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THE EFFECTS OF MEASUREMENT ERRORS ON DESIGN FLOOD ESTIMATION BY FLOOD FREQUENCY ANALYSIS

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PREFACE

The estimation of design flood is one of the most important component of planning and design of water resources projects. A reasonably accurate estimate of design flood is very much necessary. An estimate of design flood on lower side is always associated with certain degree of risk which is never desirable for all practical purposes. On the other hand, a higher estimate of the design flood value is bound to increase the cost of the project, in many cases, which may render the project as economically unviable.

The flood frequency analysis is very commonly used for estimation of design floods where the continuous data in respect of flood peaks of sufficiently long duration are available. However, such estimation are considerably affected due to errors in the observed historical data. In case of design flood estimation by frequency analysis, the observed values of peak discharges are used which are more prone to measurement and other types of errors. The effects of these errors are highly pronounced in the design flood estimation as the design flood for most of the important structures are usually estimated for considerably higher return period on the basis of relatively short term record of the data.

This report entitled "The Effects of Measurement Errors on Design Flood Estimation by Flood Frequency Analysis" is an effort to examine the effects of different types of measurement errors in the data on the estimated values of design flood using the flood frequency approach.

This report is a part of the work program of the Hydrologic Designs Division of the Institute. The study has been carried out by Shri M. E. Haque and Shri Rakesh Kumar, Scientists and Shri Mathew K. Jose, Senior Research Assistant.

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ABSTRACT

Flood frequency analysis is very commonly used for estimation of design floods of different return periods. For correct estimation of the design flood the observed data are required to be accurate, reliable and of sufficiently long duration.

Hydrological data contain errors which are introduced during measurement, recording and processing. The measurement errors in the data result in erroneous assessment of the design flood. The under-estimation or over estimation of design flood due to measurement errors in the data lead to under design or over design of the water resources structures. If any structure is under designed, then the risk of its failure increases. On the other hand, over design of any structure may lead to an uneconomic proposal.

The effects of errors in the observed data are highly pronounced on the design flood estimation. In case of design flood estimation by flood frequency analysis, the observed values of the peak discharges are used which are more prone to measurement and other types of errors than the normal flow data. Such errors may lead to wrong estimation of design flood during extrapolation; as the design floods are usually estimated for a very large recurrence interval on the basis of short record length.

In this study, an attempt has been made to examine the effects of various types of measurement errors in the data on the estimated values of design floods of different recurrence intervals using the flood frequency analysis approach. The effect of systematic measurement errors has been studied using the observed data as well as the generated data of the three sites by introducing systematic errors to the annual peak flow sequences pertaining to i) high floods, ii) medium floods, iii) low floods ; iv) all the peak floods; and v) all events except high floods. The effects of random measurement errors on design flood estimates have also been examined.

The results of the study indicate that the estimation of design flood values is considerably affected by the degree of error in observed annual peak values. However, the magnitude of the possible error in design flood estimation varies depending upon the return period, frequency distribution used and the nature of errors in the data. Errors in observation of high flood peaks result in larger deviations in the estimated values of the design floods of higher return periods as compared to the errors in the medium and low floods. It indicates that there is need for extra precaution in measurement of flow during high floods.

An over all view of the results of the study indicates that the possibility of different conditions of errors are to be given due weightage while estimating the design floods for different structures. For example, for the design of spillway of a large dam, it would be necessary to ensure accuracy in measurements of high flood peaks as errors in only a few values of the discharges during high floods may result in considerably large variations in the design flood estimates for high return periods. On the other hand, for the design of a small structure like a culvert or flood levees the degree of error in the high flood peaks do not affect the design flood estimation to a great extent. In such cases it is more important to have a flood sequence where the data corresponding to low and medium floods have been measured accurately.

It is further observed that effects of errors on design flood estimation follow a well defined trend in case of the systematic errors. Once the type of the error is identified and the extent of errors at a particular site is established, it may be suitably incorporated in the design flood estimation by flood frequency analysis after proper studies.

1.0 INTRODUCTION

Estimation of design flood is one of the most important components of planning and design of any water resources project. Flood estimates are required for design of a variety of engineering works including dams,spillways, bridges and flood protection works etc. Correct estimates of the incoming floods are also required for flood control operations, maintenance of flood levees and for evacuation operations in emergent situations. Use of flood frequency analysis is very common for estimation of design floods of different return periods. Flood frequency analysis deals with univariate process comprising of maximum peak flow values. The properties of time series are estimated from records of the historical data and longer the series, the better are the estimates of parameters describing the processes.

The peak flood data used for frequency analysis should satisfy the following assumptions in order to have the meaningful estimates.

(a) The characteristics of the sample are true representative of the characteristics of the population,
(b) The statistical characteristics derived from the sample are time invariant,
(c) The data are random,
(d) The data are homogeneous, and
(e) The data are accurate and reliable.

For carrying out flood frequency analysis the following steps are involved:

(a) Process the historical data for carrying out flood frequency analysis,
(b) Identify some of the theoretical frequency distributions which are likely to provide good fit to the data series,
(c) Fit the chosen frequency distributions to the historical flood records and estimate the parameters of the distributions adopting one or more parameter estimation techniques,
(d) Select the best fit distribution on the basis of some goodness of fit criteria, and
(e) Estimate the floods of different return periods using the parameters of the best fit distribution.

1.1 Need for Accuracy in Observed Streamflow Data

Streamflow is the combined outcome of all climatological and geomorphological factors which operate in a drainage basin. Over a region, the quantity of water flow in rivers shows considerable amount of spatial and temporal variations. Knowledge of total quantities of water and their variations is essential for proper development of human activities. The assessment, management and control of water resources can only be effective if there is access to accurate and continuous information on streamflow.

Observed records are required to be accurate, reliable and continuous for the design of hydraulic structures such as dams, bridges, flood banks and for the operation of flood warning systems.The records of low flows are also needed for evaluation of drought conditions, control of abstractions and design of water conservation measures etc. Accuracy of flow measurement means the degree of agreement between the apparent flow as measured and the actual flow. The estimation of accuracy of a measurement, therefore, consists in determining the likely magnitude of the difference between the apparent and actual flow. It is not confined to a single measurement of the instantaneous flow but also to estimation of daily mean discharge, monthly mean discharge and average flow.

Laurenson and O'Donnell (1969) state that real hydrologic data contain errors introduced during measurement, recording and processing. It is impossible usually to determine the true values contained within real data.

The International Organisation for Standardization (ISO,1969 a & b) states, "No measurement of a physical quantity can be free from uncertainties which may be associated with either systematic bias caused by errors in the standardizing equipment or a random scatter caused by a lack of sensitivity of the measuring equipment. The former is unaffected by repeated measurements and can only be reduced if more accurate equipment is used for the measurements. Repetition does, however, reduce error caused by random scatter. The precision of the average ' n ' repeated measurements is $\sqrt{n}$ times better than that of any of the points by themselves."

".....When considering the possible uncertainty of any measurement of the discharge in an open channel, it is not possible to predict this uncertainty exactly but an analysis of the individual measurements which are required to obtain the discharge can be made and a statistical estimate made of the likely tolerance. A 95 percent tolerance of measurement may be defined statistically as the band width around the calculated value which, on an average of nineteen times out of twenty, can be expected to include the true value"(IAHS - UNESCO - WMO, 1970).

Herschy et al. (1970) state that for computation of errors, the overall tolerance should be based on the 95 percent confidence level and this may be taken as approximately twice the standard deviation. However, care is required to ensure that individual or partial errors are considered initially at 68 percent confidence level and only at the final stages doubled to give the 95 percent confidence level.

1.2 Effects of Errors of Flow Data on Planning and Design of Water Resources Development Schemes

The possible effects of measurement errors in flow data on planning and design of the water resources schemes are as follows:

a) The measurement errors in flow data result in erroneous assessment of the water resources. It leads to higher or lower estimation of runoff. Due to under-assessment of water resources, some of the scarce water resources remain unutilised. Whereas, over-assessment of the water resources at the time of planning leads to shortage and consequent failure of the project at operational stage.

b) Under-estimation or over-estimation of design flood due to measurement errors in the data leads to under design or over design of the water resources projects. If any structure is under designed then risk of its failure increases. On the other hand, over-design of any structure leads to extra cost of its construction, which may on a number of occasions lead to rejection of the proposal on economic considerations.

c) The measurement errors in flow data give misleading results in research and modelling studies. For calibration and validation of a hydrological model, it is essential that the observed data used in simulation are free from errors.

The effects of measurement errors in the observation of data are highly pronounced on the design flood estimation. In case of design flood estimation by flood frequency analysis,the peak values are used which are more prone to measurement errors than the normal flow data. There is also a possibility that peak flood may pass before or after the actual measurement is carried out. In such cases it is necessary to have a proper estimate of the discharge corresponding to peak flood. If the flood frequency analysis is carried out without making proper corrections, it may lead to wrong estimation of design flood. This is more so as the design floods are usually estimated for a very large recurrence interval on the basis of short record length.

Laurenson and O'Donnell (1969) studied data error effects in unit hydrograph derivation. The types of errors in data studied by the authors are: i) assumption of uniform loss rate; ii) over - or - under estimation of the total storm rainfall; iii)errors in discharge rating curves especially due to extrapolation of this curve; iv)erroneous baseflow separation; v) lack of synchronization between the rainfall and streamflow records and vi) lack of synchronization between the rainfall records of different stations in the catchment.

It may be emphasized that the statistical analysis of river flow data is only applicable if the field data have been obtained by acceptable hydrometric principles and practices. The accuracy of data is very important for carrying out flood frequency analysis and particularly when this approach is used for estimation of design floods for higher return periods by using a shorter record length. At the same time, it remains a fact that there are a number of factors which are responsible for introduction of errors in observations of river flow data. The degree of errors in measurement of discharges during high flood is generally considered to be still higher due to obvious reasons. In a developing country like India, adequate or short record length data added with some erroneous data due to measurement errors may affect the design flood estimates, to a considerable extent. Though every effort is made to identify such erroneous data by application of suitable data processing techniques for making the data consistent, a certain degree of error is bound to be present. Such errors which may be either systematic or random in nature, have definite effects on the estimated values of the design floods.

In this study, an attempt has been made to examine the effects of various types of measurement errors in the data on the estimated values of design floods of different recurrence intervals using the flood frequency analysis approach. The effects of systematic measurement errors have been studied by introducing the systematic errors to the observed peak flood values by increasing or reducing these values by +20%, +10%, -10% and -20% for the following cases:

(a) Variations only in the annual peak flood values pertaining to high floods,
(b) Variations only in the annual peak flood values pertaining to the medium floods,
(c) Variations only in the annual peak flood values pertaining to low floods,
(d) Variations in all the annual peak flood values, and
(e) Variations in all the events except annual peak flood values pertaining to high floods.

The effects of systematic errors on design floods estimation using the generated data have also been studied in addition to the observed peak flood series, in the same way as discussed above.

Further, the effects of random measurement errors on the design flood estimates have also been examined.

2.0 ERRORS IN DISCHARGE MEASUREMENT

The error can be defined as the difference between the measured value and the true value. The true value means the water level/discharge as it occurs at the gauging site.

Measurement errors are usually classified as systematic and random errors.

2.1 Systematic Errors

Systematic errors are those which can not be reduced by increasing the number of observations, if the instruments and equipment remain unchanged. Systematic errors are essentially due to malfunctioning or incorrect use of instruments or lack of knowledge of observer. In stream flow, systematic errors may be present in water level recorder, in the reference gauge or datum and in the current meter. These errors may be generally small but in some cases, they are quite considerable.

2.2 Random Errors

Random errors are sometimes referred to as experimental errors and the observations deviate from the mean in accordance with the laws of chance.

2.3 Sources of Errors in Discharge Observation

The errors in discharge observations are of both types namely systematic errors and random errors. Some of the common causes of errors in discharge measurements are as follows.

a) Instrumentation Errors

i) Errors in current meter ratings due to over use or errors in current meter observations due to poor maintenance; and

ii) Errors due to mechanical problems with several instruments such as current meter, stop watch, revolution counter etc.

b) Observational Errors

i) Errors due to deviations in zero of the gauge, either by mistake in recording or due to disturbance of gauges at site;
ii) Use of current meter for measurement of flow above or below its established ratings;
iii) Errors introduced when the meter is not steady in the current at exact observation point; and
iv) Errors in estimation of discharge when the flow lines are oblique to the lines of cross section.

c) Errors in Data Recording and Processing

i) Misreading and transposing digits;
ii) Misreading because of faulty memory;
iii) Recording data at a wrong place on the recording sheet;
iv) Misplacing the decimal point;
v) Making reading at improper interval;
vi) Incorrect dating of the report; and
vii) Incorrectly reading or communicating the data to a reporting centre.

In addition, there are some specific causes which result in errors in discharge measurement during high and low floods. Some of them are discussed here under.

2.4 Specific Errors Associated with High Flow Measurement

a) During high floods, current meters are rarely used either due to high velocity or due to non-availability of suitable navigational facilities. As a result, the float method or the slope area method is used. These methods are definitely not very reliable. Particularly, the floating debris during the flood may affect the correct estimation of flow velocity etc;.

b) The stage measurement sites are away from banks and stage observation is to be made from a distance. This results in introduction of errors, mainly due to considerable wave formation during high flood.

c) Because of overtopping of river banks at the upstream of the discharge measurement site, there is possibility of under estimation of the discharge at the site, and

d) In many cases, due to difficult approaches during flood season, it is the tendency of the observers to skip a few observations, particularly during night hours. This may lead to improper records in respect of peak flood events.

As a matter of fact, the standard technique of discharge observations are adopted only at a few selected sites where all the necessary equipment and navigational facilities are available. For many of the Indian rivers, the normal discharge measurement is rarely adopted during high floods due to lack of suitable equipment and navigational facilities. Generally, either the float method is used for estimation of velocity or slope area method is adopted for discharge estimation under such conditions. These methods are bound to introduce a certain degree of errors in estimated values of discharge. These aspects are rarely given any consideration while using the data for flood frequency analysis. But it remains a fact that the analysis based on such data has definite effect on estimation of design flood.

2.5 Specific Errors Associated With Low flow Measurement

Some of the specific errors associated with low flow measurement are listed below.

(a) During low flow the depth of flow to be measured is quite shallow. This may result in erroneous measurement of the velocity of flow;

(b) In a number of rivers, there is formation of more than one channels, which may lead to erroneous measurement of the flow;

(c) In many rivers ,there are fair weather bridges near to the discharge measurement site. This also affects accuracy of the observed discharge; and

(d) Many a times, the observers do not take proper care in measurement of velocity while adopting wading technique for measurement of the flow.

2.6 The Effects Of Measurement Errors On Hydrological Analysis

Measurement errors lead to erroneous assessment of water resources. It may result in very high or low estimates of discharges. If water resource is under-assessed, then some of the scarce water resources remain unutilised and go as waste. On the other hand, if water resources are over-assessed, then planned utilisation falls short of requirement in actual practice. In case of design flood estimation, we rely on peak values and any measurement errors associated with these values lead to wrong estimation of design flood during extrapolation. It further results in over-design or under-design of the water resources structures. If any structure is over-designed, then it leads to extra cost of construction of the structure. Whereas under-design of the structure increases its risk of failure.

In this study, an attempt has been made to examine the effect of measurement errors on design flood estimation by flood frequency analysis with a view to understand the extent of reliability of such analysis when the possibility of introduction of such errors is well established.

The analysis has been carried by using data in respect of three sub-basins namely Narmada up to Garudeshwar, Sub-basins of Godavari at Bridge No. 807/2 and Bridge No. 912/1.

3.0 STUDY AREA AND DATA USED

With a view to examine the effect of measurement errors on estimated values of design floods of different recurrence intervals, the data in respect of three different basins having considerable variations in the catchment area and record lengths have been used. The salient features of the sub-basins and the data availability are summarised in Table-1.

The study area lies in two main basins namely the (i) Narmada basin up to gauging site at Garudeshwar and (ii) the catchments defined by bridges no. 807/2 and no. 912/1 of sub-basins of Godavari. A brief description of Narmada basin up to Garudeshwar and the salient features of the Godavari sub-basins under study are given hereunder.

Table-1: Salient Features of Catchment Area and Data Record Length

Sl. No.	Catchment Name	Catchment Area (sq.km.)	Record Length (years)	Record Period
1.	Narmada upto Garudeshwar	89,552	32	1948 - 1979
2.	Godavari sub-basin up to Bridge.No.807/2	824	19	1966 - 1984
3.	Godavari sub-basin up to Bridge.No.912/1	137	26	1959 - 1984

3.1 Narmada basin up to Garudeshwar

The Narmada basin extends over an area of 98,796 sq. kms. and lies between latitudes 21° 20' N to 23° 45' N and longitudes 72° 32' E to 81° 45' E. However, the Narmada basin up to Garudeshwar has an areal extent of 89,552 Sq.kms.

The Narmada river rises in the Amarkanatak plateau of Maikala range in the Shahdol district of Madhya Pradesh at an elevation of 1058 metres above mean sea level. The river flows over a distance of 1312 kms. before it falls into Gulf of Cambay in the Arabian sea near Bharuch in Gujarat. The first 1079 kms are in Madhya Pradesh. In the next length of 35 kms. the river forms boundary between the states of Madhya Pradesh and Maharashtra. In the next length of 39 kms., it forms boundary between Maharashtra and Gujarat. The last length of 159 kms lies in Gujarat.

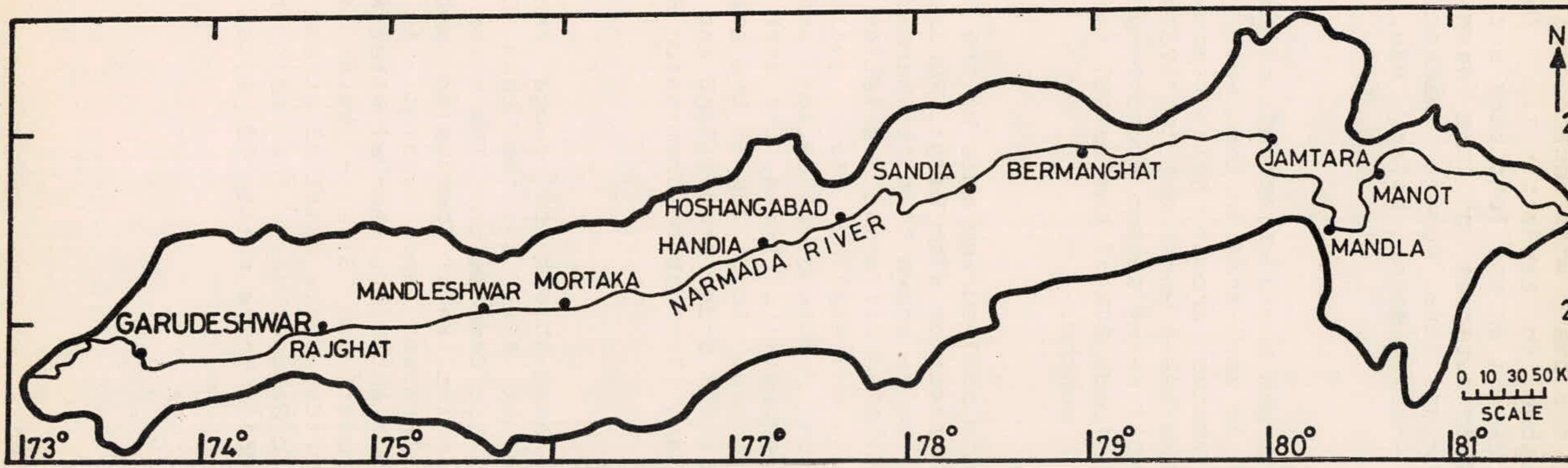
The index map of the basin with location of the gauging site at Garudeswar is shown in Exhibit- 1. The river has 41 tributaries of which 22 are on the left bank and 19 on the right. Some of the important tributaries of the Narmada are Burhner, Banjar, Sher, Tawa, Chhota Tawa, Kundi, Shakkar, Dudhi, Ganjal, Goi, Karjan, Hiran, Tendoni, Barna, Kolar, Man, Uri, Hatni and Orsang.

The basin experiences humid tropical climate ranging from sub-humid in the east to semi-arid in the west with pockets of humid or sub-humid climates around hill reaches. The normal annual rainfall for the basin works out to 1178 mm. South west monsoon is the principal rainy season accounting for nearly 90% of the annual rainfall. About 60% of the annual rainfall is received during July and August months.

The reconnaissance soil survey made by the Central Water and Power Commission in connection with Bargi, Punasa, Barna and Tawa projects lying in the basin shows that the Narmada basin comprises mainly of black soils. The different varieties are deep black soil, medium black soil and shallow black soils. In addition mixed red and black soil, red and yellow soil and skeletal soils are also observed in pockets; of these, the deep black soil covers major portion of the basin. About 32% of the area of the basin is under forest and about 60% under arable land and remaining under grassland and waste land (Irrigation Commission Report, Vol. III, Part I, 1972).

The systematic observations of gauge and discharge were started in the basin in 1947 by the then Central Waterway, Irrigation and Navigation Commission. The river Narmada is gauged at various sites by Central Water Commission and State Irrigation Department of Madhya Pradesh and Gujarat. As per information available in the report entitled, "Annual Water Account of Narmada Basin upto Sardar Sarovar Dam Site - Water Year 1985-86" by Narmada Control Authority, there exist 33 stream gauging sites in the Narmada basin upto Garudeshwar. The main river Narmada is gauged at 11 sites, while there exist 22 sites on its various tributaries.

EXHIBIT -1

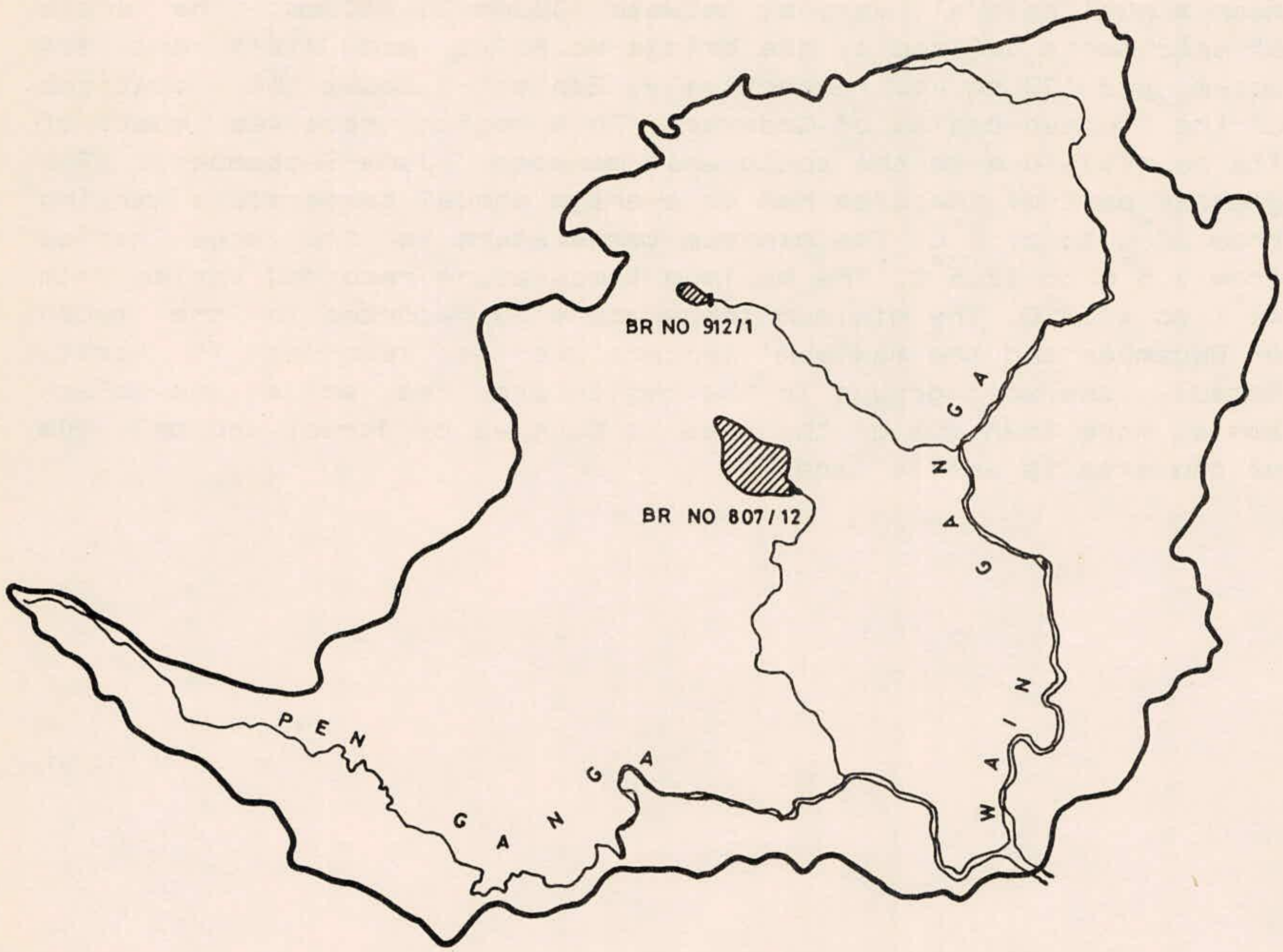


CATCHMENT AREA OF NARMADA BASIN UPTO GARUDESHWAR

3.2 Sub-basins Defined by Gauging Sites at Bridge No.807/2 and 912/1 in Godavari Basin

The Godavari basin is essentially a sub-humid region having mean annual rainfall varying between 1000mm to 1600mm. The areas of catchments defined by the bridge No.807/2 and 912/1 are 824 sq.km. and 137 sq.km. respectively. Exhibit-2 shows the locations of the two sub-basins of Godavari. This region receives most of its rainfall due to the south-west monsoon (June-September). The greater part of the area has an average annual temperature varying from 25°C to 27.5°C. The minimum temperature in the area varies from 2.5°C to 12.5°C. The maximum temperature recorded varies from 45°C to 47.5°C. The minimum temperature is recorded in the month of December and the maximum temperature is recorded in April. Broadly, the soil groups in the region are red soils and black soils. More than 50% of the area is covered by forest and only 25% of the area is arable land.

