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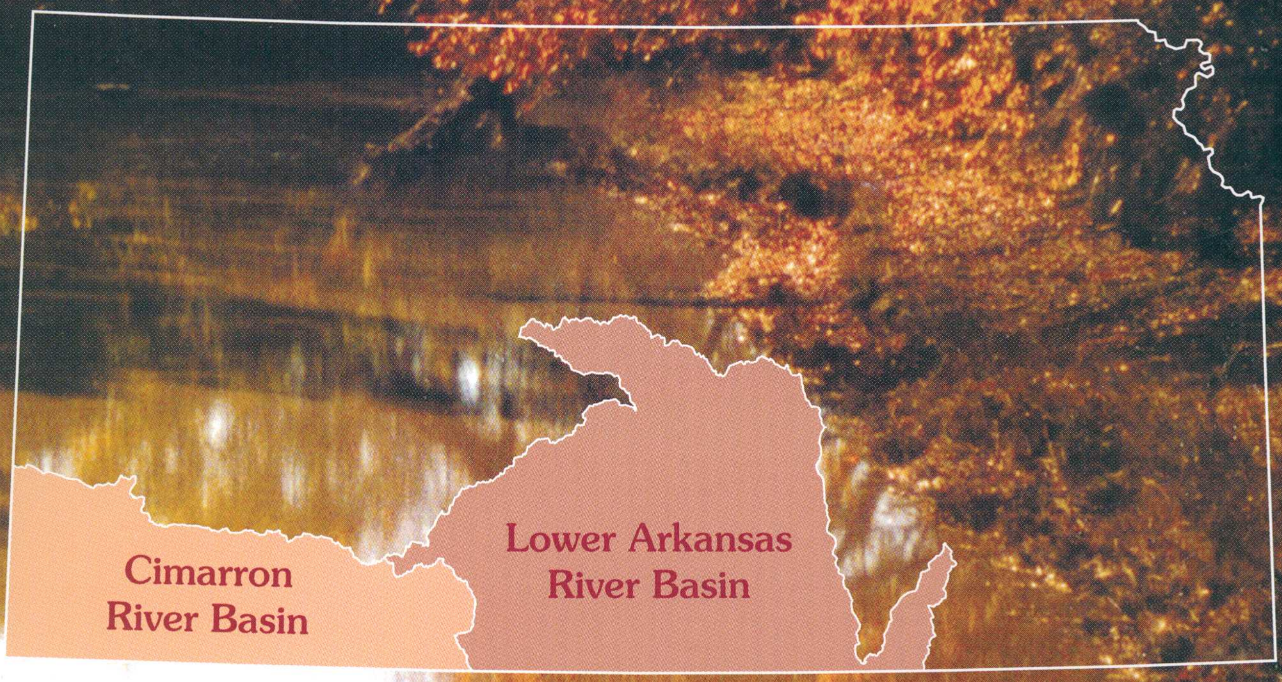
Estimated Flow-Duration Curves for Selected Ungaged Sites in the Cimarron and Lower Arkansas River Basins in Kansas

Water-Resources Investigations Report 00–4113



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Cover photograph: Cowskin Creek near Wichita, Kansas, November 1998
(photograph taken by Dennis Lacock, U.S. Geological Survey, Lawrence, Kansas)

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By SETH E. STUDLEY

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Lawrence, Kansas
2000

U.S. Department of the Interior

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CONVERSION FACTORS, ABBREVIATIONS, AND DEFINITIONS

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

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

Water year in U.S. Geological Survey reports is the 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends; thus, the year ending September 30, 1998, is called the "1998 water year."

Estimated Flow-Duration Curves for Selected Ungaged Sites in the Cimarron and Lower Arkansas River Basins in Kansas

By Seth E. Studley

Abstract

Flow-duration curves for 1968–98 were estimated for 16 ungaged sites in the Cimarron and lower Arkansas River Basins in south-central Kansas. The method of estimation used six unique factors of flow duration: (1) mean streamflow and percentage duration of mean streamflow, (2) ratio of 1-percent-duration streamflow to mean streamflow, (3) ratio of 0.1-percent-duration streamflow to 1-percent-duration streamflow, (4) ratio of 50-percent-duration streamflow to mean streamflow, (5) percentage duration of appreciable streamflow (0.10 cubic foot per second), and (6) average slope of the flow-duration curve. These factors were previously developed from a regionalized study of flow-duration curves using streamflow data for 1921–76. The method was tested on a currently measured, continuous-record streamflow-gaging station on the Little Arkansas River at Valley Center, Kansas, and was found to adequately estimate the computed flow-duration curve for the station. The low-flow parts of the estimated flow-duration curves were improved substantially using low- to medium-flow discharge measurements made concurrently with discharge measurements and flow-duration analyses performed at nearby, long-term, continuous-record, streamflow-gaging stations. The estimated flow-duration curves at the ungaged sites can be used for projecting future flow frequencies for assessment of total maximum daily loads (TMDL's) or other water-quality constituents and for water-availability studies.

INTRODUCTION

Section 303d of the 1977 Clean Water Act requires States to identify and list water bodies where State water-quality standards are not being met and to establish total maximum daily loads (TMDL's) for these waters (Kansas Department of Health and Environment, 1999a, b). A TMDL is a means for recommending controls needed to meet water-quality standards in a particular watershed. It specifies the amount a pollutant needs to be reduced to meet water-quality standards, allocates pollutant load reductions among pollutant sources in a watershed, and provides the basis for taking actions needed to restore a water body. A TMDL can identify the need for point-source and nonpoint-source controls (U.S. Environmental Protection Agency, 1998).

The State of Kansas has proposed the use of a stream's flow-duration curve to assess whether a stream's TMDL criterion is being exceeded (Kansas Department of Health and Environment, 1999a, b). Use of the duration curve yields a contaminant load that is based on the magnitude of the streamflow and also projects the expected annual duration of that load. Flow-duration curves for continuous-record, streamflow-gaging stations can be generated using the U.S. Geological Survey's (USGS) automated data processing system (ADAPS), a component of the National Water Information System (NWIS). For ungaged sites (those without continuous record), a method for estimating the flow-duration curves is needed.

One method for estimating flow-duration curves is outlined in Furness (1959) and in Searcy (1959). Furness (1959) applied the method to sites with drainage areas between 100 and 3,000 mi^2. The drainage-area limits were used because of the lack of long-term data for sites with drainage areas less than 100 mi^2 or more than 3,000 mi^2. Also, most of the basins in Kansas with drainage areas of more than 3,000 mi^2 are regulated and cannot be related to natural flow conditions. There are now (1999) several continuous-record streamflow-gaging stations in Kansas that have less than 100 mi^2 of drainage area and that have enough data available for testing the Furness method. One of the stations (Cow Creek near Claflin, station 07142860, fig. 1) is used in this report and serves as an example of how the Furness method works for ungaged sites with drainage areas less than 100 mi^2.

A 1.5-year study by the USGS, done in cooperation with the Kansas Department of Health and Environment (KDHE) to fulfill a part of the Kansas State Water Plan, was begun in January 1999 to test and refine the Furness method for estimating flow-duration curves for ungaged sites and to present estimated flow-duration curves for 16 selected ungaged sites in the Cimarron and lower Arkansas River Basins in Kansas. The specific study objectives were to:

(1) Test and, if necessary, refine the Furness method by generation of an estimated flow-duration curve for a long-term, continuous-record, streamflow-gaging station and compare the estimated curve with the computed curve for that station.

(2) Evaluate existing streamflow information for the ungaged sites for the verification and (or) refinement of the estimated flow-duration curve.

(3) Collect several, low- to medium-streamflow measurements at 16 selected ungaged sites and concurrently at respective nearby, long-term, continuous-record, streamflow-gaging stations.

(4) Construct estimated flow-duration curves for the selected ungaged sites using the Furness method and the streamflow measurements.

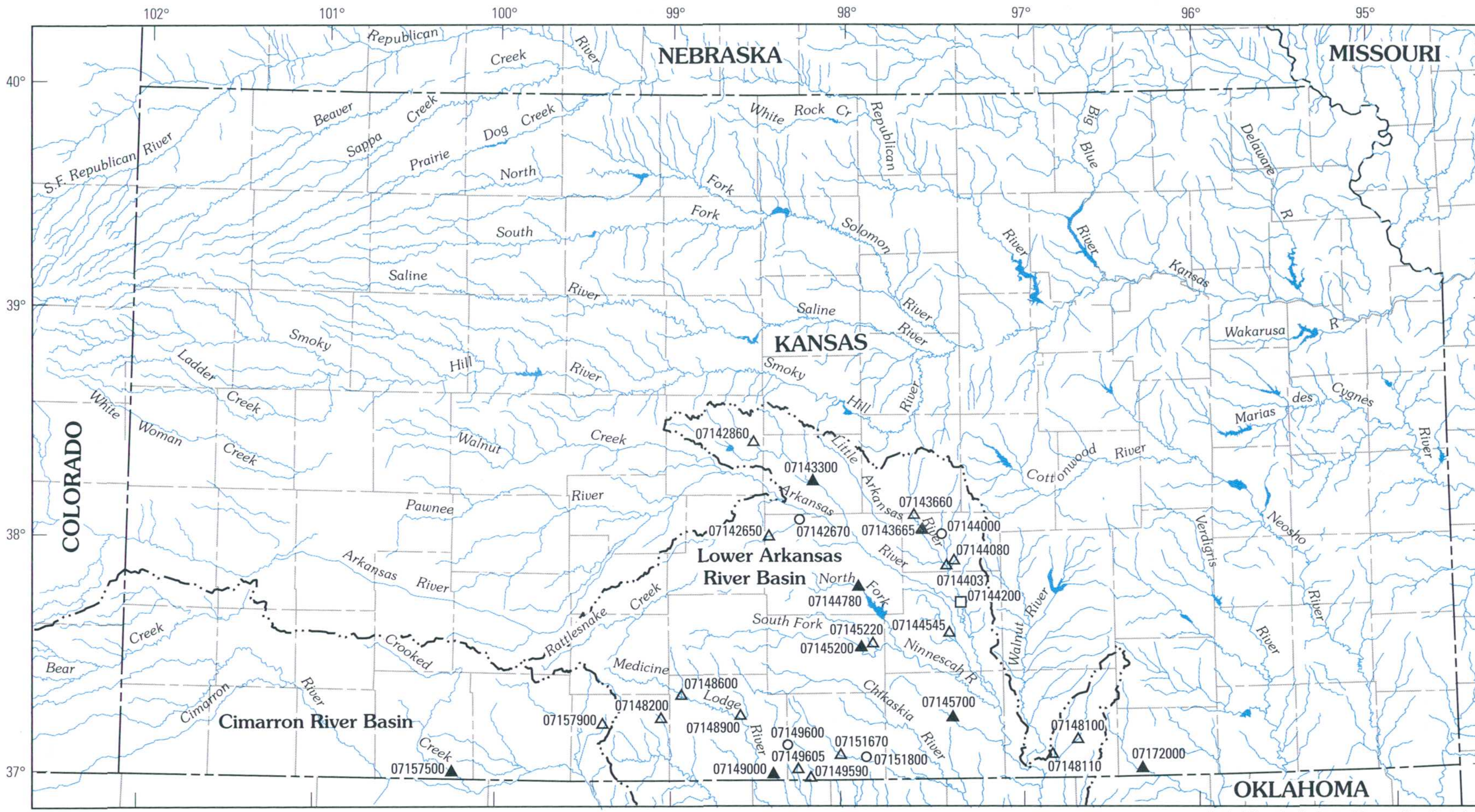
The streams that need estimated flow-duration curves were chosen on the basis of the Clean Water Act's required 303d list developed by KDHE. The ungaged sites on those streams were chosen by USGS personnel on the basis of accessibility to the stream, suitability of the site for streamflow measurement, and availability of historic streamflow data. In this report, ungaged sites are those sites that currently (1999) do not have continuous stage-recording equipment even though they may have some historical data available. Figure 1 shows the location of the 16 ungaged sites, 8 long-term, continuous-record, streamflow-gaging stations used to correlate ungaged-site streamflows to flow-duration percentages, 4 miscellaneous streamflow-measurement sites, and the station used to test the Furness method (07144200). Table 1 lists the ungaged sites and the concurrent, long-term, continuous-record, streamflow-gaging stations used for estimation of flow-duration curves.

A period of record from 1968 through 1998 was used for this study of flow durations in the Cimarron and lower Arkansas River Basins because, in the years since Furness developed the method for estimating flow-duration curves, changes in farming practices, the number of lakes and ponds, population, and land use have caused significant changes in the long-term flow-duration curves. By using 1968–98 streamflow records, the duration curves can be used to describe current flow conditions on the streams, from which planners can more accurately assess the availability of streamflow for future uses. Also, this period is long enough to include equal periods of both drought and flood conditions.

The purpose of this report is to present the results of a test of the Furness method for the estimation of flow-duration curves at a long-term, continuous-record, streamflow-gaging station and to present estimated flow-duration curves for selected ungaged sites in the Cimarron and lower Arkansas River Basins in Kansas (fig. 1, table 1). These estimated duration curves will be used by KDHE as part of the State's Water Plan to help ensure a safe and clean water supply for Kansans. From a national perspective, the methods and results presented in this report could have wide applicability for water-supply and water-quality assessments for sites where little or no streamflow data have been collected. The estimated flow-duration curves can provide a basis for evaluating streamflow on ungaged streams for water-power studies, stream-contamination studies, and other water-quality studies.

DESCRIPTION OF FURNESS METHOD

The method used in this study to estimate flow-duration curves (Furness, 1959, p. 186–211) uses maps and graphs to identify six unique factors of flow duration for ungaged sites. The factors are: (1) mean streamflow (fig. 2) and percentage duration of mean streamflow (fig. 3), (2) ratio of 1-percent-duration streamflow to mean streamflow (figs. 4 and 5), (3) ratio of 0.1-percent-duration streamflow to 1-percent-duration streamflow, (4) ratio of 50-percent-duration streamflow to mean streamflow



Base map from U.S. Geological Survey digital data, 1:2,000,000, 1994
Albers Conic Equal-Area projection,
Standard parallels 29°30' and 45°30', central meridian 96°

Basin delineation for lower Arkansas River Basin from Kansas Department of Health and Environment, 1999

EXPLANATION

—··— Boundary of river basin

07148900 △ Ungaged site and number

07157500 ▲ Concurrently measured, long-term, continuous-record streamflow-gaging station and number

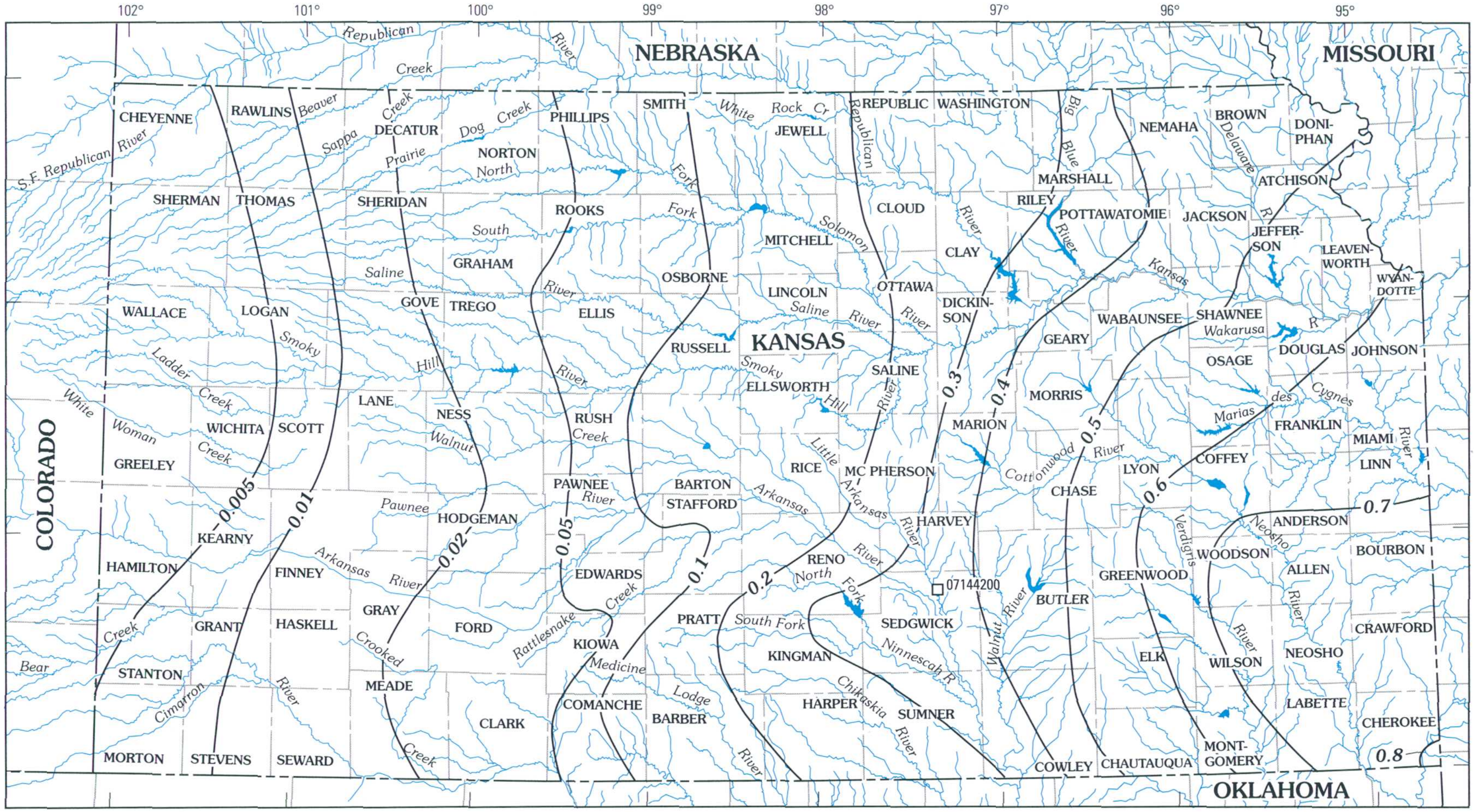
07149600 ○ Miscellaneous streamflow-measurement site and number

07144200 □ Streamflow-gaging station and number used to test Furness method for estimating flow-duration curves

Figure 1. Location of selected ungaged sites, concurrently measured, long-term, continuous-record streamflow-gaging stations, and miscellaneous streamflow-measurement sites in the Cimarron and lower Arkansas River Basins in Kansas used for estimation of flow-duration curves.

