A STUDY OF THE ANNUAL MAXIMUM FLOODS IN THE KELANI GANGA CATCHMENT AREA AND THE DERIVATION OF A REGIONAL FLOOD FREQUENCY CURVE

by

M.S. Fernando

1.0 Introduction

The sustenance and the preservation of civilised society are intimately bound with the conservation and correct utilisation of the natural resources of land, water and air.

The famous German Poet Goathe said 'the most precious, however, is water'. The economy of a nation depends on water for its survival and growth.

Water potential of a country is not unlimited. Water is a substance that can neither be created nor found a substitute for. Therefore, it is extremely necessary to study the availability of this valuable resource and plan for its optimum utilisation. Planning for water has become an inevitable necessity for Sri Lanka due to the rapid development and improvement of living standards in recent times. For planning purpose, an integrated picture of all related facts gathered and assembled in readily understandable and usable form, is necessary.

In this regard regional analysis of hydrological data is a very helpful tool which can be effectively used for solving todays drainage problems. A regional analysis allows the transfer of information from gauged sites to other sites where sufficiently detailed information is not available.

This article deals with a study of annual maximum floods in the Kelani Ganga catchment area and the derivation of a Regional Flood Frequency Curve for the area.

2.0 Regional Flood Frequency Analysis

An annual flood is defined as the largest instataneous flow in any given year. An important feature of flood hydrology is the high variability of annual floods which makes it very difficult to make reliable estimates of high return period floods even with quite long periods of record. In practice, hydrological records of 20 to 35 years, which are available in Sri Lanka, are not long enough to give reliable flood estimates. To overcome this difficulty, the flood data from a more or less hydrologically homogenious regions are pooled to provide a more stable estimate of the flood frequency curve.

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He served the Department of Highways from 1975 to 1980. From 1980 to 1985, he worked as a Consulting Engineer in Libya. He joined the National Consulting Bureau, Libya as a Resident Engineer. He was later promoted as a Chief Resident Engineer and was in charge of a 153 km. long highway project.

Presently, he is working in the Sri Lanka Land Reclamation and Development Corporation as a Chief Engineer, in charge of drainage designs and Colombo North Region.

Experience has shown that this Regional Frequency Curve, is a reliable means of predicting flood frequencies and is to be preferred to estimate made from the data of a single station.

Regional Flood Frequency Analysis is a very useful tool in Hydrology applicable to many Civil Engineering fields such as highways, irrigation, land reclamation, flood protection works, and water supply etc. The Regional Flood Frequency Curve is plotted with the return period as the horizontal axis and the corresponding mean annual peak flood (standarised) as the vertical axis. When used this together with an emperical equation correlating the catchment characteristics with the mean annual peak flood, a designer can easily calculate a design flood corresponding to any required return period, for any location in the area. This is a fairly reliable and quick method favoured by many designers all over the World.

As an effort to introduce this valuable tool in hydrology, a Regional Curve was prepared to cover the Kelani Ganga catchment area.

The correlation of catchment characteristics with the mean annual peak flood is not included in this article. This will be delt with in a future publication.

To prepare the Regional Curve the method suggested by the Flood Studies Report was adopted. (Flood Studies Report was the result of an extensive research programme carried out in the U.K. and was published by the Natural Environment Research Council, U.K.)

Altogether 258 years of flood records from 10 gauging stations were analysed in this study. The locations of these gauging stations are shown in Figure 1.

3.0 Kelani Ganga Catchment Area

Total area of the Kelani Ganga catchment is 805 sq.miles. Following is a short description about the area covered by the Kelani Ganga catchment.

<u>Western direction</u> - Western boundry is is the sea

<u>Northern Direction</u> - Extends upto Kegalle District covering villages such as Warakapola, Galgomuwa, Hettimulla and Aranayake

<u>Eastern direction</u> - Goes up to Nuwara-Eliya District covering Watawala, Ginigathhena, Norton Bridge, Dolosbage etc.

<u>Southern direction</u> - Colombo District. Covers up to Homagama, Padukka etc. and goes up to Sri Pada.