EXHIBIT- 2



SUB-BASINS DEFINED BY GAUGING SITES AT BR. NO 807/2 AND 912/1 IN UPPER GODAVARI BASIN

4.0 METHODOLOGY ADOPTED

The design floods of different return periods are generally estimated by using a frequency distribution, which provides the best fit to the given set of data. For all practical purposes either the Log Pearson Type-III or the Gumbel distributions are generally used for the estimation of design flood. Studies have been carried out by various authors and it has been observed that in specific cases the probability distributions such as Log Normal or Pearson Type-III provide the best fit.

With the limited purpose of examining the extent of variations in the estimate of design flood the following five distributions have been considered irrespective of their being the best fit distributions for the given set of data.

(i) Normal distribution
(ii) Log normal distribution
(iii) Pearson type III distribution
(iv) Log Pearson type III distribution
(v) Gumbel Distribution

The effect of systematic measurement errors and the random measurement errors have been examined for all the cases. The various distributions used in the analysis are briefly described hereunder.

(i) Normal Distribution

It is one of the most important distributions in statistical hydrology. This is used to fit empirical distributions with symmetrical histograms or with skewness coefficient close to zero. The Normal distribution occupies unique position in statistics due to its role in the central limit theorem. This theorem validates its use as an approximation to other distributions. The central limit theorem states that the distribution of sums of random variables from any distribution tends to a Normal distribution as the number of terms in the sum increases.

The probability density function (pdf) of the distribution is given by:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right] ; -\infty < x < +\infty$$

where μ is the location parameter, and σ is the scale parameter.

The density of Normal distribution is continuous $-\infty < x < +\infty$ and tends to zero as x tends to $-\infty$ or $+\infty$. It has a symmetrical bell shape and as a result the mean, mode and median are equal.

The mean, variance, coefficient of skewness and coefficient of kurtosis are:

$$E(X) = \mu$$
$$Var(X) = \sigma^2$$
$$C_s = 0$$
$$C_k = 3$$

All odd central moments of normal PDF are zero and all even central moments are given by,

$$\mu_{2m} = \frac{(2m)!\sigma^{2m}}{2^m . m!}$$

for example if $m = 2$, $\mu_4 = 3\sigma^4$

The cumulative distribution function (CDF) of the normal distribution is given by

$$F(x) = \int_{-\infty}^{x} f(x)\, dx$$

or $$F(x) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{x} \exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right] dx$$

If $z = \frac{x-\mu}{\sigma}$;where z is called the reduced variate, then the above equation reduces to:

$$F(z) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{z} \exp\left(-\frac{z^2}{2}\right) dz$$

The PDF and CDF of normal distribution corresponding to standardized variate z can be calculated from the standard tables.

(ii) Log Normal Distribution

Log normal distribution can be applied to a wide variety of hydrologic events especially in the cases in which the corresponding variable has a lower bound, the empirical frequency distribution is not symmetrical and the factors causing those events are independent and multiplicative. Chow (1964) has provided theoretical justification for the use of the log normal distribution. The causative factors for many hydrologic variables act multiplicatively rather than additively and so the logarithms of the peak flows which are the product of these causative factors follow the log normal distribution.

If $Y = \log_e(X)$ follows normal distribution, then X follows log normal distribution. Assuming that the mean and variance of Y are μ_y and σ_y^2 respectively, the PDF of X can be written as:

$$f(x) = \frac{1}{\sigma_y \sqrt{2\pi}\, x} \exp\left[-\frac{1}{2}\left(\frac{\log_e(x)-\mu_y}{\sigma_y}\right)^2\right]$$

In relation to the variable X, μ_y controls the scale, so it is called the scale parameter, while σ_y controls the skewness and hence it may be regarded as a shape parameter.

If log transformed series follows normal distribution then the following relationships exist between parameters of log-transformed series and original series (Yevjevich, 1972).

$$\mu_y = \frac{1}{2}\log_e(\mu_x^2 /(1+\eta_x^2))$$

$$\sigma_y^2 = \log_e(1 + \eta_x)$$

where η_x is the coefficient of variation , $\eta_x = \frac{\sigma_x}{\mu_x}$.

The skewness and kurtosis coefficient of the variable x are always positive and are given by

$$C_{s_x} = \eta_x^3 + 3\,\eta_x$$

$$C_{k_x} = \eta_x^8 + 6\,\eta_x^6 + 15\,\eta_x^4 + 16\,\eta_x^2 + 3$$

(iii) Pearson Type-III Distribution

The Pearson Type-III distribution is a three parameter distribution. This is also known as Gamma distribution with three parameters. The pdf of the distribution is given by:

$$f(x) = \frac{(x-x_o)^{\gamma-1}\, e^{-(x-x_o)/\beta}}{\beta^{\gamma}\,\Gamma(\gamma)}$$

where,

x_o = location parameter

β = scale parameter

γ = shape parameter

The first statistical estimates of the data are related to the Pearson type III distribution parameters as:

$$\mu = x_o + \beta\gamma$$

$$\sigma^2 = \beta^2\gamma$$

$$c_s = 2/\sqrt{\gamma}$$

(iv) Log Pearson Type-III distribution

The Log Pearson Type-III distribution has been widely used in hydrology for fitting the frequency distribution of flood data. The U.S Water Resources Council recommends the use of the Log Pearson Type- III distribution as an attempt to promote a uniform and consistent approach for flood frequency studies. As a result, the use of this distribution has become popular in the United States, and has brought the attention of practicing engineers from Federal, State and Local governme nts as well as private organisations.

The probability density function of the Log Pearson Type-III distribution is given by:

$$f(x) = \frac{1}{|\beta|.\Gamma(\gamma).x} \left[\frac{\log_e x - y_o}{\beta}\right]^{\gamma-1} \exp\left[-\frac{\log_e x - y_o}{\beta}\right]$$

where y_o is the location parameter, β is the scale parameter and γ is the shape parameter. If log transformed series of x follows Pearson Type-III distribution then x series follows Log Pearson Type-III distribution.

(V) Gumbel Distribution

EV-1 Distribution or Gumbel Distribution is a two parameter distribution widely used in meteorology and hydrology. The PDF is given by,

$$f(x) = \frac{1}{\alpha} \exp\left[-\frac{x-u}{\alpha} - e^{-(x-u)/\alpha}\right]$$

In the above equation u and α are known as location and shape parameters of the distribution.

The CDF is given by:

$$F(x) = e^{-e^{-(x-u)/\alpha}}$$

The parameters of the distribution can be estimated from the following equations using method of moments.

$$\mu = u + 0.5772\,\alpha$$

$$\sigma = \alpha.\frac{\pi}{\sqrt{6}}$$

for Gumbel distribution coefficient of skewness is equal to 1.139.

If $\left(\frac{x-u}{\alpha}\right)$ is replaced by y (the standardized reduced variate) then,

$$g(y) = e^{(-y - e^{-y})}$$

$$G(y) = e^{-e^{-y}}$$

or

$$y = -\ln[-\ln(G(y))]$$

$$= -\ln[-\ln(1 - \tfrac{1}{T})]$$

4.1 Effects of Systematic Measurement Errors

The effect of systematic measurements errors has been studied in the following two ways:

(a) Effect of systematic measurement errors on design flood estimation using the observed data; and

(b) Effect of systematic measurement errors on design flood estimation using the generated data of 100 years for all the three sites.

For the purpose of introduction of systematic measurement errors, the flood peak data have been classified in three categories namely; data pertaining to (i) high floods,(ii) medium floods and (iii) low floods. In the absence of very clear definitions for high, medium and low floods and because of non-availability of detailed flood situations during each event, it is not possible to adopt a well defined procedure for classifying the various observed flood peaks as high, medium and low floods. However, on the basis of available information about the site etc, the high, medium and low floods have been identified for the data of all the three gauging sites. In general,the peaks corresponding to the high flood have been found to have values more than $\bar{Q} + 2\sigma_Q$. The number of the annual peaks having values less than $\bar{Q}$ have been found to match with the number of low flood peaks for the respective sites. Therefore this classification has been adopted while analysing the generated data. Here $\bar{Q}$ is the mean value of the annual peak floods and σ_Q is the standard deviation for the respective sites. The number of events of the observed data pertaining to high, medium and low floods for the three sites are given in Table-2.

Table-2 Number of annual peaks corresponding to high, medium and low floods for the different sites

Sl. No.	Site	Length of Record (in Years)	Number of Flood Events		
			High	Medium	Low
1.	Narmada upto Garudeshwar	32	3	9	20
2.	Godavari sub-basin upto Bridge.No.807/2	19	1	10	8
3	Godavari sub-basin upto Bridge.No.912/1	26	2	13	11

For studying the effect of systematic measurement errors using the generated data, Gumbel-distributed data have been generated for the period of 100 years for all the three sites. These 100 years data of each of the sites have been classified in high, medium and low floods in a similar way as discussed earlier. The number of events of the generated data pertaining to high, medium and low floods are given in Table-3.

For the purpose of introduction of systematic measurement errors, the observed as well as generated data have been increased or reduced by +20%, +10%, -10%, and -20% for the following cases.

(i) +20% variations only in the annual peaks pertaining to high floods

(ii) +10% variations only in the annual peaks pertaining to high floods

(iii) -10% variations only in the annual peaks pertaining to high floods

(iv) -20% variations only in the annual peaks pertaining to high floods

(v) +20% variations only in the annual peaks pertaining to medium floods

(vi) +10% variations only in the annual peaks pertaining to medium floods

(vii) -10% variations only in the annual peaks pertaining to medium floods

(viii) -20% variations only in the annual peaks pertaining to medium floods

(xi) +20% variations only in the annual peaks pertaining to low floods

(x) +10% variations only in the annual peaks pertaining to low floods

(xi) -10% variations only in the annual peaks pertaining to low floods

(xii) -20% variations only in the annual peaks pertaining to low floods

(xiii) +20% variations in all the annual peaks

(xiv) +10% variations in all the annual peaks

(xv) -10% variations in all the annual peaks

(xvi) -20% variations in all the annual peaks

(xvii) +20% variations in all the events except those annual peaks which pertain to high floods

(xviii) +10% variations in all the events except those annual peaks which pertain to high floods

(xix) -10% variations in all the events except those annual peaks which pertain to high floods.

(xx) -20% variations in all the events except those annual peaks which pertain to high floods.

Table-3 Number of flood events corresponding to high, medium and low floods for different sites for the generated data.

Sl. No.	Site	Length of Generated Data (years)	Number of Flood Events		
			High	Medium	Low
1.	Narmada upto Garudeshwar	100	4	41	55
2.	Godavari sub-basin up to Bridge No.807/2	100	4	42	54
3.	Godavari sub-basin up to Bridge No.912/1	100	4	41	55

4.2 Effects of Random Measurement Errors

For the purpose of introduction of random errors., it has been assumed that the errors follow normal distribution. The errors have been introduced in the given data series by using the following relationship.

$$QR_i = QO_i \, (1 + \alpha z_i) \quad \text{with} \quad \alpha = 0.05 \text{ and } 0.10$$

where

QO_i is the observed peak sequence;

z_i is the normally distributed random number;

α is a constant and two values i.e. $\alpha = .05$ and $\alpha = 0.10$ have been considered; and

QR_i is peak sequence after introduction of random errors.

For the purpose of estimation of the design flood, only two probability distributions namely Gumbel and Log Pearson Type-III have been used. However, for some specific studies the probability distributions of Pearson Type III, Normal and Log normal have also been considered as these are very frequently used distributions. Using the above probability distributions, design floods corresponding to 2, 5, 10, 20, 50, 100, 200, 500 and 1000 year return periods have been estimated.

To examine the effect of random errors, analysis has been carried out with twenty series (in each case) after using different sets of normally distributed random numbers. The summary of the analysis for the above study and the results are presented in the following section.

5.0 ANALYSIS AND RESULTS

The errors were introduced in the different data sets as discussed above. Thereafter, the flood peak sequences having different types of errors were used for estimation of design floods of 2,5,10,20,50,100,200,500 and 1000 year return periods. The effects of errors on design flood estimation have been evaluated in terms of the percentage variations by comparing the design flood estimate based on the observed flood sequences with the design floods computed from data sequences after introduction of the above said errors in the observed data. Also, the Gumbel data sequences of record length 100 years have been generated for the three sites and these generated data have been used to study the effect of errors on design flood estimation in terms of the percentage variations by comparing the design flood estimation based on the generated data and the design floods computed after introduction of the above mentioned errors in the generated data as discussed above for the analysis with observed data.

For the purpose of introduction of errors, both the systematic and random errors have been considered as discussed above.

Some of the general observations are as follows:

The analysis clearly indicates that there are definite effects of errors on the estimation of design flood by frequency analysis method. The extent of deviations in the design flood estimation have been found to vary considerably depending upon:

a) The degree of error in the data;
b) The nature of errors viz. error in high floods, medium floods or low floods;
c) Type of errors i.e. systematic errors or random errors.

The effects under various conditions are discussed hereunder.

a) Degree of Error in the Data

The estimation of the design flood values is considerably affected by the degree of error in the observed peak values. In general, the errors increased in the same proportion as that of the errors introduced in data. The results of the estimates of design flood by using the data of Garudeshwar site after introducing a 10% error and a 20% error in the high floods only are illustrated in Fig. 1 .The figure clearly indicates that the variations in the design flood estimates for the various return periods are almost in the same proportion both in cases of Gumbel distribution and the Log Pearson Type III distribution. Fig.2 and Fig.3 illustrate the similar results which have been obtained for the sites at bridge No. 807/2 and bridge No.912/1 respectively. Similar results have been obtained after introducing errors in the medium and low floods also. The results obtained by using the generated data also show similar pattern. Figs. 4 to 6 illustrate the degree of variations in the estimated values of the floods of different return period when systematic errors of +20% and +10% are introduced in the peaks corresponding to high floods only for sites at Garudeswar, bridge No. 807/2 and bridge No. 912/1 respectively.

b) The Nature of Errors

As discussed earlier the errors are likely to be introduced in floods of different magnitudes depending upon the causes of the errors. For the purpose of the analysis the different possible conditions for the introduction of systematic errors are identified as follows:

i) Errors in annual peaks corresponding to high flood only;
ii) Errors in annual peaks corresponding to medium floods only;
iii) Errors in annual peaks corresponding to low floods only;
iv) Errors in annual peaks corresponding to all the flood values; and
v) Errors in all the flood values except the high floods.

The effects on the estimates of design floods considerably differ in all the above mentioned cases.

For example, the systematic error of +20% in different conditions above have been considered and the results as obtained in case of site at Garudeshwar are illustrated in Fig.7. Figure 8 illustrates similar results when error of +10% is introduced. Analysis has also been carried out by using the generated data of record length 100 of years for the site and the results corresponding to systematic error of +20% and +10% are illustrated in Figs. 9 and 10 respectively.

The results in case of data for Bridge No. 807/2 and Bridge No. 912/1 are also illustrated in Figure 11 through 18. Summary of the results for all the cases in respect of the three sites is

TABLE - 4 : PERCENTAGE OF ERROR IN THE FLOOD ESTIMATION OF VARIOUS RETURN PERIODS AFTER INTRODUCTION OF +20% OF SYSTEMATIC ERRORS FOR DATA OF GARUDESHWAR SITE

Sl. No.	ERRORS INTRODUCED IN	DISTRIBUTION USED	PERCENTAGE ERROR IN THE ESTIMATION OF FLOODS CORRESPONDING TO THE RETURN PERIODS (IN YEARS) OF								
			2	5	10	20	50	100	200	500	1000
1.	High Flood Values only	(a) Gumbel	2.67	8.77	10.88	12.26	13.52	14.22	14.78	15.36	15.72
		(b) Log-Pearson Type III	-0.48	3.69	7.33	11.20	16.63	20.97	25.49	31.78	36.77
2.	Medium Flood Values	(a) Gumbel	7.00	9.04	9.74	10.20	10.62	10.86	11.04	11.24	11.36
		(b) Log-Pearson Type III	5.71	9.64	11.48	12.88	14.30	15.17	15.89	16.69	17.19
3.	Low Flood Values only	(a) Gumbel	9.98	3.43	1.16	-0.33	-1.68	-2.43	-3.03	-3.66	-4.05
		(b) Log-Pearson Type III	13.30	6.01	1.75	-1.95	-6.28	-9.26	-12.02	-15.42	-17.83
4.	All Flood Values	(a) Gumbel	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
		(b) Log-Pearson Type III	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
5.	All Values except High Flood	(a) Gumbel	17.11	12.02	10.26	9.11	8.05	7.47	7.00	6.51	6.21
		(b) Log-Pearson Type III	20.06	15.69	12.34	9.10	4.97	1.98	-0.92	-4.59	-7.27

TABLE - 5 : PERCENTAGE OF ERROR IN THE FLOOD ESTIMATION OF VARIOUS RETURN PERIODS AFTER INTRODUCTION OF +10% OF SYSTEMATIC ERRORS FOR DATA OF GARUDESHWAR SITE

Sl. No.	ERRORS INTRODUCED IN	DISTRIBUTION USED	PERCENTAGE ERROR IN THE ESTIMATION OF THE FLOODS CORRESPONDING TO RETURN PERIODS (IN YEARS) OF								
			2	5	10	20	50	100	200	500	1000
1.	High Flood Values only	(a) Gumbel	1.36	4.30	5.32	5.98	6.59	6.93	7.20	7.48	7.66
		(b) Log-Pearson Type III	-0.17	1.94	3.71	5.54	8.03	9.97	11.95	14.62	16.70
2.	Medium Flood Values	(a) Gumbel	3.54	4.37	4.65	4.84	5.01	5.10	5.18	5.25	5.30
		(b) Log-Pearson Type III	3.06	4.87	5.62	6.14	6.61	6.85	7.02	7.17	7.23
3.	Low Flood Values only	(a) Gumbel	5.01	1.66	0.50	-0.26	-0.95	-1.34	-1.65	-1.97	-2.17
		(b) Log-Pearson Type III	6.77	3.04	0.80	-1.20	-3.58	-5.25	-6.83	-8.81	-10.23
4.	All Flood Values	(a) Gumbel	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
		(b) Log-Pearson Type III	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
5.	All Values except High Flood	(a) Gumbel	8.58	5.90	4.98	4.37	3.82	3.51	3.27	3.01	2.85
		(b) Log-Pearson Type III	10.12	7.92	6.17	4.44	2.19	0.53	-1.11	-3.22	-4.79

TABLE - 6 : PERCENTAGE OF ERROR IN THE FLOOD ESTIMATION OF VARIOUS RETURN PERIODS AFTER INTRODUCTION OF -10% OF SYSTEMATIC ERRORS FOR DATA OF GARUDESHWAR SITE

Sl. No.	ERRORS INTRODUCED IN	DISTRIBUTION USED	PERCENTAGE ERROR IN THE ESTIMATION OF THE FLOODS CORRESPONDING TO RETURN PERIODS (IN YEARS) OF								
			2	5	10	20	50	100	200	500	1000
1.	High Flood Values only	(a) Gumbel	-1.42	-4.02	-5.00	-5.61	-6.16	-6.46	-6.71	-6.96	-7.12
		(b) Log-Pearson Type III	0.04	-2.11	-3.79	-5.43	-7.56	-9.13	-10.67	-12.65	-14.12
2.	Medium Flood Values	(a) Gumbel	-3.64	-4.00	-4.13	-4.21	-4.28	-4.32	-4.36	-4.39	-4.41
		(b) Log-Pearson Type III	-3.56	-4.96	-5.32	-5.42	-5.31	-5.11	-4.84	-4.38	-3.98
3.	Low Flood Values only	(a) Gumbel	-5.04	-1.56	-0.35	0.43	1.15	1.55	1.87	2.20	2.41
		(b) Log-Pearson Type III	-6.91	-3.10	-0.71	1.48	4.21	6.19	8.13	10.64	12.57
4.	All Flood Values	(a) Gumbel	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00
		(b) Log-Pearson Type III	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00
5.	All Values except High Flood	(a) Gumbel	-8.64	-5.69	-4.67	-4.00	-3.39	-3.05	-2.78	-2.49	-2.32
		(b) Log-Pearson Type III	-10.18	-8.07	-6.30	-4.45	-1.93	0.04	2.05	4.78	6.90

TABLE - 7 : PERCENTAGE OF ERROR IN THE FLOOD ESTIMATION OF VARIOUS RETURN PERIODS AFTER INTRODUCTION OF -20% OF SYSTEMATIC ERRORS FOR DATA OF GARUDESHWAR SITE

Sl. No.	ERRORS INTRODUCED IN	DISTRIBUTION USED	PERCENTAGE ERROR IN THE ESTIMATION OF THE FLOODS CORRESPONDING TO RETURN PERIODS (IN YEARS) OF								
			2	5	10	20	50	100	200	500	1000
1.	High Flood Values only	(a) Gumbel	-2.92	-7.88	-9.59	-10.72	-11.74	-12.31	-12.77	-13.24	-13.53
		(b) Log-Pearson Type III	-0.07	-4.39	-7.62	-10.74	-14.66	-17.48	-20.19	-23.60	-26.07
2.	Medium Flood Values	(a) Gumbel	-7.40	-7.59	-7.65	-7.69	-7.73	-7.75	-7.77	-7.79	-7.80
		(b) Log-Pearson Type III	-7.73	-10.04	-10.28	-9.97	-9.04	-8.07	-6.92	-5.16	-3.68
3.	Low Flood Values only	(a) Gumbel	-10.09	-3.03	-0.59	1.02	2.48	3.29	3.94	4.62	5.03
		(b) Log-Pearson Type III	-14.13	-6.36	-1.29	3.52	9.69	14.30	18.92	25.06	29.77
4.	All Flood Values	(a) Gumbel	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00
		(b) Log-Pearson Type III	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00
5.	All Values except High Flood	(a) Gumbel	-17.35	-11.16	-9.02	-7.62	-6.34	-5.63	-5.06	-4.47	-4.10
		(b) Log-Pearson Type III	-20.48	-16.37	-12.75	-8.85	-3.32	1.15	5.85	12.46	17.77

TABLE - 8 : PERCENTAGE OF ERROR IN THE FLOOD ESTIMATION OF VARIOUS RETURN PERIODS AFTER INTRODUCTION OF +20% OF SYSTEMATIC ERRORS FOR DATA OF Brg. No.807/2 SITE

