THE BENEFIT-COST RATIO OF A
FLOOD CONTROL PROJECT
AS A STOCHASTIC VARIABLE

THE DEVELOPMENT OF A MARKOVIAN
FLOW GENERATION MODEL AND ITS
APPLICATION TO THE EVALUATION
OF FLOOD CONTROL BENEFITS

A THESIS

by

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Abstract

This thesis develops a flow generation model using the Markov stochastic process and describes its application to the evaluation of flood control benefits.

The model is developed specifically for the study of variability of the benefit-cost ratio as presented in part I. In dealing with a particular flood control project the authors have found a surprisingly large possible variation in B/C ratios. It is suggested that the traditional method of presenting the B/C ratio really yields insufficient information on which to base a decision.

Four ancillary studies present an analysis of several factors such as interest rate and project size in the light of the proposed method. The study is proposed as a first step towards formulating a more realistic and reliable decision process for water resource projects.

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CHAPTER I

STATISTICAL BACKGROUND

A. Flow simulation

This study lends itself very well to the use of flow simulation techniques. The method generates a synthetic series of random flows following a desired statistical distribution using parameters obtained from the historic record. Benefits, or damages associated with each flow, are then calculated, converted to present value. Repetition of the procedure gives a frequency curve of benefit-cost ratios for the particular project.

Theoretically, flow simulation techniques are perhaps not necessary in order to calculate the probability distribution of the benefit-cost ratio. Using mathematical techniques, equations could be found to represent the various input data (historical flow - frequency curve, project benefit curves, etc.). The entire problem could then be solved analytically. However, the mathematical difficulties are so great that this would certainly not be expedient. Streamflow generation uses a stochastic model to solve the problem experimentally.

In evaluation of the approach, it must be realized that the technique of flow simulation adds no new information to the analysis or accuracy to the results. Since the statistical parameters of the generated population are the same as those estimated from the historic data, the new information is subject to errors directly proportional to unrepresentative features of the historic record. That is to say that the historic record may not be representative of the flows which occur in the future. The flow simulation technique can also yield only approximate solutions which are subject to random errors. These two limitations are studied in some detail in the thesis. The influence of a non-representative historic record is assessed to some degree by testing the sensitivity of the system to changes in this data. The possibility of random error is checked by testing the system stability using several runs with different random flows.

The major advantage of the sequential generation process is the production of flow series that are as likely to occur as a repetition of the historic record. The application of these flow series to the project produces a range of B/C ratios rather than an average B/C ratio which results from the traditional method of assuming repetition of the historic record during the project's existence. It is possible to produce as many series of generated hydrologic data as desired for use in the economic analysis. This provides flexibility in that a broad spectrum of results may be analyzed using different sets of generated data.

The generation technique used in this thesis assumes that the flows follow a Markov stochastic process. The basis of this technique is that the state of a system at any time depends upon a knowledge of the state at the immediately preceding time and a random uncorrelated component. A mean and standard deviation may be determined mathematically from the historical record and a serial correlation coefficient may be found by assessing statistically the effect of flow at time "t-1" upon flow at time "t". These parameters may then be used in the Markov equation to generate a synthetic flow series. The Markov equation is:

$$x_t = r\ (x_{t-1}) + (1-r)\ \overline{x} + s_x\ (1-r^2)\ (\mathrm{ORD})$$

where: x_t is the value of the flow at time t.

x_{t-1} is the value of the flow at the preceding time.

r is the first order serial correlation coefficient between flows.

ORD is a random variable in standardized form following a given probability distribution.

$\overline{x}$ is the mean of the generated flows.

s_x is the standard deviation of the generated flows.

The mean, the standard deviation, and the serial correlation coefficient are determined from the historic record as will be explained below.

The standardized random variable is obtained by first generating a uniformly distributed random variable between 0 and 1 and then transforming this variable into one which follows the desired distribution.

The process of generating uniformly distributed random numbers is accomplished by use of a scientific subroutine package (RANDU) of the IBM-360-65 University computer. Since the calculation is performed mathematically on the computer, the numbers generated are better described as pseudo-random numbers. The program is as follows:

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

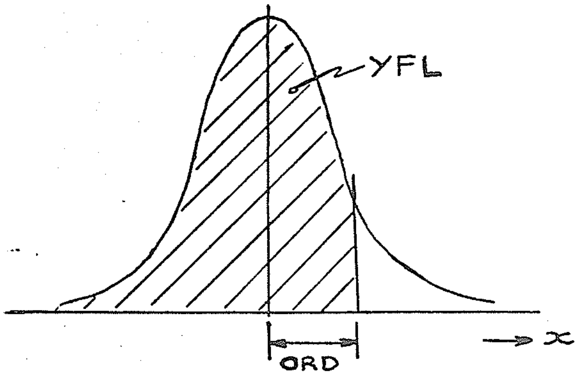
where * denotes multiplication
and E-9 $\equiv (10)^{-9}$

The technique involved is as follows: A

random odd number (IX) of between 1 and 9 digits is read by the subroutine. An IY value is calculated as shown. It is also an odd integer value. A test for negative IY value is used. If IY is negative, it is converted to a positive value by statement #5. The uniformly distributed random number (YFL) is then calculated in statements #6 & 7. The numbers involved in the subroutine are chosen such that the resulting YFL value always occurs as a number between 0 and 1 providing the IX input value is an odd integer of 1 to 9 digits. The resulting IY value may be used as IX value for the second generation of a random number.

The uniformly distributed variable, YFL, is used to obtain corresponding values of ORD (standardized normally distributed random variable by the relation:

$$YFL = \int_{-\infty}^{ORD} F\ (x)\ dx$$



A normal curve approximation[3] is used to approximate the normal curve function with an error involved of less than 4.5 x 10^{-4}.

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[3] Abramowitz & Steegun, "Handbook of Mathematical Functions", U.S. Dept. of Commerce, p. 933.

The historic mean may be determined in one of several ways. One method is to simply calculate the arithmetic mean from the historic flow record. Another method is to derive the mean from existing frequency curves. If the flows are normally distributed, the mean simply corresponds to the 50% level of exceedence on the frequency curve. If the flows follow a different statistical pattern, transformation equations[4] must be used to obtain the desired mean.

The standard deviation may also be calculated arithmetically or derived from a historical frequency curve. If the flows are normally distributed, the standard deviation is simply the value of the range of flows falling between exceedence levels of 87.13% and 50%. If the flows follow a different statistical pattern, transformation equations[4] must again be used.

The serial correlation coefficient is determined by plotting an arithmetically best fit line (least squares method) through a standardized[5] plot of the flow at time "t" (dependent variable) versus the flow at time

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[4] V.T. Chow, "Handbook of Applied Hydrology", p. 8-17 gives conversion equations for a log normal distribution.

[5] A particular value of a variable may be standardized by subtracting the mean and dividing the result by the standard deviation. This yields a variable whose mean is o.o and standard deviation = 1.0 (i.e. a standardized variable).

"t-1" (independent variable). By definition, the angle of regression (x) is the angle which the best fit line forms with the axis of the independent variable. The serial correlation coefficient (r) is defined as:

$$r = \tan x$$

The value of r^2 is a direct measure of the portion of the flow at time "t" which is determined by the value of flow at time "t-1".

B. Flow simulation as applied to the Red River

The previous section has described the general method of flow simulation which is applied in this thesis. This section descibes how this method is applied to synthetic flood peak generation for the Red River at Winnipeg.

The input parameters are determined by analyzing a frequency curve of flood peaks and the historic record of flood peaks. The flood frequency curve given in the Royal Commission Report (Plate #4) is adapted for thesis purposes in Fig. 3.1. From this figure it may be observed that flood peaks above 60,000 cfs.[6] follow very closely a straight line on log normal probability paper. This strongly indicates that the historical flood peaks above 60,000 cfs. on the Red River at Winnipeg follow a

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[6] Note: This thesis only concerns itself with flood peaks greater than 64,900 cfs. since this is the flow at which flood damages begin in absence of a floodway.

log-normal distribution.

Both theoretical and empirical evidence suggest that there is justification for assuming log-normality of flood peaks. Kuiper[7], in analyzing 100 frequency curves for North American rivers concluded that "when maximum annual flood flows . . . are plotted on logarithmic probability paper, they tend to fall on a straight line." Chow[8] has considered the situation where the occurrence of a random hydrologic event can be represented by multiplying the effect of a number of contributing factors which are random variables themselves. The central limit theorem[9] then shows that, as the number of such causative factors is large, the logarithm of the hydrologic occurrence becomes normally distributed.

This argument seems valid when applied to the hydrologic event, the flood peak on the Red River. The major factor involved in producing a Red River spring flood peak is the spring snowmelt. Many causative factors

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[7] E. Kuiper, "100 Frequency Curves of North American Rivers" ASCE Proc., Paper 1395.

[8] V.T. Chow, Proc. ASCE Vol. 80, p. 536, pp. 1-25, Nov. '54.

[9] Briefly stated, the theorem states that if the number of considerations is large, the (theoretical) sampling distribution of the mean can be closely approximated with a normal distribution.

combine to produce this spring run-off. Depth, time, and density of winter snowfall, winter snowmelt, ground water index, type of soil, spring rainfall, presence of vegetation and auxiliary drainage, wind, humidity, temperature, and snow albedo are by no means a complete list. Many of these factors must be multiplied in order to obtain their combined effect on the peak river discharge. This suggests a log-normal distribution. It would appear that the use of a log-normal distribution for flood peaks is justified and it seems to be borne out by the straight line tendency of the frequency curve on log-normal probability paper.

Once a straight line is applied to the frequency curve of recorded flood peaks (by "least squares" method or by eye,) confidence bands may be applied to the line. The most restrictive bands available in tables (80%) are applied to historic flood peak data in Fig. 3.2 using the Kolmogorov-Smirnov Test.[10] The 80% statistical confidence expressed by these bands signifies that, if a point falls outside these limits, there is an 80% probability of this occurrence being due to chance only.

The results in Fig. 3.2 indicate that the frequency curve of flood peaks falls well within the 80% level of significance, thus allowing the assumption that

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[10] The Kolmogorov-Smirnov Test, American Statistical Association Journal, March, 1951.

the flood peaks are log normally distributed.

The recorded historical flood peaks of Fig. 3.2 could be used to determine statistical properties for the Markov generation process. However, the authors decided to use the extrapolated, upper part of the Royal Commission's frequency curve (Fig. 3.1) in order to make the study results comparable to those of the Royal Commission's study.[11]

The mean and standard deviation of the peak flows may now be determined from the Royal Commission frequency curve (Fig. 3.1). This is accomplished first by transferring the log-normal line to normal probability paper. The normal mean and normal standard deviation may be read directly from this graph[12]. These parameters may be converted to corresponding log-normal mean and standard deviation by means of transformation equations[4].

The serial correlation coefficient is determined using the method described in Section A of this chapter. The process is performed mathematically, rather than graphically, with computer program REGAN, which is presented in Appendices B & C. The results of the computer run

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[11] Note: Since this thesis is concerned only with flood flows which cause damage (i.e. 64,900 Cfs.), a best fit line is drawn only through flood flows greater than 60,000 cfs.

[12] The mean corresponds to a 50% level of exceedence while the standard deviation is the range of flood peaks falling between 87.13% and 50% levels.

reveal nearly zero serial correlation between annual flood peaks on the Red River at Winnipeg. This is not surprising. It could hardly be expected that the magnitude of a spring flood in one year (depending mainly on winter and spring conditions) could be affected by the size of the previous spring flood.

Having assumed or calculated the various input parameters of statistical distribution, mean, standard deviation, and serial correlation coefficient for the particular case of flood peaks on the Red River, the Markovian model is used to generate a synthetic record of flood peaks of any desirable length.

C. Reliability, Stability, and Sensitivity of Results

As mentioned previously, it must be ensured that the results of sequential generation are both reliable and stable before the synthetic flow model can be accepted as useful.

Reliability may be checked in several ways. Several randomly chosen synthetic flood peak series were plotted with the extrapolated Royal Commission flood frequency curve of Fig. 3.1. All generated series fell well within the 80% level of significance indicating that the generated series are, in fact, closely representative of the occurrence of historical floods. Synthetic peak series are checked by comparing the actual frequency of occurrence of synthetic floods of several sizes against the frequency of occurrence predicted by the Royal Commission frequency curve. The results, which are summarized below, again indicate close agreement between synthetic and historic records.

TABLE 3.1

Flood Magnitude	Historical Frequency	Synthetic Frequency
greater than 65,000 cfs.	20 in 200 years	19.2 in 200 years
greater than 200,000 cfs.	0.666 in 200 years	0.633 in 200 years

Stability of results is analyzed by observing the change in the final result (frequency curve of benefit-cost ratios) when the procedure is repeated with a new batch of generated flows. This is done by repeating the computer runs several times using a different starting value (IX) in the computer program FLOGEN. Results, as presented in Tables 5.1, 5.2, 5.3, 5.4, and 5.5 and Figs. 3.3 and 3.4 indicate that the variation in the results due to the random nature of the flow generation process is acceptable.

A knowledge of the sensitivity of the system to a change in the parameters of the flood frequency distribution is desirable in order to estimate the possible effect on the final results of using a non-representative historic record or frequency curve.

The recorded flood data for the river may have been taken from a predominately wet or dry period of the population of floods which exist for the particular river. This would mean that it is probable that flood peaks which occur over the life of the project possess statistical properties different than the historic record.

An analysis of the economic effect of such a condition may be accomplished by using the mean end standard deviation obtained from the Royal Commission's flood frequency curve to generate an estimate of the population mean and standard deviation. These generated parameters may then be used to generate a sequence of flows which are applied to the project. These flows are statistically distinguishable from the Royal Commission's frequency curve and yield a frequency curve of B/C ratios which may be compared to those obtained by using the Royal Commission mean and standard deviation. A comparison of these frequency curves demonstrates the system sensitivity to use of a non-representative historic record.

By the central limit theorem[9], it may be stated that the means of samples taken from a population which follows any statistical distribution are normally distributed. The standard deviation of the sample means is:

$$\sigma_e = \sigma/\sqrt{N}$$ (refer to note on Page 16)

where: N = number of variables in the sample
σ = sample standard deviation

Thus an estimate of the population mean may be generated using the equation:

$$\hat{\mu} = \bar{x} + (\text{ORD})\, \sigma_e$$

where $\hat{\mu}$ = generated estimate of population mean
$\bar{x}$ = sample mean
ORD = random normally distributed standardized variable
σ_e = standard deviation of sample means

Similarly, it may be proved by statistical theory that sample variances follow a chi-squared distribution as follows:

$$S^2 \sim \frac{\sigma^2}{N-1}\, \chi^2 (N-1)$$

where N = number of variables in sample
σ = sample standard deviation
S = estimate of population standard deviation.

A chi-squared value may be generated for this equation using an equation from "The Handbook of Mathematical Functions" (Page 941) which is stated as:

$$\chi^2 \approx N \left\{ 1 - \frac{2}{9N} + (\text{ORD}) \sqrt{\frac{2}{9N}} \right\}^3$$

where ORD and N are defined previously in this chapter.

Sixty means and sixty standard deviations were generated and several values possessing a high deviation from the norms were chosen. The historic (sample) mean (31,570 cfs.) and the historic standard deviation (29,893 cfs.) may be compared with these values.[13]

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[13] Note: In each case, only one generated parameter is used. That is, in runs #1 and 2, a generated mean is used in conjunction with the historic standard deviation (29,893 cfs.). In runs #3 and 4, a generated standard deviation is used in conjunction with the historic mean (31,570 cfs.). The results, therefore, indicate system sensitivity to the one generated parameter.

TABLE 3.2

		Prob. of Exceed.
Run #1. Generated Mean	26,274 cfs.	3.3%
Run #2. Generated Mean	33,193 cfs.	72.1%
Run #3. Generated Std. Dev.	33,193 cfs.	98.36%
Run #4. Generated Std. Dev.	26,274 cfs.	1.60%

The significance of the probability value may be explained as follows. In the first case, assuming the hypothesis that the population mean is actually 26,274 cfs., the probability that the sample mean could be 31,570 cfs. or higher is 3.3%. Since this probability is small, then the hypothesis is unlikely so the assumption of a 26,274 cfs. population mean represents an unlikely (extreme) value.

Similarly, in run #2, assuming the hypothesis that the population standard deviation is actually 33,193 cfs., the probability that the sample standard deviation could be 29,893 cfs. or lower is 100.0 - 98.36 = 1.64%. Therefore, this also represents an extreme value.

The results of this analysis demonstrate the sensitivity of the frequency curve of B/C ratios to a relatively large change in either mean or standard deviation of the historic flood peak record.

Referring to Figure 5.7 and Table 5.5, it may be seen that, for run #1, which uses a generated mean with a 3.3% probability of exceedence, the mean B/C ratio decreases by 15 % while the standard deviation decreases by 7 %.

