ESTIMATING LOW-FLOW FREQUENCY FOR PERENNIAL MISSOURI OZARKS STREAMS

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 59-73

Prepared in cooperation with

Missouri Geological Survey and Water Resources

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle ESTIMATING LOW-FLOW FREQUENCY FOR PERENNIAL MISSOURI OZARKS STREAMS			5. Report Date February 1974 6.
7. Author(s) John Skelton			8. Performing Organization Rept. No. WRI 59-73
9. Performing Organization Name and Address U.S. Geological Survey 103 W. Tenth Street Rolla, Missouri 65401			10. Project/Task/Work Unit No. 11. Contract/Grant No.
12. Sponsoring Organization Name and Address U.S. Geological Survey 103 W. Tenth Street Rolla, Missouri 65401			13. Type of Report & Period Covered Final 14.

15. Supplementary Notes
Prepared in cooperation with the Missouri Geological Survey and Water Resources

16. Abstracts
A linear regression model, utilizing an independent variable described as the flow area of a stream, has been developed for use in estimating minimum streamflow at ungaged sites in the Ozarks region of Missouri. The basic premise in the method is that low-flow characteristics at any point on perennial Ozarks streams are significantly related to the average width and depth or flow area of the minimum flows.

The standard errors of regression equations defining the 7-day Q_2, 7-day Q_{10}, and 7-day Q_{20} are 41, 60, and 76 percent, respectively. These standard errors are 130 to 315 percent lower than those obtained during previous regionalization studies.

17. Key Words and Document Analysis. 17a. Descriptors
*Low flow, *Hydrologic equation, *Frequency analysis, Water supply, Surface waters

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
No restriction on distribution	UNCLASSIFIED	25
	20. Security Class (This Page) UNCLASSIFIED	22. Price

ESTIMATING LOW-FLOW FREQUENCY FOR PERENNIAL MISSOURI OZARKS STREAMS

By John Skelton

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 59-73

Prepared in cooperation with

Missouri Geological Survey and Water Resources

February 1974

UNITED STATES DEPARTMENT OF THE INTERIOR

Rogers C. B. Morton, Secretary

GEOLOGICAL SURVEY

Vincent E. McKelvey, Director

For additional information write to:

U.S. Geological Survey
P.O. Box 340
Rolla, Missouri 65401

CONTENTS

ILLUSTRATIONS

TABLES

ESTIMATING LOW-FLOW FREQUENCY
FOR PERENNIAL MISSOURI OZARKS STREAMS

By John Skelton

ABSTRACT

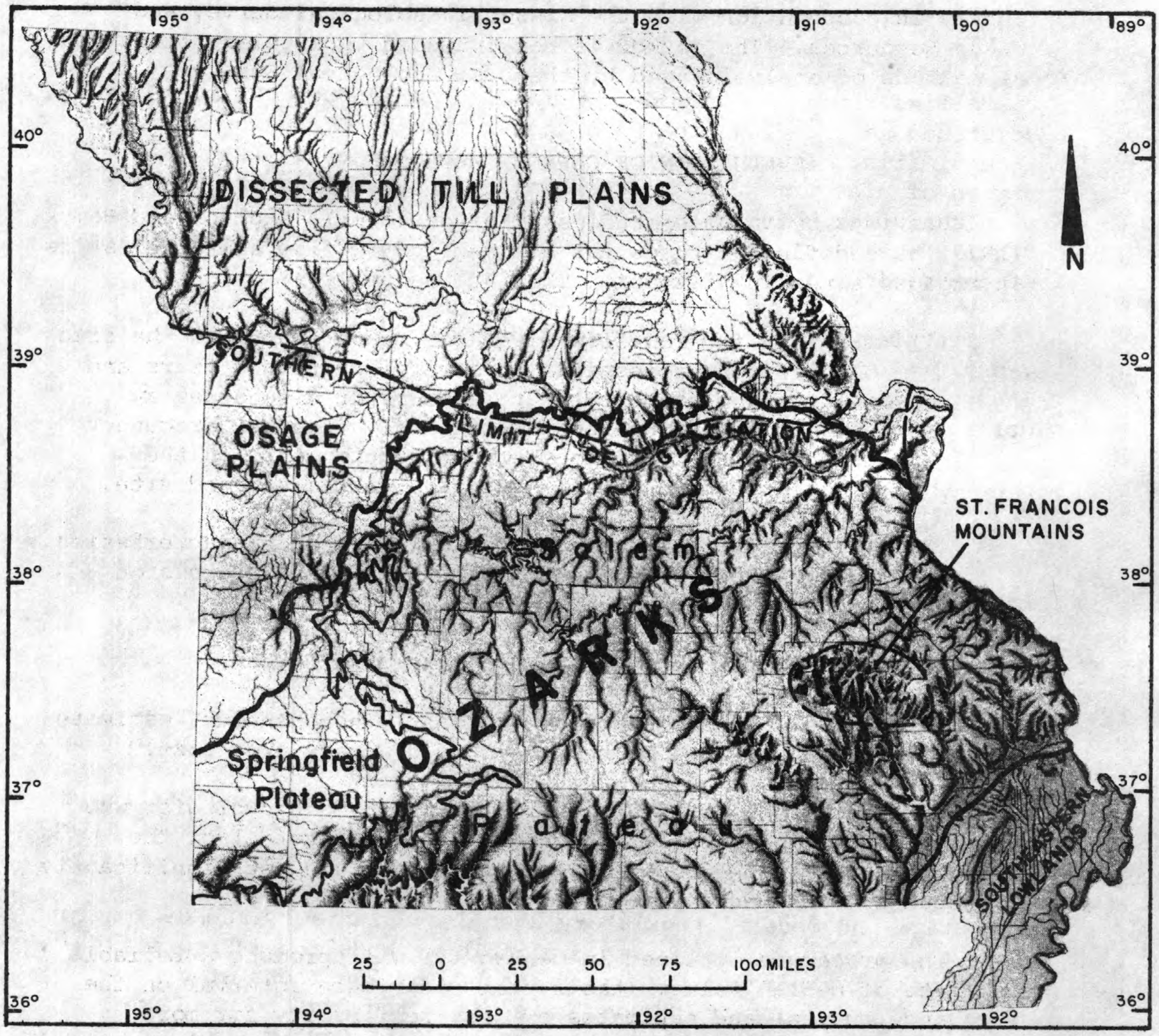
A linear regression model, utilizing an independent variable described as the flow area of a stream, has been developed for use in estimating minimum streamflow at ungaged sites in the Ozarks region of Missouri. The basic premise in the method is that low-flow characteristics at any point on perennial Ozarks streams are significantly related to the average width and depth or flow area of the minimum flows.