Sl. No.	ERRORS INTRODUCED IN	DISTRIBUTION USED	PERCENTAGE ERROR IN THE ESTIMATION OF THE FLOODS CORRESPONDING TO RETURN PERIODS (IN YEARS) OF								
			2	5	10	20	50	100	200	500	1000
1.	High Flood Values only	(a) Gumbel	1.94	7.47	8.95	9.83	10.57	10.97	11.27	11.58	11.77
		(b) Log-Pearson Type III	-0.42	2.34	4.54	6.75	9.66	11.86	14.04	16.93	19.10
2.	Medium Flood Values	(a) Gumbel	14.11	12.98	12.68	12.50	12.34	12.26	12.20	12.14	12.10
		(b) Log-Pearson Type III	11.61	16.59	18.44	19..58	20.46	20.81	20.99	21.01	20.91
3.	Low Flood Values only	(a) Gumbel	3.68	0.43	-0.44	-0.96	-1.40	-1.63	-1.81	-2.00	-2.11
		(b) Log-Pearson Type III	7.53	0.88	-2.21	-4.58	-7.07	-8.63	-9.99	-11.56	-12.61
4.	All Flood Values	(a) Gumbel	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
		(b) Log-Pearson Type III	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
5.	All Values except High Flood	(a) Gumbel	17.84	13.25	12.03	11.30	10.68	10.35	10.10	9.84	9.69
		(b) Log-Pearson Type III	20.15	17.33	15.25	13.28	10.84	9.09	7.43	5.34	3.84

TABLE - 9 : PERCENTAGE OF ERROR IN THE FLOOD ESTIMATION OF VARIOUS RETURN PERIODS AFTER INTRODUCTION OF +10% OF SYSTEMATIC ERRORS FOR DATA OF Brg. No.807/2 SITE

Sl. No.	ERRORS INTRODUCED IN	DISTRIBUTION USED	PERCENTAGE ERROR IN THE ESTIMATION OF FLOODS CORRESPONDING TO RETURN PERIODS (IN YEARS) OF								
			2	5	10	20	50	100	200	500	1000
1.	High Flood Values only	(a) Gumbel	1.00	3.65	4.36	4.78	5.14	5.33	5.48	5.63	5.72
		(b) Log-Pearson Type III	-0.18	1.21	2.30	3.38	4.78	5.81	6.84	8.16	9.15
2.	Medium Flood Values	(a) Gumbel	7.09	6.37	6.18	6.07	5.97	5.92	5.88	5.84	5.82
		(b) Log-Pearson Type III	5.98	8.31	9.10	9.55	9.83	9.91	9.89	9.78	9.64
3.	Low Flood Values only	(a) Gumbel	1.85	0.20	-0.24	-0.50	-0.72	-0.84	-0.93	-1.02	-1.07
		(b) Log-Pearson Type III	3.88	0.43	-1.21	-2.49	-3.85	-4.72	-5.48	-6.36	-6.96
4.	All Flood Values	(a) Gumbel	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
		(b) Log-Pearson Type III	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
5.	All Values except High Flood	(a) Gumbel	8.94	6.54	5.89	5.51	5.18	5.01	4.88	4.74	4.66
		(b) Log-Pearson Type III	10.12	8.70	7.64	6.61	5.33	4.40	3.51	2.37	1.55

TABLE - 10 : PERCENTAGE OF ERROR IN THE FLOOD ESTIMATION OF VARIOUS RETURN PERIODS AFTER INTRODUCTION OF -10% OF SYSTEMATIC ERRORS FOR DATA OF Brg. No. 807/2 SITE

Sl. No.	ERRORS INTRODUCED IN	DISTRIBUTION USED	PERCENTAGE ERROR IN THE ESTIMATION OF THE FLOODS CORRESPONDING TO RETURN PERIODS (IN YEARS) OF								
			2	5	10	20	50	100	200	500	1000
1.	High Flood Values only	(a) Gumbel	-1.06	-3.45	-4.09	-4.47	-4.80	-4.97	-5.10	-5.23	-5.32
		(b) Log-Pearson Type III	0.11	-1.30	-2.36	-3.38	-4.66	-5.58	-6.46	-7.58	-8.40
2.	Medium Flood Values	(a) Gumbel	-7.17	-6.11	-5.82	-5.65	-5.51	-5.43	-5.37	-5.32	-5.28
		(b) Log-Pearson Type III	-6.38	-8.34	-8.85	-9.04	-9.01	-8.86	-8.62	-8.23	-7.89
3.	Low Flood Values only	(a) Gumbel	-1.85	-0.18	0.26	0.53	0.75	0.87	0.96	1.06	1.11
		(b) Log-Pearson Type III	-4.11	-0.41	1.44	2.93	4.56	5.61	6.56	7.67	8.44
4.	All Flood Values	(a) Gumbel	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00
		(b) Log-Pearson Type III	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00
5.	All Values except High Flood	(a) Gumbel	-9.01	-6.34	-5.62	-5.20	-4.84	-4.65	-4.50	-4.35	-4.26
		(b) Log-Pearson Type III	-10.18	-8.79	-7.70	-6.63	-5.23	-4.18	-3.16	-1.82	-0.83

TABLE - 11 : PERCENTAGE OF ERROR IN THE FLOOD ESTIMATION OF VARIOUS RETURN PERIODS AFTER INTRODUCTION OF -20% OF SYSTEMATIC ERRORS FOR DATA OF Brg. No.807/2 SITE

Sl. No.	ERRORS INTRODUCED IN	DISTRIBUTION USED	PERCENTAGE ERROR IN THE ESTIMATION OF THE FLOODS OF CORRESPONDING TO RETURN PERIODS (IN YEARS)								
			2	5	10	20	50	100	200	500	1000
1.	High Flood Values only	(a) Gumbel	-2.19	-6.66	-7.86	-8.57	-9.18	-9.50	-9.74	-9.99	-10.14
		(b) Log-Pearson Type III	0.12	-2.71	-4.77	-6.71	-9.10	-10.81	-12.42	-14.45	-15.90
2.	Medium Flood Values	(a) Gumbel	-14.43	-11.90	-11.22	-10.82	-10.48	-10.30	10.16	-10.02	-9.93
		(b) Log-Pearson Type III	-13.26	-16.72	-17.42	-17.48	-17.01	-16.40	-15.64	-14.45	-13.45
3.	Low Flood Values only	(a) Gumbel	-3.71	-0.35	0.55	1.08	1.54	1.78	1.96	2.15	2.26
		(b) Log-Pearson Type III	-8.50	-0.81	3.18	6.45	10.08	12.47	14.63	17.22	19.01
4.	All Flood Values	(a) Gumbel	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00
		(b) Log-Pearson Type III	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00
5.	All Values except High Flood	(a) Gumbel	-18.08	-12.45	-10.95	-10.06	-9.30	-8.90	-8.59	-8.27	-8.08
		(b) Log-Pearson Type III	-20.44	-17.70	-15.49	-13.26	-10.29	-8.04	-5.79	-2.80	-0.52

TABLE - 12 : PERCENTAGE OF ERROR IN THE FLOOD ESTIMATION OF VARIOUS RETURN PERIODS AFTER INTRODUCTION OF +20% OF SYSTEMATIC ERRORS FOR DATA OF Brg. No.912/1 SITE

Sl. No.	ERRORS INTRODUCED IN	DISTRIBUTION USED	PERCENTAGE ERROR IN THE ESTIMATION OF THE FLOODS CORRESPONDING TO RETURN PERIODS (IN YEARS) OF								
			2	5	10	20	50	100	200	500	1000
1.	High Flood Values only	(a) Gumbel	2.76	8.25	9.79	10.72	11.52	11.95	12.28	12.62	12.82
		(b) Log-Pearson Type III	0.04	3.55	6.02	6.33	11.16	13.16	15.04	17.37	19.02
2.	Medium Flood Values	(a) Gumbel	13.00	11.94	11.64	11.46	11.30	11.22	11.16	11.09	11.05
		(b) Log-Pearson Type III	10.51	14.90	16.76	18.08	19.34	20.06	20.63	21.23	21.59
3.	Low Flood Values only	(a) Gumbel	3.95	0.76	-0.14	-0.68	-1.14	-1.39	-1.58	-1.78	-1.90
		(b) Log-Pearson Type III	8.10	1.37	-1.93	-4.49	-7.18	-8.85	-10.29	-11.92	-12.97
4.	All Flood Values	(a) Gumbel	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
		(b) Log-Pearson Type III	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
5.	All Values except High Flood	(a) Gumbel	17.00	12.51	11.25	10.49	9.83	9.49	9.22	8.94	8.77
		(b) Log-Pearson Type III	19.57	16.09	13.84	11.87	9.60	8.08	6.72	5.12	4.04

TABLE - 13 : PERCENTAGE OF ERROR IN THE FLOOD ESTIMATION OF VARIOUS RETURN PERIODS AFTER INTRODUCTION OF +10% OF SYSTEMATIC ERRORS FOR DATA OF Brg. No.912/1 SITE

Sl. No.	ERRORS INTRODUCED IN	DISTRIBUTION USED	PERCENTAGE ERROR IN THE ESTIMATION OF THE FLOODS CORRESPONDING TO RETURN PERIODS (IN YEARS) OF								
			2	5	10	20	50	100	200	500	1000
1.	High Flood Values only	(a) Gumbel	1.41	4.04	4.78	5.22	5.61	5.81	5.97	6.13	6.27
		(b) Log-Pearson Type III	0.06	1.82	3.03	4.14	5.49	6.42	7.28	8.34	9.08
2.	Medium Flood Values	(a) Gumbel	6.54	5.85	5.65	5.54	5.44	5.38	5.34	5.30	5.27
		(b) Log-Pearson Type III	5.42	7.45	8.26	8.81	9.31	9.58	9.78	9.98	10.10
3.	Low Flood Values only	(a) Gumbel	1.98	0.36	-0.09	-0.37	-0.60	-0.73	-0.82	-0.92	-0.98
		(b) Log-Pearson Type III	4.16	0.68	-1.07	-2.45	-3.93	-4.86	-5.67	-6.59	-7.19
4.	All Flood Values	(a) Gumbel	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
		(b) Log-Pearson Type III	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
5.	All Values except High Flood	(a) Gumbel	8.53	6.16	5.50	5.09	4.75	4.56	4.42	4.27	4.19
		(b) Log-Pearson Type III	9.84	8.08	6.93	5.90	4.70	3.89	3.16	2.29	1.69

TABLE - 14 : PERCENTAGE OF ERROR IN THE FLOOD ESTIMATION OF VARIOUS RETURN PERIODS AFTER INTRODUCTION OF -10% OF SYSTEMATIC ERRORS FOR DATA OF Brg. No.912/1 SITE

Sl. No.	ERRORS INTRODUCED IN	DISTRIBUTION USED	PERCENTAGE ERROR IN THE ESTIMATION OF THE FLOODS CORRESPONDING TO THE RETURN PERIODS (IN YEARS) OF								
			2	5	10	20	50	100	200	500	1000
1.	High Flood Values only	(a) Gumbel	-1.47	-3.83	-4.49	-4.89	-5.23	-5.42	-5.56	-5.70	-5.79
		(b) Log-Pearson Type III	-0.17	-1.92	-3.07	-4.09	-5.28	-6.08	-6.81	-7.67	-8.25
2.	Medium Flood Values	(a) Gumbel	-6.62	-5.57	-5.27	-5.09	-4.94	-4.85	-4.79	-4.73	-4.69
		(b) Log-Pearson Type III	-5.82	-7.45	-7.98	-8.28	-8.49	-8.56	-8.59	-8.58	-8.55
3.	Low Flood Values only	(a) Gumbel	-1.99	-0.33	0.14	0.42	0.66	0.79	0.89	0.99	1.05
		(b) Log-Pearson Type III	-4.41	-0.67	1.32	2.95	4.76	5.94	6.99	8.22	9.05
4.	All Flood Values	(a) Gumbel	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00
		(b) Log-Pearson Type III	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00
5.	All Values except High Flood	(a) Gumbel	-8.60	-5.95	-5.21	-4.76	-4.37	-4.17	-4.01	-3.85	-3.75
		(b) Log-Pearson Type III	-9.94	-8.18	-6.97	-5.85	-4.50	-3.56	-2.69	-1.62	-0.87

TABLE - 15 : PERCENTAGE OF ERROR IN THE FLOOD ESTIMATION OF VARIOUS RETURN PERIODS AFTER INTRODUCTION OF -20% OF SYSTEMATIC ERRORS FOR DATA OF Brg. No.912/1 SITE

Sl. No.	ERRORS INTRODUCED IN	DISTRIBUTION USED	PERCENTAGE ERROR IN THE ESTIMATION OF THE FLOODS CORRESPONDING TO RETURN PERIODS (IN YEARS) OF								
			2	5	10	20	50	100	200	500	1000
1.	High Flood Values only	(a) Gumbel	-3.02	-7.40	-8.62	-9.37	-10.00	-10.34	-10.61	-10.88	-11.04
		(b) Log-Pearson Type III	-0.48	-3.95	-6.16	-8.09	-10.31	-11.77	-13.09	-14.62	-15.66
2.	Medium Flood Values	(a) Gumbel	-13.35	-10.81	-10.10	-9.67	-9.30	-9.11	-8.95	-8.80	-8.70
		(b) Log-Pearson Type III	-12.11	-14.89	-15.63	-15.94	-16.01	-15.92	-15.76	-15.48	-15.23
3.	Low Flood Values only	(a) Gumbel	-3.99	-0.63	0.32	0.89	1.38	1.64	1.84	2.05	2.17
		(b) Log-Pearson Type III	-9.12	-1.35	2.94	6.53	10.60	13.30	15.75	18.66	20.64
4.	All Flood Values	(a) Gumbel	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00
		(b) Log-Pearson Type III	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00
5.	All Values except High Flood	(a) Gumbel	-17.26	-11.67	-10.10	-9.16	-8.34	-7.91	-7.57	-7.22	-7.02
		(b) Log-Pearson Type III	-19.99	-16.50	-14.01	-11.66	-8.76	-6.70	-4.74	-2.31	-0.57

TABLE- 16 : PERCENTAGE OF ERROR IN THE FLOOD ESTIMATION OF VARIOUS RETURN PERIODS AFTER INTRODUCTION OF +20% OF SYSTEMATIC ERRORS FOR GENERATED DATA OF GARUDESHWAR SITE

Sl. No.	ERRORS INTRODUCED IN	DISTRIBUTION USED	PERCENTAGE ERROR IN THE ESTIMATION OF THE FLOODS CORRESPONDING TO RETURN PERIODS (IN YEARS) OF								
			2	5	10	20	50	100	200	500	1000
1.	High Flood Values only	(a) Gumbel	4.22	10.43	12.62	14.08	15.41	16.16	16.76	17.39	17.78
		(b) Log-Pearson Type III	0.56	6.00	10.23	14.51	20.23	24.62	29.07	35.07	39.69
2.	Medium Flood Values	(a) Gumbel	14.08	10.39	9.08	8.22	7.42	6.98	6.62	6.25	6.02
		(b) Log-Pearson Type III	18.09	14.91	11.17	7.26	2.16	-1.53	-5.05	-9.45	-12.57
3.	Low Flood Values only	(a) Gumbel	1.42	0.08	-0.40	-0.71	-1.00	-1.16	-1.29	-1.43	-1.51
		(b) Log-Pearson Type III	0.75	-1.25	-1.24	-0.72	0.42	1.49	2.70	4.45	5.87
4.	All Flood Values	(a) Gumbel	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
		(b) Log-Pearson Type III	19.98	20.00	20.02	20.04	20.07	20.10	20.12	20.15	20.17
5.	All Values except High Flood	(a) Gumbel	15.54	10.33	8.49	7.27	6.15	5.52	5.02	4.49	4.16
		(b) Log-Pearson Type III	18.75	13.34	9.68	6.34	2.32	-0.48	-3.10	-6.33	-8.62

TABLE- 17 : PERCENTAGE OF ERROR IN THE FLOOD ESTIMATION OF VARIOUS RETURN PERIODS AFTER INTRODUCTION OF +10% OF SYSTEMATIC ERRORS FOR GENERATED DATA OF GARUDESHWAR SITE

Sl. No.	ERRORS INTRODUCED IN	DISTRIBUTION USED	PERCENTAGE ERROR IN THE ESTIMATION OF THE FLOODS CORRESPONDING TO RETURN PERIODS (IN YEARS) OF								
			2	5	10	20	50	100	200	500	1000
1.	High Flood Values only	(a) Gumbel	2.14	5.14	6.20	6.90	7.55	7.91	8.20	8.50	8.69
		(b) Log-Pearson Type III	0.33	3.09	5.17	7.21	9.88	11.87	13.86	16.46	18.42
2.	Medium Flood Values	(a) Gumbel	7.08	5.07	4.35	3.88	3.45	3.21	3.01	2.81	2.68
		(b) Log-Pearson Type III	9.21	7.50	5.49	3.34	0.47	-1.66	-3.73	-6.39	-8.32
3.	Low Flood Values only	(a) Gumbel	0.71	0.03	-0.21	-0.37	-0.52	-0.60	-0.66	-0.73	-0.78
		(b) Log-Pearson Type III	0.32	-0.69	-0.64	-0.31	0.36	0.97	1.65	2.62	3.40
4.	All Flood Values	(a) Gumbel	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
		(b) Log-Pearson Type III	10.05	10.01	9.96	9.91	9.84	9.79	9.74	9.67	9.61
5.	All Values except High Flood	(a) Gumbel	7.80	5.06	4.09	3.45	2.86	2.53	2.26	1.99	1.82
		(b) Log-Pearson Type III	9.51	6.74	4.80	2.98	0.75	-0.84	-2.36	-4.25	-5.61

TABLE- 18 : PERCENTAGE OF ERROR IN THE FLOOD ESTIMATION OF VARIOUS RETURN PERIODS AFTER INTRODUCTION OF -10% OF SYSTEMATIC ERRORS FOR GENERATED DATA OF GARUDESHWAR SITE

Sl. No.	ERRORS INTRODUCED IN	DISTRIBUTION USED	PERCENTAGE ERROR IN THE ESTIMATION OF THE FLOODS CORRESPONDING TO RETURN PERIODS (IN YEARS) OF								
			2	5	10	20	50	100	200	500	1000
1.	High Flood Values only	(a) Gumbel	-2.20	-4.93	-5.89	-6.53	-7.12	-7.45	-7.71	-7.98	-8.16
		(b) Log-Pearson Type III	-0.53	-3.27	-5.18	-6.96	-9.14	-10.69	-12.16	-14.00	-15.32
2.	Medium Flood Values	(a) Gumbel	-7.16	-4.80	-3.97	-3.41	-2.90	-2.62	-2.39	-2.15	-2.00
		(b) Log-Pearson Type III	-9.31	-7.64	-5.56	-3.19	0.20	2.91	5.73	9.60	12.63
3.	Low Flood Values only	(a) Gumbel	-0.72	-0.01	0.23	0.40	0.55	0.63	0.70	0.77	0.82
		(b) Log-Pearson Type III	-0.29	0.82	0.74	0.36	-0.38	-1.05	-1.77	-2.77	-3.55
4.	All Flood Values	(a) Gumbel	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00
		(b) Log-Pearson Type III	-9.98	-10.00	-10.02	-10.05	-10.08	-10.11	-10.13	-10.17	-10.19
5.	All Values except High Flood	(a) Gumbel	-7.87	-4.85	-3.79	-3.08	-2.43	-2.07	-1.78	-1.47	-1.28
		(b) Log-Pearson Type III	-9.64	-6.91	-4.86	-2.85	-0.21	1.76	3.72	6.30	8.25

TABLE - 19 : PERCENTAGE OF ERROR IN THE FLOOD ESTIMATION OF VARIOUS RETURN PERIODS AFTER INTRODUCTION OF -20% OF SYSTEMATIC ERRORS FOR GENERATED DATA OF GARUDESHWAR SITE

Sl. No.	ERRORS INTRODUCED IN	DISTRIBUTION USED	PERCENTAGE ERROR IN THE ESTIMATION OF THE FLOODS OF CORRESPONDING TO RETURN PERIODS (IN YEARS)								
			2	5	10	20	50	100	200	500	1000
1.	High Flood Values only	(a) Gumbel	-4.49	-9.57	-11.36	-12.55	-13.64	-14.25	-14.74	-15.26	-15.57
		(b) Log-Pearson Type III	-1.33	-6.72	-10.30	-13.55	-17.43	-20.10	-22.59	-25.63	-27.76
2.	Medium Flood Values	(a) Gumbel	-14.41	-9.33	-7.54	-6.35	-5.25	-4.64	-4.15	-3.64	-3.32
		(b) Log-Pearson Type III	-18.81	-15.50	-11.18	-6.07	1.62	8.09	15.10	25.23	33.56
3.	Low Flood Values only	(a) Gumbel	-1.43	-0.01	0.49	0.82	1.13	1.30	1.45	1.58	1.67
		(b) Log-Pearson Type III	-0.55	1.79	1.59	0.76	-0.82	-2.21	-3.70	-5.74	-7.30
4.	All Flood Values	(a) Gumbel	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00
		(b) Log-Pearson Type III	-20.01	-20.00	-19.99	-19.97	-19.95	-19.94	-19.92	-19.90	-19.88
5.	All Values except High Flood	(a) Gumbel	-15.80	-9.51	-7.28	-5.80	-4.45	-3.69	-3.08	-2.45	-2.05
		(b) Log-Pearson Type III	-19.51	-14.09	-9.80	-5.40	0.57	5.21	9.98	16.48	21.56

TABLE - 20 : PERCENTAGE OF ERROR IN THE FLOOD ESTIMATION OF VARIOUS RETURN PERIODS AFTER INTRODUCTION OF +20% OF SYSTEMATIC ERRORS FOR GENERATED DATA OF Brg.No.807/2 SITE

Sl. No.	ERRORS INTRODUCED IN	DISTRIBUTION USED	PERCENTAGE ERROR IN THE ESTIMATION OF THE FLOODS CORRESPONDING TO RETURN PERIODS (IN YEARS) OF								
			2	5	10	20	50	100	200	500	1000
1.	High Flood Values only	(a) Gumbel	4.79	11.01	12.87	14.01	15.02	15.56	15.98	16.41	16.68
		(b) Log-Pearson Type III	0.68	5.82	9.55	13.16	17.75	21.13	24.42	28.67	31.80
2.	Medium Flood Values	(a) Gumbel	14.46	9.67	8.27	7.40	6.64	6.23	5.91	5.59	5.39
		(b) Log-Pearson Type III	18.37	15.22	11.75	8.22	3.78	0.64	-2.29	-5.85	-8.32
3.	Low Flood Values only	(a) Gumbel	0.60	0.02	-0.15	-0.25	-0.35	-0.39	-0.43	-0.47	-0.50
		(b) Log-Pearson Type III	0.31	1.39	-1.21	-0.58	0.60	1.64	2.76	4.30	5.50
4.	All Flood Values	(a) Gumbel	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
		(b) Log-Pearson Type III	19.99	20.00	20.01	20.01	20.02	20.03	20.03	20.04	20.05
5.	All Values except High Flood	(a) Gumbel	14.97	9.66	8.07	7.09	6.23	5.77	5.41	5.04	4.81
		(b) Log-Pearson Type III	18.73	13.58	10.27	7.34	3.92	1.61	-0.51	-3.04	-4.79

TABLE - 21 : PERCENTAGE OF ERROR IN THE FLOOD ESTIMATION OF VARIOUS RETURN PERIODS AFTER INTRODUCTION OF +10% OF SYSTEMATIC ERRORS FOR GENERATED DATA OF Brg.No.807/2 SITE