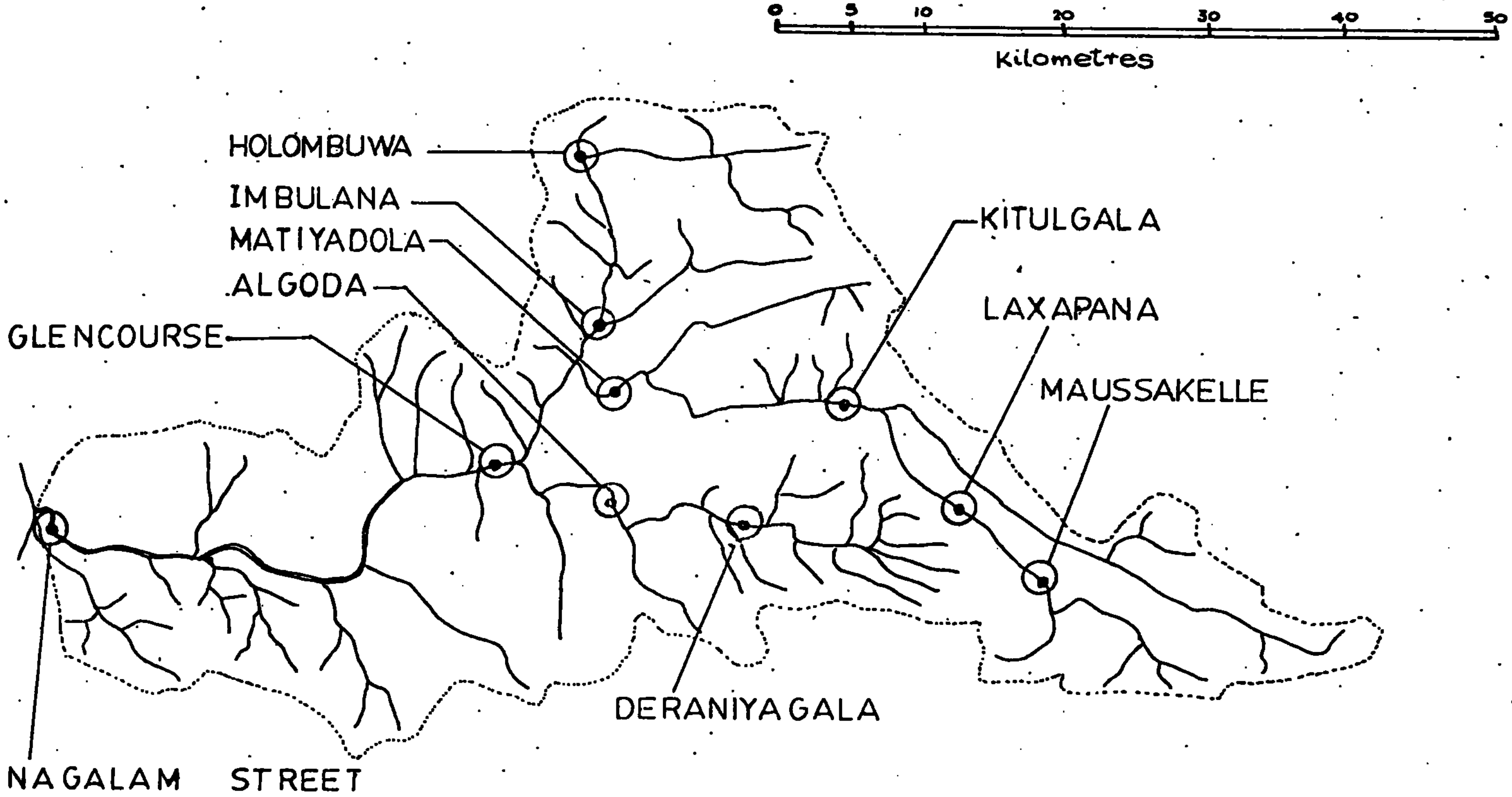
3.1 Selection of the Area

Kelani Ganga is perhaps the only river which is flowing through densely populated and mostly developed areas of the Country, as it is the only major river running across the Capital of Sri Lanka. When compared with the annual discharge to the sea, Kelani Ganga is the second highest in Sri Lanka only to be exceeded by the Mahaweli Ganga.

