USE OF FREQUENCY ANALYSIS AND THE EXTENDED STREAMFLOW PREDICTION PROCEDURE TO ESTIMATE EVACUATION DATES FOR THE JOINT-USE POOL OF PUEBLO RESERVOIR, COLORADO

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Multiply	By	To obtain
acre-foot (acre-ft)	1,233	cubic hectometer
cubic foot per second (ft^3/s)	0.028317	cubic meter per second
foot (ft)	0.3048	meters
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.59	square kilometer

ACRONYMS AND ABBREVIATED TERMS

Acronym or abbreviated term	Expanded meaning as used in this report
EP	Exceedance probability
ESP	Extended streamflow prediction
LP3	log-Pearson type III
JUP	Joint-use pool
NWSRFS	National Weather Service River Forecast System
PRJUP	Pueblo Reservoir joint-use pool (study)
RDM	Recorded daily mean (discharge)
0.01 EP discharge	Estimated daily mean discharge at the 0.01 exceedance probability
0.01 EP volume	Estimated discharge volume at the 0.01 exceedance probability
Station	Streamflow-gaging station
April-May	April 1 through May 31
April 15-May 14	April 15 through May 14
April-September	April 1 through September 30

Use of Frequency Analysis and the Extended Streamflow Prediction Procedure to Estimate Evacuation Dates for the Joint-Use Pool of Pueblo Reservoir, Colorado

By Gerhard Kuhn *and* R.C. Nickless

Abstract

Part of the storage space of Pueblo Reservoir, which is located on the Arkansas River in southeastern Colorado, consists of a 65,950 acre-foot joint-use pool (JUP). The JUP can be used to provide additional conservation capacity from November 1 to April 14. The operating procedures for Pueblo Reservoir, however, require that the JUP be completely evacuated by April 15 and be used only for flood-control capacity until November 1. During winter, the JUP primarily is used to store water for agricultural uses, but because April 15 is before the crop-growing season in southeastern Colorado, little beneficial use can be made of the water released prior to April 15. The U.S. Geological Survey completed a study during 1992, in cooperation with the Southeastern Colorado Water Conservancy District, to determine if the JUP possibly could be used for conservation storage for any number of days from April 15 through May 14 under certain hydrologic conditions.

The methods of the study were: (1) Frequency analysis of recorded daily mean discharge data for stations upstream and downstream from Pueblo Reservoir, and (2) implementation of the extended streamflow prediction (ESP) procedure for the Arkansas River basin upstream from the reservoir. The ESP procedure was implemented by applying the operational capability of the National Weather Service River Forecast System model, of which ESP is an integral part. Estimated daily discharges were derived from the frequency analysis for selected exceedance probabilities (EP), including the 0.01 EP that was used in design of the flood-storage capacity of Pueblo Reservoir. Discharges from the frequency analysis were routed through the reservoir to estimate the evacuation date of the JUP for different inflow volumes. A relation was developed between the inflow volume and the JUP evacuation date. To apply the study results, only a forecast of the April 15-May 14 reservoir inflow for a given year is needed; the forecast is made using the ESP procedure. The JUP evacuation date then is estimated from the relation between inflow volume and evacuation date. The study results indicate that the evacuation date can vary from April 23 for April 15-May 14 inflow volumes of about 169,000 acre-feet, to May 5 for inflow volumes of about 20,000 acre-feet.

INTRODUCTION

Pueblo Reservoir, which is located on the Arkansas River in southeastern Colorado (fig. 1), is the main storage facility for the Fryingpan-Arkansas Project, a multipurpose water development constructed by the Bureau of Reclamation. The primary purpose of the project is to bring surplus water from tributaries of the Colorado River across the Continental Divide into the Arkansas River basin to provide supplemental water for agricultural, municipal, and other uses.

Pueblo Reservoir has a total capacity of about 357,680-acre-ft that includes a 65,950-acre-ft joint-use pool, (U.S. Bureau of Reclamation, 1972, p. 4) (fig. 2). When the conservation pool is at full capacity, the joint-use pool (hereinafter referred to as JUP) can be used to provide additional conservation capacity from November 1 to April 14. However, the current (1993) operating procedures for Pueblo Reservoir require that the JUP be evacuated by April 15 and be used only for additional flood-control capacity until November 1 (U.S. Army Corps of Engineers, 1977).

A program implemented with the Fryingpan-Arkansas Project is the winter-water storage program. The purpose of this program is to enable downstream agricultural water users to store water in Pueblo Reservoir from November 15 to March 15; the stored water would be released during the following crop-growing season. [A detailed description of this program is beyond the scope of this report; additional description is presented by Abbott (1985, p. 46, 54), by the U.S. Bureau of Reclamation (1990, p. 15–20), and in the storage decree (case 84CW179, District Court, Water

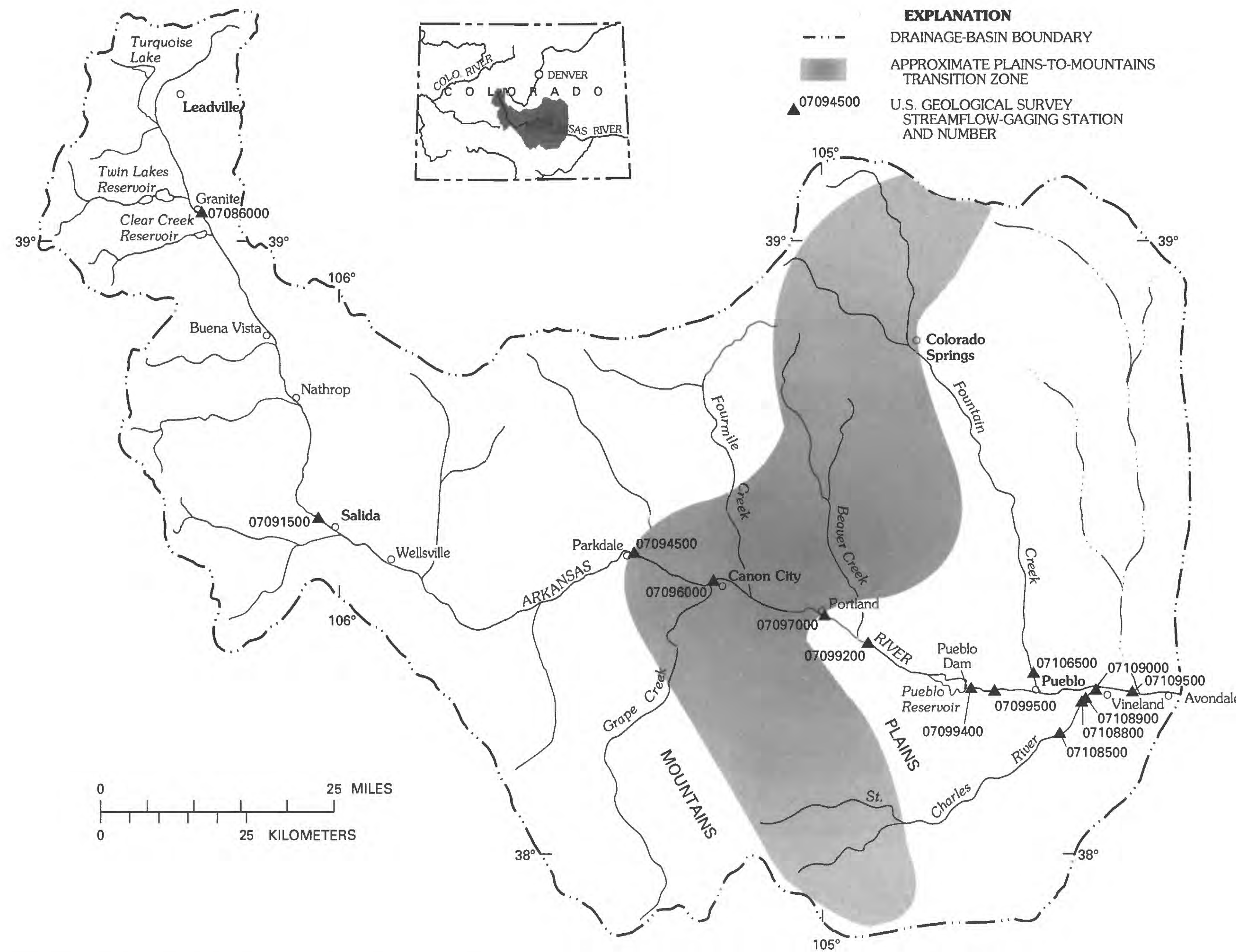

Figure 1. The Arkansas River basin upstream from Avondale.

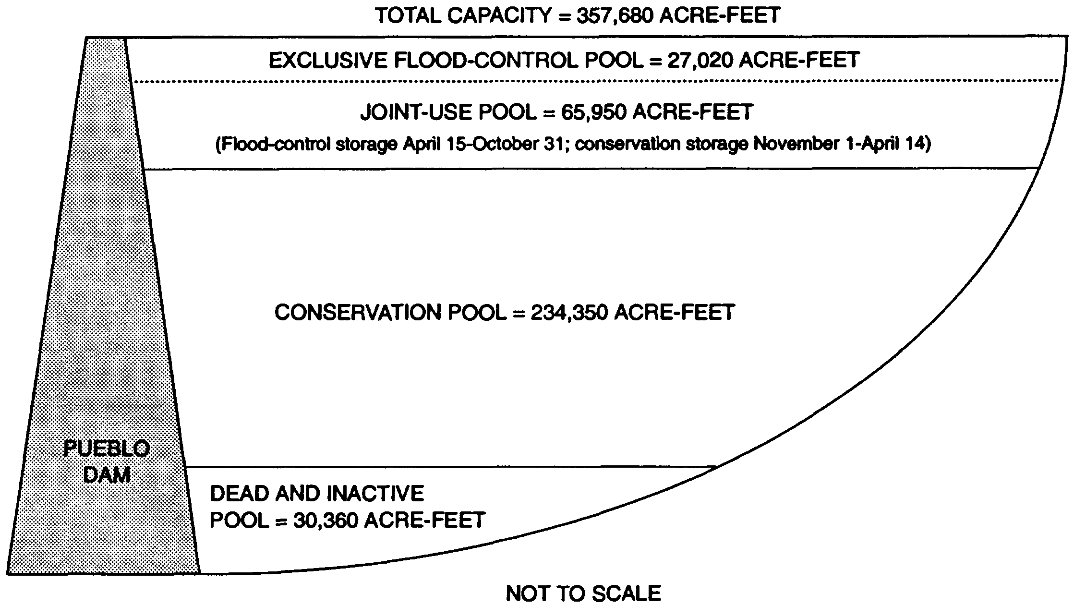

Figure 2. Cross-section schematic of Pueblo Reservoir storage-capacity pools.

Division No. 2, State of Colorado; date of appropriation November 10, 1987).]

After Pueblo Dam was completed in 1975, the winter-water storage program was initiated by the Southeastern Colorado Water Conservancy District, a Colorado agency established to administer the Fryingpan-Arkansas Project. During 1984, 1985, and 1987, some winter-stored water was stored in the JUP because the conservation pool was at full capacity. All winter-stored water that was in the JUP was released from Pueblo Reservoir prior to April 15; however, little beneficial use was made of the released water because the April 15 evacuation date generally is before the crop-growing season in southeastern Colorado.

Recognizing the possibility for better management of water resources, the Southeastern Colorado Water Conservancy District began a study in 1988, in cooperation with the U.S. Geological Survey, to determine if storage in the JUP of Pueblo Reservoir could be extended beyond April 15 under certain hydrologic conditions. Extension of the April 15 date by a few, and as many as 30, days would improve management of water resources for beneficial use and increase the long-term yield of the JUP. Hereinafter, the study described in this report will be referred to as the PRJUP (Pueblo Reservoir JUP) study.

Purpose and Scope

The purpose of this report is to describe the methods used in the PRJUP study and to discuss the results. The methods that are described include (1) frequency analysis of recorded daily mean (RDM) discharges for selected streamflow-gaging stations (stations) upstream and downstream from Pueblo Reservoir (table 1), and (2) implementation of the National Weather Service's Extended Streamflow Prediction (ESP) procedure (Twedt and others, 1977; Day, 1985) for the Arkansas River basin upstream from Pueblo Reservoir. The report discusses how the results from the frequency analysis and the ESP procedure can be used to estimate evacuation dates for the JUP of Pueblo Reservoir (that is, extend the April 15 evacuation date).

Because the flood-control storage capacity of Pueblo Reservoir is based on a design flood that has a recurrence interval of about 100 years, or a 0.01 exceedance probability (hereinafter referred to as EP) (U.S. Army Corps of Engineers, 1977, p. 8–2), the frequency analysis was done at this EP. Also, although the study objective was to evaluate the likelihood of using the JUP for additional conservation storage only from April 15 through May 14 (April 15-May 14) (C.L. Thomson, Southeastern Colorado Water Conservancy District, and R.D. Kreiner, U.S. Army Corps of Engineers, oral commun., 1989), all of April and May were

Table 1. Streamflow-gaging stations used in the frequency analysis of recorded daily mean discharges

Station number	Station name	Drainage area (square miles)	Period of record[1] (water year)	Number of years used in analysis	Generalized skew coefficient[2]
07094500	Arkansas River at Parkdale	2,548	1946–55; 1965–	36	-0.130
07096000	Arkansas River at Canon City	3,117	1889–	[3]95	-.121
07097000	Arkansas River at Portland	4,024	1940–52; 1975–	29	-.108
07099200	Arkansas River near Portland	4,280	1966–74	9	-.106
07099400	Arkansas River above Pueblo	4,670	1966–	25	-.104
07099500	Arkansas River near Pueblo	4,686	1895–1975	[3]79	-.104
07106500	Fountain Creek at Pueblo	926	1923–25; 1941–65; 1972–	45	-.102
[4]07108500	St. Charles River near Pueblo	467	1941–53	13	-.102
[4]07108800	St. Charles River near Vineland	473	1968–74	7	-.102
[4]07108900	St. Charles River at Vineland	474	1979–	12	-.102
[4]07109000	St. Charles River at mouth near Pueblo	482	1923–25	4	-.102
07109500	Arkansas River near Avondale	6,327	1940–51; 1966–	38	-.102

[1]Records through water year 1990 were used in frequency analysis; no ending year indicates station was operating at the beginning of water year 1991.

[2]Generalized skew coefficient determined from U.S. Interagency Advisory committee on Water Data (1982) map by frequency-analysis computer program (Kirby, 1981).

[3]Data for some years prior to 1910 were excluded because daily mean discharges were not available.

[4]The four St. Charles River stations were combined for the frequency analysis; combined record length is 36 years.

used in the frequency analysis to include any substantial trends in the discharges during a more extended time period.

The frequency analysis had two objectives: (1) To derive the estimated daily mean discharges at the 0.01 EP (hereinafter referred to as 0.01 EP discharges) flowing into Pueblo Reservoir during April 15-May 14, and (2) to derive 0.01 EP discharges for April 15-May 14 for tributaries downstream from the reservoir. The downstream analysis was needed because of limits in the channel capacity of the Arkansas River in the vicinity of Avondale (fig. 1). The U.S. Army Corps of Engineers (1977) determined that discharge in this area should not exceed about 6,000 ft^3/s and that Pueblo Reservoir should be operated, if possible, to prevent exceeding that discharge at station 07109500 Arkansas River near Avondale (hereinafter referred to as "the near-Avondale" station). Discharges in Fountain Creek and the St. Charles River (fig. 1), which are major tributaries to the Arkansas River between Pueblo Reservoir and the near-Avondale station, could affect the 6,000-ft^3/s criterion, and hence, the operation of Pueblo Reservoir, including the JUP. Therefore, Fountain Creek and the St. Charles River were included in the frequency analysis.

RDM discharges were used in the frequency analysis for the PRJUP study because the primary objective of the frequency analysis was to estimate reservoir inflow volume during the study period, which does not require a daily maximum instantaneous discharge. The frequency analysis for Fountain Creek and the St. Charles River was used to derive 0.01 EP discharges, not volumes; in this case, the use of RDM discharges was considered satisfactory because (1) the daily maximum instantaneous discharges for the historical record are not available, and (2) instantaneous discharges in the two tributaries are attenuated considerably by the larger Arkansas River channel. In actual application of the study results (described in the "Application of the Frequency-Analysis Results to Estimate Evacuation Dates for the Joint-Use Pool" section), there may be times when the instantaneous discharge in the two tributaries exceeds 6,000 ft^3/s, requiring a different operating procedure for Pueblo Reservoir than that based on the 0.01 EP daily mean discharges. However, the instantaneous peaks probably would be of short duration and would not substantially affect application of the study results.

The ESP procedure, which enables estimation of future discharge volumes (reservoir inflow) for a specified probability level, was implemented only for April 15-May 14 and only for the Arkansas River basin upstream from Pueblo Reservoir. Implementation of ESP for all of April and May or for the basin downstream from the reservoir was not necessary for completion of the PRJUP study.

Description of Study Area

The Arkansas River basin has an area of 4,669 mi^2 upstream from Pueblo Dam and 1,658 mi^2 from the dam downstream to the near Avondale station. The downstream area includes 926 mi^2 for the Fountain Creek basin and 482 mi^2 for the St. Charles River basin. The study area varies from plains and rolling hills in the eastern part of the basin to rugged mountains in the western part. Elevation ranges from about 4,500 to 6,500 ft in the plains to more than 14,000 ft at several mountain peaks near Leadville and Buena Vista. The transition from plains to mountains is in the vicinity of Canon City and Colorado Springs (fig. 1).

The variation in topography has a pronounced effect on precipitation. Average annual precipitation, which generally increases with elevation, ranges from about 10 in. in the plains to about 40 in. in the higher mountains (Colorado Climate Center, 1984). Precipitation in the plains is distributed unevenly in time and most precipitation is from summer storms. Because the storms usually are localized and of short duration, most of the precipitation in the plains results in little streamflow.

Precipitation in the mountains is distributed more evenly in time, but because of the higher elevations, much of the precipitation is snow. The snowfall accumulates during the winter, producing deep snowpacks that have 10 to 25 in. of water equivalent. Melting of the snowpacks during late spring and early summer provides about 50 to 80 percent of the annual streamflow over a period of about 3 months. The percentage generally is largest for streams in the mountains and decreases as distance from the mountains increases.

Hydrographs of RDM discharge for selected stations in the vicinity of Pueblo Reservoir are shown in figure 3. The hydrographs for water year 1944 are typical of an average year in which discharge generally reaches a maximum during June. By contrast, the hydrographs for water year 1942 are for an extremely wet year in which discharge during April and May generally was much larger than during the remainder of the water year. For the stations presented in figure 3, many of the maximum RDM discharges during April and May were recorded during water year 1942. Discharge peaks during July-October (fig. 3) primarily are the result of summer storms; the rapid rise and fall of the discharge illustrates the short duration of the precipitation. Although the peak discharges from the summer storms can be large, the contribution to annual volume usually is small.

Report Terminology

To avoid the repeated use of some words and phrases, acronyms and abbreviated terminology will be used in this report. Several acronyms have been introduced in the previous sections and a few more will be introduced in subsequent sections. For easy reference, a list of all acronyms used herein is presented at the beginning of this report after the table of contents.

Much of the discussion herein will focus on the streamflow-gaging stations (table 1) used in the frequency analysis. To aid in easy identification of a station when mentioned in this report, stations on the Arkansas River will be referred to in reference to their location. For example, station 07099500 Arkansas River near Pueblo (table 1) will be referred to as the "near-Pueblo station," or station 07097000 Arkansas River at Portland will be referred to as the "at-Portland station." Station 07106500 Fountain Creek at Pueblo (table 1) will be referred to as merely "Fountain Creek" and the four stations on the St. Charles River (table 1) will be referred to collectively as "St. Charles River."

Acknowledgments

Completion of the PRJUP study was greatly facilitated by the assistance of the National Weather Service. During the initial stages of the study, implementation of the ESP procedure was determined to be achieved best through use of the National Weather Service River Forecast System (NWSRFS) model, of which the ESP procedure is an integral part.

The National Weather Service cooperated with the U.S. Geological Survey to apply the operational capability of the NWSRFS model for the Arkansas River basin upstream from Pueblo Reservoir during the PRJUP study. The assistance of the National Weather Service personnel, E.A. Anderson, J.V. Bowman, G.N. Day, and S.C. Van Demark, in developing the operational capability of the NWSRFS model, including implementation of the ESP procedure, for application to the PRJUP study, therefore, is gratefully acknowledged.

