flows (October-April) should reflect changes in institutional controls within the system. These flows are predominantly independent of weather considerations, so any variations between time periods are probably artificial. Mean winter flows for the three time periods, 1911-1960, 1982-1989, and 1990-1995, are 148,000, 196,000, and 182,000 acre-feet, respectively. Winter flows from 1911-1960 can be considered reasonably consistent because of a stable institutional environment. Therefore, these values indicate over 40,000 acre-feet of additional water being passed in the winter months after 1982. This movement can be accounted for by the new movement of water from

FIGURE 4-7



Mean Daily Flow (cfs) May, June, July
1911-1960, 1982-1989, 1990-1995
Cañon City Gage

upper reservoirs to lower basin storage during the winter months to allow for spring runoff storage in the upper basin. This transfer is attributable to the Fryingpan-Arkansas Project and the construction of Pueblo Reservoir. Figure 4-8 and Table 4-3 illustrate the changes in mean daily flows by month from October-April for each of the three periods of record.

Table 4-3 also highlights the percentage variation in the flows by time period. After 1982, mean daily winter flows increased approximately 100 cfs.

FIGURE 4-8

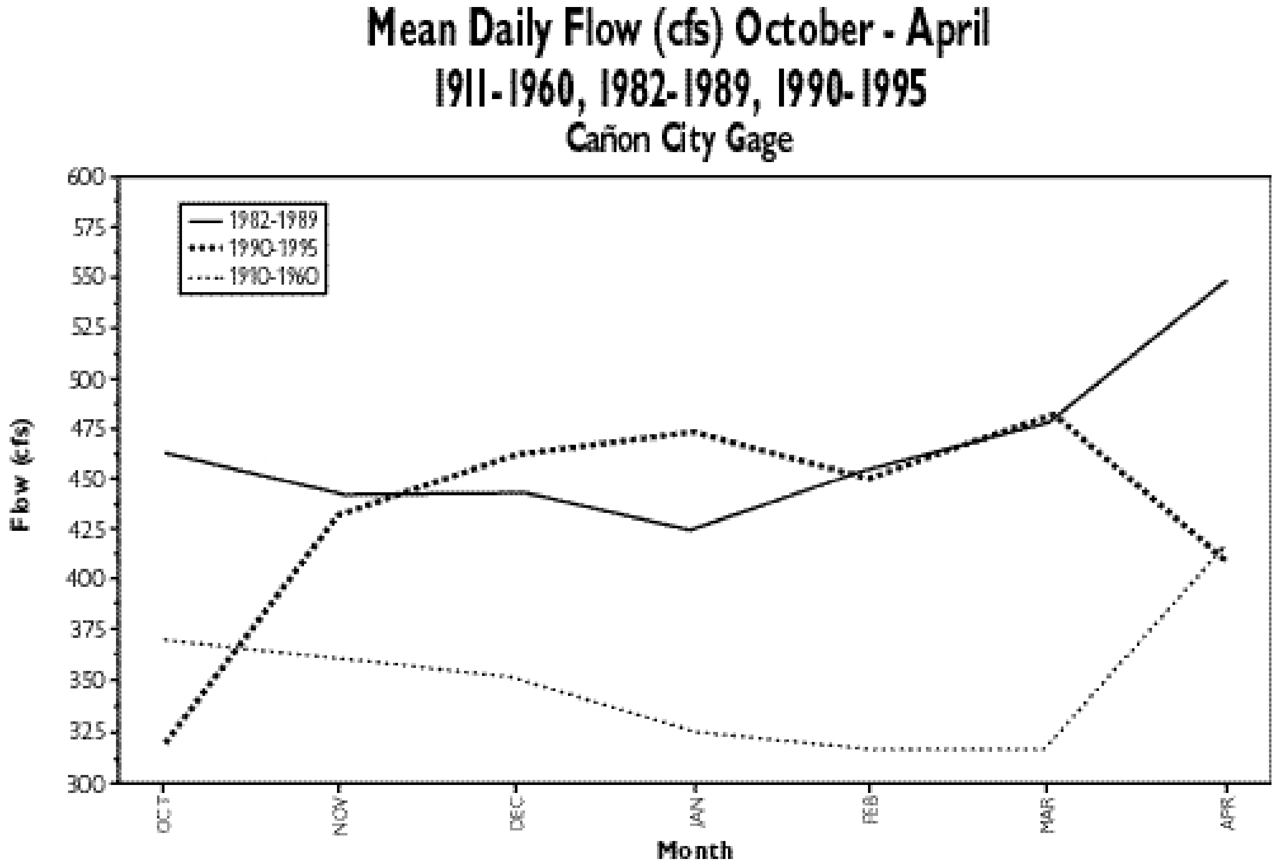


TABLE 4-3

Mean Daily Flow (cfs) October-April

1911-1969, 1982-89, 1990-95

Month	1911-60	1982-89	1990-95	% Change 1911-60 to 1982-89	% Change 1911-60 to 1990-95
Oct	370	464	320	25.4	-13.4
Nov	361	442	433	22.6	20.0
Dec	352	444	463	26.17	31.6
Jan	327	424	475	29.9	45.4
Feb	318	456	451	43.5	41.9
Mar	318	479	483	50.6	52.1
Apr	417	550	408	31.98	-1.96

This equates to a mean increase of approximately 30 percent over the 1911-1960 period. Flow duration analysis also supports this increase in winter flows. Table 4-4 compares the 180-day low flow prior to implementation of the Fryingpan-Arkansas Project (1911-1960) with postimplementation flow (1982-1995).

The 180-day flow was chosen because it predominantly reflects the winter flow period. Once again the flows exhibit a marked increase after completion of the Fryingpan-Arkansas Project. The corresponding flow frequency analysis highlights the same trend. Figures 4-9 to 4-15 illustrate the winter flow frequencies for the same time periods. There is a consistent increase in higher flows after 1982. One overall effect of project development between 1960-1982 has been a marked increase in winter flows in the system.

Late summer (August-September) flows can be difficult to interpret. There are institutional agreements to move water late in the season, such as the flow augmentation for the commercial rafting industry, but large winter snowpacks coupled with cold summer temperatures can also extend runoff into early August. The mean annual August-September flow for 1911-1960 was 79,000 acre-feet, for 1982-1989 was 95,000, and for 1990-1995 was 75,000 acre-feet. The significantly higher flows from 1982-1989 are undoubtedly due to the extremely high water during this time extending the runoff season into August.

Concern over August-September flows originates after 1989, when the annual flow management program was proposed and initiated. The critical period appears to be August 1-15, when the annual flow management program provides a minimum flow of 700 cfs at the Wellsville gage. In order to compare August 1-15 flows among the different periods in this hydrologic analysis, it was necessary to adjust historical readings at the Cañon City gage to show the corresponding flow that would have occurred at the Wellsville gage. This was accomplished by developing a linear regression equation that shows the relationships between the two gages. Using this relationship, the mean daily flow for August 1-15 at the Wellsville gage was:

~ 1911-1960 period - 1,080 cfs
~ 1982-1989 period - 1,271 cfs
~ 1990-1995 period - 973 cfs

The 1911-1960 period of record is long enough to be adequate for statistical purposes. Analysis of the August 1-15 data indicates a normal distribution of values, so 1,080 cfs is an appropriate

TABLE 4-4

180-Day Low Flow Recurrence (cfs)

Recurrence Interval (yr)	1911-1960 Flow	1982-1995 Flow	% Change
100	208	264	26
50	218	277	27
20	235	298	27
10	252	319	27
5	275	347	26
2	327	410	25
1.25	393	491	25
1.11	434	541	25
1.04	485	602	24
1.02	523	646	24
1.01	559	689	23