The standard errors of regression equations defining the 7-day Q_2, 7-day Q_{10}, and 7-day Q_{20} are 41, 60, and 76 percent, respectively. In comparison, standard errors of 170 to 390 percent were obtained during previous regionalization studies.

INTRODUCTION

One of the primary problems encountered in all low-flow analyses has been the generalization of low-flow frequency data; that is, the transfer of this information from gaged to ungaged sites. In Missouri, this problem has been most acute in the Ozarks region (fig. 1), an area where intense solutional development in the carbonate rocks, faulting, and jointing cause non-homogeneous low-flow patterns by diverting surface flows to underground storage. The effects of jointing, faulting, and solution activity have been highly difficult to define and describe; thus an already difficult statewide problem of low-flow frequency estimation at ungaged sites has been much more complex in this region.

State and Federal regulatory agencies, planners, and designers face a growing need for quick, reliable methods for making field estimates of the magnitude and frequency of low flows at ungaged sites. These "educated laymen" are often required to make on-the-spot evaluations of the low-flow potential of Ozarks streams in order to implement or comply with State and Federal laws regulating the location and design of waste treatment works and water impoundments.



From: Mo. Geol. Survey and Water Resources, 1967

Figure 1 — Map showing the physiographic divisions of Missouri

Purpose and Scope

The purpose of this report is to present a generalized procedure for use by the layman in estimating low-flow frequency at ungaged sites on perennial Ozarks streams. The procedure is referred to in this report as the "flow-area" method and was developed as part of a statewide study of low-flow characteristics of streams and springs that is being made by the U.S. Geological Survey in cooperation with the Missouri Geological Survey and Water Resources. The method is not intended to supplant traditional methods of analysis used by the U.S. Geological Survey.

EVALUATION OF CURRENT METHODOLOGY

Previous hydrologic studies [Skelton (1966), Skelton and Homyk (1970] have defined methods for estimating low-flow characteristics at ungaged sites in Missouri. They are as follows:

(1) Obtain a few low-flow discharge measurements at the site on different recessions in several different years and relate them graphically to concurrent discharges at nearby continuous-record stations. Transfer frequency data for the continuous-record station through the relationship to obtain estimates at the ungaged site.

(2) Relate low-flow characteristics to basin characteristics in equations developed by use of multiple-regression techniques applied to past data.

(3) Interpolate between gaged points on a stream.

(4) Where low-flow patterns are fairly homogeneous, estimate frequency data on the basis of drainage-area size.

These methods are most effectively utilized by a hydrologist who has access to considerable hydrologic information. Also, they are generally limited to natural streams that are not significantly affected by man's activities.

The procedure outlined in method (1) will produce a reliable estimate of median values (the 2-year recurrence interval on the frequency curves) and estimates of less reliability for more extreme events. However, a considerable amount of time is involved in obtaining the necessary discharge measurements, locating a suitable long-time "index" station for correlative purposes, and defining the regression lines. Also, there is no way to mathematically evaluate the magnitude of the errors involved in the procedure.

Method (2) was used by Skelton and Homyk (1970) to evaluate the streamflow data program for Missouri. The data matrix used in the study included the following drainage basin characteristics: drainage area, slope, length, storage in lakes and ponds, mean annual precipitation, average elevation, percent forest cover, 2-year 24-hour rainfall intensity, and soils infiltration index. After analyzing the regression equations generated from this extensive data matrix, Skelton and Homyk stated in their report (p. 30) that "low-flow characteristics cannot be satisfactorily estimated by regression analysis with the present (linear regression) model." They based this judgment upon the prohibitively high standard errors of estimate[1/] for the Ozarks equations, which ranged from 170 percent for the 7-day Q_2[2/] equation to 390 percent for the 7-day Q_{20} equation.

