1-1-1973

Mathematical Modeling of Stream Storage Potential

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WATER RESOURCES RESEARCH CENTER

Publication No. 17

In Cooperation With The

ENGINEERING EXPERIMENT STATION

Research Report No. 17

UNIVERSITY OF ARKANSAS
Fayetteville
1973

PROJECT COMPLETION REPORT

PROJECT NO: B-015-ARK AGREEMENT NO: 14-31-0001-3257

Starting Date: July 1970 Completion Date: June, 1973

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December, 1973

ABSTRACT

Streamflow data from unregulated streams in Arkansas were processed through Moran's Model for a dam. The process involved calculating a cumulative gamma distribution for each stream as the streamflow values were incremented in units of 0.1 cubic feet per second per square mile of drainage area. This gamma distribution was then used as input for Moran's Model. The output from Moran's Model includes the probability of the reservoir having zero contents as the size of the reservoir is decreased. The logarithm of the probability of zero contents, $\ln P_o$, versus reservoir size, K, is a straight line of the form $\ln P_o = -n-sK$. The constants in the equation, n and s, are functions of the logarithm of the draft when the draft is expressed as a percentage of mean annual flow.

The equations for $\ln P_o$ versus K were determined for each stream studied. In addition, a general equation for all streams was determined.

ACKNOWLEDGEMENT

The work upon which this report is based was supported in part with funds provided by the Office of Water Resources Research, U.S. Department of the Interior under Grant Number B-015-ARK and authorized under the Water Resources Research Act of 1964. P.L. 88-379 as amended by P.L 89-404.

TABLE OF CONTENTS

LIST OF FIGURES

MATHEMATICAL MODELING OF STREAM STORAGE POTENTIAL

Introduction

Adequate storage is a requisite to providing a dependable water supply. The question is "what is adequate storage?" Logical reasoning indicates that a large variation in streamflow will necessitate a large reservoir to provide a constant release equal to a large portion of the average annual flow. Conversely, if the flow in a stream did not vary, no storage would be required in order to withdraw a large portion of the mean annual flow.

A suitable algorithm is needed to determine the storage required to insure a dependable water supply of a stated quantity from a given stream. The increase in per capita use of water and the large population increases have brought the realization that we must effect higher percentage yields from streamflow for water supply purposes. The time may be near when we must develop water resources to maximum potential. Much has been written about reuse of water, and it would appear that maximum potential development of available supplies would follow closely, if not precede, water reuse in priority. In addition, preferable reservoir sites are being used for low percentage yield projects. Therefore, future development of water resources may be inhibited by current developments from the point of potential reservoir sites.

The development of a suitable algorithm for determining the design size of a water supply reservoir has occupied the interest, at times, of several eminent statisticians and engineers. Several models have been presented as suitable for such a purpose.

Most of the mathematical work considers the storage function as a stochastic process as opposed to the deterministic approach used in the mass-curve procedure. Unfortunately, most of the theories advanced have not been applied to streamflow data. In some cases, the models have been applied to very simple discrete probability distributions. The extreme example of such a distribution is the trinomial distribution where the streamflow may assume only one of three values. Other examples that are frequently used are the Poisson distribution and the negative binomial distribution. Such distributions are not very realistic when applied to streamflow.

Such investigators have approached the problem with continuous probability distributions, assuming either normal or uniform distributions. Still others have recognized that streamflow generally follows the Pearson Type III or gamma distribution, but they have developed the theory based upon the concept of an infinite dam. An infinite dam or reservoir is capable of storing any excess and supplying any deficit.

The reason for using such assumptions as normal inflow and infinite capacity is that an exact solution for a dam of finite capacity with a gamma input is very complex. This is not to criticize those presentations where these simplifying assumptions are made. Each contribution adds to our rather meager knowledge of storage systems and helps to understand the underlying processes. Therefore, each investigator has contributed to what is now known about storage systems with stochastic inputs and various types of outputs.

The purpose of this study was to investigate the applicability of a model to all gaged, unregulated Arkansas streams. This model is the expression of a unique relationship that exists, for several area streams, between reservoir size, the fraction of mean annual streamflow assumed to be drawn from the reservoir, and the probability that the reservoir will become empty as calculated by Moran's model for a dam.

The writer had previously observed that the log of the probability of a reservoir becoming empty, as calculated by Moran's model, had a linear relationship to reservoir size. This was observed while studying ten western Arkansas and eastern Oklahoma streams. After further investigation, it was determined that the slope and the intercept of this linear relationship was a function of the decimal fraction of mean annual streamflow assumed to be withdrawn from the reservoir. These findings were deemed sufficient reason for further studies to determine the applicability of the resulting model to other Arkansas streams.

PREVIOUS STUDIES

The Rippl Procedure

The method of determining reservoir size that is most commonly used at present was proposed by W. Rippl (22) in 1883. Prior to 1883, the method of design was to assume a reasonable size for a supply reservoir and further assume that the reservoir was full at the beginning of the drought period. By simple addition of the estimated monthly inflow and subtraction of the estimated monthly withdrawals and losses, the calculations were made of the quantity in the reservoir at the end of each month for a period of a year. If the calculation showed a deficiency, that is a negative quantity, the original assumed capacity was increased and the calculations repeated (22).

The Rippl procedure was far superior to the previous procedure both in the accuracy achieved and the labor necessary to determine a design capacity. However, the Rippl procedure suffers several deficiencies. This procedure is illustrated in most texts on water supply design.

Hazen's Procedure

The first attempt to overcome some of the deficiencies of the Rippl procedure was made by Allen Hazen in 1914 (7). Hazen constructed a Rippl diagram for each year of record from fourteen streams and computed the storage, assuming normal distribution of this storage, that would have been required in that year to provide assumed continuous drafts ranging from 30 to 90 percent of mean annual flow. Hazen's 1914 work was revised and updated in 1930 (6).

The assumption of the normality of the distribution of storage requirements would seem to cause storage volume requirements computed by this procedure to be low. However, Fiering (4) has shown that skewness of streamflow data is far less important than the coefficient of variation in determining the range of storage requirements. Hurst (8) reached an identical conclusion from studying several natural phenomena including the flow of the Nile river and the storage necessary to provide regulation thereof. Therefore, Hazen's criteria is acknowledged by many to provide a good first approximation to reservoir size although the streamflow data may not be normally distributed.

Moran's Model for a Dam

A probability theory of dams and storage systems was formulated by Moran in 1954 (15). The basic concept of the approach is that with a prescribed probability distribution for inflow and a prescribed release rule, an integral equation can be written for the amount of water in storage. This integral equation may then be approximated by a system of linear equations. The solution of these linear equations will provide the probability distribution of the contents of the dam. This probability distribution is the item of interest of engineers as it will reveal the probability of the dam being unable to deliver the desired draft.

Moran's original paper on this subject (15) was directed toward storage for irrigation water. First, it was assumed that water flowed in during the wet season and was stored until the dry season when it was released. Next, it was assumed the input was continuous and the release occurred once at a given time.

In a later paper (16) Moran modified the release rule to allow water to be released at shorter increments of time, for instance, monthly releases instead of yearly, and presented a method of approximating a gamma distribution with a discrete distribution. Subsequently, (17, 18) it was shown that the original model could be used to approximate the situation where the input and release were both continuous, which is what occurs in a municipal water supply situation.

The model may be described as follows: Let X_t, the streamflow during time t, be independent or without serial correlation and be equal to 0,1,2,... with probabilities, $p_0, p_1, p_2, \ldots$ respectively, and let Z_t, the dam contents, be equal to 0,1,2,... K at time t with probabilities $P_0, P_1, \ldots P_k$, and at time t+1 with probabilities P'_0, $P'_1, \ldots P'_k$, where K is the size of the reservoir. An amount of water M is taken from the reservoir and M, X_t, K, and Z_t are integral multiples of some unit.

After the reservoir has been in operation for a period of time, the probability distribution of a dam contents, Z_t, will have achieved a stable distribution so that

$$P'_i = P_i \text{ for } i = 0, \ldots, K\text{-}M.$$

From a recurrence relationship, Z_t will be defined by the system of equations

$$P_o = P_o\,(p_o + \ldots + p_m) + P_1(p_o + \ldots p_{m-1}) + \ldots P_M p_o$$

$$P_1 = P_o p_{m+1} \qquad + P_1 p_m \qquad + \ldots P_M p_1 + P_{M+1} p_o$$

$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots$$

$$P_{K-M} = P_o(p_k + \ldots) \qquad + \ldots \qquad + P_{K-M}(p_m + \ldots)$$

$$P_{K-M+1} = \ldots = P_K = 0 \qquad \text{a.}$$

In this case $0 \leq Z_t \leq K-M$, and the distribution of Z_t can be found by solving the above equations. The equations could be solved by several methods.

One method is to replace the final equation of (a.) with $P_o + P_1 + P_{K-M} = 1$, which gives a set of non-homogeneous equations, and then use the process of straightforward sucessive elimination of variables. One advantage of this method of solution is that solutions for smaller values of K are given by omitting one equation at a time from the system. For example, the solution for K one unit smaller than the original K is given by omitting the equation for P_{K-M-1}, the next to last equation, and setting P_{K-M-1} equal to zero in the other equations. Thus one can see how the distribution of Z_t varies with the size of the dam. This is precisely what the engineer needs to know.

Several works (2, 5, 10, 11, 12, 13, 19, 20, 21) dealing with the theory of dams and storage systems have been presented as a result of the interest created by Moran's work.

Walter B. Langbein (12, 13) developed a procedure from Moran's model which he called "probability routing." This procedure uses a plot of inflow versus probability and a plot of discharge versus storage to obtain a graph of discharge versus probability. This is an excellent technique for evaluating the capability of a reservoir already constructed. For design purposes, it appears to suffer the deficiency that the discharge storage relationship must be assumed in advance.

A computation of the storage requirements for various levels of streamflow regulation in the 22 major regions of the contiguous United States was made by a select committee of the United States Senate (23). Löf and Hardison (14) determined that the storage requirements given in the report of that study for high sustained-use of flows were erroneously low in all of the regions. These low storage values were caused by using linear extrapolation from low percentage yields to high percentage yields whereas the function is not linear. Therefore, they presented storage values, calculated by "probability routing" to supersede the values determined by the select committee.

Fiering (2) proposed an algorithm using queuing theory and simulation. He assumed that the inflow distribution was a truncated normal distribution and that the inflow in any year was uniform throughout the year.

Phatarfod (20) applied methods in sequential analysis to a continuous time dam model based upon Moran's discrete time model. The main objective was to derive the probability of the time at which the dam becomes empty.

Phatarfod developed the characteristic function of the time at which the dam becomes empty for the first time before overflowing, and then the characteristic function of the time at which the dam becomes empty for the first time regardless of overflow in the meantime. He developed these characteristic functions for inputs that corresponded to two discrete probability distributions, namely the Poisson and geometric. Prabhu (21) then applied Phatarfod's analysis to a continuous input when the input distribution is gamma to obtain the probability that the dam dries up before overflowing.

Kirby (11) presented three markov chain storage models for discrete time and inflow conditions. The addition to Moran's model consisted of allowing the inflows to be serially correlated.

Sequent Peak Procedure

The sequent peak procedure is a deterministic analytical procedure proposed by Thomas and Fiering (24). The cumulative difference between inflow and draft is calculated for a given period of streamflow record. As the calculations progress, peaks (local maximum) and troughs (local minimum) will occur. The maximum difference between peaks and troughs is the minimum storage necessary to prevent a deficiency in draft. It is assumed that the streamflow record will cycle in T years and two cycles or 2T years of record is needed to make the analysis.

The advantages claimed for this procedure are that the necessity for determining a value of starting storage is removed. This could erase some of the uncertainty that now exists in deterministic procedures. In applying the Rippl Method it is usually assumed that the reservoir is full at the beginning of a drought. At times this is a rather unsound assumption. It is stated that the sequent peak procedure is equivalent to a linear programming solution for optimal overflow or waste pattern (3).

The sequent peak procedure is open to some of the same criticism that the Rippl Method receives in that it is implied that the sequence of streamflow events will be repeated during the design life of the project or that a drought of greater magnitude is unlikely to occur. These assumptions appear inherent in any deterministic analytical technique.

Kartvelishvili (10) severly criticized the purely statistical approach to describing river flow as a totally chance event and ignoring the factors which cause the flow. He points out that some of the factors causing flow have a stochastic character and some a deterministic character. He proposes that the runoff process should be considered as a random process and that a full solution to the regulation of rivers by reservoirs can be obtained only on the level of the theory of random processes.