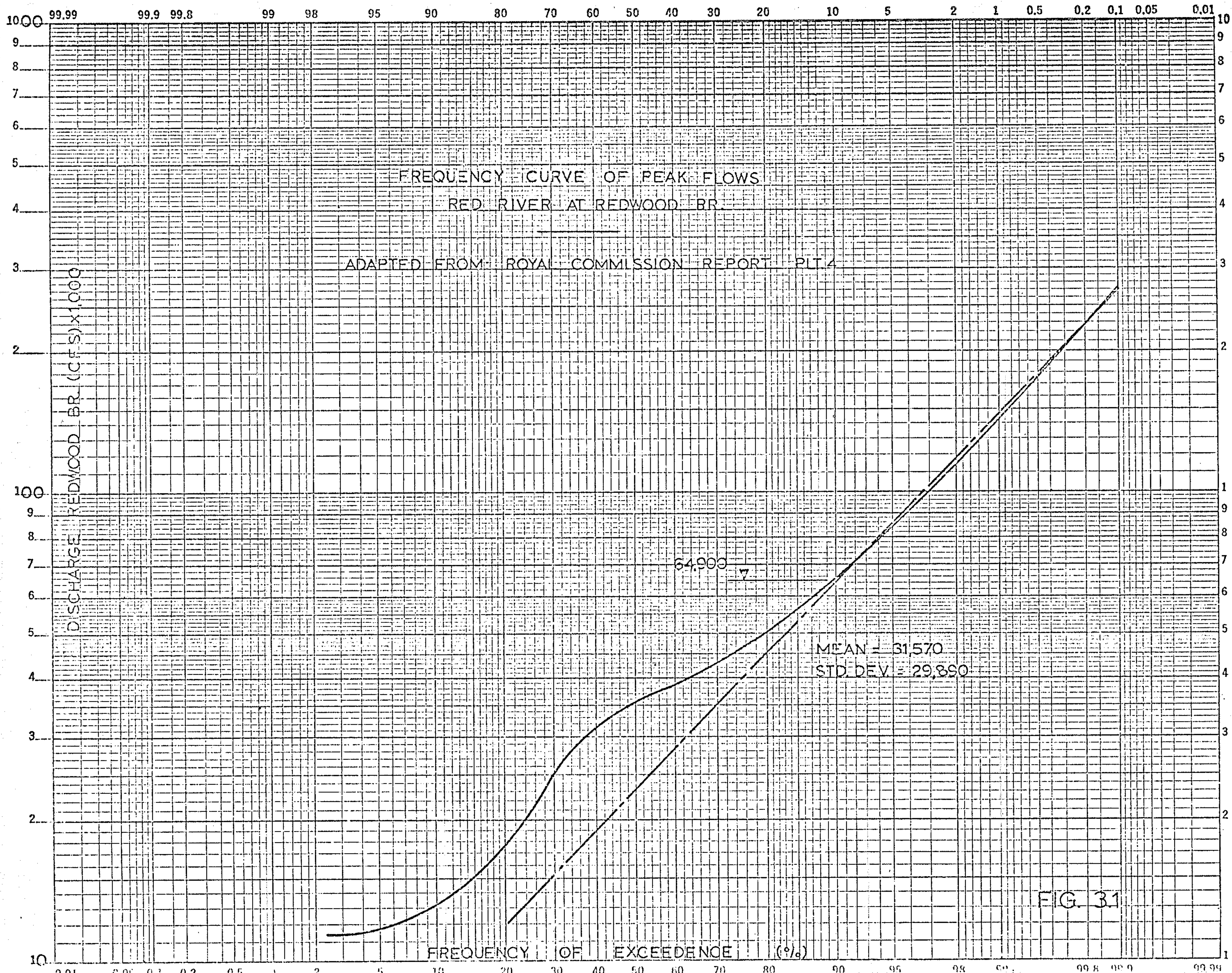
The results may be summarized as follows:

TABLE 3.3

	Synthetic Flood Peaks		B/C ratio freq. curve	
	Gen. Parameter	Prob. of Exceed.	Mean	Standard Dev.
Run #1	Mean	3.3%	2.4700	1.9777
Run #2	Mean	72.1%	3.0657	2.1916
Run #3	Std. Dev.	98.4%	3.4836	2.4756
Run #4	Std. Dev.	1.6%	2.1628	1.7033
Historic			2.9119	2.1258

In view of the evidence, it is suggested that the application of this particular flow simulation technique to this particular problem yields results which appear to be both reliable and stable.

NOTE: It is realized that, strictly speaking, the t-distribution should be used to generate estimates of the population mean. However, with the large sample size available, the normal distribution serves as an adequate approximation of the t - distribution.


FREQUENCY CURVE OF PEAK FLOWS
RED RIVER AT REDWOOD BR.

ADAPTED FROM ROYAL COMMISSION REPORT PLT.4

FIG. 3.1

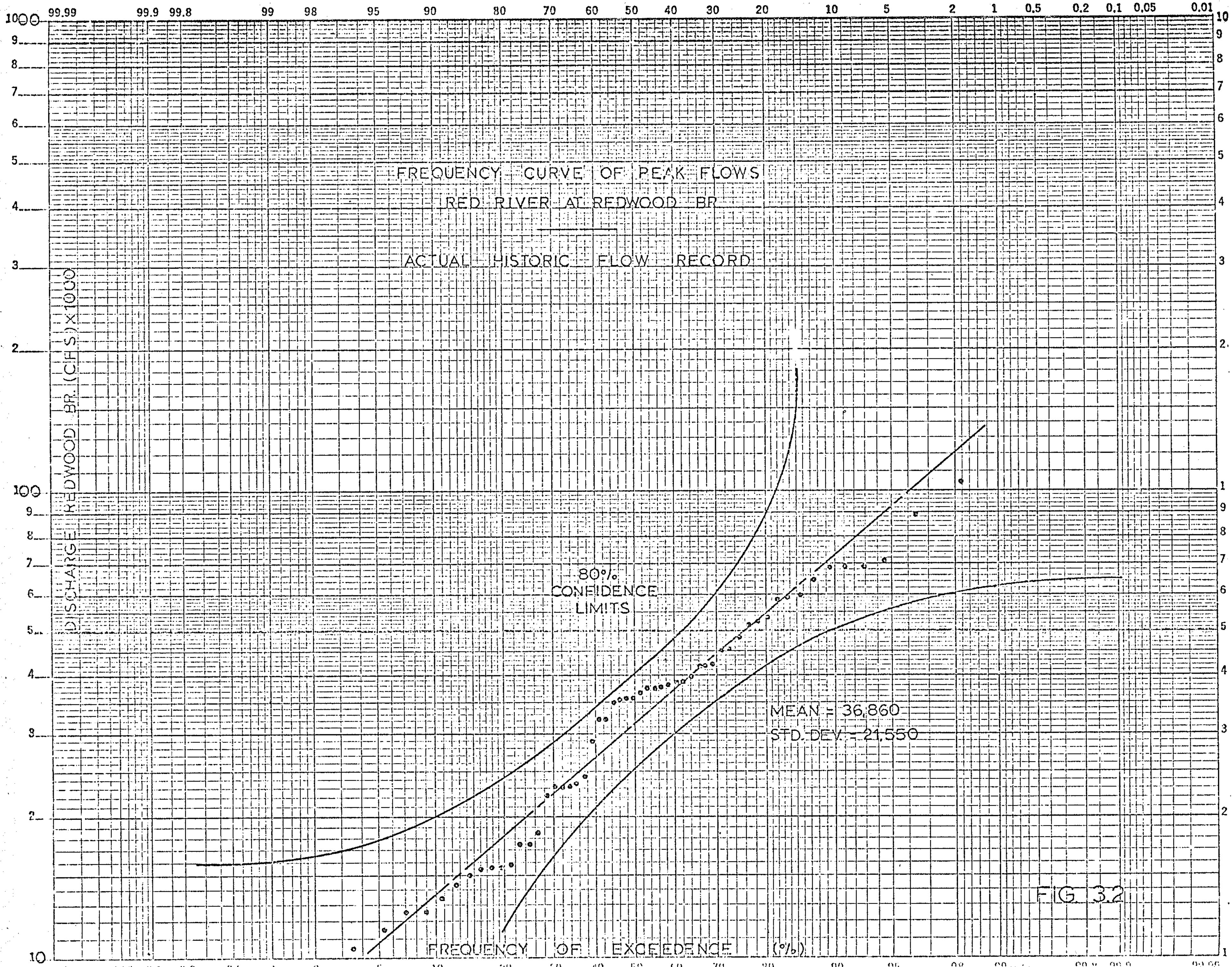

FREQUENCY CURVE OF PEAK FLOWS
RED RIVER AT REDWOOD BR
ACTUAL HISTORIC FLOW RECORD
80% CONFIDENCE LIMITS
MEAN = 36,860
STD. DEV. = 21,550
DISCHARGE REDWOOD BR. (CFS) X 1000
FREQUENCY OF EXCEEDENCE (%)
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01
10
100
1000

FIG. 3.2

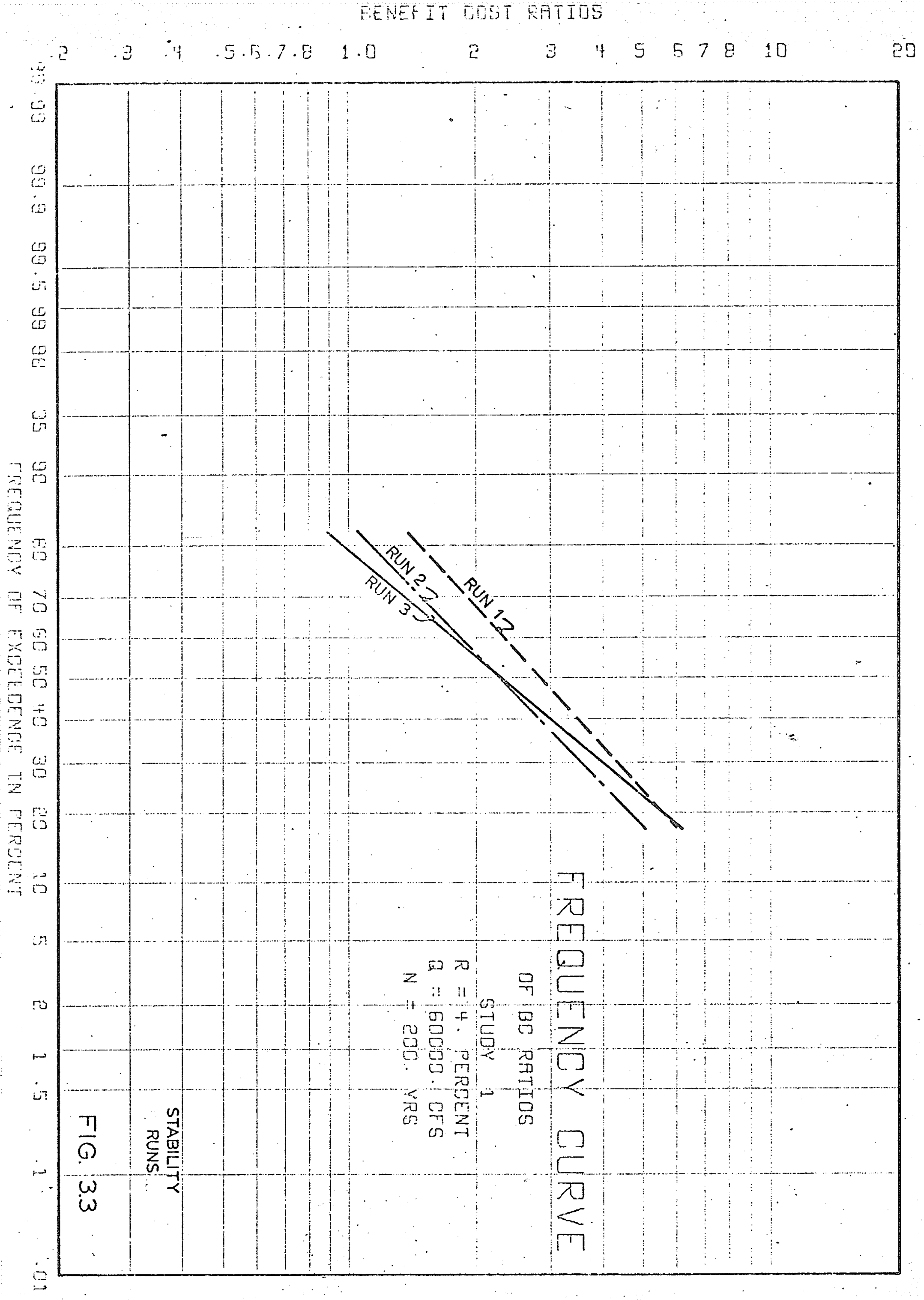

BENEFIT COST RATIOS
.2
.3
.4
.5
.6
.7
.8
1.0
2
3
4
5
6
7
8
10
20
FREQUENCY OF EXCEEDENCE IN PERCENT
99.99
99.9
99.5
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
.5
.1
.01
RUN 1
RUN 2
RUN 3
FREQUENCY CURVE
OF BC RATIOS
STUDY 1
R = 4. PERCENT
Q = 60000. CFS
N = 200. YRS
STABILITY RUNS

FIG. 3.3

CHAPTER II

METHODOLOGY

This chapter deals with the method followed in computing benefit-cost ratios. The main computer programs described herein apply to all five studies and the changes of input to each of the five studies are given. Before the advent of the electronic computer, studies such as the one undertaken here were impractical due to their vast computational load. The computer allows many calculations to be done in a short time and the effects of many different conditions may be studied.

The first step which must be performed is the generation of synthetic flood flow series. These must bear the same characteristics as the historic flow record such that the generated flow series and the historic flow record are statistically indistinguishable. The generated flow must then be applied to a mathematical model of the flood control scheme to determine the benefits of the project. The costs are then calculated and compared with the benefits to give a benefit-cost ratio. This procedure is repeated until enough benefit-cost ratios have been calculated to obtain a probability distribution of benefit-cost ratios.

a) Streamflow Generation

The synthetic streamflow generation program makes use of the statistical theory presented in the previous chapter. The input data for the program includes the mean and standard deviation which the generated flows are to have. The mean and standard deviation were determined from the flood frequency curve given by the Royal Commission.[14] The values determined were a mean of 31,570 cfs. and a standard deviation of 29,893 cfs. A correlation coefficient is included in the input to take into account any annual persistence in yearly flood peaks. The correlation coefficient found for the historic flows, when corrected for degrees of freedom was 0.0. This was expected due to the generally random nature of flood peaks. The other input to the program consists of a random integer value to start the random value generator and several counters indicating the number of cycles to be performed by the program.

The mean and standard deviation used as input are those for a log-normal distribution (as given by the Royal Commission). To facilitate the generation of random variables and to give these variables a new distribution the mean and standard deviation must be normalized

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[14] Report of the Royal Commission on Flood Cost Benefit, Winnipeg, Manitoba. Dec. 1958, Plate #4.

(made to correspond to a normal distribution). This is done with two transformation equations.[15]

$$\text{std} = \sqrt{\log\ (1 + \text{sd}^2)\ (\text{mean}^2)}$$

$$\text{amean} = \log\ (\text{mean}) - \frac{\text{std}^2}{2}$$

where: std = normal standard deviation
sd = log normal standard deviation
mean = log normal mean
amean = normal mean.

The logarithms are natural logarithms to the base e. A uniformly distributed random variate is then generated. This is done with a Scientific Subroutine Package program stored in the University of Manitoba's IBM 360 computer. The variables generated are between 0 and 1.0. The uniformly distributed random variables are then converted to normally distributed standardized random variates in subroutine "Norm". To do this the random variables are considered to represent areas under a normal curve. The areas are then converted to ordinates by means of normal curve approximation formulae.[16]

The normally distributed random variates (with a mean of 0.0 and a standard deviation of 1.0) are then converted to normally distributed random variates with a

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[15] V.T. Chow, Handbook of Applied Hydrology pp. 8-17.

[16] Abramowitz and Stegun, Handbook of Mathematical Functions (U.S. Dept. of Commerce 1958) pp. 932-933.

given mean and standard deviation. This forms the random part of the synthetic flood flow. The serially correlated portion is added and the equation becomes:

$$X = R * Y + x_p * std * \sqrt{1-R^2} - amean\ (R-1.0)$$

where: X = normally distributed variate with given mean and standard deviation.
Y = flow in year N-1
x_p = normally distributed random variate with mean of 0.0 and standard deviation of 1.0
R = correlation coefficient
std = normal standard deviation
amean = normal mean.

The normally distributed variate this generated must be then changed to match the distribution of the recorded flood peaks (log-normal). This is done by taking the natural antilogs of X and the result is a log normally distributed peak flow with a given mean and standard deviation.

By putting the above basic steps in a "do loop" the procedure is repeated many times to get sixty records of peak flows, with each record being 200 years long. A flow chart of the program used, description of variables, and an actual computer print out are included in Appendices B and C.

It should be noted that in Studies 1 and 2 flows are generated for 200 year periods. In Study 3 flows are generated for periods of 50, 100 and 200 years. Studies 4 and 5 again return to 200 year periods.

In all studies except Study 5 the mean and standard deviation used to generate the flows are found from the Royal Commission frequency curve. Since Study 5 deals with changes in this frequency curve different means and standard deviations are used. This is covered in more detail later in the chapter.

b) Benefit Evaluation

The output from the computer program "FLOGEN" consists of synthetic flow records. The flows are printed out for immediate reference and checking and also placed on magnetic tape for use in program "PRSWTH" which computes the benefit-cost ratios for the particular projects.

In addition to the synthetic flows which are read from the tape, three basic curves are needed. Natural conditions and improved condition rating curves, given in fig. 4.1, and a stage damage curve shown in fig. 4.4. Different rating curves are used for different assumed floodway capacities. (Fig. 4.2, Fig. 4.3). In all cases the curves are identical to those given by the Royal Commission[17] or were prepared from data given in the report. The details of the calculations for these curves

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[17] Report of the Royal Commission on Flood Cost Benefit, op. cit.

are given in a subsequent section. The remaining input consists of costs at each discount rate and the discount rates themselves. The calculation of costs depends on the study being performed and are also discussed in a subsequent section.

The program first reads the three curves used, the discount rates, and the costs. The flows are then read singly and tested for magnitude to insure that they fall within the limits of the rating curves given. Flows which are found to fall outside the upper limit on the natural conditions rating curve[18] are arbitrarily given a value equal to damage associated with the maximum probable flood.[19] The discharge below which no damage resulted,[20] according to values from the rating curve and stage damage curve, were not considered. If the flows are within the given range the flow values are applied to the natural conditions rating curve to determine natural stage. This is done by a method of straight line interpolation by the computer and the points on the graph are chosen in such

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[18] Flows greater than 270,000 cfs.

[19] A damage of $948,000,000

[20] Flows less than (or equal to) 64,900 cfs.

a manner as to make the error incurred negligible. When the natural stage is determined a similar interpolation process is employed to find the damages under natural conditions from the stage damage curve.