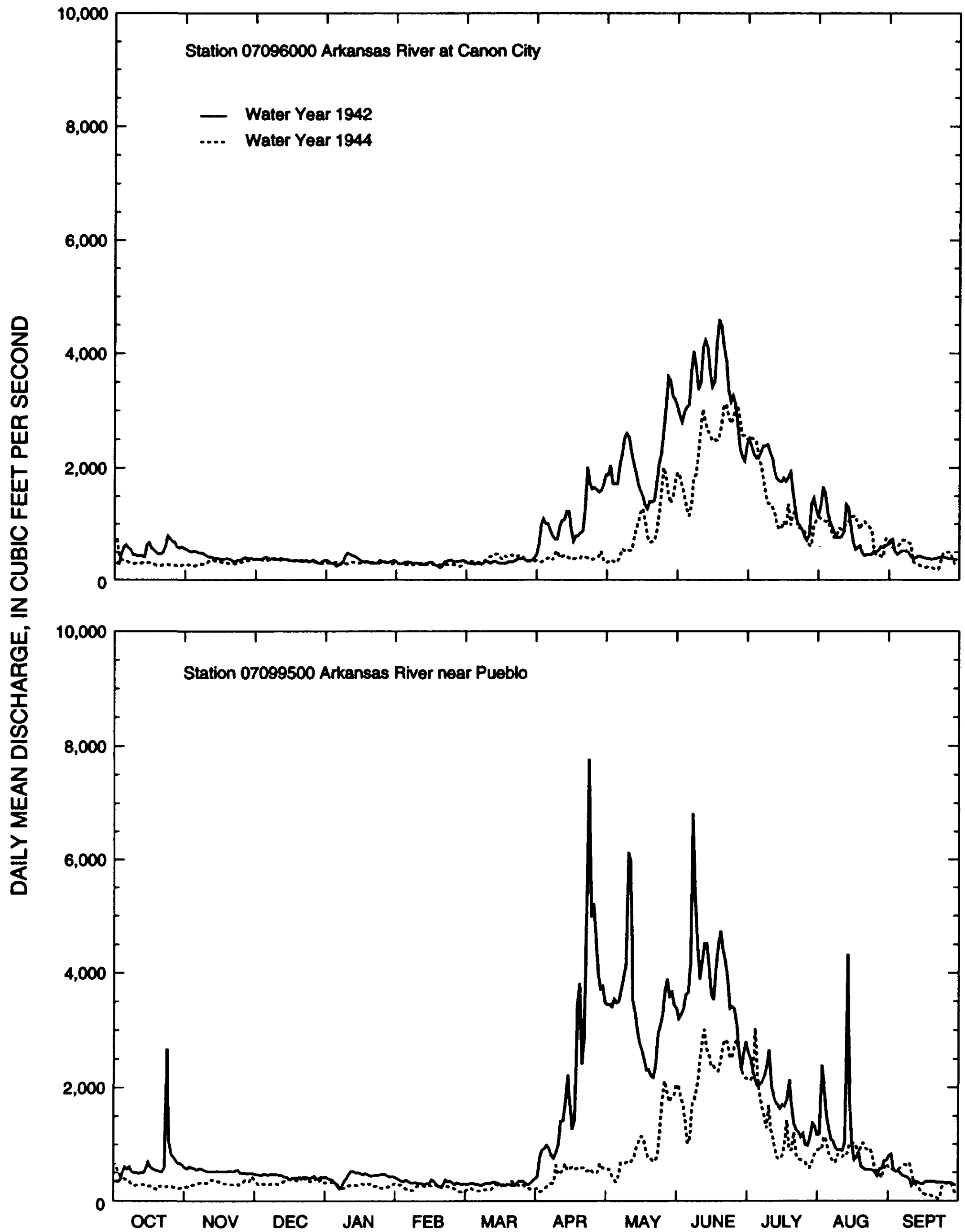

Figure 3. Recorded daily mean discharge for selected stations in the vicinity of Pueblo Reservoir.

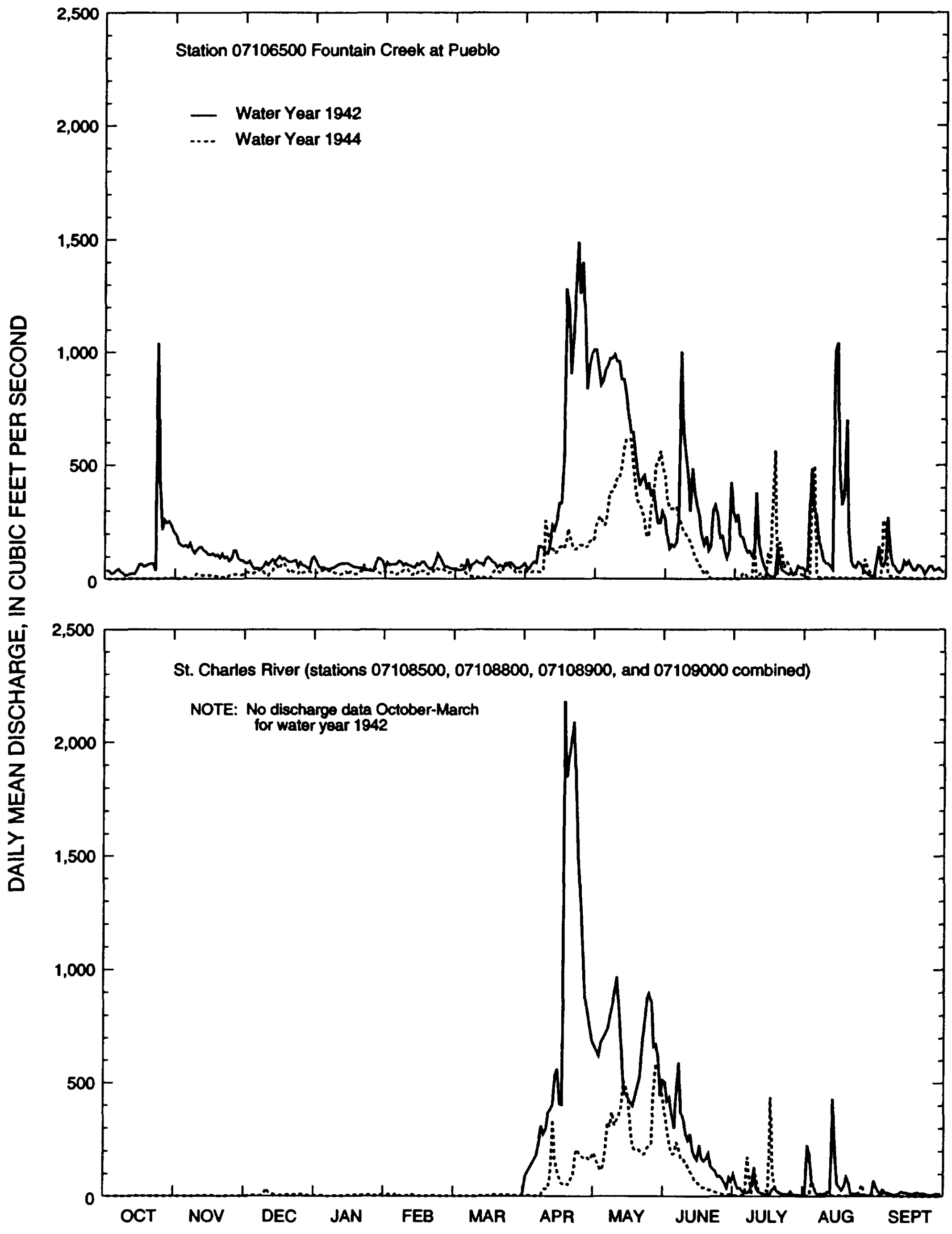

Figure 3. Recorded daily mean discharge for selected stations in the vicinity of Pueblo Reservoir --Continued.

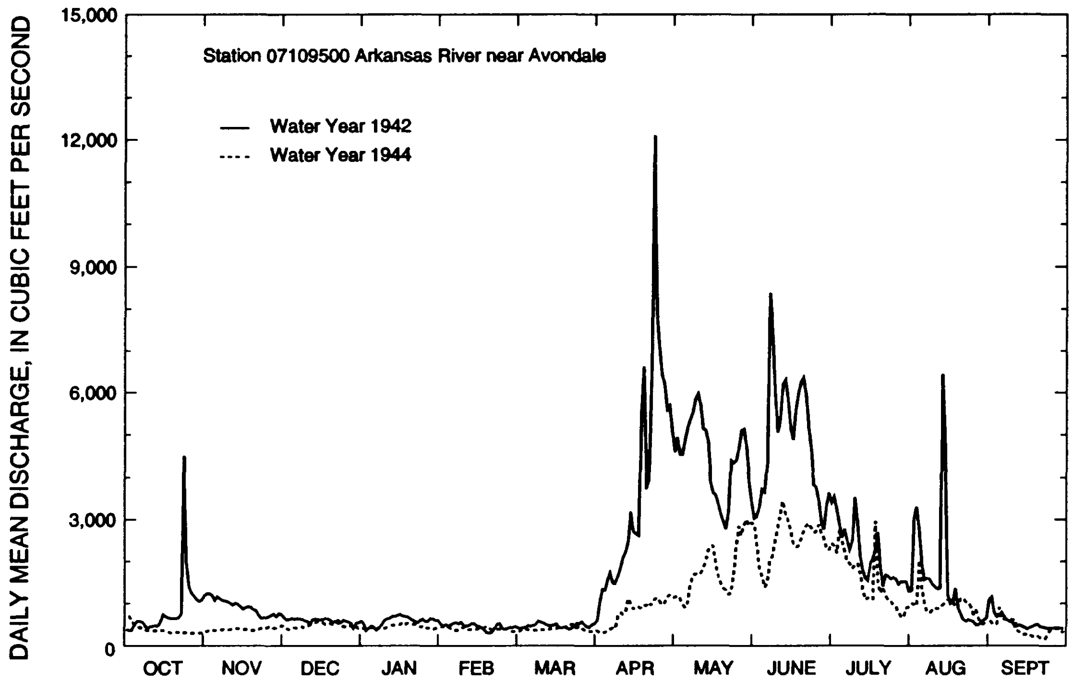

Figure 3. Recorded daily mean discharge for selected stations in the vicinity of Pueblo Reservoir --Continued.

FREQUENCY ANALYSIS OF HISTORICAL DAILY MEAN DISCHARGES

Frequency analysis (or development of a frequency curve) is a method in which the magnitude of a variable can be related to its probability (or frequency) of occurrence (Riggs, 1968, p. 1). In the PRJUP study, the variable considered is daily mean discharge and the probability level is 0.01. In the frequency analysis described in this report, the probabilities refer to exceedances based on random samples consisting of one trial per year (one daily discharge on a given day or one discharge volume for a number of days). Thus, the statement that "the 0.01 exceedance probability (EP) discharge on April 1 is 333 ft^3/s" is equivalent to the statement that "there is a 1-percent chance in any year for the discharge on April 1 to exceed 333 ft^3/s."

Frequency curves can be fitted to a number of mathematical distributions; the normal, log-normal, type I extreme value (Gumbel), and log-Pearson type-III (log-gamma) (hereinafter referred to as LP3) distributions often are used in hydrologic analysis. The LP3 distribution commonly is used in flood-frequency analysis and is the distribution recommended by the U.S. Interagency Advisory Committee on Water Data (1982) for nationwide flood-frequency analysis; the LP3 distribution was used for frequency analysis in the PRJUP study.

Log-Pearson Type-III Distribution

The LP3 distribution has three parameters, which are computed by the following equations (U.S. Interagency Advisory Committee on Water Data, 1982, p. 10):

$$\bar{x} = \frac{\Sigma x}{N} \quad (1)$$

$$S = \left[\frac{\Sigma (x-\bar{x})^2}{(N-1)}\right]^{0.5} \quad (2)$$

$$G = \frac{N\Sigma (x-\bar{x})^3}{(N-1)\,(N-2)\,S^3} \quad (3)$$

where

$\bar{x}$ = mean of the logarithms,
x = logarithm of each discharge in the sample,

N = number of discharges in the sample,
S = standard deviation of the logarithms, and
G = skew coefficient of the logarithms.

The LP3 distribution is defined by the general formula (U.S. Interagency Advisory Committee on Water Data, 1982, p. 9):

$$x_p = \bar{x} + K_{P,G}S \qquad (4)$$

where
x_P = discharge or variate value exceeded with probability P in any year,
$K_{P,G}$ = the LP3 frequency factor for exceedance probability P and skewness G, and
$\bar{x}$ and S = the same as defined in equations 1 and 2.

Frequency factors for skew coefficients ranging from -9.0 to 9.0 and for EP's ranging from 0.0001 to 0.9999 are reported by the U.S. Interagency Advisory Committee on Water Data (1982).

Skew-Coefficient Analysis

Reliability of the sample skew coefficient (station skew) decreases as sample size (years of record) becomes small (fig. 4); the station skew also is sensitive to extreme events (U.S. Interagency Advisory Committee on Water Data, 1982, p. 10). To improve reliability of the station skew, the U.S. Interagency Advisory Committee on Water Data (1982, p. 10) recommends that a generalized skew coefficient (generalized skew) be used in the frequency analysis. The generalized skew is used to calculate a weighted skew estimate (weighted average of station and generalized skew) under the assumption that the generalized skew is unbiased and independent of station skew (U.S. Interagency Advisory Committee on Water Data, 1982, p. 12). Methods for estimating generalized skew for an area are described by the U.S. Interagency Advisory Committee on Water Data (1982, p. 11–15); however, if data are insufficient, generalized skew can be estimated from the national generalized-skew-coefficient map provided in that report (also see Hardison, 1974).

Because the national map of generalized skews (U.S. Interagency Advisory Committee on Water Data, 1982) was developed from annual instantaneous peak discharges, station skews for RDM discharges were analyzed for selected stations in the vicinity of Pueblo Reservoir to determine if generalized skews from the national map were applicable to the PRJUP study. For the frequency analysis of RDM discharges upstream from Pueblo Reservoir, station skews were analyzed for stations at Canon City, at Portland, and near Pueblo (fig. 1; table 1). The near-Pueblo station, although downstream from Pueblo Reservoir (fig. 1), was included because the period of record (table 1) is prior to construction of Pueblo Dam. The above-Pueblo station was not included because only 10 years of non-regulated discharge data were available. The near-Portland station also was not included because only 9 years of record were available (table 1); the record for this station could not be combined with that for the near-Portland station because of tributary flow from Beaver Creek (fig. 1).

Station skews and the skews for plus or minus one root mean square error for logarithms of RDM discharge during April and May for three stations on the Arkansas River are shown in figure 5. No definite temporal or spatial trend in station skew is evident at the stations; moreover, the error bars generally are not very large. Also, the station skews for the annual instantaneous peak discharge logarithms for the at-Canon City station (0.28), for the at-Portland station (0.72), and for the above-Pueblo station (1.09) were within the range of station skews for RDM discharge logarithms (fig. 5). Therefore, the generalized skew from the national map (U.S. Interagency Advisory Committee on Water Data, 1982) was considered appropriate in the frequency analysis of RDM discharges upstream from Pueblo Reservoir.

For the frequency analysis downstream from Pueblo Reservoir, station skews were analyzed for Fountain Creek, the St. Charles River, and the near-Avondale station (fig. 1; table 1). Discharge records for the four St. Charles River stations (table 1) were combined into a single record because the difference in drainage area is only about 3 percent and the few ephemeral tributaries between the most upstream and downstream stations do not contribute substantial discharge. The period of analysis for the near-Avondale station includes 15 years of record after the completion of Pueblo Dam; however, because (1) Pueblo Reservoir usually is operated as a flow-through reservoir during April and May, (2) Fountain Creek and the St. Charles River often have substantial effects on the discharge at this station, and (3) this station would not be used in the actual frequency analysis; the analysis of skew coefficient for this station would be helpful in the analysis of skew coefficients downstream from Pueblo Reservoir.

Station skews and the skews for plus or minus one root mean square error for logarithms of RDM discharge during April and May for Fountain Creek, the St. Charles River, and the near-Avondale station are shown in figure 6. Some increasing and some decreasing trends in station skew with time can be seen in figure 6; however, most of the station skews are

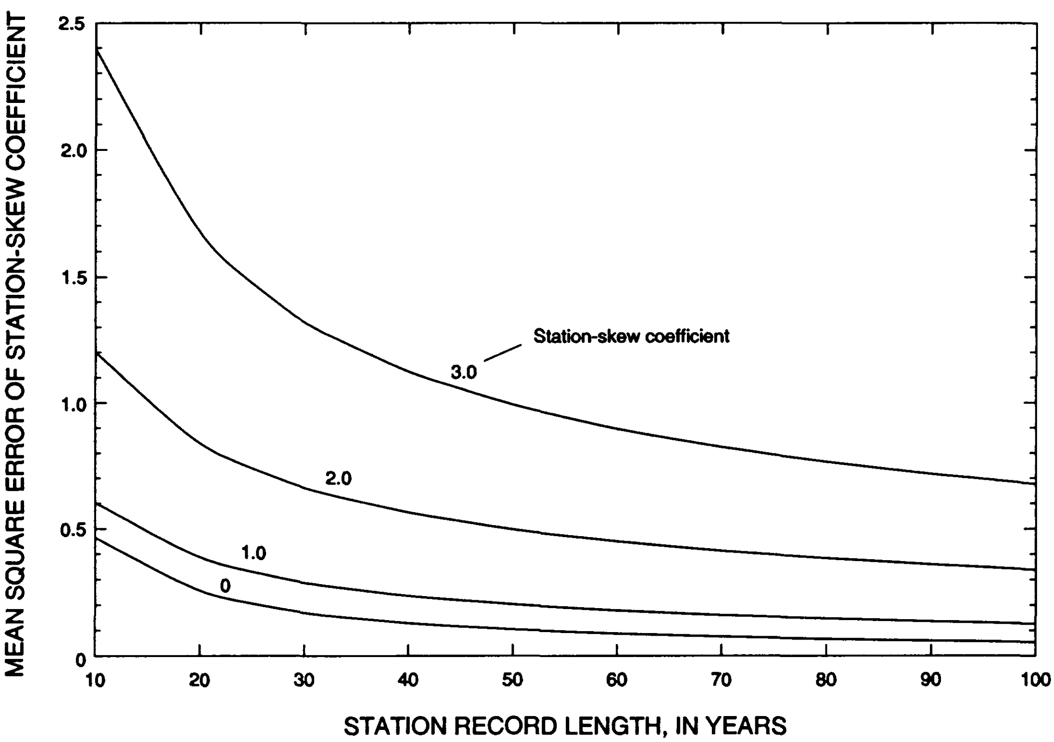

Figure 4. Mean square error of station-skew coefficient as a function of station record length for selected values of station-skew coefficient.

between -0.5 and 0.5. Generalized skews from the national map (U.S. Interagency Advisory Committee on Water Data, 1982) also were considered appropriate in the frequency analysis of daily RDM discharges downstream from Pueblo Reservoir.

Analysis for Adequacy of Record Length

Discharge records may fall within a high or low climatic cycle and, therefore, may not accurately represent the long-term conditions. The errors in frequency analysis due to climatic variations usually are small for long periods of record, but may be extremely large for short periods of record (McCain and Jarrett, 1976, p. 3). An analysis was made of the April and May discharge records for six stations on the Arkansas River to evaluate the effects of climatic variations and adequacy of record length. This analysis was made by performing a frequency analysis of the April 1 through May 31 (April-May) discharge volumes; the discharge volumes were derived by summing the April-May RDM discharges each year and converting to acre-feet (by multiplying by 1.9835). The variability of April-May discharge volumes with time for the at-Canon City and the combined near-Pueblo/at-Portland stations is shown in figure 7.