Objections to probability methods are answered by Kartvelishvili (10) as follows: {1. Probability theory should not be considered as compensation for insufficient information about hydrologic processes. Such a consideration would imply that the probability would increase or decrease with the development of the science, and would lead eventually to simple confidence in the authenticity or impossibility of the studies event. This would, therefore, negate the objective character of probability principles, exclude probability theory from the mathematical sciences, and assign it a role in psychology. 2. Demands for proof of the accidental nature of river flow are not logical because there does not exist one fact confirming the deterministic character of flow, nor does there exist one fact refuting the accidental character of the process. 3. Chance should not be equated with unsystematicness. The fact that regularities are observed in streamflow does not mean that probability theory is inapplicable in the study of streamflow and its regulation. Regularities observed in streamflow, which some writers think contradict probability theory, can be correctly reflected only by probability methods.} Laws of accidental deterministic nature, which place limits on the amount of streamflow, should always be included in a study.

Linear Programming

The application of linear programming to both deterministic and stochastic models for water-resources design is cited by Chow (1). He gives an example for determining the design capacity when the objective function is to maximize net benefits. This is a correct procedure for a given project, but it is particularly difficult to generalize in an analysis such as this as to cost and benefits when so many factors involved in costs and benefits depend upon conditions that could not be determined until a specific project has been planned.

The model given by Chow is confined to a duration of one year and it was assumed that there was not carry-over from year to year. Thus, the stated model is useful for illustrative purposes only. Chow states that the actual situation for the design of reservoirs is much more complicated. Thomas and Watermeyer (25) used linear programming and dam theory to formulate what they termed a stochastic sequential approach to determine optimal reservoir capacity.

A linear programming application to sizing a reservoir when the objective function is to minimize the design capacity simplifies to repetitive solution of the continuity equation for storage. Thus, the solution is analogous to the sequent peak procedure mentioned earlier and is exactly the same as a mass curve analysis of the entire streamflow record.

Dynamic Programming

Dynamic programming is applicable to problems where the consideration of time is essential and the decision sequence is important. Chow (1) cites several examples of dynamic programming application to various hydroelectric projects. The major contribution of dynamic programming, that is the decision making, is absent to a large degree in municipal water supply situations, but is very much present in hydroelectric, irrigation, and flood control projects where a decision on the amount of release must be made.

Procedure

Streamflow data were taken from United States Geological Survey - surface water records. The mean, standard deviation, coefficient of variation, variance, and skewness were calculated for the data from each gaging station. These parameters were then used to compute the gamma distribution in accordance with the following:

$$f(x;\, \alpha,\beta) = \frac{1}{\alpha!\beta^{\alpha+1}} x^{\alpha} e^{-x/\beta} \qquad 0<x<\infty$$

$$\text{mean} = \mu = \beta(\alpha+1)$$
$$\text{variance} = \sigma^2 = \beta^2(\alpha+1)$$

α is then a shape factor and must be greater than -1. β is a scale factor and must be positive (see Figure 1).

The cumulative gamma distribution for each gaging station was calculated by increasing x, the streamflow value, in increments of 0.1 cubic feet per second per square mile. The range used for streamflow values was from zero flow to that flow which would not be exceeded 99.95 percent of the time. This cumulative gamma distribution was used to provide input to Moran's model for a dam.

The probability of zero contents in the reservoir, P_o, was plotted versus reservoir size, K. This information was also punched on cards. All calculations and plotting were, of course, done by the computer. The punched cards were then sorted to discard probabilities outside the range of 0.05 to .0005. The thought being that a reservoir would rarely be built with a probability of going dry outside this range. This information was then processed to obtain equations relating the slope and the intercept of the relationship of P_o to K to the draft ratio when the draft ratio is expressed as a decimal fraction of mean flow. These equations were obtained by the method of least squares.

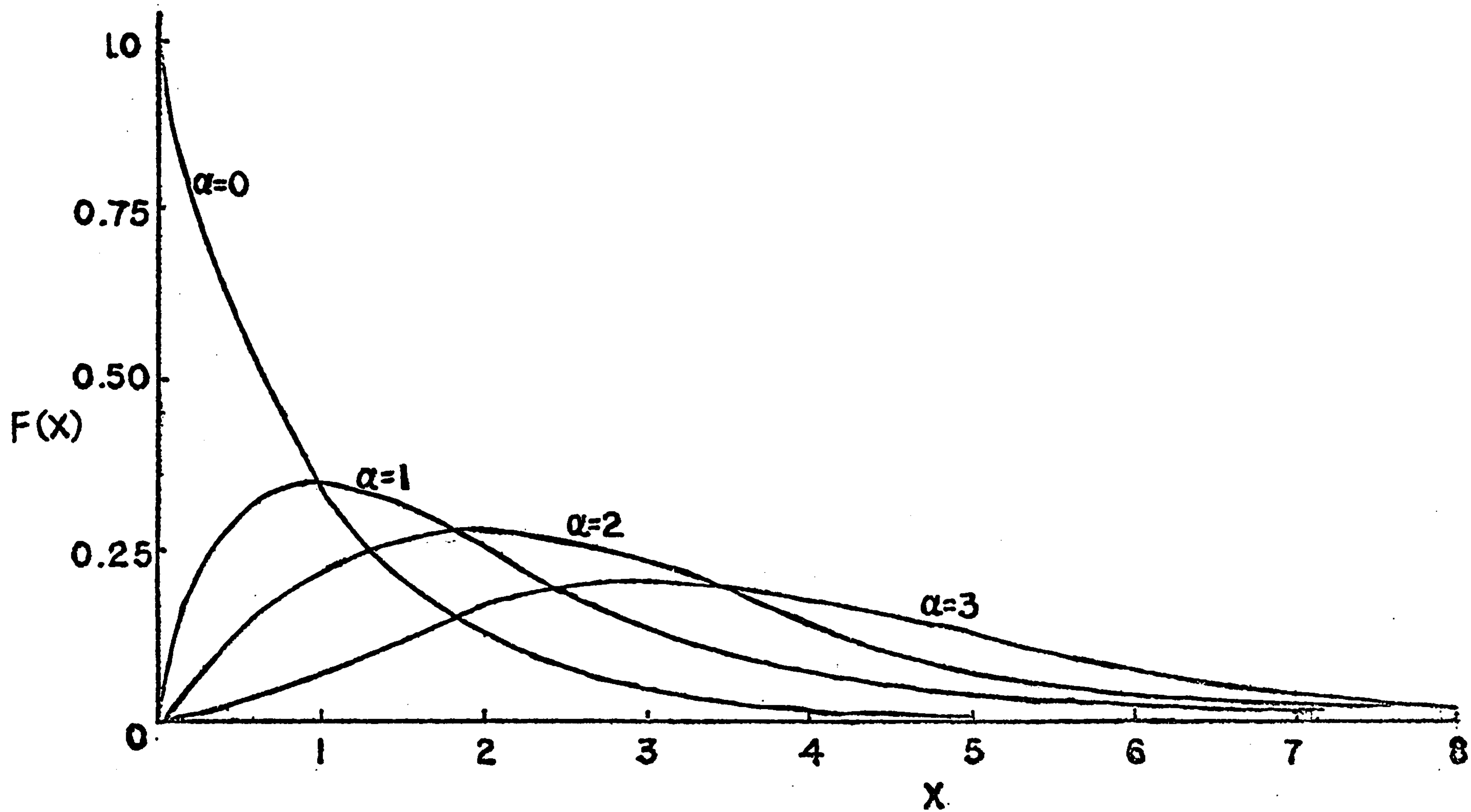


FIGURE I. THE GAMMA DISTRIBUTION
$\beta = 1.0$

The foregoing procedure was followed using both mean annual streamflow and mean monthly streamflow.

The same procedures were followed to determine the results should the streamflow follow a probability distribution corresponding to the Weibull distribution rather than the gamma distribution.

RESULTS

The data from all gaging stations in Arkansas were examined. It was determined that thirty-nine stations existed where the flow was not regulated in some manner. The regulation at some stations was due to upstream reservoirs, at other stations it was due to runoff from irrigation practices, at others it was due to backwater from other streams. The thirty-nine stations used, with the streamflow parameters, are given in Appendix A.

It was decided that the gamma distribution was preferable to the Weibull distribution for characterising streamflow in Arkansas, especially for monthly flows. This decision was based upon the fact that the gamma distributions can easily accommodate zero flow and the gamma distribution seemed to fit the data well. The logarithms of the streamflow data are used to calculate the Weibull distribution. This presents a problem when zero flows are encountered.

From plots of actual streamflow data versus a calculated Weibull and a calculated gamma, no definite conclusions could be reached as to the preference of either probability distribution. For some streams, the Weibull fit the data better at the lower flows and the gamma fit better at the higher flows. For a few streams, this pattern was reversed. Figure 2 through 6 are examples of monthly flow data versus the two calculated distributions.

Figure 7 is an example of the unique relationship that exists between the logarithm of the probability of having zero contents in a reservoir, P_o, versus the reservoir size, K, as a function of draft rate in Cfsm.