The synthetic flows are then compared to the improved conditions rating curve and the stage in the affected area is found. Again a value below which there are no damages under improved conditions[21] is found and flows below this level are considered to have natural damages only. When the "improved stage" has been found the stage-damage curve is again used to determine the damages incurred under improved conditions with the particular flow. Therefore each flow which falls above the zero damage level for natural conditions has two damages associated with it; a damage which occurs under natural conditions and a damage which occurs under improved conditions with the flood control project in place. The damages prevented or benefits accruing from the flood control project, are then the difference between the two damage values.

The value of benefits thus determined is for one flow at one time in the future. It is necessary now to determine the present value of the benefits associated

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[21] Flows less than (or equal to) 116,500 cfs.

with the particular flow. In the computer program this is done in a separate subroutine called "PRWTH". The present worth factors which are multiplied by the benefits are calculated in the program according to the standard formula for a single payment. Therefore, in effect, the benefits at the present time of a flood prevented by the flood control scheme sometime in the future are determined.

The above procedure is carried out for all the flows generated in the particular series. As each flow is processed the computer program automatically places the following flow an additional year in the future. Each flow is associated with one year even though there may be no damages caused by it. When the present worth of the benefits of each flow in the series is determined they are added up and represent the total present worth value of the benefits accruing from the project for that particular flow sequence.

The next step is the application of costs. The costs are used directly as read in and all calculations to determine cost values are done outside the computer program. The value read in is the total present worth of costs and when the total present worth of benefit is divided by this value the result is a cost-benefit ratio. This procedure yields one benefit-cost ratio for one particular flow series.

The computer performs the above calculations as many times as there are flow series. Therefore many different benefit-cost ratios are determined depending on the particular stream flow sequence. When all the benefit-cost ratios have been determined and printed out, subroutine "FREQ" is employed to put the values in descending order and calculate their Weibull plotting positions. The actual position is calculated with the formula:

$$\text{FREQ} = \frac{M}{N+1} \text{ X } 100$$

Where: FREQ = frequency of occurrence in percent
M = relative position of variable (benefit-cost ratio)
N = number of variables

The output from "FREQ" consists of the benefit-cost ratios and their plotting positions. This information is printed out and in addition punched on cards to facilitate plotting of the results.

c) Frequency Curve Plotting

The authors were fortunate in having at their disposal a CALCOMP plotter connected to an IBM 1620 computer. Since a great many frequency curves resulted from the calculations a program was written for the IBM 1620 to plot the results in final form. A program was written which converted the frequency curve plotting positions to rectangular co-ordinates (in terms of inches for the CALCOMP plotter).

Several frequency curves of benefit-cost ratios were plotted by hand on different types of frequency paper. It was observed that the best straight line occurred on log-normal paper. Since the authors were more interested in general trends than in extreme values it was decided to use a log normal plotting system and to use as final results the least square best-fit straight line through the centre 2/3 of the data.

The computer program calculates and draws a log normal grid and then plots the points on this grid. To find the rectangular co-ordinate vertical plotting position the log of the benefit-cost ratio is taken and then converted to inches according to a scale factor which depends on the desired height of the graph. The horizontal plotting position is determined by using the normal curve approximation formula previously cited and converting all plotting positions in percents to standard deviations from the mean. The standard deviations are then converted to inches with a horizontal scale factor depending on the length of the graph.

When the points are plotted the middle two thirds of the points are used to calculate a best-fit straight line by the least squares method. The line is drawn on the graph according to a calculated ordinate and slope.

It will be noticed that the line drawn is drawn only through the points used in its calculation. The plotting of the points is facilitated by an internally stored subroutine called "PLOT" and the characters are drawn using a subroutine called "CHAR".

Essentially then, the calculations are now complete. Several areas which were previously mentioned will now be discussed.

d) Rating Curves

The rating curves used are calculated entirely from data given in the engineering and economic reports. The natural conditions rating curve shown in fig. 4.1 is as given in the Report of the Royal Commission[22] and the Engineering Investigations Board.[23] The improved conditions rating curve is calculated with the data given in the Report of the Royal Commission[24]. The table given therein gives the assumed operation of the floodway and, for each flow in the entire system, the flow in the river alone is given. This value is converted to stage and plotted against the flow in the entire system. The curve

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[22] Report of the Royal Commission on Flood Cost Benefit, op. cit., Plate 24.

[23] Report on Investigations into Measures for the Reduction of the Flood Hazard in the Greater Winnipeg Area, March 1953, Plate 24, Appendix "C."

[24] Report of the Royal Commission on Flood Cost Benefit, op. cit., pp. 72, Table 10.3.

must then be corrected for backwater according to data given in the Preliminary Engineering Reports.[25] Most of the work requires only the rating curves (natural and improved) for the 60,000 cfs. floodway. These curves are given in fig. 4.1. For Study 4 rating curves are required for the 40,000 cfs. and 80,000 cfs. floodways. These are calculated in the same manner as for the 60,000 cfs. floodway rating curves with data from the same sources. See figs. 4.2 and 4.3.

e) Stage-Damage Curves

The stage-damage curve remains the same for all studies in all cases. The Royal Commission in their calculations divided Winnipeg and surrounding area into several reaches, and worked separately with each reach, adding the damages. The approach used here was to consider the Greater Winnipeg area as one unit. For this reason the curves given in the report of the Royal Commission[26] were combined with the assumption of progressive dike

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[25] Report on Investigations into Measures for the Reduction of the Flood Hazard in the Greater Winnipeg Area, op. cit., Plate 13, Appendix "G."

[26] Report of the Royal Commission on Flood Cost Benefit, op. cit., Plates 6, 7, and 8.

failure. The final result is shown on Fig. 4.4. Table 4.1 shows the damages in each of the Greater Winnipeg reaches assuming progressive dike failure[27] and the total values are used for the curve.

f) Costs

Each study is designed to demonstrate a particular aspect of the variation of the benefit-cost ratio with streamflow. Since the benefit-cost ratio is strongly dependent on costs it follows that the costs must vary from study to study. To facilitate the use of the same basic computer programs for each study the costs were calculated outside the computer program and entered as input data depending on the particular study. In all studies costs values were based on discount rates varying from 1 to 8%. Basically the procedure was to calculate costs as annual charges and then convert these annual charges to present value. All basic assumptions and cost figures were taken from the Royal Commission Report in order to make comparisons possible. A description of the cost values for each study follows.

Study 1

Study 1 shows the variation of the benefit-cost

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[27] The Report of the Royal Commission shows three curves. The values used were determined by adding up damages obtained by using curve 2.

ratio with streamflow for five different discount rates; 1, 2, 4, 6, and 8%. This study may be considered the anchor study to which all other studies may be referred and compared. It considers the 60,000 cfs. floodway recommended by the Royal Commission on Flood Cost Benefit and its purpose, besides showing the variation of the benefit-cost ratio with streamflow, is to show the effect of varying discount rates on the final results.

In this study costs are calculated as the present worth of all charges associated with building and maintaining the 60,000 cfs. floodway in perpetuity. For all intents and purposes the term perpetuity may be replaced by a period of 200 years. This may be explained by considering benefits. If a flood occurs in the future and a floodway is in place the present value of damages prevented or benefits will be less than the actual value at the time of the occurrence of the flood. The longer the period of time between the present and the incurring of a benefit, the smaller the present value. (i.e. present worth factors decrease with increasing length of time). When the total present worth of all floods in the future is found, it may be observed that benefits occurring after a 200 year period do not add significantly to the total. Therefore considering floods over a 200 year period is equivalent to considering floods in perpetuity. It should be noted that this fact is true only at the 2, 4, 6, and 8% discount rates. A discount rate of 1% yields a present value of benefits which is still significant. The ideal situation would have been the generation of flows for different periods depending on discount rate, and the time needed to render additional benefits negligible. This detail is beyond the scope of the study and the errors incurred at the 1% level, by assuming 200 years to represent perpetuity, are insignificant.

The costs of building and operating a floodway consist of interest, amortization, and maintenance. The three components are calculated on an annual basis and summed to yield the total annual cost. The present worth of the annual cost is then determined by means of the appropriate (depending on discount rate) present worth factor for a series payment.

The Royal Commission used a useful life of structure of 50 years and hence amortized the cost over a 50 year period. By considering benefits in perpetuity or 200 years it is necessary to consider the structure in place for 200 years. Following the same useful life of structure assumption of 50 years, the annual cost of a recurrent capital expenditure equal to the capital cost of the works every 50 years is calculated for each assumed rate. This is, in effect, providing money to replace the project every 50 years for a period of 200 years. The amortization value based on the above assumption together with the other components of cost and the present worth is shown on Table 4.2.

Study 2

Study 2 attempts to show the effect on the benefit-cost ratio of a changed interest rate in the future. It is assumed that the project is started and arrangements are made for payment at a time when the prevailing interest rate is 4%. The further assumption (perhaps practically improbable) is made that the bonds issued to pay for the project are not renegotiated for the entire 200 year period. Therefore the agency building the project must pay for it at the fixed rate of 4%. The study shows what happens to the benefit-cost ratio should the discount rate, at which the agency must discount the benefits, change in the future.

The cost calculations required for Study 2 are similar to those carried out in Study 1 in that the same basic steps are required. The studies differ in that the costs in Study 2 are amortized over a 50 year period at a constant discount rate of 4% rather than at the varying discount rates. This essentially means that the annual costs for each of the assumed discount rates are the same. The present value of the annual costs is then found depending on discount rate. Again 200 years is used as the period of consideration and the results are shown in Table 4.3.

Study 3

Study 3 deals with the effect on the benefit-cost ratio of considering benefits over a period less than perpetuity, (200 years). It may be said that this study attempts to justify the choosing of a 200 year period by showing that lesser periods reduce benefits and hence reduce the benefit cost ratio.

Three economic time horizons were chosen for this study; 50, 100, and 200 years. The cost values are calculated for each of the five discount rates. The cost calculations for the economic time horizon of 100 years are similar to those carried out in Study 1. Study 1, however, necessitated the building of the project 4 times to provide protection for 200 years. This study considers only 100 years, and hence assuming a useful life of project of 50 years, and a like amortization period, the total present worth of the costs must only provide the funds for a recurrent capital expenditure every 50 years for the 100 year period. In a similar manner the total present worth of costs for the 50 year economic time

Study 5

Study 5 deals with the effects on the overall economic results of use of a non-representative historic record to calculate the statistical parameters for flow generation. This sensitivity analysis is useful in that it presents to decision makers the consequences of different interpretations of the basic flood frequency curve.

The cost values used are the same in all respects as those used in Study 1. This is done in order to make the necessary comparison of results of this study and those obtained using what was considered to be the "correct" frequency curve. Table 4.2 gives cost values for Study 1; the same values as used in this study.

This chapter has presented the methodology followed generally and in each of the five studies. In some cases the results obtained were expected, while in other cases the results were more revealing. A presentation of the results obtained by following the above methods and discussion of these results follows.

TABLE 4.1

DAMAGES ASSUMING PROGRESSIVE DIKE FAILURE

Flood Designation	Discharge Redwood Br.	Damage x 1000			
		Reach 1	Reach 2	Reach 3	Total
1948	69,000	270	230	150	650
26' Above Datum	81,000	1,000	1,600	4,000	3,000
1950	103,600	11,500	61,500	19,800	92,800
1861	125,000	33,500	154,000	79,200	266,700
1852	165,000	59,700	340,000	193,500	593,200
1826	225,000	76,500	523,500	252,500	852,500
Max. Prob.	270,000	84,700	602,000	261,000	947,700

TABLE 4.3

COST VALUES FOR STUDY 2

GENERATION LENGTH = 200 YEARS

FLOODWAY SIZE = 60,000 CFS.

Discount Rate	Cost	Interest	Amortization	Maintenance	Annual Cost	Present Worth
1	63,097,100	2,523,900	413,300	224,500	3,161,700	316,170,000
2	"	"	"	"	"	158,350,000
4	"	"	"	"	"	79,042,000
6	"	"	"	"	"	52,781,000
8	"	"	"	"	"	39,588,000

TABLE 4.4

COST VALUES FOR STUDY 3

FLOODWAY SIZE = 60,000 CFS.

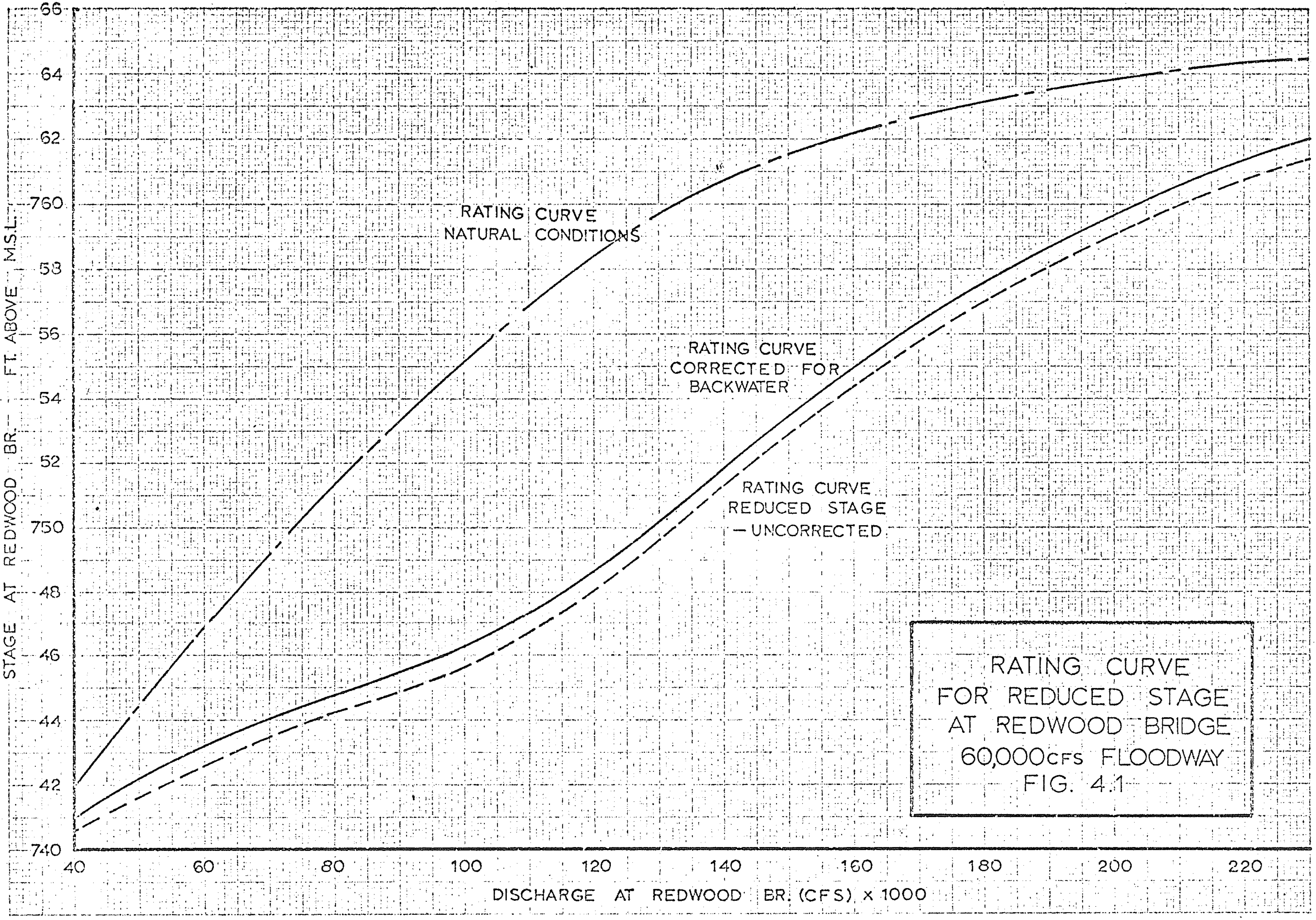
Discount Rate	Cost	Interest	Amortization	Maintenance	Annual Cost	Present Worth
Generation Length = 50 Years						
1	63,097,000	630,971	978,800	224,500	1,834,300	71,897,000
2	"	1,261,942	746,000	"	2,232,500	70,153,000
4	"	2,523,884	413,300	"	3,161,700	67,919,000
6	"	3,785,826	217,300	"	4,227,650	66,636,000
8	"	5,047,768	109,900	"	5,382,200	65,841,000
Generation Length = 100 Years						
1	63,097,000	630,971	978,800	224,500	1,834,300	115,613,000
2	"	1,261,942	746,000	"	2,232,500	96,214,000
4	"	2,523,884	413,300	"	3,161,700	77,477,000
6	"	3,785,826	217,300	"	4,227,650	70,255,000
8	"	5,047,768	109,900	"	5,382,200	67,246,000
Generation Length = 200 Years						
1	63,097,000	630,971	978,800	224,500	1,834,300	183,428,000
2	"	1,261,942	746,000	"	2,232,500	111,623,000
4	"	2,523,814	413,300	"	3,161,700	79,042,000
6	"	3,785,826	217,300	"	4,227,650	70,458,000
8	"	5,047,768	109,900	"	5,382,200	67,278,000