Table 1. Selected ungaged sites and concurrently measured, long-term, continuous-record, streamflow-gaging stations in the Cimarron and lower Arkansas River Basins in Kansas used for estimation of flow-duration curves

Ungaged sites			Concurrently measured, long-term, continuous-record, streamflow-gaging stations	
Site number (fig. 1)	Site name	Drainage area (square miles)	Station number (fig. 1)	Station name
07142650	Peace Creek near Sylvia	62.4	07144780	North Fork Ninnescah River above Cheney Reservoir
07142860	Cow Creek near Claflin	43.4	07143300	Cow Creek near Lyons
07143660	Turkey Creek near Buhler	180	07143665	Little Arkansas River at Alta Mills
07144037	Emma Creek 3 miles north and 0.75 mile west of Sedgwick	177	do.	do.
07144080	Sand Creek 3 miles north and 2 miles east of Sedgwick	86.5	do.	do.
07144545	Cowskin Creek near Oatville	152	07145700	Slate Creek near Wellington
07145220	Smoots Creek near Murdock	142	07145200	South Fork Ninnescah River near Murdock
07148100	Grouse Creek near Dexter	170	07172000	Caney River near Elgin
07148110	Silver Creek at Highway 166 east of Arkansas City	86.1	do.	do.
07148200	Mule Creek near Wilmore	127	07149000	Medicine Lodge River near Kiowa
07148600	Medicine Lodge River at Sun City	335	do.	do.
07148900	Elm Creek at Medicine Lodge	168	do.	do.
07149590	Sandy Creek near Waldron	161	do.	do.
07149605	Little Sandy Creek near Corwin	124	do.	do.
07151670	Bluff Creek south of Anthony	185	do.	do.
07157900	Cavalry Creek at Coldwater	39.0	07157500	Crooked Creek near Englewood



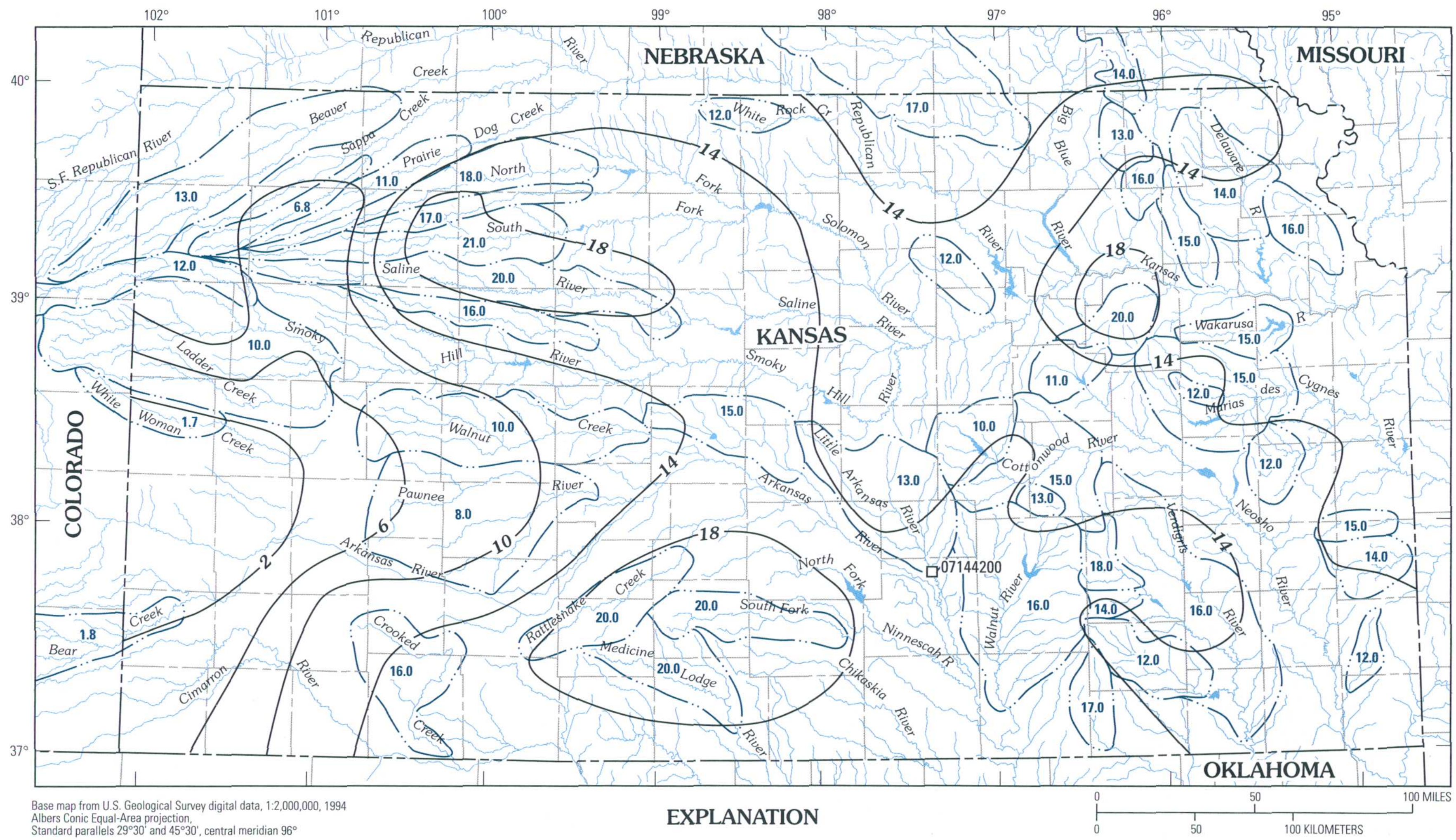
Base map from U.S. Geological Survey digital data, 1:2,000,000, 1994
Albers Conic Equal-Area projection,
Standard parallels 29°30' and 45°30', central meridian 96°

EXPLANATION

—*0.02*— Line of equal mean streamflow, in cubic feet per second per square mile—Interval varies

07144200 □ Streamflow-gaging station and number used to test Furness method for estimating flow-duration curves

Figure 2. Geographic variation of mean streamflow in Kansas (from Jordan, 1983, fig. 7).



Base map from U.S. Geological Survey digital data, 1:2,000,000, 1994
Albers Conic Equal-Area projection,
Standard parallels 29°30' and 45°30', central meridian 96°

EXPLANATION

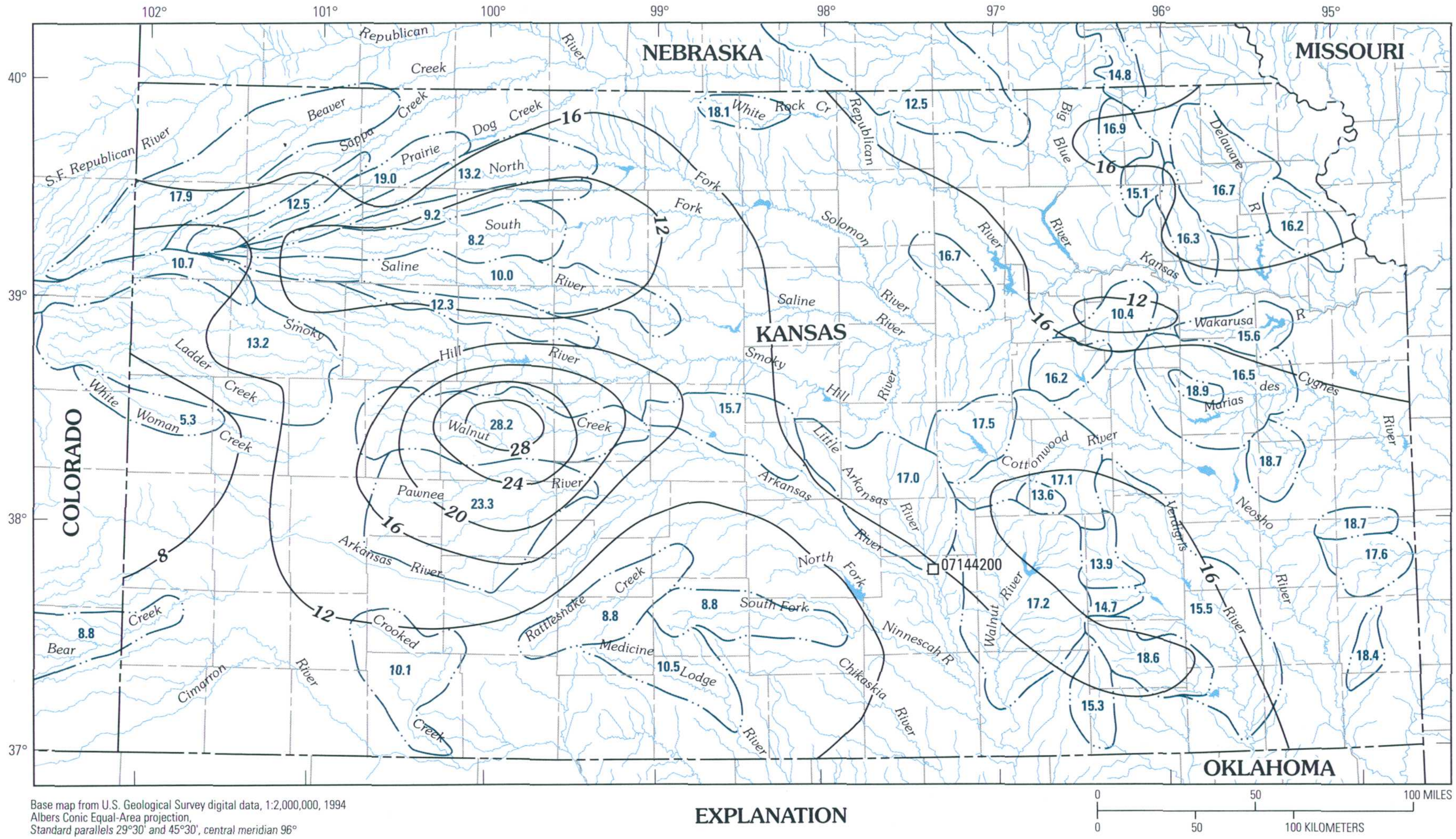
—*10*— Line of equal percentage duration—Interval 4 percent

—·· — Basin boundary

16.0 Percentage duration of mean flow for basin outlined

07144200□ Streamflow-gaging station and number used to test Furness method for estimating flow-duration curves

Figure 3. Percentage duration of mean streamflow in Kansas (from Jordan, 1983, fig. 8).



Base map from U.S. Geological Survey digital data, 1:2,000,000, 1994
Albers Conic Equal-Area projection,
Standard parallels 29°30' and 45°30', central meridian 96°

EXPLANATION

— *16* — Line of equal ratio—Interval 4 (nondimensional)

— · · — Basin boundary

10.5 Ratio of 1-percent flow to mean flow, for basin outlined, as adjusted to 500 square-mile drainage area

07144200□ Streamflow-gaging station and number used to test Furness method for estimating flow-duration curves

Figure 4. Ratios of 1-percent-duration streamflow to mean streamflow adjusted to drainage area of 500 square miles in Kansas (from Jordan, 1983, fig. 9).

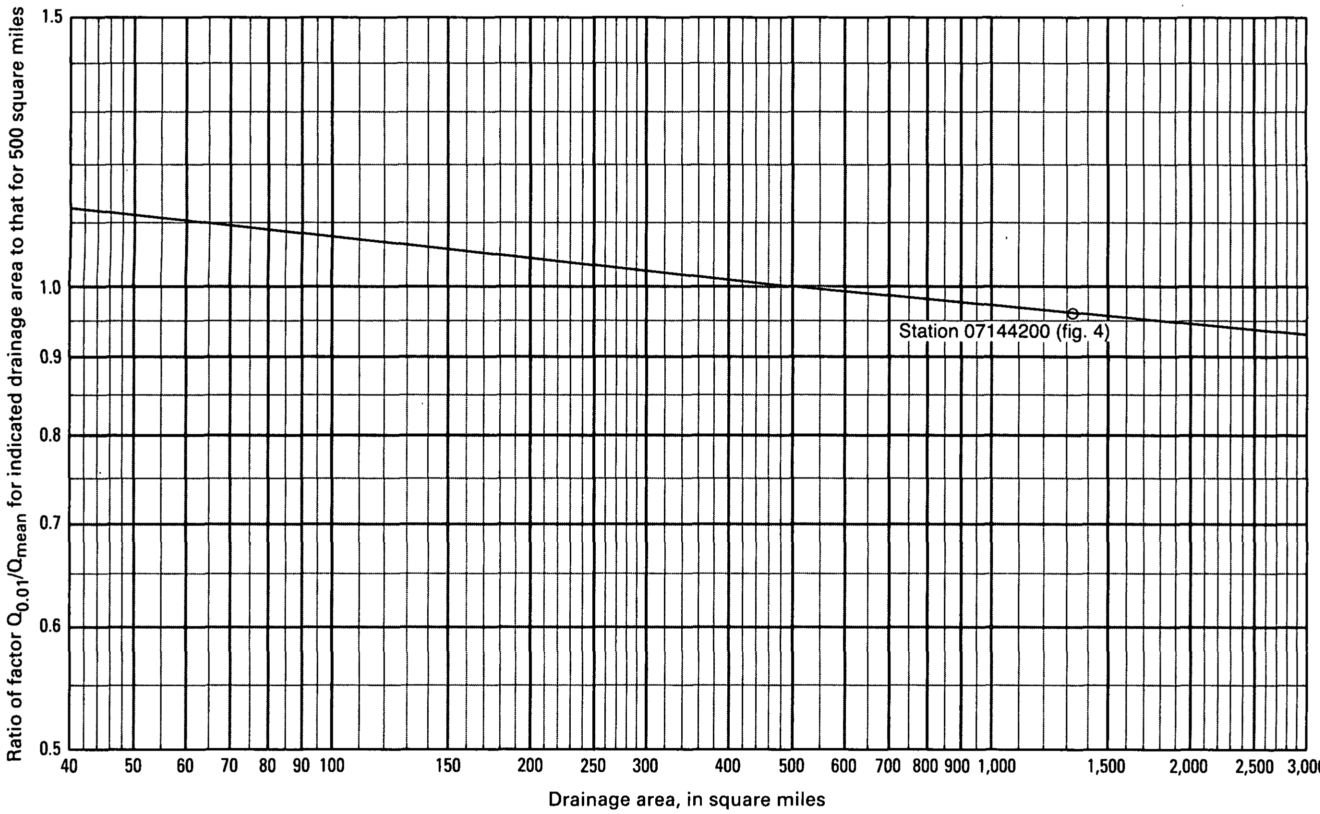


Figure 5. Relation between drainage area and ratio of 1-percent-duration streamflow to mean streamflow (Furness, 1959, fig. 142).

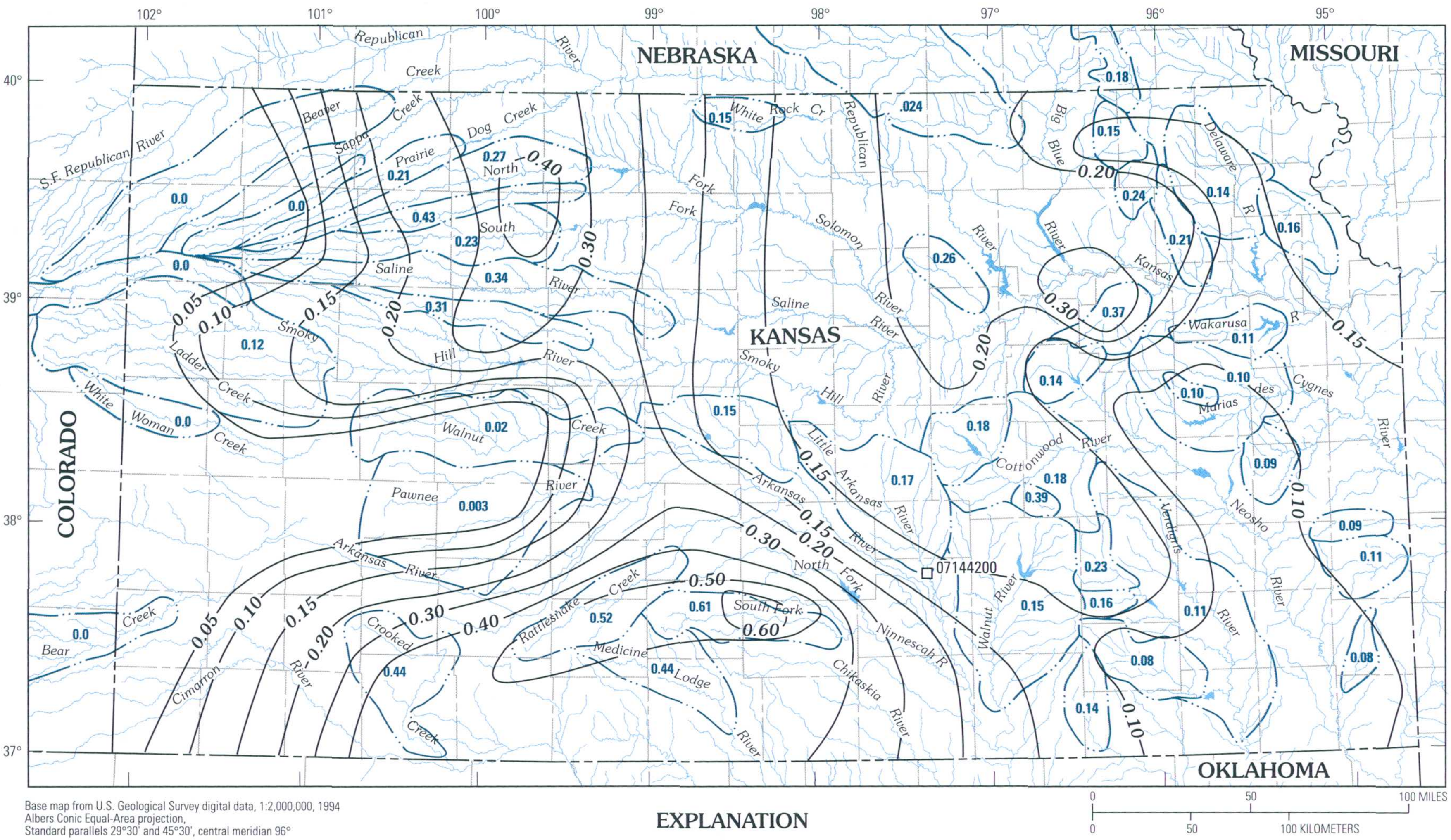
(figs. 6 and 7), (5) percentage duration of appreciable (0.10 ft^3/s) streamflow (figs. 8 and 9), and (6) average slope of the flow-duration curve (variability index) (figs. 10 and 11). The maps and graphs in Furness (1959) were originally created using streamflow data for 1921–56. In 1983, the maps were updated by Jordan (1983, p. 15–30) using an additional 20 years of data (1957–76) (in figure 2, data from 1965–80 were used for stations west of 99 degrees longitude) and data from many additional streamflow-gaging stations (Carswell, 1982).

To test the method of estimating flow-duration curves, a long-term, continuous-record, streamflow-gaging station on the Little Arkansas River at Valley Center, Kansas (station 07144200, fig. 1), was used. This station has operated continually since October 1923, has a drainage area of 1,327 mi^2, and is located in Sedgwick County (fig. 1). Comparison of the estimated flow-duration curve with the computed flow-duration curve for this station provides a test of the method for estimating flow duration. The estimated factors were developed for figure 12 as follows:

Mean streamflow: From figure 2, the mean streamflow for the Little Arkansas River at Valley Center (station 07144200, fig. 2) is 0.35 $(ft^3/s)/ mi^2$ or 0.35 x 1,327 = 464 ft^3/s. From figure 3, the percentage duration for mean streamflow for the Little Arkansas River at Valley Center (07144200, fig. 3) is 16 percent. The coordinates of mean streamflow are now defined and are plotted in figure 12 as 464 ft^3/s at 16-percent duration (point A).

1-percent-duration streamflow: From figure 4, the ratio of 1-percent-duration streamflow to mean streamflow for Little Arkansas River at Valley Center (station 07144200, fig. 4) is about 16. From figure 5, the adjustment from 500 to 1,327 mi^2 is 0.96. The ratio of 1-percent-duration streamflow to mean streamflow is 16 x 0.96 = 15.36. Therefore, the 1-percent-duration streamflow is 15.36 x 464 ft^3/s = 7,127 ft^3/s. In figure 12, the 1-percent-duration point is plotted at 7,127 ft^3/s (point B).

0.1-percent-duration streamflow: Using the average ratio of 0.1-percent-duration streamflow to 1-percent-duration streamflow as calculated by Jordan



Base map from U.S. Geological Survey digital data, 1:2,000,000, 1994
Albers Conic Equal-Area projection,
Standard parallels 29°30' and 45°30', central meridian 96°

EXPLANATION

—*0.01*— Line of equal ratio—Interval 0.05 and 0.10 (nondimensional)

—··— Basin boundary

0.17 Ratio of 50-percent flow to mean flow, for basin outlined, as adjusted to 500-square-mile drainage area

07144200 □ Streamflow-gaging station and number used to test Furness method for estimating flow-duration curves

Figure 6. Ratios of 50-percent-duration streamflow to mean streamflow adjusted to drainage area of 500 square miles in Kansas (from Jordan, 1983, fig. 11).

