LECTURE - 11

FORECASTING METHODS BASED ON STATISTICAL APPROACH

by

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OBJECTIVES:

After attending this lecture the participants would be able to understand various methods of flood forecasting based on statistical approach.

1.0 INTRODUCTION

Methods based on statistical approach makes use of the statistical techniques to analyse the historical data with an objective to develop methods for the formulation of flood forecasts. The methods thus developed can be presented either in the form of graphical relations or mathematical equations.A large number of data, covering a wide range conditions are, analysed to derive the relationships which inter-alia include gauge to guage relationship with or without additional parameter and rainfall peak stage relationship.

These methods are more commonly used in India as well as other countries of the world. These are discussed in detail in the subsequent sections. Most of the lecture contents have been adopted from 'Manual on Flood Forecasting Central Flood Forecasting Organisation,Patna,(CWC)(1988).

2.0 CORRELATION BETWEEN UPSTREAM AND DOWNSTREAM GAUGES/DISCHARGES

In the technique of gauge/discharge correlation the various variables which affect the stage at the forecasting point are :

a) Stage and discharge of the base station

b) Stage and discharge of the forecasting station

c) Change in stage and discharge of the base station

d) Travel time at various stages

e) The rainfall(amount,intensity and duration) in the intercepting catchment

f) Topography, nature of vegetation, type of soil,land use, density of population, depth of gw table, soil moisture deficiency etc. of the intercepted catchment

g) The atmospheric and climatic conditions; and

h) Stage and discharge of any important tributory joining the main stream between the base station and the forecasting station.

Factor (a) to (d) are basic parameters used in developing the correlation curves. Factors (e) and (f) are taken into account by introducing the rainfall and API. Factor (g) is a minor one and can be considered by introducing an additional parameter as week number of year. However, it is not very important for Indian rivers as most of the floods occur during monsoon period only.

The factor (h) is very important and can be neglected if the contribution of the tributary is very small.

One of the most simple and very useful graphical relation is the 'FLOOD PROFILE MOMOGRAM' This diagram indicate the peak stage at each station along with river for a storm. A number of such lines are drawn for various conditions of storms.The various line should be drawn in different inks and the specific meteorological condition such as heavy concentrated rainfall or other conditions such as breach of embankment etc should be mentioned on such Nomogram for river Yamuna is shown in fig.1. Although the diagram does not help in accurate forecast formulation, it serves as a very good guide in checking the formulated forecast.

The various type of graphs which are used in forecast formulation can be classified as :

i) Direct correlation between gauges or discharges of U/S

FLOOD PROFILE CHART OF RIVER YAMUNA FOR KALANAUR DELHI BEACH

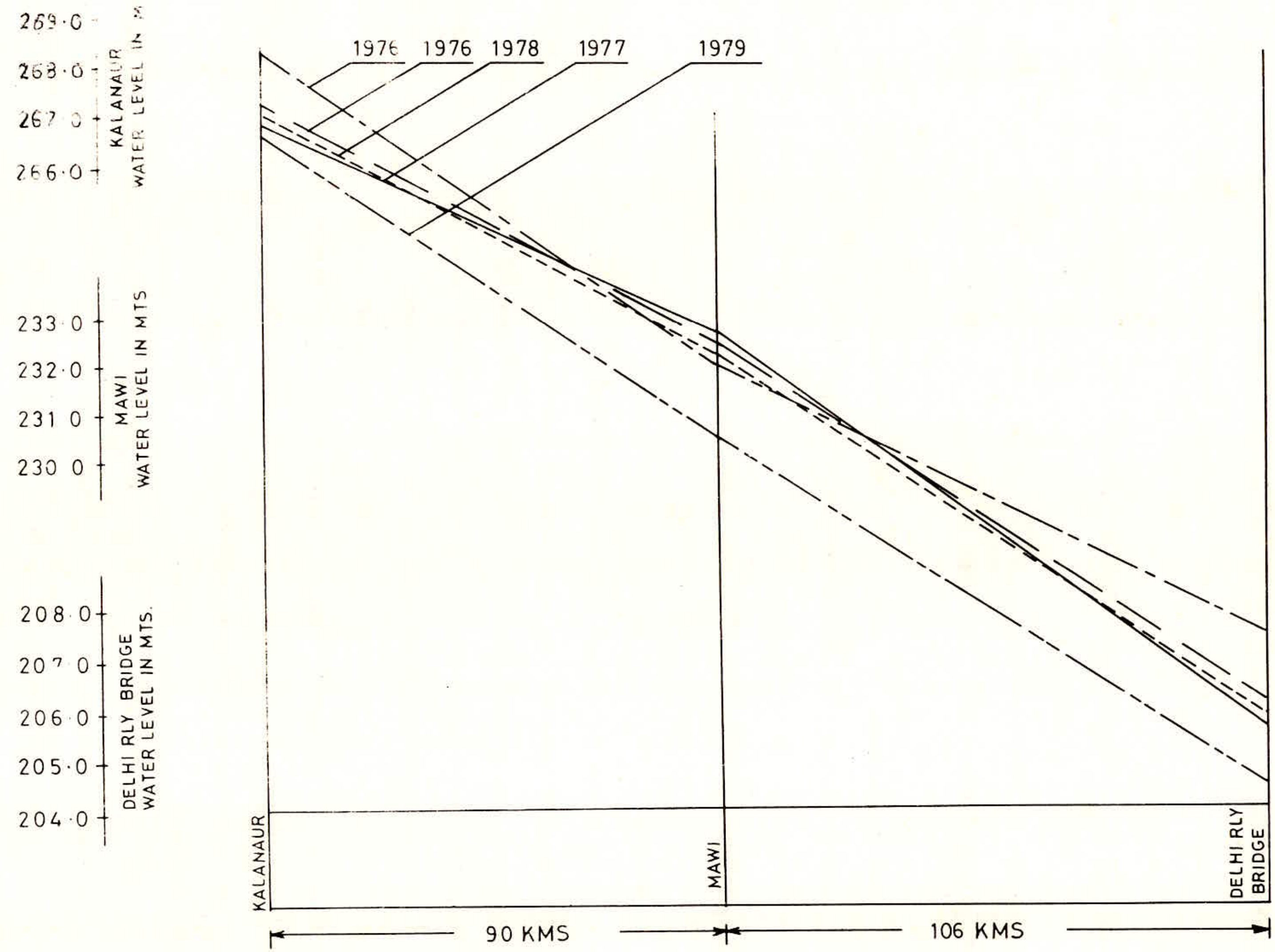


FIG. 1

and D/S station.

ii) Correlation between gauges or discharges at U/S and D/S stations with additional parameters.

Some of the correlation diagrams which are commonly in use are discussed hereunder:

2.1 DIRECT CORRELATION BETWEEN GAUGE AND DISCHARGE AT U/S AND D/S

In such graph basically, only gauge and discharge data forecasting stations and the base stations are utilised in different forms. The following type of correlations are generally used.

A) The simplest of all is the correlations between the N^{th} hours stage of base station and $(N+T)^{th}$ hour stage of forecasting stations; where T is the travel time of flood wave between the base station and forecasting station .Fig.2 shows one such graph which is used for forecasting the river stage in River Brahmini in Orissa.

This type of graph can be developed and used for a reach the river where there is no major tributary with considerable discharge, catchment between the two station is small so that the effect of rain is negligible and the travel time from base station to the forecasting stations is fairly constant for various stages.