FIGURE 4-9

Arkansas River Flow Duration, October, Cañon City Gage

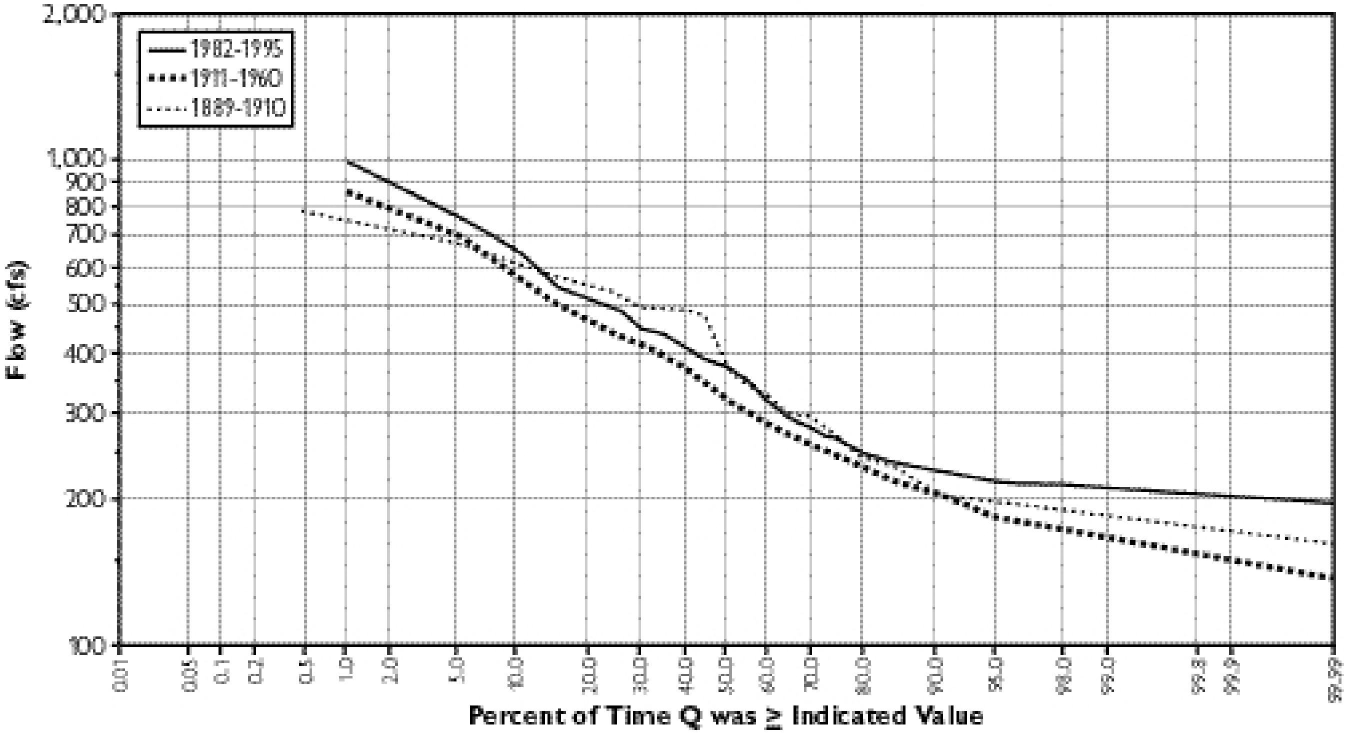


FIGURE 4-10

Arkansas River Flow Duration, November, Cañon City Gage

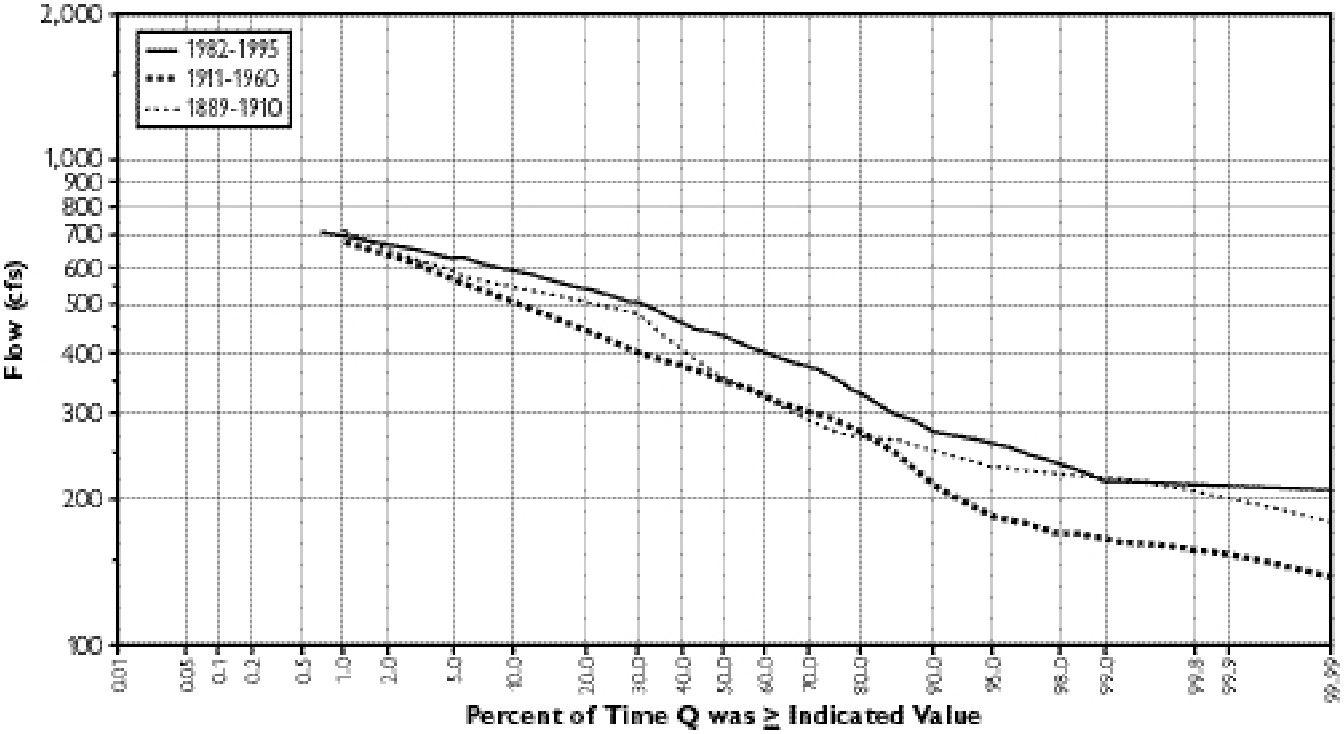


FIGURE 4-11

Arkansas River Flow Duration, December, Cañon City Gage

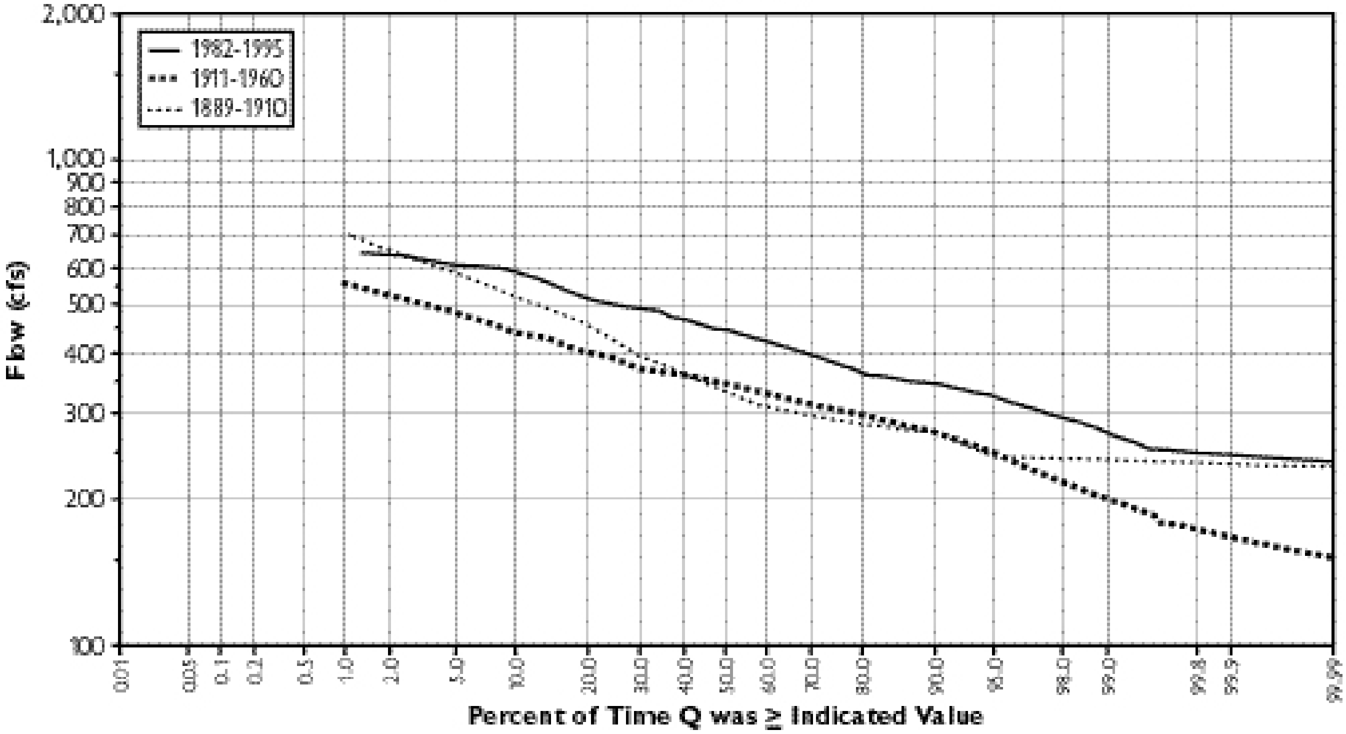


FIGURE 4-12

Arkansas River Flow Duration, January, Cañon City Gage

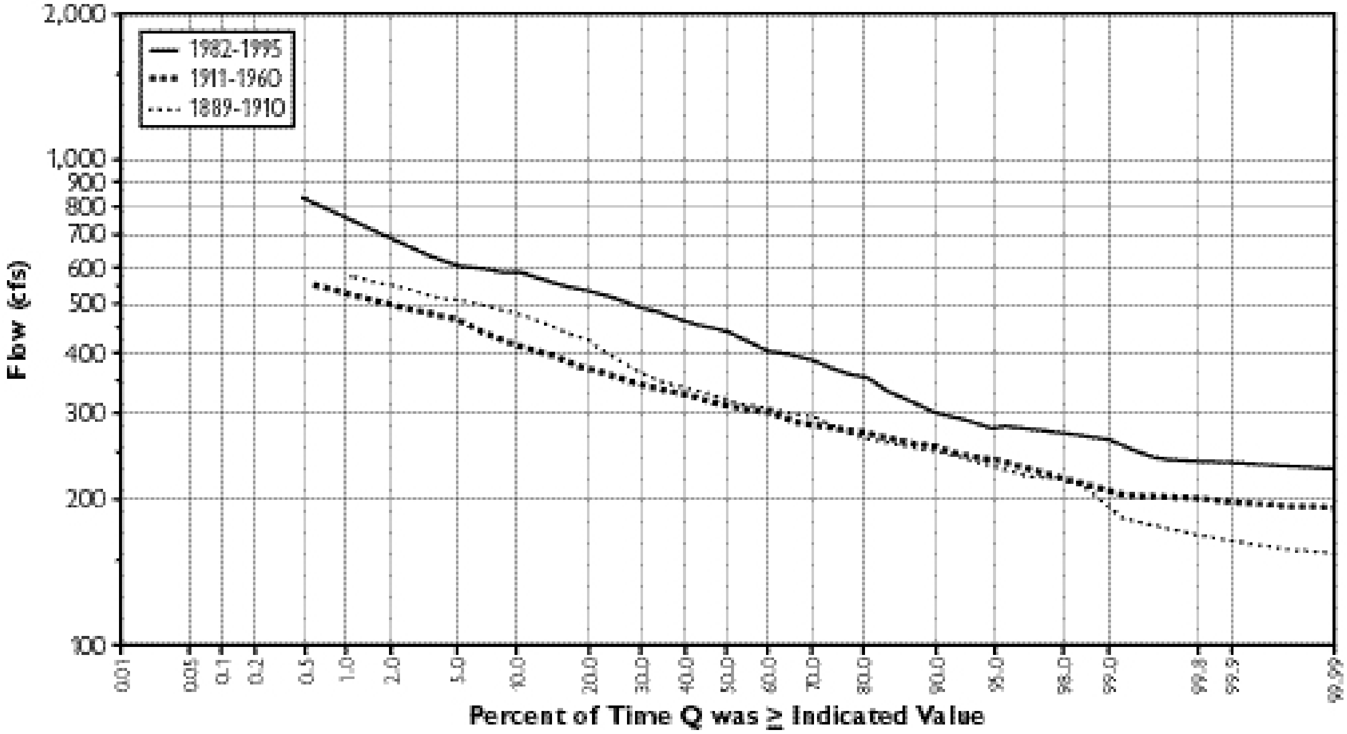


FIGURE 4-13

Arkansas River Flow Duration, February, Cañon City Gage

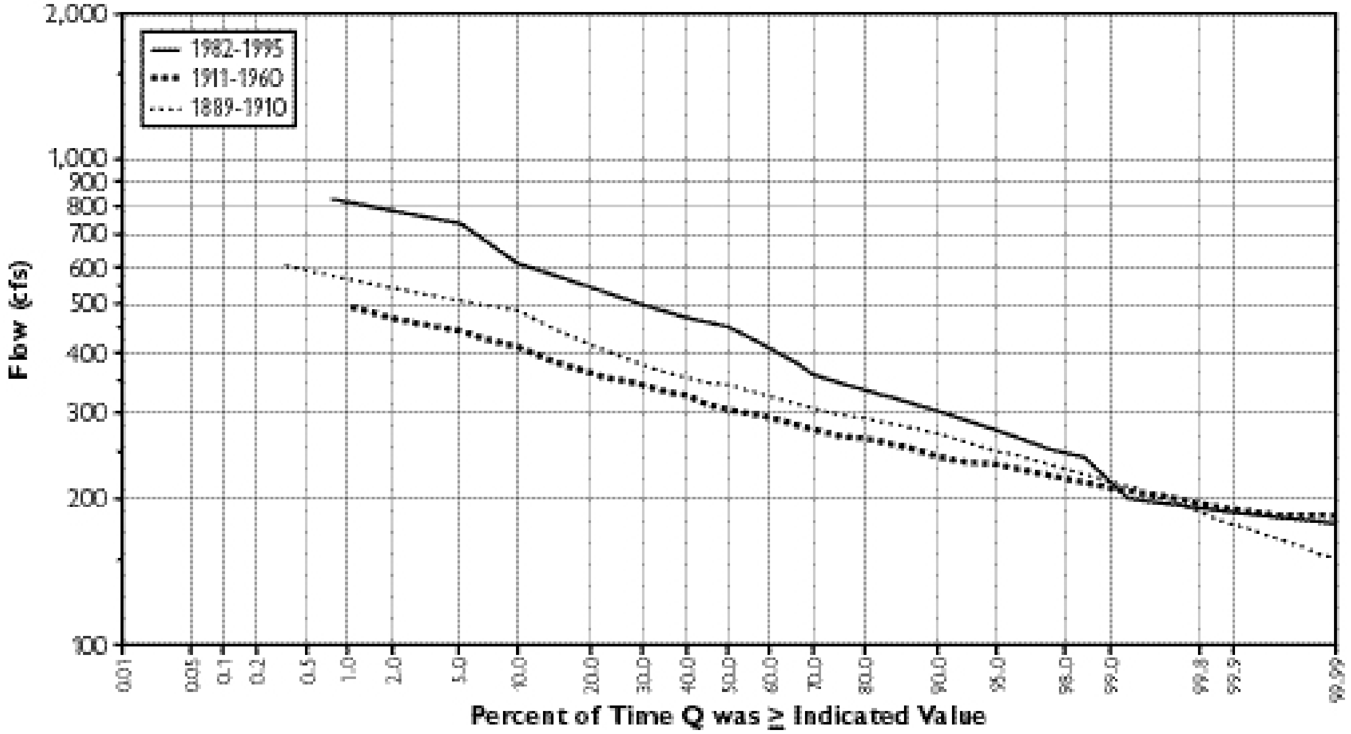


FIGURE 4-14

Arkansas River Flow Duration, March, Cañon City Gage

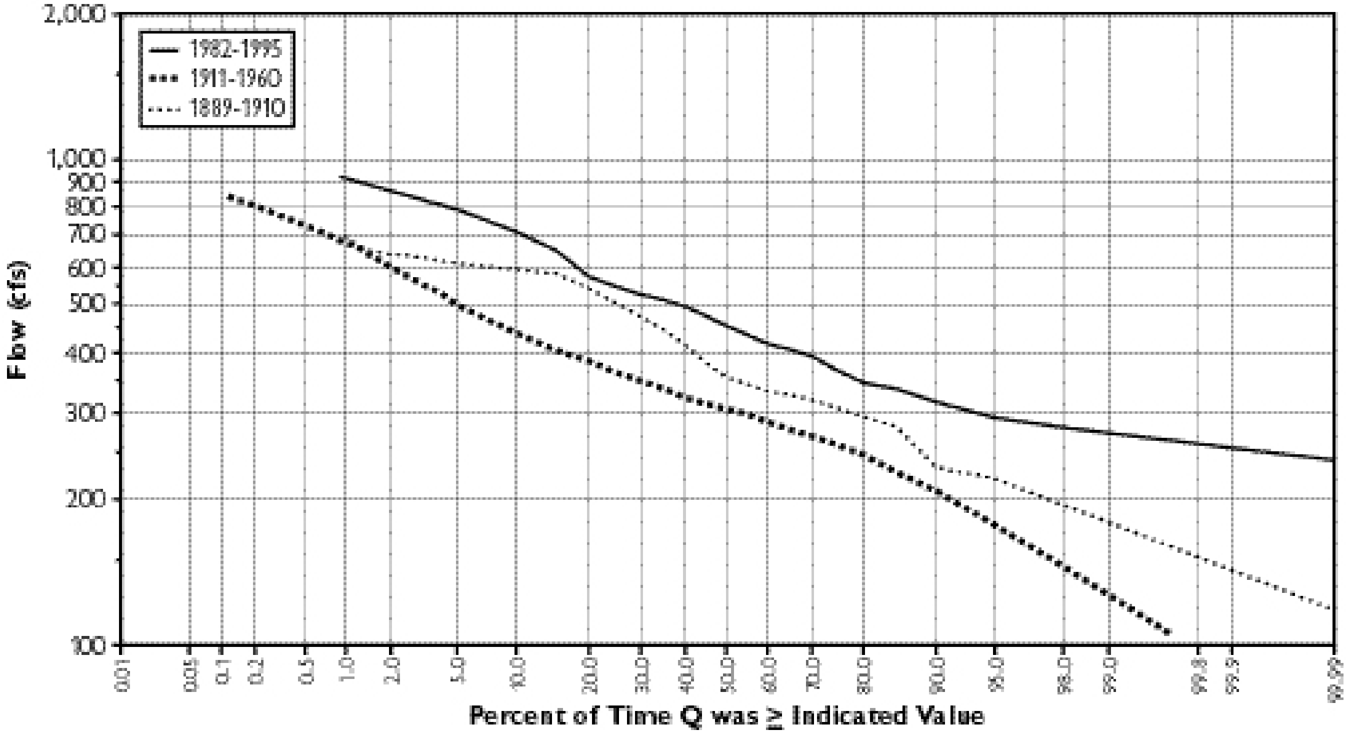
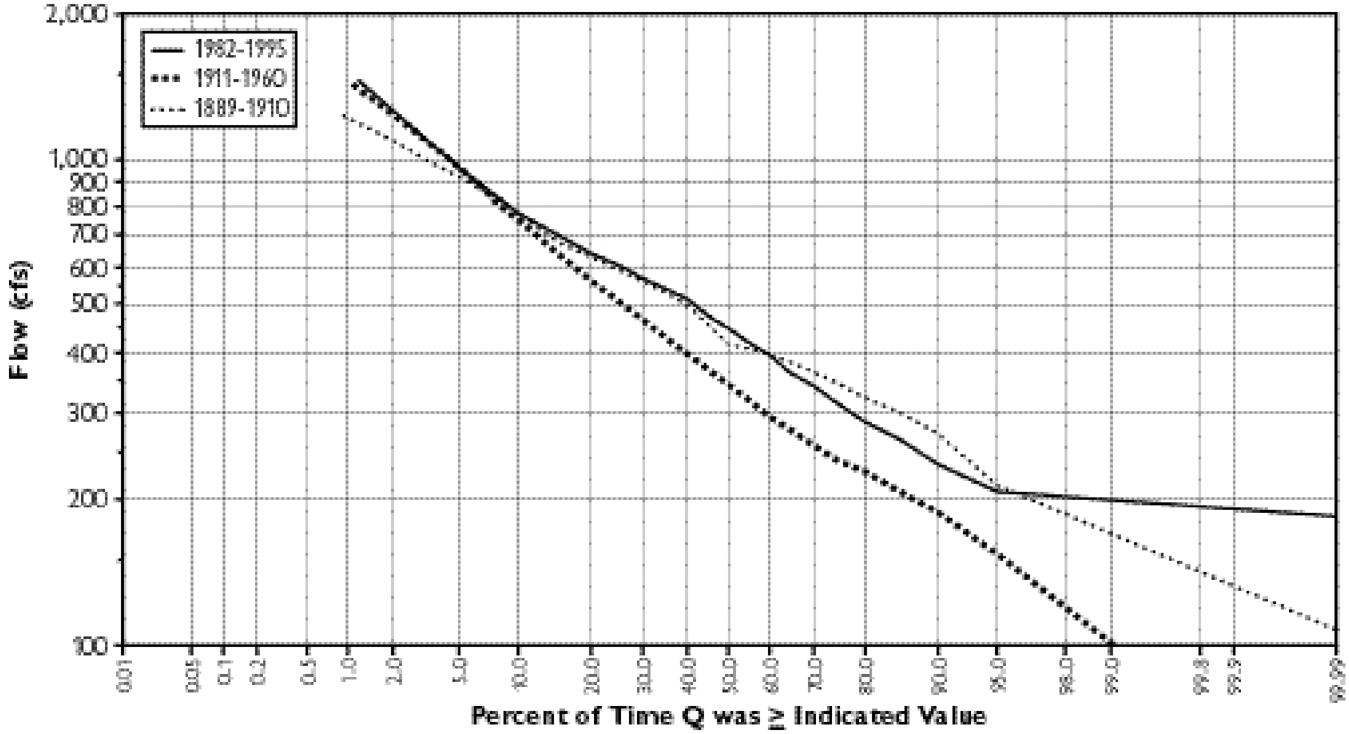


FIGURE 4-15

Arkansas River Flow Duration, April, Cañon City Gage

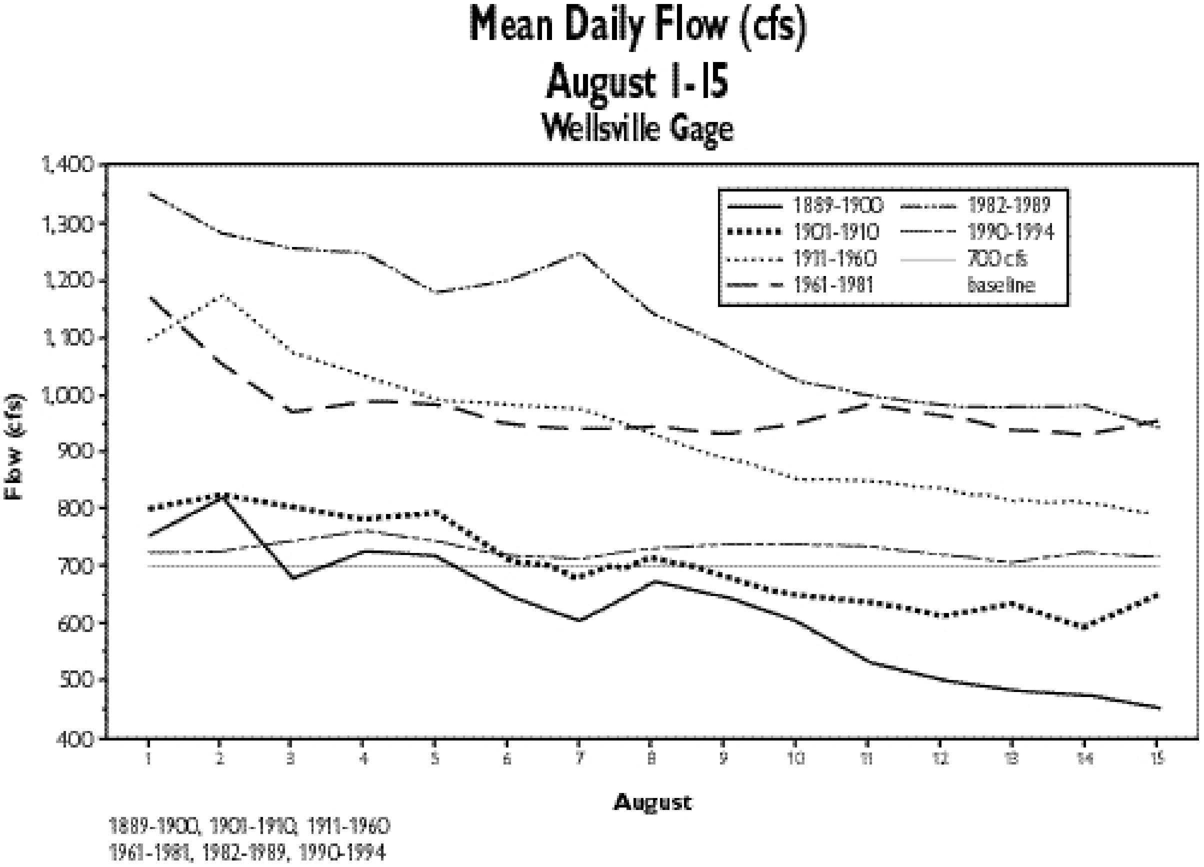


flow estimate over this period of record. Data from earlier than 1911 is comprised of short periods of record and sampling that is too infrequent for reliable interpretation of medians or flow frequency analysis, but mean flows can be determined. For the period from 1898-1900, before any upper basin storage was available, mean August 1-15 flows at Wellsville were approximately 680 cfs. After 1900, but before 1911, when three storage facilities were constructed in the upper basin, mean August 1-15 flows rose to 740 cfs. The proportion of days exceeding 700 cfs for each time period provides an indicator of August 1-15 flow changes:

- 1889-1900 period - 40 percent (limited data set, but only data available)
- 1911-1960 period - 75 percent
- 1982-1989 period - 80 percent
- 1990-1995 period - 77 percent

Figure 4-16 provides mean daily flows for August 1-15 for all time periods, including during Fryingpan-Arkansas Project construction from 1960-1982. The figure includes a baseline flow of 700 cfs. Even with the annual flow management program, the system does not appear to exhibit any radical change from its long-term history. The current 700 cfs augmentation target flow