THE UNIVERSITY OF MANITOBA

ANNUAL VARIABILITY OF IRRIGATION BENEFITS RELATED TO PARTIAL RIVER FLOW REGULATION

by

DAVID BRUCE LETVAK

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ABSTRACT

Synthetic flow generation is a useful tool in the design and analysis of water resource engineering projects. For irrigation projects, a measurement of maximum accumulated water deficit for the design life of the project is an important requirement. The "range" of a series of events is a statistical parameter which serves this purpose. For reservoir design, the range corresponds to the size of reservoir needed to supply a dependable flow which is equal to the mean flow for the length of the series.

H.E. Hurst studied this parameter, both in theory and for natural phenomena, and found significant differences in these regards. That is, natural phenomena were found to behave in a manner which is different than theory would predict for independent events. The difference is related to the grouping of high and/or low events in the series, and is called the Hurst phenomenon. A statistical parameter, called the Hurst Constant, describes the relationship between the range and the number of events in the series.

Hurst also dealt with the problem of partial flow regulation, where the dependable flow is less than the mean flow and the required reservoir size is correspondingly smaller. A relationship was found relating storage and range to dependable flow and mean flow.

In this thesis, it was attempted to generate

synthetic annual flow series for the Red River which exhibit the Hurst phenomenon. This was accomplished with respect to the Hurst constant for 60-year annual flow series, by the use of a seasonal version of the Thomas-Fiering model.

The resulting synthetic flow series were then used to check Hurst's equations for partial regulation, and to determine the distribution of benefits for a hypothetical irrigation project on the Red River. Routing the synthetic flows through reservoirs of different sizes and with different demand flows confirmed the validity of Hurst's equations. Also, a description of the variability of irrigation benefits was found for each reservoir size and demand.

ACKNOWLEDGEMENTS

Sincere appreciation is expressed to my faculty advisor, Professor C. Booy, for his advice on the choice and development of this thesis topic, and his assistance in obtaining the necessary use of computer facilities.

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INTRODUCTION

Chapter I

INTRODUCTION

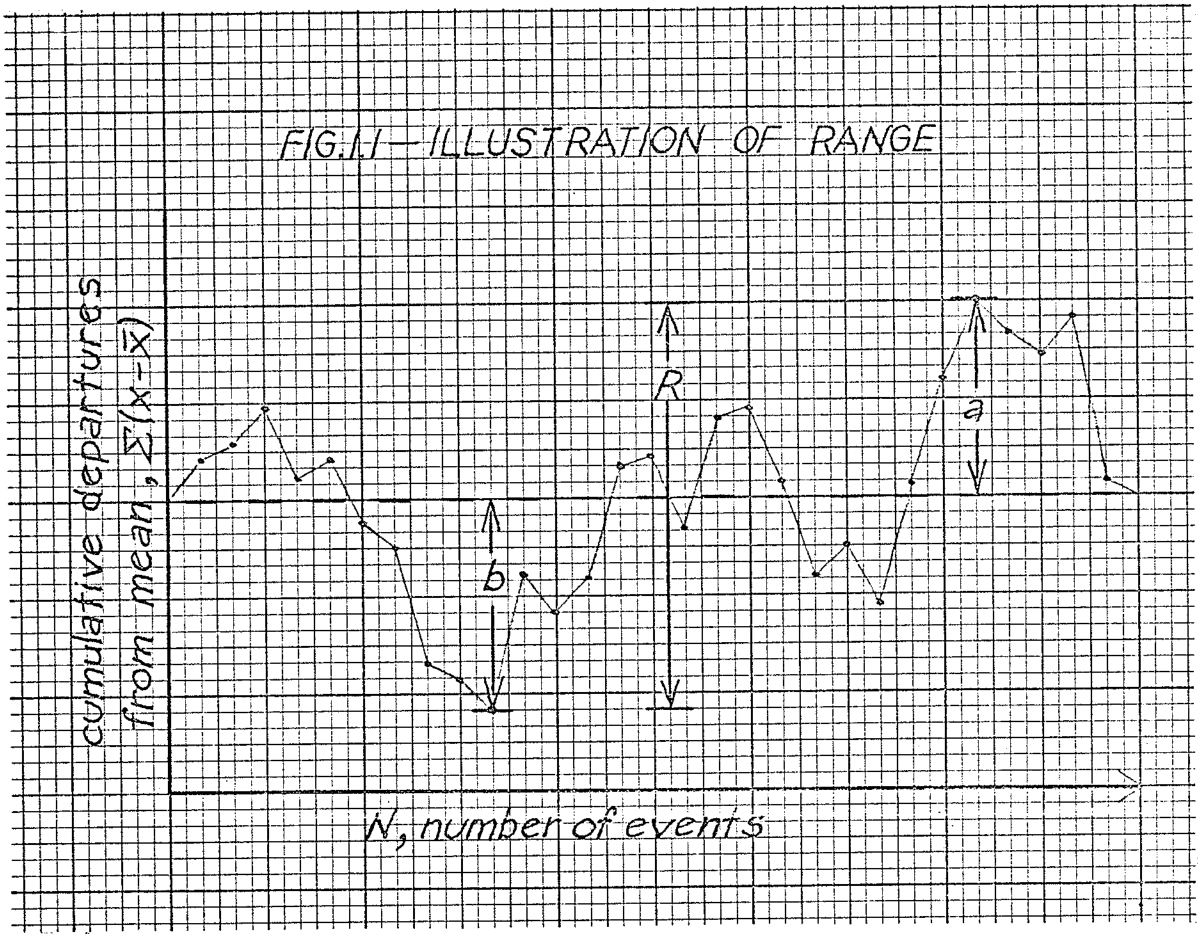
Simple engineering techniques based on the accumulated flow diagram, such as the Ripple diagram, suffice to determine the size of reservoir that will achieve the degree of regulation necessary to meet predetermined irrigation requirements up to the point where the available river flow is fully utilized. Engineers find such techniques particularly attractive for two reasons; firstly, they lead to a single unequivocal answer, and secondly, they employ only flow data that actually have been observed. The techniques thus involve the engineer in a minimum of uncertainty and speculation.

This is also the basic weakness of these techniques. Determining the required size of a reservoir for future use is a matter in which there are no single answers and where certainty is an illusion.

The alternative technique is to go beyond the recorded flows and to raise the question of what flows one might expect in the future. In other words, synethetic flow series will have to be generated that are "equally possible" as the recorded series, as far as we can tell, and the behaviour of the reservoir must be tested with these.

Synthetic traces of riverflow must be statistically indistinguishable from the recorded series with regard to the hydrological properties that determine the engineering requirements. These hydrological properties differ for different projects, dependent on their purpose whether it is flood control, low flow regulation, recreation, irrigation, etc. In the case of irrigation projects, the size of the reservoir needed to meet the demand depends on the severity of the dry periods. For over-year storage the grouping of dry years is the crucial factor. It follows that one needs a statistical parameter which measures this tendency of any particular river if one wishes to generate synthetic flows that are statistically indistinguishable from the recorded flow series.

The correlation coefficient is not completely adequate in this regard. It measures the tendency for dry years to follow each other, but it does not measure how severe a dry period actually can get. For this purpose the so-called range is a better indicator. By definition, the range of a series of events (such as hydrologic data) is the difference between the highest and the lowest values in a series of cumulative departures from the mean. The range of a series of river flows corresponds to the reservoir size which is needed to have a dependable flow out of the reservoir equal to the mean flow over the period covered by the series. Figure 1.1 illustrates the concept; the range R is equal to the sum of a and b.



For a series of independent events the value of R, which evidently is a statistical variable dependent on the length of the series, has been studied by several investigators. While the value of the range varies from sample to sample, the mean value can be shown to increase with the number of events in the series, N, according to the relation:

$$E(R) = 1.25\,\sigma N^{\frac{1}{2}}$$

In this equation, σ stands for the standard deviation of the events in the series.

The relationship shown above, however, cannot be used to determine the size of reservoir required, for two reasons; firstly, one hundred percent regulation is rarely if ever attempted, and secondly, it was found that natural rivers behave quite differently than the relationship would indicate. Both problems have been dealt with by Hurst (1951).

Regarding the first problem of partial regulation, Hurst searched in vain for a theoretical relation between S, the storage required to meet, on the average, the specified draft B, and the range R, assuming B to be smaller than the average flow M. He conducted, however, a large number of experiments with coins and cards to generate synthetic series from which he determined an experimental relationship between the variables mentioned above. He also analysed natural phenomena in two groups: 1) tree rings, varves, and river levels (Roda Gauge - Nile River), and 2) river discharge, rainfall, and temperature. He found that either of the two following relationships adequately describe the relationship of all the above observations:

$$\log_{10} \frac{S}{R} = - 0.08 - 1.05 \frac{(M - B)}{\sigma}$$

or

$$\frac{S}{R} = 0.94 - 0.96 \left\{\frac{M - B}{\sigma}\right\}^{\frac{1}{2}}$$

The second problem is substantially more serious. When studying a large number of natural events Hurst found that the range almost invariably increases more rapidly with N than the formula given above indicates, and that the formulas given above would seriously underestimate reservoir capacity. For the purpose of plotting the masses of data he accumulated, and which are summarized in Table 1.1, Hurst rewrote the above equation by taking the logarithm of the terms as follows:

$$\log (R/\sigma) = K \log N/2$$

The exponent K, which in the theoretical formula given above has the value of 0.5 now becomes an experimental constant. It is commonly called the Hurst constant.

Table 1.1

SUMMARY OF K-VALUES

Phenomena	No.	Mean	Standard Deviation
River levels, discharges, etc.	99	0.75	0.077
Rainfall	168	0.70	0.069
Temperature and pressure	115	0.70	0.085
Annual growth of tree rings	85	0.81	0.078
Varves (Lake Saki in the Crimea)	114	0.69	0.064
Varves (Tamiskaming, Ont., Canada, and Moen, Norway)	90	0.77	0.094
Sunspot numbers and wheat prices (combined as miscellaneous phenomena)	25	0.69	0.086
Means and totals	690	(0.729)	(0.092)

Differentiating the previous equation with respect to K, and using the data in TABLE 1.1, Hurst found that the following relation described the mean results:

$$\frac{R}{\sigma} = \frac{N}{2}^{0.72} = .61\ N^{0.72}$$

Thus, R/σ was found to increase more rapidly with N for natural phenomena than for chance events (for which K = 0.5).

Hurst found the K values to be approximately normally distributed. It can be seen that the deviation from the value 0.5 in the theoretical formula is quite significant.

At first it was generally assumed that the difference between the value of 0.5 found theoretically for independent values in a series and the larger values of the Hurst constant for natural series was due to annual correlation between successive elements in the natural series. This assumption has proven to be untenable; the irregular long term fluctuations of the sample means (say of 50-year samples) exhibited by numerous natural series cannot be explained by any short memory dependence mechanism. The effect of serial correlation is to raise the Hurst constant for relatively short time series; if N is increased then K drops gradually towards the value of 0.5 for any artificially generated series using simple serial correlation (Markov chain).

During trial attempts at generating flows for the Red River it was found that adequate values of the Hurst constant could be obtained for a 60-year period when using a two season model, one season corresponding to the relatively dry season from August to March and one corresponding to the relatively wet season from April to July. Correlations were calculated and used between successive seasons. While this model is not likely to be acceptable for longer time horizons and more sophisticated models such as Fractional Noise Models would have to be employed, it was considered that the procedure that had been developed would be adequate for the purpose of analyzing the variability of irrigation benefits with partial river regulation.

The study is purely hypothetical. There is no reservoir on the Red River, nor is there any opportunity for building one. The purpose of the study is to determine the type of statistical distribution of irrigation benefits one could expect for a river with considerable flow fluctuation. In particular, the relationships determined by Hurst for partial regulation will be examined and checked for adequacy.

The study is divided into three parts; the first, described in Chapter 2, deals with the generation of the synthetic flow series. Chapter 3 considers the variability of the irrigation benefits assuming various degrees of development of the irrigation potential in the form of percentage of the average flow utilized and various degrees of control in the form of reservoir size in terms of average yearly flow. Chapter 4 gives the conclusions.

Chapter II

GENERATION OF SYNTHETIC FLOWS

Chapter II

GENERATION OF SYNTHETIC FLOWS

Synthetic flow traces, while different from the recorded series, must be alike to the recorded series in so far as the important statistical characteristics are concerned. For the purpose of analyzing required reservoir capacity the important statistical parameters are: the mean, the standard deviation, the correlation between successive flows, the range and Hurst's constant K.

(a) Recorded Data

The data used in this thesis are from the Red River (of the North) and consist of 60 years of consecutive mean monthly flows at Emerson, Manitoba.

The analysis of the recorded data consisted of the calculation of the typical statistical parameters of mean and standard deviation of monthly and annual flows, and correlation coefficients for monthly flows and annual flows. Also, the Hurst's K and the Range were calculated, for future comparison. The data were plotted on normal and log-normal probability paper in order to determine the distribution types of monthly and annual flows. These may be seen in Appendix A.

For the purpose of examining the Hurst phenomenon, only the annual flows are needed. The parameters for annual flows are as follows:

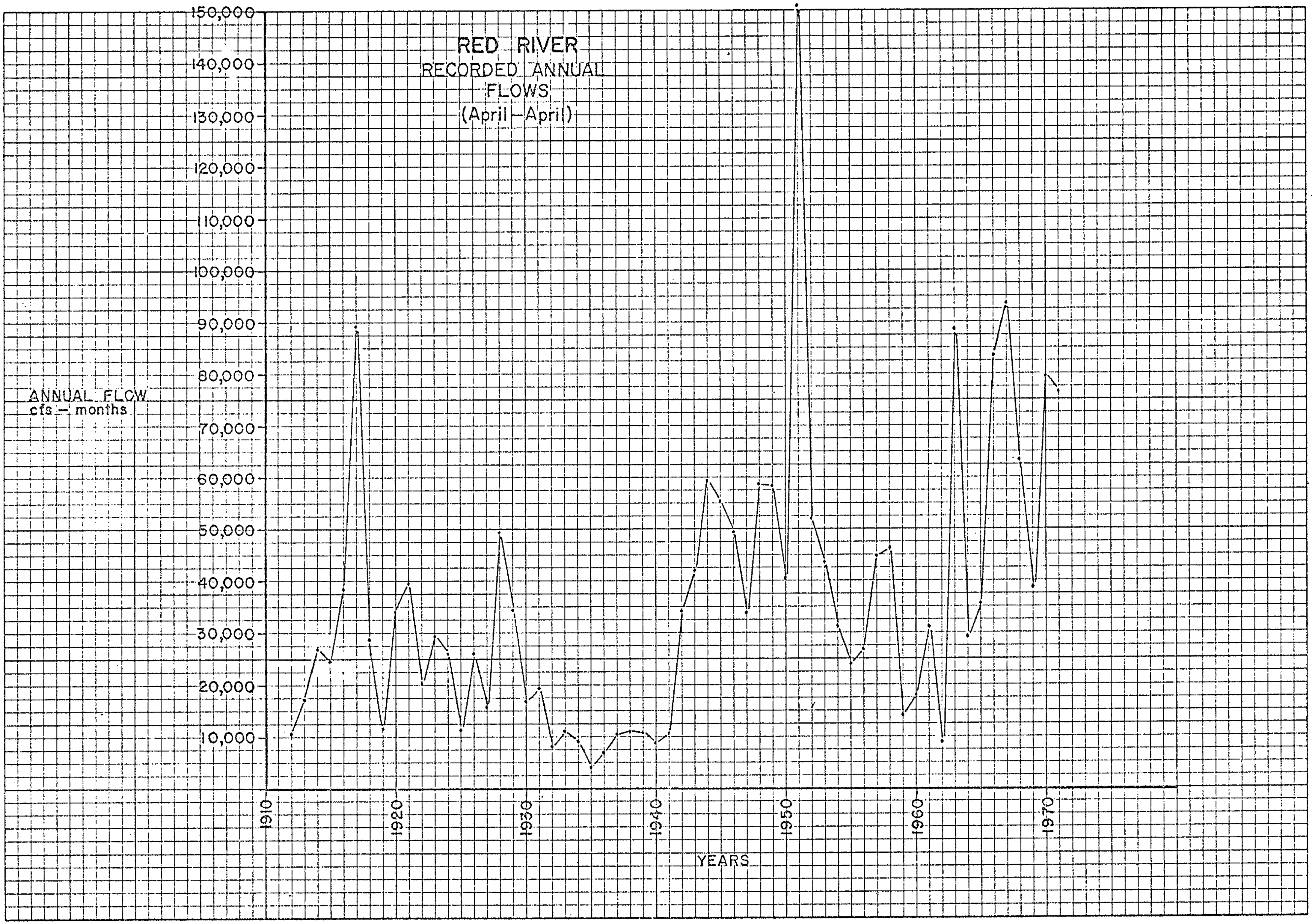
	Real Number Flows	Logs of Flows
Mean	36,892 cfs-months	4.456
Standard deviation	26,690 cfs-months	.3241
Range	428,908 cfs-months	6.1
K	.816	.861
Annual serial correlation	.4076	.6005

Note: flow units are in cfs-months; attained by summing mean monthly flows in cfs units.

These figures would seem to indicate that this recorded series for the Red River exhibits the Hurst Phenomenon. Note here that the values of the Hurst constant are a little on the high side of the naturally observed ranges ($M \pm \sigma$) of 0.73 ± 0.09 for all observations, or 0.75 ± 0.077 for river statistics.

Figure 2.1 on the following page shows a sequential plot of the recorded annual flow series. Figure 2.2 on the next following page is a scatter diagram of these annual flows, that is $flow_i$ vs. $flow_{i+1}$. The data do not group closely enough to enable a graphical estimate of the correlation coefficient.

The Red River annual flows were found to be log-normally distributed, as shown by the plotting results (see <u>Appendix A</u>). The computer program used for plotting this data is listed and explained in <u>Appendix G</u>.


RED RIVER
RECORDED ANNUAL
FLOWS
(April - April)
ANNUAL FLOW
cfs - months
150,000
140,000
130,000
120,000
110,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
1910
1920
1930
1940
1950
1960
1970
YEARS

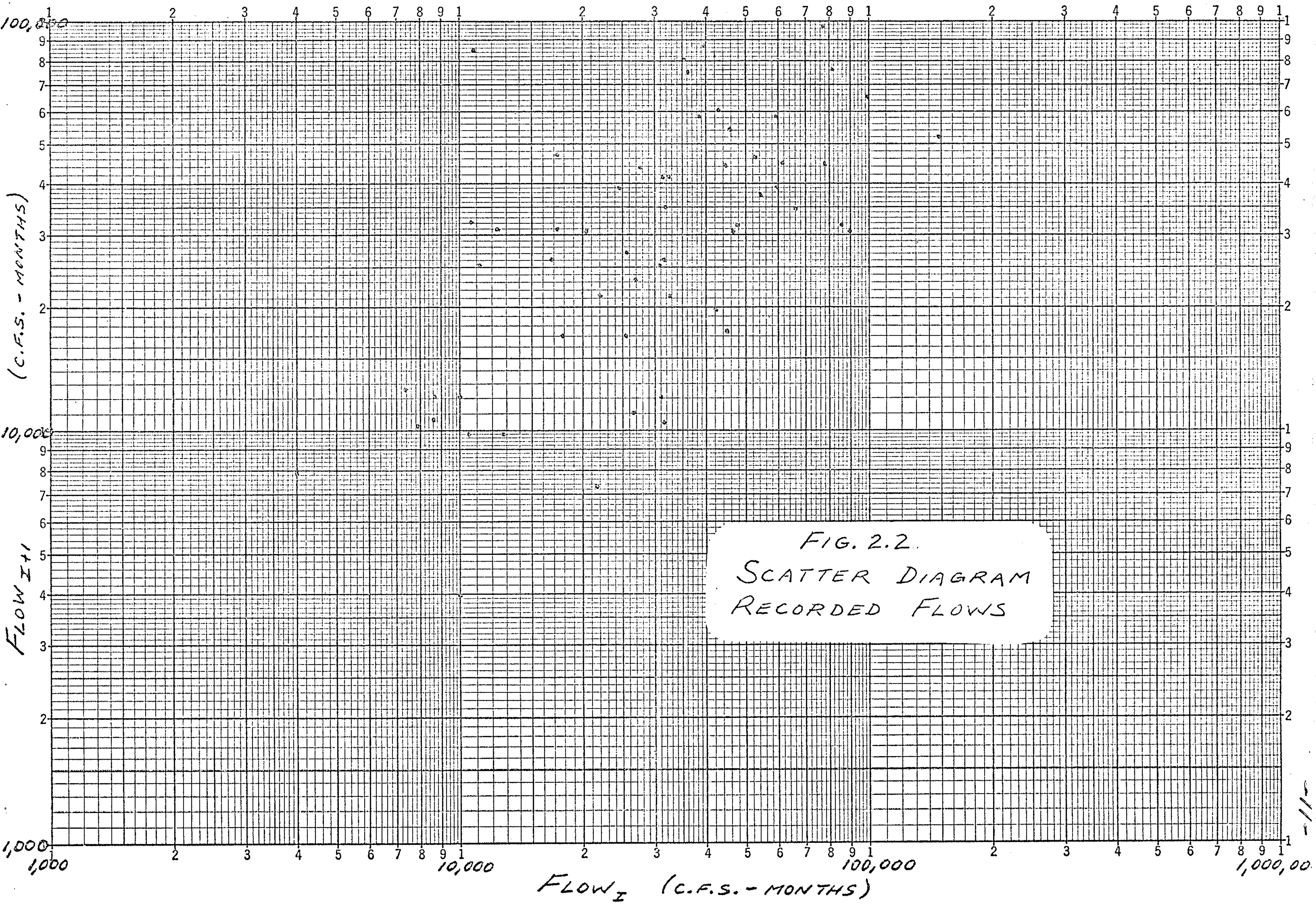


FIG. 2.2
SCATTER DIAGRAM
RECORDED FLOWS
FLOW $_{I+1}$ (C.F.S. - MONTHS)
FLOW $_{I}$ (C.F.S. - MONTHS)
1,000
10,000
100,000
1,000,000
100,000
10,000
1,000

(b) Preliminary Attempts at Flow Generation.

H.A. Thomas and later M.B. Fiering have developed a relatively simple model for the generation of normally distributed flows which exhibit single serial correlation. A transformation is necessary to generate flows that follow a log-normal distribution but this does not present any problem. The method can be used for the generation of annual flows as well as monthly flows.

When generating monthly flows the dependence between successive flows is expressed in the serial correlation between successive months. Since the correlation between flows that are more than one month apart in time reduces rapidly this model results in annual flows that are virtually indpendent.

An annual model, on the other hand is too coarse for reservoir design. For the purpose of preliminary investigation, five 60-year series of monthly flows and ten 60-year series of annual flows have been generated. The results are tabulated in Appendix B.

However, it was noticed that the statistical distribution of monthly flows for the different months were not similar. The monthly flows for the "wet" months of April to July were log-normally distributed. The monthly flows for August to March were of lower magnitude and had a distribution between normal and log-normal. Appendix A contains probability paper plots of these monthly flows.

Therefore, it was decided to attempt another approach using two seasons formed by the addition of monthly flows for the above mentioned months. These seasons shall be called the "wet" and "dry" seasons, for lack of more suitable terminology. The wet season has flows which are log-normally distributed, while the dry season has flows which are in between a normal and a log-normal distribution. The distribution of annual flows (from wet season to wet season, or April to April) remains log-normal. These graphs may be seen in <u>Appendix A</u>.

The statistical parameters for the "seasonal" (April-April) annual flows are slightly different than for the calendar annual flows, but rather insignificantly so, as a comparison with the table on page 9 shows.

	Real Number Flows	Logs of Flows
Mean	36,381	4.443
Standard deviation	27,336	.332
Range	426,969	5.8
Hurst K	.808	.842
Annual serial correlation	.3930	.5814

It was decided to use the Thomas-Fiering method to generate wet and dry season flows and then form annual flows by addition. It was further assumed that the dominant wet season flows are log-normally distributed. To obtain a normal distribution for the T-F model the logarithms of the flows were used. The dry season flows were left as real numbers which would imply a normal distribution when used in the T-F model. Therefore, the numerical analysis gave the mean and standard deviation of the logarithms of the wet season flows as well as the real values of the dry season flows, and gave the correlation between the time series of alternating logarithm-real-logarithm-real-logarithm etc. numbers for the series of wet-dry-wet-dry-wet etc. seasons. Correspondingly, the generation process produced in alternating fashion the log of a wet season flow, the real value of a dry season flow, etc. To obtain the annual flow series, the annual flow for each year was found by adding the antilogarithm of the synthetic wet season flow to the synthetic dry season flow, resulting in a series of real number annual flows.

The mean, standard deviation, and correlation coefficients for the seasonal flows are:

	Wet Season	Dry Season	Symbol
Mean	4.310	8868.	MEAN
Standard deviation	0.3394	6682.	SIGMA
Correlation coefficient	0.4987	0.6511	ROE

The wet season correlation coefficient describes the dependence of the log value of the wet season flow values on the preceeding real number flow values, and vice versa for the dry season correlation coefficient.

Using the notation of the above table, and the subscripts 1 and 2 for wet and dry seasons respectively, the generation process is described by the following two equations used in alternating fashion. The subscript N represents the year of the generated flow value, and thus increases by one each time the cycle returns to the first equation. In the third term, V is a random number from a distribution with a mean of 0.0 and a standard deviation of 1.0; a new value of which is used for each step in the process.

$$\begin{aligned} \mathrm{FLOW}(1,N) = {} & \mathrm{MEAN}(1) \\ & + \mathrm{SIGMA}(1) \times \mathrm{ROE}(1) \times \left[\frac{\mathrm{FLOW}(2,n-1) - \mathrm{MEAN}(2)}{\mathrm{SIGMA}(2)}\right] \\ & + V \times \mathrm{SIGMA}(1) \times \sqrt{1 - \mathrm{ROE}(1)^2} \end{aligned}$$

$$\begin{aligned} \mathrm{FLOW}(2,N) = {} & \mathrm{MEAN}(2) \\ & + \mathrm{SIGMA}(2) \times \mathrm{ROE}(2) \times \left[\frac{\mathrm{FLOW}(1,n-1) - \mathrm{MEAN}(1)}{\mathrm{SIGMA}(2)}\right] \\ & + V \times \mathrm{SIGMA}(2) \times \sqrt{1 - \mathrm{ROE}(2)^2} \end{aligned}$$

As in the Thomas-Fiering method, the first term is the mean for the season, the second term is the component due to the influence of the preceeding value, and the third term is a random component. For the first generation of a wet season flow, the second term was assumed to be equal to zero in order to begin the process.

The preliminary runs for this approach indicated promise, with all of the parameters being relatively close to the desired recorded or theoretical values. These figures may be seen in <u>Appendix B</u>.

This method of generation was then applied to a more intensive study, with 50 different flow series of 60 years of annual flows being generated and analysed.

The figures for the average values of all the parameters and the standard deviations of their distributions (which were assumed to be normal) are given below and discussed:

Parameter	Mean of Generated Values	Standard Deviation	Recorded Values
	REAL NUMBER FLOW VALUES:		
Mean Annual Flow	37674.	5703.	36,381
Standard Deviation of Annual Flows	27427.	7272.	27,336
Range	309550.	106764	426,969
Hurst Constant	.711	.063	.808
Yearly Correlation	.325	.143	.393
	LOGARITHMIC FLOW VALUES:		
Mean Annual Flow	4.466	.063	4.443
Standard Deviation of Annual Flows	.314	.030	.332
Range	3.628	.862	5.8
Hurst Constant	.720	.056	.842
Yearly Correlation	.348	.113	.581

For the real number flows, the mean annual flow and standard deviation are very close to the recorded values. The mean value of the range of generated flows is about one standard deviation below the range of recorded flows. The mean and spread of values for the Hurst constant is quite satisfactory, having nearly duplicated the world wide trends for this parameter. The average generated annual serial correlation is about 0.5 σ below the recorded serial correlation.

For the log number flows, the mean annual value and the standard deviation are both quite close to the recorded value. Once again the values of the Hurst constant approximate closely the world-wide natural distribution. The mean value of the range of generated values is about 2.5 standard deviations below that of the recorded log number flows. The mean generated annual serial correlation is about 2 standard deviations below the recorded value.

The flow data distribution types were reproduced as faithfully as could be expected. Four series of synthetic wet season, dry season, and annual flows for varying values of K and R were plotted for comparison with recorded flow distributions. The four plotted series had values of Hurst's K, and Range which were:

1. small
2. large
3. close to the values for the recorded flow series
4. close to the mean values for all the generated flow series.

For all four example series the seasonal and annual flows were distributed similarly to the recorded flows.* These may be seen in Appendix C. For the log normally

*Note: the dry season synthetic flow distributions are irregular at the bottom end because of the built-in check to curtail generation of negative flows, which can happen when using this procedure for a normal distribution.

distributed wet season and annual flows, the best fit line from the recorded flow distribution is shown for comparison with the generated flow series.

The computer programs used in this analysis and generation are shown and explained in Appendix D.

Also, the four sample generated flow series were plotted in sequential order and may be seen in Appendix C. These compare reasonably well with the recorded flow series, except that the high correlation of recorded annual flows for the dry decade of the 1930's is not exhibited to the same extent in the generated series.

Chapter III

VARIABILITY OF IRRIGATION BENEFITS

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VARIABILITY OF IRRIGATION BENEFITS

The synthetic flow model will now be used, firstly to verify Hurst's equations for the required reservoir capacity as a function of the demand in terms of the average river flow. Secondly, the distribution of irrigation benefits resulting from different capacities will be studies.

Hurst's equation for partial flow regulation expresses the required reservoir storage in terms of the range. Both demand and mean flow are made dimensionless by dividing their difference by the standard deviation. The empirical formula is as follows:

$$\frac{S}{R} = .94 - .96 \; \frac{M-B}{\sigma}$$

where S = reservoir size

R = range

M = mean annual flow

B = annual flow demand (mean flow)

σ = standard deviation of annual flows

It is evident from this formula that it is not valid over the entire range of values since for M = B, S = R. Hurst pointed this out in his paper. For M, σ, and R the average parameter values of all generated flow series were used:

$$M = 37{,}674 \text{ c.f.s.-months}$$

$$\sigma = 27{,}427 \text{ c.f.s.-months}$$

$$R = 309{,}551 \text{ c.f.s.-months}$$

For the purpose of this study three cases have been analyzed, corresponding to three degrees of flow regulation

(1) Demand B = Mean Flow M = 37,674 cfm.
This means full regulation S = R = 309,551 cfm.

(2) Demand B = M - 0.1 σ = 34.931 cfm.
Hurst's formula gives for this case
S = 0.65 R = 205,000 cfm.

(3) Demand B = M - 0.2 σ = 32,188 cfm.
Hurst's formula gives for this case
S = 0.511 R = 158,000 cfm.

With these three reservoir sizes, S = R, S = 0.65 R and S = 0.511 R, and the corresponding annual demands, the behaviour of the reservoir was analyzed for 50 periods, each of 60 years duration. Irrigation benefits were also calculated for each case and each period in a manner that will be explained below.

The reservoir regulation criteria were established only for annual regulation as in Hurst's work, because the variations of flow and demand during the year can be dealt with separately. The criteria are as follows:

1. The reservoir is assumed to be full at the start of the flow series. Storage losses are ignored.

2. Change in storage = annual flow - annual demand. i.e. Storage is increased when annual flow is greater than annual demand and vice versa. The reservoir supplies the required supplement or stores the excess, except as in 3 and 4 following.

3. When annual flow exceeds annual demand and the required change in storage is greater than the available volume, the excess is wasted, and the reservoir is full.

4. When the annual demand is greater than the annual flow, and the reservoir storage is less than the required supplement, the reservoir storage is added to the annual flow, demand is not met, and the reservoir is empty.

The results of the analysis are assembled in Appendix E in the form of cumulative distribution curves. The most important result is that for each case the reservoir provides the demand flow without failure in 50% of the generated flow series. Full irrigation benefits are thus obtained in half of the series. This confirms the validity of the Hurst formula for partial regulation in the sense that the specified demand is met with a 50% probability. It should be noted that the period of 60 years used is the same as the one for which the range was calculated; this is of course a prerequisite.

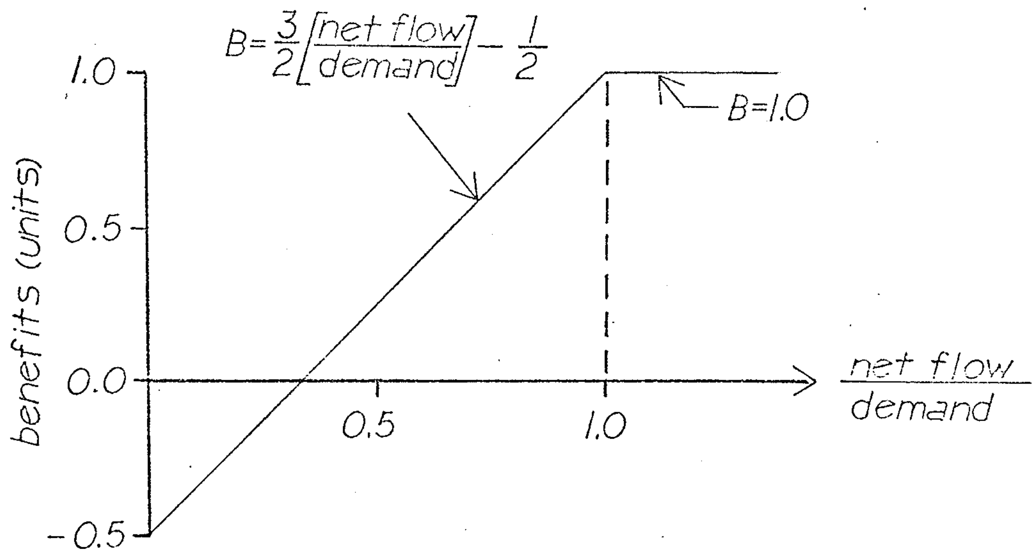
The number of times the reservoir was full in each 60-year synthetic series was also recorded and the results are shown on the graphs in the Appendix E. This number is an indicator of the amount of water wasted; it can be expected to increase as the reservoir size and the demand are decreased. Average number of times full in 60 years were found to be 4, 8 and 13 for the three reservoirs in order of decreasing size.

To determine the irrigation benefits for any given flow series a simplified benefit function was derived from which the irrigation benefits for each year were determined; these were then converted to a present worth value.

It was assumed that the irrigation benefits are proportional to the amount of water supplied up to the point where the design demand is fully met; beyond this point the benefits are assumed to remain constant. Since irrigation entails operational costs, a total crop loss corresponds to negative benefits; these were assumed to amount to one half of the maximum positive benefits. This amounts to assuming that the operational costs are equal to one third of the crop value when irrigation demands are met. The resulting benefit function is shown on Figure 3.1.

In this theoretical study the interest was not a very critical factor. Hence, without any great amount of justification, a value of 6% was chosen. This figure is used to determine the present worth of benefits derived in the future.

FIG. 3.1 — BENEFIT FUNCTION



The total benefits (Sumben) of any given flow series are reduced to a present worth value found by summing the present worths $P.W._n$ of the benefits (B_n) of each year (n = the number of years in the future of the annual benefit).

$$P.W._n = \frac{B_n}{(1+i)^n} \qquad i = \text{interest} = 6\%$$

$$\text{Sumben} = \sum_{n=1}^{60} P.W._n$$

Cumulative distribution curves of the total benefits thus calculated are shown in Appendix E.

The Hurst equations are based on the means of empirical observations, and therefore contain the inherent requirement that the demand be fully met with a probability of 50% in the design period. This requirement is not related to economics nor to any social objective. All one can say for it is that it corresponds to present engineering practice as determined by the use of the Rippl diagram (mass flow analysis). The study was therefore extended to include a reservoir size considerably smaller than demanded by the Hurst equations.

The demand was taken equal to the smallest demand of the previous three cases, namely 32,188 cfm. However, instead of using a reservoir size of 158,000 cfm as required by the Hurst equations a size of 60,000 cfm was used. This reservoir size was determined by trial and error to give zero times empty in 60 years for the most favourable of the 50 generated flow series, or at least once empty for all other flow series.

Using the same benefit function and reservoir regulation criteria, it would be expected that:

1. Maximum benefits should be about the same as in the three previous cases, but should occur only at the extreme end of the probability scale.

2. The maximum number of times empty in 60 years for any flow series should be greater in this case than for the reservoir size designed by Hurst's equation. There should be no flat section at the low end of the curve.

3. The number of times full might also be expected to be somewhat greater on the average.

As can be seen from the graphs in Appendix E, these expectations were realized to a high degree.

The distribution of benefits for the reservoir size of 60,600 cfs-months was almost Gaussian up to a frequency of exceedence of about 30%, where the curve flattened considerably, most likely due to the nature of the benefit function in combination with the relation between the reservoir size and demand. It is speculated that using the same demand with a still smaller reservoir would result in a Gaussian distribution of benefits.

The distribution of the number of times full in 60 years was Gaussian, with the average number of times full being 15 and the maximum being 31. These are slightly higher than in the pervious case for the same reservoir size, but possibly not significantly so.

The number of times empty in 60 years was distributed normally as well, and the maximum number of times empty was 23, significantly greater than the previous study, as expected.

In Appendix F, the computer program for the reservoir regulation and economic analysis of this hypothetic irrigation project is shown.

Chapter IV

CONCLUSIONS

Chapter IV

CONCLUSIONS

The seasonal version of the Thomas-Fiering model was able to produce flows which exhibited values of the Hurst Constant quite similar to those observed for natural phenomena the world over, and with flow distributions similar to that of the period of record. Although the synthetic flows were deficient with respect to the annual serial correlation and range as compared with recorded flows, they were still useful in checking Hurst's equations for partial regulation, and evaluating the variation of benefits for a hypothetical irrigation project.

Because the reservoirs designed by Hurst's equation for partial regulation met the demand flow requirements for one half of the generated flow series, the equation was found to be valid, at least for the 60-year period used in the study. The variability of benefits from a hypothetical irrigation project was established based on the different synthetic flow series.

In general terms it is concluded that for a river displaying the Hurst pheonomenon, reservoir design may be based on the Hurst equation(s). Synthetic flow series which exhibit similar behaviour with respect to the Hurst constant may be used in economic analyses to determine the distribution of benefits which may result from possible future flow series in the design life of a project.

LIST OF REFERENCES

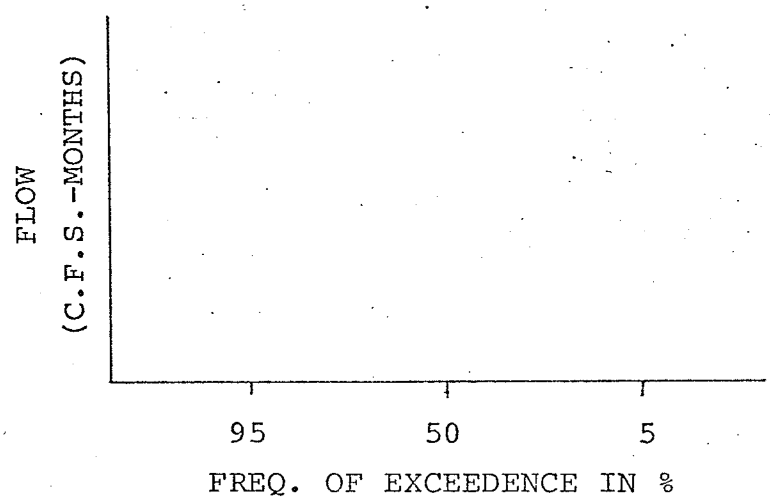
1. H.E. Hurst, Long-Term Storage Capacity of Reservoirs. Transactions, American Society of Civil Engineers, Paper No. 2447, 1951.

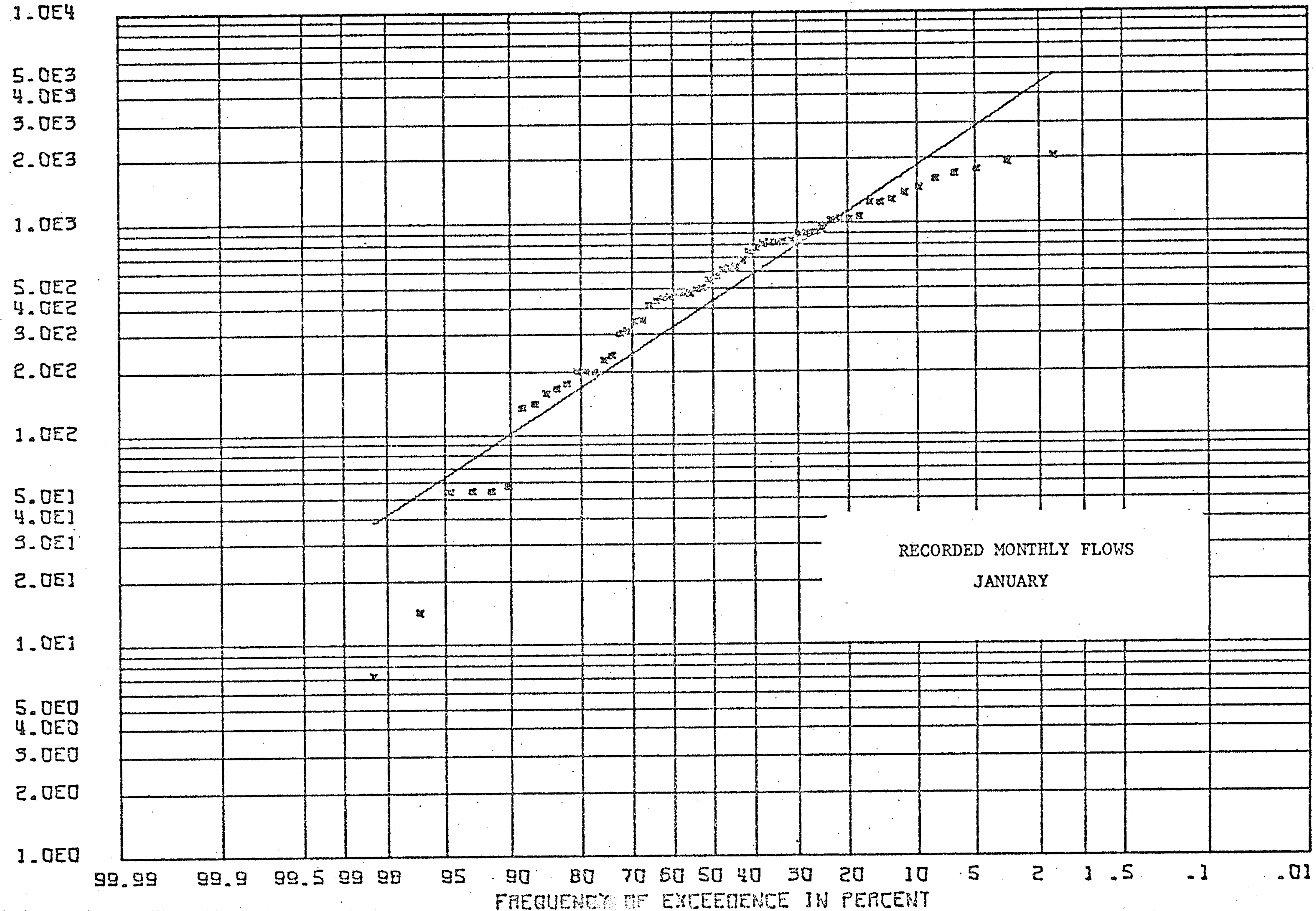
2. H.E. Hurst, Methods of Using Long-Term Storage in Reservoirs.