The estimated April-May discharge volumes at the 0.01 EP (0.01 EP volumes) are shown in figure 8; the frequency curves for each station are shown in figure 9. When the period of record at a station is considered, figure 8 seems to indicate (1) that there is a downstream increasing trend in the 0.01 EP volume for the at-Parkdale, at-Canon City, and near-Pueblo stations; and (2) that the 0.01 EP volumes for the at-Portland, above-Pueblo, and near-Avondale stations are much larger than the 0.01 EP volume indicated by the trend for the first three stations. The frequency curves for the latter three stations that have the shorter periods of record (fig. 9) may be affected more by the largest discharge volumes (table 2) than the frequency curves for stations that have longer periods of record (the at-Canon City and near-Pueblo stations) (fig. 9). Because the at-Parkdale station is upstream from low-elevation snowmelt and rainfall during April and May, extremely large discharge volumes may be more infrequent at this station than they are at the downstream

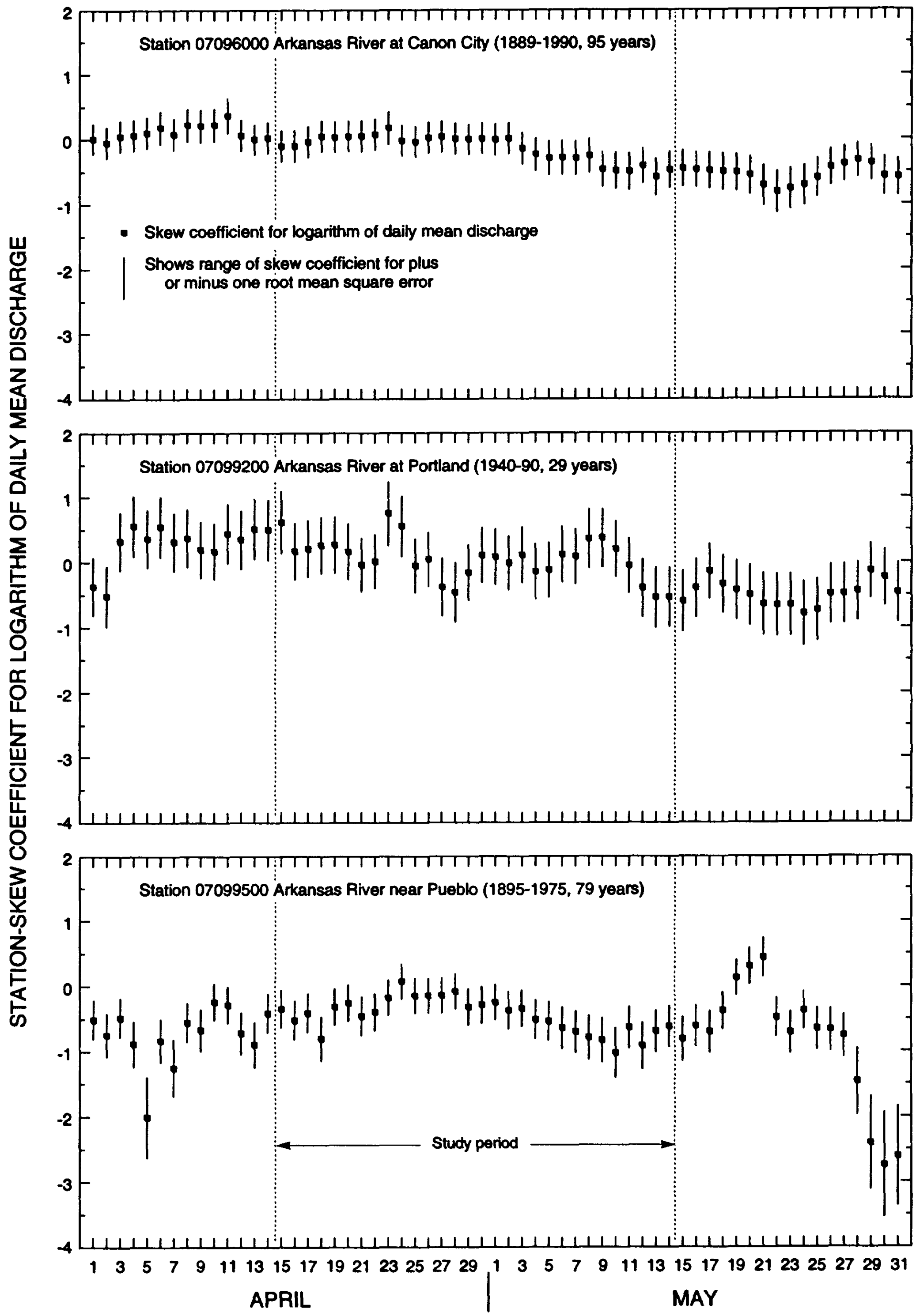

Figure 5. Station-skew coefficients for logarithms of daily mean discharge during April and May for selected stations on the Arkansas River.

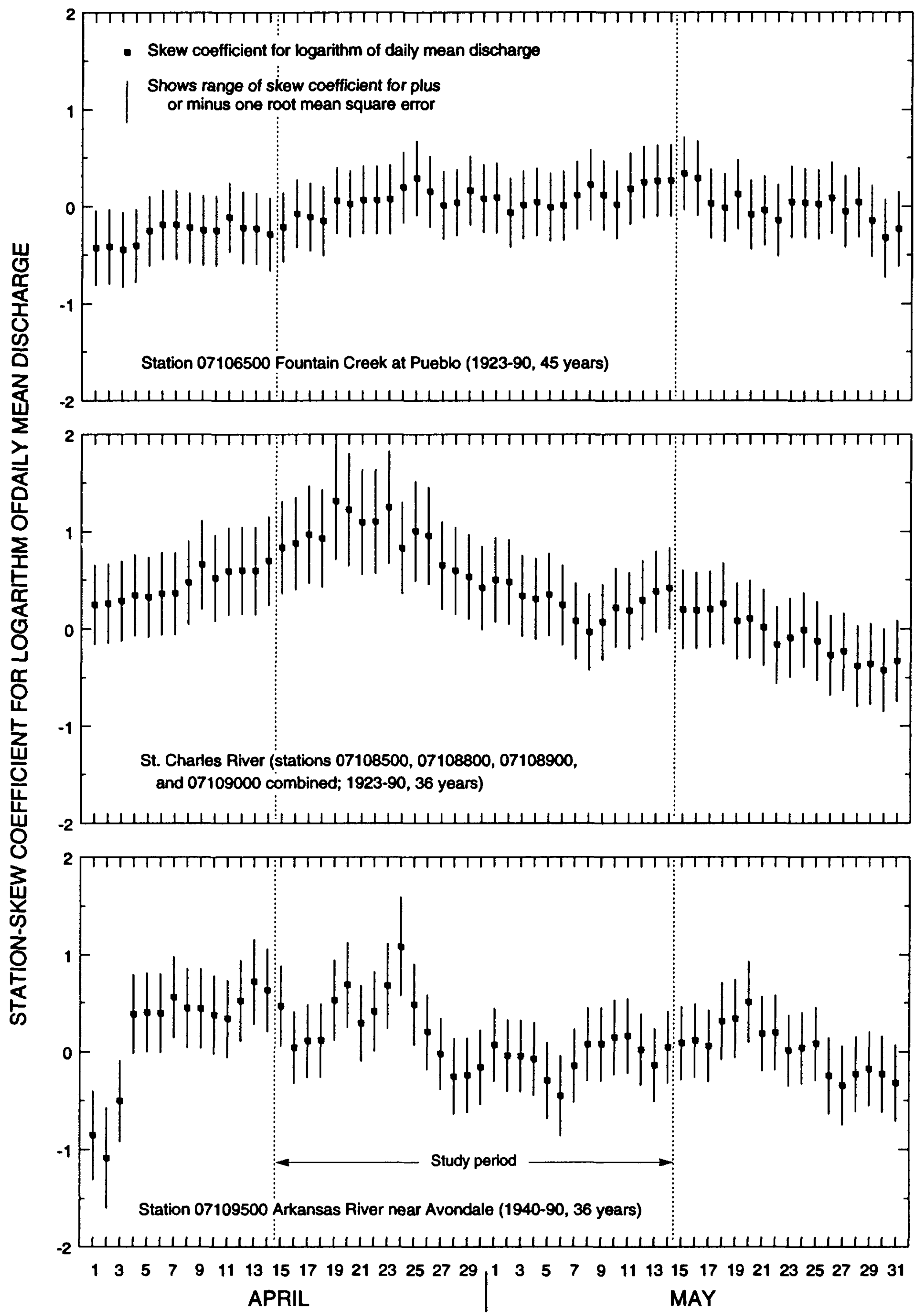

Figure 6. Station-skew coefficients for logarithms of daily mean discharge during April and May for selected stations downstream from Pueblo Reservoir.

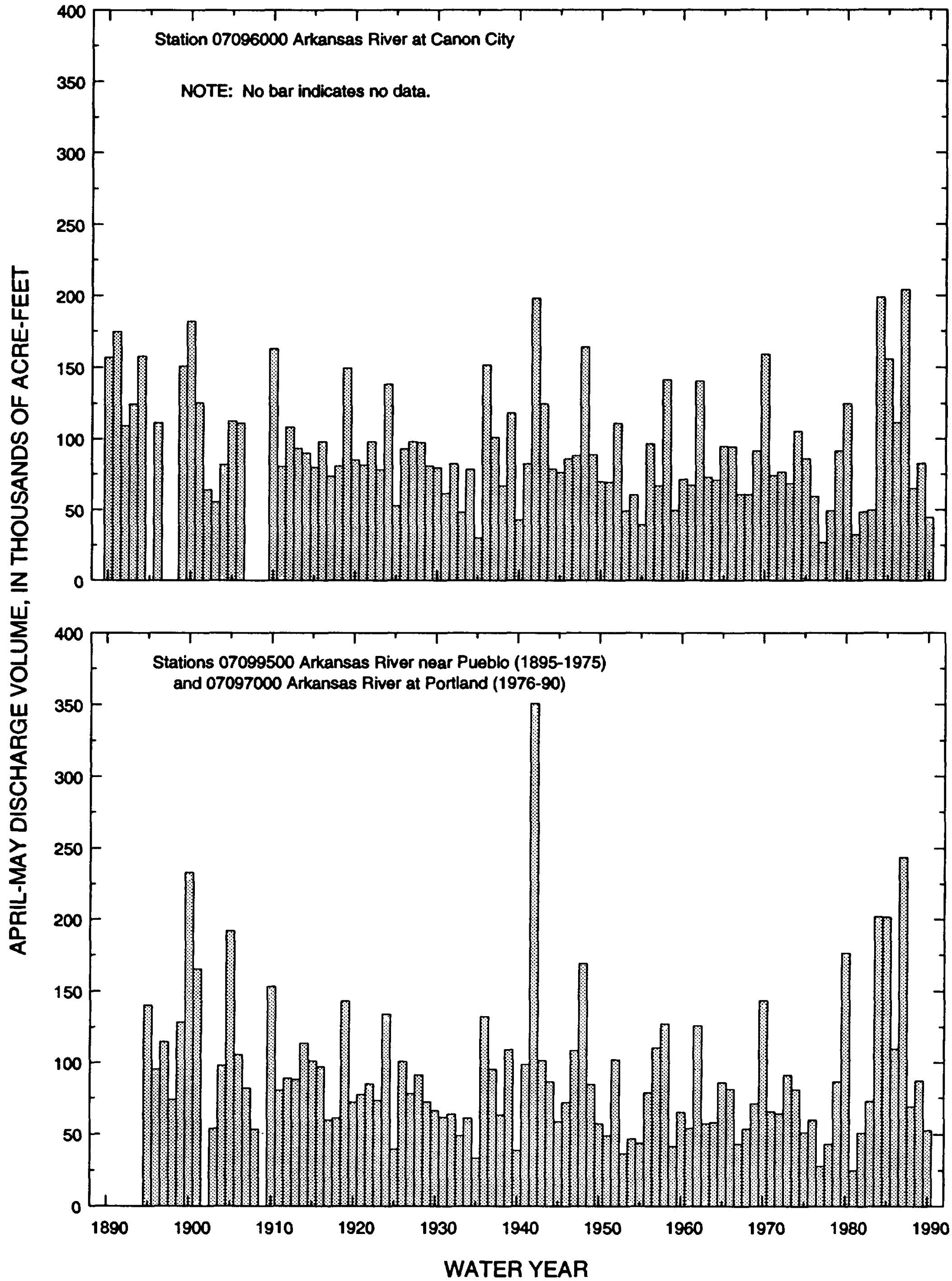

Figure 7. April-May discharge volumes for water years 1890–1990 for selected stations on the Arkansas River.

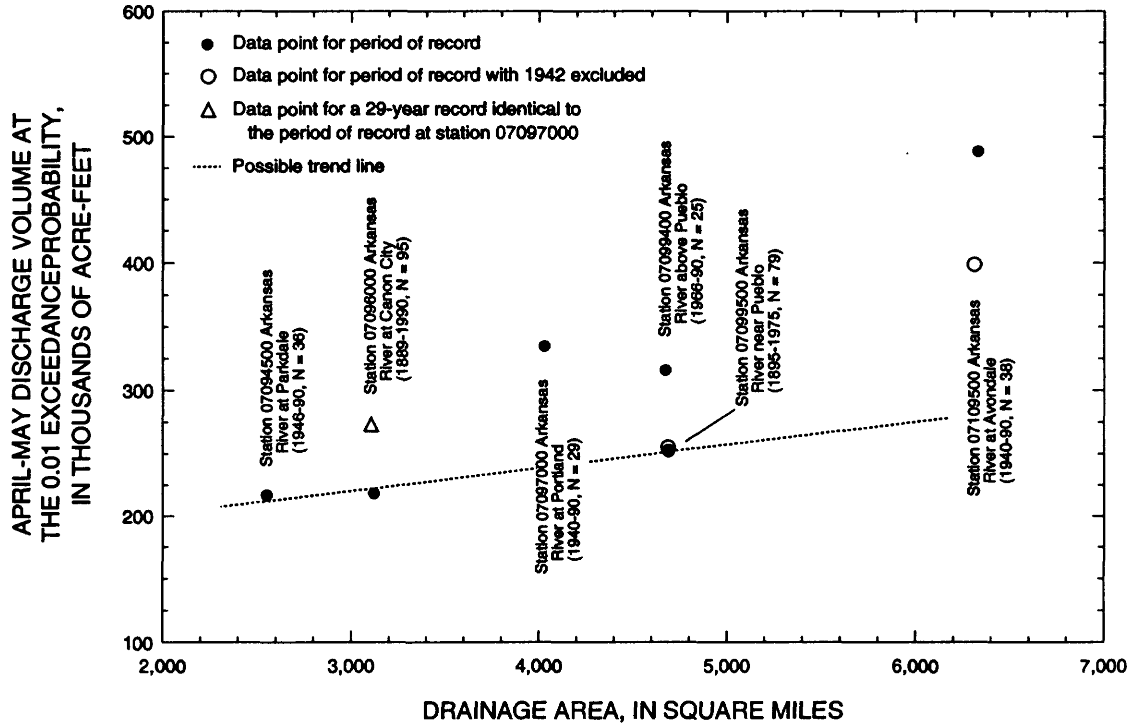

Figure 8. Estimated April-May discharge volume at the 0.01 exceedance probability for selected stations on the Arkansas River.

stations (compare graphs for at-Canon City and near-Pueblo stations in figure 7).

Adequacy of record length was further evaluated by performing a frequency analysis for the at-Canon City station for a 29-year period of record identical to the period of record for the at-Portland station (table 1). This resulted in about a 25-percent increase in the 0.01 EP volume for the at-Canon City station (fig. 8). Additionally, the effect of a single, very large discharge on short and long periods of record was evaluated. Record for water year 1942 was excluded from the frequency analyses for the near-Pueblo and near-Avondale stations; the April-May volume for water year 1942 was about 50 percent larger than the next largest April-May volume at each of these two stations (table 2). Exclusion of water year 1942 from the longer record at the near-Pueblo station had practically no effect on the 0.01 EP volume, but the exclusion from the shorter record at the near-Avondale station resulted in about a 20-percent decrease in the 0.01 EP volume (fig. 8).

Based on the analysis just described, the near-Pueblo station was selected for use in the PRJUP study to derive the 0.01 EP discharges flowing into Pueblo Reservoir. Although the 79-year record at this station seemed to be of adequate length for reliable frequency analysis, several years (primarily during the 1980's) that had large discharges (table 2) are not included in the record for that station (table 1). However, record for those years is available for the at-Portland and above-Pueblo stations (fig. 1; table 1); records for these stations were used to extend the period of record for the near-Pueblo station.

Frequency curves for the April-May discharge volumes for Fountain Creek and the St. Charles River are shown in figure 10; the ten largest recorded April-May discharge volumes are listed in table 3. No stations with longer periods of record are available for these tributaries to evaluate the adequacy of the record length. However, the 0.01 EP volume is not a substantial extrapolation beyond the available data; therefore, the record lengths for Fountain Creek and the St. Charles River were considered adequate for the frequency analysis of RDM discharges.

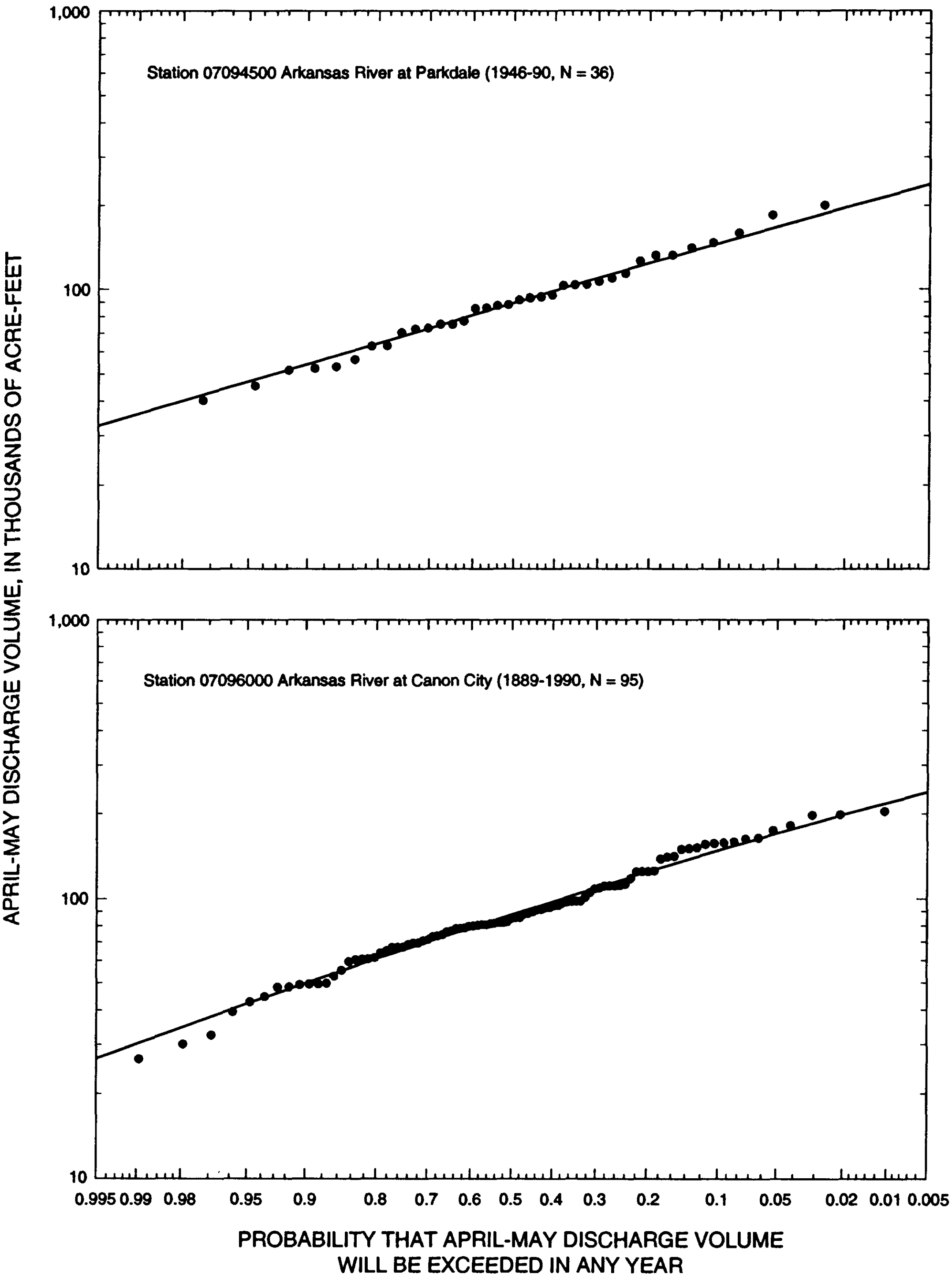

Figure 9. Log-Pearson type-III frequency curves of April-May discharge volume for selected stations on the Arkansas River.