TABLE 4.5

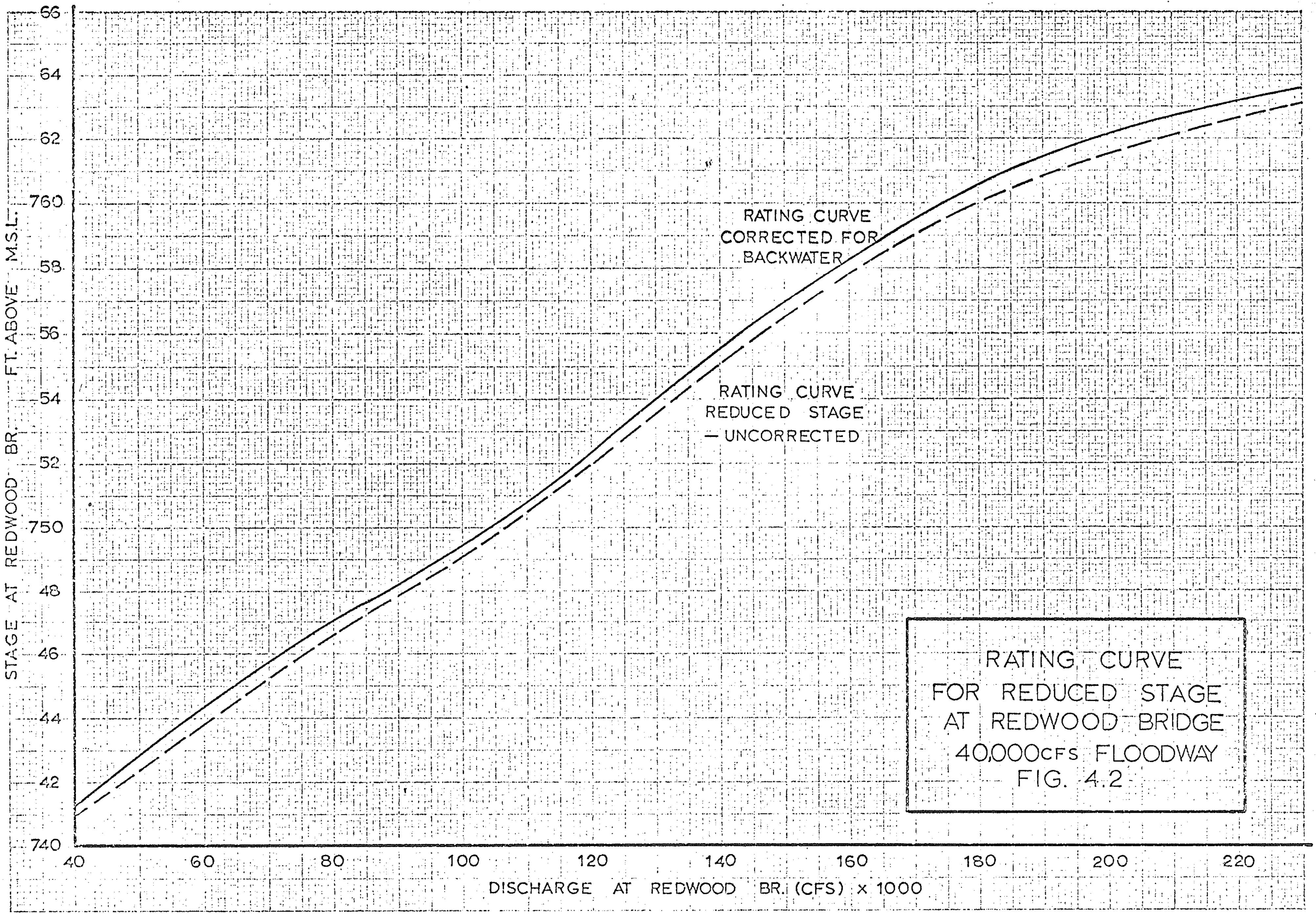
COST VALUES FOR STUDY 4

GENERATION LENGTH = 200 YEARS

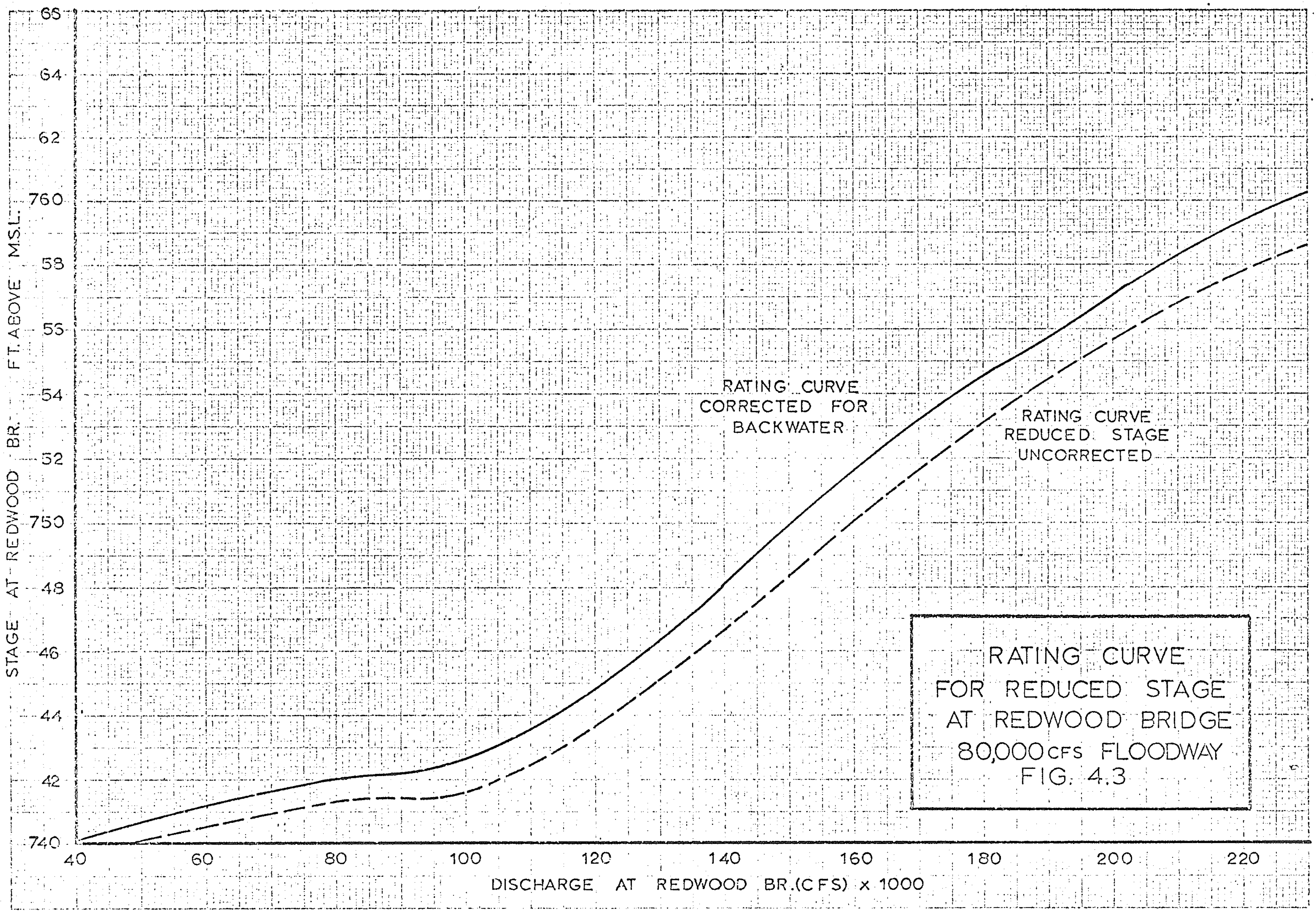
Discount Rate	Cost	Interest	Amortization	Maintenance	Annual Cost	Present Worth
Floodway Size = 40,000 cfs.						
1	45,196,400	458,900	712,000	166,900	1,337,800	133,784,000
2	"	917,900	542,600	"	1,627,500	81,374,000
4	"	1,835,900	300,600	"	2,303,400	57,585,000
6	"	2,753,800	158,100	"	3,078,800	51,311,000
8	"	3,671,700	80,000	"	3,918,602	48,983,000
Floodway Size = 60,000 cfs.						
1	63,097,100	630,900	978,800	224,500	1,834,300	183,428,000
2	"	1,261,900	746,000	"	2,232,500	111,623,000
4	"	2,523,900	413,300	"	3,161,700	79,042,000
6	"	3,785,800	217,300	"	4,227,650	70,458,000
8	"	5,047,800	110,000	"	5,382,200	67,278,000
Floodway Size = 80,000 cfs.						
1	78,579,600	785,800	1,219,000	273,900	2,278,700	227,868,000
2	"	1,571,600	929,000	"	2,774,600	138,728,000
4	"	3,143,200	514,700	"	3,931,800	98,295,000
6	"	4,714,800	270,650	"	5,259,300	87,652,000
8	"	6,286,400	137,000	"	6,697,200	83,715,000



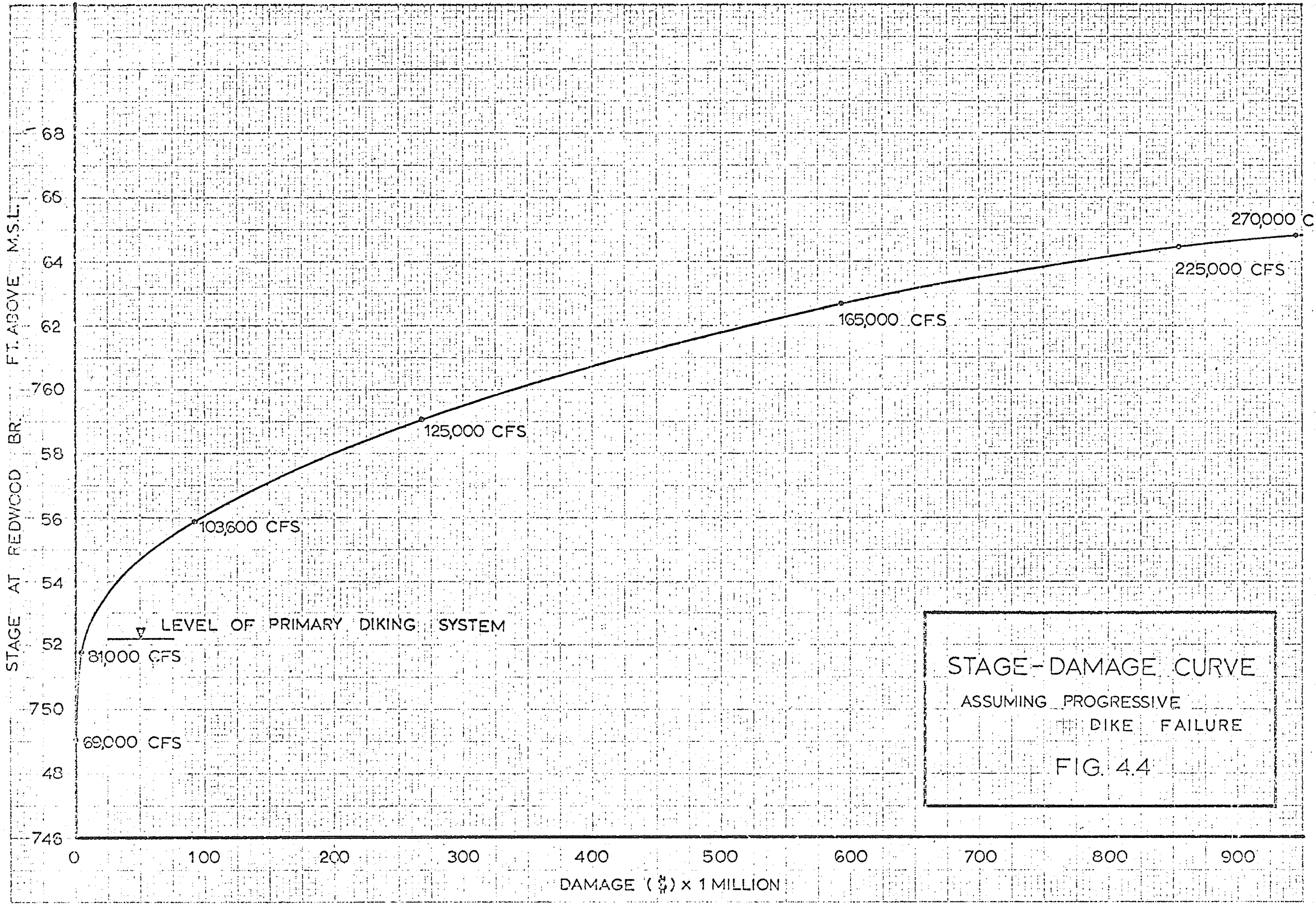
RATING CURVE
FOR REDUCED STAGE
AT REDWOOD BRIDGE
60,000 CFS FLOODWAY
FIG. 4.1



RATING CURVE
FOR REDUCED STAGE
AT REDWOOD BRIDGE
40,000CFS FLOODWAY
FIG. 4.2



RATING CURVE
FOR REDUCED STAGE
AT REDWOOD BRIDGE
80,000 CFS FLOODWAY
FIG. 4.3



STAGE-DAMAGE CURVE
ASSUMING PROGRESSIVE DIKE FAILURE

FIG. 4.4

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APPENDIX B

DESCRIPTION OF PROGRAM FLOGEN

This program generates a series of random variates using a given mean, standard deviation, and serial correlation coefficient. A Markov stochastic process is used in the generation process.

The program is used, in this case, to generate a synthetic series of flood peaks following a log-normal distribution using an historic mean, standard deviation and serial correlation coefficient. The flows are stored on tape for use in program PRSWTH.

Subroutines used: NORM

FLØGEN

DESCRIPTION OF VARIABLES:

R - SERIAL CØRRELATION CØEFFICIENT FØR GENERATED FLOWS

AMEAN - ESTIMATED PØPULATION MEAN

SD - ESTIMATED PØPULATION STANDARD DEVIATION

N - NUMBER ØF GENERATED FLOWS IN A SERIES

NØS - NUMBER ØF SERIES TØ BE GENERATED

Y - GENERATED VARIABLE ØF YEAR N-I

IX - STARTING VARIABLE FØR SUBRØUTINE RANDU

STD - NØRMAL STANDARD DEVIATIØN

ANØRM - NØRMAL MEAN

I YEAR - CØUNTER INDICATING YEAR FLOW OCCURS

ATØT - SUM ØF THE FLØWS

BTØT - SUM ØF THE SQUARES ØF THE FLØWS

X - GENERATED NØRMAL DIMENSIONLESS VARIATE

PEAK - PEAK FLØW GENERATED ACCØRDING TØ DESIRED DISTRIBUTIØN

ØRD - NUMBER ØF STANDARD DEVS GENERATED VARIABLE IS FRØM EST. MEAN

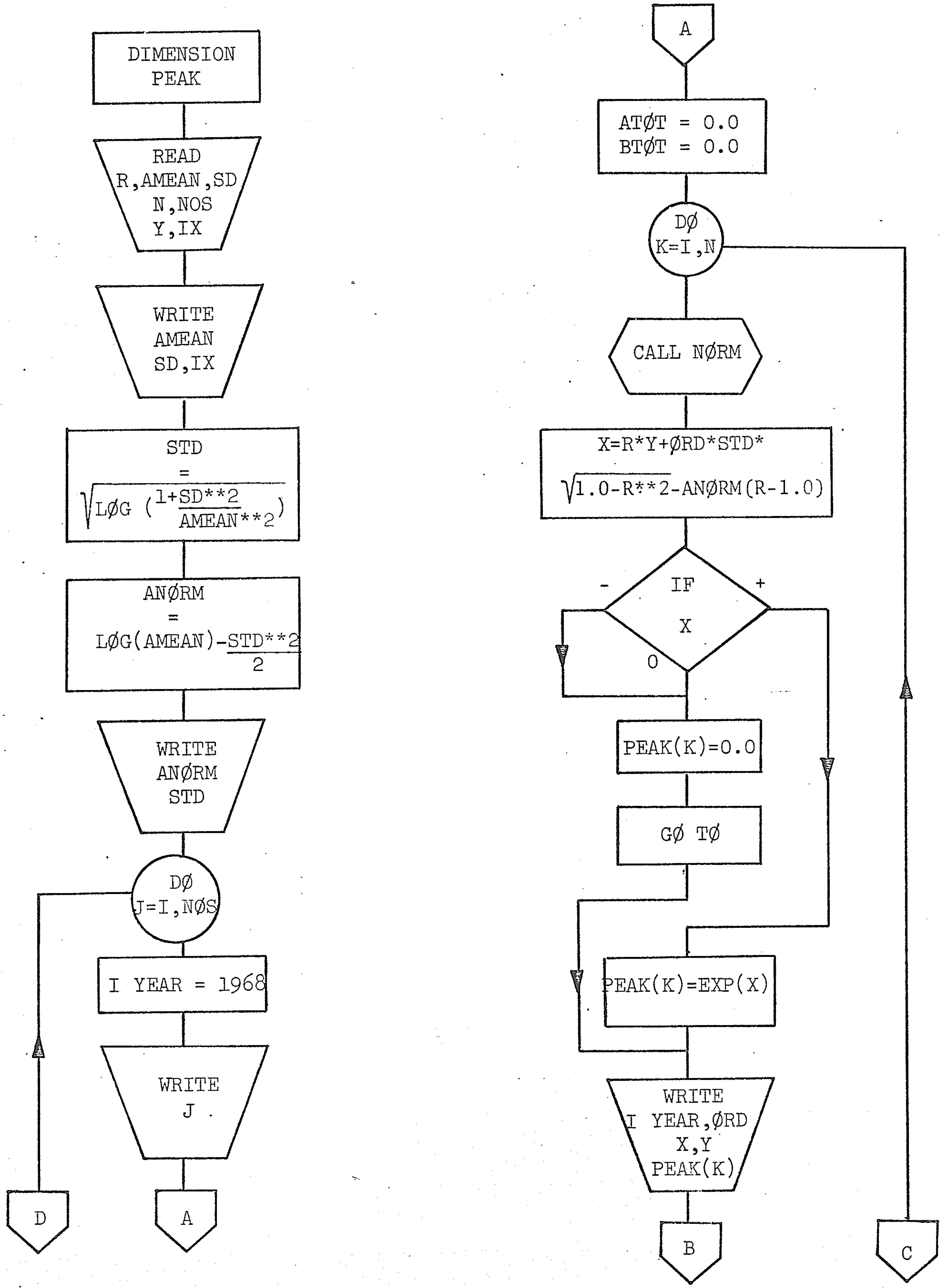
SQR - SØURCE ØF THE FLØWS

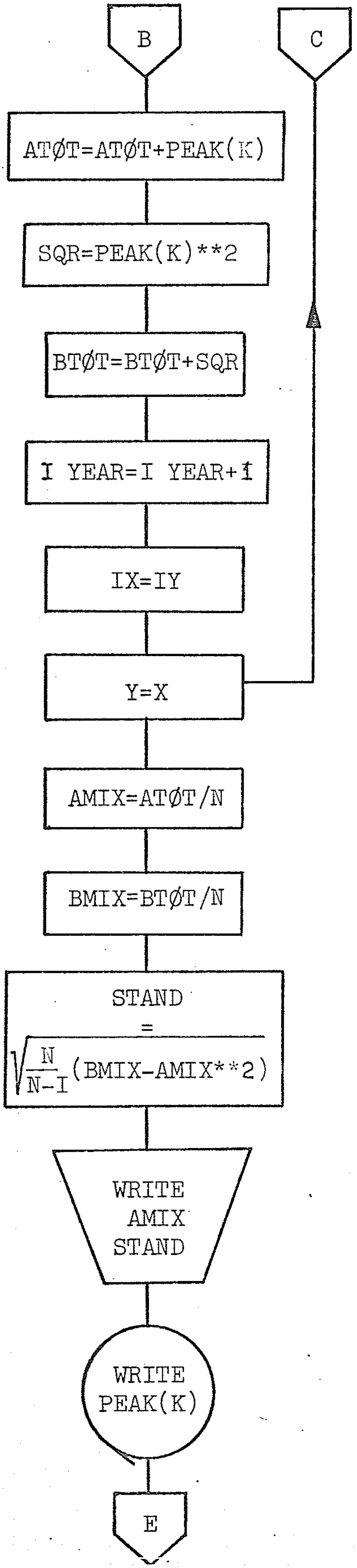
AMIX - MEAN ØF GENERATED PEAK SERIES

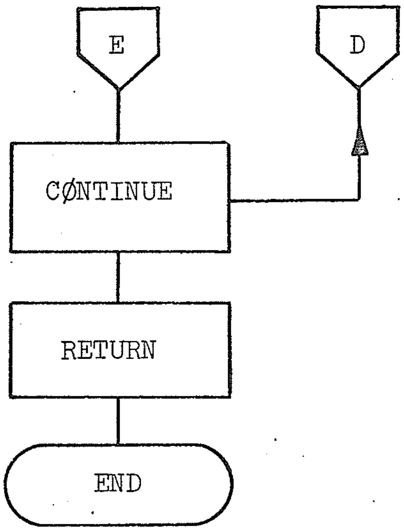
BMIX - MEAN ØF SQUARES ØF GENERATED PEAK SERIES