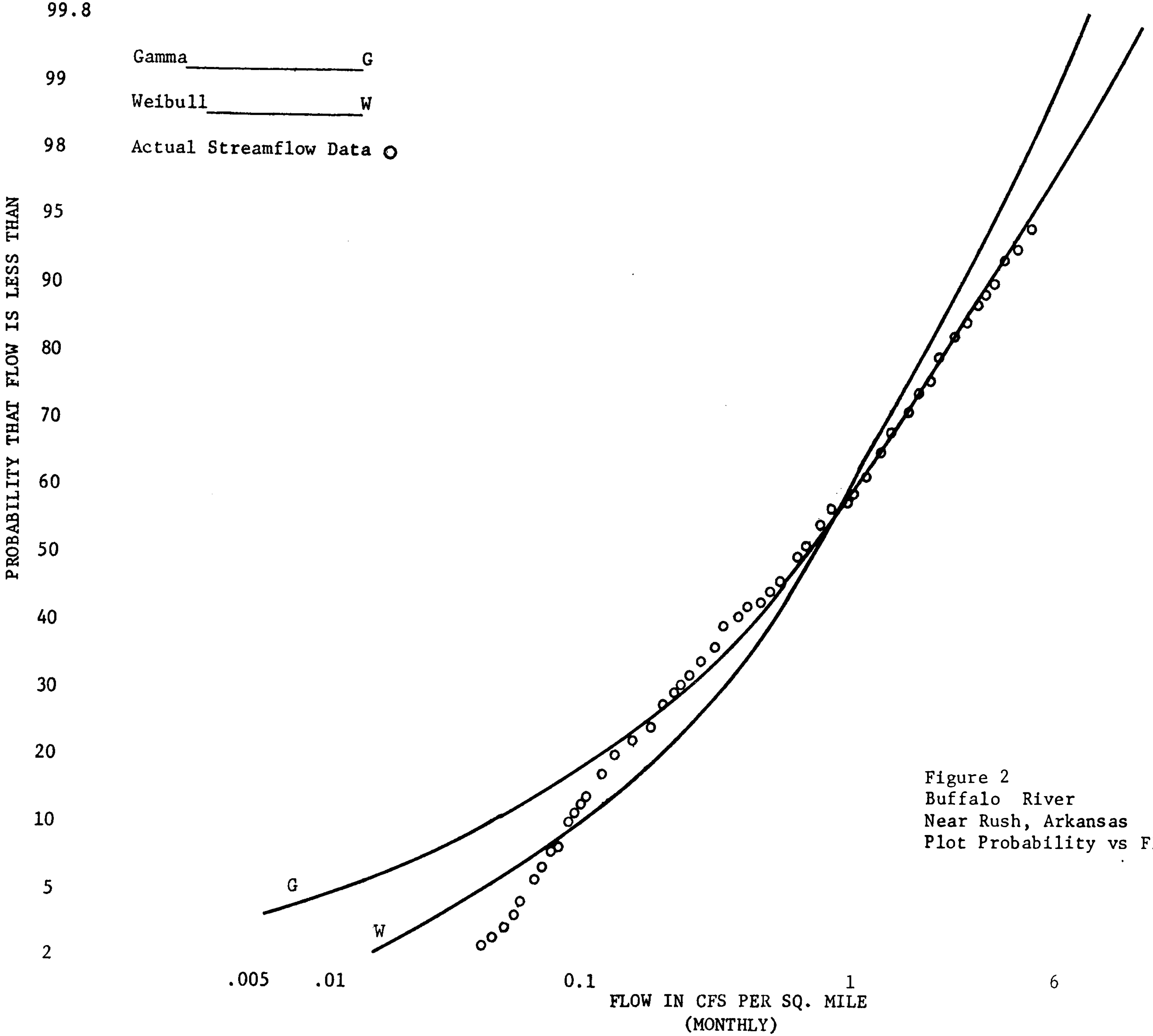


Figure 2
Buffalo River
Near Rush, Arkansas
Plot Probability vs Flow

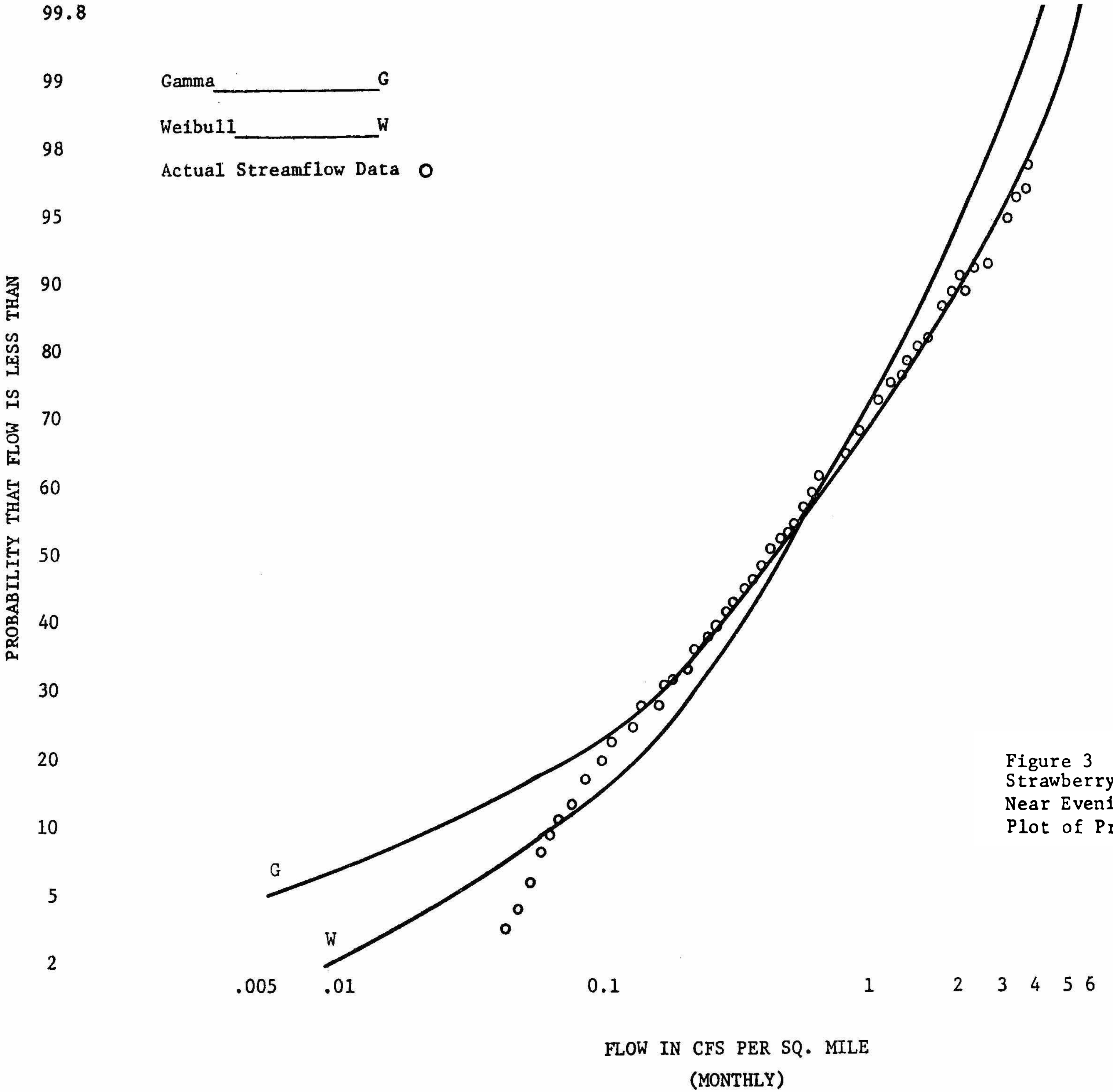


Figure 3
Strawberry River
Near Evening Shade, Arkansas
Plot of Probability vs Flow