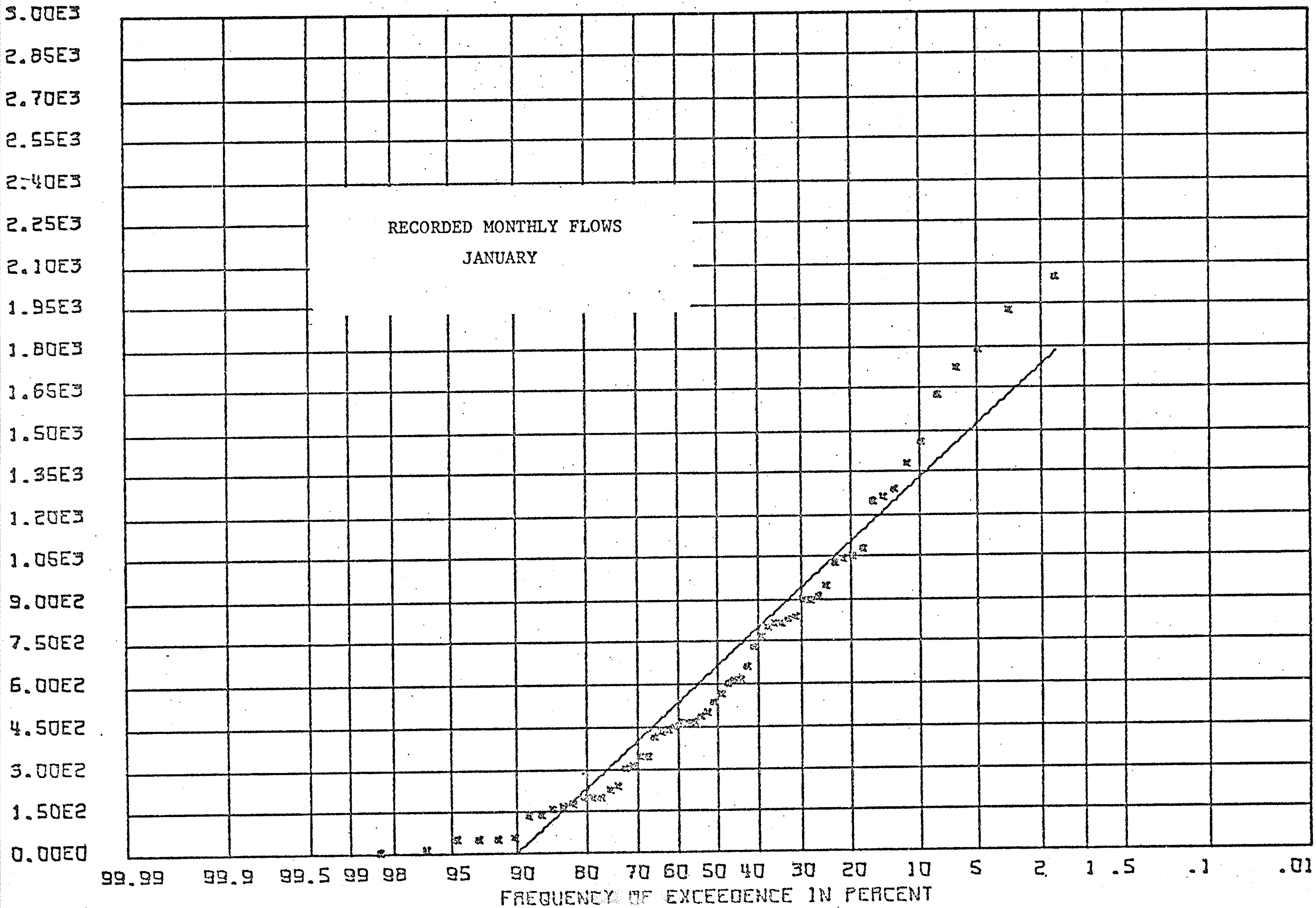
It should be noted that this thesis was based mainly on the phenomenon described in the above two papers by Hurst, even though it contains few specific references to these papers.

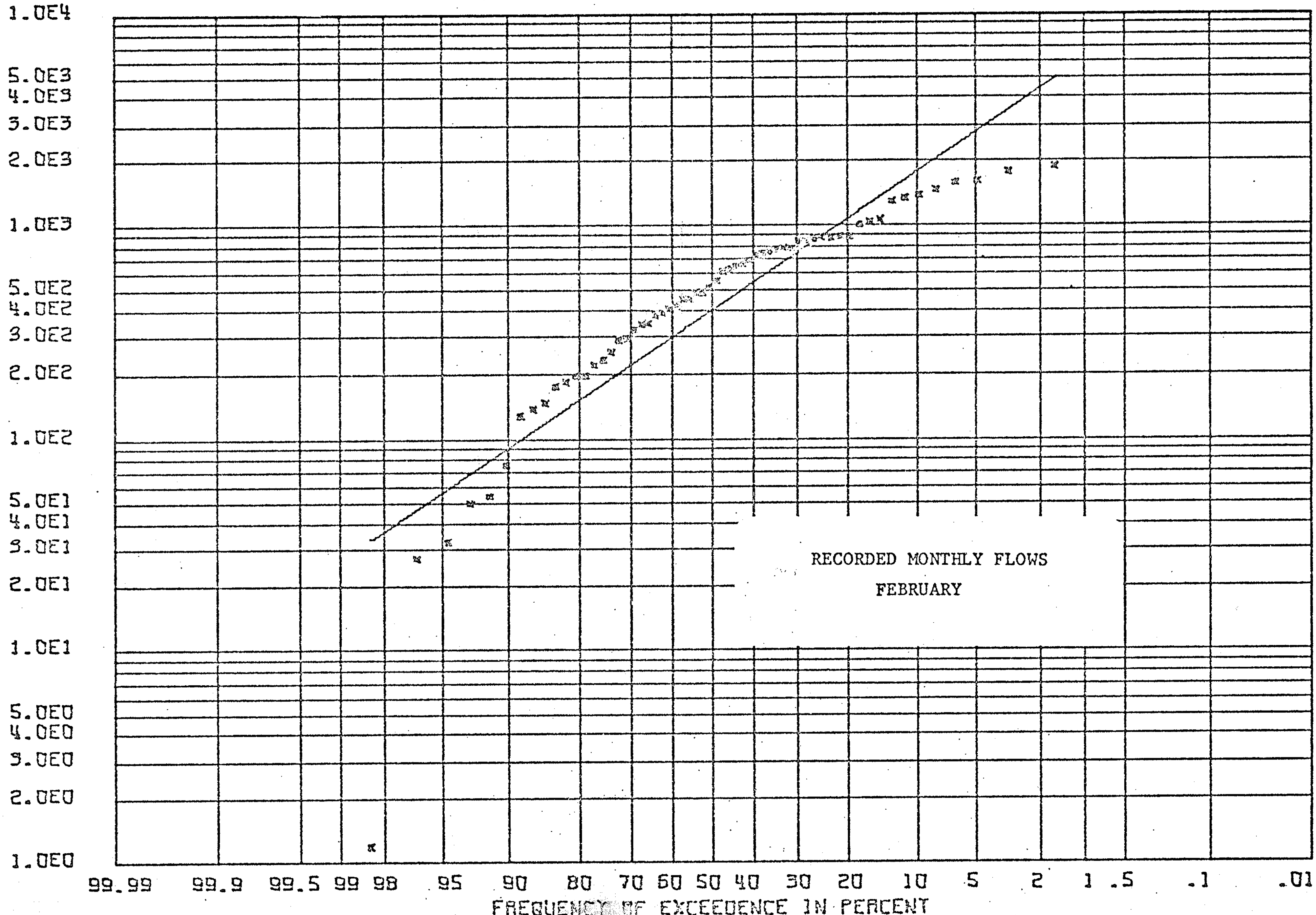
Appendix A

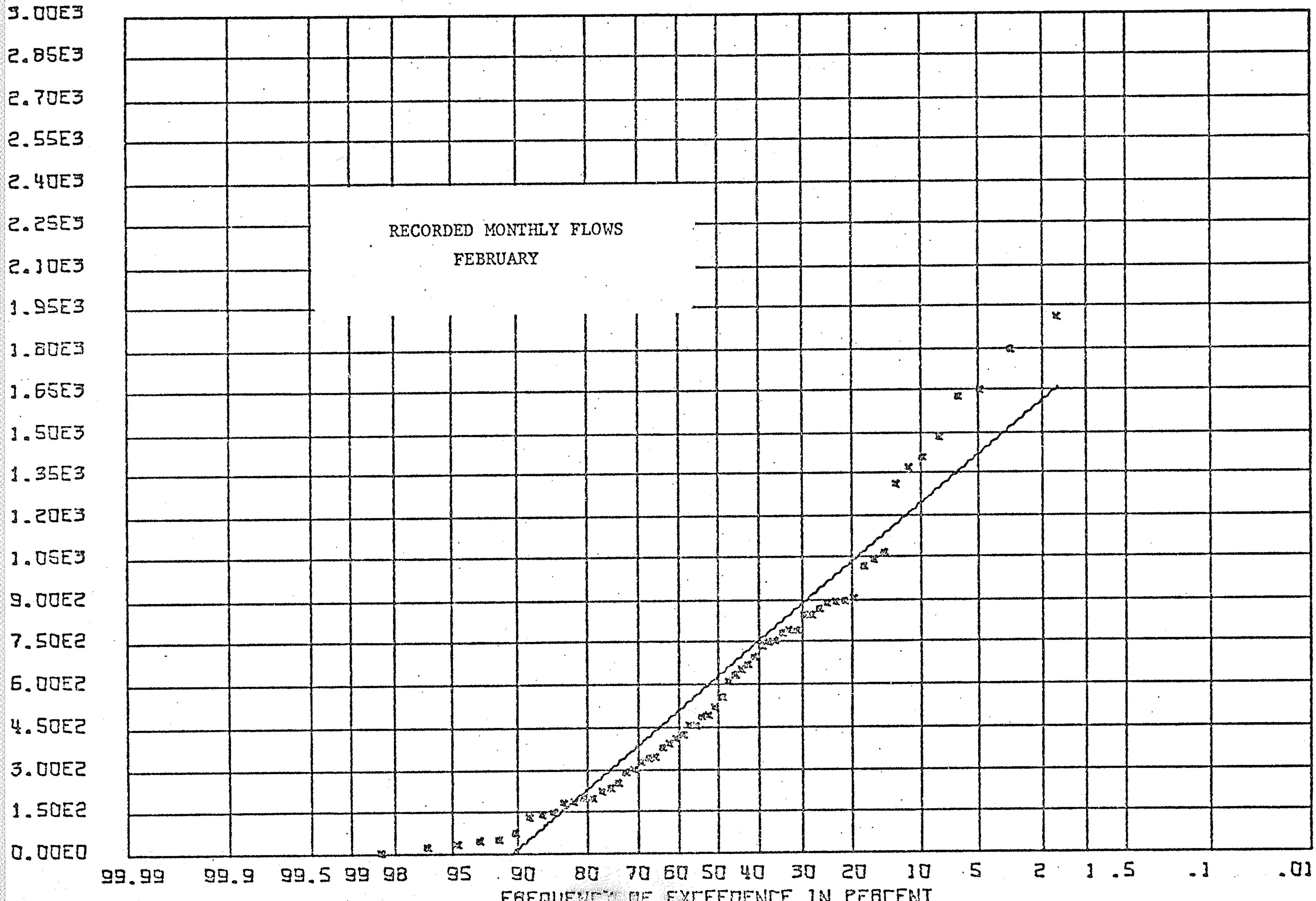
GRAPHS SHOWING STATISTICAL DISTRIBUTIONS OF RECORDED FLOWS




RECORDED MONTHLY FLOWS
JANUARY
1.0E4
5.0E3
4.0E3
3.0E3
2.0E3
1.0E3
5.0E2
4.0E2
3.0E2
2.0E2
1.0E2
5.0E1
4.0E1
3.0E1
2.0E1
1.0E1
5.0E0
4.0E0
3.0E0
2.0E0
1.0E0
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT


RECORDED MONTHLY FLOWS
JANUARY
3.00E3
2.85E3
2.70E3
2.55E3
2.40E3
2.25E3
2.10E3
1.95E3
1.80E3
1.65E3
1.50E3
1.35E3
1.20E3
1.05E3
9.00E2
7.50E2
6.00E2
4.50E2
3.00E2
1.50E2
0.00E0
99.99
99.9
99.5
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
.5
.1
.01
FREQUENCY OF EXCEEDENCE IN PERCENT


RECORDED MONTHLY FLOWS
FEBRUARY
1.0E4
5.0E3
4.0E3
3.0E3
2.0E3
1.0E3
5.0E2
4.0E2
3.0E2
2.0E2
1.0E2
5.0E1
4.0E1
3.0E1
2.0E1
1.0E1
5.0E0
4.0E0
3.0E0
2.0E0
1.0E0
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT



RECORDED MONTHLY FLOWS
FEBRUARY
3.00E3
2.85E3
2.70E3
2.55E3
2.40E3
2.25E3
2.10E3
1.95E3
1.80E3
1.65E3
1.50E3
1.35E3
1.20E3
1.05E3
9.00E2
7.50E2
6.00E2
4.50E2
3.00E2
1.50E2
0.00E0
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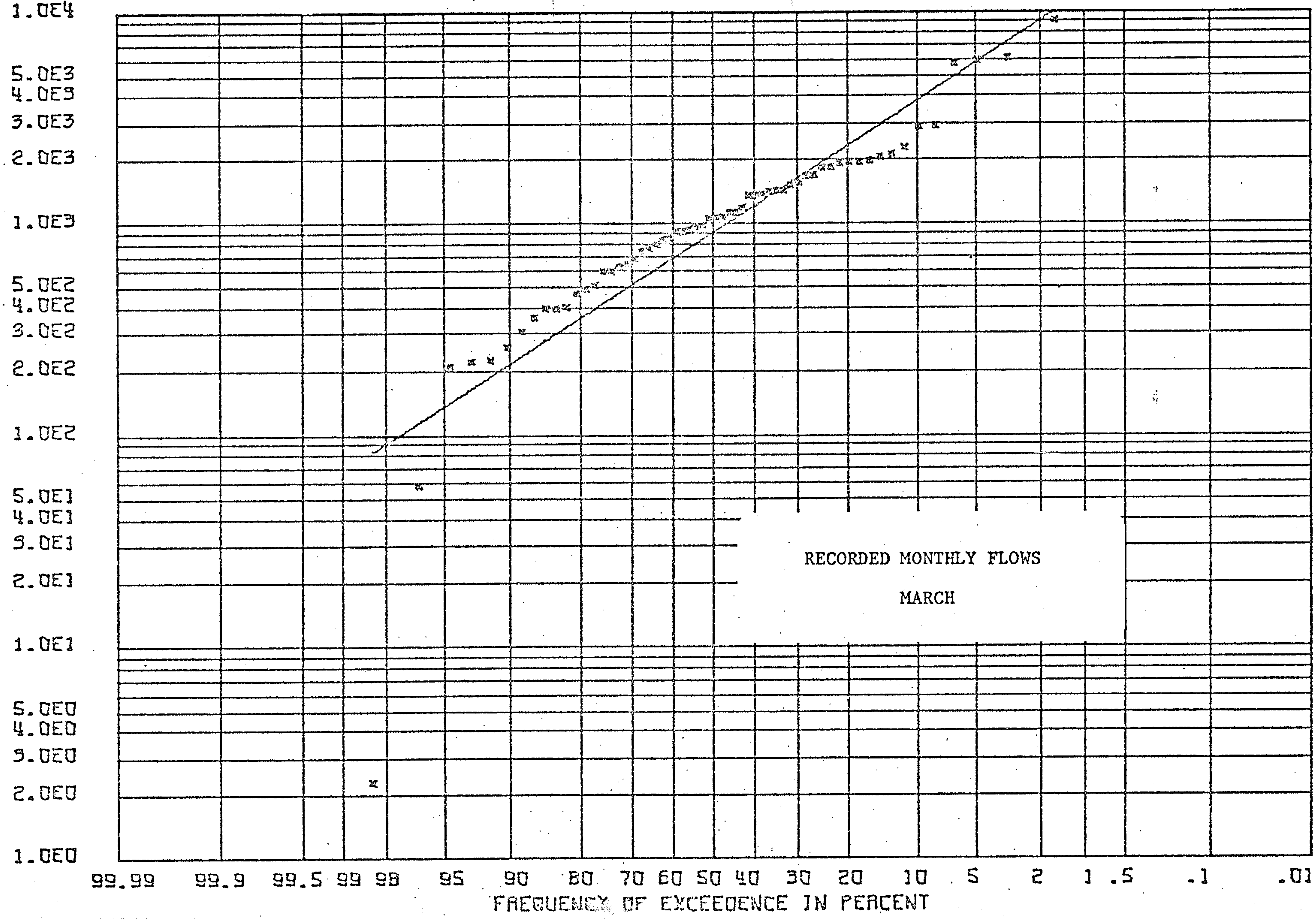
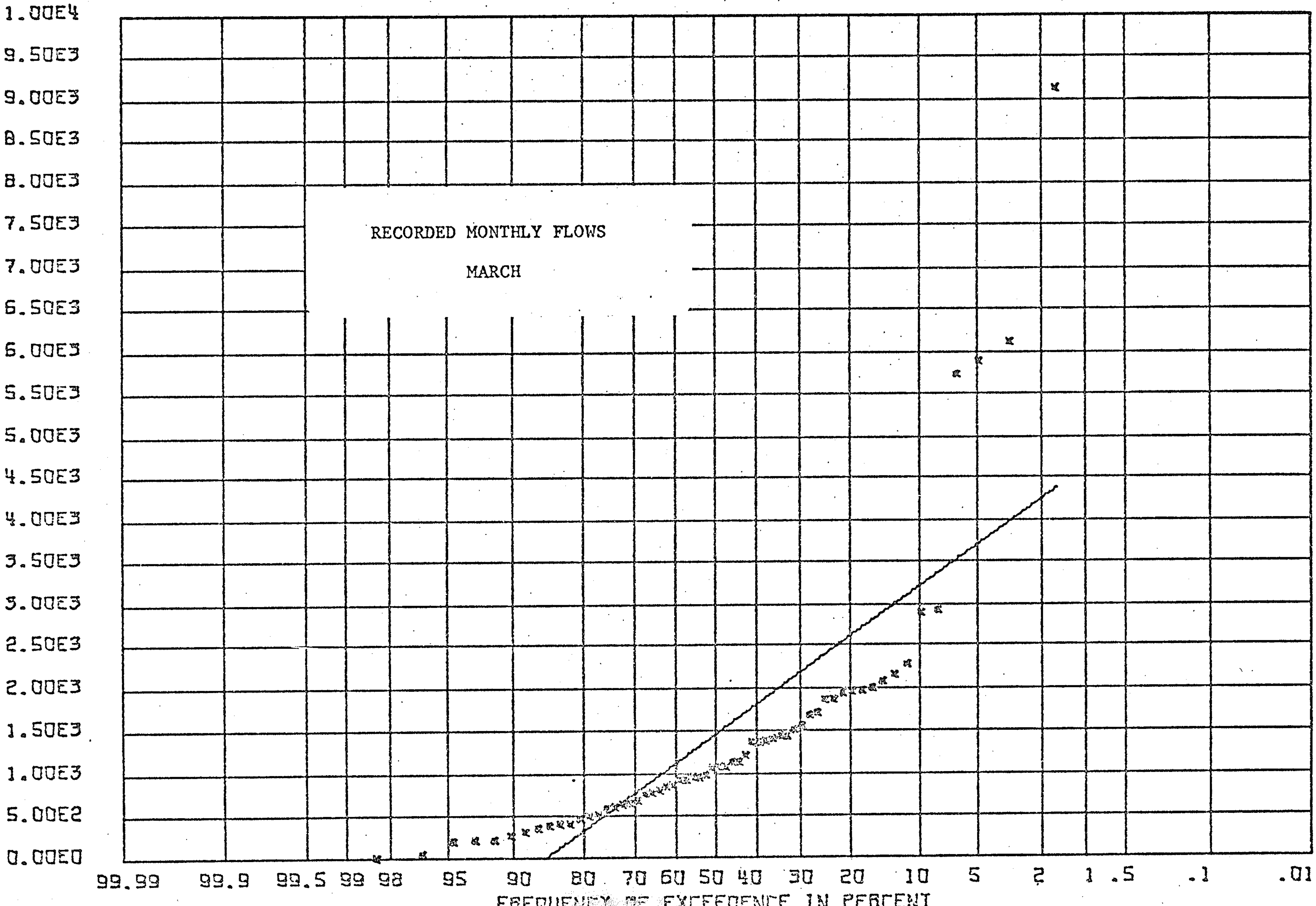
FREQUENCY OF EXCEEDENCE IN PERCENT

A5



RECORDED MONTHLY FLOWS
MARCH
1.0E4
5.0E3
4.0E3
3.0E3
2.0E3
1.0E3
5.0E2
4.0E2
3.0E2
2.0E2
1.0E2
5.0E1
4.0E1
3.0E1
2.0E1
1.0E1
5.0E0
4.0E0
3.0E0
2.0E0
1.0E0
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT


RECORDED MONTHLY FLOWS
MARCH
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9.50E3
9.00E3
8.50E3
8.00E3
7.50E3
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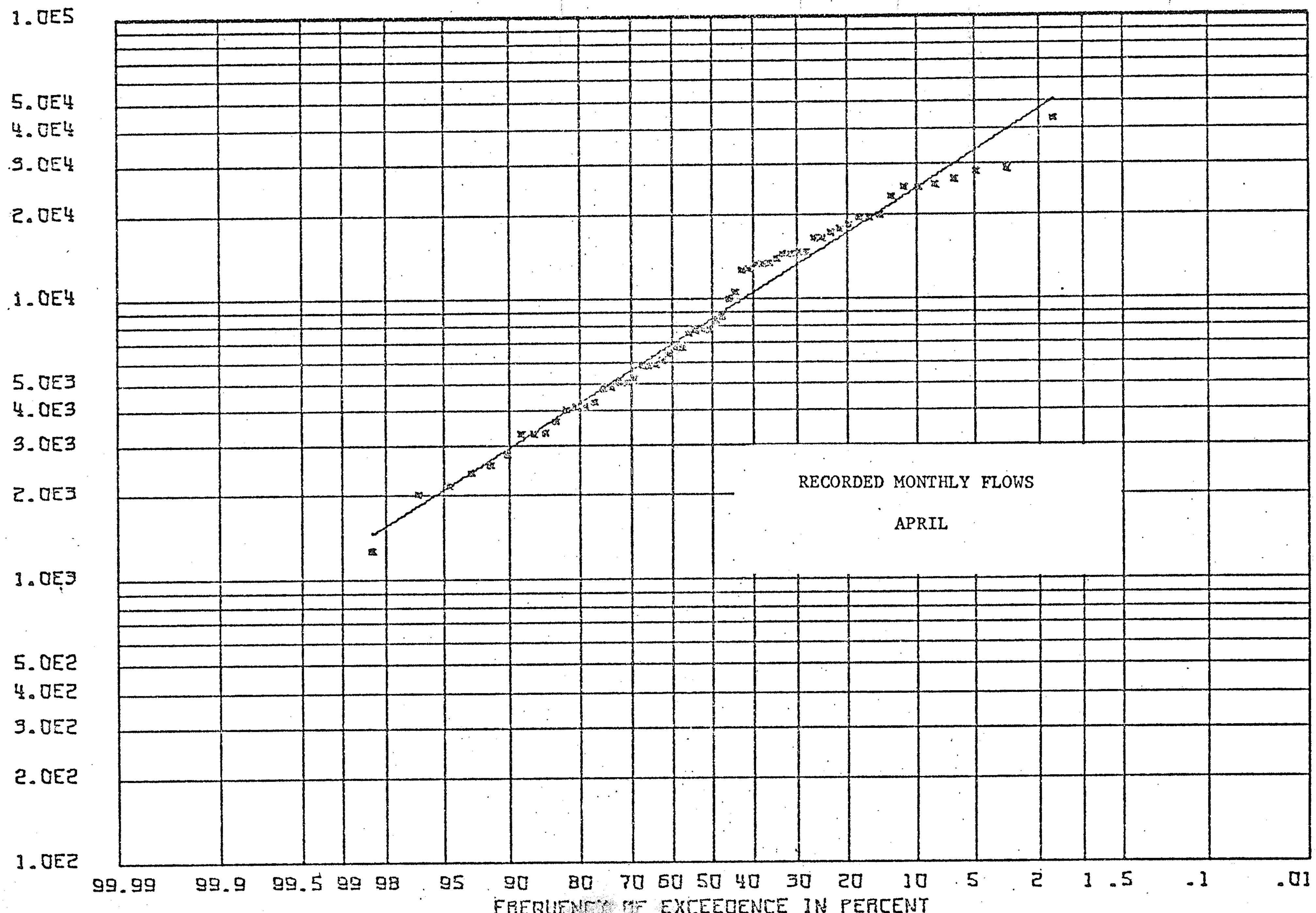
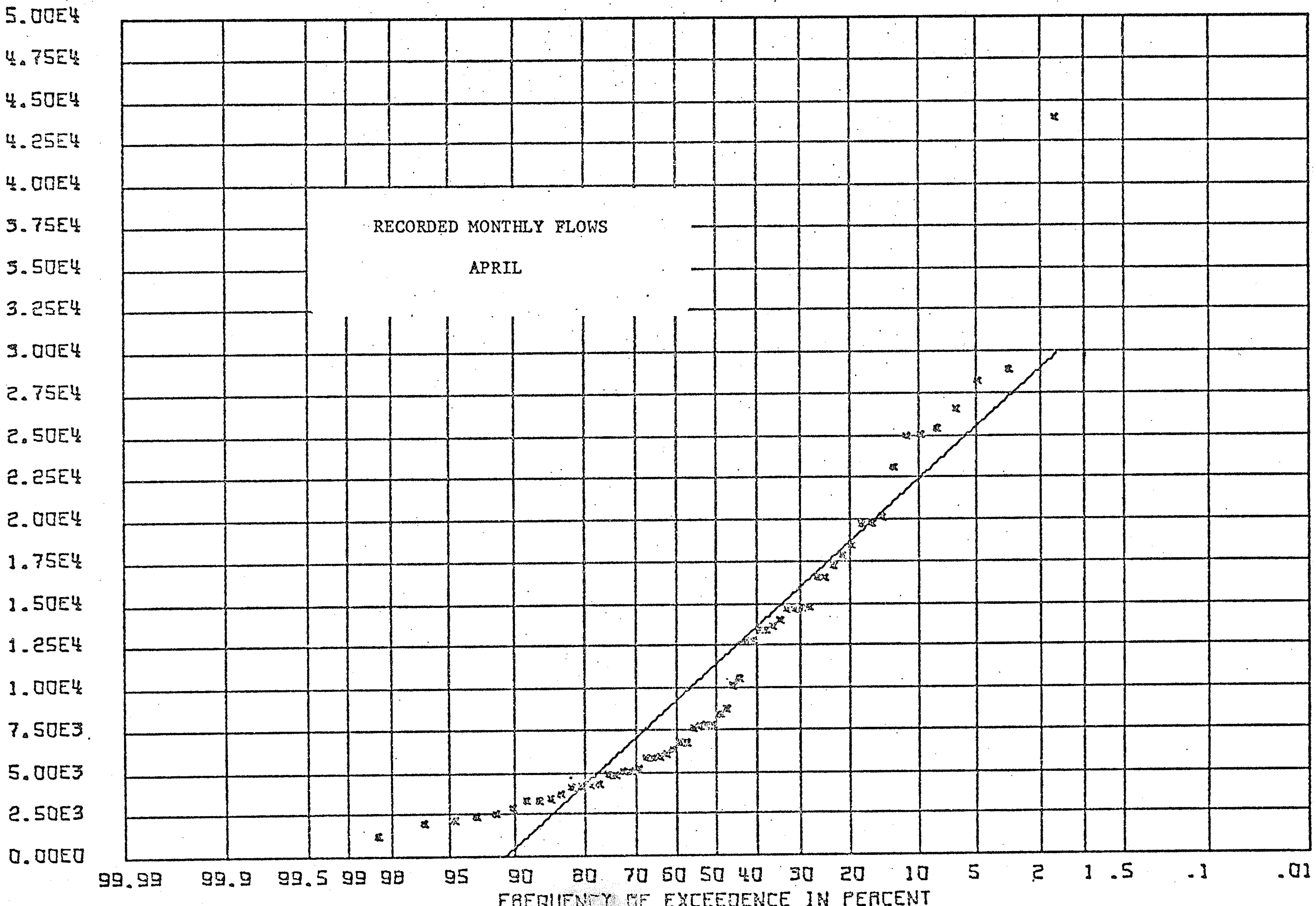
6.50E3
6.00E3
5.50E3
5.00E3
4.50E3
4.00E3
3.50E3
3.00E3
2.50E3
2.00E3
1.50E3
1.00E3
5.00E2
0.00E0
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT


RECORDED MONTHLY FLOWS
APRIL
1.0E5
5.0E4
4.0E4
3.0E4
2.0E4
1.0E4
5.0E3
4.0E3
3.0E3
2.0E3
1.0E3
5.0E2
4.0E2
3.0E2
2.0E2
1.0E2
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT



RECORDED MONTHLY FLOWS
APRIL
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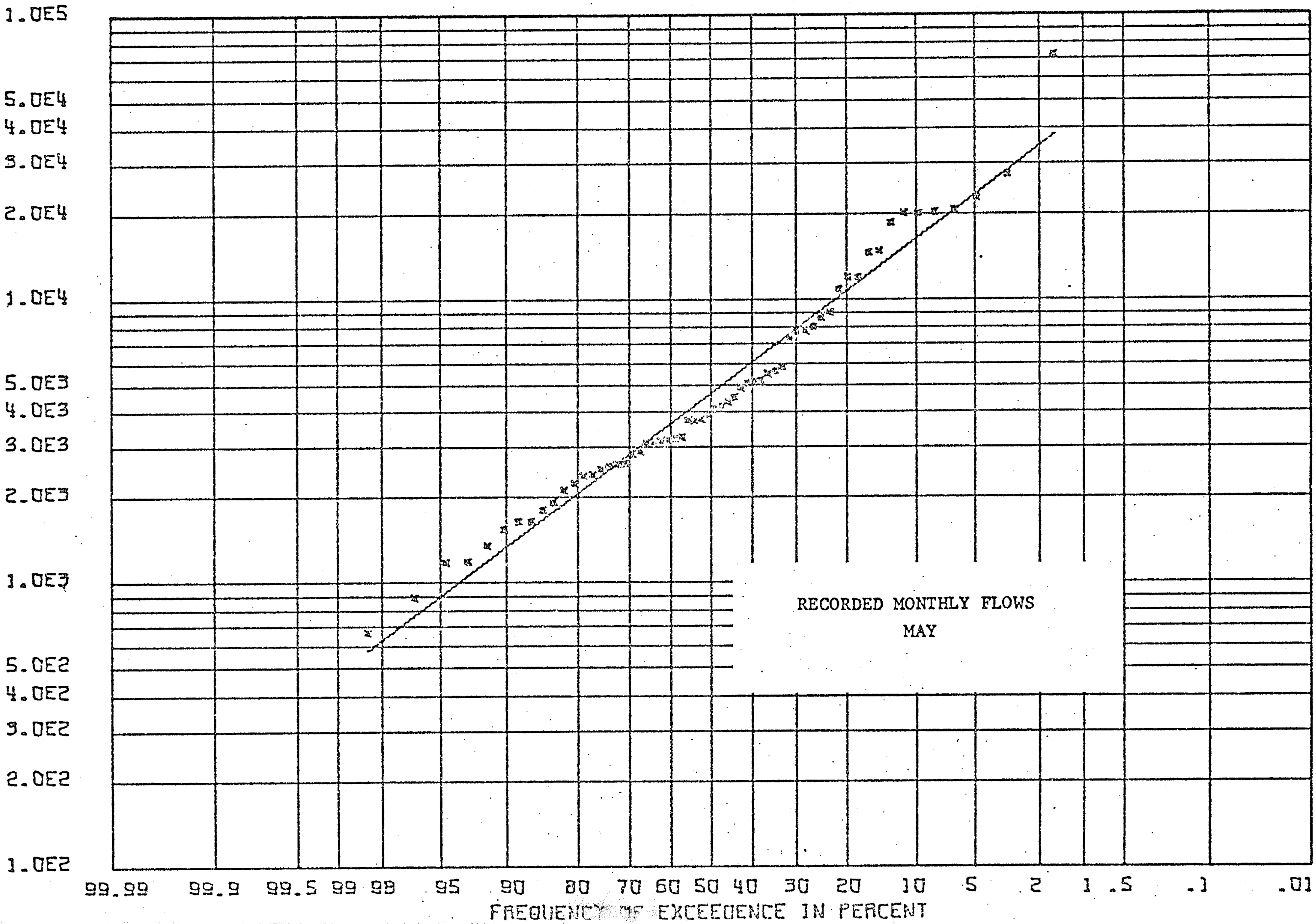
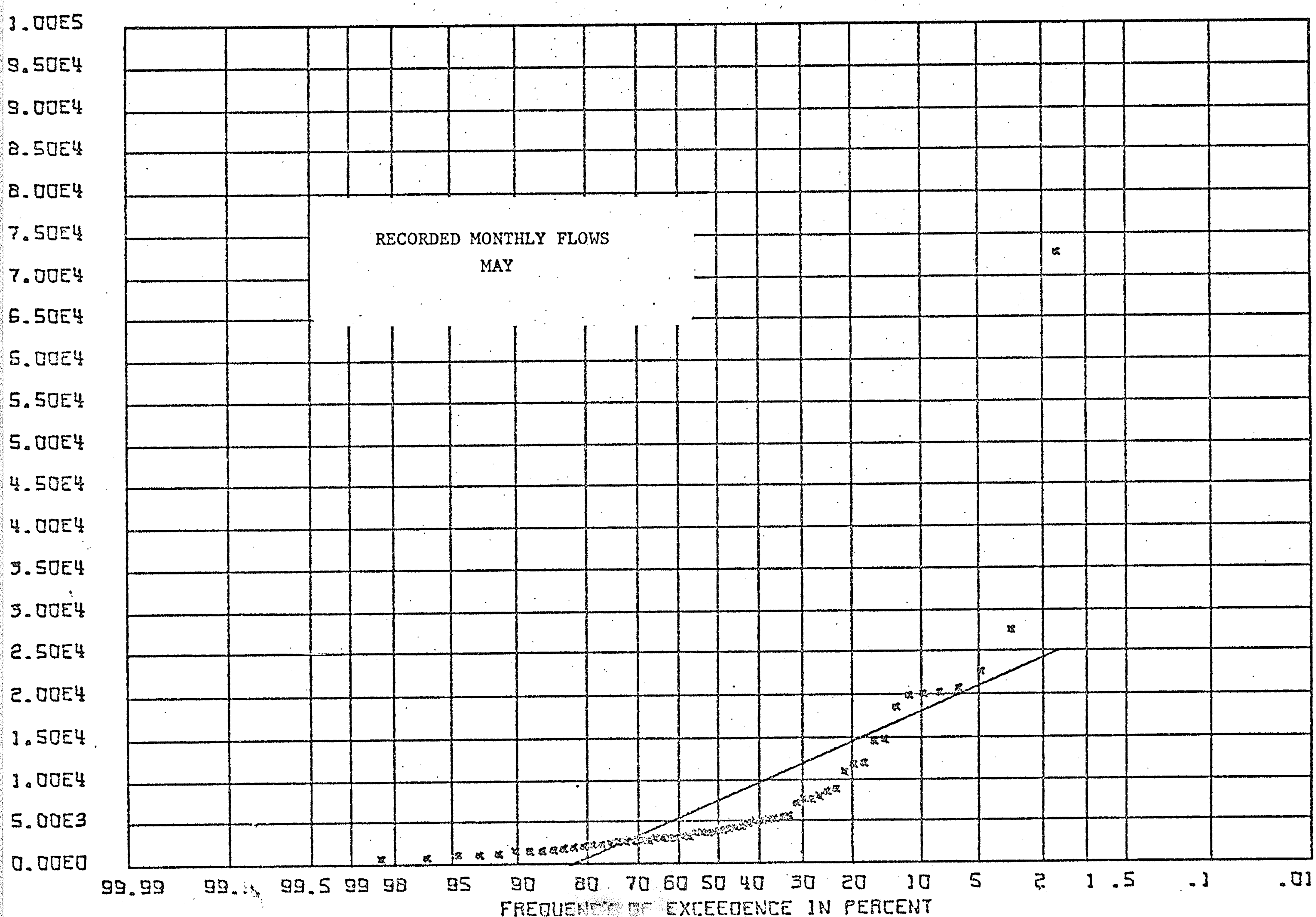
4.75E4
4.50E4
4.25E4
4.00E4
3.75E4
3.50E4
3.25E4
3.00E4
2.75E4
2.50E4
2.25E4
2.00E4
1.75E4
1.50E4
1.25E4
1.00E4
7.50E3
5.00E3
2.50E3
0.00E0
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT

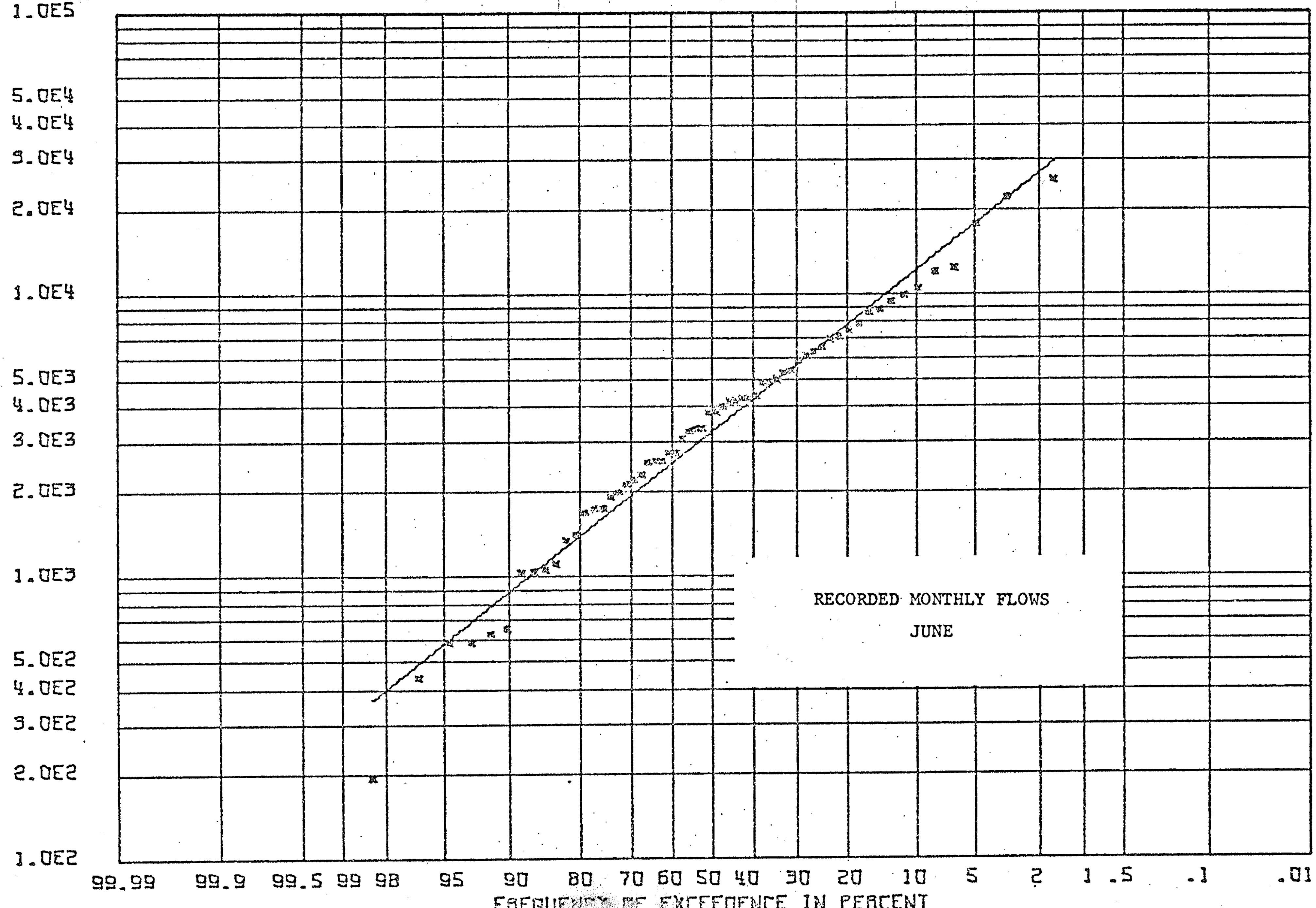


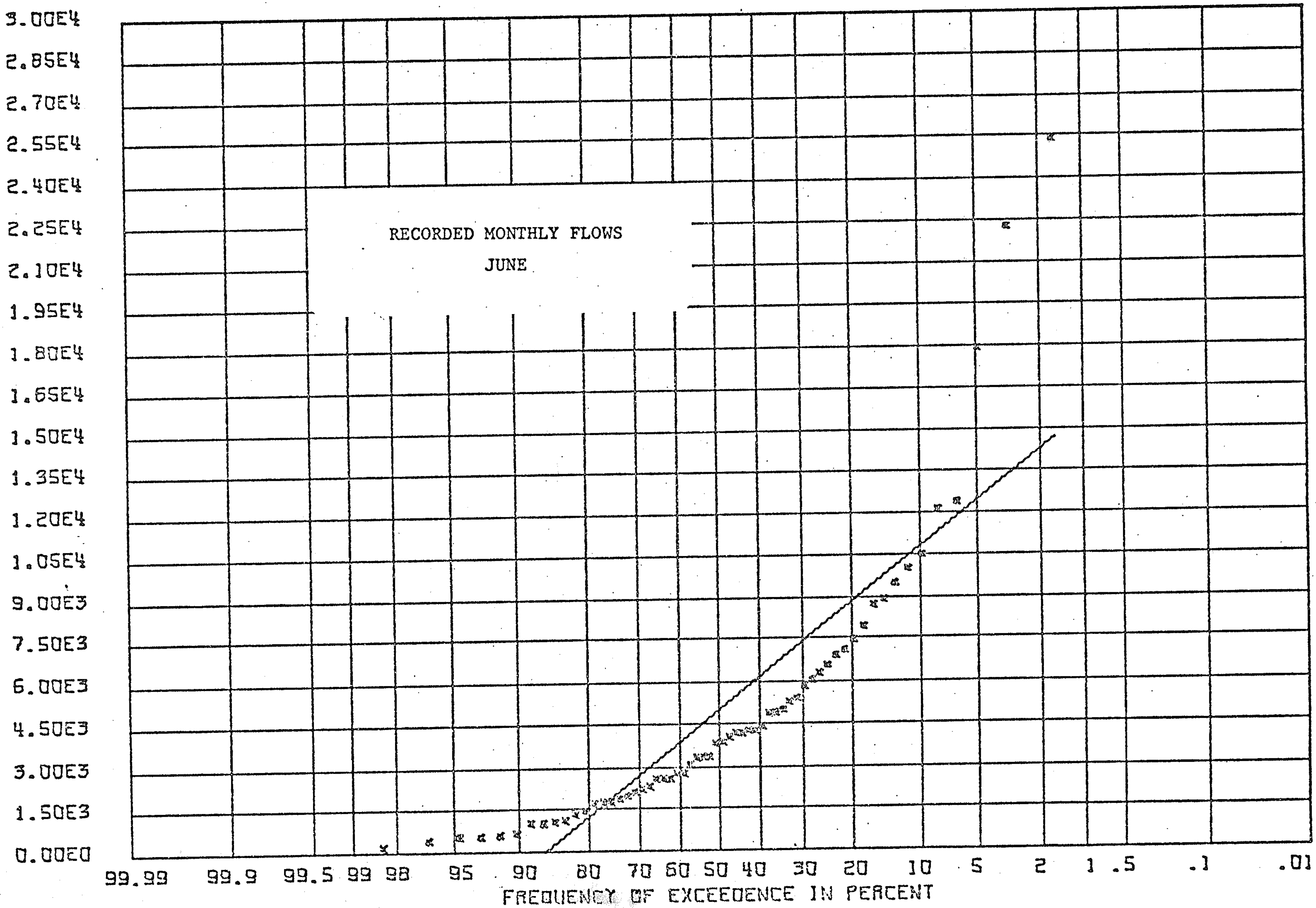
RECORDED MONTHLY FLOWS
MAY
1.0E5
5.0E4
4.0E4
3.0E4
2.0E4
1.0E4
5.0E3
4.0E3
3.0E3
2.0E3
1.0E3
5.0E2
4.0E2
3.0E2
2.0E2
1.0E2
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT

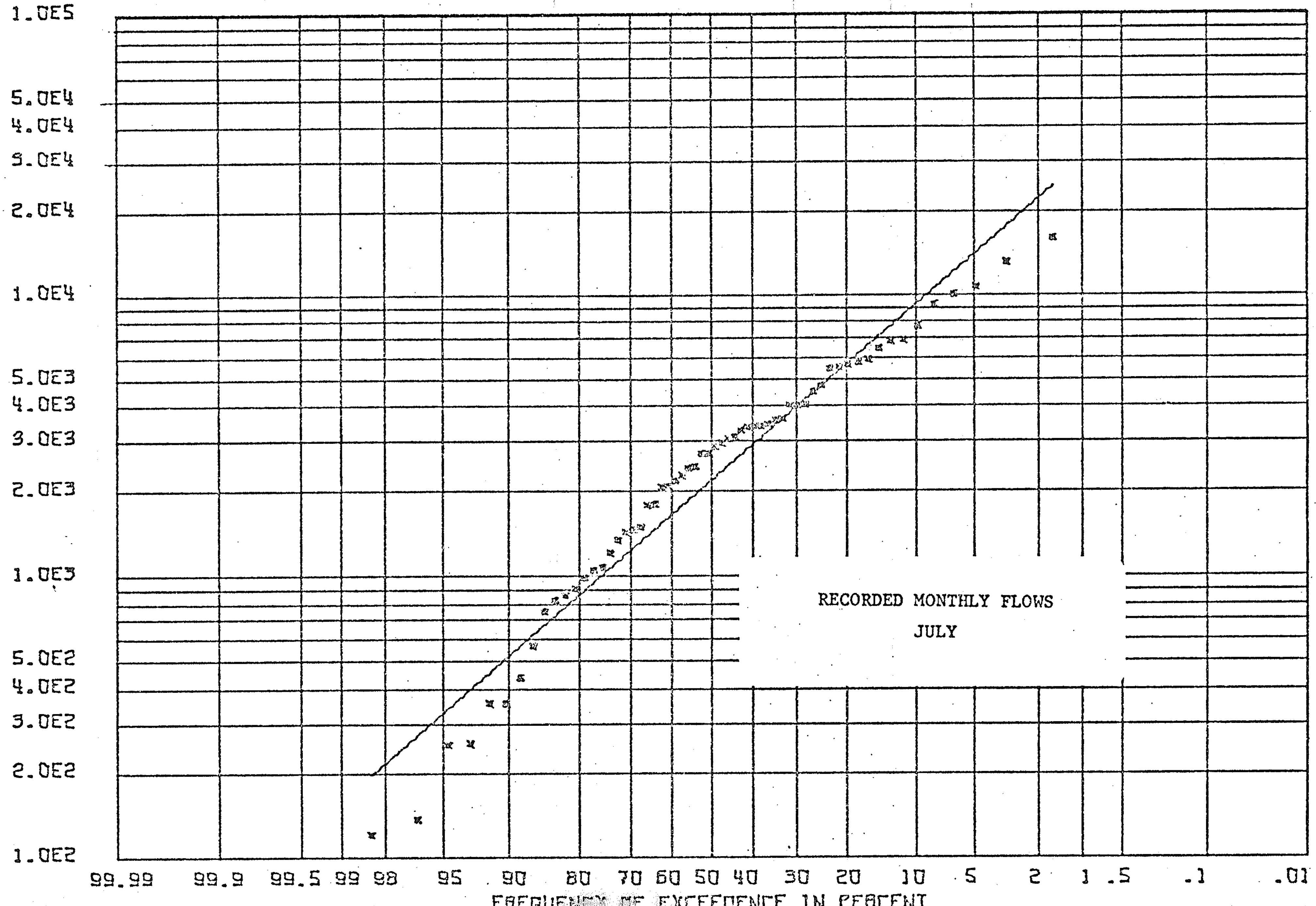
A10


RECORDED MONTHLY FLOWS
MAY
1.00E5
9.50E4
9.00E4
8.50E4
8.00E4
7.50E4
7.00E4
6.50E4
6.00E4
5.50E4
5.00E4
4.50E4
4.00E4
3.50E4
3.00E4
2.50E4
2.00E4
1.50E4
1.00E4
5.00E3
0.00E0
99.99
99.5 99 98
95
90
80
70 60 50 40
30
20
10
5
2
1 .5
.1
.01
EXCEEDENCE IN PERCENT

A11


RECORDED MONTHLY FLOWS
JUNE
1.0E5
5.0E4
4.0E4
3.0E4
2.0E4
1.0E4
5.0E3
4.0E3
3.0E3
2.0E3
1.0E3
5.0E2
4.0E2
3.0E2
2.0E2
1.0E2
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT


RECORDED MONTHLY FLOWS
JUNE
3.00E4
2.85E4
2.70E4
2.55E4
2.40E4
2.25E4
2.10E4
1.95E4
1.80E4
1.65E4
1.50E4
1.35E4
1.20E4
1.05E4
9.00E3
7.50E3
6.00E3
4.50E3
3.00E3
1.50E3
0.00E0
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT



RECORDED MONTHLY FLOWS
JULY
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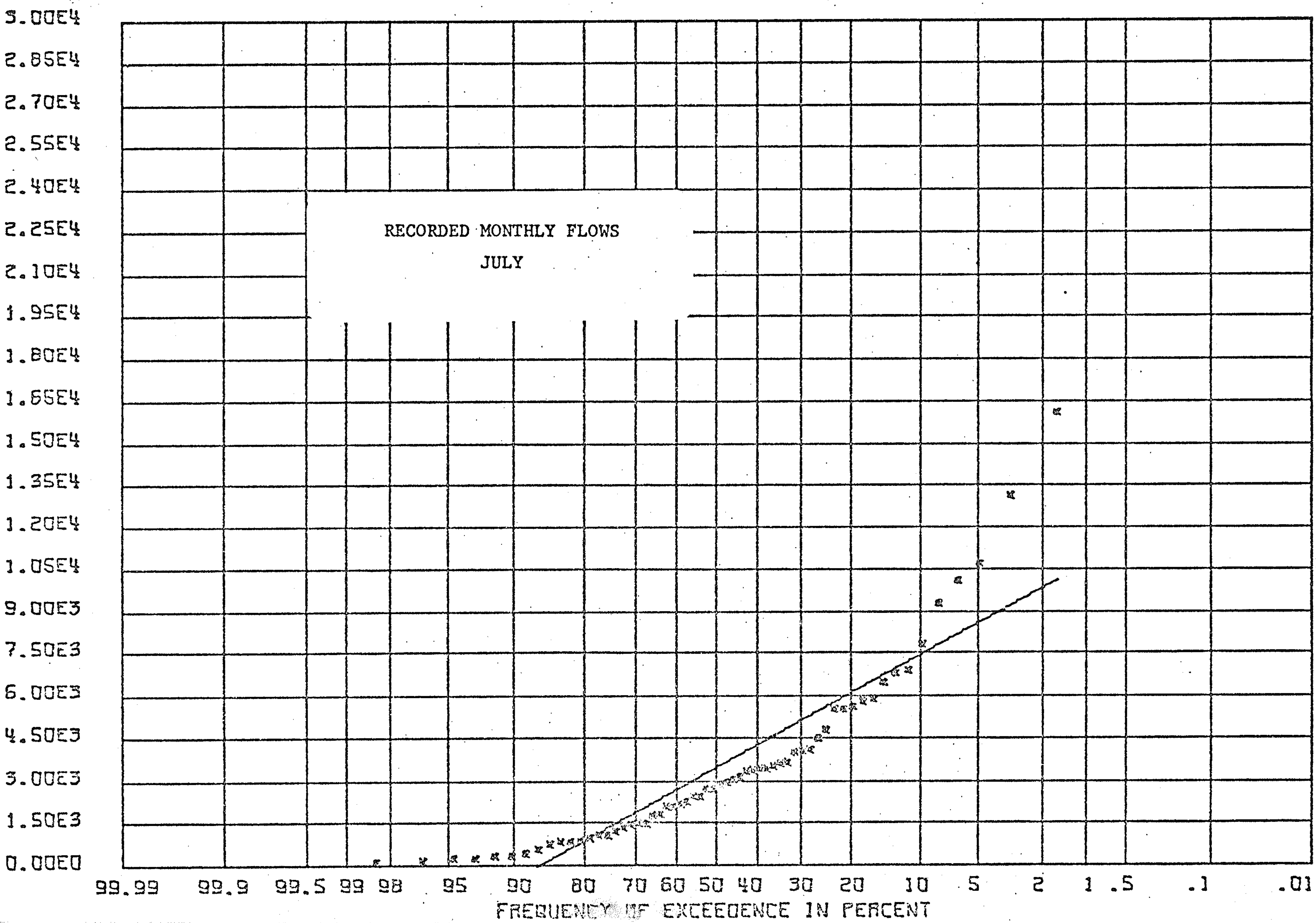
4.0E4
3.0E4
2.0E4
1.0E4
5.0E3
4.0E3
3.0E3
2.0E3
1.0E3
5.0E2
4.0E2
3.0E2
2.0E2
1.0E2
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT


RECORDED MONTHLY FLOWS
JULY
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2.85E4
2.70E4
2.55E4
2.40E4
2.25E4
2.10E4
1.95E4
1.80E4
1.65E4
1.50E4
1.35E4
1.20E4
1.05E4
9.00E3
7.50E3
6.00E3
4.50E3
3.00E3
1.50E3
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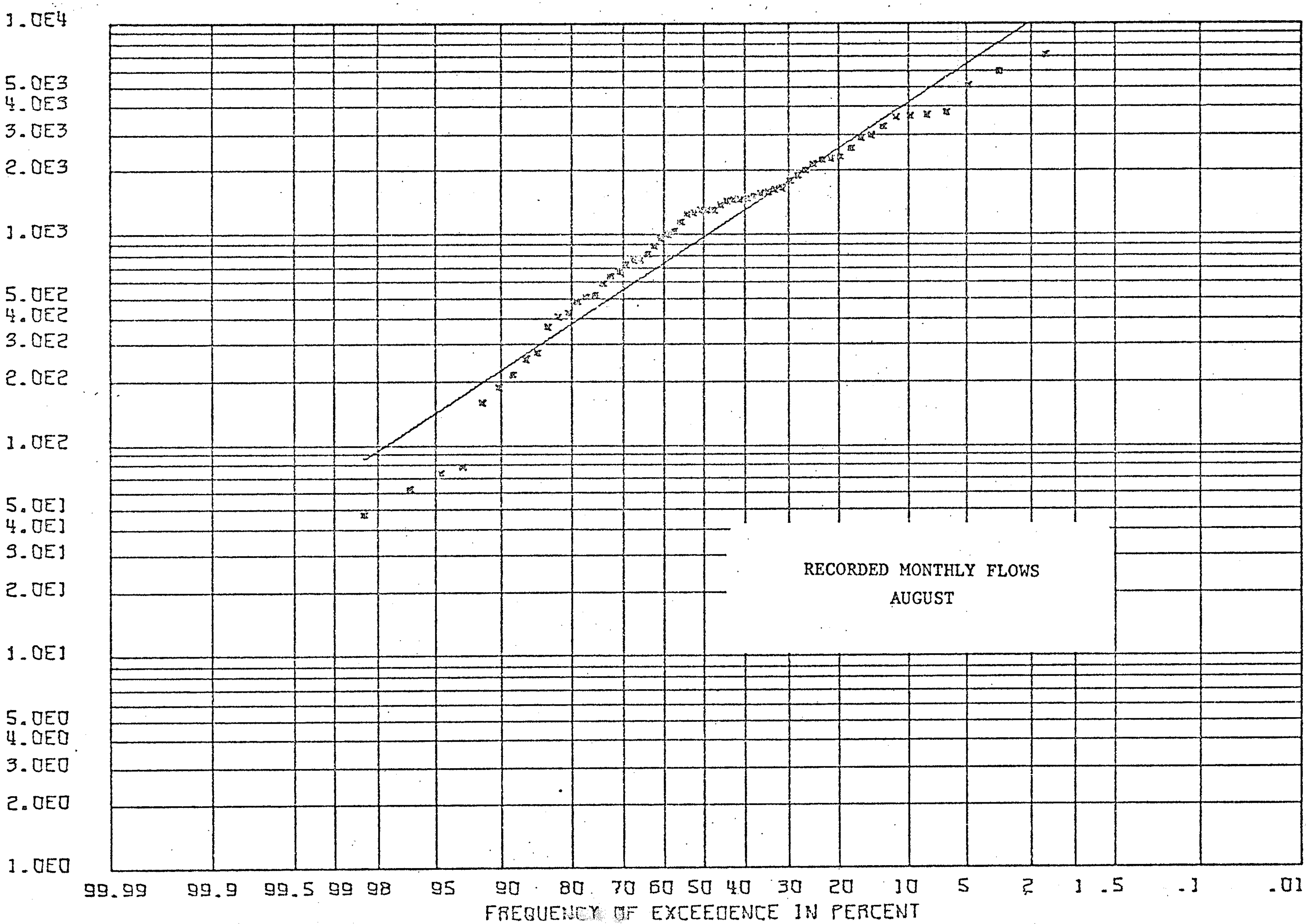
FREQUENCY OF EXCEEDENCE IN PERCENT

A16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4.0E3
3.0E3
2.0E3
1.0E3
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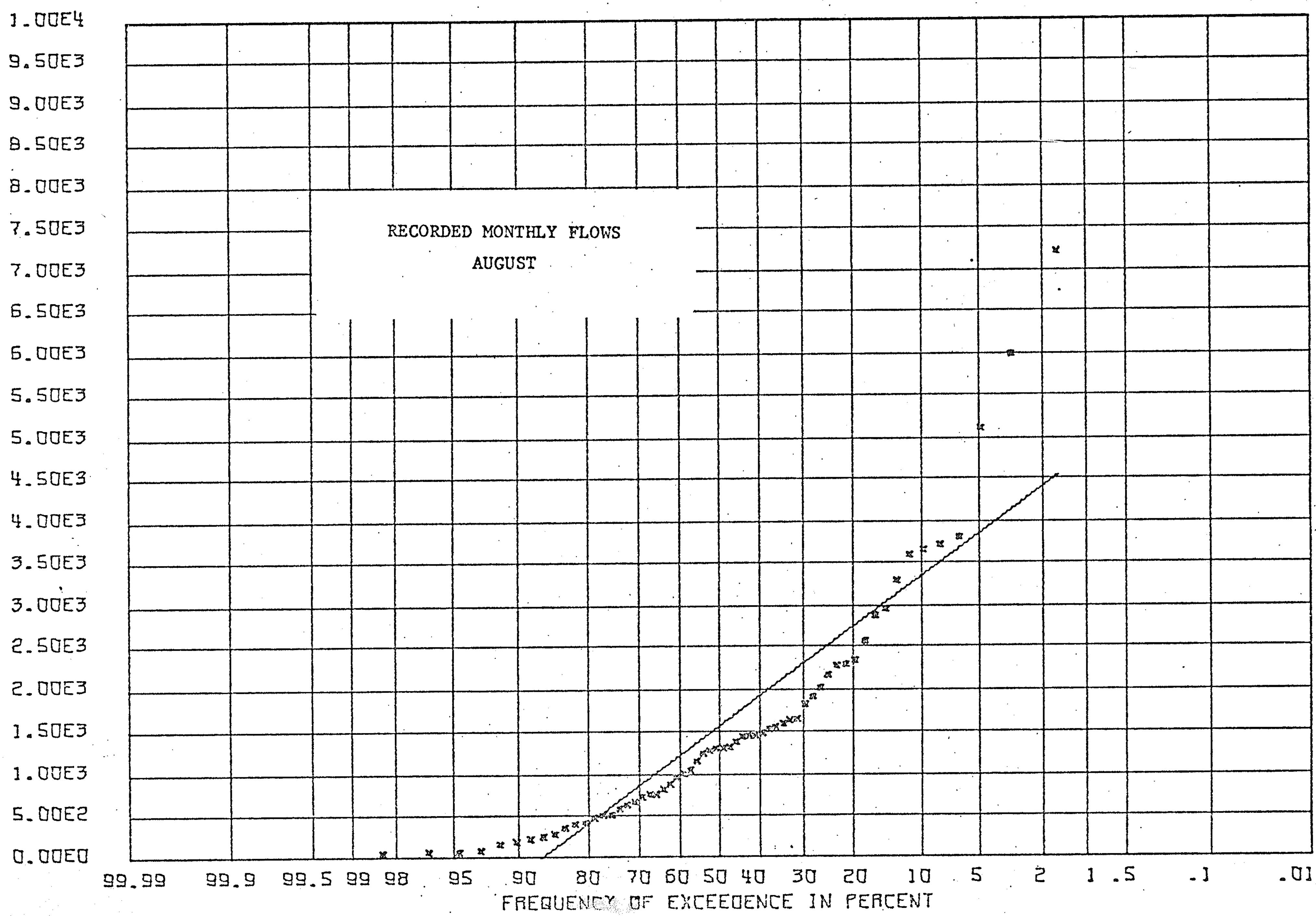
4.0E2
3.0E2
2.0E2
1.0E2
5.0E1
4.0E1
3.0E1
2.0E1
1.0E1
5.0E0
4.0E0
3.0E0
2.0E0
1.0E0
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT
RECORDED MONTHLY FLOWS
AUGUST


RECORDED MONTHLY FLOWS
AUGUST
1.00E4
9.50E3
9.00E3
8.50E3
8.00E3
7.50E3
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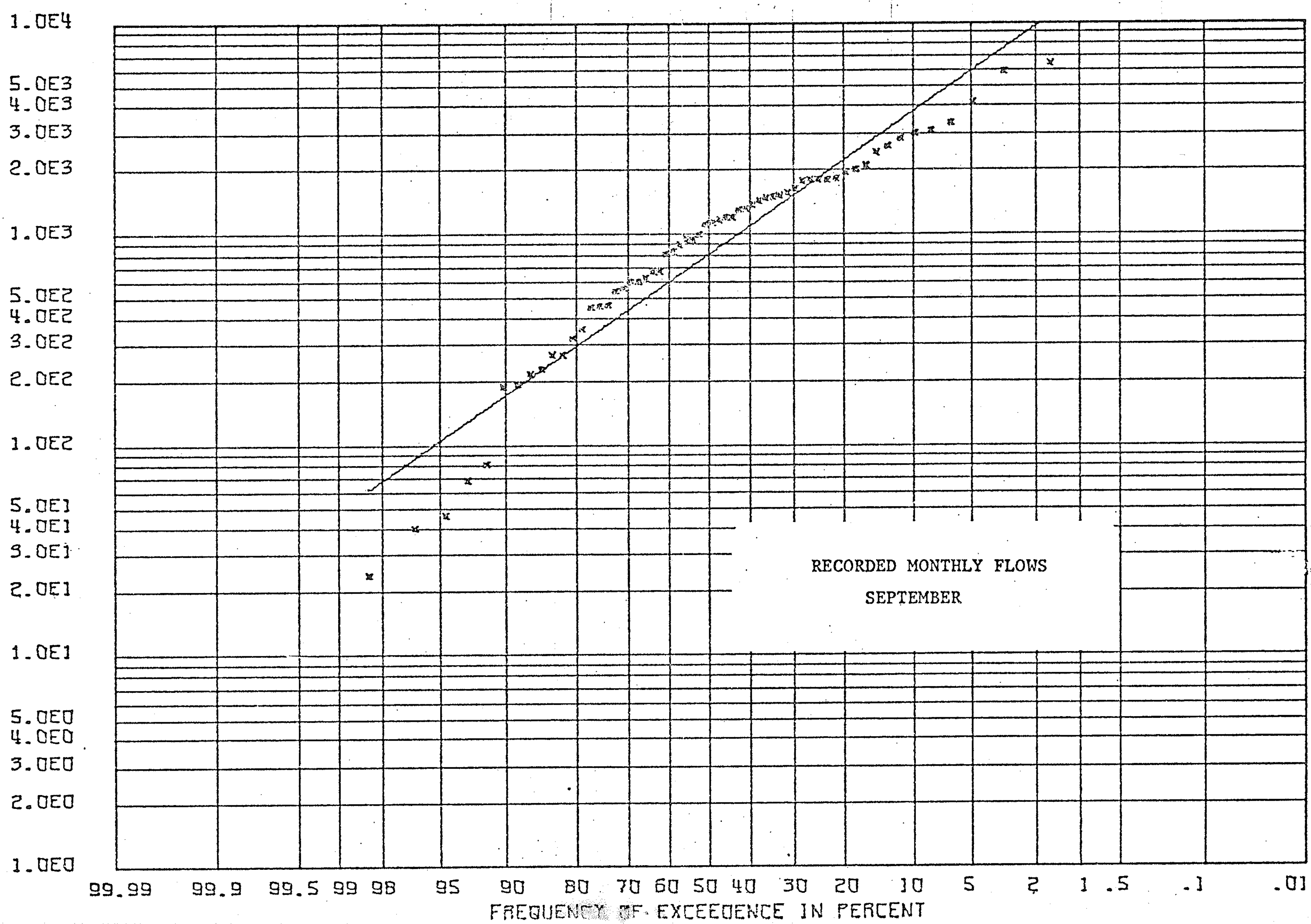
6.50E3
6.00E3
5.50E3
5.00E3
4.50E3
4.00E3
3.50E3
3.00E3
2.50E3
2.00E3
1.50E3
1.00E3
5.00E2
0.00E0
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT


RECORDED MONTHLY FLOWS
SEPTEMBER
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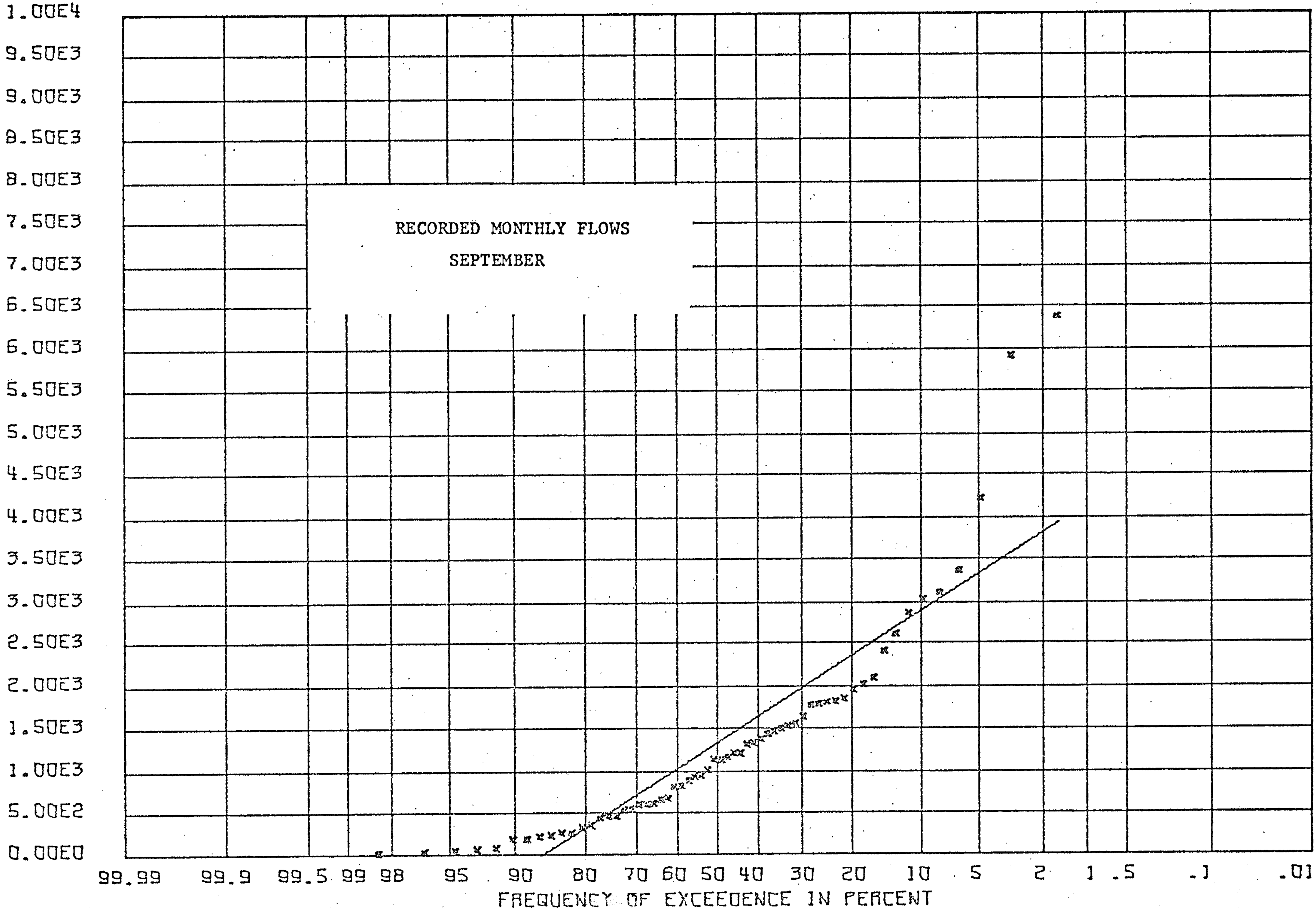
5.0E3
4.0E3
3.0E3
2.0E3
1.0E3
5.0E2
4.0E2
3.0E2
2.0E2
1.0E2
5.0E1
4.0E1
3.0E1
2.0E1
1.0E1
5.0E0
4.0E0
3.0E0
2.0E0
1.0E0
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT



RECORDED MONTHLY FLOWS
SEPTEMBER
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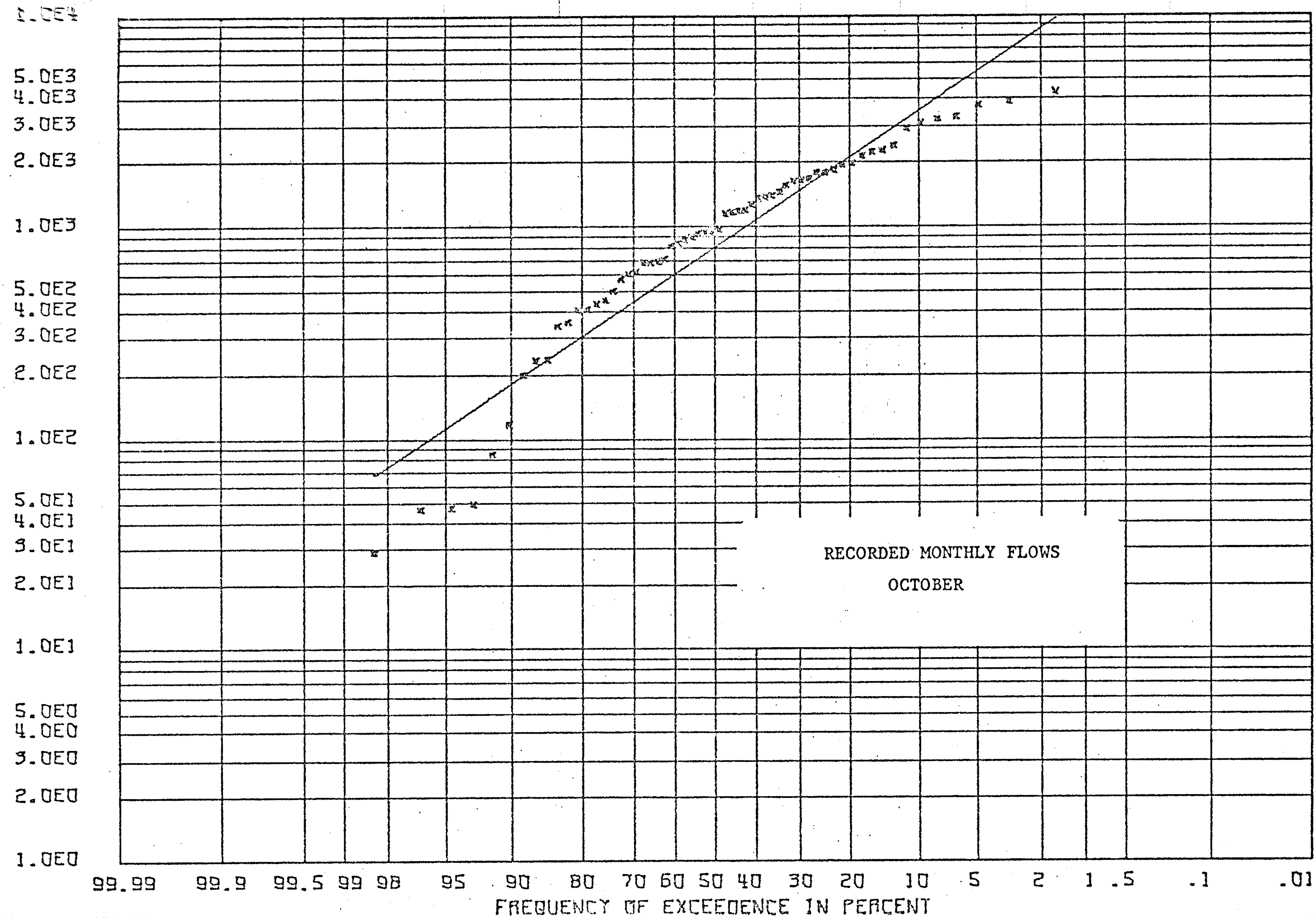
9.00E3
8.50E3
8.00E3
7.50E3
7.00E3
6.50E3
6.00E3
5.50E3
5.00E3
4.50E3
4.00E3
3.50E3
3.00E3
2.50E3
2.00E3
1.50E3
1.00E3
5.00E2
0.00E0
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT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2.0E3
1.0E3
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4.0E2
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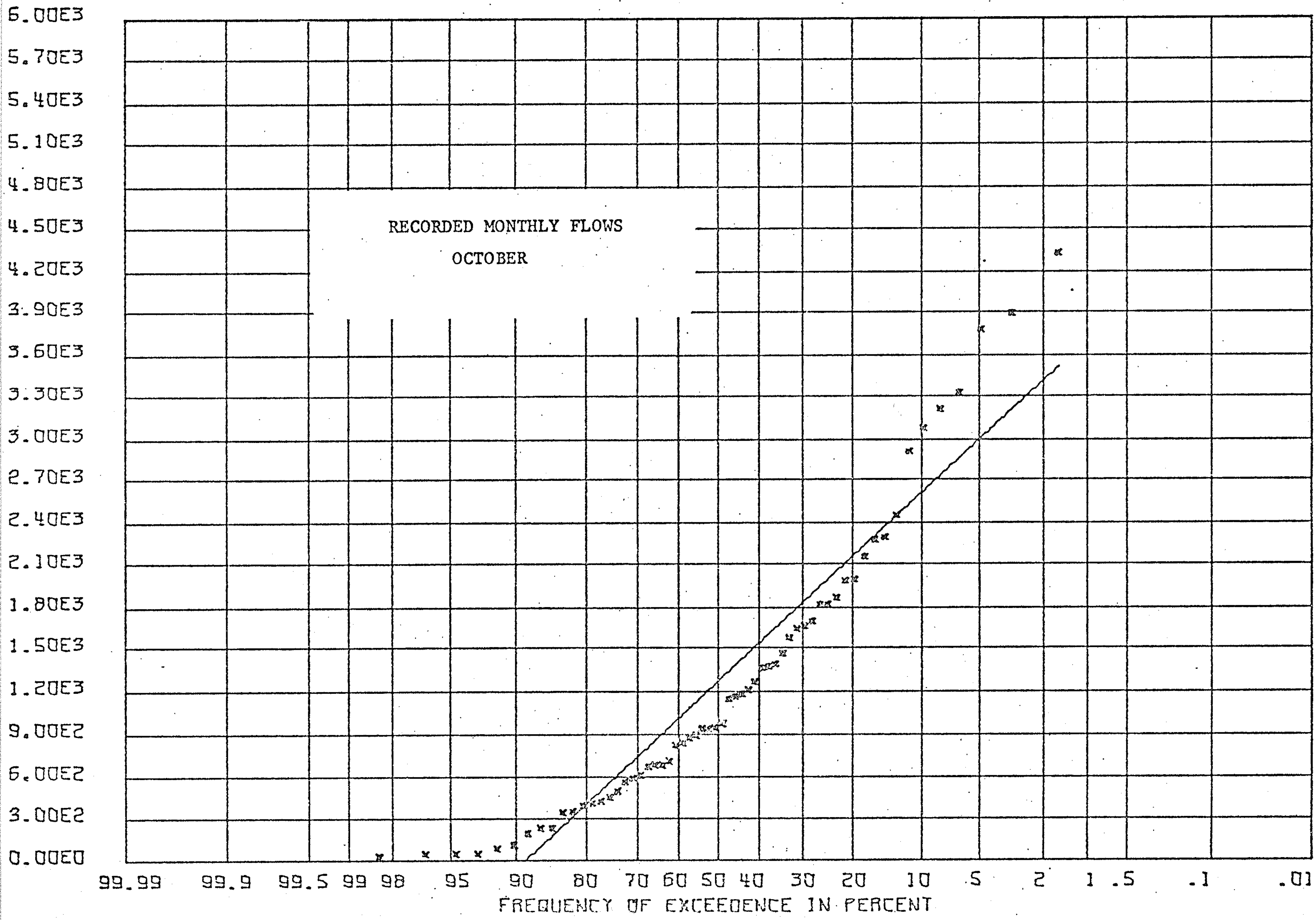
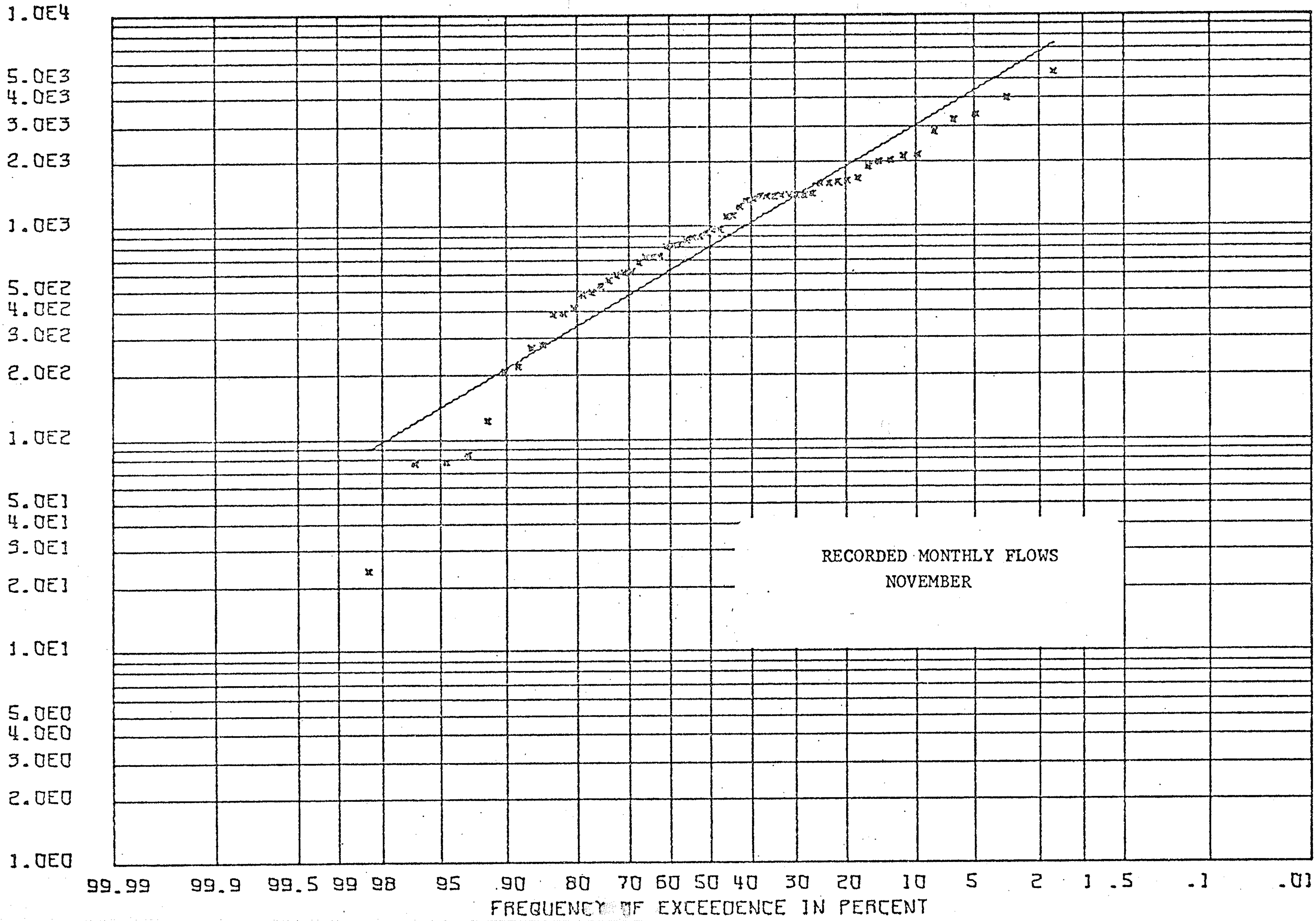
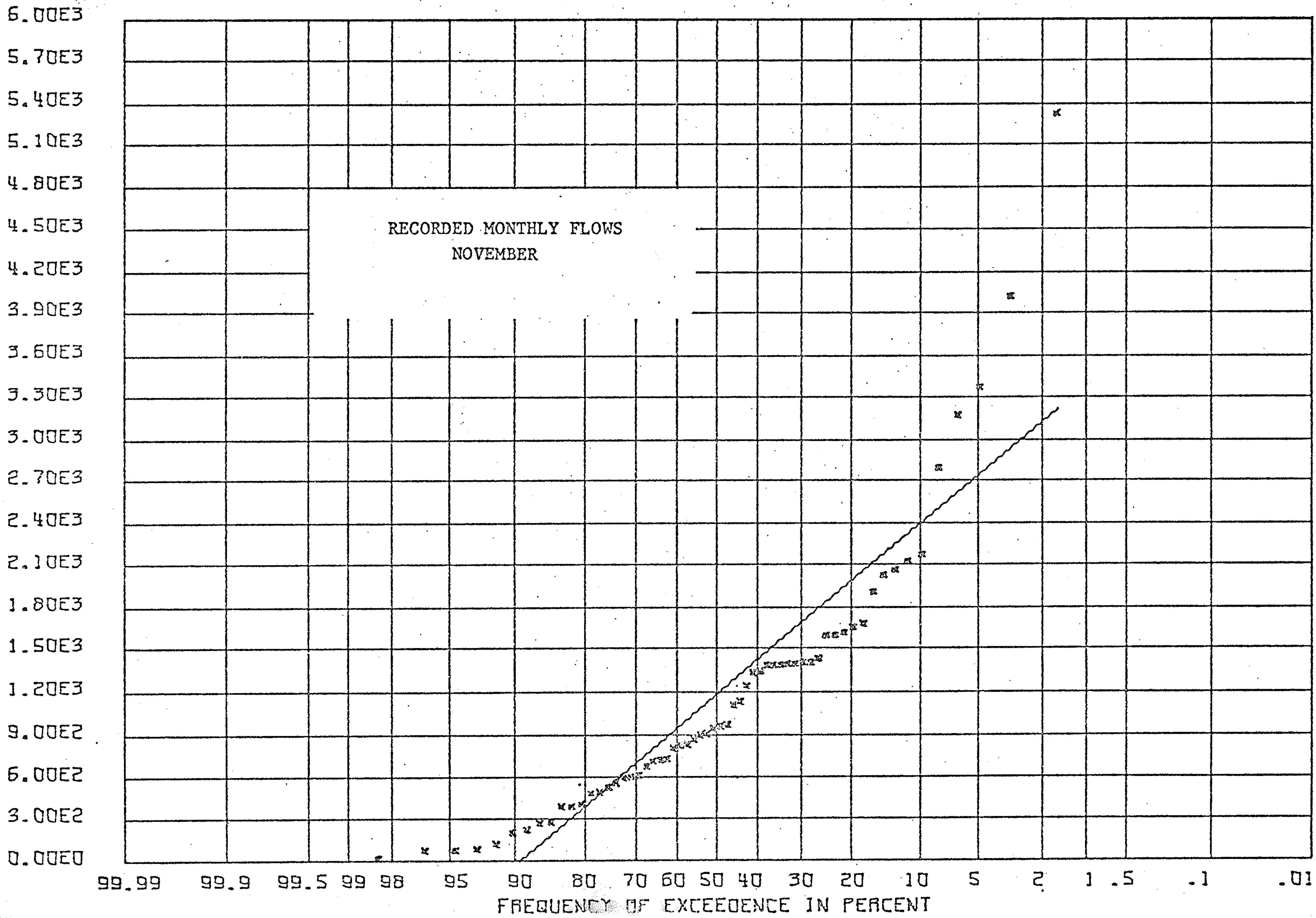
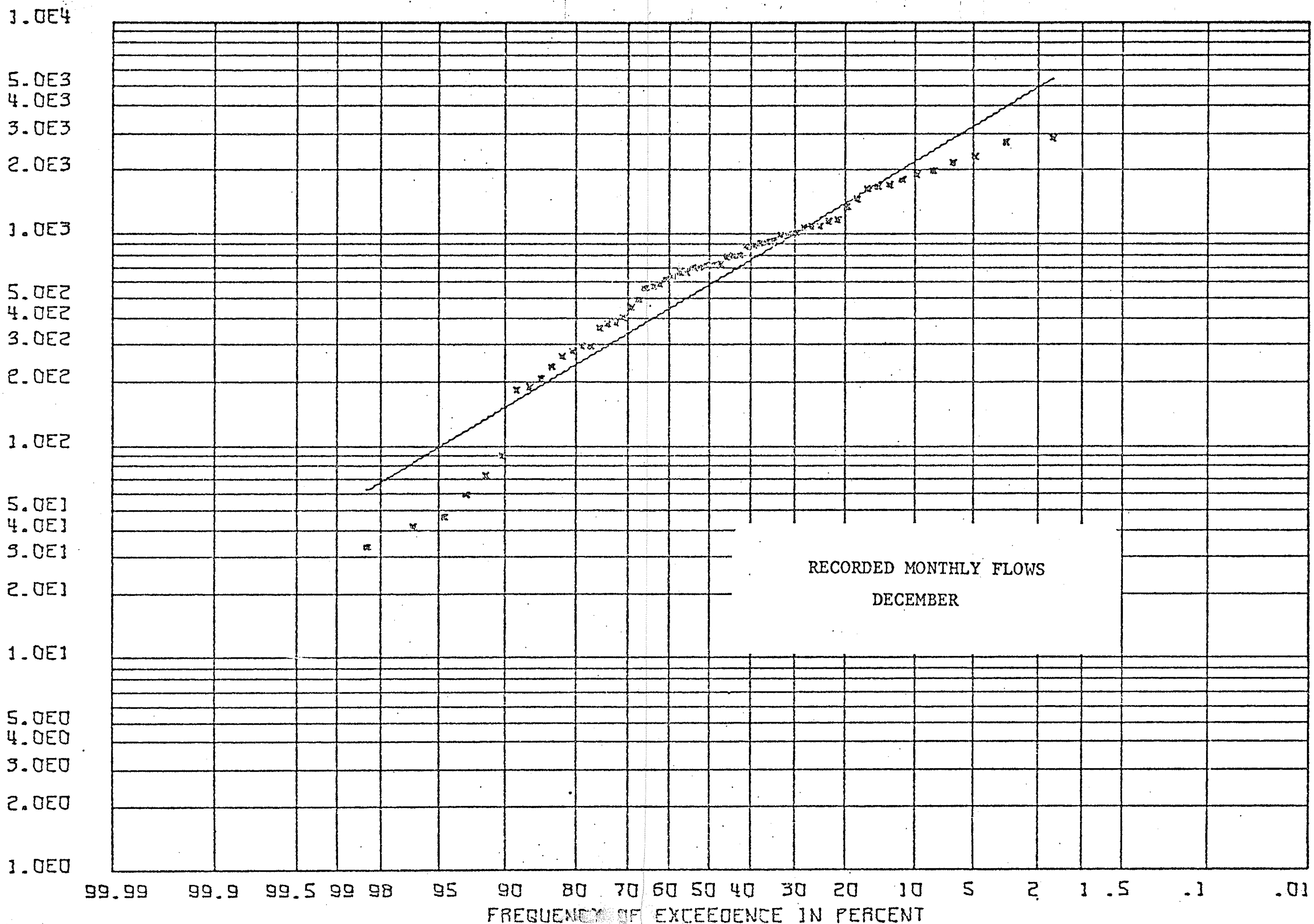
2.0E2
1.0E2
5.0E1
4.0E1
3.0E1
2.0E1
1.0E1
5.0E0
4.0E0
3.0E0
2.0E0
1.0E0
RECORDED MONTHLY FLOWS
OCTOBER
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT


RECORDED MONTHLY FLOWS
OCTOBER
6.00E3
5.70E3
5.40E3
5.10E3
4.80E3
4.50E3
4.20E3
3.90E3
3.60E3
3.30E3
3.00E3
2.70E3
2.40E3
2.10E3
1.80E3
1.50E3
1.20E3
9.00E2
6.00E2
3.00E2
0.00E0
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT

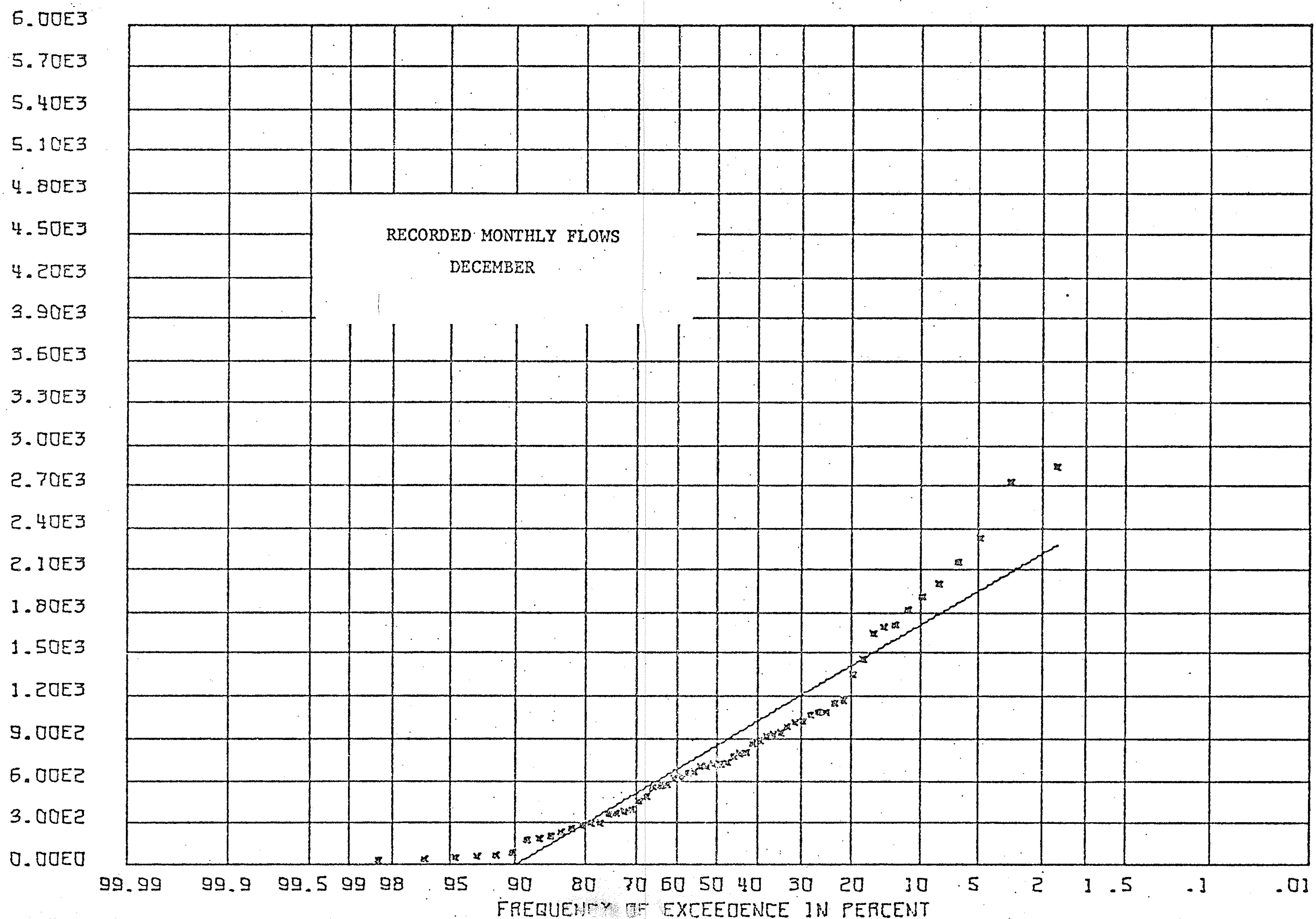

RECORDED MONTHLY FLOWS
NOVEMBER
1.0E4
5.0E3
4.0E3
3.0E3
2.0E3
1.0E3
5.0E2
4.0E2
3.0E2
2.0E2
1.0E2
5.0E1
4.0E1
3.0E1
2.0E1
1.0E1
5.0E0
4.0E0
3.0E0
2.0E0
1.0E0
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT


RECORDED MONTHLY FLOWS
NOVEMBER
6.00E3
5.70E3
5.40E3
5.10E3
4.80E3
4.50E3
4.20E3
3.90E3
3.60E3
3.30E3
3.00E3
2.70E3
2.40E3
2.10E3
1.80E3
1.50E3
1.20E3
9.00E2
6.00E2
3.00E2
0.00E0
99.99
99.9
99.5
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
.5
.1
.01
FREQUENCY OF EXCEEDENCE IN PERCENT

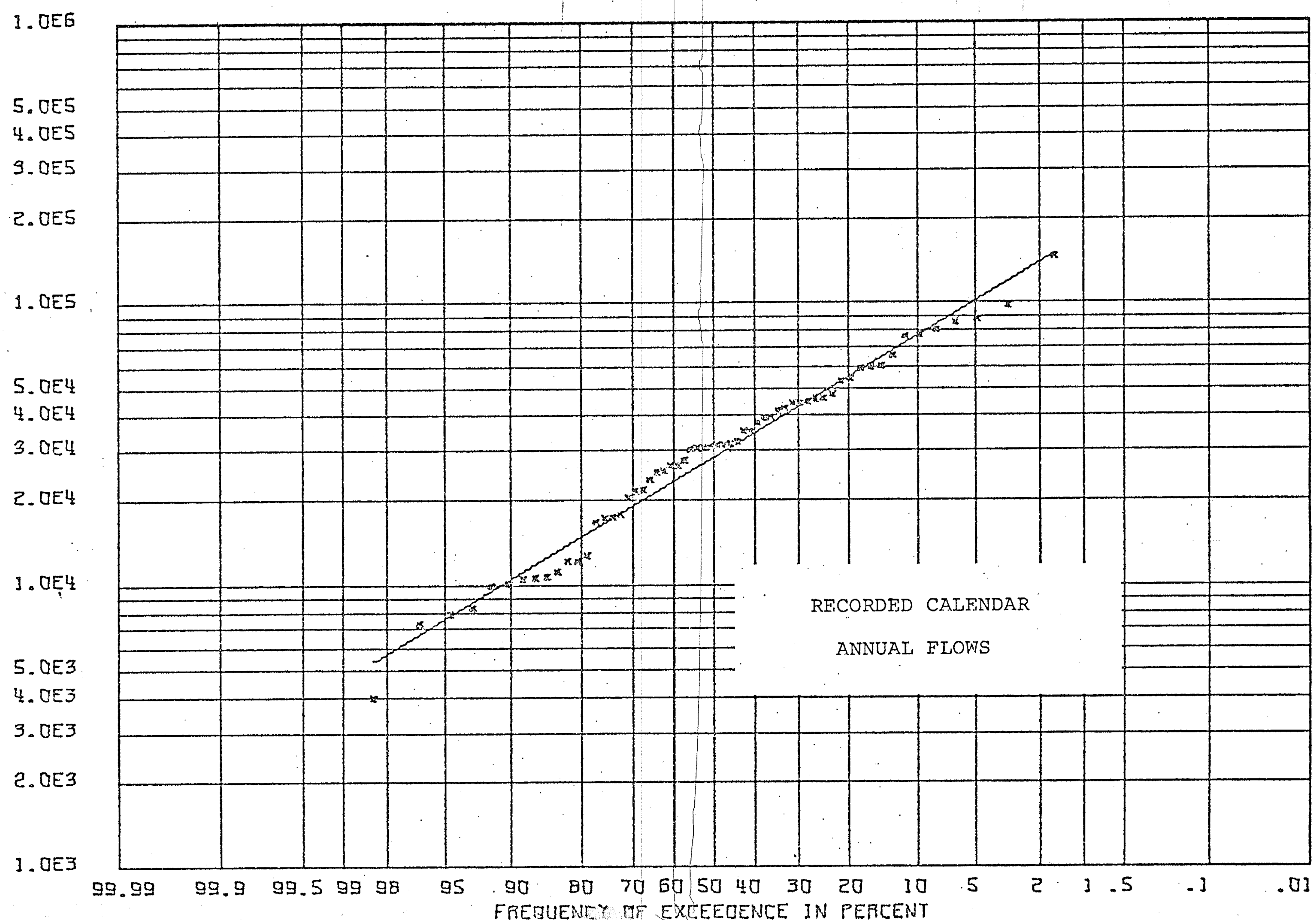


1.0E4
5.0E3
4.0E3
3.0E3
2.0E3
1.0E3
5.0E2
4.0E2
3.0E2
2.0E2
1.0E2
5.0E1
4.0E1
3.0E1
2.0E1
1.0E1
5.0E0
4.0E0
3.0E0
2.0E0
1.0E0
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT
RECORDED MONTHLY FLOWS
DECEMBER

A24


RECORDED MONTHLY FLOWS
DECEMBER
6.00E3
5.70E3
5.40E3
5.10E3
4.80E3
4.50E3
4.20E3
3.90E3
3.60E3
3.30E3
3.00E3
2.70E3
2.40E3
2.10E3
1.80E3
1.50E3
1.20E3
9.00E2
6.00E2
3.00E2
0.00E0
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT

A25



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4.0E5
3.0E5
2.0E5
1.0E5
5.0E4
4.0E4
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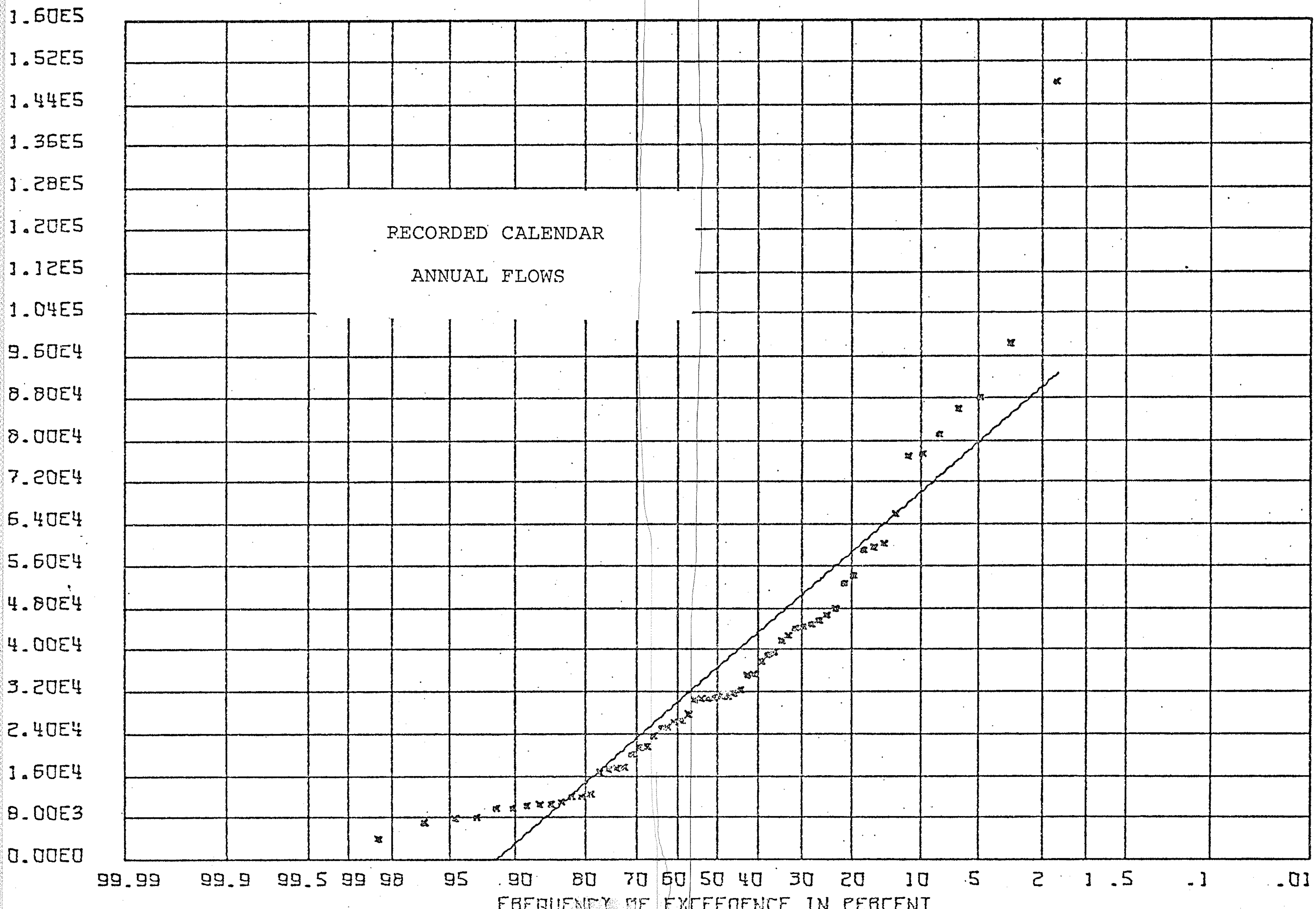
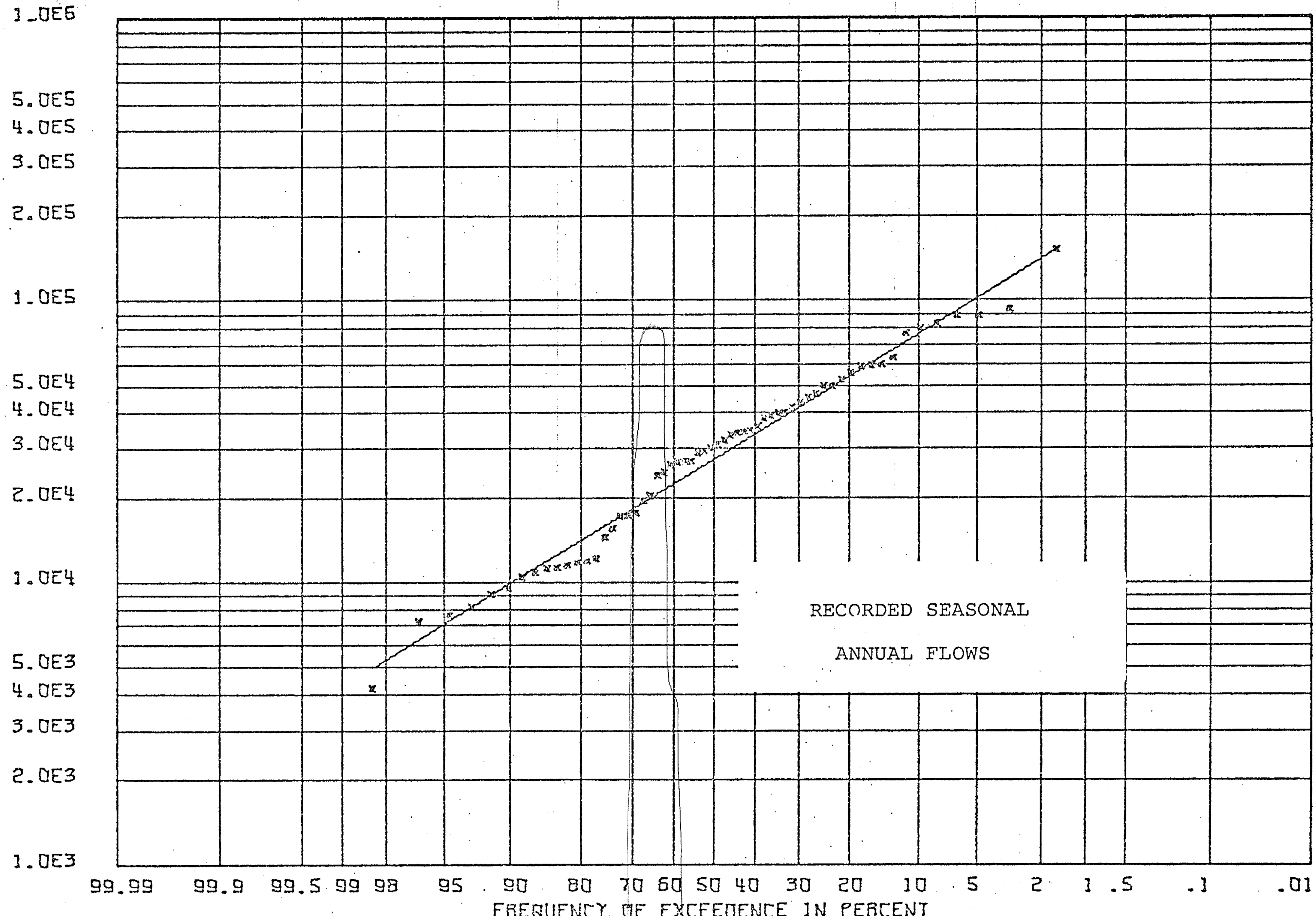
2.0E4
1.0E4
5.0E3
4.0E3
3.0E3
2.0E3
1.0E3
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT
RECORDED CALENDAR
ANNUAL FLOWS

M20



RECORDED CALENDAR
ANNUAL FLOWS
1.60E5
1.52E5
1.44E5
1.36E5
1.28E5
1.20E5
1.12E5
1.04E5
9.60E4
8.80E4
8.00E4
7.20E4
6.40E4
5.60E4
4.80E4
4.00E4
3.20E4
2.40E4
1.60E4
8.00E3
0.00E0
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT


RECORDED SEASONAL
ANNUAL FLOWS
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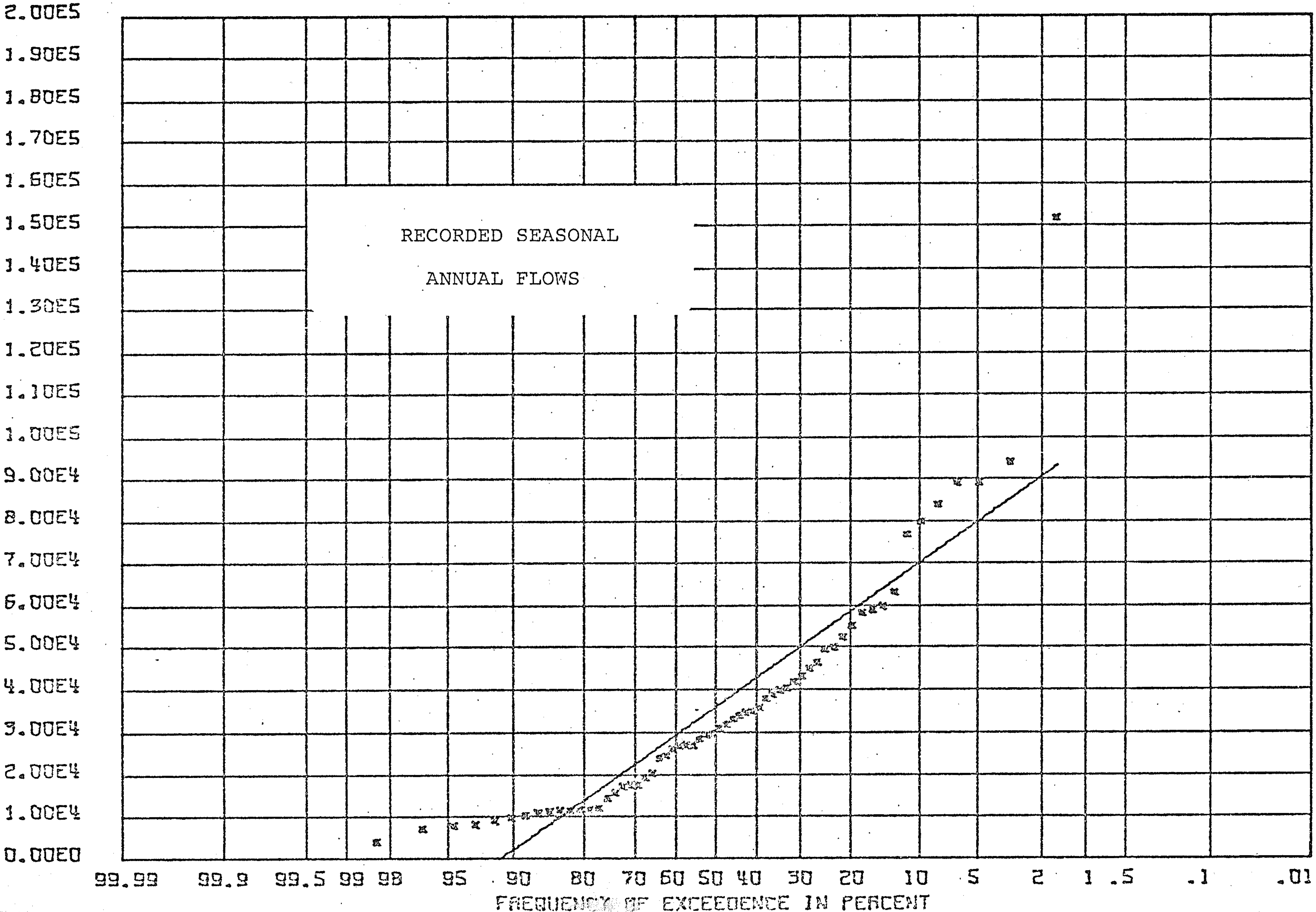
4.0E5
3.0E5
2.0E5
1.0E5
5.0E4
4.0E4
3.0E4
2.0E4
1.0E4
5.0E3
4.0E3
3.0E3
2.0E3
1.0E3
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT


RECORDED SEASONAL
ANNUAL FLOWS
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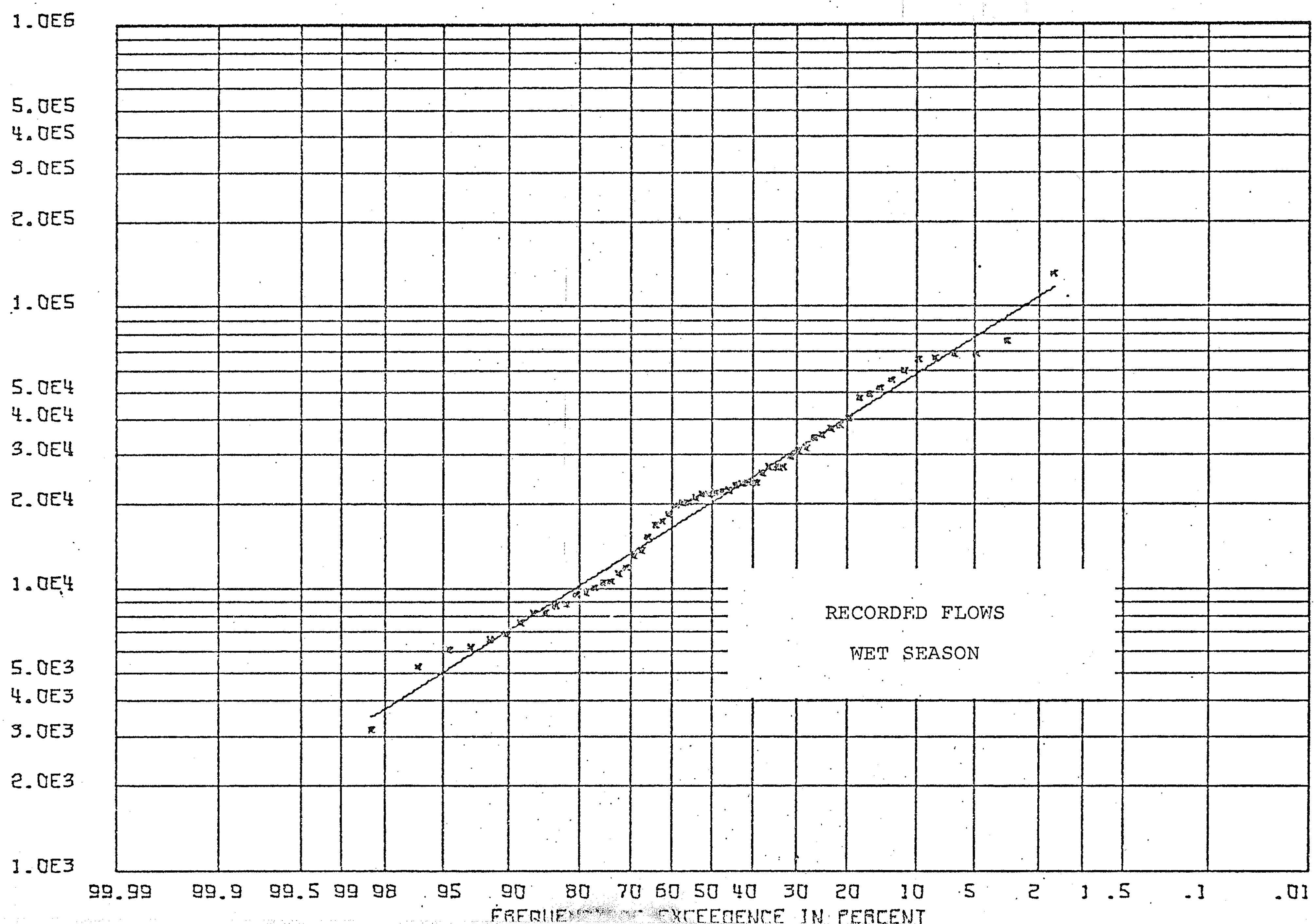
1.80E5
1.70E5
1.60E5
1.50E5
1.40E5
1.30E5
1.20E5
1.10E5
1.00E5
9.00E4
8.00E4
7.00E4
6.00E4
5.00E4
4.00E4
3.00E4
2.00E4
1.00E4
0.00E0
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT



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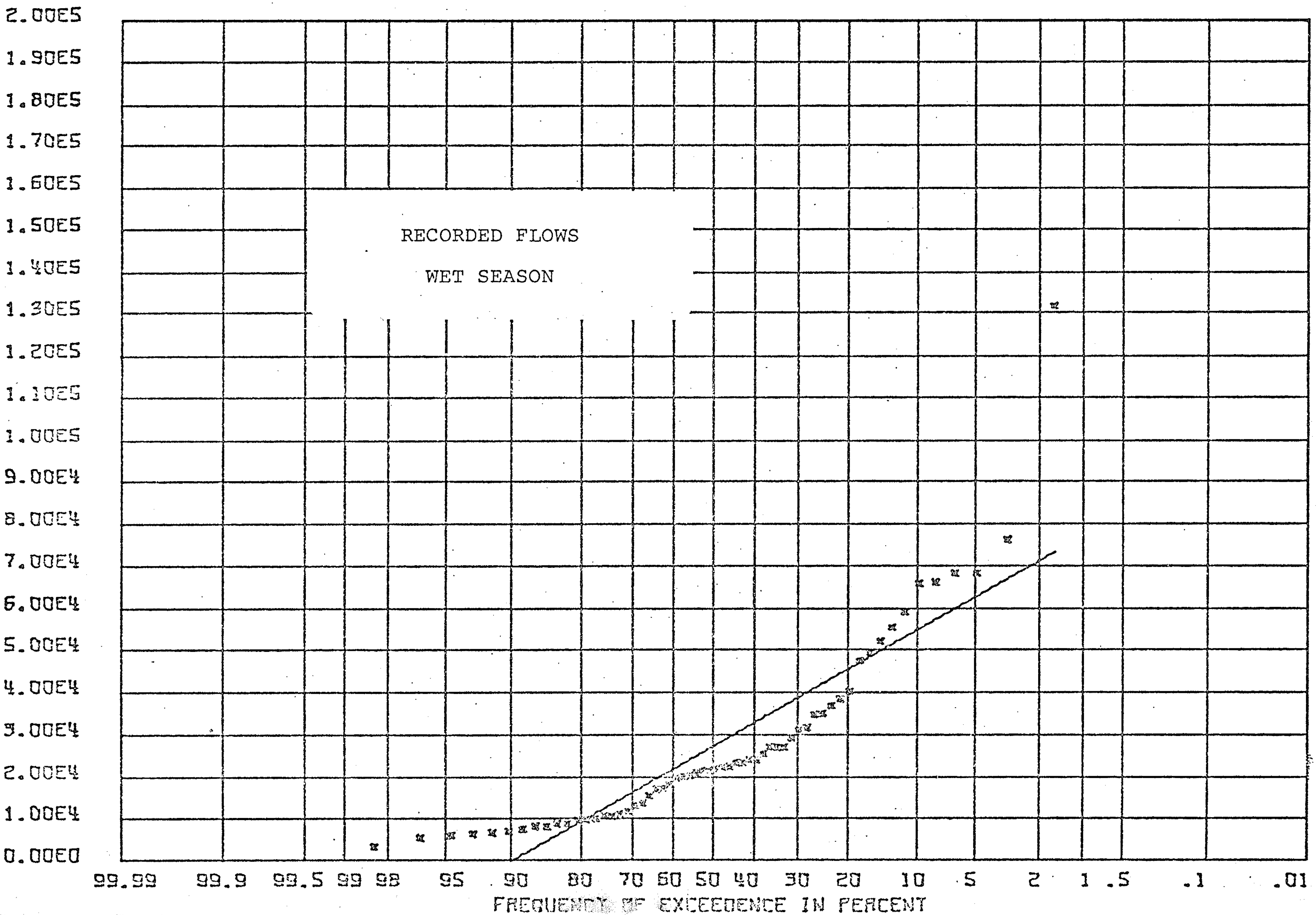
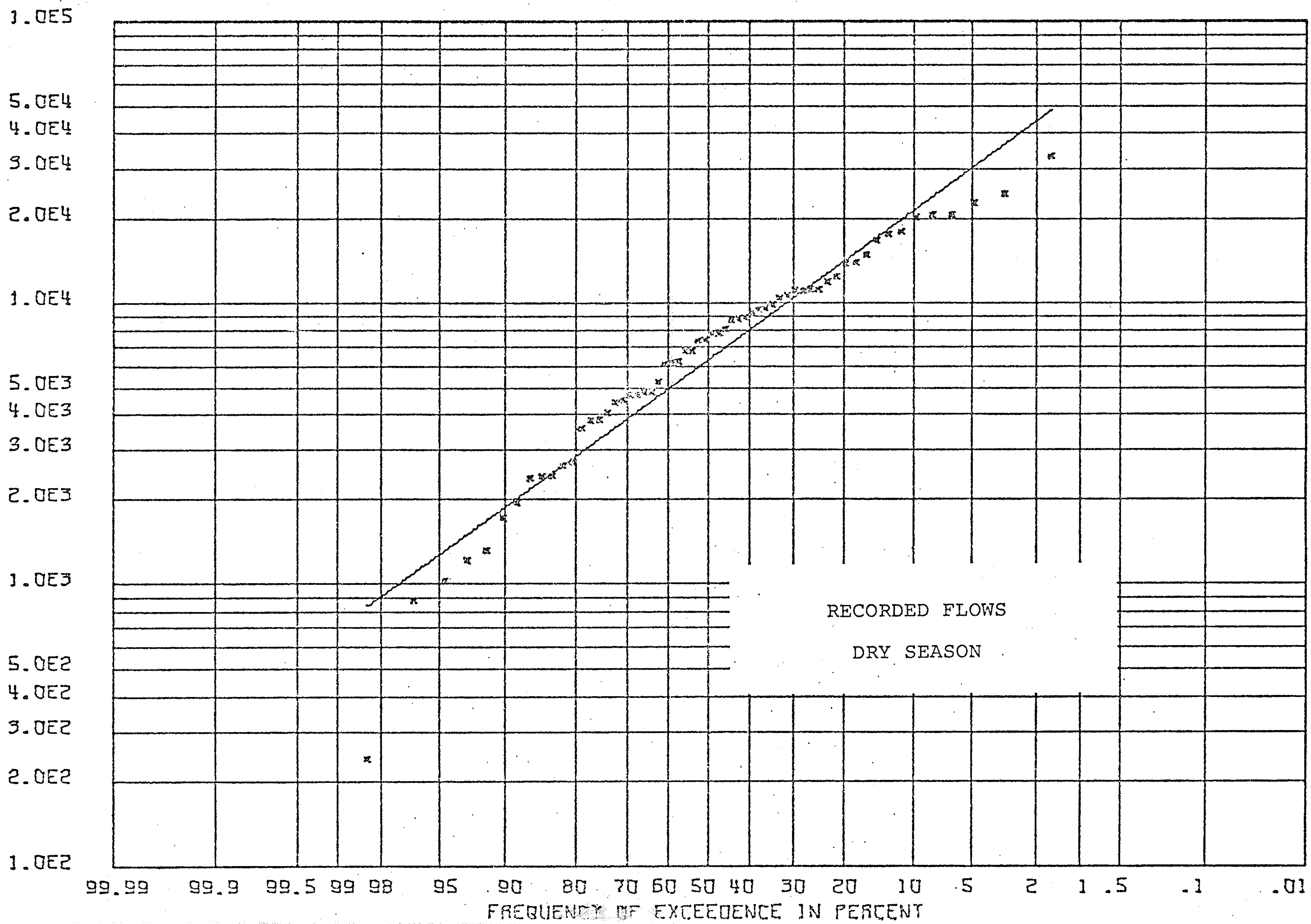
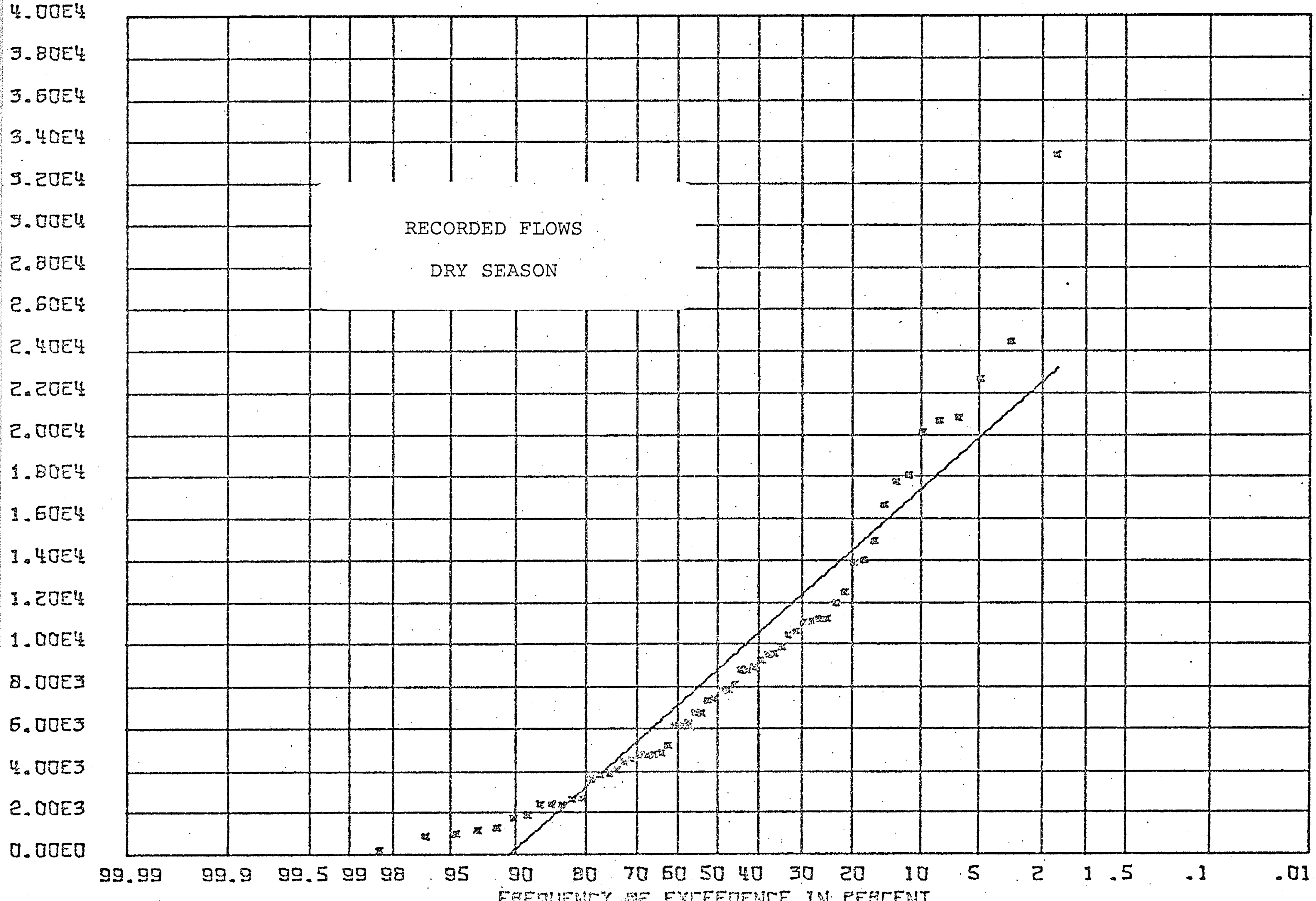
5.0E5
4.0E5
3.0E5
2.0E5
1.0E5
5.0E4
4.0E4
3.0E4
2.0E4
1.0E4
5.0E3
4.0E3
3.0E3
2.0E3
1.0E3
RECORDED FLOWS
WET SEASON
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
EXCEEDENCE IN PERCENT

A30

A31


RECORDED FLOWS
WET SEASON
2.00E5
1.90E5
1.80E5
1.70E5
1.60E5
1.50E5
1.40E5
1.30E5
1.20E5
1.10E5
1.00E5
9.00E4
8.00E4
7.00E4
6.00E4
5.00E4
4.00E4
3.00E4
2.00E4
1.00E4
0.00E0
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT


RECORDED FLOWS
DRY SEASON
1.0E5
5.0E4
4.0E4
3.0E4
2.0E4
1.0E4
5.0E3
4.0E3
3.0E3
2.0E3
1.0E3
5.0E2
4.0E2
3.0E2
2.0E2
1.0E2
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT



RECORDED FLOWS
DRY SEASON
4.00E4
3.80E4
3.60E4
3.40E4
3.20E4
3.00E4
2.80E4
2.60E4
2.40E4
2.20E4
2.00E4
1.80E4
1.60E4
1.40E4
1.20E4
1.00E4
8.00E3
6.00E3
4.00E3
2.00E3
0.00E0
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT

A33

Appendix B

TABLES OF RESULTS FOR PRELIMINARY FLOW GENERATION ATTEMPTS

Note:

In the final analysis of output, it was discovered that a computer programming error had resulted in erroneous values of annual correlation, for recorded and synthetic flows. The values of annual correlation were too high in all cases, but the error was found to be consistently of the same proportion. The erroneous figure for annual correlation of recorded flows was used as a basis for trial runs of flow generation by the Thomas-Fiering annual model only. In the cases of the trial series using the Thomas-Fiering monthly model and the final method (2 seasons), flows were generated based on correct values of monthly and seasonal correlations, respectively. The resulting annual correlations were erroneously calculated in all cases.

The error was corrected and calculations were re-done for recorded flows and the 50 synthetic flow series. The statistical comparison of output data with recorded data was found to be the same with both the erroneous and the correct values of annual correlation. This is because the error was of an approximately constant proportion. Therefore, the erroneous values of annual correlation for these trial runs have been stroked out, but left legible for comparison. Corrected values of recorded flows have been included.

APPENDIX B

1. Recorded calendar annual flow parameters

	M.A. Flow	Annual σ	Range	K	Annual Correlation	← Corrected values
(a) Real flows	36,892	26,690	428,908	.816	~~.6333~~	.4076
(b) Logs of flows	4.456	.3241	6.1	.861	~~.7967~~	.6005

2. Thomas-Fiering method - monthly flows (5 trial series - 60 yrs)

					ERROR
(a) Generated real number annual flows	47,693	(63,504)⊕	476,813	0.649	~~0.3563~~
	39,184	37,858	265,257	0.572	~~0.5656~~
	36,484	24,734	364,347	0.791	~~0.5464~~
	36,854	25,053	220,400	0.639	~~0.4160~~
	34,120	23,887	251,233	0.692	~~0.2827~~
Mean value	38,867	35,007	315,610	0.669	~~0.4334~~
Standard Deviation	5,250	16,945	105,008	0.081	~~0.1217~~
Comments	O.K.	high	low	a bit low	low

					ERROR
(b) Logs of generated annual flows	4.522	.3453	3.6	0.686	~~0.5044~~
	4.429	.3682	3.3	0.641	~~0.4705~~
	4.459	.3111	4.9	0.809	~~0.4613~~
	4.482	.2647	2.3	0.641	~~0.4538~~
	4.432	.3040	4.1	0.768	~~0.6106~~
Mean value	4.465	.3187	3.6	0.709	~~0.5001~~
Standard Deviation	.039	.0398	1.0	0.076	~~0.0647~~
Comments	O.K.	O.K.	low	O.K. with theory	quite low

⊕ this figure is questionable, but this is not very significant with regard to the results of the thesis.

3. Thomas-Fiering method - annual flows (10 trial series - 60 yrs)

		M.A.flow	Annual σ	Range	K	*ERROR* Corre-lation	(Annua
(a)	Generated real number annual flows	22,412	19,376	441,292	0.919	0.895	
		25,501	21,127	411,999	0.873	0.844	
		38,008	33,115	735,648	0.912	0.816	
		34,661	26,150	444,041	0.833	0.878	
		51,843	41,092	691,859	0.830	0.883	
		28,929	19,381	405,272	0.894	0.889	
		35,003	23,725	296,841	0.743	0.879	
		41,226	32,344	654,878	0.884	0.776	
		19,202	11,050	112,007	0.681	0.677	
	Mean value	32,976	25,262	465,981	0.841	0.837	
	Standard Deviation	9,602	8,523	188,861	0.076	0.068	
	Comments	O.K.	O.K.	O.K.	too high for theory	high	

						ERROR
(b)	Logs of generated annual flows	4.216	0.245	2.8	0.717	0.931
		4.485	0.354	7.7	0.906	0.899
		4.435	0.328	4.9	0.792	0.945
		4.339	0.356	8.0	0.915	0.905
		4.603	0.306	5.0	0.822	0.823
		4.437	0.305	5.9	0.869	0.879
		4.427	0.370	8.3	0.915	0.864
		4.272	0.343	7.0	0.886	0.914
		4.256	0.348	7.3	0.894	0.899
	Mean value	4.386	0.328	6.3	0.857	0.895
	Standard Deviation	0.118	0.036	1.7	0.064	0.034
	Comments	O.K.	O.K.	O.K.	high for theory. O.K. with recorded data	high

4. Recorded "seasonal" annual flow parameters

							Corrected values
(a)	Real flows	36,381	27,336	426,969	0.808	~~0.621~~	.3930
(b)	Logs of flows	4.443	.332	5.8	0.842	~~0.805~~	.5814

5. Final method - preliminary study (10 trial series - 60 yrs)

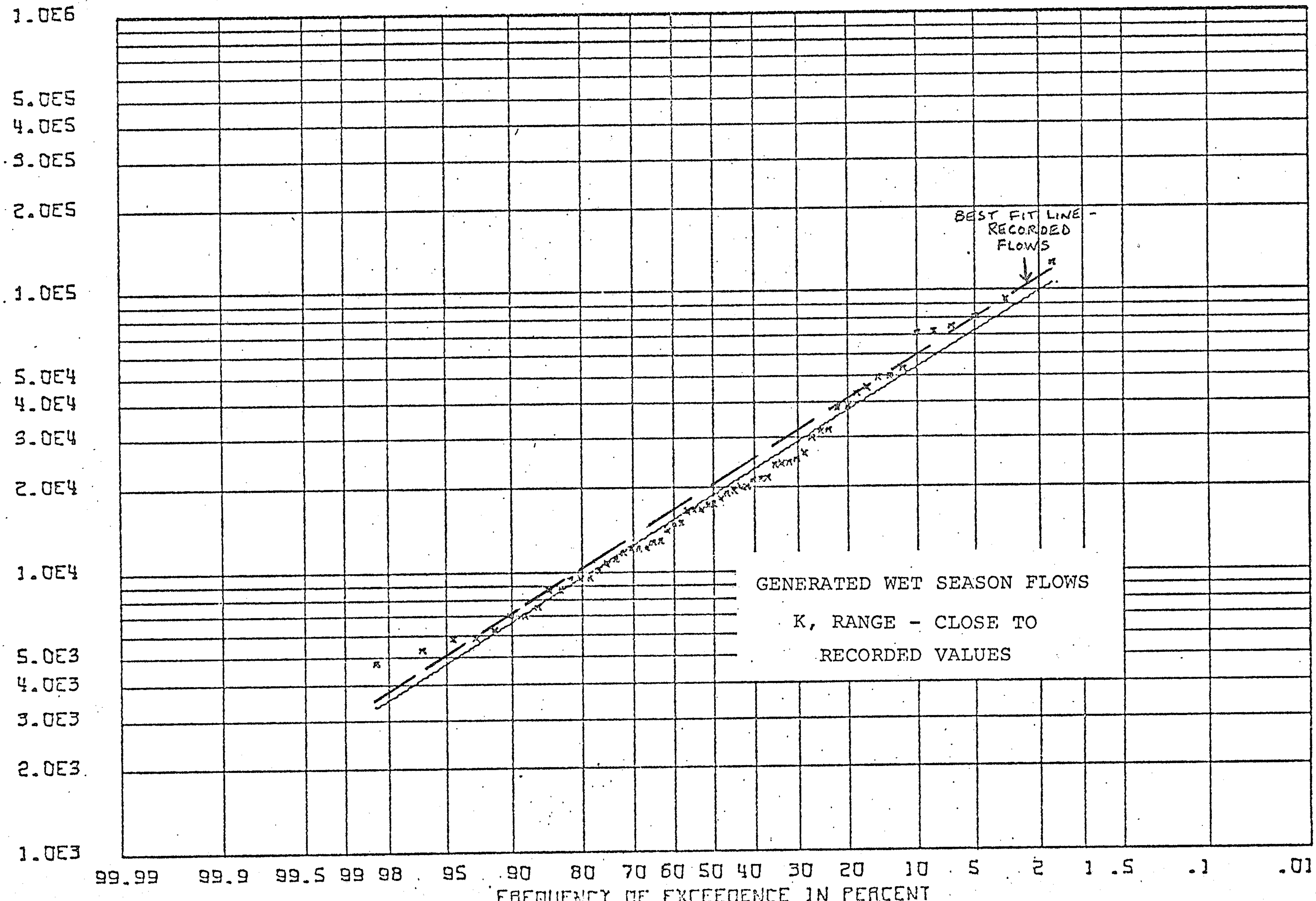
	M.A. Flow	Annual σ	Range	K	*ERROR* Correlation (Annua
(a) Generated real number annual flows	44,537	41,348	531,323	0.751	0.575
	43,591	27,793	444,278	0.815	0.781
	31,663	24,111	219,459	0.649	0.619
	41,884	33,524	266,693	0.610	0.444
	33,830	21,909	163,769	0.591	0.546
	42,795	40,291	514,057	0.749	0.571
	38,826	31,499	422,586	0.763	0.529
	38,708	32,474	410,584	0.746	0.594
	26,812	17,260	255,873	0.793	0.495
	30,561	19,491	158,521	0.616	0.513
Mean value	37,320	28,970	338,714	0.708	0.567
Standard Deviation	5,888	7,890	134,362	0.079	0.086
Comments	O.K.	O.K.	a bit low	O.K.	O.K.