Sl. No.	ERRORS INTRODUCED IN	DISTRIBUTION USED	PERCENTAGE ERROR IN THE ESTIMATION OF THE FLOODS CORRESPONDING TO RETURN PERIODS (IN YEARS) OF								
			2	5	10	20	50	100	200	500	1000
1.	High Flood Values only	(a) Gumbel	2.42	5.44	6.33	6.89	7.38	7.64	7.84	8.05	8.18
		(b) Log-Pearson Type III	0.40	2.99	4.81	6.53	8.68	10.22	11.70	13.57	14.92
2.	Medium Flood Values	(a) Gumbel	7.22	4.74	4.00	3.54	3.14	2.93	2.76	2.58	2.48
		(b) Log-Pearson Type III	9.29	7.66	5.85	3.98	1.57	-0.17	-1.82	-3.88	-5.33
3.	Low Flood Values only	(a) Gumbel	0.30	0.01	-0.07	-0.13	-0.17	-0.20	-0.22	-0.24	-0.25
		(b) Log-Pearson Type III	0.15	-0.74	-0.64	-0.30	0.32	0.85	1.43	2.21	2.82
4.	All Flood Values	(a) Gumbel	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
		(b) Log-Pearson Type III	10.00	10.00	10.00	10.01	10.01	10.01	10.02	10.02	10.02
5.	All Values except High Flood	(a) Gumbel	7.52	4.74	3.91	3.40	2.95	2.71	2.52	2.33	2.21
		(b) Log-Pearson Type III	9.45	6.86	5.14	3.60	1.76	0.50	-0.67	-2.10	-3.09

TABLE - 22 : PERCENTAGE OF ERROR IN THE FLOOD ESTIMATION OF VARIOUS RETURN PERIODS AFTER INTRODUCTION OF -10% OF SYSTEMATIC ERRORS FOR GENERATED DATA OF Brg.No.807/2 SITE

Sl. No.	ERRORS INTRODUCED IN	DISTRIBUTION USED	PERCENTAGE ERROR IN THE ESTIMATION OF THE FLOODS CORRESPONDING TO RETURN PERIODS (IN YEARS) OF								
			2	5	10	20	50	100	200	500	1000
1.	High Flood Values only	(a) Gumbel	-2.49	-5.25	-6.08	-6.59	-7.03	-7.27	[illegible].46	-7.65	-7.77
		(b) Log-Pearson Type III	-0.56	-3.15	-4.86	-[illegible].40	-8.23	-9.48	-10.64	-12.04	-13.03
2.	Medium Flood Values	(a) Gumbel	-7.29	-4.54	-3.72	-3.21	-2.77	-2.53	-2.34	-2.15	-2.03
		(b) Log-Pearson Type III	-9.47	-7.79	-5.85	-3.75	-0.87	1.35	3.56	6.49	8.69
3.	Low Flood Values only	(a) Gumbel	-0.30	-0.01	0.08	0.13	0.18	0.20	0.22	0.24	0.26
		(b) Log-Pearson Type III	-0.14	0.84	0.72	0.36	-0.31	-0.88	-1.48	-2.28	-2.88
4.	All Flood Values	(a) Gumbel	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00
		(b) Log-Pearson Type III	-9.99	-10.00	-10.01	-10.01	-10.02	-10.03	-10.03	-10.04	-10.04
5.	All Values except High Flood	(a) Gumbel	-7.58	-4.56	-3.65	-3.09	-2.61	-2.34	-2.14	-1.93	-1.80
		(b) Log-Pearson Type III	-9.60	-7.02	-5.20	-3.48	-1.33	0.22	1.71	3.59	4.96

TABLE - 23 : PERCENTAGE OF ERROR IN THE FLOOD ESTIMATION OF VARIOUS RETURN PERIODS AFTER INTRODUCTION OF -20% OF SYSTEMATIC ERRORS FOR GENERATED DATA OF Brg.No.807/2 SITE

Sl. No.	ERRORS INTRODUCED IN	DISTRIBUTION USED	PERCENTAGE ERROR IN THE ESTIMATION OF THE FLOODS OF CORRESPONDING TO RETURN PERIODS (IN YEARS)								
			2	5	10	20	50	100	200	500	1000
1.	High Flood Values only	(a) Gumbel	-5.06	-10.26	-11.81	-12.77	-13.60	-14.06	-14.41	-14.77	-14.99
		(b) Log-Pearson Type III	-1.35	-6.47	-9.73	-12.60	-15.91	-18.14	-20.16	-22.57	-24.22
2.	Medium Flood Values	(a) Gumbel	-14.65	-8.87	-7.15	-6.08	-5.15	-4.65	-4.26	-3.85	-3.61
		(b) Log-Pearson Type III	-19.13	-15.78	-11.78	-7.28	-0.85	4.29	9.63	16.98	22.73
3.	Low Flood Values only	(a) Gumbel	-0.60	-0.02	0.16	0.27	0.36	0.41	0.45	0.49	0.52
		(b) Log-Pearson Type III	-0.28	1.80	1.56	0.78	-0.62	-1.80	-3.02	-4.63	-5.84
4.	All Flood Values	(a) Gumbel	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00
		(b) Log-Pearson Type III	-19.99	-20.00	-20.01	-20.02	-20.04	-20.05	-20.06	-20.07	-20.08
5.	All Values except High Flood	(a) Gumbel	-15.23	-8.93	-7.05	-5.88	-4.87	-4.32	-3.89	-3.45	-3.18
		(b) Log-Pearson Type III	-19.36	-14.26	-10.50	-6.83	-2.11	1.39	4.84	9.33	12.68

TABLE - 24 : PERCENTAGE OF ERROR IN THE FLOOD ESTIMATION OF VARIOUS RETURN PERIODS AFTER INTRODUCTION OF +20% OF SYSTEMATIC ERRORS FOR GENERATED DATA OF Brg.No.912/1 SITE

Sl. No.	ERRORS INTRODUCED IN	DISTRIBUTION USED	PERCENTAGE ERROR IN THE ESTIMATION OF THE FLOODS CORRESPONDING TO RETURN PERIODS (IN YEARS) OF								
			2	5	10	20	50	100	200	500	1000
1.	High Flood Values only	(a) Gumbel	4.74	10.89	12.75	13.90	14.91	15.45	15.88	16.31	16.58
		(b) Log-Pearson Type III	0.66	6.49	10.35	13.82	17.87	20.58	23.01	25.81	27.64
2.	Medium Flood Values	(a) Gumbel	14.24	9.79	8.45	7.61	6.89	6.49	6.19	5.87	5.68
		(b) Log-Pearson Type III	17.16	14.35	11.71	9.26	6.44	4.65	3.13	1.52	0.58
3.	Low Flood Values only	(a) Gumbel	0.77	0.04	-0.18	-0.31	-0.43	-0.50	-0.55	-0.60	-0.63
		(b) Log-Pearson Type III	1.29	-1.01	-1.50	-1.63	-1.55	-1.41	-1.22	-0.97	-0.78
4.	All Flood Values	(a) Gumbel	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
		(b) Log-Pearson Type III	20.00	20.00	20.00	19.99	19.99	19.99	19.99	19.99	19.99
5.	All Values except High Flood	(a) Gumbel	15.02	9.79	8.21	7.23	6.37	5.91	5.55	5.18	4.95
		(b) Log-Pearson Type III	18.72	12.94	9.59	6.87	4.00	2.26	0.83	-0.66	-1.52

TABLE - 25 : PERCENTAGE OF ERROR IN THE FLOOD ESTIMATION OF VARIOUS RETURN PERIODS AFTER INTRODUCTION OF +10% OF SYSTEMATIC ERRORS FOR GENERATED DATA OF Brg.No.912/1 SITE

Sl. No.	ERRORS INTRODUCED IN	DISTRIBUTION USED	PERCENTAGE ERROR IN THE ESTIMATION OF THE FLOODS CORRESPONDING TO RETURN PERIODS (IN YEARS) OF								
			2	5	10	20	50	100	200	500	1000
1.	High Flood Values only	(a) Gumbel	2.40	5.38	6.27	6.83	7.32	7.58	7.79	8.00	8.13
		(b) Log-Pearson Type III	0.40	3.32	5.20	6.84	8.70	9.92	10.99	12.19	12.95
2.	Medium Flood Values	(a) Gumbel	7.15	4.79	4.08	3.64	3.26	3.05	2.88	2.72	2.61
		(b) Log-Pearson Type III	8.71	7.18	5.76	4.42	2.87	1.85	0.98	0.03	-0.54
3.	Low Flood Values only	(a) Gumbel	0.38	0.02	-0.09	-0.16	-0.22	-0.25	-0.28	-0.30	-0.32
		(b) Log-Pearson Type III	0.66	-0.55	-0.81	-0.88	-0.84	-0.76	-0.67	-0.54	-0.44
4.	All Flood Values	(a) Gumbel	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
		(b) Log-Pearson Type III	10.00	10.00	10.00	9.99	9.99	9.99	9.99	9.99	9.99
5.	All Values except High Flood	(a) Gumbel	7.54	4.80	3.98	3.47	3.02	2.77	2.58	2.39	2.27
		(b) Log-Pearson Type III	9.44	6.53	4.79	3.34	1.78	0.81	0.00	-0.86	-1.38

TABLE - 26 : PERCENTAGE OF ERROR IN THE FLOOD ESTIMATION OF VARIOUS RETURN PERIODS AFTER INTRODUCTION OF -10% OF SYSTEMATIC ERRORS FOR GENERATED DATA OF Brg.No.912/1 SITE

Sl. No.	ERRORS INTRODUCED IN	DISTRIBUTION USED	PERCENTAGE ERROR IN THE ESTIMATION OF THE FLOODS CORRESPONDING TO RETURN PERIODS (IN YEARS) OF								
			2	5	10	20	50	100	200	500	1000
1.	High Flood Values only	(a) Gumbel	-2.46	-5.19	-6.01	-6.52	-6.96	-7.21	-7.39	-7.59	-7.71
		(b) Log-Pearson Type III	-0.57	-3.48	-5.21	-6.64	-8.19	-9.14	-9.94	-10.79	-11.29
2.	Medium Flood Values	(a) Gumbel	-7.23	-4.59	-3.79	-3.30	-2.87	-2.63	-2.45	-2.26	-2.15
		(b) Log-Pearson Type III	-8.99	-7.23	-5.58	-3.95	-1.96	-0.59	0.65	2.10	3.06
3.	Low Flood Values only	(a) Gumbel	-0.39	-0.02	0.09	0.16	0.22	0.26	0.28	0.31	0.32
		(b) Log-Pearson Type III	-0.71	0.66	0.96	1.04	1.00	0.92	0.82	0.68	0.58
4.	All Flood Values	(a) Gumbel	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00
		(b) Log-Pearson Type III	-10.00	-10.00	-10.00	-9.99	-9.99	-9.99	-9.98	-9.98	-9.98
5.	All Values except High Flood	(a) Gumbel	-7.61	-4.62	-3.72	-3.16	-2.67	-2.40	-2.19	-1.98	-1.85
		(b) Log-Pearson Type III	-9.61	-6.69	-4.80	-3.15	-1.26	-0.02	1.06	2.29	3.07

TABLE - 27 : PERCENTAGE OF ERROR IN THE FLOOD ESTIMATION OF VARIOUS RETURN PERIODS AFTER INTRODUCTION OF -20% OF SYSTEMATIC ERRORS FOR GENERATED DATA OF Brg.No.912/1 SITE

Sl. No.	ERRORS INTRODUCED IN	DISTRIBUTION USED	PERCENTAGE ERROR IN THE ESTIMATION OF THE FLOODS CORRESPONDING TO RETURN PERIODS (IN YEARS) OF								
			2	5	10	20	50	100	200	500	1000
1.	High Flood Values only	(a) Gumbel	-5.01	-10.13	-11.67	-12.62	-13.46	-13.91	-14.27	-14.63	-14.85
		(b) Log-Pearson Type III	-1.37	-7.11	-10.39	-13.04	-15.80	-17.46	-18.81	-20.20	-20.99
2.	Medium Flood Values	(a) Gumbel	-14.53	-8.96	-7.29	-6.24	-5.33	-4.84	-4.45	-4.06	-3.82
		(b) Log-Pearson Type III	-18.28	-14.58	-11.01	-7.41	-2.79	0.51	3.62	7.41	10.01
3.	Low Flood Values only	(a) Gumbel	-0.77	-0.03	0.19	0.33	0.45	0.52	0.57	0.62	0.66
		(b) Log-Pearson Type III	-1.47	1.45	2.10	2.29	2.21	2.04	1.83	1.53	1.32
4.	All Flood Values	(a) Gumbel	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00
		(b) Log-Pearson Type III	-20.00	-20.00	-20.00	-19.99	-19.99	-19.98	-19.98	-19.98	-19.97
5.	All Values except High Flood	(a) Gumbel	-15.28	-9.04	-7.16	-6.00	-4.97	-4.42	-3.99	-3.55	-3.28
		(b) Log-Pearson Type III	-19.40	-13.59	-9.67	-6.11	-1.89	0.96	3.55	6.57	8.58

presented in Tables 4 to 27.

Figures 1,2 and 3 indicate that the nature of the curve (of the plot of percentage errors for different return periods) is almost similar. However, it is observed that the quantum of variations in the estimates of floods of the different return periods vary for the three sites. This may be partly because of the large variations in the catchment areas and the discharge values at the three sites. Similar results have also been observed when the systematic errors of magnitudes of -10% and -20% are introduced.

Figures 1 and 4 represent the extent of variations in the estimated values of the floods of different return periods in case of Garudeshwar site by using the natural data series and the generated data series respectively. The comparison of the two Figures (i.e.1 and 4) indicates that the variations in the estimate of design floods for the two series of data are more or less similar. The magnitude of the variations in case of the generated data series is only slightly higher than that of the natural series but the nature of the two curves is exactly similar. The results in respect of other sites also indicate similar findings.

USE OF DIFFERENT PROBABILITY DISTRIBUTIONS

For the limited purpose of illustrating the effects of errors on estimates of the design floods using the different probability distributions, the following methods have been used.

a) Normal Distribution;
b) Log Normal Distribution;
c) Gumbel Distribution;
d) Pearson Type-III Distribution; and
e) Log Pearson Type-III Distribution.

Figures 19 to 24 illustrate the results obtained by all the five distributions.

The nature of curves have been found to differ considerably when the different distributions are used which is quite obvious.

However the nature of the curves for the different sites as well as for the different sets of data (i.e. the natural flow sequences and the generated flow sequences) are similar for the

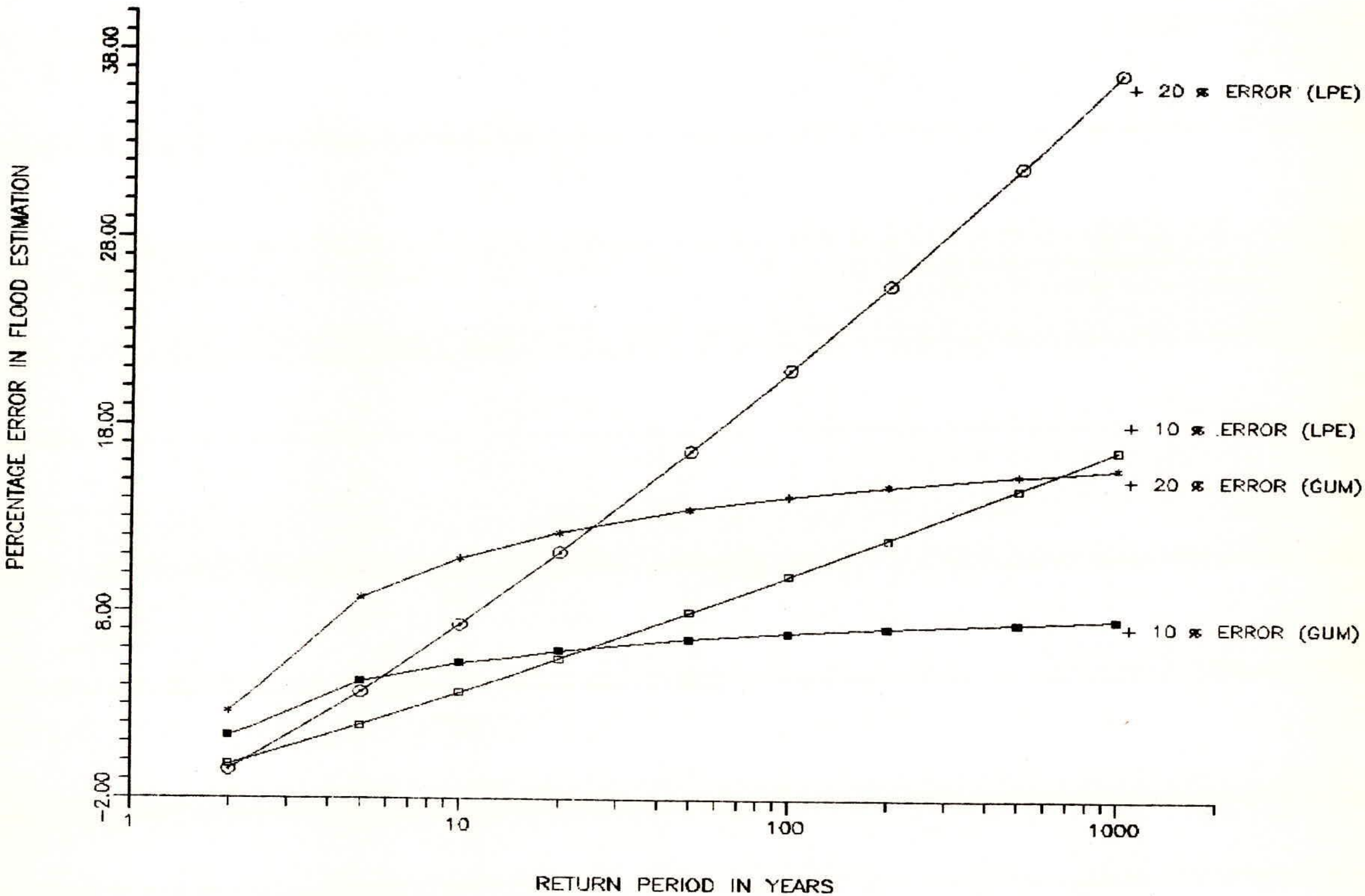


Fig. 1. Percentage variation in estimates of design floods of different return periods for Garudeswar site using observed data.

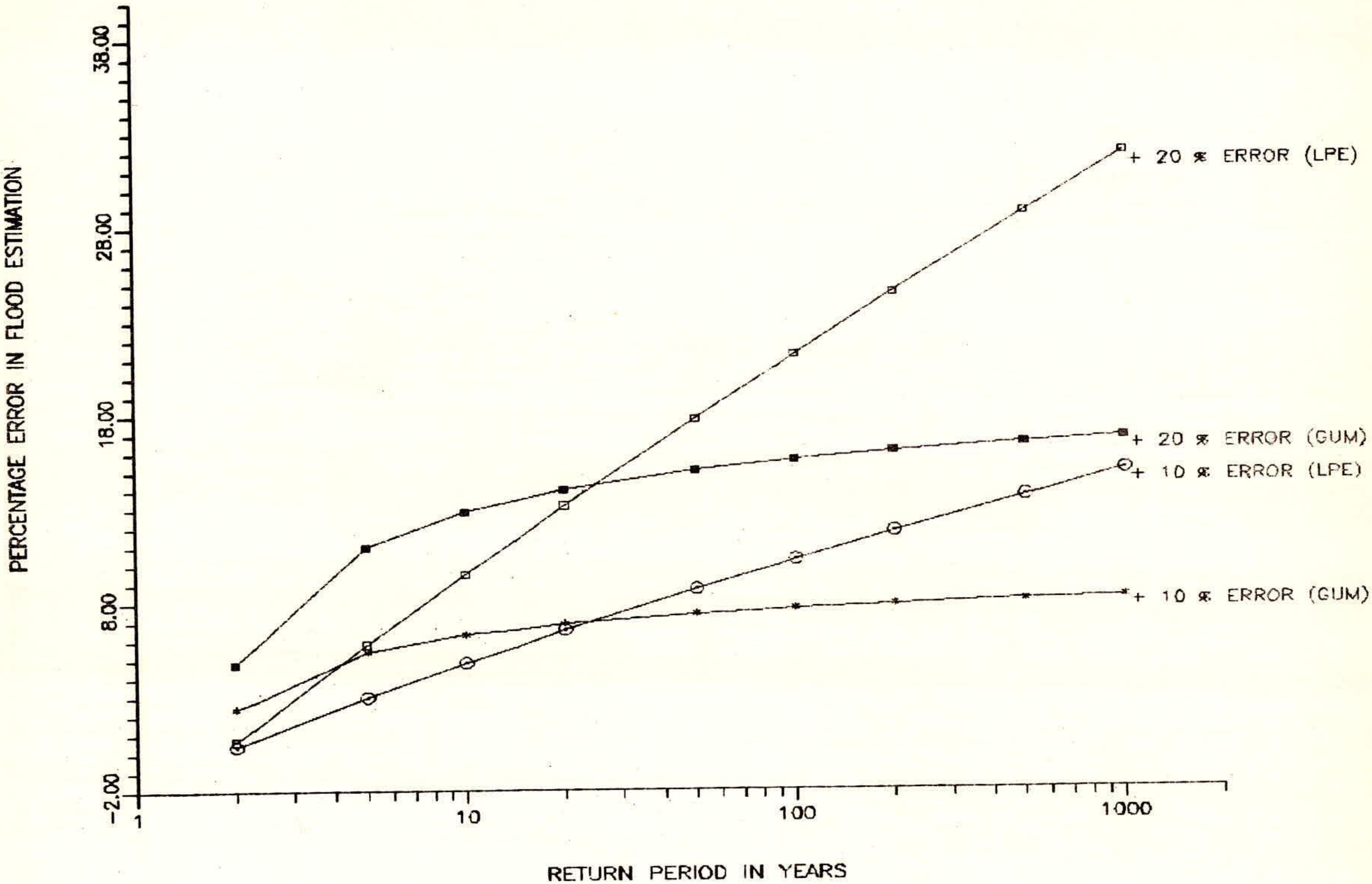


Fig. 2. Percentage variation in estimates of design floods of different return periods for Garudeswar site using generated data.

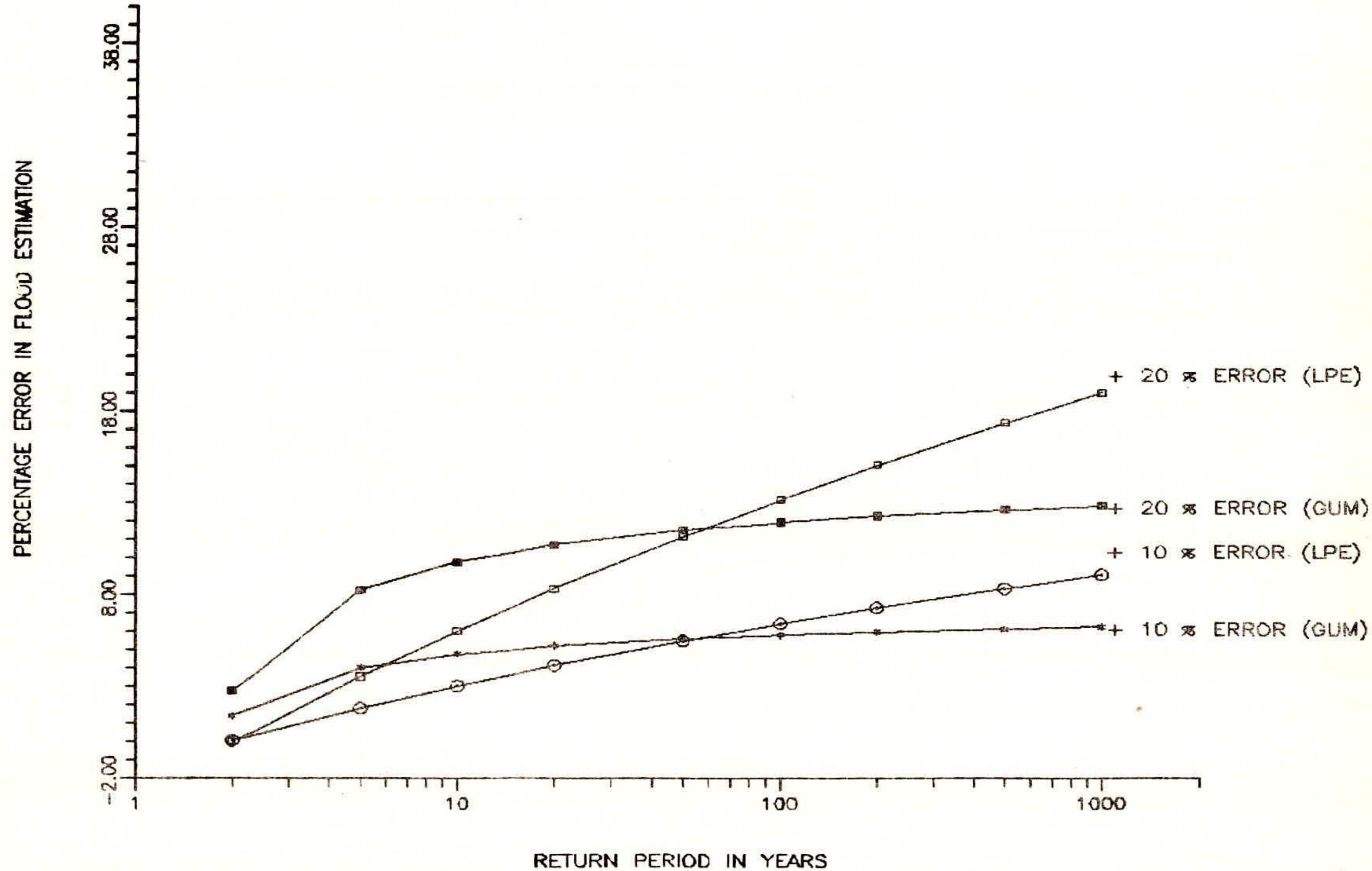


Fig. 3. Percentage variation in estimates of design floods of different return periods for site at Bridge No.807/2 using observed data.