Methods (3) and (4) have been used with some success in the Plains and Southeastern Lowlands, but are not practicable in the Ozarks without extensive field reconnaissance because of the non-homogeneous low-flow patterns.

THE FLOW-AREA METHOD

Studies of the relationships of channel size to mean annual runoff and flood peaks have been conducted by Hedman (1970, 1972) and others in recent years. The major disadvantage of the method has been the difficulty of identifying "channel and point bars" in the field as a basis for measuring channel size. This skill is essential before the method can be utilized to estimate streamflow characteristics at ungaged sites.

1/Standard error of estimate is the principal measure of the accuracy with which a streamflow characteristic can be determined and is expressed as a percentage of the average value of the characteristic. It is the estimated limit above and below the average within which about 67 percent of future values of the streamflow characteristics are expected to fall. Thus, there is one chance in three that future values will differ from the average by more than one standard error.

2/ 7-day Q_2 is the annual minimum 7-day flow with a recurrence interval, or return period, of 2 years. The 7-day Q_{10} flow has a recurrence interval of 10 years and the 7-day Q_{20} represents a low flow with recurrence interval of 20 years. The probabilities of streamflows being less than the 7-day Q_2, Q_{10}, and Q_{20} in any given year are 50 percent, 10 percent, and 5 percent, respectively.

The flow-area method is proposed as a simplified channel-size method of estimating low-flow characteristics and one that may be utilized by a layman without extensive field training.

The basic premise in the flow-area method is that low-flow characteristics at any point on perennial Ozarks streams are related to the cross-sectional area (average width and depth) of the minimum flows. The similarity in the shape of low-flow cross-sections in stream channels in the Ozarks region of Missouri indicates that channel geometry is an important key to the estimate of base-flow quantity. If the appropriate flow area for this concept can be defined as occurring at a cross-section of the stream that is also suitable for making low-flow discharge measurements, then a wealth of area and discharge data is available from discharge measurements in the U.S. Geological Survey files.

Accordingly, for continuous- and partial-record gaging stations in the Ozarks, frequency data and cross-sectional areas from recent low-flow measurements were tabulated as shown in table 1. The following procedures were used in the data tabulation:

(1) Only information from late August through November low-flow measurements were used since this is the period during which annual low flows usually occur in Missouri.

(2) Cross-sectional areas of low-flow measurements from recent (mid-1960's to date) low-flow seasons were averaged to obtain the flow area to be used in the analysis.

(3) Cross-sectional area from the latest (generally 1970-72) low-flow measurements also was listed for comparative purposes. The estimated recurrence interval of most of these low-flows was 1.5 to 2 years.

Figures 2, 3, and 4 illustrate the relationship between average flow areas at gaged sites on Ozarks streams and the minimum 7-day flow to be expected at average intervals of 2, 10, and 20 years. The regression equations shown on the illustrations were computed mathematically to achieve a "best-fit" line for the data. Standard errors of estimate were also computed and are shown on the figures. Note that scatter of the data points increases somewhat below 10 square feet although the standard error is assumed to be the same throughout the range of data. This indicates that the computed standard error is somewhat excessive for streams with large flow areas.

Table 1.--Flow-frequency and flow-area data for perennial Ozarks streams
[A_L=flow area from most recent low-flow measurement;
A_a=average flow area from recent low-flow measurements;
$ft^2 X 0.0929 = m^2$; $ft^3/s X 0.0283 = m^3/s$]