However, in most of the cases the travel time is not constant and varies with water level. Apart from this such relations give considerable errors under different conditions. These relations can be considerably improved if the following aspects are taken into account.

i) The variation in travel time- This can be taken into account by appropriately drawing a travel time-curve (U/S stage Vs.travel time).

ii) Varying conditions during rising and falling stages of the flood- It is always desirable to draw separate curves for

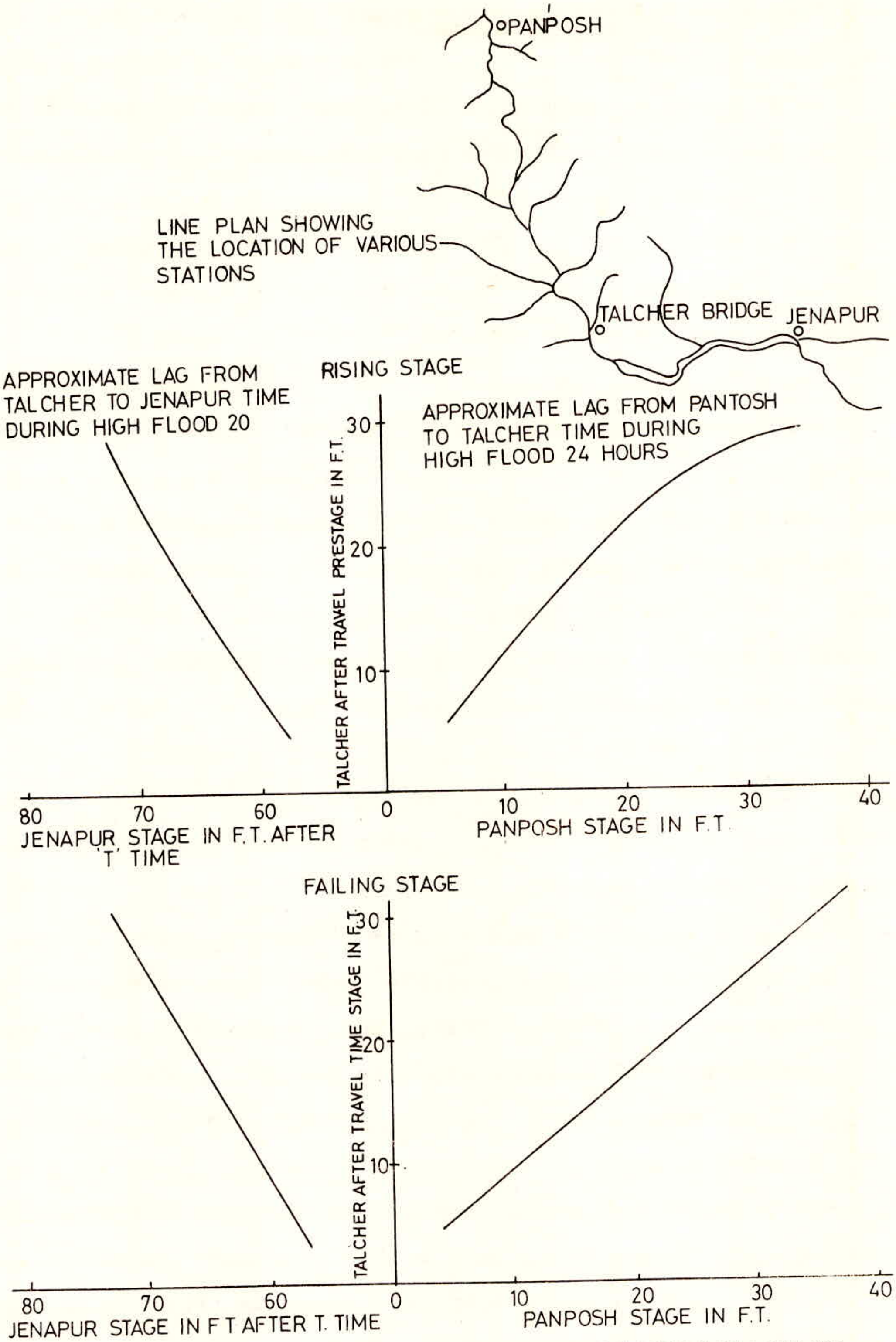


FIG. 2- CORRELATION DIAGRAM OF RIVER BRAHMANI BETWEEN GAUGE AT PANPOSH TALCHER AND JENAPUR

rising and falling conditions as already shown in fig.2.

iii) Antecedent Moisture Conditions of the stream - It is observed that during first few storms the actual observed water level is generally lower than the forecast level.This is presumably due to the fact that during dry conditions of soil, there is more infiltration and hence lesser runoff in the stream. This can be roughly taken into account by drawing two different sets of curve, one for the few initial flood waves and the other for remaining flood waves.

iv) Downstream Boundary Conditions - This is also a very important factor, especially for the forecasting in the lower reaches of the river which falls in the sea or a larger river. When the out fall channel is in high stage or there is high tide in the sea, it will definitely have back water effect and the water level in the falling stream will be different than that in normal conditions. Hence it is always desirable to take into account the tidal effect or the water level of outfall channel. The data from the tidal gauge in conjunction with the annual tidal table (published by the Survey of India) will be very useful in determining the tidal influence and back water effect on the lower reaches of the river.

v) Characteristic of Flood Wave - Generally the forecast at D/ stations are quite reliable when the storm results in formation of single peak. But when one flood wave is immediately followed by another, there is considerable effect in the water level at downstream station in different conditions.

For example when a smaller flood wave is followed by a comparatively larger flood wave with high peak, the two flood wave may overlap resulting in slight increase in the level at D/S station than that in normal case. On the contrary,if a larger flood wave is followed by a smaller flood wave,the smaller flood wave may not any effect by the time it reaches the D/S station. This is very important aspect and can be taken care of, to some extent, by using the modified routing equations.

Various other correlation diagrams which taken into account the above discussed and some other factors are described in brief in the subsequent paragraph.

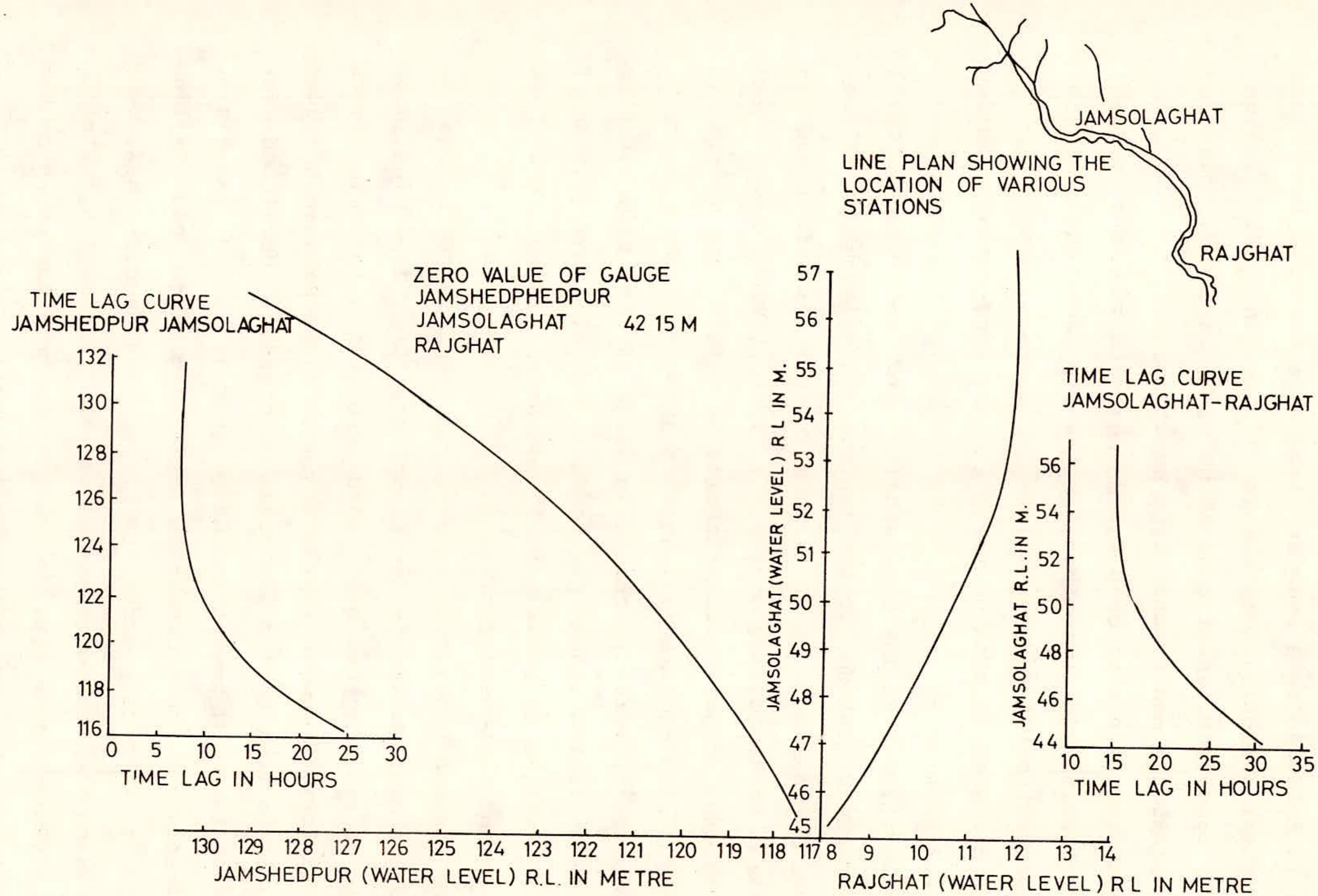
B) Direct correlation between the peaks, at forecasting station and base station :

The gauge (peak) at the base station and the gauge (peak) at the forecasting station for the various intensities of flood are plotted. The travel time at various intensities of flood is also plotted corresponding to peak. Such graphs have been successfully used for river Subernarekha in Orissa. The graph is shown in fig.3 warning time available is about 24-30 hrs.