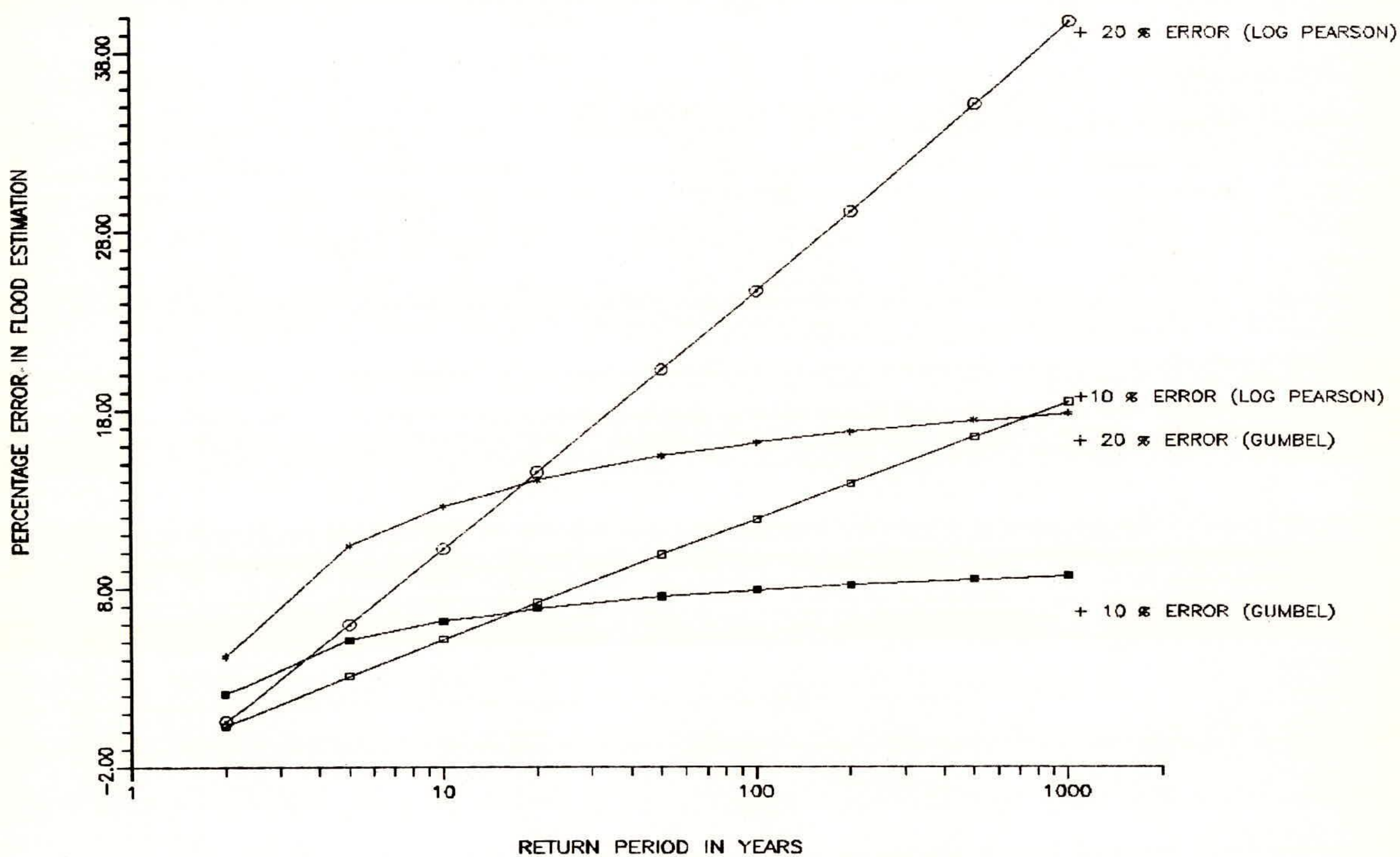


Fig. 4. Percentage variation in estimates of design floods of different return periods for site at Bridge No.807/2 using generated data.

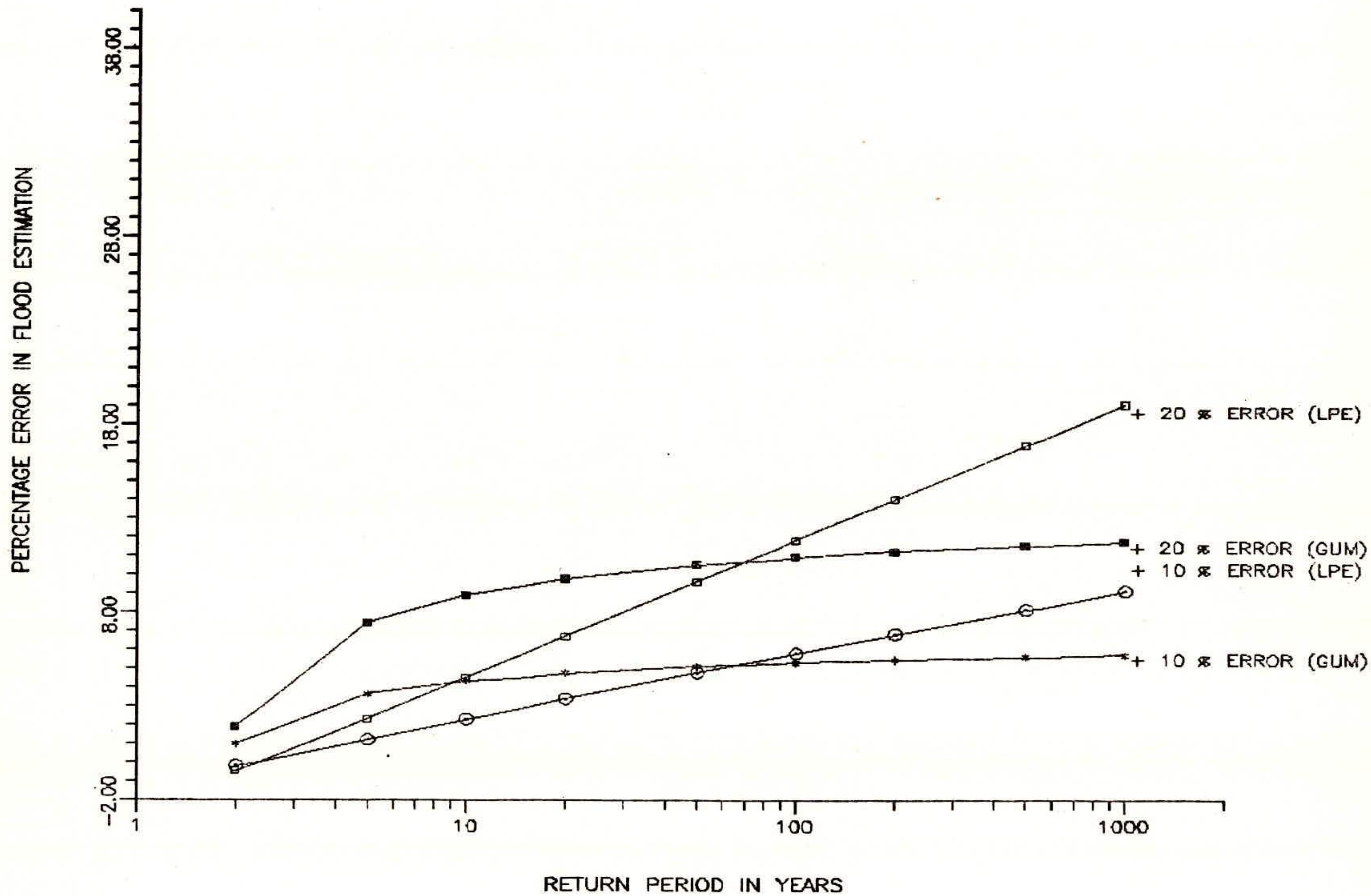


Fig. 5. Percentage variation in estimates of design floods of different return periods for site at Bridge No.912/1 using observed data.

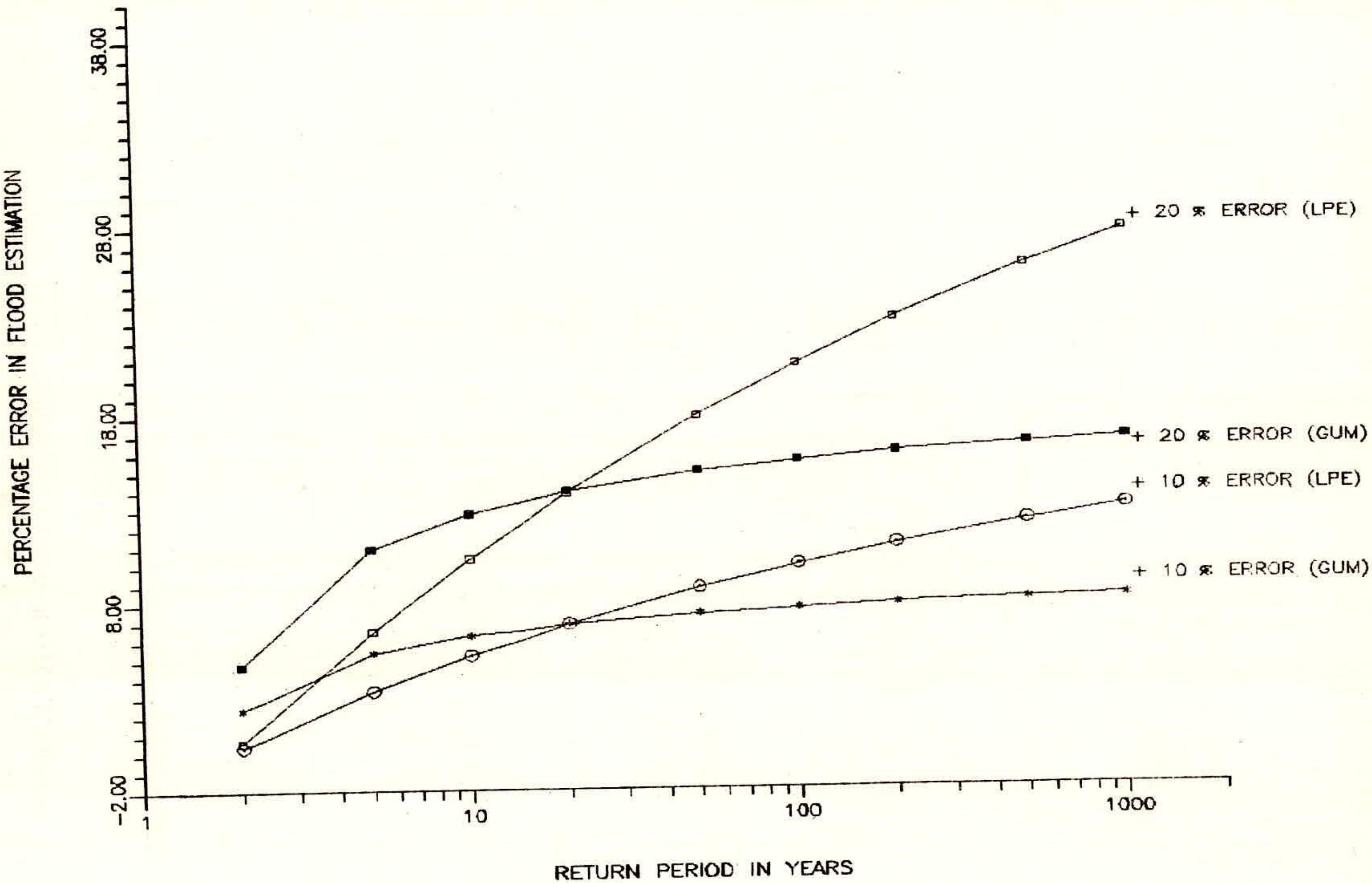


Fig. 6. Percentage variation in estimates of design floods of different return periods for site at Bridge No.912/1 using generated data.

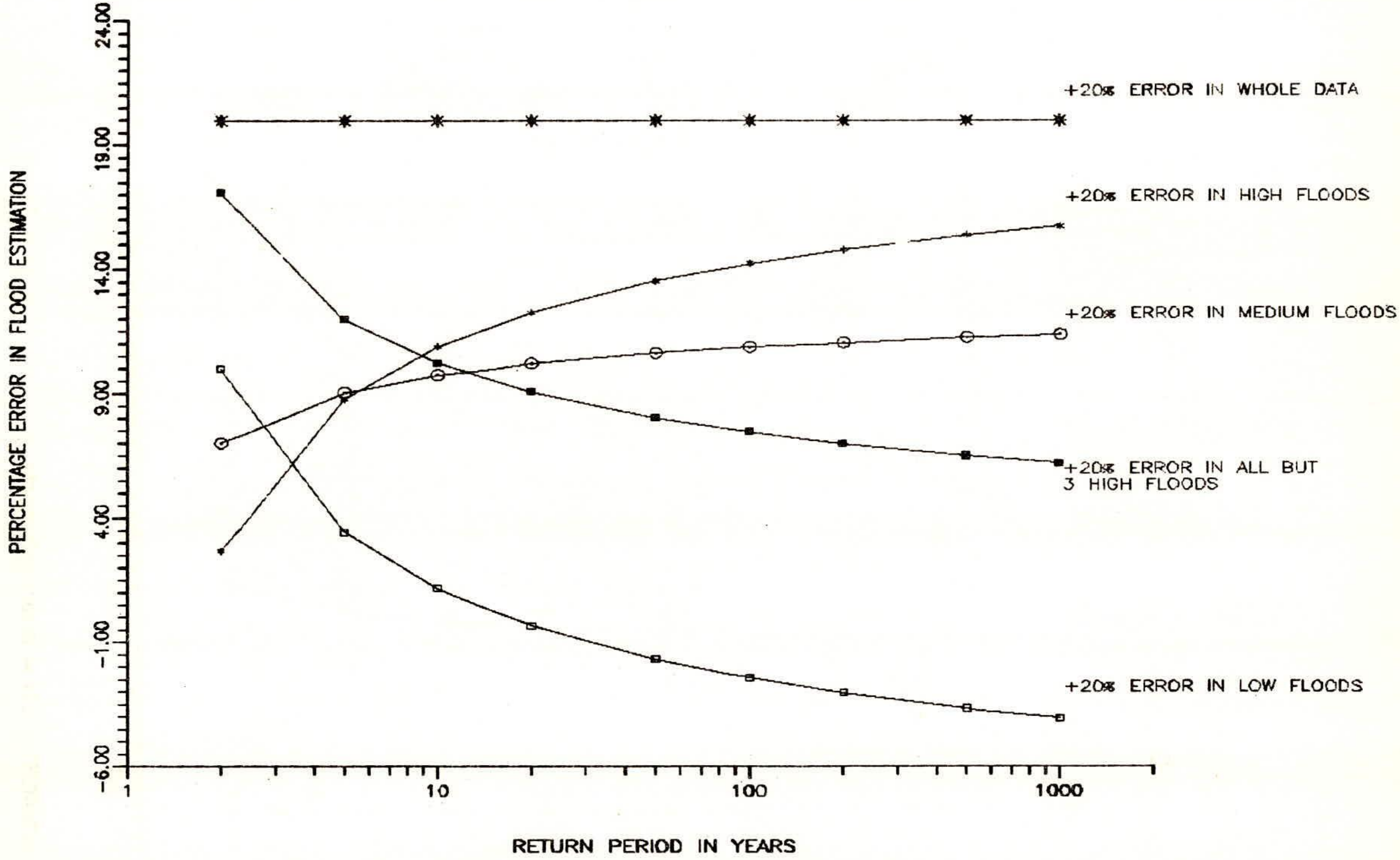


Fig. 7. Percentage variation in estimates of design floods of different return periods for Garudeswar site using observed data under different conditions of systematic error introduced in the data.

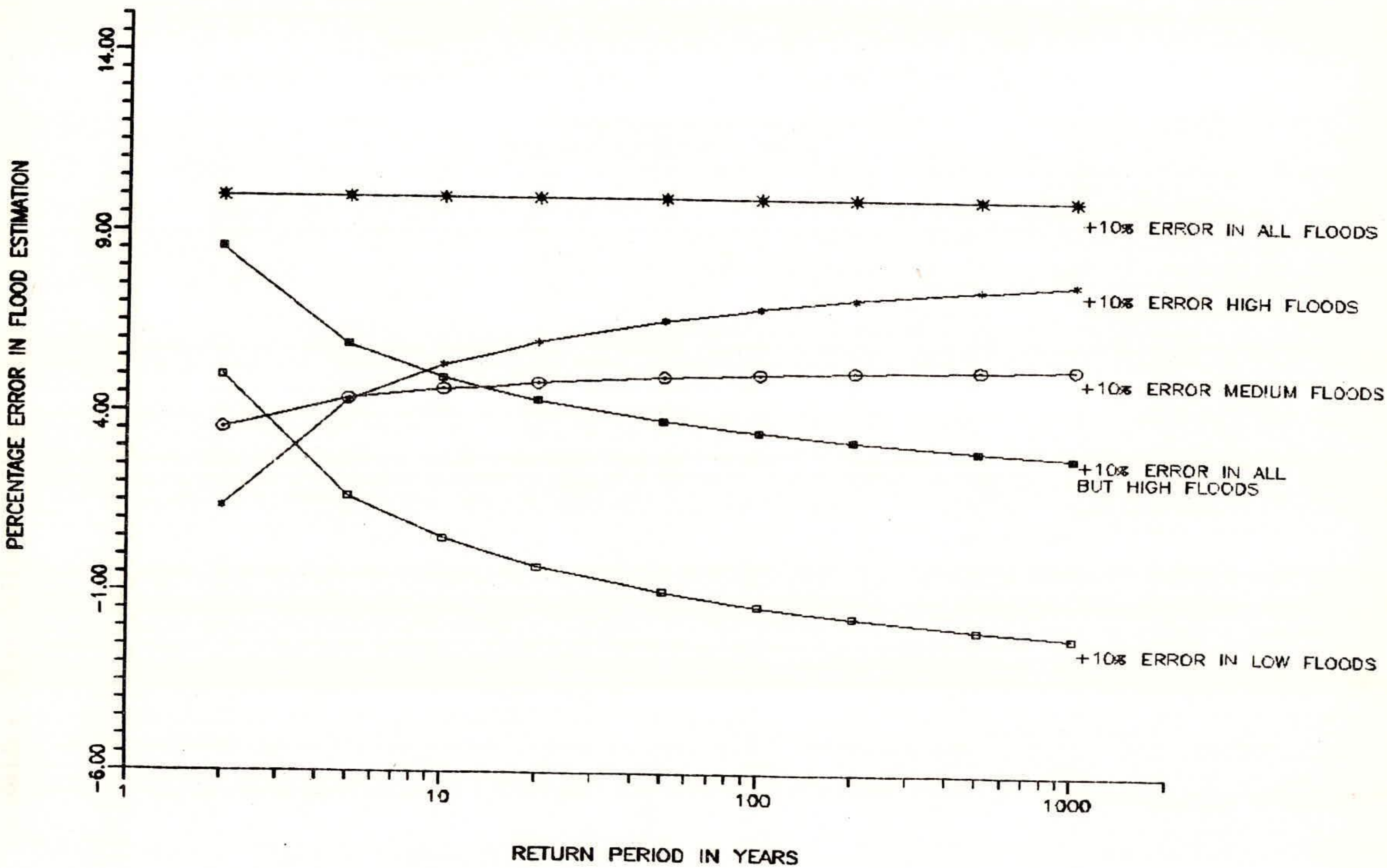


Fig. 8. Percentage variation in estimates of design floods of different return periods for Garudeswar site using observed data under different conditions of systematic error introduced in the data.

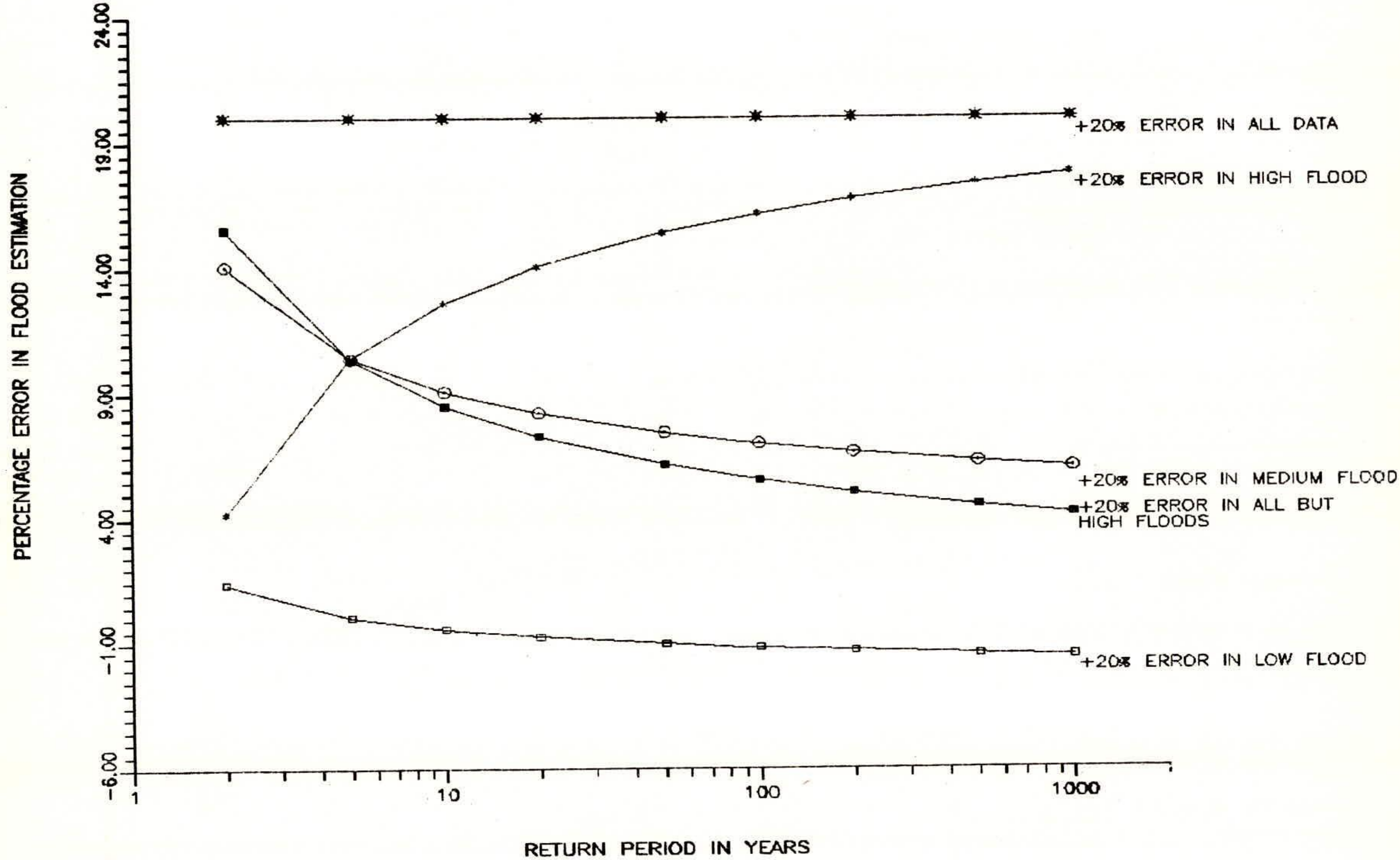


Fig. 9. Percentage variation in estimates of design floods of different return periods for Garudeswar site using generated data under different conditions of systematic error introduced in the data.