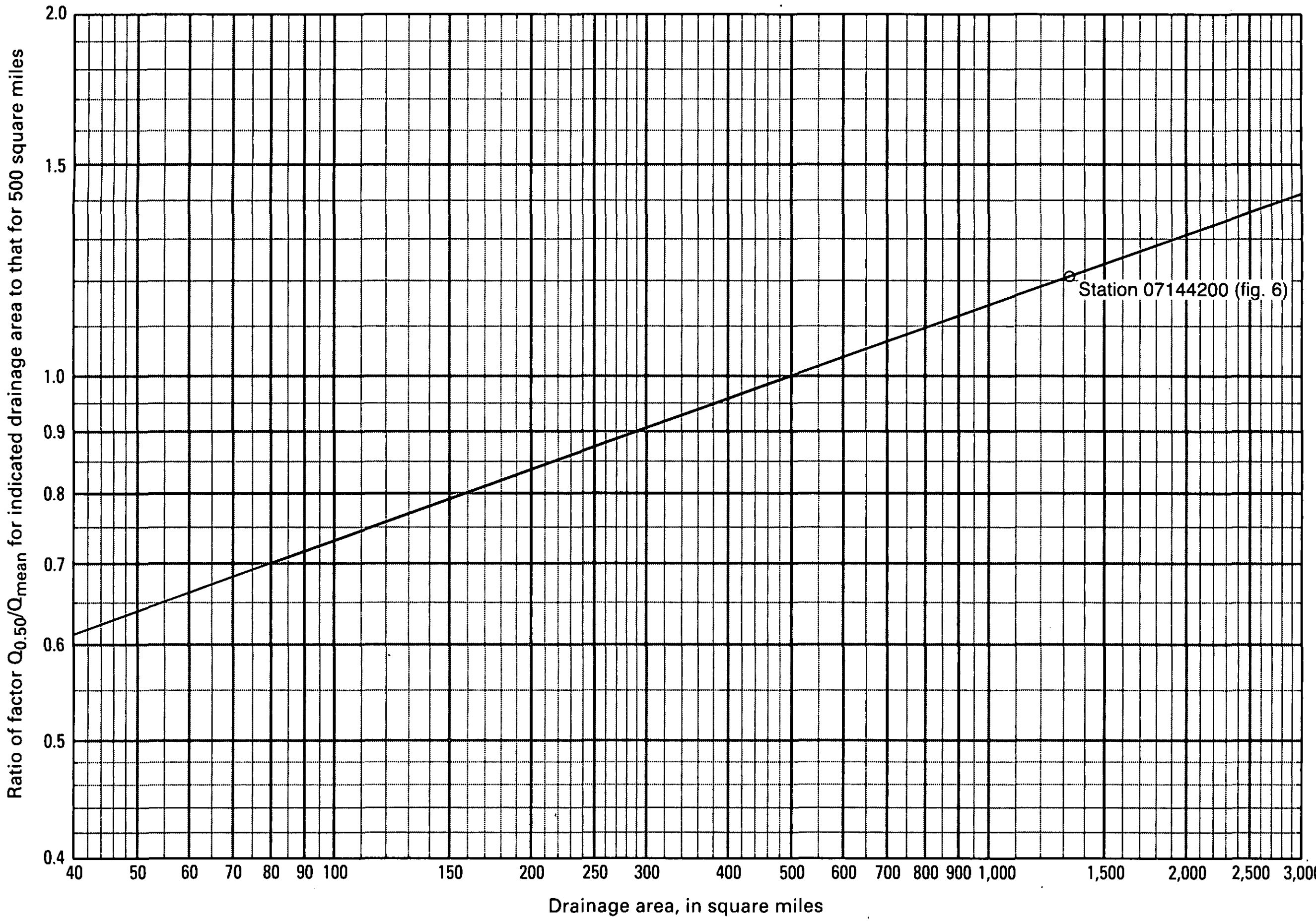


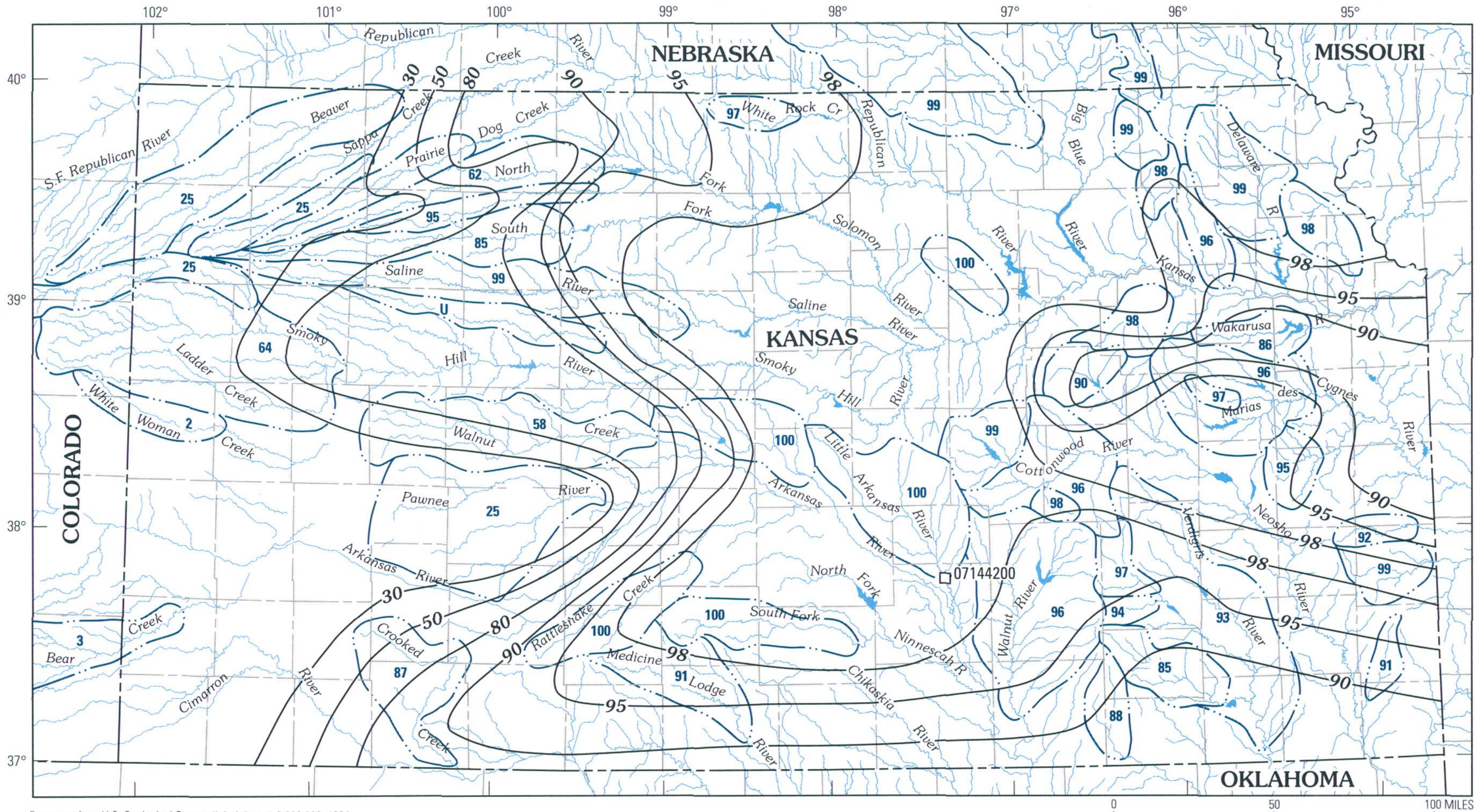
Figure 7. Relation between drainage area and ratio of 50-percent-duration streamflow to mean streamflow (from Furness, 1959, fig. 144).

(1983, p. 21), the value plotted in figure 12 for 0.1-percent duration is 7,127 x 3.1 = 22,100 ft^3/s (point C). If the Valley Center station were located west of 99° longitude, the 1-percent-duration streamflow would be multiplied by 5.7, instead of 3.1, to obtain the 0.1-percent-duration streamflow.

50-percent-duration streamflow: Figure 6 indicates that the ratio of 50-percent-duration streamflow to mean streamflow for the Valley Center station (07144200, fig. 6) is about 0.15, and figure 7 shows that the adjustment to 1,327 mi^2 is 1.21; therefore, the 50-percent-duration streamflow is 0.15 x 1.21 x 464 = 84 ft^3/s as plotted in figure 12 (point D).

Duration percentage of appreciable flow: "Appreciable flow" is the name given by Furness (1959) to represent a streamflow of 0.10 ft^3/s. This value of streamflow was important because, for many years, this was the smallest non-zero streamflow value reported in most streamflow records. Figure 8 shows that the percentage duration of 0.10 ft^3/s adjusted to 500 mi^2 at the Valley Center station (07144200, fig. 8) is about 99 percent. To find the duration of appreciable flow for 1,327 mi^2 in figure 9, a point representing 99-percent duration and a drainage area of 500 mi^2 was plotted. Following the diagonal line to 1,327 mi^2 of drainage area, the percentage duration of 0.10 ft^3/s was found to be about 99.6 percent. In figure 12, the point is plotted as 0.10 ft^3/s at the 99.6-percent duration (point E). If an estimated duration curve is to be developed for a site where appreciable flow occurs more than 99 percent of the time, as in this example, the value of the duration of appreciable flow is ignored, and the curve is developed using the other five factors.

Average slope of the duration curve: The average slope of the duration curve is a graphical approximation of the variability index, which is the standard deviation of the logarithms of the stream discharges (Furness, 1959, p. 202–204, figs. 147 and 148). On a duration curve that fits the log-normal distribution



Base map from U.S. Geological Survey digital data, 1:2,000,000, 1994
Albers Conic Equal-Area projection,
Standard parallels 29°30' and 45°30', central meridian 96°

EXPLANATION

—95— Line of equal percentage duration of appreciable flow for basins adjusted to 500-square-mile drainage area—Interval varies

—·· — Basin boundary

0.17 Percentage duration of appreciable flow (0.10 cubic foot per second) adjusted to 500-square-mile drainage area, plotted near streamflow-gaging station for basin outlined—U, undefined

07144200□ Streamflow-gaging station and number used to test Furness method for estimating flow-duration curves

Figure 8. Percentage duration of appreciable flow (0.10 cubic foot per second) adjusted to drainage area of 500 square miles in Kansas (from Jordan, 1983, fig. 13).

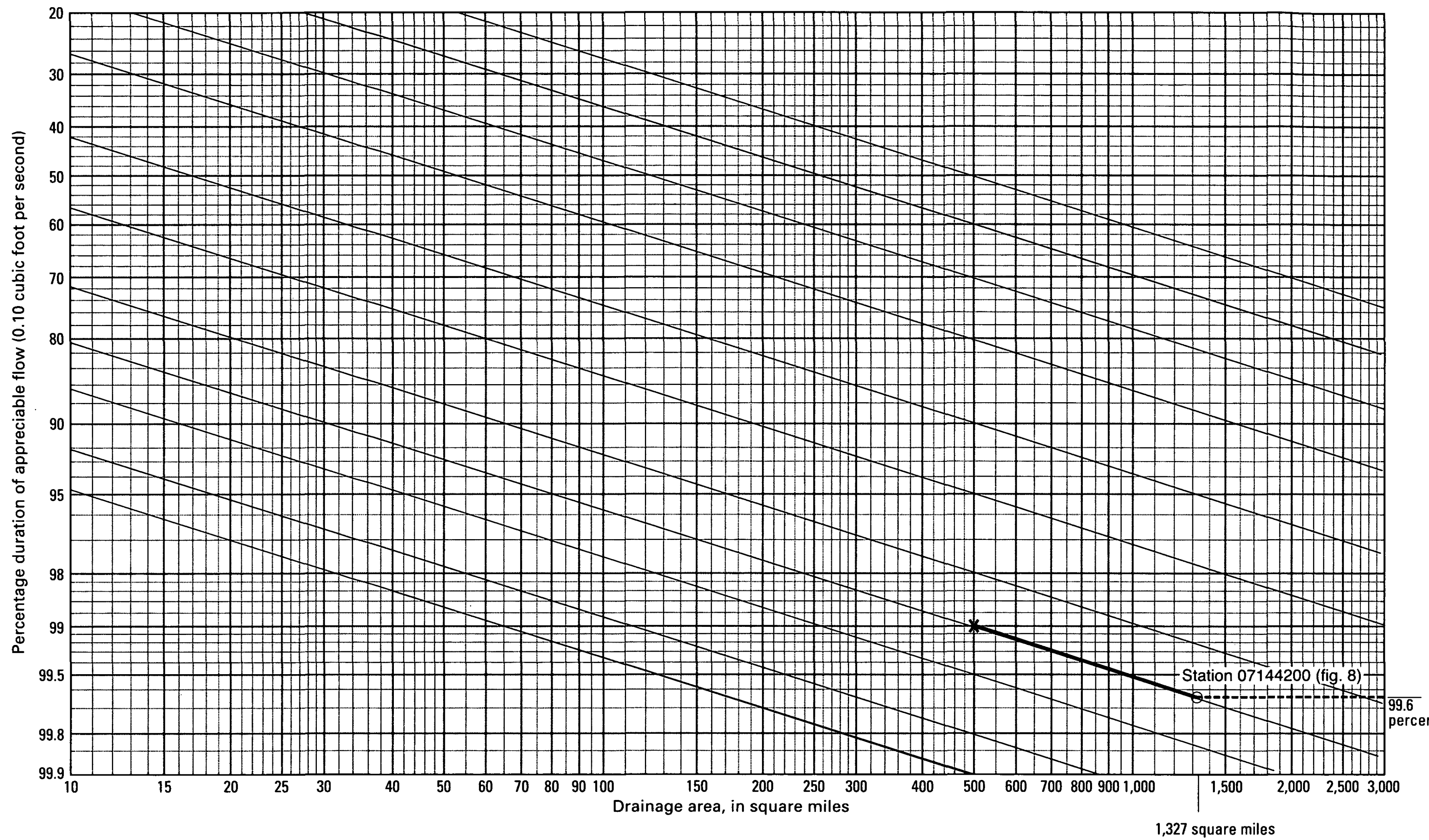
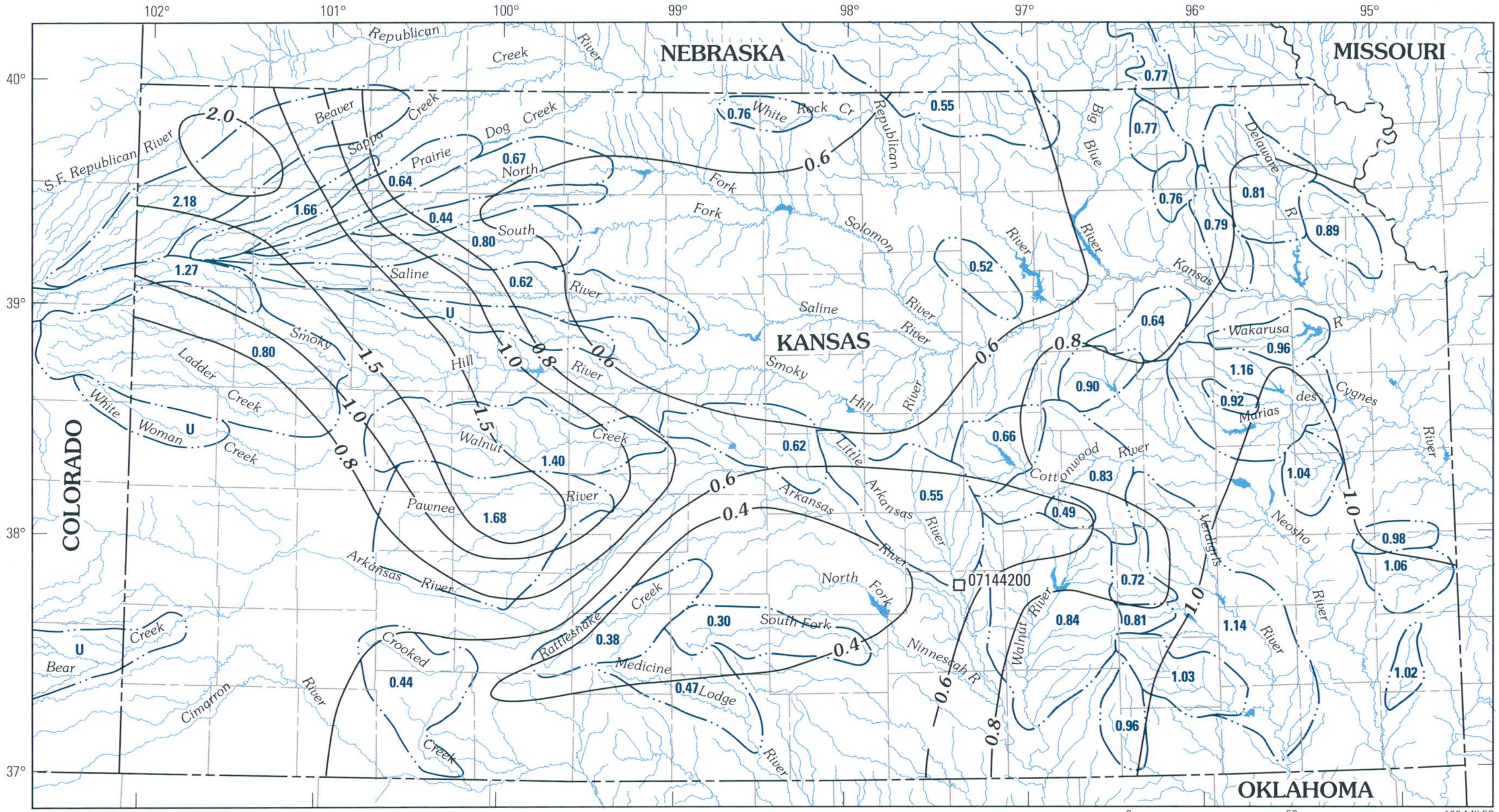


Figure 9. Relation between drainage area and duration of appreciable flow (0.10 cubic foot per second) (from Furness, 1959, fig. 145).



Base map from U.S. Geological Survey digital data, 1:2,000,000, 1994
Albers Conic Equal-Area projection,
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EXPLANATION

—0.6— Line of equal average slope of duration curve—Interval 0.2 and 0.5 logarithm unit

—··— Basin boundary

0.44 Average slope of duration curve for basin outlined, adjusted to 500-square-mile drainage area—U, undefined

07144200□ Streamflow-gaging station and number used to test Furness method for estimating flow-duration curves

Figure 10. Average slopes of flow-duration curves adjusted to drainage area of 500 square miles in Kansas (from Jordan, 1983, fig. 15).

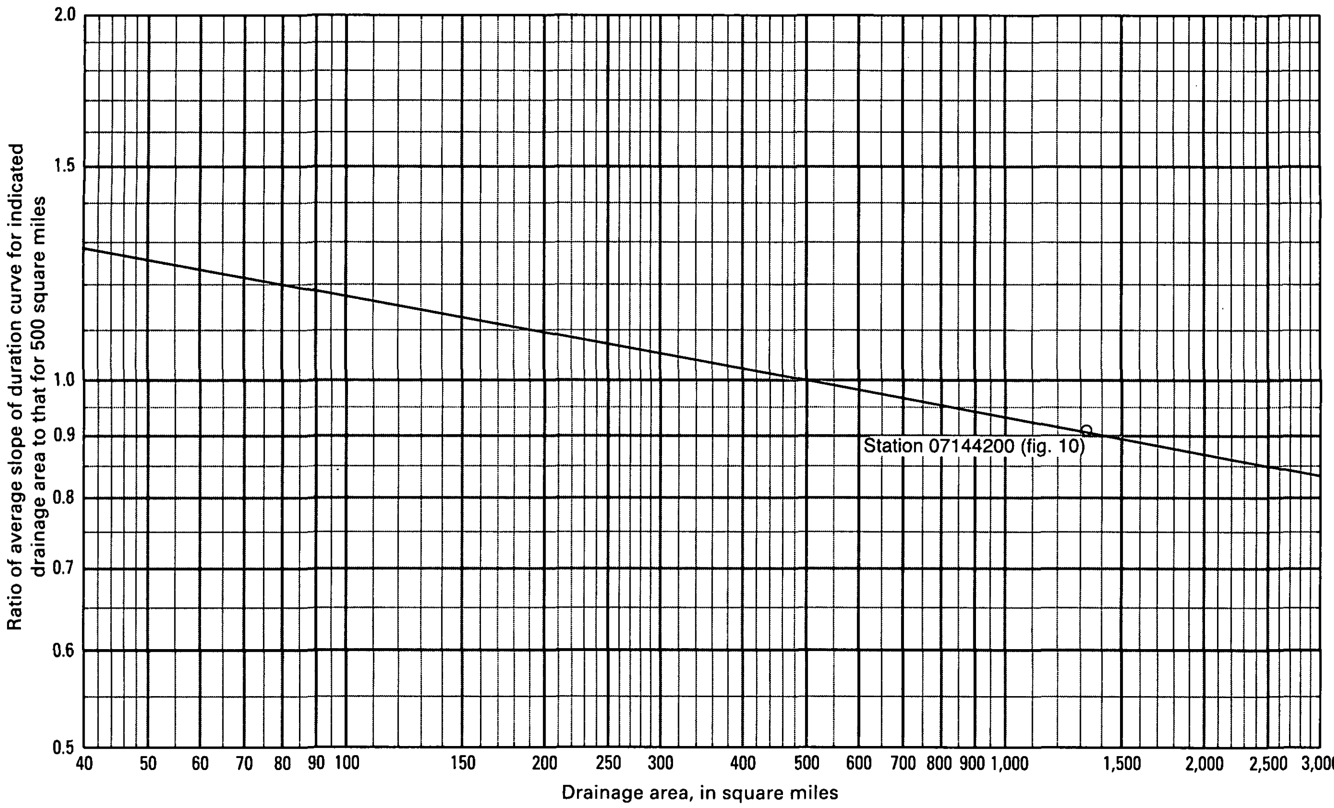

Figure 11. Relation between drainage area and average slope of flow-duration curve (from Furness, 1959, fig. 147).

exactly, the variability index is equal to the ratio of the discharge at the 15.87-percent-duration point to the discharge at the 50-percent-duration point. Because duration curves usually do not exactly fit the log-normal distribution, the average-slope line is drawn through an arbitrary point, and the slope is transferred to a position approximately defined by the previously estimated points.

Figure 10 provides an average slope of about 0.55 for a 500-mi^2 drainage area for the Valley Center station (07144200, fig. 10). Figure 11 shows an adjustment of 0.91 for 1,327 mi^2 of drainage area. Thus, the average slope for the Valley Center station is 0.55 x 0.91 = 0.50. The average-slope line is plotted in figure 12 by drawing a straight line between a point defined by 0.50 times the height of one log cycle, or about 3,300 ft^3/s on the 1,000-to-10,000 cycle, plotted at 15.87-percent duration and a point at 1,000 ft^3/s at 50-percent duration. Because the Valley Center station has appreciable flow more than 95 percent of the time, the average-slope line defines the average slope of the duration curve from 5- to 95-percent duration. If the duration percentage of appreciable flow is less than 95 percent, then the average-slope line defines a line for 1/19 to 19/19 times the duration percentage of appreciable flow. For example, if the duration percentage of appreciable flow is 93 percent, then the slope is applied to the area of the curve between 4.9- and 93-percent duration.