is significantly lower than mean flows from the previous 87 years. In addition, the augmentation target flow does not differ dramatically from mean flows from 1889 to 1900. Higher flows during the 1982-1989 period are undoubtedly due to the extremely high precipitation during this time, which extended the runoff period into August. Flows during the 1990-95 period declined to the lowest of any period since 1910, but this could be attributed to the dry years associated with this period.

FIGURE 4-16



Post Fryingpan-Arkansas Project Streamflow

The construction of upper basin reservoirs after 1900, development of transbasin imports after 1910, the Homestake project, and the Fryingpan-Arkansas Project have all permanently altered the flow regime of the Upper Arkansas River Basin. Because comprehensive records of imported water volumes, reservoir operations, and streamflow are available after 1982, the impact of the largest of these projects, the Fryingpan-Arkansas, can be assessed. The following analysis and discussion are correlated with the Wellsville USGS streamflow gage.

Table 4-5 provides the annual flows by month (acre-feet x 1,000) from 1982-1995 for the Wellsville gage(Q_{act}). These values can be adjusted based on the following equation to estimate natural flows without the effects of transbasin imports and water projects(Q_{adj}):

Q_{adj} = Q_{act} - total imports + total change in reservoir content + total losses out of the system

The total imports (acre-feet x 1,000) to the system are represented by the following:

1. Columbine Ditch
2. Ewing Ditch
3. Wurtz Ditch
4. Homestake Tunnel import
5. Boustead Tunnel import (Fryingpan-Arkansas Project)
6. Busk-Ivanhoe Tunnel import
7. Twin Lakes Tunnel import

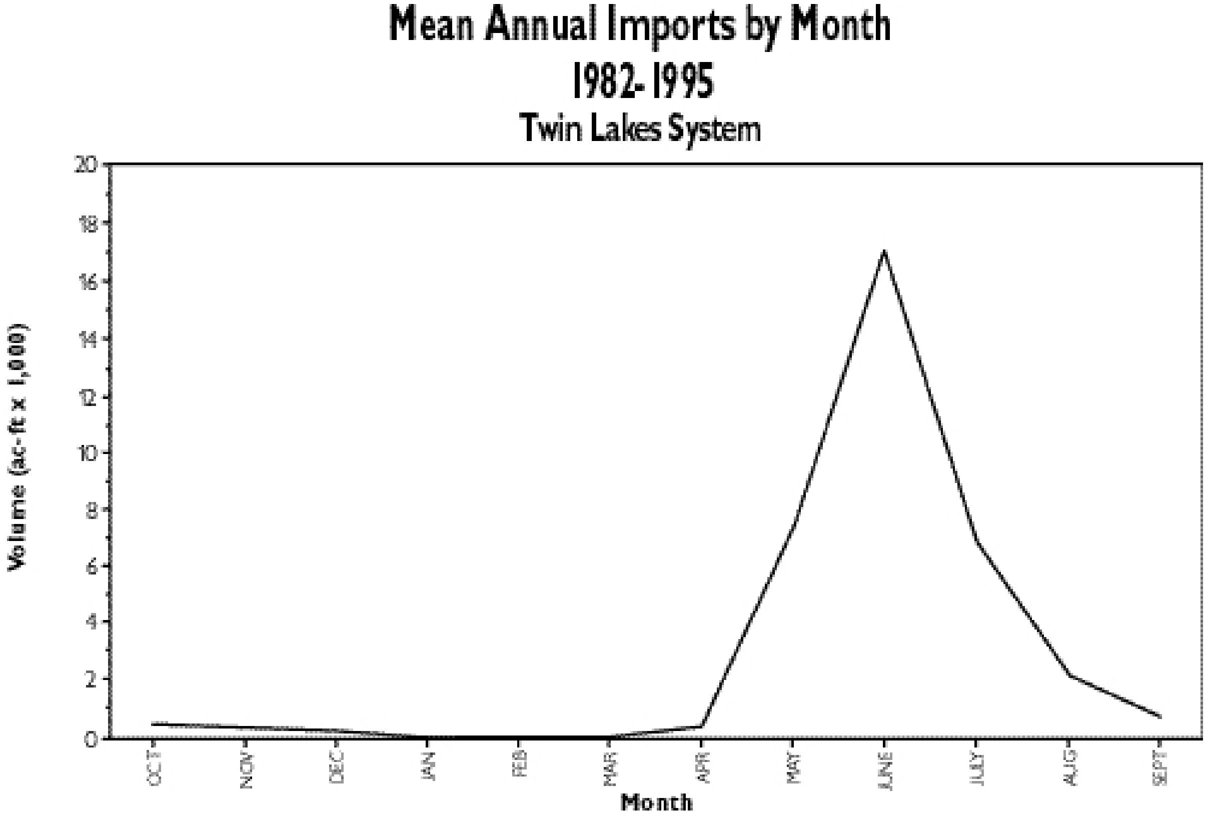
Figures 4-17 to 4-20 illustrate the mean annual imports by month from 1982-1995 for each of the ditches and tunnels above. The majority of imported water occurs from May-July with the exception of Homestake Tunnel imports.