C) Correlation between the change in stage of the base station and change in the stage of forecasting stations during T hours (T = time of travel of flood wave between the base station and forecasting site)

Such a method obviates errors, to some extent, due to aggradation or degradation in the river section, depending upon flows. This correlation has been found more suited to large rivers with more uniform change in levels and discharges between the base stations and the forecasting stations. Such graphs developed for river Ganga between Dighaghat and Gandhighat in shown in Fig.4. Separate graphs have been developed for Rising stage and Falling stages. A multi-tributary model for river Brahmaputra has been developed using the change in stages at the forecasting station and three different base stations on various tributaries which has been discussed in details in sub-section 2.2.1.

D) Correlation between the N^{th} hour and $(N+T)^{th}$ hour stages of



TIME LAG CURVE
JAMSHEDPUR JAMSOLAGHAT
132
130
128
126
124
122
120
118
116
0 5 10 15 20 25 30
TIME LAG IN HOURS
ZERO VALUE OF GAUGE
JAMSHEDPHEDPUR
JAMSOLAGHAT 42 15 M
RAJGHAT
LINE PLAN SHOWING THE
LOCATION OF VARIOUS
STATIONS
JAMSOLAGHAT
RAJGHAT
JAMSOLAGHAT (WATER LEVEL) R L IN M.
57 56 55 54 53 52 51 50 49 48 47 46 45
130 129 128 127 126 125 124 123 122 121 120 119 118 117
JAMSHEDPUR (WATER LEVEL) R.L. IN METRE
8 9 10 11 12 13 14
RAJGHAT (WATER LEVEL) R L IN METRE
TIME LAG CURVE
JAMSOLAGHAT-RAJGHAT
JAMSOLAGHAT R.L. IN M.
56 54 52 50 48 46 44
10 15 20 25 30 35
TIME LAG IN HOURS

FIG. 3

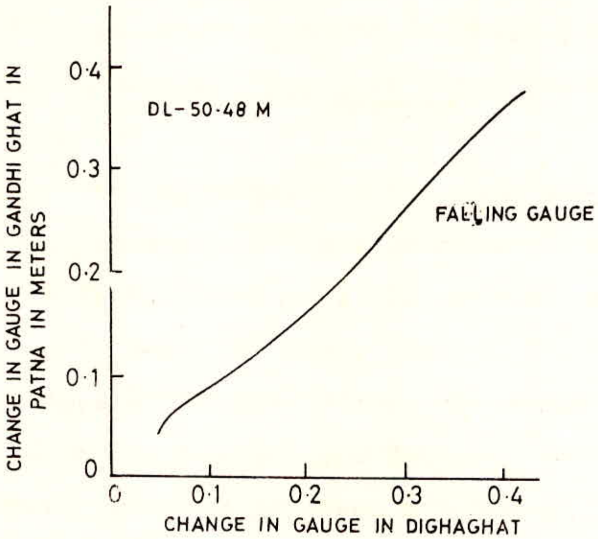


FIG. 4 - CORRELATION GRAPH FOR DIGHAGHAT PATNA

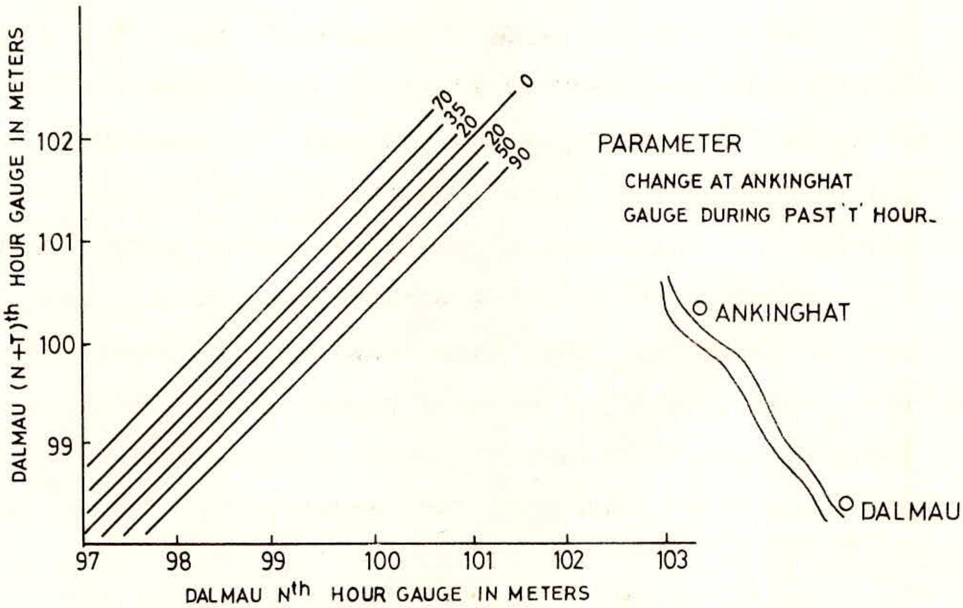


FIG. 5 - CORRELATION GRAPH FOR DALMAU SITE ON RIVER GANGA

the forecasting station with change in stages at the base station during past 'T' hours as variable. Different sets of graphs are drawn for rising and falling conditions of the river :

Such graphs are used for forecasting river stages at a number of site. One such correlation used for forecasting Dalmau stage on river Ganga (under Lucknow Division is shown at fig.5). If there is larger fluctuation in the stage of the base stations, the parameter of average gauge within past 'T' hrs at the base station is introduced in the Ist quadrane instead of change in stage of the base station. In the 2nd quadrant N^{th} hour stage of the base station is also leveled to account for the intensity of flood. This has been found suitable when the base station is D/S of a control structure on the river, through which the flows are released with wide fluctuations. Such correlation is shown in Fig.6.

E) In rivers having wide fluctuation in U/S stages and relatively much less reduced fluctuations in lower reaches due to large scale inundation/valley storage in between the two points,tendency effect is considered. This is done by correlating N^{th} and $(N+T)^{th}$ hour stage of the forecasting site in Past 'T' hours as variable in the Ist quadrant. Then in the 2nd quadrant, the average gauge of the base station is considered as a variable. This type of graph have proved quite useful in Bagmati and Adhwara group of rivers of Bihar in Ganga Basin.

One such graph developed for Kamtaul site of River Adhwara is shown in Fig.7.

F) Gauge to Gauge correlation in Coastal Rivers:

The coastal rivers pose special problems is regards to formulation of forecast because of the tidal effect.The simple gauge to gauge relation will not yield satisfactory result.