Following are some of the reasons for selecting the Kelani Ganga catchment area for this study :-

1. This is the area which is having a dense network of heavily trafficked roads. Failure of any drainage structure on any of these roads may not only cause destruction of valuable property but also results in loss of human lives. An accurate and quick method is necessary for the designers to calculate peak floods corresponding to required return periods.

2. For the fast growing population in the area, many unsuitable



kelani ganga catchment area

fig. 1

low lying lands have to be reclaimed. Also proper drainage facilities have to be provided. A study of this nature is beneficial to Engineers engaged in planning and designs works.

3. For those who are engaged in flood control works in the City of Colombo and suburbs, calculation of design flood is essential.

There are vast number of Engineers who are engaged in various types of hydrological studies relating to floods in Colombo City and suburbs. This type of study is very useful to them in calculating floods, corresponding to required return periods.

3.2 Hydrological characteristics of the catchment area

Physiography

Most of the catchment area is covered with laterite up to about 50 ft. thick on hillocks edging into valleys. There is a small area covered with littoral deposits of gravel, sand and wind blown sand.

Extensive, unconsolidated alluvial deposits are found in the flood plain of the river.

Yellow, grey and brown molted plastic clays underlying yellowish brown sandy clays and clayey sands are found in most places in the flood plain with occasional layers of peat.

Geology

The main rock types in the area are given below with their ages:-

Age	Rock types
Recent	Residual deposits, alluviums, wind blown sands, sands and gravels, littoral deposits and coastal sand stones
Pleistocene	Gravels and latterite
Precambrian	Granite, biotite gneises, gravel-biotite gneises, banded gneises, granitted gneises and charnokites.

Rainfall

Average annual rainfall of the area ranges from 40 inches to 80 inches. Most of the catchment area, this varies from 40 inches to 60 inches.

Hydrological characteristics such as rainfall, evaporation, soil type, geology and topography of the area are not varying much within the Kelani Ganga catchment area. This area can be considered as a hydrologically homogenious region.

3.3 Applicability of the regional frequency analysis to the area selected

The concept of the regional frequency analysis is applicable to hydrologically homogenious regions in terms of rainfall, evaporation, soil type, geology and topography. But it is very difficult to identify the exact boundaries corresponding to these factors mentioned above. Even if these factors are analysed critically and regional curves and prepared for small areas, the variations of each curve are neglegible. Therefore, this technique is normally applied to bigger areas in other Countries. The region selected in this analysis is very small in extend and the hydrological factors mentioned above can be considered same throughout this region.

However, it was decided to check whether the area selected was hydrologically homogenious. Out of the hydrological factors mentioned, the more influential factor relevant to Sri Lanka is rainfall. According to the 'Rainfall Depth - Duration - Frequency Studies of Sri Lanka' published in Journal of Hydrology, 37 - 1978, Sri Lanka is divided into six hydrological zones. Kelani Ganga basin falls into two such zones. The stream gauge recording stations of Deraniyagala, Laxapana and Maussakelle are falling into one zone and the others falling into a separate zone.

To find out whether there would be significant differences, regional frequency curves were prepared for each of these two zones separately and then they were compared with each other and with the regional curve prepared for the whole region. It was found out that the differences were negligible.

Considering all the facts mentioned above, it was decided to treat the Kelani Ganga basin as one hydrologically homogenious region and to develop a Regional Frequency Curve covering this area.

4.0 Derivation of a Regional Frequency Curve

4.1 Definitions

Return period (T) - Average interval (in years) between occurrences of a flood greater than or equal to a given value (this is also the reciprocal of the exceedence probability of a flood in any given year).

Annual flood - Q - largest instantaneous flow corresponding to any desired return period T.

Mean annual flood Q - arithmatic mean of annual floods.

Procedure

In the derivation of the regional flood frequency curve, the flood data (Q) of each gauging station are assembled according to the order of the magnitude and the mean values ($\bar{Q}$) are calculated for each station.

Annual floods (Q) are standardised by dividing by mean annual floods ($\bar{Q}$).

Flood Studies Report has recommended to use Extreme Value Distribution - type 1 (i.e. Gumbel Distribution) for analysing mean annual floods which give lenear curves. But departures from lenearity are allowed for in the graphical derivation of the regional curve.