STAND - STANDARD DEVIATION ØF GENERATED PEAK SERIES

FLOWCHART FOR FLOGEN




B
C
ATOT=ATOT+PEAK(K)
SQR=PEAK(K)**2
BTOT=BTOT+SQR
I YEAR=I YEAR+1
IX=IY
Y=X
AMIX=ATOT/N
BMIX=BTOT/N
STAND
=
$\sqrt{\frac{N}{N-I}(BMIX-AMIX**2)}$
WRITE
AMIX
STAND
WRITE
PEAK(K)
E


E
D
CONTINUE
RETURN
END

DESCRIPTION OF SUBROUTINE NORM

This subroutine is used in the main program FLOGEN. Its purpose is to generate normally distributed random standardized numbers which are converted to log normally distributed flood peaks in the main program.

The subroutine takes uniformly distributed random numbers generated by RANDU (a scientific subroutine package of the IBM 360-65 computer) and converts them to normally distributed standardized random numbers.

Subroutines used: RANDU

SUBRØUTINE NØRM

DESCRIPTION OF VARIABLES:

IX - STARTING ØDD INTEGER FØR RANDU

IY - INTERMEDIATE ØUTPUT FRØM RANDU

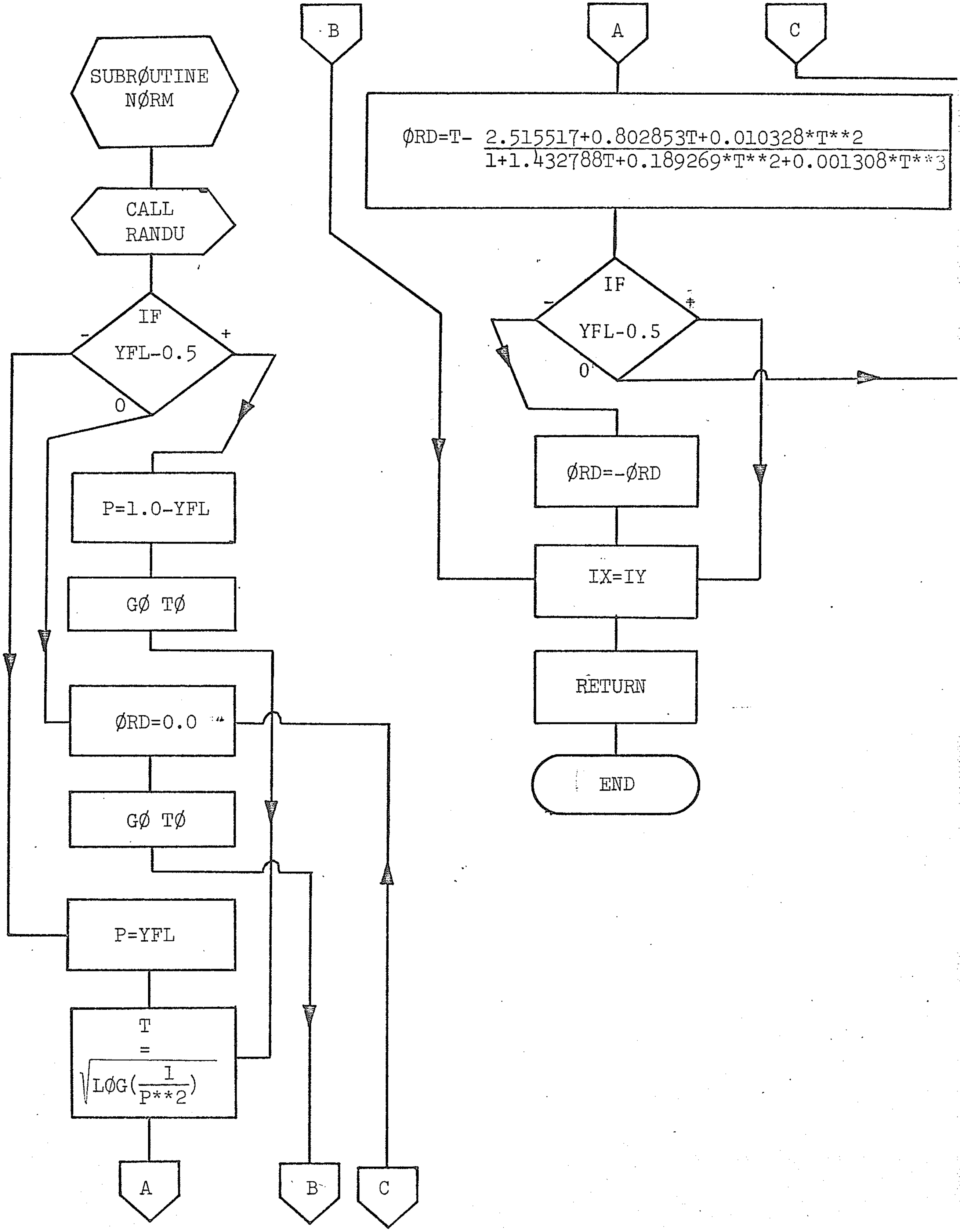
YFL - ØUTPUT FRØM RANDU - UNIFØRMALLY DISTRIBUTED RANDØM VARIATE

P - USED IN ØRD CALCULATIØN

T - USED IN ØRD CALCULATIØN

ORD - NØRMALLY DISTRIBUTED STANDARDIZED RANDØM VARIATE

FLØW CHART FOR SUBRØUTINE NØRM



DESCRIPTION OF PROGRAM PRSWTH

This program reads generated flood peak series from tape, and using stage-damage curves, rating curves, and project costs, determines a benefit-cost ratio for each flow series entered. The program orders the benefit-cost ratios from highest to lowest and outputs a table of benefit-cost ratios and corresponding Weibull plotting positions for plotting frequency curves. Punched cards bearing this information are produced also and used as input data for program PLOT.

Subroutines used:	PRWTH
	FREQ

PRSWTH

DESCRIPTION OF VARIABLES:

ELEV -
Q - | CØØRDINATES OF RATING CURVE FOR NATURAL CONDITIONS

FLØW - THE GENERATED FLOWS

H -
DAM - | CØØRDINATES OF STAGE DAMAGE CURVE

DAMAGE - DAMAGES PREVENTED BY FLOOD CØNTRØL WORKS

PWDAM - PRESENT WORTH OF ABOVE DAMAGES

DISC -
HT - CØØRDINATES OF RATING CURVE FØR IMPROVED CØNDITIØNS

ELIMP - STAGE UNDER IMPROVED CONDITIONS

ELNAT - STAGE UNDER NATURAL CONDITIONS

DAMIMP - DAMAGES UNDER IMPROVED CONDITIONS

DAMNAT - DAMAGES UNDER NATURAL CONDITIONS

BINT - DISCOUNT RATES USED

TØTAL - TØTAL PRESENT WORTH OF DAMAGES PREVENTED (BENEFITS)

CØST - CØSTS CALCULATED ACCORDING TO ABOVE DISCOUNT RATES

BNCST - BENEFIT-COST RATIOS

SUM - SUM OF B-C RATIOS

BSUM - SUM OF SQUARES OF B-C RATIOS (ΣAEXP)