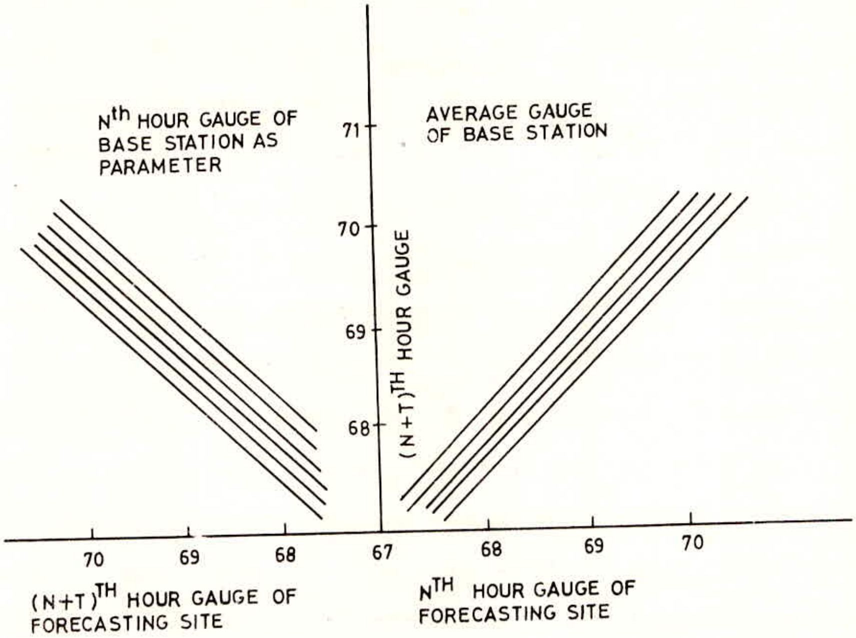


FIG. 6

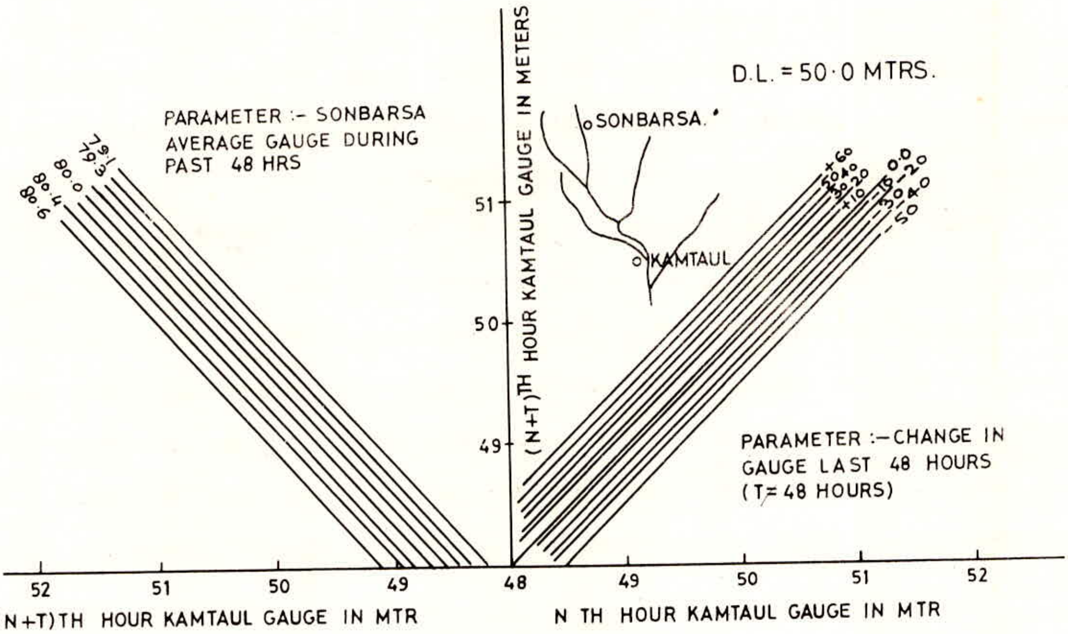


FIG. 7- CORRELATION GRAPH FOR THE SITE KAMTAUL RIVER ADHWARA

Before developing a G-G correlation charts, it is considered imperative to analyse the various cases, arising in coastal rivers, separately and develop different set of curves, for the formulation of forecasts. The various cases, encountered in the coastal rivers,are discussed below in brief:-

i) The river is in high stage and there is no tidal effect.

ii) The river is in low stage and there is a tidal effect. As a result of which there will be backwater effects in the lower reaches of the river. The backwater effect has to be incorporated in the formulation of forecast.

iii) The river is in high stage and there is a tidal effect. The river will not be able to drain freely and there will be locking effect which will affect the forecast significantly. This aspect has to be considered, while developing the charts etc for the formulations of forecast.

Thus, it is seen that the three cases, mentioned in the preceding sections, call for development of different sets of charts to be utilised for the formulation of forecast.

Realising the necessity of considering the tidal effect in the formulation of forecast for the area below Akhuapada in Baitarni river basin a tidal gauge has been recently installed at Chandbali. The data from the tidal gauge in conjunction with the annual tidal table (published yearly by the Survey of India) forecast will be quite useful in determining the tidal influence and backwater effects on the lower reaches of the river. This will be of particular importance when tides are enhanced by storm surges accompanying the movement of tropical cyclone on shore. The data, obtained from the tidal gauges will come quite handy in development of charts for forecast formulation,considering tidal effect.

Some of the correlation diagrams which have been developed using the U/S and D/S gauges have been discussed above. Besides these the discharges at U/S and D/S stations are also used for formulation of the forecast and some mathematical equations have been developed and are in use. A few of them are discussed below:

(G) Poanta - Tajewala Model (For River Yamuna)

The travel time from Poanta to Tajewala being 2 hours, Poanta gauge in ft. at t hours, $G_p(t)$ is correlate to Tajewala discharge in cusecs, $Q_T(t+2)$

$$Q_T(t+2) = 7.4045 \times 10^5 \quad G_P(t)^{4.333} \qquad \ldots(1)$$

This is for the Rising limb.

Another relation has been developed for falling limb when the travel time of 3 hours is found to be more appropriate and the relationship is :

$$Q_T(t+3) == 1.819 \times 10^{-6} \quad xG_P(t)^{5.555} \qquad \ldots(2)$$

The graphical representation is shown in Fig.8.

(H) Gauge-Rise Models for various reaches of Yamuna.

The height of the flood wave at D/S section is related to its height at the U/S section :

$$(G_{DP}-G_{DO}) = a(G_{UP}-G_{UO}) + b \qquad \ldots.(3)$$

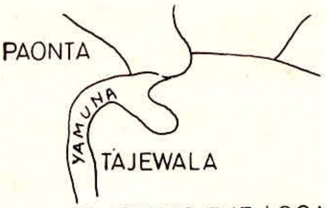
Where G_{DP} and G_{UP} are the peak gauge at the D/S and U/S sections.

G_{DO} and G_{UO} are the estimated gauges at the time of recorded peak, had the recession prior to the start of the flood wave continued.

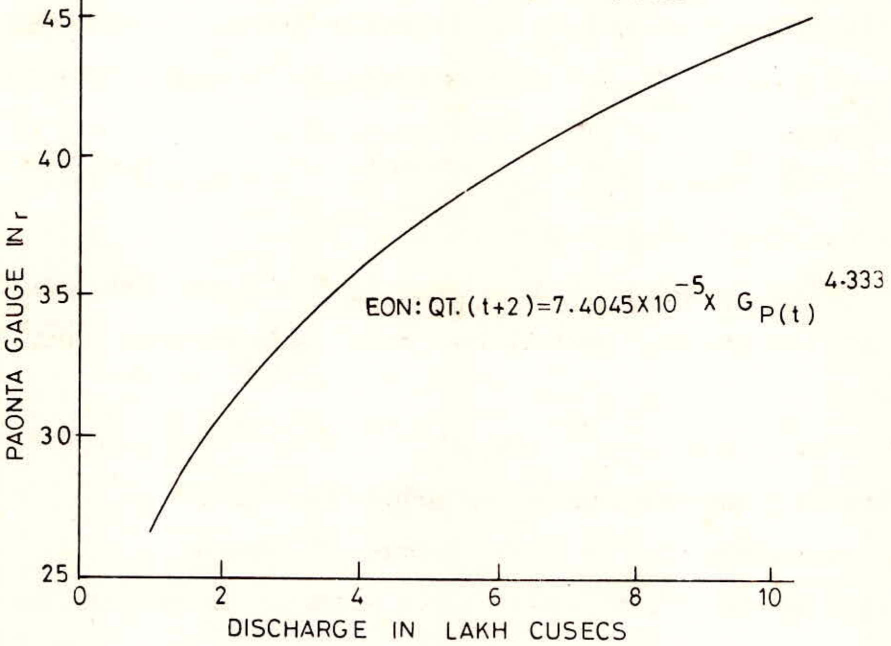
a & b are constant, to be evaluated on the basis of past flood data. One such equation developed for Kalanur and Delhi reach of the Yamuna is shown in the Fig.9.

(I) Discharge-Rise Models

The discharge rise due to a flood wave at a D/S section is related to chat on an U/S section, if the effect of the..