Station name and number		Flow area, in ft^2 A_L	A_a	7-day Q_2, in ft^3/s	7-day Q_{10}, in ft^3/s	7-day Q_{20}, in ft^3/s
Partial-record stations (Salem Plateau)						
07020600	Apple Creek at Appleton	12	11	10	6.8	6.0
07054150	Beaver Creek at Kissee Mills.	33	42	38	14	9.0
07054040	Beaver Creek near Bradleyville.	30	33	19	11	---
06931700	Beaver Creek near Newburg	3.5	5	2.6	1.1	.9
07058900	Bennett Bayou at Bakersfield.	8.0	11	6.5	2.2	1.5
07037000	Big Creek at Des Arc	15	21	9.0	4.8	4.5
06928900	Big Piney River near Houston.	13	21	24	17	15
07017600	Big River near Bonne Terre.	51	47	32	12	---
07018100	Big River near Richwoods.	66	59	89	44	35
07057700	Bryant Creek near Evans	22	23	30	19	16
07053800	Bull Creek at Walnut Shade.	8	9	3.0	.5	.2
07038000	Clark Creek at Patterson.	7	8	2.8	1.4	---
07014200	Courtois Creek at Berryman.	55	60	22	15	12
07014100	Courtois Creek at Courtois.	1.4	5.2	1.3	.7	---
07021150	Crooked Creek at Lutesville.	4.3	4.7	2.3	.8	---
07064950	Current River at Round Spring.	190	202	320	230	220
07068865	Dry Creek near Poynor	1.5	1.1	.4	.3	.2
07012050	Dry Fork near St. James	2.1	2.2	1.2	.3	---
07020100	Establishment Creek at Bloomdale.	10	11	6.5	---	---
07068855	Fourche Creek near Poynor.	5.8	4.9	2.8	1.0	.8
06927700	Gasconade River near Nebo.	39	44	31	16	14
06933800	Gasconade River near Vienna.	250	292	480	325	290
06925440	Grandglaize Creek near Brumley.	28	30	22	16	14
07013100	Huzzah Creek at Dillard	18	18	13	8.5	8.0
07014000	Huzzah Creek near Steelville.	35	35	36	25	21
07014800	Indian Creek near St. Clair.	32	32	17	---	---
07065200	Jacks Fork near Mt. View.	13	22	20	14	12
07019050	Joachim Creek at Hematite.	3.5	7.4	3.4	.8	.4
07068500	Little Black River at Fairdealing.	17	19	23	14	12
06926020	Little Gravois Creek at Bagnell.	1.0	4.2	.8	.4	---
06925250	Little Niangua River near Macks Creek.	19	16	10	3.6	2.8
06930900	Little Piney Creek at Yancy Mills.	9	4.6	3.5	0	0
07010400	Meramec River near St. James.	20	25	22	12	9.2
07061170	Middle Fork Black River near Lesterville.	29	29	18	9.0	8.0
06933300	Mill Creek near Newburg	5.0	7.7	6.0	4.5	4.0

Table 1.--Flow-frequency and flow-area data for perennial Ozarks streams--continued
[A_L=flow area from most recent low-flow measurement;
A_a=average flow area from recent low-flow measurements;
ft^2X0.0929=m^2; ft^3/sX0.0283=m^3/s]

Station name and number	Flow area, in ft^2		7-day Q_2, in ft^3/s	7-day Q_{10}, in ft^3/s	7-day Q_{20}, in ft^3/s
	A_L	A_a			
Partial-record stations (Salem Plateau)--cont.					
07017800 Mineral Fork near Potosi.	34	37	26	9.5	---
06923200 Niangua River near Buffalo.	19	16	17	8.0	---
07057400 North Fork River at Twin Bridges.	23	44	42	24	21
07017900 Old Mines Creek near Potosi.	3.4	4.6	1.9	---	---
06927750 Osage Fork near Orla	22	26	25	13	11
06928450 Roubidoux Creek at Waynesville.	19	14	10	2.6	1.8
07034000 St. Francis River near Roselle.	1.5	1.7	1.2	.1	0
07064800 Sinking Creek near Round Spring.	27	36	38	28	26
06930100 Spring Creek at Spring Creek.	35	33	21	11	9.5
07057450 Spring Creek at Twin Bridges.	16	16	21	16	15
06926300 Tavern Creek near St. Elizabeth.	3.5	3.2	2.8	.5	---
07061150 West Fork Black River at Centerville.	20	29	25	15	14
07068860 West Fork Fourche Creek near Poynor.	4	4	1.9	1.0	.9
06925430 Wet Glaize Creek near Brumley.	20	21	20	12	11
07021400 Whitewater River at Millersville.	22	20	14	8.2	7.0
Continuous-record stations (Salem Plateau)					
06930000 Big Piney River near Big Piney.	61	106	115	82	75
07061500 Black River near Annapolis.	70	80	98	68	66
07058000 Bryant Creek near Tecumseh.	65	94	150	110	100
07021000 Castor River at Zalma	48	68	46	27	23
07068000 Current River at Doniphan.	700	660	1,170	940	890
07067000 Current River at Van Buren.	320	343	700	540	510
07066500 Current River near Eminence.	240	260	512	382	358
07071500 Eleven Point River near Bardley.	100	105	270	185	170
07070500 Eleven Point River near Thomasville.	10	9.2	7.2	4.1	3.4
06933500 Gasconade River at Jerome.	400	383	470	320	290
06928000 Gasconade River near Hazelgreen.	70	53	66	30	25
06928500 Gasconade River near Waynesville.	92	136	130	66	56
07066000 Jacks Fork at Eminence	68	80	122	86	78
06932000 Little Piney Creek at Newburg.	30	44	41	25	23
07013000 Meramec River near Steelville.	140	118	120	90	80
07057500 North Fork River near Tecumseh.	220	264	295	210	195
06927800 Osage Fork at Drynob	16	30	27	15	---
06921000 Pomme de Terre River near Bolivar.	20	9	2.6	.4	.2

Table 1.--Flow-frequency and flow-area data for perennial Ozarks streams--continued

[A_L=flow area from most recent low-flow measurement;
A_a=average flow area from recent low-flow measurements;
$ft^2 X0.0929=m^2$; $ft^3/sX0.0283=m^3/s$]