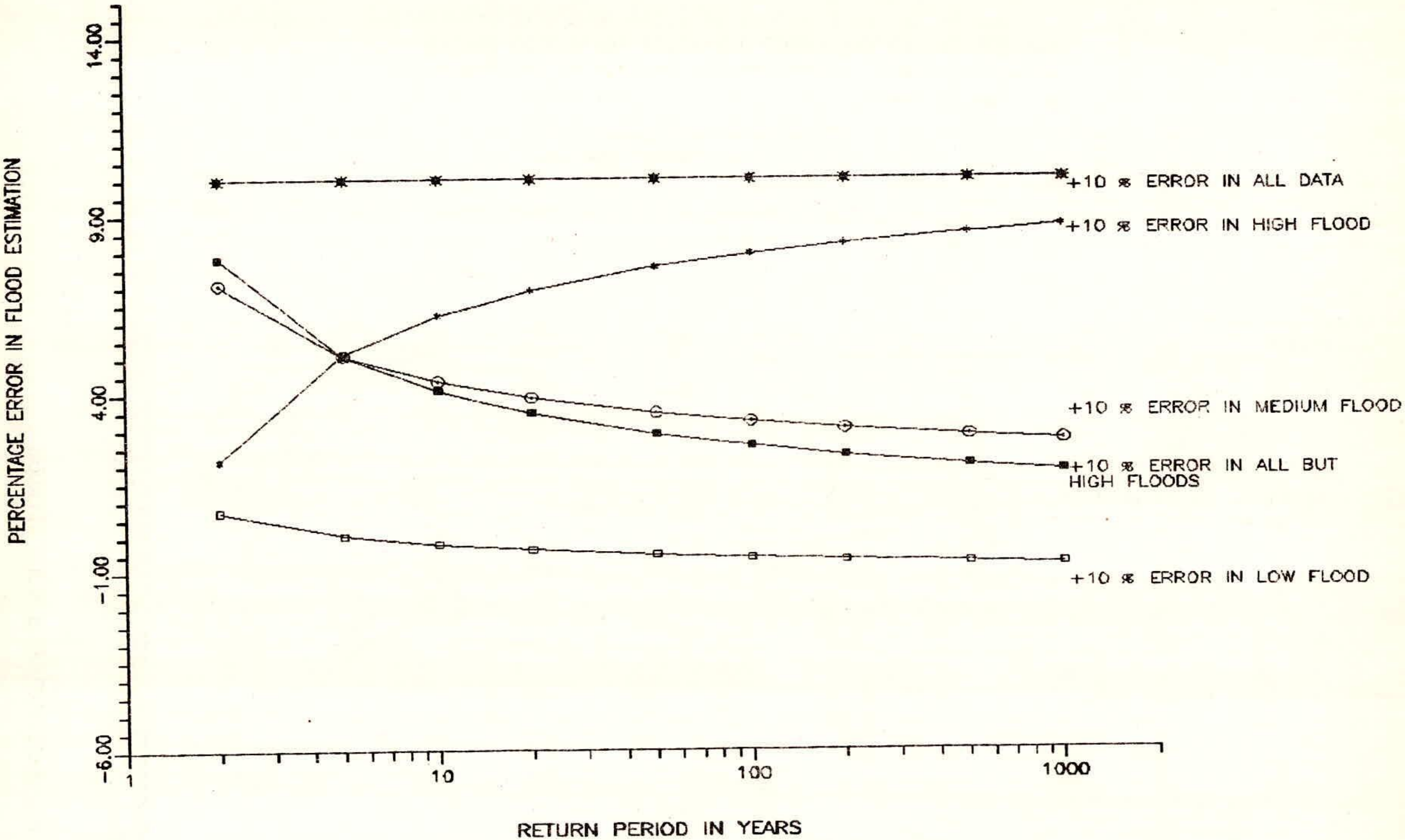


Fig. 10. Percentage variation in estimates of design floods of different return periods for Garudeswar site using generated data under different conditions of systematic error introduced in the data.

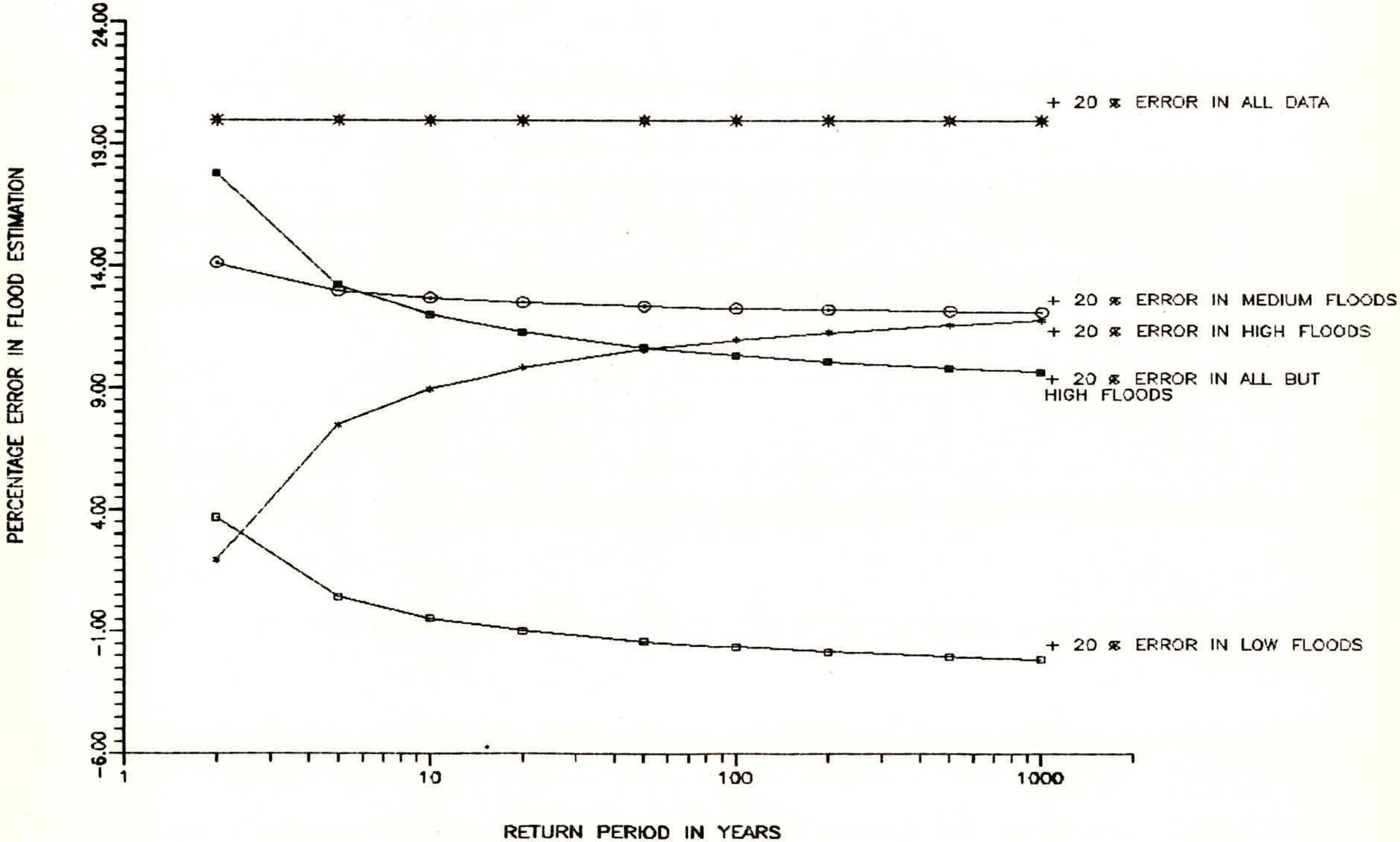


Fig. 11. Percentage variation in estimates of design floods of different return periods for site at Bridge No.807/2 using observed data under different conditions of systematic error introduced in the data.

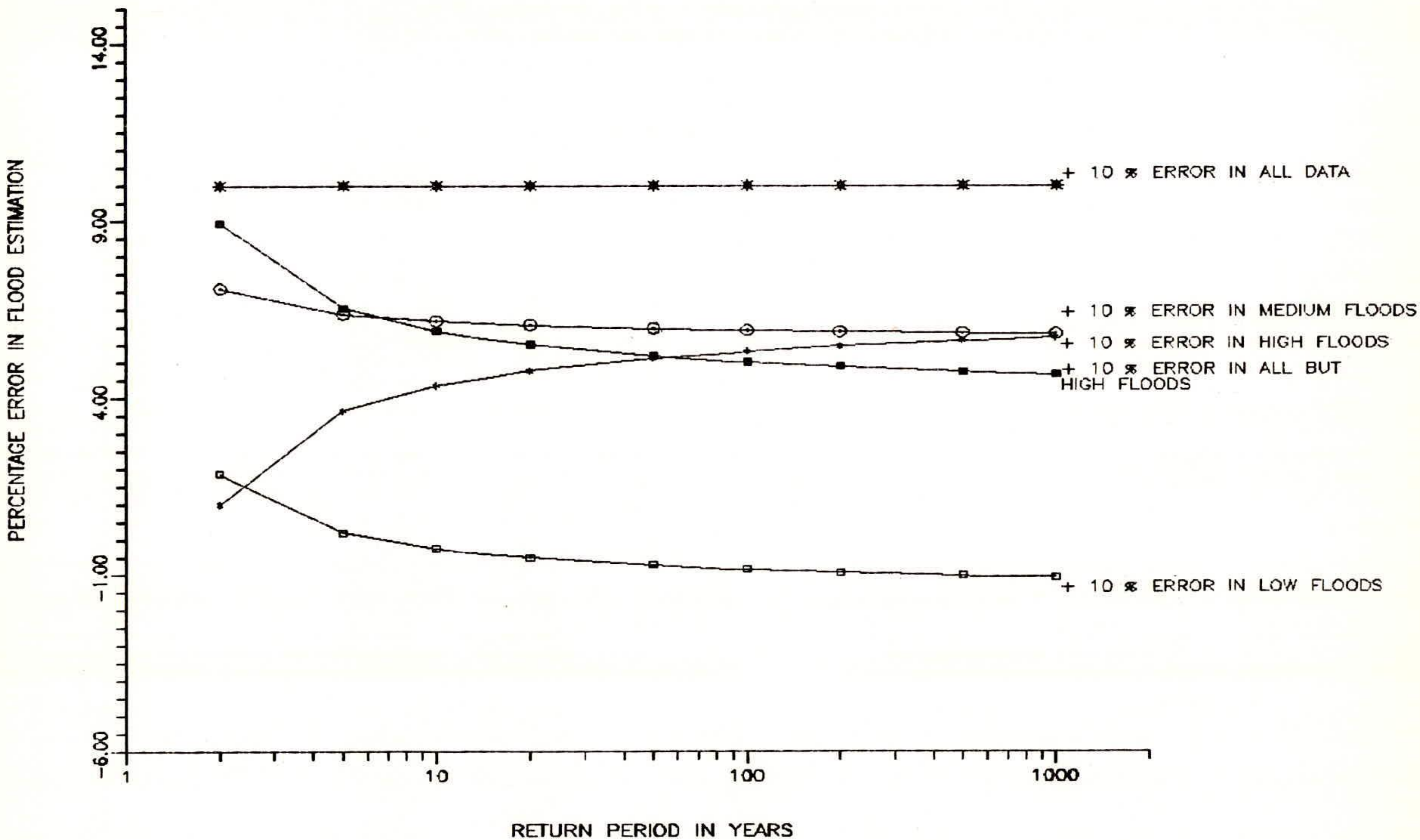


Fig. 12. Percentage variation in estimates of design floods of different return periods for site at Bridge No.807/2 using observed data under different conditions of systematic error introduced in the data.

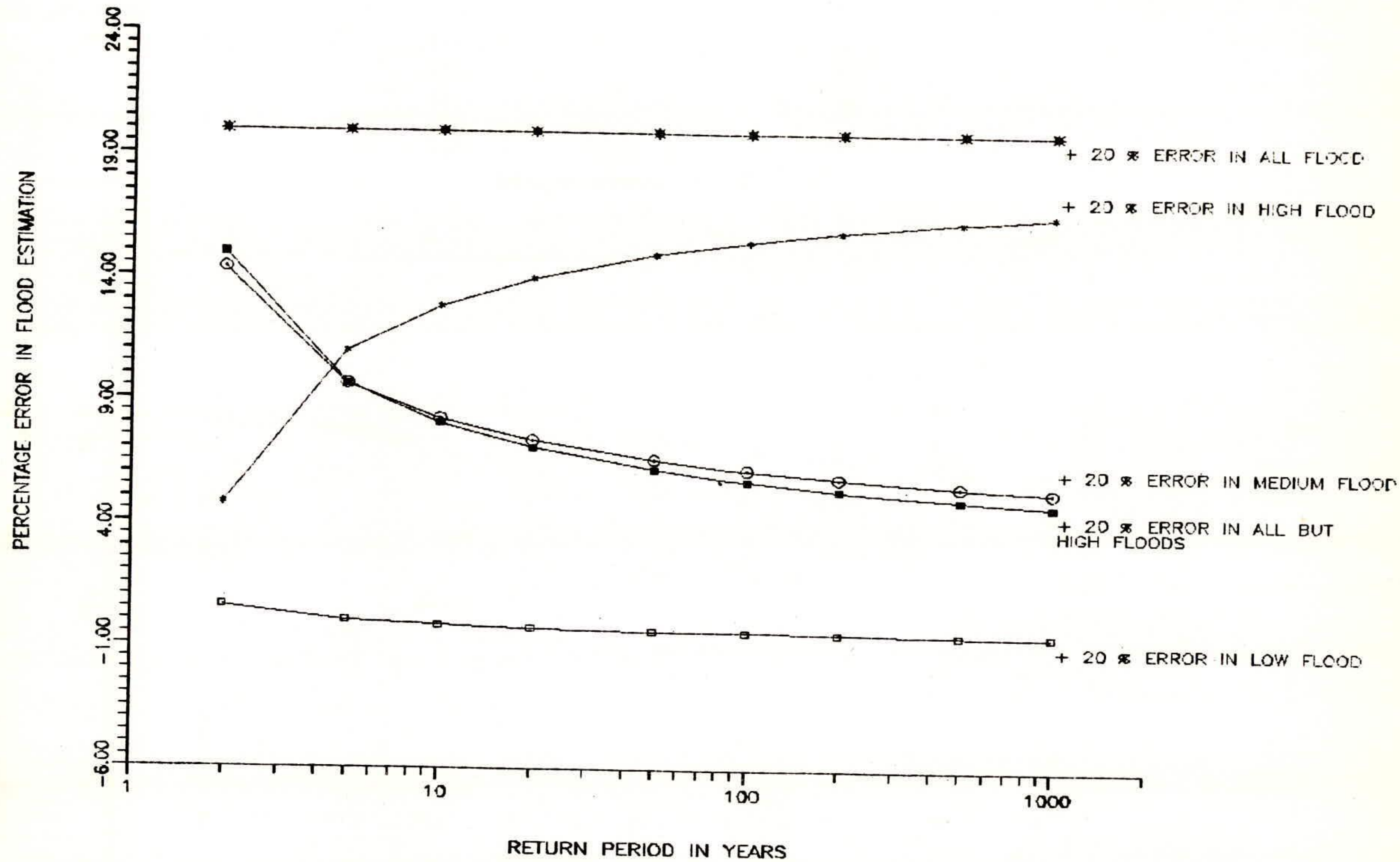


Fig. 13. Percentage variation in estimates of design floods of different return periods for site at Bridge No.807/2 using generated data under different conditions of systematic error introduced in the data.

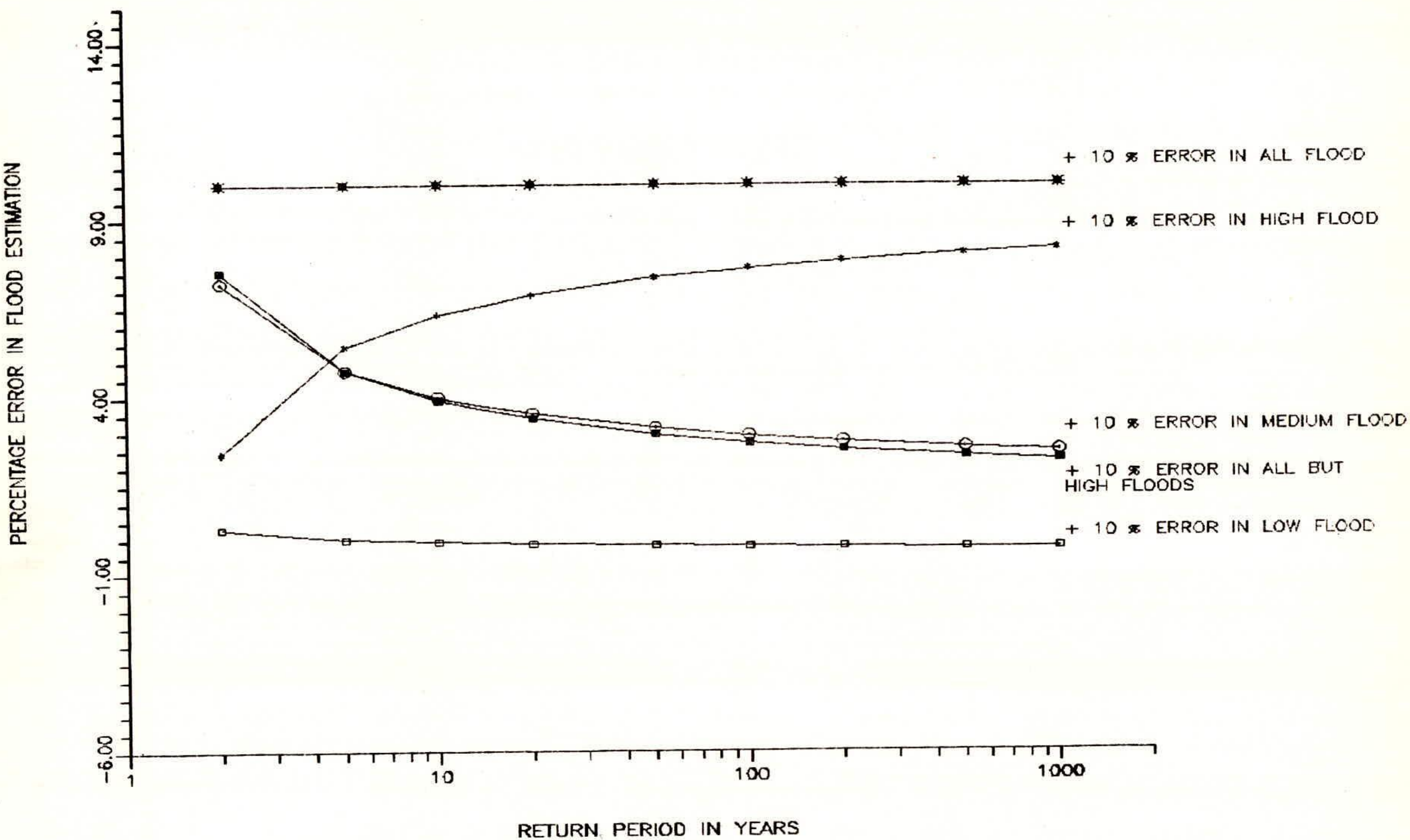


Fig. 14. Percentage variation in estimates of design floods of different return periods for site at Bridge No.807/2 using generated data under different conditions of systematic error introduced in the data.

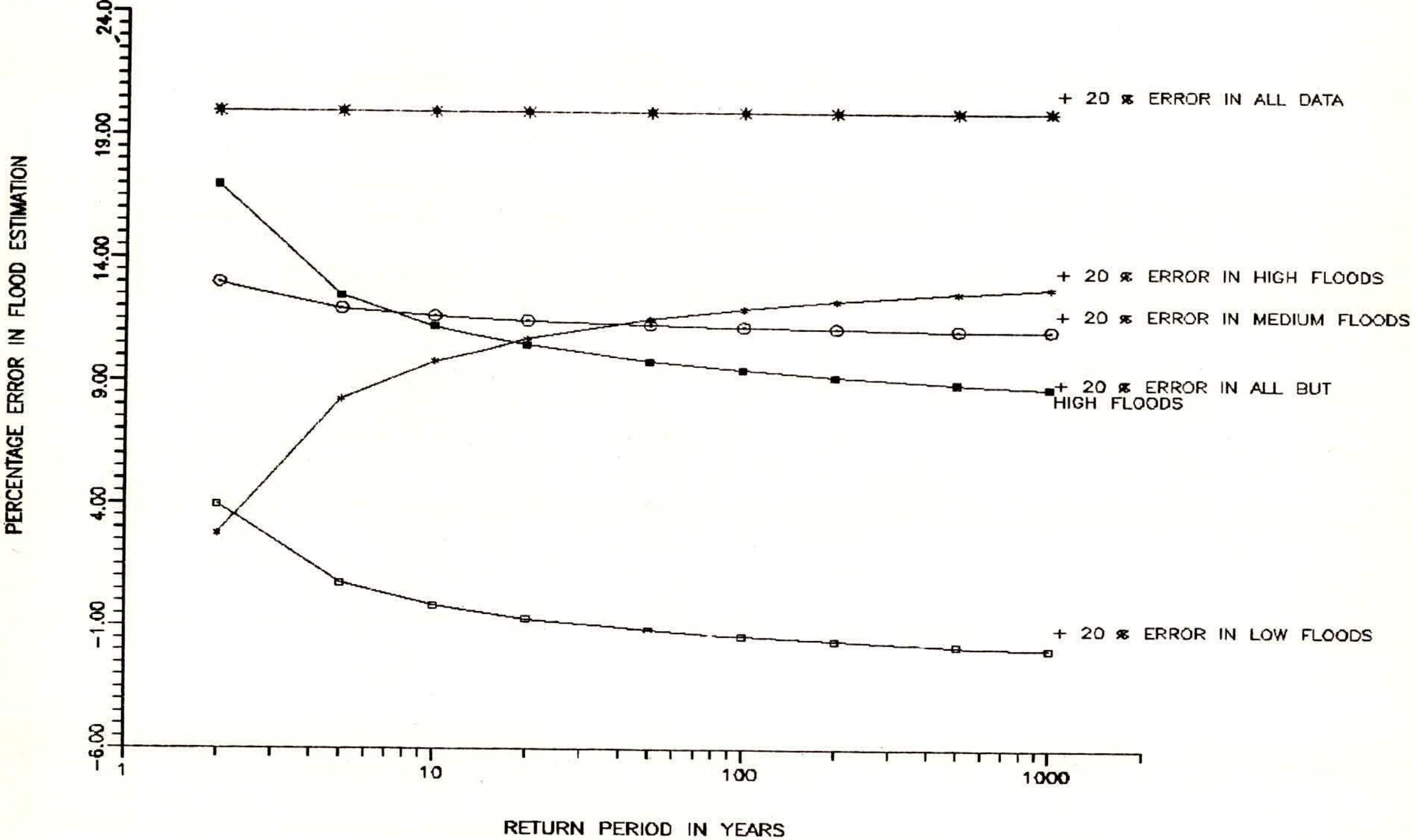


Fig. 15. Percentage variation in estimates of design floods of different return periods for site at Bridge No.912/1 using observed data under different conditions of systematic error introduced in the data.