LINE PLAN SHOWING THE LOCATION VARIOUS STATIONS



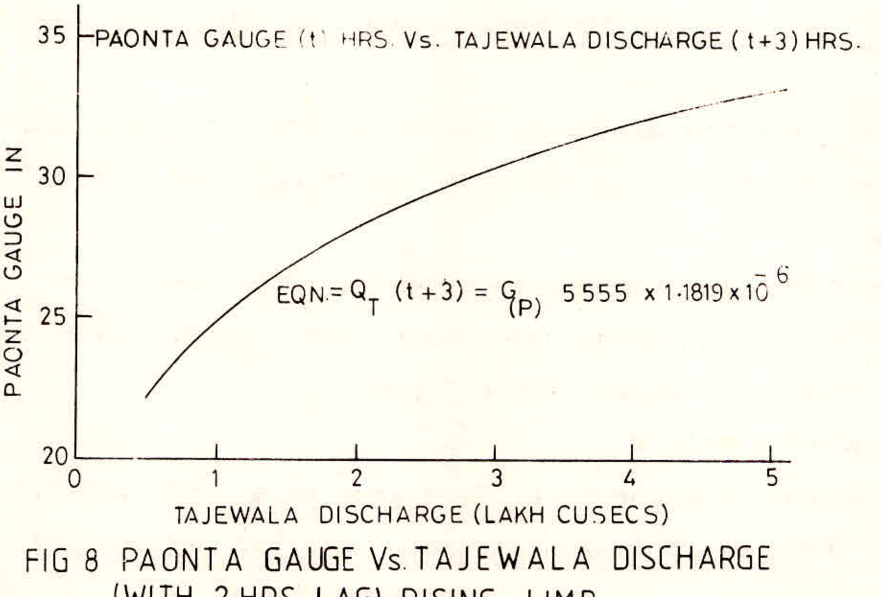
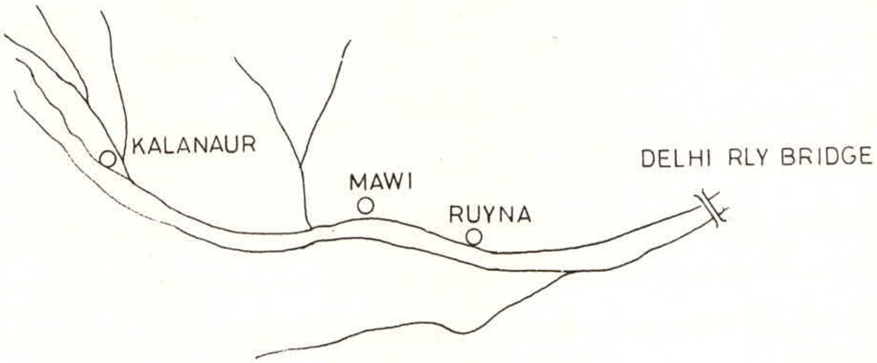


FIG 8 PAONTA GAUGE Vs. TAJEWALA DISCHARGE (WITH 2 HRS. LAG) RISING LIMB



LINE PLAN SHOWING THE LOCATION
OF VARIOUS STATION

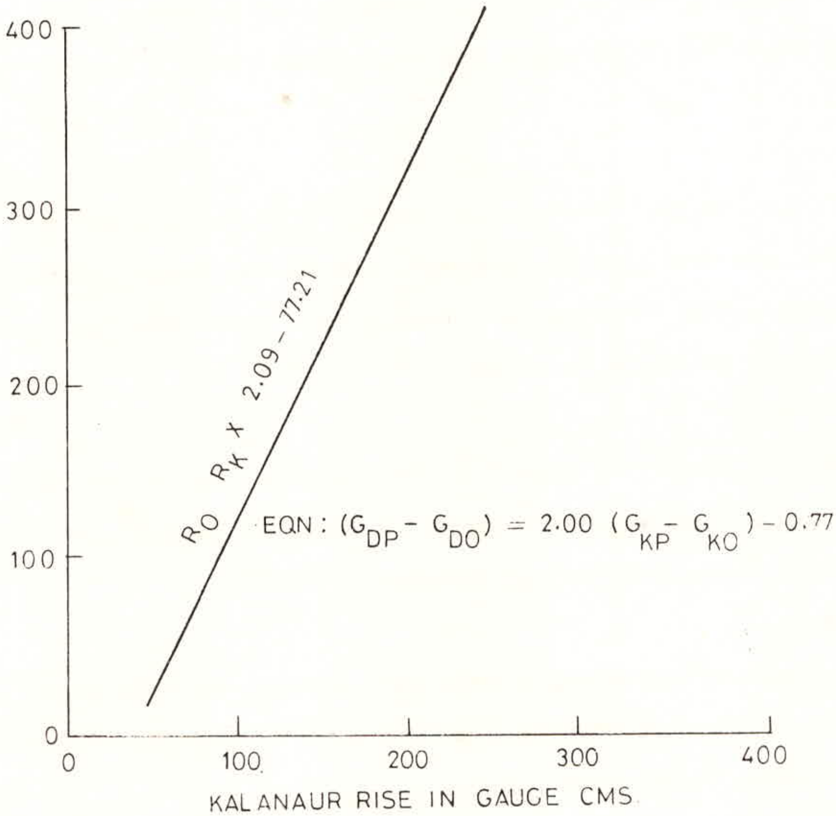


FIG. 9

intermediate catchment contribution is not significant.

$$(Q_{DP}-Q_{DO}) = m(Q_{UP} - Q_{UO}) + n \quad ..(4)$$

Where Q_{DP} and Q_{UP} are the discharges at the D/S and U/S sections Q_{DO} and Q_{UO} are the estimated discharges at the time of recorded peak, had the recession prior to the start of flood wave continued and m and n are constant to be evaluated on the basis of past flood data. On such relation developed for Kalanaur -Mawi reach of Yamuna is shown in Fig.10.

Example 1

The flood data from 1971 to 1979 for river Sone at Japla and Koelwar site were scruitinised and the peak flood at Japla, the corresponding peak at Koelwar and the travel time are given in Table 1. Establish suitable correlation between the peaks. Also establish relationship to estimate the time of occurrence of the peaks.

Solution

Since only the gauge data for upstream and downstream stations are available, a simple gauge to gauge relation is to be developed. The following steps are to be followed for the development of such relation.

Step No.1

Plot a graph as shown in Fig.11 with gauge at Japla on Y-axis and gauge at Koelwar on X-axis. A look at the graph indicates that a straight line can be conveniently drawn.

Step No.2

Instead of drawing a straight line by personal judgement, equation of the straight line Y = ax + b can be developed by using least square technique.