Station name and number	Flow area, in ft^2 A_L	A_a	7-day Q_2, in ft^3/s	7-day Q_{10}, in ft^3/s	7-day Q_{20}, in ft^3/s
Continuous-record stations (Salem Plateau)--cont.					
07037500 St. Francis River near Patterson.	40	28	32	15	11
Partial-record stations (Springfield Plateau)					
07188840 Big Sugar Creek at Powell	15	16	7.2	1.2	---
07189100 Buffalo Creek at Tiff City	5	8	1.9	0	0
07186800 Capps Creek near Berwick	33	15	20	11	---
07186460 Center Creek near Carl Junction.	83	40	35	13	9.0
07186200 Center Creek near Fidelity.	35	23	22	7.6	---
07186100 Center Creek near Sarcoxie.	24	17	16	6.8	---
06918430 Clear Creek near Phenix	8	9	5.0	1.0	---
07186850 Clear Creek near Ritchey	7.2	7.1	7.0	2.2	---
07188850 Elk River at Pineville	36	25	28	7.0	---
07052260 Finley Creek near Linden.	8	15	7.6	---	---
07052300 Finley Creek near Ozark	20	14	16	5.2	---
07052750 Flat Creek at Cassville	5.9	5.3	4.0	1.4	.8
07052800 Flat Creek at Jenkins	13	16	27	10	6.5
07052900 Flat Creek near Cape Fair.	42	45	31	---	---
07186900 Hickory Creek at Neosho	33	14	9.8	3.9	---
07188870 Indian Creek at Anderson	30	28	37	11	---
Partial-record stations (Springfield Plateau)--cont.					
06918450 Limestone Creek at South Greenfield.	5.8	4	2.3	0.3	---
06918420 Sac River at Ash Grove	20	22	13	3.5	2.5
07186890 Shoal Creek at Neosho	54	43	60	23	16
07186880 Shoal Creek at Ritchey	54	37	54	20	13
07186700 Shoal Creek near Fairview.	16	15	17	7.0	5.0
07185650 Spring River near Stotts City.	56	28	42	19	15
06918470 Turnback Creek near Greenfield.	23	35	23	4.5	---
07185400 Williams Creek near Mt. Vernon.	4	5	4.7	2.0	1.5
Continuous-record stations (Springfield Plateau)					
07186400 Center Creek near Carterville.	26	23	26	9.4	---
07052500 James River at Galena	70	70	100	38	24
07050700 James River near Springfield.	19	8	11	1.0	.3
07187000 Shoal Creek above Joplin	45	67	92	35	22
07185700 Spring River at Larussell.	35	47	47	20	15
07186000 Spring River near Waco	72	73	53	18	11