Using five of the six factors plotted in figure 12 (point E is ignored), duration-curve estimation was attempted for the Little Arkansas River at Valley Center. A smooth curve was drawn through the four estimated points, keeping in mind the average slope and the duration range for which that slope applies. After the estimated duration curve was drawn, a line parallel to the average-slope line was drawn to verify that the average slope of the estimated duration curve, between the limits of 5- and 95-percent duration, is close to the estimated slope from the map. The final curve is the estimated duration curve for the station, shown as a dashed line in figure 12. The computed duration curve for the station for 1968–98 is shown as a solid line. The agreement between the estimated duration curve and the computed duration curve for the Little Arkansas River at Valley Center is close. Accuracy may be improved with the use of low- to medium-flow measurements made at the Valley Center station and correlating them with the durations at a nearby, long-term, continuous-record, streamflow-gaging station.

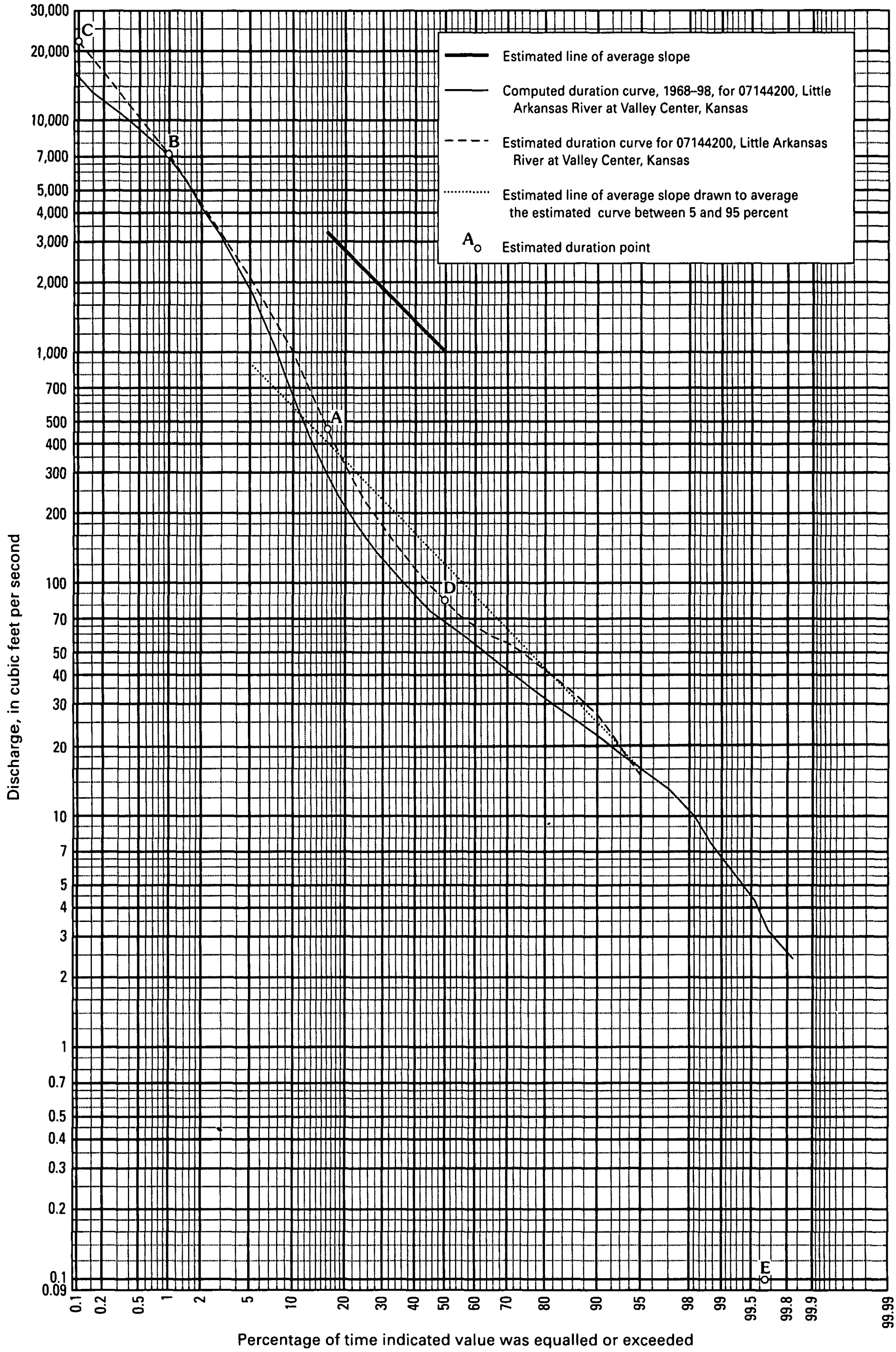

Figure 12. Comparison of estimated flow-duration curve with computed flow-duration curve for 1968–98 for Little Arkansas River at Valley Center (station 07144200, fig. 1).

If additional accuracy for the estimated duration curve is needed, the area under the curve is computed, and then the solution for the mean discharge is found using the method described by Furness (1959, p. 179). Then, if necessary, the curvature of the upper part of the estimated curve is revised to obtain the desired agreement between the area under the curve and the mean discharge.

The estimated duration curve for Cow Creek near Claflin, station 07142860 (fig. 15, appendix A at the end of this report), is an example of how the Furness method may be applied to sites with drainage areas less than 100 mi^2. The Claflin station has a drainage area of 43.4 mi^2 and has 15 years of continuous streamflow data from 1967–81. The computed duration curve and estimated duration curve for this site are plotted using discharge per square mile, which is the duration discharge divided by the drainage area. The estimated duration points and streamflow measurements define an estimated curve that closely resembles the computed duration curve for the 1967–81 period. From this example, it appears that the Furness method is applicable to smaller drainage-area sites when miscellaneous low-flow discharge measurements are used.

USE OF MISCELLANEOUS MEASUREMENTS

Because there are many factors that affect low-flow duration, that part of the flow-duration curve is usually the most difficult to accurately estimate. The maps and graphs used thus far reflect only the average regional low-flow trends, which in most cases, are inadequate for studies that need more accurate data. A few appropriately timed low- to medium-flow measurements at an ungaged site will greatly improve the accuracy of the low-flow part of the estimated flow-duration curve. The measurements can be correlated directly with a nearby, long-term, continuous-record streamflow-gaging station for improvement of the low-flow part of the estimated duration curve. Historic measurements also may be used by correlating them to the daily discharge duration percentage at a nearby, long-term station. Only those measurements made after any surface runoff has ceased (base flow) and before the correlation site reaches zero flow are useful.

It is important to choose a long-term station that is not affected by streamflow regulation or noticeably different climatic conditions for correlation to an ungaged site. The station also should have a period of record that includes the period that is being estimated at the ungaged site. If there is no station close enough to the ungaged site meeting these criteria, a station with a shorter period of record can be used, and the data can be extended using methods outlined by Furness (1959) and Searcy (1959).

An example of how discharge measurements at ungaged sites are used to improve the estimated duration curve is shown in figure 13. The estimated curve that was developed in figure 12 shows a close approximation to the actual duration curve for 1968–98. The part of the duration curve that is the most difficult to estimate is the low-flow part, and with the use of some miscellaneous low-flow measurements, this part of the curve can be verified or improved. A retrieval of data stored in NWIS for the Valley Center station provided 62 measurements, dating back to 1987, with discharges less than 84 ft^3/s, which is the estimated 50-percent-duration discharge. Of those 62 measurements, 49 were made when the stream appeared to represent base-flow conditions (no apparent surface runoff). These 49 discharge values were correlated with mean daily streamflow values from the Little Arkansas River at Alta Mills station (07143665, fig. 1). The duration percentages for each daily discharge value then were taken from the 1968–98 duration curve for the Alta Mills station and assigned to the same day's discharge value for the Valley Center station (07144200, fig. 1). The measurements were plotted in figure 13 at the correlated duration percentages acquired from the Alta Mills station. The measurements indicate that the low-flow part of the curve should be shifted to the right and also extended beyond 95-percent duration to 99.8-percent duration as shown by the blue line in figure 13. The extended estimated duration curve appears reasonable when compared to the computed 1968–98 duration curve for the site.

Tests were performed on all of the other concurrently measured streamflow-gaging stations listed on the right in table 1. Although the results are not shown in this report, they were similar to those for the Little Arkansas River at Valley Center station. The estimated curves were fairly accurate in the high-flow part of the curve and less accurate in the low-flow part of the curve when compared with the computed duration data for 1968–98. The computed curves for the concurrently measured stations listed on the right in table 1 were all improved when low-flow discharge

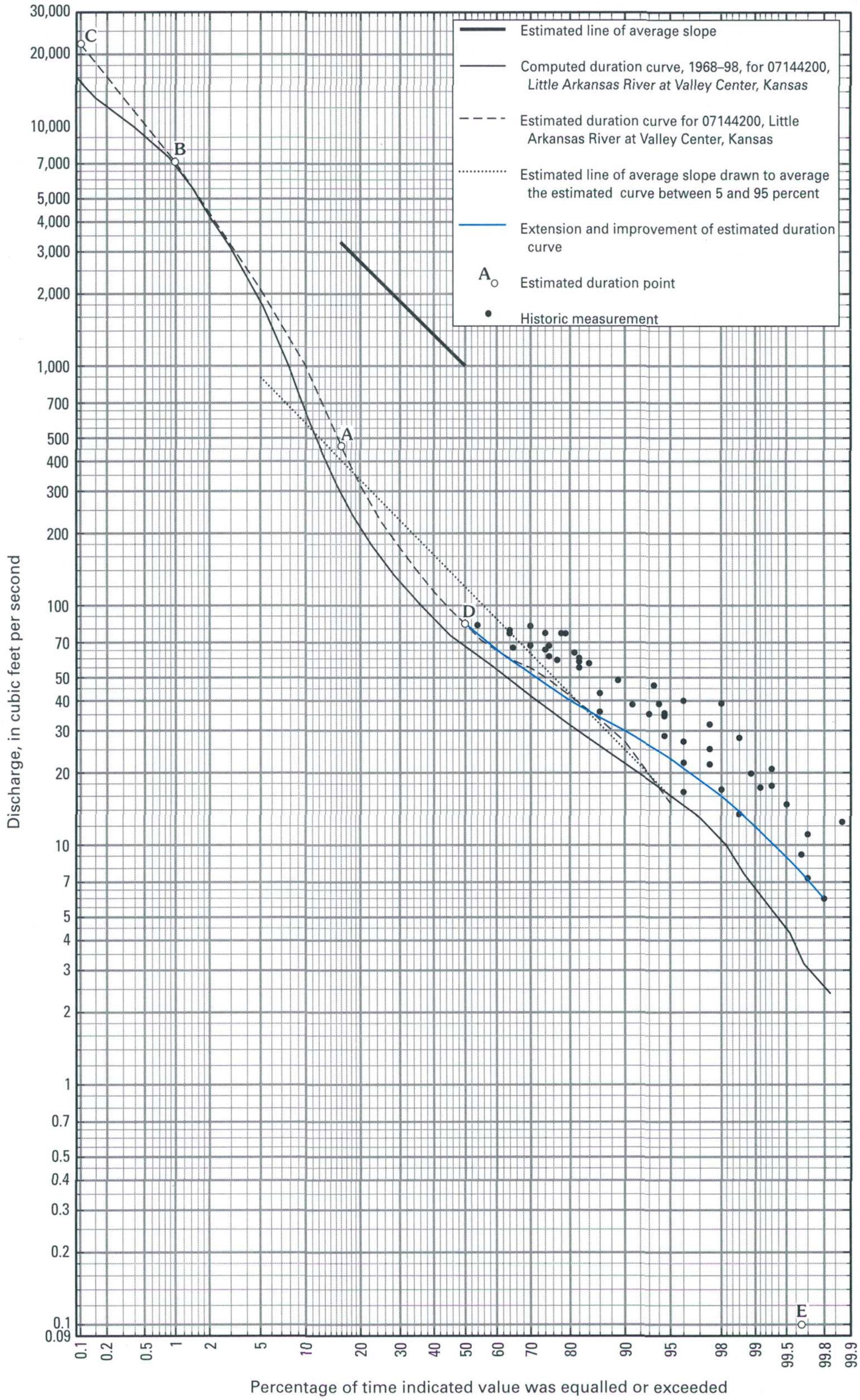

Figure 13. Improvement of estimated flow-duration curve by use of low-flow measurements for Little Arkansas River at Valley Center (station 07144200, fig. 1).

measurements were correlated with nearby stations for 1968–98.

EXISTING STREAMFLOW INFORMATION AT UNGAGED SITES

The use of existing historic streamflow data for an ungaged site that needs an estimated duration curve will help to make the estimate more accurate. Much of the streamflow data for the ungaged sites in this study was in the form of miscellaneous measurements made for previous studies. Some of the data were collected at exactly the same ungaged site, whereas other data were collected at a different site on the same stream. If the streamflow measurements are from a site that is on the same stream near the site to be estimated, the measurements can be related to the desired site by converting the measurements to discharge per square mile of drainage area at the measurement site and then multiplying it by the drainage area of the desired ungaged site. The new discharge then is correlated with the discharge at a nearby, long-term, continuous-record, streamflow-gaging station to assign its duration percentage. Some of the most useful data come from discontinued, continuous-record, streamflow-gaging stations that were operated at the currently (1999) ungaged sites. These stations were in operation for several years and then discontinued. The daily streamflow data from these discontinued stations can be used to calculate a flow-duration curve for the currently (1999) ungaged site. Although the calculated data will not necessarily represent the duration curve for the desired period of record, it will give an approximation of the general shape of the duration curve for the ungaged site.

Fourteen of the 16 selected ungaged sites for this study had historic streamflow data available for use in the estimation process. Most of the available streamflow information was in the form of miscellaneous streamflow measurements either at the ungaged site or at a nearby site on the same stream. Two of the currently ungaged sites (Cow Creek near Claflin and Cavalry Creek at Coldwater) had a short period of continuous streamflow data. The computed short-term duration curve for these two sites was valuable in refining the estimated duration curves. These two sites also have drainage areas of less than 100 mi^2 and are outside the range of drainage area for which Furness (1959) had indicated this estimation method is applicable. They can, however, be estimated more accurately using the Furness method for the high-flow part of the duration curve and using the short-term computed duration data and miscellaneous measurements for the low-flow part of the curve. The miscellaneous measurements made at the sites with smaller drainage areas are very important for the verification or improvement of the estimated duration curve.

COLLECTION OF BASE-FLOW MEASUREMENTS

Base-flow measurements made at ungaged sites can be useful when refining an estimated duration curve. These measurements should only be made when the ungaged site and the concurrently measured, long-term, continuous-record, streamflow-gaging station are not affected by runoff. Base-flow measurements eliminate inconsistencies that may be caused by variable rainfall-runoff rates. By monitoring the streamflow at the long-term, continuous-record, streamflow-gaging station, specific flow-duration percentage discharges can be targeted for measurement at the ungaged site. This is useful when a range of flow-duration percentages is needed to thoroughly define the estimated curve. The most accurate duration percentages are obtained when both the ungaged and gaged sites are measured concurrently and at a steady flow.

For this study, a total of 52 discharge measurements were made during 1999 water year at the ungaged sites, an average of about three measurements per site. Due to a very wet spring and early summer in 1999, fewer measurements were made than desired. Unpredictability of the weather makes it important to begin collecting data as far ahead as possible when additional discharge measurements will be needed. In most cases, a concurrent measurement was made at a nearby, long-term, continuous-record, streamflow-gaging station. There were a few instances when this was not accomplished, and a computed hourly discharge data value was retrieved from NWIS for the gaged site that then was used to determine the duration percentage.

CONSTRUCTION OF ESTIMATED FLOW-DURATION CURVES

The procedures for constructing the estimated flow-duration curves are those given in the section describing the Furness method. Five plotted points are used to draw a smooth curve, and then the average-slope line is used to help refine the middle 90 percent of the curve. If the percentage duration of appreciable flow is greater than 99 percent, then the point pertaining to appreciable flow is ignored, and the curve is drawn using the other four points and the average slope of the curve from 5- to 95-percent duration. This procedure will yield a duration curve that reflects the long-term flow duration for 1921–76.

The low-flow part of the duration curve is the most difficult part of the curve to accurately estimate because there are many variables that affect the shape of that part of the curve. Geology, geography, land use, changes in water use, and whether or not the stream flows perennially are some of the factors that affect the low-flow part of the duration curve. If low-flow measurements have been made at a site in the past, they can be used to improve the low-flow part of the duration curve. Also, a few current, well-timed, low-flow discharge measurements will help to improve the low-flow part of the curve.

If the period of record desired for a site is different from 1921–76, then data from the long-term, continuous-record, streamflow-gaging station used as the comparison site should be examined. The flow-duration curve for the desired period of record should be computed and compared to the estimated curve for that station to assess any changes that may be appropriate for the ungaged site's estimated duration curve. If, for example, the computed 20-percent duration streamflow at the gaging station is 5 percent higher than the estimated 20-percent duration discharge, then it would be appropriate to increase the estimated 20-percent duration discharge for the ungaged site by 5 percent. In general, it was found through development of flow-duration curves for the eight long-term, continuous-record, streamflow-gaging stations used for correlation in this study that the high-flow part of the duration curves can be closely estimated using the maps and graphs provided. The low-flow part of the duration curves generally were poorly estimated using the maps and graphs provided; however, the low-flow part of the duration curves were greatly improved by the use of low-flow measurements. Ungaged sites that have only a few measurements would benefit from additional measurements that would add more accuracy to the estimated curve or provide a basis for modifying the low-flow part of the estimated curve.

The estimated flow-duration curves for the 16 selected ungaged sites are presented in appendix A. In most cases, the low-flow part of the curves have been modified from the originally estimated curve on the basis of streamflow measurements. Appendix B provides the site descriptions for the 16 ungaged sites, and appendix C provides a listing of the miscellaneous streamflow measurements made at the 16 ungaged sites during 1999. The curves have been presented in discharge per square mile of drainage area so that they may used for sites on the same stream that are near the estimated site. To use the curve at a different site, multiply the discharge per square mile value of the curve by the drainage area of the desired site to obtain the discharge for the site. Care should be taken not to use the estimated duration curves at sites too far away because other factors may affect the duration curve at the estimated site that may not affect the flow duration at a different site on the same stream. It is more accurate to estimate a flow-duration curve for the intended site rather than trying to use the estimated curve for a different site on the same stream.

SUMMARY AND CONCLUSIONS

Flow-duration curves were estimated for 16 ungaged sites in the Cimarron and lower Arkansas River Basins in south-central Kansas for 1968 through 1998 on the basis of regionalized, long-term streamflow data as well as discharge measurements. The method for estimating flow-duration curves used six unique factors of flow duration that can be applied to ungaged sites. The six factors are (1) mean streamflow and percentage duration of mean streamflow, (2) ratio of 1-percent-duration streamflow to mean streamflow, (3) ratio of 0.1-percent-duration streamflow to 1-percent-duration streamflow, (4) ratio of 50-percent-duration streamflow to mean streamflow, (5) percentage duration of appreciable streamflow (0.10 cubic foot per second), and (6) average slope of the flow-duration curve. These factors were previously developed from a regionalized study of flow-duration using data for 1921–76. The factors then were used to draw a smooth, estimated duration curve for each of the 16 ungaged sites. The low-flow parts of the estimated flow-duration curves were verified or improved substantially on the basis of historic streamflow data collected at the ungaged site (if available) and (or) several historic and recent (1999) low- to medium-flow streamflow measurements made concurrently with nearby, long-term, continuous-record, streamflow-gaging stations. The method was tested on a currently measured, continuous-record, streamflow-gaging station on the Little Arkansas River at Valley Center, Kansas, and was found to adequately estimate the computed flow-duration curve for the station. The estimated flow-duration curves can be used for projecting future flow frequencies for total maximum daily load (TMDL) assessments or other water-quality assessments and for water-availability studies.

Miscellaneous streamflow records were available for use with all but 3 of the 16 ungaged sites for which estimated duration curves were developed. A majority of the records were miscellaneous streamflow measurements for either the ungaged sites or nearby sites on the same streams. Two of the currently (1999) ungaged sites, Cow Creek near Claflin and Cavalry Creek at Coldwater, had 15 years (1967–81) of continuous streamflow data from which short-term, flow-duration information was computed. This information, along with several miscellaneous streamflow measurements at each site, was valuable for the refinement of the estimated flow-duration curves. Because these two sites have less than the minimum drainage area of 100 mi^2 recommended by Furness for this method of estimating flow duration, the 15 years of data for these two sites were helpful for verification and refinement of their estimated duration curves. These two sites also provide a basis for the use of this method at other ungaged sites in Kansas with drainage areas less than 100 mi^2.