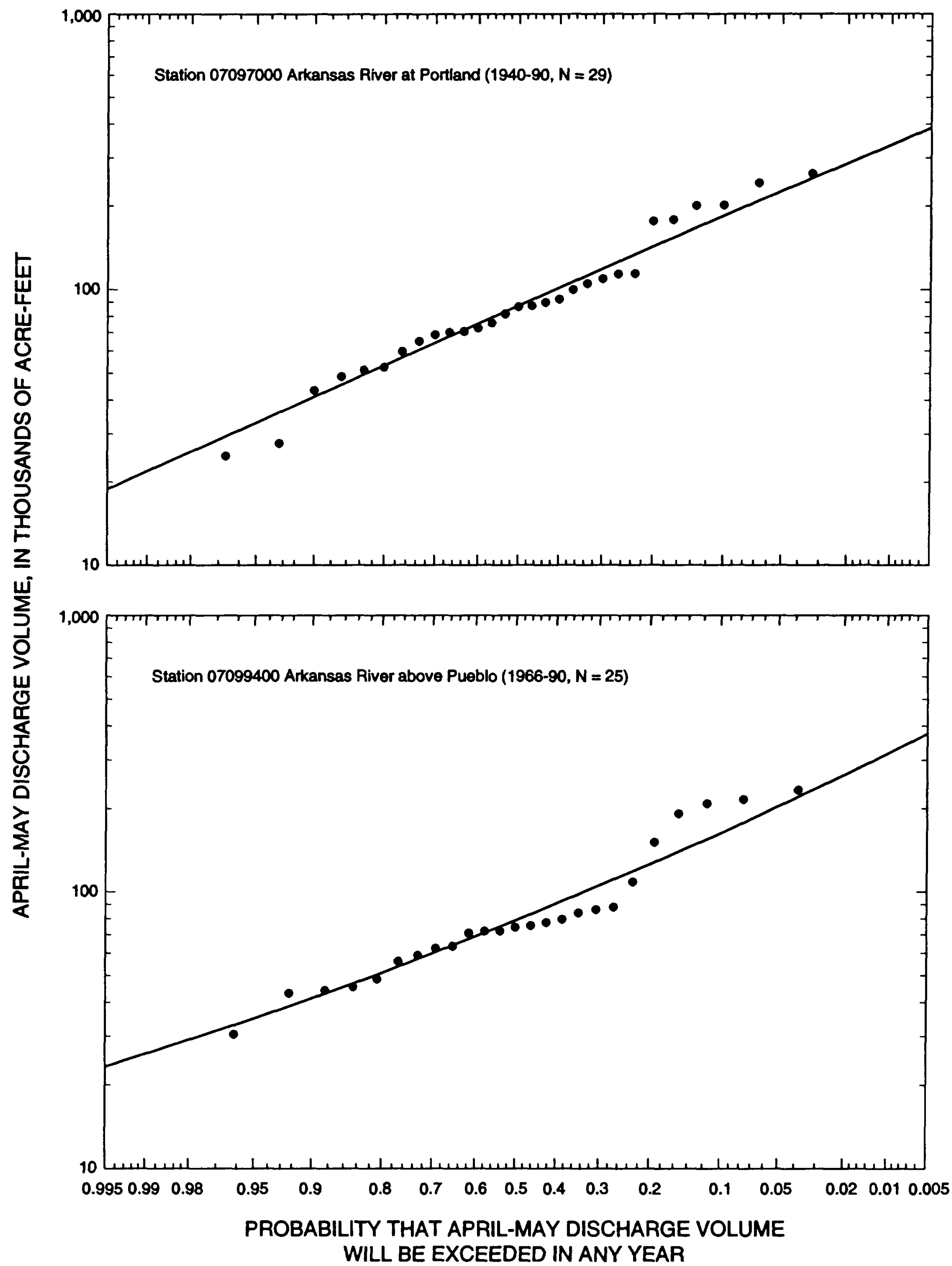

Figure 9. Log-Pearson type-III frequency curves of April-May discharge volume for selected stations on the Arkansas River--Continued.

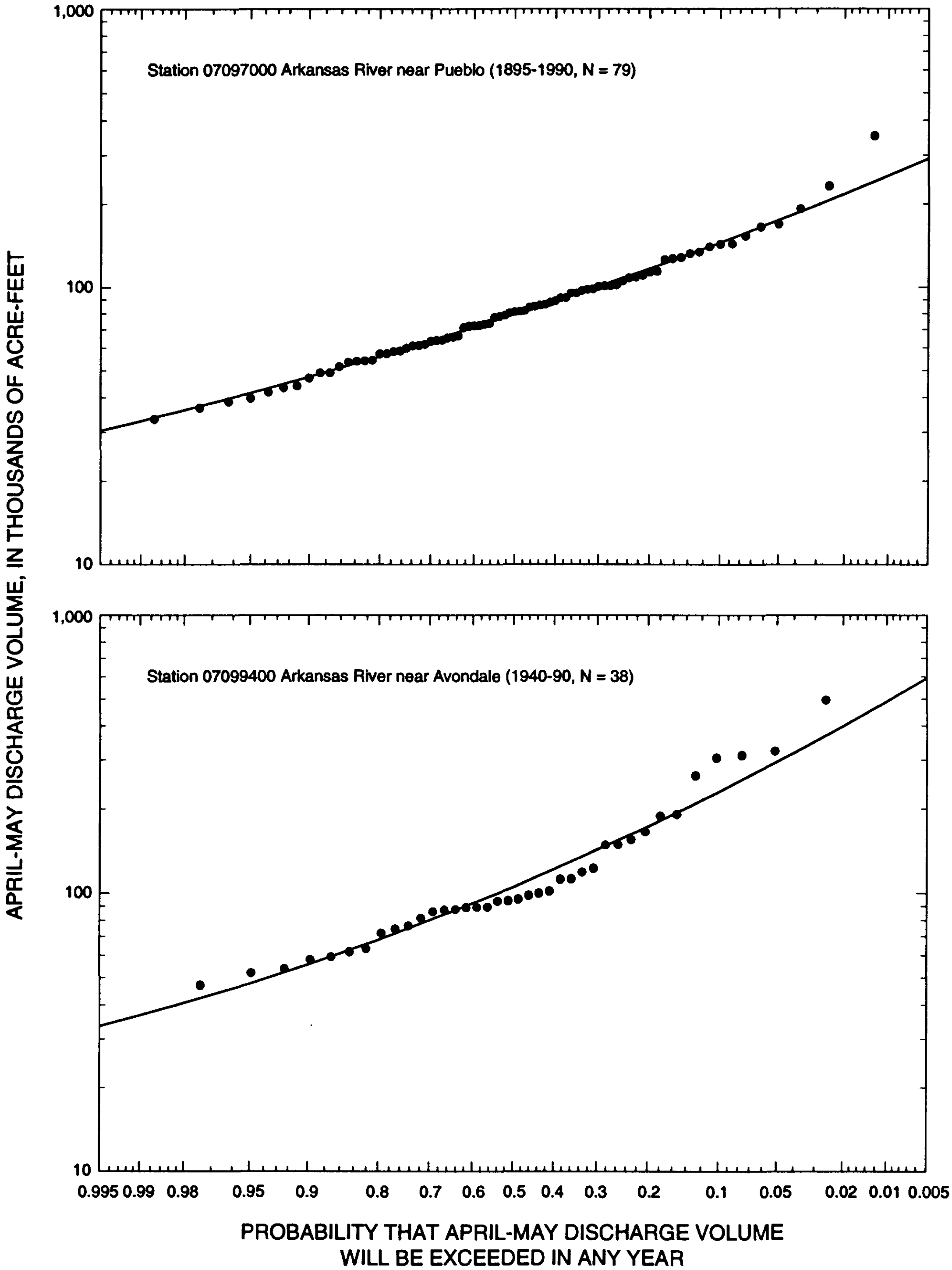

Figure 9. Log-Pearson type-III frequency curves of April-May discharge volume for selected stations on the Arkansas River--Continued.

Table 2. Ten largest April-May discharge volumes for selected stations on the Arkansas River

[Periods of record for the stations are listed in table 1]

April-May discharge volume (acre-feet)	Rank of April-May discharge volume	Water year	Number of days ranked equal to or higher than rank of discharge volume[1]
STATION 07094500 ARKANSAS RIVER AT PARKDALE			
201,000	1	1984	10
184,900	2	1987	25
159,300	3	1948	20
146,700	4	1985	22
141,100	5	1970	17
132,300	6	1980	25
132,200	7	1952	23
126,000	8	1986	17
113,700	9	1974	19
109,400	10	1969	15
STATION 07096000 ARKANSAS RIVER AT CANON CITY			
204,200	1	1987	11
198,900	2	1984	10
198,000	3	1942	26
182,200	4	1900	8
174,900	5	1891	25
164,300	6	1948	22
162,900	7	1910	19
159,100	8	1970	13
157,900	9	1894	12
157,000	10	1890	21
STATION 07097000 ARKANSAS RIVER AT PORTLAND			
263,500	1	1942	21
243,800	2	1987	33
202,200	3	1984	16
201,700	4	1985	41
179,200	5	1948	39
176,600	6	1980	38
114,400	7	1952	20
113,600	8	1943	32
109,600	9	1986	21
105,200	10	1947	23

Table 2. Ten largest April-May discharge volumes for selected stations on the Arkansas River --Continued

April-May discharge volume (acre-feet)	Rank of April-May discharge volume	Water year	Number of days ranked equal to or higher than rank of discharge volume[1]
STATION 07099400 ARKANSAS RIVER ABOVE PUEBLO			
233,800	1	1987	18
216,800	2	1985	32
208,800	3	1984	24
192,600	4	1980	32
151,200	5	1970	27
108,900	6	1986	34
88,200	7	1973	14
86,200	8	1979	14
84,000	9	1974	21
79,700	10	1989	30
STATION 07099500 ARKANSAS RIVER NEAR PUEBLO			
350,800	1	1942	32
233,000	2	1900	17
192,300	3	1905	17
169,500	4	1948	21
165,400	5	1901	8
153,300	6	1910	19
143,800	7	1970	10
143,200	8	1919	18
140,200	9	1895	22
134,300	10	1924	20
STATION 07109500 ARKANSAS RIVER NEAR AVONDALE			
496,500	1	1942	29
323,400	2	1987	22
312,300	3	1980	28
304,800	4	1985	43
262,800	5	1984	24
191,500	6	1948	28
188,800	7	1947	18
165,800	8	1970	24
155,500	9	1944	29
149,200	10	1983	28

[1]This column indicates the number of days in which rank of recorded daily mean discharge during April and May of indicated year was equal to or higher than rank of April-May discharge volume.

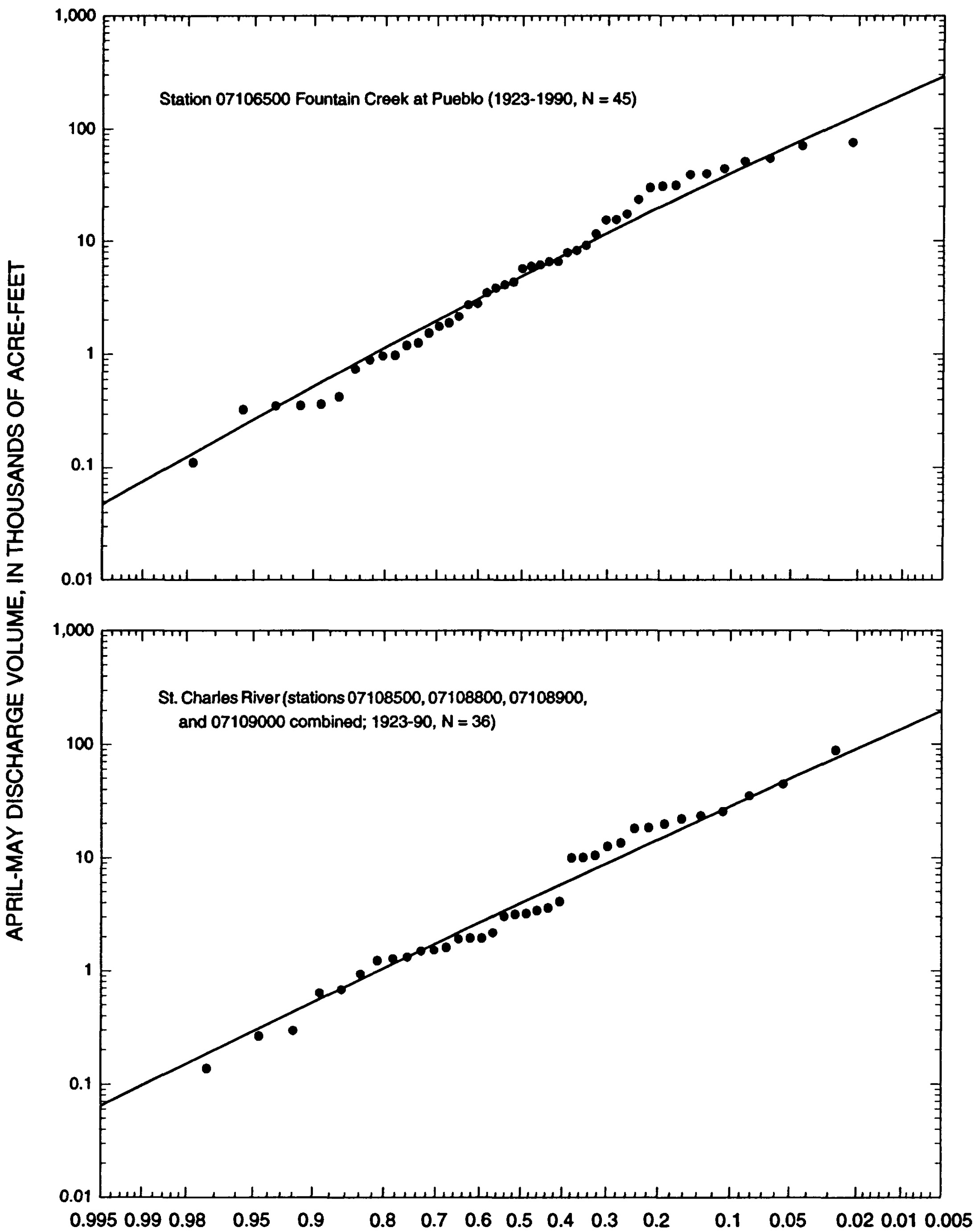

Figure 10. Log-Pearson type-III frequency curves of April-May discharge volume for Fountain Creek and the St. Charles River.

Table 3. Ten largest April-May discharge volumes for Fountain Creek and the St. Charles River

April-May discharge volume (acre-feet)	Rank of April-May discharge volume	Water year	Number of days ranked equal to or higher than rank of discharge volume[1]
STATION 07106500 FOUNTAIN CREEK AT PUEBLO			
75,200	1	1942	21
70,000	2	1980	19
53,700	3	1985	30
50,700	4	1973	16
43,600	5	1957	21
39,600	6	1983	41
38,900	7	1947	21
30,700	8	1944	32
30,400	9	1984	46
29,300	10	1987	51
ST. CHARLES RIVER—STATIONS 07108500, 07108800, 07108900, AND 07109000			
87,700	1	1942	46
44,100	2	1987	23
34,800	3	1980	20
25,400	4	1983	25
23,400	5	1944	21
21,800	6	1947	21
19,700	7	1984	37
18,400	8	1924	40
17,900	9	1941	24
13,400	10	1985	31

[1]This column indicates the number of days in which rank of recorded daily mean discharge during April and May of indicated year was equal to or higher than rank of April-May discharge volume.

Adjustment and Extension of Discharge Record

Discharge in the Arkansas River is affected to varying degrees by diversion and reservoir regulation. Generally, the effects are not substantial upstream from Pueblo Reservoir during April and May; also, the effects decrease as discharge in the river increases. However, three diversions (the Bessemer Ditch, the West Pueblo Ditch, and the Pueblo Water Works intake), which are downstream from Pueblo Reservoir, have a direct effect on discharge at the near-Pueblo station; hence, recorded discharge at the station is somewhat less than the reservoir inflow.

The Bessemer Ditch has the largest effect on discharge at the near-Pueblo station; the ditch has a decree to divert as much as 392 ft^3/s. The West Pueblo Ditch has a decree to divert as much as 18 ft^3/s and the Pueblo Water Works has a decree to divert as much as 83 ft^3/s (Abbott, 1985, p. 60–63). Daily records of the quantity of discharge diverted at the three diversion structures were compiled for the PRJUP study in conjunction with applying the operational capability of the NWSRFS model, but only for water years 1949–87. The records that were compiled indicate that the diversions usually do not operate at maximum capacity during April and May and that the quantities that are diverted during this time generally are smallest during early April and largest during late May.

To adjust the record for the near-Pueblo station for the effects of diversion, the 75th percentile of the daily mean discharge diverted by the three structures was computed for each day during April and May. The April-May RDM discharges for the near-Pueblo station for water years 1895–1975 then were adjusted for the effects of diversion by adding the 75th percentiles of the daily April-May diversions. Although the actual diversion amounts could have been used for water years 1949–75, the 75th percentiles were used for consistency. Use of the 75th percentiles for the discharge adjustment is subject to some error; however, use of the 75th percentile results in a long-term over-adjustment of the discharge record at the near-Pueblo station. The over-adjustment would ensure that the 0.01 EP discharges would not be underestimated in the frequency analysis. The 0.01 EP April-May volume for the near-Pueblo station (79-year record) was about 253,000 acre-ft before adjustment (fig. 9); when the adjusted discharges were used in the frequency analysis, the 0.01 EP April-May volume was about 270,000 acre-ft.

The record for the near-Pueblo station could be extended for water years 1976–90 by two methods: (1) By discharge correlation with the upstream at-Portland station, or (2) by adjusting the record for the above-Pueblo station for the effects of diversion and regulation by Pueblo Reservoir. Both methods were evaluated.

The at-Portland and near-Pueblo stations have concurrent discharge record for 13 years—water years 1940–52 (table 1). A least-squares, linear regression between the RDM discharges for the at-Portland station and the diversion-adjusted discharges for the near-Pueblo station was computed. For the regression model, the coefficient of determination was 0.89, the standard error of the estimate was 312, and 793 data pairs were used. The model was used to estimate daily discharges during April and May for the near-Pueblo station for water years 1976–90.

Reliable daily contents data, and hence, change-in-storage data are available for Pueblo Reservoir; therefore, nonregulated discharge can be estimated for the above-Pueblo station. Recorded discharge at this station also is affected by diversion, but only by the Bessemer Ditch; the estimated nonregulated daily mean discharge for the above-Pueblo station also was adjusted for the effects of diversion by the Bessemer Ditch. In this case, however, the recorded daily diversion amounts were used for the adjustment, except that the 75th percentiles were used for water years 1988–90.

Overall, there was about a 12-percent difference in the discharges estimated for the near-Pueblo station by the two methods. Because it was not possible to determine which method provided the most accurate estimates of discharge, the results from both methods were averaged to provide the estimated daily mean discharges for the near-Pueblo station for the 1976–90 record extension. The record extension resulted in a 94-year period of record. A frequency curve for the April-May volume for the 94-year record was developed for comparison to the frequency curve for the 79-year record. The characteristics of the curve that includes the adjusted and extended record (fig. 11) are similar to the characteristics of the curve for the unadjusted 79-year record (fig. 9). The 0.01 EP April-May volume from figure 11 is about 291,000 acre-ft. The extended record for the near Pueblo station was considered satisfactory for use in the PRJUP study.

Frequency Analysis Results

The frequency analyses of RDM discharges to derive the 0.01 EP discharges flowing into Pueblo Reservoir and the 0.01 EP discharges on Fountain Creek and the St. Charles River were made using a computer program (Kirby, 1981) that incorporates all of the LP3 techniques described by the U.S. Interagency Advisory Committee on Water Data (1982); this computer program also was used in the preliminary analyses described in the previous two report sections.

The April-May 0.01 EP discharges for the near-Pueblo station are shown in figure 12. The 95-percent upper and lower confidence limits (fig. 12) indicate the range in which the 0.01 EP discharges would be estimated 95 percent of the time from different random samples of daily mean discharge (all sample sizes are the same as in this analysis). The discharges in the 95-percent upper confidence limit generally are about 20 to 25 percent larger and the discharges in the 95-percent lower confidence limit generally are about 15 to 20 percent smaller than the 0.01 EP discharges.

The 0.01 EP discharges for April 15-May 14 (the actual period of analysis for the PRJUP study) for the near-Pueblo station are listed in table 4. The maximum RDM discharge (adjusted for diversion) for each day and the year of these maxima also are listed in table 4. All, except two, of the maximum RDM discharges for the 30 days were recorded during water year 1942. These maximum discharges in 1942 resulted from substantial precipitation that was coupled with low-elevation snowmelt (Follansbee and Sawyer, 1948, p. 105–108).