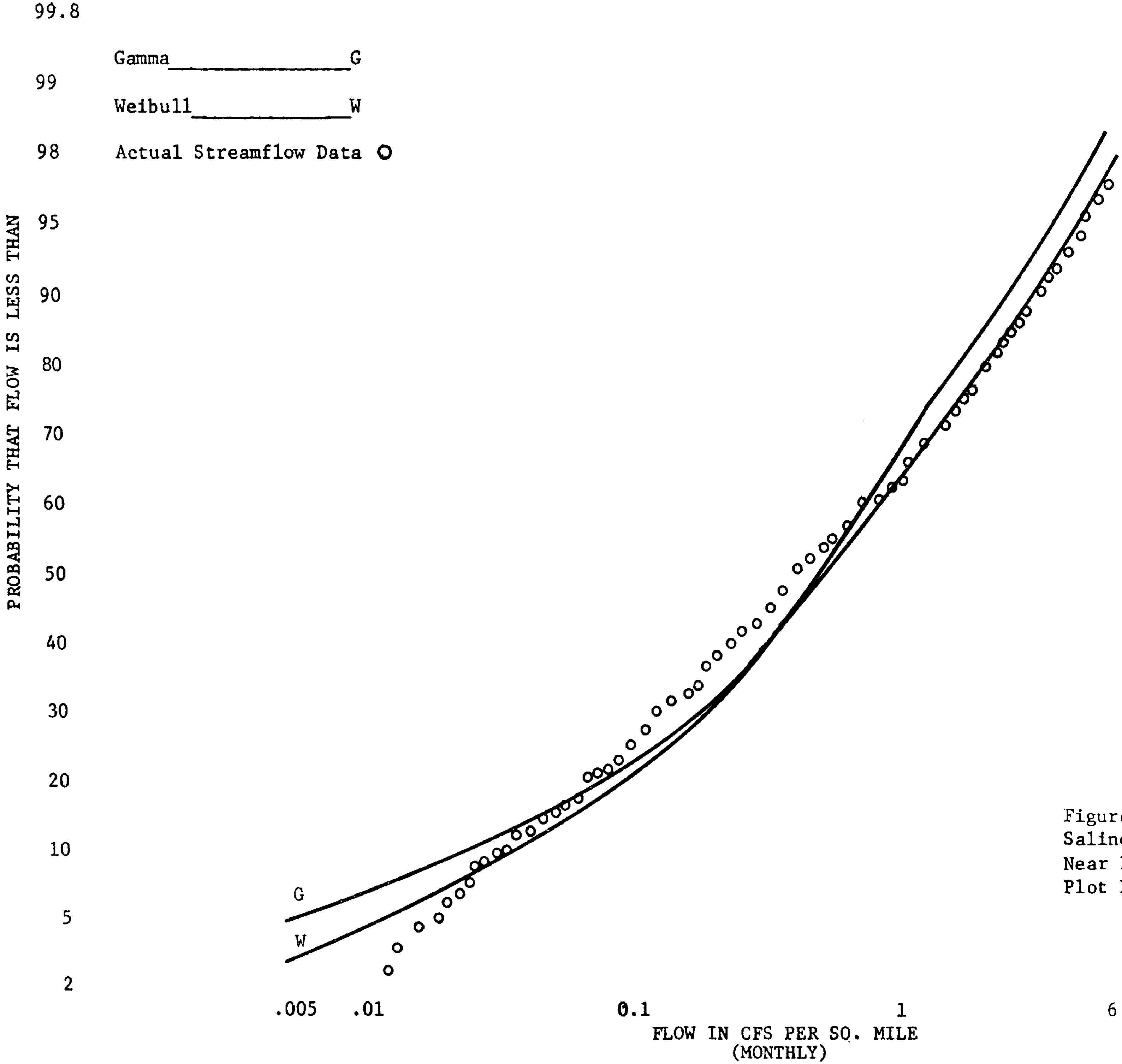


Figure 4
Saline River
Near Rye, Arkansas
Plot Probability vs Flow

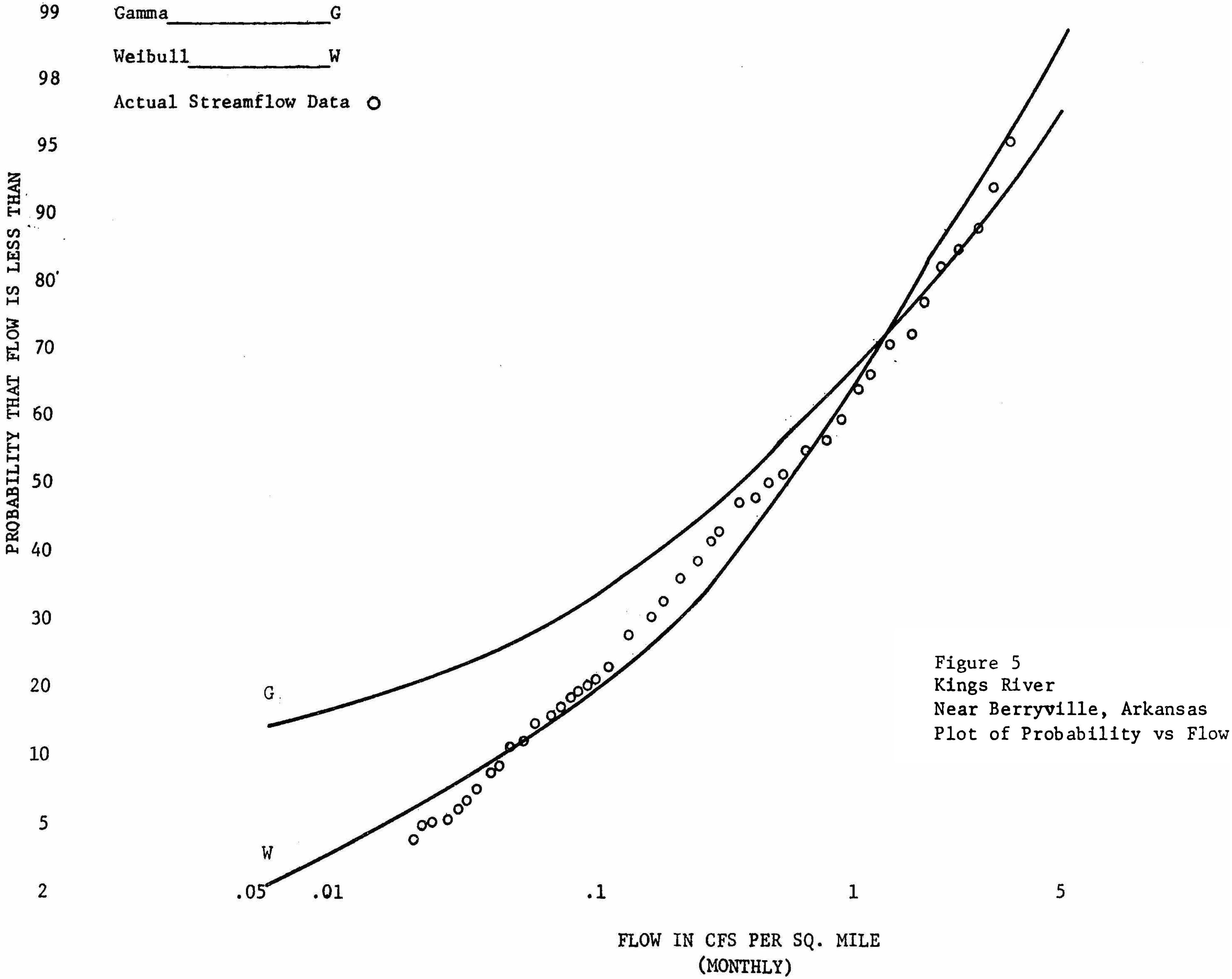


Figure 5
Kings River
Near Berryville, Arkansas
Plot of Probability vs Flow

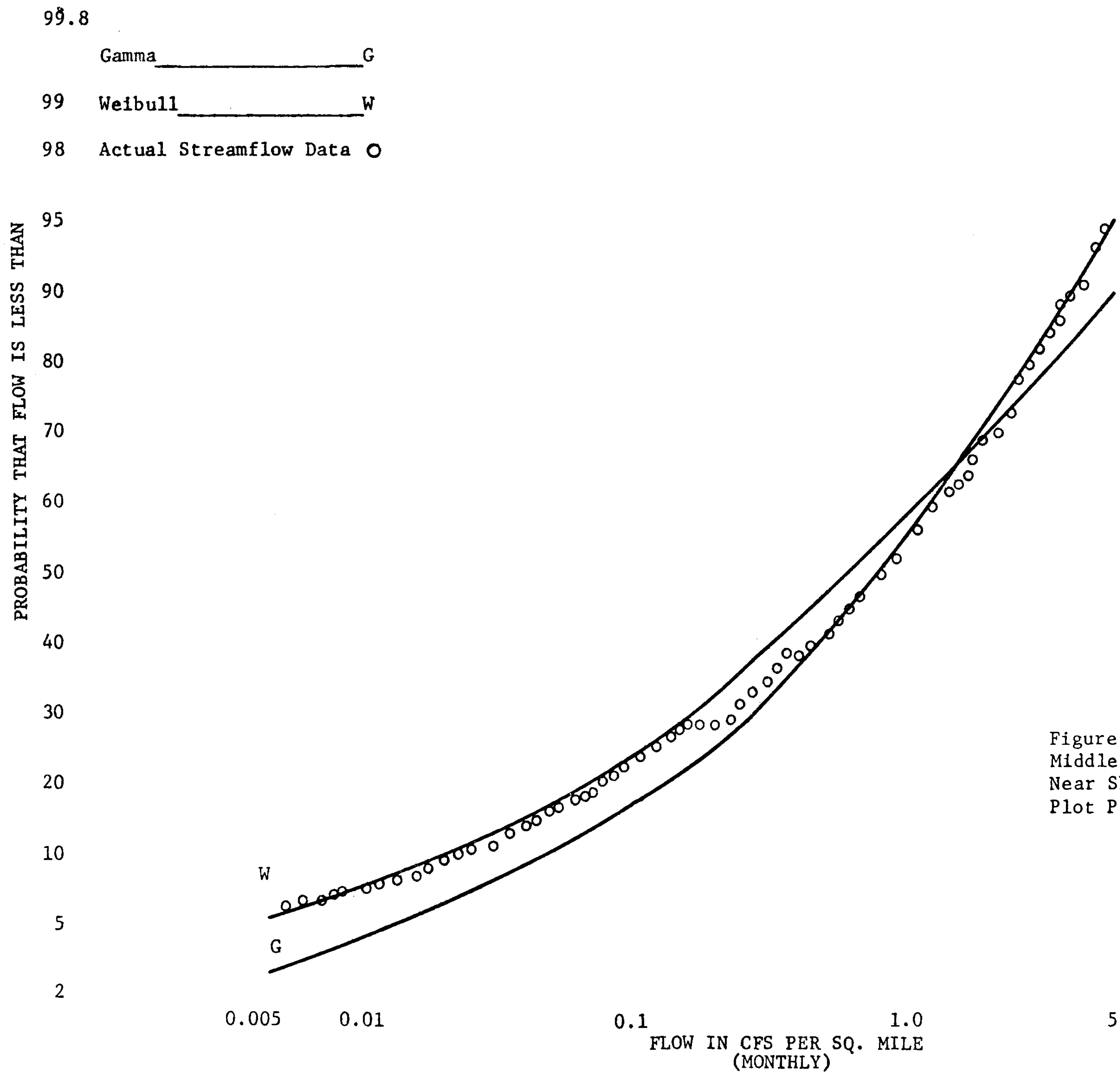
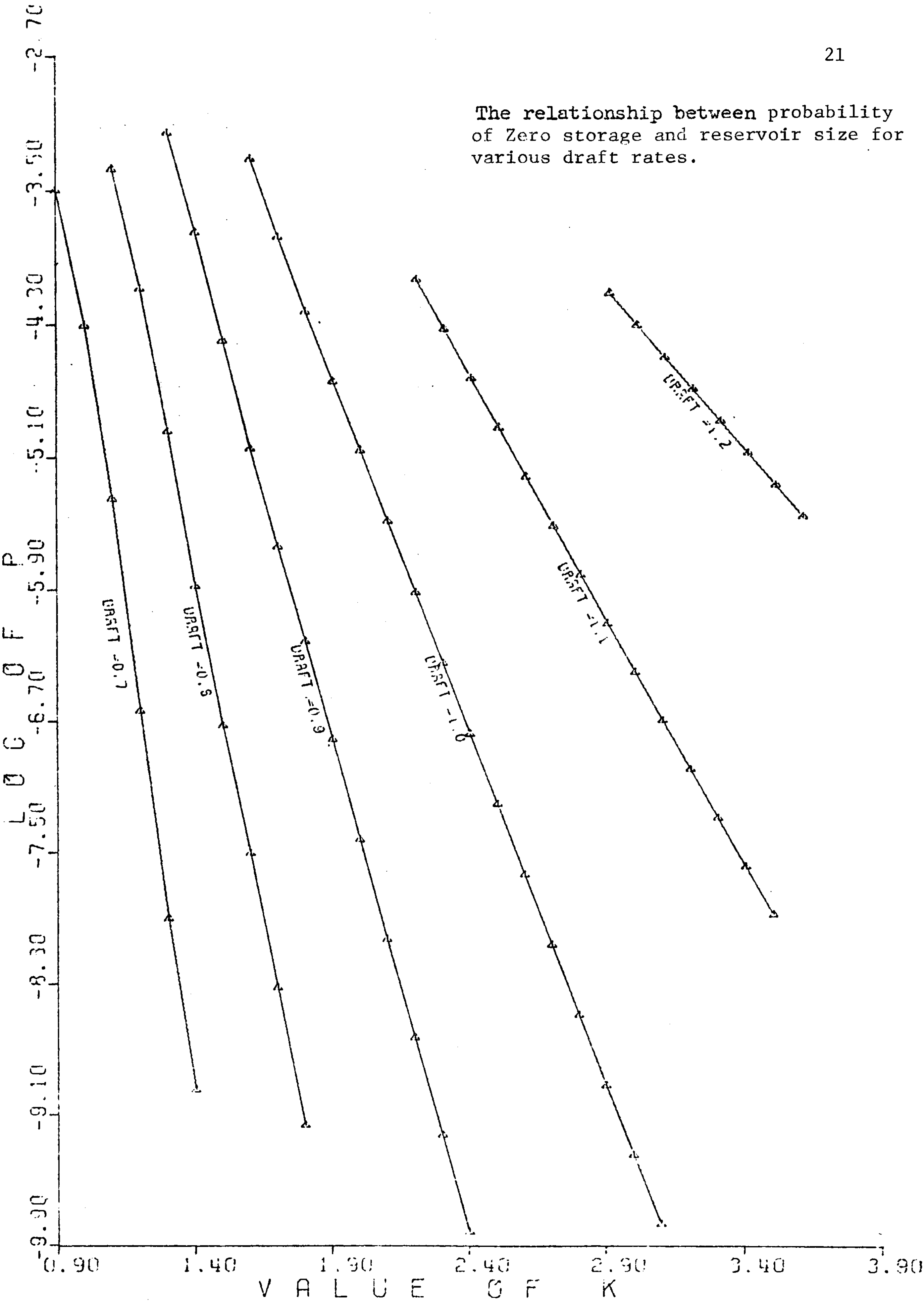


Figure 6
Middle Fork Little Red River
Near Shirley, Arkansas
Plot Probability vs Flow



The relationship between probability of Zero storage and reservoir size for various draft rates.

Figure 7

Figure 8 is a plot of the intercepts of the relationship P_o versus K when annual mean flow from each of the thirty-nine stations is used to generate the gamma distributed input to Moran's model.

Figure 9 is a plot of the slopes of the relationship P_o versus K using annual flow from each of the thirty-nine stations when the flow is gamma distributed.

The equations expressing the relationship shown in Figures 7, 8, and 9 are:

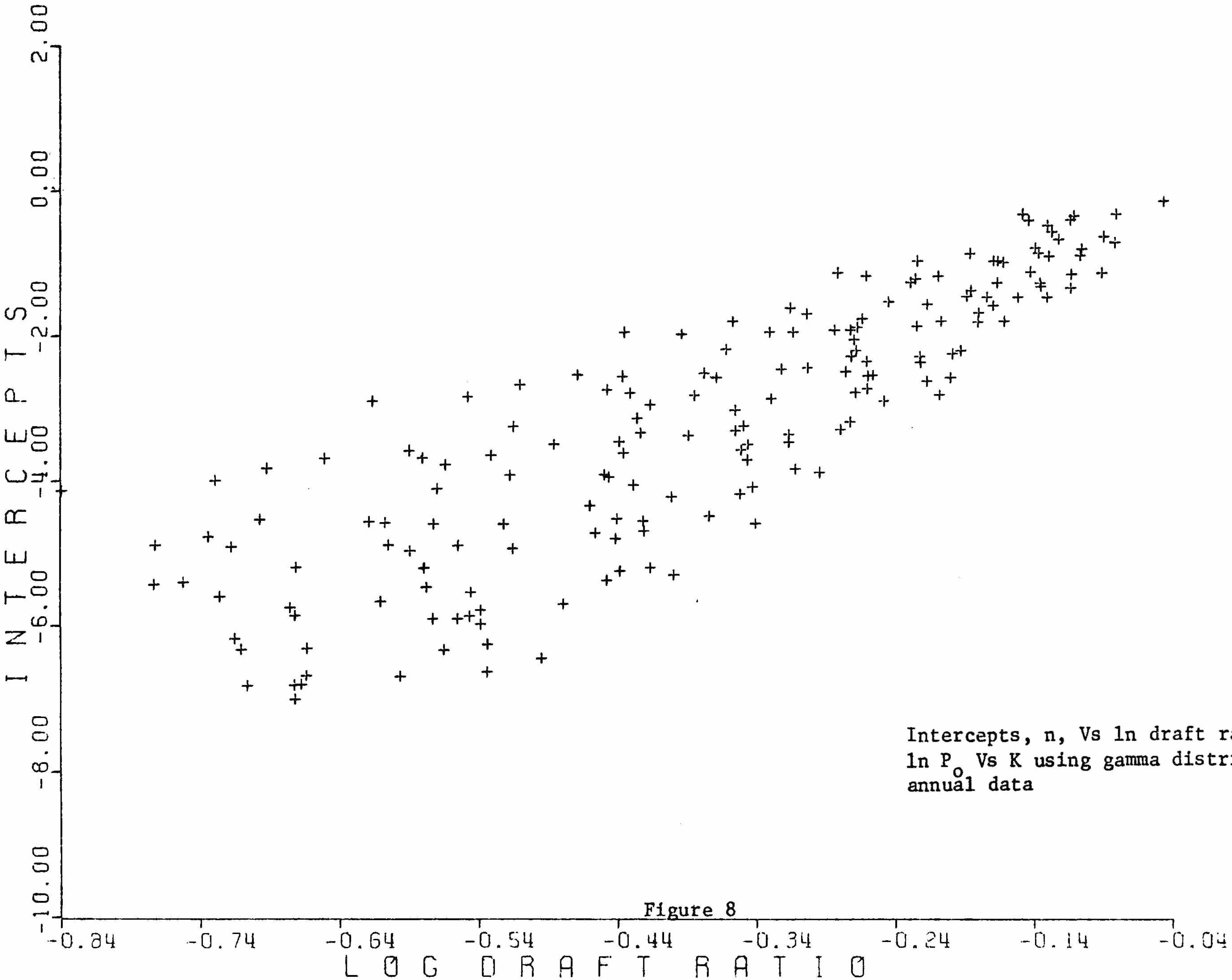
$$\ln P_o = -n - sK$$
$$n = -0.138 + 8.06 \ln \text{draft ratio} \qquad 1.)$$
$$\ln s = 0.187 - 3.23 \ln \text{draft ratio}$$

Draft ratio is herein defined as the decimal fraction of draft to mean annual streamflow. The coefficient of determination (R^2) between the natural logarithm of slope and the natural logarithm of draft ratio is 0.874 and the coefficient of determination (R^2) between intercept and the natural logarithm of draft ratio is 0.727.

Figure 10 shows the relationship of the intercepts (from logarithm P_o versus K) to draft ratio when monthly data are used to calculate the gamma input to Moran's model. Figure 11 shows the logarithm of slopes (from logarithm P_o versus K) as a function of the logarithm of the draft ratio when gamma distributed monthly streamflow data is the input to Moran's model.