Fifty-two measurements were collected at the ungaged sites during water year 1999. These measurements then were correlated with either the measured streamflow at the concurrently measured station or the computed hourly discharge from the concurrently measured station if a measurement was not made. These measurements were useful for verifying or refining the low-flow part of the duration curves; higher flow measurements likely would be affected by unmeasured climatic variations such as different rainfall-runoff rates between the ungaged basin and the gaged basin.

Tests of the method for estimating flow-duration curves in the Cimarron and lower Arkansas River Basins for ungaged sites show that the method generally worked well for estimating the high-flow part of the curves regardless of the period of record desired for the estimated curves. The method also worked well for estimating the low-flow part of the curves provided the period of record desired was the same as that used to develop the maps and graphs (1921–76). If the period of record desired was different from that used to develop the maps and graphs, then the estimation method was not as accurate. Miscellaneous streamflow measurements at the ungaged sites, however, substantially improved the low-flow part of the estimated duration curves.

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APPENDICES

APPENDIX A. ESTIMATED FLOW-DURATION CURVES AND TABLES FOR 16 UNGAGED SITES IN THE CIMARRON AND LOWER ARKANSAS RIVER BASINS IN KANSAS

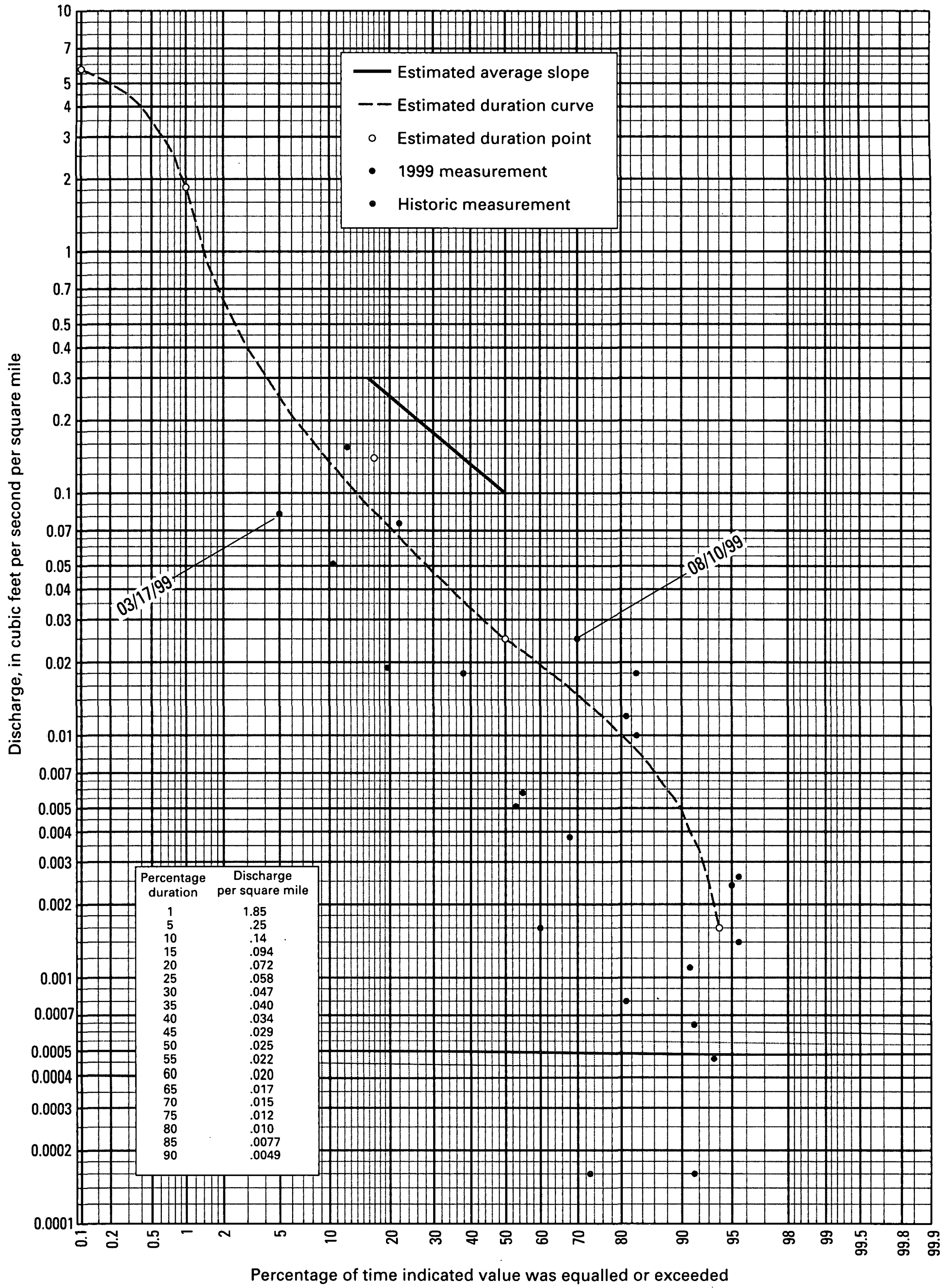
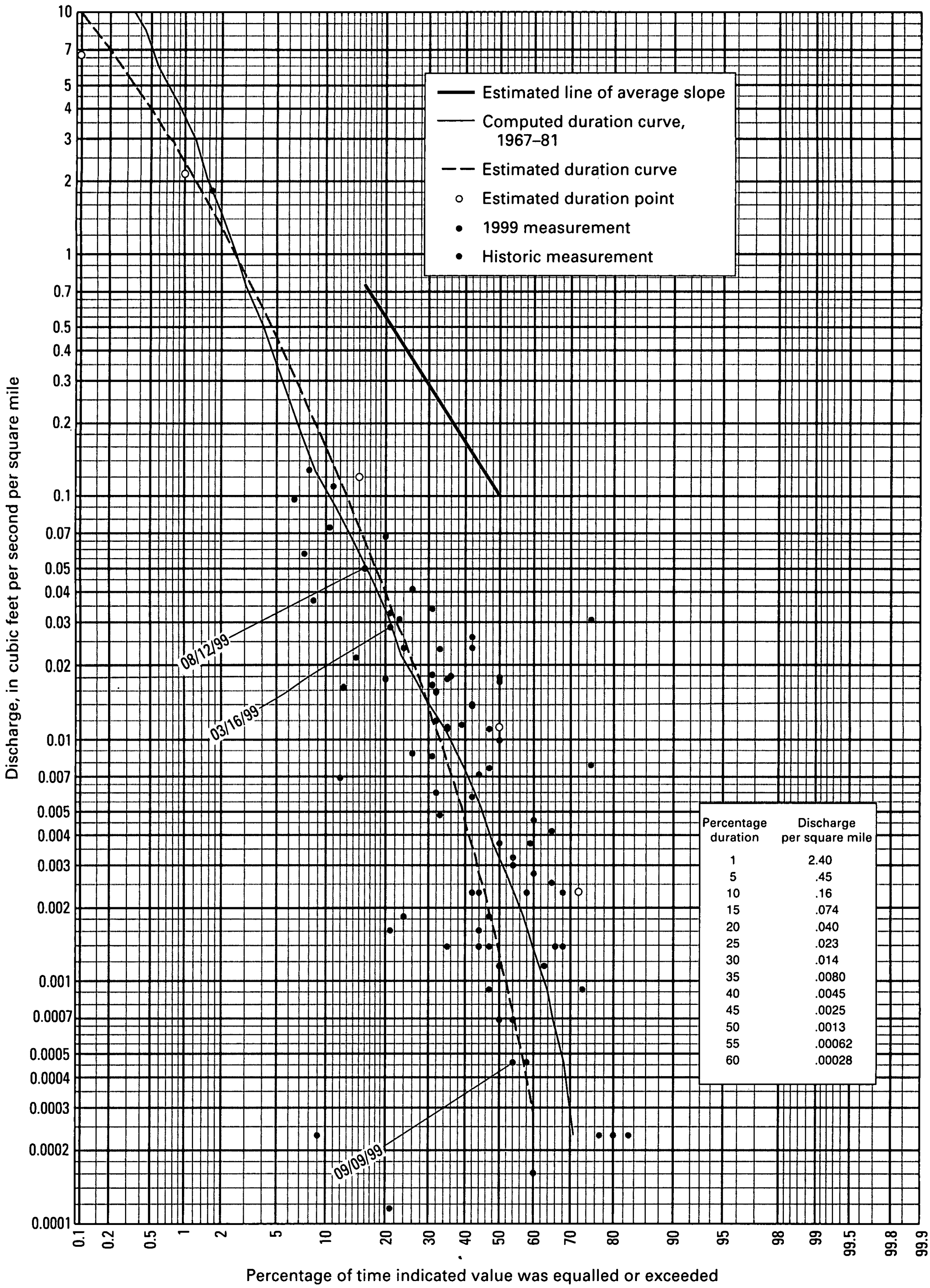


Figure 14. Estimated flow-duration curve for 1968–98 for site 07142650, Peace Creek near Sylvia. Location of site shown in figure 1.



Percentage duration	Discharge per square mile
1	2.40
5	.45
10	.16
15	.074
20	.040
25	.023
30	.014
35	.0080
40	.0045
45	.0025
50	.0013
55	.00062
60	.00028

Figure 15. Estimated flow-duration curve for 1968–98 for site 07142860, Cow Creek near Claflin. Location of site shown in figure 1.

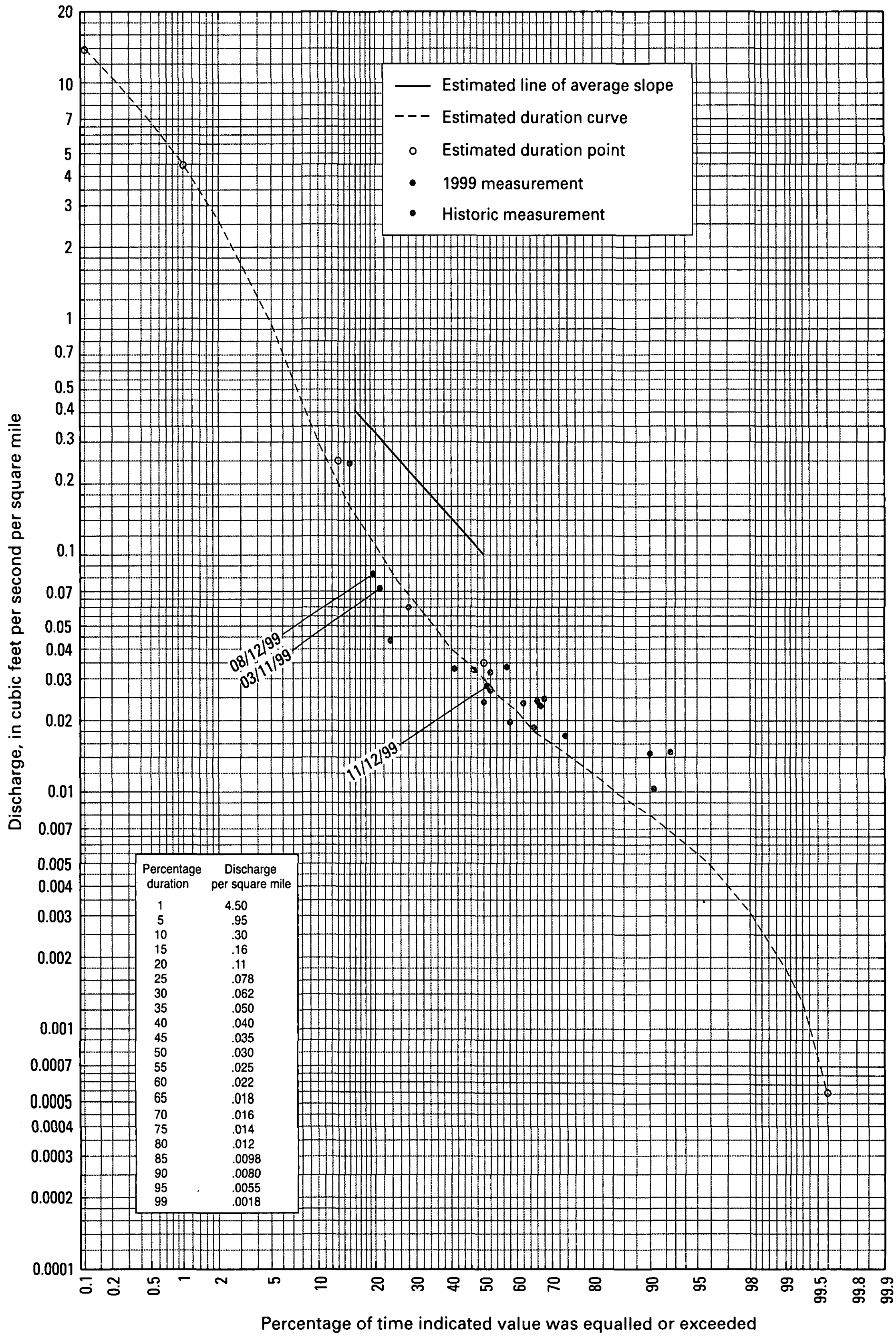
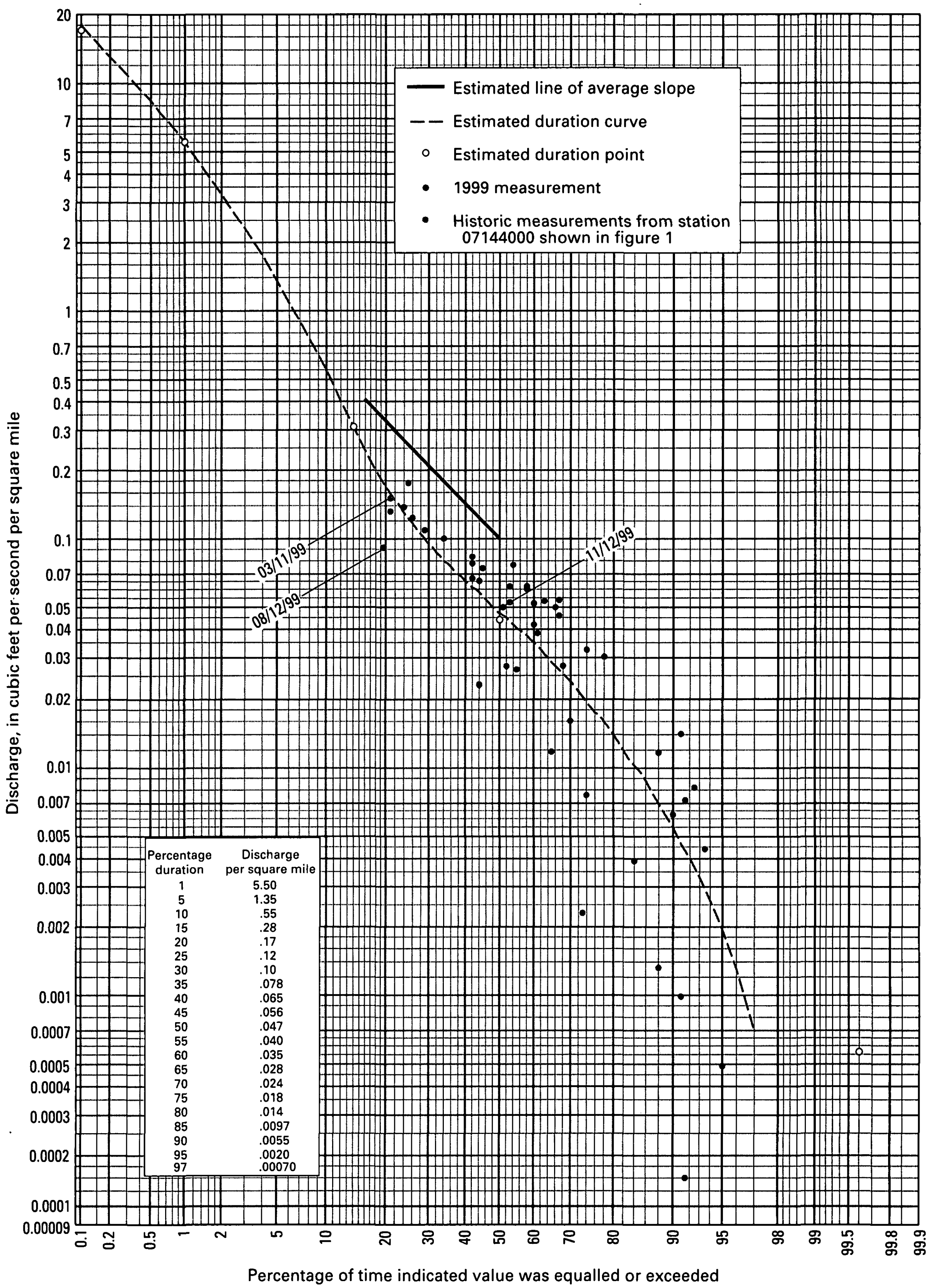
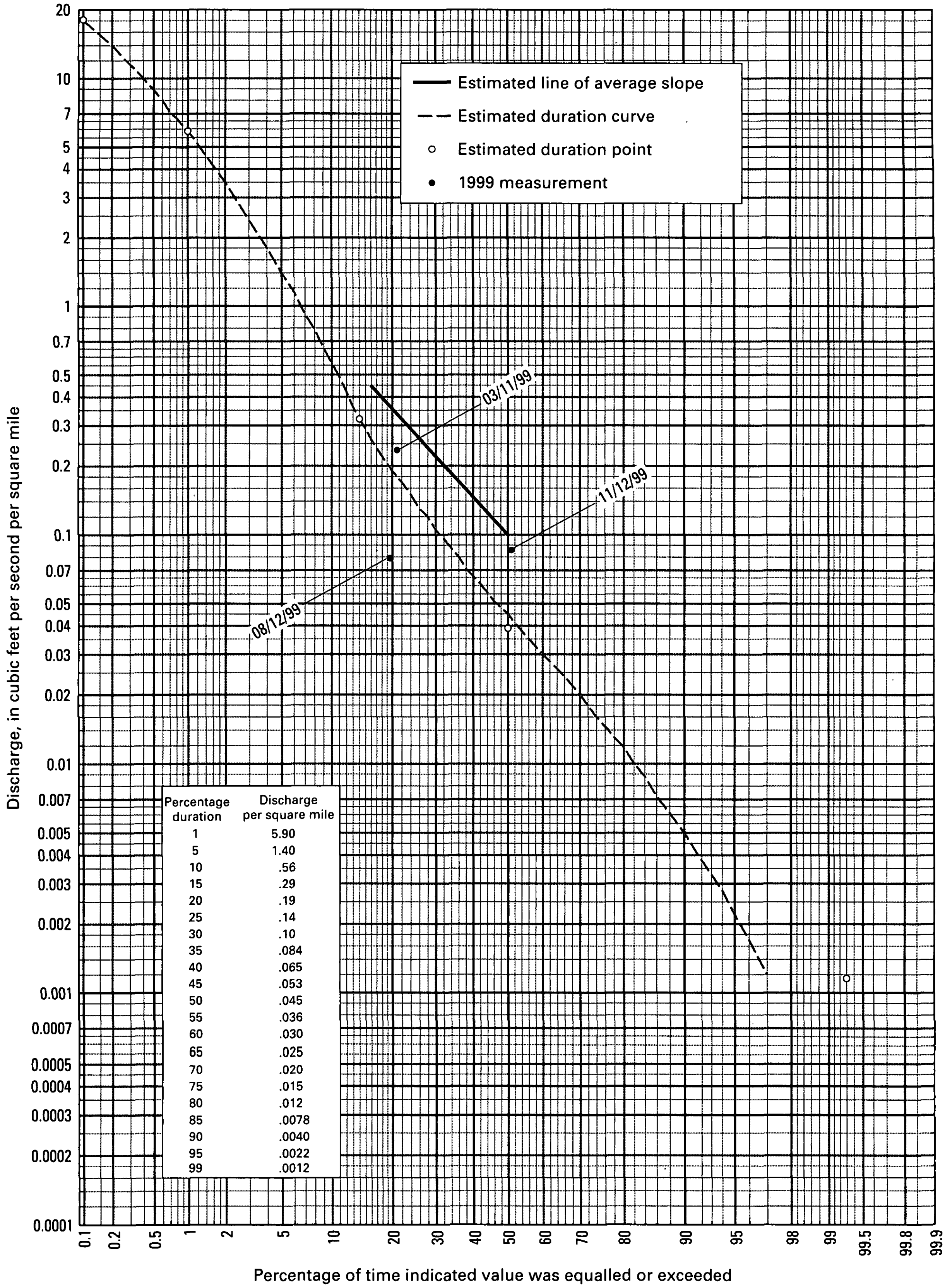


Figure 16. Estimated flow-duration curve for 1968–98 for site 07143660, Turkey Creek near Buhler. Location of site shown in figure 1.