AMEAN - MEAN OF B-C RATIOS

BMEAN - MEAN OF SQUARES OF B-C RATIOS

AEXP - SQUARES OF B-C RATIOS

SD - STANDARD DEVIATION OF B-C RATIOS

ADD - TØTAL DAMAGES PREVENTED

DARRAY - ORDERED B-C RATIOS

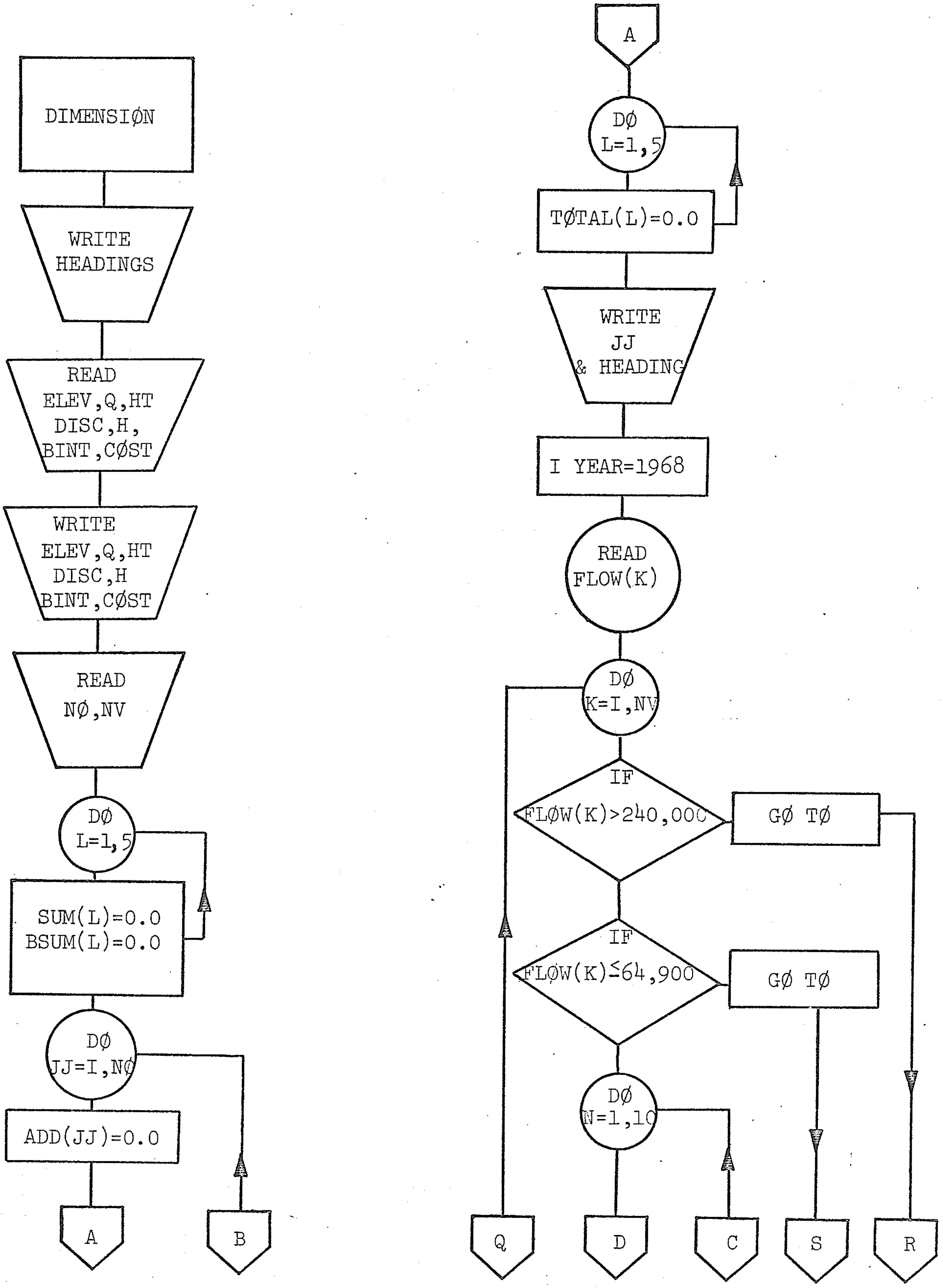
FREQUE - RECURRENCE INTERVAL

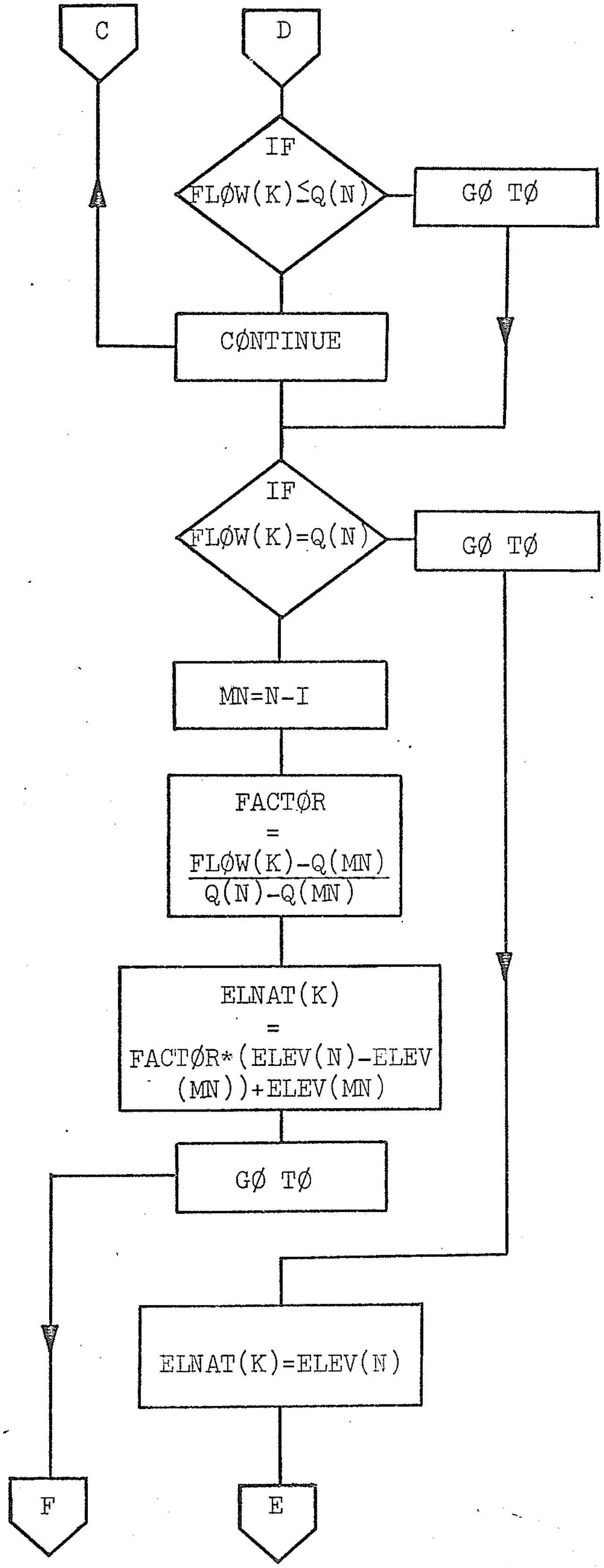
PERC. - FREQUENCY OF EXCEEDENCE

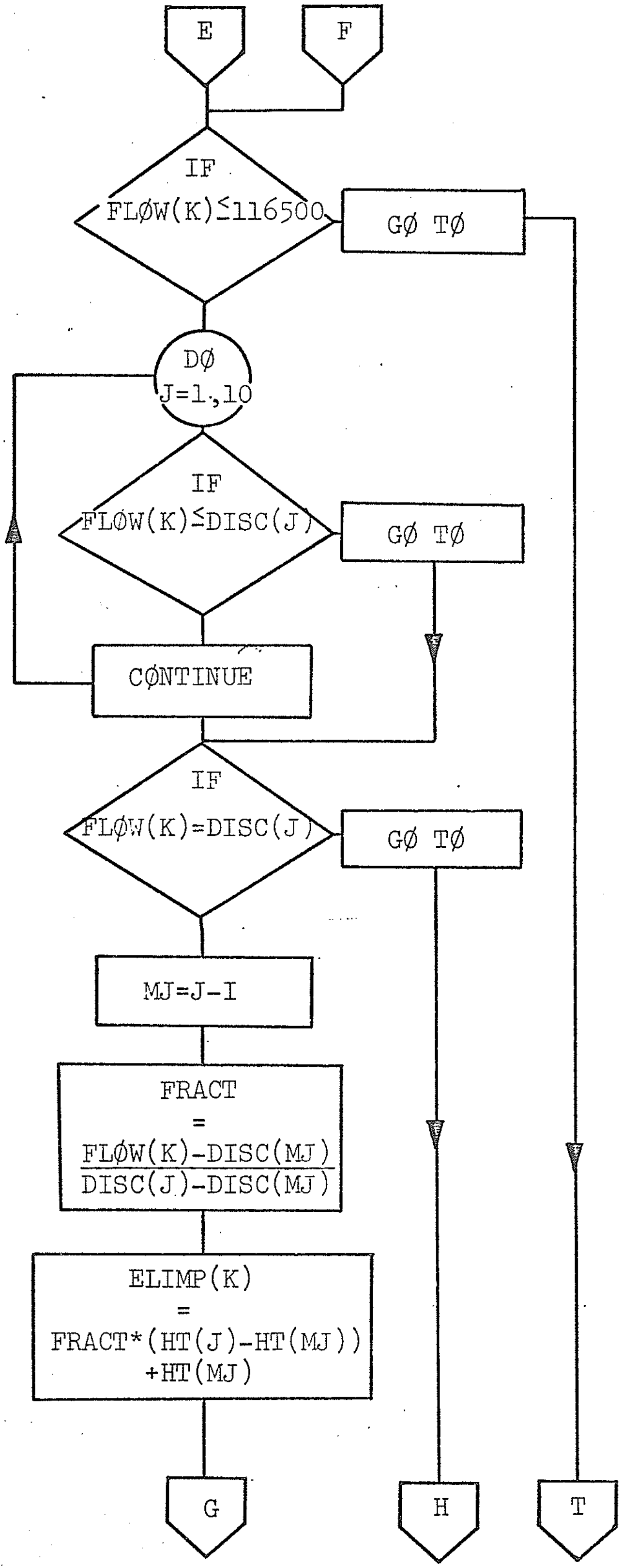
NØ - NUMBER OF SERIES GENERATED

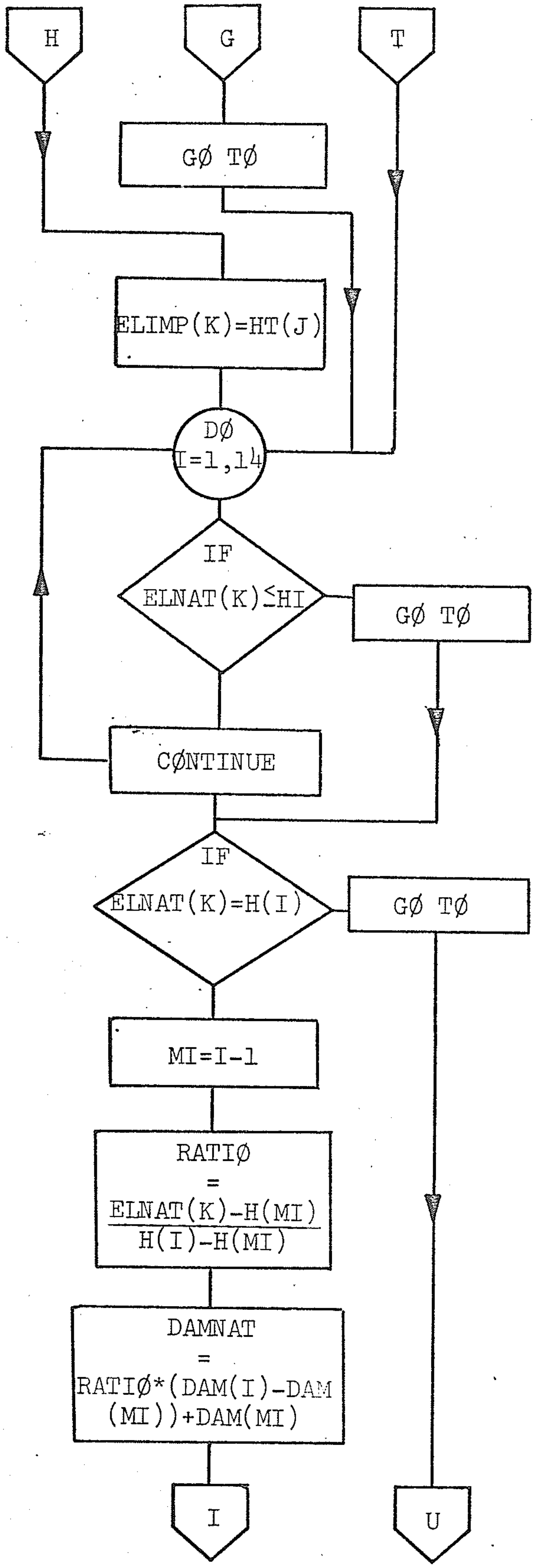
NU - NUMBER OF VARIABLES PER SERIES

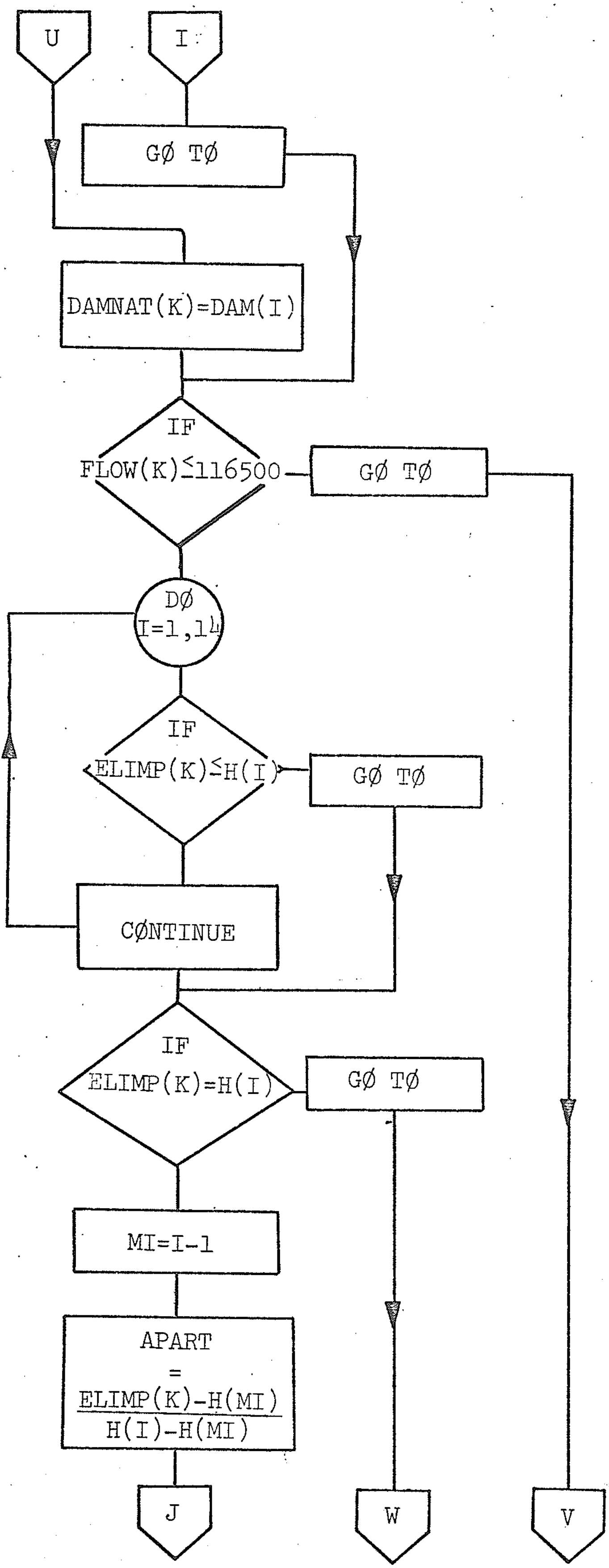
FLØW CHART FØR PRSWTH

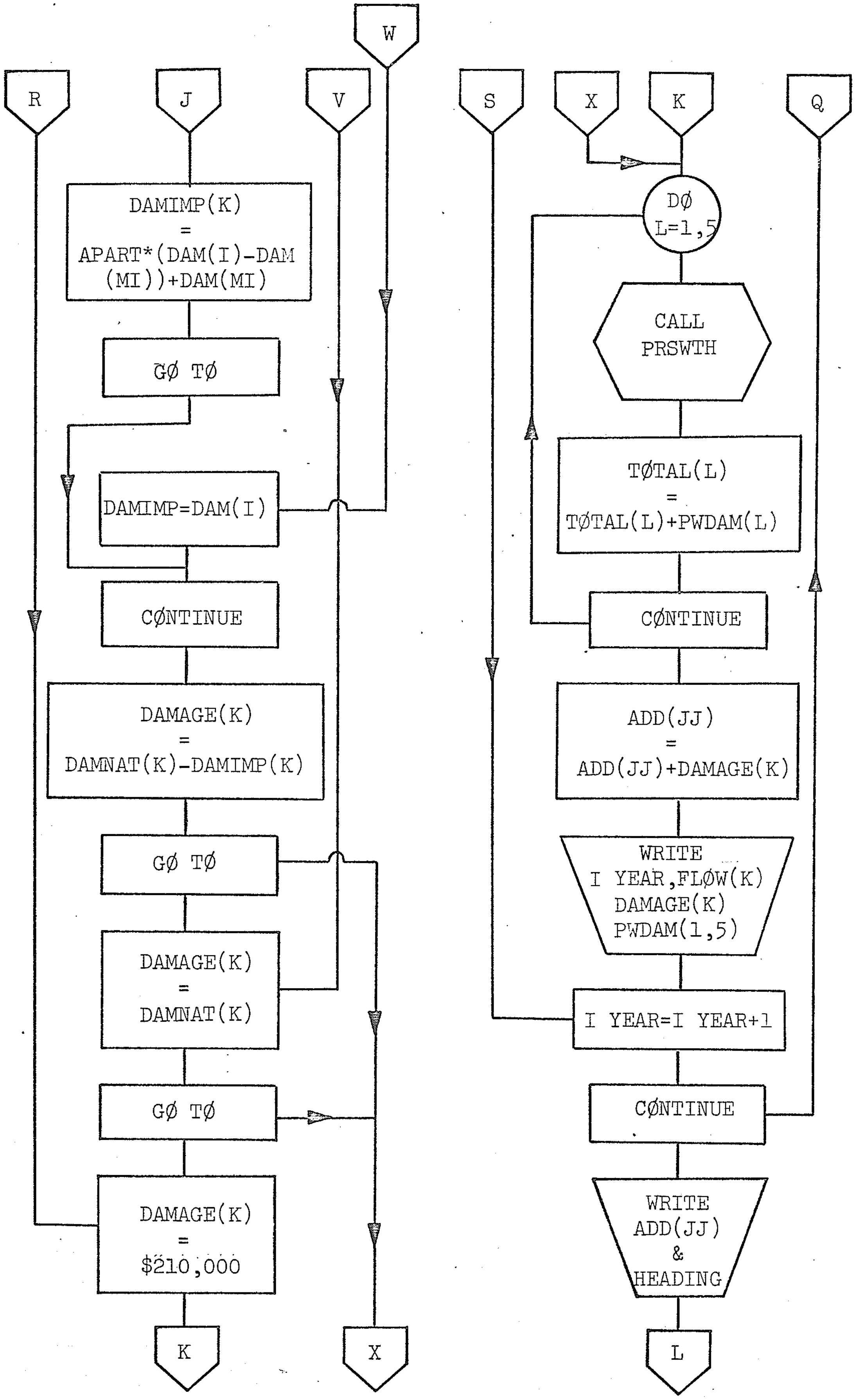


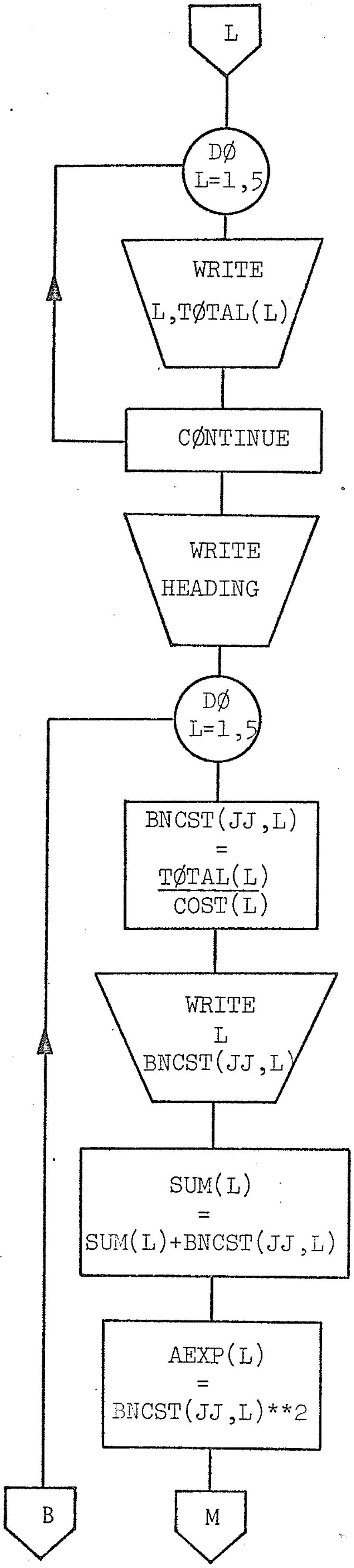

C
D
IF
FLØW(K)≤Q(N)
GØ TØ
CØNTINUE
IF
FLØW(K)=Q(N)
GØ TØ
MN=N-I
FACTØR = FLØW(K)-Q(MN) / Q(N)-Q(MN)
ELNAT(K) = FACTØR*(ELEV(N)-ELEV(MN))+ELEV(MN)
GØ TØ
ELNAT(K)=ELEV(N)
F
E

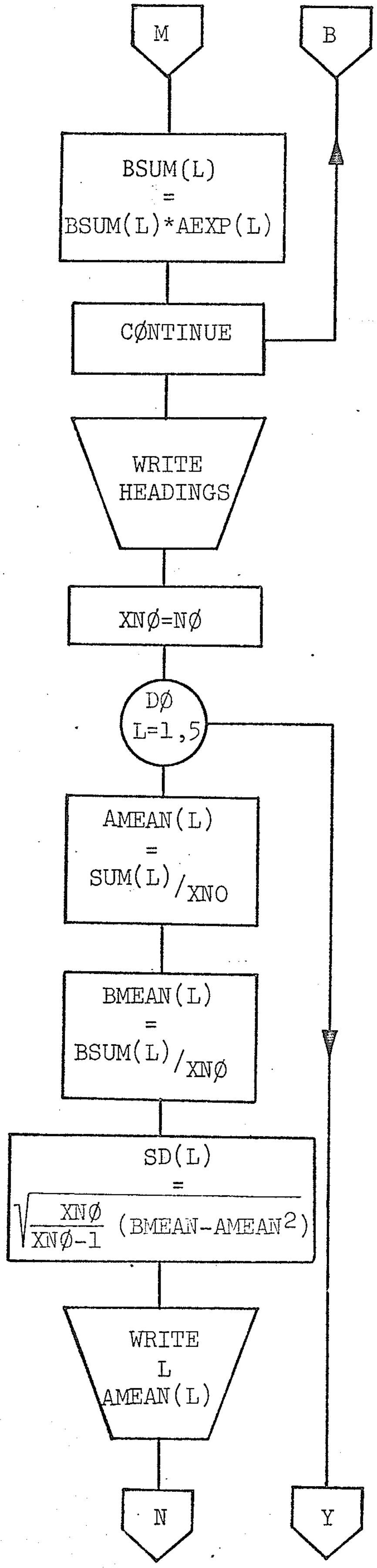

E
F
IF
FLØW(K)≤116500
GØ TØ
DØ J=1,10
IF
FLØW(K)≤DISC(J)
GØ TØ
CØNTINUE
IF
FLØW(K)=DISC(J)
GØ TØ
MJ=J-I
FRACT = FLØW(K)-DISC(MJ) / DISC(J)-DISC(MJ)
ELIMP(K) = FRACT*(HT(J)-HT(MJ))+HT(MJ)
G
H
T