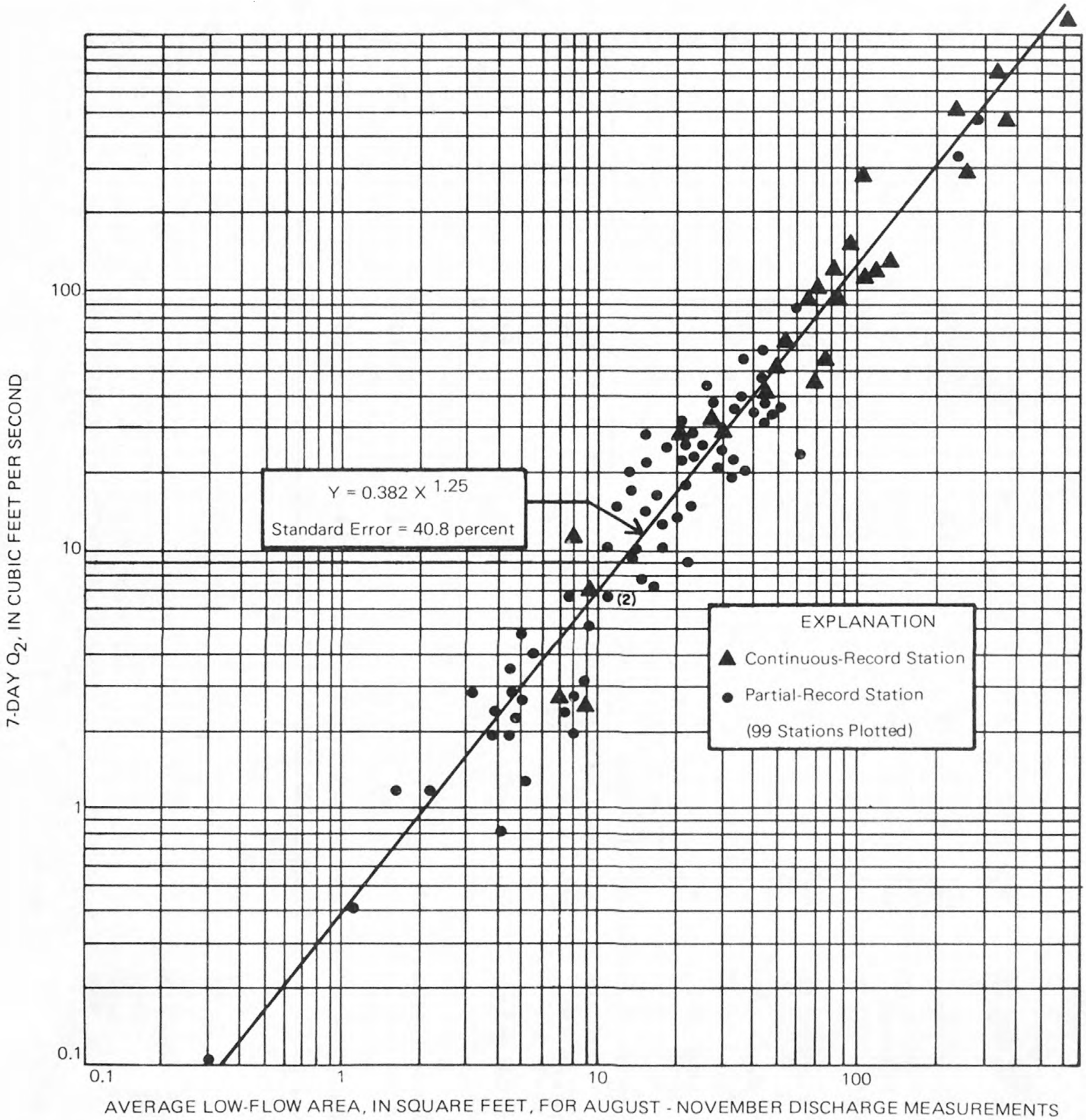


Figure 2 — Plot of 7-day Q_2 vs. flow area for perennial Ozarks streams, showing computed regression line.

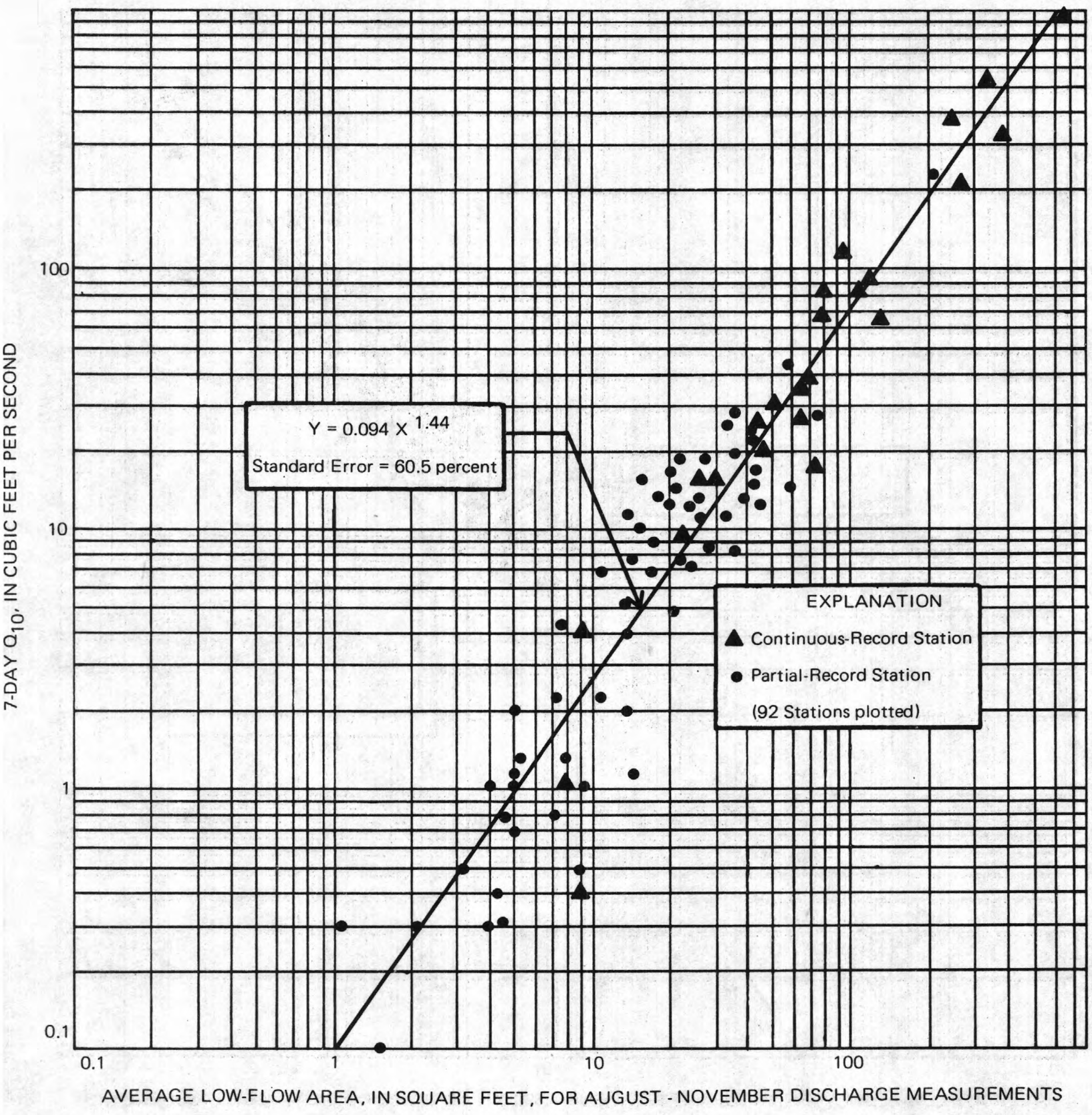


Figure 3 — Plot of 7-day Q_{10} vs. flow area for perennial Ozarks streams, showing computed regression line.