TABLE 4-5

Q_{act}, Monthly Flow (acre-feet x 1,000), Wellsville Gage by Year

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1982	23.6	19.7	22.5	25.2	25.4	24.9	20.2	41.5	124.0	93.4	73.3	43.2	536.9
1983	37.9	34.6	39.1	35.4	31.6	25.1	15.7	25.1	170.7	188.5	88.1	34.1	725.8
1984	26.3	22.0	24.2	20.8	16.6	18.8	30.6	144.1	200.0	152.7	116.2	51.8	824.0
1985	46.1	32.2	27.1	29.2	40.5	37.2	37.5	93.5	189.8	112.4	45.9	28.4	719.9
1986	32.3	29.4	26.2	20.1	16.7	17.6	24.3	85.5	188.9	134.7	51.6	36.1	663.3
1987	32.4	33.6	25.1	21.2	18.6	22.6	34.3	92.5	135.6	60.0	40.4	24.7	541.0
1988	22.0	23.8	22.4	19.1	16.8	18.5	20.0	48.2	90.1	44.5	32.5	22.3	380.1
1989	18.8	20.8	21.8	18.2	14.8	35.1	41.2	48.7	73.2	74.5	57.5	20.5	444.8
1990	19.9	24.1	20.3	17.6	15.1	15.4	13.4	30.6	1,16.5	64.0	38.8	19.5	395.2
1991	25.6	27.6	23.3	31.3	27.3	23.0	26.5	58.4	99.3	51.8	34.0	18.7	446.8
1992	17.2	28.4	29.5	30.2	26.7	27.7	19.9	58.1	69.0	50.6	42.9	25.2	425.3
1993	21.1	24.1	27.2	27.0	28.0	39.8	22.7	85.8	148.6	107.1	41.6	31.8	604.7
1994	29.1	28.1	30.2	31.0	27.0	28.3	24.1	58.5	128.6	45.7	34.4	20.1	485.3
1995	26.5	29.6	33.8	30.7	23.1	28.9	30.5	65.2	178.4	216.5	109.4	48.9	821.5
Mean	27.1	27.0	26.6	25.5	23.4	25.9	25.8	66.8	136.6	99.7	57.6	30.4	572.5

FIGURE 4-17



Mean Annual Imports by Month
1982- 1995
Twin Lakes System

FIGURE 4-18

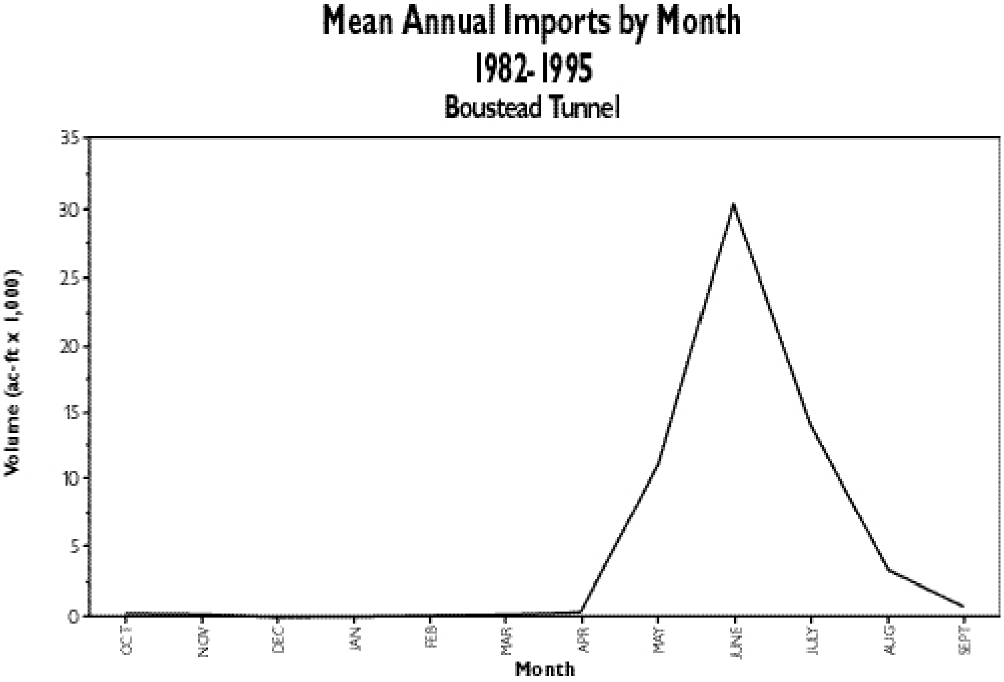


FIGURE 4-19

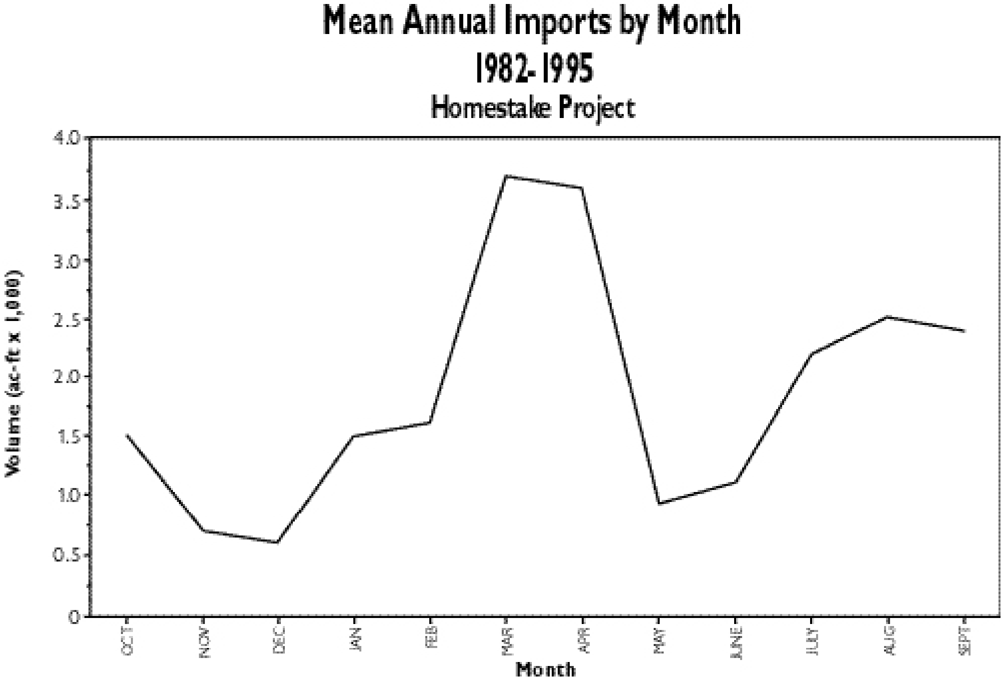
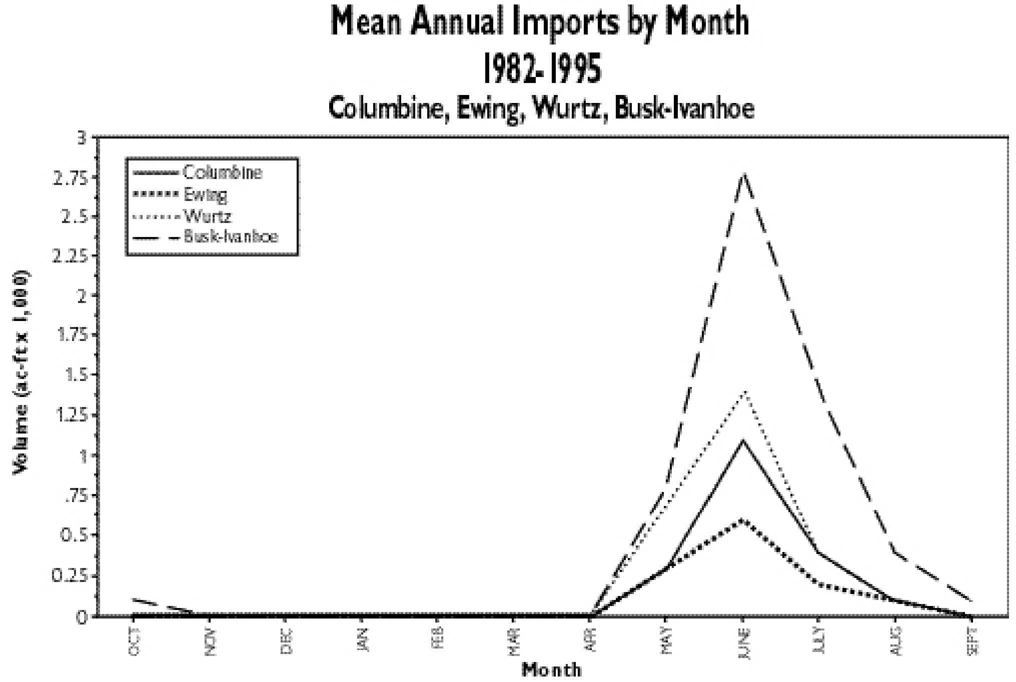


FIGURE 4-20



The net losses (acre-feet x 1,000) to the system are represented by the following:

1. Evaporative losses from Turquoise Reservoir

2. Evaporative losses from Clear Creek Reservoir

3. Evaporative losses from Twin Lakes and Mt. Elbert Forebay

4. Otero Pipeline: Otero Pipeline moves Homestake water directly out of the reservoir system via the Otero pump station to the Cities of Aurora and Colorado Springs. This water never enters the main stem of the Arkansas even though it is imported.

Figure 4-21 illustrates the mean annual reservoir evaporation (acre-feet x 1,000) during the period 1982-1995. These volumes are small and occur only in the summer months.

The Otero Pipeline losses (Figure 4-22) are relatively consistent year-round during this period, with slightly lower values in the winter and slightly higher values in the spring and summer. Most of this water is earmarked for municipal and industrial use, so it is not subject to the large seasonal fluctuations associated with irrigation.

Changes in reservoir content (acre-feet x 1,000) are represented by the three reservoirs in the Upper Basin:

1. Turquoise Reservoir
2. Clear Creek Reservoir
3. Twin Lakes Reservoir and Mt. Elbert Forebay

Figure 4-23 provides mean annual monthly reservoir level changes (acre-feet x 1,000) from 1982-1995 for each of the upper basin reservoirs. A negative value denotes reservoir drawdown/release and a positive value denotes an increase in reservoir level (storage). The majority of reservoir drawdown occurs during the winter months and storage occurs during runoff (May-July). The August release from Twin Lakes can be attributed to the post-1990 flow augmentation program.