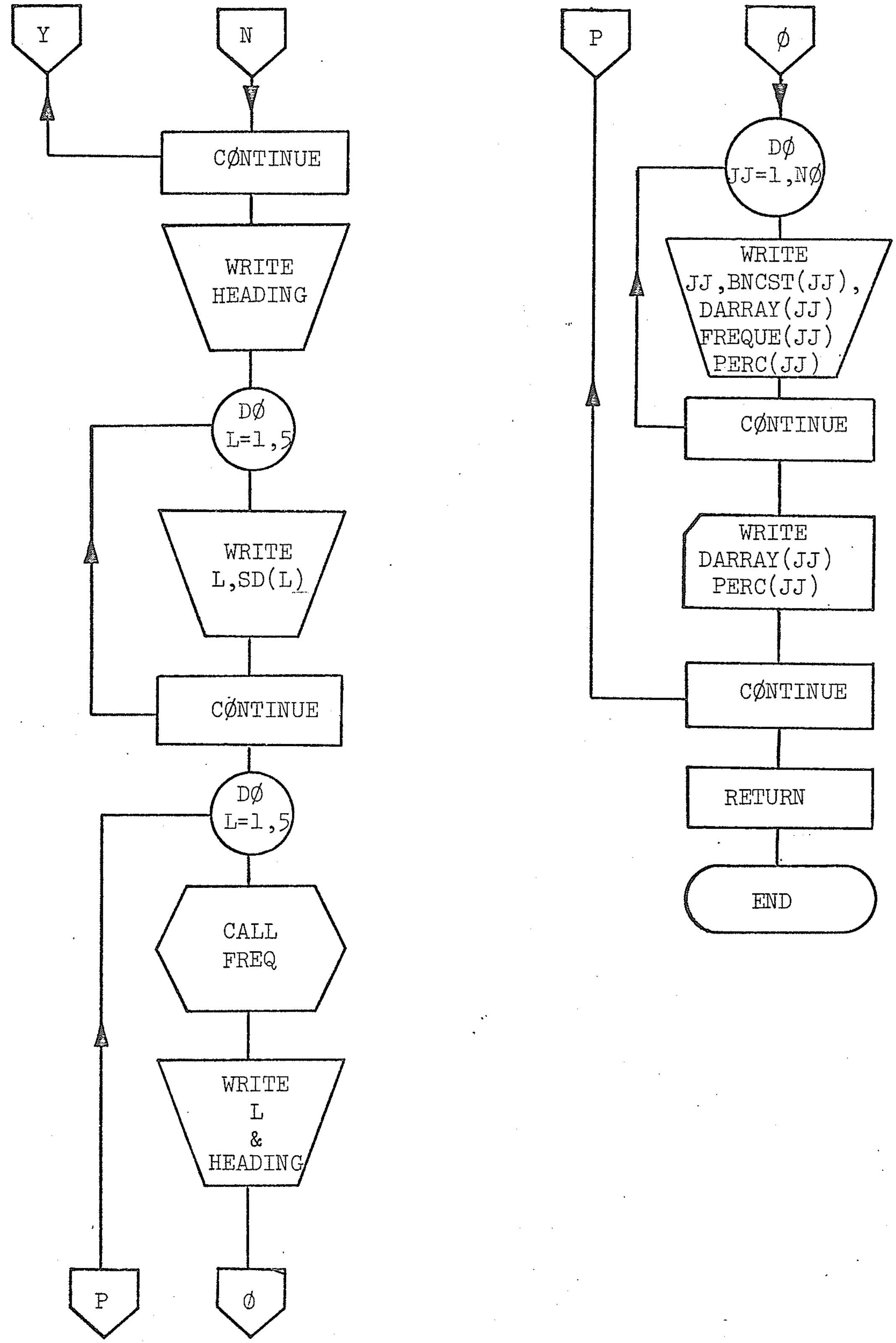

H
G
T
GØ TØ
ELIMP(K)=HT(J)
DØ
I=1,14
IF
ELNAT(K)≤HI
GØ TØ
CØNTINUE
IF
ELNAT(K)=H(I)
GØ TØ
MI=I-1
RATIØ
=
ELNAT(K)-H(MI)
H(I)-H(MI)
DAMNAT
=
RATIØ*(DAM(I)-DAM
(MI))+DAM(MI)
I
U


U
I
GØ TØ
DAMNAT(K)=DAM(I)
IF
FLOW(K)≤116500
GØ TØ
DØ
I=1,14
IF
ELIMP(K)≤H(I)
GØ TØ
CØNTINUE
IF
ELIMP(K)=H(I)
GØ TØ
MI=I-1
APART
=
ELIMP(K)-H(MI)
H(I)-H(MI)
J
W
V


W
R
J
V
S
X
K
Q
DAMIMP(K) = APART*(DAM(I)-DAM(MI))+DAM(MI)
GØ TØ
DAMIMP=DAM(I)
CØNTINUE
DAMAGE(K) = DAMNAT(K)-DAMIMP(K)
GØ TØ
DAMAGE(K) = DAMNAT(K)
GØ TØ
DAMAGE(K) = $210,000
K
X
DØ L=1,5
CALL PRSWTH
TØTAL(L) = TØTAL(L)+PWDAM(L)
CØNTINUE
ADD(JJ) = ADD(JJ)+DAMAGE(K)
WRITE I YEAR,FLØW(K) DAMAGE(K) PWDAM(1,5)
I YEAR=I YEAR+1
CØNTINUE
WRITE ADD(JJ) & HEADING
L


L
DØ
L=1,5
WRITE
L,TØTAL(L)
CØNTINUE
WRITE
HEADING
DØ
L=1,5
BNCST(JJ,L)
=
TØTAL(L)
COST(L)
WRITE
L
BNCST(JJ,L)
SUM(L)
=
SUM(L)+BNCST(JJ,L)
AEXP(L)
=
BNCST(JJ,L)**2
B
M


M
B
BSUM(L)
=
BSUM(L)*AEXP(L)
CØNTINUE
WRITE
HEADINGS
XNØ=NØ
DØ
L=1,5
AMEAN(L)
=
SUM(L)/XNO
BMEAN(L)
=
BSUM(L)/XNØ
SD(L)
=
√(XNØ/(XNØ-1) (BMEAN-AMEAN2))
WRITE
L
AMEAN(L)
N
Y


Y
N
CØNTINUE
WRITE HEADING
DØ L=1,5
WRITE L,SD(L)
CØNTINUE
DØ L=1,5
CALL FREQ
WRITE L & HEADING
P
Ø
P
Ø
DØ JJ=1,NØ
WRITE JJ,BNCST(JJ), DARRAY(JJ) FREQUE(JJ) PERC(JJ)
CØNTINUE
WRITE DARRAY(JJ) PERC(JJ)
CØNTINUE
RETURN
END

DESCRIPTION OF SUBROUTINE PRWTH

This subroutine takes input data of flood damages (with and without flood protection) and time of occurrence of the particular damage in the flow sequence. For any number of different discount rates, the present worth of this damage is calculated and returned to program PRSWTH.

Subroutines used: None.

SUBRØUTINE PRWTH

DESCRIPTION OF VARIABLES:

BINT - DISCOUNT RATES

K - COUNTER - REFERS TO YEAR IN THE SEQUENCE

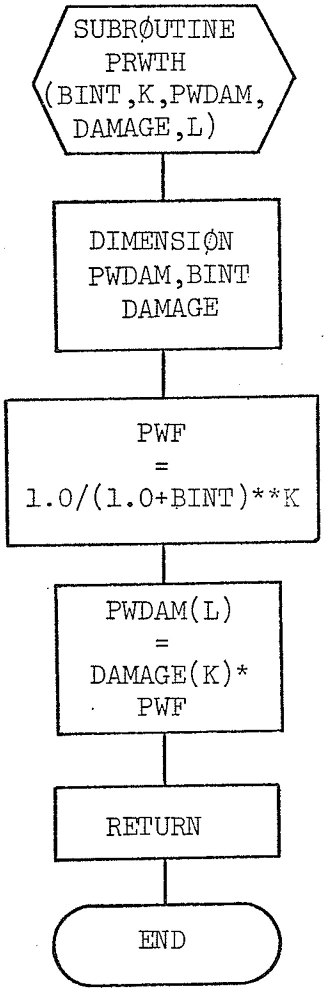
PWDAM - PRESENT WORTH OF DAMAGES PREVENTED

DAMAGE - DAMAGES PREVENTED

L - COUNTER - REFERS TO DISCOUNT RATES

PWF - PRESENT WORTH FACTOR

FLØW CHART FØR SUBRØUTINE PRWTH



DESCRIPTION OF SUBROUTINE FREQ

This program accepts an array of variables(in this case, benefit-cost ratios) as input data. The program orders the variables from highest to lowest and calculates the corresponding Weibull plotting positions. Results are returned to main program PRSWTH.

Subroutines used: ORDERED

SUBR0UTINE FREQ

DESCRIPTION OF VARIABLES:

N - COUNTER - T0TAL N0. OF VARIABLES

BC - VARIABLES TO BE 0RDERED (ONE DIMENSIONAL)

BCI - VARIABLES TO BE 0RDERED (TWO DIMENSIONAL)

L - COUNTER - REFERS TO DISCOUNT RATES

FREQUE - RECURRENCE INTERVAL

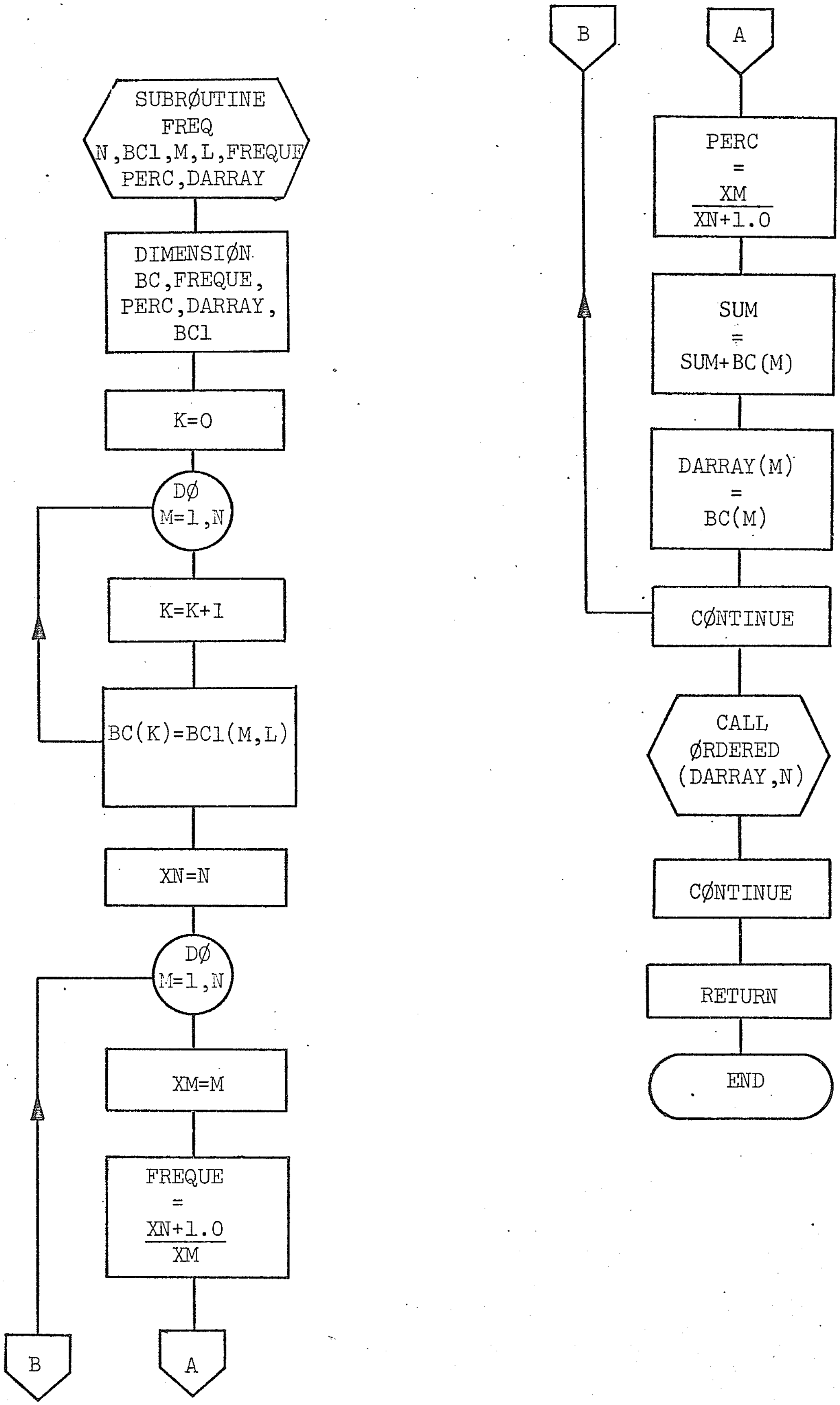
PERC - FREQUENCY OF EXCEEDENCE

DARRAY - THE 0RDERED VARIABLES

M - COUNTER - RELATIVE POSITION OF VARIABLE

SUM - SUM OF VARIABLES

FLØW CHART FØR SUBRØUTINE FREQ



DESCRIPTION OF SUBROUTINE ORDERED

This subroutine takes, as input data, variables (benefit-cost ratios) calculated from main program PRSWTH and passed through subroutine FREQ. The subroutine places the variables in order from highest to lowest and returns them to subroutine FREQ.

Subroutines used: None.

SUBRØUTINE ØRDERED

DESCRIPTION ØF VARIABLES:

A - THE VARIABLES TO BE ØRDERED

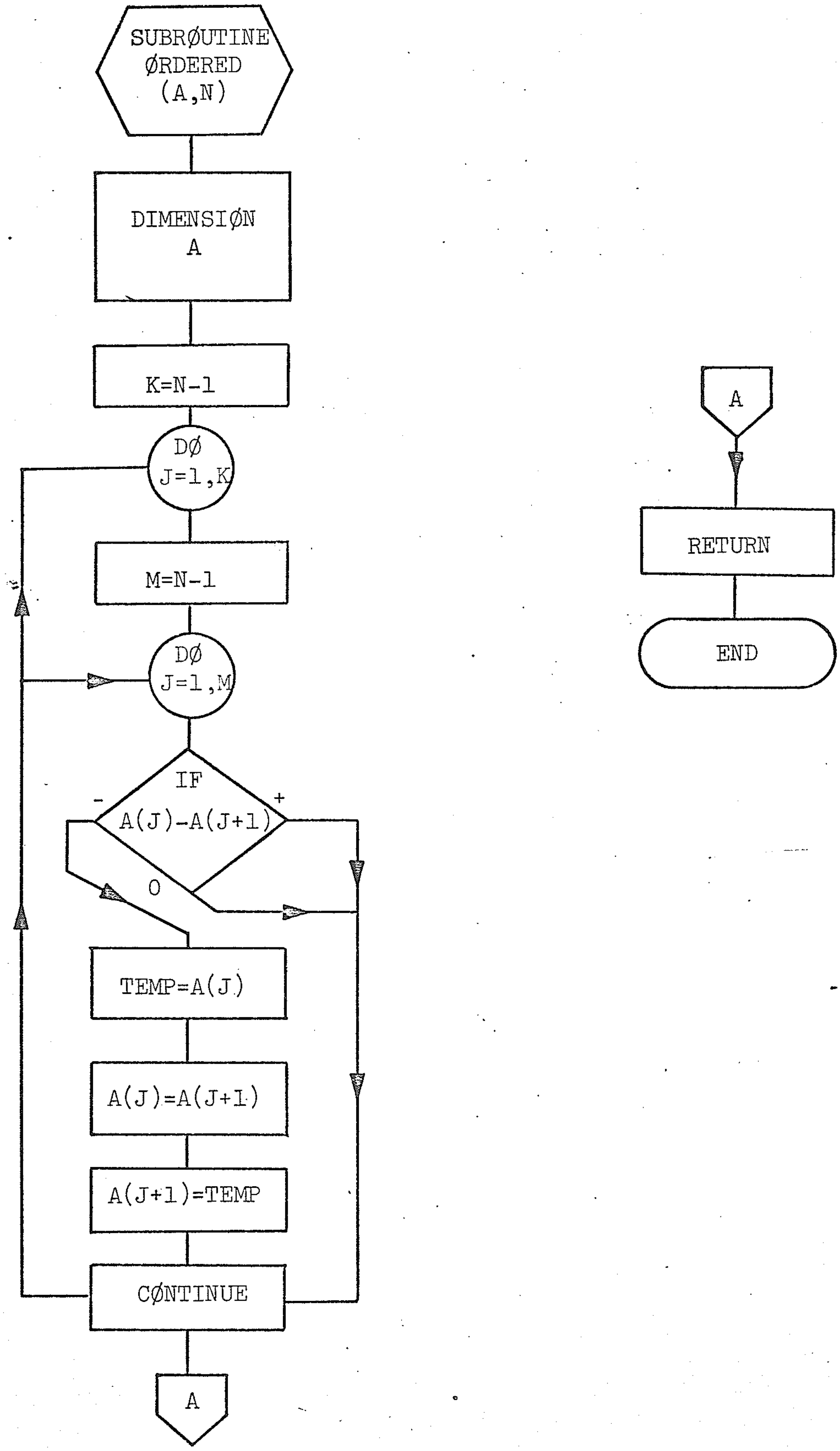
N - NUMBER OF VARIABLES

TEMP - TEMPØRARY VARIABLE

K - CØUNTER

M - CØUNTER

FLØW CHART FØR SUBRØUTINE ØRDERED



DESCRIPTION OF PROGRAM REGAN

This program calculates straight line regression between two arrays of input variables. Output consists of the slope and intercept of the best fit line through a plot of the independent versus dependent variables, the correlation coefficient, standard error of estimate, and residuals.

In the thesis, this program is used to determine the serial correlation coefficient between annual peak flows by setting the independent variable equal to flow in year N and the dependent variable equal to flow in year N+1.