The 0.01 EP discharges for Fountain Creek and the St. Charles River are shown in figure 13. The range of the confidence limits is considerably larger for these two streams than the range for the near-Pueblo station (fig. 12); the difference is largely explained by greater variability in daily discharge because of rapid runoff

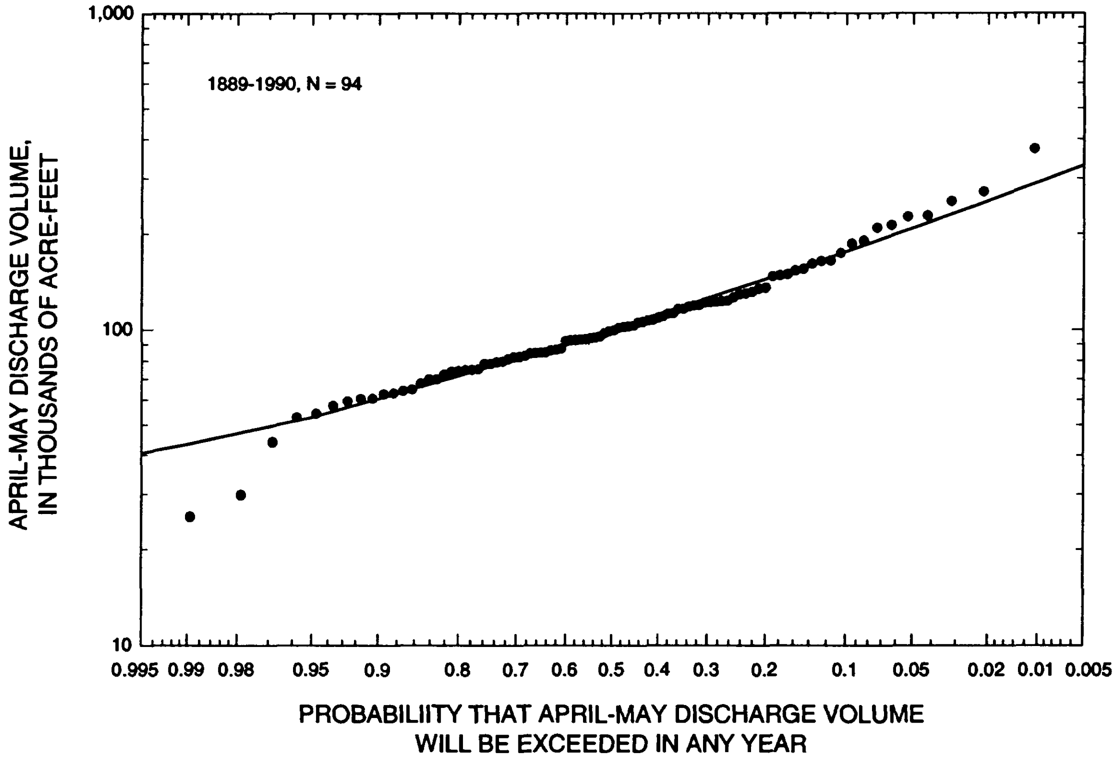

Figure 11. Log-Pearson type-III frequency curve of April-May discharge volume for station 07099500 Arkansas River near Pueblo including estimated discharge for 1976–90.

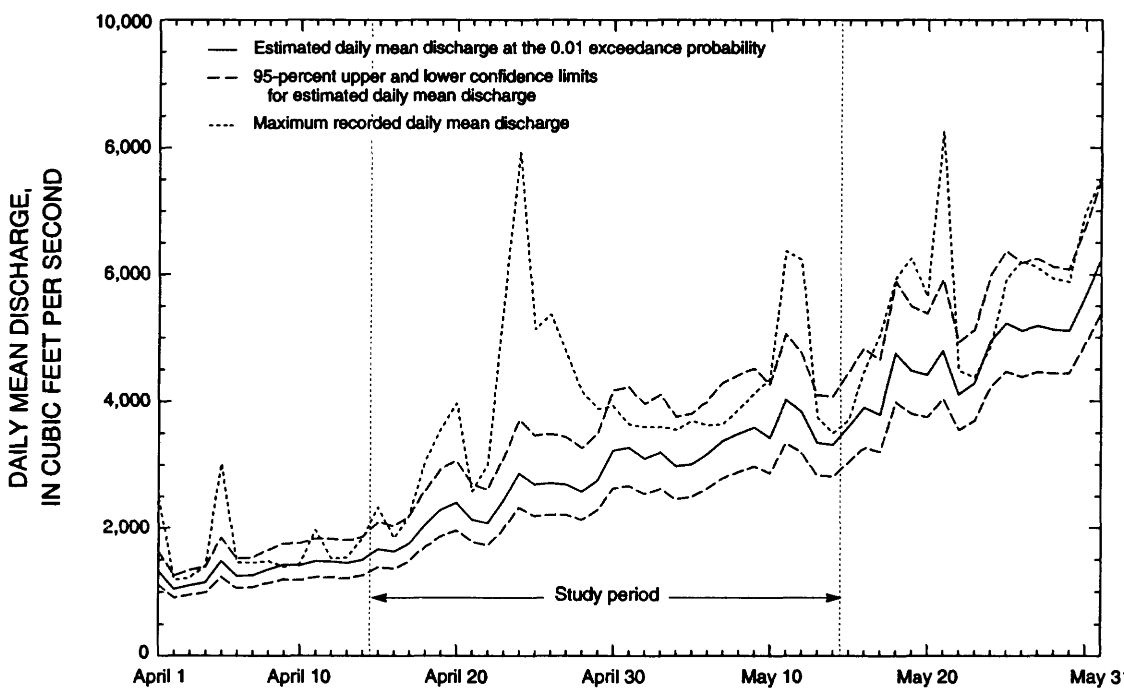

Figure 12. Estimated daily mean discharge at the 0.01 exceedance probability and maximum recorded daily mean discharge for station 07099500 Arkansas River near Pueblo.

Table 4. Results of frequency analysis of recorded daily mean discharges for April 15-May 14 for station 07099500 Arkansas River near Pueblo

[Discharges are in cubic feet per second]

Date	Estimated daily mean discharge at the 0.01 exceedance probability	Maximum recorded daily mean discharge[1]	75th percentile diversion discharge[2]	Water year of maximum recorded daily mean discharge
April 15	1,670	2,330	108	1942
April 16	1,630	1,840	117	1942
April 17	1,760	2,190	141	1987
April 18	2,050	3,050	142	1987
April 19	2,290	3,570	122	1942
April 20	2,400	3,970	150	1942
April 21	2,140	2,570	159	1942
April 22	2,080	3,010	157	1942
April 23	2,430	5,510	152	1942
April 24	2,860	7,940	156	1942
April 25	2,690	5,130	149	1942
April 26	2,710	5,370	149	1942
April 27	2,690	4,770	148	1942
April 28	2,580	4,160	148	1942
April 29	2,750	3,880	158	1942
April 30	3,230	3,920	153	1942
May 1	3,270	3,640	158	1942
May 2	3,100	3,600	147	1942
May 3	3,200	3,600	150	1942
May 4	2,980	3,550	140	1942
May 5	3,010	3,690	137	1942
May 6	3,170	3,620	135	1942
May 7	3,380	3,640	142	1942
May 8	3,490	3,870	160	1942
May 9	3,590	4,120	186	1942
May 10	3,420	4,340	210	1942
May 11	4,020	6,370	235	1942
May 12	3,830	6,230	238	1942
May 13	3,350	3,750	230	1942
May 14	3,320	3,500	188	1942

[1]Listed discharges include adjustment with 75th percentile diversion discharge; discharges after 1975 are estimated; see text for detailed explanation.

[2]75th percentile diversion discharge is sum of 75th percentile diversion discharges at Bessemer Ditch, West Pueblo Ditch, and Pueblo Water Works.

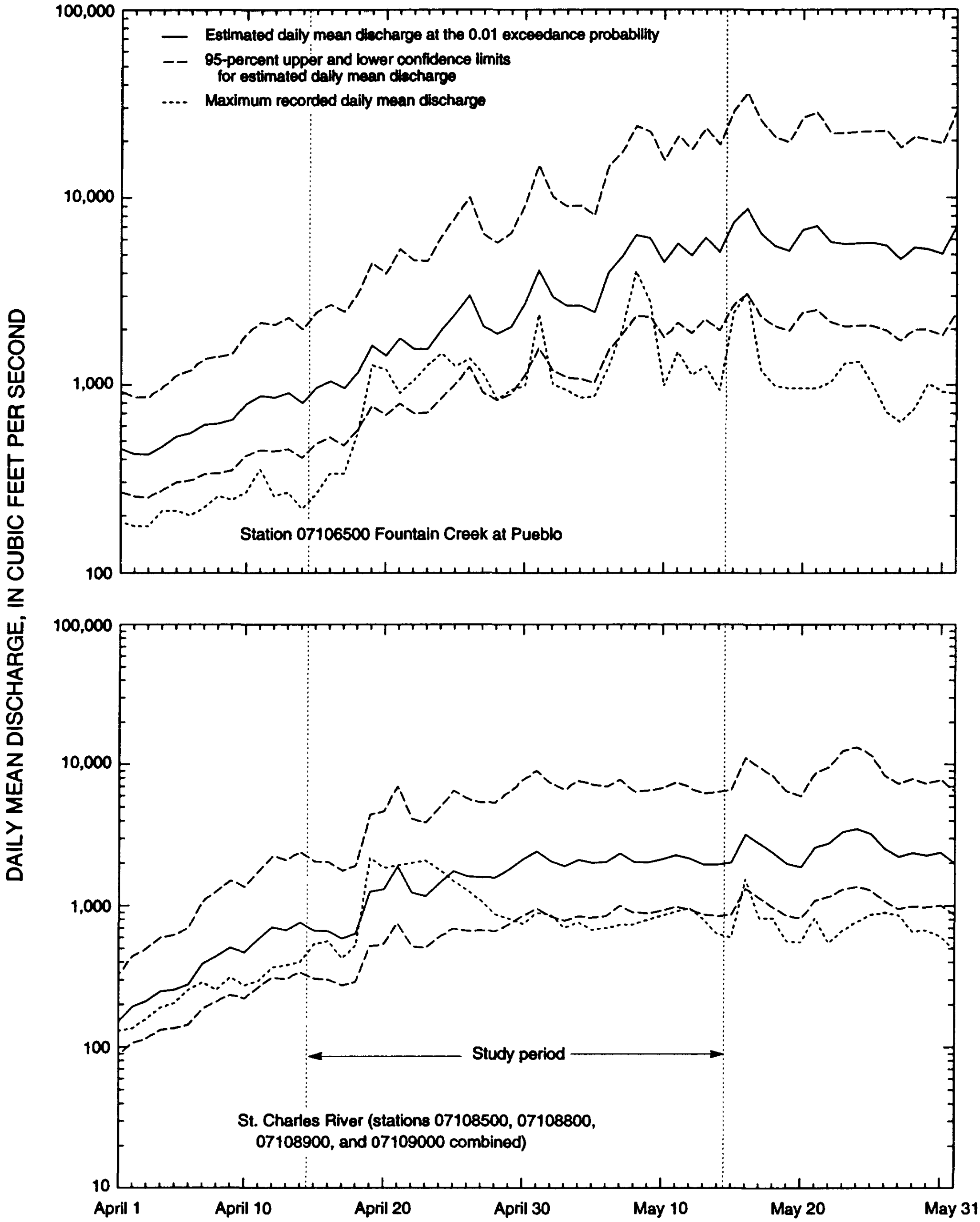

Figure 13. Estimated daily mean discharge at the 0.01 exceedance probability and maximum recorded daily mean discharge for Fountain Creek and the St. Charles River.

from low-elevation basins and partly by the shorter periods of record. However, based on the available data, the estimated 0.01 EP discharges (fig. 13) are the best possible; the estimates should improve and the confidence limits should narrow as more data become available (U.S. Interagency Advisory Committee on Water Data, 1982, p. 23). The 0.01 EP discharges for April 15-May 14, the maximum RDM discharges, and the year of the maxima for Fountain Creek and the St. Charles River are listed in tables 5 and 6. The 0.01 EP discharges for Fountain Creek and the St. Charles River (tables 5 and 6) generally are substantially larger than the maximum RDM discharges, except for a few days in April on the St. Charles River. Most of the maximum RDM discharges for these streams also were recorded during 1942.

Perspective of Daily Mean Discharges Recorded During April and May 1942

The data listed in tables 2–6 clearly indicate that 1942 was a year of exceptionally large discharge during April and May on the Arkansas River downstream from Canon City, on Fountain Creek, and on the St. Charles River. April 1942 also was one of the wettest months recorded in Colorado (Follansbee and Sawyer, 1948, p. 105). In the Purgatoire River basin, a major tributary entering the Arkansas River about 80 mi downstream from Pueblo, the precipitation was especially large from April 20 to 25 and resulted in a major flood on the Purgatoire River; details of the flood are described by Follansbee and Sawyer (1948, p. 105–108). Establishment of April 15 as the date by which the JUP of Pueblo Reservoir would need to be completely evacuated of winter-stored water was based, in part, on the April 23–24 flood on the Purgatoire River (R.K. Livingston, U.S. Geological Survey, written commun., 1988).

Data listed in table 2 indicate that the 1942 April-May discharge volume is the third largest on record for the at-Canon City station and the largest on record for the near-Pueblo and near-Avondale stations (as of water year 1990). The frequency analyses for the April-May volumes for these three stations (fig. 9) indicate that: (1) For the at-Canon City station, the 1942 volume has an EP of about 0.02; (2) for the near-Pueblo station, the volume has an EP smaller than 0.005 (this also is indicated in fig. 11, which includes the estimated discharges for water years 1976–90); and (3) for the near-Avondale station, the volume has an EP of about 0.01. To further analyze the 1942 discharges at the near-Pueblo station, frequency analyses were performed for RDM discharges on April 23 and 24 (fig. 14), which were the days of the largest RDM discharges during April (table 4). The probability that daily mean discharge on April 23 and 24 would be equal to or larger than the RDM discharge on those days during 1942 is substantially smaller than 0.01 (fig. 14).

For Fountain Creek and the St. Charles River, the 1942 April-May volume is the largest on record for both streams (table 3); for the St. Charles River the 1942 volume is almost twice as large as the second largest volume (table 3). The EP's for the 1942 April-May volumes are about 0.05 for Fountain Creek and about 0.02 for the St. Charles River (fig. 10). Frequency analyses of RDM discharges for April 23 and 24, 1942, for the two tributaries are shown in figures 15 and 16. The probability that daily mean discharge on April 23 and 24 would be equal to or larger than the RDM discharge on those days during 1942 is about 0.015 for Fountain Creek and about 0.005 or smaller for the St. Charles River (figs. 15 and 16).

APPLICATION OF FREQUENCY-ANALYSIS RESULTS TO ESTIMATE EVACUATION DATES FOR THE JOINT-USE POOL

Estimation of evacuation dates for the Pueblo Reservoir JUP is made by using the 0.01 EP discharges for the near-Pueblo station, Fountain Creek, and the St. Charles River (tables 4–6). Discharges for the near-Pueblo station, which are the inflow to Pueblo Reservoir, are routed through Pueblo Reservoir and downstream to the at-Avondale station; discharges for Fountain Creek and the St. Charles River also are routed downstream to the at-Avondale station to determine a total discharge at the station. To estimate the evacuation dates, daily reservoir outflow was assumed to be equal to daily reservoir inflow (the daily discharge at the near-Pueblo station), except (1) when outflow needs to be decreased to maintain the downstream 6,000-ft^3/s discharge criterion at the near-Avondale station, or (2) when outflow can be increased because discharge at the near-Avondale station would be less than 6,000 ft^3/s and the JUP contains some previously stored inflow. Data to estimate the evacuation date for the JUP using the 0.01 EP discharges (tables 4–6) are listed in table 7; diversions were not considered in the estimation. The discharge-routing computations to estimate evacuation dates for the JUP consists of the following steps:

Table 5. Results of frequency analysis of recorded daily mean discharges for April 15-May 14 for station 07106500 Fountain Creek at Pueblo

[Discharges are in cubic feet per second]

Date	Estimated daily mean discharge at the 0.01 exceedance probability	Maximum recorded daily mean discharge	Water year of maximum recorded daily mean discharge
April 15	967	259	1977
April 16	1,050	334	1942
April 17	960	334	1942
April 18	1,170	542	1942
April 19	1,630	1,280	1942
April 20	1,440	1,220	1942
April 21	1,790	904	1942
April 22	1,570	1,060	1942
April 23	1,570	1,280	1942
April 24	1,990	1,490	1942
April 25	2,430	1,260	1942
April 26	3,050	1,400	1942
April 27	2,070	1,150	1942
April 28	1,890	838	1942
April 29	2,070	938	1942
April 30	2,750	989	1942
May 1	4,120	2,410	1980
May 2	2,980	1,010	1942
May 3	2,680	938	1942
May 4	2,670	854	1942
May 5	2,460	870	1942
May 6	4,010	1,250	1973
May 7	4,860	2,000	1973
May 8	6,310	4,080	1980
May 9	6,100	2,800	1980
May 10	4,550	989	1942
May 11	5,710	1,520	1947
May 12	4,950	1,130	1973
May 13	6,110	1,270	1947
May 14	5,150	936	1973

Table 6. Results of frequency analysis of recorded daily mean discharges for April 15-May 14 for the St. Charles River

[Discharges are in cubic feet per second; data are for stations 07108500, 07108800, 07108900, and 07109000 combined (see table 1)]

Date	Estimated daily mean discharge at the 0.01 exceedance probability	Maximum recorded daily mean discharge	Water year of maximum recorded daily mean discharge
April 15	671	533	1942
April 16	665	564	1942
April 17	591	424	1987
April 18	636	524	1987
April 19	1,250	2,180	1942
April 20	1,310	1,850	1942
April 21	1,890	1,930	1942
April 22	1,230	2,010	1942
April 23	1,170	2,090	1942
April 24	1,450	1,790	1942
April 25	1,750	1,490	1942
April 26	1,610	1,290	1942
April 27	1,590	1,080	1942
April 28	1,580	874	1942
April 29	1,800	813	1942
April 30	2,130	751	1942
May 1	2,430	890	1980
May 2	2,070	868	1980
May 3	1,900	703	1980
May 4	2,110	766	1980
May 5	2,020	681	1942
May 6	2,040	700	1942
May 7	2,360	735	1987
May 8	2,050	742	1942
May 9	2,030	800	1942
May 10	2,120	850	1942
May 11	2,290	910	1942
May 12	2,150	968	1942
May 13	1,960	802	1942
May 14	1,960	636	1942

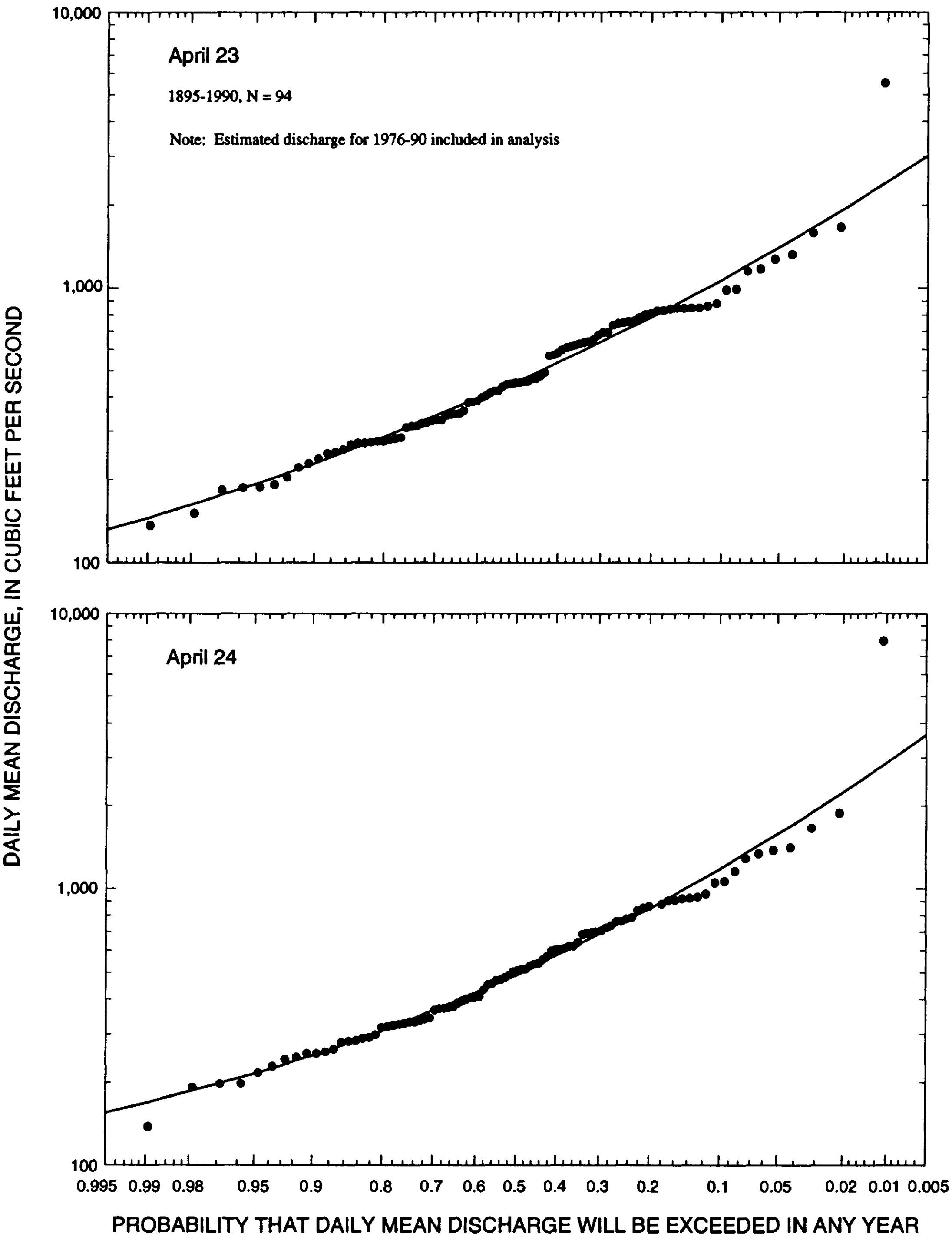

Figure 14. Log-Pearson type-III frequency curves of daily mean discharge for April 23 and 24 for station 07099500 Arkansas River near Pueblo.