Table 4-6 provides a summary of the mean monthly changes in the system at Wellsville from 1982-1995 based on the variables discussed

FIGURE 4-21

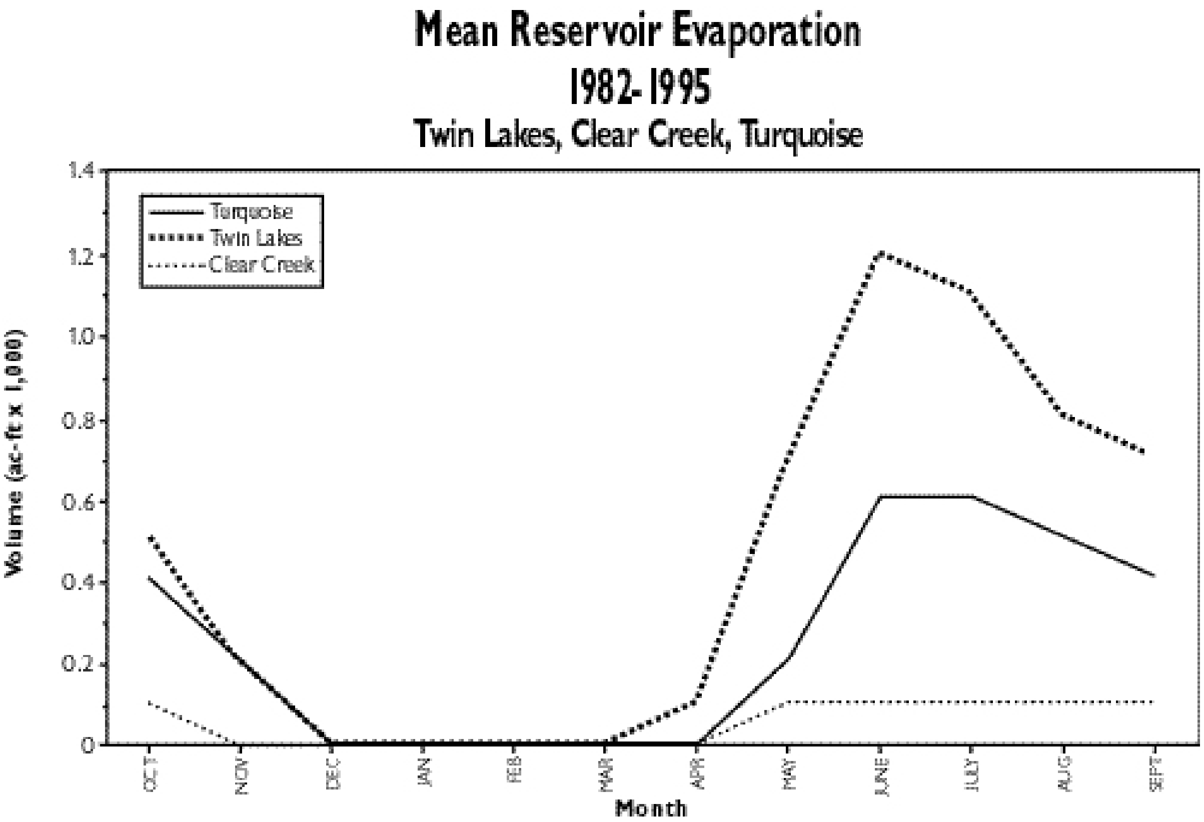


FIGURE 4-22

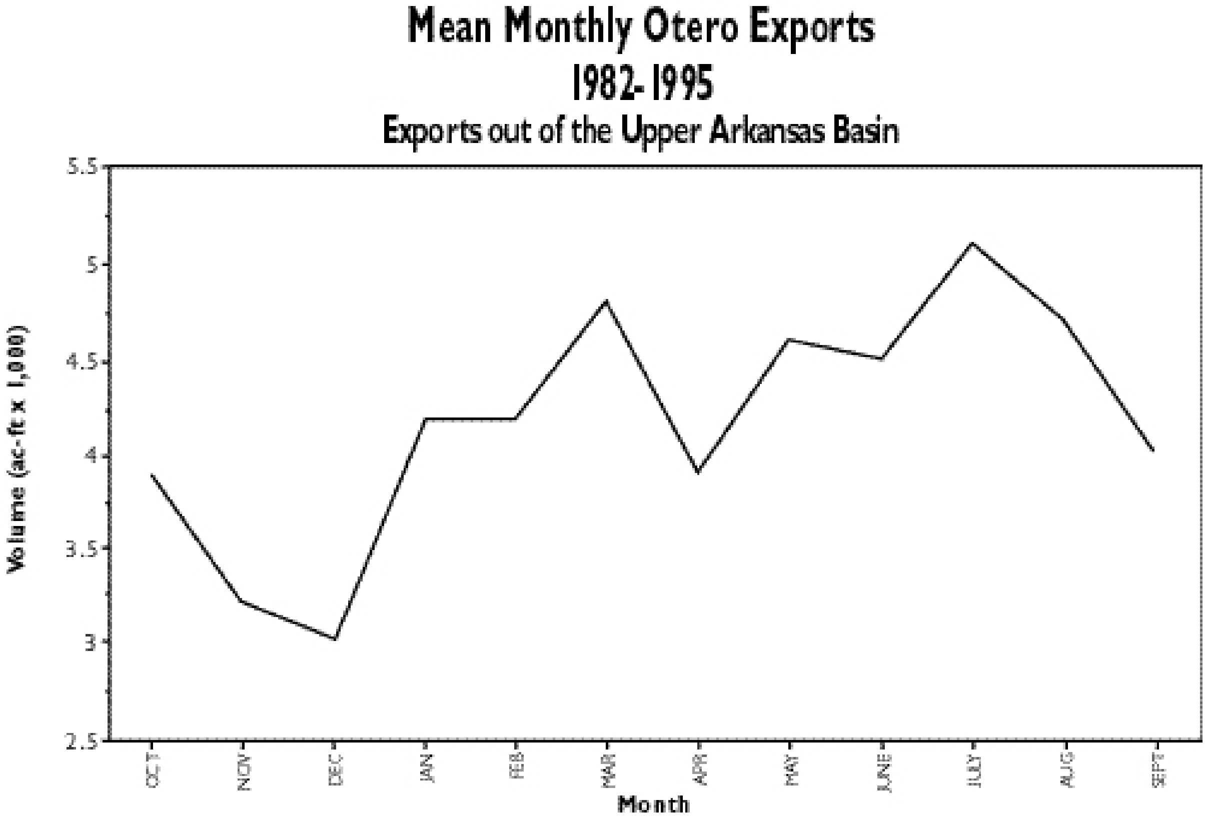
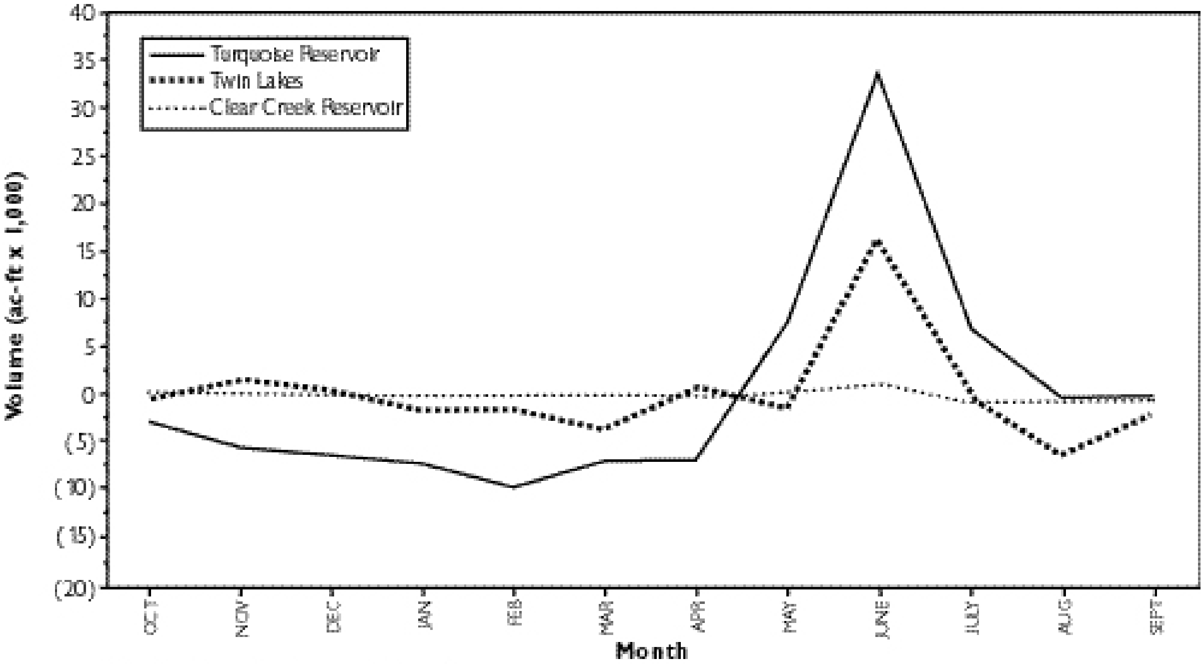


FIGURE 4-23

Mean Monthly Reservoir Changes
1982-1995



Negative values denote reservoir drawdown
Positive values denote reservoir gains

TABLE 4-6

Estimated Mean Monthly Changes (acre-feet x 1,000), Wellsville Gage by Year

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1982	1.9	-0.4	3.8	9.2	13.8	11.0	2.8	3.4	-2.7	0.7	15.1	-0.2	58.4
1983	2.6	7.9	17.1	17.5	15.9	8.5	1.2	-8.3	-13.0	59.3	4.8	6.7	1,20.2
1984	-3.7	-11.1	-15.6	-4.2	16.2	17.9	19.3	38.1	9.8	-0.2	27.3	6.7	100.5
1985	0.2	0.0	0.2	8.0	20.8	16.6	8.1	3.7	-9.4	18.5	4.8	1.1	72.6
1986	0.2	-0.1	1.0	-0.3	-0.5	0.7	1.8	35.8	18.1	16.6	3.1	0.0	76.4
1987	-1.8	0.3	-1.2	-1.3	-0.7	0.2	-2.3	-2.2	3.1	1.2	4.1	0.8	0.2
1988	0.6	0.3	-0.2	-1.4	-1.0	-0.7	3.0	11.4	-2.5	0.3	0.2	-1.3	8.7
1989	-0.8	0.7	0.5	0.7	0.0	16.4	21.1	-3.1	-3.8	25.7	20.7	-0.6	77.5
1990	-0.6	0.3	0.6	0.4	0.9	0.7	-0.5	-3.5	0.2	11.7	10.9	-1.8	19.3
1991	-1.2	-0.1	2.9	12.9	12.5	6.9	13.0	6.3	1.0	2.5	5.1	-1.2	60.6
1992	-0.1	4.9	10.0	13.1	12.8	11.2	2.8	2.9	1.2	4.8	9.0	-0.3	72.3
1993	-0.5	0.1	6.3	8.2	12.5	22.4	7.5	21.7	2.1	25.3	6.8	6.5	118.9
1994	5.8	4.2	10.2	13.0	12.5	11.1	2.6	-12.1	-3.2	13.4	10.3	-1.0	66.8
1995	1.5	7.8	13.3	12.2	6.3	10.5	10.4	29.4	-50.6	-6.2	19.7	1.7	56.0
Mean	0.3	1.1	3.5	6.3	8.7	9.5	6.5	8.8	-3.6	12.4	10.1	1.2	64.9

above. Positive values denote additional water in the system and negative values denote less water, both of which are due to institutional controls. Based on this table, approximately 64,000 acre-feet of additional water annually has been introduced to the system since 1982. However, approximately 43,000 acre-feet of this water was already in place by 1935. The majority of this water was moved from mid-July through September. So the net impact of the water projects brought online between 1960-1982 is approximately 20,000 acre-feet of additional flow annually in the main stem of the Arkansas. Probably the largest effect of the Fryingpan-Arkansas Project is the timing of additional flows in the system and not the additional volume. Prior to 1960, winter flows were reduced to fill upper basin reservoirs. After 1982, with the construction of Pueblo Reservoir, winter flows were markedly increased as water was moved lower in the system to make room for spring runoff storage in the upper reservoirs. Based on the values in Table 4-6, of the 64,000 acre-feet of additional water, approximately 42,000 acre-feet is passed during the winter months. Approximately two-thirds of the additional water passed through the system is moved from October-April.

Resource Considerations

Resource analysis was completed at various locations from near Leadville to Parkdale. This extensive range of locations presents a problem for determining how flow rates in various locations are related to each other. What would a recommended flow rate in the lower portion of the basin correspond to in the upper portion of the basin?

To mitigate this problem, the flow analysis associated with the biological work is indexed to the Wellsville USGS gage. The three other gages that represent flows corresponding to areas of biological analysis, Granite, Nathrop, and Parkdale, were regressed on the measured flows at the Wellsville gage. This allows all flows to be indexed to a single location and then adjusted to each individual point of interest. Table 4-7 provides the regression equation results and flows over the range of interest.

TABLE 4-7

Ordinary Least Squares Regression Estimates of Daily Mean Discharge on Arkansas River

$$\text{estimate} = e^{[a + (b \times \ln q) + [c \times (\ln q)2] + (d 2 + 2)]}$$

$$95 \text{ percent confidence interval} = e^{[(\ln \text{ estimate} - [d 2 + 2]) \pm (d \times 1.98)]}$$

Granite regression based on daily mean discharge values from water years 1982 to 1987, a = -3.376913, b = 1.624432, c = -0.321887, d = 0.342872
Nathrop regression based on daily mean discharge values from water years 1978 to 1982, a = -3.363741, b = 1.8927, c = -0.0595647, d = 0.1577784
Parkdale regression based on daily mean discharge values from water years 1983 to 1987, a = 2.648973, b = 0.2921178, c = 0.0495163, d = 0.1132864

Note: all units in cubic feet per second.