where Y = gauge at Koelwar

X = gauge at Japla

and a and b are constant s to be estimated with the help of

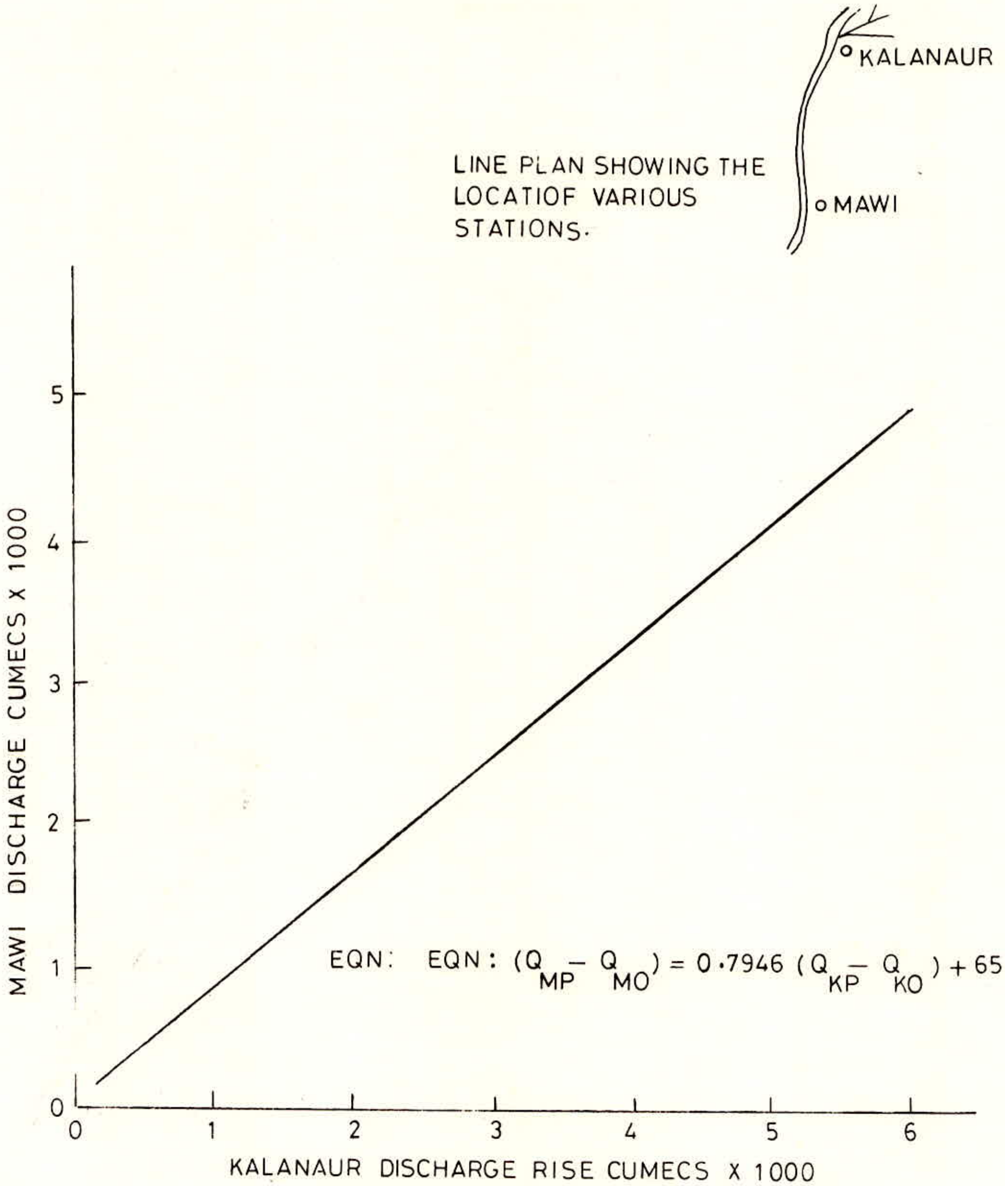


FIG. 10 - CORRELATION BETWEEN RISE IN DISCHARGE AT KALANAUR AND MAWI

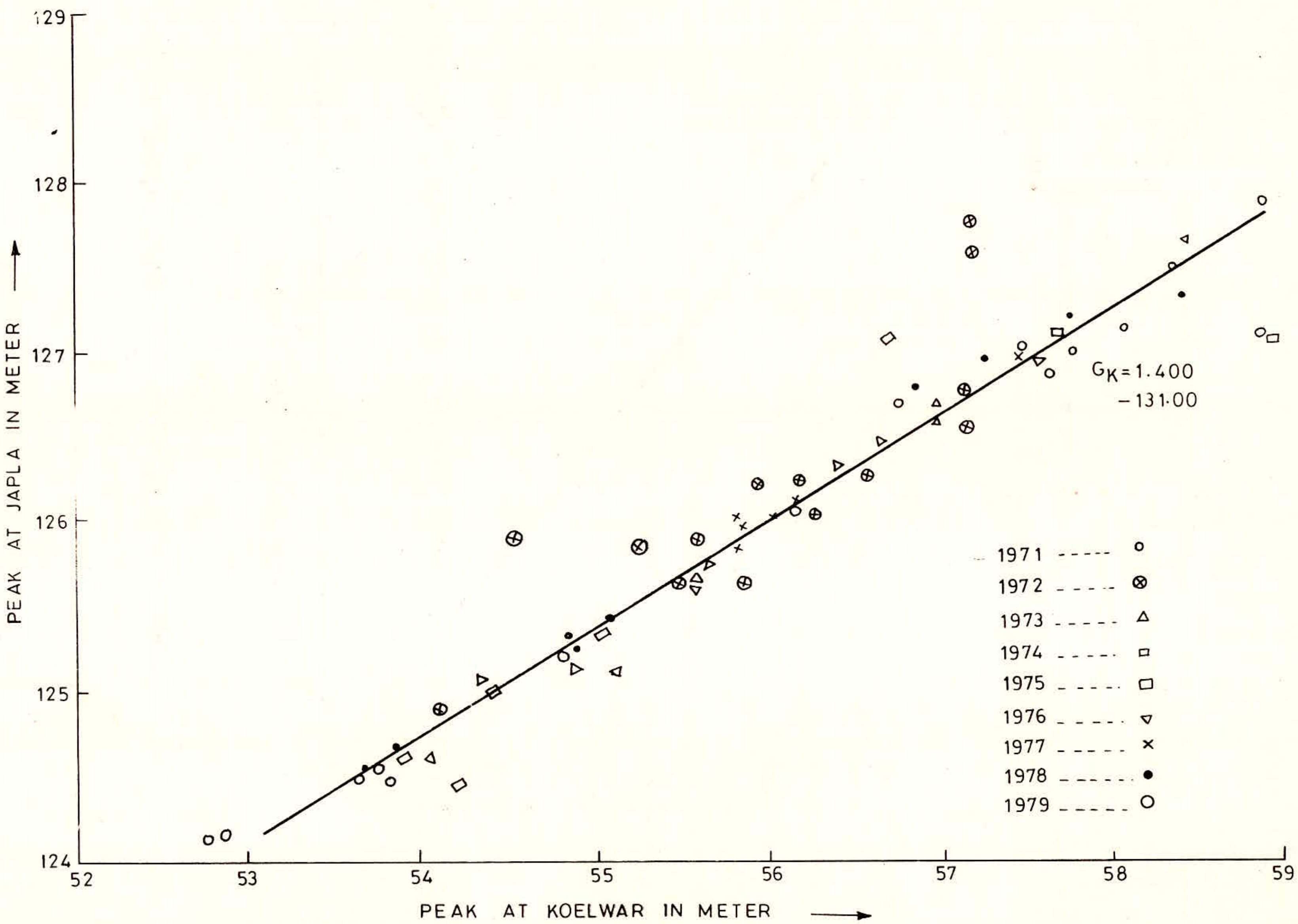


FIG. 11 - GAUGE TO GAUGE RELATION BETWEEN JAPLA AND KOELWAR

observed data.

StepNo.3

The gauge at Japla (G_j) and the gauge at Koelwar(G_k) are noted down under columns 2 and 3 respectively of Table 1.The lowest value of the observed peak at Japla and Koelwar are 124.140 and 52.754 respectively and hence in order to facilitate the computation the reduced variate i.e. X and Y are obtained by deducting 124.00 and 52.00 from peaks at Japla and Koelwar respectively and are noted down under column 4 & 5 of the table 2.

Step No.4

Compute the values of X^2,Y^2 and XY and write under column 6,7 and 8 respectively. Compute the sum of the values under column 4 to 8 to get ΣX, SY, ΣX^2,ΣY^2 and ΣXY

Step No.5

For the straight line equation Y = aX+b, the normal equations for least square error will be

$$Y = a \Sigma X + b.n$$

$$\Sigma XY = a \Sigma X^2 + b \Sigma X$$

Here from Table No.5.2, we get

ΣX = 108.63

ΣY = 216.577

ΣX^2 = 263.995

ΣY^2 = 955.652

ΣXY = 497.573

Table 1

Date	Peak at Japla in metre	Peak at Koelwar in metre	Travel Time (in hours)
26.6.71	126.060	56.167	30
20.7.71	127.880	58.884	13
29.7.71	127.500	58.396	18
05.8.71	126.990	57.794	18
10.8.71	127.040	57.484	21
1.9.71	126.890	57.644	20
		Year 1972	
6.7.72	124.755	53.959	38
14.7.72	125.900	54.539	33
17.7.72	125.890	55.599	33
8.8.72	127.790	57.174	24
16.8.72	126.050	56.269	26
31.8.72	126.250	56.529	26
15.9.72	125.770	55.884	30
		Year 1973	
14.7.73	124.160	52.834	37
20.7.73	125.090	54.354	33
24.7.73	125.140	54.689	36
20.8.73	126.340	56.404	26
30.8.73	126.490	56.654	26
6.9.73	125.770	55.664	31
26.9.73	125.610	55.594	31
		Year 1974	
20.6.74	124.140	52.754	34
20.7.74	124.615	53.894	35
19.8.74	127.080	57.689	14
27.8.74	125.340	55.064	33
		Year 1975	
5.7.75	124.500	53.634	43
20.7.75	126.940	57.594	20
11.8.75	125.020	54.424	34
22.8.75	128.040	58.814	13
8.9.75	125.310	55.634	32
6.10.75	124.450	54.249	46