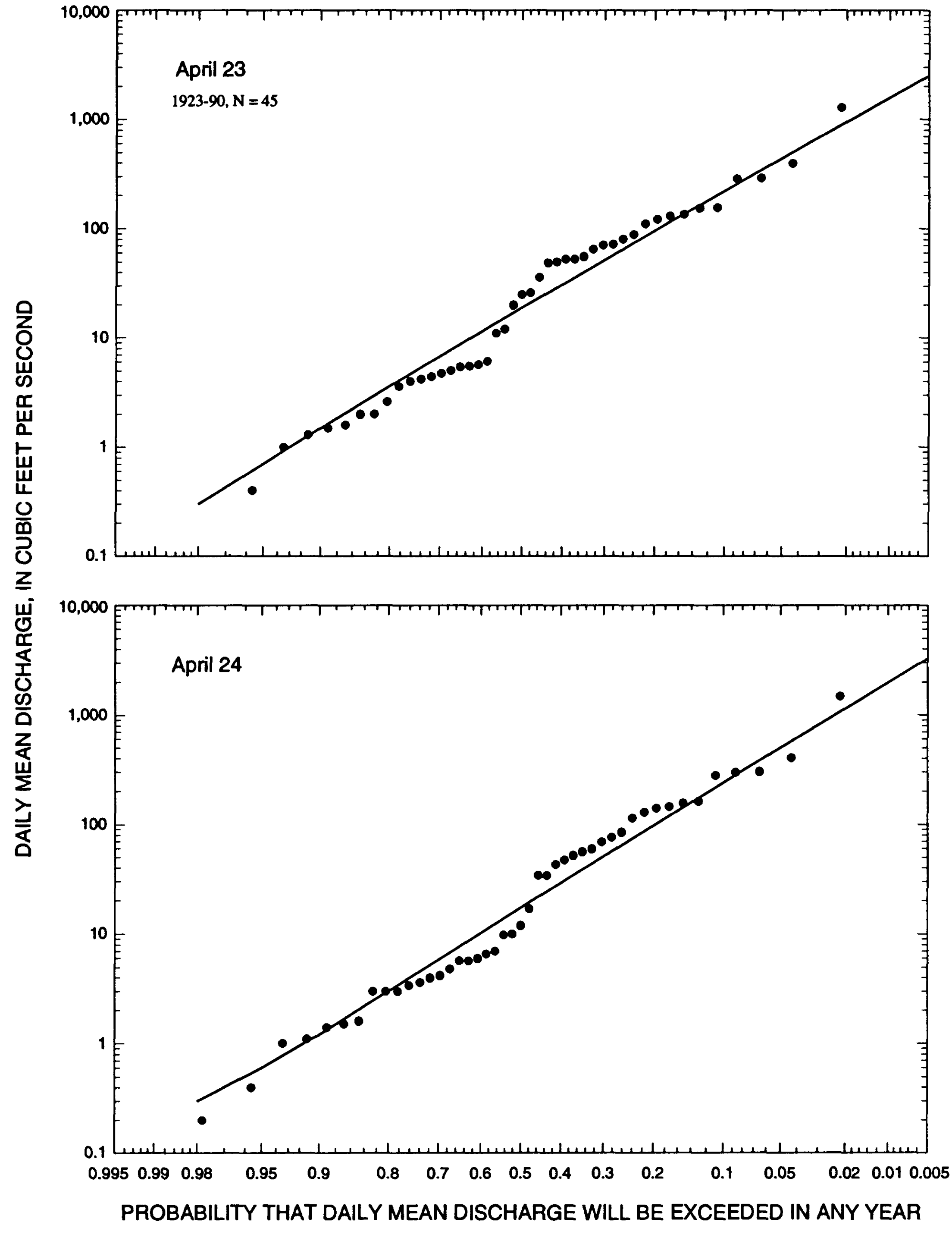

Figure 15. Log-Pearson type-III frequency curves of daily mean discharge for April 23 and 24 for station 07106500 Fountain Creek at Pueblo.

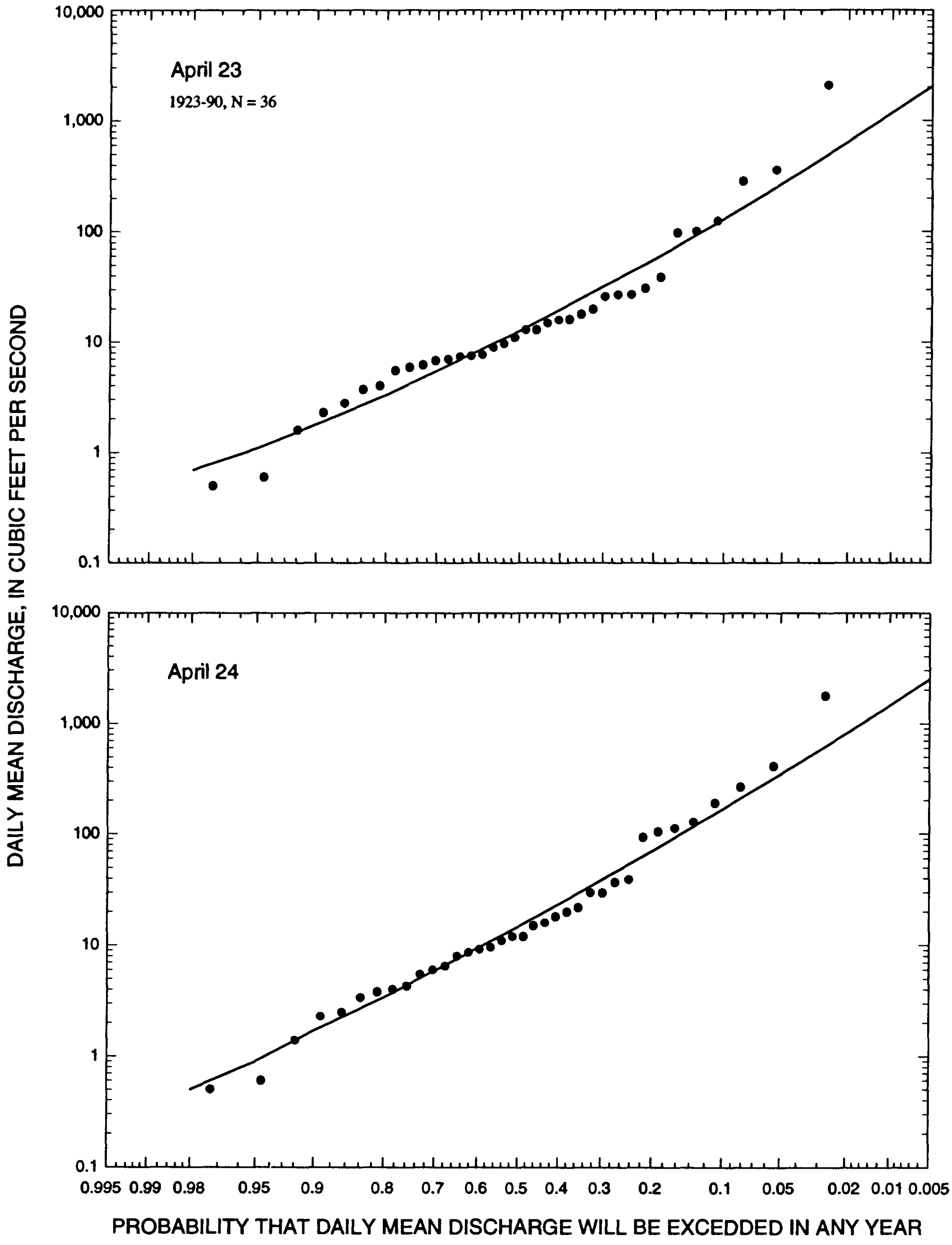

Figure 16. Log-Pearson type-III frequency curves of daily mean discharge for April 23 and 24 for the St. Charles River.

Table 7. Estimated evacuation date for the joint-use pool of Pueblo Reservoir for daily inflow discharges at the 0.01 exceedance probability

[Station 07099500 is Arkansas River near Pueblo—discharge for this station is the reservoir inflow; station 07109500 is Arkansas River near Avondale]

Date	Estimated daily mean discharge at the 0.01 exceedance probability for tributary streams		Sum of estimated daily mean discharges on tributaries (cubic feet per second)	Estimated daily mean discharge at the 0.01 exceedance probability for station 07099500 (cubic feet per second)	Quantity of reservoir inflow that is reservoir outflow (cubic feet per second)	Quantity of reservoir inflow that is stored in joint-use pool (cubic feet per second)	Discharge released from joint-use pool (cubic feet per second)	Total reservoir outflow (cubic feet per second)	Estimated discharge for station 07109500 (cubic feet per second)	Joint-use pool change-in-storage (acre-feet)	Joint-use pool contents (acre-feet)
	Fountain Creek (cubic feet per second)	St. Charles River (cubic feet per second)									
April 15	967	671	1,638	1,670	1,670	0	0	1,670	3,310	0	0
April 16	1,050	665	1,715	1,630	1,630	0	0	1,630	3,350	0	0
April 17	960	591	1,551	1,760	1,760	0	0	1,760	3,310	0	0
April 18	1,170	636	1,806	2,050	2,050	0	0	2,050	3,860	0	0
April 19	1,630	1,250	2,880	2,290	2,290	0	0	2,290	5,170	0	0
April 20	1,440	1,310	2,750	2,400	2,400	0	0	2,400	5,150	0	0
April 21	1,790	1,890	3,680	2,140	2,140	0	0	2,140	5,820	0	0
April 22	1,570	1,230	2,800	2,080	2,080	0	0	2,080	4,880	0	0
April 23	1,570	1,170	2,740	2,430	2,430	0	0	2,430	5,170	0	0
April 24	1,990	1,450	3,440	2,860	2,560	300	0	2,560	6,000	600	600
April 25	2,430	1,750	4,180	2,690	1,820	870	0	1,820	6,000	1,730	2,320
April 26	3,050	1,610	4,660	2,710	1,340	1,370	0	1,340	6,000	2,720	5,040
April 27	2,070	1,590	3,660	2,690	2,340	350	0	2,340	6,000	690	5,730
April 28	1,890	1,580	3,470	2,580	2,530	50	0	2,530	6,000	100	5,830
April 29	2,070	1,800	3,870	2,750	2,130	620	0	2,130	6,000	1,230	7,060
April 30	2,750	2,130	4,880	3,230	1,120	2,110	0	1,120	6,000	4,190	11,250
May 1	4,120	2,430	6,550	3,270	0	3,270	0	0	6,550	6,490	17,730
May 2	2,980	2,070	5,050	3,100	950	2,150	0	950	6,000	4,260	22,000
May 3	2,680	1,900	4,580	3,200	1,420	1,780	0	1,420	6,000	3,530	25,530
May 4	2,670	2,110	4,780	2,980	1,220	1,760	0	1,220	6,000	3,490	29,020

Table 7. Estimated evacuation date for the joint-use pool of Pueblo Reservoir for daily inflow discharges at the 0.01 exceedance probability --Continued

Date	Estimated daily mean discharge at the 0.01 exceedance probability for tributary streams		Sum of estimated daily mean discharges on tributaries (cubic feet per second)	Estimated daily mean discharge at the 0.01 exceedance probability for station 07099500 (cubic feet per second)	Quantity of reservoir inflow that is reservoir outflow (cubic feet per second)	Quantity of reservoir inflow that is stored in joint-use pool (cubic feet per second)	Discharge released from joint-use pool (cubic feet per second)	Total reservoir outflow (cubic feet per second)	Estimated discharge for station 07109500 (cubic feet per second)	Joint-use pool change-in-storage (acre-feet)	Joint-use pool contents (acre-feet)
	Fountain Creek (cubic feet per second)	St. Charles River (cubic feet per second)									
May 5	2,460	2,020	4,480	3,010	1,520	1,490	0	1,520	6,000	2,960	31,970
May 6	4,010	2,040	6,050	3,170	0	3,170	0	0	6,050	6,290	38,260
May 7	4,860	2,360	7,220	3,380	0	3,380	0	0	7,220	6,700	44,970
May 8	6,310	2,050	8,360	3,490	0	3,490	0	0	8,360	6,920	51,890
May 9	6,100	2,030	8,130	3,590	0	3,590	0	0	8,130	7,120	59,010
May 10	4,550	2,120	6,670	3,420	0	3,420	0	0	6,670	6,780	65,790
May 11	5,710	2,290	8,000	4,020	0	4,020	0	0	8,000	7,970	73,770
May 12	4,950	2,150	7,100	3,830	0	3,830	0	0	7,100	7,600	81,360
May 13	6,110	1,960	8,070	3,350	0	3,350	0	0	8,070	6,640	88,010
May 14	5,150	1,960	7,110	3,320	0	3,320	0	0	7,110	6,590	94,590

Note: Some discharge sums and differences are not exact because of rounding.

1. Sum the 0.01 EP discharges for Fountain Creek and the St. Charles River.
2. If the sum from step 1 is equal to or greater than 6,000 ft^3/s, then all the discharge for the near-Pueblo station (reservoir inflow) is stored in the JUP. Discharge for the near-Avondale station is equal to the sum from step 1.
3. If the sum from step 1 is less than 6,000 ft^3/s, then any of the discharge for the near-Pueblo station that will not cause the 6,000-ft^3/s criterion to be exceeded is assumed to be reservoir outflow and is added to the sum from step 1; the new sum is the discharge for the near-Avondale station. Any inflow discharge for the near-Pueblo station that would cause the 6,000-ft^3/s criterion to be exceeded is stored in the JUP.
4. If the new sum from step 3 includes all the inflow discharge for the near-Pueblo station and the sum is less than 6,000 ft^3/s, then a release can be made from the JUP if some inflow discharge was stored in the JUP on a previous day, to increase the discharge for the near-Avondale station to 6,000 ft^3/s.
5. The estimated evacuation date for the JUP is the day prior to the date when continuous storage is required in the JUP.

The computation using the 0.01 EP discharges for the near-Pueblo station (table 7) provides an estimate of the date by which the JUP should be evacuated for a reservoir inflow volume equal to the sum of the 0.01 EP discharges for the near Pueblo station (table 4). This inflow volume is about 168,800-acre-ft (note: acre-feet = cubic feet per second × 1.9835); the estimated evacuation date for the JUP for that inflow volume is April 23 (table 7).

To estimate the evacuation dates for other April 15-May 14 inflow volumes, estimated daily mean discharges for several other EPs were derived from the frequency analysis for the near-Pueblo station. To accurately evaluate how the estimated evacuation date varies for other inflow volumes, all variables, except the variable affecting inflow volume, should be the same as in the estimation listed in table 7. Therefore, the 0.01 EP discharges for Fountain Creek and for the St. Charles River (tables 5 and 6) were used to estimate the evacuation date for other inflow volumes. Primarily for purposes of comparison to the data to estimate the evacuation date using the 0.01 EP daily inflow discharges (table 7), data to estimate the evacuation date using the 0.50 EP daily inflow discharges are listed in table 8. The estimated evacuation date for the JUP using the 0.50 EP daily inflow discharges is May 5. Data for estimating the JUP evacuation date for daily inflow discharges other than the 0.01 and 0.50 EP daily inflow discharges (tables 7 and 8) are not presented herein; however, results of all the evacuation date estimates are listed in table 9. The assumptions and computations for the additional evacuation-date estimations were the same as those described in the previous paragraphs in this section. Results from estimating the JUP evacuation date indicated a relation between the estimated April 15-May 14 inflow volume (the sum of the daily inflow discharges derived from the frequency analysis) and the JUP evacuation date; the relation is shown in figure 17.

The relation shown in figure 17 may be subject to some error because of the method by which the inflow volumes were derived—by summing the daily inflow discharges for the various EPs (table 9). The inflow volumes derived by this method are different from the inflow volumes derived by frequency analysis of recorded April 15-May 14 inflow volumes (table 9). It is not likely that all the April 15-May 14 daily inflow discharges in a given year would be equal to the daily discharges at a specific EP, which was assumed in estimating the evacuation dates (tables 7–9). Analysis of RDM discharges for the ten years of largest April-May discharge volume did not indicate a dominant correlation between rank of a discharge volume and the number of days for which the daily discharge rank was equal to or greater than the volume rank (tables 2–4).

To evaluate the possible error in the inflow volume/evacuation date relation (fig. 17), the diversion-adjusted RDM discharges for April 15-May 14 for all years of record (including the extended record for 1976–90) were routed through Pueblo Reservoir. The routing technique was identical to that previously described and shown in tables 7 and 8, except that the RDM discharges for the near-Pueblo station were used for reservoir inflow. The 0.01 EP discharges for Fountain Creek and the St. Charles River were used. A cumulative frequency distribution of the April 15-May 14 inflow volumes derived from the April 15-May 14 RDM inflow discharges is shown in figure 18.