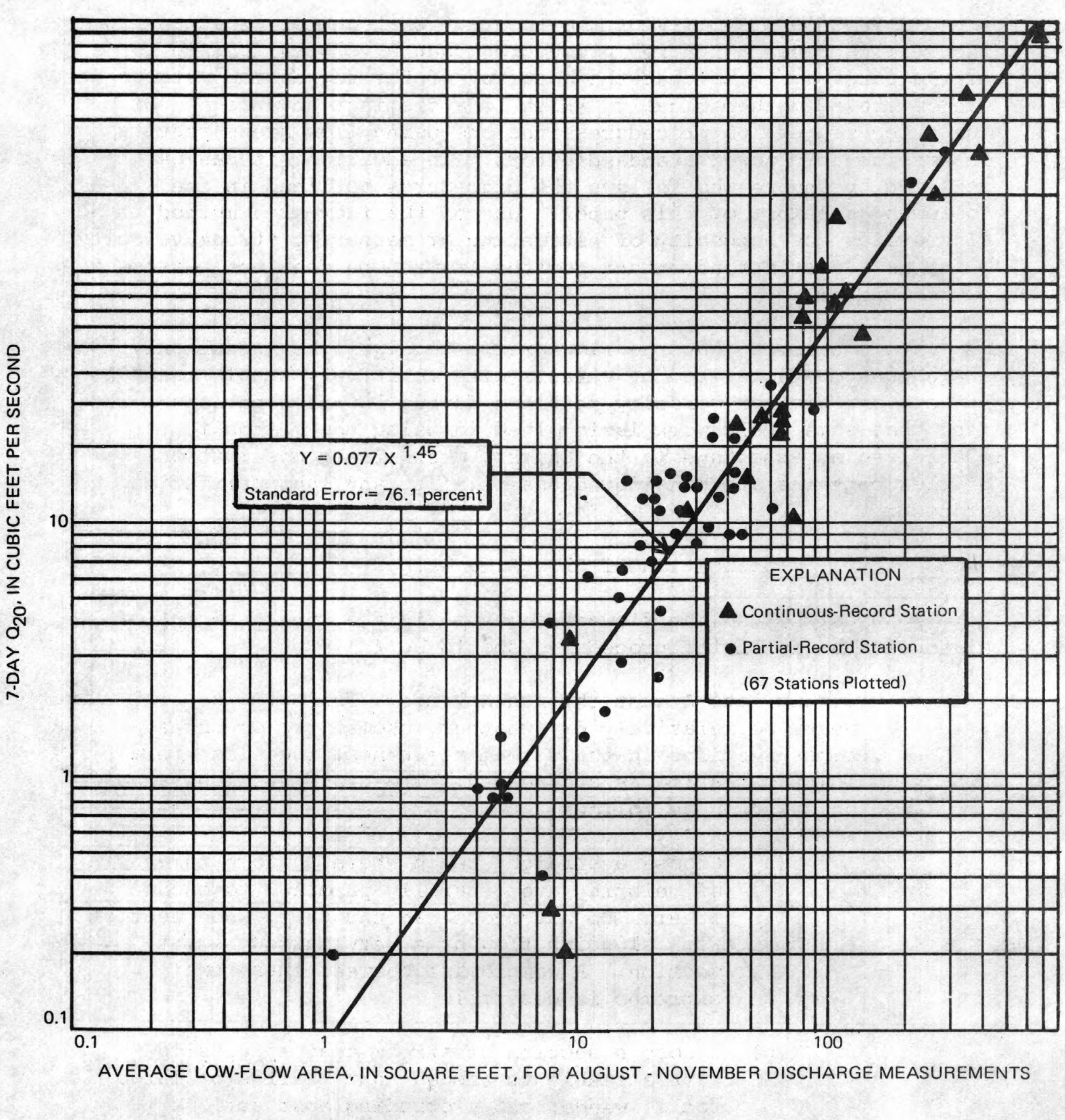


Figure 4 – Plot of 7-day Q_{20} vs. flow area for perennial Ozarks streams, showing computed regression line.

Table 2 is a summary of the accuracy that can be expected from the various regionalization procedures that have been applied to Ozarks streams. Note that the accuracy of the regression methods can be stated mathematically, which is a distinct advantage. Of the three regression procedures, the one using flow areas results in considerably lower standard errors. In addition, it can be utilized by anyone who follows the procedures outlined in the following sections of this paper. Use of the flow-area method also avoids the necessity of estimating or measuring stream velocity, which is a distinct advantage for the layman who does not possess a current meter.

It is believed that the flow-area method will be useful only in regions characterized by streams with relatively stable channel bottoms and similar velocity patterns during low-flow periods. The fact that some field work is involved in using the method is considered an advantage in the Ozarks, where field observations of flow patterns are considered essential to any regionalization procedure.