The equations relating the probability of reservoir emptiness to reservoir storage size if monthly data are used are:

$$\ln P_o = -n - sK$$
$$n = 0.747 + 1.54 \ln \text{draft ratio} \qquad 2.)$$
$$\ln s = -1.34 - 2.36 \ln \text{draft ratio}$$



Intercepts, n, Vs ln draft ratio for ln P_o Vs K using gamma distributed annual data

Figure 8

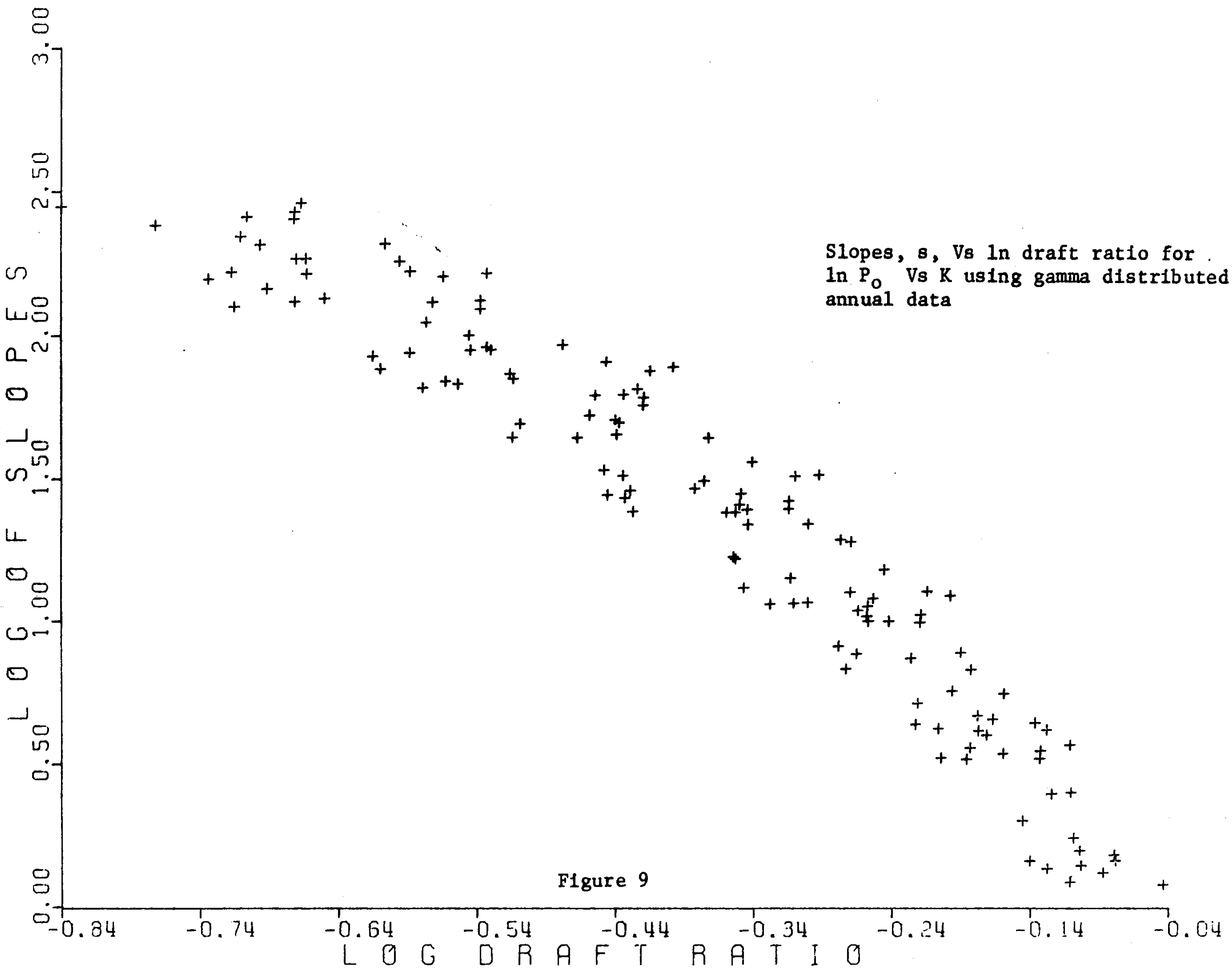
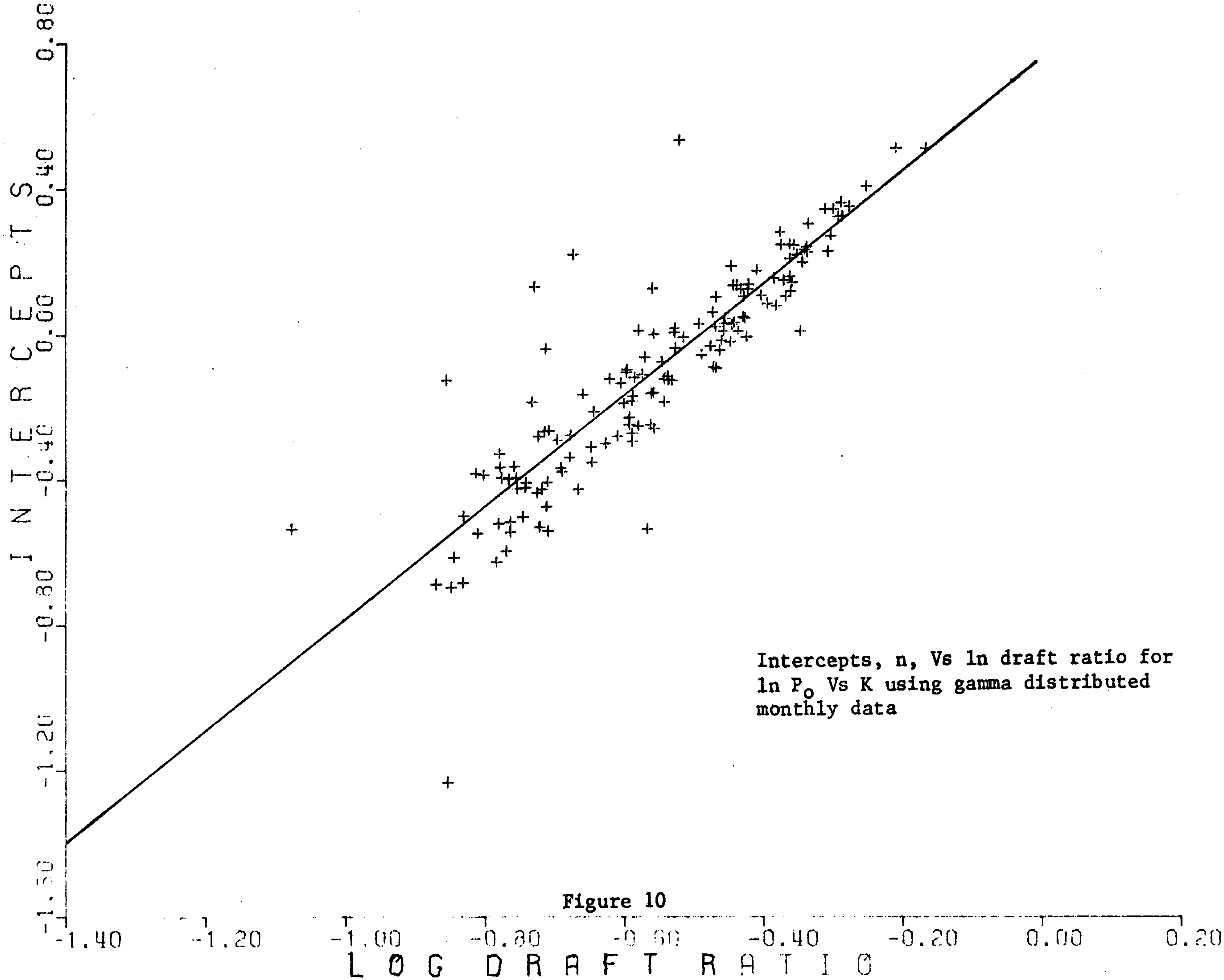
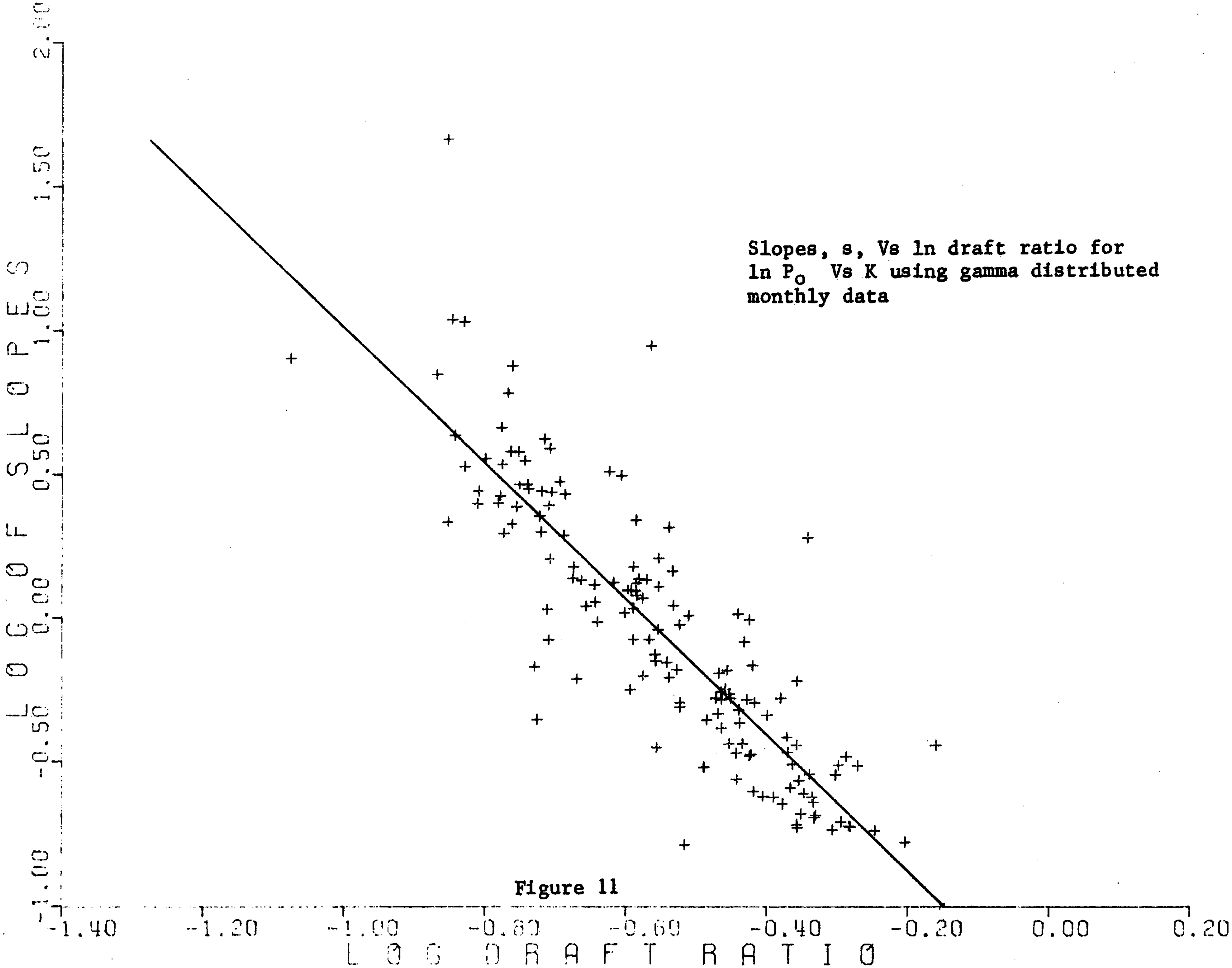

Slopes, s, Vs ln draft ratio for
ln P_o Vs K using gamma distributed
annual data
LOG OF SLOPES
0.00
0.50
1.00
1.50
2.00
2.50
3.00
-0.84
-0.74
-0.64
-0.54
-0.44
-0.34
-0.24
-0.14
-0.04
LOG DRAFT RATIO

Figure 9



Intercepts, n, Vs ln draft ratio for ln P_o Vs K using gamma distributed monthly data

Figure 10


Slopes, s, Vs ln draft ratio for
ln P_o Vs K using gamma distributed
monthly data
LOG OF SLOPES
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
LOG DRAFT RATIO
-1.40
-1.20
-1.00
-0.80
-0.60
-0.40
-0.20
0.00
0.20
Figure 11

The equations relating reservoir size to probability of emptiness if the Weibull distribution is assumed to apply to annual streamflow data used to determine equations 1.) are:

$$\begin{aligned} \ln P_o &= -n - sK \\ n &= 0.093 + 5.77 \quad \ln \text{draft ratio} \\ \ln s &= 0.081 - 2.75 \quad \ln \text{draft ratio} \end{aligned} \qquad 3.)$$

The equations for both Weibull and gamma are the equations of lines of best fit obtained by the method of least squares using the data from all thirty-nine streams. A comparison of the reservoir sizes for various draft rates are shown in the following table for annual streamflow data.