		Year 1976	
11.7.76	124.480	53.842	43
23.7.76	124.620	54.079	44
29.7.76	125.660	55.514	31
16.8.76	126.710	56.954	21
22.8.76	125.140	55.144	29
17.9.76	127.640	58.434	10
		Year 1977	
27.6.77	125.210	54.820	38
29.6.77	125.840	55.834	29
8.7.77	125.840	55.744	33
17.7.77	126.140	56.184	30
30.7.77	126.960	57.464	14
8.8.77	126.580	56.974	22
15.8.77	126.040	56.044	27
10.9.77	126.020	55.814	28
		Year 1978	
26.6.78	125.190	55.144	38
18.7.78	124.700	53.864	42
28.7.78	125.340	54.854	37
5.8.78	126.790	56.854	20
12.8.78	125.990	56.044	30
27.8.78	125.270	54.894	36
4.9.78	127.220	57.774	14
24.9.78	127.340	58.414	23
5.10.78	125.440	55.141	33
		Year 1979	
2.7.79	124.850	53.994	40
19.7.79	124.900	54.154	41
10.8.79	126.060	56.154	27
18.8.79	125.860	55.274	34

Table 2

Sl. No.	Gauge at Japla Gj (m)	Gauge at Koelwar Gk (m)	G_j-124 X	G_{k-52} Y	X^2	Y^2	XY
1	2	3	4	5	6	7	8
1.	126.060	56.167	2.060	4.167	4.244	17.364	8.584
2.	127.880	58.884	3.880	6.884	15.054	47.389	26.710
3.	127.500	58.369	3.500	6.369	12.250	40.564	22.292
4.	126.990	57.794	2.990	5.794	8.946	33.570	17.324
5.	127.040	57.484	3.040	5.484	9.242	30.074	16.671
6.	126.890	57.644	2.890	5.644	8.353	31.855	16.311
7.	124.755	53.959	0.755	1.959	0.570	3.838	1.479
8.	125.900	54.539	1.900	2.539	3.610	6.446	4.824
9.	125.890	55.599	1.890	3.599	3.572	12.953	6.802
10.	127.790	57.174	3.790	5.174	14.364	26.770	19.609
11.	126.050	56.269	2.050	4.269	4.203	18.224	8.751
12.	126.250	56.529	2.250	4.529	5.063	20.512	10.190
13.	125.770	55.884	1.770	3.884	3.133	15.085	6.875
14.	124.160	52.834	0.160	0.834	0.026	0.696	0.133
15.	125.090	54.354	1.090	2.354	1.188	5.541	2.566
16.	125.140	54.689	1.140	2.689	1.300	7.231	3.065
17.	126.340	56.404	2.340	4.404	5.476	19.395	10.305
18.	126.490	56.654	2.490	4.654	6.200	21.660	11.588
19.	125.770	55.664	1.770	3.664	3.133	13.425	6.485
20.	125.610	55.594	1.610	3.594	2.592	12.917	5.786
21.	124.140	52.754	0.140	0.754	0.020	0.569	0.106
22.	124.615	53.894	0.615	1.894	0.378	3.587	1.220
23.	127.080	57.689	3.080	5.689	9.486	32.365	17.522
24.	125.340	55.064	1.340	3.064	1.796	9.388	4.106
25.	124.500	53.634	0.500	1.634	0.250	2.670	0.817
26.	126.940	57.594	2.940	5.594	8.644	31.293	16.446
27.	125.020	54.424	1.020	2.424	1.040	5.876	2.472
28.	128.040	58.814	4.040	6.814	16.322	46.431	27.529
29.	125.310	54.634	1.310	2.634	1.716	13.206	3.451
30.	124.450	54.249	0.450	2.249	0.203	5.058	1.012
31.	124.480	53.824	0.480	1.824	0.230	3.327	0.876
32.	124.620	54.079	0.620	2.079	0.384	4.322	1.289
33.	125.660	55.514	1.660	3.514	2.756	12.384	5.833
34.	126.710	56.954	2.710	4.954	7.344	24.542	13.425
35.	125.140	55.144	1.140	3.144	1.300	9.885	3.584
36.	127.640	58.434	3.640	6.434	13.250	41.448	23.420
37.	125.210	54.820	1.210	2.820	1.464	7.952	3.412
38.	125.840	55.834	1.840	3.834	3.386	14.700	7.055

39.	125.840	55.744	1.840	3.744	3.386	14.018	6.889
40.	126.140	56.184	2.140	4.184	4.580	17.056	8.954
41.	126.960	57.464	2.960	5.464	8.762	29.855	16.173
42.	126.580	56.974	2.580	4.974	6.656	24.741	12.833
43.	126.040	55.044	2.040	4.044	4.162	16.354	8.250
44.	126.020	55.814	2.020	3.814	4.080	14.547	7.704
45.	125.190	55.144	1.190	3.144	1.416	9.885	3.741
46.	124.700	53.864	0.700	1.864	0.490	3.474	1.305
47.	125.340	54.854	1.340	2.854	1.800	8.145	3.824
48.	126.790	56.854	2.790	4.854	7.784	23.561	13.543
49.	125.990	56.044	1.990	4.044	3.960	16.354	8.048
50.	125.270	54.894	1.270	2.894	1.613	8.375	3.675
51.	127.220	57.774	3.220	5.774	10.368	33.339	18.592
52.	127.340	58.414	3.340	6.414	11.156	41.139	21.423
53.	125.440	55.114	1.440	3.114	2.074	9.697	4.484
54.	124.850	53.994	0.850	1.994	0.723	3.976	1.695
55	.124.900	54.134	0.900	2.134	0.810	4.554	1.921
56.	126.060	56.154	2.060	4.154	4.244	17.256	8.557
57.	125.860	55.274	1.860	3.274	3.460	10.719	6.090
		Total	108.63	216.577	263.995	955.652	497.573

Substituting the values, we get the equation

$$216.577 = 108.63a + 57\,b \qquad (5)$$

$$497.573 = 163.995\,a + 108.63b \qquad (6)$$

or

$$3.7996 = 1.9058a + b \qquad (7)$$

$$4.5804 = 2.4302a + b \qquad (8)$$

From equation (7) and (8),

$$a = \frac{0.7808}{0.5244} = 1.4889$$

and b = 0.9620

The equation is

$$Y = 1.4889x + 0.9620$$

Substituting $Y = G_k - 52$

$X = G_j - 124$

$$(G_k - 52) = (G_j - 124) \times 1.4889 + 1.9620$$

or

$$G_k = 1.4889\ G_j - 131.6616 \qquad (9)$$

Equation (9) gives the relation between the peak at Japla and Koelwar.

The coefficient of correlation (γ) is calculated as follows:

$$\gamma = \frac{\Sigma XY - \frac{\Sigma X .\ \Sigma Y}{n}}{\sqrt{\Sigma X^2 - \frac{(\Sigma X)^2}{n}}\ \sqrt{\Sigma Y^2 - \frac{(\Sigma Y)^2}{n}}}$$

Substituting the values:

$$\gamma = \frac{497.573 - \frac{108.63 \times 216.577}{57}}{\sqrt{263.955 - \frac{(108.63)^2}{57}}\ \sqrt{955.652 - \frac{(216.577)^2}{57}}}$$

$$\text{or } \gamma = \frac{84.8228}{56.9691 \times 132.7468}$$

$$= \frac{84.8228}{86.9624} = 0.9754$$

The co-efficient of correlation (γ) = 0.9754. This indicates a very good correlation and the equation can be used for operational flood forecast. However, from the graph it may be seen that a few points are very much out. A verification of these data indicated that some of these values refers to high observations and hence accuracy is doubtful. Such data were deleted and another equation was developed in which case the values of co-efficient of correlation works-out to be 0.99 and the equation is

$$G_k = 1.574\ G_j - 142.362 \qquad (10)$$

In order to establish a relation for estimating the time of occurrence of the predicted peak, a similar procedure is adopted as in case of peak to peak relation as already developed above.

A relation has been developed by using least square technique and adopting the similar procedure as already discussed above. The relation works-out to be

$$T = 1085.93 - 8.3906\ G_j$$

The correlation co-efficient works out to be 0.93. Alternatively a suitable graphical relation can also be developed for operational use.