Wellsville	Granite			Nathrop			Parkdale			Wellsville
Measured discharge	Lower 95% confidence interval	Estimated discharge at Granite	Upper 95% confidence interval	Lower 95% confidence interval	Estimated discharge at Nathrop	Upper 95% confidence interval	Lower 95% confidence interval	Estimated discharge at Parkdale	Upper 95% confidence interval	Measured discharge
100	17.0	35.6	66.1	43.7	60.4	81.6	124	156	194	100
105	18.2	38.0	70.5	46.6	64.5	87.1	129	162	201	105
110	19.4	40.4	75.1	49.6	68.7	92.7	133	168	209	110
115	20.5	42.9	79.7	52.6	72.8	98.3	138	174	216	115
120	21.8	45.4	84.4	55.7	77.1	104	142	179	223	120
125	23.0	48.0	89.1	58.8	81.3	110	147	185	230	125
130	24.2	50.5	93.9	61.9	85.6	116	151	191	237	130
135	25.4	53.1	98.7	65.0	90.0	121	156	196	244	135
140	26.7	55.8	104	68.2	94.4	127	160	202	251	140
145	28.0	58.4	109	71.4	98.8	133	165	208	258	145
150	29.3	61.1	113	74.6	103	139	169	213	265	150
155	30.6	63.8	119	77.8	108	145	174	219	272	155
160	31.9	66.5	124	81.1	112	151	178	224	279	160
165	33.2	69.3	129	84.4	117	158	183	230	286	165
170	34.5	72.2	134	87.6	121	164	187	235	293	170
175	35.8	74.9	139	91.0	126	170	191	241	300	175
180	37.2	77.7	144	94.3	130	176	196	247	307	180
185	38.6	80.5	150	97.6	135	182	200	252	313	185
190	39.9	83.4	155	101	140	189	205	258	320	190
195	41.3	86.2	160	104	144	195	209	263	327	195
200	42.7	89.1	166	108	149	201	213	269	334	200
205	44.1	92.1	171	111	154	208	218	274	341	205
210	45.5	95.0	176	115	159	214	222	280	348	210
215	46.9	97.9	182	118	163	220	226	285	354	215
220	48.3	101	187	121	168	227	231	290	361	220
225	49.7	104	193	125	173	233	235	296	368	225
230	51.2	107	199	128	178	240	239	301	375	230
235	52.6	110	204	132	182	246	244	307	381	235
240	54.1	113	210	135	187	253	248	312	388	240
245	55.5	116	215	139	192	259	252	318	395	245
250	57.0	119	221	142	197	266	257	323	402	250
255	58.5	122	227	146	202	273	261	328	408	255
260	60.0	125	233	149	207	279	265	334	415	260
265	61.4	128	238	153	212	286	269	339	422	265
270	62.9	131	244	157	217	292	274	345	429	270
275	64.4	135	250	160	221	299	278	350	435	275
280	65.9	138	256	164	226	306	282	356	442	280
285	67.5	141	262	167	231	312	287	361	449	285
290	69.0	144	268	171	236	319	291	366	455	290
295	70.5	147	273	174	241	326	295	372	462	295
300	72.0	150	279	178	246	332	299	377	469	300
305	73.6	154	285	182	251	339	304	382	476	305
310	75.1	157	291	185	256	346	308	388	482	310
315	76.6	160	297	189	261	353	312	393	489	315
320	78.2	163	303	192	266	359	316	399	496	320
325	79.8	167	309	196	271	366	321	404	502	325
330	81.3	170	315	200	276	373	325	409	509	330
335	82.9	173	321	203	281	380	329	415	516	335
340	84.5	176	328	207	286	387	334	420	522	340
345	86.0	180	334	211	291	393	338	425	529	345

TABLE 4-7 (continued)

Ordinary Least Squares Regression Estimates of Daily Mean Discharge on Arkansas River

estimate = $e^{[a + (b \times \ln q) + [c \times (\ln q)2] + (d\ 2 + 2)]}$

95 percent confidence interval = $e^{[(\ln \text{estimate} - [d\ 2 + 2]) \pm (d \times 1.98)]}$

Granite regression based on daily mean discharge values from water years 1982 to 1987, a = -3.376913, b = 1.624432, c = -0.321887, d = 0.342872
Nathrop regression based on daily mean discharge values from water years 1978 to 1982, a = -3.363741, b = 1.8927, c = -0.0595647, d = 0.1577784
Parkdale regression based on daily mean discharge values from water years 1983 to 1987, a = 2.648973, b = 0.2921178, c = 0.0495163, d = 0.1132864

Note: all units in cubic feet per second.

Wellsville Measured discharge	Lower 95% confidence interval	Granite Estimated discharge at Granite	Upper 95% confidence interval	Lower 95% confidence interval	Nathrop Estimated discharge at Nathrop	Upper 95% confidence interval	Lower 95% confidence interval	Parkdale Estimated discharge at Parkdale	Upper 95% confidence interval	Wellsville Measured discharge
350	87.6	183	340	214	296	400	342	431	536	350
355	89.2	186	346	218	302	407	346	436	542	355
360	90.8	190	352	222	307	414	351	442	549	360
365	92.4	193	358	225	312	421	355	447	556	365
370	94.0	196	365	229	317	428	359	452	562	370
375	95.6	200	371	233	322	434	363	458	569	375
380	97.2	203	377	236	327	441	368	463	576	380
385	98.8	206	383	240	332	448	372	468	582	385
390	100	210	390	244	337	455	376	474	589	390
395	102	213	396	247	342	462	380	479	596	395
400	104	217	402	251	347	469	385	485	602	400
410	107	223	415	258	358	483	393	495	616	410
420	110	230	428	266	368	497	402	506	629	420
430	114	237	441	273	378	511	410	517	642	430
440	117	244	453	281	389	524	419	527	656	440
450	120	251	466	288	399	538	427	538	669	450
460	124	258	479	296	409	552	436	549	682	460
470	127	265	492	303	420	566	444	560	696	470
480	130	272	506	311	430	580	453	570	709	480
490	134	279	519	318	440	594	461	581	723	490
500	137	286	532	326	451	608	470	592	736	500
510	141	294	545	333	461	622	478	603	749	510
520	144	301	558	341	471	636	487	613	763	520
530	147	308	572	348	482	650	495	624	776	530
540	151	315	585	356	492	664	504	635	789	540
550	154	322	599	363	503	678	513	646	803	550
560	158	330	612	371	513	693	521	656	816	560
570	161	337	626	378	524	707	530	667	830	570
580	165	344	639	386	534	721	538	678	843	580
590	168	352	653	393	544	735	547	689	856	590
600	172	359	667	401	555	749	555	699	870	600
610	175	366	680	409	565	763	564	710	883	610
620	179	374	694	416	576	777	572	721	897	620
630	183	381	708	424	586	791	581	732	910	630
640	186	389	722	431	597	805	590	743	923	640
650	190	396	736	439	607	820	598	753	937	650
660	193	404	750	446	618	834	607	764	950	660
670	197	411	763	454	628	848	615	775	964	670
680	200	419	777	461	639	862	624	786	977	680
690	204	426	791	469	649	876	633	797	991	690
700	208	434	805	477	660	890	641	808	1,000	700
710	211	441	820	484	670	904	650	819	1,020	710
720	215	449	834	492	681	919	659	829	1,030	720
730	219	456	848	499	691	933	667	840	1,040	730
740	222	464	862	507	702	947	676	851	1,060	740
750	226	472	876	515	712	961	684	862	1,070	750
760	230	479	890	522	722	975	693	873	1,090	760
770	233	487	905	530	733	989	702	884	1,100	770
780	237	495	919	537	743	1,000	710	895	1,110	780
790	241	503	933	545	754	1,020	719	906	1,130	790

TABLE 4-7 (continued)

Ordinary Least Squares Regression Estimates of Daily Mean Discharge on Arkansas River

estimate = $e^{[a + (b \times \text{lnq}) + [c \times (\text{lnq})2] + (d\ 2 + 2)]}$

95 percent confidence interval = $e^{[(\text{ln estimate} - [d\ 2 + 2]) \pm (d \times 1.98)]}$

Granite regression based on daily mean discharge values from water years 1982 to 1987, a = -3.376913, b = 1.624432, c = -0.321887, d = 0.342872
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Parkdale regression based on daily mean discharge values from water years 1983 to 1987, a = 2.648973, b = 0.2921178, c = 0.0495163, d = 0.1132864

Note: all units in cubic feet per second.

Wellsville	Granite			Nathrop			Parkdale			Wellsville
Measured discharge	Lower 95% confidence interval	Estimated discharge at Granite	Upper 95% confidence interval	Lower 95% confidence interval	Estimated discharge at Nathrop	Upper 95% confidence interval	Lower 95% confidence interval	Estimated discharge at Parkdale	Upper 95% confidence interval	Measured discharge
800	244	510	948	552	764	1,030	728	917	1,140	800
810	248	518	962	560	775	1,050	736	928	1,150	810
820	252	526	977	568	785	1,060	745	938	1,170	820
830	256	534	991	575	796	1,070	754	949	1,180	830
840	259	541	1,010	583	806	1,090	763	960	1,190	840
850	263	549	1,020	590	817	1,100	771	971	1,210	850
860	267	557	1,030	598	827	1,120	780	982	1,220	860
870	271	565	1,050	605	838	1,130	789	993	1,240	870
880	274	573	1,060	613	848	1,140	797	1,000	1,250	880
890	278	581	1,080	620	859	1,160	806	1,020	1,260	890
900	282	588	1,090	628	869	1,170	815	1,030	1,280	900
910	286	596	1,110	636	879	1,190	824	1,040	1,290	910
920	289	604	1,120	643	890	1,200	832	1,050	1,300	920
930	293	612	1,140	651	900	1,220	841	1,060	1,320	930
940	297	620	1,150	658	911	1,230	850	1,070	1,330	940
950	301	628	1,170	666	921	1,240	859	1,080	1,340	950
960	305	636	1,180	673	932	1,260	867	1,090	1,360	960
970	308	644	1,200	681	942	1,270	876	1,100	1,370	970
980	312	652	1,210	688	953	1,290	885	1,110	1,390	980
990	316	660	1,230	696	963	1,300	894	1,130	1,400	990
1,000	320	668	1,240	703	973	1,310	903	1,140	1,410	1,000
1,010	324	676	1,260	711	984	1,330	911	1,150	1,430	1,010
1,020	328	684	1,270	718	994	1,340	920	1,160	1,440	1,020
1,030	331	692	1,290	726	1,000	1,360	929	1,170	1,460	1,030
1,040	335	700	1,300	733	1,010	1,370	938	1,180	1,470	1,040
1,050	339	708	1,320	741	1,030	1,380	947	1,190	1,480	1,050
1,060	343	716	1,330	748	1,040	1,400	956	1,200	1,500	1,060
1,070	347	724	1,350	756	1,050	1,410	964	1,210	1,510	1,070
1,080	351	732	1,360	763	1,060	1,430	973	1,230	1,520	1,080
1,090	355	741	1,380	771	1,070	1,440	982	1,240	1,540	1,090
1,100	359	749	1,390	778	1,080	1,450	991	1,250	1,550	1,100
1,110	362	757	1,410	786	1,090	1,470	1,000	1,260	1,570	1,110
1,120	366	765	1,420	793	1,100	1,480	1,010	1,270	1,580	1,120
1,130	370	773	1,440	801	1,110	1,500	1,020	1,280	1,590	1,130
1,140	374	781	1,450	808	1,120	1,510	1,030	1,290	1,610	1,140
1,150	378	789	1,470	816	1,130	1,520	1,040	1,300	1,620	1,150
1,160	382	798	1,480	823	1,140	1,540	1,040	1,320	1,640	1,160
1,170	386	806	1,500	831	1,150	1,550	1,050	1,330	1,650	1,170
1,180	390	814	1,510	838	1,160	1,570	1,060	1,340	1,660	1,180
1,190	394	822	1,530	846	1,170	1,580	1,070	1,350	1,680	1,190
1,200	398	830	1,540	853	1,180	1,590	1,080	1,360	1,690	1,200
1,210	402	839	1,560	861	1,190	1,610	1,090	1,370	1,710	1,210
1,220	406	847	1,570	868	1,200	1,620	1,100	1,380	1,720	1,220
1,230	409	855	1,590	876	1,210	1,640	1,110	1,390	1,730	1,230
1,240	413	863	1,600	883	1,220	1,650	1,120	1,410	1,750	1,240
1,250	417	872	1,620	890	1,230	1,660	1,130	1,420	1,760	1,250
1,260	421	880	1,630	898	1,240	1,680	1,130	1,430	1,780	1,260
1,270	425	888	1,650	905	1,250	1,690	1,140	1,440	1,790	1,270
1,280	429	896	1,670	913	1,260	1,700	1,150	1,450	1,800	1,280
1,290	433	905	1,680	920	1,270	1,720	1,160	1,460	1,820	1,290

TABLE 4-7 (continued)

Ordinary Least Squares Regression Estimates of Daily Mean Discharge on Arkansas River

$$\text{estimate} = e^{[a + (b \times \ln q) + [c \times (\ln q)2] + (d\ 2 + 2)]}$$

$$\text{95 percent confidence interval} = e^{[(\ln \text{estimate} - [d\ 2 + 2]) \pm (d \times 1.98)]}$$

Granite regression based on daily mean discharge values from water years 1982 to 1987, a = -3.376913, b = 1.624432, c = -0.321887, d = 0.342872
Nathrop regression based on daily mean discharge values from water years 1978 to 1982, a = -3.363741, b = 1.8927, c = -0.0595647, d = 0.1577784
Parkdale regression based on daily mean discharge values from water years 1983 to 1987, a = 2.648973, b = 0.2921178, c = 0.0495163, d = 0.1132864

Note: all units in cubic feet per second.