TABLE I

Draft Ratio (Po = .05)	Reservoir Size, K (ratio of mean annual flow)	
	Gamma	Weibull
0.8	1.97	2.14
0.6	1.16	1.32
0.4	0.46	0.59

The draft in all cases is assumed to contain all losses from the reservoir except overflow.

Figure 12 shows a comparison of the output from Moran's model with a curve for the Lower Arkansas-White-Red as given by Löf and Hardison (14) when the input is gamma and when the input is Weibull. The gamma and Weibul were generated using the parameters obtained from streamflow data of the West Fork of the White River at Greenland, Arkansas. The coefficient of variation for their streams annual flow is 0.464. The coefficient of variation used by Löf and Hardison for the Lower Arkansas-White-Red area is 0.45.

DISCUSSION OF RESULTS

The relationship between reservoir size, K, and the logarithm of the probability of zero storage is linear within the range of probabilities considered. However, this linearity does not hold for extremely small draft ratios or for large probabilities of zero storage. This is due to the fact that if the draft from a stream becomes small enough, no reservoir is needed. A zero storage point, for a probability of 0.05, would occur when the draft ratio was equal to or less than the flow expected 95 percent of the time.

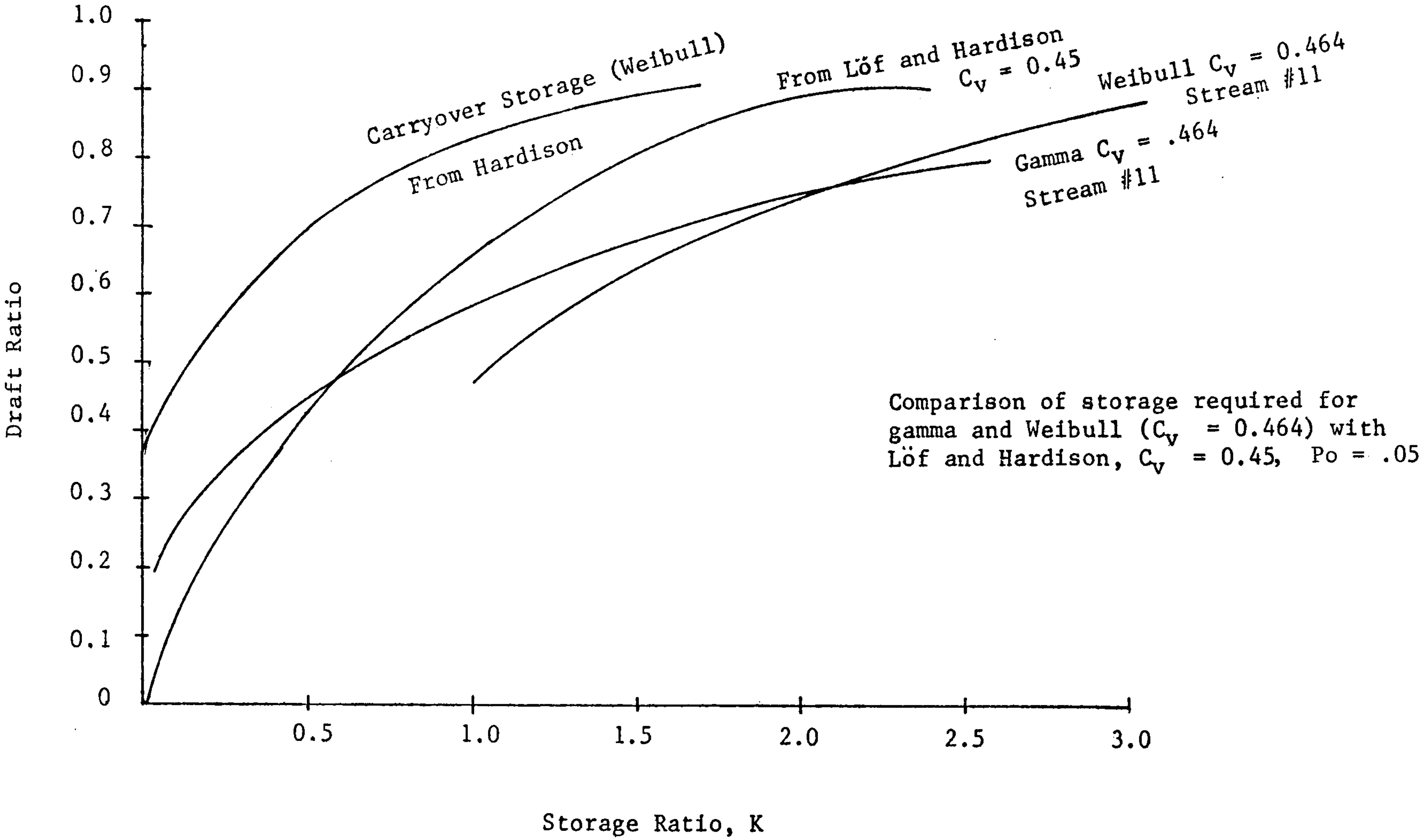
The data in Figure 9 has an appearance that suggests that a second order equation might fit better than a first order equation. However, the correlation coefficient compiled for the second order equation was no greater than the correlation coefficient compiled for the first order equation.

Equations 1.) are suitable for a quick approximation of reservoir size needed to supply a given draft ratio with a given probability of going dry at that draft ratio. This will be very useful for planning purposes; i.e., if a stated quantity of water is needed in a stated location, quick calculations will determine if the streams in the area will supply that amount of water and what size reservoir will be needed. Planimetry of an area map will determine if a reservoir of that size would be feasible. For detailed design, the regression coefficients for that particular stream should be used. (See Appendix B)

The results using monthly data pose some questions. The monthly streamflow data have much larger coefficients of variation than does yearly data. This causes the calculated reservoir size to be much larger than that calculated using annual data. The use of monthly data would imply that the period of emptiness would be of much shorter duration than the period of emptiness when using annual data. For example, for a probability of 0.05 the reservoir size determined as a ratio of mean annual flow, would be insufficient, on the average, once every 20 years. The same probability using monthly data would result in a reservoir size in units that are a ratio of mean monthly flow and would be inadequate once in 20 months on the average. For yearly data, we are not told how long the period of emptiness would last during the year. An examination of past records will reveal that it could last several months. On the other hand, the monthly data do not reveal the length of time during the month that the reservoir will be inadequate, but it would be a much shorter period of time than the yearly calculation.

Therefore, the sizes calculated using yearly data cannot be compared with those using monthly data because we are considering two different sets of information.

Table I and Figure 12 show that, in general, a stream with flow distributed statistically as Weibull requires more storage than if the flow is distributed statistically as gamma. Figure 12 also raises some questions as to why the curve for a Weibull distribution on this stream (West Fork of the White River at Greenland, Arkansas, coefficient of variation of 0.464) does not coincide with the general values given by Löf and Hardison (14, Table 8). The opinion of the writer is that the general values given by Löf and Hardison are too low. This might be due to the assumptions made in arriving at the generalized storage values.



1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Draft Ratio
Carryover Storage (Weibull)
From Hardison
From Löf and Hardison
C_v = 0.45
Weibull C_v = 0.464
Stream #11
Gamma C_v = .464
Stream #11
Comparison of storage required for
gamma and Weibull (C_v = 0.464) with
Löf and Hardison, C_v = 0.45, Po = .05
0.5
1.0
1.5
2.0
2.5
3.0
Storage Ratio, K

Figure 12

The monthly streamflow records were investigated for linear correlation with the result that no significant correlation was found. Annual streamflow records were not investigated for linear correlation, but a study by the Corps of Engineers (26) of forty-two streams throughout the country showed only two to have serial correlation between annual flow. It was further determined that the correlation existing in those two streams was due to man-made influences.

The length of record of the stream studied ranged from 5 to 40 years. The streams that were omitted from the study and the reason are given as part of Appendix A. Synthetic data could have been generated to provide more data. Much has been written about "operational hydrology" and simulation of streamflow. There seemed to be little point in this study of generating synthetic data that are statistically indistinguishable from the observed data. It is claimed that the estimate of the range of the deviations in streamflow and hence the range is storage requirements can be improved by data generation. Yevdjevich (27) states, "It is claimed that the range reliability is improved (or the information is increased) by this method. It should also be noted that this claim is a point of controversy. ---Here is the essence of the controversy: Can a problem solving technique yield an increase in information? The data generation method as a technique for solving mathematical problems with stochastic variables may be compared with the numerical finite differences method for solving differential equations when both cannot be solved analytically. As the numerical-finite-differences method does not improve the information contained in ordinary or partial differential equations, except to produce their solutions, it may be expected that the same conclusion would be valid for the data generation method as currently used in solving stochastic problems. ---Any claim that the data generation method increases information should be subjected to a rigorous mathematical statistical analysis."

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APPENDIX A

11 WEST FORK WHITE RIVER AT GREENLAND, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	23	1.24924	0.58070	0.46484	0.12108	0.08562	0.08202	-0.11033	-0.15111
Monthly Data	288	1.27305	1.68742	1.32549	0.09943	0.07031	0.11734	1.03577	1.06634

13 WAR EAGLE CREEK NEAR HINDSVILLE, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	16	1.03666	0.62201	0.60001	0.15550	0.10996	0.139111	0.33593	0.51440
Monthly Data	204	1.06184	1.49825	1.41099	0.10490	0.07417	0.15592	1.46340	1.52437

15 WHITE RIVER AT BEAVER, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	35	1.29961	0.65922	0.50724	0.11143	0.07879	0.07461	0.33411	0.41525
Monthly Data	456	1.26261	1.59425	1.26266	0.07466	0.05279	0.08557	1.24096	1.26409

16 KINGS RIVER NEAR BERRYVILLE, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	30	1.06054	0.55314	0.52156	0.10099	0.07141	0.08367	0.26087	0.33478
Monthly Data	360	1.22080	2.11149	1.72960	0.11129	0.07869	0.17033	2.84768	2.91492

18 BUFFALO RIVER NEAR ST. JOE, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	29	1.23996	0.60680	0.48937	0.11268	0.07968	0.07815	0.48396	0.62581
Monthly Data	360	1.25616	1.66526	1.32568	0.08777	0.06206	0.10498	1.26985	1.29984

19 BUFFALO RIVER NEAR RUSH, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	40	1.17896	0.55552	0.47119	0.08784	0.06211	0.06331	0.40061	0.48574
Monthly Data	492	1.20728	1.57224	1.30230	0.07088	0.05012	0.08700	1.20189	1.22266

27 ELEVEN POINT RIVER AT RAVENDEN SPRINGS, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	30	0.98367	0.39208	0.39859	0.07158	0.05062	0.05907	0.29879	0.38345
Monthly Data	457	0.96895	0.74928	0.77330	0.03509	0.02481	0.03795	1.04453	1.06400

29 STRAWBERRY RIVER NEAR EVENING SHADE, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	29	0.91528	0.46659	0.50978	0.08664	0.06127	0.08252	0.34090	0.44082
Monthly Data	360	0.93280	1.26380	1.35485	0.06661	0.04710	0.10913	1.25624	1.28590

30 PINEY FORK STRAWBERRY RIVER AT EVENING SHADE, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	30	0.91758	0.48161	0.52487	0.08793	0.06218	0.08439	0.27280	0.35009
Monthly Data	372	0.91770	1.23910	1.35023	0.06424	0.04543	0.10670	1.30668	1.33653

31 STRAWBERRY RIVER NEAR POUGHKEEPSIE, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	32	1.04504	0.46129	0.44141	0.08155	0.05766	0.06504	0.24145	0.30559
Monthly Data	384	1.11291	1.63167	1.46612	0.08327	0.05888	0.12178	2.92368	2.98839

34 MIDDLE FORK LITTLE RIVER AT SHIRLEY, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	29	1.56685	0.71867	0.45867	0.13345	0.09437	0.07179	0.25253	0.32654
Monthly Data	360	1.63014	2.21522	1.35892	0.11675	0.08256	0.10971	1.55746	1.59424

35 SOUTH FORK LITTLE RED RIVER AT CLINTON, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	22	1.84091	0.80148	0.43537	0.17088	0.12083	0.07708	0.15925	0.22078
Monthly Data	360	1.51839	2.02018	1.33048	0.10647	0.07529	0.10565	1.09331	1.11912