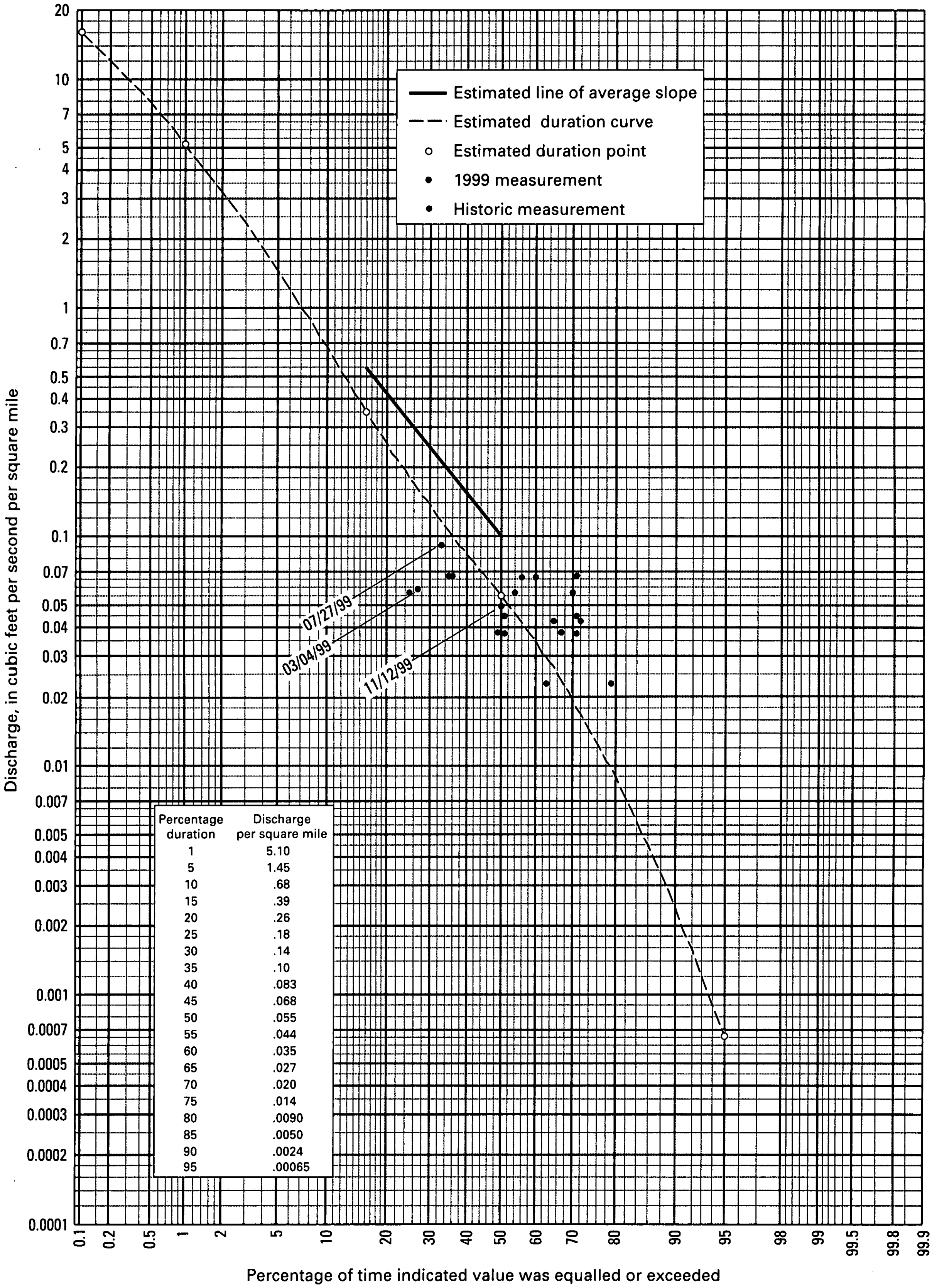
Percentage duration	Discharge per square mile
1	5.50
5	1.35
10	.55
15	.28
20	.17
25	.12
30	.10
35	.078
40	.065
45	.056
50	.047
55	.040
60	.035
65	.028
70	.024
75	.018
80	.014
85	.0097
90	.0055
95	.0020
97	.00070

Figure 17. Estimated flow-duration curve for 1968–98 for site 07144037, Emma Creek 3 miles north and 0.75 mile west of Sedgwick. Location of site shown in figure 1.



Percentage duration	Discharge per square mile
1	5.90
5	1.40
10	.56
15	.29
20	.19
25	.14
30	.10
35	.084
40	.065
45	.053
50	.045
55	.036
60	.030
65	.025
70	.020
75	.015
80	.012
85	.0078
90	.0040
95	.0022
99	.0012

Figure 18. Estimated flow-duration curve for 1968–98 for site 07144080, Sand Creek 3 miles north and 2 miles east of Sedgwick. Location of site shown in figure 1.



Percentage duration	Discharge per square mile
1	5.10
5	1.45
10	.68
15	.39
20	.26
25	.18
30	.14
35	.10
40	.083
45	.068
50	.055
55	.044
60	.035
65	.027
70	.020
75	.014
80	.0090
85	.0050
90	.0024
95	.00065

Figure 19. Estimated flow-duration curve for 1968–98 for site 07144545, Cowskin Creek near Oatville. Location of site shown in figure 1.

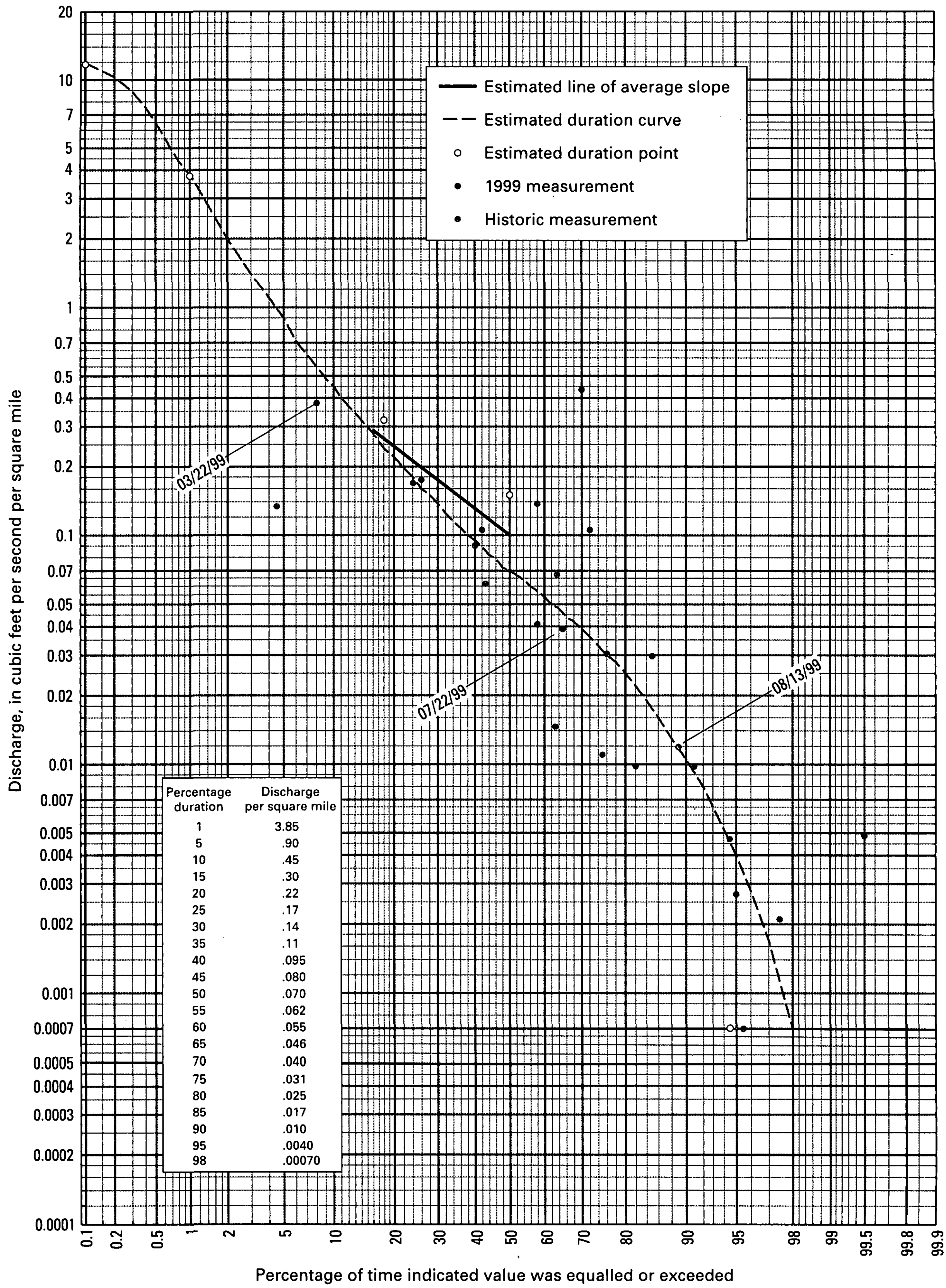
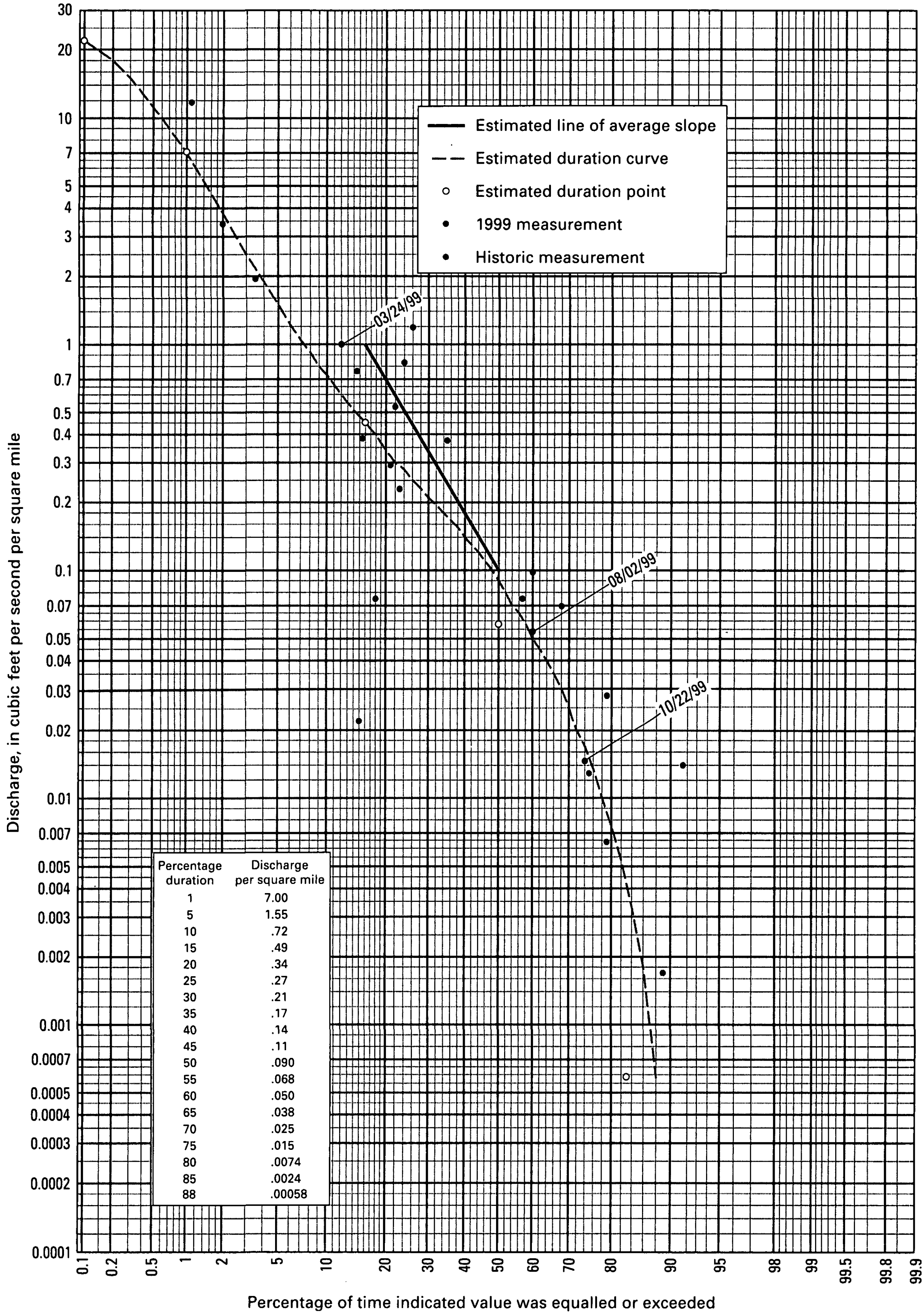
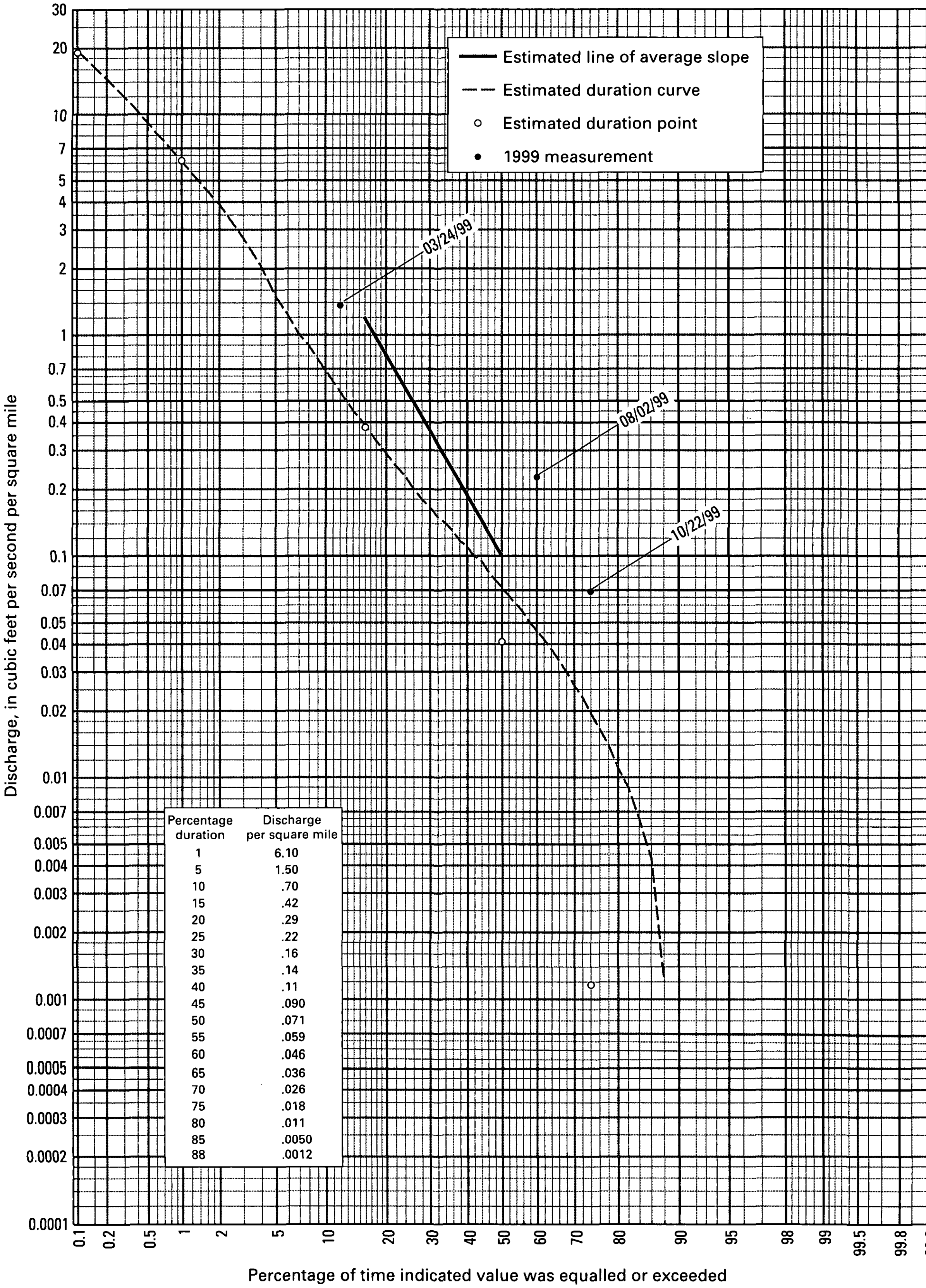


Figure 20. Estimated flow-duration curve for 1968–98 for site 07145220, Smoots Creek near Murdock. Location of site shown in figure 1.



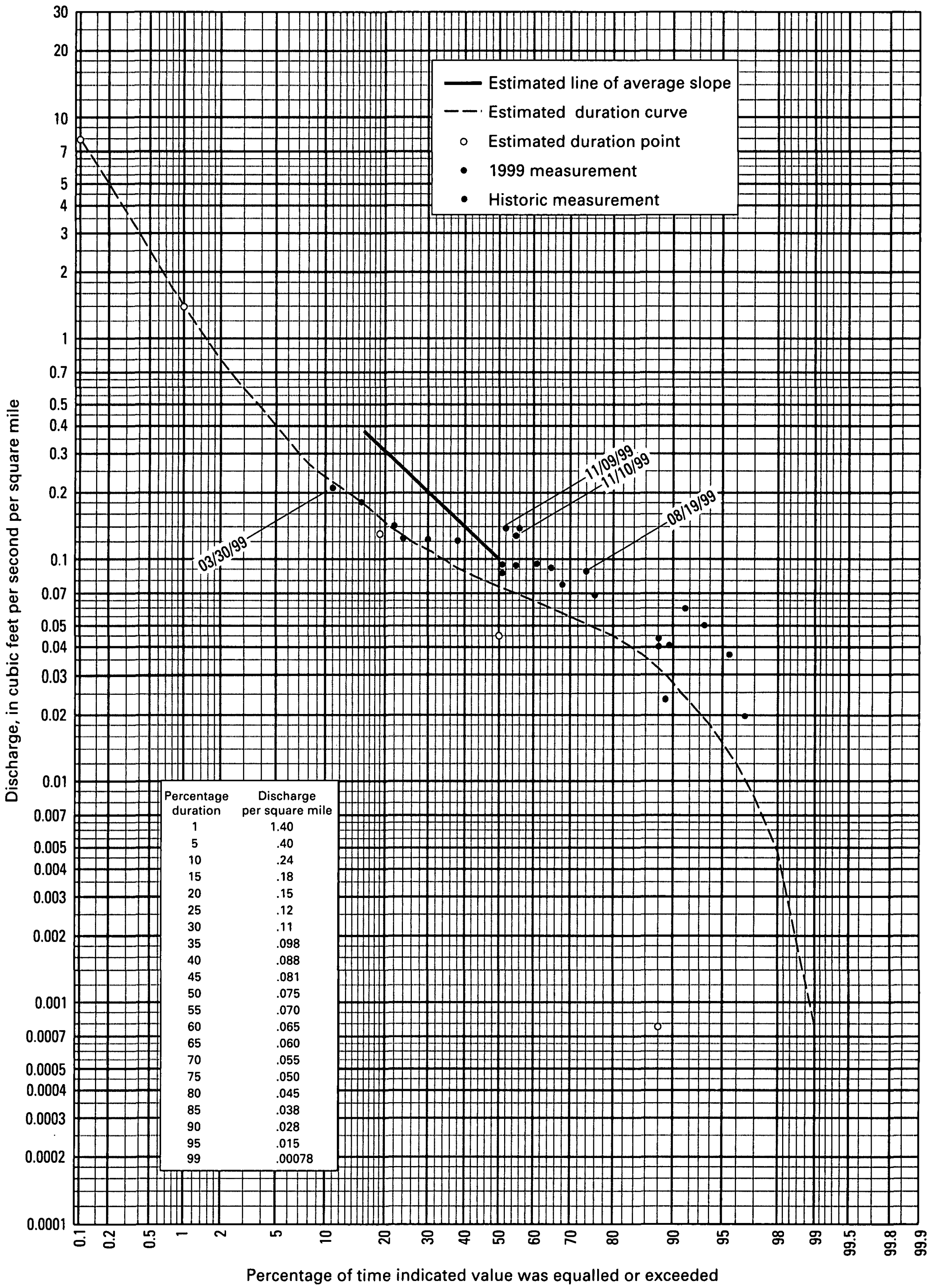
Percentage duration	Discharge per square mile
1	7.00
5	1.55
10	.72
15	.49
20	.34
25	.27
30	.21
35	.17
40	.14
45	.11
50	.090
55	.068
60	.050
65	.038
70	.025
75	.015
80	.0074
85	.0024
88	.00058

Figure 21. Estimated flow-duration curve for 1968–98 for site 07148100, Grouse Creek near Dexter. Location of site shown in figure 1.