In the Gumbel distribution, the reduced variate Y is related to the return period T, by the following equation :-

$$F_i = 1 - \frac{1}{T}$$

$$Y_i = -\ln(-\ln F_i)$$

Where F_i - Exceedence probability
i - Rank from smallest upwards
T - Return period
Y_i - Reduced variate

Values of Y corresponding to various return periods of T are given in Table 1. If T is greater than 5, this relationship may be approximated by $Y_i = \ln(T - \frac{1}{2})$.

For each station $Q/\bar{Q}$ are assembled together with plotting positions appropriate to the Gumbel Distribution. A table of these plotting positions is given in the Flood Studies Report which can be approximated to the Gringorten's formula.

$$F_i = \frac{i - 0.44}{n + 0.12}$$

Where n is the number of years of record.

Y axis was devided into categories of width 0.5 units such as - 2.0 to 1.5, - 1.5 to 1.0 etc. Average values of $Q/\bar{Q}$ were plotted against average values of Y.

TABLE 1

Return Period T (years)		Reduced variate Y
2	-	0.37
4	-	1.25
5	-	1.50
10	-	2.25
20	-	2.97
40	-	3.68
50	-	3.90
100	-	4.60
200	-	5.30
400	-	5.99
500	-	6.21
1000	-	6.91

4.3 Flood data

With the kind permission of the Irrigation Department, stream gauge records of the stations along the Kelani Ganga were extracted for this study.

Stations having at least 10 years of records were considered for this analysis.

Records from the following stream gauge stations were used.

Stream gauge recording station		No. of years of records
1. Gurugoda Oya at Holombuwa	-	18
2. Gurugoda Oya at Imbulana	-	26
3. Maskeli Oya at Laxapana	-	13
4. Maskeli Oya at Maussakelle	-	19
5. Kelani Ganga at Kitulgala	-	33
6. Kelani Ganga at Matiyagoda	-	34
7. Sitawaka ganga at Deraniyagala	-	29
8. Sitawaka ganga at Algoda	-	17
9. Kelani Ganga at Glencourse	-	34
10. Kelani Ganga at Naglam St.	-	35
Total number of years of record		258

4.31 Data Quality

It is to be noted that the number of years of records mentioned here were not continuous records. Some gaps of records were found mainly due to washing away of gauge posts due to floods. In some less important gauging stations, records were taken only twice a day.

Although the above reasons have contributed to inaccurate data in some instances, considering all the stations dealt with, the accuracy of records were found to be satisfactory.

There were only 7 years of continuous records at the Hanwella gauging station and therefore records from this gauging station were not included in the analysis.

4.32 Data Processing

The stage-discharge relationship of high flows of all the stations mentioned were thoroughly studied and the instantan ous maximum floods were identified. There were many instances where the maximum floods could not be directly obtained from flood data. In these cases either runoff hydrographs were plotted and extended or other corelation techniques were used to find out missing peaks. From these instantaneous peak floods, maximum flood peak was selected and identified as the annual flood.

Water Year was taken as from 1st October to 31st of September.

Table 2 shows mean annual floods of each gauging station.

TABLE 2

Gauging station	No. of years of records	Cusec x 10^3 mean annual flood	Catchment areas (Sq.miles)
Gurugoda Oya at Holombuwa	18	6.696	60.0
Gurugoda Oya at Imbulana	26	12.101	127.0
Maskeliya at Laxapana	13	8.258	59.35
Maskeliya at Maussakelle	19	12.260	47.0
Kelani Ganga at Kitulgala	33	25.361	148
Kelani Ganga at Matiyadola	34	28.337	234
Sitawaka Ganga at Deraniyagala	29	11.697	59.5
Sitawaka Ganga at Algoda	17	22.124	133.0
Kelani Ganga at Glencourse	34	58.163	565.0
Kelani Ganga at Nagalam St.	35	40.720	805.0

With the cordinates obtained from the analysis, it was possible to draw the Regional Frequency Curve only up to about Y = 4 or 60 years. As there was no way of reading values corresponding to higher return periods it was necessary to extend the curve using the method mentioned below.