36 LITTLE RED RIVER NEAR HEBER SPRINGS, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	30	1.59597	0.73354	0.45962	0.13393	0.09470	0.07077	0.09998	0.12831
Monthly Data	504	1.52522	1.90102	1.24639	0.08468	0.05988	0.07956	1.00236	1.01926

40 CACHE RIVER AT PATTERSON, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	29	1.22979	0.65246	0.53055	0.12116	0.08567	0.08709	0.38225	0.49429
Monthly Data	372	1.21773	1.47303	1.20965	0.07637	0.05400	0.08788	0.97280	0.99502

45 POTEAU RIVER AT CAUTHRON, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	30	1.08200	0.60822	0.56213	0.11105	0.07852	0.09271	0.30445	0.39072
Monthly Data	360	1.08598	1.58727	1.46161	0.08366	0.05915	0.12508	1.26565	1.29554

47 COVE CREEK NEAR LEE CREEK, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	19	1.02008	0.54570	0.53496	0.12519	0.08852	0.10882	0.22341	0.32335
Monthly Data	228	1.02313	1.38019	1.34898	0.09141	0.06463	0.13607	1.25758	1.30447

48 LEE CREEK NEAR VAN BUREN, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	18	1.00371	0.55868	0.55662	0.13168	0.09311	0.11806	0.22056	0.32471
Monthly Data	300	1.07392	1.52439	1.41947	0.08801	0.06223	0.12996	1.25203	1.28751

52 MULBERRY RIVER NEAR MULBERRY, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	30	1.42509	0.63579	0.44614	0.11608	0.08208	0.06810	0.36215	0.46476
Monthly Data	372	1.44253	1.80721	1.25281	0.09370	0.06626	0.09344	0.94059	0.96208

55 PINEY CREEK NEAR DOVER, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	18	1.37064	0.57143	0.41691	0.13469	0.09524	0.08066	0.06303	0.09280
Monthly Data	228	1.39407	1.77274	1.27163	0.11740	0.08302	0.12253	0.91488	0.94899

58 PETIT JEAN CREEK NEAR BOONEVILLE, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESSS
Yearly Data	29	0.99874	0.59843	0.59918	0.11112	0.07858	0.10312	0.40385	0.52222
Monthly Data	360	1.01324	1.50158	1.48195	0.07914	0.05596	0.12825	1.25250	1.28208

60 DUTCH CREEK AT WALTREAK, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	22	1.17365	0.59201	0.50442	0.12622	0.08925	0.09341	0.20187	0.27986
Monthly Data	288	1.23439	1.75484	1.42163	0.10341	0.07312	0.13301	1.12030	1.15337

63 FOURCHE LAFAVE RIVER NEAR GRAVELLY, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	29	1.25031	0.67804	0.54230	0.12591	0.08903	0.08974	0.32729	0.42321
Monthly Data	360	1.27826	1.76980	1.38453	0.09328	0.06596	0.11344	1.32173	1.35294

65 SOUTH FOURCHE LAFAVE RIVER NEAR HOLLIS, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	27	1.37107	0.58009	0.42309	0.11164	0.07894	0.06710	0.30323	0.39869
Monthly Data	336	1.45317	2.21127	1.52168	0.12063	0.08530	0.13929	2.13456	2.18856

72 ROLLING FORK NEAR DE QUEEN, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	20	1.55304	0.66318	0.42702	0.14829	0.10486	0.07887	0.31804	0.45320
Monthly Data	264	1.57233	1.97495	1.25606	0.12155	0.08595	0.11143	0.99208	1.02420

73 LITTLE RIVER NEAR HORATIO, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF. VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	37	1.41914	0.60957	0.42953	0.10021	0.07086	0.05842	0.30470	0.37470
Monthly Data	432	1.38556	1.69975	1.22676	0.08178	0.05783	0.08357	1.03259	1.05291

81 OUACHITA RIVER NEAR MOUNT IDA, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF. VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	19	1.55417	0.64699	0.41629	0.14843	0.10496	0.07837	0.19827	0.28697
Monthly Data	336	1.74883	2.03955	1.16623	0.11127	0.07868	0.08677	1.07215	1.09928

82 SOUTH FORK OUCHITA RIVER AT MOUNT IDA, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF. VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	19	1.40765	0.56648	0.40243	0.12996	0.09189	0.07511	0.12142	0.17573
Monthly Data	240	1.43751	1.71604	1.19376	0.11077	0.07833	0.10691	0.98400	1.01884

83 OUCHITA RIVER NEAR MOUNTAIN PINE, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF. VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	14	1.70448	0.67338	0.39507	0.17997	0.12726	0.08552	0.17360	0.27900
Monthly Data	168	1.71374	2.05187	1.19730	0.15830	0.11194	0.12845	1.02908	1.08115

91 OZAN CREEK AT MC CASKILL, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	7	1.12461	0.60054	0.53399	0.22698	0.16050	0.17884	0.39258	0.86928
Monthly Data	96	1.24507	1.90765	1.53216	0.19470	0.13767	0.26388	1.25716	1.36847

92 ANTOINE RIVER AT ANTOINE, ARKANSAS

	N	MEAN	STD. DEV.	CONEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	14	1.32991	0.53647	0.40339	0.14338	0.10138	0.08777	0.50469	0.81111
Monthly Data	180	1.34510	1.90485	1.41614	0.14198	0.10039	0.16708	1.31251	1.37449

96 SMACKOVER CREEK, SMACKOVER, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	5	0.70806	0.37920	0.53554	0.16958	0.11991	0.21244	-0.09505	-0.25662
Monthly Data	108	0.85742	1.21681	1.41915	0-11709	0.08279	0.21652	0.91234	0.98415

98 MORO CREEK NEAR FORDYCE, ARKANSAS

	N	MEAN	STD. DEV.	CONEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	17	0.95831	0.56919	0.59396	0.13805	0.09762	0.13303	0.46639	0.69958
Monthly Data	216	1.03339	2.38603	2.30894	0.16235	0.11480	0.37937	3.07634	3.19740

101 HURRICANE CREEK AT SHERIDAN, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data									
Monthly Data	120	1.00064	1.44281	1.44189	0.13171	0.09313	0.21138	1.03061	1.10361

106 BAYOU BARTHOLOMEW NEAR MC GEHEE, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	14	1.08144	0.52732	0.48761	0.14093	0.09965	0.11194	0.56254	0.90408
Monthly Data	156	1.07798	1.37473	1.27528	0.11007	0.07783	0.14889	1.29972	1.37054

108 CYPRESS BAYOU NEAR BEEBE, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data									
Monthly Data	108	1.25796	1.65534	1.31589	0.15929	0.11263	0.18915	0.83392	0.89955

110 CADRON CREEK NEAR GUY, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	15	1.45276	0.58157	0.40032	0.15016	0.10618	0.08399	0.20602	0.32276
Monthly Data	192	1.62423	2.00996	1.23748	0.14506	0.10257	0.12729	0.95617	0.99850

111 CORNIE BAYOU NEAR THREE CREEKS, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	14	0.92587	0.59440	0.64199	0.15886	0.11233	0.16387	0.75507	1.21350
Monthly Data	168	0.86978	1.39836	1.60772	0.10789	0.07629	0.21786	1.78816	1.87863

112 BARREN FORKS (BARON FORK) NEAR DUTCH MILL, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	11	0.73687	0.44229	0.60023	0.13336	0.09430	0.16786	-0.11522	-0.20425
Monthly Data	144	0.70381	0.85179	1.21026	0.07098	0.05019	0.14137	0.78348	0.82973

113 JAMES FORK NEAR HACKETT, ARKANSAS

	N	MEAN	STD. DEV.	COEFF. VAR.	STD.DEV. MEAN	STD.DEV. STD.DEV.	STD.DEV. COEFF.VAR.	SKEW-NESS	ADJ. SKEWNESS
Yearly Data	11	0.85712	0.52802	0.61603	0.15920	0.11257	0.17419	0.26068	0.46212
Monthly Data	144	0.84451	1.17283	1.38878	0.09774	0.06911	0.18036	1.17163	1.24079

DATA FROM FOLLOWING STREAMS WAS DELETED FROM

FINAL PROGRAMS AND PLOTS

Number	Name	Reason
1	St. Francis River, St. Francis	Flow Regulated
2	St. Francis River, Lake City	Flow Regulated
3	Big Lake Outlet, Manila	Flow regulated by Big Lake and only 6 years record
4	Right Hand Chute of Little River, Riverdale	Flow regulated by Wappapello Lake and portion flow diverted from St. Francis River Bypass
5	St. Francis River Floodway, Marked Tree	Flow regulated by Wappapello Lake and portion flow diverted from St. Francis River Bypass
6	St. Francis River, Marked Tree	Flow Regulated
7	Tyronza River, Tyronza	Flow affected by backwater from St. Francis River
8	St. Francis River, Parkin	Flow Regulated
9	St. Francis River, Riverfront	Flow regulated and insufficient record
10	L'Anquille River, Palestine	Flow affected by high water of Mississippi River and insufficient record
12	West Fork White River, Fayetteville	Insufficient records and city of Fayetteville takes water from stream above gage
14	White River, Rogers	Discontinued because of Beaver Reservoir
17	White River, Flippin	Flow Regulated

20	North Fork River, Henderson	Discontinued 1943 as a result of backwater from Norfork Dam
21	North Fork River at Norfork Dam	Flow Regulated
22	White River, Calico Rock	Flow Regulated
23	White River, Batesville	Flow Regulated by Norfork and Bull Shoals Dam
24	Black River, Corning	Flow Regulated
25	Black River, Pocahontas	Flow Regulated
26	Spring River, Imboden	Flow Regulated
28	Black River, Black Rock	Flow regulated by Clear Lake
32	White River, Newport	Flow Regulated
33	White River, Augusta	Insufficient Records
37	White River, Georgetown	Insufficient Records
38	White River, DesArc	Insufficient Records
39	White River, DeValls Bluff	Flow Regulated
41	Bayou DeView, Morton	Insufficient Records
42	White River, Clarendon	Flow Regulated
43	Lagrue Bayou, Stuttgart	Diversion upstream for Irrigation, Records discontinued in 1954
44	Osage Creek, Elm Springs	Flow regulated by small Reservoir at Cave Springs
46	Arkansas River, Ft. Smith	Insufficient Records
49	Arkansas River, Van Buren	Flow Regulated
50	Frog Bayou, Mountainburg	Flow regulated by Lake Ft. Smith and Lake Sheppard Springs
51	Frog Bayou, Rudy	Flow regulated by Lake Ft. Smith

53	Arkansas River, Ozark	Insufficient Records
54	Spadra Creek, Clarksville	Flow regulated by Clarksville water treatment plant
56	Illinois Bayou, Scottsville	Flow Regulated
57	Arkansas River, Dardanelle	Flow Regulated
59	Petit Jean Creek, Waveland	Flow regulated by Blue Mt. Lake
61	Petit Jean Creek, Danville	Flow Regulated
62	Arkansas River, Morrilton	Insufficient Records
64	Fourche la Fave River, Nimrod	Flow regulated by Lake Nimrod
66	Arkansas River, Little Rock	Flow Regulated
67	Arkansas River, Pine Bluff	Flow regulated and insufficient records
68	Bayou Meto, North Little Rock	Insufficient Records
69	Bayou Meto, Lonoke	Flow influenced by rice field runoff at low flows
70	Bayou Meto, Stuttgart	Flow diverted for irrigation
71	Red River, Index	Flow regulated by Lake Texoma
74	Cossatot River, DeQueen	Some flow used by DeQueen Water Plant
75	Little River, White Cliffs	Insufficient Records
76	Saline River, Dierks	Flow Regulated
77	Red River, Fulton	Flow regulated by Lake Texoma and Millwood Reservoir
78	Red River, Garland	Insufficient Records
79	McKinney Bayou, Garland	Insufficient Records

80	Red River, Springbank	Insufficient Records
84	Ouachita River, Hot Springs	Flow Regulated
85	Ouachita River, Malvern	Flow regulated by Lake Catherine, Lake Hamilton, and Lake Ouachita
86	Caddo River, Glenwood	Insufficient Records
87	Caddo River, Alpine	Insufficient Records
88	Ouachita River, Arkadelphia	Flow Regulated
89	Muddy Fork Creek, Murfressboro	Insufficient Records
90	Little Missouri River, Murfressboro	Flow regulated by Lake Greeson
93	Little Missouri River, Boughton	Flow Regulated
94	Terre Noire Creek, Gurdon	Insufficient Records
95	Ouachita River, Camden	Flow regulated by Lakes DeGray, Catherine, Hamilton, Greeson, Ouachita
97	Ouachita River at Lock and Dam No. 8 Champagnolle Landing	Insufficient Records
99	Saline River, Benton	Flow regulated by Lakes Winona and Worrell
100	Saline River and Gamble Creek, Sheridan	Insufficient Records
102	Saline River, Rye	Flow Regulated
103	Saline River, Warren	Insufficient Records
104	Ouachita River at Lock and Dam No. 6 Felsenthal	Insufficient Records
105	Bayou Bartholomew, Star City	Insufficient Records
107	Bayou Bartholomew, Wilmot	Insufficient Records
109	Hurricane Creek, Branch	Flow regulated by flood control dams upstream
114	Ozan Creek, McCaskill	Insufficient Records
115	Big Creek, Moro	Insufficient Records and low flow regulated by drainage from rice fields.