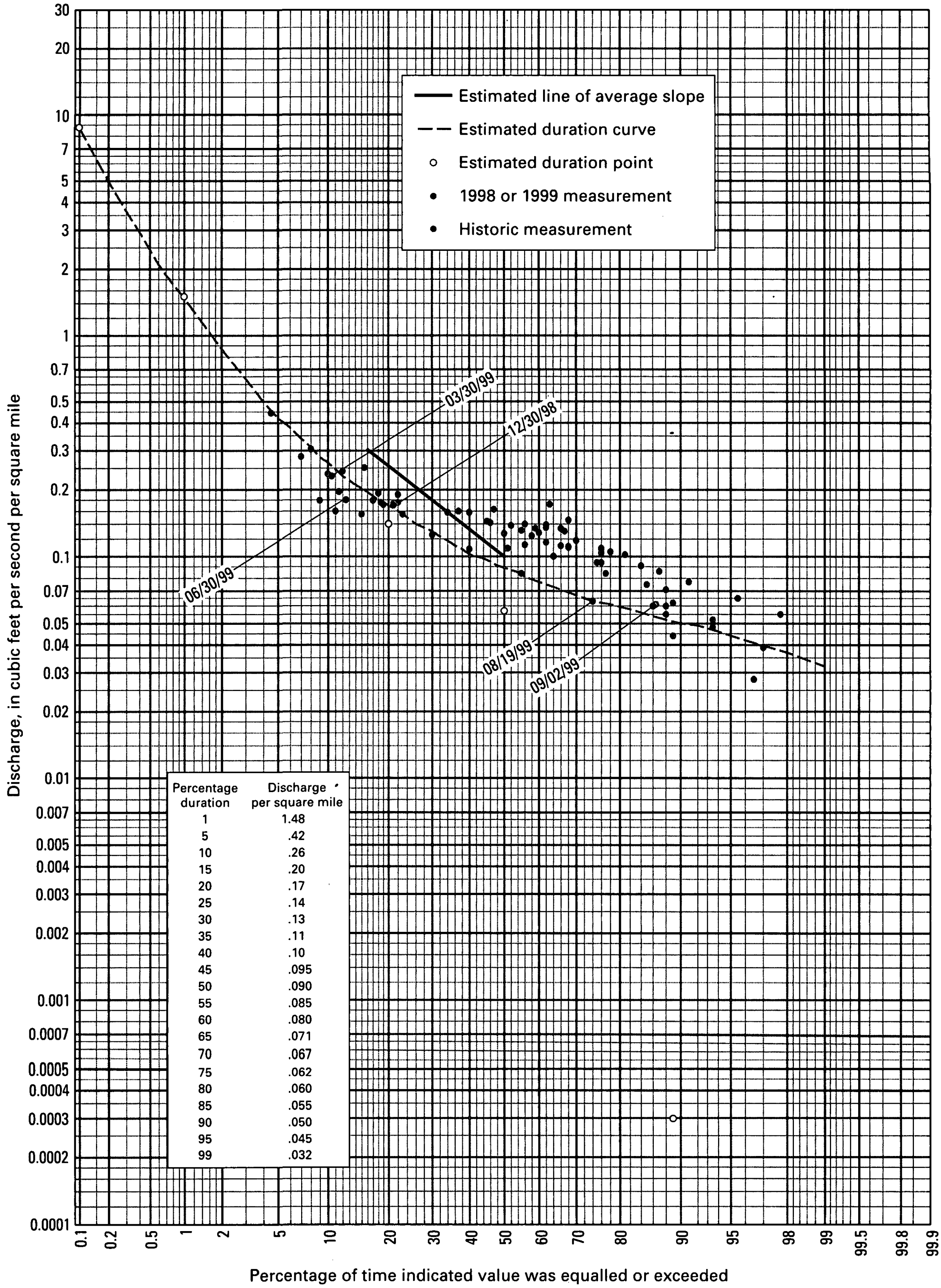
Percentage duration	Discharge per square mile
1	6.10
5	1.50
10	.70
15	.42
20	.29
25	.22
30	.16
35	.14
40	.11
45	.090
50	.071
55	.059
60	.046
65	.036
70	.026
75	.018
80	.011
85	.0050
88	.0012

Figure 22. Estimated flow-duration curve for 1968–98 for site 07148110, Silver Creek at Highway 166 east of Arkansas City. Location of site shown in figure 1.



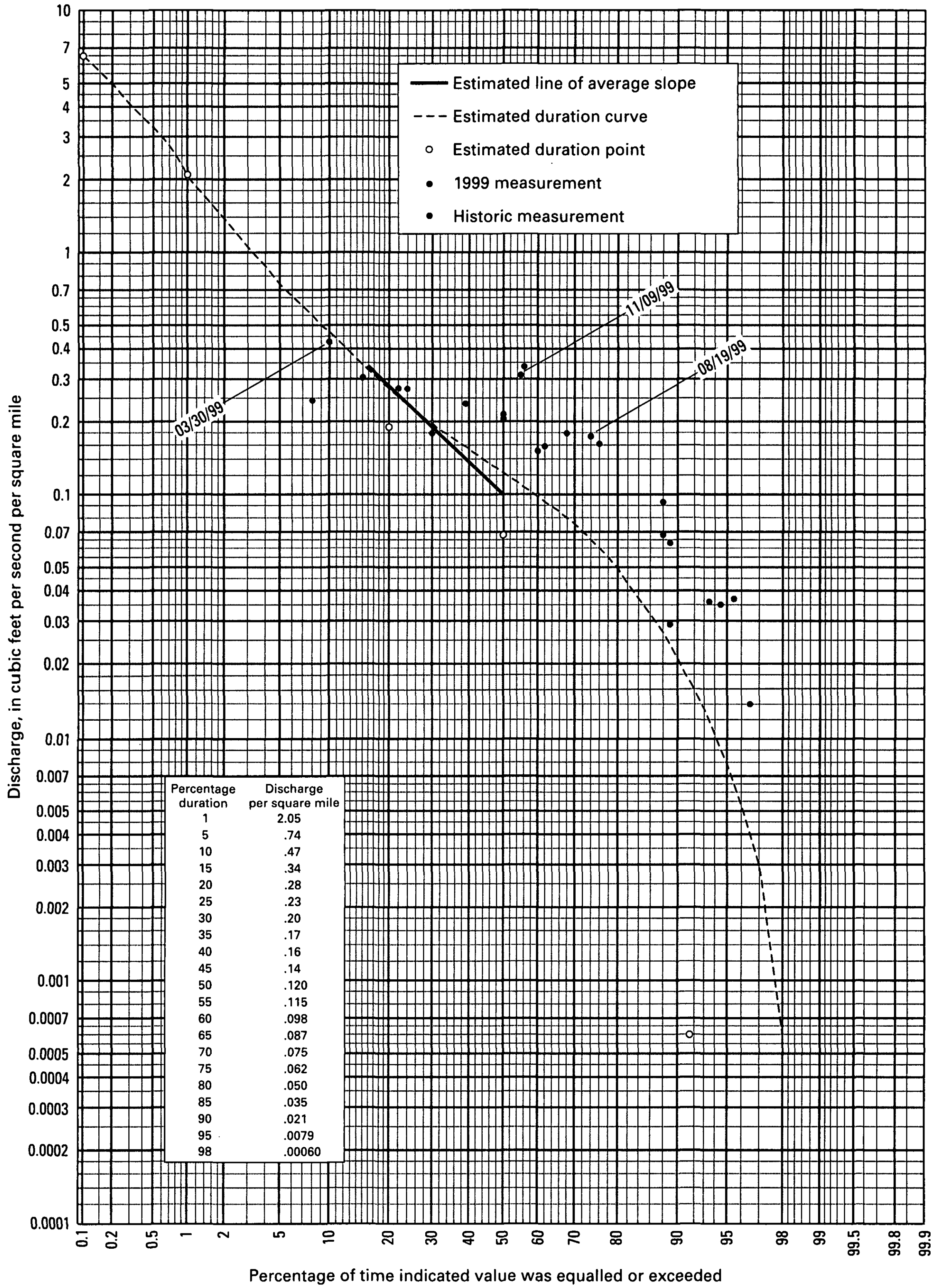
Percentage duration	Discharge per square mile
1	1.40
5	.40
10	.24
15	.18
20	.15
25	.12
30	.11
35	.098
40	.088
45	.081
50	.075
55	.070
60	.065
65	.060
70	.055
75	.050
80	.045
85	.038
90	.028
95	.015
99	.00078

Figure 23. Estimated flow-duration curve for 1968–98 for site 07148200, Mule Creek near Wilmore. Location of site shown in figure 1.



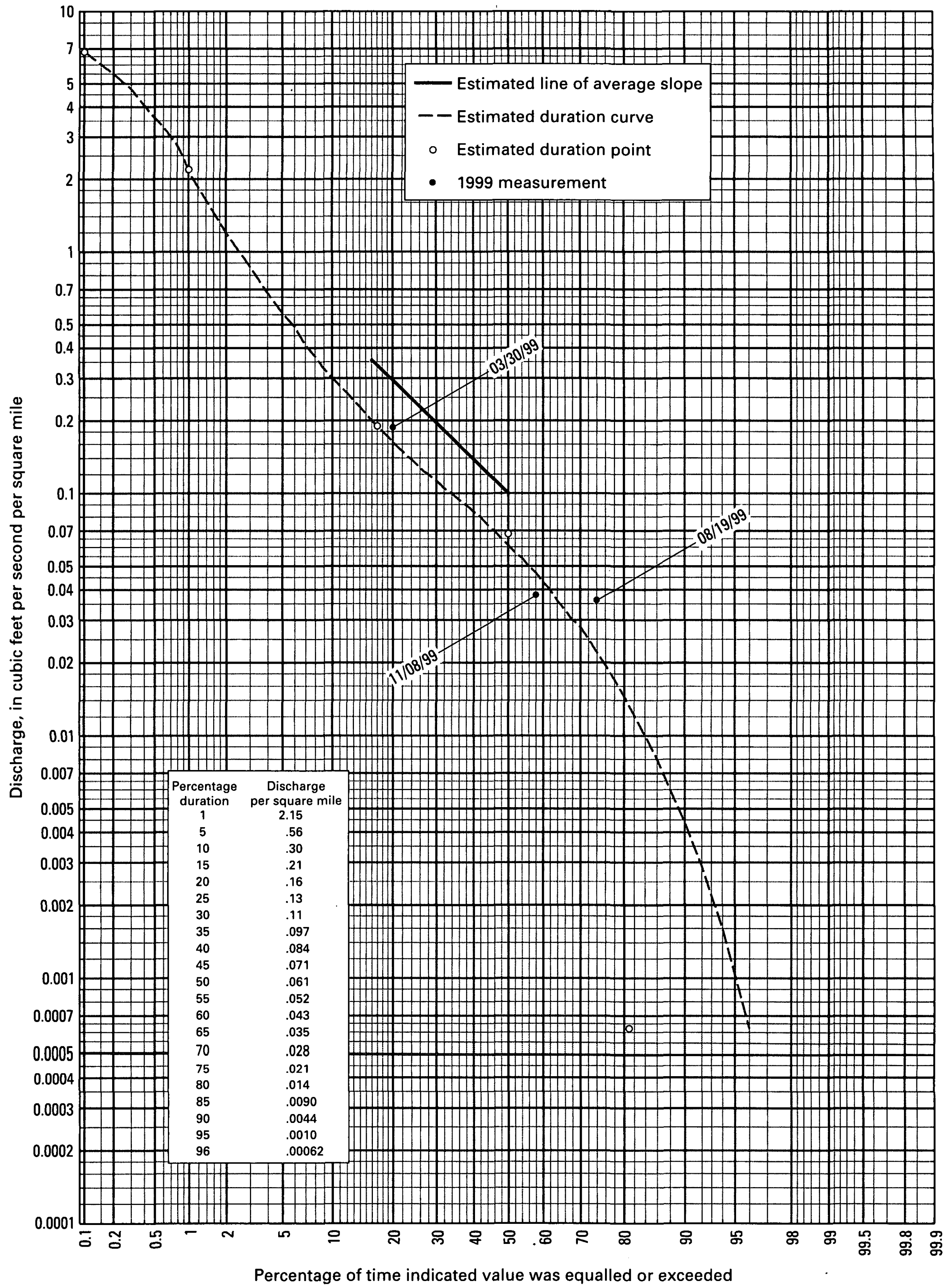
Percentage duration	Discharge per square mile
1	1.48
5	.42
10	.26
15	.20
20	.17
25	.14
30	.13
35	.11
40	.10
45	.095
50	.090
55	.085
60	.080
65	.071
70	.067
75	.062
80	.060
85	.055
90	.050
95	.045
99	.032

Figure 24. Estimated flow-duration curve for 1968–98 for site 07148600, Medicine Lodge River at Sun City. Location of site shown in figure 1.



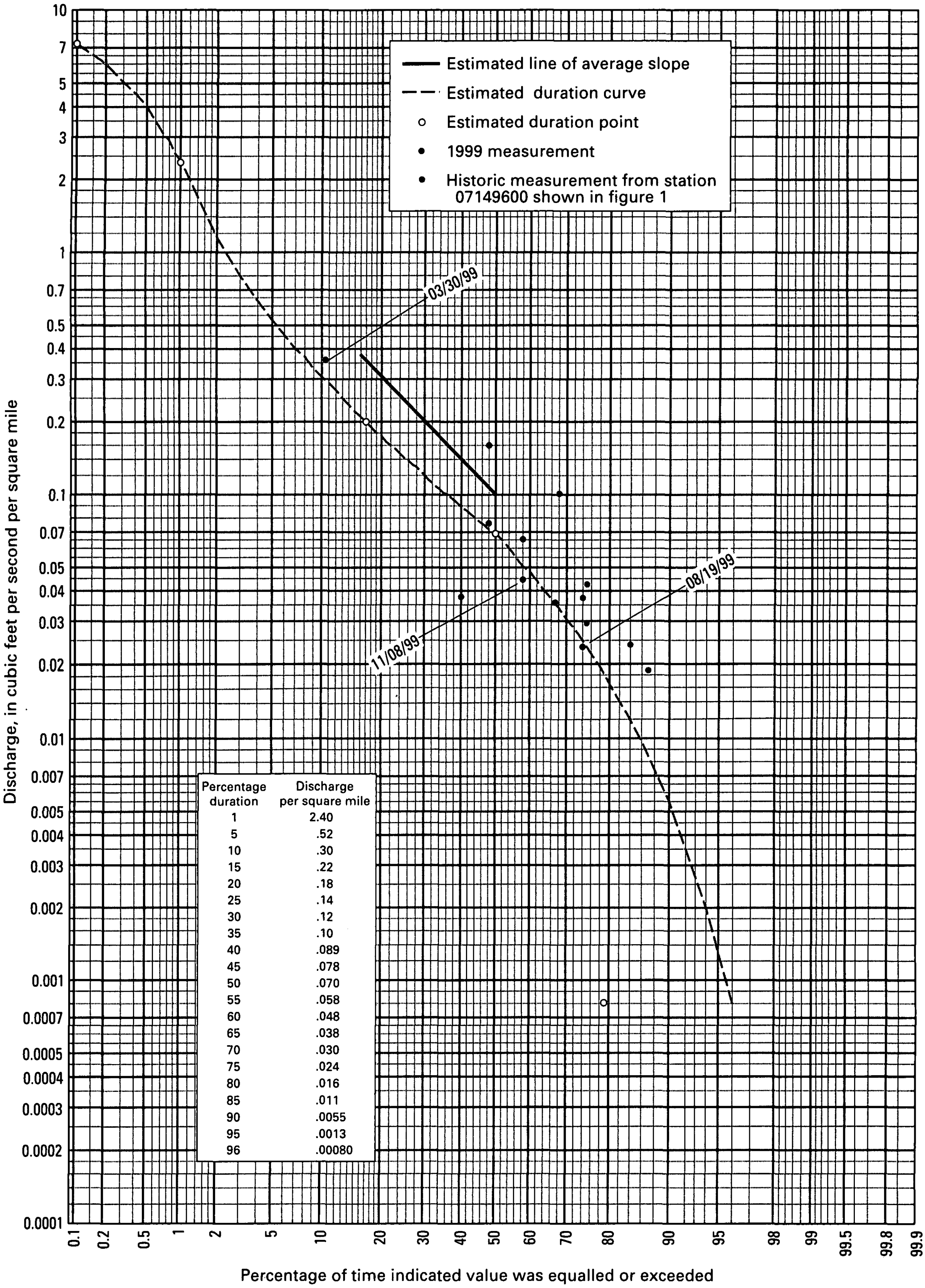
Percentage duration	Discharge per square mile
1	2.05
5	.74
10	.47
15	.34
20	.28
25	.23
30	.20
35	.17
40	.16
45	.14
50	.120
55	.115
60	.098
65	.087
70	.075
75	.062
80	.050
85	.035
90	.021
95	.0079
98	.00060

Figure 25. Estimated flow-duration curve for 1968–98 for site 07148900, Elm Creek at Medicine Lodge. Location of site shown in figure 1.



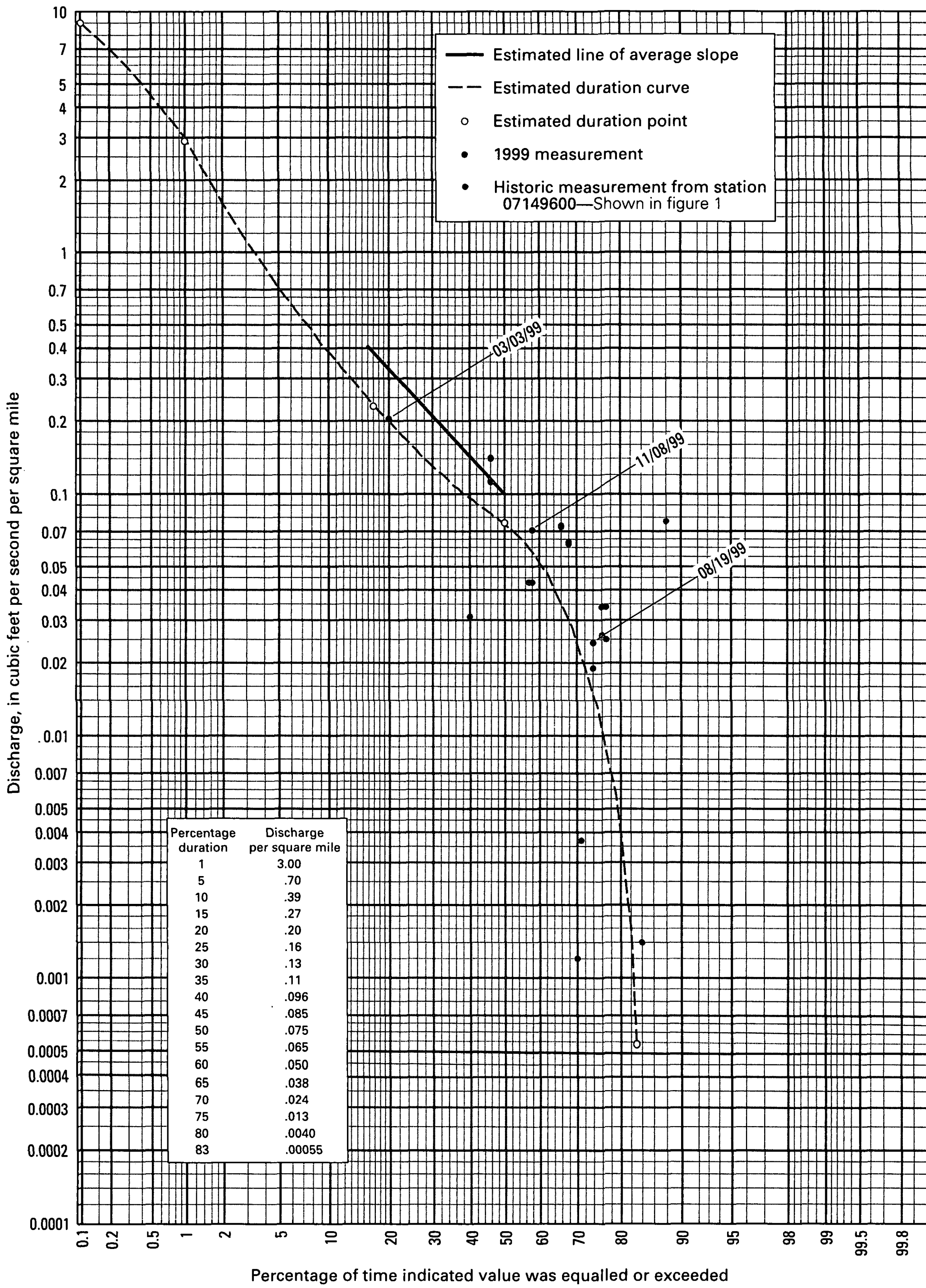
Percentage duration	Discharge per square mile
1	2.15
5	.56
10	.30
15	.21
20	.16
25	.13
30	.11
35	.097
40	.084
45	.071
50	.061
55	.052
60	.043
65	.035
70	.028
75	.021
80	.014
85	.0090
90	.0044
95	.0010
96	.00062

Figure 26. Estimated flow-duration curve for 1968–98 for site 07149590, Sandy Creek near Waldron. Location of site shown in figure 1.