					ERROR
(b) Logs of generated annual flows	4.509	.359	5.4	0.798	0.627
	4.525	.359	4.8	0.762	0.718
	4.368	.367	3.9	0.692	0.633
	4.504	.326	3.4	0.693	0.488
	4.434	.311	2.8	0.641	0.557
	4.468	.387	5.0	0.751	0.588
	4.477	.315	4.7	0.798	0.670
	4.393	.293	2.9	0.675	0.463
	4.453	.351	5.1	0.785	0.752
	4.338	.290	4.5	0.808	0.633
Mean value	4.447	.336	4.3	0.740	0.613
Standard Deviation	.063	.033	0.9	0.060	0.092
Comments	O.K.	O.K.	low	O.K.	low

Appendix C

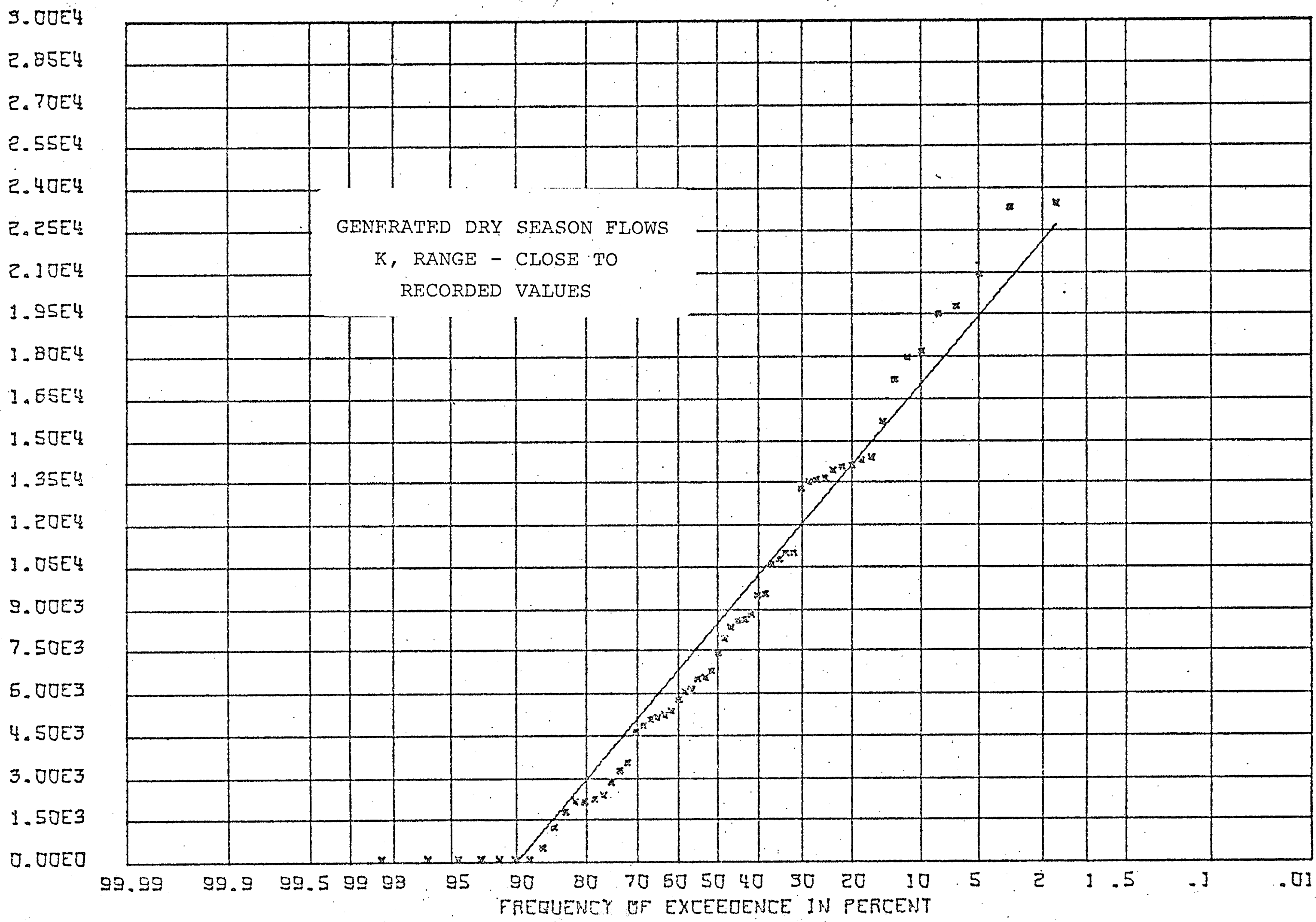
GRAPHS SHOWING STATISTICAL DISTRIBUTIONS OF SAMPLE GENERATED FLOW SERIES - FOR WET AND DRY SEASONS AND ANNUAL VALUES.

SEQUENTIAL PLOTS - SAMPLE GENERATED FLOW SERIES



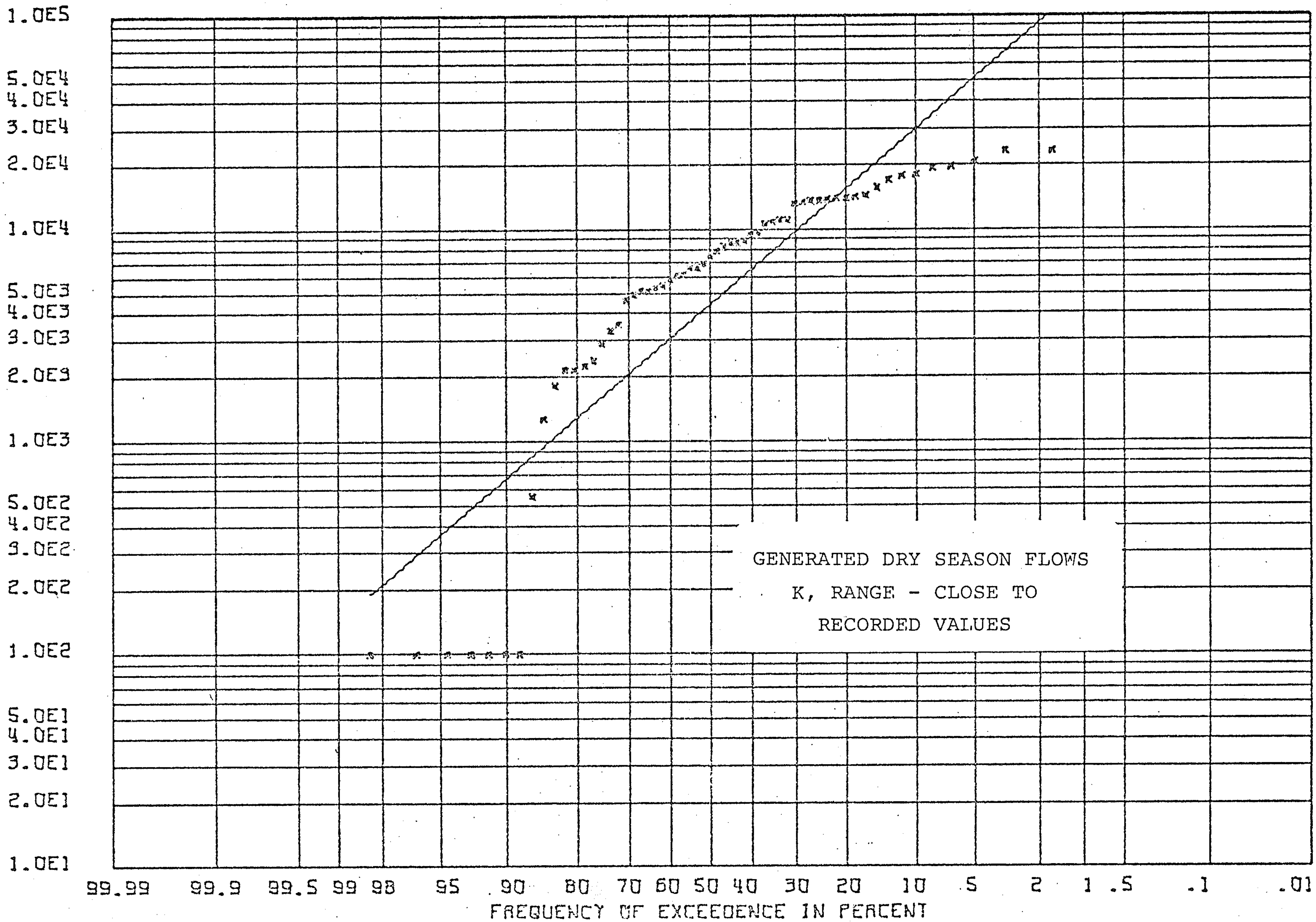
GENERATED WET SEASON FLOWS
K, RANGE - CLOSE TO
RECORDED VALUES
BEST FIT LINE - RECORDED FLOWS
1.0E6
5.0E5
4.0E5
3.0E5
2.0E5
1.0E5
5.0E4
4.0E4
3.0E4
2.0E4
1.0E4
5.0E3
4.0E3
3.0E3
2.0E3
1.0E3
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT

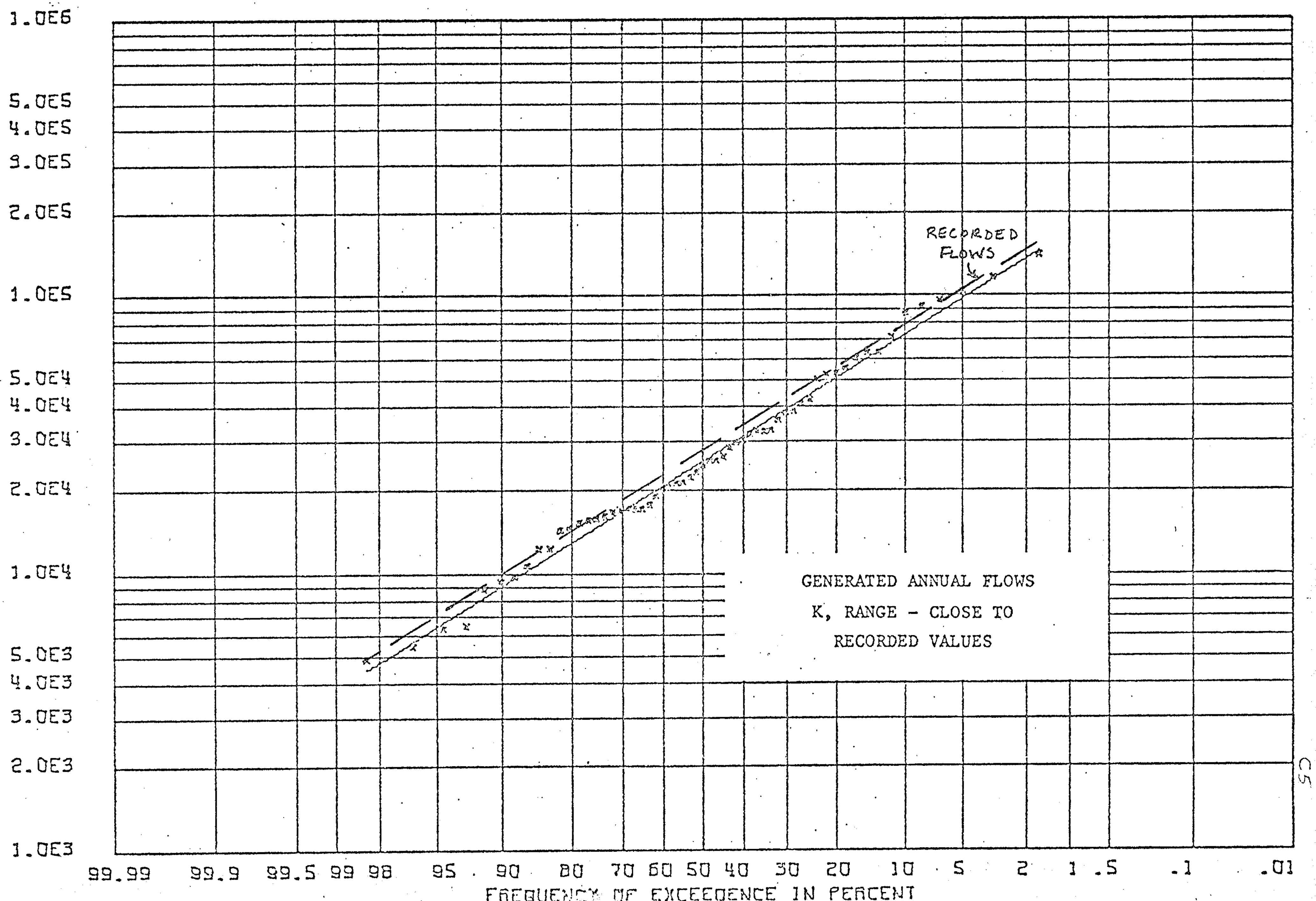
C3

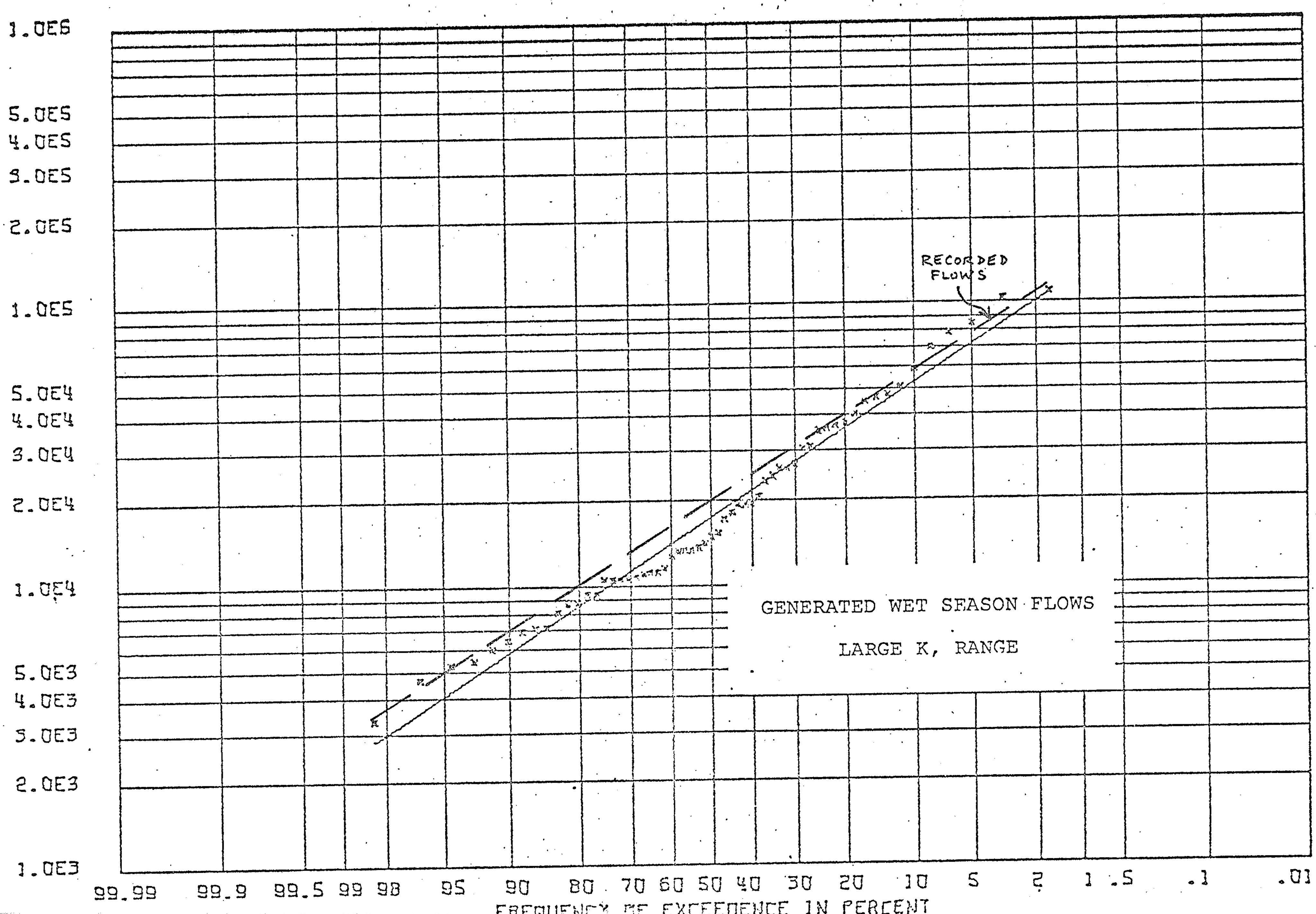


GENFRATFD DRY SEASON FLOWS
K, RANGE - CLOSE TO
RECORDED VALUES
3.00E4
2.85E4
2.70E4
2.55E4
2.40E4
2.25E4
2.10E4
1.95E4
1.80E4
1.65E4
1.50E4
1.35E4
1.20E4
1.05E4
9.00E3
7.50E3
6.00E3
4.50E3
3.00E3
1.50E3
0.00E0
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT

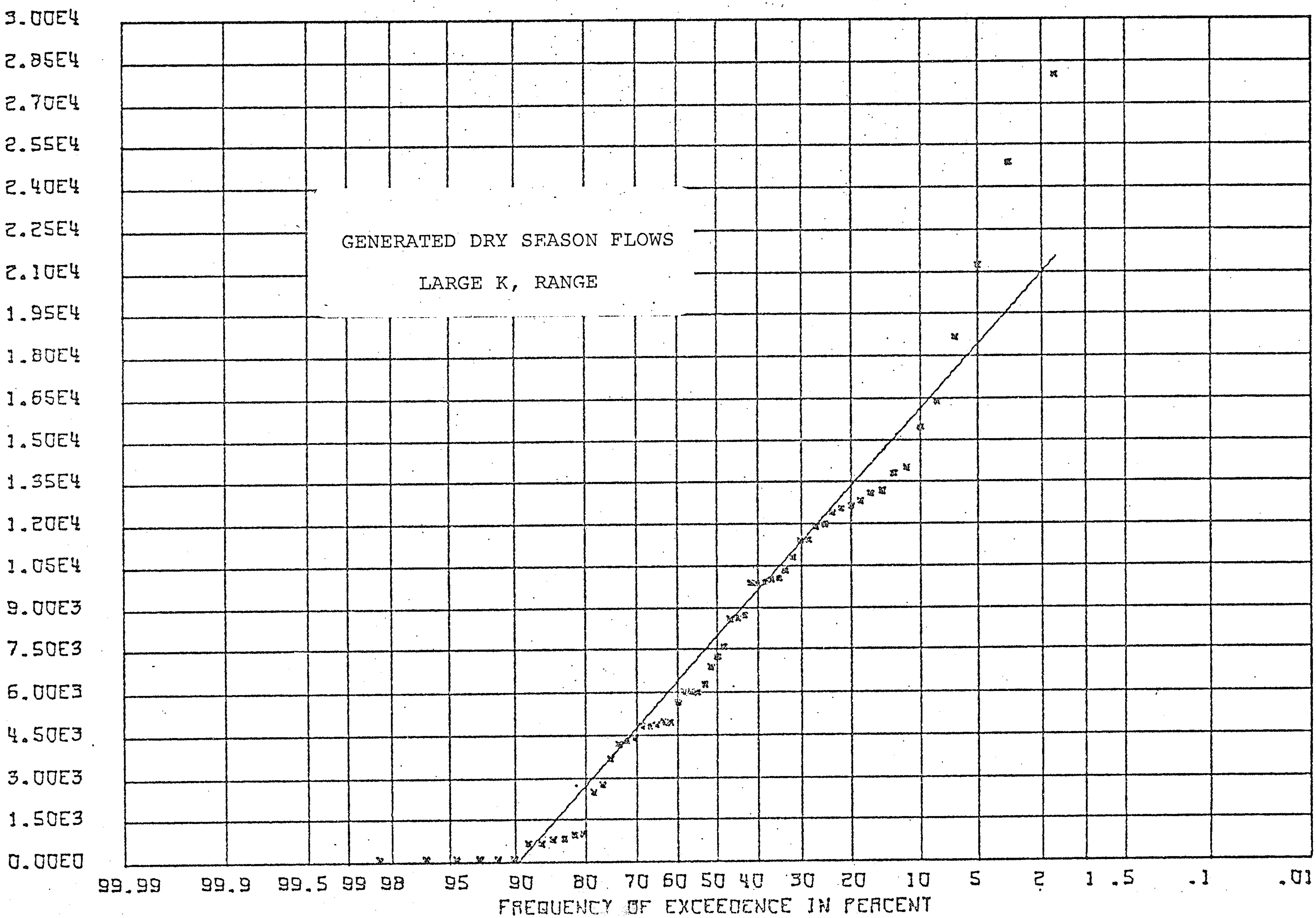
C4


GENERATED DRY SEASON FLOWS
K, RANGE - CLOSE TO
RECORDED VALUES
1.0E5
5.0E4
4.0E4
3.0E4
2.0E4
1.0E4
5.0E3
4.0E3
3.0E3
2.0E3
1.0E3
5.0E2
4.0E2
3.0E2
2.0E2
1.0E2
5.0E1
4.0E1
3.0E1
2.0E1
1.0E1
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT


C5
1.0E6
5.0E5
4.0E5
3.0E5
2.0E5
1.0E5
5.0E4
4.0E4
3.0E4
2.0E4
1.0E4
5.0E3
4.0E3
3.0E3
2.0E3
1.0E3
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT
RECORDED FLOWS
GENERATED ANNUAL FLOWS
K, RANGE - CLOSE TO
RECORDED VALUES

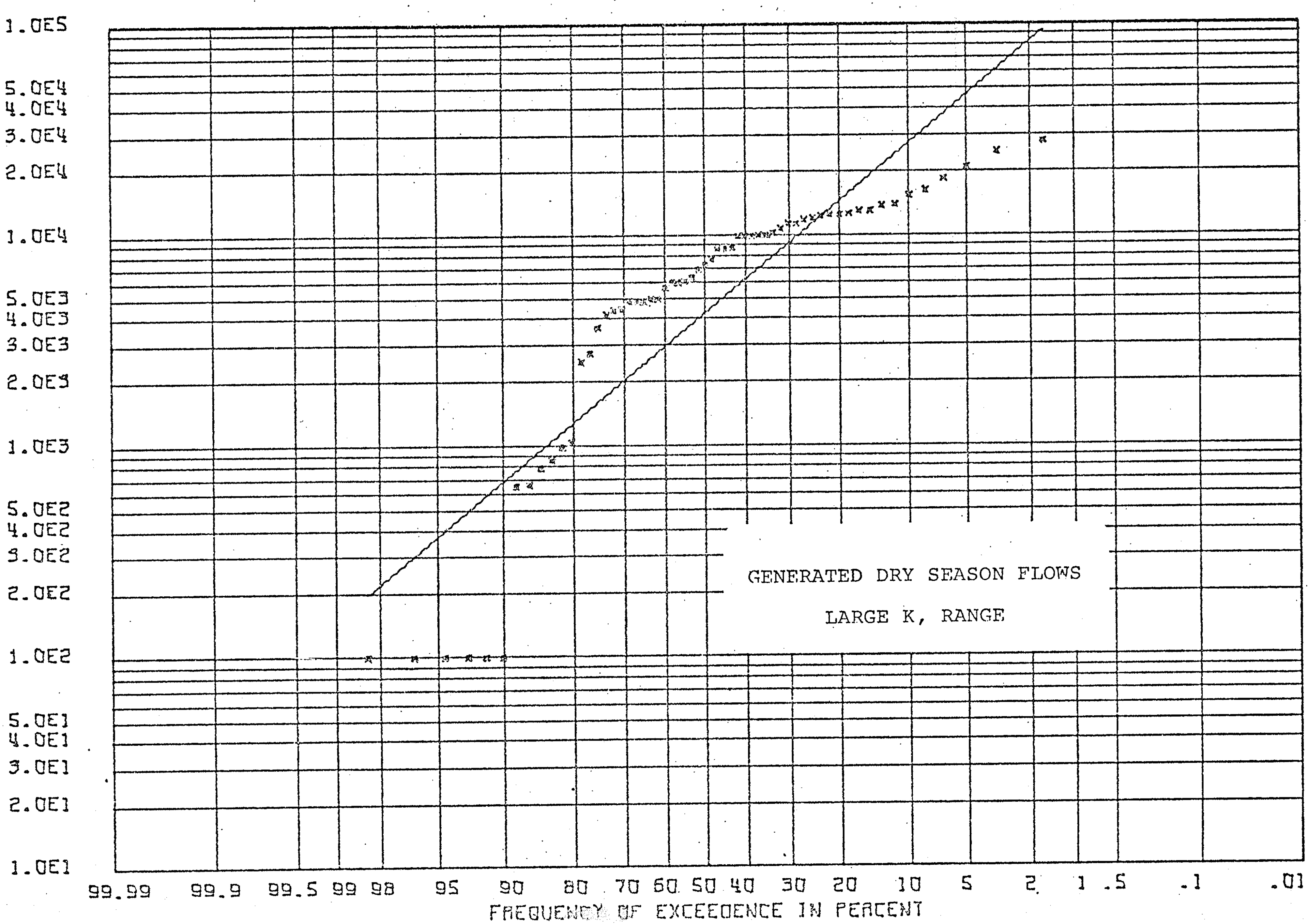


GENERATED WET SEASON FLOWS
LARGE K, RANGE
RECORDED FLOWS
1.0E6
5.0E5
4.0E5
3.0E5
2.0E5
1.0E5
5.0E4
4.0E4
3.0E4
2.0E4
1.0E4
5.0E3
4.0E3
3.0E3
2.0E3
1.0E3
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT



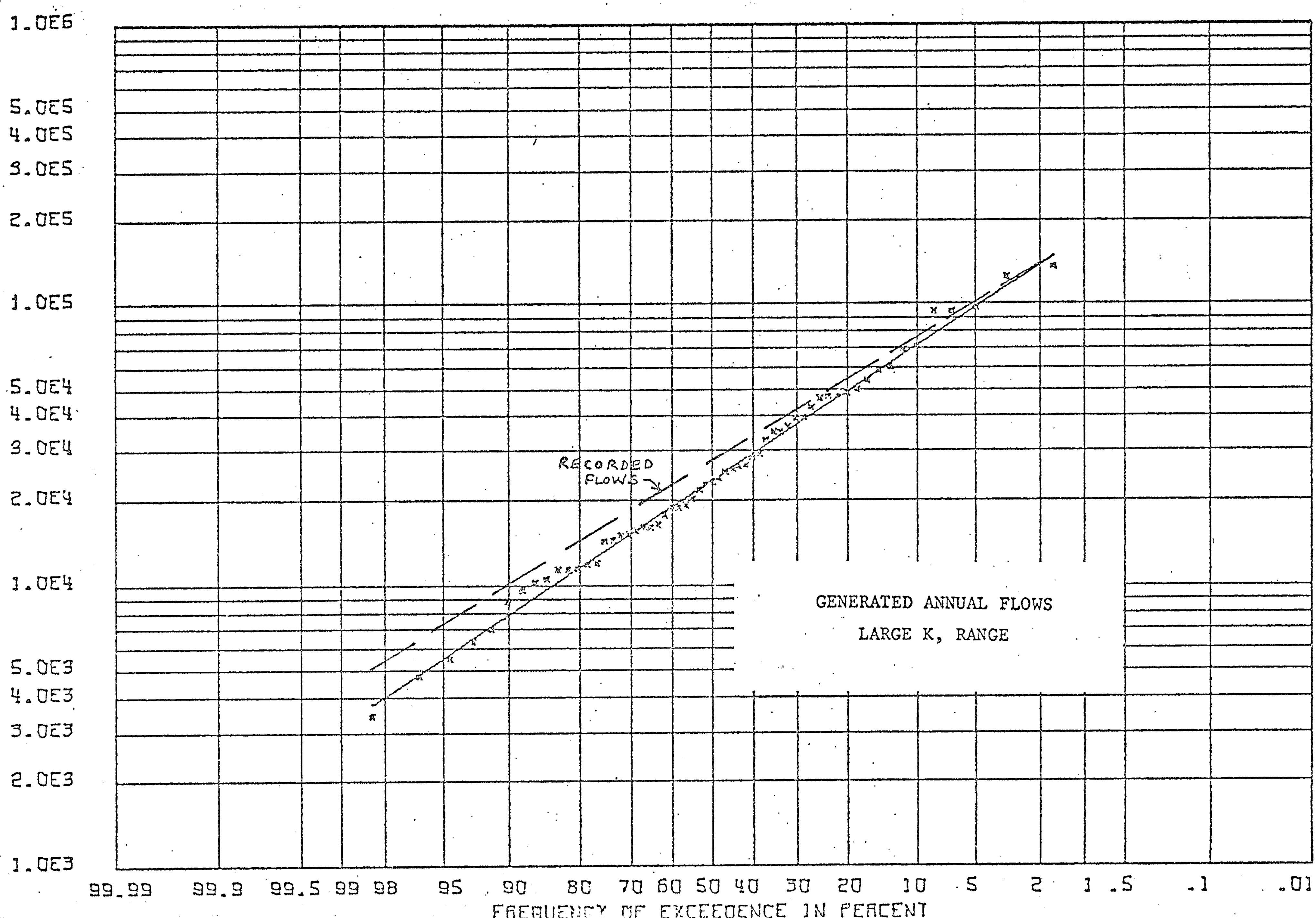
GENERATED DRY SEASON FLOWS
LARGE K, RANGE
3.00E4
2.85E4
2.70E4
2.55E4
2.40E4
2.25E4
2.10E4
1.95E4
1.80E4
1.65E4
1.50E4
1.35E4
1.20E4
1.05E4
9.00E3
7.50E3
6.00E3
4.50E3
3.00E3
1.50E3
0.00E0
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT

C7

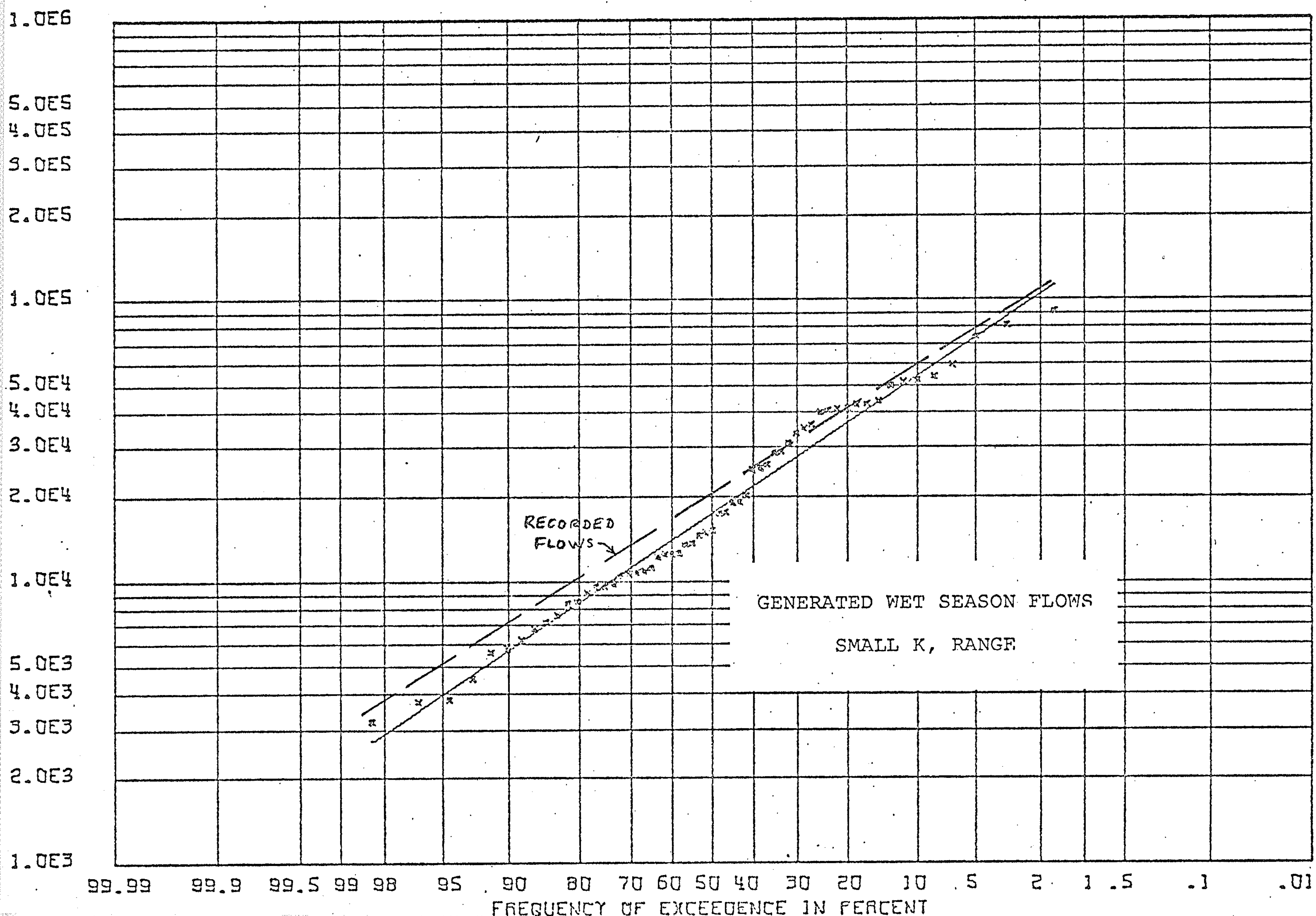


1.0E5
5.0E4
4.0E4
3.0E4
2.0E4
1.0E4
5.0E3
4.0E3
3.0E3
2.0E3
1.0E3
5.0E2
4.0E2
3.0E2
2.0E2
1.0E2
5.0E1
4.0E1
3.0E1
2.0E1
1.0E1
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT
GENERATED DRY SEASON FLOWS
LARGE K, RANGE

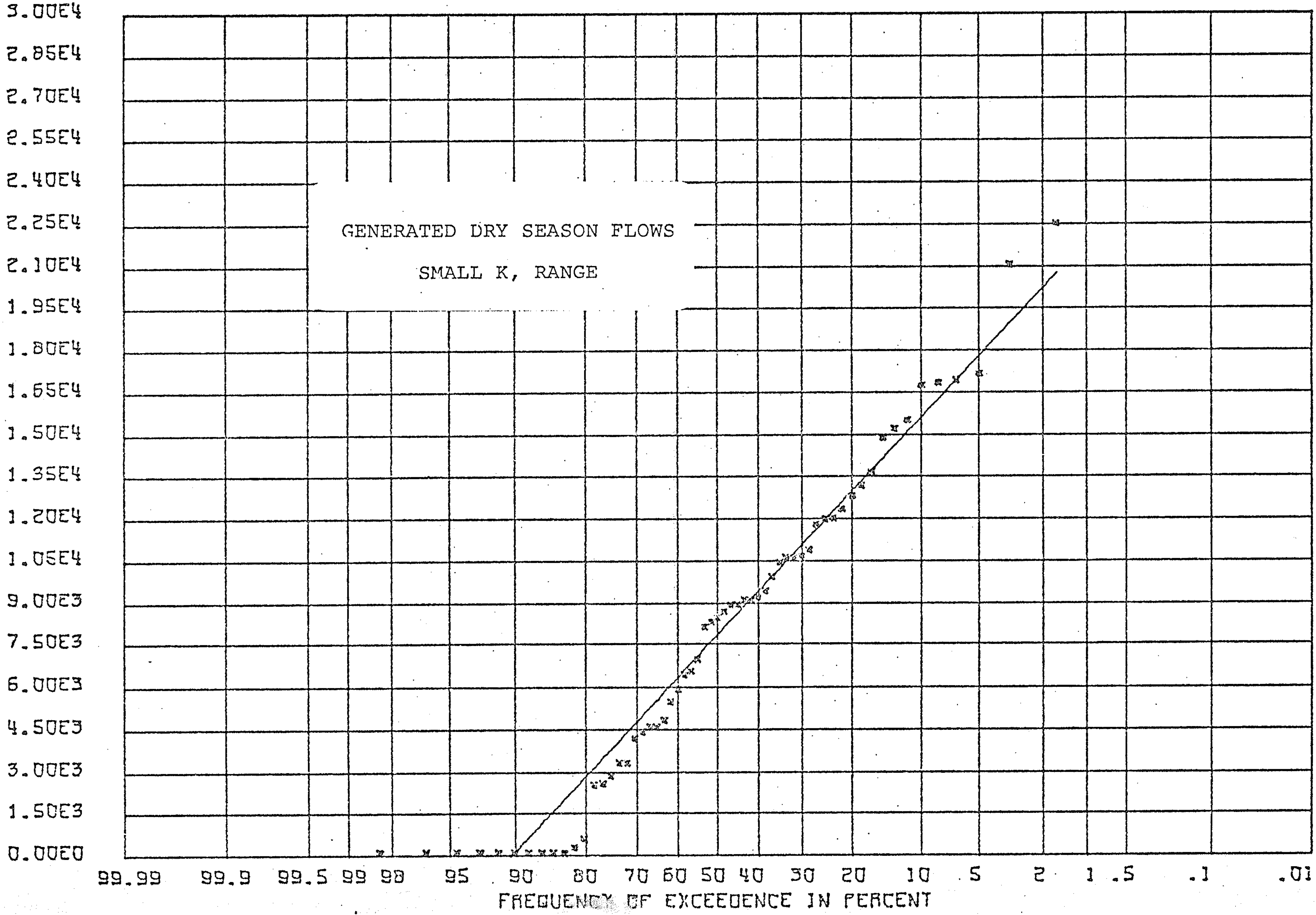
C8



GENERATED ANNUAL FLOWS
LARGE K, RANGE
RECORDED FLOWS
1.0E6
5.0E5
4.0E5
3.0E5
2.0E5
1.0E5
5.0E4
4.0E4
3.0E4
2.0E4
1.0E4
5.0E3
4.0E3
3.0E3
2.0E3
1.0E3
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT

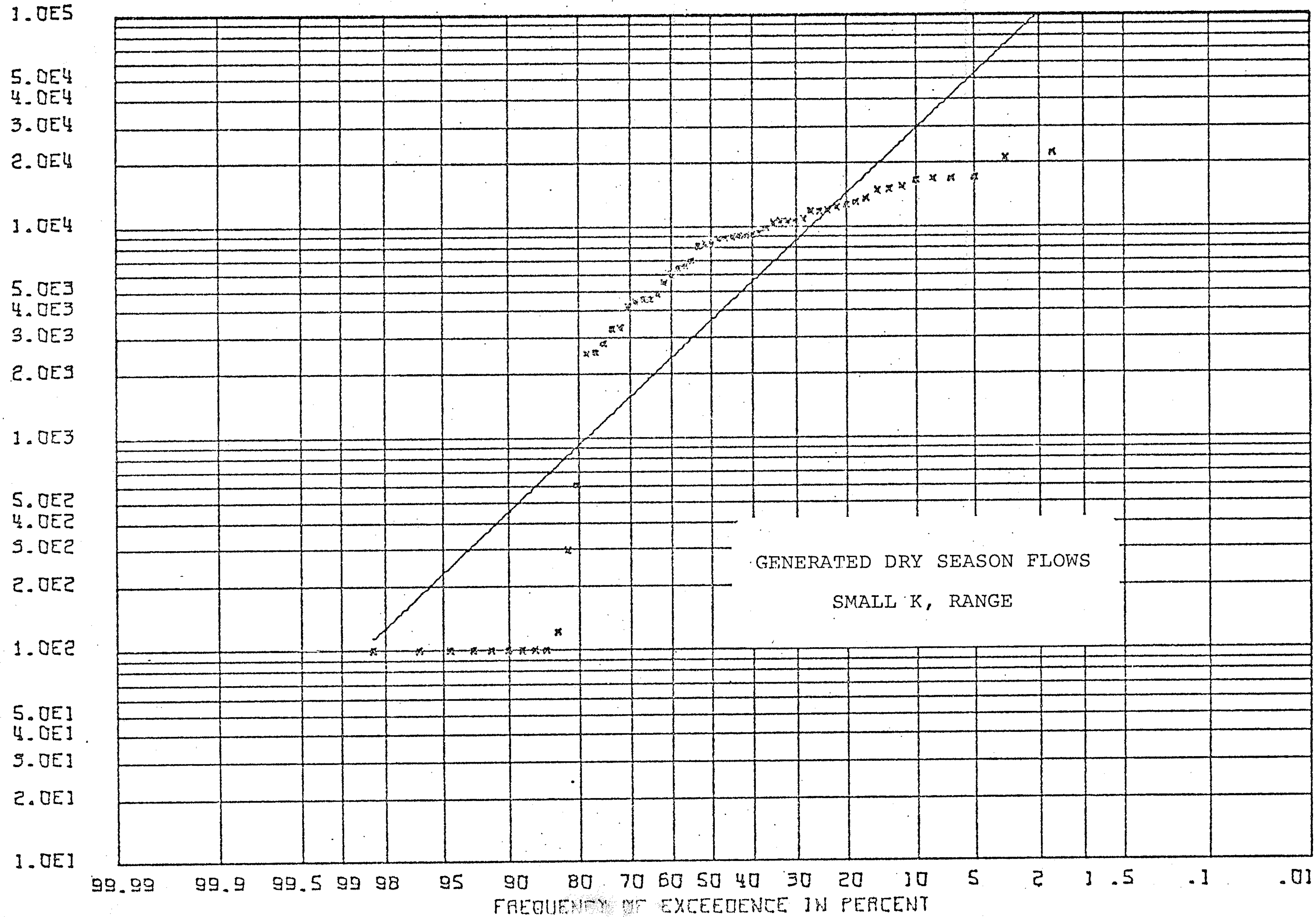

GENERATED WET SEASON FLOWS
SMALL K, RANGE
RECORDED FLOWS
1.0E6
5.0E5
4.0E5
3.0E5
2.0E5
1.0E5
5.0E4
4.0E4
3.0E4
2.0E4
1.0E4
5.0E3
4.0E3
3.0E3
2.0E3
1.0E3
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT

C10


GENERATED DRY SEASON FLOWS
SMALL K, RANGE
3.00E4
2.85E4
2.70E4
2.55E4
2.40E4
2.25E4
2.10E4
1.95E4
1.80E4
1.65E4
1.50E4
1.35E4
1.20E4
1.05E4
9.00E3
7.50E3
6.00E3
4.50E3
3.00E3
1.50E3
0.00E0
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT

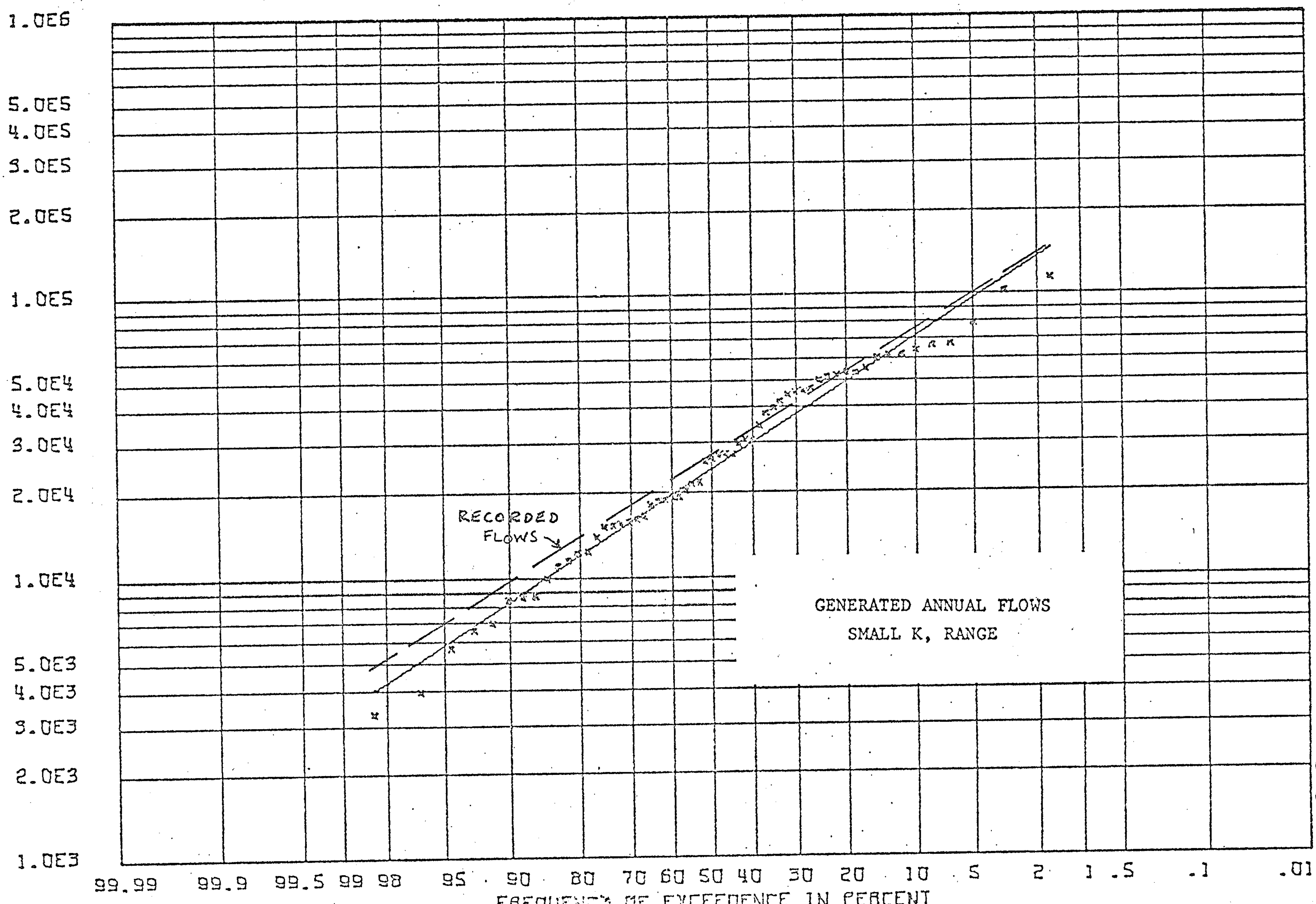
C11

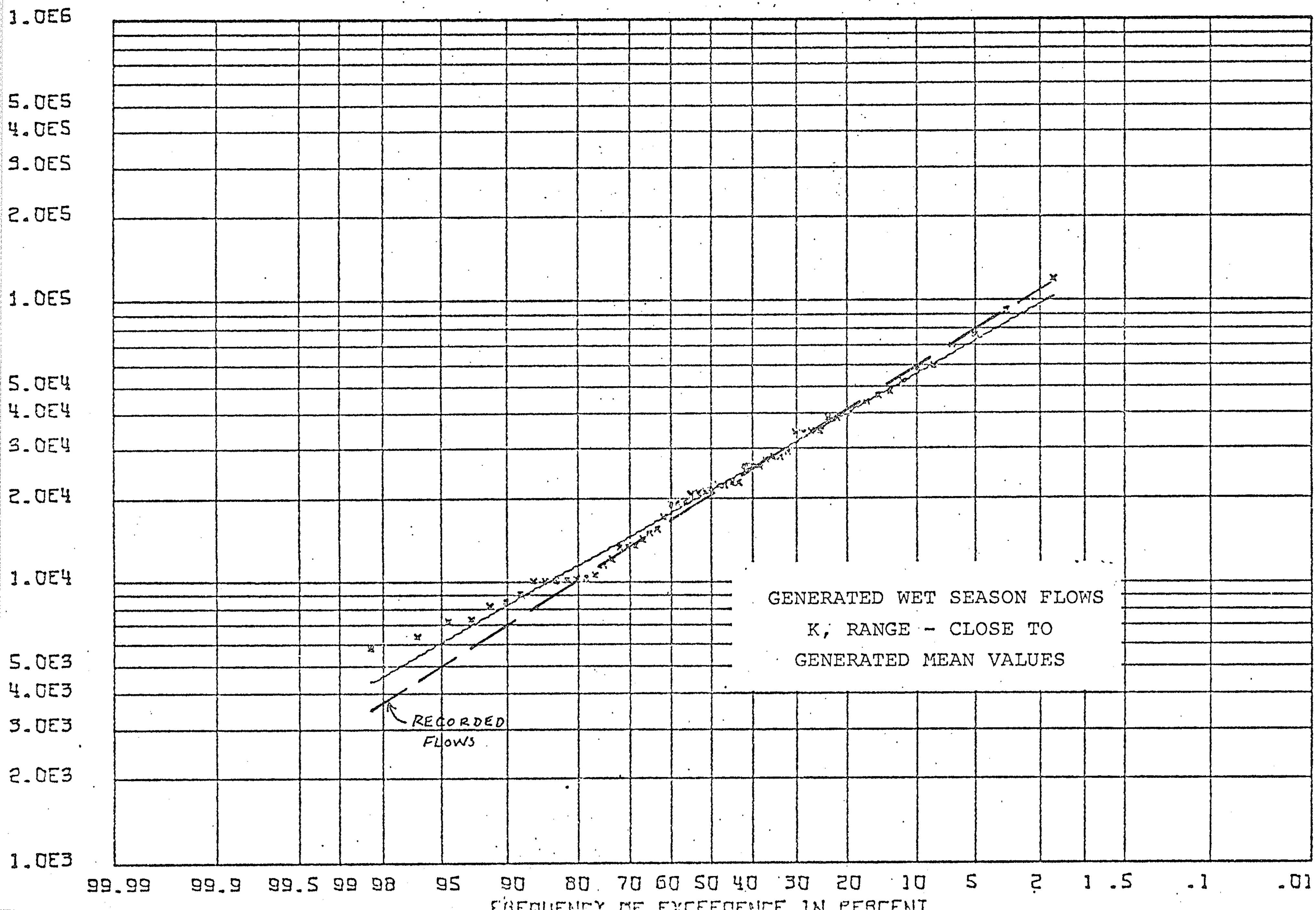
C12



1.0E5
5.0E4
4.0E4
3.0E4
2.0E4
1.0E4
5.0E3
4.0E3
3.0E3
2.0E3
1.0E3
5.0E2
4.0E2
3.0E2
2.0E2
1.0E2
5.0E1
4.0E1
3.0E1
2.0E1
1.0E1
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT
GENERATED DRY SEASON FLOWS
SMALL K, RANGE

C13


GENERATED ANNUAL FLOWS
SMALL K, RANGE
RECORDED FLOWS
1.0E6
5.0E5
4.0E5
3.0E5
2.0E5
1.0E5
5.0E4
4.0E4
3.0E4
2.0E4
1.0E4
5.0E3
4.0E3
3.0E3
2.0E3
1.0E3
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT


1.0E6
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2.0E5
1.0E5
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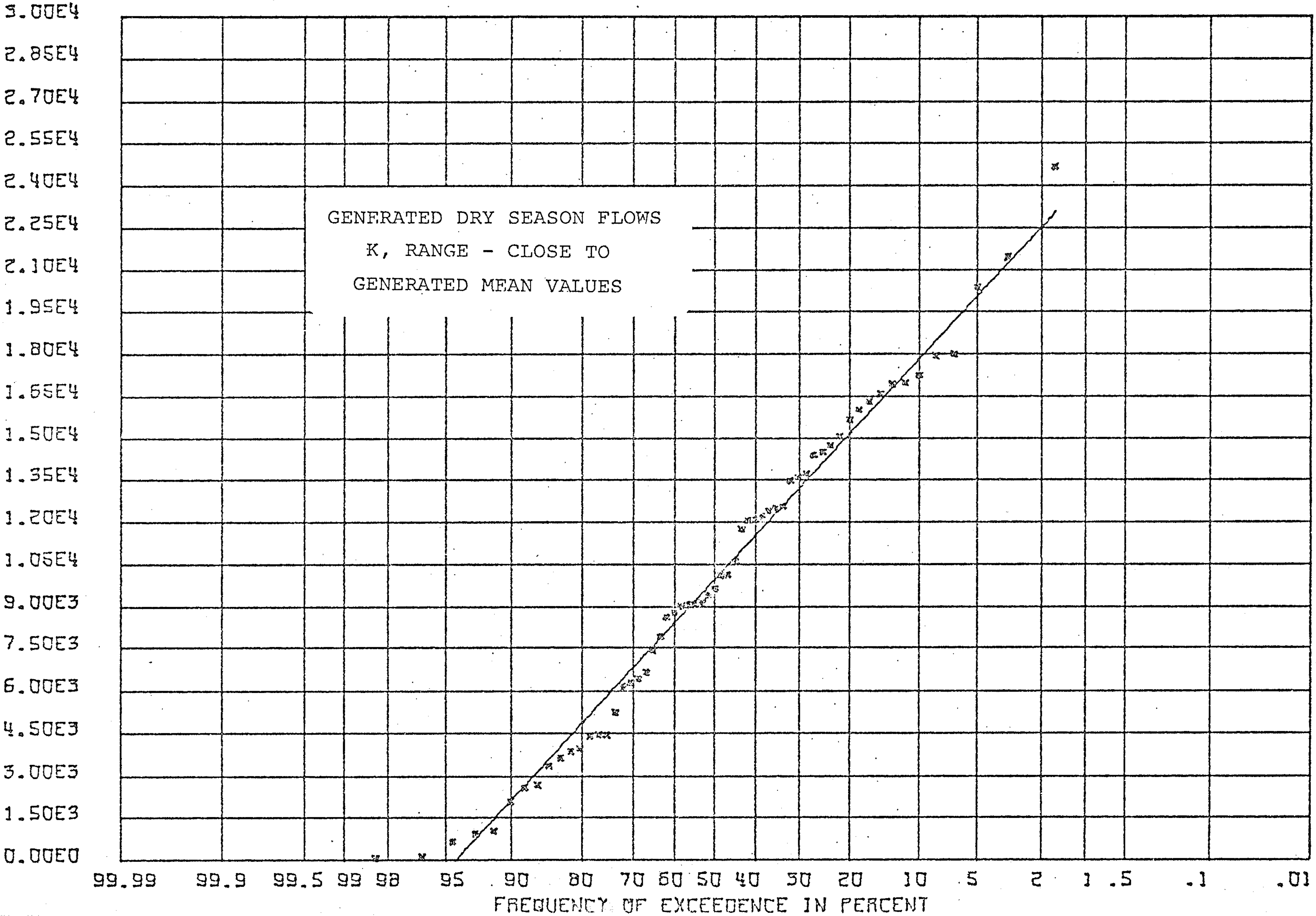
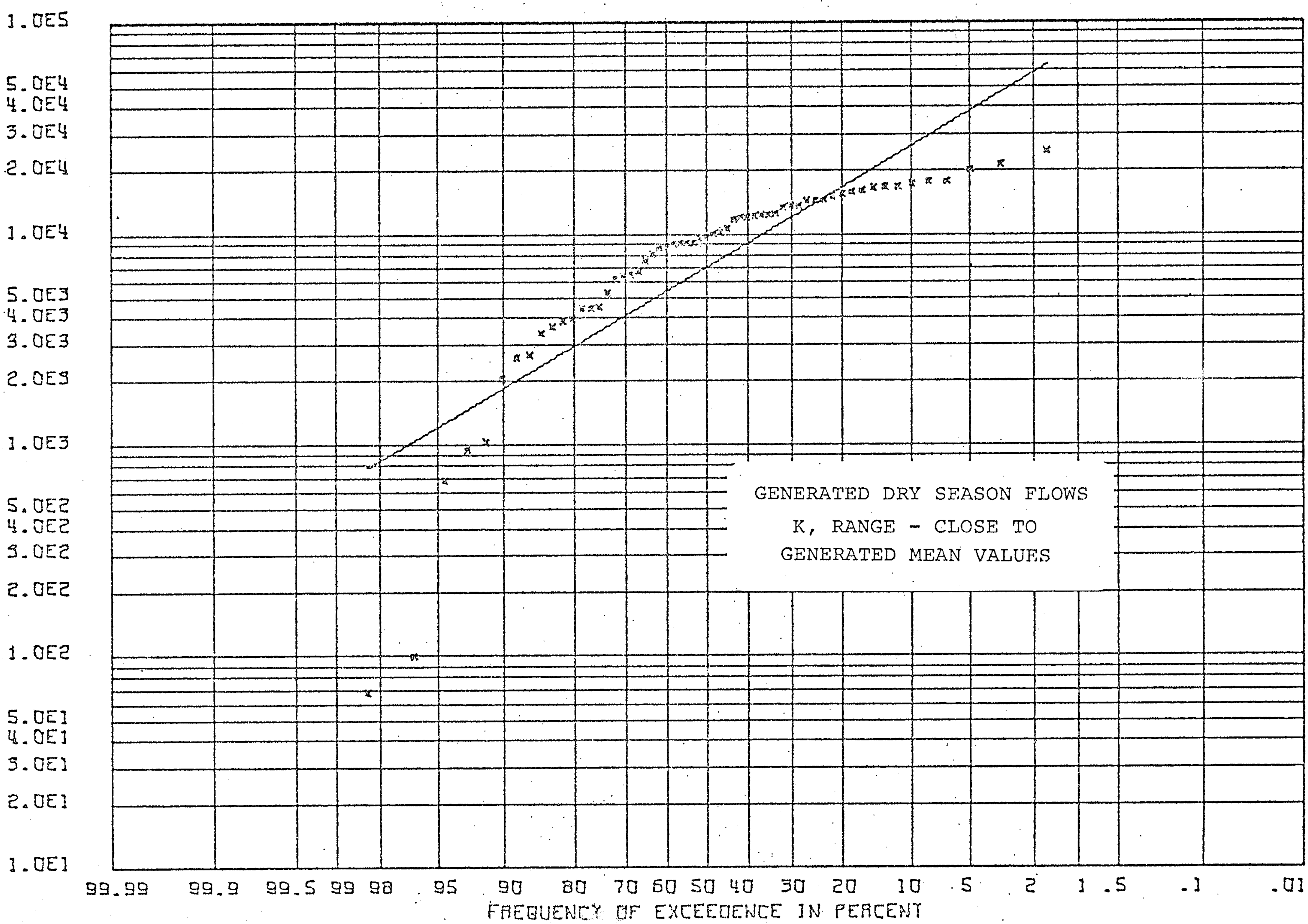
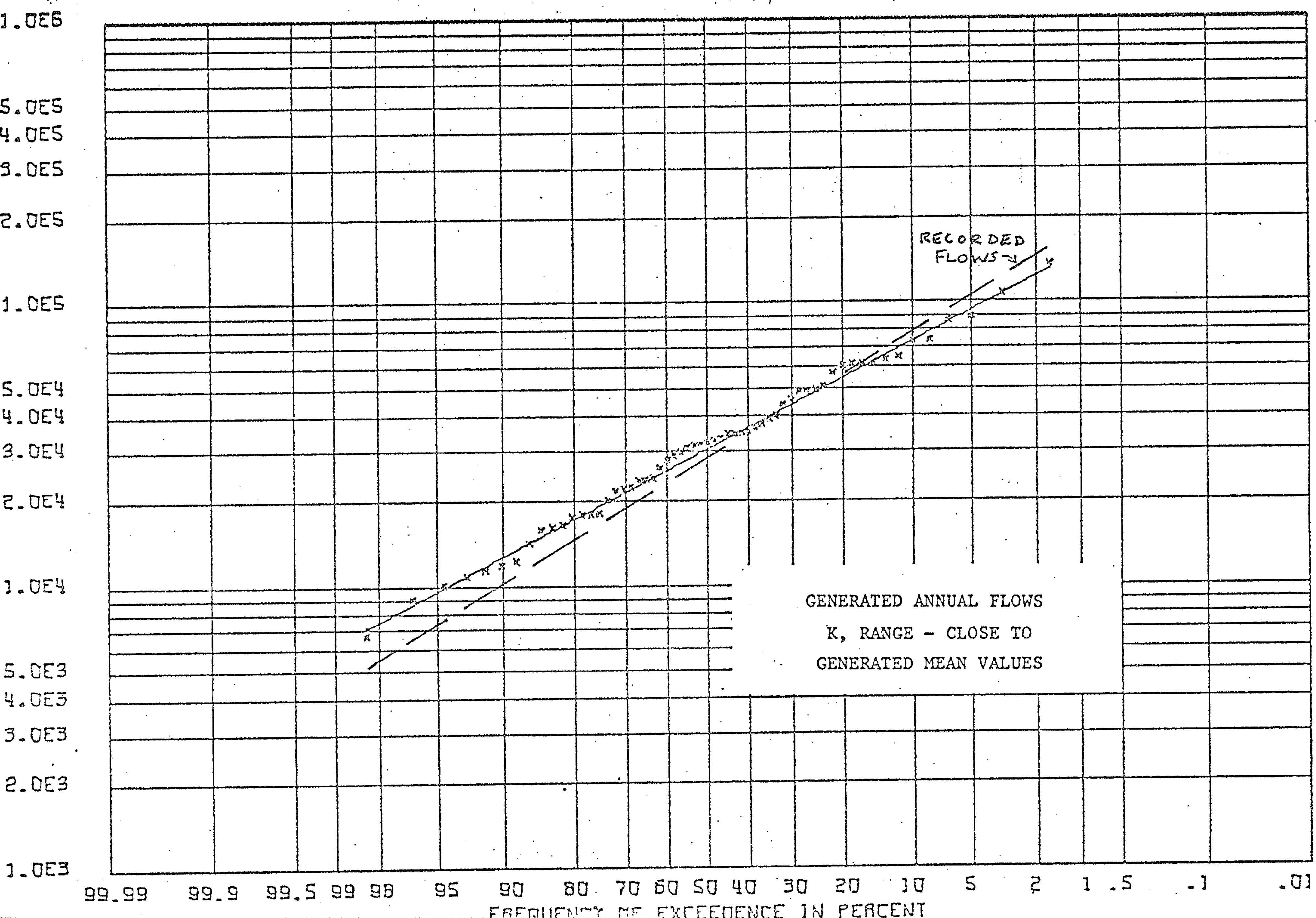
4.0E4
3.0E4
2.0E4
1.0E4
5.0E3
4.0E3
3.0E3
2.0E3
1.0E3
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT
GENERATED WET SEASON FLOWS
K, RANGE - CLOSE TO
GENERATED MEAN VALUES
RECORDED
FLOWS


GENERATED DRY SEASON FLOWS
K, RANGE - CLOSE TO
GENERATED MEAN VALUES
3.00E4
2.85E4
2.70E4
2.55E4
2.40E4
2.25E4
2.10E4
1.95E4
1.80E4
1.65E4
1.50E4
1.35E4
1.20E4
1.05E4
9.00E3
7.50E3
6.00E3
4.50E3
3.00E3
1.50E3
0.00E0
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT

C15

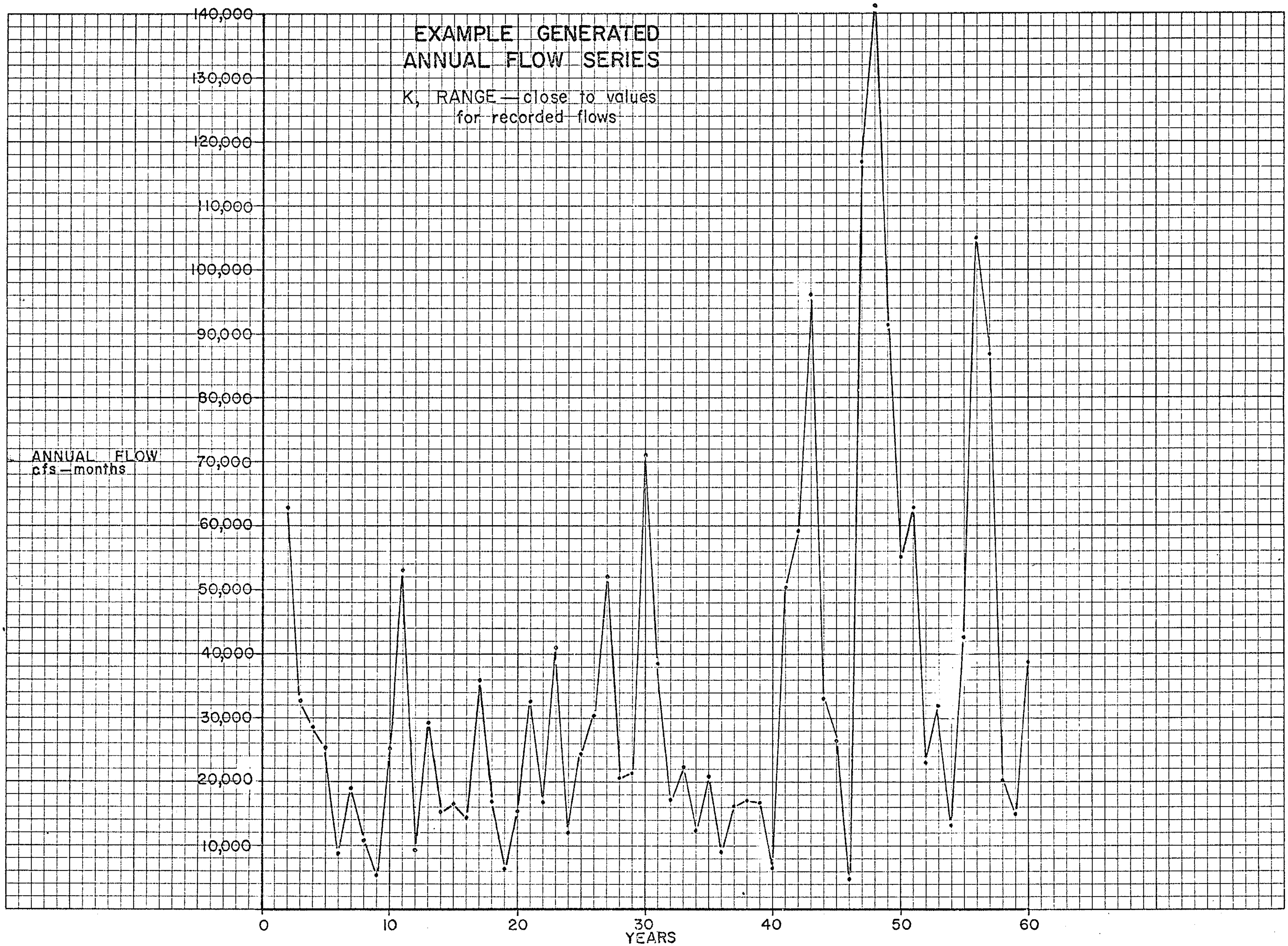

GENERATED DRY SEASON FLOWS
K, RANGE - CLOSE TO
GENERATED MEAN VALUES
1.0E5
5.0E4
4.0E4
3.0E4
2.0E4
1.0E4
5.0E3
4.0E3
3.0E3
2.0E3
1.0E3
5.0E2
4.0E2
3.0E2
2.0E2
1.0E2
5.0E1
4.0E1
3.0E1
2.0E1
1.0E1
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT

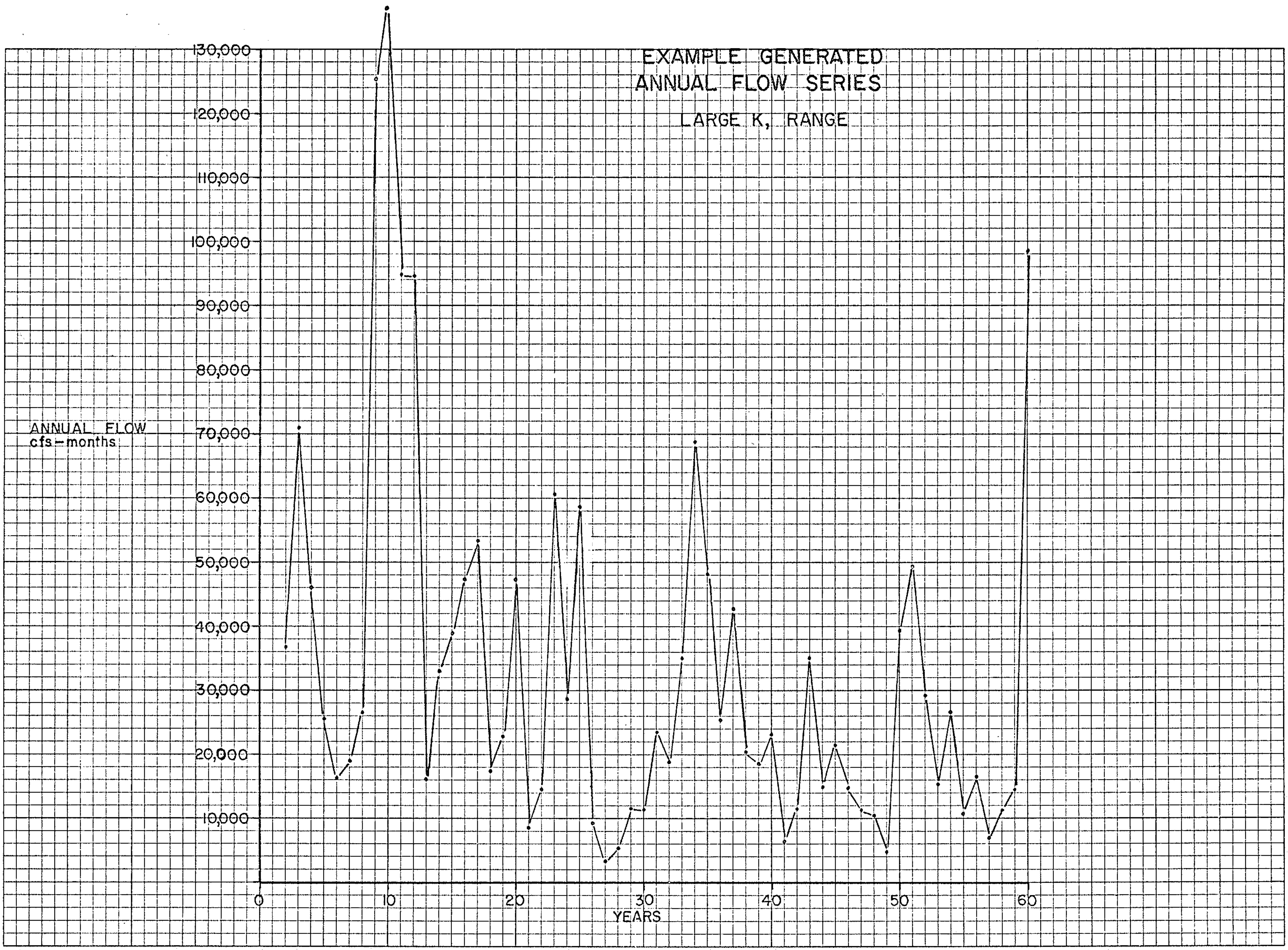
C/6



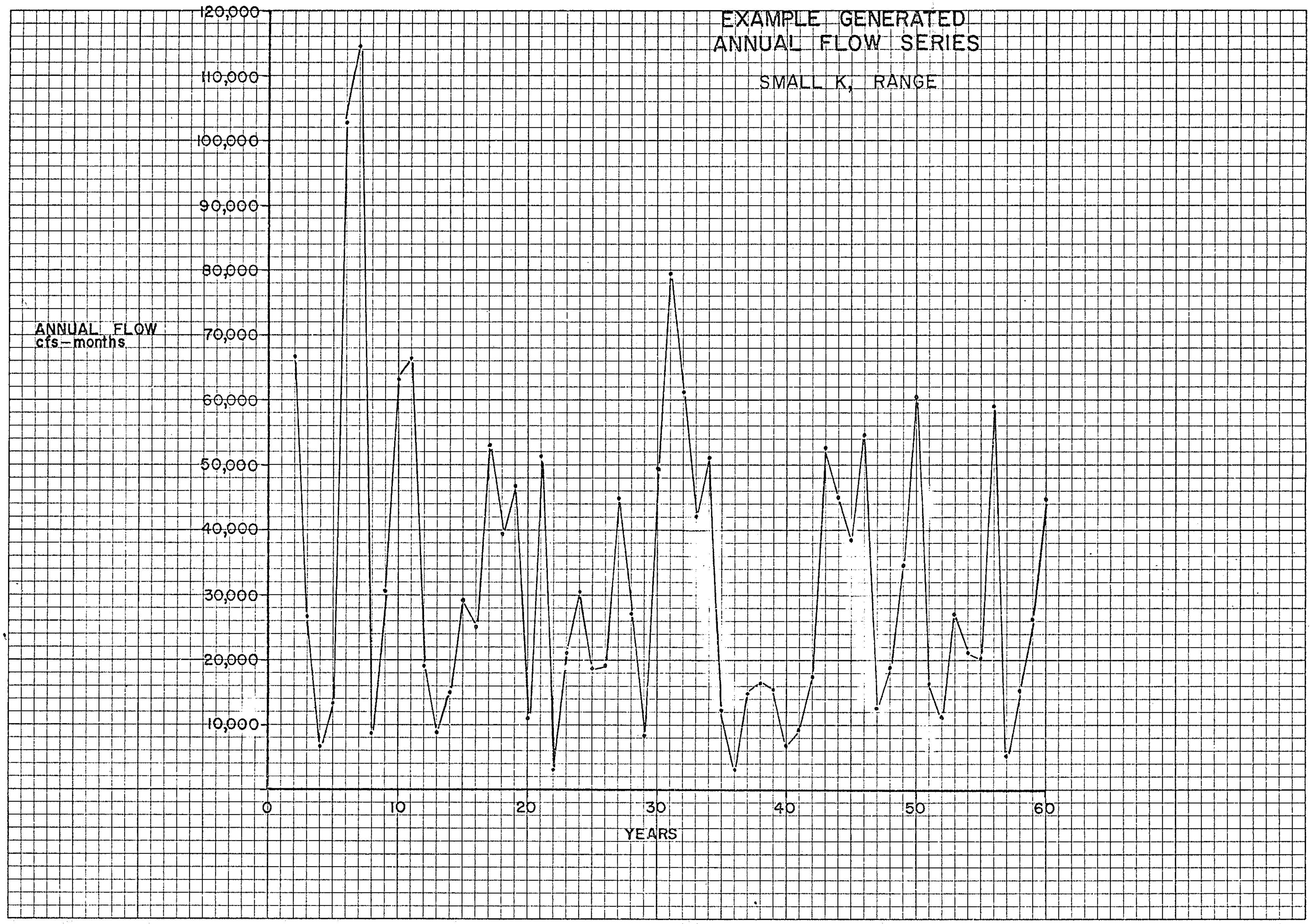
1.0E6
5.0E5
4.0E5
3.0E5
2.0E5
1.0E5
5.0E4
4.0E4
3.0E4
2.0E4
1.0E4
5.0E3
4.0E3
3.0E3
2.0E3
1.0E3
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT
RECORDED FLOWS
GENERATED ANNUAL FLOWS
K, RANGE - CLOSE TO
GENERATED MEAN VALUES

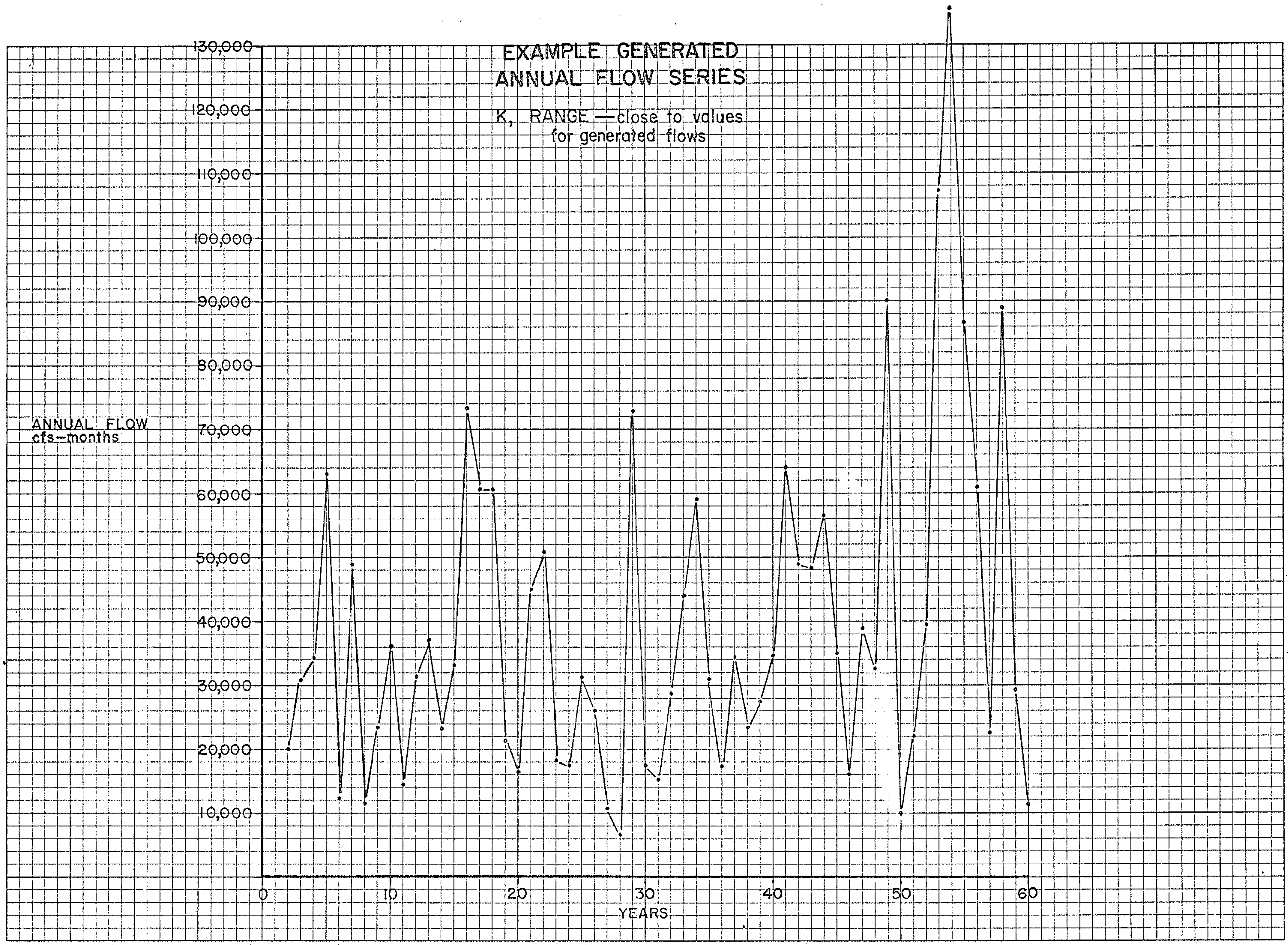
C17


EXAMPLE GENERATED
ANNUAL FLOW SERIES
K, RANGE — close to values
for recorded flows
ANNUAL FLOW
cfs — months
140,000
130,000
120,000
110,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
10
20
30
40
50
60
YEARS


EXAMPLE GENERATED
ANNUAL FLOW SERIES
LARGE K, RANGE
ANNUAL FLOW
cfs-months
130,000
120,000
110,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
10
20
30
40
50
60
YEARS

C19


EXAMPLE GENERATED
ANNUAL FLOW SERIES
SMALL K, RANGE
ANNUAL FLOW
cfs–months
120,000
110,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
10
20
30
40
50
60
YEARS


EXAMPLE GENERATED
ANNUAL FLOW SERIES
K, RANGE —close to values
for generated flows
ANNUAL FLOW
cfs—months
130,000
120,000
110,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
10
20
30
40
50
60
YEARS

Appendix D

FLOW GENERATION PROGRAM - FINAL VERSION

includes:

Explanation of program

Table of symbols

Listing of program

APPENDIX D

FLOW GENERATION PROGRAM - FINAL VERSION

The program shown here is the final version of the flow generation and statistical analysis program. It is identical except for the main data input to the one used to analyse the recorded flow data.

The main program is broken into sections with self-explanatory labels which indicate the steps involved in the analysis and generation process. A great portion of the statements are not inherent to the method, but were necessary for the logical handling of the great amounts of output. Three subroutines are used. Subroutine TEST is used in calculating the range of the data, and its purpose is to scan an array and locate the largest and smallest number. Subroutines GAUSS and RANDU are commercial subroutines which were used in conjunction to produce a normally distributed random number series with a given mean and standard deviation (0.0, 1.0). This is used for the random component of the generated flow value.

A list of some of the significant symbols in the program follows:

Symbol	Explanation
MEAN (3)	Array of mean values of seasonal and annual flows
SIGMA (3)	Array of standard deviations of seasonal and annual flows
ROE (3)	Array of correlation coefficients of seasonal and annual flows
FLOW (100, 3) FLOW A (100, 3) FLOW B (100, 3)	Arrays of flows, logs of flows, and deviations from mean flows
SUMDEV (100)	Array of cumulative deviations from mean flow values
T(3), Y(3), VV(200)	Miscellaneous arrays used for temporary storage of intermediate values, etc.
RANGE	Range of values of cumulative deviations from mean flows
HURST	Hurst's constant

Following is a listing of the program.

D4

```
C
C
C
C     FINAL VERSION OF SYNTHETIC FLOW GENERATION PROGRAM
C        APPLYING THE HURST PHENOMENON THEORY
C        FOR THE RED RIVER
C
C
C     N=NUMBER OF YEARS OF COMPLETE RECORD OF MONTHLY MEAN FLOWS
C     IYEARS=NUMBER OF YEARS OF SYNTHETIC FLOWS DESIRED
C
C
      REAL SIGMA(3),ROE(3),FLOW(100,3),T(3)
      REAL MEAN(3),VV(200),Y(3),FLOWA(100,3)
      REAL FLOWB(100,12),SUMDEV(100)
100   FORMAT ('0',///)
101   FORMAT (I5)
102   FORMAT (20X,12F5.0)
103   FORMAT (' ',2X,13F9.1)
C
C
C      RECORDED FLOW PARAMETERS
      MEAN(1)=4.310
      MEAN(2)=8868.785
      MEAN(3)=4.443
      SIGMA(1)=.3394
      SIGMA(2)=6682.714
      SIGMA(3)=.3322
      ROE(1)=.4987
      ROE(2)=.5511
      ROE(3)=.8052
      NUMB=2
      GO TO 44
C
C
C      MANIPULATION & STORAGE OF FLOW ARRAYS
51    WRITE(6,113)
      IF(NUMB.NE.3) GO TO 43
      WRITE(7,120) MEAN(3),SIGMA(3),RANGE,HURST,ROE(3)
      DO 45 I=2,N
45    FLOWB(I,3)=FLOWA(I,3)
43    CONTINUE
120   FORMAT (5F15.3)
113   FORMAT ('0',10X,'LOGARITHMS OF FLOWS')
      DO 52 I=2,N
      FLOW(I,3)= ALOG10(FLOWA(I,3))
      FLOW(I,2)=FLOWA(I,2)
52    FLOW(I,1)= ALOG10(FLOWA(I,1))
      DO 36 I=2,N
36    WRITE(6,109)(FLOW(I,J),J=1,3)
109   FORMAT(' ',2X,4F15.3)
      ICOUNT=0
      GO TO 55
54    CONTINUE
      N=IYEARS
55    CONTINUE
C
C
C      CALCULATION OF MEANS OF SEASONAL FLOWS FOR EACH SEASON
      WRITE (6,100)
      DO 3 J=1,3
      T(J)=0
      DO 2 I=2,N
2     T(J)=T(J) + FLOW(I,J)
      MEAN (J) = T(J)/(N-1)
      WRITE (6,104) J,MEAN(J)
104   FORMAT (' ',5X,'MEAN FLOW FOR MONTH',I2,'=',F10.3)
3     CONTINUE
      IF (NUMB.EQ.2)GO TO 57
      TMEAN=MEAN(3)
      WRITE(6,116)TMEAN
57    CONTINUE
116   FORMAT ('0',5X,'MEAN ANNUAL FLOW=',F10.4)
      WRITE (6,100)
C
C
C     FORM NEW ARRAY OF DEVIATIONS FROM MEAN FLOWS
      DO 56 I=2,N
      DO 56 J=1,3
      FLOWA(I,J)=FLOW(I,J)
56    FLOW(I,J)=FLOW(I,J)-MEAN(J)
C
```

```
C
C          CALCULATION OF SEASONAL & ANNUAL STANDARD DEVIATIONS
          DO 5 J=1,2
          Y(J)=0
          DO 4 I=2,N
4         Y(J)=Y(J)+(FLOW(I,J))*(FLOW(I,J))
          SIGMA(J)=SQRT(Y(J)/(N-1))
5         WRITE (6,105) J,SIGMA(J)
105       FORMAT ('  ',5X,'STANDARD DEVIATION FOR MONTH',I2,'=',F10.4)
94        CONTINUE
          Y(3)=0.0
          DO 58 I=2,N
          Y(3)=Y(3)+(FLOW(I,3))*(FLOW(I,3))
58        TSIGMA=SQRT(Y(3)/(N-1))
          SIGMA(3)=TSIGMA
          WRITE (6,117)TSIGMA
117       FORMAT ('0',5X,'OVERALL STANDARD DEVIATION=',F10.4)
C
C
C          CALCULATION OF RANGE & HURST CONSTANT
          SUMDEV(1)=0.0
          DO 12 I=2,N
          L=I-1
12        SUMDEV(I)=SUMDEV(L)+FLOW(I,3)
          CALL TEST (SUMDEV,100,N,BIG,SMALL)
          RANGE =BIG+ABS(SMALL)
          ND=N-1
          WRITE (6,118) RANGE,ND
118       FORMAT ('0',5X,'RANGE=',F13.1,'        N=',I3)
          V=ALOG10(RANGE/TSIGMA)
          P=(N-1)/2
          W=ALOG10(P)
          HURST=V/W
          WRITE(6,119)HURST
119       FORMAT ('0',5X,'HURST CONSTANT=',F5.3)
C
C
C          CALCULATION OFSEASONAL CORRELATION COEFFICIENTS
          WRITE (6,100)
          FLOW(1,2) =0.0
          DO 10 J=1,2
          A=0
          C=0
          DO 9 I=2,N
          IF (J.NE.1) GO TO 7
6         K=2
          L=I-1
          GO TO 8
7         K=J-1
          L=I
8         CONTINUE
          A=A+(FLOW(I,J)*FLOW(L,K))
9         C=C+(FLOW(L,K))*(FLOW(L,K))
          D=Y(J)*C
          ROE(J)=A/(SQRT(D))
10        WRITE (6,106) J,ROE(J)
106       FORMAT ('  ',5X,'ROE(',I2,')=',F10.4)
C
C
C          CALCULATION OF ANNUAL CORRELATION
          FLOW(1,3) =0.0
          A=0.0
          C=0.0
          DO 73 I=2,N
          J=I-1
73        A=A+FLOW(I,3) *FLOW(J,3)
*ERROR -> C=A-FLOW(N,3) ----- should be C=Y(3)-FLOW(N,3) * FLOW(N,3)
          D=Y(3) *C
          ROE(3) =A/(SQRT(D))
74        FORMAT('0',5X,'YEARLY CORRELATION= ',F10.4)
          WRITE(6,74) ROE(3)
          NUMB=NUMB+1
C
22        CONTINUE
          WRITE (6,100)
53        CONTINUE
          IF(NUMB.EQ.1)GO TO 51
          IF(NUMB.EQ.3)GO TO 51
          IF(NUMB.EQ.4)GO TO 23
C
```

D 6.

```
C
C
C        GENERATION OF SYNTHETIC FLOW SERIES
C
44       CONTINUE
         S=1.0
         AM=0.0
         READ (5,107) IX
         WRITE(6,112)IX
112      FORMAT('0','  SEED IX= ',I9)
         WRITE(7,107) IX
205      FORMAT ('IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII')
107      FORMAT (I9)
         I=0
         X=MEAN(2)
         IYEARS=60
         M=IYEARS+1
         N=IYEARS
         DO 14 IA=2,N
         W=MEAN(2)
         SIG=SIGMA(2)
         I=I+1
         CALL GAUSS (IX,S,AM,V)
         VV(I)=V
         J=1
         X=MEAN(1)+SIGMA(1)*ROE(1)*(X-W)/SIG
        1     +V*SIGMA(1)*SQRT(1-(ROE(1)*ROE(1)))
         FLOW(IA,J)=10**(X)
         W=MEAN(1)
         SIG=SIGMA(1)
         I=I+1
         CALL GAUSS(IX,S,AM,V)
         VV(I)=V
         J=2
         X= MEAN(2)+ SIGMA(2)* ROE(2)*(X-W)/SIG
        1     +V* SIGMA(2)*SQRT(1-( ROE(2)* ROE(2)))
         IF(X.LE.10.0) X=10.0
         FLOW(IA,J)=X
         IF(X.EQ.10.0) FLOW(IA,J)=100.0
         FLOW(IA,3)=FLOW(IA,1)+FLOW(IA,2)
14       CONTINUE
         WRITE (6,111)
111      FORMAT (' ',10X,'RANDOM NUMBER SERIES')
         WRITE (6,109) (VV(J),J=1,I)
         WRITE (6,100)
C
C
C         PRINTING GENERATED SYNTHETIC FLOW SERIES
18       WRITE (6,114)
114      FORMAT('0',10X,'SYNTHETIC FLOW SERIES')
         DO 19 I=2,N
19       WRITE(6,103) (FLOW(I,J),J=1,3)
         GO TO 54
23       CONTINUE
         WRITE(7,120) MEAN(3),SIGMA(3),RANGE,HURST,ROE(3)
         WRITE(7,205)
         WRITE(7,204) (FLOWB(I,3),I=2,N)
204      FORMAT(6F12.0)
C
         STOP
         END
C
C
C
C         SUBROUTINE TEST
C
C
         SUBROUTINE TEST (ARRAY,MROW,IR,B,S)
         REAL ARRAY(100)
         S=0
         B=0
         DO 3 I=2,IR
         IF (ARRAY(I).GT.B)B=ARRAY(I)
         IF (ARRAY(I).LT.S)S=ARRAY(I)
       3 CONTINUE
         RETURN
         END
C
```