APPENDIX B

EQUATIONS FOR STREAMS - GAMMA YEARLY

Data from program:

Intercept vs ln draft ratio — ln slope vs ln draft ratio

Fitted line from all data, general equations

n = -0.138 + 8.06 ln dr ratio — ln s = 0.187 - 3.23

R^2 = 0.727 — R^2 = 0.874

NUMBER	NAME
011	West Fork White River, Greenland, Arkansas
	n = - 0.370 + 9.614 ln draft ratio
	ln s = 0.052 - 3.733 ln draft ratio
013	War Eagle Creek, Hindsville, Arkansas
	n = - 0.513 + 6.139 ln draft ratio
	ln s = -0.077 - 3.257 ln draft ratio
015	White River, Beaver, Arkansas
	n = - 0.288 + 7.583 ln draft ratio
	ln s = 0.054 - 3.110 ln draft ratio
018	Buffalo River, St. Joe, Arkansas
	n = - 0.305 + 8.322 ln draft ratio
	ln s = 0.049 - 3.381 ln draft ratio
019	Buffalo River, near Rush, Arkansas
	n = - 0.209 + 8.965 ln draft ratio
	ln s = 0.251 - 3.294 ln draft ratio
027	Eleven Point River, Raven Springs, Arkansas
	n = - 0.051 + 13.258 ln draft ratio
	ln s = 0.490 - 4.196 ln draft ratio

029 Strawberry River, near Evening Shade, Arkansas

$n = - 0.368 + 8.678 \ln \text{draft ratio}$

$\ln s = 0.299 - 3.562 \ln \text{draft ratio}$

030 Piney Fork Strawberry River, Evening Shade, Arkansas

$n = - 0.382 + 8.164 \ln \text{draft ratio}$

$\ln s = 0.249 - 3.536 \ln \text{draft ratio}$

031 Strawberry River, Poughkeepsie, Arkansas

$n = - 0.363 + 11.334 \ln \text{draft ratio}$

$\ln s = 0.106 - 4.384 \ln \text{draft ratio}$

034 Middle Fork, Little Red River, Shirley, Arkansas

$n = - 0.324 + 9.275 \ln \text{draft ratio}$

$\ln s = -0.0003 - 3.276 \ln \text{draft ratio}$

035 South Fork, Little Red River, Clinton, Arkansas

$n = - 0.096 + 9.239 \ln \text{draft ratio}$

$\ln s = -0.135 - 3.328 \ln \text{draft ratio}$

040 Cache River, Patterson, Arkansas

$n = - 0.478 + 7.506 \ln \text{draft ratio}$

$\ln s = 0.124 - 3.446 \ln \text{draft ratio}$

045 Poteau River, Cauthron, Arkansas

$n = - 0.482 + 6.912 \ln \text{draft ratio}$

$\ln s = 0.096 - 3.067 \ln \text{draft ratio}$

047 Cove Creek, Lee Creek, Arkansas

$n = - 0.440 + 7.678 \ln \text{draft ratio}$

$\ln s = 0.002 - 3.808 \ln \text{draft ratio}$

048 Lee Creek, Van Buren, Arkansas

$n = - 0.479 + 7.194 \ln \text{draft ratio}$

$\ln s = 0.015 - 3.467 \ln \text{draft ratio}$

052 Mulberry River, Mulberry, Arkansas

$n = - 0.101 + 9.329 \ln \text{draft ratio}$

$\ln s = 0.173 - 3.205 \ln \text{draft ratio}$

055 Piney Creek, Dover, Arkansas

$n = - 0.066 + 10.863 \ln \text{draft ratio}$

$\ln s = 0.239 - 3.452 \ln \text{draft ratio}$

058 Petit Jean Creek, Booneville, Arkansas

$n = -0.485 + 6.191 \ln \text{draft ratio}$

$\ln s = 0.090 - 3.070 \ln \text{draft ratio}$

060 Dutch Creek, Waltreak, Arkansas

$n = -0.418 + 8.342 \ln \text{draft ratio}$

$\ln s = 0.103 - 3.349 \ln \text{draft ratio}$

063 Fourche La Fave River, Gravelly, Arkansas

$n = -0.483 + 7.151 \ln \text{draft ratio}$

$\ln s = -0.137 - 3.338 \ln \text{draft ratio}$

065 South Fourche La Fave, Hollis, Arkansas

$n = -0.094 + 10.586 \ln \text{draft ratio}$

$\ln s = 0.211 - 3.450 \ln \text{draft ratio}$

072 Rolling Fork, DeQueen, Arkansas

$n = -0.167 + 10.162 \ln \text{draft ratio}$

$\ln s = -0.034 - 3.631 \ln \text{draft ratio}$

073 Little River, Horatio, Arkansas

$n = -0.187 + 10.318 \ln \text{draft ratio}$

$\ln s = 0.042 - 3.612 \ln \text{draft ratio}$

081 Ouachita River, Mount Ida, Arkansas

$n = -0.134 + 10.684 \ln \text{draft ratio}$

$\ln s = 0.016 - 3.631 \ln \text{draft ratio}$

082 South Fork Ouachita River, Mount Ida, Arkansas

$n = -0.171 + 11.923 \ln \text{draft ratio}$

$\ln s = 0.048 - 4.093 \ln \text{draft ratio}$

083 Ouachita River, Mountain Pine, Arkansas

$n = -0.159 + 12.125 \ln \text{draft ratio}$

$\ln s = 0.113 - 3.574 \ln \text{draft ratio}$

092 Antoine River, Antoine, Arkansas

$n = -0.273 + 13.935 \ln \text{draft ratio}$

$\ln s = 0.123 - 4.584 \ln \text{draft ratio}$

101 Hurricane Creek, Sheridan, Arkansas

$n = -0.421 + 9.179 \ln \text{draft ratio}$

$\ln s = 0.020 - 3.961 \ln \text{draft ratio}$

110 Cadron Creek, Guy, Arkansas

n = - 0.089 + 11.733 ln draft ratio

ln s = 0.139 - 3.775 ln draft ratio

111 Cornie Bayou, Three Creeks, Arkansas

n = - 0.527 + 5.547 ln draft ratio

ln s = 0.0008 - 3.042 ln draft ratio

EQUATIONS FOR STREAMS - GAMMA MONTHLY

Data from program:

Intercept vs ln draft ratio	ln slope vs ln draft ratio
Fitted line from all data, general equations	
$y = 0.747 + 1.537x$	$y = -1.338 - 2.359x$
$R^2 = 0.782$	$R^2 = 0.737$

NUMBER	NAME		
011	West Fork White River, Greenland, Arkansas		
		$y = 0.775 + 1.596x$	$y = -1.512 - 2.656x$
013	War Eagle Creek, Hindsville, Arkansas		
		$y = 0.825 + 1.621x$	$y = -1.477 - 2.768x$
015	White River, Beaver, Arkansas		
		$y = 0.791 + 1.742$	$y = -1.432 - 2.693x$
018	Buffalo River, St. Joe, Arkansas		
		$y = 0.783 + 1.612$	$y = -1.515 - 2.690x$
019	Buffalo River, near Rush, Arkansas		
		$y = 0.811 + 1.728x$	$y = -1.422 - 2.663x$
029	Strawberry River, near Evening Shade, Arkansas		
		$y = 0.849 + 1.828x$	$y = -1.219 - 2.712x$
030	Piney Fork Strawberry River, Evening Shade, Arkansas		
		$y = 0.854 + 1.855x$	$y = -1.216 - 2.754x$

031 Strawberry River, Poughkeepsie, Arkansas

$y = 0.799 + 1.479x$ $y = -1.531 - 2.637x$

034 Middle Fork, Little Red River, Shirley, Arkansas

$y = 0.702 + 1.355x$ $y = -1.726 - 2.476x$

035 South Fork, Little Red River, Clinton, Arkansas

$y = 0.745 + 1.475x$ $y = -1.646 - 2.526x$

036 Little Red River, Heber Springs, Arkansas

$y = 0.728 + 1.602x$ $y = -1.524 - 2.522x$

040 Cache River, Patterson, Arkansas

$y = 0.808 + 1.908x$ $y = -1.368 - 2.804x$

045 Poteau River, Cauthron, Arkansas

$y = 0.814 + 1.520X$ $y = -1.531 - 2.701x$

047 Cove Creek, Lee Creek, Arkansas

$y = 0.847 + 1.782x$ $y = -1.414 - 2.893x$

048 Lee Creek, Van Buren, Arkansas

$y = 0.816 + 1.588x$ $y = -1.483 - 2.734x$

052 Mulberry River, Mulberry, Arkansas

$y = 0.762 + 1.662x$ $y = -1.548 - 2.656x$

055 Piney Creek, Dover, Arkansas

$y = 0.770 + 1.648x$ $y = -1.516 - 2.593x$

058 Petit Jean Creek, Booneville, Arkansas

$y = 0.819 + 1.531x$ $y = -1.452 - 2.692x$

060 Dutch Creek, Waltreak, Arkansas

$y = 0.775 + 1.461x$ $y = -1.546 - 2.572x$

063 Fourche La Fave River, Gravelly, Arkansas

$y = 0.778 + 1.505x$ $y = -1.587 - 2.637x$

065 South Fourche La Fave, Hollis, Arkansas

$y = 0.754 + 1.514x$ $y = -1.517 - 2.486x$

072 Rolling Fork, DeQueen, Arkansas

$y = 0.730 + 1.578x$ $y = -1.609 - 2.567x$

073 Little River, Horatio, Arkansas

$y = 0.769 + 1.752x$ $y = -1.503 - 2.696x$

081 Ouachita River, Mount Ida, Arkansas

$y = 0.732 + 1.740x$ $y = -1.593 - 2.581x$

082 South Fork Ouachita River, Mount Ida, Arkansas

$y = 0.762 + 1.794x$ $y = -1.463 - 2.675x$

083 Ouachita River, Mountain Pine, Arkansas

$y = 0.719 + 1.657x$ $y = -1.638 - 2.613$

091 Ozan Creek, McCaskill, Arkansas

$y = 0.777 + 1.315x$ $y = -1.087 - 1.330x$

092 Antoine River, Antoine, Arkansas

$y = 0.751 + 1.392x$ $y = -1.625 - 2.513x$

096 Smackover Creek, Smackover, Arkansas

$y = o.884 + 1.812x$ $y = -1.321 - 2.945x$

101 Hurricane Creek, Sheridan, Arkansas

$y = 0.828 + 1.612x$ $y = -1.407 - 2.731x$

106 Bayou Bartholomew, McGehee, Arkansas

$y = 0.824 + 1.853x$ $y = -1.300 - 2.752x$

108 Cypress Bayou, Beebe, Arkansas

$y = 0.779 + 1.626x$ $y = -1.501 - 2.687x$

110 Cadron Creek, Guy, Arkansas

$y = 0.708 + 1.572x$ $y = -1.631 - 2.611x$

111 Cornie Bayou, Three Creeks, Arkansas

$y = 0.847 + 1.512x$ $y = -1.387 - 2.657x$

112 Barren Forks, Butch Mills, Arkansas

$y = 0.901 + 2.516x$ $y = -0.827 - 3.004x$

113 James Fork, Hackett, Arkansas

$y = 1.523 + 1.919x$ $y = -2.278 - 3.003x$

The following were eliminated because their flow was regulated:

027 Eleven Point River, Raven Springs, Arkansas

$y = 0.768 + 4.072x$ $y = -0.574 - 3.250x$

044 Osage Creek, Elm Springs, Arkansas

$y = 0.912 + 2.703x$ $y = -0.882 - 3.076x$

056 Illinois Bayou, Scottsville, Arkansas

$y = -6.766 - 9.716x$ $y = -0.236 - 5.844x$