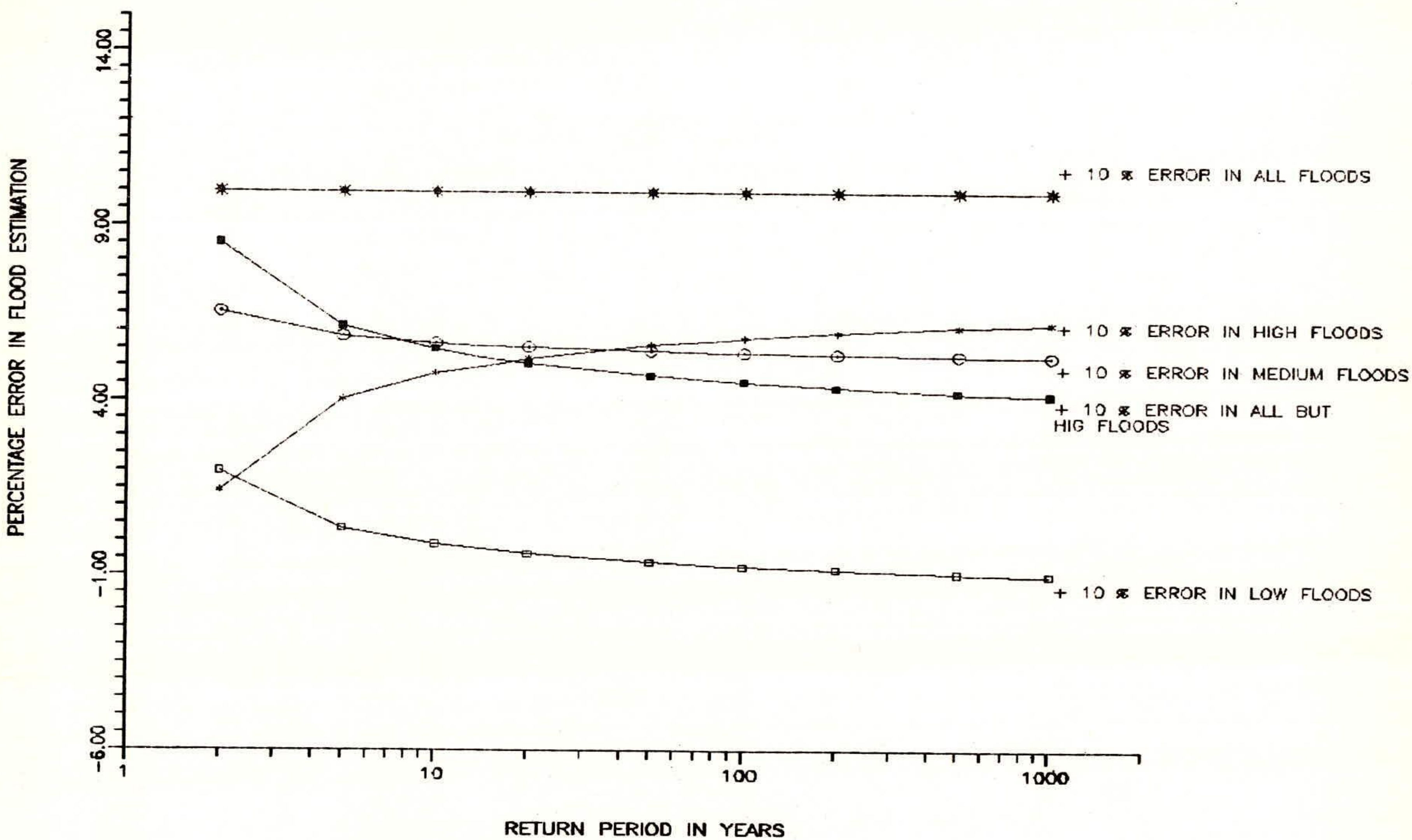


Fig. 16. Percentage variation in estimates of design floods of different return periods for site at Bridge No.912/1 using observed data under different conditions of systematic error introduced in the data.

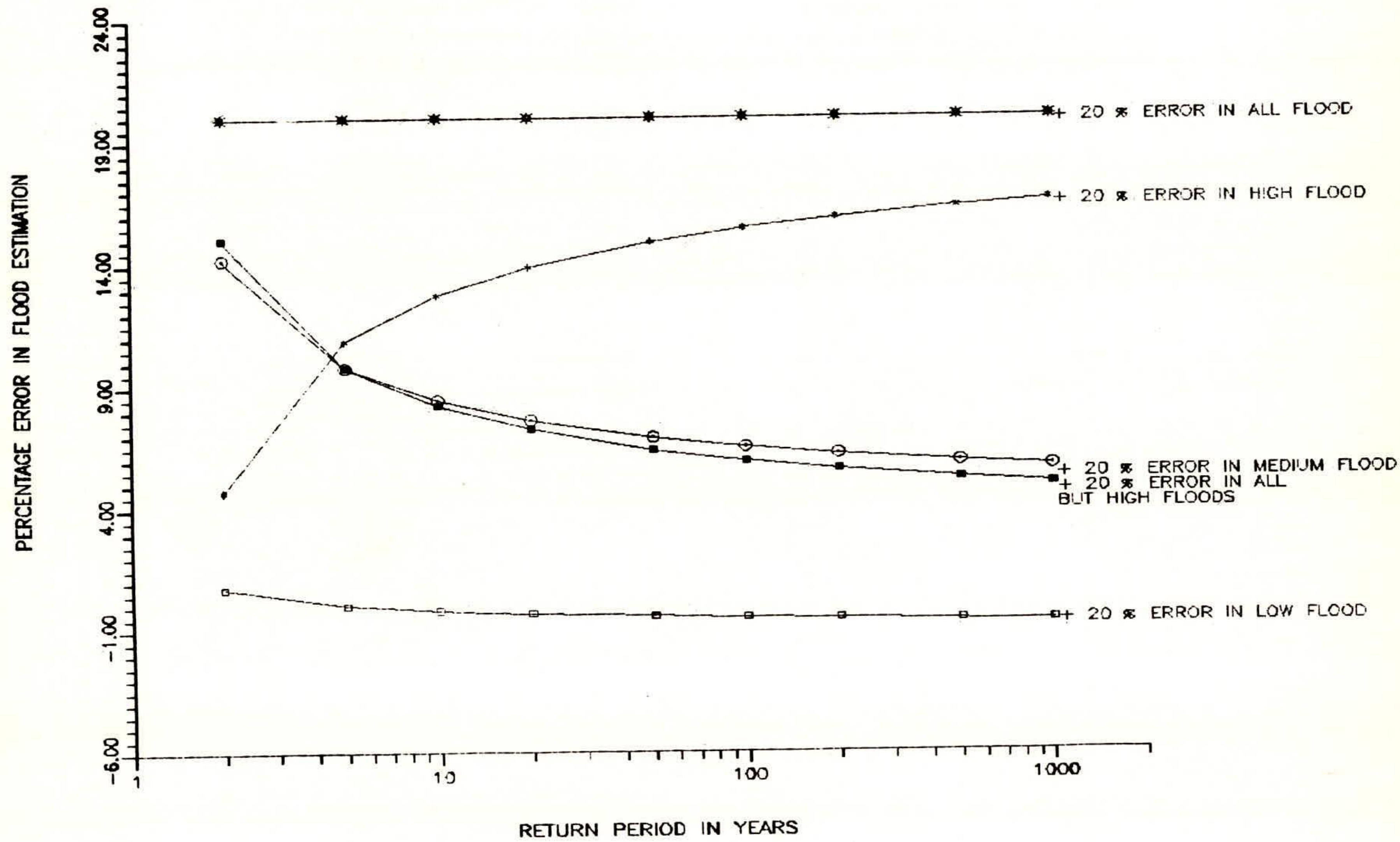


Fig. 17. Percentage variation in estimates of design floods of different return periods for site at Bridge No.912/1 using generated data under different conditions of systematic error introduced in the data.

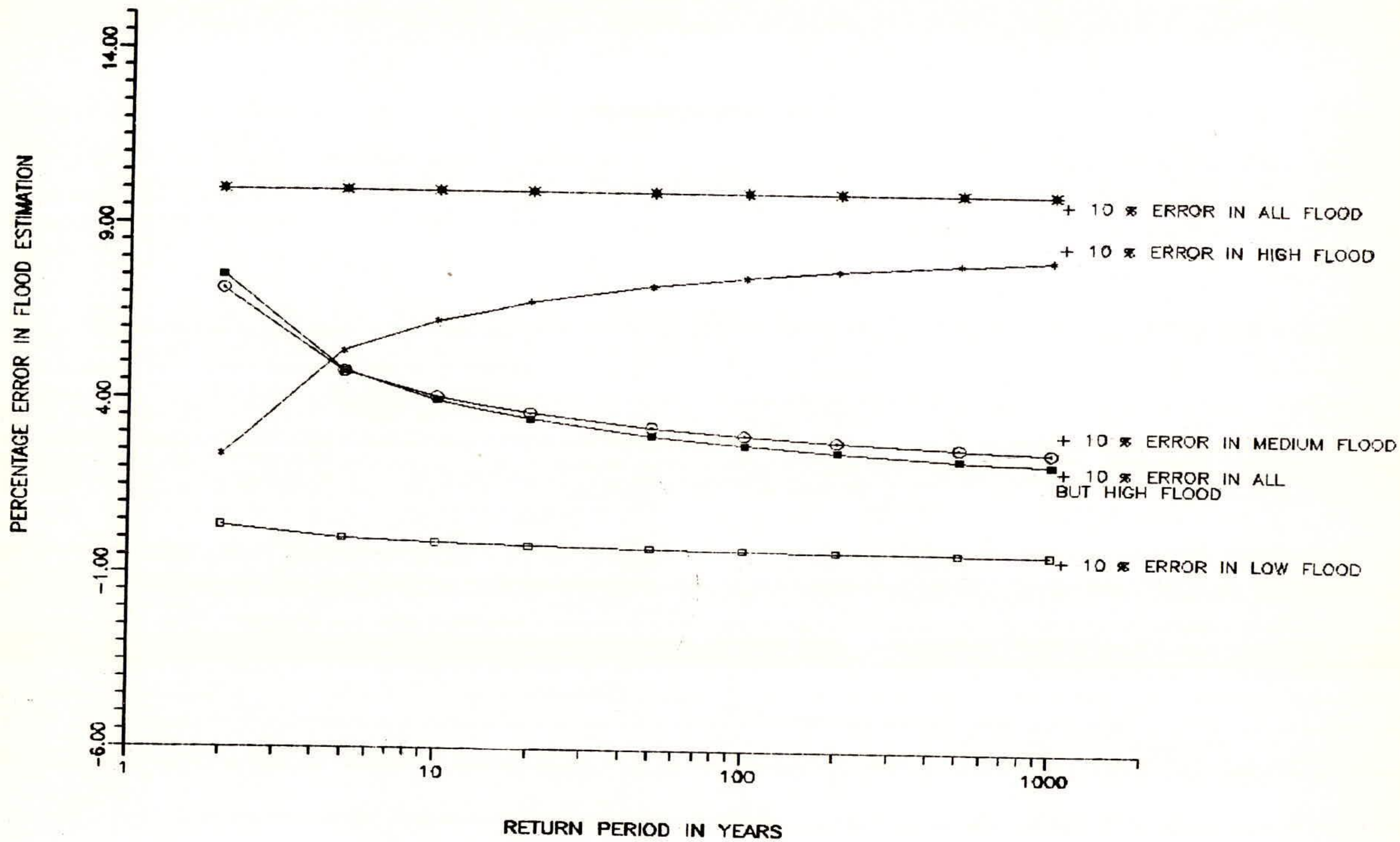


Fig. 18. Percentage variation in estimates of design floods of different return periods for site at Bridge No.912/1 using generated data under different conditions of systematic error introduced in the data.

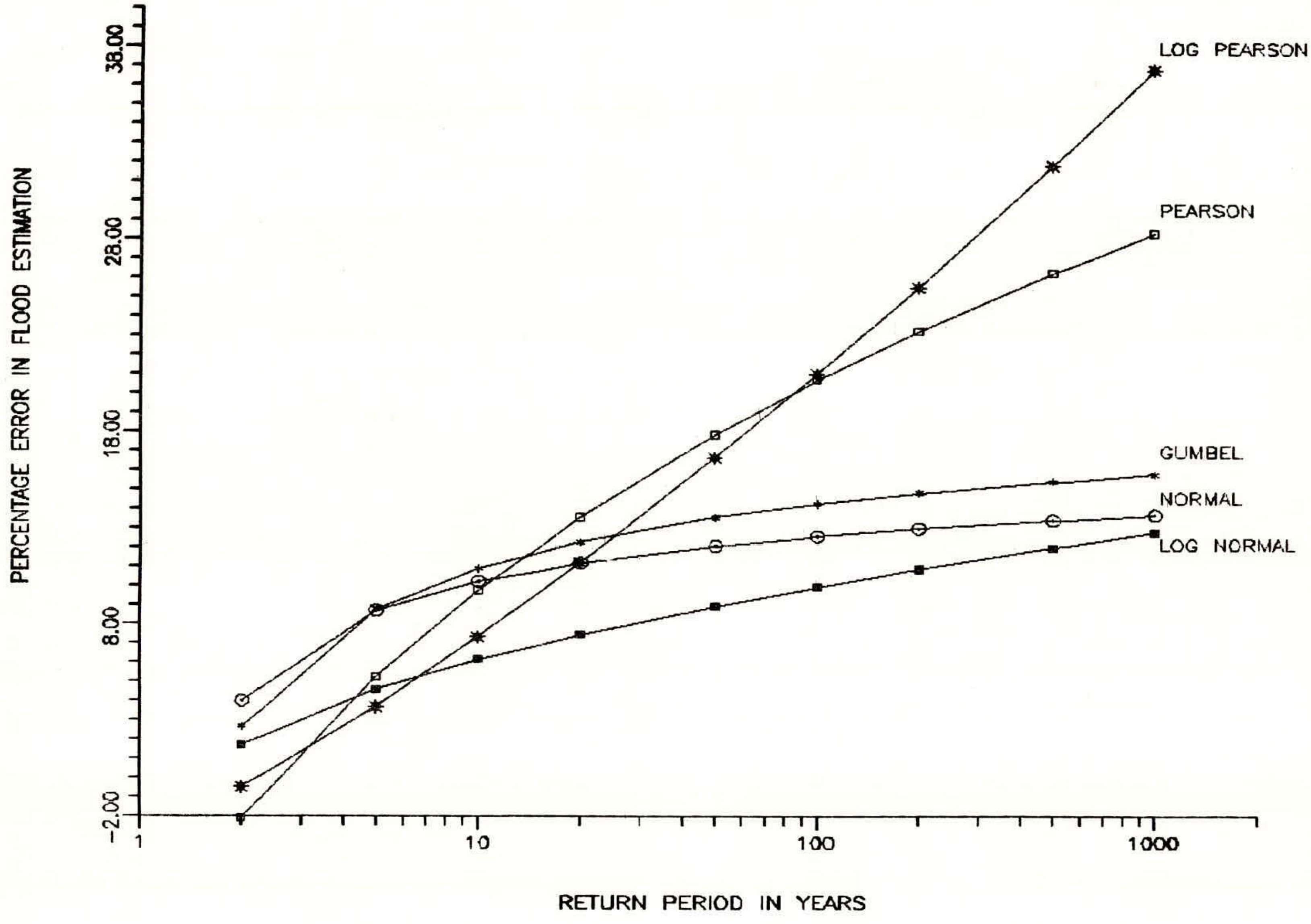


Fig. 19. Percentage variation in estimates of design floods of different return periods for Garudeswar site using observed data under different probability distributions .

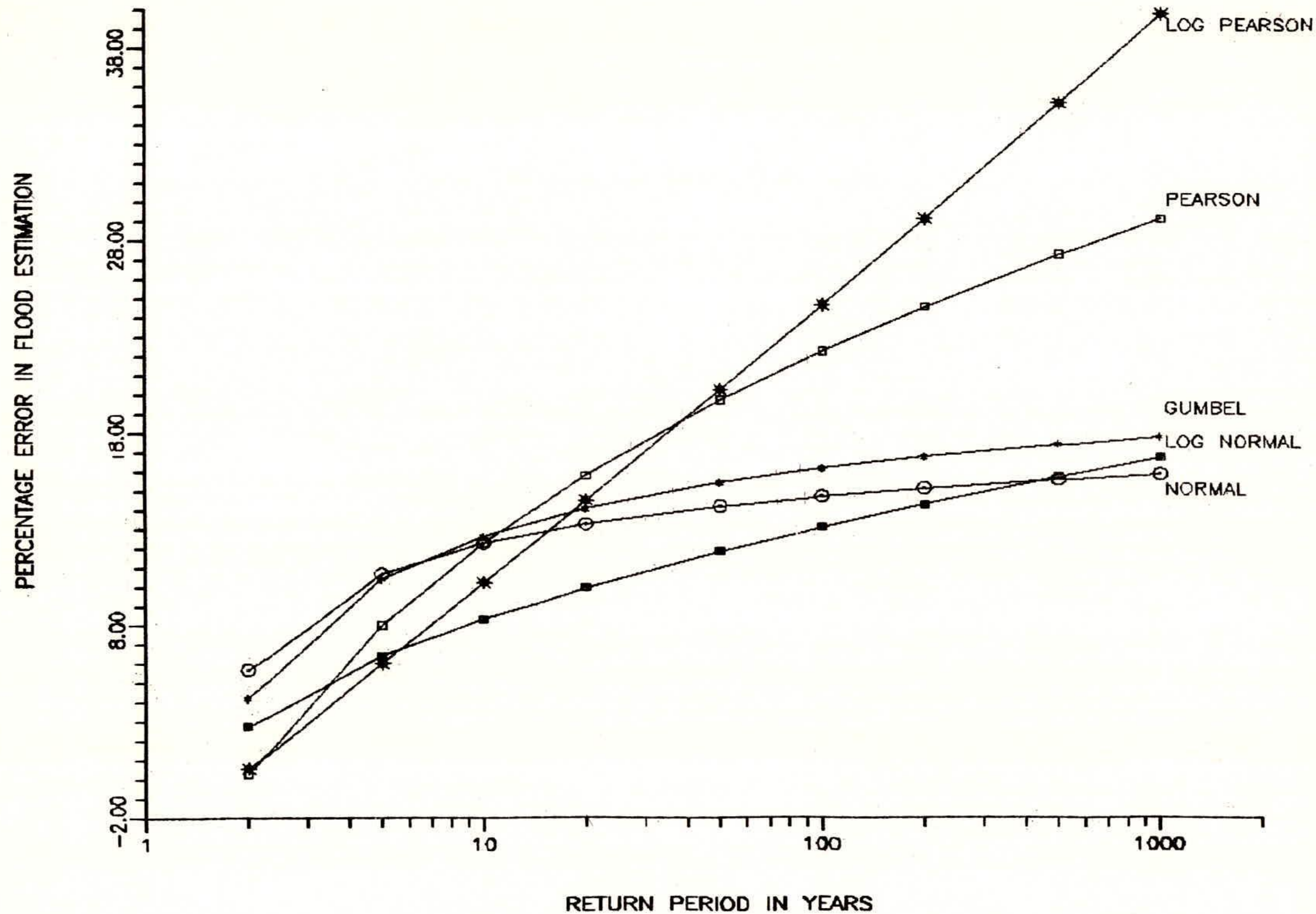


Fig. 20. Percentage variation in estimates of design floods of different return periods for Garudeswar site using observed data under different probability distributions

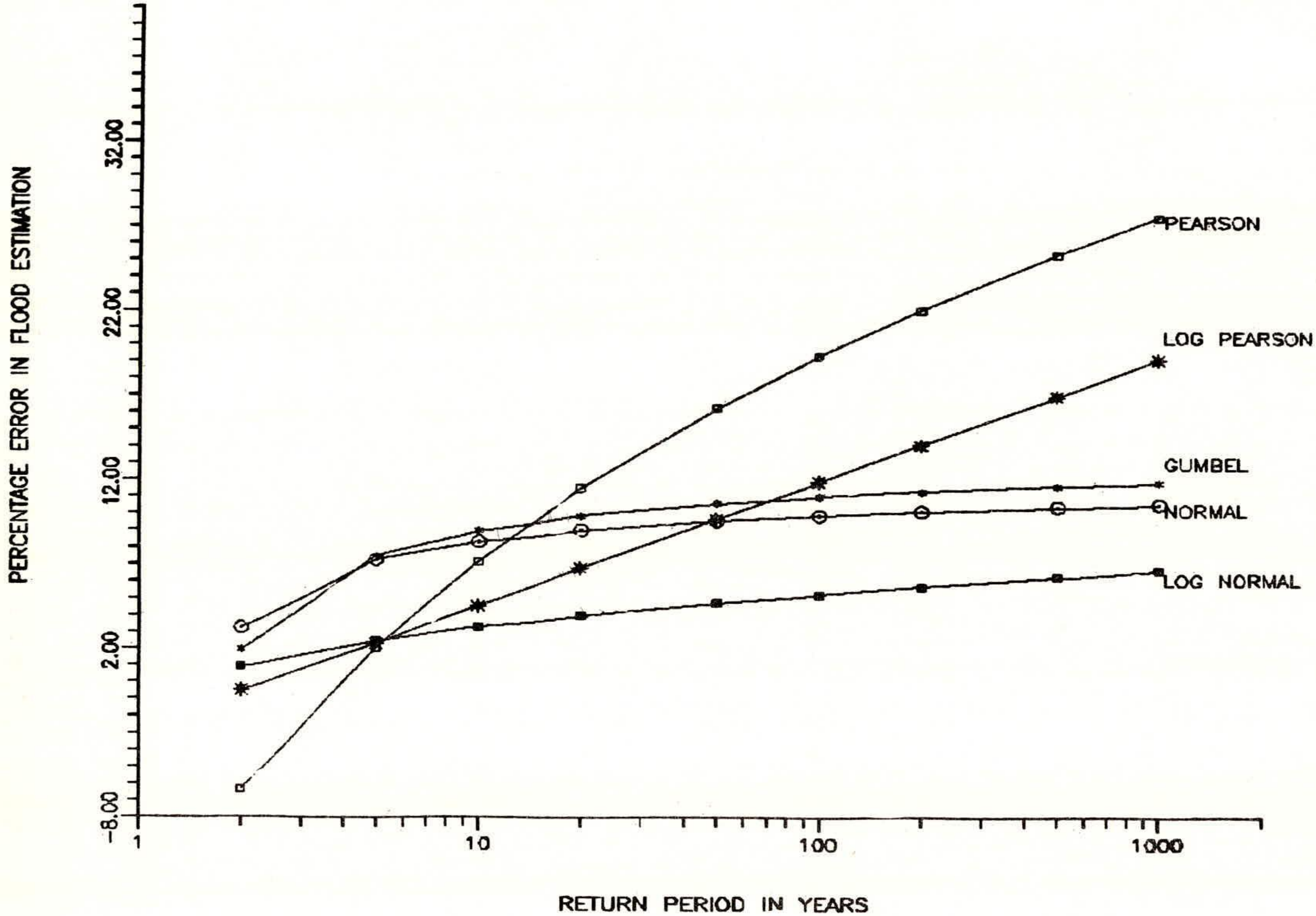


Fig. 21. Percentage variation in estimates of design floods of different return periods for site at bridge No.807/2 using observed data under different probability distributions .