It was observed in the past that while forecasting on the basis of equation (10), there were substantial errors in the prediction of forecasts for first few unprecedented peaks of the season keeping this in view, the first few unprecedented floods of the season were sagregated from the rest and attempts were made to fit two separate straight lines which give the equation as below

For the unprecedented flood peaks of the season, the equation developed was

$$G_k = 1.587\ G_j - 143.256 \qquad (11)$$

With the correlation coefficient of 0.993 and for the rest of the flood peaks

$$G_k = 10556\ G_j - 142.102 \qquad (12)$$

with the coefficient of correlation as 0.991

The various steps involved in the development of a simple relationship between the peaks at U/S and D/S stations have been discussed in detail. However, it is not always necessary that this particular method will give the best result and hence it is desirable to attempt various other alternative as well. The different alternative which have been tried to improve the forecast performance for river sone are discussed below in brief:

(a) Correlations between the peak discharge at Japla and Koelwar have also been derived. For the purpose, the peak discharges have been computed from the gauge-discharge curves for the Koelwar and

Japla. Peak discharges at Koelwar have been plotted on Y-axis and peak discharge at Japla on the X-axis and a straight line equation was developed by using least square techniques. The resultant equation works out to

$$Q_k = 1.524 \quad Q_j \quad -1677 \qquad ..(13)$$

where Q_k is the peak discharge at Koelwar in cumecs; and

Q_j is the corresponding peak discharge at Japla in cumecs.

The correlation coefficient in this case works out to 0.989 which is quite satisfactory and can be confidently used for operational flood forecasting as well.

(b) A similar correlation was attempted for peak discharges at Koelwar and Chopan, a station further upstream of Japla on river sone, which issued for giving advisory forecasts for Koelwar, and corresponding peak discharges at Koelwar. An additional feature of this reach is that, North Koel, a tributary of river Sone, joins it, a few kilometers upstream of Japla.Therefore, instead of directly correlating the Koelwar peak discharge with the Chopan peak discharge,it was correlated to peak discharge at Chopan plus contribution of North Koel as obtained from gauges discharge curve of Daltonganj site on the river, with proper lag time. Peak discharges at Koelwar were plotted on the Y-axis and the peak discharge of Chopan plus corresponding contribution of North Koel at Daltonganj on the X-axis, and a straight line was attempted which have a coefficient of correlation as 0.92 and the equation as follows:-

$$Q_K(N+T) = (Q_{c(N)} + Q_{D(N+T-T')}) \times 0.998 + 400 \qquad ...(14)$$

where

$Q_{K(N+T)}$ is the peak discharge of Koelwar at (N+T) th hrs in cumecs.

$Q_{c(N)}$ is the corresponding peak dicoharge of Chopan in cumecs.

$Q_{D(N+T-T')}$ is the discharge at Daltonganj at (N+T-T')th hrs.

where

T is the travel time between Chopan and Koelwar

T'is the travel time between Daltonganj and Koelwar.

(c) One of the major difficulties faced in forecasting for Koelwar on river Sone is the forecast for intermediate stage, i.e. stages before the peak is attained. For the purpose, attempts were made to predict the concentration segment of the hydrgraph for Japla. In order to predict the concentration segment of Koelwar hydrograph, two parameters need be evaluated. First is the peak which is likely to be attained and second, the time in which this peak will be attained. First parameter can be determined as discussed in the preceding paragraphs. For determination of second parameter, i.e. the time of rise at Koelwar, attempts were made to correlate, the time of rise to peak at Japla vis-a-vis time to rise at Koelwar. The following equation with correlation coefficient as 0.85 developed.

$$T_{RK} = 0.657 \quad T_{RJ} + 8.28 \qquad \ldots(15)$$

where

T_{RK} is time of rise to peak at Koelwar in hrs.

T_{RJ} is time of rise to peak at Japla in hrs.

The correlation coefficient is not satisfactory for operational use. Attempts to improve the correlation coefficient by taking the average gauge of Japla, peak of Japla and initial gauge of Japla at the time of beginning as parameters were also not successful.

2.2 CORRELATION BETWEEN GAUGES AT U/S AND D/S WITH ADDITIONAL PARAMETERS.

When the direct gauge to gauge correlation are not successful because of appreciable contribution due to rainfall in the in reach catchment, intermediate tributaries or the varying soil moisture condition etc., then the introduction of additional parameters of discharge of the tributary, average rainfall over the intercepting catchment, API etc. become necessary and it gives better results.

With the availability of more and more data and introduction of better data transmission facilities, the correlation diagrams are being developed with more and more additional parameters. The various parameters are introduced in different quadrants.

Some of such diagrams which are at present under use are discussed below in brief.

a) Correlation between the N^{th} hour, and $(N+T)^{th}$ hour gauge of forecasting station with change in the level of a tributary during past T_1 hours and change in level of the base station during past T hour.

b) Correlation between n^{th} hour and $(N+T)^{th}$ hour gauge of forecasting station with following parameters:

   i) Rise/Fall at U/S base station

   ii) Rainfall observed at the U/S base station.

When a number of tributaries affect the water level at the forecasting station, then the change in the base station on the main river as well as base stations on the tributary can be considered as additional parameters.

2.2.1 MULTI TRIBUTARY MODEL

A discrete, linear, time-invariant model has been developed for operational flood forecast of river Brahmaputra at Dibrugargh. This model is based on the difference of the gauge reading at the forecasting station and the upstream base station in the tributary. The use of differences of gauge readings as input in the model takes care of the aggradation or deggradation of the river bed of the tributary and the main river.The model in general is expressed as :

$$g_{(i+T),i} = A_{1}, g_{i(i-T)} + \sum_{j=1}^{m} A_{2,j} \, h_{(i-T_j+T),(i+T_j)} + \sum_{j+1}^{m} A_{3,j} \, h_{(i-T_j),(i-T_j-T)} \quad ..(16)$$

where m = Number of tributary (=3 in this case)

T = Forecasting time

T_j = Lag time between the forecasting station ($T \leq T_j$) and jth tributary gauging site.

$h_{(i-T_j+T),(i-T_j)}$ = Difference in gauges at the U/S station on the tributary between $(i-T_j+T)$ and $(i-T_j)$ th instant.

$h_{(i-T_j),(i-T_j-T)}$ = difference in gauges at the U/S station on the tributary between $(i-T_j)$ and $(i-T_j-T)$th instant.

$g_{i,(i-T)}$ = difference in gauge at ith and (i-T) the instant of time at the forecasting station.

$g_{(i-T),i}$ = difference in gauge at (i-T)th and ith instant of time at the forecasting station i.e. the forecast value.

$A_{i,j}, A_{2,j}, A_{3,j}$ are the paramteres which are to be found out.

The parameters $A_{1,j}, A_{2,j}$, and $A_{3,j}$ can be estimated by the method of least square technique. In this case the forecast of Dibrugarh is formulated with the help of observed gauge data on three major upstream tributaries namely Dihang, Debang and Lohit.

2.3 RAINFALL-STAGE METHOD

The relationship for estimating the peak discharge or the peak stage with the help of rainfall data is of great operational significance in the sense that it enables one to find the expected peak discharge or stage which is one of the important requirements in flood warning. In its simplest form it is the relation between the average rainfall over the catchment and the peak stage. This relation may be either a graphical of mathematical and can be very easily established by using the statistical technique. The results can be further improved by incorporating other parameters such as API etc These relations are used un many places with quite good result but the deficiency in this method is that the time of occurrence of the peak or the full shape of hydrograph can not be forecast.

One such relation has been developed for Anandpur site on river Baitarni where the peak discharge is estimated by using the relation.

$$Q_{max} = 1.451 \quad - 0.1678 \quad +0.0129\ x^2 \qquad \ldots(17)$$

where Q_{max} = peak discharge at Anandpur in lakhs of cusec.

$x = x_1 + x_2$

x_1 = Weighted storm rainfall over the Catchment in cms.

X_2 = Effective Antecedent rainfall in Cms

The weighted storm rainfall over the catchment is estimated by assigning certain weights to the various stations, depending upon the area and geographical condition.

$$x = 1\ 0.2A \ + (0.7\ B \ + \ C \ + 0.6D$$

where A,B,C and D represent the rainfall at various stations in Cms.

The effective antecedent rainfall is taken as certain percentage of the antecedent rains.

The following table has been assumed and used in all calculation.

Weighted antecedent Rainfall in mm	Percentage of antecedent rainfall to be taken as effective
0 - 15	Nil
15 - 20	20%
20 - 40	25%
40 - 60	30%
60 - 80	35%
80 - 100	40%
100 - 120	45%
120 - 140	50%
140 - 160	60%
160 - 180	70%
180 - 200	80%
More than 200	90%

The relation has been developed by analysing data of previous 23 storm and the results are quite satisfactory.

REFERENCE

1. Central Water Commission (1980),'Manual on Flood Forecasting', Central Flood Forecasting Organisation Patna.
2. Rangachari,R.(1986),'Flood Forecasting and Warning Network in Interstate Rivers of India'. Central Water Commission,New Delhi.