Results of routing the diversion-adjusted RDM discharges through Pueblo Reservoir to estimate evacuation dates for the corresponding inflow volumes (fig. 18) are shown in figure 19. The estimated evacuation dates are clustered around only a few dates (figs. 17 and 19) because of peaks in the 0.01 EP discharges for Fountain Creek and the St. Charles River (fig. 20). Because the relation of inflow volume to evacuation date when the RDM inflow discharges were routed through Pueblo Reservoir (fig. 19) is not sub-

Table 8. Estimated evacuation date for the joint-use pool of Pueblo Reservoir for daily inflow discharges at the 0.50 exceedance probability

[Station 07099500 is Arkansas River near Pueblo—discharge for this station is the reservoir inflow; station 07109500 is Arkansas River near Avondale]

Date	Estimated daily mean discharge at the 0.01 exceedance probability for tributary streams		Sum of estimated daily mean discharges on tributaries (cubic feet per second)	Estimated daily mean discharge at the 0.50 exceedance probability for station 07099500 (cubic feet per second)	Quantity of reservoir inflow that is reservoir outflow (cubic feet per second)	Quantity of reservoir inflow that is stored in joint-use pool (cubic feet per second)	Discharge released from joint-use pool (cubic feet per second)	Total reservoir outflow (cubic feet per second)	Estimated discharge for station 07109500 (cubic feet per second)	Joint-use pool change-in-storage (acre-feet)	Joint-use pool contents (acre-feet)
	Fountain Creek (cubic feet per second)	St. Charles River (cubic feet per second)									
April 15	967	671	1,638	384	384	0	0	384	2,020	0	0
April 16	1,050	665	1,715	401	401	0	0	401	2,120	0	0
April 17	960	591	1,551	434	434	0	0	434	1,980	0	0
April 18	1,170	636	1,806	449	449	0	0	449	2,250	0	0
April 19	1,630	1,250	2,880	444	444	0	0	444	3,320	0	0
April 20	1,440	1,310	2,750	479	479	0	0	479	3,230	0	0
April 21	1,790	1,890	3,680	498	498	0	0	498	4,180	0	0
April 22	1,570	1,230	2,800	470	470	0	0	470	3,270	0	0
April 23	1,570	1,170	2,740	456	456	0	0	456	3,200	0	0
April 24	1,990	1,450	3,440	486	486	0	0	486	3,390	0	0
April 25	2,430	1,750	4,180	499	499	0	0	499	4,680	0	0
April 26	3,050	1,610	4,660	514	514	0	0	514	5,170	0	0
April 27	2,070	1,590	3,660	529	529	0	0	529	4,190	0	0
April 28	1,890	1,580	3,470	547	547	0	0	547	4,020	0	0
April 29	2,070	1,800	3,870	574	574	0	0	574	4,440	0	0
April 30	2,750	2,130	4,880	585	585	0	0	585	5,470	0	0
May 1	4,120	2,430	6,550	604	0	604	0	0	6,550	1,200	1,200
May 2	2,980	2,070	5,050	622	622	0	328	950	6,000	-650	550
May 3	2,680	1,900	4,580	630	630	0	276	907	5,490	-550	0
May 4	2,670	2,110	4,780	650	650	0	0	650	5,430	0	0

Table 8. Estimated evacuation date for the joint-use pool of Pueblo Reservoir for daily inflow discharges at the 0.50 exceedance probability --Continued

Date	Estimated daily mean discharge at the 0.01 exceedance probability for tributary streams		Sum of estimated daily mean discharges on tributaries (cubic feet per second)	Estimated daily mean discharge at the 0.50 exceedance probability for station 07099500 (cubic feet per second)	Quantity of reservoir inflow that is reservoir outflow (cubic feet per second)	Quantity of reservoir inflow that is stored in joint-use pool (cubic feet per second)	Discharge released from joint-use pool (cubic feet per second)	Total reservoir outflow (cubic feet per second)	Estimated discharge for station 07109500 (cubic feet per second)	Joint-use pool change-in-storage (acre-feet)	Joint-use pool contents (acre-feet)
	Fountain Creek (cubic feet per second)	St. Charles River (cubic feet per second)									
May 05	2,460	2,020	4,480	670	670	0	0	670	5,150	0	0
May 06	4,010	2,040	6,050	717	0	717	0	0	6,050	1,420	1,420
May 07	4,860	2,360	7,220	758	0	758	0	0	7,220	1,500	2,920
May 08	6,310	2,050	8,360	790	0	790	0	0	8,360	1,570	4,490
May 09	6,100	2,030	8,130	840	0	840	0	0	8,130	1,670	6,160
May 10	4,550	2,120	6,670	899	0	899	0	0	6,670	1,780	7,940
May 11	5,710	2,290	8,000	930	0	930	0	0	8,000	1,840	9,780
May 12	4,950	2,150	7,100	968	0	968	0	0	7,100	1,920	11,700
May 13	6,110	1,960	8,070	972	0	972	0	0	8,070	1,930	13,630
May 14	5,150	1,960	7,110	960	0	960	0	0	7,110	1,900	15,530

Note: Some discharge sums and differences are not exact because of rounding.

Table 9. Estimated evacuation date for joint-use pool of Pueblo Reservoir for selected April 14-May 15 inflow volumes

Exceedance probability of daily mean discharges	April 14-May 15 inflow volume derived from sum of daily mean discharges[1] (acre-feet)	Estimated evacuation date for joint-use pool for inflow volume derived from sum of daily mean discharges	April 14-May 15 inflow volume derived from frequency analysis of recorded inflow volumes[2] (acre-feet)
0.002	249,000	April 18	210,720
.005	200,900	April 23	172,880
.01	168,800	April 23	147,360
.02	140,000	April 24	124,230
.04	114,200	April 29	103,230
.10	83,750	April 29	78,230
.20	63,080	April 30	60,930
.50	37,200	April 30	38,820
.80	22,330	May 5	25,610
.90	17,210	May 5	20,880
.95	13,940	May 5	17,770

[1]Inflow volume is sum of estimated daily mean discharges for indicated exceedance probability derived from frequency analysis of recorded daily mean discharges (sum is converted to volume by multiplying by 1.9835).

[2]Inflow volume has same exceedance probability as that listed in column 1.

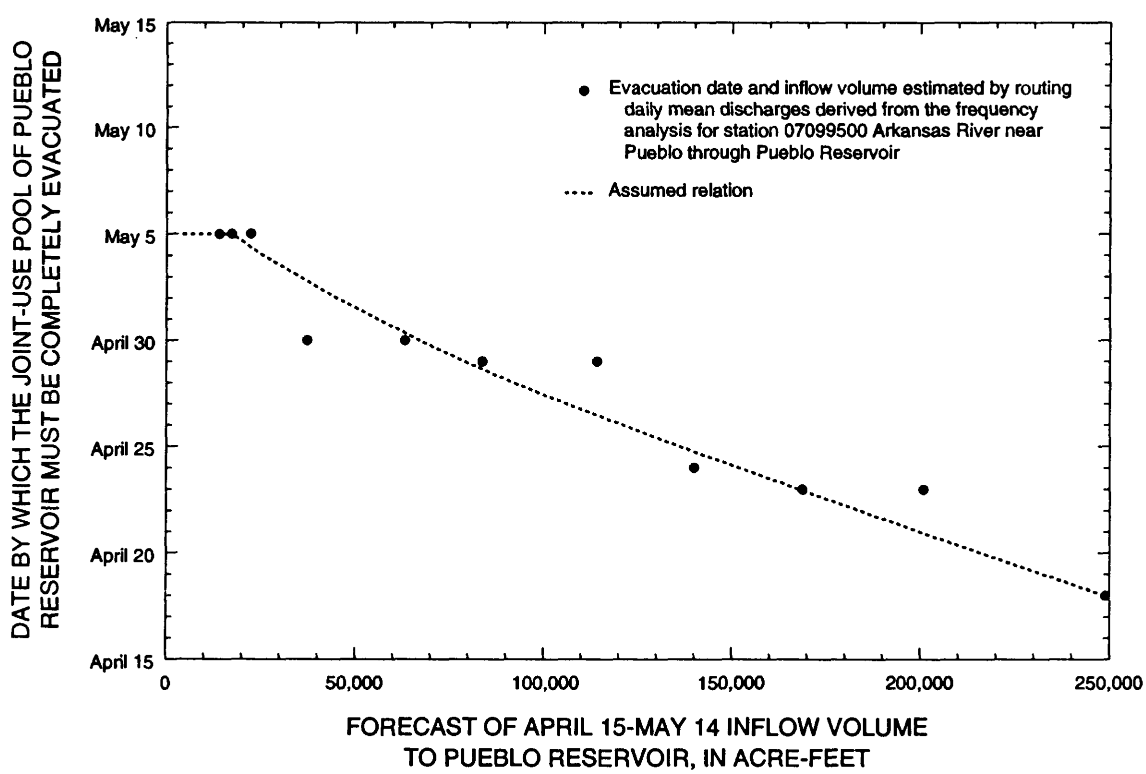

Figure 17. Relation of the forecast of April 15-May 14 inflow volume to Pueblo Reservoir to the date by which the joint-use pool must be completely evacuated.

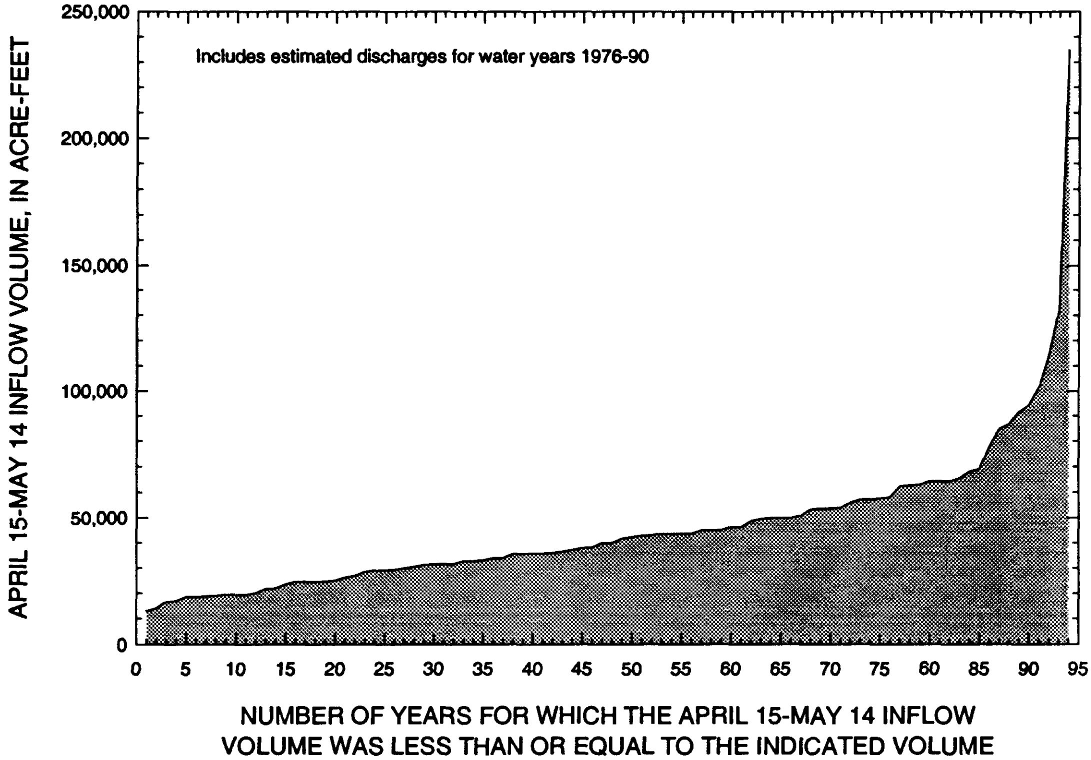

Figure 18. Cumulative frequency distribution of recorded April 15-May 14 discharge volumes for station 07099500 Arkansas River near Pueblo.

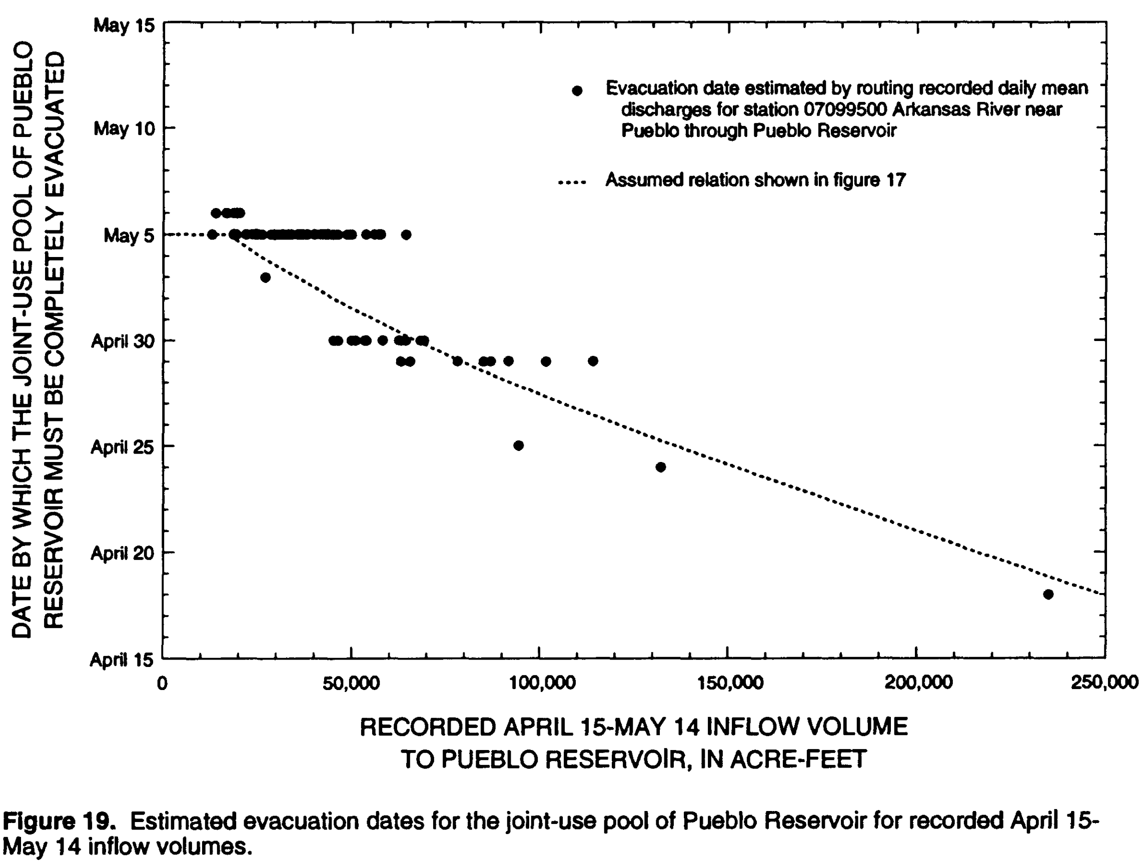

Figure 19. Estimated evacuation dates for the joint-use pool of Pueblo Reservoir for recorded April 15-May 14 inflow volumes.

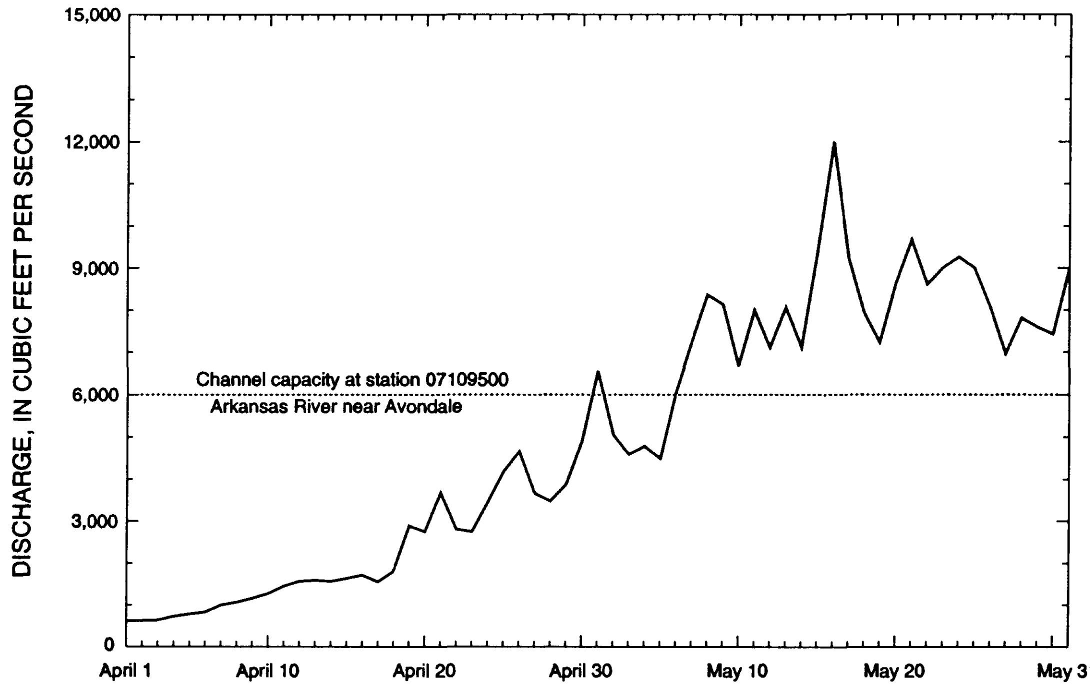

Figure 20. Sum of the estimated daily mean discharges at the 0.01 exceedance probability for Fountain Creek and the St. Charles River.

stantially different from that shown in figure 17, evacuation dates estimated from the relation in figure 17 are considered reasonable. Although the evacuation dates are clustered (figs. 17 and 19), a smooth trend in the relation of the inflow volume to evacuation date was assumed (fig. 17).

To apply the study results, only a forecast of the April 15-May 14 inflow volume to Pueblo Reservoir is needed. The JUP evacuation date for the forecast inflow volume then is estimated using figure 17. The study results would be applied only in years in which the conservation capacity of Pueblo Reservoir (fig. 2) is fully utilized and the storage capacity of the JUP has been used to provide additional conservation capacity.

Forecasts of April 15-May 14 inflow volume will be made by the National Weather Service using the ESP procedure (J.V. Bowman, National Weather Service, written commun., June, 1989). The forecast of inflow volume always is made at a 0.50 EP on the basis of the current hydrologic conditions; the forecast volume will vary for each year that the study results are applied. In applying of the study results, it is important that the two EPs, (1) the 0.50 EP of the forecast April 15-May 14 inflow volume with respect to the current hydrologic conditions; and (2) the EP of the forecast inflow volume with respect to historical inflow volumes, are not confused. Knowledge of the EP of the forecast inflow volume with respect to historical inflow volumes is not needed to apply the study results. However, some knowledge of the magnitude and frequency of historical April 15-May 14 inflows (fig. 18) probably would be beneficial in evaluating a forecast inflow volume. Inflow volumes were less than 60,000 acre-ft for about 75 of the 94 years of record and exceeded 100,000 acre-ft in only 3 years (fig. 18).

An application of the study results implies that some winter-stored water is contained in the JUP of Pueblo Reservoir; this water will need to be released by the estimated evacuation date (fig. 17) for the current April 15-May 14 forecast of inflow volume. To aid in estimating release rates for any winter-stored water, the computations to estimate evacuation date for different inflow volumes (tables 7 and 8) were used to estimate maximum allowable storages in the JUP for different forecasts of inflow volume (fig. 21). The dates by which the JUP needs to be emptied were derived from the assumed relation in figure 17. The dates for the maximum contents of the JUP were derived from the evacuation-date estimations by (1) calculating the volume of discharge that could be released from reservoir storage each day that daily mean discharge at the Avondale station was less than 6,000 ft^3/s prior to the evac-

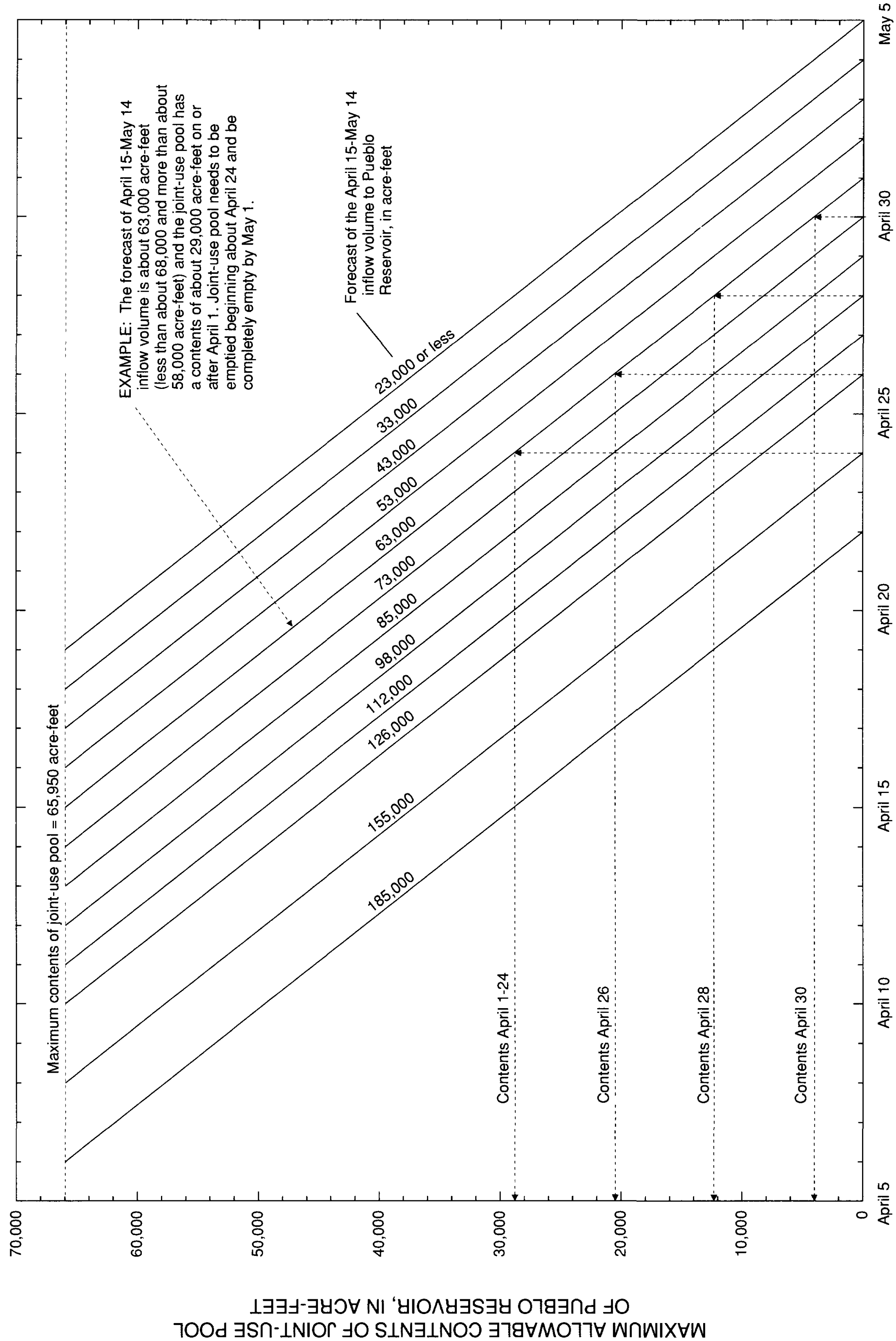

Figure 21. Maximum allowable contents of the joint-use pool of Pueblo Reservoir between April 5 and May 5 for selected forecasts of April 15-May 14 inflow volume.

uation date, and (2) summing the calculated release discharge volumes from the evacuation date back in time until the cumulated contents was about equal to the capacity of the JUP. The curves shown in figure 21, which are intended to provide an approximation of the maximum allowable JUP contents, are based on 0.01 EP daily mean discharges in Fountain Creek and the St. Charles River.