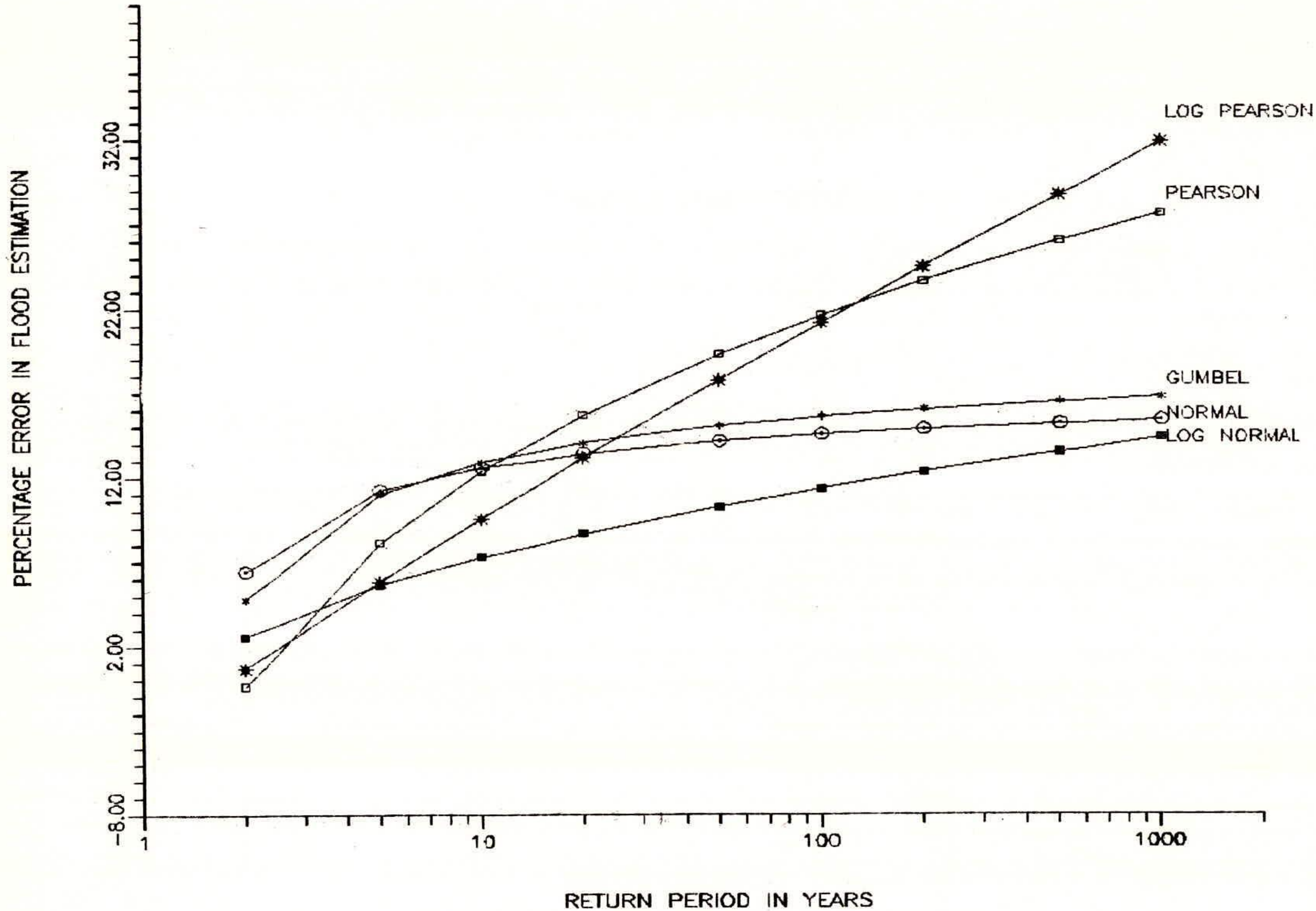


Fig. 22. Percentage variation in estimates of design floods of different return periods for site at bridge No.807/2 using generated data under different probability distributions .

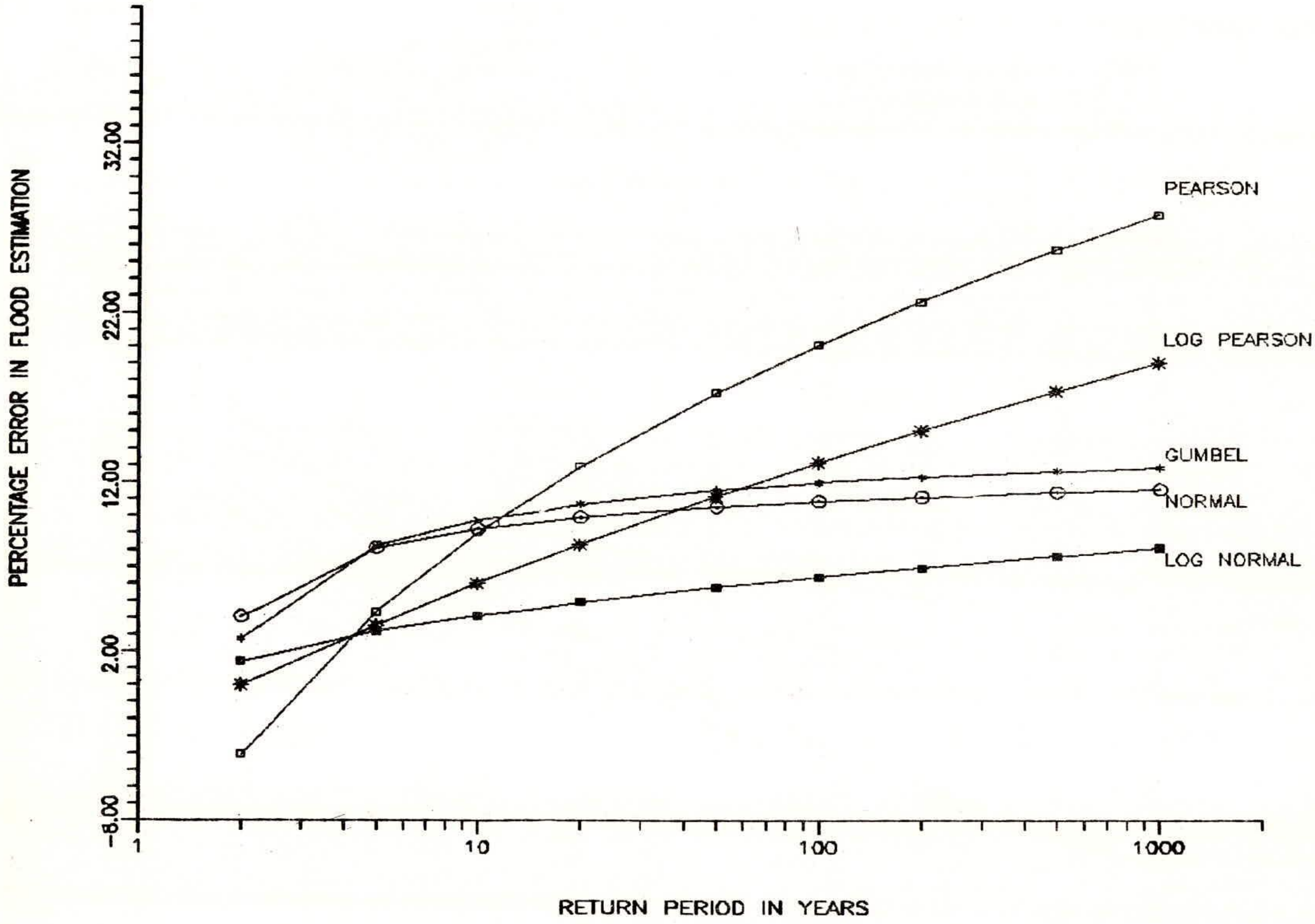


Fig. 23. Percentage variation in estimates of design floods of different return periods for site at bridge No.912/1 using observed data under different probability distributions .

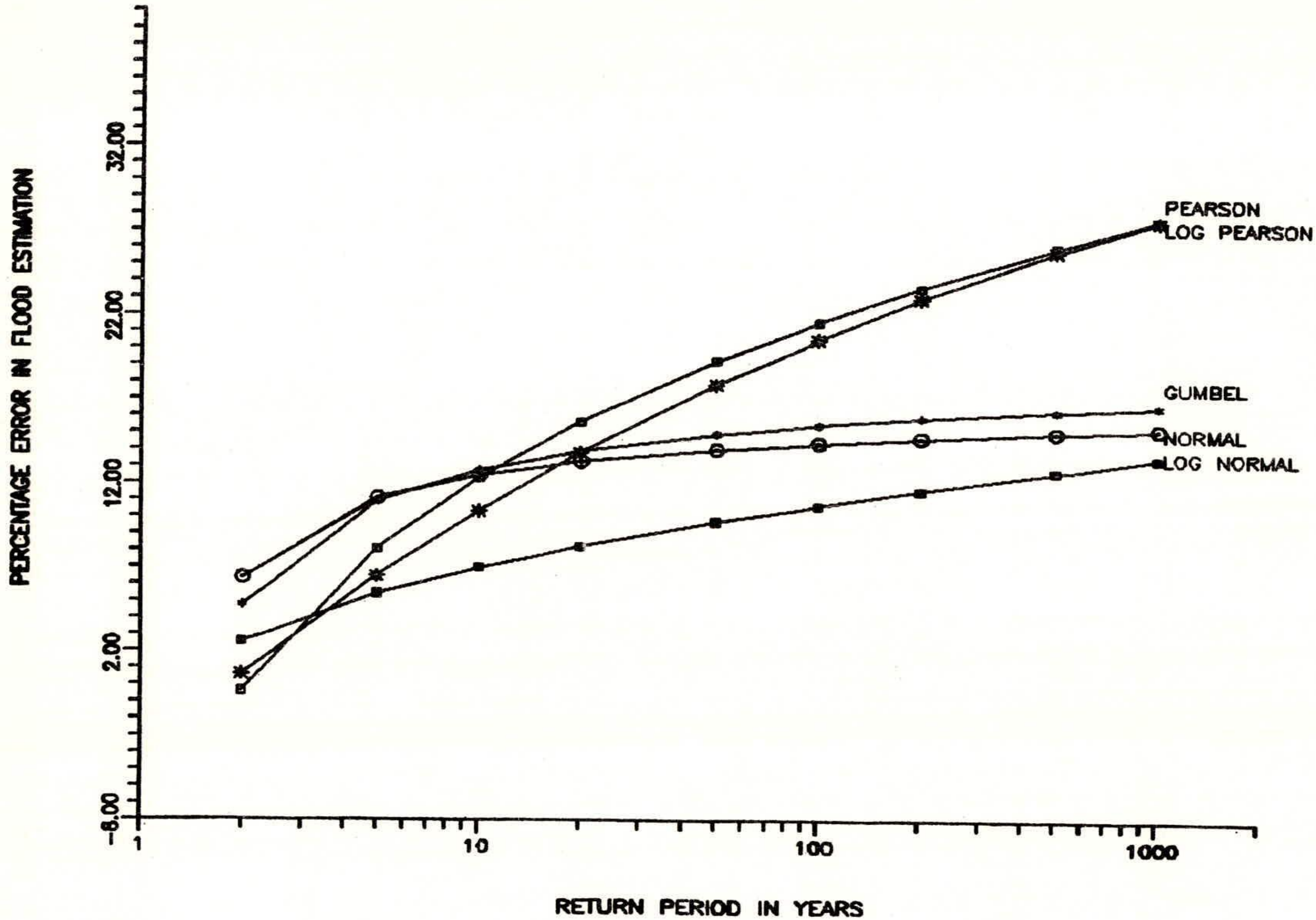


Fig. 24. Percentage variation in estimates of design floods of different return periods for site at bridge No.807/2 using generated data under different probability distributions .

specific probability distributions.

c) Types of Errors (Random or Systematic Errors)

The nature of errors in the estimates of design floods of different return periods vary under different conditions. However, for systematic errors some trend can always be established and that can be used for making necessary adjustment in the estimated design flood values. On the other hand no such trend is possible when random errors of certain magnitude are introduced.

In this particular analysis random errors are introduced by using the relation.

$$QR_i = QO_i (1 + \alpha z_i) \quad \text{with} \quad \alpha = 0.05 \text{ and } 0.10$$

where

QO_i is the observed peak sequence;

z_i is the normally distributed random number;

α is a constant and two values i.e. α = .05 and α = 0.10 have been considered; and

QR_i is peak sequence after introduction of random errors.

This in effect means that for α = 0.10 possible error may be as high as +30% to + 40% and that with α = 0.05 this range may be about + 15% to + 20%. The random errors have been introduced and 20 sets of data with possible errors have been generated. Variation of errors due to random errors of different return periods for various data sets of Garudeswar site for Gumbel distribution in case of α = 0.10 is shown in fig. 25. It may be observed that the range of variation in the errors in case of a particular flood say 100 year return period flood varies from -11.86% to 12.72%, the average value of the error being only 2.97%. The effect of degree of possible error i.e. errors with α = 0.05 and α = 0.10 for 100 year return period in case of various data sets of Garudeshwar site is illustrated in Fig. 26.

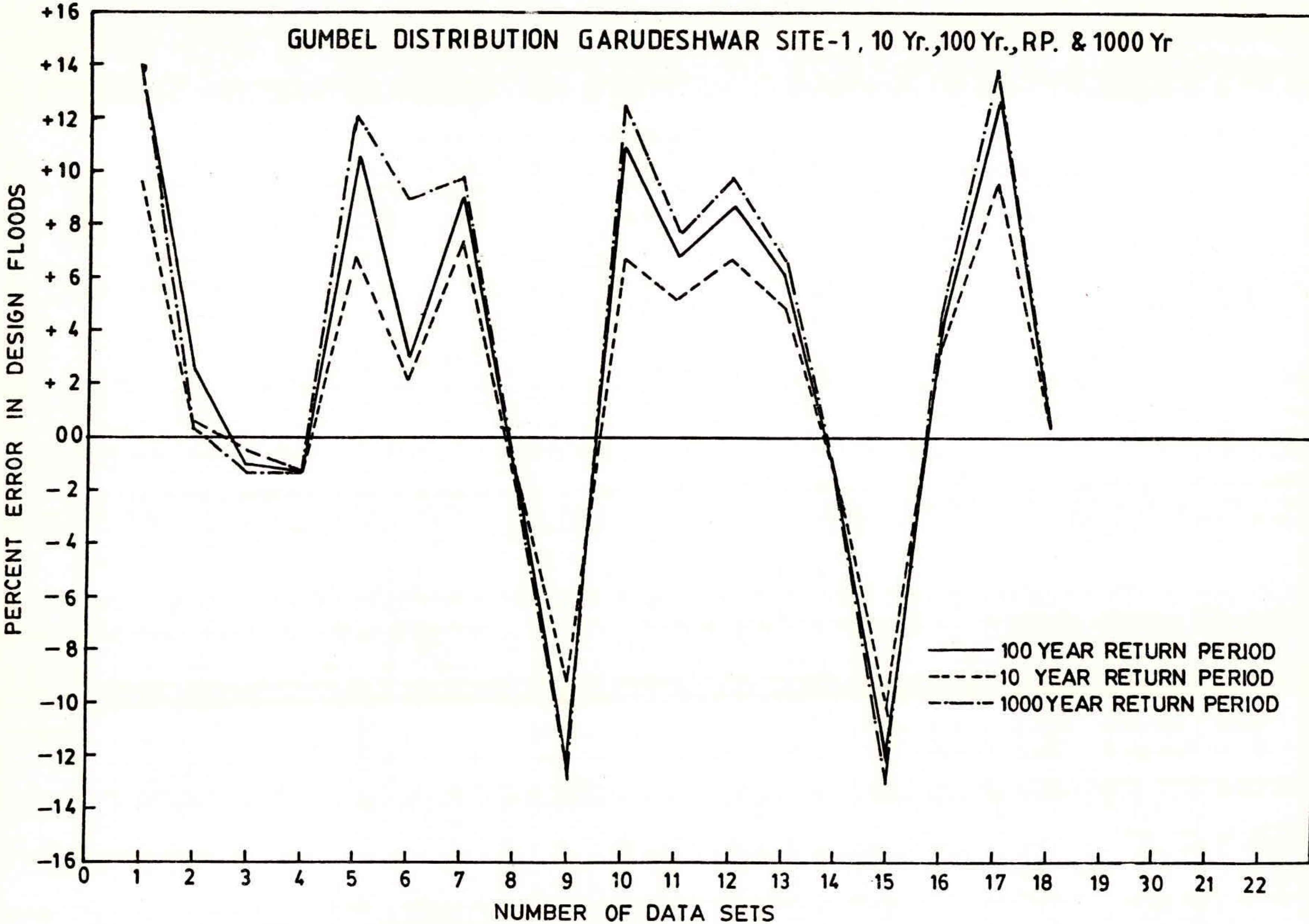


FIG. 25. VARIATION OF ERRORS DUE TO RANDOM ERRORS OF DIFFERENT RETURN PERIODS FOR VARIOUS DATA SETS OF GARUDESHWAR SITE FOR $\alpha = 0.10$

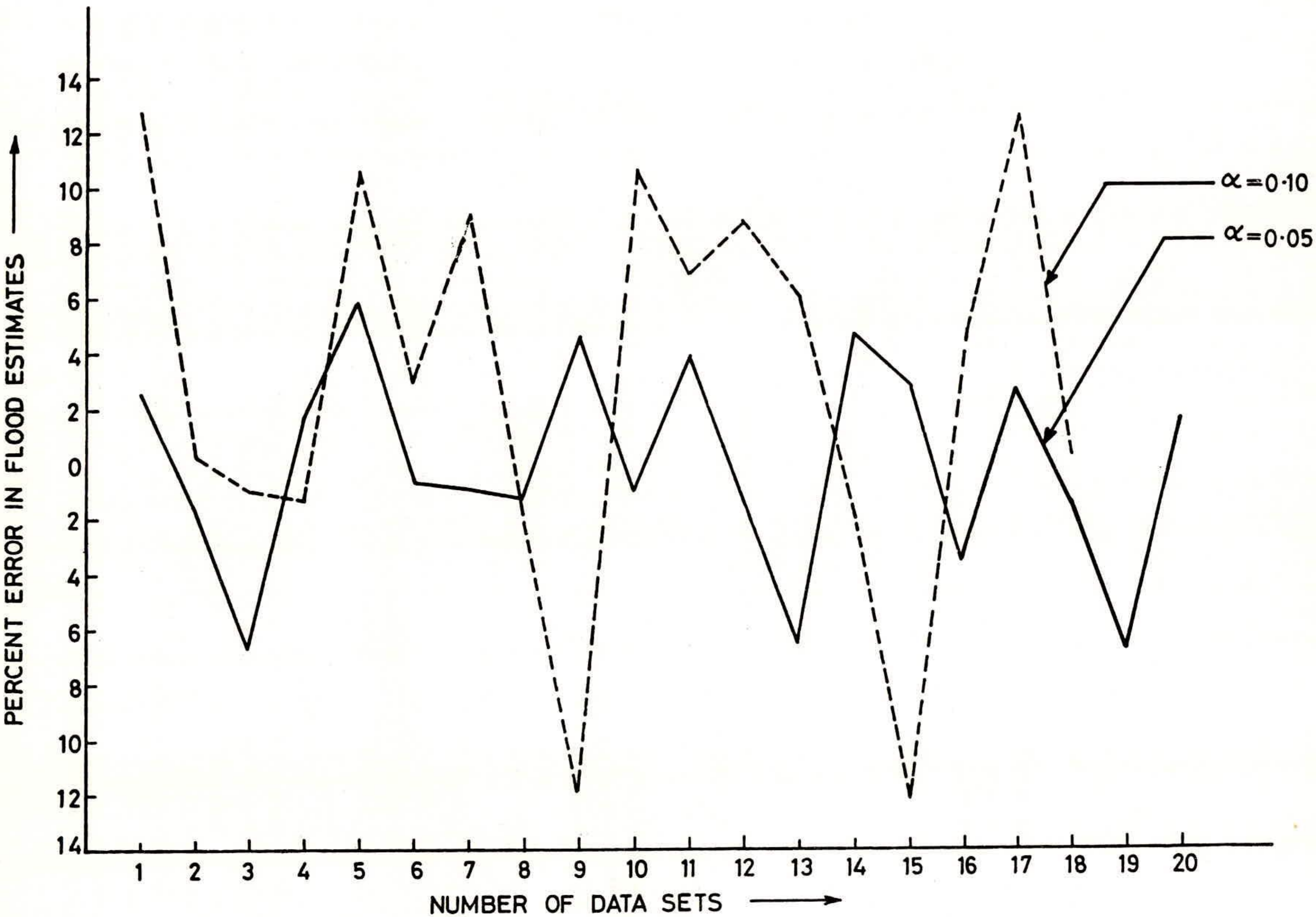


FIG. 26—VARIATION OF ERRORS DUE TO RANDOM ERRORS FOR VARIOUS DATA SETS FOR 100 YEAR RETURN PERIOD FOR GARUDESHWAR SITE FOR $\alpha = 0{\cdot}05$ AND $0{\cdot}10$

6.0 CONCLUSIONS

The results of the above analysis very clearly indicate that there are definite effects of the errors in the flow data sequence on estimation of design flood. Some of the important conclusions which can be drawn on the basis the analysis are as follows.

a) The effects of systematic errors are quite considerable in some of the cases. However, the magnitude of possible errors in design flood estimation varies depending upon the return period, frequency distribution used and the nature of errors in the data. A variation of as high as 36.77% for 1000 year return period has been observed with Log Pearson Type III distribution when error of only +20% is introduced in 3 high flood peak data (out of 32 annual peaks). When errors of the same magnitude, i.e +20%, are introduced in 29 annual peak values (out of 32 values) and the peaks corresponding to high flood are not changed, the variation in 1000 year return period is of the order of -7.27% . On the other hand, the extent of variations in the floods of 2, 5 and 10 year return period floods are only of the order of -0.48%, 3.69% and 7.33% respectively, when errors of +20% are introduced in high floods.

With the Gumbel distribution, the extent variation in 1000 year return period flood is of the order of 15.72%, when +20% error is introduced in the peak corresponding to high floods only. When the errors are introduced in all other peaks except those corresponding to high floods the variation in 1000 year return period flood is of 6.21% .

Similarly, the variations differ considerably when different frequency distributions are used and errors are introduced for various conditions.

An over all view of the results of the study indicates that the possibility of different conditions of errors are to be given due weightage while estimating the design floods for different structures. For example, for the design of spillway of a large dam, it would be necessary to ensure accuracy in measurements of high flood peaks, as errors only in a few values of high floods may result in considerably large variations in design flood estimates for high return periods. On the other hand, for the design of a small structure like a culvert or flood levees the degree of error in the high flood peaks do not affect the design flood estimation to a great extent. In such cases, it is more important to have a flood sequence when the data corresponding to low and medium floods have been measured accurately.

b) In the above analysis, the various percentage of errors have been introduced assuming the given data series to be free from all types of errors. In order to have a realistic representation, it is desirable to collect and analyse data where all possible precautions have been taken meticulously and the data can be safely considered to be error free for all practical purposes.

c) The above study is only illustrative. It is necessary to carry out further studies based on data of a good number of river basins.

However, it is quite clear that the effects of errors on design flood estimation follow a well defined trend particularly in case of the systematic errors. Once the extent of error at an observation site is established, it should be properly studied to incorporate it suitably in design flood estimation. For example, if a site has reliable data for low floods and erroneous data for high floods, then relatively lower return period floods can be estimated with confidence using the data of this site. However, while estimating the design floods for higher return periods using such data, it will be necessary to ascertain the possible range of errors likely to creep in. The design of the structure must, therefore, take into account such features.

REFERENCES

1. Chow,V.T. (1964), "Handbook of Applied Hydrology", McGraw Hill Book Company.

2. Herschy, R.W.(1978),"Hydrometry - Principles and Practices", John Wiley & Sons, New York.

3. Herschy, R.W. (1985), "Streamflow Measurement", Elsevier Applied Science, London.

4. Herschy (1970), "The Magnitude of Errors at Flow Measurement Stations". Symposium on Hydrometry. IAHS-UNESCO-WMO. Vol. I, held at Coblence, September.

5. IAHS-UNESCO-WMO (1970), "Symposium on Hydrometry", Vol.I and II, held at Coblence, September.

6. ISO (1969 a) International organisation for standardization. R.748. "Velocity Area Methods". Geneva.

7. ISO (1969 b) International Organisation for standardization. R.1100. "Establishment and operation of a Gauging Station and Determination of the Stage Discharge Relation". Geneva.

8. Irrigation Commission (1972), " Irrigation Commission Report", Vol.III, part.I.

9. Laurenson, E.M and O'Donnell, T. (1969), "Data Error Effects in Unit Hydrograph Derivation." Journal of Hydraulics Div., ASCE, Hy6, November, pp.1899-1917.

10 Narmada Control Authority (1985-86), "Annual Water Account of Narmada upto Sardar Sarovar Dam Site - Water Year-1985-86".

11. Yevjevich, V. (1972), "Probability and Statistics in Hydrology ". Water Resources Publications, Fort Collins, Colorado.