Application of Flow-Area Method

In order to use the flow-area method in the Ozarks region of Missouri, the following procedures should be followed:

(1) During late August through November, following several weeks of relatively dry weather, choose two or three cross-sections in the stream reach near the site where low-flow estimates are needed. The cross-sections should be selected as follows:

   (a) Choose a straight reach where uniform threads of velocity are generally parallel to each other. Do not choose an unusually wide section with sluggish flow or a very narrow, swift section. A compromise between these two extremes is desirable.

   (b) Choose a section of stream that appears to have a stable streambed that is free of large rocks, weeds, and protruding obstructions that cause turbulence.

   (c) The profile of the streambed in the selected section should be flat enough to eliminate most turbulence; that is, do not select a section on a shoal or riffle section of the stream. In the Ozarks, a section slightly upstream from a riffle, where the water surface is smooth, is often satisfactory.

Table 2.--Accuracy of regionalization procedures that have been applied to Ozarks streams

Flow characteristics	Multiple regression, using extensive data matrix	Regression, using basin drainage area only	Regression, using average flow areas from recent measurements	Regression, using flow areas from latest low-flow measurements	Obtain low-flow measurements and relate to nearby long-term records	Interpolate between gaged points
	Standard error, in percent	Standard error, in percent	Standard error, in percent	Standard error, in percent		
7-day Q_2	170 (+268 / - 73)	230 (+375 / - 79)	41 (+49 / -33)	50 (+62 / -38)	Adequate for 7-day Q_2, but less accurate for 7-day Q_{10} and 7-day Q_{20}. Standard error cannot be measured.	Cannot be used in Ozarks without extensive field reconnaissance. Standard error cannot be measured.
7-day Q_{10}	270 (+450 / - 82)	480 (+880 / - 80)	60 (+76 / -45)	86 (+118 / - 54)		
7-day Q_{20}	390 (+690 / - 87)	520 (+950 / - 90)	76 (+101 / - 51)	76 (+101 / - 51)		

(2) After locating a suitable cross-section, measure the total width of the stream at the section. Choose approximately 10 uniformly spaced points across the section in order to adequately define the bottom profile of the stream and measure the total depth of water at these points. Obtain an average depth for the section by adding the depths together and dividing by the number of observation points. Multiply average depth by stream width to obtain flow area in square feet.

The U.S. Geological Survey uses a weighted average of stream depth[1] in computing discharge, and these are the data shown in table 1 and used in preparing figures 2, 3, and 4. However, by comparing "weighted" and "arithmetic" cross-sectional areas at 12 representative low-flow stations in the Ozarks, the author has determined that an arithmetic average of the depths at 10 equally spaced points across a section will usually be sufficiently accurate. The difference between weighted and arithmetic areas at the stations ranged from 0 to 14 percent, but the median percentage difference was only 7.7.

(3) Obtain an average of the flow areas for the several cross-sections chosen.

(4) Utilize figures 2, 3, or 4 to estimate low-flow frequency data for the site.

It is preferable to measure flow areas during several low-flow periods in different years and average the results to obtain optimum estimates. Table 2, column 5, indicates that the use of only one flow-area measurement could result in an increase in the expected standard error. However, the author was unable to field-check this assumption because of unusually high streamflow conditions in 1972-73.

Limitations of Flow-Area Method

The following limitations should be considered when this method is used to estimate low-flow frequencies for ungaged Ozarks streams:

(1) This method is applicable only to perennial Ozarks streams and does not apply to reaches of streams where flow is intermittent in most years.

(2) The method is not applicable to regulated streams and should not be used for estimates on any stream that is significantly affected by man's activities (for example, during periods of extensive irrigation withdrawals).

(3) Regression lines should not be extended beyond the limits defined by the data.

(4) Measurements of flow area in the field must be made from late August through November, following several weeks of relatively dry weather.

(5) The relationships of figures 2, 3, and 4 were defined by flow areas that were measured during drought events with recurrence intervals ranging from less than 1 year to approximately 5 years. Thus, if flow areas are measured during a severe drought in a region, frequency estimates at ungaged sites would tend to be conservative (low).

REFERENCES CITED

Hedman, E. R., 1970, Mean annual runoff as related to channel geometry in selected streams in California: U.S. Geol. Survey Water-Supply Paper 1999-E, 17 p.

_____1972, Selected streamflow characteristics as related to channel geometry of perennial streams in Colorado: U.S. Geol. Survey open-file rept., 14 p.

Missouri Geological Survey and Water Resources, 1967, Physiography, in Mineral and Water Resources of Missouri: Missouri Geol. Survey and Water Resources, ser. 2, v. 42, p. 14.

Skelton, John, 1966, Low-flow characteristics of Missouri streams: Water Resources Report 20, Missouri Geol. Survey and Water Resources, 97 p.

Skelton, John, and Homyk, Anthony, 1970, A proposed streamflow data program for Missouri: U.S. Geol. Survey open-file rept., 77 p.

☆ U. S. GOVERNMENT PRINTING OFFICE: 1974--762629/46 REGION NO. 6