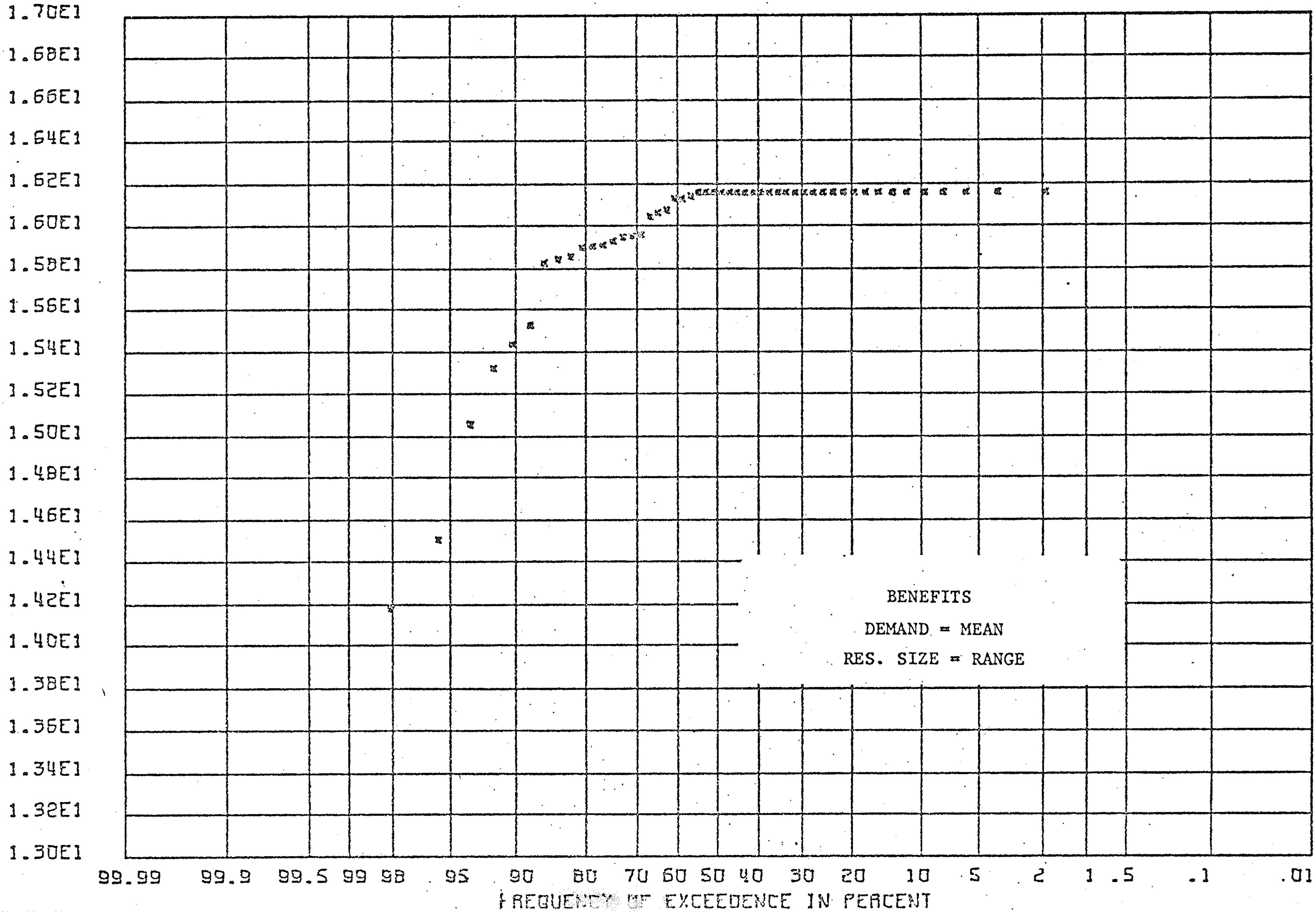
```
.....................................................................

   SUBROUTINE GAUSS

   PURPOSE
      COMPUTES A NORMALLY DISTRIBUTED RANDOM NUMBER WITH A GIVEN
      MEAN AND STANDARD DEVIATION

   USAGE
      CALL GAUSS(IX,S,AM,V)

   DESCRIPTION OF PARAMETERS
      IX -IX MUST CONTAIN AN ODD INTEGER NUMBER WITH NINE OR
            LESS DIGITS ON THE FIRST ENTRY TO GAUSS. THEREAFTER
            IT WILL CONTAIN A UNIFORMLY DISTRIBUTED INTEGER RANDOM
            NUMBER GENERATED BY THE SUBROUTINE FOR USE ON THE NEXT
            ENTRY TO THE SUBROUTINE.
      S  -THE DESIRED STANDARD DEVIATION OF THE NORMAL
            DISTRIBUTION.
      AM -THE DESIRED MEAN OF THE NORMAL DISTRIBUTION
      V  -THE VALUE OF THE COMPUTED NORMAL RANDOM VARIABLE

   REMARKS
      THIS SUBROUTINE USES RANDU WHICH IS MACHINE SPECIFIC

   SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
      RANDU

   METHOD
      USES 12 UNIFORM RANDOM NUMBERS TO COMPUTE NORMAL RANDOM
      NUMBERS BY CENTRAL LIMIT THEOREM. THE RESULT IS THEN
      ADJUSTED TO MATCH THE GIVEN MEAN AND STANDARD DEVIATION.
      THE UNIFORM RANDOM NUMBERS COMPUTED WITHIN THE SUBROUTINE
      ARE FOUND BY THE POWER RESIDUE METHOD.

.....................................................................

      SUBROUTINE GAUSS(IX,S,AM,V)
      A=0.0
      DO 50 I=1,12
      CALL RANDU(IX,IY,Y)
      IX=IY
   50 A=A+Y
      V=(A-6.0)*S +AM
      RETURN
      END

.....................................................................

   SUBROUTINE RANDU

   PURPOSE
      COMPUTES UNIFORMLY DISTRIBUTED RANDOM REAL NUMBERS BETWEEN
      0 AND 1.0 AND RANDOM INTEGERS BETWEEN ZERO AND
      2**31. EACH ENTRY USES AS INPUT AN INTEGER RANDOM NUMBER
      AND PRODUCES A NEW INTEGER AND REAL RANDOM NUMBER.

   USAGE
      CALL RANDU(IX,IY,YFL)

   DESCRIPTION OF PARAMETERS
      IX - FOR THE FIRST ENTRY THIS MUST CONTAIN ANY ODD INTEGER
           NUMBER WITH NINE OR LESS DIGITS. AFTER THE FIRST ENTRY,
           IX SHOULD BE THE PREVIOUS VALUE OF IY COMPUTED BY THIS
           SUBROUTINE.
      IY - A RESULTANT INTEGER RANDOM NUMBER REQUIRED FOR THE NEXT
           ENTRY TO THIS SUBROUTINE. THE RANGE OF THIS NUMBER IS
           BETWEEN ZERO AND 2**31
      YFL- THE RESULTANT UNIFORMLY DISTRIBUTED, FLOATING POINT,
           RANDOM NUMBER IN THE RANGE 0 TO 1.0

   REMARKS
      THIS SUBROUTINE IS SPECIFIC TO SYSTEM/360 AND WILL PRODUCE
      2**29 TERMS BEFORE REPEATING.  THE REFERENCE BELOW DISCUSSES
      SEEDS (65539 HERE), RUN PROBLEMS, AND PROBLEMS CONCERNING
      RANDOM DIGITS USING THIS GENERATION SCHEME.  MACLAREN AND
      MARSAGLIA, JACM 12, P. 83-89, DISCUSS CONGRUENTIAL
```

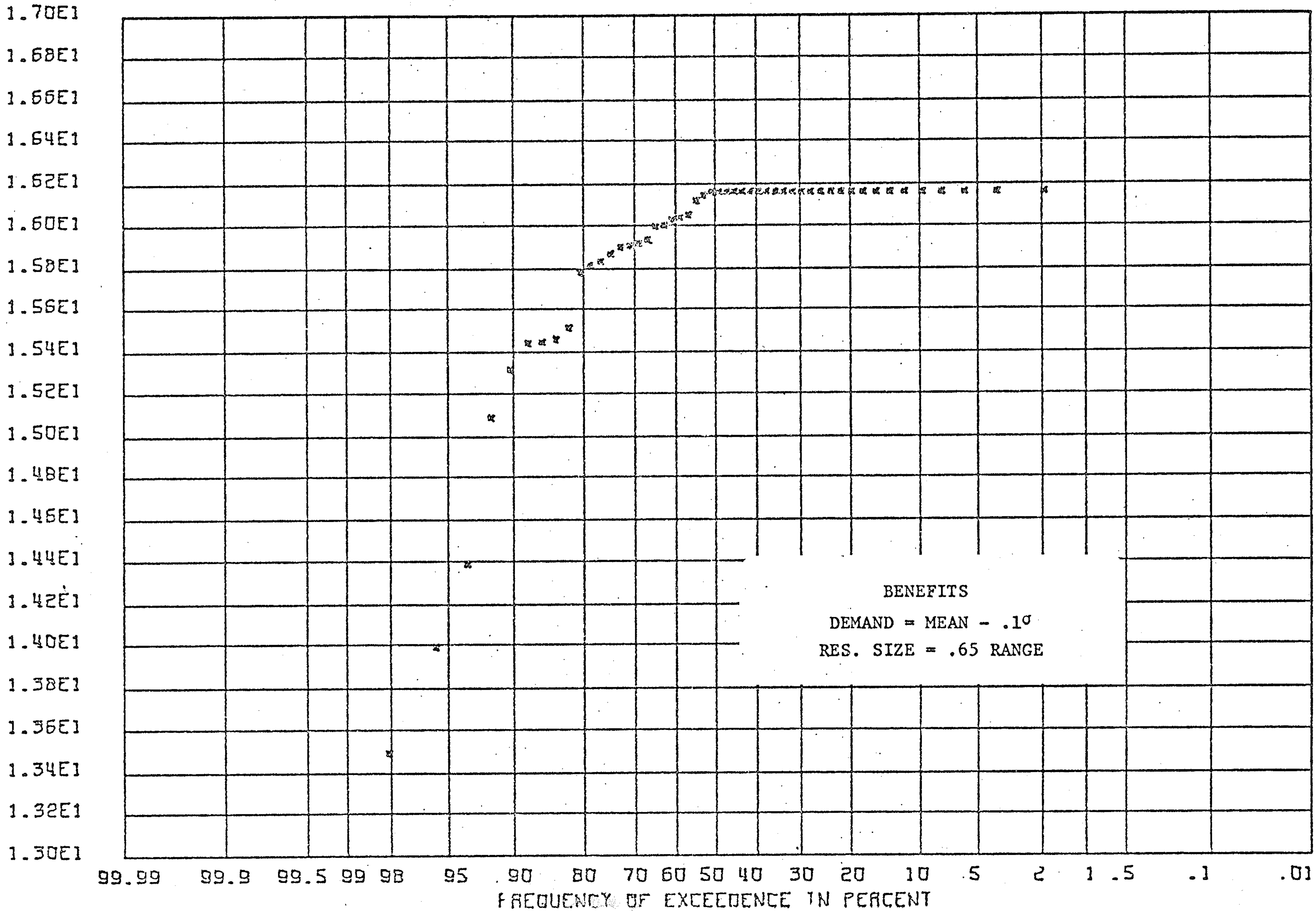
```
        GENERATION METHODS AND TESTS.  THE USE OF TWO GENERATORS OF
        THE RANDU TYPE, ONE FILLING A TABLE AND ONE PICKING FROM THE
        TABLE, IS OF BENEFIT IN SOME CASES.  65549 HAS BEEN
        SUGGESTED AS A SEED WHICH HAS BETTER STATISTICAL PROPERTIES
        FOR HIGH ORDER BITS OF THE GENERATED DEVIATE.
        SEEDS SHOULD BE CHOSEN IN ACCORDANCE WITH THE DISCUSSION
        GIVEN IN THE REFERENCE BELOW.  ALSO, IT SHOULD BE NOTED THAT
        IF FLOATING POINT RANDOM NUMBERS ARE DESIRED,AS ARE
        AVAILABLE FROM RANDU, THE RANDOM CHARACTERISTICS OF THE
        FLOATING POINT DEVIATES ARE MODIFIED AND IN FACT THESE
        DEVIATES HAVE HIGH PROBABILITY OF HAVING A TRAILING LOW
        ORDER ZERO BIT IN THEIR FRACTIONAL PART.

     SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
        NONE

     METHOD
        POWER RESIDUE METHOD DISCUSSED IN IBM MANUAL C20-8011,
        RANDOM NUMBER GENERATION AND TESTING

  ..................................................................

      SUBROUTINE RANDU(IX,IY,YFL)
      IY=IX*65539
      IF(IY)5,6,6
    5 IY=IY+2147483647+1
    6 YFL=IY
      YFL=YFL*.4656613E-9
      RETURN
      END
```

Appendix E

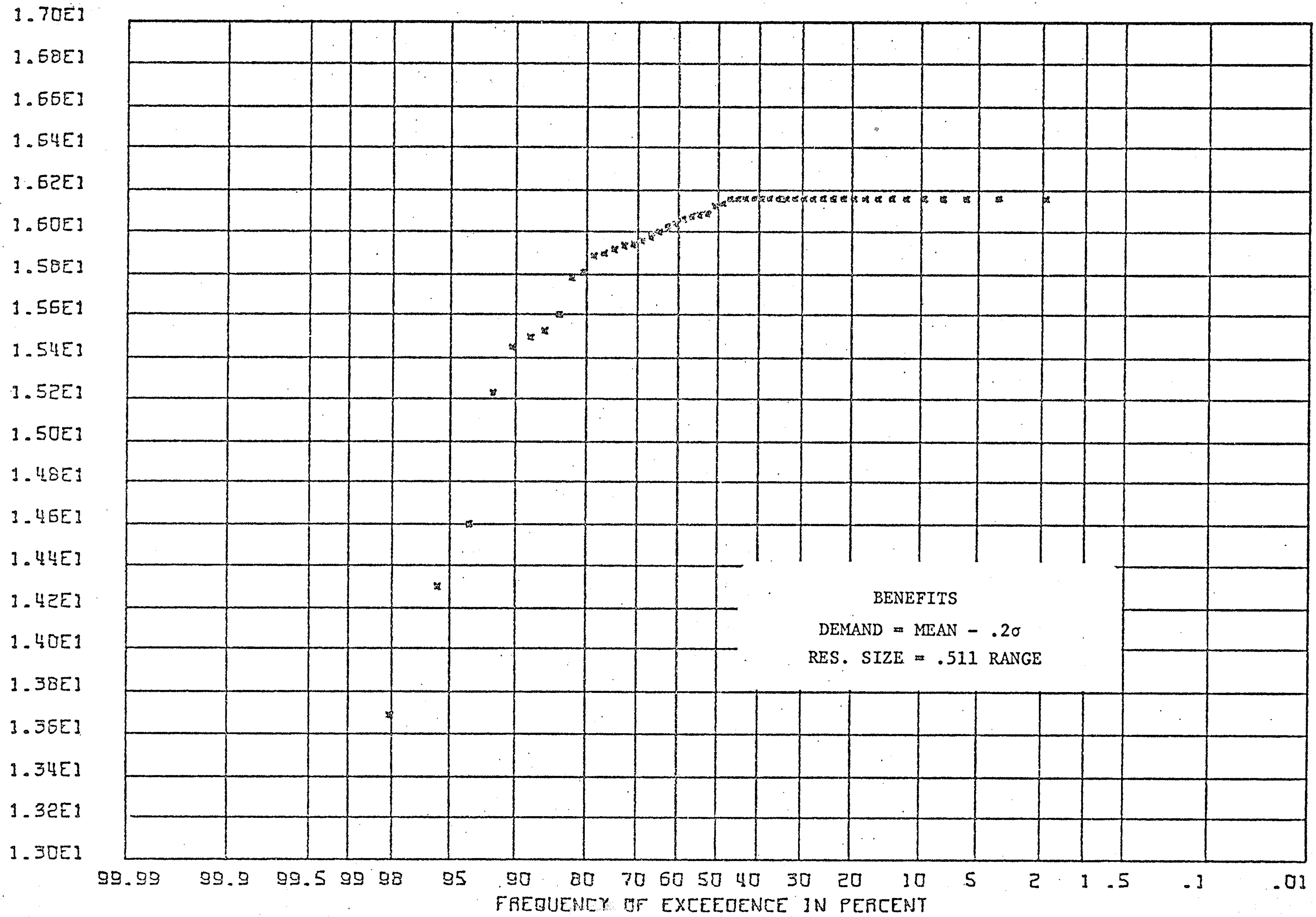
GRAPHS SHOWING STATISTICAL DISTRIBUTION OF PARAMETERS FOR RESERVOIR REGULATION AND ECONOMIC ANALYSIS

E2

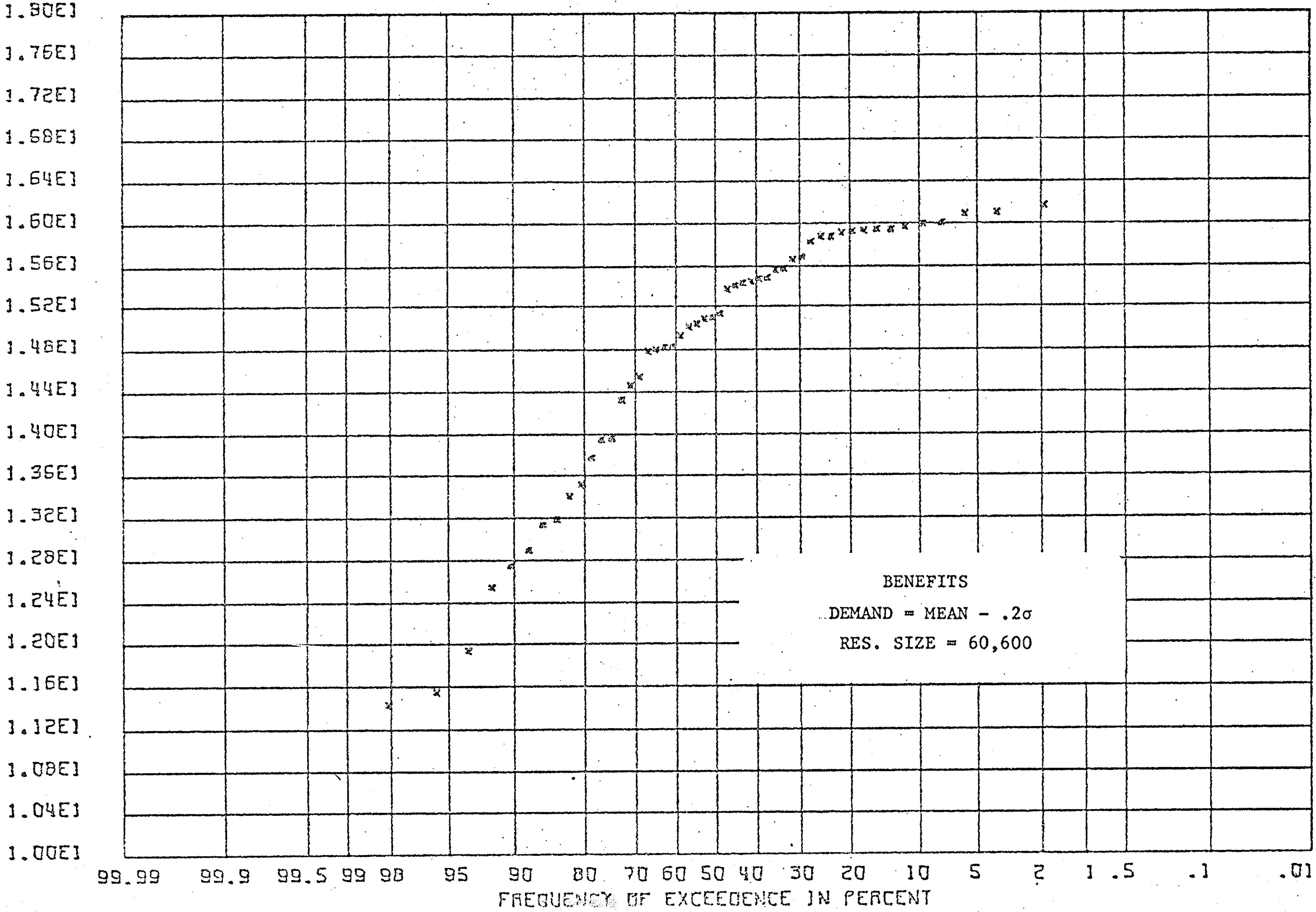

1.70E1
1.68E1
1.66E1
1.64E1
1.62E1
1.60E1
1.58E1
1.56E1
1.54E1
1.52E1
1.50E1
1.48E1
1.46E1
1.44E1
1.42E1
1.40E1
1.38E1
1.36E1
1.34E1
1.32E1
1.30E1
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT
BENEFITS
DEMAND = MEAN
RES. SIZE = RANGE

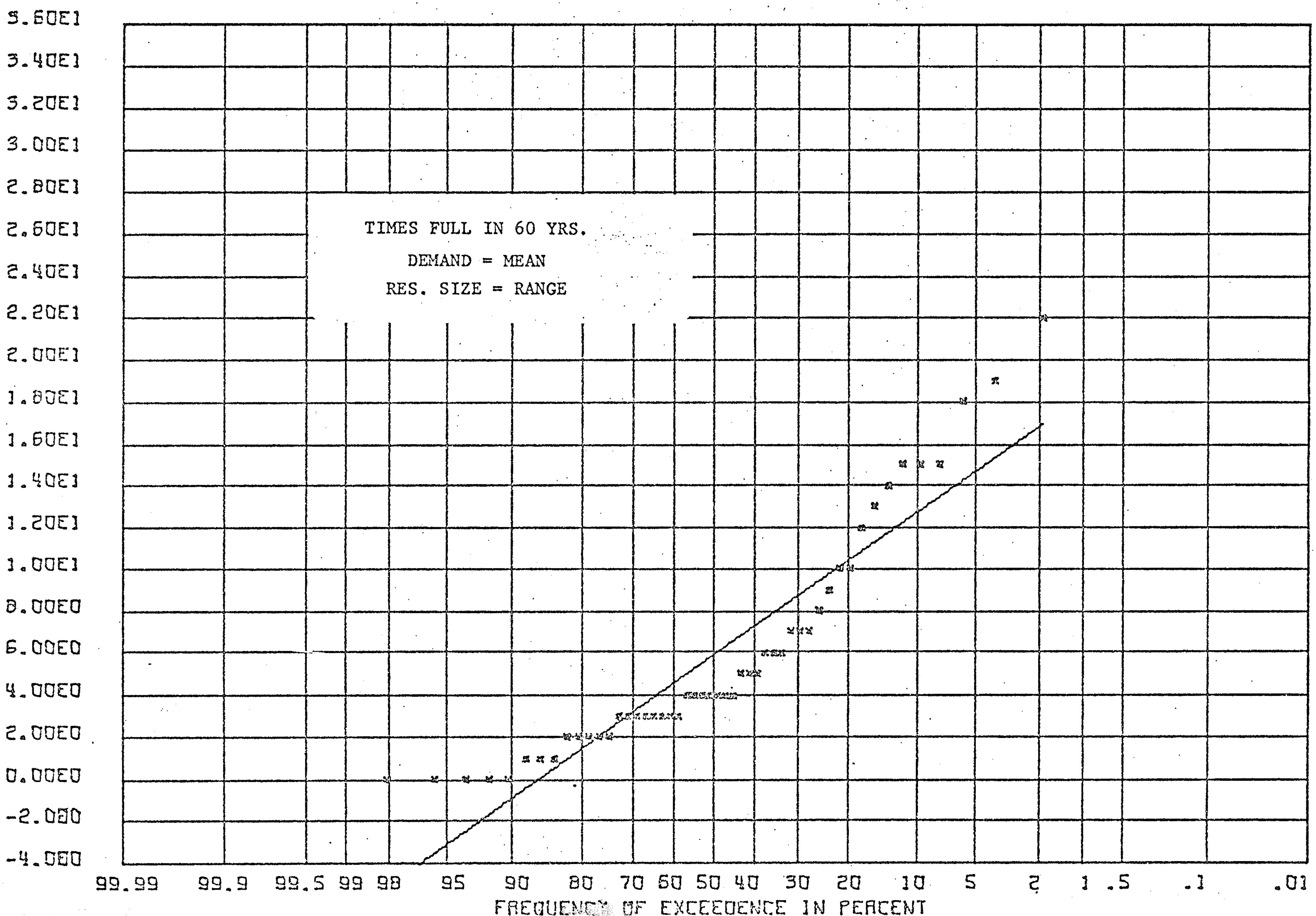

1.70E1
1.68E1
1.66E1
1.64E1
1.62E1
1.60E1
1.58E1
1.56E1
1.54E1
1.52E1
1.50E1
1.48E1
1.46E1
1.44E1
1.42E1
1.40E1
1.38E1
1.36E1
1.34E1
1.32E1
1.30E1
BENEFITS
DEMAND = MEAN - .1σ
RES. SIZE = .65 RANGE
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT

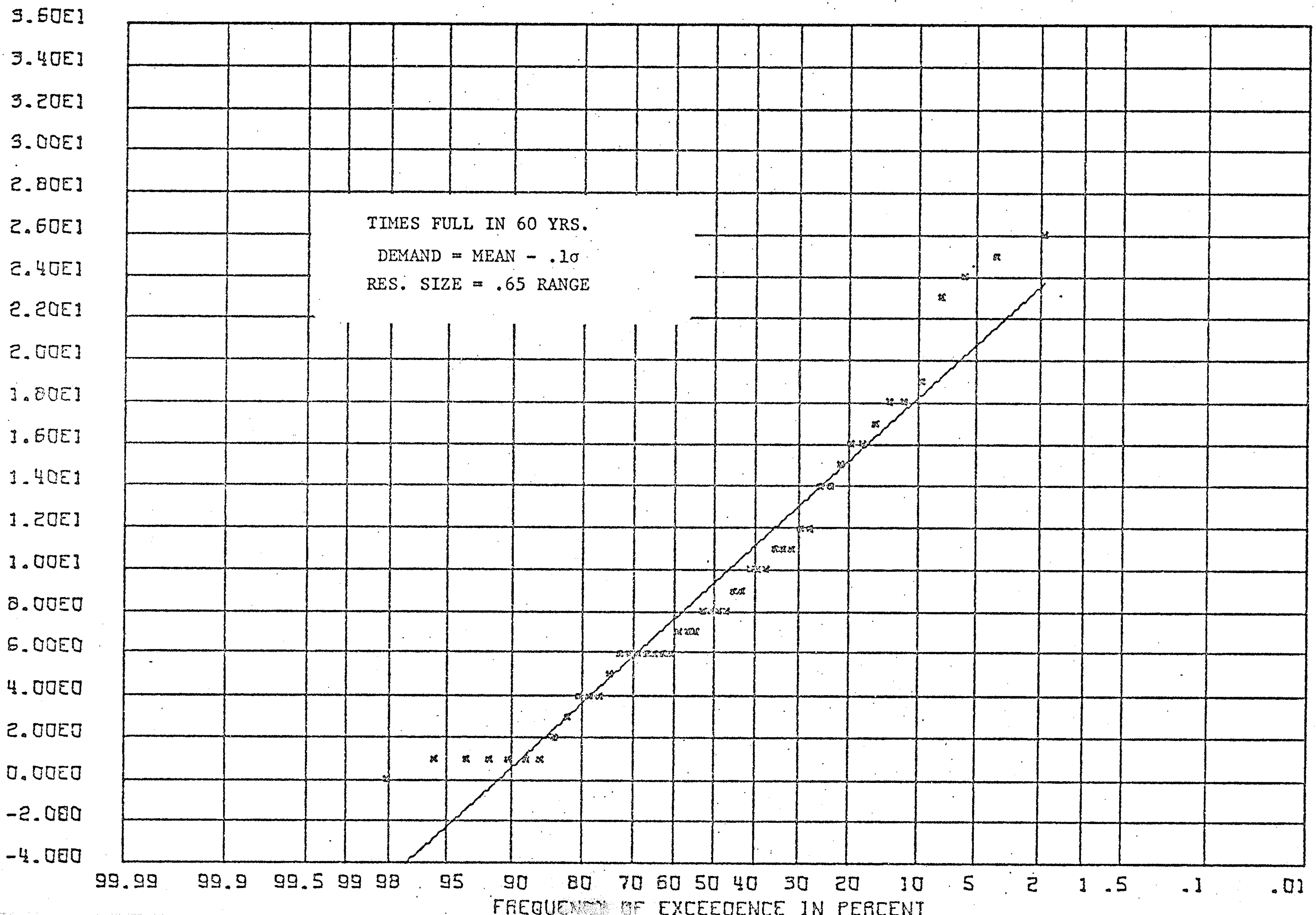
E4



1.70E1
1.68E1
1.66E1
1.64E1
1.62E1
1.60E1
1.58E1
1.56E1
1.54E1
1.52E1
1.50E1
1.48E1
1.46E1
1.44E1
1.42E1
1.40E1
1.38E1
1.36E1
1.34E1
1.32E1
1.30E1
BENEFITS
DEMAND = MEAN - .2σ
RES. SIZE = .511 RANGE
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT

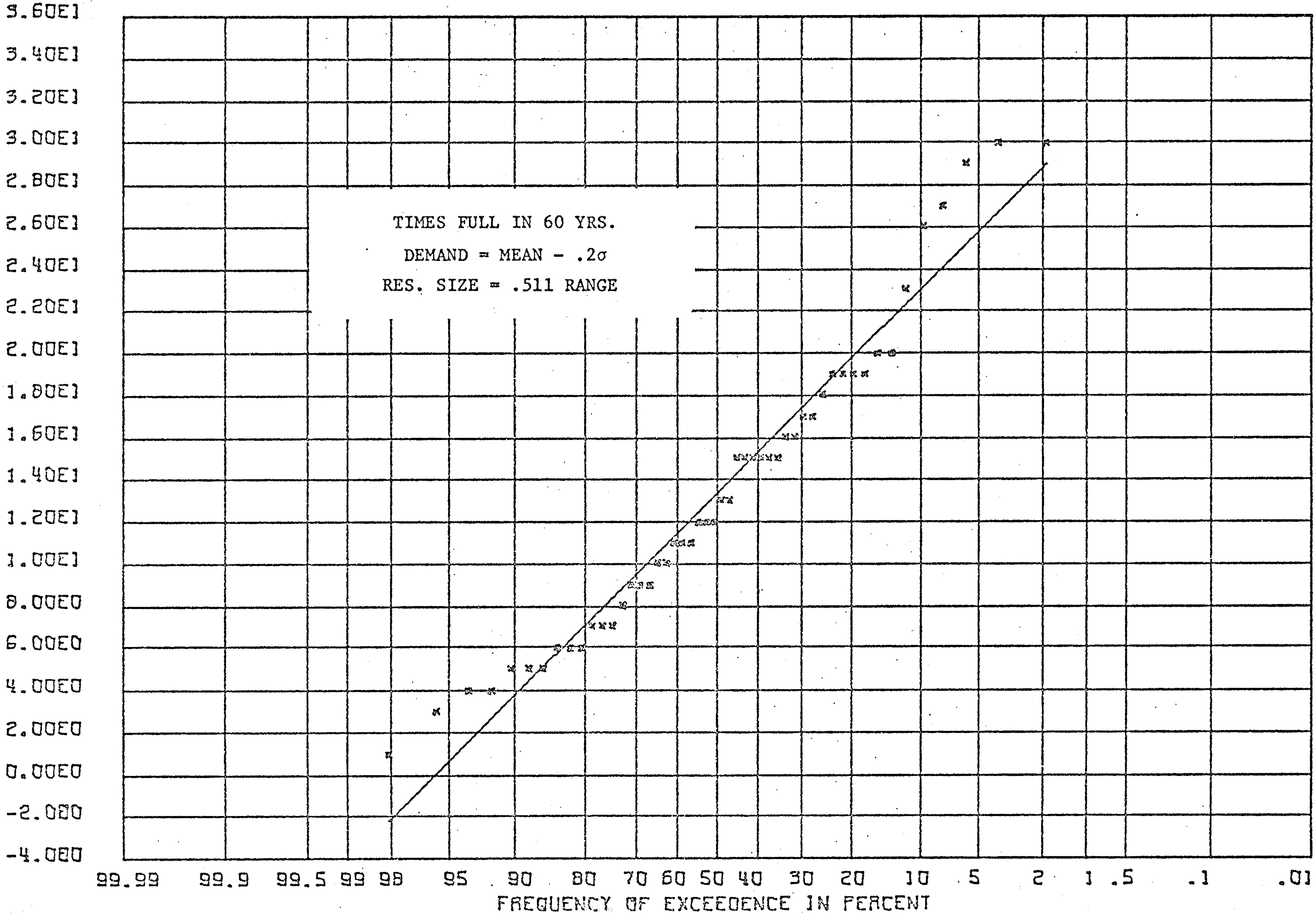

BENEFITS
DEMAND = MEAN - .2σ
RES. SIZE = 60,600
1.80E1
1.76E1
1.72E1
1.68E1
1.64E1
1.60E1
1.56E1
1.52E1
1.48E1
1.44E1
1.40E1
1.36E1
1.32E1
1.28E1
1.24E1
1.20E1
1.16E1
1.12E1
1.08E1
1.04E1
1.00E1
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT

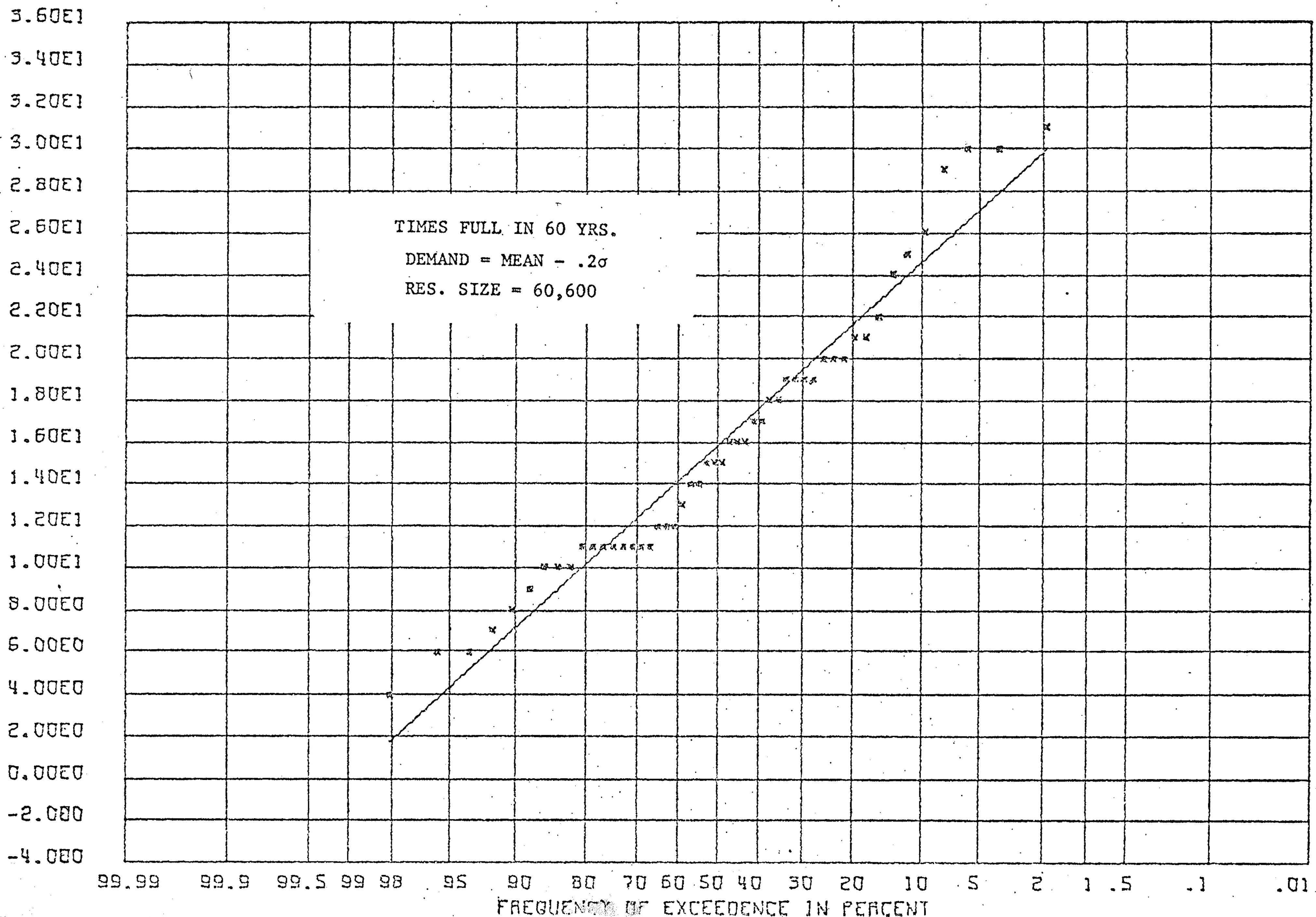

TIMES FULL IN 60 YRS.
DEMAND = MEAN
RES. SIZE = RANGE
3.60E1
3.40E1
3.20E1
3.00E1
2.80E1
2.60E1
2.40E1
2.20E1
2.00E1
1.80E1
1.60E1
1.40E1
1.20E1
1.00E1
8.00E0
6.00E0
4.00E0
2.00E0
0.00E0
-2.0E0
-4.0E0
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT



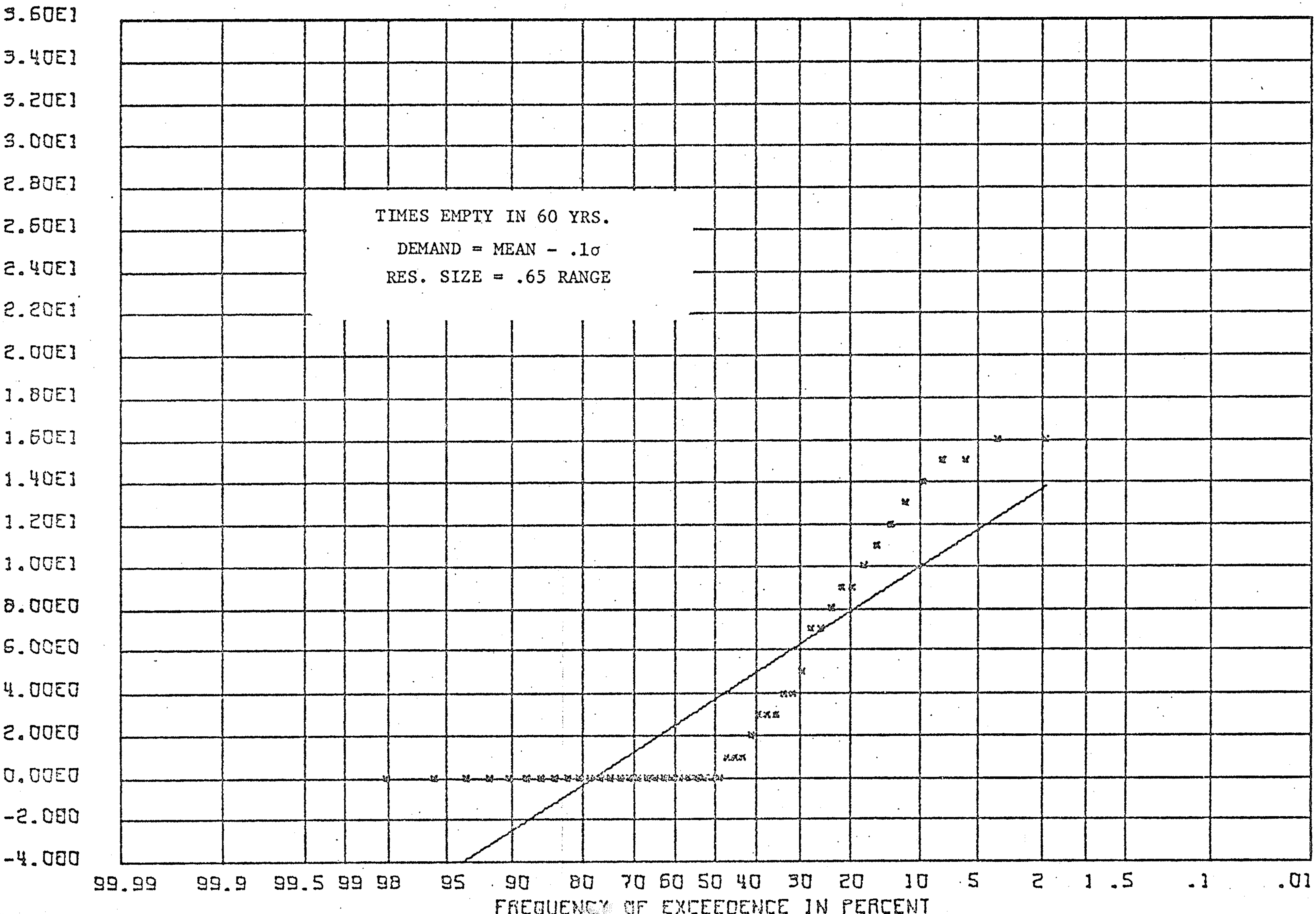
TIMES FULL IN 60 YRS.
DEMAND = MEAN - .1σ
RES. SIZE = .65 RANGE
3.60E1
3.40E1
3.20E1
3.00E1
2.80E1
2.60E1
2.40E1
2.20E1
2.00E1
1.80E1
1.60E1
1.40E1
1.20E1
1.00E1
8.00E0
6.00E0
4.00E0
2.00E0
0.00E0
-2.080
-4.080
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT