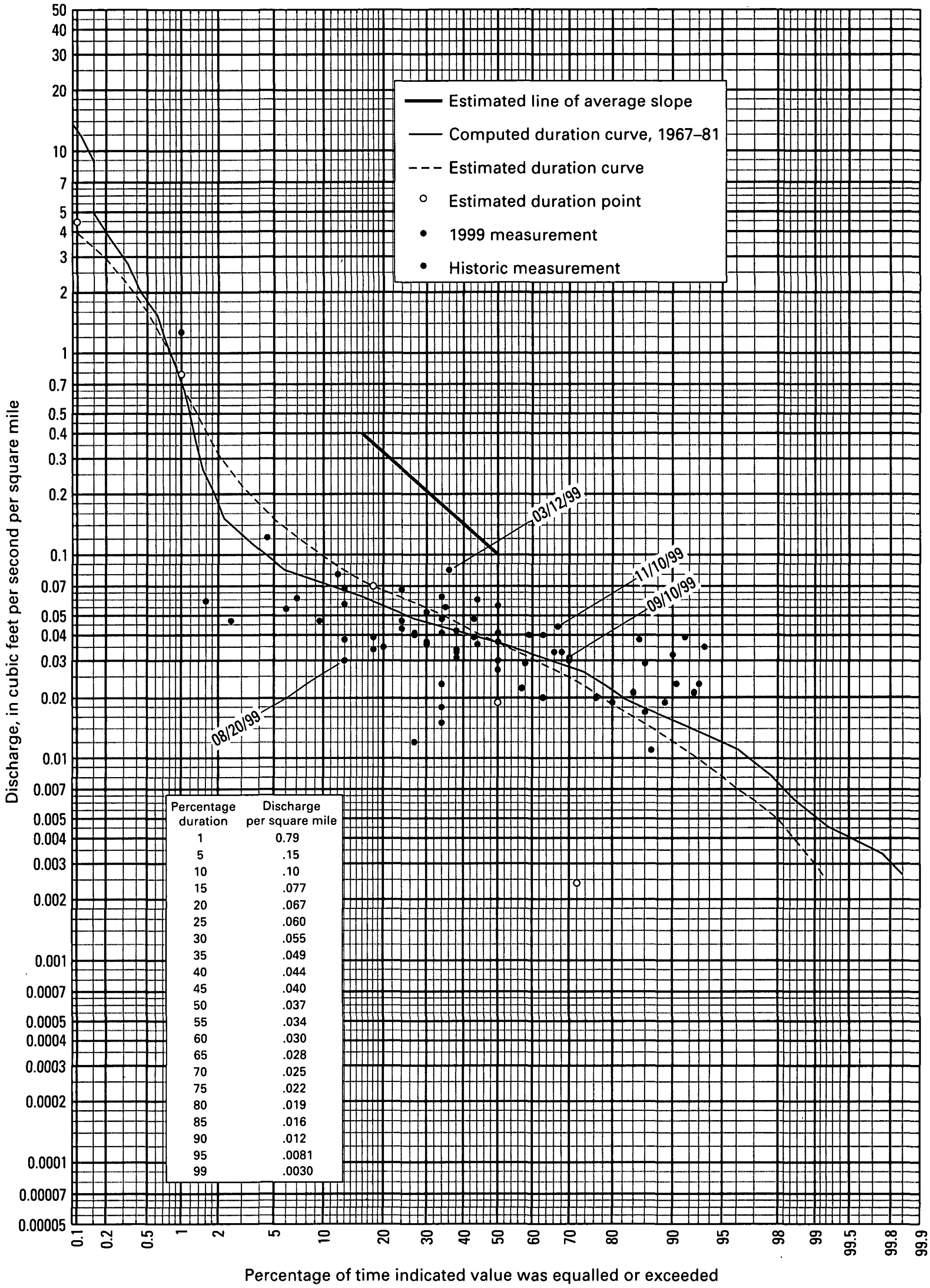
Percentage duration	Discharge per square mile
1	2.40
5	.52
10	.30
15	.22
20	.18
25	.14
30	.12
35	.10
40	.089
45	.078
50	.070
55	.058
60	.048
65	.038
70	.030
75	.024
80	.016
85	.011
90	.0055
95	.0013
96	.00080

Figure 27. Estimated flow-duration curve for 1968–98 for site 07149605, Little Sandy Creek near Corwin. Location of site shown in figure 1.



Percentage duration	Discharge per square mile
1	3.00
5	.70
10	.39
15	.27
20	.20
25	.16
30	.13
35	.11
40	.096
45	.085
50	.075
55	.065
60	.050
65	.038
70	.024
75	.013
80	.0040
83	.00055

Figure 28. Estimated flow-duration curve for 1968–98 for site 07151670, Bluff Creek south of Anthony. Location of site shown in figure 1.



Percentage duration	Discharge per square mile
1	0.79
5	.15
10	.10
15	.077
20	.067
25	.060
30	.055
35	.049
40	.044
45	.040
50	.037
55	.034
60	.030
65	.028
70	.025
75	.022
80	.019
85	.016
90	.012
95	.0081
99	.0030

Figure 29. Estimated flow-duration curve for 1968–98 for site 07157900, Cavalry Creek at Coldwater. Location of site shown in figure 1.

APPENDIX B. SITE DESCRIPTIONS FOR 16 UNGAGED SITES IN THE CIMARRON AND LOWER ARKANSAS RIVER BASINS IN KANSAS

Description of low-flow site on Peace Creek near Sylvia, Kansas, 07142650

LOCATION.—Lat. 38° 04'31", long. 98°26'09", in NW1/4NE1/4SW1/4 sec. 08, T. 23 S., R. 10 W., Reno County, hydrologic unit 11030010, at bridge on Brownlee Road, 8.5 mi. northwest of Sylvia, Kansas, and at mile 17.2.

DRAINAGE AREA.— 62.4 mi^2.

Description of streamflow-gaging station on Cow Creek near Claflin, Kansas, 07142860

LOCATION.—Lat. 38° 31'20", long. 98° 35'00", in NE1/4NW1/4 sec. 6, T. 18 S., R. 11 W., Barton County, hydrologic unit 11030011, at downstream side of State Highway 4 bridge, 2.5 mi west of Claflin, and at mile 97.8. Station can be reached by driving 2.5 mi west of Claflin or 4.5 mi east of Red Wing.

DRAINAGE AREA.—43.4 mi^2, from U.S. Army Corps of Engineers data.

Description of low-flow site on Turkey Creek near Buhler, Kansas, 07143660

LOCATION.—Lat. 38° 08'42", long. 97° 37'31", in NE1/4NW1/4NW1/4 sec. 14, T. 22 S., R. 03 W., Harvey County, hydrologic unit 11030012, at Dutch Avenue bridge over Turkey Creek. From Hesston, travel west on Dutch Avenue approximately 10 mi to bridge over Turkey Creek.

DRAINAGE AREA.—180 mi^2.

Description of low-flow site on Emma Creek 3 miles north and 0.75 mile west of Sedgwick, Kansas, 07144037

LOCATION.—Lat. 37° 58'14", long. 97° 26'34", in NE1/4NW1/4NW1/4 sec. 16, T. 24 S., R. 01 W., Harvey County, hydrologic unit 11030012, at 60th Road bridge over Emma Creek and approximately 0.75 mi west of Ridge Road. From Sedgwick, travel north on Ridge Road approximately 3.5 mi to 60th Road, then travel west approximately 0.75 mi to site.

DRAINAGE AREA.—177 mi^2.

Description of low-flow site on Sand Creek 3 miles north and 2 miles east of Sedgwick, Kansas, 07144080

LOCATION.—Lat. 37° 58'14", long. 97° 23'25", in NE1/4NE1/4NE1/4 sec. 14, T. 24 S., R. 01 W., Harvey County, hydrologic unit 11030012, at 60th Road bridge over Sand Creek and approximately 2 mi east of Ridge Road. From Sedgwick, travel north on Ridge Road approximately 3.5 mi to 60th Road, then travel west approximately 2 mi to site.

DRAINAGE AREA.—86.5 mi^2.

Description of low-flow site on Cowskin Creek near Oatville, Kansas, 07144545

LOCATION.—Lat. 37° 36'01", long. 97° 24'25", in NW1/4NW1/4NW1/4 sec. 23, T. 28 S., R. 01 W., Sedgwick County, hydrologic unit 11030013, at West 55th Street bridge over Cowskin Creek and approximately 1.5 mi south of West 39th Street. From I-235 exit to West 39th Street on the south side of Wichita, travel west approximately 4 mi to West 55th Street, then south approximately 1.5 mi to site.

DRAINAGE AREA.—152 mi^2.

Description of low-flow site on Smoots Creek near Murdock, Kansas, 07145220

LOCATION.—Lat. 37°38'03", long. 97° 53'58", in NW1/4SW1/4SW1/4 sec. 05, T. 28 S., R. 05 W., Kingman County, hydrologic unit 11030015, at SE 120th Avenue bridge over Smoots Creek and approximately 1.1 mi north of SE 20th Street and at mile 6.6. From Murdock, travel 0.5 mi north to SE 20th Street, then east 1.8 mi to SE 120th Avenue, then 1.1 mi north to site.

DRAINAGE AREA.—142 mi^2.

Description of streamflow-gaging station on Grouse Creek near Dexter, Kansas, 07148100

LOCATION.—Lat. 37°13'38", long. 96° 42'44", in NW1/4NW1/4 sec. 31, T. 32 S., R. 7 E., Cowley County, hydrologic unit 11060001, on right bank at downstream side of bridge on county road 0.25 mi east of State Highway 15, 3.2 mi north of Dexter, and 16.5 mi east of Winfield. From Winfield, beginning at junction of U.S. Highway 77 and State Highway 15, follow State Highway 15 15.5 mi east and 1.2 mi south, then 0.2 mi east on county road to gage.

DRAINAGE AREA.—170 mi^2 (revised). Furnished by U.S. Corps of Engineers, Dallas, Texas.

Description of low-flow site on Silver Creek at Highway 166 east of Arkansas City, Kansas, 07148110

LOCATION.—Lat. 37° 04'42", long. 96° 51'33", in SW1/4SW1/4NW1/4 sec. 23, T. 34 S., R. 05 E., Cowley County, hydrologic unit 11060001, at U.S. Highway 166 bridge over Silver Creek and approximately 10.25 mi east of Arkansas City. From Arkansas City, travel 10.25 mi east on U.S. Highway 166 to site.

DRAINAGE AREA.—86.1 mi^2.

Description of low-flow site on Mule Creek near Wilmore, Kansas, 07148200

LOCATION.—Lat. 37° 16'52", long. 99° 02'38", in NE1/4NW1/4NE1/4 sec. 10, T. 32 S., R. 16 W., Comanche County, hydrologic unit 11060002, at U.S. Highway 160 bridge over Mule Creek and approximately 15.5 mi east of U.S. Highway 183. From junction of U.S. Highway 183 and 160, travel 15.5 mi east on U.S. Highway 160 to site.

DRAINAGE AREA.—127 mi^2.

Description of low-flow site on Medicine Lodge River at Sun City, Kansas, 07148600

LOCATION.—Lat. 37°22'13", long. 98° 54'53", in SE1/4SW1/4SE1/4 sec. 2, T. 31 S., R. 15 W., Barber County, hydrologic unit 11060003, at bridge on County Road 1346, 0.5 mi south of Sun City, 0.2 mi downstream from Turkey Creek, at mile 75.8. Elevation of gage is approximately 1,685 ft above sea level. Site can be referenced from the Sun City quadrangle, 7.5-minute series, USGS topographic map.

DRAINAGE AREA.—335 mi^2.

Description of low-flow site on Elm Creek at Medicine Lodge, Kansas, 07148900

LOCATION.—Lat. 37°16'33", long. 98°34'22", in NW1/4 NE1/4SE1/4 sec. 12, T. 32 S., R. 12 W., Comanche County, hydrologic unit 11060003, at U.S. Highway 160 bridge over Elm Creek.

DRAINAGE AREA.—168 mi^2.

Description of low-flow site on Sandy Creek near Waldron, Kansas, 07149590

LOCATION.—Lat. 37°00'25", long. 98°12'47", in NE1/4NW1/4NW1/4 sec. 17, T. 35 S., R. 08 W., Harper County, hydrologic unit 11060004, at SW 100 Road bridge over Sandy Creek. From Waldron, travel west 1.75 mi to site.

DRAINAGE AREA.—161 mi^2.

Description of low-flow site on Little Sandy Creek near Corwin, Kansas, 07149605

LOCATION.—Lat. 37°03'55", long. 98°17'03", in NE1/4NE1/4NW1/4 sec. 27, T. 34 S., R. 09 W., Harper County, hydrologic unit 11060004, at SW 60 Road bridge over Little Sandy Creek. From Corwin, travel south 0.25 mi to SW 50 Road, then east 0.5 mi to SW 140 Avenue, then south 1.0 mi to SW 60 Road, then east 0.5 mi to site.

DRAINAGE AREA.—124 mi^2.

Description of low-flow site on Bluff Creek south of Anthony, Kansas, 07151670

LOCATION.—Lat. 37°06'40", long. 98°02'18", in NW1/4SW1/4SW1/4 sec. 01, T. 34 S., R. 07 W., Harper County, hydrologic unit 11060005, at State Highway 179 bridge over Bluff Creek. From Anthony, travel south approximately 3.0 mi on State Highway 179 to site.

DRAINAGE AREA.—185 mi^2.

Description of streamflow-gaging station on Cavalry Creek at Coldwater, Kansas, 07157900

LOCATION.—Lat. 37°16'00", long. 99°20'40", on NE1/4NE1/4 sec. 14, T. 32 S., R. 19 W., Comanche County, hydrologic unit 11040008, at county highway bridge, 1.0 mi west of Coldwater and at mile 18.3. From intersection of Highways 160 and 183, just north of railroad crossing in Coldwater, follow dirt road 1.0 mi west to gage. This road jogs to the south slightly about 0.2 mi from intersection.

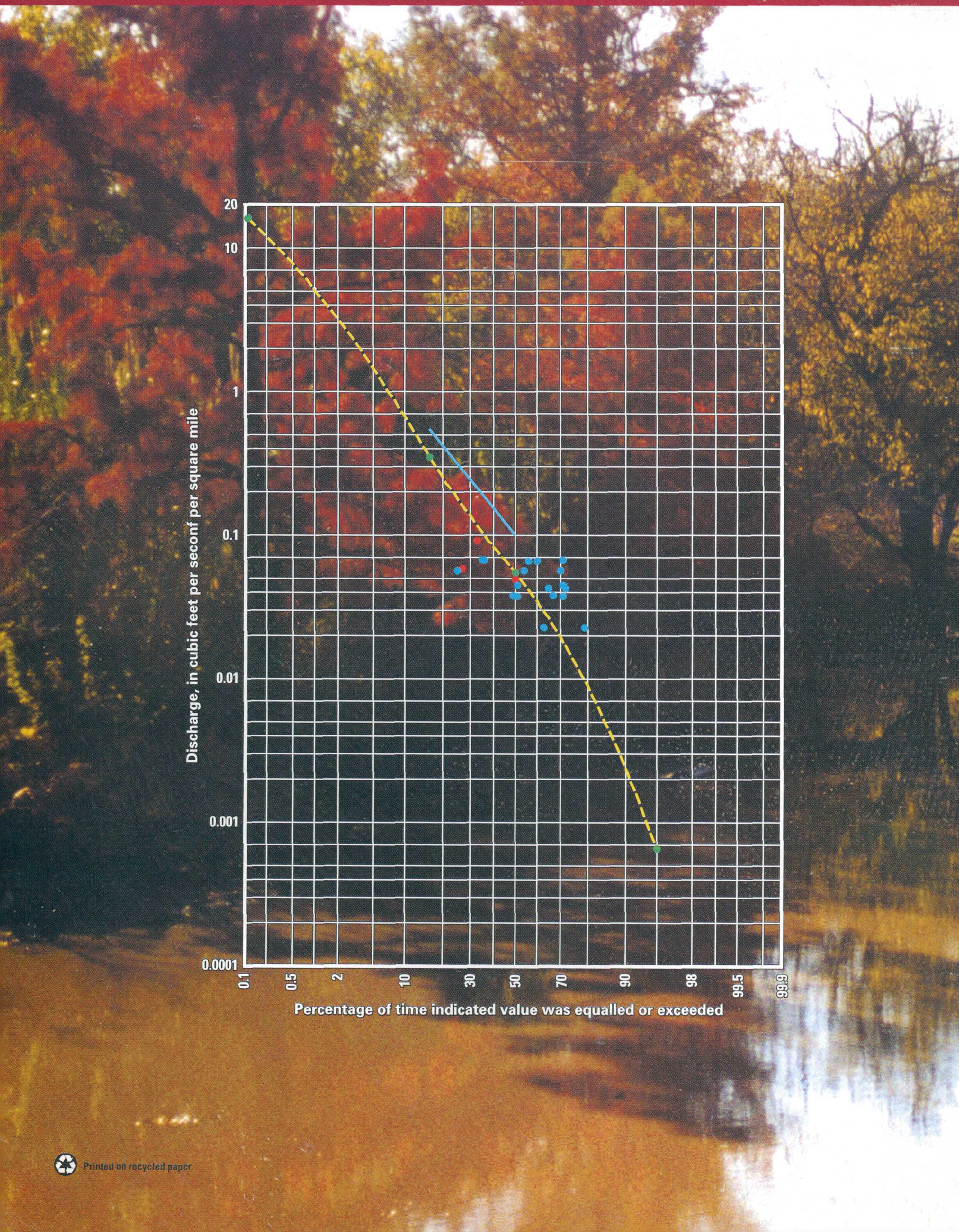
DRAINAGE AREA.—39 mi^2.

APPENDIX C. MISCELLANEOUS STREAMFLOW MEASUREMENTS MADE DURING 1999 AT 16 UNGAGED SITES IN THE CIMARRON AND LOWER ARKANSAS RIVER BASINS IN KANSAS

[ft^3/s, cubic feet per second; $(ft^3/s)/mi^2$, cubic feet per second per square mile]

Site name and number	Date (month/day)	Discharge (ft^3/s)	Discharge [$(ft^3/s)/mi^2$]	Percentage duration
07142650	03/17	5.13	0.082	5
Peace Creek near Sylvia	08/10	1.57	.025	70
07142860	03/16	1.23	.028	21
Cow Creek near Claflin	08/12	2.17	.050	16
	09/09	.02	.00046	54
07143660	03/11	13.0	.072	21
Turkey Creek near Buhler	08/12	15.0	.083	19.5
	11/12	5.01	.028	51
07144037	03/11	26.7	.15	21
Emma Creek 2 miles north and	08/12	16.2	.092	19.5
0.75 mile west of Sedgwick	11/12	8.87	.050	51
07144080	03/11	20.3	.23	21
Sand Creek 3 miles north and 2 miles	08/12	6.85	.079	19.5
east of Sedgwick	11/12	7.41	.086	51
07144545	03/04	8.93	.059	27
Cowskin Creek near Oatville	07/27	13.9	.091	33
	11/12	7.52	.049	50
07145220	03/22	53.9	.38	8
Smoots Creek near Murdock	07/22	5.55	.039	65
	08/13	1.64	.012	89
07148100	03/24	171	1.00	12
Grouse Creek near Dexter	08/02	9.18	.054	60
	10/22	2.50	.015	74
07148110	03/24	117	1.36	12
Silver Creek at Highway 166 east of	08/02	19.5	.23	60
Arkansas City	10/22	5.94	.069	74
07148200	03/30	26.7	.21	11
Mule Creek near Wilmore	08/19	11.2	.088	74
	11/09	16.2	.13	55
	11/10	17.5	.14	52

Site name and number	Date (month/day)	Discharge (ft^3/s)	Discharge [$(ft^3/s)/mi^2$]	Percentage duration
07148600	03/30	77.9	0.24	10.5
Medicine Lodge River at Sun City	06/30	61.2	.18	13.5
	08/19	21.0	.063	74
	09/02	20.2	.061	86
	11/09	43.3	.13	55
	12/30	57.9	.18	22
07148900	03/30	71.6	.43	10
Elm Creek at Medicine Lodge	08/19	29.2	.17	74
	11/09	101	.60	55
07149590	03/03	30.2	.19	20
Sandy Creek near Waldron	08/19	5.85	.036	74
	11/08	13.1	.081	58
07149605	03/30	44.6	.36	10.5
Little Sandy Creek near Corwin	08/19	2.91	.023	74
	11/08	5.52	.044	58
07151670	03/03	37.7	.042	20
Bluff Creek south of Anthony	08/19	4.48	.024	74
	11/08	13.1	.071	58
07157900	03/12	3.49	.084	36
Cavalry Creek at Coldwater	08/20	1.24	.030	13
	09/10	1.29	.031	70
	11/10	1.85	.044	67



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