4.33 Extension of the Curve

Gauging stations were grouped into 3 groups taking care not to appear neighbouring stations in the same group. Four highest values from each group were selected and they were associated with expected order statistics of the Gumbel Distribution using the plotting positions as was done earlier.

<u>Group No. 1</u>

Gurugoda Oya at Holombuwa
Kelani Ganga at Kitulgoda
Kelani Ganga at Glencourse

Total No. of records - 85 years
Mean annual flood - 34.53 x 10^3 cusec.

<u>Group No. 2</u>

Gurugoda Oya at Imbulana
Maskeliya Oya at Lakshapana
Sitawaka Ganga at Deraniyagala

Total No. of records - 103 years
Mean annual flood - 21.23 x 10^3 cusec.

<u>Group No. 3</u>

Maskeliya Oya at Maussakelle
Kelani Ganga at Mahoadola
Sitawaka Ganga at Algoda

Total No. of years of record = 70 years
Mean annual flood = 22.12 x 10^3 cusec.

Average values of Y calculated in this method and the corresponding values $Q/\bar{Q}$ were plotted on the same curve. The cordinates thus obtained were used to improve the curve. Table 3 shows the cordinates of the Regional Flood Frequency Curve for the Kelani Ganga catchment area, derived using the method described above.

Figure 2 shows the Regional Flood Frequency Curve which is a free hand drawn curve.

5.00 Conclusions & Suggestions

The flood frequency curve derived here and shown on Fig. 2 is reliable up to about 100 year return period. Beyond this, it has to be used with some care.

Very accurate curve for higher return periods (from 100 years upwards) could be obtained by preparing an Island wide flood frequency curve.

Therefore, it is suggested that the action may be taken to prepare a curve to cover the whole Island.

The curve derived here could be used for ungauged sites after deriving a correlation between the mean annual flood and the catchment characteristics.

6.00 Acknowledgement

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7.00 References

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TABLE 3

Regional Frequency curve cordinates

Range of Y	Average values of Y	Average values of Q/$\bar{Q}$	No. of readings
-1.5-1.0	-1.204	0.449	16
-1.0/05	-0.727	0.564	31
-0.5/00	-0.247	0.679	47
0.0/0.5	+0.243	0.867	45
0.5/1.00	+0.742	1.040	40
1.00/1.5	+1.236	1.204	26
1.50/2.00	+1.746	1.414	22
2.00/2.50	+2.277	1.589	11
2.50/3.00	+2.710	1.690	7
3.00/3.50	+3.240	2.192	11
3.50/4.00	+3.792	2.598	6
4.00/4.50	+4.112	2.812	5
4.50/5.00	+4.83	3.684	1
5.00/5	+5.115	4.809	2

Note - The procedure of calculating a design flood for a gauged station is illustrated in the Appendix.