Wellsville Measured discharge	Lower 95% confidence interval	Granite Estimated discharge at Granite	Upper 95% confidence interval	Lower 95% confidence interval	Nathrop Estimated discharge at Nathrop	Upper 95% confidence interval	Lower 95% confidence interval	Parkdale Estimated discharge at Parkdale	Upper 95% confidence interval	Wellsville Measured discharge
1,300	437	913	1,700	927	1,280	1,730	1,170	1,470	1,830	1,300
1,310	441	921	1,710	935	1,290	1,750	1,180	1,490	1,850	1,310
1,320	445	930	1,730	942	1,300	1,760	1,190	1,500	1,860	1,320
1,330	449	938	1,740	950	1,310	1,770	1,200	1,510	1,870	1,330
1,340	453	946	1,760	957	1,320	1,790	1,210	1,520	1,890	1,340
1,350	457	955	1,770	964	1,330	1,800	1,220	1,530	1,900	1,350
1,360	461	963	1,790	972	1,340	1,820	1,220	1,540	1,920	1,360
1,370	465	971	1,800	979	1,360	1,830	1,230	1,550	1,930	1,370
1,380	469	980	1,820	987	1,370	1,840	1,240	1,560	1,950	1,380
1,390	473	988	1,840	994	1,380	1,860	1,250	1,580	1,960	1,390
1,400	477	977	1,850	1,000	1,390	1,870	1,260	1,590	1,970	1,400
1,410	481	1,000	1,870	1,010	1,400	1,880	1,270	1,600	1,990	1,410
1,420	485	1,010	1,880	1,020	1,410	1,900	1,280	1,610	2,000	1,420
1,430	489	1,020	1,900	1,020	1,420	1,910	1,290	1,620	2,020	1,430
1,440	493	1,030	1,910	1,030	1,430	1,930	1,300	1,630	2,030	1,440
1,450	497	1,040	1,930	1,040	1,440	1,940	1,310	1,650	2,050	1,450
1,460	501	1,050	1,940	1,050	1,450	1,950	1,320	1,660	2,060	1,460
1,470	505	1,060	1,960	1,050	1,460	1,970	1,320	1,670	2,070	1,470
1,480	509	1,060	1,980	1,060	1,470	1,980	1,330	1,680	2,090	1,480
1,490	513	1,070	1,990	1,070	1,480	1,990	1,340	1,690	2,100	1,490
1,500	518	1,080	2,010	1,070	1,490	2,010	1,350	1,700	2,120	1,500
1,510	522	1,090	2,020	1,080	1,500	2,020	1,360	1,710	2,130	1,510
1,520	526	1,100	2,040	1,090	1,510	2,030	1,370	1,730	2,150	1,520
1,530	530	1,110	2,050	1,100	1,520	2,050	1,380	1,740	2,160	1,530
1,540	534	1,110	2,070	1,100	1,530	2,060	1,390	1,750	2,170	1,540
1,550	538	1,120	2,090	1,110	1,540	2,080	1,400	1,760	2,190	1,550
1,560	542	1,130	2,100	1,120	1,550	2,090	1,410	1,770	2,200	1,560
1,570	546	1,140	2,120	1,130	1,560	2,100	1,420	1,780	2,220	1,570
1,580	550	1,150	2,130	1,130	1,570	2,120	1,430	1,800	2,230	1,580
1,590	554	1,160	2,150	1,140	1,580	2,130	1,430	1,810	2,250	1,590
1,600	558	1,170	2,160	1,150	1,590	2,140	1,440	1,820	2,260	1,600
1,610	562	1,170	2,180	1,160	1,600	2,160	1,450	1,830	2,280	1,610
1,620	566	1,180	2,200	1,160	1,610	2,170	1,460	1,840	2,290	1,620
1,630	570	1,190	2,210	1,170	1,620	2,180	1,470	1,850	2,300	1,630
1,640	575	1,200	2,230	1,180	1,630	2,200	1,480	1,870	2,320	1,640
1,650	579	1,210	2,240	1,180	1,640	2,210	1,490	1,880	2,330	1,650
1,660	583	1,220	2,260	1,190	1,650	2,230	1,500	1,890	2,350	1,660
1,670	587	1,230	2,280	1,200	1,660	2,240	1,510	1,900	2,360	1,670
1,680	591	1,230	2,290	1,210	1,670	2,250	1,520	1,910	2,380	1,680
1,690	595	1,240	2,310	1,210	1,680	2,270	1,530	1,920	2,390	1,690
1,700	599	1,250	2,320	1,220	1,690	2,280	1,540	1,940	2,410	1,700
1,710	603	1,260	2,340	1,230	1,700	2,290	1,550	1,950	2,420	1,710
1,720	607	1,270	2,360	1,230	1,710	2,310	1,560	1,960	2,440	1,720
1,730	611	1,280	2,370	1,240	1,720	2,320	1,560	1,970	2,450	1,730
1,740	616	1,290	2,390	1,250	1,730	2,330	1,570	1,980	2,460	1,740
1,750	620	1,290	2,400	1,260	1,740	2,350	1,580	1,990	2,480	1,750
1,760	624	1,300	2,420	1,260	1,750	2,360	1,590	2,010	2,490	1,760
1,770	628	1,310	2,440	1,270	1,760	2,370	1,600	2,020	2,510	1,770
1,780	632	1,320	2,450	1,280	1,770	2,390	1,610	2,030	2,520	1,780
1,790	636	1,330	2,470	1,290	1,780	2,400	1,620	2,040	2,540	1,790

TABLE 4-7 (continued)

Ordinary Least Squares Regression Estimates of Daily Mean Discharge on Arkansas River

estimate = $e^{[a + (b \times lnq) + [c \times (lnq)2] + (d 2 + 2)]}$

95 percent confidence interval = $e^{[(ln\ estimate - [d 2 + 2]) \pm (d \times 1.98)]}$

Granite regression based on daily mean discharge values from water years 1982 to 1987, a = -3.376913, b = 1.624432, c = -0.321887, d = 0.342872
Nathrop regression based on daily mean discharge values from water years 1978 to 1982, a = -3.363741, b = 1.8927, c = -0.0595647, d = 0.1577784
Parkdale regression based on daily mean discharge values from water years 1983 to 1987, a = 2.648973, b = 0.2921178, c = 0.0495163, d = 0.1132864

Note: all units in cubic feet per second.

Wellsville Measured discharge	Lower 95% confidence interval	Granite Estimated discharge at Granite	Upper 95% confidence interval	Lower 95% confidence interval	Nathrop Estimated discharge at Nathrop	Upper 95% confidence interval	Lower 95% confidence interval	Parkdale Estimated discharge at Parkdale	Upper 95% confidence interval	Wellsville Measured discharge
1,800	640	1,340	2,480	1,290	1,790	2,410	1,630	2,050	2,550	1,800
1,810	644	1,350	2,500	1,300	1,800	2,430	1,640	2,060	2,570	1,810
1,820	649	1,350	2,520	1,310	1,810	2,440	1,650	2,080	2,580	1,820
1,830	653	1,360	2,530	1,310	1,820	2,450	1,660	2,090	2,600	1,830
1,840	657	1,370	2,550	1,320	1,830	2,470	1,670	2,100	2,610	1,840
1,850	661	1,380	2,560	1,330	1,840	2,480	1,680	2,110	2,630	1,850
1,860	665	1,390	2,580	1,340	1,850	2,490	1,690	2,120	2,640	1,860
1,870	669	1,400	2,600	1,340	1,860	2,510	1,700	2,140	2,660	1,870
1,880	673	1,410	2,610	1,350	1,870	2,520	1,700	2,150	2,670	1,880
1,890	678	1,410	2,630	1,360	1,880	2,530	1,710	2,160	2,680	1,890
1,900	682	1,420	2,640	1,360	1,890	2,550	1,720	2,170	2,700	1,900
1,910	686	1,430	2,660	1,370	1,900	2,560	1,730	2,180	2,710	1,910
1,920	690	1,440	2,680	1,380	1,910	2,570	1,740	2,190	2,730	1,920
1,930	694	1,450	2,690	1,390	1,920	2,590	1,750	2,210	2,740	1,930
1,940	698	1,460	2,710	1,390	1,930	2,600	1,760	2,220	2,760	1,940
1,950	703	1,470	2,720	1,400	1,940	2,610	1,770	2,230	2,770	1,950
1,960	707	1,480	2,740	1,410	1,950	2,630	1,780	2,240	2,790	1,960
1,970	711	1,480	2,760	1,410	1,960	2,640	1,790	2,250	2,800	1,970
1,980	715	1,490	2,770	1,420	1,970	2,650	1,800	2,270	2,820	1,980
1,990	719	1,500	2,790	1,430	1,980	2,670	1,810	2,280	2,830	1,990
2,000	723	1,510	2,810	1,430	1,990	2,680	1,820	2,290	2,850	2,000
2,050	744	1,550	2,890	1,470	2,030	2,750	1,870	2,350	2,920	2,050
2,100	765	1,600	2,970	1,510	2,080	2,810	1,910	2,410	3,000	2,100
2,150	786	1,640	3,050	1,540	2,130	2,880	1,960	2,470	3,070	2,150
2,200	807	1,690	3,130	1,580	2,180	2,940	2,010	2,530	3,150	2,200
2,250	828	1,730	3,120	1,610	2,230	3,010	2,060	2,590	3,220	2,250
2,300	850	1,770	3,300	1,650	2,280	3,070	2,110	2,650	3,300	2,300
2,350	871	1,820	3,380	1,680	2,320	3,140	2,160	2,710	3,380	2,350
2,400	892	1,860	3,460	1,710	2,370	3,200	2,200	2,780	3,450	2,400
2,450	913	1,910	3,540	1,750	2,420	3,270	2,250	2,840	3,530	2,450
2,500	935	1,950	3,620	1,780	2,470	3,330	2,300	2,900	3,600	2,500
2,550	956	2,000	3,710	1,820	2,510	3,390	2,350	2,960	3,680	2,550
2,600	977	2,040	3,790	1,850	2,560	3,460	2,400	3,020	3,760	2,600
2,650	999	2,090	3,870	1,890	2,610	3,520	2,450	3,090	3,840	2,650
2,700	1,020	2,130	3,960	1,920	2,660	3,590	2,500	3,150	3,910	2,700
2,750	1,040	2,180	4,040	1,950	2,700	3,650	2,550	3,210	3,990	2,750
2,800	1,060	2,220	4,120	1,990	2,750	3,710	2,600	3,270	4,070	2,800
2,850	1,080	2,270	4,210	2,020	2,800	3,770	2,650	3,340	4,150	2,850
2,900	1,110	2,310	4,290	2,050	2,840	3,840	2,700	3,400	4,230	2,900
2,950	1,130	2,360	4,370	2,090	2,890	3,900	2,750	3,460	4,310	2,950
3,000	1,150	2,400	4,460	2,120	2,930	3,960	2,800	3,530	4,390	3,000
3,050	1,170	2,450	4,540	2,150	2,980	4,020	2,850	3,590	4,470	3,050
3,100	1,190	2,490	4,630	2,190	3,030	4,080	3,900	3,660	4,550	3,100
3,150	1,210	2,540	4,710	2,220	3,070	4,150	2,950	3,720	4,620	3,150
3,200	1,240	2,580	4,790	2,250	3,120	4,210	3,000	3,780	4,710	3,200
3,250	1,260	2,630	4,880	2,280	3,160	4,270	3,060	3,850	4,790	3,250
3,300	1,280	2,670	4,960	2,320	3,210	4,330	3,110	3,910	4,870	3,300
3,350	1,300	2,720	5,050	2,350	3,250	4,390	3,160	3,980	4,950	3,350
3,400	1,320	2,760	5,130	2,380	3,300	4,450	3,210	4,040	5,030	3,400
3,450	1,350	2,810	5,220	2,410	3,340	4,510	3,260	4,110	5,110	3,450

TABLE 4-7 (continued)

Ordinary Least Squares Regression Estimates of Daily Mean Discharge on Arkansas River

$$\text{estimate} = e^{[a + (b \times \ln q) + [c \times (\ln q)2] + (d 2 + 2)]}$$

$$\text{95 percent confidence interval} = e^{[(\ln \text{estimate} - [d 2 + 2]) \pm (d \times 1.98)]}$$

Granite regression based on daily mean discharge values from water years 1982 to 1987, a = -3.376913, b = 1.624432, c = -0.321887, d = 0.342872
Nathrop regression based on daily mean discharge values from water years 1978 to 1982, a = -3.363741, b = 1.8927, c = -0.0595647, d = 0.1577784
Parkdale regression based on daily mean discharge values from water years 1983 to 1987, a = 2.648973, b = 0.2921178, c = 0.0495163, d = 0.1132864

Note: all units in cubic feet per second.