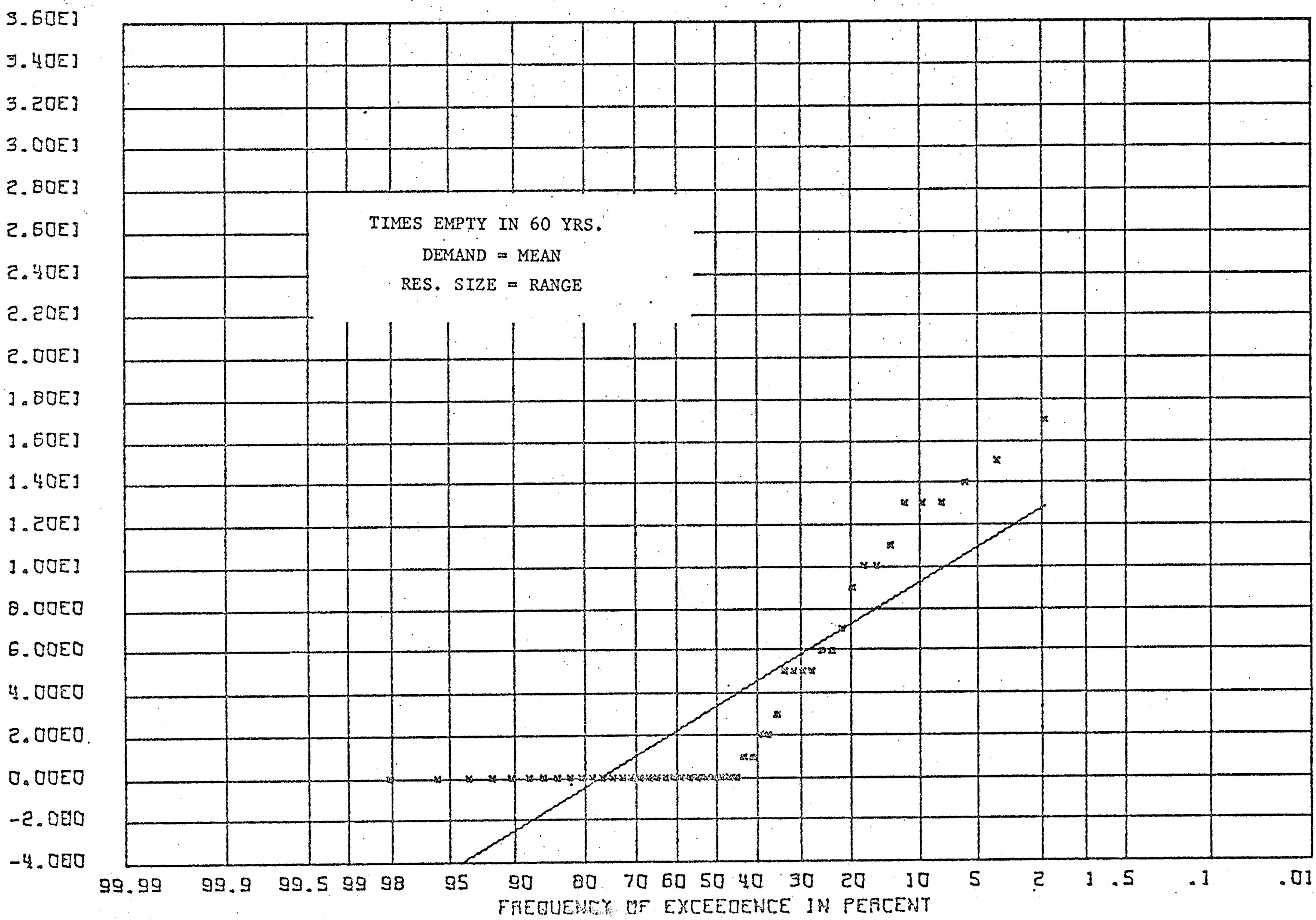
17


TIMES FULL IN 60 YRS.
DEMAND = MEAN - .2σ
RES. SIZE = .511 RANGE
3.60E1
3.40E1
3.20E1
3.00E1
2.80E1
2.60E1
2.40E1
2.20E1
2.00E1
1.80E1
1.60E1
1.40E1
1.20E1
1.00E1
8.00E0
6.00E0
4.00E0
2.00E0
0.00E0
-2.000
-4.000
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT

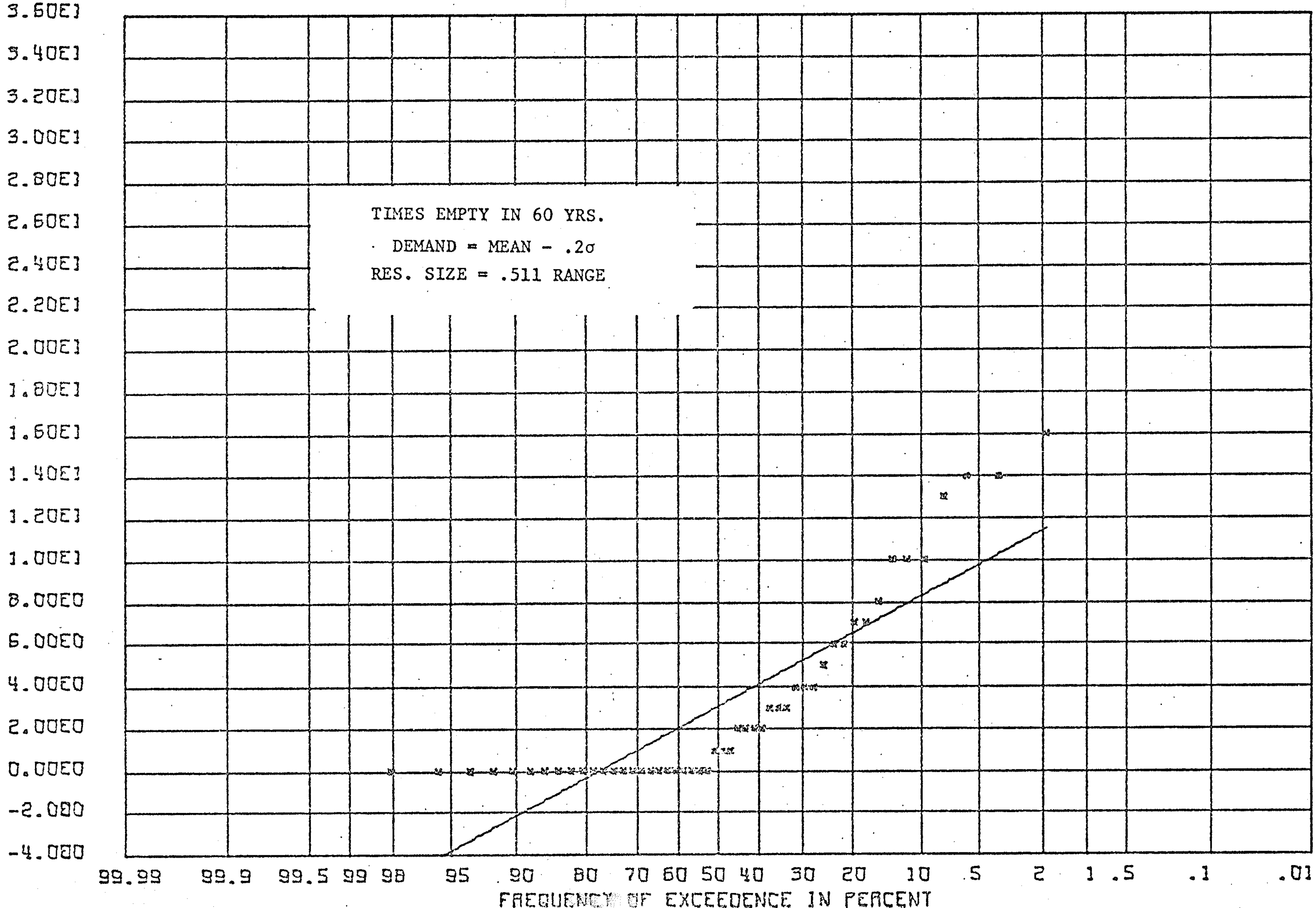


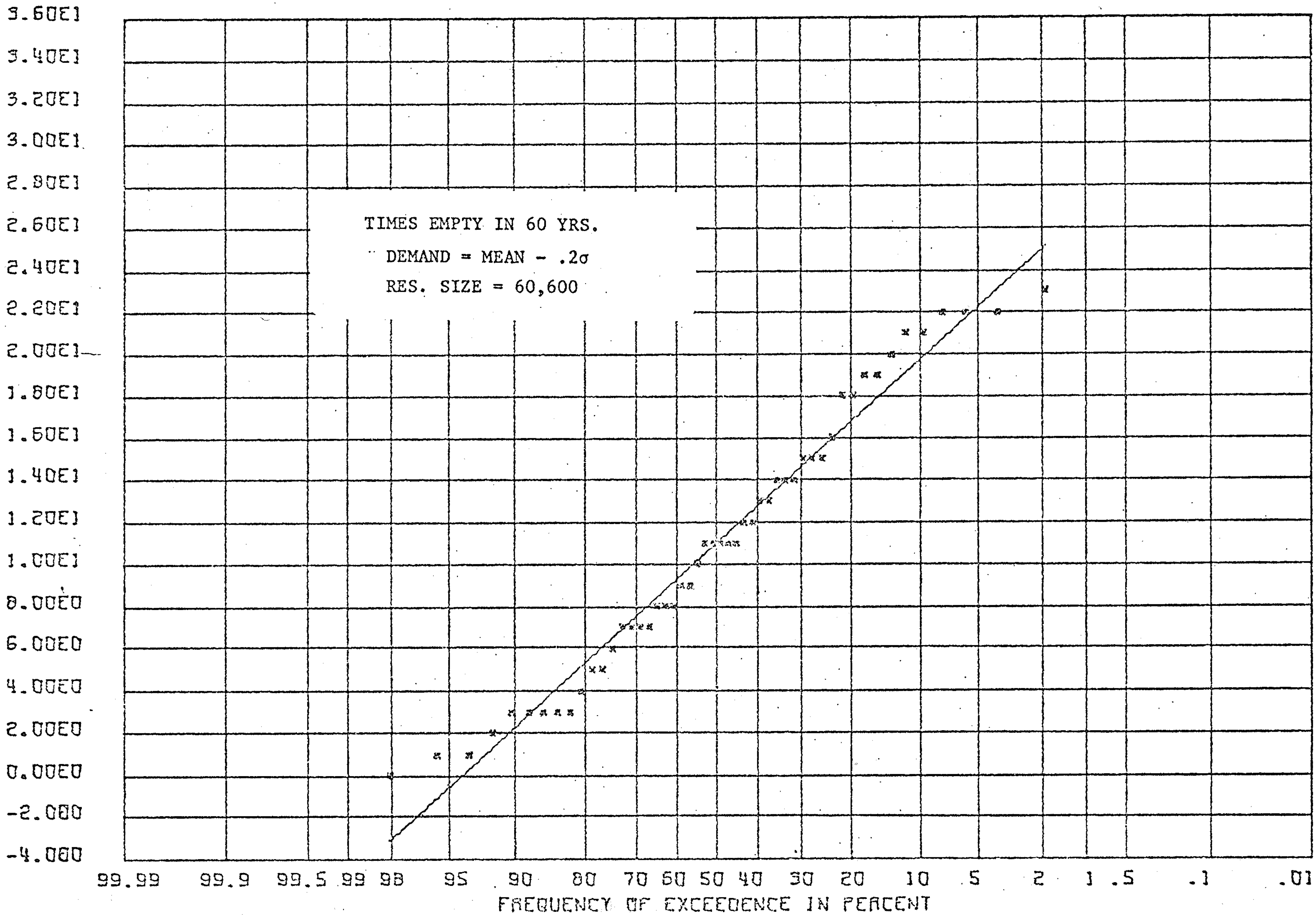
TIMES FULL IN 60 YRS.
DEMAND = MEAN - .2σ
RES. SIZE = 60,600
3.60E1
3.40E1
3.20E1
3.00E1
2.80E1
2.60E1
2.40E1
2.20E1
2.00E1
1.80E1
1.60E1
1.40E1
1.20E1
1.00E1
8.00E0
6.00E0
4.00E0
2.00E0
0.00E0
-2.000
-4.000
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT


TIMES EMPTY IN 60 YRS.
DEMAND = MEAN - .1σ
RES. SIZE = .65 RANGE
3.60E1
3.40E1
3.20E1
3.00E1
2.80E1
2.60E1
2.40E1
2.20E1
2.00E1
1.80E1
1.60E1
1.40E1
1.20E1
1.00E1
8.00E0
6.00E0
4.00E0
2.00E0
0.00E0
-2.0E0
-4.0E0
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT



TIMES EMPTY IN 60 YRS.
DEMAND = MEAN
RES. SIZE = RANGE
3.60E1
3.40E1
3.20E1
3.00E1
2.80E1
2.60E1
2.40E1
2.20E1
2.00E1
1.80E1
1.60E1
1.40E1
1.20E1
1.00E1
8.00E0
6.00E0
4.00E0
2.00E0
0.00E0
-2.000
-4.000
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT


TIMES EMPTY IN 60 YRS.
DEMAND = MEAN - .2σ
RES. SIZE = .511 RANGE
3.60E1
3.40E1
3.20E1
3.00E1
2.80E1
2.60E1
2.40E1
2.20E1
2.00E1
1.80E1
1.60E1
1.40E1
1.20E1
1.00E1
8.00E0
6.00E0
4.00E0
2.00E0
0.00E0
-2.000
-4.000
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT



TIMES EMPTY IN 60 YRS.
DEMAND = MEAN - .2σ
RES. SIZE = 60,600
3.60E1
3.40E1
3.20E1
3.00E1
2.80E1
2.60E1
2.40E1
2.20E1
2.00E1
1.80E1
1.60E1
1.40E1
1.20E1
1.00E1
8.00E0
6.00E0
4.00E0
2.00E0
0.00E0
-2.000
-4.000
99.99 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .1 .01
FREQUENCY OF EXCEEDENCE IN PERCENT

Appendix F

RESERVOIR REGULATION AND ECONOMIC ANALYSIS PROGRAM

including:

- Explanation of program
- Table of symbols
- Listing of program

APPENDIX F

RESERVOIR REGULATION AND ECONOMIC ANALYSIS PROGRAM

This program is used to carry out the process described in Chapter 3. This involves the evaluation of reservoir inflow, outflow, and storage as well as economic benefits (discounted to present worth) for each year of the flow series. The program is labelled in sections which are self-explanatory when referred to the following table of symbols:

Symbol	Explanation
FLOW (60)	Annual inflow to reservoir
DEMAND (3)	Annual flow demand
SIZE (3)	Reservoir size corresponding to above demand
SUMBEN	Summation of present values of economic benefits
STOR (61)	Reservoir storage for any year
REQ	Required flow supplement (positive or negative)
DEF	Reservoir deficit (i.e. size-storage)
NETFLO	Reservoir outflow

Symbol	Explanation
BEN	Economic benefits for each particular year
M, N	Counters for number of times full and times empty

Following is a listing of the program, as used for the analysis of 3 reservoir sizes and corresponding demands.

```
C
C
C
C           RESERVOIR REGULATION & ECONOMIC ANALYSIS PROGRAM
C
C
C           INPUT DATA: FLOW SERIES, DEMANDS, RESERVOIR SIZES
      REAL FLOW(60),DEMAND(3),STOR(61),SIZE(3),SUMBEN(3)
      READ(5,100)
      READ(5,101) (FLOW(I),I=1,60)
  100 FORMAT('1')
  101 FORMAT (6F12.0)
      J=1
      WRITE (6,100)
      DEMAND(1)=72188.0
      SIZE(1)=56600.0
      SUMBEN(J)=0.0
      STOR(1)=SIZE(J)
      M=0
      N=0
C
C
C           RESERVOIR REGULATION & STORAGE CALCULATIONS
      DO 10 I=1,60
      K=I+1
      REQ=DEMAND(J)-FLOW(I)
      DEF=SIZE(J)-STOR(I)
      IF(REQ.LT.0.0.AND.ABS(REQ).GT.DEF) GO TO 3
      IF(REQ.GT.0.0.AND.REQ.GT.STOR(I)) GO TO 4
C
      NETFLO=DEMAND(J)
      STOR(K)=STOR(I)-REQ
      GO TO 5
C
3     M=M+1
      NETFLO=DEMAND(J)
      STOR(K)=SIZE(J)
      WRITE(6,102)M,I
  102 FORMAT ('0','RES.FULL ',I2,' TIMES,YEAR=',I2)
      GO TO 5
C
4     N=N+1
      NETFLO=FLOW(I)+STOR(I)
      STOR(K)=0.0
      WRITE(6,103)N,I
  103 FORMAT('0','RES.EMPTY ',I2,' TIMES,YEAR=',I2)
5     CONTINUE
C
C
C           ECONOMIC ANALYSIS
      IF(NETFLO.GE.DEMAND(J)) GO TO 6
      BEN=1.50*(NETFLO/(DEMAND(J)))-0.50
      GO TO 7
6     BEN=1.0
7     CONTINUE
      PRES=BEN/(1.06**(I))
10    SUMBEN(J)=SUMBEN(J)+PRES
C
C
C           DATA OUTPUT
      WRITE (6,107)
  107 FORMAT('0',///)
      WRITE(6,104) SIZE(J),DEMAND(J)
  104 FORMAT('0','RES.SIZE=',F12.0,'          DEMAND=',F12.0)


      WRITE(6,105)SUMBEN(J)
  105 FORMAT('0','TOTAL PRESENT VALUE OF BENEFITS=',F12.3)
      WRITE(7,106)SUMBEN(J),M,N
  106 FORMAT (F15.3,2I15)
   11 CONTINUE
      STOP
      END
```

Appendix G

PROBPLOT - PROBABILITY PLOTTING PROGRAM

including:

- Explanation
- User's guide with examples
- Listing of program

CIVIL ENGINEERING PROGRAM LIBRARY
Department of Civil Engineering
University of Manitoba

PROBPLOT

Identification

PROBPLOT - This program produces a normal or log-normal probability plot on the Calcomp Plotter.

Programmed by Dick Beare.
Modified by D. B. Letvak, summer, 1972

Description

Up to 200 data points are plotted, using the Weibull method on linear or logarithmic probability paper. The linear scale is divided into 20 increments, and the logarithmic scale may have from one to four cycles. The probability scale is standard in both cases, and the whole plot is framed in an 8½" x 11" boundary.

Input Preparation

Card 1: Control Card (A3, 1X, A4, 1X, A4)

Columns

1 - 3 punch LIN if a linear probability plot is desired;
punch LOG if a log probability plot is desired.

5 - 8 punch NPOW if the powers are to be left off the vertical scale which describes the data values (e.g. 5.60 E4, will be written as 5.60 - an incomplete description of the value).
Leave blank if a complete description of the number in E-format is desired.

10-13 punch PLSQ to have the best fit line calculated by the method of least squares and plotted with the data.
punch NLSQ to suppress least squares fitting.

Card 2: Grid limits (2F10.3)

Columns

1-10 minimum ordinate (lower limit of grid)

11-20 maximum ordinate (upper limit of grid)

NOTE: that in the case of a LOG plot the second value should be equal to the first value multiplied by 10, 100, 1000 or 10,000.

(I5)

Card 3: Data Count (I5)

Column
1 - 5 the number of points to be plotted (N points), right-justified.

Next N cards: Data Cards (F15.3)

Column
1 -15 value to be plotted (one per card)

Last Card: (A4)

Column
1 - 4 punch STOP if no more data is to be processed.
punch CONT if another data group is to be processed; the next data group is presented in the same format as the previous one, from card 1 to this last card.

Example

This example plots two graphs and demonstrates log and linear probability plots, the best fit line through the data, and the different ways of labelling the values of the data (with and without powers).

The data cards are as follows:

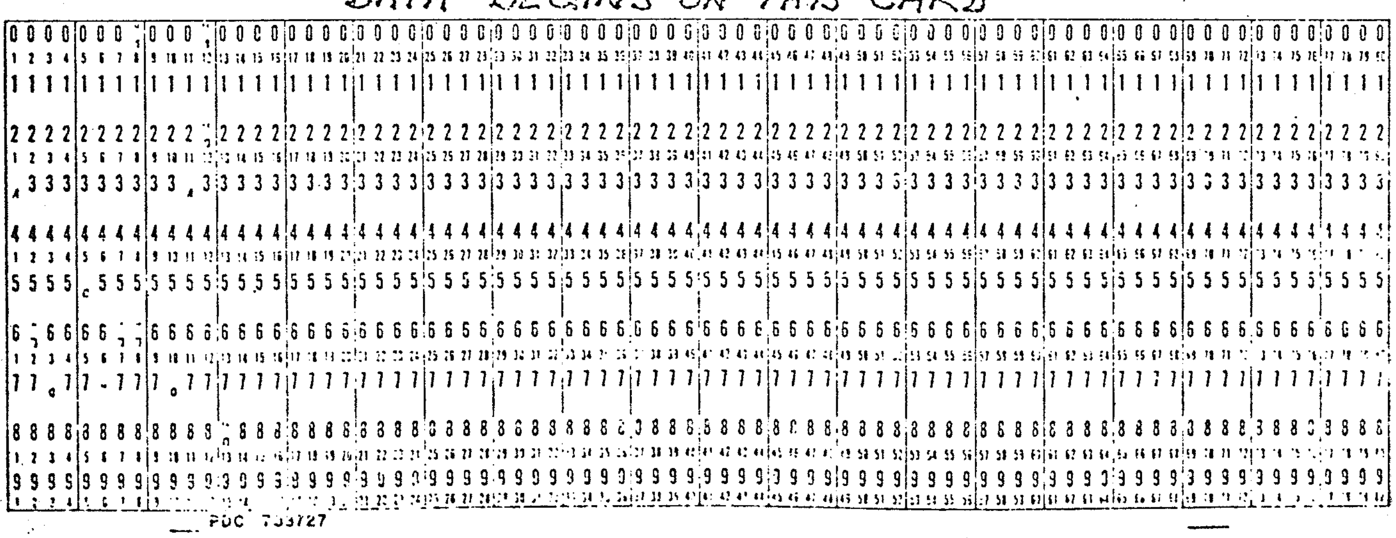
```
STOP
   19.8
    8.9
    2.5
    1.4
    0.98
    0.9
    0.45
   16.0
    0.3
   10.8
   10
0.0          20.0
LIN         NLSQ
```

GRAPH "B"

```
CONT
   19.8
   16.0
   10.8
    0.9
    0.45
    0.3
    2.5
    1.4
    0.98
    8.9
   10
   0.2          20.0
LOG NPOW PLSQ
```

GRAPH "A"

DATA BEGINS ON THIS CARD



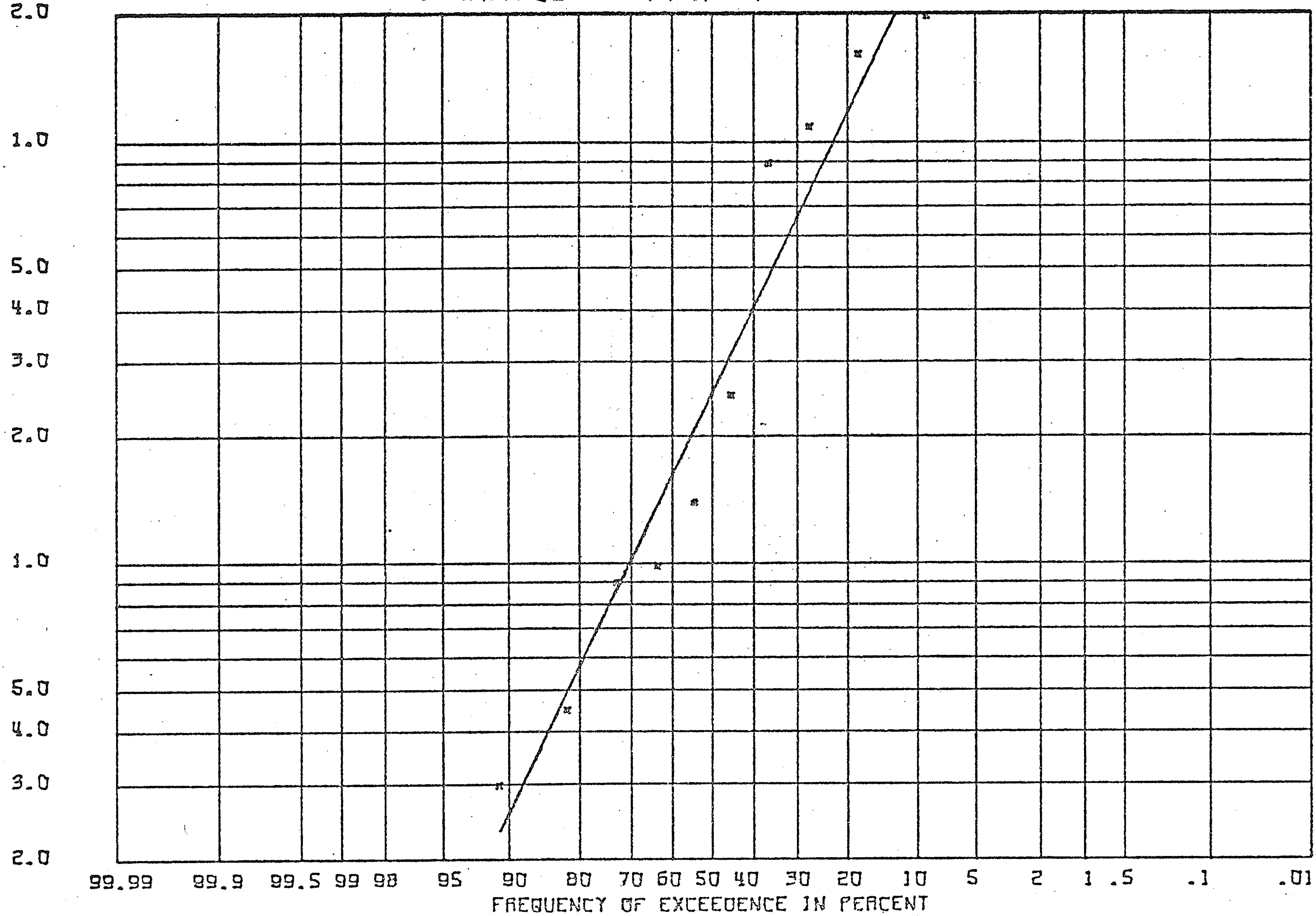
Output

Output consists of printed output as well as the plotter diagram.

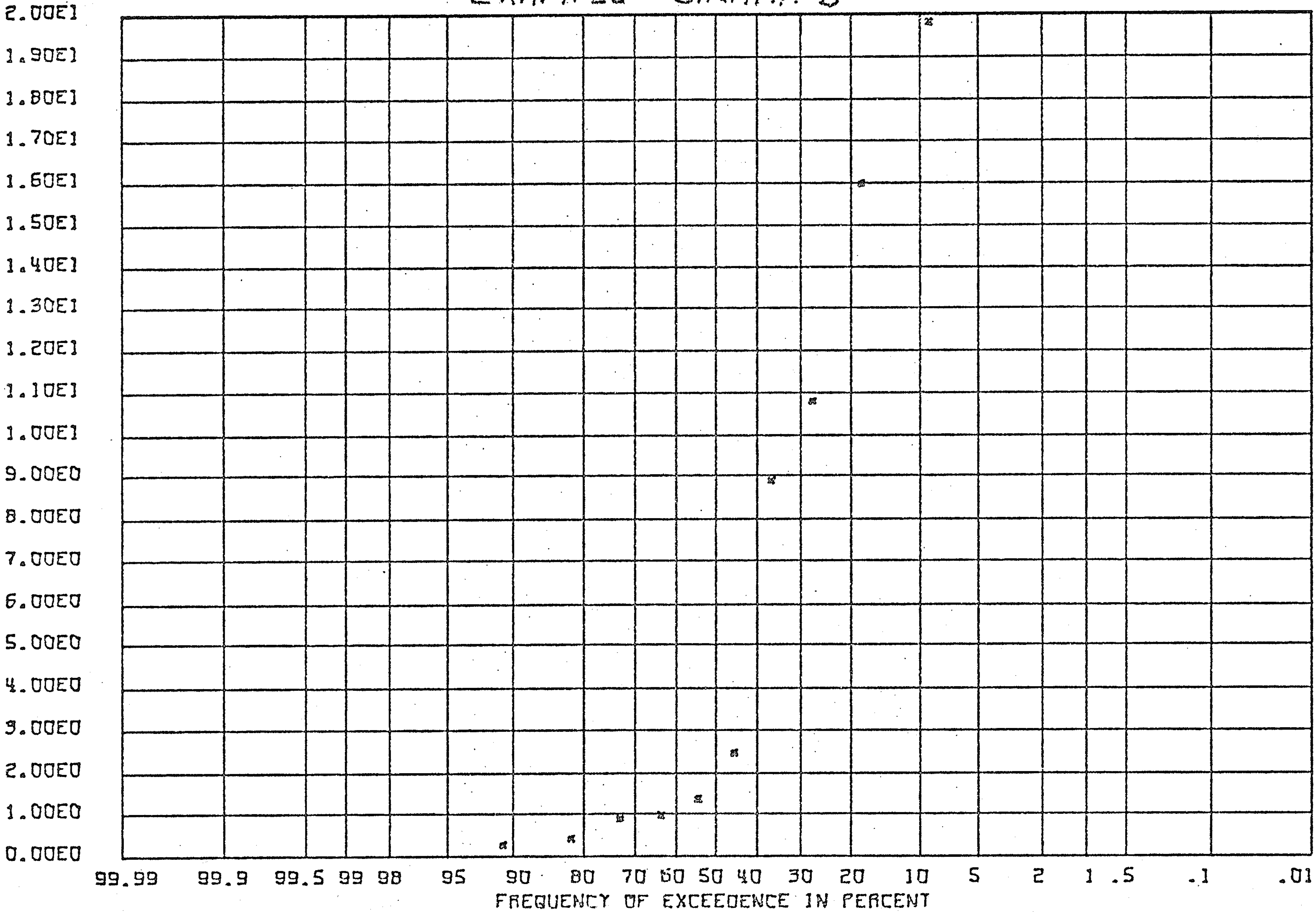
For each graph plotted, the printer output consists of a list of the data in the order submitted and a list of the data arranged from smallest to largest.

In the case where the least squares best fit line is plotted, the slope and intercept of this line are included in the printed output.

EXAMPLE - GRAPH "A"



EXAMPLE - GRAPH. "B"



```
//TAPE PLOTTAPE
//  EXEC FORTGCG,SIZE=90K
//FORT.SYSIN DD *
C---  **************************************************************
C---  **************************************************************
C---  PROGRAM FOR PLOTTING PROBABILITY .
C---  **************************************************************
C---  **************************************************************
      DIMENSION IBUF(1000),Y(204),X(200),BC(200),POS(200),Q(11),P(22),
     1VP(10)
      DATA P /.79,1.43,1.74,2.08,2.53,3.04,3.59,3.99,4.31,4.62,4.94,
     15.28,5.67,6.21,6.66,7.16,7.50,7.81,8.47,9.25/
      DATA Q /2.,3.,4.,5.,6.,7.,8.,9./
      INTEGER TYPE(6),RD,WT,VTYPE,PLTYPE,POWER
      DATA TYPE /'LOG','LIN','PLSQ','NLSQ','CONT','NPOW'/
      RD=5
      WT=6
      HSCALE=1.242
      YMIN=0.
      YMAX=6.55
      XMIN=0.
      XMAX=9.25
      ALONG=YMAX
      CALL PLOTS(IBUF,1000)
      CALL PLOT(0.,-10.8,-3)
      XX=.5
      CALL PLOT(6.0,10.8,-3)
C---  **************************************************************
C---  READ IN "LIN" OR "LOG" IN THE FIRST THREE COLUMNS,NPOW OR 4 BLANKS
C---  IN COLUMN'S FIVE THROUGH EIGHT AND "PLSQ" OR"PLND" WITH THE
C---  FIRST LETTER IN COLUMN TEN AND THE LAST LETTERIN COLUMN THIRTEEN.
C---  LIN  MEANS PLOT LINEAR HORIZONTAL GRID
C---  LOG  MEANS PLOT LOGARITHMIC HORIZONTAL GRID
C---  NPOW MEANS THE POWERS ON THE HORIZONTAL GRID LABBELING WILL BE
C---  LEFT OFF THE REAL NUMBERS.IF BLANKS ARE ENCOUNTERED THE POWERS
C---  WILL BE PRINTED ON THE GRAPH.
C---  PLSQ  MEANS TO CALCULATE THE BEST FIT LINE THROUGH THE POINTS
C---  BY THE METHOD OF LEAST SQUAES AND PLOT IT.
C---  NLSQ MEANS THAT THE LEAST SQUARES  COMPUTATION IS NOT REQUIRED.
C---  **************************************************************
    1 READ(RD,200)VTYPE,POWER,PLTYPE
  200 FORMAT(A3,1X,A4,1X,A4)
C---  **************************************************************
C---  READ IN LOWEST GRID LINE VALUE AND HIGHEST GRID LINE VALUE FOR
C---  FOR HORIZONTAL SCALE.
C---  **************************************************************
      READ(RD,201)EXTL,EXTH
  201 FORMAT(2F10.3)
C---  **************************************************************
C---  READ IN NUMBER OF POINTS TO BE PLOTTED
C---  **************************************************************
      READ(RD,203)MM
  203 FORMAT(I5)
C---  **************************************************************
C---  READ IN VERTICAL POINTS
C---  **************************************************************
```

```
      READ(RD,204)(BC(I),I=1,MM)
204   FORMAT (F15.3)
C
C
C     ARRANGE FLOWS FROM SMALLEST TO LARGEST
712   FORMAT(////)
      PRINT 712
      PRINT 99,(BC(I),I=1,MM)
      CALL SORTS(BC,MM)
      PRINT 712
      PRINT 99,(BC(I),I=1,MM)
99    FORMAT ('0',10F10.1)
C
C
      IF(VTYPE.EQ.TYPE(1).OR.VTYPE.EQ.TYPE(2)) GO TO 206
      WRITE(WT,205)
  205 FORMAT(' INPUT ERROR -- PROGRAM REQUIRES TYPE OF HORIZONTAL GRID
     1BEFORE EXECUTION CAN CONTINUE')
      CALL EXIT
  206 CALL PLOT(0.,-10.8,-3)
      CALL PLOT(0.,0.6,-3)
  207 IF(VTYPE.EQ.TYPE(2)) GO TO 300
C---  ..................................................................
C---  PLOT OF LOGARITHMIC HORIZONTAL GRID
      M=1
  208 BCT=EXTL*1.00001*10.**M
      IF(BCT.GE.EXTH) GO TO 209
      M=M+1
      GO TO 208
  209 IF(M.LE.4) GO TO 211
      WRITE(WT,210)
  210 FORMAT(' PROGRAM WILL NOT ATTEMPT MORE THAN 4 CYCLE LOGARITHMIC P
     1PER')
      CALL EXIT
  211 FAC=M
      GL=EXTL
      N=0
  212 IF(GL.LT.10.) GO TO 213
      N=N+1
      GL=GL/10.
      GO TO 212
  213 IF(GL.GE.1.) GO TO 214
      N=N-1
      GL=GL*10
      GO TO 213
  214 NN=0
      G=GL
      DO 215 I=1,9
      IF(G.GT.9.9) NN=1
      G=G+(1.*(10.**NN))
      Q(I)=G
  215 CONTINUE
      GH=GL*10.
      AGL=ALOG10(GL)
      AGH=ALOG10(GH)
      DIFF=AGH-AGL
```

```
      VSC=ALONG/DIFF
      XN=FAC*(-.8)
      XN1=FAC*(-.5)
      XN2=FAC*(-.4)
      HEIGHT= FAC * .1
      XMAX=XMAX*FAC
      FAC=1.0/FAC
      PFAC=0.0
      CALL FACTOR (FAC)
      FPN=GL
      CALL NUMBER(XN,YMIN,HEIGHT,FPN,0.0,1)
      IF(POWER.EQ.TYPE(6)) GO TO 10
      CALL SYMBOL(XN1,YMIN,HEIGHT,1HE,0.0,1)
      FPN=N
      CALL NUMBER(XN2,YMIN,HEIGHT,FPN,0.0,-1)
   10 CALL PLOT(0.0,0.0,3)
      DO 217 J=1,M
      DO 12 I=1,9
      ALQ= ALOG10(Q(I))
      VAB=ALQ-AGL
      VP(I)=(VAB*VSC)+PFAC
   12 CONTINUE
      DO 216 I=1,9,2
      K=I
      LL=0
   14 IF(Q(K).GT.50.) GO TO 13
      IF(Q(K).GT.5.9.AND.Q(K).LT.9.9) GO TO 13
      FPN= Q(K)
      IF(FPN.LT.9.5) GO TO 540
      INN=-1
      FPN=FPN*(10.**INN)
  540 CALL NUMBER(XN,VP(K),HEIGHT,FPN,0.0,1)
      IF(POWER.EQ.TYPE(6)) GO TO 13
      CALL SYMBOL(XN1,VP(K),HEIGHT,1HE,0.0,1)
      IF(FPN.GT.1.5) GO TO 11
      N=N+1
   11 FPN=N
      CALL NUMBER(XN2,VP(K),HEIGHT,FPN,0.0,-1)
   13 LL=LL+1
      IF(LL.GT.1) GO TO 216
      CALL PLOT(XMIN,VP(K),3)
      CALL PLOT(XMAX,VP(K),2)
      K=K+1
      IF(K.GT.8) GO TO 216
      CALL PLOT(XMAX,VP(K),3)
      CALL PLOT(XMIN,VP(K),2)
      GO TO 14
  216 CONTINUE
      PFAC=VP(9)
      CALL PLOT(XMIN,VP(9),3)
  217 CONTINUE
      CALL PLOT(0.0,0.0,3)
      XMAX=XMAX*FAC
      CALL FACTOR(1.0)
C---  ..........................................................
C---  CALCULATION OF VERTICAL LOGARITHMIC POSTION
```

```
      AEXTL=ALOG10(EXTL)
      AEXTH=ALOG10(EXTH)
      DIFF=AEXTH-AEXTL
      VSCALE=ALONG/DIFF
      IF(BC(MM).GT.BC(1)) GO TO 411
      MR=MM
      DO 409 I=1,MM
      Y(I)=BC(MR)
      MR=MR-1
  409 CONTINUE
      DO 410 I=1,MM
      BC(I)=Y(I)
  410 CONTINUE
  411 DO 218 I=1,MM
      ABC=ALOG10(BC(I))
      ABOVE=ABC-AEXTL
      Y(I)=ABOVE*VSCALE
  218 CONTINUE
      GO TO 219
C---  ..........................................................
C---  PLOT LINEAR HORIZONTAL GRID
  300 GL=ABS(EXTL)
      N=0
  700 IF(GL.LT.9.9999) GO TO 701
      GL=GL*.01
      N=N-1
      GO TO 700
  701 U=(EXTH-EXTL)/20.
      G=EXTL
      FPN=EXTL*10.**N
      CALL NUMBER(-.9,YMIN,.1,FPN,0.0,2)
      IF(POWER.EQ.TYPE(6)) GO TO 703
      CALL SYMBOL(-.5,YMIN,.1,1HE,0.0,1)
      FPN=-N
      CALL NUMBER(-.4,YMIN,.1,FPN,0.0,-1)
  703 VSCALE=6.55/20.
      V=0
  302 V=V+VSCALE
      IF(V.GT.YMAX) GO TO 303
      LL=1
  707 G=G+U
  704 FPN=G*10.**N
      IF(FPN.LE.9.9999) GO TO 705
      N=N-1
      GO TO 704
  705 CALL NUMBER(-.9,V,.1,FPN,0.0,2)
      IF(POWER.EQ.TYPE(6)) GO TO 706
      CALL SYMBOL(-.5,V,.1,1HE,0.0,1)
      FPN=-N
      CALL NUMBER(-.4,V,.1,FPN,0.0,-1)
  706 IF(LL.GT.1) GO TO 302
      CALL PLOT(XMIN,V,3)
      CALL PLOT(XMAX,V,2)
      V=V+VSCALE
      IF(V.GT.YMAX) GO TO 303
      CALL PLOT(XMAX,V,3)
```

```
      CALL PLOT(XMIN,V,2)
      LL=2
      GO TO 707
303   VSCALE=6.55/(EXTH-EXTL)
      DO 304 I=1,MM
      Y(I)=(BC(I)-EXTL)*VSCALE
  304 CONTINUE
C---  .......................................................................
C---  PLOT VERTICAL GRID
  219 DO 220 I=1,19,2
      J=I
      CALL PLOT(P(J),YMIN,3)
      CALL PLOT(P(J),YMAX,2)
      J=I+1
      CALL PLOT(P(J),YMAX,3)
      CALL PLOT(P(J),YMIN,2)
  220 CONTINUE
      CALL PLOT(XMIN,YMIN,3)
      DO 221 I=1,1
      CALL PLOT(XMAX,YMIN,2)
      CALL PLOT(XMAX,YMAX,2)
      CALL PLOT(XMIN,YMAX,2)
      CALL PLOT(XMIN,YMIN,2)
  221 CONTINUE
C---  .......................................................................
C---  CALCULATION OF WEIBULL PLOTTING POSITIONS
      PM=MM+1
      DO 222 I=1,MM
      PI=PM-I
      POS(I)=PI/PM
  222 CONTINUE
C---  .......................................................................
C---  HORIZONTAL AXIS LETTERING
      CALL SYMBOL(-.3,-.2,.1,47H 99.99   99.9  99.5 99 98   95   90   8
     1 70 60,0.0,47)
      CALL SYMBOL(4.4,-.2,.1,49H 50 40  30  20    10    5    2   1 .5
     11     .01,0.0,49)
      CALL SYMBOL(2.62,-.4,.1,37H   FREQUENCY OF EXCEEDENCE IN PERCENT,
     1.0,37)
C---  .......................................................................
C---  CALCULATION OF HORIZONTAL POSITION AND PLOT OF POSITIONS.
      DO 61 I=1,MM
      APOS=1-POS(I)
      IF(APOS-0.5)30,40,50
   30 R=APOS
      T=SQRT(ALOG(1./R**2))
      ORD=T-(2.515517+0.802853*T+0.010328*T**2)/(1.+1.432788*T+0.189269
     1*T**2+0.001308*T**3)
      DIST=ORD*HSCALE
      X(I)=4.625-DIST
      GO TO 60
   40 X(I)=4.625
      GO TO 60
   50 R=1.0-APOS
      T=SQRT(ALOG(1./R**2))
      ORD=T-(2.515517+0.802853*T+0.010328*T**2)/(1.+1.432788*T+0.189269
```

```
     1*T**2+0.001308*T**3)
      DIST=ORD*HSCALE
      X(I)=DIST+4.625
   60 CALL SYMBOL(X(I),Y(I),.05,4,0.0,-1)
   61 CONTINUE
C---  ..........................................................
C---  CALCULATION OF BEST FIT LINE
      IF(PLTYPE.NE.TYPE(3)) GO TO 108
   62 XNO=MM
      XSUM=0.
      YSUM=0.
      X2SUM=0.
      EXY=0.
      DO 70 I=1,MM
      XSUM=XSUM+X(I)
      YSUM=YSUM+Y(I)
      X2SUM=X2SUM+(X(I)**2)
      EXY=EXY+(X(I)*Y(I))
   70 CONTINUE
C---  SLOPE OF LINE
      B=((XNO*EXY)-(XSUM*YSUM))/((XNO*X2SUM)-(XSUM**2))
      WRITE(WT,65) B
   65 FORMAT(' SLOPE OF LINE =',F10.3)
C---  INTERCEPT
      A=((X2SUM*YSUM)-(EXY*XSUM))/((XNO*X2SUM)-(XSUM**2))
      WRITE(WT,75) A
   75 FORMAT(' INTERCEPT =',F10.3)
C---  ..........................................................
C---  PLOTTING BEST FIT LINE .
      IF(A) 500,503,504
  500 XT=ABS(A/B)
      XD=X(MM)-XT
      YL=XD*B
      IF(YL.LE.6.55) GO TO 510
      YL=6.55
      X(MM)=XT+(YL/B)
  510 IF(X(1)-XT)501,501,502
  501 CALL PLOT(XT,YMIN,3)
      CALL PLOT(X(MM),YL,2)
      GO TO 108
  502 YS=B*(X(1)-XT)
      CALL PLOT(X(1),YS,3)
      CALL PLOT(X(MM),YL,2)
      GO TO 108
  503 YS=B*X(1)
      YL=B*X(MM)
      IF(YL.LE.6.55) GO TO 509
      YL=6.55
      X(MM)=XT+(YL/B)
  509 CALL PLOT(X(1),YS,3)
      CALL PLOT(X(MM),YL,2)
      GO TO 108
  504 YS=A+(B*X(1))
      YL=A+(B*X(MM))
      IF(YL.LE.6.55) GO TO 508
      YL=6.55
```

```
      X(MM)=(6.55-A)/B
  508 CALL PLOT(X(1),YS,3)
      CALL PLOT(X(MM),YL,2)
  108 CALL PLOT(-1.1,-0.5,3)
      CALL PLOT(-1.1,7.9,2)
      CALL PLOT(9.9,7.9,2)
      CALL PLOT(9.9,-0.5,2)
      CALL PLOT(12.00,0.0,-3)
C---  ****************************************************************
C---  READ IN THE WORD "CONT" IF MORE DATA IS TO BE PROCESSED AND
C---  PLOTTED .
C---  READ IN THE WORD "STOP" IF NO MORE DATA IS TO BE PROCESSED.
C---  ****************************************************************
      READ(RD,511,END=999) IROUTE
  511 FORMAT(A4)
      IF(IROUTE.EQ.TYPE(5)) GO TO 1
  999 CALL PLOT(12.00,0.0,999)
  109 CALL EXIT
      END
C
C
      SUBROUTINE SORTS(BC,N)
      REAL BC(N),LARGE
      M=N
8     LARGE=BC(1)
      K=1
      DO 3 I=1,M
      IF(LARGE.GE.BC(I)) GO TO 3
      LARGE=BC(I)
      K=I
3     CONTINUE
      TEMP=BC(M)
      BC(M)=BC(K)
      BC(K)=TEMP
      M=M-1
      IF(M.NE.0)GO TO 8
      RETURN
      END
C
C
C     REPLACE THIS CARD WITH A /* CARD
//GO.PLOTTAPE DD DSN=PLOT,DISP=SHR
//GO.SYSIN DD *
LOG       PLSQ
   0.2        20.0
  10
   8.9
   0.98
   1.4
   2.5
   0.3
   0.45
   0.9
  10.8
  16.0
  19.8
```

```
CONT
LIN        NLSQ
    0.2          20.0
   10.8
   10
    0.3
   16.0
    0.45
    0.9
    0.98
    1.4
    2.5
    8.9
   19.8
STOP
```