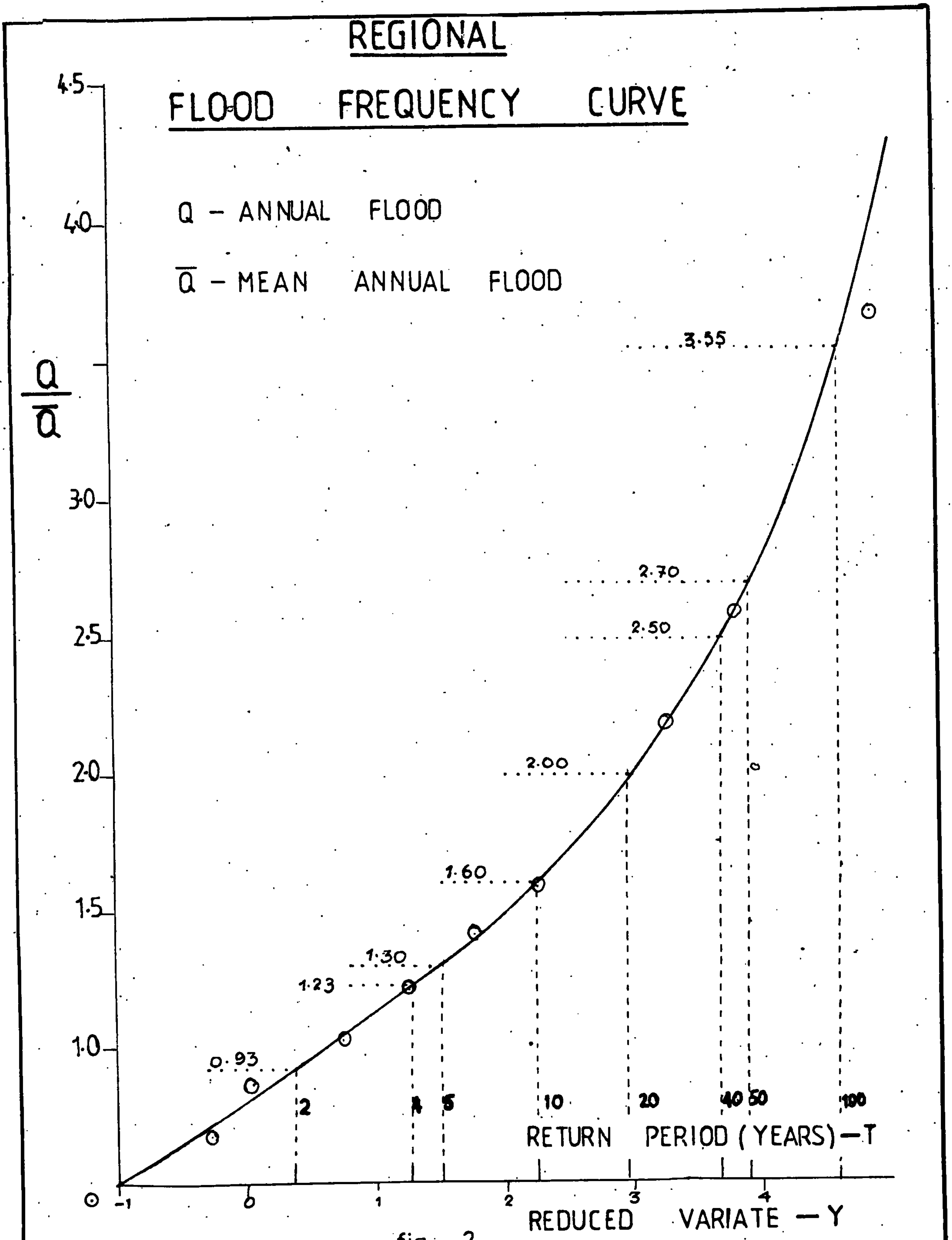
REGIONAL
FLOOD FREQUENCY CURVE
Q - ANNUAL FLOOD
Q̄ - MEAN ANNUAL FLOOD
Q/Q̄
4.5
4.0
3.0
2.5
2.0
1.5
1.0
3.55
2.70
2.50
2.00
1.60
1.30
1.23
0.93
2
4
5
10
20
40
50
100
RETURN PERIOD (YEARS) — T
-1
0
1
2
3
4
REDUCED VARIATE — Y

fig. 2

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APPENDIX

Worked example illustrating the Estimation Procedure

Consider the case of constructing a bridge at Hanwella across the Kelani Ganga. It is required to design this bridge for a design flood corresponding to 100 year return period.

The gauging station at Hanwella has seven years records of floods. The following maximum annual floods were extracted from these records :-

Year		Maximum annual flood cusecs ($\times 10^3$)
1974	-	84.00
1975	-	92.50
1976	-	60.19
1977	-	62.75
1978	-	67.50
1979	-	78.30
1980	-	20.48

Procedure :

(1) Find out the mean annual flood which is the arithmatic mean of the annual floods -

$$= \frac{\text{Summation of mean annual floods}}{\text{Number of years of record}}$$

$$= 66.53 \times 10^3 \text{ cusecs}$$

(2) Find out $Q/\bar{Q}$ from the Regional Flood Frequency curve corresponding to a return period of 100 years.

From the above curve $Q/\bar{Q} = 3.55$

$Q = 66.53 \times 10^3$ cusecs.

Therefore, design flood corresponding to 100 year

return period is $Q = 3.55 \times 66.53 \times 10^3$ cusecs

$= 236.18 \times 10^3$ cusecs