Wellsville	Granite			Nathrop			Parkdale			Wellsville
Measured discharge	Lower 95% confidence interval	Estimated discharge at Granite	Upper 95% confidence interval	Lower 95% confidence interval	Estimated discharge at Nathrop	Upper 95% confidence interval	Lower 95% confidence interval	Estimated discharge at Parkdale	Upper 95% confidence interval	Measured discharge
3,500	1,370	2,850	5,300	2,450	3,390	4,570	3,310	4,170	5,190	3,500
3,550	1,390	2,900	5,390	2,480	3,430	4,630	3,370	4,240	5,270	3,550
3,600	1,410	2,950	5,470	2,510	3,470	4,690	3,420	4,310	5,350	3,600
3,650	1,430	2,990	5,560	2,540	3,520	4,750	3,470	4,370	5,440	3,650
3,700	1,450	3,040	5,640	2,570	3,560	4,810	3,520	4,440	5,520	3,700
3,750	1,480	3,080	5,730	2,610	3,610	4,870	3,580	4,500	5,600	3,750
3,800	1,500	3,130	5,810	2,640	3,650	4,930	3,630	4,570	5,680	3,800
3,850	1,520	3,170	5,900	2,670	3,690	4,990	3,680	4,640	5,770	3,850
3,900	1,540	3,220	5,980	2,700	3,740	5,050	3,740	4,700	5,850	3,900
3,950	1,560	3,270	6,070	2,730	3,780	5,100	3,790	4,770	5,930	3,950
4,000	1,590	3,310	6,150	2,760	3,830	5,160	3,840	4,840	6,020	4,000
4,050	1,610	3,360	6,240	2,800	3,870	5,220	3,900	4,910	6,100	4,050
4,100	1,630	3,400	6,320	2,830	3,910	5,280	3,950	4,970	6,190	4,100
4,150	1,650	3,450	6,410	2,860	3,950	5,340	4,000	5,040	6,270	4,150
4,200	1,670	3,500	6,490	2,890	4,000	5,400	4,060	5,110	6,350	4,200
4,250	1,700	3,540	6,580	2,920	4,040	5,450	4,110	5,180	6,440	4,250
4,300	1,720	3,590	6,670	2,950	4,080	5,510	4,170	5,250	6,520	4,300
4,350	1,740	3,630	6,750	2,980	4,120	5,570	4,220	5,310	6,610	4,350
4,400	1,760	3,680	6,840	3,010	4,170	5,620	4,270	5,380	6,690	4,400
4,450	1,780	3,730	6,920	3,040	4,210	5,680	4,330	5,450	6,780	4,450
4,500	1,810	3,770	7,010	3,070	4,250	5,740	4,380	5,520	6,870	4,500
4,550	1,830	3,820	7,090	3,100	4,290	5,800	4,440	5,590	6,950	4,550
4,600	1,850	3,870	7,180	3,130	4,340	5,850	4,490	5,660	7,040	4,600
4,650	1,870	3,910	7,270	3,160	4,380	5,910	4,550	5,730	7,120	4,650
4,700	1,900	3,960	7,350	3,190	4,420	5,960	4,600	5,800	7,210	4,700
4,750	1,920	4,010	7,440	3,220	4,460	6,020	4,660	5,870	7,300	4,750
4,800	1,940	4,050	7,520	3,250	4,500	6,080	4,710	5,940	7,380	4,800
4,850	1,960	4,100	7,610	3,280	4,540	6,130	4,770	6,010	7,470	4,850
4,900	1,980	4,140	7,700	3,310	4,580	6,190	4,830	6,080	7,560	4,900
4,950	2,010	4,190	7,780	3,340	4,630	6,240	4,880	6,150	7,650	4,950
5,000	2,030	4,240	7,870	3,370	4,670	6,300	4,940	6,220	7,730	5,000
5,050	2,050	4,280	7,960	3,400	4,710	6,350	4,990	6,290	7,820	5,050
5,100	2,070	4,330	8,040	3,430	4,750	6,410	5,050	6,360	7,910	5,100
5,150	2,100	4,380	8,130	3,460	4,790	6,460	5,110	6,430	8,000	5,150
5,200	2,120	4,420	8,210	3,490	4,830	6,520	5,160	6,500	8,090	5,200
5,250	2,140	4,470	8,300	3,520	4,870	6,570	5,220	6,570	8,180	5,250
5,300	2,160	4,520	8,390	3,550	4,910	6,630	5,280	6,650	8,260	5,300
5,350	2,180	4,560	8,470	3,580	4,950	6,680	5,330	6,720	8,350	5,350
5,400	2,210	4,610	8,560	3,610	4,990	6,740	5,390	6,790	8,440	5,400
5,450	2,230	4,660	8,650	3,640	5,030	6,790	5,450	6,860	8,530	5,450
5,500	2,250	4,700	8,730	3,660	5,070	6,850	5,510	6,930	8,620	5,500
5,550	2,270	4,750	8,820	3,690	5,110	6,900	5,560	7,010	8,710	5,550
5,600	2,300	4,800	8,910	3,720	5,150	6,950	5,620	7,080	8,800	5,600
5,650	2,320	4,840	8,990	3,750	5,190	7,010	5,680	7,150	8,890	5,650
5,700	2,340	4,890	9,080	3,780	5,230	7,060	5,740	7,220	8,980	5,700
5,750	2,360	4,940	9,170	3,810	5,270	7,110	5,790	7,300	9,070	5,750
5,800	2,390	4,980	9,250	3,840	5,310	7,170	5,850	7,370	9,160	5,800
5,850	2,410	5,030	9,340	3,870	5,350	7,220	5,910	7,440	9,250	5,850
5,900	2,430	5,080	9,430	3,890	5,390	7,270	5,970	7,520	9,350	5,900
5,950	2,450	5,120	9,510	3,920	5,430	7,330	6,030	7,590	9,440	5,950

TABLE 4-7 (continued)

Ordinary Least Squares Regression Estimates of Daily Mean Discharge on Arkansas River

estimate = $e^{[a + (b \times lnq) + [c \times (lnq)2] + (d\ 2 + 2)]}$

95 percent confidence interval = $e^{[(ln\ estimate - [d\ 2 + 2]) \pm (d \times 1.98)]}$

Granite regression based on daily mean discharge values from water years 1982 to 1987, a = -3.376913, b = 1.624432, c = -0.321887, d = 0.342872
Nathrop regression based on daily mean discharge values from water years 1978 to 1982, a = -3.363741, b = 1.8927, c = -0.0595647, d = 0.1577784
Parkdale regression based on daily mean discharge values from water years 1983 to 1987, a = 2.648973, b = 0.2921178, c = 0.0495163, d = 0.1132864

Note: all units in cubic feet per second.

Wellsville	Granite			Nathrop			Parkdale			Wellsville
Measured discharge	Lower 95% confidence interval	Estimated discharge at Granite	Upper 95% confidence interval	Lower 95% confidence interval	Estimated discharge at Nathrop	Upper 95% confidence interval	Lower 95% confidence interval	Estimated discharge at Parkdale	Upper 95% confidence interval	Measured discharge
6,000	2,480	5,170	9,600	3,950	5,470	7,380	6,080	7,660	9,530	6,000
6,050	2,500	5,220	9,690	3,980	5,510	7,430	6,140	7,740	9,620	6,050
6,100	2,520	5,260	9,770	4,010	5,540	7,480	6,200	7,810	9,710	6,100
6,150	2,540	5,310	9,860	4,030	5,580	7,540	6,260	7,880	9,800	6,150
6,200	2,560	5,360	9,950	4,060	5,620	7,590	6,320	7,960	9,900	6,200
6,250	2,590	5,400	10,000	4,090	5,660	7,640	6,380	8,030	9,990	6,250
6,300	2,610	5,450	10,100	4,120	5,700	7,690	6,440	8,110	10,100	6,300
6,350	2,630	5,500	10,200	4,150	5,740	7,740	6,500	8,180	10,200	6,350
6,400	2,650	5,540	10,300	4,170	5,780	7,800	6,560	8,260	10,300	6,400
6,450	2,680	5,590	10,400	4,200	5,810	7,850	6,620	8,330	10,400	6,450
6,500	2,700	5,640	10,500	4,230	5,850	7,900	6,670	8,410	10,500	6,500
6,550	2,720	5,680	10,600	4,260	5,890	7,950	6,730	8,480	10,500	6,550
6,600	2,740	5,730	10,600	4,280	5,930	8,000	6,790	8,560	10,600	6,600
6,650	2,770	5,780	10,700	4,310	5,970	8,050	6,850	8,630	10,700	6,650
6,700	2,790	5,820	10,800	4,340	6,000	8,100	6,910	8,710	10,800	6,700
6,750	2,810	5,870	10,900	4,370	6,040	8,150	6,970	8,780	10,900	6,750
6,800	2,830	5,920	11,000	4,390	6,080	8,210	7,030	8,860	11,000	6,800
6,850	2,860	5,960	11,100	4,420	6,120	8,260	7,090	8,940	11,100	6,850
6,900	2,880	6,010	11,200	4,450	6,150	8,310	7,160	9,010	11,200	6,900
6,950	2,900	6,060	11,300	4,470	6,190	8,360	7,220	9,090	11,300	6,950
7,000	2,920	6,100	11,300	4,500	6,230	8,410	7,280	9,170	11,400	7,000
7,050	2,950	6,150	11,400	4,530	6,270	8,460	7,340	9,240	11,500	7,050
7,100	2,970	6,200	11,500	4,550	6,300	8,510	7,400	9,320	11,600	7,100
7,150	2,990	6,240	11,600	4,580	6,340	8,560	7,460	9,400	11,700	7,150
7,200	3,010	6,290	11,700	4,610	6,380	8,610	7,520	9,470	11,800	7,200
7,250	3,040	6,340	11,800	4,640	6,410	8,660	7,580	9,550	11,900	7,250
7,300	3,060	6,390	11,900	4,660	6,450	8,710	7,640	9,630	12,000	7,300
7,350	3,080	6,430	11,900	4,690	6,490	8,760	7,700	9,700	12,100	7,350
7,400	3,100	6,480	12,000	4,710	6,520	8,810	7,770	9,780	12,200	7,400
7,450	3,130	6,530	12,100	4,740	6,560	8,860	7,830	9,860	12,300	7,450
7,500	3,150	6,570	12,200	4,770	6,600	8,910	7,890	9,940	12,400	7,500
7,550	3,170	6,620	12,300	4,790	6,630	8,950	7,950	10,000	12,500	7,550
7,600	3,190	6,670	12,400	4,820	6,670	9,000	8,010	10,100	12,600	7,600
7,650	3,210	6,710	12,500	4,850	6,710	9,050	8,080	10,200	12,600	7,650
7,700	3,240	6,760	12,600	4,807	6,740	9,100	8,140	10,200	12,700	7,700
7,750	3,260	6,810	12,600	4,900	6,780	9,150	8,200	10,300	12,800	7,750
7,800	3,280	6,850	12,700	4,920	6,820	9,200	8,260	10,400	12,900	7,800
7,850	3,300	6,900	12,800	4,950	6,850	9,250	8,330	10,500	13,000	7,850
7,900	3,330	6,950	12,900	4,980	6,890	9,300	8,390	10,600	13,100	7,900
7,950	3,350	6,990	13,000	5,000	6,920	9,340	8,450	10,600	13,200	7,950
8,000	3,370	7,040	13,100	5,030	6,960	9,390	8,510	10,700	13,300	8,000
8,050	3,390	7,090	13,200	5,050	6,990	9,440	8,580	10,800	13,400	8,050
8,100	3,420	7,140	13,300	5,080	7,030	9,490	8,640	10,900	13,500	8,100
8,150	3,440	7,180	13,300	5,110	7,070	9,540	8,700	11,000	13,600	8,150
8,200	3,460	7,230	13,400	5,130	7,100	9,590	8,770	11,000	13,700	8,200
8,250	3,480	7,280	13,500	5,160	7,140	9,630	8,830	11,100	13,800	8,250
8,300	3,510	7,320	13,600	5,180	7,170	9,680	8,890	11,200	13,900	8,300
8,350	3,530	7,370	13,700	5,210	7,210	9,730	8,960	11,300	14,000	8,350
8,400	3,550	7,420	13,800	5,230	7,240	9,780	9,020	11,400	14,100	8,400
8,450	3,570	7,460	13,900	5,260	7,280	9,820	9,080	11,400	14,200	8,450