FORECASTING INFLOW VOLUME TO PUEBLO RESERVOIR USING THE EXTENDED STREAMFLOW PREDICTION PROCEDURE

Historically, discharge-volume forecasts usually have been made using regression techniques that correlate recorded discharge volumes to measured water equivalent at snow courses in and adjacent to a basin. These forecasts usually are made for April 1 through September 30. Although an April-September forecast possibly could have been incorporated into the development of figure 17, the many factors that can affect discharge volume for this longer period probably would have increased the complexity of applying the study results.

To provide the capability to forecast April 15-May 14 inflow volume to Pueblo Reservoir, the operational capability of the NWSRFS model was applied to the Arkansas River basin upstream from Pueblo Reservoir. The reservoir inflow forecasts are made using the ESP procedure, which is a component of the NWSRFS model. The National Weather Service routinely uses the NWSRFS model to provide short- and long-term forecasts for a variety of uses by National, State, and local agencies, and by the general public. Therefore, forecasts of the April 15-May 14 inflow volume to Pueblo Reservoir would be readily available for any year in which the PRJUP study results would be applied. The following sections of this report present brief descriptions of (1) the NWSRFS model, (2) the ESP procedure, and (3) examples of ESP discharge volume forecasts. Detailed descriptions of these topics can be found in the cited references.

National Weather Service River Forecast System Model

Initial development of the NWSRFS model is described by the National Weather Service (1972); however, continued development and improvement of the model have resulted in a dynamic, multi-volume users manual that is continually revised and updated by the National Weather Service. The NWSRFS model has three major components, the calibration system component, the operational forecast system component, and the ESP component. The following descriptions are derived from Day (1985) and Anderson (1986).

The calibration system primarily is a collection of programs that are mathematical representations of various components of the hydrologic cycle. The two primary components that were calibrated for the PRJUP study are a snow-accumulation and -ablation model (Anderson, 1973) and a soil-moisture accounting model (Burnash and others, 1973). To ensure that streamflow simulated by the NWSRFS model compares closely to recorded streamflow, values for the model parameters (the coefficients of the mathematical representations) were optimized by using trial-and-error or computer techniques, or a combination of both (Brazil and Hudlow, 1981).

The calibration system also includes preprocessor programs that manipulate data used in the calibration program and compute mean areal precipitation and mean areal temperature time series data for input to the calibration programs. A 39-year (water years 1949 through 1987) data base of discharge, precipitation, temperature, diversion, and reservoir-contents data was compiled for use in calibrating the NWSRFS model and in implementing the ESP procedure for the PRJUP study. Although discharge data are available for longer periods (table 1), the number and the locations of precipitation and temperature stations prior to about 1948 are inadequate for model calibration.

The operational forecast system then uses the calibrated model components with real-time hydrometeorological data to provide forecasts of discharge. The operational forecast system contains (1) a data-entry component, (2) a preprocessor component, and (3) the forecast component. The data-entry component assimilates real-time data from various sources and then formats the data for input to the preprocessor component. The preprocessor component estimates missing data and also calculates the mean areal precipitation and mean areal temperature time-series data for input to the forecast component. The forecast component then performs the hydrologic and hydraulic simulations needed to make the forecast.

Use of the operational forecast system to make a discharge forecast requires estimation of precipitation and temperature data for the forecast period. Because these data cannot be estimated reliably for more than a few days into the future, the operational forecast system cannot be used to make forecasts for more than a few days into the future (Day, 1985, p. 158). Development of the ESP procedure (Twedt and others, 1977;

Day, 1985) provided the capability to make long-term forecasts using the NWSRFS model.

Extended Streamflow Prediction Procedure

The ESP procedure uses the historical mean areal precipitation and mean areal temperature time-series data to simulate future streamflows under the assumption that each year of historical data represents a possible future occurrence of precipitation and temperature. For each year of historical data, a simulation is made with the NWSRFS model by inputting the existing hydrologic conditions up to the present and by inputting the historical data beyond the present. Thus, a simulated hydrograph is generated for the forecast period for each year of historical data. The ESP procedure then performs a frequency analysis of the simulated future hydrographs; the frequency analysis provides the means to make probabilistic forecasts for the period of interest.

Probabilistic forecasts can be made for different types of hydrologic data, such as discharge, reservoir volume or elevation, river stage, or snowpack water-equivalent. Also, different output variables can be considered in the analysis, such as maximum, minimum, or daily average value; maximum instantaneous value; cumulative value (volume); or number of days that some specified value is or is not exceeded (Day, 1985, p. 164–165). In the application of ESP for the PRJUP study, forecasts are made for daily average discharge, and the output variable is volume.

The ESP procedure produces output for a conditional simulation, a historical simulation, and the observed (recorded) data. The conditional simulation output is produced by using the existing hydrologic conditions with the historical mean areal precipitation and mean areal temperature data. The historical simulation output is produced by continuous simulation of the historical data without resetting the initial conditions at the beginning of the forecast period to the existing conditions. ESP output includes frequency curves for the conditional simulation, the historical simulation, and the recorded data.

Simulation of streamflow always is subject to some error; therefore, there will be some difference between the frequency curves for the historical simulation and the recorded data. Based on the difference between these two frequency curves, an adjustment can be made to the conditional simulation frequency curve before a probabilistic forecast is made (Day, 1985, p. 165). The data output by the ESP procedure may be fitted to the empirical, normal, or log-normal distributions.

Example Forecasts Using the Extended Streamflow Prediction Procedure

During development of the operational capability of the NWSRFS model for the PRJUP study, discharge forecasts made using the ESP procedure were compared with water-supply forecasts prepared annually by the U.S. Soil Conservation Service and the National Weather Service by using regression techniques. The forecasts are made for the April-September period on the first day of each month from January through May; only the April 1 forecast was used in the comparisons. The water-supply forecasts (U.S. Soil Conservation Service and National Weather Service, 1991, 1992) for the at-Granite and at-Salida stations (fig. 1) were used for comparison to the ESP forecasts. [These stations were used because the ESP procedure was not implemented downstream to Pueblo Reservoir until after April 1992, even though the NWSRFS model had been calibrated downstream to Pueblo Reservoir during 1991; therefore, ESP forecasts of inflow volume to the reservoir could not be made in 1991 and 1992.]

Comparison of the water-supply forecasts and the ESP forecasts is shown in figures 22 and 23. Generally, the differences between the forecasts made by each method are not substantial. Use of the ESP procedure, though, has the additional benefit of the capability to provide forecasts for any time period, such as April 15 through May 14, whereas the published water-supply forecasts are only for the April-September period.

SUMMARY

Part of the storage space of Pueblo Reservoir, which is located on the Arkansas River in southeastern Colorado, consists of a 65,950 acre-ft joint-use pool (JUP). The JUP can be used to provide additional conservation capacity from November 1 to April 14. The operating procedures for Pueblo Reservoir, however, require that the JUP be completely evacuated by April 15 and used only for flood-control capacity until November 1. During winter, the JUP primarily is used to store water for agricultural uses, but because April 15 is before the crop-growing season in southeastern Colorado, little beneficial use can be made of the water released prior to April 15. A study was completed during 1992 by the U.S. Geological Survey, in cooperation with the Southeastern Colorado Water Conservancy District to determine if the April 15 evacuation date could be extended for any number of days from April 15 through May 14 under certain hydrologic conditions.

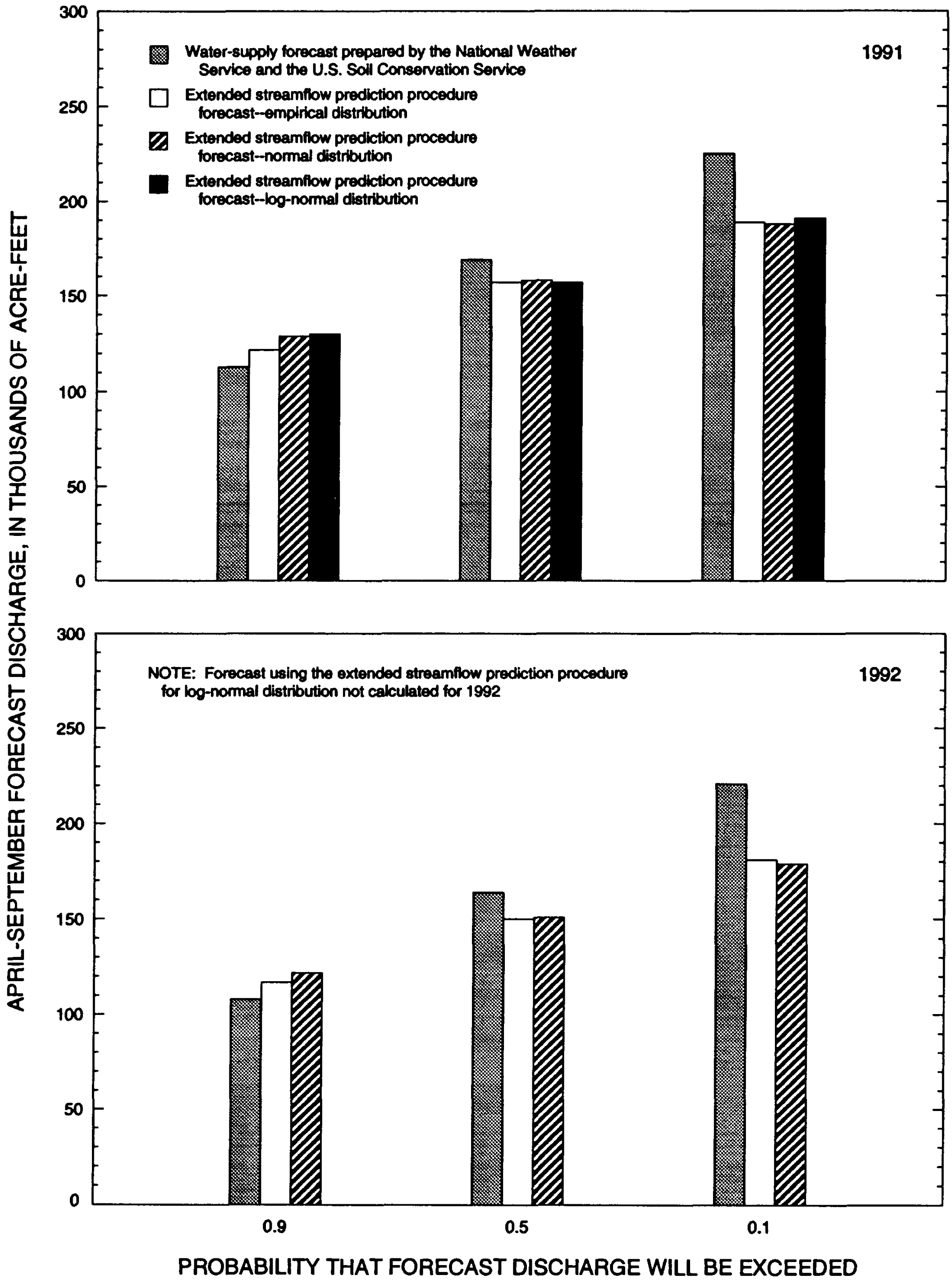

Figure 22. April-September extended streamflow prediction procedure forecasts and water-supply forecasts for station 07086000 Arkansas River at Granite.

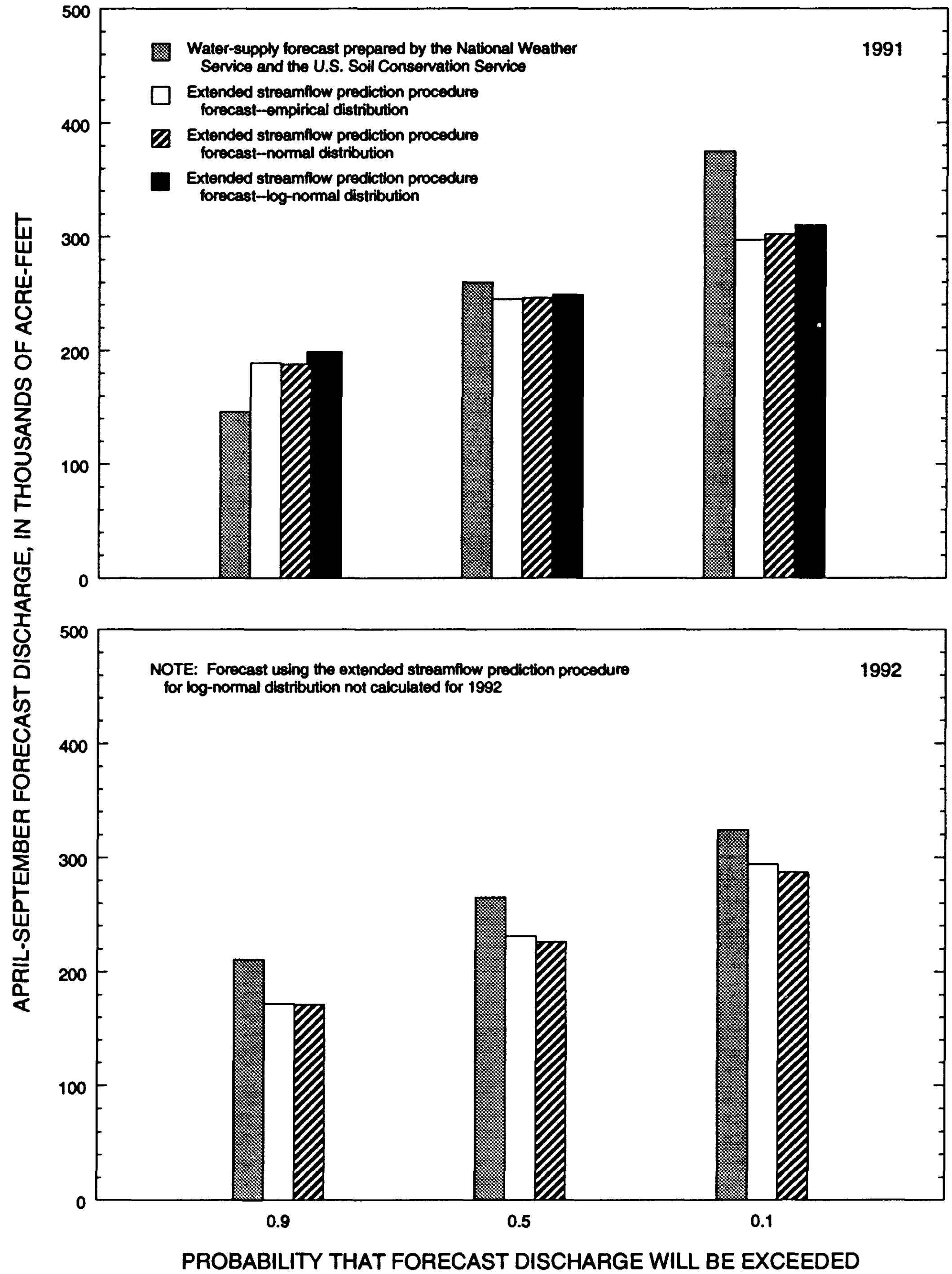

Figure 23. April-September extended streamflow prediction procedure forecasts and water-supply forecasts for station 07091500 Arkansas River at Salida.

The Pueblo Reservoir JUP (PRJUP) study consisted of two major components: (1) Frequency analysis of recorded daily mean discharge data for selected streamflow-gaging stations (stations) upstream and downstream from Pueblo Reservoir, and (2) implementation of the extended streamflow prediction (ESP) procedure for the Arkansas River basin upstream from Pueblo Reservoir. Upstream from the reservoir, the objective of the frequency analysis was to derive an estimate of the 0.01 exceedance probability (EP), April 15-May 14 daily inflow discharges; this EP was considered in design of the flood-storage capacity of Pueblo Reservoir. Downstream from the reservoir, the objective of the frequency analysis was to derive estimates of 0.01 EP discharges for two tributaries, Fountain Creek and the St. Charles River.

Frequency analysis for the tributaries was needed because channel capacity of the Arkansas River in the vicinity of Avondale (about 20 miles downstream from the reservoir) is limited to about 6,000 ft^3/s; the operating procedures of Pueblo Reservoir require that this discharge criterion be maintained, if possible. Because discharges in Fountain Creek and the St. Charles River affects discharge in the Arkansas River at Avondale, discharge in the tributaries can affect operation of Pueblo Reservoir, including the JUP. The study area has an area of 4,669 mi^2 upstream from Pueblo Dam and 1,658 mi^2 downstream from Pueblo Dam. Most discharge is derived from snowmelt in mountainous headwaters during spring and early summer.

The frequency analyses were made by fitting the data to the log-Pearson type-III distribution. Station-skew coefficients were analyzed for selected stations to determine an appropriate generalized-skew coefficient. Preliminary analysis of the April-May discharge volume at six stations on the Arkansas River was made to evaluate the adequacy of record length and effect of climatic variations. This analysis indicated that the near-Pueblo station, which had a 79-year record, could be used to reliably estimate the 0.01 EP reservoir inflow volume. However, because this station was discontinued after completion of Pueblo Dam (in 1975) and because some large discharges were recorded on the Arkansas River during the 1980's, the record for the near-Pueblo station was extended for water years 1976–90.

The record extension was made by two methods. The first method consisted of using a linear least-squares regression between discharges for the near-Pueblo station and the at-Portland station (about 20 mi upstream from the near-Pueblo station). The second method consisted of adjusting the discharge record for the above-Pueblo station (immediately downstream from Pueblo Dam) for the effects of reservoir regulation. In both methods, discharge data also were adjusted for the effects of diversion. Results from the two methods were averaged for use in the PRJUP study.

The 0.01 EP discharges from the frequency analyses were routed through Pueblo Reservoir to estimate evacuation dates for the JUP for the corresponding inflow volume. The frequency analyses also were used to derive additional sequences of daily inflow discharges for which evacuation dates also were estimated. A relation was indicated between the April 15-May 14 inflow volume and the estimated evacuation date; the date ranged from about April 23 for an inflow volume of about 168,800-acre-ft to May 5 for an inflow volume of about 20,000 acre-ft.

To apply the study results, only a forecast of the April 15-May 14 inflow volume to Pueblo Reservoir is needed; the relation derived between inflow volume and evacuation date then is used to estimate the evacuation date. To provide the capability to make forecasts of April 15-May 14 reservoir inflow, the operational capability of the National Weather Service River Forecast System (NWSRFS) model was applied for the PRJUP study. The operational capability of the NWSRFS model is applied by personnel of the National Weather Service, which maintains and updates the model and the associated data bases. The ESP procedure, which is an integral part of the NWSRFS model, is used to make probabilistic forecasts of reservoir inflow volume.

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