Subroutines used: LINE

REGAN

DESCRIPTION OF VARIABLES:

N - LENGTH OF INPUT ARRAY OF DEPENDENT VARIABLE

XI - DEPENDENT VARIABLE x 10,000

X2 - INDEPENDENT VARIABLE x 10,000

Q1 - INPUT DEPENDENT VARIABLE

Q2 - INPUT INDEPENDENT VARIABLE

X1NAME - NAME OF DEPENDENT VARIABLE

X2NAME - NAME OF INDEPENDENT VARIABLE

A - OUTPUT INTERCEPT (OF BEST FIT LINE)

B - SLOPE

R - CORRELATION COEFFICIENT

RBAR - CORRECTED CORRELATION COEFFICIENT

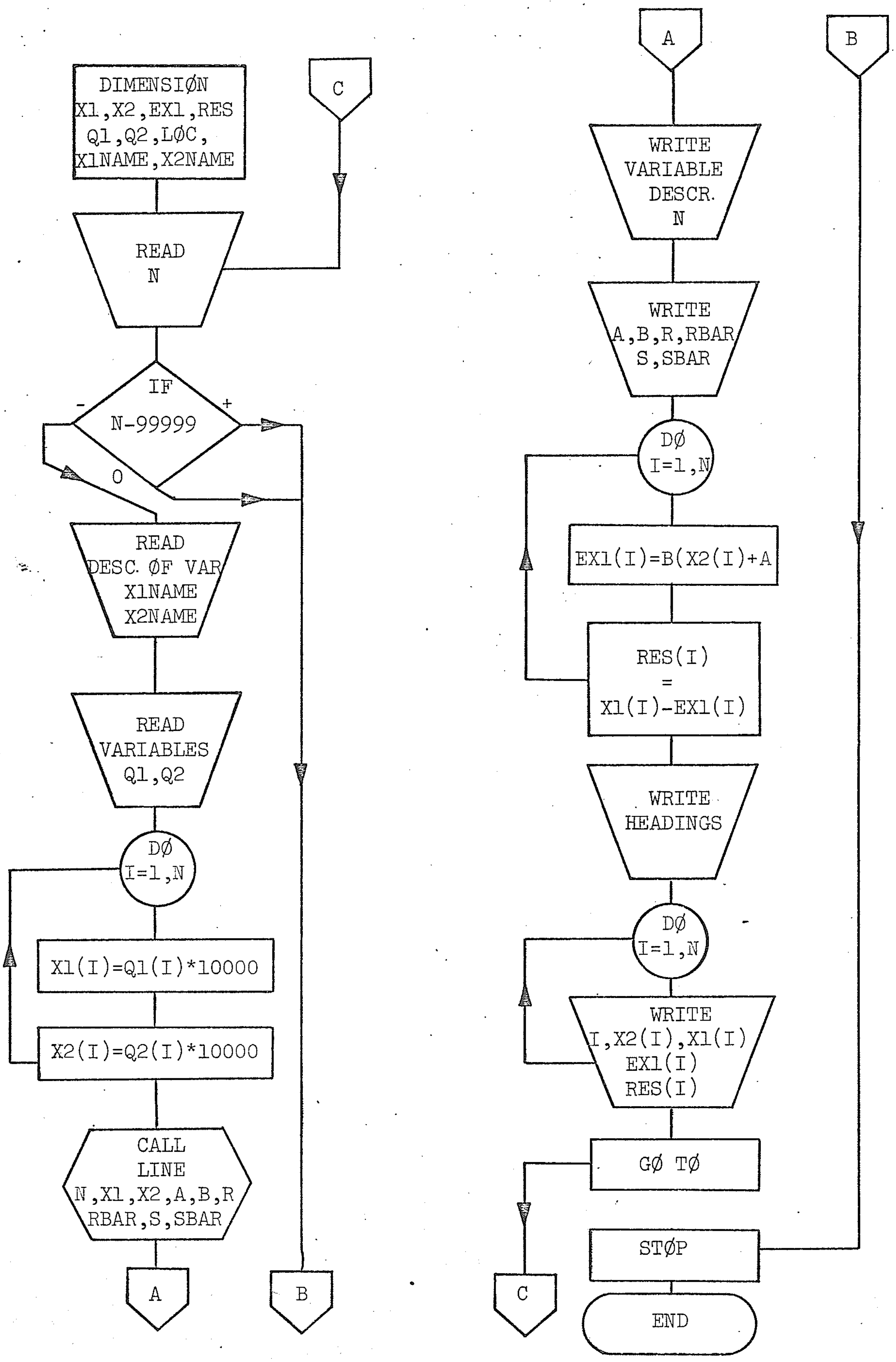
S - STANDARD ERROR OF ESTIMATE

SBAR - CORRECTED STANDARD ERROR OF ESTIMATE

EXI - ESTIMATED XI

RES - RESIDUALS

FLØW CHART FØR REGAN



DESCRIPTION OF SUBROUTINE LINE

This subroutine calculates for input arrays of independent and dependent variables the slope and intercept of best fit line, correlation coefficient, adjusted correlation coefficient, standard error of estimate, and adjusted standard error of estimate. The calculations are relayed back to program REGAN for output purposes.

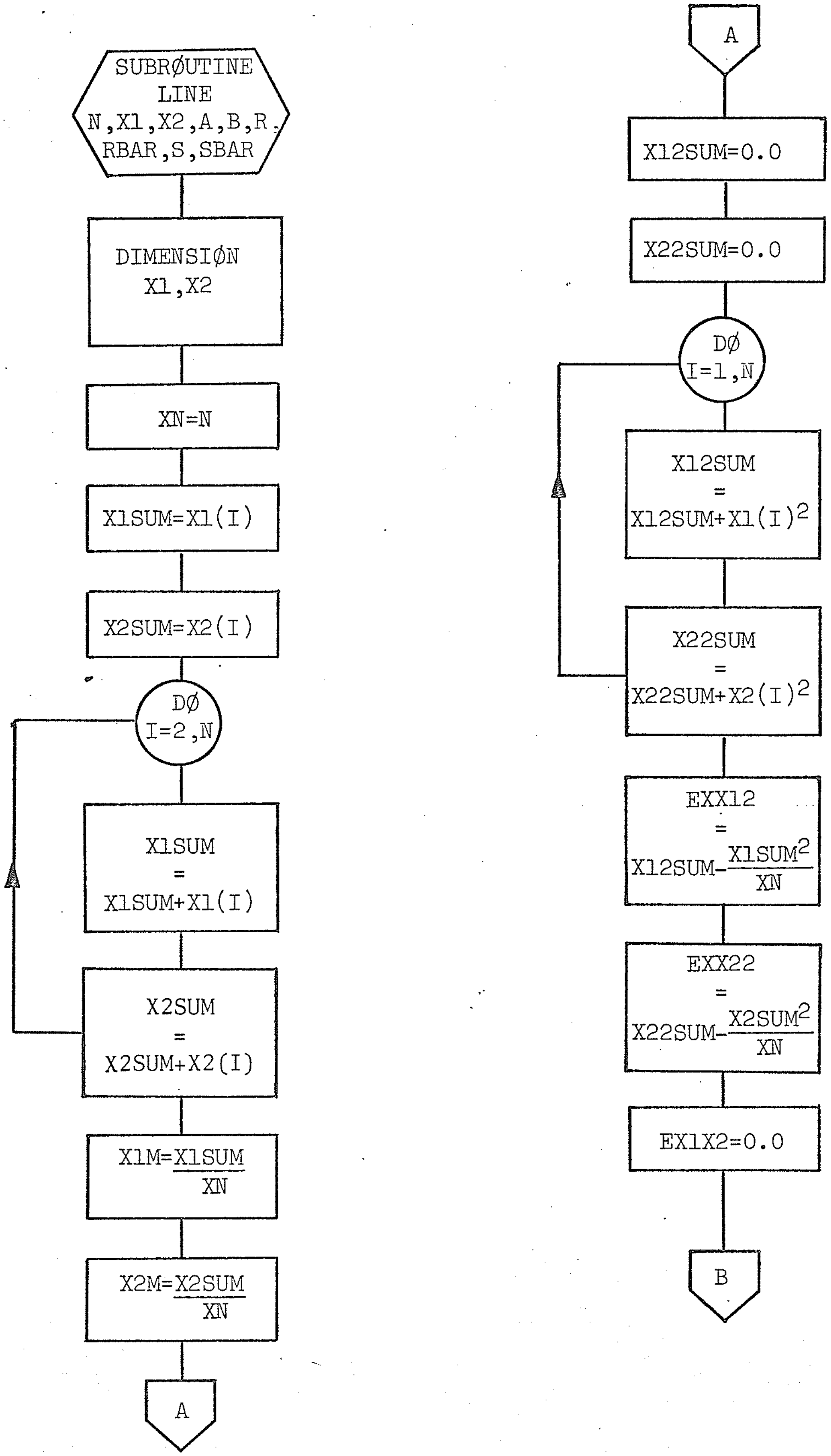
Subroutines used: None.

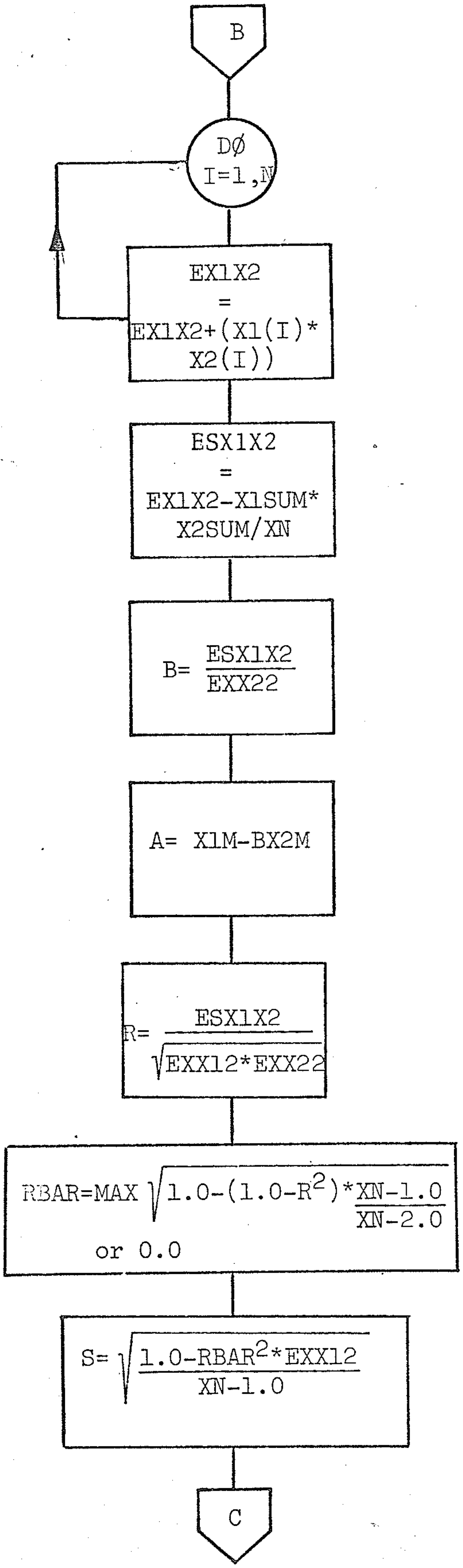
SUBROUTINE LINE

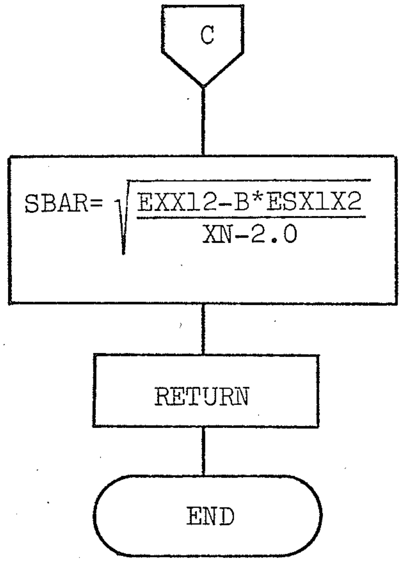
DESCRIPTION OF VARIABLES:

N	LENGTH OF INPUT ARRAY OF DEPENDENT VARIABLE
X1	DEPENDENT VARIABLE
X2	INDEPENDENT VARIABLE
A	INTERCEPT
B	SLOPE
R	CORRELATION COEFFICIENT
RBAR	CORRECTED CORRELATION COEFFICIENT
S	STANDARD ERROR OF ESTIMATE
SBAR	CORRECTED STANDARD ERROR OF ESTIMATE
X1SUM	SUM OF DEPENDENT VARIABLES
X2SUM	SUM OF DEPENDENT VARIABLES
X1M	MEAN OF DEPENDENT VARIABLES
X2M	MEAN OF INDEPENDENT VARIABLES

FLOW CHART FOR SUBRØUTINE LINE




B
DO I=1,N
EX1X2 = EX1X2+(X1(I)*X2(I))
ESX1X2 = EX1X2-X1SUM*X2SUM/XN
B= ESX1X2 / EXX22
A= X1M-BX2M
R= ESX1X2 / √EXX12*EXX22
RBAR=MAX √1.0-(1.0-R²)*XN-1.0 / XN-2.0
or 0.0
S= √1.0-RBAR²*EXX12 / XN-1.0
C


C
SBAR= √EXX12-B*ESX1X2 / XN-2.0
RETURN
END

DESCRIPTION OF PROGRAM PLOT

This program is written for an IBM 1620 computer with a CALCOMP plotter. The program accepts an array of input variables (benefit-cost ratios, in this case) versus corresponding Weibull plotting positions on punched cards.

The program is set up to draw a two cycle log versus probability grid, plot the benefit-cost ratios, and draw a best fit straight line through the center two-thirds of the plotted points. The program also letters the axes and completes the title box. Size of graph is scaled using input variables.

Subroutines used: None.

PL0T

DESCRIPTION OF VARIABLES:

EXTH - HIGHEST VERTICAL VALUE

EXTL - LOWEST VERTICAL VALUE

AL0NG - HEIGHT OF GRAPH IN INCHES

BC - VARIABLES (INPUT) ORDINATES

P0S - VARIABLES (INPUT) ABSCISSA

MM - NUMBER OF POINTS TO BE PLOTTED

HSCALE - HORIZ. SCALE IN INCHES PER STANDARD DEV. (INPUT)

VSCALE - VERT. SCALE IN INCHES PER LOG VALUE (CALCULATED)

VABOVE - CALC. PLOTTING POS. FOR H0RIZ. GRID

L - STUDY NUMBER

R - DISC0UNT RATE

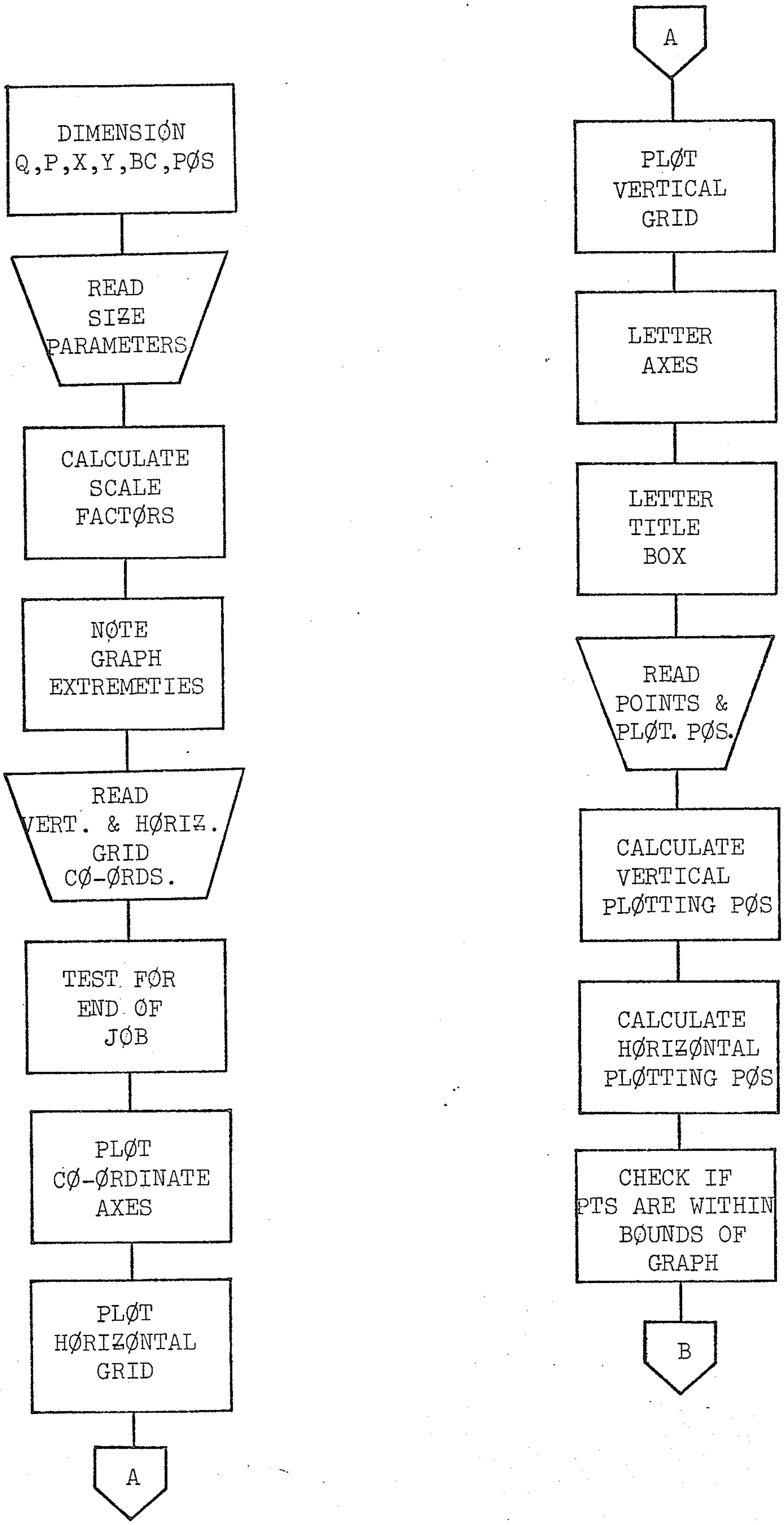
S - FL00DWAY SIZE

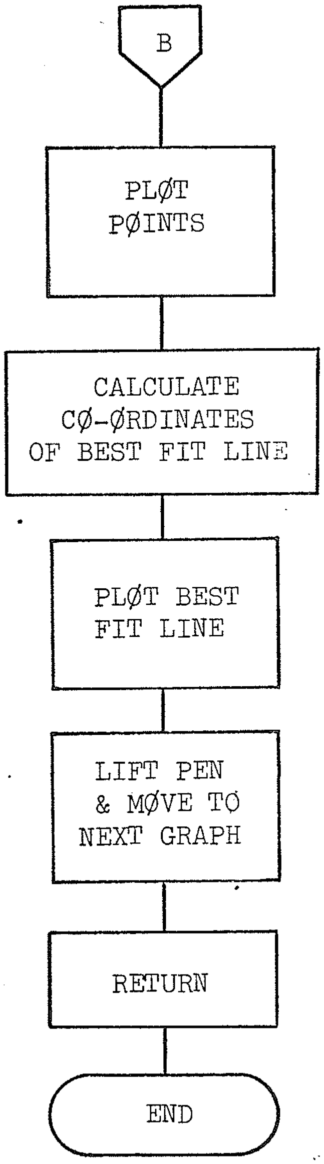
AN - GENERATION LENGTH

Q - Y - C00RDINATES F0R PL0TTING HORIZ. GRID

P - X - C00RDINATES F0R PL0TTING VERT. GRID

GENERAL FLØW CHART FØR PLØT




B
PLØT POINTS
CALCULATE CØ-ØRDINATES OF BEST FIT LINE
PLØT BEST FIT LINE
LIFT PEN & MØVE TO NEXT GRAPH
RETURN
END